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The Emission Inventory Water, 
A Planning Support System aimed at reducing the pollution emissions in the surface waters of Flanders, Belgium

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Abstract: The Emission Inventory Water-Planning Support System (EIW-PSS) enables the Flemish Environmental Agency to fulfill its day-to-day monitoring and reporting obligations regarding the pressures and impacts of point and diffuse emissions on surface waters vis-à-vis the Flemish, Belgian and European authorities. Moreover, it helps in the design, prioritization and evaluation of alternative measures to reduce water pollution. It consists of an advanced MS Excel/Visual Basic core intimately linked to an ArcGIS module. The latter is used for locating the sources of pollutants and their pathways to the surface waters at high spatial resolutions. Scenario and “what if” analysis featuring changes of a technical nature, as well as uses of space are supported. This paper discusses the aims of the newest version of the system, its generic approach to surface water pollution and its spatial component. Part of the discussion will dwell on a first case fully implemented namely the emission of heavy metals caused by the building stock. In particular, the heavy metals lead, zinc and copper released by corrosion in the outer skin of the buildings and in the plumbing systems are considered. Literature research and measuring campaigns were carried out to gather the required technical data alongside the development of the methodology and associated models. The outputs were calibrated and validated against independent data. The analytical capabilities of the new version, its explicitly geographical nature, as well as its direct usefulness for policy and planning support, were the main criteria for continuing its development aimed at the incorporation of more sectors and more pollutants.

Keywords: emissions; planning support systems; sewage infrastructure; surface waters.

1. INTRODUCTION

The Emission Inventory Water-Planning Support System (EIW-PSS) is foremost a water emissions accounting tool linking a wide variety of sources of pollutants to their impacts on the water quality. To that effect it couples spatially-explicitly mathematical models and their underlying databases. Pollutants considered are mostly nitrogen, phosphates, heavy metals and polycyclic aromatic hydrocarbons (PAHs). They are of concern because some compounds have been identified as carcinogenic, mutagenic and teratogenic. The EIW-PSS is developed by the Flemish Environmental Agency (VMM) to support it in its monitoring and reporting obligations vis-à-vis the Water Information System for Europe (WISE), especially under art. 3, 5 and 8 of the Water Framework Directive (WFD, 2000/60/EC). They need this tool for two reasons: firstly to determine the significant emission sources and their contribution to the pollution of the surface waters in order to formulate mitigation measures, and secondly, to control and monitor compliance with the
objectives to gradually terminate or stop and decrease pollution as defined in article 4, part 1, under a, point iv of the WFD. Instead of the emission reduction concept from the European Urban WasteWater Treatment Directive (UWWTD, 91/271/EEC), the WFD focuses on immision reduction. The proposed planning support system deals with this new concept, because it considers the pressure on the surface water and follows the pollution from source to sink. The innovative character consists of the generic approach for the quantification of emissions, discharges and losses of hazardous substances from a broad range of point and diffuse sources and the explicit geographical link between source and sink. The latter permits identifying the problematic zones on a high resolution and takes the existing inventories like in the Netherlands [Emissieregistratie Nederland, 2007] one step further [Crouzet and Bogestrand, 1999].

The current EIW-PSS is the result of experiences gained by the Flemish region of Belgium with the development of a tool meant to integrate sources and pollutants required for different reporting obligations. In 2005, the first complete emission inventory (EIW) for heavy metals was realised by Syncera water B.V. [2005] as an accounting system keeping track of the pollutants from a variety of sources towards their sinks in the surface waters. This instrument addressed the problem at a high level of abstraction and simplification. It consists of a sophisticated MS Excel/Visual Basic application and its underlying databases calculating results at the level of the so-called Smallest Geographical Units (SGU), unique polygons created as the intersection of municipalities, Water Treatment Areas (WTA) and sub-catchments. Deficiencies and unexplained loads in the results of the EIW pointed at the need for a more in-depth analysis based on a more geographically explicit approach. Thus, a new version of the EIW was developed as an operational prototype in December 2006 by the Flemish Institute For Technological Research [Engelen et al., 2006]. This prototype focused on quantifying the emissions of one particular type of pollutants only, namely heavy metals, caused by one single sector only, namely the building stock. It calculated and located the emissions and their transport at a 60 metre resolution. With a view to test the applicability, robustness and sensitivity of the tool and the models incorporated, a follow-up study [Engelen and Van Esch, 2007] focused on a historical analysis for the years 1998, 2002 and 2005 and carried out a number of policy relevant scenario-analysis. Based on the experiences gained in the context of both projects, a decision was made to extend the methodology to all pollutants and all emission generating sectors and stakeholders. Thus, the concept of a generic EIW-PSS was born.

2. EIW – PSS: CONCEPTUAL FRAMEWORK

In Figure 1 the elements of a complete Emission Inventory Water (EIW) are depicted schematically. The components of the system are the inventory of sources, the calculation of the gross emission, the pathway, the material flow analyses and the geographical allocation of the discharge into the surface water (pressure). The sources are classified in categories, with distinction between point (in italic) and diffuse sources (See also Figure 2). They are represented in the various boxes on the left side of the diagram. They can be opened to retrieve information at a more detailed level and new sources of pollution can be added in case relevant new information and knowledge becomes available. Emissions are calculated on a sector-by-sector basis including: agriculture, industry, households and traffic. Emissions caused by materials used in buildings and road infrastructure, as well as natural processes such as atmospheric deposition are also considered. Pollutants follow different pathways from the source to the receiving aquatic environment. These pathways may involve: direct losses to the surface water, discharge to the sewer system or running of at the surface. For wastewaters delivered to the urban wastewater treatment plants, technical coefficients are applied to calculate the amounts of various compounds removed as part of the treatment. The pollutants that finally arrive in the surface water generate pressure. Transport of emissions in water courses and loads thus entering the study region are currently beyond the scope of the EIW-PSS. Rather, they are dealt with by hydrological modelling tools running in parallel. Thus, the EIW-PSS focuses strongly on emission sources, material flows and the pathways to the surface waters.
In order to implement the depicted EIW, various modules are invoked in function of the precise characteristics of the pollutant considered and its transport. Three sets of modules are available in the EIW-PSS to process the pollutant from its source to the surface waters (see Figure 2).

**Figure 1.** Functional scheme of the EIW-PSS: emission sources and pathways.

**Figure 2.** Representation of various modules integrated in the EIW-PSS.

The first set comprises modules enabling an adequate geographical distribution of the source itself and the amount of pollutant that it generates. Sources can be point sources, meaning that they are precisely located by means of their X-Y coordinates. Industrial facilities are a good example of this. But sources can just as well be diffuse and cover the entire territory in pockets of higher or lower density. This is the case among others for atmospheric deposition. Finally sources can be distributed along networks or line objects. Various forms of traffic and road infrastructure are examples of the latter. A special case are rivers and canals. Sources associated with the latter, such as PAHs emitted by the skin...
of boats, end up directly in the surface waters and need no further processing relative to their transportation.

The second set of modules enable the transport of the pollutants from the source to the surface waters. Overland transport of diffuse sources will be handled by a run-off algorithm. Pollutants thus transported will end up directly in the surface waters, in ditches and other drainage networks and/or in the sewage network. Point sources will often deliver their waste waters directly to the sewage system. Parts of the sewage networks will transport the waste waters and dissolved pollutants to the sewage treatment plants where the pollutants are partly removed. The remainder will be discharged in the surface waters as part of the effluent. Part of the pollutants will infiltrate into the soil and further into the groundwater. They are transported dissolved in the groundwater to the surface waters.

The characteristics of the treatment infrastructure and the territorial coverage subject to waste water treatment is known to the accounting modules of the third set. Accounts are produced at various nodes in the Material Flow Scheme (See Section 3.3) for pollutants removed and those reaching the surface waters and for relevant administrative or hydrological entities by aggregating the information available at the cellular level, polygons and/or line segments.

Fundamental principles underlying the accounting and the calculation of the transport of pollutants in the EIW-PSS are Conservation of Mass and Material Flow Analyses. They are not discussed here, rather will be dealt with in the example of Section 3.

For every source and every pollutant the relevant modules are selected from the three sets discussed. They are processed in a linked and sequential manner. In Figure 2 the modules are represented by means of map-layer symbols as they are predominantly geographically explicit sub-models implementing various spatial allocation, networking, dis-aggregation and aggregation algorithms. The modules in green operate currently as part of the EIW-PSS in a more or less final form, while layers in orange still need to be developed. Section 3 of this paper will discuss in greater detail the application of the above-mentioned as it has been applied to heavy metals caused by the building stock sector. This is a typical example of a diffuse source with transportation mainly through the sewage system. Models to calculate run-off at the surface and infiltration are not (yet) incorporated in this first prototype (orange in Figure 2).

In order to calculate the gross emission of a particular chemical compound generated by a sector, the Emission Explanatory Variables (EEV) and associated Emission Factors (EF) are estimated. The beauty of both concepts resides in their generic and the recursive applicability. Simply stated, an Emission Explanatory Variable is a further specification of the size of the source, a statistical number which can be updated on a for instance yearly basis. When applied to PAHs generated by transportation (exhaust of vehicles, wear of tyres, wear of the asphalt, oil spilled on parkings, etc.), EEVs include the number of driven kilometres, the surface of the parkings, etc.. EEVs have an explicit geographical distribution, meaning that they can be located on a map to result in areas of higher and lower densities. Emissions Factors are estimates of the amount of pollution generated per unit length, surface, weight or any relevant unit used to represent the EEVs. The more information is available about the pollution in the sector the more EEVs can be subdivided in smaller components and sub-components. For example for the sector building stock EEVs were several hundreds of hierarchically nested components exposed to atmospheric influences and water in the plumbing systems of various types of buildings. Multiplication of the EEV, its size (expressed as a length, a surface, a volume, …) and its associated EF results in the Gross Emission Value (GEV). In the EIW-PSS the GEV are calculated per unit length or area. Hence, the aforementioned multiplication requires a further summation, if not a multiplication with the units of EEV per unit length or area.

3. SPATIAL ANALYSIS OF THE BUILDING STOCK

The spatial component of the EIW-PSS allocates the main sources of pollution in a raster representation at a 60 metre resolution, incorporates the detailed representation of the sewage collection systems canalizing the pollutants to Urban WasteWater Treatment
Plants (UWWTPs), generates gross (prior to treatment) and net (after treatment) emission maps and produces accounts for catchment and administrative entities at different hierarchical levels.

In order to clarify the concepts introduced in the previous section as well as their practical implementation in the EIW-PSS, a closer look is taken at the example of the building stock currently implemented. Building stock refers here to all buildings for residential, commercial and social activities. It also includes the housing and office buildings of small industrial production units and farms, but excludes the industrial installations. The latter are an integral part of the analysis at the level of the industrial and/or agricultural sector itself. Building stock also includes materials used for fencing off and for equipping the terrains surrounding the buildings. The discussion is limited to the spatial component of the EIW-PSS. Readers interested in the estimation of the EEVs and EFs and in technical details about the mathematical models are referred to the original study [Engelen et al., 2006].

The spatial component of the EIW-PSS can be described in three successive steps (3.1, 3.2 and 3.3, Figure 3) described below. They are related to the three modules of Figure 2: ‘spatial distribution of the source’ in 3.1 and 3.2 and the modules ‘transport route from source to surface water’ and ‘accounting’ in 3.3. Chapter 3.4 shows an example of validation, based on the measured influent at UWWTPs.

3.1 Step 1: Spatial distribution of the building stock

Based on the data available, and taking into consideration typical function, morphology, location in space and application of building components, the following eight building types were withheld:

- row house;
- semi-detached house;
- detached house, farm or castle;
- apartment building;
- commercial building;
- industrial building;
- shack, garage and other small buildings including greenhouses;
- other building.

From the Belgian Federal Statistics data are available at the municipality level (308 in Flanders) for all building types. For the first four types, data are also available at the level of the so-called statistical sector which is a sub-division of the municipality (some 9500 in Flanders). The most detailed information (municipality or statistical sector) was used to spatially allocate the eight building types at a higher spatial resolution. A dasymetric mapping algorithm nearly identical to that of Mennis [2003] was chosen to that effect. It is generic, hence it also applies to other sectors covering the full territory.

Dasymetric mapping [Eicher and Brewer, 2001], [Mennis, 2003] is a technique enabling a cartographic representation of a spatial feature, in the given case buildings of a particular type, for which data are available at the level of relatively arbitrary spatial units, in the given case municipalities and statistical sectors, reflecting more realistically the precise spatial location of the feature within those spatial units. To that effect, use is made of ancillary (cartographic) information representative of the location of the feature. In the given case, the ancillary data is derived from the land-use map of Flanders at the 15 metre resolution available from the AGIV, the Agency for Geographical Information Flanders. The original map is resampled at the 60 metre resolution. The latter is in part a pragmatic choice enabling a straightforward aggregation of the original 15 metre cells, but it also recognizes the Flemish environmental legislation stating that buildings within a 50 metre buffer from a sewage collection pipe are to connect to that pipe. When overlaying the detailed location of the sewage system (in Step 3 of the procedure), it thus is possible to distinguish between grid cells that should and should not connect. Prior to the resampling, the original 20 land uses of the map were grouped into seven classes most relevant for the location of the building types.
The dasymetric mapping algorithm is performed in MS Excel. A distribution code has been established to link the eight building types with the seven land use types. Row houses are for instance for almost 100% allocated in the urban fabric land use category. The distribution equation contains also a component to correct for the fact that every land use type is not equally present in every statistical sector.

In the calibration and validation of the procedure, the amount of buildings allocated per cell was compared with reality and the distribution code together with other technical coefficients were adjusted through iteration until a best fit with reality was obtained. The typical density of buildings allocated per land use cell could be estimated based on statistical sectors where only one land use type was present. It was further adjusted based on expert knowledge. Around 2.5 million buildings (situation 2005) were thus allocated. The result of Step 1 is a set of eight maps representing the distribution of each building type.

**Figure 3.** The spatial component of the EIW-PSS applied to the building stock.
3.2 Step 2: Generating gross emission maps

Once the detailed distribution of each building type is known, the next step consists in calculating the gross emissions generated in situ. To that effect, the Belgian Building Research Institute developed an elaborate database of building components used now and in the recent past (+/- 30 years ago). Regional differences in the building practice and tradition were taken into consideration. Only components in the outer shell exposed to the atmosphere and those in the plumbing circuits were withheld. Data was collected relative to quantities used in each of the eight types and the amount of metals emitted on a yearly basis. Metals withheld were copper (Cu), zinc (Zn), lead (Pb), aluminum (Al), chromium (Cr) and nickel (Ni) but sufficient information to perform all steps of the analysis was only available for the first three. The information is obtained from literature research, a survey among building practitioners and major producers and distributors of zinc and copper. In addition, high resolution remote sensing images from Google Earth combined with field visits were used to define prototypical buildings with their associated building components.

Gross Emission Values (GEV) were established for the eight building types and for the three metals. A distinction was made between metals corroded in the outer shell of the buildings, hence feeding the surface run-off, and the sanitary waters originating in the plumbing circuits. As a result, the EIW-PSS provides maps for both the surface and sanitary waters for both gross and net emissions (see Step 3). The reason for this distinction is based on the growing importance given to decoupling in Flanders involving separate systems for the transport of surface run-off and sanitary waste waters.

The GEV are multiplied with the number of buildings (obtained from Step 1) on a cell-by-cell basis to result in gross emission maps per building type, per metal and per type of transport. The sum over all building types results in the gross emission maps per metal and per type of transport. The latter are input in Step 3.

3.3 Step 3: Transporting the emissions from source to sink and accounting

The Material Flow Scheme (Figure 4) is applied to the gross emission maps. This is another generic cornerstone of the methodology that can be applied for each sector individually. It shows how pollutants flow from the source to a sink via a number of nodes, mostly intermediate stations relevant for monitoring and reporting purposes. Conservation of mass applies, hence, the amount of pollutant entering a node is equal to that leaving the node. In this first prototype, no chemical reactions or leakages in the sewer system during transportation are taken into account.

**Figure 4.** Material flow scheme of the EIW-PSS.
When applied to the building stock, pollutants running off at the surface to end up directly in the surface waters or infiltrating in the groundwater (node ‘Direct losses and discharges’) are estimated on the basis of coefficients obtained from hydrological models external to the system. This will change in the future when run-off and infiltration algorithms will be incorporated in the EIW-PSS (See Section 2). Most importantly for VMM are pollutants physically transported and treated by means of the sewage infrastructure (Figure 4: node ‘Sewer system’). In the spatial analysis, this is implemented by overlaying the gross emissions with the vector layer representing the highly detailed sewage collection system of Flanders. A reasonably limited number of cells deliver their waste waters and emissions to a sewage collection system to be transported to an UWWTP (Figure 4: zone A). Zone B has a sewer system that is not yet connected to an UWWTP, but will be in the near future while for zone C there is no intention at all to connect the sewer system to an UWWTP. The application of the EIW-PSS to the building stock revealed that 57 per cent of the waste waters generated by the population of Flanders is treated in an UWWTP (‘Zone A’) and that 78 per cent of the population is connected to a sewage system (‘Zone A’ + ‘Zone B’ + ‘Zone C’). These numbers match very closely the ones used by the Flemish Environmental Agency based on alternative sources (respectively 60 and 80 per cent). Technical coefficients concerning treatment efficiency of the UWWTP (purification rates for each UWWTP and each metal, measured by the VMM), physical pre-treatment (Figure 4: node ‘UTD’, also available for each UWWTP and each metal) and storm weather overflow (Figure 4: node ‘Overflow’) are applied to calculate net emissions. This results in a net emission map per metal and per type of transport. By way of example, Figure 5 shows the net emission map for zinc summed for the two types of transport (surface and sanitary waters). The discharges of pollutants at the outlet of the UWWTPs are represented by bars.

Figure 5. Net emissions of zinc due to the corrosion of the building stock.

3.4 Example of calibration and validation

It is possible to examine the quality of the model by comparing the calculated amounts of a heavy metal with the measured amounts at the inlet of the UWWTPs. The measured influent involves all sources while the prototype for the moment only calculates for the building stock. However, the first version of the EIW (Syncera water B.V., 2005) calculated emissions for all sectors and these estimates can be used to complete the prototype temporarily for the missing sectors. Figure 6 shows this validation applied onto zinc. In the first version of the EIW, the building stock represented 56% of the total calculated load. In the above-described prototype, completed with data of the first EIW, 71% of the calculated influent originates from the building stock. When confronting the total calculated influent with the total measured influent of zinc (181 ton/year), 64% of the
measured load could not be linked to a source in the first version of the EIW. In the above-described model, this proportion already decreased to 45%.

![Figure 6](image.png)

**Figure 6.** Validation at the inlet of the UWWTPs, confronting calculations with measurements for zinc.

4. **THE EIW-PSS: PLANNING AND POLICY APPLICATIONS**

The EIW-PSS provides the VMM with an important planning support system enabling a quantification of the pressures and impacts of point and diffuse emissions caused by different sectors and stakeholders. The algorithms implemented conserve the true geographical nature of the processes at high spatial resolutions, thus enabling an analysis and establishment of spatially explicit mitigation measures. Such spatial approach is most relevant for regions like Flanders, typified by high population densities and associated environmental pressures.

The study of the building stock revealed the benefit of a generic system enabling the straightforward assessment of scenarios. One such exercise analysed the evolution relative to heavy metal emissions in the period 1998-2005. It analysed improvements in the sewage system and treatment facilities (more area of zone A, more UWWTPs, higher purification rates, less UTD …) as well as changes in the mix of buildings, their location in space and changes in the building materials used. The latter is especially interesting for historical analyses but also to explore the influence of land use change in the future (indicated by external land use change models, calculating 30 years ahead for instance). The sensitivity of several policy relevant parameters was also examined, among which the efficiency of septic tanks and the obligatory installation of individual treatment plants servicing remotely located buildings. Figure 7 demonstrates among other things the reduction in total emissions that could be realized if zone B would be connected to an UWWTP. Alternatively, similar reductions of the emissions could be attained in the ‘individual treatment’ zone with individual WWTPs featuring higher purification rates.

![Figure 7](image.png)

**Figure 7.** Quantification of the heavy metals in the nodes of the material flow scheme.
5. CONCLUSIONS

The EIW-PSS is an innovative tool supporting the Flemish Environmental Agency in their monitoring and reporting obligations as well as their scenario, planning and policy assessments. The conceptual framework and methodology have been elaborated with a generic usage in mind, and, their application to a first sector, namely the emission of heavy metals caused by corrosion in the building stock, showed satisfactory results. Among others, the study reduced the unexplained emission loads of Cu, Pb and Zn at the inlet of UWWTPs substantially. The results of the analysis carried out as well as the scenario capabilities of the first prototype were an impetus to continue the development.

Clearly, the deployment of the full framework in all its details will take time and effort. Effort will go into the development, integration and calibration of the various algorithms as part of the modules required to complete the scheme of Figure 2. Knowledge and modelling components to that effect will be derived from the literature, but also from state of the art applications. This should result in a system as generic as possible, yet, enabling the implementation of all the sectors and pollutants of interest. A system also which is sufficiently straightforward in its application so that it can be used for a wide range of policy relevant exercises by its envisaged end users. Specific studies will need to be carried out sector-by-sector and pollutant-by-pollutant. This will typically involve exhaustive literature research supplemented with measuring campaigns. Hence, at any particular point in time, the availability of information and resources will determine largely the level of depth that can be attained in representing sectors and their emissions. However, such type of development will not withstand the usage of intermediate versions of the system for practical purposes as the methodology allows for the representation of different sectors at different levels of detail. In the course of time the EIW-PSS can be upgraded with more and better information to evolve into an increasingly powerful planning support system.

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