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Rodolfo Avila			2013-12-12	
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Martin Sjölund			2015-05-13	

Procedure for estimation of water fluxes and associated Transfer Rate Coefficients in the Pandora Model

Contents

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel and Waste Management Co
PO Box 250, SE-101 24 Stockholm
Visiting address Blekholmstorget 30
Phone +46-8-459 84 00 Fax +46-8-579 386 10
www.skb.se
556175-2014 Seat Stockholm

1. Introduction

In the Pandora model for the biosphere that was used in SR-Site, a parameterization of the water fluxes was adopted, which allows the model to be applicable for a whole range of mire-lake objects. This parameterization also allows taking into account the effect on the water fluxes of changes in the mire-lake objects and the landscape that are considered in the long term assessments.

In this report we present how the parameterization of the water fluxes was implemented and provide details of how required parameter values were estimated on the basis of MIKE SHE simulations that were carried out for 6 lakes existing today in the Forsmark area. This report is focused on the mire-lake objects and does not address the parameterization of water fluxes used for the period when the biosphere objects are submerged under the sea. For the latter period a very simple representation of the water fluxes is used, consisting basically of using a constant low water flux through the sediment layer and into the sea water.

2. Water mediated transport in the Pandora model

Figure 1 shows the different compartments in the Pandora model for the biosphere and the water fluxes considered in the modelling of the radionuclide transport. The water fluxes (in m^3/m^2/year) are used in the Pandora model for calculating the Transfer Rate Coefficients (in 1/year) between different model compartments and downstream from the biosphere objects. The Transfer Rate Coefficients are then used in the model to calculate radionuclide fluxes (in Bq/year) between compartments and downstream from the biosphere objects.

The compartments in the Pandora model are defined as follows:

- **REGOLITH_LOW** - is the moraine layer from the bottom of the lake to the rock (geosphere). The thickness of this layer is constant. The area of this compartment is also constant.
- **Aqu_REGOLITH_MID** - is the sediment layer consisting of the glacial clay (with constant thickness) and the post-glacial clay (with time varying thickness). The area of this compartment decreases with time due to the growth of the mire.
- **Aqu_REGOLITH_UP** – is the sediment layer (with constant thickness) from where resuspension can take place. The area of this compartment decreases with time due to the growth of the mire.
- **Aqu_WATER** - is the water column with area and mean depth varying in time.
- **Ter_REGOLITH_MID** – is the sediment layer of the mire that has been covered by the Ter_REGOLITH_UP of the newly growth mire. The depth of this compartment increases in the same way as the depth of the Aqu_REGOLITH_MID increases. The area of this compartment increases due to the growth of the mire.
- **Ter_REGOLITH_UP** – this is the upper layer of the mire that growths due to biomass production. The thickness and area of this layer increases with time.

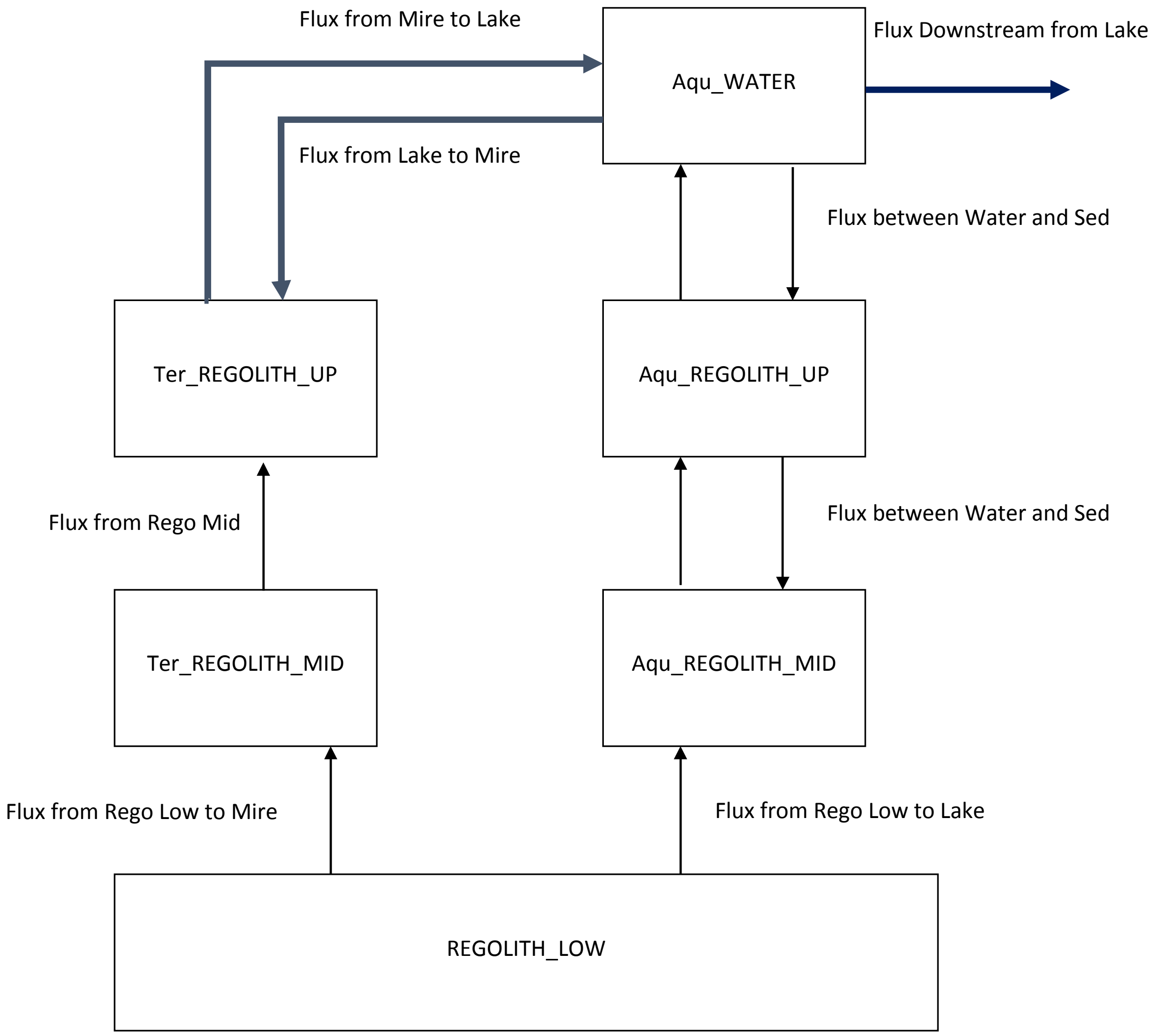

Figure 1*. Conceptual representation of the water fluxes included in the Pandora model*

3. Parameterization of water fluxes

In principle, for an existing lake-mire object the water fluxes could be measured. But for modelling future landscapes, the fluxes have to be simulated or estimated. In the SR-Site biosphere modelling, several future lake-mire objects were considered, which experience transformations in time that may have an effect on the water fluxes. It is practically very difficult, and an unjustified level of detail, to derive water flux values for all future biosphere objects and assessment time points. Instead, a simplified parameterization of the water fluxes was adopted which is outlined below:

- It was assumed that the water fluxes, both vertical and horizontal, near the surface (Regolith Up, Regolith Mid layers of the sediments and the lake water) are proportional to the runoff fluxes through the biosphere object defined as the runoff rate (m/year) times the sub-catchment area (for the mire) or the watershed area (for the lake). The following equations were used to represent the fluxes normalized by the mire-lake object area (see Figure 1):

$$Flux\ from\ Mire\ to\ Lake\ (m/y) = \left(1 + \boldsymbol{f_{flood}}\right) * \frac{area_{catch}}{area_{obj}} * runoff \quad (1)$$

$$Flux\ from\ Lake\ to\ Mire\ (m/y) = \boldsymbol{f_{flood}} * \frac{area_{catch}}{area_{obj}} * runoff \quad (2)$$

$$Flux\ from\ Rego\ Mid\ (m/y) = \boldsymbol{Ter\_adv\_mid\_up\_norm} * \frac{area_{catch}}{area_{obj}} * runoff \quad (3)$$

$$Flux\ between\ Water\ and\ Sed\ (m/y) = \boldsymbol{Aqu\_adv\_mid\_up\_norm} * \frac{area_{catch}}{area_{obj}} * runoff \quad (4)$$

$$Flux\ Dowstream\ from\ Lake\ (m/y) = \frac{area_{watershed}}{area_{obj}} * runoff \quad (5)$$

- Further, it was assumed that the fluxes from the Regolith Low to the mire and the lake are weakly influenced by the surface runoff fluxes and a constant value was assigned to these. The following equation was used to calculate the fluxes to the lake and the mire from the lower regolith:

$$Flux\ from\ Rego\ Low\ to\ Mire\ (m/y) = \boldsymbol{fract_{mire}} * \boldsymbol{adv\_low\_mid} \quad (6)$$
$$Flux\ from\ Rego\ Low\ to\ Lake\ (m/y) = (1 - \boldsymbol{fract_{mire}}) * \boldsymbol{adv\_low\_mid} \quad (7)$$

The above parameterization of the water fluxes requires that values for the following parameters are estimated:

adv_low_mid is the area normalized total advective flux from the rego_low to the Ter_rego_mid and Aqu_rego_mid (m/y)

fract_mire is the fraction of the advective flux from the rego_low that goes to the mire (-)

Ter_adv_mid_up_norm is the advective flux in the terrestrial object from the rego_mid to the rego_up normalized by the net lateral advective fluxes from the mire (-)

Aqu_adv_mid_up_norm is the advective flux in the aquatic object between the rego_mid and the rego_up and between the rego_up and the water normalized by the net lateral advective fluxes from the mire (-)

$\boldsymbol{f_{flood}}$ is a coefficient used to calculate the flux from the lake to the mire by flooding (-)

4. Parameter estimation using MIKE SHE simulations

Values for the parameters needed to calculate the water fluxes in the Pandora model (Section 3) were derived (see below) using water fluxes in mire-lake systems obtained from simulations with MIKE SHE. The MIKE SHE simulations were carried out for 6 lakes existing today in the Forsmark area. Based on these simulations, area normalized fluxes shown in Figure 2 were obtained for an average lake. As can be seen from comparing Figures 1 and 2, the water fluxes obtained with MIKE SHE are not the same as those required by the Pandora model. The fluxes required by the Pandora model (Figure 1) could, however, be derived from the fluxes obtained in the MIKE SHE simulations (Figure 2); as shown in Table 1 below. This calculation of the Pandora fluxes is nothing more than a model calibration using the flux values generated with MIKE SHE.

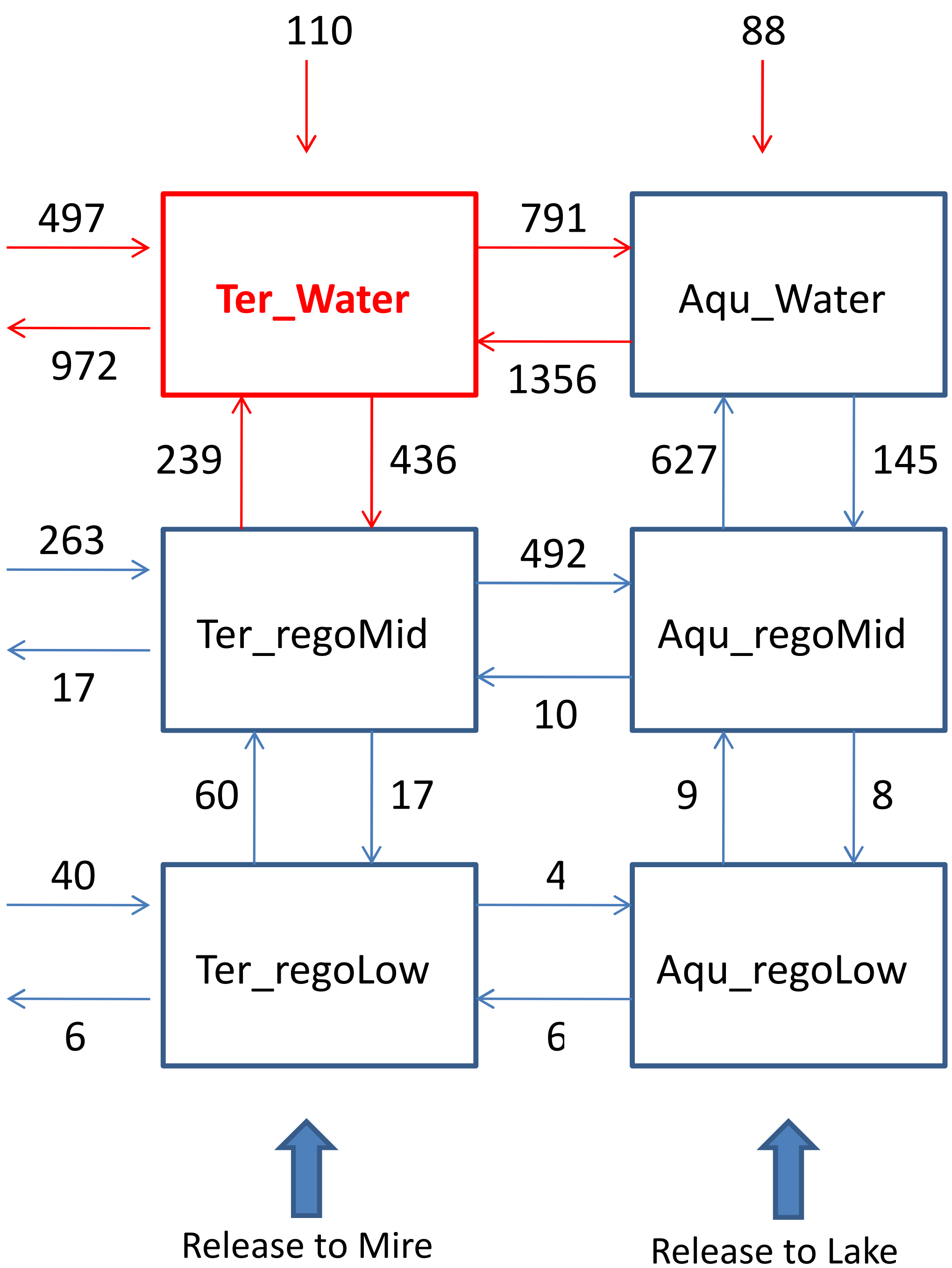

Figure 2. *Advective fluxes for an average lake-mire object obtained from the MIKE SHE simulations. Values of area normalized fluxes are given in units of mm/year. Some very small deviations observed in this diagram are due to rounding errors*

Table 1. Estimation of water fluxes required by the Pandora model (Figure 1) from the values obtained from the MIKE SHE simulations for an average lake-mire object (Figure 2).

Flux in Pandora model (Figure 1)	**Description**	**Calculated values (mm/year) (using Fluxes in Figure 2)**
Flux from Mire to Lake	Total flux from the mire to the lake/river (for biosphere objects that have a lake/river). We assume that all downstream water passes the lake/river. Sum of all fluxes that go from Ter_Water and Ter_regoMid to the lake/river in Figure 2	= 791 + 492 + 972 + 17 = 2272
Flux from Lake to Mire	Total flux from the lake/river to the mire (for biosphere objects that have a lake/river). . Sum of all fluxes that go from Aqu_Water and Aqu_regoMid to the lake/river in Figure 2	= 1356 + 10 = 1366
Flux from Rego Mid	Net flux from Regolith Mid to Regolith Up of the mire plus Net flux from Regolith Mid of the mire to the lake. This is the total net flux from Rego Mid shown in Figure 1.	= 239 + 492 +17 – 436 – 10 = 302
Flux from Rego Low to Mire	Net flux from Regolith low to Regolith mid of the mire. This is the total net flux from Rego Low to Mire shown in Figure 1.	= 60 -17 = 43
Flux from Rego Low to Lake	Net flux from Regolith low to Regolith mid of the lake. This is the total net flux from Rego Low to Lake shown in Figure 1.	= 9 -8 = 1
Flux between water and sediment	Total flux from sediment to lake water, which equals the flux from the lake water to the sediment. The same flux values are used between the lake Regolith Up and Water and between lake Regolith up and lake Regolith mid (see Figure 1)	= 627 + 10 = 637 = 492 + 145 = 637
Flux downstream from lake	Total flux downstream from the lake. In this case, the watershed area of the lake equals the sub-catchment area of the mire. This is the total flux out from the lake-mire object.	= 972 + 17 = 989

The calculated values of the fluxes shown in Table 1 (after conversion to units of m/year) were applied, together with equations (1) to (7), for estimating values for the parameters required for calculation of water fluxes in the Pandora model. The calculations made are shown in Table 2.

Table 2. Estimation of parameter values required for calculation of water fluxes in the Pandora model using calculated values of water fluxes presented in Table 1.

Parameter (Unit)	Estimated value	Description of how the value were estimated
adv_low_mid (m/y)	0.044	Flux from regoLow to Mire + Flux from regoLow to Lake
fract_mire (-)	0.98	Flux from regoLow to Mire / *adv_low_mid*
Ter_adv_mid_up_norm (-)	0.30	Flux from Rego Mid/Flux downstream from lake
Aqu_adv_mid_up_norm (-)	0.64	Flux between water and sediment/ Flux downstream from lake
f_{flood} (-)	1.5	Solving equation $(1+f_{flood})/f_{flood}$ = Flux from Mire to Lake / Flux from Lake to Mire

5. Discussion

A main advantage of the parameterization of water fluxes that was used in the Pandora model is that it allows obtaining the water fluxes for all future mire-lake objects included in the landscape model and for all time points.

In addition, most of the parameters required, with the exception of the normalized flux from the regoLow (*adv_low_mid*), are relative measures that can be assigned values heuristically. For example, the parameter *fract_mire* (-) can in principle be assigned any value between 0 and 1 and this way all possible situations can be easily studied. The same argument is also valid for other parameters. This was used in the sensitivity and uncertainty analyses that were performed, where the parameters were varied within a range derived from the MIKE SHE simulations for the 6 existing lakes. These studies showed that these parameters had a weak effect on the LDF values calculated with the Pandora model.