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Ministerie van Infrastructuur en Milieu

Manual SEDIAS

User guide to the SEDImentASsistant spreadsheet

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1 Introduction to the SEDImentASsistant (SEDIAS)

1.1 Structure of the spreadsheet

The spreadsheet SEDIAS, which is short for SEDImentASsistant, contains most of the suggested calculation methods as described in the Guidance Document for Sediment. The **SEDIAS** spreadsheet contains several worksheets:

General worksheets:

1. Partition
2. Diffusion,Dispersion & seepage
3. Resuspension
4. Contribution stat. conc.
5. msPAF
6. SPM & MTR

"Ad-worksheets" containing additional calculations and background information:

1. Ad 1 Partition coefficients
2. Ad 1 Contr. dissolved
3. Ad 3 Shipping parameters
4. Ad 3 Calculation resusp. wind

The *general worksheets* are visible and accessible at all times. If these worksheets are modified (except for the blue input cells), the user is alarmed by the colour of the cell involved, which is subsequently modified. This modification is checked by comparing the contents of the cell with the corresponding cell on a (hidden) *copy of the worksheet*. Of each *general worksheet* therefore, there is an exact copy of the original worksheet. The *copies of the worksheets* have names similar to those of the general worksheets but have the letter C added to them. The *copies of the worksheets* contain no buttons and bear the title Copy!! in red capitals at the top of the worksheet.

The "Ad-worksheets" are hidden by default and can be unhidden by using the buttons on the corresponding general worksheets. By selecting a different worksheet the "Ad-worksheets" are automatically hidden again.

1.2 General use

The spreadsheet starts in all cases with worksheet 1 Partition, since that's where the substances have to be entered. In this worksheet the total contaminant contents in the sediment can be entered, from which concentrations in the pore water are calculated. It is also possible to enter contaminant concentrations in pore water directly. Subsequent calculations are conducted in the appropriate worksheets

In column D one can select or deselect substances. One can do this by using the buttons "Select all substances" or "Deselect all substances" or by clicking the X's in column D. The result of the selection is that only the selected substances are presented in the other worksheets. Bear in mind that the msPAF calculation

preferably uses at least the substances of the standard substances list[1] (even if these substances are not actually causing water quality problems).

One is allowed to overwrite cells with formulas or values that are considered more reliable for the site of concern. In that case the cells get a brighter colour. If formulas are overwritten, the spreadsheet is not directly suitable for a standard assessment. Therefore, a button "Default values" has been added to every worksheet, which can be used to reset all cells, except the blue input cells, to their default values or formulas.

1.3 Modifying SEDIAS

SEDIAS is a tool for assessing sediments as best as one can. **The user is allowed to modify SEDIAS** to (for a specific situation) enable a better assessment of the relation between sediment quality and water quality. If one modifies a worksheet, it is important to implement these modifications in the copy of the worksheet too.

To do this, these are the steps to take:

1. Open the file without enabling the macros;
2. Unhide the copy of the worksheet involved via Format – Sheet – Unhide.
3. Activate the general worksheet and click, while pressing the shift key, on the tab of the copy of the worksheet (both tabs are now highlighted).
4. Make the changes. (Because the copy of the worksheet has also been selected, all changes are implemented in the copy of the worksheet at the same time).
5. Click on a different tab (the selection of the 2 worksheets is cancelled).
6. Hide the copy of the worksheet again via Format – Sheet –Hide.
7. Store the file (preferably under a new name).
8. Close the file and reopen it, this time with the macros enabled.

[1] The standard substances list is a Dutch list of substances which has (refereert naar list end us enkelvoud) to be measured whenever one conducts a survey in the sediment.

2 Partition (worksheet 1)

2.1 Use

Contaminant concentrations can only be entered in worksheet 1 Partition. Basically, one is expected to enter (column F) total contaminant contents in the sediment (measured non-standardized values). Subsequently, concentrations in (pore) water are calculated from these total contents (for metals after sediment type correction) assuming equilibrium partitioning. It is important that the values of the general parameters in cells F9-F15 have been entered correctly. Organic matter can both be entered (blue cells) as organic matter (OM) and as organic carbon (OC). Subsequently, the OC-content is, if applicable, minimized to 0.0116 (2% OM) or maximized to 0.174 (30% OM) for organic contaminants. Clay content is, if applicable, minimized to 2%. The calculated values are presented in the green cells.

Input of available contents or concentrations in pore water

If available contaminant contents or concentrations in pore water have been measured, these can be entered in the following manner:

- Available contents can be entered as total contents. Subsequently, concentrations in pore water are calculated assuming equilibrium partitioning.
- Concentrations in pore water can be entered in column I. **In that case the formulas are overwritten and the spreadsheet can no longer be used for calculating partitioning.**
- The relevant standard can be entered in column J. This is particularly useful if one uses SEDIAS frequently. It enables a quick testing of concentrations in pore water against the standard.

Worksheet 1 Partition uses Koc/Kd-values. These values show a wide range in literature. The references from which the Koc/Kd values have been adopted to be used in SEDIAS are presented in worksheet Ad1 Partition coefficients (these can be found through button "Partition coefficients" on worksheet 1 Partition.

2.2 Technical description of equilibrium partitioning

If total contaminant contents have been measured, the concentration in the pore water can be calculated assuming equilibrium partitioning. This is done in the following manner:

Measured metal contents have to be converted to contents in standard sediment because the K_d values apply to standard sediment:

This conversion involves the following equation:

$$Q_{sed,standard} = Q_{sed,measured} \cdot \frac{\mathrm{A} + \mathrm{B} \cdot 25 + \mathrm{C} \cdot 10}{\mathrm{A} + \mathrm{B} \cdot \mathrm{clay}\,(\%) + \mathrm{C} \cdot \mathrm{OM}(\%)}$$

where:

$Q_{sed,\ standard}$	=	standardized contaminant content in sediment (mg/kg)
$Q_{sed,\ measured}$	=	measured contaminant content in sediment (mg/kg)
A, B, C	=	metal dependent parameters (see table 1)
clay (%)	=	measured clay content in sediment (minimally 2%)
OM (%)	=	measured organic matter content in sediment (minimally 2%)

Table 1. Metal dependent parameters

Metal	A	B	C
Antimony	1	0	0
Arsenic	15	0.4	0.4
Barium	30	5	0
Beryllium	8	0,9	0
Cadmium	0.4	0.007	0.021
Chrome	50	2	0
Cobalt	2	0.28	0
Copper	15	0.6	0.6
Lead	50	1	1
Mercury	0.2	0.0034	0.0017
Molybdenum	1	0	0
Nickel	10	1	0
Thallium	1	0	0
Tin	4	0.6	0
Vanadium	12	1.2	0
Zinc	50	3	1.5

The standardized contaminant content in sediment is subsequently converted to a concentration in the (pore) water in accordance with:

$$c_{pw} = \frac{Q_{sed}}{K_d}$$

where:

c_{pw} = dissolved contaminant concentration in pore water (mg/l)
Q_{sed} = contaminant content in sediment (mg/kg)
K_d = equilibrium partitioning coefficient (l/kg)

For organic contaminants:

$$c_{pw} = \frac{Q_{sed}}{f_{OC} \cdot K_{OC}}$$

where:

c_{pw} = dissolved contaminant concentration in pore water (mg/l)
Q_{sed} = contaminant content in sediment (mg/kg)
f_{OC} = organic carbon fraction (-)
K_{OC} = equilibrium partitioning coefficient (l/kg)

2.3 Sediment type correction

In the approach presented above, the contaminant contents are corrected for the organic matter and clay contents of the sediment in accordance with Annex G of the Dutch Soil Quality Regulation, except for PAHs. In SEDIAS, PAHs are not corrected for a minimum of 10% organic matter (Annex G) but for a minimum of 2%, comparable to the correction for other contaminants. Using a minimum of 2% is justified by the fact that at low organic matter contents the inorganic fraction also contributes to the binding capacity of sediment with respect to contaminants. The minimum of 10% organic matter was policy-based and not risk-based..

3 Diffusion/dispersion and seepage (worksheet 2)

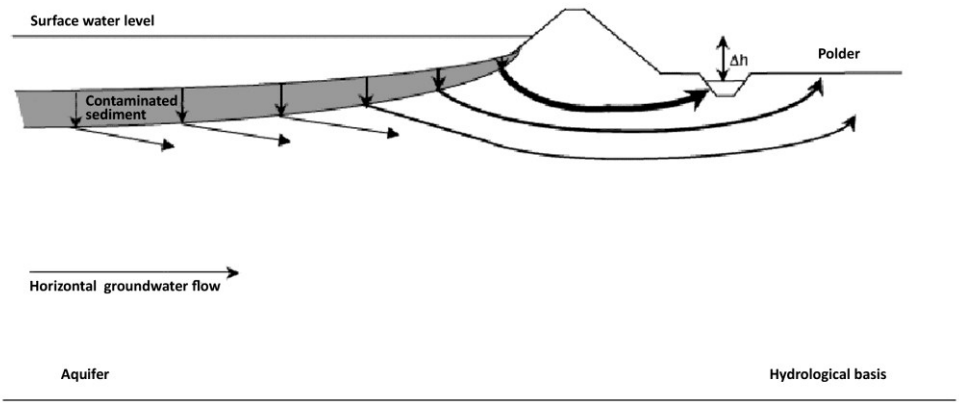
3.1 Use

For heavy metals (for which the WFD standards have been defined in filtered water, meaning that that samples are filtered over a 0.45 µm filter), transport by advection may be significant. In case of transport by advection the dissolved contaminant is transported through the sediment with the water flow. For organic contaminants the total concentration in water is measured, including the contaminant bound to suspended particulate matter. Transport by advection of dissolved organic contaminant is therefore usually not a relevant process. Only for relatively mobile organic contaminants advection of the dissolved phase may be significant in cases where resuspension does not occur (stagnant waters). In case of upward seepage, this process can contribute to the dissolved transport. In case of downward seepage this factor becomes negative.

To calculate seepage, the following general parameters are required:

k	=	hydraulic conductivity of the resistant sediment layer in m/day (in SEDIAS values are given depending on the sediment type).
dp	=	hydraulic potential (pressure gradient) over the sediment in m. This is determined by the difference in water level between the aquifer and the body of surface water involved. In polders for example, this is represented by the difference in water level between a polder water and the "boezem" water (outlet/drainage water). (In the sketch dp is represented by Δh). For brooks the difference between surface water level and groundwater level determines the seepage.
d(layer)	=	thickness of the resistant sediment layer (between aquifer and surface water) in m. If several resistant layers are present (for example peat and clay), the thickness of the layer having the lowest hydraulic conductivity (the highest resistance) must be entered.

After these parameters have been entered, a contaminant flux caused by seepage is calculated for each contaminant (row 16).



In addition to seepage, diffusion can contribute to the transport of dissolved contaminants from the sediment to the water column. Diffusive transport can be of importance for heavy metals (for which the WFD-standards have been defined in filtered water) and in situations where no resuspension occurs (stagnant waters).

To calculate diffusive transport, the following parameters are required:

Θ	=	porosity of the sediment (-) (default value is 0.35; this may be modified)
a	=	correction factor for bioturbation and bioirrigation (-) (option: 1 to 5)
c_w	=	contaminant concentration in surface water (diffusion is maximal if this concentration is 0)

After entering these parameters in the worksheet, a diffusive contaminant flux from the sediment to the surface water is calculated (row 30).

These two fluxes (seepage and diffusion) are added and subsequently the contribution of this total flux to the concentration in the surface water is calculated. In this calculation the water flow rate through the water body is taken into account. This water flow rate and the surface area of the contaminated sediment must therefore be entered in the worksheet.

If the contaminated sediment does not cover the entire surface area of the water body but only a part of it, the "local" concentration directly above the contaminated part can be calculated by replacing water flow rate Q of the entire water body by partial water flow rate Qpart which is representative for the contaminated part. This partial water flow rate can be roughly estimated using the ratio between the width of the contaminated part in the direction of the water flow and the width of the entire water body.

This finally results in a steady state concentration in the water column that is caused by the contaminated sediment.

3.2 Technical description of seepage and diffusion

3.2.1 Seepage

Calculating the contaminant flux caused by seepage

The contaminant flux from the sediment to the water column can be calculated from the seepage water flux and the contaminant concentration in the pore water using the following formula:

<u>Dissolved transport – Seepage</u>

$$F_s = F_w \cdot c_{pw}$$

where:

F_s	=	contaminant flux caused by seepage (g/m^2.day)
F_w	=	seepage water flux (m^3/m^2.day)
c_{pw}	=	contaminant concentration in het pore water (g/m^3)

The seepage water flux F_w can be calculated using Darcy's Law:

$$F_w = \mathrm{k} \cdot \frac{\mathrm{dp}}{\mathrm{d(layer)}}$$

where:

k	=	hydraulic conductivity of the sediment (m/day)
dp	=	hydraulic potential (difference in height) over the sediment between aquifer and water (m)
D(layer)	=	thickness of the most resistant layer (m)

The hydraulic conductivity of the sediment layer strongly depends on the sediment type (sand, clay or peat). If the top sediment layer consists of unconsolidated mud, the hydraulic conductivity will be determined by the first consolidated deeper lying sediment layer.

The hydraulic gradient over this sediment layer is determined by the difference in groundwater level or surface water level (for example the difference between the water level of a canal and the water level of a ditch in the adjacent polder, directly behind the dike, or the difference between the ground water levels in different areas such as between the higher Dutch Veluwe and the lower Gelderse Vallei).

3.2.2 Diffusion

The driving force for diffusive transport of contaminants from the sediment to the water column is the difference between the contaminant concentration in the pore water of (the top layer of) the sediment and the concentration in the overlying water column. All other circumstances being constant, diffusion will cause a gradual loading of the water.

This diffusive flux under steady conditions can be described using Fick's first law:

$$F_d = D_{eff} \cdot \frac{\mathrm{dc}}{\mathrm{dz}}$$

where:

F_d = diffusive flux from the sediment to the surface water (g/m^2.day)
D_{eff} = effective diffusion coefficient (m^2/day)
$\frac{dc}{dz}$ = concentration gradient on the sediment - water interface (g/m^3.m)

The effective diffusion coefficient D_{eff} can be calculated in accordance with:

$$D_{eff} = D_{mol} \cdot \theta \cdot \frac{\mathrm{a}}{\tau}$$

where:

D_{mol} = molecular diffusion coefficient (m^2/day) (default value: 0.00013 m^2/day)
θ = porosity of the sediment (-) (default value 0.35; may be modified)
τ = tortuosity of the sediment structure (-) (default value 3)
Due to the sediment structure, the real path of diffusion is longer than the direct vertical path. The tortuosity τ accounts for this longer path.
a correction factor for bioturbation and bioirrigation (-) (option: 1 to 5)

The default value of D_{mol} has been adopted from Van der Heijdt *et al.* (2000). The tortuosity has been adopted from Bhatia (1985).

The effect of bioturbation strongly depends on the abundance and activity of sediment dwelling fauna and fish. The values 1 (no bioturbation) to 5 (extremely high bioturbation) are based on De Lange *et al.* (2006). In water systems dominated by bentivorous fish (carp / bream) a value of 5 is entered. In water systems with a 100% cover of water plants a value of 1 is entered.

Steady state calculation in surface water (in semi-stagnant water)

The easiest way to roughly estimate the water quality (mg/l) resulting from contaminant emissions from the sediment is by dividing the total contaminant source strength from the sediment by the water flow rate of the water body:

$$c_{tw} = \frac{F_{tot} \cdot \mathrm{A}}{\mathrm{Q}} =$$

where:

c_{tw}	=	average steady state total contaminant concentration in water resulting from emissions from the sediment (g/m^3)
F_{tot}	=	total contaminant flux from the sediment (g/m^2.day) This flux is calculated by adding the fluxes caused by seepage and caused by diffusion
Q	=	water flow rate through the water body (m^3/day)
A	=	surface area of the contaminated sediment (m^2)

4 Resuspension (worksheet 3)

4.1 Use

4.1.1 Shipping

Considering the depths of the shipping routes in The Netherlands, it appears that virtually all canals and shallow lakes in The Netherlands have such shallow depths that passing ships almost always cause resuspension of the sediment. This conclusion can be drawn both when looking at propeller jets and at return currents. At low navigation speeds the return current may be small, but the propeller jet causes much resuspension. At high navigation speeds the propeller jet induced resuspension is relatively small, but now the return current prevails. In the spreadsheet only the resuspension caused by propeller jets has been implemented. In relatively narrow shipping channels return currents could contribute significantly to resuspension. More information can be found in Eelkema *et al.* (2006).

If the rules of thumb presented in the Guidance Document for Sediment Assessment do not clearly allow conclusions whether resuspension occurs or not, or if the magnitude of the resuspension has to be quantified, worksheet 3 Resuspension can be used. In that case the water depth and the critical shear stress of the sediment have to be entered (general parameters). In addition, the number of ships per twenty-four hour period and the average navigation speed of the ship must be entered for each type of ship.

SEDIAS then calculates the average concentration of suspended particulate matter resulting from shipping in the directly affected area.

The concentration of suspended particulate matter in the area of shipping can be divided by the total surface area of the water body in order to assess the influence of shipping on the entire water body. To do this, one has to enter the length of the navigational route (L-route) and the surface area of the entire water body (Area). The water authorities have to decide for themselves whether they want to assess only the directly affected area or the entire water body.

Worksheet 3 Resuspension only presents the concentration of suspended particulate matter itself, but the effects on the water quality only become clear after multiplying the concentration of suspended particulate matter with the quality of the suspended particulate matter. This calculation is done in worksheet 4 Contribution stat. conc.

4.1.2 Wind

Wind can cause occasional peaks in the concentration of suspended particulate matter (SPM). These peaks won't affect the annually averaged SPM-concentration, but can be very high during short periods of time. In the Guidance document for Sediment Assessment the following steps are followed, using the formula:

$$c_{SPM,water} = Q_{spm} \cdot \frac{\mathrm{SPM}}{1000}$$

where:

$c_{SPM,water}$ ccontribution of contaminant bound to suspended particulate matter to the total concentration in water (µg/l)
Q_{spm} = contaminant content in suspended particulate matter (mg/kg)
SPM = suspended particulate matter concentration in water (mg/l)

Will wind waves cause resuspension?

1. Go to cell F70 in worksheet 3 Resuspension (Determining the critical orbital velocity by optimizing the input). The relation between the critical orbital velocity (cell F70) and the critical shear stress of the sediment (cell F74) is complex. However, for relatively flat sediments the easiest way to determine the critical orbital velocity is by adjusting (optimizing) the critical orbital velocity 'trial and error'-wise, until the correct critical shear stress of the sediment is calculated. The default value of the critical orbital velocity is 0.224, because this results in a critical shear stress of the sediment of 0.3 (unconsolidated sediment). The optimized critical orbital velocity is automatically copied to worksheet Ad3 Calculation resusp. wind (cell D9), which can be opened by clicking button "Resuspension by wind".
2. Open worksheet Ad3 Calculation resusp. wind: Enter the fetch length in row 14 of table "Critical orbital velocity" (only if > 1 km) and enter the wind speed at which the critical orbital velocity at the sediment surface (cell D9) is exceeded in row 15. These (critical) wind velocities can be found in "Lookup table orbital velocities at the sediment surface caused by wind waves". This table presents orbital velocities at the sediment surface for several combinations of fetch length, water depth and wind speed (6 to 20 m/s) that are relevant for the site of interest. If the value in the table is higher than the critical orbital velocity (cell D9), one can look up the corresponding wind speed (6 to 20 m/s) in the top row of the table. With pull down buttons one can show or hide parts of the table.
3. Are these wind velocities (in certain wind directions) exceeded in the area of interest? If so, enter the number of hours during which this wind speed is exceeded in row 16 and do this for all wind directions. This information can be found in wind frequency distribution tables. Download de wind frequency distribution table of the nearest meteorological station or (for The Netherlands) use the data of meteorological station De Bilt (see the table starting at row 77).

Above which (critical) SPM concentration will the Maximum Allowed Concentration (MAC) be exceeded?

1. Open worksheet 1 Partition and click button 'Contribution dissolved'. Here (worksheet Ad 1 Contr. dissolved) a total contaminant concentration is calculated from the content in the sediment and the concentration in the pore water, assuming that the suspended particulate matter originates from the sediment and is in equilibrium with the surface water[2].
2. Adjust the SPM concentration for substances for which the water standards are exceeded (for each contaminant separately) in cell E8 in such a way that the MAC of the contaminant involved is exceeded. The resulting total concentration in water corresponding to the SPM concentration is shown in column G.
3. If the critical SPM concentration has been calculated for several contaminants, the lowest value is selected.

The question posed in the Guidance Document for Sediment Assessment whether this lowest calculated SPM concentration is realistic, cannot be answered with SEDIAS. This answer must come from expert judgement or from measurements.

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[2] If one overwrites the contaminant concentration in the pore water or the total contaminant concentration with values measured in the surface water, one can also calculate non-equilibrium situations.

Calculate the annual number of hours during which the critical orbital velocity is exceeded.

If the critical orbital velocity is exceeded, one can easily calculate the amount of resuspended sediment. However, this calculation often results in high concentrations of suspended particulate matter. If, for example, the critical orbital velocity is 0.22 m/s, a SPM concentration of 400 mg/l is already calculated for an orbital velocity of 0.23 m/s.

If the question posed in the Guidance Document for Sediment Assessment whether the calculated critical SPM concentration is realistic, is answered with 'yes', it is assumed that exceeding the critical orbital velocity also results in exceeding the standard. The final assessment is therefore expressed in the number of hours that the standard is exceeded. This number has already been calculated in worksheet Ad 3 Calculation resusp. wind (cell E16).

4.1.3 Bioturbation by fish

Especially in water bodies with little shipping, fish can contribute significantly to the concentration of suspended particulate matter. SEDIAS uses a simple formula, in which the estimated weight (kg) of benthivorous fish must be entered.

4.2 Technical description resuspension

4.2.1 Shipping

Ship types

In SEDIAS six ship types have been defined (see the Lookup table in worksheet Ad 3 Shipping parameters). The relevant shipping parameters are incorporated in the calculations in worksheet 3 Resuspension. It has to be established how many ships and of what type pass on average during a twenty-four hour period. In column K one has the possibility to add another ship type. The default number of ships per twenty-four hours is 1. Furthermore, the average velocity of the ship v_{ship} must be entered. If this velocity is not known, the following starting points can be used: in situations where a lot of manoeuvring occurs, such as in harbours, locks and near bridges, v_{ship} = 0 m/s; in situations where some steering is necessary, such as in bends and in heavy traffic, v_{ship} = 2 m/s; in situations where mostly a steady course is steered, v_{ship} = default value. The default travelling speed of the ship is based on a straight steering ship (no acceleration or deceleration and no manoeuvring).

Water velocity at the water-sediment interface

The flow velocity in the propeller jet of a ship depends on the diameter of the propeller and the applied engine power and is calculated in relation to the travelling speed of the ship (Eelkema *et al.*, 2006). SEDIAS supplies a table containing several ship types. Select a relatively big ship type from this table that frequently occurs in the water body of concern. When in doubt, use several ship types.

The axial outflow velocity is calculated in accordance with:

$$u_0 = 1.15 \cdot \left(\frac{P}{\rho D^2}\right)^{1/3} - v_{ship}$$

where:

u_0	=	axial outflow velocity directly behind the propeller (= 0.7 x installed engine power) corrected for the shipping speed (m/s)
P	=	applied engine power (kW)
ρ	=	density of water (kg/m^3)
D	=	effective diameter of the propeller (m) (= 0.7 x diameter for a conventional propeller; for a ducted propeller, one may enter the full diameter, but the default factor in the worksheet is 0.7)
v_{ship}	=	average velocity of this ship type on this site (m/s)(see text below)

The velocity of the ship is very important for this calculation. If the ship is not navigating or if it is manoeuvring, the calculated velocity is also the actual velocity at the water-sediment interrface. If the ship is navigating, the calculated velocity at the water-sediment interrface must be corrected for the velocity of the ship.

The jet behind the propeller will widen, where the radial distance to the jet axis will amount approximately one fifth of the distance behind the propeller. At the same time the effect of the propeller jet is less once a ship is navigating at a constant velocity and is steering straight. This is strongly site-dependent (harbour, canal, bend, etc). The water velocity at the water-sediment interrface can be calculated in accordance with:

$$u_s = \frac{0.3 \cdot u_0 \cdot D}{z_s}$$

where:

u_s	=	the water velocity at the water-sediment interrface (m/s)
z_s	=	the difference between water depth and average draught (m)

Resuspension flux caused by shipping

Resuspension of sediment will occur if the critical shear stress of the sediment (τ_{cr}) is exceeded by the actual shear stress along the sediment (τ_s). As soon as τ_{cr} is exceeded, the sediment will be eroded with an intensity depending on the shear stress and the properties of the sediment in accordance with:

$$E = 0 \quad \text{for} \quad \tau_s < \tau_{cr}$$

$$E = M \cdot \left(\frac{\tau_s - \tau_{cr}}{\tau_{cr}}\right) \quad \text{for} \quad \tau_s > \tau_{cr}$$

$$\tau_b = \rho \cdot \frac{g}{C^2} \cdot u_s^2$$

where:

E	=	erosion flux (kg/m^2/s)
M	=	erosion coefficient (kg/m^2/s) (range: $10^{-5} < M < 0.5*10^{-3}$)
τ_s	=	actual shear stress along the sediment (N/m^2)
τ_{cr}	=	critical shear stress of the sediment (N/m^2)
ρ	=	density of water (kg/m^3) (fresh water: 1000 kg/m^3)
C	=	Chézy coefficient (m$^{1/2}$/s) (in Dutch surface waters mostly between 40 and 60)
u_s		water velocity at the water-sediment interface (m/s)

The erosion coefficient M and the critical shear stress of the sediment strongly depend on the properties of the sediment. The erosion coefficient M can have values

that vary several orders of magnitude (between 10^{-5} and $0.5*10^{-3}$) (Winterwerp and Van Kesteren (2004). In the spreadsheet M has been given a relatively high default value ($0.5*10^{-3}$), which presents a worst case with much resuspension. The user can assign M a lower value.

The value of the critical shear stress of the sediment varies between 0.05 and 1.2 N/m^2. Both erosion coefficient and the critical shear stress of the sediment can be affected by biological factors. Benthivorous fish can lower the critical shear stress of the sediment and enhance the erosion flux. A dense cover of water plants on the other hand can prevent erosion.

Attention: M and τ_{cr} depend on the properties of the sediment and not on the hydraulic conditions. Although the critical shear stress τ_{cr} is determined in experiments on the basis of measured water velocities, τ_{cr} determines the critical water velocity and not the other way round. If the Chézy coefficient changes, τ_b also changes but τ_{cr} does not.

Calculating the concentration increase resulting from resuspension

The average concentration increase resulting from resuspension that is caused by shipping can be calculated in accordance with:

$$SPM = \frac{E_{ship} \cdot n \cdot L}{W \cdot v_{ship} \cdot 86400}$$

where:

SPM	=	suspended particulate matter concentration in water (mg/l)
E_{ship}	=	resuspension flux density per ship ($kg/m^2/s$)
n	=	number of ships per twenty-four hour period (-)
L	=	length of propeller jet (m), this is the length of the affected area at a certain moment
v_{ship}	=	travelling speed of the ship (m/s)
W	=	settling velocity of resuspended sediment particles (m/s)

The length of the propeller jet equals the maximum effective diameter of the propeller or twice the distance between propeller axis and sediment.

Because different type of ships might be navigating in the water body of concern, the average concentration increase of all selected ship types is summed. In the end, the concentration increase of suspended particulate matter in the overlying water column due to resuspension of sediment is calculated (row 57).

The increased SPM concentration in the shipping area can be divided by the surface area of the entire water body in order to assess the influence of shipping on the entire water body. This calculation can be done in accordance with:

$$SPM_{avg} = \left(\frac{L_{route} \cdot W_{res}}{A}\right) \cdot SPM_{sum}$$

where:

SPM_{avg}	=	average concentration increase of suspended particulate matter in the entire water body (not only the affected part) due to shipping (mg/l)
L_{route}	=	length of the shipping route (m)
W_{res}	=	weighted average of the width of the resuspension track (m)
A	=	surface area of the entire water body (not only the affected part) (m^2)
SPM_{sum}	=	average concentration increase of suspended particulate matter in the affected part of the water body due to shipping (mg/l).

4.2.2 *Wind*

Resuspension caused by wind waves occurs if the critical shear stress of the sediment in the water system is exceeded. The actual shear stress along the sediment surface due to wind waves depends on the orbital velocity. This orbital velocity on its turn depends on water depth, the wind speed and the fetch length of the wind over the water surface. The relation between the critical orbital velocity and the critical shear stress of the sediment is complex. However, for relatively flat sediments the easiest way to determine the critical orbital velocity is by adjusting (optimizing) the critical orbital velocity 'trial and error'-wise, until the correct critical shear stress of the sediment is calculated.

The formula to calculate the maximum shear stress along the sediment surface is:

$$\hat{\tau}_s = {}^{1}/_{2} \cdot \rho \cdot c_f \cdot \hat{u}_s^2$$

where:

$\hat{\tau}_s$	=	maximum shear stress along the sediment surface under a wave (N/m2)
ρ	=	density of water (kg/m3)
c_f	=	friction coefficient (-)
$\hat{u}_s$	=	maximum (amplitude) orbital velocity along the sediment (m/s)

The friction coefficient c_f of the sediment surface can be calculated for a hydraulically smooth surface in accordance with:

$$c_f = 0.09 \cdot \left(\frac{(\hat{u}_s)^2 \cdot T}{v \cdot 2\pi}\right)^{-0.2}$$

where:

$\hat{u}_s$	=	maximum (amplitude) orbital velocity along the sediment (m/s)
T	=	wave period (s)
v	=	viscosity of water (m^2/s)

4.2.3 *Bioturbation by fish*

Resuspension due to bioturbation is calculated in accordance with:

$$\text{Concentration SPM } (mg/l) = 0.062 \cdot \text{benthivorous fish } (kg/ha)$$

5 Contribution of sediment to the total concentration in water (worksheet 4)

5.1 Use

From the resuspension that is calculated in worksheet 3 Resuspension one cannot conclude whether standards are exceeded. Only the amount of suspended particulate matter that enters the water column due to resuspension is calculated.

In worksheet 4 SPM & MTR the contribution of contaminants bound to resuspended sediment is converted to the total concentration in water. In this worksheet, the user is not required to enter any data.

5.2 Technical description

In cells F11, F12 and F13 the data are imported from worksheet 3 Resuspension. The contribution of the resuspended sediment to the total concentration in the surface water is calculated in accordance with:

$$\text{Contribution of a contaminant via SPM } (\mu g/l) = \left(SPM_{shipping} + SPM_{bioturbation}\right) \cdot Q_{sed}/1000$$

where:

SPM = concentration suspended particulate matter in water (mg/l)
Q_{sed} = contaminant content in the sediment (mg/kg)

In the worksheet the contribution of shipping is calculated both for the directly affected area and for the entire water body.

6 msPAF (worksheet 5)

6.1 Use

The msPAF calculations of worksheet 5 msPAF use the data that have been entered in worksheet 1 Partition. Subsequently, SEDIAS calculates the PAF for all individual contaminants. At the bottom of worksheet 5 a table containing additional contaminants is presented, but these substances require manual input of the concentration. In rows 11 to 14 the msPAF values (fraction and percentage) are shown both for all substances and for specific groups of substances. Exceptions are:

- Barium (Ba) is not included in the msPAF calculation, because the chemical form of barium in soils and sediments causes uncertainty about its toxicity.
- TBT is presented separately, because this substance is extremely toxic and it would completely dominate the calculated msPAF. Presenting a PAF-TBT separately gives better understanding of the toxicity.
- Substances with PAF values lower than 3% are not included in the msPAF. Extremely high and extremely low PAF values are very uncertain. By not including these uncertain low values, it is prevented that large a number of low PAF values together result in a high msPAF value.

SEDIAS distinguishes four different msPAF types:

- msPAF for macro invertebrates (macrofauna). This msPAF is purely based on macrofauna data and is used in sections 3.6 and 4.6 of the Guidance Document for Sediment Assessment.
- msPAF for all organisms. This msPAF has been included solely for background information. This msPAF in not only based on macrofauna data, but also, for example, on data for fish and algae. The Guidance Document for Sediment Assessment does not specifically refer to this msPAF for all organisms.
- msPAF for higher organisms – fish eaters. This msPAF is used in order to estimate the importance of bioaccumulation (sections 3.7 and 4.7 of the Guidance Document for Sediment Assessment). Only for a limited number of substances a PAF for fish eating higher organisms can be calculated. Therefore no msPAF for fish eating higher organisms could be included in SEDIAS. For some substances no PAF curve is available, but a BCF is. In that case the concentration in the fish eating higher organism (C-fish eater) is tested against the HC50. The HC50 (column AD) is coloured red if it is exceeded.
- msPAF for higher organisms – mussel eaters. This msPAF is also used in order to estimate the importance of bioaccumulation (sections 3.7 and 4.7 of the Guidance Document for Sediment Assessment). Only for a limited number of substances a PAF for mussel eating higher organisms can be calculated. Therefore no msPAF for mussel eating higher organisms could be included in SEDIAS. For some substances no PAF curve is available, but a BCF is. In that case the concentration in the mussel eating higher organism (C-mussel eater) is tested against the HC50. The HC50 (column AM) is coloured red if it is exceeded.

In the menu at the top of the worksheet, one can select the desired msPAF type.

6.2 Technical description msPAF

In column E the concentrations in water are copied from worksheet 1 Partition. For Cd, Cu, Zn, Ni and Pb a correction for complexation has been applied, by assuming that part of the dissolved metal has formed complexes (inorganic complexes are for example $CdCl^+$, organic complexes are complexes with DOC) and that this fraction has a toxicity of only 25% of the toxicity of the freely dissolved metal. This approach is equal to the Dutch approach for the spreading of dredged material on land adjacent to the water body. For Cd, Cu and Zn the following DOC correction factors have been used (Table 2):

Table 2a. Correction factors for complexation for Cd, Cu and Zn (adopted from Osté and Wintersen, 2008).

Metal	Freely dissolved fraction (%)	Fraction of metal complex (%)	DOC correction factor (cf)
Cd	1.8	98.2	0.26
Cu	0.007	100	0.25
Zn	25.6	74.4	0.44

Table 2b. Correction factors for complexation for Ni and Pb using calculated ion speciation.

Metal	Freely dissolved fraction (%)	Fraction of metal complex (%)	DOC correction factor (cf)
Ni	51	49	0.63
Pb	11	89	0.34

For metals therefore, the following formula is applied:

$$c_{pw} = c_f \cdot \frac{Q_{sed,standard}}{K_d}$$

where:

c_f = correction factor for dissolved organic carbon (DOC)

In column F the DOC corrected concentration is shown. Subsequently the ^{10}log-values of the concentrations and the DOC corrected concentration are calculated and shown in columns G and H respectively. The PAF is calculated with the Excel standard formula NORMDIST:

$$\text{PAF} = \text{NORMDIST}\ (\log C_i\ , \mu, \sigma, 1\ )$$

where:

$\log C_i$ = the ^{10}log (concentration) of substance i (mg/l)
μ = the ^{10}log (geometric average of the toxicity data) (mg/l) (column I, P, Z)
σ = standard deviation of the log-transformed toxicity data (column J, Q, AA)

μ and σ have been calculated by the Rijkswaterstaat Centre for Water Management (Van den Ende, pers. communication) based on data from an extensive database (Witteveen+Bos, in preparation).

In order to calculate a multi-substance PAF (msPAF) from individual PAFs, a distinction is made between:

1. Substances with equal toxic modes of action
2. Substances with different toxic modes of action

For the calculation of the overall msPAF, first all substances with a comparable toxic mode of action (TMoA) are summed to a msPAF for this group of substances ($msPAF_{TMoA}$).

6.2.1 *Substances with equal toxic modes of action*

Metals all have their own toxic mode of action, but with respect to organic contaminants the following groups have been distinguished:

- Substances causing non-polar narcosis (PAHs and chlorobenzenes)
- Pesticides affecting the nervous system (OCB and pentachlorophenol)
- PCBs
- Hexachlorobutadiene
- TBT

TBT has not been incorporated in the msPAF, but is separately mentioned as PAF-TBT.

For substances with equal toxic modes of action the number of HUs (Hazardous Units) for the entire toxic mode of action (TMoA) is calculated in accordance with:

$$\mathrm{HU}_{TMoA} = \sum_{1}^{j} \frac{C_i}{10^{\mu_i}}$$

Subsequently the msPAF is calculated on the basis of logHU and $\bar{\sigma}$, the average of all sigma values of the substances with equal TMoA, in accordance with:

$$ms\mathrm{PAF}_{TMoA} = \mathrm{NORMDIST}(\log\ \mathrm{HU}_{TMoA}, 0, \bar{\sigma}, 1)$$

6.2.2 *Substances with different toxic modes of action*

In order to calculate the ecotoxicological risk of the entire local mixture, the msPAFTMoA contribution of the various toxic modes of action are 'added' in a response additive way, in accordance with:

$$ms\mathrm{PAF}_{overall} = 1 - \prod_{TMoA} (1 - ms\mathrm{PAF}_{TMoA})$$

where:

$$\prod_{\mathrm{TMoA}} = \text{the product of the various } (1 - \mathrm{msPAF}_{\mathrm{TMoA}}) \text{ terms}$$

7 SPM & MPC in standard water (worksheet 6)

7.1 Use

In general, the user does not have to enter any data in this worksheet. If the data entered in worksheet 1 Partition are correct, the contribution of the sediment to the contaminant content in standard suspended particulate matter (SPM) and to the concentration in standard water (for the purpose of testing against the Maximum Allowable Concentration (MAC)) are automatically calculated. These calculations are based on the assumption that the quality of the suspended particulate matter is entirely determined by the local sediment quality. The mixing of local suspended particulate matter and suspended particulate matter from other areas is not implemented in SEDIAS.

7.2 Technical description

7.2.1 The contribution of the sediment to the contaminant content in standard SPM

The contribution of the sediment to the quality of the suspended particulate matter is calculated by converting the contaminant content in the sediment to the contaminant content in standard suspended particulate matter[3].

For metals this conversion is done in accordance with:

$$Q_{spm,standard} = Q_{sed,measured} \cdot \frac{A + (B \cdot 40) + (C \cdot 20)}{A + \left(B \cdot clay\ (\%)\right) + \left(C \cdot OM\ (\%)\right)}$$

where:

$Q_{spm,\ standard}$	=	standardized contaminant content in suspended particulate matter, assuming the SPM entirely consists of sediment particles (mg/kg)
$Q_{sed,\ measured}$	=	measured contaminant content in sediment (mg/kg)
A, B, C	=	substance dependent metal parameters (see table 1)
clay (%)	=	measured clay content in sediment (minimally 2%)
OM (%)	=	measured organic matter content in sediment (minimally 2%)

For organic contaminant the first step of the conversion is done in accordance with:

$$Q_{spm,standard} = Q_{sed,measured} \cdot \frac{0.116}{f_{OC}}$$

where:

$Q_{spm,\ standard}$	=	contaminant content in standard suspended particulate matter[4] (mg/kg)
$Q_{sed,\ measured}$	=	measured contaminant content in sediment (mg/kg)
f_{OC}	=	fraction organic carbon (-)

[3] Standard SPM contains 20% organic matter and 40% clay
[4] In standard SPM it is assumed that 50% of OM consists of OC (20% OM = 11,6% OC)

7.2.2 The contribution of contaminants bound to SPM to the contaminant concentrations in standard water

The contribution of the sediment to the contaminant concentration in standard water[5] is calculated by converting the contaminant content in the sediment to the contaminant content in standard suspended particulate matter, as illustrated in paragraph 7.2.1, and subsequently converting this to the concentration in standard water[6].

The standardized contaminant content in suspended particulate matter is converted to a concentration in standardized water in accordance with:

$$c_{standard\ water} = Q_{SPM,standard} \cdot \frac{SPM}{1000}$$

where:

$c_{standard\ water}$	=	concentration in standard water (µg/l)
$Q_{spm,\ standard}$	=	contaminant content in standard suspended matter (mg/kg)
SPM	=	suspended particulate matter concentration in standard water (mg/l); in standard water this is 30 mg/l

[5] Standard water contains 30 mg/l of standard SPM (20% OM, 40% clay).
[6] Only for Cu and As a standard (MPC) in standard water has been derived. For all other metals a standard for dissolved concentrations has been derived.

8 Log of modifications in SEDIAS

Update 4-4-2011:

In msPAF All organisms (worksheet 5 msPAF, selection menu, All organisms) cells T35 and T36 have, as of 4-4-2011, also been included in the msPAF for metals (calculation in cell T41)

Update 15-5-2011:

In worksheet 3 Resuspension the formula for calculating parameter M (cell F17) was incorrect. The result of this calculation was 0.005 instead of 0.0005. As of 15-5-2011 parameter M has a default value of 0.0005, with the advice to alter this value if the sediment involved is relatively consolidated (the remark in cell F17 was correct and remains unchanged).

Update 6-5-2015

The manual has been transferred to a general format and minor linguistic errors have been corrected. The manual has been translated in English.

9 References

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