The GeDSeT project: constitution of a decision support tool (DST) for the management and material recovery of waterways sediments in Belgium and Northern France.

Authors:
Bruno Lemière [a], Pascale Michel [a], Nor-Edine Abriak [b], Laurence Haouche [c], Claire Alary [b], Rabia Badreddine [e], Philippe Descamps [d], Benoît Hazebrouck [e], Jérôme Meerseman [d], Christian Lucion [d], Agnès Laboudigue [b].

[a]: BRGM, Service Environnement et Procédés, Orléans, France
[b]: EMDouai, MPE-GCE, F-59500 Douai, et Univ Lille Nord de France, F-59000 Lille, France
[c]: Institut scientifique de service public, Colfontaine, Belgique
[d]: Centre technologique international de la Terre et de la Pierre (CTP), Tournai, Belgique
[e]: INERIS, Comportement des Contaminants dans les Sols et Matériaux, DRC Pôle Risques, Verneuil en Halatte, France

Corresponding author:
Bruno LEMIERE
BRGM EPI
3 Av. Claude Guillemin, 45060 Orléans, France
Phone: (33 or 0)2 38 64 35 04 - Fax : (33 or 0)2 38 64 30 62
email: b.lemiere@brgm.fr - Homepage: www.brgm.fr

The European InterReg IV GeDSeT project (2008-2011) is a contribution to a sustainable management of waterways sediments, in order to develop good practice in a perspective of water resource protection and of the development of regional fluvial transport.

Waterways sediments are a major environmental issue in the Walloon region of Belgium - Northern France trans-boundary region for several reasons, all of them resulting from the dense habitat, industrial pattern and waterways network, and of a long industrial history. Sediments affect water resources quality, through pollution, and availability, through flooding. Sediment dredging allows the development of environmentally-friendly regional fluvial transport, but also generates important waste deposits. Therefore material recovery for reuse in buildings or infrastructure is a key issue, as it allows a reduction of waste and limits the need for natural resources for the same use.

In order to address waterways sediments management in a global way, the GeDSeT project intends to capitalise know-how regarding the criteria to take into account for a sustainable management, and to include them in a decision support methodology applicable to the transboundary context. Such decision support aims at developing good practice in a perspective of water resource management and development of regional fluvial transport. Relevant criteria include:
- criteria evaluating the physical and chemical characteristics of the sediments to be dredged, and their level of contamination,
- costs of dredging operations and benefits with respect to improved waterways,
- potential material value and costs of sediment treatment for material recovery versus costs of sediment deposit management.

The decision support methodology will rely in part on previous BRGM and European experience in the development of an environmentally extended, physical, quasi-dynamic input-output model for waste management. Experience from other specific DSTs on sediments will be valorised with the project partners.

Potential recovery of secondary resources from dredged sediment will be addressed through a review and economic evaluation of available technologies, technical and economical constraints, side effects on the uses of recovered products, and a global balance of the environmental costs and benefits. Social and employment impacts, as well as land use issues in this densely populated area will be fully acknowledged as primary decision-support criteria. The expected benefit of the project comprises also the transboundary comparison of specific situations and methods, issued from a different history.

THE ISSUE, THE CONTEXT

Regional and European challenges

Waterways in the Walloon region of Belgium and in northern France are at the centre of an European network connecting major industrial and urban areas of Netherlands, Germany, Belgium and France (the Seine-Rhine network). After the decline of the coal and metallurgy sectors, they found a new importance for the sustainable transportation of building materials, and other heavy freight, as reflected by a recent increase of freight volume.

The maintenance of waterways – both canals and rivers - meets several major issues: the preservation and improvement of navigability, the management of floods, the environmental impacts of polluted sediments on surface and groundwater quality, the land occupation and environmental impact of disposal sites.

On the opposite, the dredged material is potentially a valuable resource in minerals and building materials, in a densely populated region. Developing new technologies for dredged sediment valorisation, and new uses is thus a contribution to several major objectives of the European Union, namely water resources protection, sustainable transportation, land and mineral resources management.

Waterways sediments management requires a wide array of tools, covering deposition monitoring, dredged sediment processing and disposal management. Many dedicated tools were developed by waterways operators, local administrations, territorial authorities and building sector companies. However, no global approach was developed to be shared between them, allowing to account for indirect costs and benefits. Furthermore, all existing tools and approaches are country-specific and based on national regulations and practice.

There is a real need for a decision support tool (DST) that allows to take into account the potential value of sediments as a resource, not only through their treatment cost, but also with their other relationships to sustainability (alternatives to extraction, land use, environmental impacts, economic development of the treatment sector, of new materials and new applications in the building sector). It will contribute thus to the development of integrated approaches to sustainability (Tiruta-Barna et al., 2007).

This tool must have transboundary applications, as both the waterways network, and the regional economy and employment are increasingly integrated. This is intrinsic to multicriteria DSTs, provided that the theoretical conception and the database supporting the models take carefully into account the situation in each country, and the possible exchanges. Regulatory obstacles to transboundary applications have to be identified. The tool provides an ideal framework for the evaluation of the effects of harmonised regulations.

The knowledge base for such a tool must take into account a) the volume and characteristics of sediments to be dredged, b) the various relevant management techniques, c) their positive and negative environmental impacts, d) their operational cost (work and follow-up), and e) the social consequences of the management options, including the development of economic sectors for works, for sediment treatment and for sediment reuse.

The expected outcome of the development of the tool comprises the ability to model the medium and long term consequences and costs of each option, in order to improve the selection of priorities and to provide a sound basis for the discussions between the actors and stakeholders, but also with the general public.

Lessons from another major issue

A similar approach was developed for another topic with major economical and social, technical and investment, energy and environmental implications: the simulation of the main options of municipal solid waste (MSW) management. This was the subject of the EU-funded AWAST project (5th Framework Programme, 2001-2003, http://awast.brgm.fr/).

The main options of MSW management are not independent, they affect all the above implications and cannot be modelled using process-specific tools. Furthermore, they imply complex policy level decisions: technology selection, investment and operating costs, energy requirements and production, environmental emissions throughout the system boundaries, social consequences for acceptability and employment, regulatory and normative aspects.

The AWAST tool was dedicated to MSW management system assessment. It was derived from a mineral industry process simulator (USIM PAC ™, © BRGM). It contains specific models for waste collection, transportation, sorting plants, incineration, composting, aerobic digestion, and waste storage facilities. The process-based approach, focussed on material flows balance, allow to optimise the representation of the actual operation of waste processing facilities. Its database is enriched by readily available operators data.

The AWAST tool may be used to evaluate the compared impacts of relevant scenarios, through the quantitative determination of several indicators: material flows (valorisation rates), energy consumption and production, investment and operation costs, environmental (GHG, acidification, other emissions…), social impacts and employment, …
This allows to provide quantitative elements to support public discussions and promote a neutral approach to decisions, especially for investment.

It was first developed as a theoretical model, applied to three urban communities (Lisboa, Stuttgart and Orleans) but this model was later successfully applied to specific case studies such as SYCTOM Paris (Villeneuve et al., 2009), in which the AWAST approach was used to determine the key outcome of strategic decisions for the future of a large ageing incineration plant.
In this case study, several scenarios were evaluated for the predictable amount of MSW in 2015, according to various hypotheses on the effect of waste policies (waste reduction) and population increase. Technical options (incineration, mechanical and biological treatment based on anaerobic digestion plus incineration of combustible residuals, mechanical and biological treatment based on anaerobic digestion plus landfilling of residuals), localisation of the new facility, with its consequence on waste collection, imports of other waste and facility dimensioning were all considered to simulate their consequences in all areas (cost, energy, emissions,…). Examples of functional flow charts and summary of data flows are given by Villeneuve et al. (2009). These data allow to establish performance and impact comparisons between scenarios.

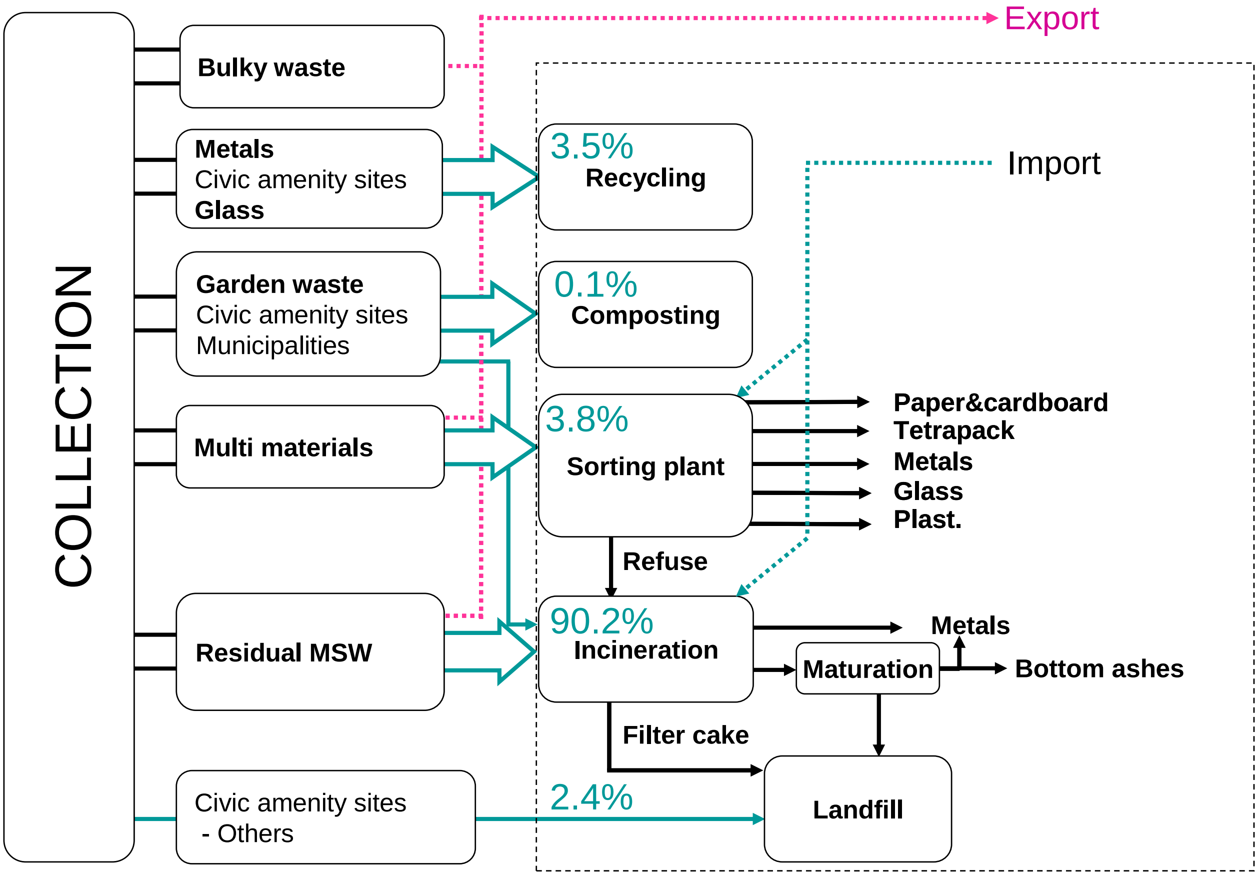

Figure 1: Simplified operational material flow summary for MSW processing at SYCTOM (2003)

During the development of this model, a list of result indicators was established during discussions with the operator and various stakeholders, and introduced in the model to be applied with the selected scenarios. This iterative process was repeated after a first examination of results, and led to the selection of new indicators and new scenarios to be tested.

Previous experience in DSTs on sediment management

Earlier experience on DSTs applied to sediment management was mainly gathered on harbour dredging sediments, either on dredging techniques, on the possible valorisation of the dredged material, or on the hazardousness of their disposal (PREDIS, 2006; Abriak et al., 2006; Junqua et al., 2006; Grégoire, 2004; LIFE, 2002, IFREMER, 2001). Thus, the implementation of this methodology enables to reach a consensus for the dredging solution retained. It also proposes an environmental follow-up, which will allow an evaluation during its application (Abriak and Junqua, 2005; Abriak et al, 2005, Abriak et al, 2006). However, there are significant differences between these DSTs and AWAST: the sediments databases are fully documented rather than evolutive, and scoring criteria allowed to rank all options under a single algorithm. These features allow to reach a single solution from a large set of data and criteria, with adjustable parameters through ranking scores. Such tools are particularly adequate to identify a management option, or to evaluate the relevance of a pre-defined option.

STRATEGY FOR THE CONSTITUTION OF THE GEDSET DST

The objective: best solution tools and what-if tools

Single-solution tools (or “best solution” tools) are aimed at providing in a controlled way one recommended solution for their beneficiary. They can be adjusted through the entry of new data in their database, but more so, through fitting the ranking score coefficients (Khan and Faisal, 2008). Such an approach will fit the needs of a single end-user, who will be in a position to adjust the model through trial and testing.

On the opposite, what-if models, such as AWAST, do not provide a single solution to a given scenario, but rather behave like a working bench on which several solutions may be tested and their consequences may be evaluated for each issue. In a multi user environment, with many stakeholders and conflicting expectations, such models allow to test scenarios without any a priori, and show evidence for unexpected secondary effects. The comparison of the scenarios can be conducted collectively, each stakeholder feeding the database with its own data and concerns. The selection of the best solution is no longer done by the model, but it results from the political debate, which can use the model to test the effect of various options.

Development plan for the tool

The development of such a tool comprises:

- a theoretical conception phase,
- the adaptation of generic simulation software, which leads to a dedicated simulator,
- the fine-tuning of the simulator, and its use for scenario simulation

The development of a dedicated simulator will require fitting the software to the problem environment and logics:

- graphical representation of scenarios, supported by the programming of specific symbols,
- global model development, comprising the development of elementary models dedicated to dredging, transport, disposal and treatments; and the constitution of the base for the data associated to the models.

These elements are the basis of the construction of a dedicated simulator using the new symbols and elementary models.

The theoretical conception phase includes:

- an analysis of the problem environment,
- a precise definition of the space and time boundaries of the system,
- a comprehensive list of relevant evaluation criteria for the technical options (results indicators)

The list of criteria shall be elaborated in collaboration with all project partners, along with the data required for the estimation of indicator values.

The target groups will be identified, along with the different actors of sediments management (waterways agencies, operators, communities, administrations, water or brownfields agencies...), and interviews will be done, with regards to each person’s sensitivity to specific aspects of the problem.

Each process in the system has to be modelled and described by a set of mathematical equations. The level of detail to be reached will be defined during the conception phase, with regard to available data and simulation objectives. For instance, model development can be initiated with literature data and later refined with locally validated data.

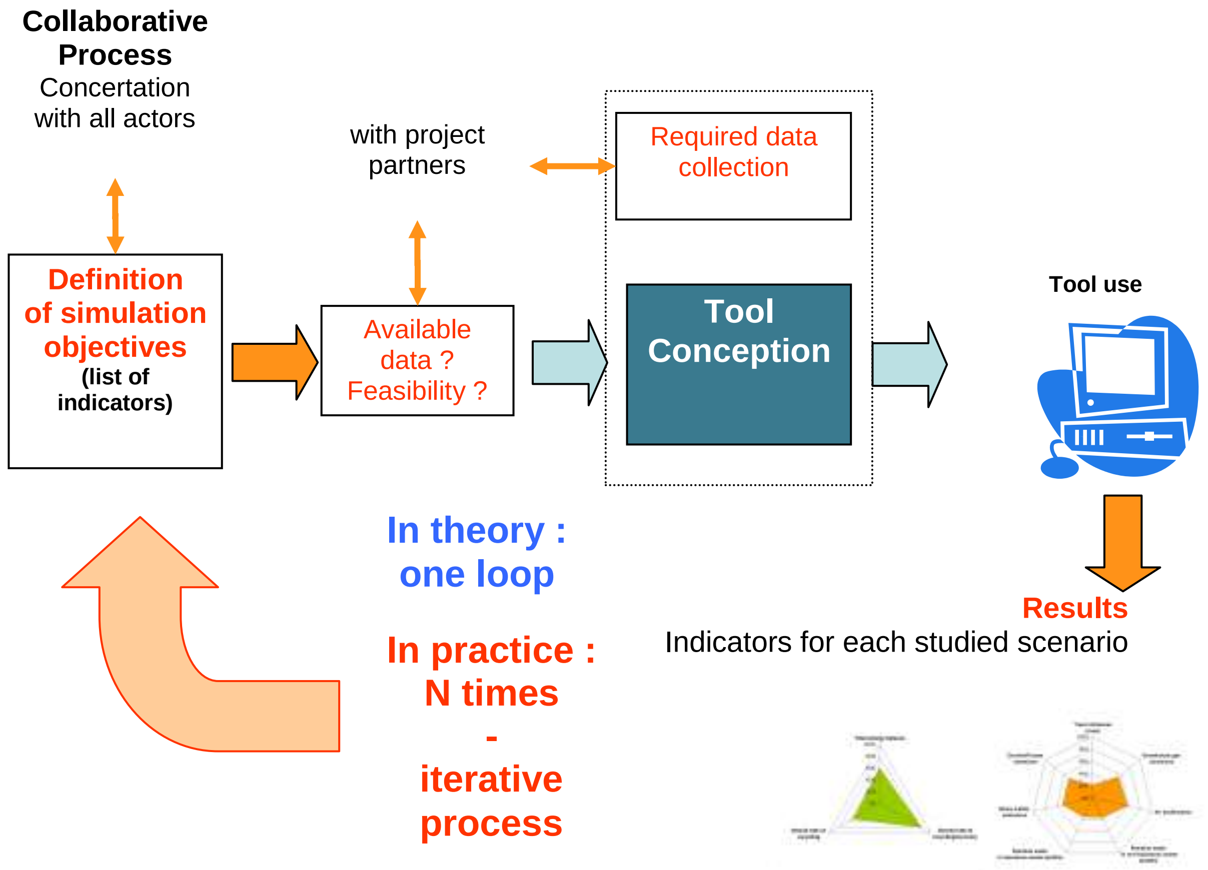

Figure 2: Theoretical and practical conception scheme

During the conception phase, it is of key importance to carefully define the relevant results indicators, in order to limit the number of iterations to be performed later. A clear definition allows an earlier collection of the data, and a better implementation of the test tool.
The definition of results indicators has thus to be done in collaboration with all the actors of waterways sediments management, as soon as the project begins, and it is one of the key milestones.
Data collection is a lengthy and labour intensive part of the project, so the data requirements and formats have to be designed as early as possible.
It results from this that the person, or team, in charge of the conception and development of a DST has to be an « integrator » at the interface between the scientists and the actors of waterways sediments management.

The objectives of the decision support tool and its results indicators need to be further detailed at this level. The DST should simulate the consequences and mid-term costs of the various management options (no dredging but monitoring, in-situ treatment to reduce pollutants emissions to water, dredging and storing dredged sediments, treating moderately polluted sediments, confining the most polluted ones,…). It should take into account:

- the volume and characteristics (physical, chemical) of sediments in place,
- the diversity of applicable management techniques, and for each of them:
  1) environmental impacts (both positive and negative) during and after dredging work,
  2) the cost of works (dredging operations, sediment decontamination and beneficiation, temporary or final disposal sites, but also the cost on the long term (monitoring, maintenance, land use),
  3) social impacts (both positive and negative) such as new services and sediment valorisation industries, and employment.

Evaluation criteria may encompass technical (efficiency, energy requirements…), organisational (time allowed for implementation, land use…), qualitative or quantitative criteria.

Mapping the interrelationships

The first step of the theoretical conception phase is not a desktop one. It is based on extensive consultation of all stakeholders and on general purpose documentation. The consultation of previous work on DSTs at this level is especially counter-productive, as it will focus the attention onto the already identified relationships. On the opposite, the DST designer should have an open approach, collecting any relevant information without attempting to build connections. The information is then organised in a graphical manner, using direct interaction or proximity rules. The resulting graph is closer to a factor representation in correspondence multivariate analysis, than to a decision tree.

Dependencies are drawn on this map, and further requirements for information are identified, resulting in further enquiries.

It is unadvisable to use existing flowcharts at this stage, because most of the time, DSTs were developed for the needs of a specific actor or stakeholder, and they miss part of the possible areas for resource valorisation or waste reuse.

However, the map with its interactions turns progressively into a flowchart.

From the interrelationships to the flowchart

A simulator dedicated to the management of a resource (minerals) or an undesirable matter flow (waste, pollutants) is best represented, during the next step, graphically, in the same way as the flowsheet of an industrial process. This requires the identification of all material flow routes, and all flow convergence knots.

Material flows should all be described with the following elements:

- chemical and mineral composition, physical characteristics. For sediments, the chemical information comprises the major element information in oxides, and the most significant trace elements (potentially toxic elements, elements subject to regulations on emissions or reuse, and elements which have adverse effects in a reuse process). Mineral composition data comprises the main phases, and accessory phases when they may have adverse effects in a reuse process. Physical characteristics depend on the considered use; they may be the water contents, grain size distribution, mechanical or hydraulic properties;
- mass flow data: these data are usually based on operation or economic statistics. Examples of such are the amount of sediments that is usually dredged by a waterways operator, based on its operations budget, or the requirements of the regional building sector in a given class of sands. They provide usually constraints on the model, by limiting the maximum volume of reuse flows;
- the characteristics of the deposit: volume and composition of sediments in place, location vs the treatment facilities or reuse markets, accessibility to transport, pollution data (when available). Such characteristics will control the potential duration of a valorisation scheme, or the investment limitations for the facilities.

Each treatment or reuse option should be described as an elementary model, itself determined by a set of equations, and a number of parameters representing the possible adjustments during operation or facility design.

The resulting flowsheet allows the identification of all material flows, and all involved processes. Material flows are represented by arrows, while processes are represented by boxes or icons. Dedicated simulator software and mathematical software have usually flowsheet design capabilities, and may be used with profit at this stage.

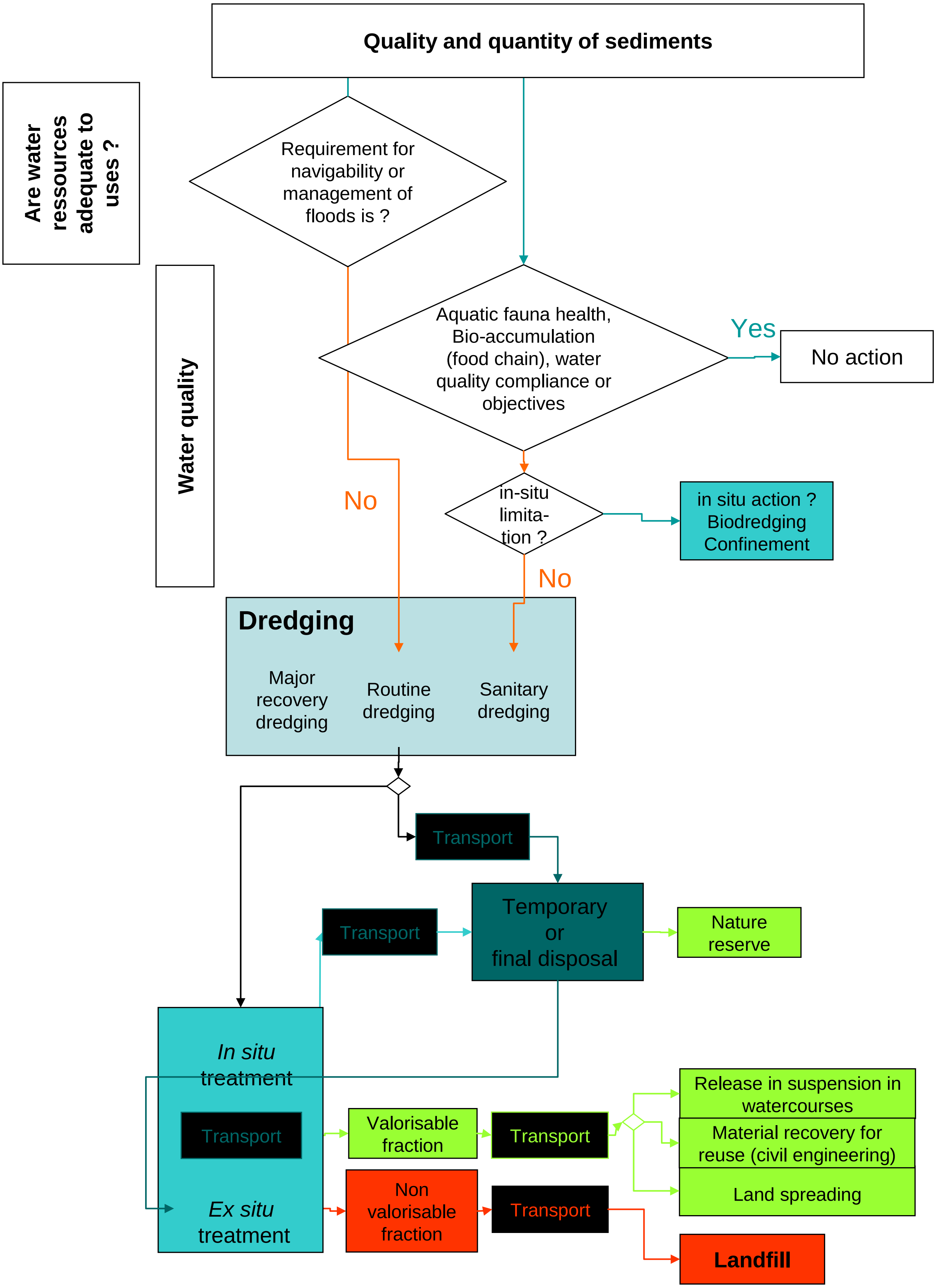

Figure 3: Provisional schema of sediments management

From the flowchart to the tool

Once the system analysis provides the structure and functional relationships of the simulator, a software environment can be chosen. It would be a major mistake to select it before the analysis is completed, as the available software functionalities should not lead the model development, but fit the desired functions.

Several types of software environments are currently considered, and none is yet chosen:

- dedicated simulation software: an example of such is the UsimPac chemical process simulator (© BRGM). This environment, originally developed for the needs of the minerals industry, was used for the AWAST tool. It is highly reliable and allows rich functionalities, but it requires skilled developers and is expensive to implement and to maintain;
- off the shelf mathematical, database or even spreadsheet software. Many programs of this family accept parametric subjects, application development and allow what-if simulator development. They come at a fraction of the cost of simulation software, and can be used by less skilled operators. They are increasingly available in open-source environments;
- custom built software. Dedicated code is written down, usually in open source languages (example: Racicot, 2006). This requires little or no software investment, but lots of programming time.

The choice of the software environment logiciel must result of the function analysis models and its requirements.

The future tool

The main components of the decision support tool are described here following the software development terminology: 1) a knowledge base, 2) prior functional specifications, 3) a supporting software environment, 4) a multidisciplinary database, 5) specific code elements, 6) a scenarios library.

1) The knowledge base is mainly built with professional and sector know-how. It will increase along project development, above all through exchange between stakeholders (operators, waterways managers, local communities and authorities...), researchers and professionals, and the project’s DST development team.

2) Prior functional specifications are conveniently expressed in graphical form, using flowcharts on which elements of the knowledge base can be attached to the functional links;

3) The supporting software environment has to be compatible with the functional specifications, but also with the constraints of valorisation and dissemination.

4) A multidisciplinary database, comprising data on sediments, emissions, management and treatment techniques, and socio-economic issues (market, user sector, employement data,…) is constituted, and organised in relation with the software environment, to allow its use for the simulation tests and the DST restitutions.

5) Specific code elements are written for data extraction from the base, support simulation scenarios and allow the introduction of user options. This code may be a computer language, macro instructions, queries or any other technique leading to the desired outputs.

6) A scenarios library, directly usable at the end of the project for demonstration purposes, but also as templates for further scenarios or improved options, will be developed in close cooperation with waterways operators and stakeholders.

APPLICATIONS, AND LESSONS TO BE LEARNT

The expectations of the operators: the cost of sediment disposal

The main limitation to the maintenance and improvement of the waterways network, and subsequently of the short term development of fluvial transport, is the disposal burden of dredged sediments. Either they have to be considered as potentially hazardous waste, with the associated disposal costs, either their temporary or final disposal needs valuable land in this densely populated area. Besides the cost of dredging, the cost of the management of the sediments to be dredged limits thus the length of upgraded waterways, but also the active gauge, as partial dredging is often the only option.

The expectations of the building sector and processing companies: a valuable or cost-effective resource

From the builder’s point of view, sediments are an easily available but difficult resource. Beyond their frequently contaminated character, sediments have a large number of unfavourable features (high water content, variable mineral composition and grain size properties within the same lot, presence of variable amounts of compounds with undesirable effects in construction (organic matter, salt, etc). Most of these features may be improved by appropriate treatment, similarly to the products of the extractive industry. However, these treatments have a cost, and in many cases treated sediments cannot compete with minerals from the extractive industry. In order to become competitive, dredged sediments have to be either used without treatment, either offered with a negative value. The latter option is traditional in the cement industry, as contaminated material can be disposed of this way for cheaper than in regulated landfills.

Raw sediments with acceptable contamination levels can be used as backfill or cover in remediation operations (contaminated brownfields and derelict areas, closed landfill dumps), either as an intermediate layer, either as a surface cover (Wells & Sibrel, 2001). Their high concentration in organic matter and nutriments will promote the fast development of spontaneous vegetation, but their contamination level is not always compatible with strict soil protection regulations.

It was reported that most of reused sediments are in raw form, while treated sediments used in higher value building materials are only a minor part (US-EPA, 2005; Palermo et al., 2008). This share may be improved by the development of low-cost treatments, but above all, by taking into account the global eco-accounting of valorisation vs. extraction from quarry.

The development of sediment valorisation strategies is probably more advanced for harbour sediments (for instance Agostini et al., 2007, Dubois et al., 2009) than for inland waterways. This may be the result of both physical and flow characteristics, regardless of pollution. Harbour sediments may have more desirable characteristics for building needs (coarser grain, homogeneity, lower organic matter content) than waterways sediments. Harbour dredging operations are conducted more globally, while waterways dredging operations are conducted step by step, according to yearly budgets, hence larger volumes available from harbours in one operation.

The expectations of the territorial authorities: reduce the requirements for mineral extraction, improve the quality of brownfields

Territorial authorities comprise municipalities, regions, agencies and even state administrations, as long as they are involved in regional development and land management. They have to deal with conflicting requirements in economy growth, employment safeguarding and development, and the resulting compromises are translated in urban and territory land use plans.

Developing urban areas have high requirements in building materials and minerals, while the large areas required by quarries and their environmental impacts lead to push them away, with significant economic and environmental impacts of transport.

Waterways are often present in urban areas and interconnected. This allows an easy availability of dredged sediments through navigation.

On this point of view, the reuse of sediments has a triple advantage: it reduces the requirements in land use, both for quarries and for sediment disposal sites; it reduces the pressure on the road transport network, by transferring to waterways bulky materials; it promotes the revitalisation of derelict industrial sites, often connected to waterways.

Integrated approaches, such as LCA or LCIA applied to land use (Schmidt, 2008) allow to take into account the global benefits of reuse material for building.

Sustainability bonus: more fluvial transport, innovative sector development, more employment

The decision tool is expected to be a contribution to a more sustainable regional development, from at least three points of view:

- by facilitating the disposal of dredged sediments, it contributes to the competitivity of fluvial transport, especially by allowing larger ships to be operated and restoring the navigability of abandoned waterways;
- by promoting the substitution of primary by secondary resources, and optimising the use of available sediments, it contributes to the reduction of the urban pressure on natural resources, and of land use by extractive industries. It favors the reduction of waste flows;
- by contributing to the development of treatment technologies, it promotes local economic development and employment, with a lesser environmental footprint than mineral extraction and transport.

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