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Web-based decision support to set up cost effective programs of measures for multiple water aspects

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Abstract: The Water Framework Directive (WFD) requires Member States to ensure that all waters meet 'good status' and to publish river basin management plans that include programs of cost-effective measures. VITO supported the policy makers in Flanders (Belgium) with the preparation of the first generation of river basin management plans and more specifically with the assessment of the costs and effects of programs of measures. The environmental costing model was used to select cost effective measures to improve surface water quality. The public consultation process of the river basin management plans and a user requirements analysis resulted in recommendations for further development of the model, As a result, the scope of the model was expanded with a more extensive analysis of multiple water aspects, such as surface water quality, hydromorphology, floods and sediments. A web-based decision support tool was developed to make the reporting structure more transparent. This tool includes all the necessary data to assess costs, effects, benefits and affordability of packages of measures. Information about status, pressures, costs and effects of measures can be retrieved and simulation results can be generated on different scales, from individual water bodies to regional level. End users can build up draft packages of measures (scenarios), assess their costs and effects and share these scenarios with other users (e.g. users building scenarios for other aspects or for other water bodies). The tool will be used by the policy makers in Flanders in preparation of the next generation of river basin management plans.

***Keywords**:* Cost effectiveness analysis, water framework directive, decision support.

1 INTRODUCTION

Inspired by the proclamation of water as economic good, the European Water Framework Directive (European Commission, 2000), adopted in 2000, explicitly integrates economics into both water management and water policy decision-making in Europe. The main objective of the Directive is to meet good status of all waters by 2015. To ensure that this goal will be met, member states have to assess the current state of all waters, existing pressures, identify significant water management issues and publish river basin management plans to tackle these issues. The Water Framework Directive clearly integrates economics into water management and water policy decision-making. To achieve its environmental objectives and promote integrated river basin management, the Directive calls for the application of economic principles (for example, the polluter-pays principle), economic approaches and tools (e.g. cost-effectiveness analysis) and instruments (e.g. water pricing) (WATECO, 2003) in order to achieve its environmental objectives and promote river basin management.

Member states spent a lot of effort to put these principles into practice in the first River Basin Management Plans, published in 2009. This also lead to a large range of recent articles on cost-effectiveness analysis, hydro-economic modelling and decision support systems. Recent articles on cost-effectiveness analysis include (Bedru Babulo Balana, Vinten, & Slee, 2011; Berbel, Martin-Ortega, & Mesa, 2011; Cardenas et al., 2011; Panagopoulos, Makropoulos, & Mimikou, 2011, 2012; A. J. A. Vinten et al., 2012). An important drawback of existing analyses is that they are single effect approaches. Measures are typically ranked by cost effect ratios representing one specific effect, mostly surface water quality (nutrients) or water consumption. This means that measures with impacts on multiple water aspects are difficult to consider in this analysis and that their true benefit is only partly taken into account. A review by Balana et al, 2011 confirmed that most CEAs concentrate on a single ecological effect of measures and examine less co-benefits. This is an important drawback as integrated water management is specifically aimed to reach good water status for different aspects (water quality and quantity, groundwater and surface water, ecological quality, sediments) and wants to stimulate an increased implementation of multi-purpose measures creating win-win situations for multiple water aspects. Typical tools are designed for a specific purpose which is difficult to match with the requirements of the Water Framework Directive.

The decision support system we discuss in this paper is a web based tool specifically aimed to support policy makers in developing cost effective programs of measures for different water aspects as required for the 2nd generation management plans in Flanders, Belgium. This tool deals with different water aspects, different scales and integrates outcomes of hydrological models with economic aspects.

2 STUDY AREA

Flanders is a highly urbanized region with a surface of 13,521 km² and a population of more than 6 million inhabitants. The region is part of two international river basin districts, the Scheldt and the Meuse. The water system mainly consists of lowland rivers with wide valleys and slow flow velocities. Highly industrialized areas are the ports of Antwerp and Ghent. Agriculture is mainly intensive and cultivated land occupies 45% of the area. Pressures on the water system are high. The assessment of the current status in 2009 (Coordinatiecommissie Integraal Waterbeleid, 2009) indicated that a very small amount of surface and groundwater bodies are in good status. Significant water management issues are surface and groundwater quality (nutrients, chemicals), flooding (sea level rise), sediments (dredging and processing polluted sediments), hydromorphology, restoring natural conditions and droughts (groundwater quantity in specific areas).

The need for additional measures is clear. However, both from a technical and economic side it is very difficult to reach the objectives. From a technical point of view, it is especially difficult to restore rivers in a highly urbanized area and to tackle diffuse pollution and historic pollution stocks present in groundwater and sediments in a short term. From an economic point of view, reaching good water status is very expensive. A large share (60%) of the environmental expenditures by the government is already going to water policy. Also, the financial burden for the different sectors (households, industry, agriculture) related to water increased significantly in the last decade. The drinking water price for households increased by 63% between 2005 and 2011 (VMM-MIRA, 2012).

These facts and figures indicate that the added value of setting up cost effective management plans is high and that important attention needs to be given in establishing win-win situations by implementing measures impacting different water aspects simultaneously. The cost effectiveness analysis for the first generation river basin management plans was based on a mixture of qualitative assessments based on scores for both costs and effects and a quantitative assessment for basic surface water quality parameters as described in (S Broekx, Meynaerts, Wustenberghs, D'Heygere, & De Nocker, 2011; Cools et al., 2011). Though results were used for designing the program of measures, several issues were identified in public consultation procedures. A major challenge is related to scaling issues. What is cost effective on a regional scale is not necessarily cost effective on a local water body scale. A second challenge is related to multiple water aspects. What is cost effective for a specific water aspect, might be less cost effective when we try to realise the good water status in general. A third challenge is related to transparency. Especially to find the necessary support to actually influence decision making processes, the data both for costs and effects and calculation methods need to be documented extensively.

To tackle these challenges, a web based tool was proposed that looks into multiple water aspects, provides information for multiple scales and gives a clear view on available data and uncertainty. The design of this tool depended significantly on a user requirements analysis.

3 USER REQUIREMENTS

User requirements for a decision support tool were derived from a series of interviews with expert groups, responsible for setting up programs of measures for specific water aspects, and river basin managers, responsible for setting up management plans on local and regional scales.

A first user requirement is to provide information in a structured way in order to contribute to decision making. This includes a representation of the state of the water system, the pressures coming from different economic sectors and the potential impact of measures. Data on measures need to be detailed, include uncertainty margins and include the source of information. Boundary conditions for applying certain measures are also considered as important information.

The economic analysis needs to include cost effectiveness analysis but also information on benefits and affordability as a basis for disproportionate cost analysis. If no quantitative data exist, qualitative information is also considered useful. Marginal cost curves are considered an informative instrument to get a better view on cost effectiveness analysis in general. Extensive, multi-objective optimization algorithms are less desired by potential end users. Reasons for this are twofold. On the one hand, optimal solutions do not exist in many cases as not enough technical reduction potential exists to realize all targets. Consequently, multi-objective optimization problems cannot be solved or only be solved by reducing targets to the maximum potential, which in the end leads to a selection of all measures and to relatively little insight in the cost effectiveness of individual measures. On the other hand, a cost effectiveness analysis has difficulties in dealing with qualitative information as public acceptance and implementation complexity. End users see more added value in scenario development on a trial & error basis, as the amount of potential measures is not very large (< 100), especially on a local scale. The ability to easily compose and exchange scenarios across different water aspects was considered very interesting.

Actualisation of data is another big challenge. The proposed reference year for the next generation management plans is 2012. This means we need to be able to integrate data on state, pressures and measures in a very short time frame (6 months). Also, end users need to be able to integrate more accurate information of local circumstances where available.

4 SOFTWARE DESIGN

The public consultation process of the river basin management plans and a user requirements analysis resulted in recommendations for further development involving a more extensive analysis covering multiple water aspects as water quality, hydromorphology and sediments, a more transparent structure reporting information on different scales and for different scenarios.

The web-based decision support tool focuses on:

- Functionalities: information about status, pressure, costs and effects of measures and simulation of costs, effects, cost-effectiveness, benefits and affordability of packages of measures.
- Scales: information retrieval and simulation results that can vary from individual water bodies to regional level.
- Water aspects: surface water quality, sediments, hydromorphology, floods.
- Interactive: users can built up draft packages of measures (scenarios), assess their costs and effects and share these scenarios with other users (e.g. users building scenarios for other aspects or for other water bodies).

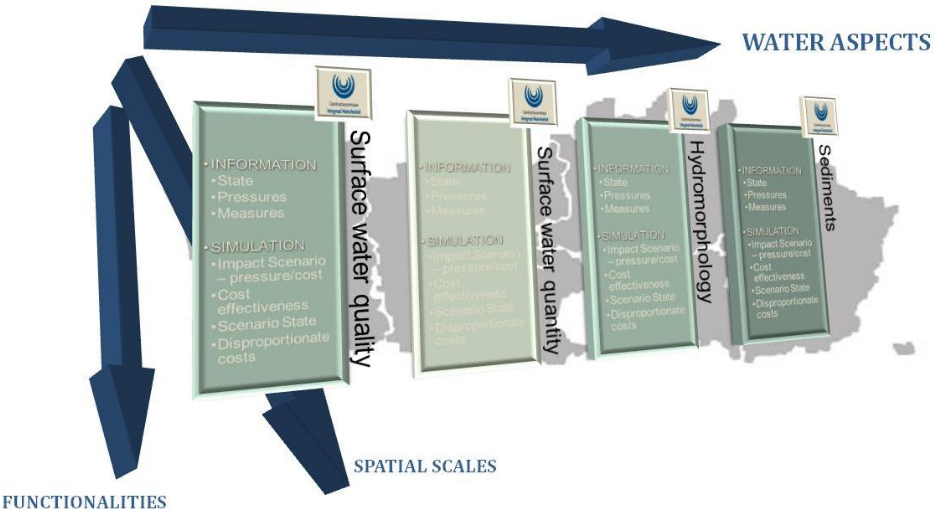


Figure 1. 3D requirement matrix of decision support tool

The web application is developed using JSF (Java Server Faces), a Java-based framework that supports the construction of web applications. The most important Java libraries used are RichFaces, Hibernate and JFreeChart. Also GIS data on the water system, location of sources and measures can be consulted. To make the GIS data available in the web application, GeoServer is used as GIS server. GeoServer implements the OGC standards WMS and WFS, which are standard protocols for serving GIS data over the Internet. To display these maps in the web application, two javascript libraries are used: OpenLayers and GeoExt.

5 METHODOLOGY

5.1 Scales

The web-based tool can produce results at different spatial scales ranging from the larger regional scale (Flanders), over river basin scale down to water body scale. One reason for producing results at higher levels of scale is that spatial differentiation of programs of measures is not always practical from a policy perspective (for instance emission reduction targets for agriculture or wastewater treatment). However, results of lower scale levels also indicate that results on these scales are useful and can lead to significantly different results as described in (Broekx et al., 2011).

Spatial interdependencies are also specifically challenging for water management. Measures installed upstream, also have an impact downstream. Two approaches are possible. Extending the optimisation problem to include multiple location constraints is a first option. Another approach is stepwise scenario building where cost effective measures are first determined in upstream regions and are a starting point of the analysis in downstream regions. For tidal areas this stepwise approach can be opposite. To determine measures for tidal floods for instance, downstream areas are more likely to be the starting point and effects propagate upstream.

5.2 Information on state, pressures and measures

Databases are set up on pressures, state and measures. For pressures it is important to know the contribution of the different sources to an environmental issue. The pressure database is important as it will be used by both the hydrological models and the cost effectiveness analysis. Information on measures consist of costs and effects. Effects are expressed as the effectiveness of reducing pressures from a specific source. Costs are investment and operational costs for installing a certain measure. Mostly all costs are transferred to discounted annual costs.

Table 1. Overview state, pressures and measures for different water aspects

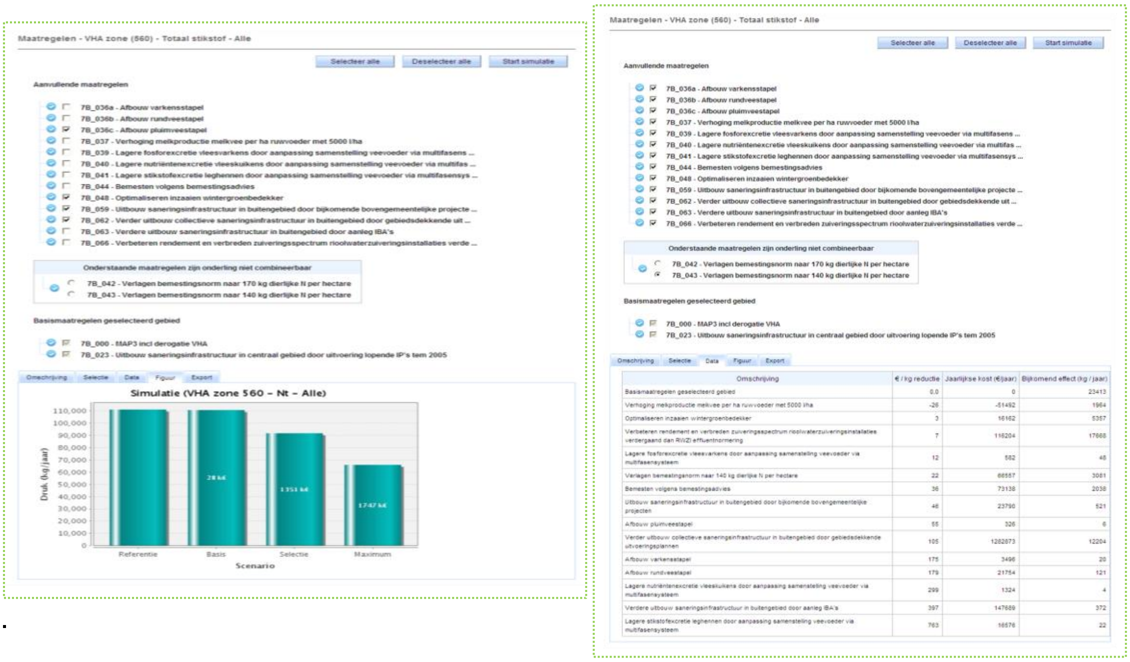
Water aspect	State	Pressures	Measures
Surface water quality	Concentrations BOD, COD, SS, Nt, Pt	Households not connected, WWTP, industry point sources, agriculture diffuse sources	Sewage – WWTP Indiv. treatment households and industry Reducing livestock Manure treatment Erosion prevention
Sediments	Sediment quantity and quality	Point sources suspended soils, erosion losses	Reducing point souces suspended solids Erosion prevention: buffer strips, cover crops, reduced tillage Dredging, sediment traps
Hydro-Morphology	Hydromorphological quality indices	/	Fish stairs, river restoration
Flood risk	Flood risk 2000 – 2100	Climate change (risk 2100)	Dykes, flood plain restoration

5.3 Building scenarios and impact on pressures

Scenario building was identified by end users as an important feature. A scenario consists of a selection of measures which can be easily adapted. A number of predefined scenarios relate to the basic measures and the program of measures as defined in the 1st river basin management plan. Users can develop, change, share and publish scenarios. Scenarios are mostly used as a starting point to perform simulations on the impact on pressures and cost effectiveness analysis. The impact on pressures is expressed as reduced emissions, reduced sediment losses or reduced flood risk. Sediment losses were derived from calculations with the WaTEM/SEDEM model (Water and Tillage Erosion Model / Sediment Delivery Model)(Van Rompaey A.J.J. Verstraeten G., Oost, Govers, & Poesen, 2001;

Verstraeten, Oost, Rompaey, Poesen, & Govers, 2002). Flood risk is based on a combination of flood simulations and damage assessments as described in (Steven Broekx et al., 2010). For hydromorphology no quantitative indicators are available in Flanders to assess the impact of measures. We use a qualitative approach to demonstrate that measures impacts specific aspects of hydromorphology

End users are able to change scenarios in every simulation screen. If measures are added to preselected scenarios and prove to be interesting, users expressed the need to save these changes in a new or updated scenario.



Maatregelen - VHA zone (560) - Totaal stikstof - Alle

Aanvullende maatregelen

☐ 7B_036a - Afbouw varkensstapel
☐ 7B_036b - Afbouw rundveestapel
☑ 7B_036c - Afbouw pluimveestapel
☐ 7B_037 - Verhoging melkproductie melkvee per ha ruwvoeder met 5000 l/ha
☐ 7B_039 - Lagere fosforexcretie vleesvarkens door aanpassing samenstelling veevoeder via multifasens ...
☐ 7B_040 - Lagere nutriëntenexcretie vleeskuikens door aanpassing samenstelling veevoeder via multifas ...
☐ 7B_041 - Lagere stikstofexcretie leghennen door aanpassing samenstelling veevoeder via multifasensys ...
☐ 7B_044 - Bemesten volgens bemestingsadvies
☑ 7B_048 - Optimaliseren inzaaien wintergroenbedekker
☑ 7B_059 - Uitbouw saneringsinfrastructuur in buitengebied door bijkomende bovengemeentelijke projecte ...
☑ 7B_062 - Verder uitbouw collectieve saneringsinfrastructuur in buitengebied door gebiedsdekkende uit ...
☐ 7B_063 - Verdere uitbouw saneringsinfrastructuur in buitengebied door aanleg IBA's
☐ 7B_066 - Verbeteren rendement en verbreden zuiveringsspectrum rioolwaterzuiveringsinstallaties verde ...

Onderstaande maatregelen zijn onderling niet combineerbaar

○ 7B_042 - Verlagen bemestingsnorm naar 170 kg dierlijke N per hectare
○ 7B_043 - Verlagen bemestingsnorm naar 140 kg dierlijke N per hectare

Basismaatregelen geselecteerd gebied

☑ 7B_000 - MAP3 incl derogatie VHA
☑ 7B_023 - Uitbouw saneringsinfrastructuur in centraal gebied door uitvoering lopende IP's tem 2005

Maatregelen - VHA zone (560) - Totaal stikstof - Alle

Aanvullende maatregelen

☑ 7B_036a - Afbouw varkensstapel
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☑ 7B_048 - Optimaliseren inzaaien wintergroenbedekker
☑ 7B_059 - Uitbouw saneringsinfrastructuur in buitengebied door bijkomende bovengemeentelijke projecte ...
☑ 7B_062 - Verder uitbouw collectieve saneringsinfrastructuur in buitengebied door gebiedsdekkende uit ...
☑ 7B_063 - Verdere uitbouw saneringsinfrastructuur in buitengebied door aanleg IBA's
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Omschrijving	€ / kg reductie	Jaarlijkse kost (€/jaar)	Bijkomend effect (kg / jaar)
Basismaatregelen geselecteerd gebied	0.0	0	23413
Verhoging melkproductie melkvee per ha ruwvoeder met 5000 l/ha	-26	-51492	1964
Optimaliseren inzaaien wintergroenbedekker	3	16162	5357
Verbeteren rendement en verbreden zuiveringsspectrum rioolwaterzuiveringsinstallaties verdergaand dan RWZI effluentnormering	7	116204	17668
Lagere fosforexcretie vleesvarkens door aanpassing samenstelling veevoeder via multifasensysteem	12	582	48
Verlagen bemestingsnorm naar 140 kg dierlijke N per hectare	22	66557	3081
Bemesten volgens bemestingsadvies	36	73138	2038
Uitbouw saneringsinfrastructuur in buitengebied door bijkomende bovengemeentelijke projecten	46	23790	521
Afbouw pluimveestapel	55	326	6
Verder uitbouw collectieve saneringsinfrastructuur in buitengebied door gebiedsdekkende uitvoeringsplannen	105	1282873	12204
Afbouw varkensstapel	175	3496	20
Afbouw rundveestapel	179	21754	121
Lagere nutriëntenexcretie vleeskuikens door aanpassing samenstelling veevoeder via multifasensysteem	299	1324	4
Verdere uitbouw saneringsinfrastructuur in buitengebied door aanleg IBA's	397	147689	372
Lagere stikstofexcretie leghennen door aanpassing samenstelling veevoeder via multifasensysteem	763	16576	22

.

Figure 2. Selection of measures, impact on pressures (druk) and cost-effect ratios (€/kg reductie)

5.4 Cost effectiveness analysis

A straight forward cost-effect ratio calculation is performed for different water aspects. The applied effect indicator is described in the table below. For surface water quality we apply load reduction expressed as kg/year. Flooding is based on avoided flood risk calculation (material damage) for both the reference situation and the reference situation including measures. The difference or avoided flood risk is the effect indicator and is expressed as €/year. For sediments, effects are expressed as m³ removed/buffered. This applies for erosion reduction, load reduction of suspended solids in waste water treatment, sediment trapping and dredging.

Table 2. Effect-indicators cost effectiveness analysis

Water aspect	**Effect-indicator cost effectiveness analysis**
Surface water quality	Load reduction BOD, COD, Nt, Pt (kg load)
Floods	Avoided flood risk (€/year)
Hydromorphology	Qualitative impact hydromorphological status indicators (+/0)
Sediments	Erosion reduction, load reduction suspended solids, dredged sediments (m³ sediments)

5.5 Disproportionate cost analysis

The disproportionate cost analysis is considered crucial by end users as it is a possible motive for exemptions. Though widely discussed, no widely accepted methodologies exist on how to determine whether costs are disproportionate. The tool makes use of affordability assessments on a larger scale and indicators to benchmark between water bodies on a smaller scale. To be able to perform these assessments, the total financial burden for each individual sector is estimated (households, industry, agriculture, government). Benchmarking indicators on water body scale include €/km watercourse, €/km² watershed, €/household/year, €/industrial company, €/farm. Affordability criteria include percentage of the available household income for average and low income categories, percentage of added value and revenue for industry and agriculture.

6 CONCLUSION AND RECOMMENDATIONS

We discussed the development of a web-based tool to support the set up of cost effective programs of measures in Flanders. Stakeholders in the public consultation clearly pointed out the need for a clearer, transparent, uniform and scientifically underpinned assessment for the selection of measures. An important concern expressed by stakeholders is the difference in cost effectiveness between different areas and scales. Also important is the ability to assess the impacts of measures on multiple water aspects and the ability to identify win-win situations. The stakeholders did not confirm the need for complicated modelling procedures and extensive optimisation exercises.

How to include these water aspects in a final assessment remains a challenge. This requires the use of multi-objective procedures, a weighting procedure or valuation of benefits combined with a cost-benefit approach. Recent work on ecosystem service valuation might be an inspiration to perform water service valuation and assess the total benefits of individual measures for multiple water aspects. Multi-objective optimization will not be straightforward to apply as for most water aspects no clear objectives (no legal targets) can be identified.

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