Development of a harbour design toolbox: opportunities for multi-disciplinary rapid assessment in harbour development

R. Hoekstra[1] , F. Scheel[2] , W.P. de Boer[2], A.P. Luijendijk[2]
[1] Deltares, Delft, the Netherlands; roderik.hoekstra@deltares.nl
[2] Deltares, Delft, the Netherlands

Abstract
A prototype of a harbour design toolbox is developed, disseminated in a Graphical User Interface, incorporating tools and simple model instruments to rapidly assess the impact of a harbour construction on a coastal environment, such as expected siltation rates and impact on the coastline evolution. The toolbox can be useful for different stakeholders, particularly in early phases of a harbour development project to explore order of magnitude impacts, relevant design parameters and dominant processes. This paper will set out the current status of a prototype of the harbour design toolbox and investigate the benefits of use for specific stakeholders. The ambition is to further extend the harbour design toolbox towards an integral coastal design tool, facilitating the implementation of other type of interventions and linking to other disciplines such as ecology and navigation. The aim is to facilitate a multi-disciplinary approach to aid in the feasibility, design, construction or maintenance phase of a harbour development project.

Keywords: harbours, siltation, rapid-assessment, multi-disciplinary, coastal design tool.

1. Introduction

1.1 Background
Ship transport has been the largest carrier of freight throughout recorded history. Economic welfare and growth of the global population put a high pressure on the excavation and transportation of increasing volumes of commodities and bulk goods. Vessel dimensions increase to comply with this increasing demand and sea ports are either expanded or newly constructed to be able to host large vessels and ensure an efficient way of serving the hinterland by handling and distributing the goods.

The location of a sea harbour is very much dependent on the nature of the products that are imported and/or exported, handled and further distributed. An important aspect for determining the location of a sea harbour is often the efficiency on which the products can be handled and transported once the harbour is operational, rather than the feasibility and maintenance, which is largely depending on the local geometry and ambient conditions. In this context, feasibility studies are often complex and involve major costs, but are still required for the final development, to obtain the necessary environmental permits and establish maintenance work agreements.

The scale growth of sea harbour constructions potentially causes considerable adverse impacts on the marine and terrestrial environment. Nowadays, there is a lot of attention for retaining (dying) marine life and ecological assets, by implementing environmental restrictions, both during the construction and while in operation. Harbour authorities, contractors and other parties who can financially profit from the harbour development and activities are supposed to comply with these restrictions, which are commonly introduced by governmental bodies and environmental task forces.

In general, this makes the scope of harbour development complex and multi-disciplinary, with involvement of different stakeholders and requiring complex feasibility studies on inter-related disciplines, such as hydrodynamics, morphodynamics and ecology.

1.2 Harbour design tool
The aim is to develop a toolbox with a Graphical User Interface (GUI) that allows stakeholders involved in the development of harbours to assess the effects of a harbour construction on various indicators. The platform valorises existing knowledge and relatively simple tools in the field of coastal and harbour engineering, while providing basic information to be considered in an early stage of the harbour development. This toolbox is supposed to facilitate:

- Obtaining a quick insight in trends, order of magnitude effects and environmental impacts of harbour constructions.
- Assessing the sensitivity of processes determining the feasibility and maintenance of harbour constructions.
- Identifying the main design parameters of a harbour construction
- Introducing eco-dynamic design options in an early stage of a harbour layout development, by incorporating inter-related effects of different processes and disciplines

It is explicitly noted that this toolbox is supposed to be complementary to - and not a replacement of - state-of-the-art modelling and acknowledged analysing techniques, which are commonly used to assess harbour constructions in a high level of detail. The added value of this product is in the qualitative first-order effects it provides, showing the interactions between different multi-disciplinary processes. The insights obtained from the toolbox can be useful input for detailed modelling studies in a later stage.

This paper describes the set-up of a prototype of the harbour design tool and the ambitions to further develop the concept of rapid-assessment tools to be used in coastal settings, towards an integral coastal design tool incorporating and linking knowledge and tools from various disciplines relevant for coastal engineering applications.

Chapter 2 will describe the status and contents of the current prototype of the harbour design tool. Chapter 3 will go into more detail about the potential application and benefits of the tool for different stakeholders. Chapter 4 will look forward to the ambitions for further development of the tool, towards an integral tool for rapid assessments of coastal engineering developments.

2. Harbour design tool

The first section of this chapter describes the tools and simplified models embedded in the current state of the prototype harbour design tool, the second section describes the procedure to operate the tool.

2.1 Set-up of the tool

A graphical user interface (GUI) is set-up, incorporating different tools to be used for rapidly assessing the effects of harbour constructions on various aspects of the environment. The current state prototype incorporates tools and simplified models simulating the following processes:

- Depth-averaged hydrodynamics
- Siltation in harbour basins
- Siltation in navigation channels
- Coastline impact
- Navigation channel maintenance

The subsequent sections will briefly describe the fundamentals of these tools and refer to relevant literature.

2.1.1 Depth-averaged hydrodynamics

A depth-averaged, flexible mesh numerical model is implemented to simulate the plan view hydrodynamics around a harbour construction, based on user-defined hydrodynamic boundary conditions, bathymetry and a schematic harbour design, including a navigation channel, breakwaters and a harbour basin.

2.1.2 Siltation in harbour basins

The time-dependent behaviour of the suspended sediment concentration in a harbour basin, with similar depth to that outside the basin can be easily represented by schematizing the basin to a rectangular box, see Figure 1. A sediment mass balance considers an amount of sediment entering the basin by the constituents: tidal filling, eddy development and density driven currents. Part of the sediment will deposit by effective settling, part will remain in suspension and the remaining part will leave the basin by tidal emptying. For more information about this method, one is referred to [7].

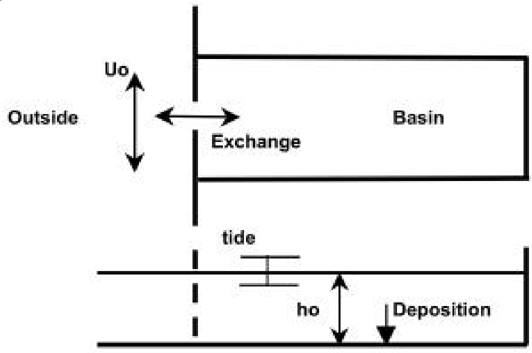

Figure 1 Rectangular schematization of a harbour basin (Source: [7]).

This approach is particularly useful for relatively small harbour basins with rectangular appearance and uniform behaviour of sediment deposition.

2.1.3 Siltation in navigation channels

[7] describes a method schematizing the cross-section of a navigation channel into a rectangular shape; see Figure 2 (centre plot). The sedimentation in the channel can be computed based on a trapping efficiency method, for a predefined channel geometry, flow-, wave- and sediment characteristics.

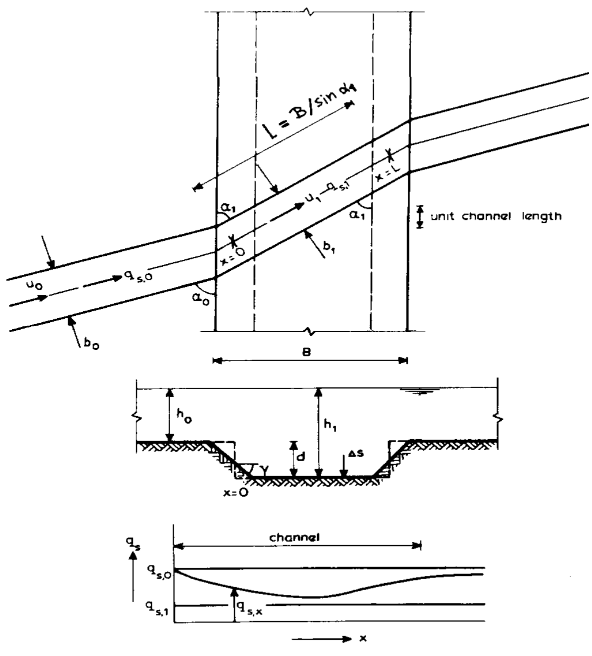

Figure 2 Schematization of a navigation channel (Source: [1]). Top plot: planform view, centre plot: cross-

section, bottom plot: sediment transport capacity over channel width.

The effective sedimentation in the navigation channel is based on the reduced sediment transport capacity over the channel width; see also Figure 2 (bottom plot). For more information about this method is referred to [7].

2.1.4 Coastline evolution

The wave-induced longshore sediment transport along a uniform coastline can be computed based on theory according to [2], [4] and [7]. The theory according to [7] also includes the effect of skewness in tidal-induced currents on the sediment transport.

A coastline model is included based on the analytical single-line theory, which was first presented by [6]. In this theory the coast is schematized into a single line and the displacement of this line is described as a function of time and longshore position and based on gradients in longshore sediment transport. It is assumed that the dynamic area of the cross-shore bottom profile moves in cross-shore direction without changing its shape during the process of erosion or accretion.

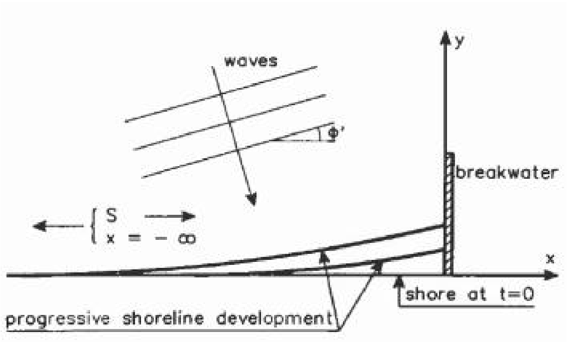

Figure 3 Schematization of the coastline evolution model based on the single-line theory (Source: [6]). This figure indicates accretion upstream of an impermeable breakwater construction.

Figure 3 indicates the process of accretion upstream of an impermeable breakwater. An identical approach is used downstream of the breakwater, where upstream accretion and harbour trapping (from by-passing sediment) introduce a negative gradient in alongshore sediment transport. Using this coastline model, the impact of a harbour construction on the coastline evolution can be rapidly assessed.

2.2 Use of the tool

This section describes the procedure to use the functionality embedded in the current harbour design tool prototype, starting from the schematization of a harbour lay-out to subjecting the lay-out to the different assessment tools. Figure 4 presents the Graphical User Interface (GUI) of the harbour design tool prototype. The left part of the interface shows all graphical representations, allowing users to interactively draw the lay-out of a harbour and instantly visualising tool and model results. The right part of the interface lists various user-defined, numerical settings and buttons to switch to other embedded functionality, like the previously described tools.

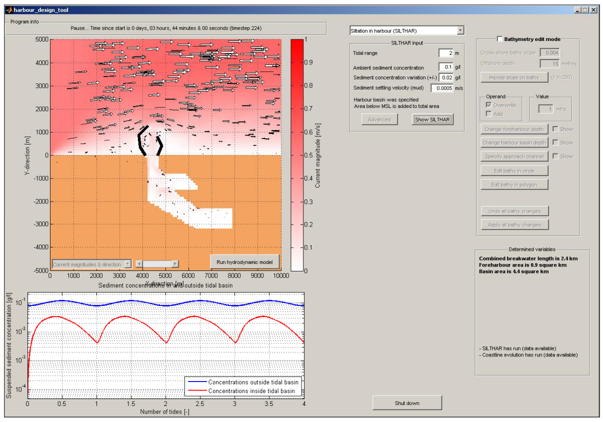

Figure 4 Snap shot of the harbour design tool GUI, showing the graphical environment on the left side and the user-defined settings on the right side.

Figure 5 zooms in on the left part of the GUI (map view), showing an example of a fictitious harbour lay-out. The lay-out of the navigation channel, the -breakwaters and the harbour basin can be drawn in a schematized coastal environment with a straight coastline and a uniform sloping bathymetry. Besides designing a harbour construction at the coast, random changes (e.g. an offshore island) can also be imposed in the bathymetry.

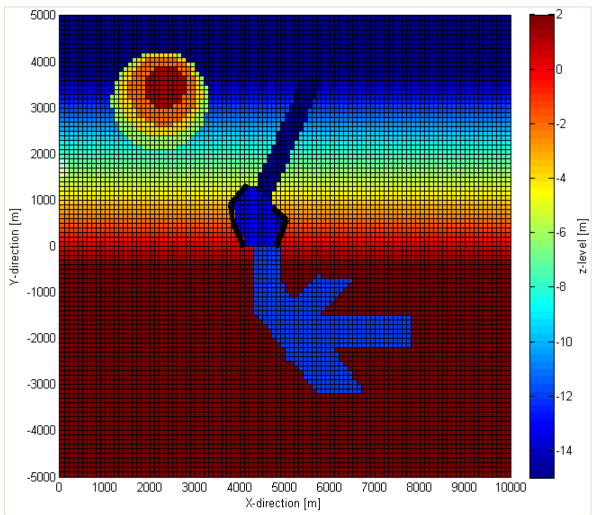

Figure 5 Snap shot of the map view window in the harbour design tool GUI, showing the schematized coastal environment in which the harbour lay-out can be drawn and altered interactively.

Once the geometry is defined, the harbour design can be used in a depth-averaged hydrodynamic model, simulating water levels and current velocities. Maximum flood- and ebb flow velocities along with direction can be imposed on the boundaries. The hydrodynamic model computes local hydrodynamic conditions in and around the harbour design, see Figure 6. The computed conditions can be used as input parameters for rapidly assessing the navigation channel or harbour basin siltation.

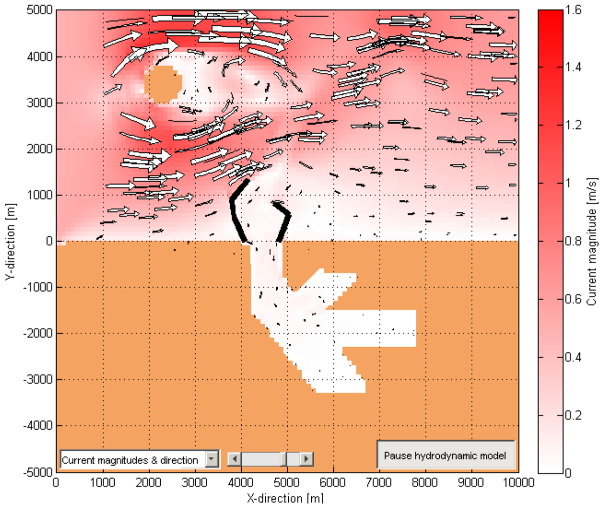

Figure 6 Snap shot of the map view window in the harbour design tool GUI, showing the harbour lay-out and computed hydrodynamics by a hydrodynamic model.

Subsequently, the siltation rates in the navigation channel can be computed based on local hydrodynamic and sedimentary conditions, and the channel geometry which was drawn and visualized in the map view in Figure 5. Figure 7 shows the schematization of the channel lay-out indicating that the expected annual siltation in the navigation channel sums up to 2m per unit length, which is nearly half of the channel capacity.

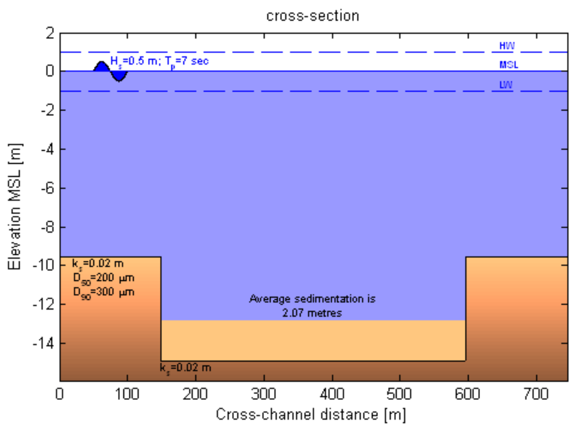

Figure 7 Snap shot of the harbour design tool GUI showing the schematized and averaged cross-section of the navigation channel (not to scale) and the average computed annual siltation per unit length (average is based on results from various discretised channel sections).

Suspended sediment concentration and siltation in the harbour basin can be computed using similar input parameters. Figure 8 shows the time evolution of suspended sediment concentration inside-(red curve) and outside the basin (blue curve).

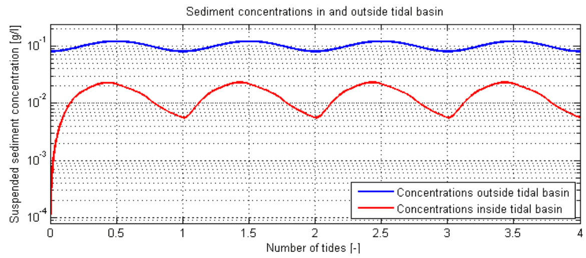

Figure 8 Snap shot of the harbour design tool GUI showing computed suspended sediment concentrations (SSC) in- and outside the harbour basin.

Figure 9 presents the impact of the harbour design (particularly the harbour breakwaters protruding into the sea) on the coastline evolution. Based on averaged wave conditions, the autonomous net longshore sediment transports can be computed and subsequently the impact of the harbour construction interfering with the sediment transport on the coastline evolution (as described in section 2.1.4).

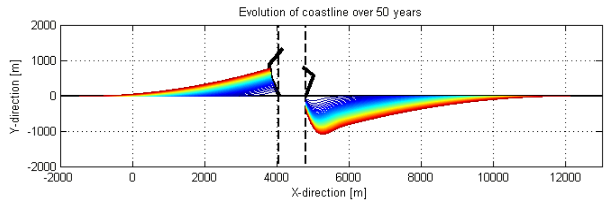

Figure 9 Snap shot of the harbour design tool GUI showing a schematized harbour lay-out and the computed impact on the coastline in time (chronological from blue (1 year) to red (50 years)).

2.3 Sensitivity and uncertainty

An important feature of the harbor design tool is its rapid-assessment character, which allows for a more probabilistic approach by verifying the outcome for a range of design alternatives or parameter settings. By intertwining uncertainty and sensitivity aspects within the various tools, the deterministic (single result) is extended to a range of outcomes. This allows users to quickly identify the dominant design parameters and the sensitivity of the tool input parameters on the final results.

3. Applications of the tool

This chapter makes an inventory of the different stakeholders who are commonly involved in harbour development projects, exploring the potential benefits from using the harbour design tool for each of them. It is explicitly stated that for this inventory the harbour design tool is assumed to be in an advanced state of development, i.e. extended both in functionality and lay-out. This also requires support (feedback and suggestions) from the various stakeholders mentioned in this chapter. Similar investigations have been performed in stakeholder platforms to test and tailor other rapid-assessment applications, developed within the scope of research program ‘Building with Nature’ [3] and the ‘Initiatiefgroep Atelier Kustkwaliteit’ (AKK – Design Workshop Coastal Quality) [1].

In general, the tool has the ability to bring stakeholders together, educate non-experts and to provide insights in inter-related processes and impacts of harbour design. Impacts and processes are rapidly computed by simple numerical models and tools in a matter of seconds to minutes, allowing evaluating series of possible measures in a short time frame. In this way, the tool could contribute to engage stakeholders in the decision making process, enhance interaction between different stakeholders while gaining awareness of relevant processes and sensitivity.

The tool can be interesting for *decision makers* who would like to be able to rapidly explain and communicate advantages and disadvantages of different project strategies or design alternatives, but also to test new ideas raised in stakeholder meetings. Particularly interesting for decision-makers is the tool's ability to give an overall indication of all potential impacts and inter-related processes to have a rough but clear overview of relevant effects and indicators.

Engineers may benefit from the tool's powerful GUI, which could assist them in translating their specialist knowledge to non-experts in their field of expertise (i.e. authorities, project developers, stakeholders). The tool could assist them in providing rapid indications of the feasibility and expected maintenance of different harbour lay-outs, which may enhance mutual understanding between the engineer and his client. Besides, the tool can provide the required insights for efficiently setting-up complex modelling exercises and allows an efficient verification of the sensitivity of the final results to design parameters.

Researchers and scientists, typically working with complex modelling software to assess the feasibility and expected maintenance of harbour projects can use the harbour design tool to obtain an initial insight in dominant processes, uncertainties and potential environmental impacts. In an early phase of a study where complex numerical model instruments are implemented, the harbour design tool can provide initial information to facilitate the set-up of an efficient modelling strategy.

Contractors can use the harbour design tool in tender phases to quickly obtain an initial indication of the most important design parameters with respect to feasibility and maintenance work. The tool can also be useful during project construction to be able to quickly anticipate on sudden changes in ambient conditions, operational plans or other unforseen developments.

Again it is stressed that the harbour design tool is complementary to state-of-the art, complex modelling software, particularly useful in the early phases of a harbour development project to obtain insight in the system and enhance the decision making process between different stakeholders. This way, the complementary nature of the tool can aid in the effectiveness of future project phases.

4. Outlook: future opportunities and applications

4.1 Integral Coastal Design Tool

So far, this paper presented the proceedings of the development of a harbour design tool prototype, which incorporates various simple model instruments and tools to rapidly asses and identify dominant processes and impact of a harbour construction. This section describes the ambitions to further develop the harbour design tool towards a coastal design toolbox. Stakeholders, as identified in the previous chapter, will be involved in further development of the harbour design tool and in other rapid-assessment applications in the coastal design toolbox (according to market demands).

It is envisaged to develop a multi-disciplinary, integral coastal design toolbox, offering tools in different disciplines related to the field of coastal engineering on different complexity levels to be used in different project phases. The concept of the integral coastal design tool is schematically presented in Figure 10.

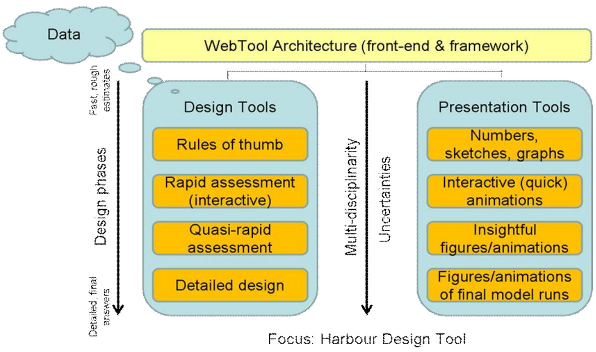

Figure 10 Conceptual framework of the integral coastal design tool incorporating assessment tools on different complexity levels and covering different inter-related disciplines.

Figure 11 presents an initial inventory of 'design objects', such as 'harbours', 'nourishments', 'dredge operations', 'breakwaters' and 'offshore structures', selected to be potentially embedded in an integral coastal design platform. The design object 'harbours' was selected to start the development of a prototype, as a vast amount of tools is already available and relatively easy to compile and embed in a prototype. This prototype is developped to gain experience with use and applications of such tools and to collect feedback and suggestions from different stakeholders for further development.

The potential to link with other disciplines such as navigation, ecology, dune growth will be investigated and implemented in case the knowledge is available.

Figure 11 Overview of 'design objects' related to coastal engineering, potentially to be implemented in the integral coastal design tool. The design object 'harbours' is highlighted since this object is selected to build the prototype on.

In the past similar rapid-assessment tools were developped, i.e. the Interactive Dredge Planning Tool [5] to rapidly assess the impact of a dredge operation on the surrounding ecology and the Interactive Coastal Design Tool [5] to rapidly assess the impact of a coastal intervention (nourishment, breakwater, revetment) on the coastline evolution.

Particularly important with respect to the envisaged multi-disciplinary character of the toolbox is to focus on a generic and modular set-up, allowing for an easy extension towards other applications in the future, driven by market needs or newly developped insights and knowledge.

The developped tool framework can eventually be disseminated through a web-interface, to make it easily accessible for a wide group of people, without the need to install supportive software to be able to use the tools.

5. Conclusions

This paper describes the current state of a prototype of the harbour design tool, incorporating rapid assessment tools and simple model instruments to assess various effects and environmental impacts of harbour constructions.

Based on the experience gained during the development of the harbour design tool and previous developped design tools (i.e. Interactive Dredge Planning Tool and the Interactive Coastal Design Tool [5]), the following conclusions can be drawn:

- A prototype of the harbour design tool has been developped, i.e. the set-up of a generic framework and the incorporation of a set of existing tools to rapidly assess siltation in harbour basins and navigation channels and to assess the coastline impact, while taking inter-related aspects into account.
- The development of the harbour design tool is initiated to gain (further) experience with such a set-up and investigate the interest in the use of rapid assessment platforms in general.
- An inventory is made of different stakeholders who might be interested in using the harbour design tool and describing how they can benefit from effectively implementing it in their workflow. These stakeholders will be involved in further development of the tool; they are invited to give their feedback and suggestions or possibly actively contribute to the development.
- It is envisaged to extend the development of rapid-assessment tools towards a multi-disciplinary, integral coastal design tool. 'Harbours' is selected as one of the design products to be incorporated, along with 'nourishments', 'dredge operations', 'breakwaters' and 'offshore structures' (along with possible market demands).
- The supposed added value of an integral coastal design tool is its multi-disciplinary character, ideally being able to indicate inter-related processes from different disciplines and translate computed effects to stakeholder relevant indicators. Furthermore, the 'rapid' nature of the tools allows for a better understanding of uncertainty and sensitivity, the tools should support exploitation of this possibility.

6. Acknowledgements

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7. References

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