ENVIRONMENTAL IMPACT ASSESSMENT THROUGH THE APPLICATION OF wPOLIS INTERACTIVE TOOL

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ABSTRACT

In the framework of the SWITCH-ON project (EU FP7 project No 603587) water concerns and untapped potential of open data for improved water management across the EU, are addressed. The overall goal of the project is to establish a "one-stop-shop" for European water information that make use of open data, and add value to society by repurposing and refining data from various sources. The vision of the project is to improve public services and to foster business opportunities and growth by establishing new forms of water research and facilitating the development of new products and services based on principles of sharing.

At a regional level, the Water Directories are responsible for implementing the River Basin Management Plans and establishing relevant programme of measures (PoM) for the protection of the water bodies, whereas establishment of specific water quality objectives and emission limit values (ELV) related to the industrial activities that will enable the conformity to these objectives is a difficult and complex task. In addition, the Water Directories are responsible for issuing environmental permits for any activity (private or public) including the industrial sector.

Our goal, through wPOLIS, which is one of the products developed within SWITCH-ON that focuses on industrial emissions, is to aid the policy makers, environmental agencies and the private sector to improve the quality of surface waters through strategic limitation of pressures from discharges of selected pollutants.

More specifically, wPOLIS can be used to optimise allocation of new activities in order to meet the environmental objectives and protect water quality. Towards this, the competent authorities will benefit from a screening process, operational through an interactive web environment, where different criteria could be used (planning limitations, environmental restrictions, or other legal regulations) in order to limit down the areas suitable for industry allocation. Water quality criteria through the implementation of a water quality model, are also introduced to supplement this application.

Another functionality of wPOLIS is to establish appropriate and realistic ELVs for selected pollutants on the basis of the impact of emissions to the quality of water bodies. These ELVs can be differentiated in space and time and serve as a guide for competent authorities during the environmental permit procedure. This approach gives the possibility to adopt reasonable emission limit values, depending on the circumstances and existing conditions in each river basin, instead of adopting horizontal stricter emission limits.

Keywords: wPOLIS, Water Framework Directive, Environmental Quality Standards, Emission Limit Values, industrial emissions, environmental management

1. Introduction

wPOLIS is an interactive map application which focuses on surface water pollution from industrial emissions. Its main goal is to aid the policy makers, environmental agencies and the private sector to improve the quality of surface waters through strategic limitation of pressures from discharges of selected pollutants.

2. Methods and tools involved
2.1. Models employed

In order to describe the fate of a pollutant in the surface water bodies the advection-diffusion-reaction equation has to be solved for every pollutant, which in 1d is written

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - u\frac{\partial C}{\partial x} + R \qquad (1)$$

where C pollutant concentration [ML^{-3}], D the diffusion coefficient [L^2T^{-1}], u the stream velocity [LT^{-1}] and R the external sink or sources of the pollutant [$ML^{-3}T^{-1}$].

Short computational times are essential for the responsiveness of the wPOLIS web application since the model will be invoked upon user request and will be executed at the web server, therefore complex model with increased data requirements and large computational times should be avoided. The rivers are simulated as 1 dimensional bodies (1d) while lakes and reservoirs are considered as fully mixed cells. Furthermore the steady state solution is sought so this eliminates all time derivatives from the equation. However in order to account for the seasonal variation of river discharges and pollutions loads, the model is applied in a monthly basis in order to obtain representative results of the anticipated concentrations in every water body.

River water bodies are discretized as a network of finite, completely mixed cells connected only by convective terms while dispersion is neglected. This assumption could be valid for small rivers where the dispersive terms could be safely ignored especially at steady state conditions. The elimination of the dispersive terms, which propagate information (concentration) in both directions (from upstream to downstream, but also from downstream to upstream), allows for the analytical solution of the advection reaction equation to be calculated in every segment.

Under these assumptions the general steady state solution for the concentration of a first order decay pollutant can be expressed as

$$C_{i,m}^X = \left(UM_{i,m}^X + SM_{i,m}^X \right) \cdot A_{i,m}^X \qquad (2)$$

where $C_{i,m}^X$ the concentration of pollutant X in cell i at month m [ML^{-3}], $UM_{i,m}^X$ the mass rate [MT^{-1}] of the pollutant X entering the cell i from all upstream cells for month m calculated from $UM_{i,m}^X = \sum_{u}^{u \in u_i} C_{u,m}^X \cdot Q_{u \to i,m}$, $SM_{i,m}^X$ all external sources of pollutant X entering the cell expressed as mass rate [MT^{-1}], $A_{i,m}^X$ a factor [$L^{-3}T$] for each cell and pollutant calculated from $A_{i,m}^X = \left(Q_{i,m}^{out} + k_{i,m}^X \cdot V_{i,m} \right)^{-1}$, $Q_{i,m}^{out}$ the total discharge from cell i to all downstream cells [L^3T^{-1}] for month m calculated from $Q_{i,m}^{out} = \sum_{d}^{d \in d_i} Q_{i \to d,m}$, $k_{i,m}^X$ the decay rate for pollutant X in cell i at month m [T^{-1}], $V_{i,m}$ the volume of cell i at month m [L^3], $Q_{u \to i,m}$ the discharge [L^3T^{-1}] from an upstream cell u to a downstream cell i at month m, d_i the set of downstream cells directly connected with cell i, $\mathcal{D}_i$ the set of downstream cells directly or indirectly connected with cell i, u_i the set of upstream cells directly connected with cell i and $\mathcal{U}_i$ the set of upstream cells directly or indirectly connected with cell i.

A constraint arising from the upwind scheme used for the spatial derivative is that when applying the analytical solution technique at a specific segment all upstream conditions must be known beforehand. Therefore this technique must be applied sequentially from upstream to downstream segments. The model automatically determines which (upstream) water bodies must be simulated and the solution order in order to calculate the pollutants concentrations in an area of interest selected by the user.

Simulated Substances and Processes: The water quality model is applied for suspended sediments and selected heavy metals. An appropriate lumped first order decay rate is used in order to account for biodegradation, volatilization and oxidation of every heavy metal inside the water column.

Suspended Sediments: Settling velocities are used in order to describe the transport of suspended sediment and the absorbed metal from the water column to the sediment bed. The sediment bed is not explicitly simulated therefore the amount of solids and the absorbed metal content that are transferred to the sediment bed are permanently removed from the system. Decay rate for SS can be calculated as $k_{i,m}^{SS} = \frac{v_{i,m}^{settling}}{h_{i,m}}$ where $v_{i,m}^{settling}$ [LT^{-1}] and $h_{i,m}$ [L] the settling velocity of suspended sediment and the water column depth in cell i at month m respectively. Typical values for settling velocities used in the model are 1 m/d.

Heavy Metals: Regarding heavy metals, the effect of sorption i.e. bonding onto solid phases, which greatly affects their dissolved concentrations, is taken into account by introducing a metal partition coefficient which is expressed as the sorbed metal mass (in mg metal per kg sorbing material) to the dissolved metal concentration (in mg metal per L of water). The partitioning of the metal to the soluble and solid phase is assumed to be instantaneous, which is regarded as a realistic assumption (Table 1). The same applies for desorption which although slower than sorption, it is assumed fast when compared to other simulated processes. Equations 3 and 4 describe the distribution of metal between dissolved and particulate phase.

$$C_{i,m}^{M\,diss} = \frac{C_{i,m}^{M\,tot}}{1+P \cdot C_{i,m}^{SS}} \tag{3}$$

$$C_{i,m}^{M\,part} = C_{i,m}^{M\,tot} - C_{i,m}^{M\,diss} \tag{4}$$

where $C_{i,m}^{M\,diss}$, $C_{i,m}^{M\,part}$, $C_{i,m}^{M\,tot}$ the dissolved, particulate and total metal concentrations [ML^{-3}] at month m, P the partition coefficient in [L^{3}M^{-1}] and $C_{i,m}^{SS}$ the suspended sediment concentration [ML^{-3}].

When applying equation (2) for a heavy metal (as total concentration) the decay coefficient k is expressed as $k_{i,m}^{M\,tot} = k_{i,m}^{0} + \frac{P \cdot C_{i,m}^{SS}}{1+P \cdot C_{i,m}^{SS}} \cdot k_{i,m}^{SS}$ where $k_{i,m}^{0}$ [T^{-1}] the metal decay rate due to oxidation and volatilization. As it can be seen metals are depended from SS concentration and must be solved after equation for SS has been solved in the entire domain.
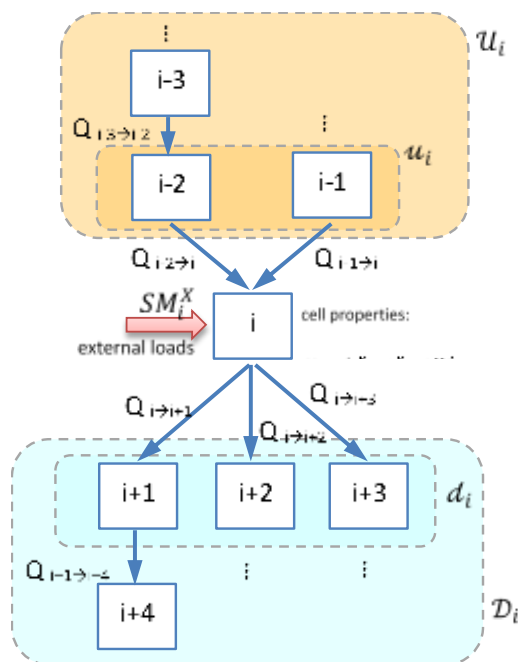

Figure 1: Representation of a river network with mixed cells.

Table 1: Range and typical values of partition coefficients for heavy metals used in wPOLIS (US EPA, 2005)

Metal	Partition coefficient between suspended matter and water (L water/kg SS)	
	Typical value	Range
Cadmium	0,050	0,0006 – 2,00
Chromium	0,126	0,0079 – 1,00
Copper	0,050	0,0016 – 2,00
Zinc	0,126	0,0032 – 7,94
Nickel	0,040	0,0031 – 0,50
Lead	0,398	0,0025 – 3,16

2.2. Technical data

wPOLIS is an interactive web map application accessed through a web browser. The water quality model and its main functionalities are implemented in C#. PostgreSQL is used for data storage along with PostGIS for spatial data. The front end application is written in HTML5 with Bootstrap and Leaflet. Data exchange with the custom models is achieved through JSON standard format.

3. Data processing

3.1. Hydrological data

The HYPE model is used for the calculation of river discharge of the main, surface water bodies of the sub-basins defined in the Greek National River Basin Districts. HYPE simulations provide daily discharges at each sub-basin for an extended hydrologic period. These discharges are then averaged to produce average monthly discharges which are used by the water quality model. Further statistical processing enables the production of synthetic hydrological years.

When flows are known for every river segment, the velocity and the wet area are calculated assuming uniform flow. The slope is estimated from DEM in a sub basin or water body level and not in a segment level, due to limitations arising from the DEM scale and precision. Manning coefficients are estimated for every water body according to its typology available from RBMPs. In mountainous areas where steep gradients may result from the DEM (e.g. >3%), manning coefficients may be increased internally, in order to account for cascade (step-pool) flow conditions. For lakes and reservoirs relevant data for their depths and volumes are obtained from the River Basin Management Plans.

3.2. Pollution Loads

Regarding point source pollution from industrial facilities wPOLIS uses open data from the European Pollutant Release and Transfer Register (E-PRTR). Since E-PRTR contains limited data for Greece, an attempt to supplement these data could be based on the IPPC inventory of Greek facilities and data included in the RBMPs. Another point source of heavy metal quantities entering surface water bodies is related to discharges from Urban Wastewater Treatment Plants. An inventory of Greek UWWTPs with operational data (e.g. discharge, served population, effluent characteristics) is available from Special Secretariat for Water in the context of the implementation of Directive 91/271/EC. When metal concentrations are not being measured on a regular basis, typical metal concentrations (UKWIR, 2014) are used in order to estimate UWWTPs contribution in metal loads.

4. Product functionalities and results visualisation

Exclusion zones. wPOLIS creates maps with areas where the establishment of a new industrial facility should be avoided due to legislative or land planning limitations. Through a step by step process the user selects an area of interest and then specifies the sector, the type of activity and the capacity of the industrial facility, according to the classification defined in the Common Ministerial Decree 3137/191/Φ.15 (Government Gazette B'1048/4.04.2012), while wPOLIS immediately categorizes the disturbance level of the specific facility into high, medium, low or zero.

After the identification of the disturbance level wPOLIS examines several legislative, environmental and land planning rules and limitations in order to limit down the areas suitable for industry allocation. For example activities of high disturbance should be banned from Natura 2000 Areas according to the regulations of Law 3937/2011 (Government Gazette A'60/31.03.20110). Apart from Natura 2000 sites, limitations related to other type of areas e.g. Nature Absolute Protection Areas, National Parks and Forests, Wildlife Reserve Areas, Nature Monuments and Aesthetic Forests have been incorporated into the database of wPOLIS.

The user may also incorporate water quality criteria in the screening procedure, in order to further eliminate the candidate areas. In such case the user provides an estimation of the seasonal variation of selected pollutant loads in kg/month discharged by the industrial facility in the surface water. The model then examines all candidate positions in the area of interest and excludes these areas where the establishment of the industrial facility would result in an exceedance of the annual average or maximum EQS in any of the downstream surface water bodies.

The incorporation of water quality criteria requires the calculation of a contribution factor $B^X_{i \to p, m}$ [L^{-3}T] which is defined between a cell i and a downstream cell p for every pollutant X and for every month m. This factor has units L^{-3}T and actually converts the pollution load discharged in cell i at a rate [MT^{-1}] into concentration [ML^{-3}] in cell p at month m. The model calculates this factor for every month, and for every combination of a cell i and its downstream cells. Contribution factor $B^X_{i \to p, m}$ is calculated from

$$B^X_{i \to p,m} = A^X_{i,m} \cdot \left(\sum_n^{n \in d_i} Q_{i \to n,m} \cdot B_{n \to p,m} \right) \tag{5}$$

As it can be seen the equation of contribution factor B contains in RHS the evaluation of B for the downstream cells in a recursive way, which means that the equation has to be solved beginning from downstream cells. For the point of interest itself the contribution factor B is defined as $B^X_{p \to p,m} = A^X_{p,m}$. For any other downstream boundary cell b, apart from the point of interest itself we set $B^X_{b \to p,m} = 0$. The remaining assimilative capacity $R^X_{i,m}$ [MT^{-1}] of cell i for pollutant X in month m to satisfy the maximum EQS can be expressed as kg/month from

$$R^X_{i,m} = \min_{j \in D_i} \left(\frac{EQS_{max} - C^X_{j,m}}{B^X_{i \to j,m}} \right) \tag{6}$$

where P^X_m the pollution load [MT^{-1}] of industry in month m.
The remaining assimilative capacity $\bar{R}^X_i$ [MT^{-1}] of cell i for pollutant X to satisfy the annual average EQS can be expressed as kg/year from

$$\bar{R}^X_i = \min_{j \in D_i} \left(\frac{12 \cdot EQS_{mean} - \sum_{m=1}^{12} \left(C^X_{j,m} \right)}{\sum_{m=1}^{12} \left(f^X_m \cdot B^X_{i \to j,m} \right)} \right) \tag{7}$$

where f^X_m the seasonal distribution of the pollution load P^X_m calculated from $f^X_m = P^X_m / \sum_{m=1}^{12} \left(P^X_m \right)$. The average assimilative capacity of a cell is not a unique value since it depends on the seasonal distribution f^X_m of the pollution load. A cell i is suitable for the allocation of an industrial facility with pollution load P^X_m if the following expressions hold simultaneously true.

$$P^X_m < R^X_{i,m} \quad \forall \; m \in [1,12] \tag{8}$$

$$\sum_{m=1}^{12} P^X_m < \bar{R}^X_i \tag{9}$$

Otherwise the cell is unsuitable due to an exceedance of EQS annual or maximum in a downstream cell. Equations (8) and (9) should be satisfied for all pollutants X that the industry emits.

ELV determination. This functionality provides a way to determine the Emission Limit Value as the maximum concentration or mass of a pollutant that all facilities can simultaneously discharge while no exceedance of the maximum or annual EQS is expected. User has the option to calculate the ELV either as a steady value throughout the year or as a variable. A second option is to

calculate the ELV either as concentration or as mass rate. In order to calculate the ELV the model ignores the current pollution loads of the industrial facilities in the area of interest and runs a hypothetical scenario where all industrial facilities discharge load $Q_m \cdot ELV_C$ when the user opts for concentration or ELV_M when the user opts for mass rate, where Q_m [L^{3}T^{-1}] the discharge of the industrial facility at month m, ELV_C [ML^{-3}] and ELV_M [MT^{-1}] the ELV expressed as concentration or mass rate respectively. The model runs repeatedly and seeks for the maximum values of ELV_C or ELV_M where the compliance with annual and maximum EQS is achieved for all water bodies in the area of interest and downstream.

Another approach enables the calculation of a variable $ELV_{C,m}$ or $ELV_{M,m}$ for each month m in order to account for the seasonal variation of river discharges. In order to define the seasonal ELV, the maximum EQS is ignored and the model seeks for every month m the maximum value of $ELV_{C,m}$ or $ELV_{M,m}$ so that the maximum observed concentration of all waterbodies equals to the annual EQS. It should be mentioned that the proposed approaches for the ELV determination depend on the hydrological scenario. In order to account for dry hydrological years or for future industrial activity in the area of interest the user may reduce the EQS for selected pollutants.
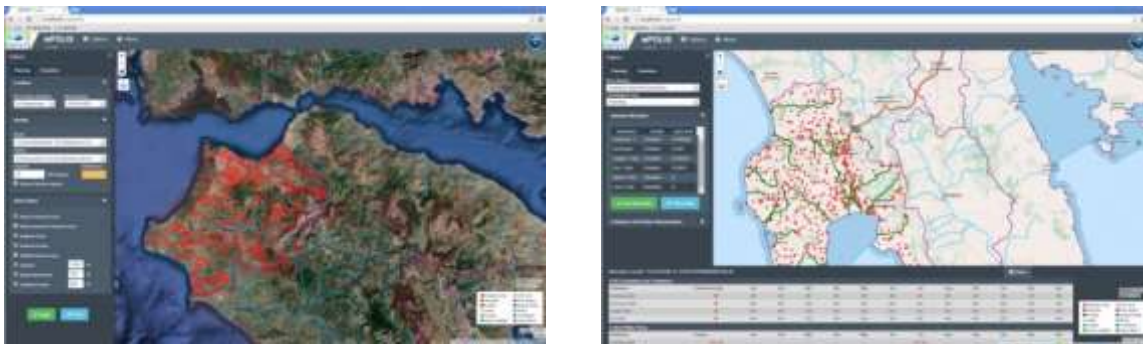

Figure 2: Web environment of wPOLIS

5. Conclusions

wPOLIS is a dynamic tool with high potential that facilitates the examination of candidate areas for the establishment of new industrial facilities inside a river basin district, generates maps with areas where installation of a new facility of specific industrial activity and capacity is restricted, due to environmental, legislative and water quality criteria, and enables estimation of Emission Limit Values of specific pollutants in the effluent of industrial facilities that ensure compliance with the EQS of downstream areas.

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