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Radionuclide transport in running waters, sensitivity analysis of bed-load, channel geometry and model discretisation

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Abstract

In this report, further investigations of the model concept for radionuclide transport in stream, developed in the SKB report TR-05-03 /Jonsson and Elert 2005/ is presented.

Especially three issues have been the focus of the model investigations. The first issue was to investigate the influence of assumed channel geometry on the simulation results. The second issue was to reconsider the applicability of the equation for the bed-load transport in the stream model, and finally the last issue was to investigate how the model discretisation will influence the simulation results.

The simulations showed that there were relatively small differences in results when applying different cross-sections in the model. The inclusion of the exact shape of the cross-section in the model is therefore not crucial, however, if cross-sectional data exist, the overall shape of the cross-section should be used in the model formulation. This could e.g. be accomplished by using measured values of the stream width and depth in the middle of the stream and by assuming a triangular shape.

The bed-load transport was in this study determined for different sediment characteristics which can be used as an order of magnitude estimation if no exact determinations of the bed-load are available. The difference in the calculated bed-load transport for the different materials was, however, found to be limited.

The investigation of model discretisation showed that a fine model discretisation to account for numerical effects is probably not important for the performed simulations. However, it can be necessary for being able to account for different conditions along a stream. For example, the application of mean slopes instead of individual values in the different stream reaches can result in very different predicted concentrations.

Sammanfattning

I denna rapport presenteras vidare undersökningar av modellkonceptet för radionuklidtransport i vattendrag som utvecklats i SKB rapporten TR-05-03 /Jonsson och Elert 2005/.

Fokus i denna modellundersökning har legat främst på tre problemställningar. Den första utredningen gällde att undersöka hur den antagna kanalgeometrin påverkar simuleringsresultaten. Den andra undersökningen inriktade sig på att vidare undersöka ekvationen för sedimenttransport ("bed-load") i vattendragsmodellen och slutligen den sista utredningen inriktades på att utreda hur modelldiskretiseringen påverkar simuleringsresultaten.

Simuleringarna visade på relativt små skillnader i resultat då olika antagna om tvärsnittens utseende gjordes i modellen. En exakt representation av tvärsnittetsgeometrin i modellen är inte kritisk, men om data finns på tvärsnitt bör information om den övergripande formen på tvärsnittet användas vid modellformuleringen. Detta kan t ex göras genom att mäta bredden på vattendraget samt djupet i mitten av kanalen och genom att anta en triangulär form.

Sedimenttransporten ("bed-load") bestämdes i denna studie för olika sedimenttyper och kan användas för storleksordningsuppskattningar av transporten då inga andra exakta bestämningar finns tillgängliga. Resultaten visar dock att skillnaderna i de beräknade sedimenttransporterna var begränsade för de olika sedimenttyperna.

Undersökningen av modelldiskretiseringen visade att en finare modelldiskretisering troligtvis inte är nödvändig för att undvika numeriska effekter. Däremot kan detta vara nödvändigt om olika förhållanden längs ett vattendrag skall beaktas. Exempelvis kan användandet av medellutningar istället för värden för olika delsträckor ge upphov till stora skillnader i de predikterade koncentrationerna.

Contents

1 Introduction

1.1 Background

At present SKB is investigating possible sites for a repository of spent nuclear waste. As a part of the safety assessment, SKB has formulated biosphere models for different ecosystems in order to calculate the dose to humans and biota from a possible radionuclide discharge to the biosphere. The biosphere model is to be used for predictions at the two sites under investigation: the Forsmark area in Östhammar and the Simpevarp/Laxemar area in Oskarshamn. The model will be used in the ongoing investigations of the suitability of the sites for a repository of spent nuclear waste.

In a previous report, /Jonsson and Elert 2005/, a model concept describing radionuclide transport in running water was presented. This report deals with further consideration of this model concept.

1.2 Objectives

The objective with the further consideration of the model for radionuclide transport in running waters was concentrated to three issues:

- To investigate the influence of assumed channel geometry on the predicted concentrations.
- To reconsider the applicability of the equation for the bed-load transport in the stream model.
- To investigate how the model discretisation will influence the predicted concentrations.

2 Channel geometry

2.1 Stream cross-sections

In the proposed model concept for radionuclide transport in running waters, reported in /Jonsson and Elert 2005/, a triangular cross section was assumed. At the time for the model formulation, no site-specific information on cross-sections was available to support or discard this shape as a general cross-section along the stream. After the publication of this report, cross-sections along the streams in Laxemar have been determined /SKB 2006/.

Studying the data, it is possible to see that cross-sections of different types exist in the watershed, ranging from triangular shapes to more circular or almost rectangular in shape. In Figure 2-1 a few cross-sections from the watercourse in Laxemar are illustrated.

To be able to determine how the geometry of the watercourse will influence the simulation results, calculations were made for two extreme cross-sections, one triangular and one rectangular, both with the same width of the water surface (Figure 2-2).

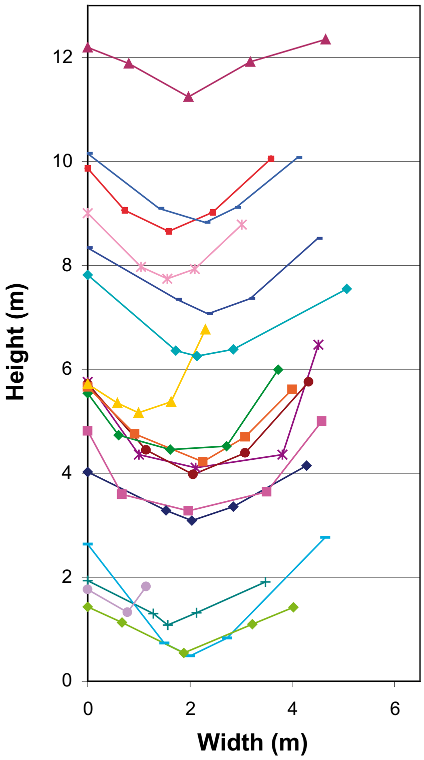

Figure 2-1. *Example of stream cross-sections in Laxemar /SKB 2006/.*

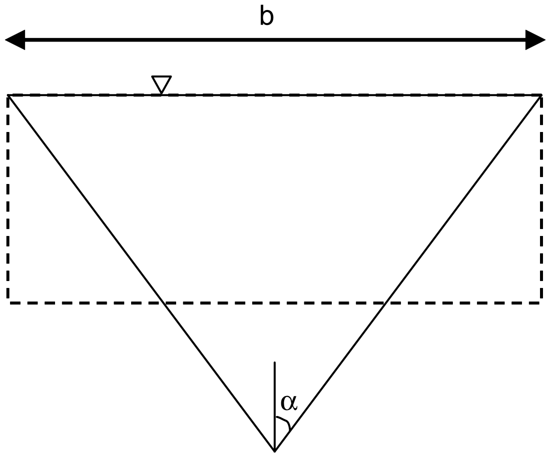

Figure 2-2. *Two different types of cross-sections (triangular and rectangular) with the same surface width, b, for which the results from simulations are to be compared.*

2.2 Effect of stream cross-sections on hydraulic radius

Different channel geometries result in different values on the hydraulic radius (R_h). The hydraulic radius appears in the equations for the transfer rates, describing the exchange with the sediment due to an advective and diffusive exchange, as well as due to sedimentation. Therefore, the geometry can affect the magnitude of the resulting exchange between the stream water and the sediment.

For the triangular shape, the hydraulic radius was calculated according to the description in /Jonsson and Elert 2005/ (Equations (2)–(5)). For the rectangular cross-section, an iterative calculation had to be made to determine the hydraulic radius. This due to the fact that the Manning equation does not allow for a direct solution of the normal depth for this cross-section.

For the rectangular cross-section, the area of the cross section and the hydraulic radius are given by:

$$A_{cross} = b\,y_n \tag{1}$$

$$R_h = \frac{b\,y_n}{b + 2y_n} \tag{2}$$

where y_n is the normal depth and b the surface width.

The Manning equation that had to be solved by iteration for a given flow and for a similar width of the water surface as in the case of a triangular cross-section is given by:

$$Q = \left(\frac{b\,y_n}{b + 2y_n} \right)^{\frac{2}{3}} \frac{S_b^{\frac{1}{2}} b\,y_n}{n} \tag{3}$$

where S_b is the slope of the channel [–] and n is the Manning roughness coefficient ($m^{-1/3}s$).

In Figure 2-3, the hydraulic radius is plotted as a function of the stream water flow for the triangular and rectangular shape, respectively. Two different angles for the triangular shape have been investigated, one with rather steep walls (α=45°), and another with a more flat triangular shape (α=80°). Corresponding determinations of the hydraulic radius was then made for a rectangular cross-section, where the width of the water surface is set equal for the two shapes. The deviation in hydraulic radius between the two different types of cross-sections is rather small, where the triangular shape at its maximum gives around 7% larger hydraulic radius than the rectangular shape, for the tested range in water flow as in Figure 2-3.

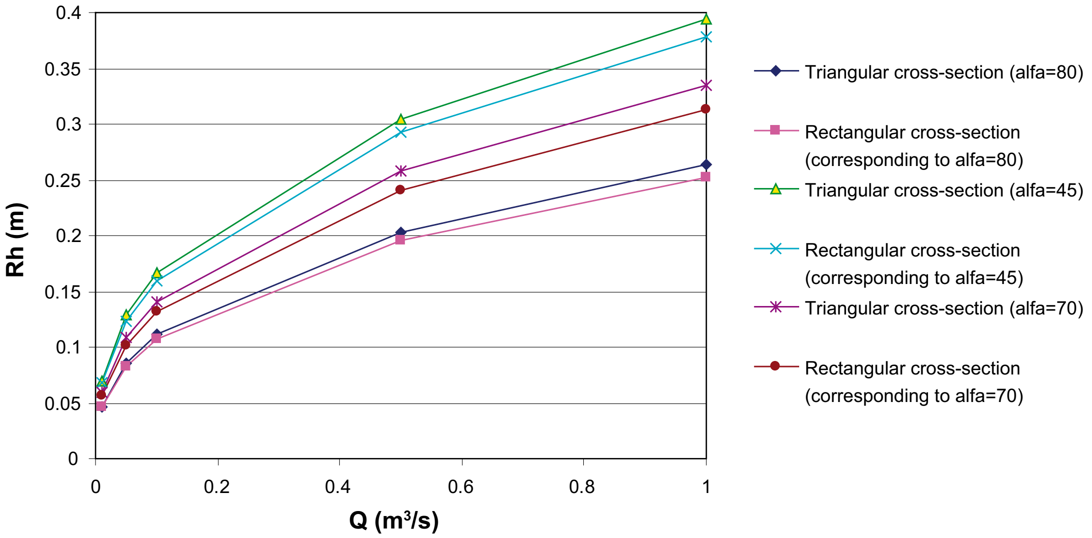

Figure 2-3. *Hydraulic radius as a function of water flow for different cross-sections (triangular and rectangular).*

The variation in hydraulic radius, due to the different applied cross-sections is most probably of minor importance for the model calculations of the resulting concentrations in the biosphere originating from a possible radionuclide discharge from a repository of spent nuclear waste. In the calculations, the simulations are based on assumptions of similar conditions in the future as today. Considering the change of stream morphology over time, the channel geometry could not be determined more exact than the variation between the different shapes in the presented example.

2.3 Effect of varying Manning roughness coefficient

The results of different channel geometry could also be compared with the variation in hydraulic radius, related to the uncertainty of the exact value of the Manning roughness coefficient, n (Figure 2-4). The range in roughness coefficient is taken from the literature, where "rivers free from large stones and heavy weeds" have a roughness coefficient of 0.025 and where "canals and rivers with many stones and weeds" are given the value 0.035 /Fox and McDonald 1994/. The range in the roughness coefficient of 0.02–0.04 will therefore probably cover a realistic value for the streams. In this case the resulting variation in hydraulic radius between the lower and the higher value on the roughness coefficient differ by 16% i.e. more than the difference resulting from assuming a triangular or rectangular cross-section.

2.4 Effect on concentration in surface sediment

In Figure 2-5 an example of resulting concentration in the surface sediment when applying the rectangular or triangular shape is shown. In this simulation, a stream reach of 2,000 m is considered, and an input of 1 Bq/m^3 is applied to the dissolved fraction in the stream water (corresponding to Figure 5-14 in /Jonsson and Elert 2005/ where K_d=10 m^3/kg, K_B=1 m^3/kg, T_k=0.001 year, V_Z=5×10^{-6} m/s, $V_{partsed}$=400 m/year, BCF=200 (Bq/kg fw)/(Bq/l), Q=0.029 m^3/s, α=45°). In this example, the resulting concentration in the sediment using the different cross-sectional shapes practically coincide. This also applies for the concentration in the stream water.

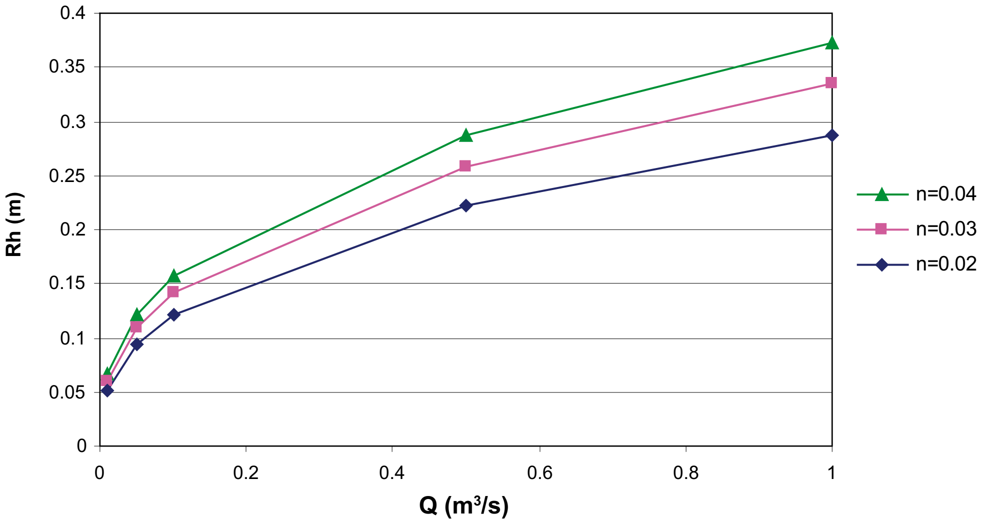

Figure 2-4. *Hydraulic radius as a function of water flow for different values on the Manning roughness coefficient.*

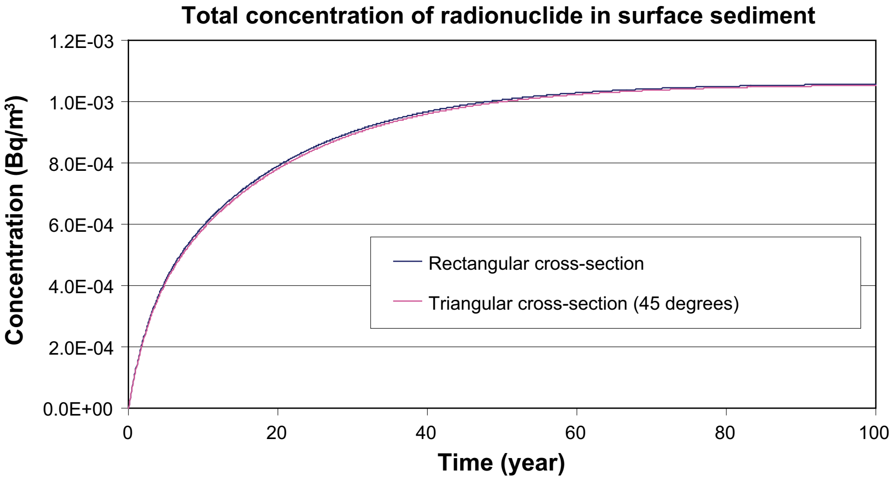

Figure 2-5. *Resulting concentration in surface sediment for the different cross-sections (K_d=10 m³/kg, K_B=1 m³/kg, T_k=0.001 year, V_Z=5×10⁻⁶ m/s, $V_{partsed}$=400 m/year, BCF=200 (Bq/kg fw)/(Bq/l), Q=0.029 m³/s).*

2.5 Conclusions concerning shape of stream cross-section

Considering the model calculations presented above, it is therefore possible to conclude that the previously assumed triangular shape could be used as a general shape of the stream cross-section for the order of magnitude calculations of the accumulation of radionuclides. A more detailed description of the channel geometry is not important for the order of magnitude predictions using the rather simple model proposed in /Jonsson and Elert 2005/. However, the angles for the triangular shape should be based on observations of channel geometry from the actual site.

3 Bed-load transport

A further consideration of the incorporation of the semi-empirical equations of the bed-load transport by /van Rijn 1984/ has been made.

Also other alternative equations have been considered, however, all of the semi-empirical equations describing bed-load transport are based on the same principle, where the bed-load transport is dependent on whether some kind of critical velocity in the stream is exceeded.

The bed-load transport is a complex process. Site-specific conditions will of course influence the possibility for bed-load transport. For example the sediment characteristics, e.g. grain size, will influence the possibility for motion. The conditions for bed-load transport are different if the sediment is consolidated or unconsolidated. In the streams under consideration it is probable that friction material is present while streams with consolidated sediments are not as probable.

Almost all semi-empirical equations describing bed-load are based on observations in the laboratory where the conditions are more controlled than in natural streams. However, the bed-load equations, e.g. the one by van Rijn should provide an order of magnitude prediction of the bed load in absence of measurements in the specific watercourse.

3.1 Particle size distribution

In the bed-load equation (describing the transport on the sediment surface) one has to assign values on the particle size distribution for the sediment. This information is often not known. A sensitivity analyses with different types of sediment have therefore been made to investigate the effect of different assumptions of grain size distribution on the predictions. For the sensitivity analyses, different soil types have been assumed to constitute the sediment. The four different soil types are:

- Fine grained moraine
- Outwash-sand
- Coarse grained moraine
- Outwash-gravel

The grain-size, i.e. values on D_{50} and D_{90} is based on grain-size distribution curves reported by /Byggforskningsrådet 1992/. The applied values are those given in Table 3-1.

Table 3-1. Values describing the grain-size distribution in different materials (based on information in /Byggforskningsrådet 1992/.

Soil type	D_{50} (μm)	D_{90} (μm)
Fine grained moraine	100	2,000
Outwash-sand	400	800
Coarse grained moraine	1,000	6,000
Outwash-gravel	2,000	40,000

3.2 Predicted bed-load transport

In Figure 3-1 the amount of particulate material (not radionuclides) transported by bed-load for the different types of materials are plotted for different flow conditions when a triangular cross section (α=70°) is used. The range in flow velocity for which the equations by van Rijn are valid is 0.5–2.5 m/s. In Figure 3-1, the sediment transport has been calculated by the equations also for a slightly lower velocity. However, in the absence of better information e.g. from measurements, these equations seems to give reasonable predictions also for lower velocities. Furthermore, the bed-load transport is of little importance at low flow velocities.

It is possible to conclude that the different materials for which bed-load has been determined does not give bed-load predictions that differs several orders of magnitudes. The largest bed-load is given for the material fine grained moraine, which as it maximum is around 40% higher than the lowest predicted sediment transport for outwash gravel.

3.3 Conclusions concerning bed-load parameters

From the further consideration of the van Rijn equations it is concluded that the equations could be used for order of magnitude predictions in the absence of real measurements.

When the material of the sediment is not exactly characterised, the types of materials given in Table 3-1 could be used as an indication of what values that should be used for the grain size parameters in the equations.

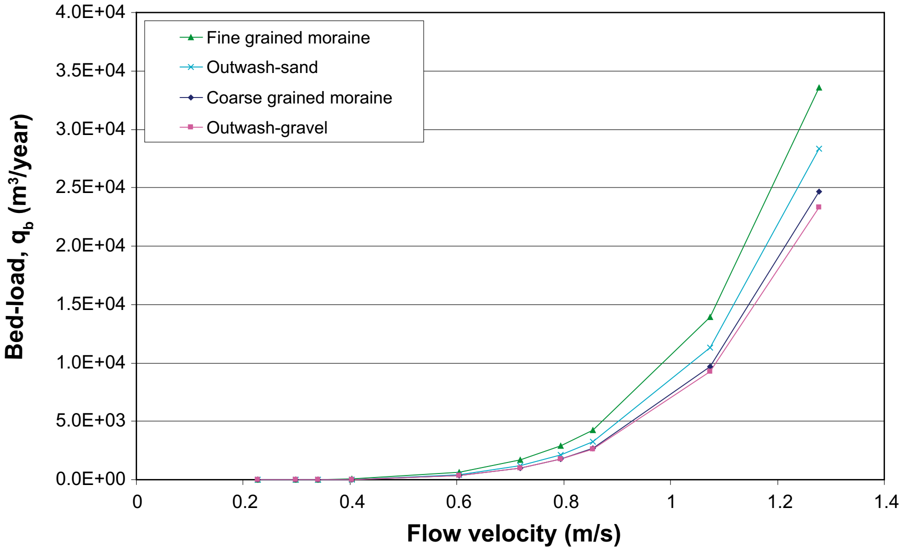

Figure 3-1. *Bed-load transport predicted using relationships by van Rijn for different types of materials as a function of flow velocity in the stream water.*

4 Model discretisation

The sensitivity analysis of the proposed model presented in /Jonsson and Elert 2005/ was performed by treating the whole stream reach as one compartment (in both stream water and sediment).

In this study a further investigation is made on how the model discretisation of the stream in the longitudinal direction will influence the model predictions. For this investigation, a number of simulations were done with the same parameter set-up as in /Jonsson and Elert 2005/, differing only in the number of boxes along the stream. Also a case with a higher water flow and longer reach was tested as the data of water flow at different streams in Laxemar indicates that the flow could be higher than previously tested.

The model discretisation will influence the results differently, depending on the type of inflow of radionuclides at the boundary. In this specific case, a continuous inflow of dissolved radionuclides in the stream water phase at the boundary is the most probable scenario. Therefore the model discretisation has been investigated with that prerequisite.

4.1 Effect on equilibrium concentration in the surface sediment

In Figure 4-1, the resulting concentration in the surface sediment at equilibrium is plotted for different cases where the 2,000 m long stream reach is represented with one, five or ten compartments, respectively, in the longitudinal direction (simulation with K_d=10 m^3/kg, K_B=1 m^3/kg as in Figure 5-14 in /Jonsson and Elert 2005/). For this case, it is clear that a model discretisation of 1 or 10 compartments is not of vital importance for the predicted concentration, as the difference is very small.

4.2 Effect on equilibrium concentration in the surface sediment with higher sorption

Results from a similar simulation as in Figure 4-1, with one or ten compartments, but with a higher assigned sorption, is found in Figure 4-2 (simulation with K_d=100 m^3/kg, K_B=1 m^3/kg as in Figure 5-17 in /Jonsson and Elert 2005/). At first the lower concentration in the surface sediment at the first compartments might seem illogical. However, this is a combined effect of the assigned time-scale of the sorption process in the stream water and the transport downstream in the system by bed-load. For this calculation example, the effect of treating the whole stream reach as one compartment (dx=2,000 m) instead of 10 compartments (dx=200 m), is an overestimation of the concentration in the beginning of the stream reach and a underestimation of the concentration in the end of the stream. However, the difference is rather small.

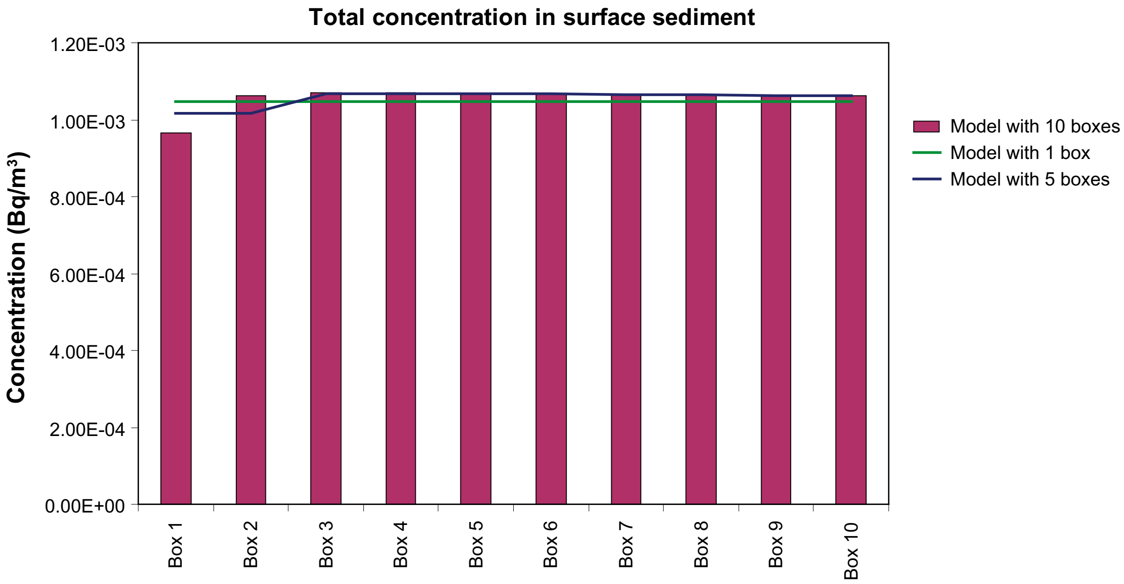

Figure 4-1. *Concentration of radionuclides in surface sediment at equilibrium along a 2,000 m long stream reach for the case where the stream reach is represented with 1, 5 or 10 boxes ($V_Z=5\times10^{-6}$ m/s, $T_k=0.001$ year, $V_{partsed}=400$ m/year, $K_d=10$ m³/kg, $K_B=1$ m³/kg, BCF=200 (Bq/kg fw)/(Bq/l), $Q=0.029$ m³/s, α=45°).*

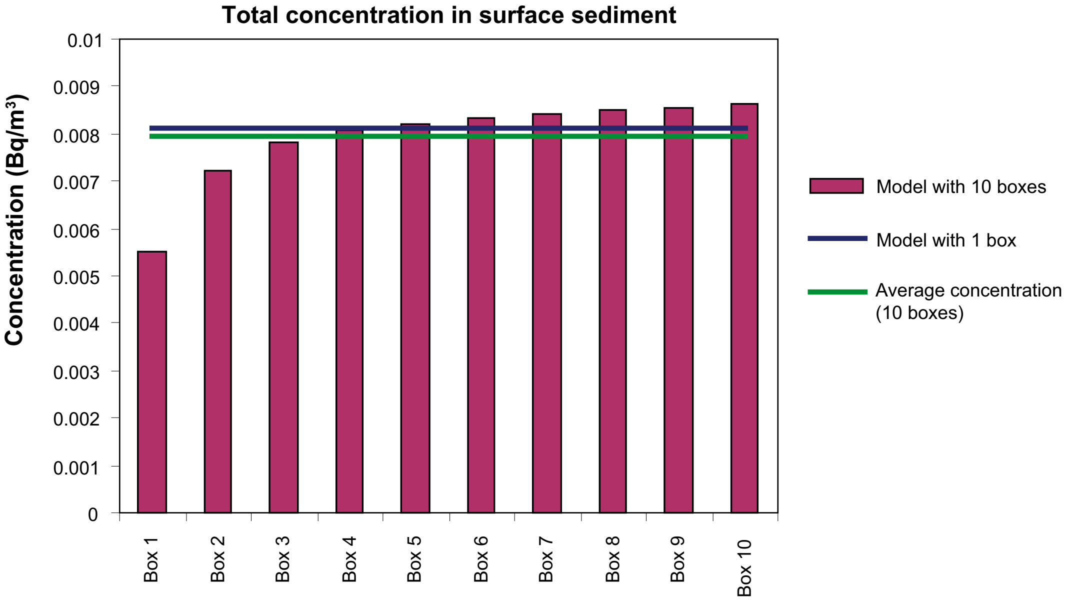

Figure 4-2. *Concentration of radionuclides in surface sediment at equilibrium along a 2,000 m long stream reach for the case where the stream reach is represented with 1 or 10 boxes ($V_Z=1\times10^{-5}$ m/s, $T_k=0.001$ year, $V_{partsed}=400$ m/year, $K_d=100$ m³/kg, $K_B=10$ m³/kg, BCF=200 (Bq/kg fw)/(Bq/l), $Q=0.029$ m³/s, α=45°).*

Simulation of stream with longer reach

Results from another example, where a longer reach (10,000 m) with a higher flow (0.5 m^3/s) is considered ($V_Z=1\times10^{-5}$ m/s, $T_k=0.001$ year, $V_{partsed}=400$ m/year, $K_d=100$ m^3/kg, $K_B=10$ m^3/kg), is given in Figure 4-3. In this case the difference in concentration in the first and last compartment is more pronounced than in previous example. This is a result of a combined effect of a longer reach and a higher flow affecting e.g. the bed-load transport. However, the use of only one compartment instead of 10 will only result in a concentration that is approximately 1.2 times higher than the average concentration in the 10 compartments.

Simulation with more rapid sorption on suspended particles

In Figure 4-4 the resulting concentration in the surface sediment is shown when a more rapid sorption onto suspended particles in the stream water than in Figure 4-3 is applied. A 10 km long stream reach is considered and the model is divided in 1, 2 or 5 boxes. Here, the use of only one compartment instead of five results in a concentration that is approximately 1.1 times higher than the average concentration in the 5 compartments, i.e. the effect is small. However, if it is important to consider not only average conditions along the stream, but rather to gain information on the distribution in accumulated radionuclides in the different parts of the system, a fine model discretisation could be necessary to perform. In the example given in Figure 4-3, the concentration in the last box has a concentration that is approximately 5 times higher than the first box. Corresponding value for box five and one in Figure 4-4 is ~2.6 times.

Effect of neglecting bed-load transport

If the bed-load process is neglected, another trend in concentration is gained, where the concentration is highest in the uppermost part of the stream reach at the beginning of the simulation, whereas the equilibrium concentration practically is the same along the whole stream (Figure 4-5). To verify the predicted bed-load transport using the equations by van Rijn, field measurements of the bed-load should be needed.

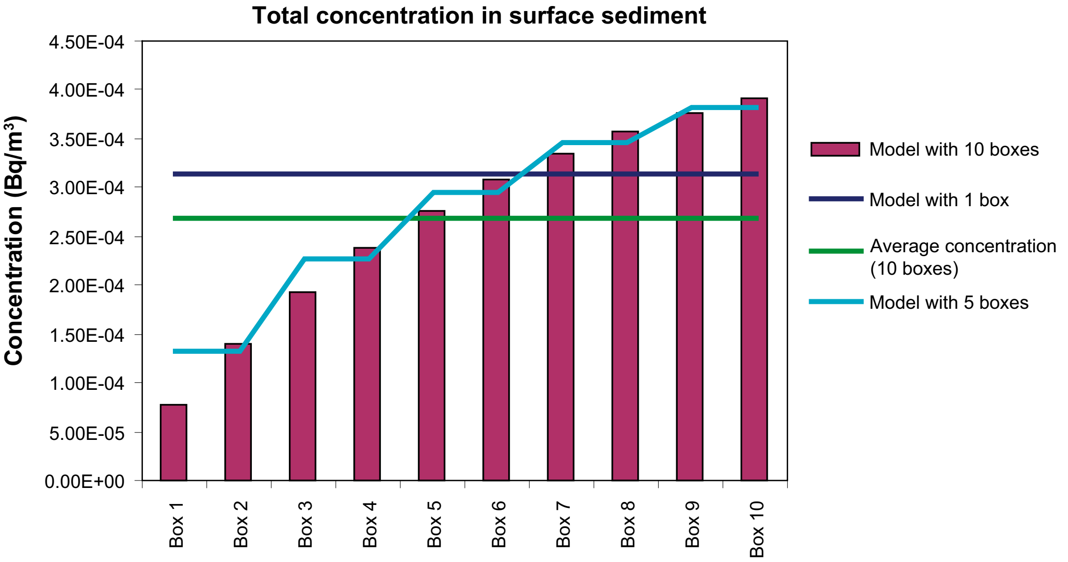

Figure 4-3. *Concentration of radionuclides in surface sediment at equilibrium along a 10,000 m long stream reach for the case where the stream reach is represented with 1, 5 or 10 boxes ($V_Z=1\times10^{-5}$ m/s, $T_k=0.001$ year, $V_{partsed}=400$ m/year, $K_d=100$ m^3/kg, $K_B=10$ m^3/kg, BCF=200 (Bq/kg fw)/(Bq/l), $Q=0.5$ m^3/s, $\alpha=70°$).*

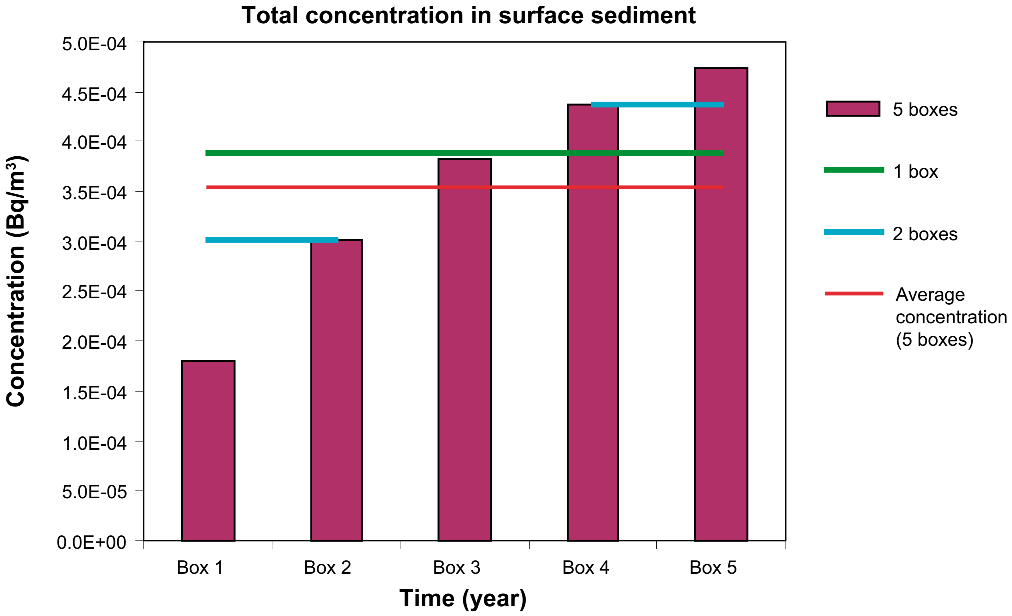

Figure 4-4. *Concentration of radionuclides in surface sediment at equilibrium along a 10,000 m long stream reach for the case where the stream reach is represented with 1, 2 or 5 boxes (*$V_Z=1\times10^{-5}$ *m/s,* $T_k=1\times10^{-6}$ *year,* $V_{partsed}=400$ *m/year,* $K_d=100$ *m³/kg,* $K_B=10$ *m³/kg, BCF=200 (Bq/kg fw)/(Bq/l),* $Q=0.5$ *m³/s, α=70°).*

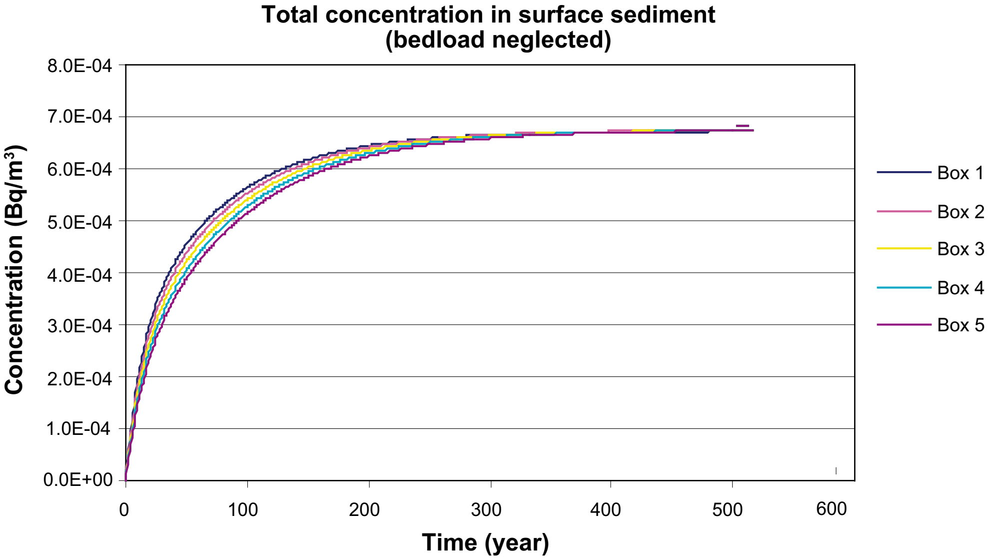

Figure 4-5. *Concentration of radionuclides in surface sediment at equilibrium along a 10,000 m long stream reach when bed-load transport is neglected (*$V_Z=1\times10^{-5}$ *m/s,* $T_k=1\times10^{-6}$ *year,* $V_{partsed}=400$ *m/year,* $K_d=100$ *m³/kg,* $K_B=10$ *m³/kg, BCF=200 (Bq/kg fw)/(Bq/l),* $Q=0.5$ *m³/s, α=70°).*

Stream reaches with different characteristics

A probably larger effect is obtained if also different stream characteristics along the stream are considered, i.e. different geometry and slopes, flow conditions etc and not just the model discretisation itself. For example, the channel slope controls the flow condition and thereby the exchange and transport processes along the stream. This is illustrated in an example in Figure 4-6. A stream reach of 3,000 m is divided in two sections, the first with the slope of the channel of 0.07% and the second reach with the slope 2%. The order of magnitude of the slopes is based on observed changes of the slopes along a stream reach at Laxemar. The resulting concentration is then compared with the case when a mean value of the two slopes is applied on the whole stream reach.

As is shown, the resulting concentrations in the two stream reaches are rather different. This is due to the fact that the flow condition to a large extent is governed by the channel slope. For example, in a stream reach with a lower slope, the bed-load transport is less pronounced, whether for a steep stream reach, the conditions for bed-load transport is more favourable.

In a real case also the advective velocity regulating the advective exchange with the sediment should be different for different flow conditions as the velocity in the stream water changes. In /Jonsson and Elert 2005/ an order of magnitude of the velocity was estimated by generalising results from another stream using theories by /Wörman et al. 2002a,b/. The advective exchange coefficient varies to some extent in the model with flow condition, e.g. the hydraulic radius change when flow conditions change. However, the advective velocity itself is not assigned to vary with flow conditions as this requires more detailed information from e.g. experimental investigations using tracer tests. The interval for the advective velocity given in /Jonsson and Elert 2005/, generalised from another stream system, could however be used as an approximation in the absence of more detailed investigations.

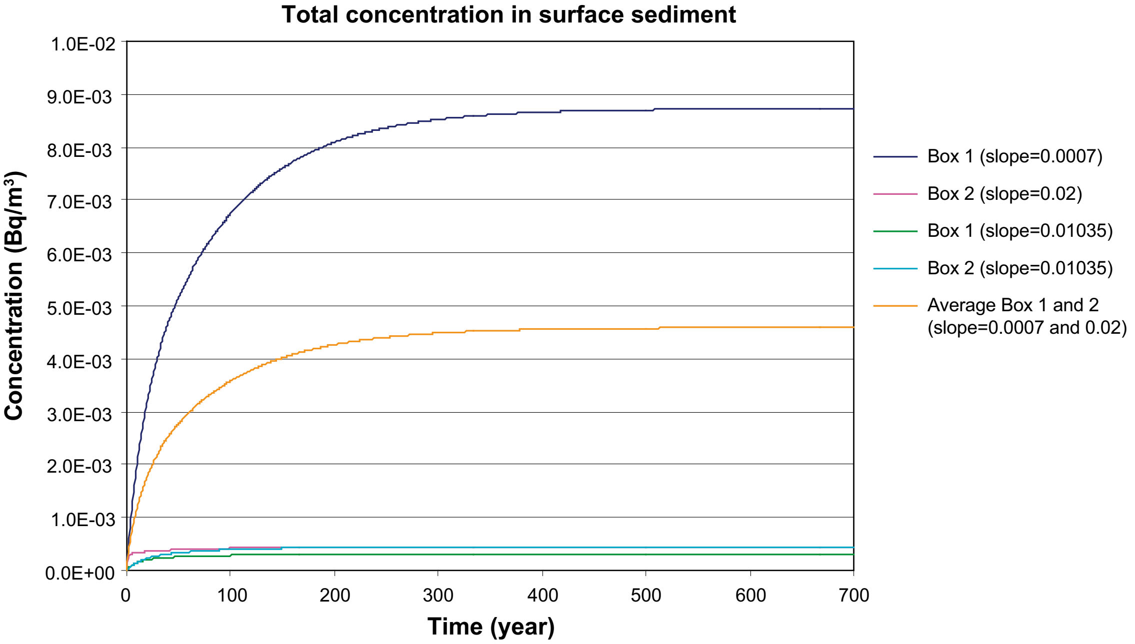

Figure 4-6. *Concentration of radionuclides in surface sediment in a 3,000 m long stream reach with different slopes (0.0007 and 0.02) and corresponding results when an average slope of 0.01035 is used along the whole stream reach* ($V_Z=1\times10^{-5}$ *m/s,* $T_k=1\times10^{-3}$ *year,* $V_{partsed}=400$ *m/year,* $K_d=100$ m^3*/kg,* $K_B=10$ m^3*/kg, BCF=200 (Bq/kg fw)/(Bq/l), Q=0.029* m^3*/s, α=70°).*

In the simulation example with two different slopes, the concentration in the surface sediment is approximately 19 times higher in the first reach than in the steeper reach. The resulting concentration when applying a mean value of the two slopes on the whole stream reach (3,000 m), is slightly increasing along the stream as a combined effect of a slow sorption and bed-load transport of adsorbed radionuclides downstream in the system. The average concentration for the whole stream reach in the case of two different slopes is 12 times higher than the average concentration in the two compartments when a mean value of the two slopes is applied on the whole stream reach.

Conclusions on model discretisation

A conclusion is therefore that a fine model discretisation for being able to account for numerical effects has moderate impact on the resulting predicted concentrations. However, a discretisation of the model where several compartments are assigned in the model to account for stream reaches with very different characteristics e.g. different flow conditions, could however, be more important. The degree of the discretisation is dependent on how different the stream reaches are.

5 Discussion and conclusions

The investigations of the impact of channel geometry on the predicted transport in running waters reveals that a general triangular cross-sectional shape could be applied for order of magnitude calculations of the radionuclide transport. The angle for the triangular shape should however be based on observations of channel geometry from the actual site. In practice this could be accomplished by measuring the width of the channel and the depth at the middle of the stream. An inclusion of more detailed information of the cross sectional geometry is, however, not of vital importance for the order of magnitude predictions.

The bed-load transport is dependent on flow conditions as well as sediment characteristics. The sediment characteristics will influence the magnitude of the predicted bed-load, even though the magnitude of the predicted bed-load does not differ considerable for the different tested materials. This is especially the case when the flow velocity is rather small. For the case when the sediment is not exactly characterised, the parameters describing the grain size listed in this report for different materials could be used as standard cases for different types of sediment.

Outflow of radionuclides from the stream system is both due to transport in the flowing water and due to bed-load transport of sediment. Depending on flow conditions and sediment characteristics, the transport of radionuclides out of the stream by bed-load will be more or less pronounced. In the example in Figure 4-1, the outflow of radionuclides due to bed-load transport constitutes only ~0.2% of the outflow with the streaming water, where the corresponding values for Figure 4-2, Figure 4-3, Figure 4-4, Figure 4-6 are 1, 14, 18 and 19%, respectively. Especially for cases where the magnitude of the outflow by bed-load becomes significant, it is important to consider also this outflow as an inflow to the next system in the watershed e.g. a lake or coast.

The effect of model discretisation on the predicted average concentrations in the simulation examples in this report indicates that a fine model discretisation has moderate impact. This is valid if other conditions and parameter values are unchanged. However, if knowledge on spatial distribution of the accumulated radionuclides along a stream is desired, a higher discretisation of the model might become necessary. For the examples presented in this report, a mean value of the concentrations in the different sediment compartments along the stream will not deviate significantly from the predicted concentration when only one sediment compartment is assigned. The use of one compartment in the longitudinal direction (10 km) yields, in the presented example, a concentration in the sediment that is in the order of ~10–20% higher than the average concentration when 5 or 10 compartments are assigned.

A fine model discretisation to account for numerical effects is probably not of vital importance for order of magnitude predictions. However, if the conditions along the stream changes, e.g. different slopes and flow conditions, it is necessary to divide the stream reach in different compartments. This must be done e.g. because the use of average slopes instead of different slopes for the sub-reaches will not necessarily result in average concentrations of the same order of magnitude. As an example, a reach was divided in two parts with different slopes based on measured slopes in watercourses in Laxemar. The concentration in the sediment was then ~12 times higher when the different stream reaches was treated separately than when an average slope for the whole stream reach was assigned.

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