Building with Nature

EcoShape

Guidelines on the application of the Framework of Reference for the adaptive execution of low-impact dredging works

EcoShape – Building with Nature

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Abstract

Considering the projected demographic changes in coastal zones and river beds there will be an increasing need for dredging globally. It becomes more important to be able to satisfactorily manage the positive and negative dredging impacts on the environment and their inhabitants. However, a growing number of uncertainties, degraded environments, (environmental) restrictions, stakeholders and factors increasingly co-determine the programming and execution of dredging projects.

We show that most execution techniques, support systems and monitoring approaches accompanying dredging operations include process control and adjustments, and primarily focus on target compliance. Based on fixed knowledge they need clear thresholds to function. Even so, there is a severe lack of timely cause-effect knowledge and consequently “business as usual” seems not a viable option anymore.

We argue here the need for an applicable, structured and true adaptive approach for the way dredging works are executed in the face of uncertainty, with an aim to reducing this uncertainty over time via system monitoring, i.e., an approach that aims at closing the gap to what we know and what we should know.

This document presents an overarching frame for the renewed definition and design of monitoring, evaluating, and reports on improving common approaches to managing key assets of dredging activities. We explain the overarching conceptual Frame of Reference (FoR) that, when implemented well, provides better guidance to the development, implementation but also evaluation of low-impact dredging activities in vulnerable regions.

1 Introduction

1.1 Adaptive Monitoring & Management cycles

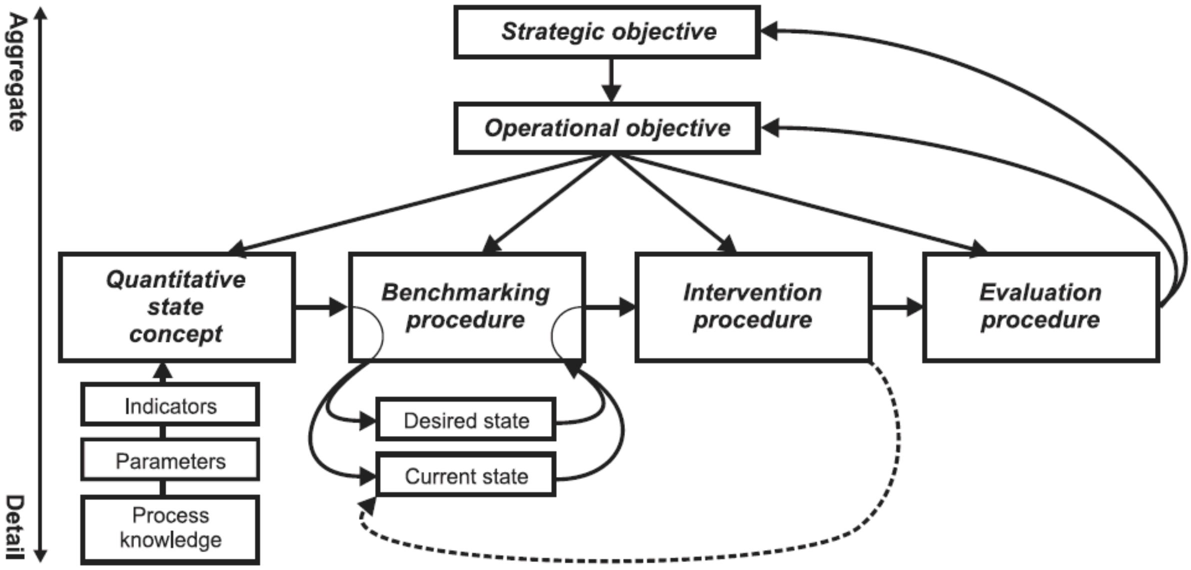


Figure 1. Schematics of the Frame of Reference (FoR).

Monitoring of the ecosystem affected by marine construction works has become an important part of any large-scale development. The use of information obtained during these extensive monitoring campaigns is varying, making the 'success' of using these monitoring efforts as a tool to protect the ecosystem variable. To promote sustainable development with an economic use of monitoring and management in marine infrastructure, an 'adaptive' approach seems very promising. By using a cyclical and adaptive process, the assessment of impacts is optimised and approved 'on the go' and the project can be managed by its quantified monitored impacts.

Generally, the precautionary principle forms the basis for monitoring and management requirements when ecological uncertainties arise in the (pre-)design phases. Implementing the adaptive approach for future dredgingworks signifies a paradigm shift away from the application of the precautionary principle.

The guidelines presented here provide methodologies to structure and help organize an adaptive cyclic approach including monitoring and assessment, and to get the process started.

In this first Chapter, the structure of the adaptive execution cycle is introduced and the success factors of its working, being the advantages of the principles of 'learning by doing' and continuity, are further elaborated.

1.2 Plan, act, evaluate and adjust!

The basic strength of the adaptive cycle is that the execution of work can be adjusted during operation in order to reach environmental goals. Since adjustments should be based on the monitoring of effects, a complete cycle of planning, execution of monitoring and evaluation of results is necessary to facilitate adjustment. In this way the well-known management cycle of Plan, Act, Evaluate & Adjust is created (for further reading see Deming , 1986).

When this cycle is applied to the adaptive executive cycle, it follows that within the 'plan' phase, the monitoring objectives and information needs are determined, and that the key performance indicators are identified. Finally, a monitoring program is established that can be executed during the 'act' phase. Within the 'evaluate' phase the status of the performance indicators are compared with the desired state which will either lead to the 'adjust' phase within the execution of work or within a review on the overall monitoring program. Figure 2 shows a simplified cycle.

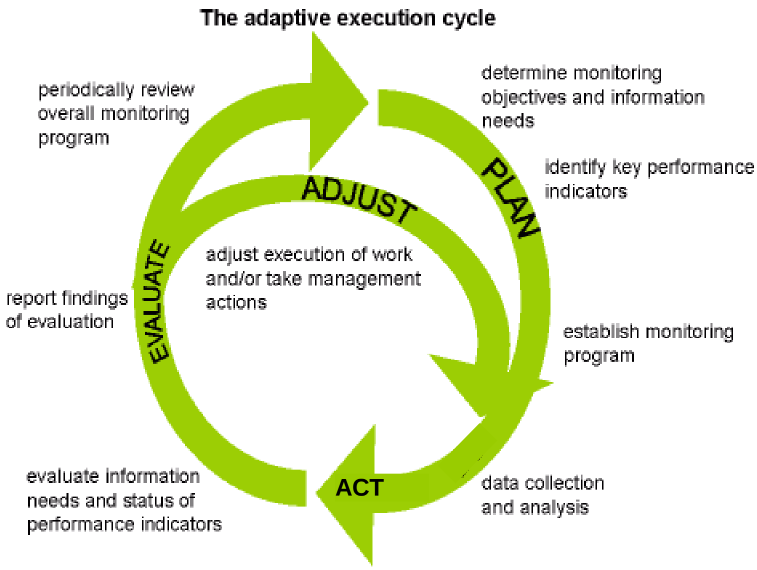


Figure 2. Schematics of the Plan, act, Evaluate and Adjust cycle.

When looking at this management cycle, a clear indication of the cycle within an adaptive process is given. However, it is unclear where this cycle is 'started' and how the adaptive process should be designed to be successful. In addition, the different steps and needs within the planning phase to get from objective to monitoring program are not clear. For that reason, it was thought that the cycle should be re-adjusted to a framework that consists of the essential components of the complete adaptive approach including the dredging execution management process. For this, use is made of the so-called Frame of Reference (FoR) as introduced by Van Koningsveld (2003 and Figure 1). Figure 3 illustrates the schematics and flows that are included in the application of the Frame of Reference.

1.3 Frame of Reference (FoR)

"Gone are the days where environmental considerations were second to economic interest…" (Bray, 2008). These days, a thorough inclusion of numerous environmental aspects has become mandatory, complicating previous ways of programming dredging projects.
There is an increasing need for an applicable, structured but adaptive approach because of a growing number of pressing issues that affect or determine the way we execute dredging works. E.g.:

1. Projects take place in complex and dynamic systems
2. The world is constantly and unpredictably changing
3. Clients and financers are changing, issuing more restrictions
4. Unclear environmental impacts (and restrictions)
5. Non-dredgers engage with environmental aspects at increasing rates

6. Immediate action is required to stop worldwide ecosystem degradation
7. There is no such thing as complete information
8. We can learn and improve

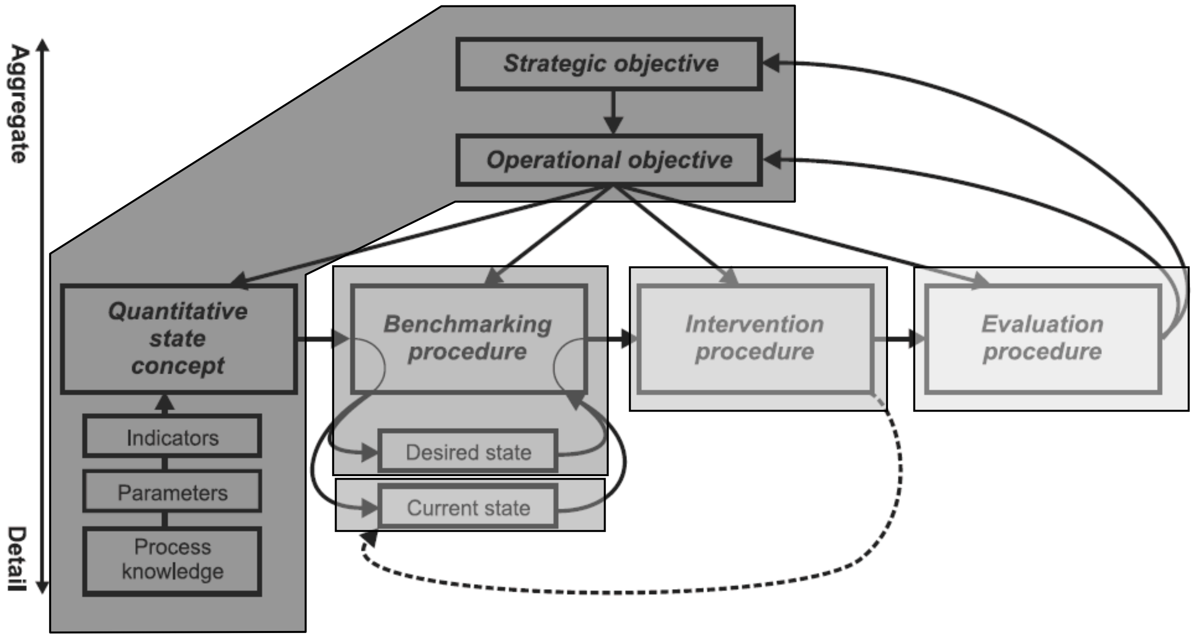


Figure 3. From dark to light grey: The Planning, Act, Adjust and Evaluate high-lighted in the FoR.

To tackle the above mentioned uncertainties it is necessary to realise that "adjusting" to new circumstances or developments as well as introducing new and clear (environmental) objectives become part of the whole execution process. The "adjusting" also entails new roles for clients and stakeholders and possibly new stakeholders as well (local governments, communities, NGOs, entrepreneurs, etc).
The purpose of the FoR here is that we seek to manage better the integration of the conservation of sensitive ecosystems with development of cost-effective dredging. Monitoring, benchmarking, evaluation, reporting and improvement are integral components of the FoR. These activities provide approaches to assess the impact, appropriateness, effectiveness, efficiency and legacy of programs and a process to promote accountability.
FoR provides guidance for assessing program performance and the state of and change over time in assets against planned immediate, intermediate and longer-term outcomes. It provides opportunities to improve program and project design and delivery and to reorient dredging execution at key decision points throughout the life of the strategy or policy. We designed the FoR to make change transparent so that all parties can learn, through reflection and discussion, which interventions are most appropriate, effective and efficient. Its four components — Quality Status Concept (QSC), benchmarking, intervention and evaluation support a 'learning by doing' approach to adaptation.

In order to make improvements in consecutive execution cycles of the adaptive process possible, it is important that all the information gathered within previous cycles is well-defined, correctly designed and documented before being used for adjustments. For instance, within the QSC and the benchmarking, evaluation cycles will update (process) knowledge and databases in such workable way that the earlier defined decisions can be reconsidered based on the new, more complete data set.

1.4 Adaptive approach

The origin of the adaptive management concept can be traced back to the early concepts of scientific management pioneered by Frederick Taylor in the early **1900's (Haber 1964).** The term 'adaptive management' evolved in natural resource management workshops through decision makers, managers and scientists focussing on building simulation models to uncover key assumptions and uncertainties (Bormann et al., 1999). Holling (1978) and Walters (1986) further developed the adaptive management practice.

Adaptive management for resource management purposes has probably been most frequently applied in Australia and North America, initially applied in fishery management, it received more broad application in the 1990s and 2000s (Biodiversity Support Program of the WWF, The Nature Conservancy (TNC), and World Resources Institute).

Adaptive management is foremost an iterative process of optimal decision making in the face of uncertainty (chapter 1.3), with an aim to structure and reduce uncertainty over time via system monitoring. In this way, decision making simultaneously maximizes one or more resource objectives and accrues information needed to improve future management. In short, adaptive management is a tool that should be used not only to change a system, but also to learn about the system (Holling 1978). And because adaptive management is based on a learning process, it improves long-run management outcomes. The challenge in using adaptive approaches lies in finding the correct balance between gaining knowledge to improve management in the future and achieving the best short-term outcome based on current knowledge (Stankey et al., 2005).

Implementing adaptive monitoring for the execution of a lower-impact dredging project involves the integration of project design, management, and monitoring to systematically test assumptions in order to adapt and learn.

The three principle components of adaptive management in environmental practice are:

a) Testing assumptions, which encompass systematically trying different actions to achieve a desired outcome (contrary to random trial-and-error processes). It involves using knowledge about the specific site to select the best known strategy, laying out the assumptions behind how that strategic approach will work, and then collecting monitoring data to determine if the assumptions hold true.

b) Adaptation, which involves changing assumptions and interventions to respond to new or different information obtained through monitoring and project experience.

c) Learning, which is about explicitly documenting a team's planning and implementation processes and its successes and failures for internal learning as well as learning across the stakeholder community.

1.5 Adaptive execution cycle as Frame of Reference

When applying the FoR for the adaptive monitoring strategy, the FoR is first designed from the "objective phase" onward. Based on a strategic objective, that is usulay an aggregate and project-wide, operational objectives for specific project parts can be identified. These objectives in turn require a management recipe based on the quantitative state concept, benchmark, intervention and evaluation. The necessity to come up with a quantitative state concept is to enable objective and reproducible decision making. Based on knowledge on the ecosystem, the appropriate parameters and indicators should be selected to describe this state.

When applying adaptive execution cycles this process knowledge of course will evolve on-the-go, so the appropriate quantitative state concept is not rigid for complete project execution. From the quantitative state concept, a so-called desired (or reference) state, describing an acceptable (quantitative) state of the ecosystem, can be defined. The benchmark then basically compares that desired state with the current state that should be monitored in sufficient detail on the appropriate spatial and temporal scales. Based on this comparison, action might be required. Within the adaptive approach, the action need can be divided in three categories:

a) no action needed (as there is sufficient room for stress levels to rise/vary)

b) preparatory action needed (as stress levels are rising, but still at acceptable levels), or

c) intervention needed (as the stress levels are above acceptable levels).

The interventions should directly influence the current state in order to avoid overstressing the ecosystem. After the (non-) intervention the process should be evaluated not only whether the decision recipe was successful, but also as feedback on the realism of the pre-defined objectives and to see whether the process knowledge has undergone relevant changes. In this way the process contains feedback loops in diverse directions with clear realistic objectives at the basis and always in view. This makes the scheme useful in all stages of a marine infrastructure development and not only strictly applicable to the execution phase.

1.6 Continuity

By describing the adaptive process in the way above, continuity in management is better guaranteed. Not only is the current state continuously evaluated with the desired state to manage the impacts, but also the lessons learned are brought back into the process of defining the quantitative state concept and the management processes to realize the objectives for the project.

In addition, the continuous generation, disclosure and use of new valuable knowledge to address the uncertainties enables the proliferation of several scientific and social processes as vital components of future adaptive management. These are foremost:

a) Contractor, clients and stakeholders may be linked better to appropriate temporal and spatial scales and retain a focus on statistical power and controls.

b) Better use of computer models to build synthesis and an embodied ecological consensus

c) Workable use of embodied ecological consensus to evaluate strategic alternatives

d) Clearer communication of alternatives during negotiation of a selection or intervention

As such, these insights enable the design and management of dredging projects better and avoid some of the flaws others have encountered, especially in cases where management decisions are repeated (Stankey et al. 2005; Rout et al. 2009).

1.7 Mind your (learning) step!

When organisations need to ensure their preparedness for the unexpected change, then adaptive management applied to ecosystems makes sense when considering ever

changing environmental conditions. The flexibility and constant learning of an adaptive management approach is a logical application for these organizations seeking sustainability methodologies.
Sustainable development here implicitly requires recognition of the relationship between environment, economics and social instruments within the stakeholder community and helps creating durable policies and practices that emphasize the connection and confluence of those elements (see Holling, 2010).
However, in recent times, the term ¨adaptive management¨ has become a rather confusing catchphrase that means many things to many people —as Salafsky et al. (2001) quoted: "*Adaptive management is merely an excuse to change your mind*."
In fact, there exist many "derivatives" of adaptive monitoring and cyclic management approaches that claim to hold an adaptive approach to resource management operations, intend to comprise a "learning by doing" element, or propose cyclic processes allowing some sort of adjusting.
In the context of guiding operational processes there are e.g., Decision Support System (Common in river basin management), Decision execution cycle (broad application organisational), Adaptive execution cycle (Broad application in resource management), Adaptive management cycle (see Work of Holling, 70's), Adaptive Environmental monitoring and management planning (Bray, 2008; Doorn-Groen, 2007) and the Adaptive Monitoring Cycle (UN/ECE, 1993; UNESCO, 2005, Verine, 2008).
Seemingly similar, they are easily separated into two types of approaches. The difference lies in the fact that most execution cycles, support systems and monitoring approaches primarily focus on target compliance. They are based on fixed knowledge and to function they need a clear demand of thresholds. As such, they mainly include process control and adjustments. For these approaches, no cause-effect knowledge is needed here; it involves no new knowledge-gaining. The "learning" involves adjustment of behaviour (including hardware) based on previously developed knowledge.
On the other hand, Adaptive Monitoring and Management cycles are structured, iterative processes of optimal decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring. The "learning" aspects here involve adjustment of behaviour based on creative problem-solving resulting in change in the previous knowledge. Suited for closing the gap to what we know and what we should know. It aims at achieving information production for the integration of a growing number of different goals. The latter applies to the adaptive character of the FoR.
The purpose of applying adaptive monitoring and management feedbacks within the FoR is to establish a clear and common purpose, make use of system modelling, and develop a management plan that maximises results and learning. This enables the development of monitoring plans that tests pre-defined assumptions, focus the analyses and communication of the results, and finally better use the results to adapt and learn
By applying an adaptive management approach to dredging, we expect it to function as an integrated system, adjusting and learning from a multi-faceted network of influences. These influences are not just environmental but also, economic and social (Bray, 2008). The goal of a sustainable organization guided by adaptive management must be to engage in active learning. The learning aspects help to direct change in these complex settings towards true sustainability. This "learning to manage by managing to learn" must be at the core of a more sustainable business strategy (Bormann, 1999).

The FoR as presented here aims to:

a) make the links between the planning process, monitoring and evaluation activities, and adaptive management of low impact dredging in sensitive areas explicit

b) provide a structure to inform the development of clear evaluation questions in relation to the impact, appropriateness, effectiveness, efficiency of FoR policies, programs and initiatives

c) inform the development of logical programme execution strategies across scales and across timeframes, including setting achievable targets

d) improve capacity to report on FoR performance

e) provide tools for progressively developing a picture of progress towards longer-term FoR goals

f) improve analysis of the successes and shortcomings of strategies

g) improve the performance of programs, initiatives and projects and to enable development of better instruments and policies for sustainable resource

1.8 Challenge

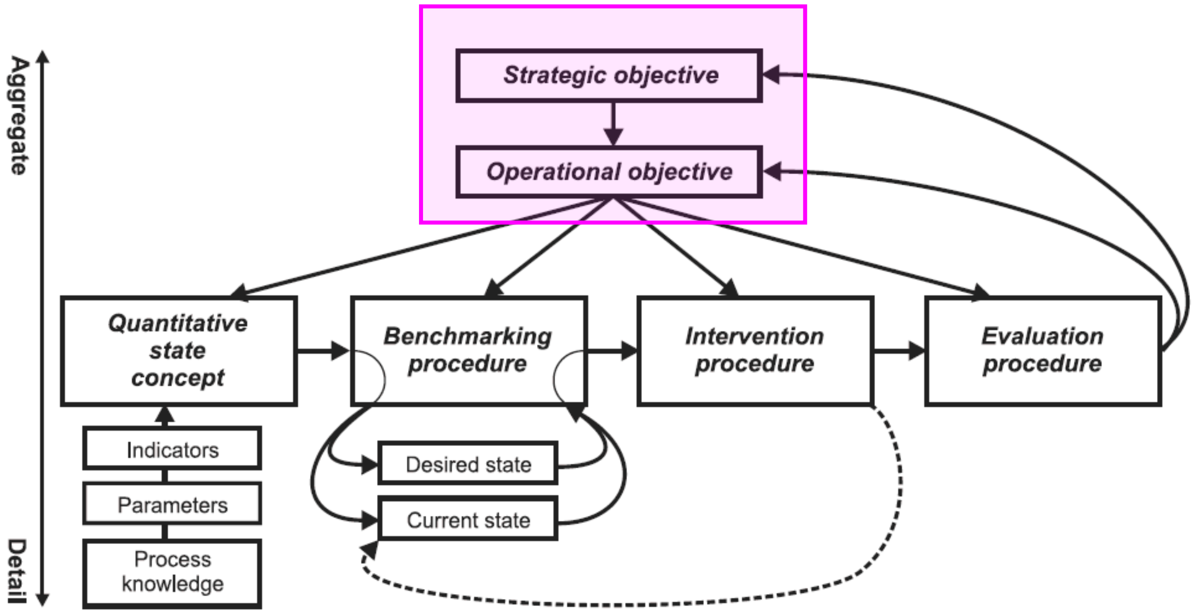
The aquatic environment is a complex combination of natural features and phenomena, supporting diverse populations that show rather unpredictable dynamics in resilience and carrying capacity. Because of this complexity, predicting the effects of human-induced changes on these ecosystems is extremely difficult. Even more difficult it is to unravel the relative importance of short-term dredging operations as part of all possible anthropogenic influence.

For example and as quoted before (Kaly, 2000: South Pacific Applied Geoscience Commission):

"the concept of health in relation to reefs, or any ecosystem, is a slippery one. We have no way of indicating the ideal number of species, community characteristics, energy flows or ecosystem services for even a single reef. Let alone arrive at some guidelines for the range of complex systems we are concerned with across the globe. Despite not really being ready for the challenge, we are forced by necessity to start taking action and learn as we go".

Partly through the worldwide globalisation and growing international networks, "The Not In My Backyard (NIMBY) syndrome" becomes less applicable. Globally, there is a growing recognition that despite decades of hard work, hundreds of projects, thousands of trained professionals, and billions of dollars, we have not yet substantially slowed the degradation of terrestrial and aquatic ecosystems. It is clear that "business as usual" is not a viable option and that newer, more powerful approaches for sustainable development must be tried.

2 Setting FoR objectives



2.1 Introduction

Dredging projects will make changes to the environment. They will have an effect on the environment. These effects can be seen by the stakeholders as acceptable or unacceptable. As pointed out in the introduction of chapter 1, there are a growing number of uncertainties, (environmental) restrictions, stakeholders and factors that nowadays increasingly co-determine the programming and execution of dredging projects. Consequently, what constitutes as an unacceptable dredging effect is based on socio-political, socio-ecological and economical decisions.

Unavoidably, the "adjusting" to new circumstances or developments as well as establishing new and clear (environmental) objectives is part of the whole execution process and entails new roles for clients and stakeholders.

A critical step towards the formulation of the project objectives is the recognition of the needs of the stakeholders related to the planned project. To determine the needs of the users involved in management, governance, conservation or other fields, it is necessary to identify who they are. Needs of both managers and stakeholders will be affected by the types of decisions required and the objectives being pursued. It is important to realise that at multiple stages of the project it is the consensus of these stakeholders that allow it to proceed or not.

When programming new accountable[1] dredging operations, the relative importance of these (previously unaddressed) user functions, values, benefits or interests in the Targeted Area of Interest (TAI) must be offset with the specification of the problem (present vs. desired system state and the related tolerance margin).

In order to do so, it is imperative to formulate a strategic management objective that puts the issues and related values and interests that play within the TAI in the proper perspective. I.e., it is essential to define the wider context of the problem first where the objective must address the external dimensions or boundary conditions of the problem. This concerns different aspects of, for example:

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1 In terms of low-impact, appropriate, effective and efficient.

a) the socio-economic context (present economical and aesthetical functions, social acceptance)

b) the administrative context (legal, political, strategic aspects);

c) the physical context (environmental and technical conditions).

Secondly, when an inventory of values and interests at stake and the definition of the desired state of the relevant themes including their context and dimensions are made clear, operational objectives may be formulated that will determine the set-up of the integral components of the FoR (i.e., the final selection of indicator, monitoring, benchmarking, evaluation, reporting).
The adaptive approach of the FoR improves the placement of dredging projects in an integrated management framework with other human activities (Chapter 1 but see also Belfiore, 2003; FAO, 2002), by identifying and specifying the major avenues, issues and functions by which each of the activities may hamper achievement of objectives. It is advised to assess these in a driver-pressure-state-impact-response framework (e.g. OECD, 1998; Bowen and Riley, 2003 and see appendix 1).
For this guidance document we are less concerned in the final formulation of the strategic and operational objectives. General approaches for identifying stakeholders and developing consensus-based objectives provide useful guidance (Smith et al., 1999; Walker et al., 2002; FAO, 2002; Mulder, 2001**;** Bray, 2008). In this chapter we will merely highlight what management actions, specific key functions of the TAI and information issues should be considered and clarified in order to establish accountable objectives that are needed to achieve the overarching aim of the FoR:

… the establishment of low-impact adaptive execution of dredging projects in sensitive coastal ecosystems in such way that the proposed project remains cost-effective and has no unacceptable environmental impacts on short and long term.”…

2.2 Functions and issues

2.2.1 General background

It is essential to relate the planned activities in context of other pressing issues in the region to be able to know how the relative impact of the project will affect the other functions and issues. What matters here are answers to the key questions like: What do we need to know? what will we give us the information? and who will be involved?
Various human and ecological functions and uses of the TAI can be identified from existing policy frameworks, international conventions, bilateral and multilateral agreements and strategic action plans for coastal zone management. Uses may compete or even conflict, in particular if TAI are under pressure and its quality deteriorating.
A multi-functional approach as introduced here seeks to strike a balance between the most important and desired uses, including ecosystem functioning. It allows the introduction of a hierarchy in uses and provides flexibility for the different levels of development of water resources management policies and for prioritisation in time and place.
This could be important for those countries where coastal development is so urgent that other uses will have lower priority, or for countries where coastal resources have deteriorated to such an extent that "higher" uses can be gradually restored only over a long period of time and in priority order.

When managing dredging projects in coastal zones one regularly faces conflicts of interests. Other issues that play are commonly linked with these conflicts. The sources of conflicts are threefold:

a) The competition for resources (consumptive uses vs. non-consumptive uses, e.g. navigation, tourism, fisheries, cabling, conservation, practice area)

b) The conflicts between all human interventions and nature (and vice versa)

c) Different interests of riparian regions (e.g. upstream/downstream regions, political priorities).

In the analysis of dredging management issues, political priorities should be made clear; the analysis of sources of (potential) conflicts is a precondition for the setting of priorities.

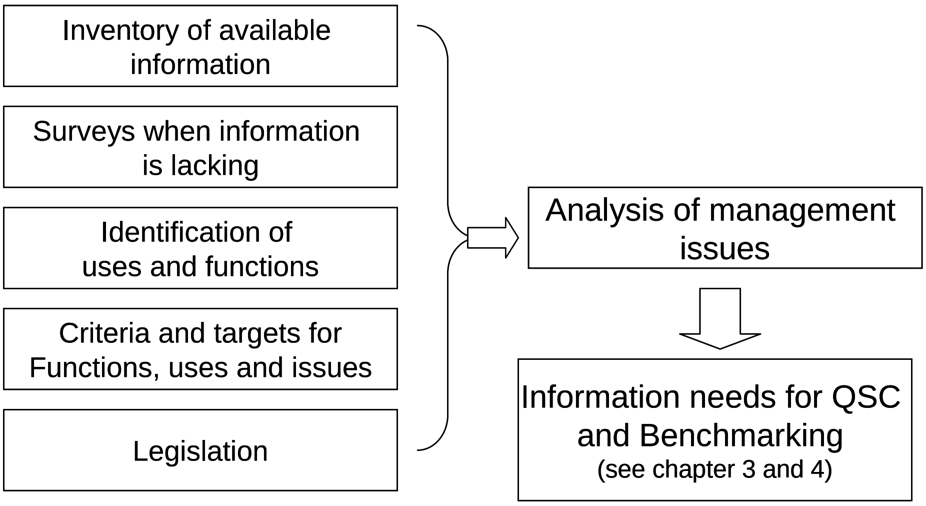


Figure 4. Analysing the issues, establishing information needs

To identify issues and priorities for the protection and use of a TAI, several activities are essential. These include the identification of functions and uses, inventories on the basis of available (and accessible) information, surveys when information is lacking, the identification of criteria and targets, and the evaluation of the resource legislation in the riparian countries (Figure 4). A well developed management plan must provide an overview of the actual status.

2.2.2 Identification

The operational objectives of the intended dredging activities should address the core elements in the management of the TAI and on the active use of information in the decision making process (see also chapter 4: benchmarking). These elements refer to the functions of the TAI, the issues (identified problems) and pressures (threats), and the expected impact of measures on the overall status and function of the ecosystem (Figure 5).

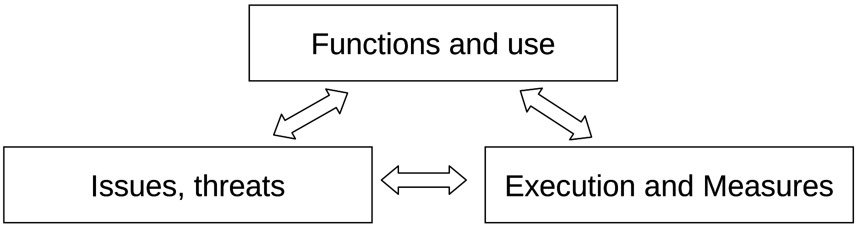


Figure 5. Key elements in execution management.

Ideally, the stakeholders involved need to individually identify and collectively agree upon:

a) Specific human uses of primary ecosystem services and the ecological function of the TAI

b) The conflicts between human use of primary ecosystem services and the ecological functioning of the TAI

c) The existing and future pressures which constitute the issues

d) The relation between the state of the TAI and the functioning of adjacent waters

e) Criteria for ecosystem services use and functions (e.g. water en sediment quality objectives at extraction and dumping location, definition of good ecological quality, etc.)

f) Quantified management targets (e.g. nutrient reduction targets, phasing out of pollutants, seafloor disturbance reduction), to be implemented within a specified time period.

When executing project management that involves considerations of an environmental nature and economic and operational feasibility; also actual or envisaged measures, policies and action plans should be taken into account.
This specification of human uses and the ecological functioning of the TAI and the identification of pressures, issues and targets should include the full range of qualitative and quantitative aspects in TAI management (see table 1).
The dredger must be sure that the dredging impact does not interfere with, or devalue legitimate commercial and economic uses of the marine environment nor produce undesirable effects on vulnerable marine ecosystems.[2]
Before prioritising, it is advisable to be sure at what agreement level issues, targets and information needs apply to (E.g., local, provincial, national or global). In this way all human (mostly controllable) activities are at the same level playing field and can be viewed together. This so-called "cumulative effects" analysis facilitates better a prioritisation (Bray, 2008).
The prioritisation in TAI management includes legislation. It is important to clarify these when specifying the issues and environmental functions. Thus, in addition to the uses and functions overview, the program owners should make an inventory of related environmental legislation and classification methods in and around the TAI, including regulations for data exchange and compare them, for both functions and issues, with international recognised standards, assessment criteria and global legislation.

[2] This includes also the fact that dredging (and dumping) may augment existing effects attributable to inputs of contaminants to coastal areas or enhance ecosystem vulnerability in general.

When all key elements are identified and the context is known, it is possible to oversee the solution domain and better specify the relevant internal dimensions related to the proposed dredging. Subsequently, Within the FoR the (qualitative) strategic objective as stated in chapter 2.1 may be transformed more easily into specific (and preferably) quantifiable operational objective.
For establishing SMART operational objectives within the FoR (see chapter 2.3) it is a prerequisite to have a coherent set of design parameters and combination of quantifiable aspects/coastal state indicators and cause-effect hypotheses. Frequent interaction with stakeholders is necessary to ensure their support for the selected indicators and hypotheses. Without their support the operational design parameters are less effective as arguments in the decision process. The decision which indicator(s) and hypotheses are fit to be design parameter(s), given a certain problem, is one of the most difficult considerations for coastal managers. Approaches to tackle the key elements needed in establishing indicator-based decision making are presented in the chapter 2: "Quality Status Concept".

Table 1. Example of relations between functions and issues within a coastal TAI. Presented are the situations around Singaporean coasts (See SI. 1.3.) and the Adriatic Sea combined.

		Functions / Uses														
		Human health	Ecosystem functioning	Dredging	landfill	Sludge dumping	Coastal contruction	Surface mining	Ports	Maritime transportation	Docking	Aquaculture	Fisheries	Recreation	Industry	Waste water discharge
	Changes in pH		X									X			X	X
	Changes in Salinity		X												X	X
	Changes in Turbidity		X	X	X	X	X	X		X		X		X	X	X
	Change in Oxygen	X	X	X			X	X				X			X	X
	Introduction of antifouling	X	X						X	X	X	X		X	X	X
	Introduction of heavy metals	X	X		X	X			X	X	X	X			X	X
	Introduction of microbial pathogens	X	X		X	X				X		X	X			X
	Introduction of PAH, PCBs	X	X		X	X			X	X	X				X	X
	Introduction of pesticides	X	X									X				X
	introduction of petroleum/oil	X	X			X			X	X	X				X	
	Introduction of radio nuclides	X	X		X	X									X	
	Nutrient enrichment	X	X	X	X	X	X	X				X	X	X	X	X
Issues	Organic enrichment	X	X	X	X	X	X	X				X	X		X	X
	Pollution general	X	X	X	X	X	X	X	X	X	X	X		X	X	X
	Resuspension from sediment		X	X		?	X	X		X						
	Resuspension of plankton resting stages	X	X	X			X	X		X						
	Non-selective extraction of species		X	X				X				?	X			
	Selective extraction	X	X									X	X			
	Abrasion		X	X			X	X		X		X	X	X		
	Sealing		X			X	X					X				
	Smothering	X	X	X	X	X	X	X				X				
	Conversion/destruction	X	X	X	X	X	X	X				X				
	Sedimentation	X	X	X	X	X	X	X				X				
	Erosion	X	X	X			X	X								
	Reduction of Sedimentation		X				X									
	Introduction of non-native species	X	X				X			X		X		X		
	Introduction of litter	X	X		X	X			X	X	X	X	X	X		
	Introduction of noise	X	X	X	X	X	X	X	X	X	X	X	X	X		
	Migration barrier	X	X				X			X						
	Water/tidal flwo changes		X	X	X	X	X	X								

2.2.3 Targets and criteria

Criteria for uses or functions should be specific requirements that follow from risk assessment considerations. Quantified management targets for the TAI should be based on water management policies agreed upon by the stakeholders (Figure 6).
However, depending on the agreement level, different assessment criteria, water management targets and water-quality classification system exist. These often include legal measurement obligations. Logically, international, national and regional stakeholder' groups must agree upon common assessment criteria and management targets. This can be done when at different levels water legislation and legal and other obligations for monitoring and assessment arising from conventions, other environmental legislation, agreements, criteria, policies and other arrangements are being compared and evaluated.
It is recommended that optimal use should be made of international standards and internationally recognised risk assessment criteria, as far as these are based on experimental data and actual knowledge (e.g. water quality criteria based on ecotoxicity data). The recent achievements and experiences of international organisations and coastal zone commissions is often very helpful.

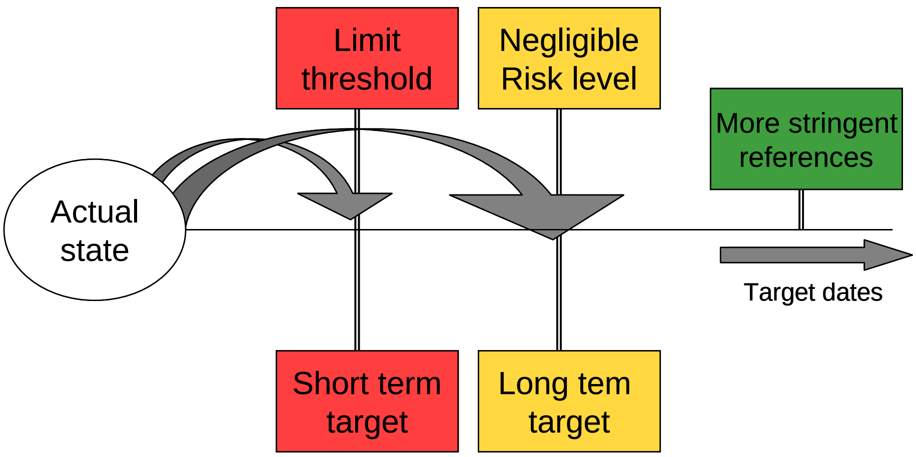


Figure 6. Targets and target dates for ecological impacts.

As important, the set limits or levels should be based on local conditions and local environmental sensitivities as well, not copied from another climate or site or coast etc, with different biophysical and socioecological characteristics.
Unfortunately, in most regions, a lack of monitoring or in-depth knowledge makes it difficult to conclusively identify the linkage between dredging pressures and a specific environmental effect and thus the setting of quantifiable objectives.
Also, there is a strong influence on these thresholds by cumulative effects, and seasonal and historical events of all issues and functions in the TAI. E.g., earlier or nearby dredging works, storms, biological outbreaks of pest organisms, chronic pollution and enrichment may drastically lower the resilience of the ecosystems in the TAI and thus appropriate risk levels.
Information and knowledge on these crucial aspects should be included as comprehensively as possible. In those cases, where the information still remains too vague providing too little guidance for selecting appropriate indicators and targets, the management body and the stakeholders should be involved in a selection process to ensure that the final suite of information needs matches the concerns behind the objectives, even when their wording reflects compromises among differing points of view. Then, agreed-upon limits of levels are set, not to exceed environmental quality objectives on all the various environmental variables of concern (issues/functions).

Since the adaptive character of the FoR and the best-practice monitoring are linked to the DPSIR approach, the initial signals from the responsive and adaptive cause-effect monitoring will always generate new process data and knowledge that will give additional local and temporal insights in whether the agreed-upon risk levels are appropriate for that moment or place.
With full cooperation of all stakeholders, and transparency on process and process outcome (data), one may relax or make more stringent the risk level at hand. This paradigm shift would allow a better interpretation of letting the dredging pressure levels move with the dynamics of the impacted ecosystem without loosing precise control of your operations in the field.
When the FoR is backed up by long-term pre- and post-project monitoring, it has the full opportunity of generating specific knowledge that would make it less difficult to conclusively identify the effects due to dredging. Knowledge that forms a significant contribution to the sciences dealing with ecological impact studies world wide and which fosters future strategies in a changing world.

2.2.4 Inventories and surveys

To identify issues and recognise problems and risk factors, preliminary investigations such as inventories and surveys are needed. These should clarify and specify what the relative importance of all issues and potential conflicts are. Inventories should gather all the information which is readily available. Information that is often incoherent and distributed among different agencies/institutions. This includes both the screening and interpretation of all information relevant to the aspects under consideration. Sources of information must be come clear and verified.
Inventories should cover the major aspects that are relevant to the identification of the issues (See Table 1). E.g., water uses in the TAI; riverine and terrestrial run-off characteristics, local and regional water current regimes; water and sediment quality (not only physico-chemical, but also sanitary, biological, ecotoxicological); the most important pollution point sources from industry and municipal waste (including their production process, chemical composition and discharge load); coastal zone uses and diffuse pollution sources from them, with an inventory of the use of fertilisers and pesticides (from agriculture and municipalities); and other sources of diffuse pollution (these may include traffic, pipelines, airborne pollution; potential sources of accidental pollution. A review of the findings of previous and ongoing studies can be a useful source of information.
The creation of new data through additional surveys is needed when insufficient data are available from the inventory to identify a problem and to specify what monitoring is needed. Surveys could be related to a broad range of subjects, such as the evaluation of site conditions (e.g. post-dredging surveys), the variability of monitoring parameters in space and time, or the screening of the occurrence of pollutants or toxic effects in water and sediments (water quality surveys). The latter may also include the closer investigation of effluent discharges or other (possible) "hotspots".
There are different approaches to determine when the moment of sufficient data and information is reached, the operational objectives may be quantified and the further design of the FoR can commence. Appropriate ways in doing so are explained in chapters 3 (QSC) and 4 (Benchmarking)

2.3 SMART vs. RASTM

From the strategic management and project management literature, one can learn that objectives of the indicator-based FoR should be SMART, i.e. that they should be Specific, Measurable, Achievable, Relevant, and Timed (Doran, 1981; Favell, 2004; Hametner & Steurer, 2007).

a) Specific: Objectives should describe what a strategy, a policy or a project wants to achieve in a focused and precise way; objectives should be well-defined;

b) Measurable: Objectives should be measurable so that their achievement can be assessed; this requires that they are quantified and timed (see below);

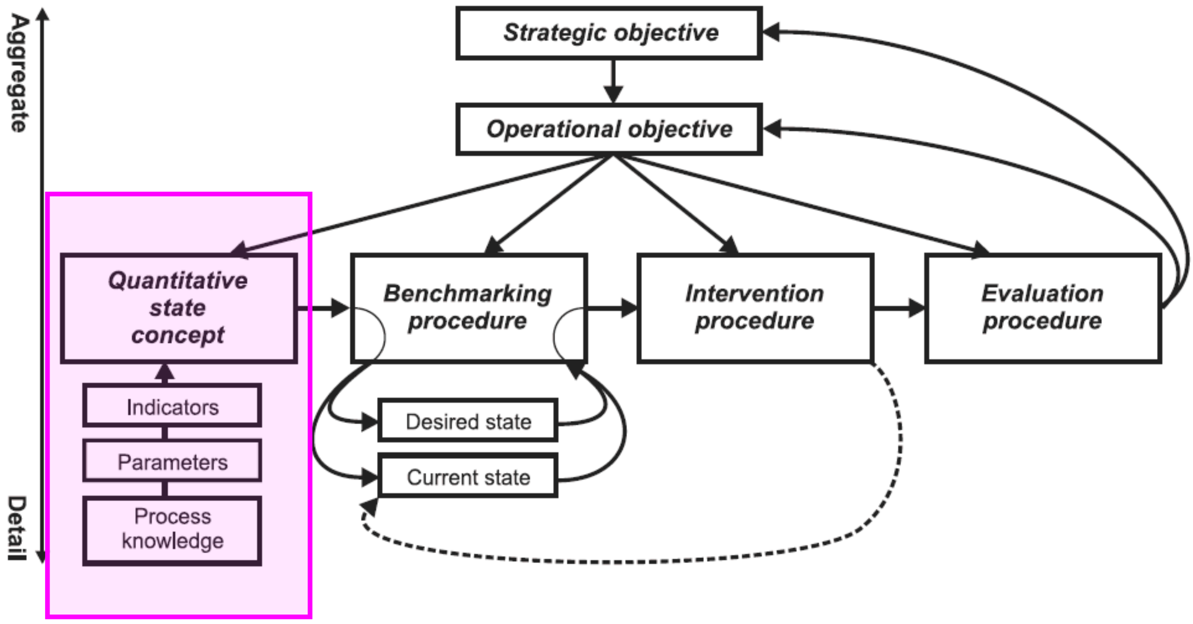
c) Achievable: Objectives should be attainable with a reasonable amount of effort (in terms of work time, budget, actors involved etc.), and achieving them should be neither too easy nor too hard (or even impossible);

d) Relevant/realistic: Objectives should be relevant to those who have the power and resources to realise them, and the resources necessary to achieve them should be available;

e) Timed/Time-bound: It must be clear in what timeframe an objective should be achieved within the FoR; objectives that do not state a "deadline" or "target year" are not measurable.

When objectives within the FoR are formulated or revised, it is important to first think about their relevance and achievability, then about making them as specific as possible, and finally formulating them timed and measurable. In other words, the memory aid "SMART" can in reality play out as RASTM.
Regarding the monitoring of FoR objectives with indicators, the characteristics S, M and T are obviously very important. It is difficult to monitor objectives if one of the three characteristics is not given, and it becomes impossible when objectives are unspecific, not measurable and not timed.

3 Quantitative state concept (QSC)



3.1 Introduction

Without reliable information on the current condition of the quality of the environment and the causes of changes in its condition, decision making can not deal efficiently with these issues; hence any operations or interferences in the natural coastal systems would be unmanageable.

To enable objective and reproducible decision making, the first step in the implementation of the targets is an objective assessment of the actual state of the system or certain aspects thereof in an appropriate form.

The appropriate form with respect to usefulness in decision processes is determined by the strategic and operational objectives as well as by the next steps in the decision recipe of the Frame of reference. With respect to practical effectiveness there is a strong link with knowledge of the system's behaviour to natural and anthropogenic pressures. Commonly, the information from many indicators is used to assess the state of the environment enabling objective and reproducible decision making.

3.1.1 Indicators

Environmental indicators play a crucial role in the simplification, quantification, standardization, and rational explanation or communication of environmental conditions to regulators, industry and policy-makers. As such, environmental indicators represent imperative tools for disclosing information on environmental values needed to safeguard the biological resources.

Currently, indicator-based approaches to coastal management are widely used and implemented. Indicators have a more and more prominent and legitimate role in assessing, and understanding ecosystem status, impacts of human activities, and effectiveness of management measures in achieving objectives. They encompass a still growing role in rule-based decision-making. (OECD, 1998; FAO, 2002; World Bank, 2002).

3.1.2 Definition

"Indicate", from the Latin indicatore, is to disclose, point out, and to make known. Characteristics of efficient environmental indicators have been summarized by many scientists, sectors and organizations working in this field. However, the term indicator is a profoundly ambiguous term that has been given different meanings in different contexts (see Heink and Kowarik, 2010 for elaborate definition study). It is of importance to always define and actualise the indicator term clearly and to put it in a broad context. In this guiding FoR document we adopt the all-encompassing definition of indicators given by the OECD (2003):

''An indicator in environmental planning is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals. Environmentally relevant phenomena are pressures, states, and responses as defined by the OECD (2003)''.

3.2 Indicators types

The execution objectives within the adaptive strategy of the FoR intend to address the different restrictive objectives set by the ruling ecological, sociological and economical structures. This basically means that different types of indicators are required within the FoR.

Recent studies have shown that for successful implementation, some indicators should be scientifically specific and designed to further unravel the ecosystem responses to variable human impacts, while other indicators, with less explanatory power, will have to monitor anthropogenic drivers and pressures (Langenberg and Troost, 2008).

Three types of indicators are particularly needed for monitoring the execution objective in the context of conservation, protection and sustainable use.

a) Indicators describing the state ("quality") of a part of the ecosystem. A state indicator could be a series of numbers along a time scale where each number gives a message about the state of a part of the ecosystem at that point in time. In order for the message to be clear and unambiguous there must also be one or more reference levels which allow differentiation between "good" and "bad" states, and there may be a target level which describes a desired state for this part of the ecosystem. For the indicator to be useful for management the part of the ecosystem which it refers to must be sensitive to human activities.

b) Indicators describing the state of human activities. Typically, such indicators used in dredging management would be information on the ambient concentrations of suspended matter in coastal waters. Such indicators can warn about possibly negative changes at an early stage, before the effects have had time to accumulate and show up in the state indicators.

c) Indicators describing the impact by human activities on the ecosystem. This type of indicator would tell about changes in a part of the ecosystem which are due to human activities. However, serious changes in the ecosystem are usually not due to human activities alone, but often to human activities in combination with changes in the physical part of the ecosystem (temperatures, currents, tides, etc.). This type of indicator is therefore often difficult to interpret.

Regarding objectives, several guiding documents emphasise that management strategies should be based on sound analyses of economic and environmental data, and must provide a short and long-term vision and clear achievable objectives (UNDESA, 2002; OECD, 1993). Clear objectives are a prerequisite to assess the degree to which

stakeholders have achieved their own objectives. However, what are "good indicators" and how does one achieve them?
It is important here to note that we considered the DPSIR (Driver-Pressure-State-Impact-Response) framework to structure the context of the listed indicators. The DPSIR framework is compatible with evaluating the ecosystem effects of human activities and has played a prominent role in selecting indicators and sometimes objectives in areas of environmental quality and sustainable development (see Appendix 1).

3.2.1 Suites

For evaluations of ecosystem effects of coastal works, marine ecosystems have so many properties of concern and so few proven general state measures that there is generally no shortage of proposals for indicators (e.g. CSAS, 2001; ICES, 2001; Link et al., 2001). Indeed, experts that promote science-based management note that coastal ecosystems are in general so complex and unpredictable that suites of indicators are needed to give an adequate picture of their state, let alone manage it (FAO, 2003).
Subsequently, there is clear risk that the capacity for meaningful dialogue and the processing ability of rule-based decision-making systems such as the FoR become saturated when overloaded with information from too many indicators (FAO, 2002, 2003; OSPAR 2007). Most seriously, with even modest numbers of indicators, ''current values'' of different indicators are likely to support arguments for incompatible management actions.
Furthermore, each indicator implies monitoring, evaluation, and costs involving the implementation and thus the attuning of operations. Therefore, to be cost-effective and to provide clear management guidance, suites of indicators should be kept as small as possible while still fulfilling the needs of all users. The challenge here is to identify the suite that best meets the needs in each particular application.
It must be noted that marine ecosystems differ in availability of historical data, monitoring capacity, prosecution of coastal resources, other human uses, and governance system, as well as in their ecological properties. All these factors may affect the utility of a specific indicator (Belfiore, 2003; Olsen, 2003), making it obvious that no single suite of indicators is universally the best.

3.2.2 Objective

Indicator-based decision-making in the framework of reference may give managers structured insight into the likely effects of alternative actions. This is only true if the performance characteristics of the (suites of) indicators are understood, and if their trends, underlying causal relationships and current values relative to reference points can be interpreted correctly (see chapter 4 Benchmarking).
Up to now, both the scientific and managing community continue to struggle to agreeon, validate, and mobilize marine environmental indicators. This is to all intents and purposes due to the fact that at a global and regional level, it has become increasingly clear that the difficulties in assessing progress against overarching goals for sustainable coastal management lack objective and consistent indicator–evaluation frameworks (ICES, 2003; and OSPAR-MON, 2009). Consequently, despite the central role the indicators (see chapters before) play in any decision system, they are mostly not chosen wisely and pragmatically.
These flaws in indicator-based management are characteristic for poor science. As any tool developed by research, indicators must be elaborated according to a scientific approach. One of the important steps of this elaboration is an objective and thorough justification.
Therefore, we introduce here as part of the QSC of the FoR a generic approach that outlines certain crucial steps and guidelines necessary to:

a) develop meaningful indicators and;

b) select from the long lists of diverse, potential indicators and;

c) compose workable suites for FoR for low impact dredging

The approach presented is designed as a guide for practice, and therefore consists of a number of steps and specific tasks to be performed at each step. The approach is flexible, since too rigid procedures are unlikely to be followed. However, the matters described in each step must be addressed to select the final suite of indicators, and for some of these steps this must be done in chronological order. (e.g. criteria must be weighted before indicators are scored).

The justification, definition and analyses of the applicability for the selected indicators have concisely been drawn up in this chapter. During this selection a modified version of the ICES (2003) and Rice and Rochet template (2005) was used to evaluate the indicators. We adapted the guidance frameworks for selecting good indicators as outlined by many expert groups (e.g., the evaluation criteria of UNCSD, 2001; ICES, 003, 2005; EEA, 2003; OSPAR, 2005; WorldBank, 2002; FAO, 2003; UN/ECE, 1993; AID environment2004 and Rochet and Rice, 2005).

3.3 Developing and justifying indicators

Once the operational objectives have been clearly set (see chapter 2), guidance for selecting appropriate indicators is provided.

However, to be sure that the indicators truly measure ecosystem status relative to the objectives set earlier, the available information must set out the true justification for the pre-selected or proposed indicator, its definition and an analysis of the applicability of the indicator (i.e., design, output and end-use). For guidelines to validate indicators see appendix 3.

Ideally, a background document per indicator (or indicator element) should be prepared that is well-structured, concise, and written in a language that should be unambiguous.

Given the indicators' importance in subsequent management of dredging operations in coastal zones, a justifying background document would be an improvement over the common ambiguous approaches, and a step towards the rigour and transparency required and justified.

3.3.1 Developing Back ground document

Background Documents should contain the following information:

1 Indicator Issue;

The subject at hand. What are we talking about?

2 Indicator Element(s);

Are we dealing with single or composed indicators? If needed. Check separately the elements. Is the problem at hand satisfactorily described? Does it tell us what is happening and why?

An initial information collection stage should include the collection of existing information on, among other things, the monitoring of the ecological quality element, current and historic levels of the indicator and its elements, reference levels, sensitivity to human activities and potential sensitivity to management actions.

3 Indicator Objective;

Indicators should send a clear message and provide information at a level appropriate for policy and management decision making by assessing changes in the status of biodiversity (or pressures, responses, use or capacity), related to baselines and agreed policy targets if possible.

4 Justification for indicator development;
The elements must provide a representative picture of the pressures, biodiversity state, responses, uses and capacity (coverage). What are the potential threats? What sensitivity? And where? Are key properties of biodiversity or related issues as state, pressures, responses, use or capacity properly addressed? Are existing indicators based on clearly defined, verifiable and scientifically acceptable data and collected by using standard methods with known accuracy and precision? Or are they based on traditional knowledge that has been validated in an appropriate way? Is the design scientifically sound?

5 A comprehensive Technical Evaluation must be carried out and considers the following elements and criteria:

a) Understandable. The power of an indicator depends on its broad acceptance and the common understanding of its concreteness. To achieve a general acceptance of the validity of the indicator by all relevant stakeholders it is imperative that the (suites of) indicators are relatively easy to understand by non-scientists and those who will decide on their use. The realisation is generally facilitated by the involvement of the policy makers, stakeholders and experts in the development of an indicator itself.

b) Responsiveness. Indicators within the FoR are predominantly meant to assess the (anticipated) impacts of large-scale human activities as basis of the benchmarking process so that consequently an optimisation in execution may be implemented. In these settings it is imperative that the indicator is able to detect changes before it is too late to correct the problems being detected. Indicators should therefore be relatively tightly linked in time to human-induced stressors. For compensation and mitigation purposes they should be able to detect changes in systems in time frames and on the scales that are relevant to the decisions.

c) Specificity. Several environmental factors and human activities may contribute to the indicator’s response. The risk of misinterpretation of this cause/effect relationship is substantially reduced when the indicator is primarily responsive to a human activity, with low responsiveness to other causes of change. I.e., they should be adequately sensitive to show trends and permit distinction between human-induced and natural changes.

d) Measurement. The indicator must be able to easily and accurately measure the human pressures and their direct and indirect effect on the system with a low error rate. The indicator and all the underlying techniques or respective elements (sensors, variables) exhibit low measurement error, are stable during the sampling period, and must be robust having sufficiently low variation to detect ecologically significant changes.

e) Accuracy. It is imperative that all necessary elements of a monitoring programme and guidance are available for accurate measurement and monitoring of the pressures and/or effects should be performed in a coherent way, and with appropriate frequency and area coverage but also with a quality assurance system in place (see chapter 4 benchmarking for more details).

f) Sensitivity. The indicators are adequately sensitive to a manageable human activity. They should be adequately sensitive to show trends in human-induced changes.

g) It should be noted that, the links between pressure and direct and indirect effects may be spatially and temporally separated through transboundary effects. Ecosystem or environmental factors may cause time lags. Also, to obtain a regionally wide responsiveness, the indicator must reflect changes in ecosystem condition and respond to stressors (pressures) of concern across several resource classes and habitats within the monitored region (An examples of an appropriate in-depth study for the determination of the probable link between indicator and pressures is presented by Heink and Kowarik, 2010; Kruchten and van der Hammen, 2010).

h) Applicability. The pressures and impacts are measurable over a large proportion of the area to which the indicator metric is to apply. A robust indicator that may be quantified by synoptic monitoring or by cost-effective automated monitoring over a larger area is valuable in establishing underlying cause/effect relationships.

i) Historical data. Indicators (and underlying elements) should be based on an existing body or time-series of data to allow a realistic setting of objectives.

j) Time-series with satisfactory frequency and spatial coverage of monitoring greatly improves the indicator performance.

k) Ecological relevance/basis for the metric. The ecological relevance of the indicators is high and data on the indicator can be collected effectively and economically across the whole range to which it applies. The indicator needs a clear scientific basis, linking it to significant aspects of the quality of a coastal ecosystem.

l) Current and historic levels. Quality data on historical levels are needed to construct area-specific background levels against which the current levels may be assessed and evaluated. Background levels are considered when setting reference levels.

m) Reference level. A reference level is the level of the indicator at which the anthropogenic influence on the ecological system is minimal. The criteria on which the reference level is set can change from indicator to indicator, or over time, leading to changes in the reference level as well. The reference level may refer to a range of possible points that allows for natural variation around a point. It is imperative that a clear reference level or "target" (i.e., an assessment level, related to background levels) is established against which the data on the indicator can be evaluated.

n) Limit point. A limit point is an area-specific assessment level. Where a limit indicates a value of the indicator that, if violated, is taken as *prima facie* evidence of a conservation concern, i.e. there is an unacceptable risk of serious or irreversible harm to the environment.

o) A limit point must be unambiguously interpretable, relating to an assessment endpoint (relevant exposure/stressor/habitat variable) that forms part of the ecosystem's overall conceptual model of ecological structure and function.

p) Time frames. The time frame, during which detectable changes can be demonstrated, must be sufficiently appropriate to allow management to establish the area specific target level, i.e., values of the indicator that management should be trying to maintain with high probability.

q) The time lags between taking action, system response to pressures and detection of change is an important criteria for selecting suitable indicators for FoR and should be kept as short as possible.

r) Monitoring regimes. Robust, standardised and attuned monitoring practices are necessary. Monitoring protocols must be clearly documented and available. Monitoring should be implemented in different selected areas and reference areas should be chosen. Monitoring rates need to be established including the management of the data produced and the generation of the indicator information.

s) Management measures. It should be known whether management measures for reaching certain indicator levels are in place within the targeted area/region. The monitoring implemented for FoR may help in establishing whether the existing measures are successful, or that additional measures would be required.

t) Broader applicability. The strength and success of the indicator increases when it can be made applicable to other targeted regions

u) Further considerations. Indicators should preferably be based on measurement tools that are widely available and inexpensive to use compared to those that are in need of new, costly, dedicated, and complex instrumentation.

v) The smaller the total number of indicators, the more communicable (interfacing of dataflows) they are to the benchmarking process. Also, small indicators suites become sooner understandable to policy makers and the public and lower the cost.

w) The sampling procedures of the (suites of) indicators in the field should have minimal environmental impact.

x) Indicators should be designed in a manner that facilitates aggregation at a range of scales for different purposes.

y) To insure appropriate quality assurance levels, where possible, peer review of indicators and background documents should be by relevant specialists (i.e., dredgers, PIANC, IADC, CEDA, OSPAR, IMO, etc.)

z) Conclusions and future needs for full development do also include costs. Its development and chance for adaptation within the FoR.

aa) References. For scientific rigor, the sources of information to which the indicator is being developed or assessed must be stated in the background document.

Examples of backgrounds documents of environmental indicators or ecological quality objectives may be found at ICES and OSPAR organisations. Also, in Appendix 3 a technical evaluation is given for the indicator underwater light availability.

3.3.2 Weighing of indicators

The elements and criteria set in the background document of the indicator are not equally important in every case. E.g., depending on local structures and different user groups, different relative importance is given to the criteria set in chapter 3.3 (Table 2).

Table 2. Relative importance (little, moderate and high) that three user-groups are expected to attach to some important criteria used in the developing or screening process of candidate indicators (numbers in parenthesis are given and represent tentative rankings within each group).

Criterion/ elements	*Technical expert*	*Decision maker*	*Audience*
A Understandable	Little	Moderate/high, makes decisions easy to explain to public and compliance to management (5/6)	High, to relate personal experience to indicator (2)
B Responsiveness	Moderate (5/6)	High, feedback on management efficiency must be given upon demand (1)	Little
C Specificity	Moderate (5/6)	High, needed to take remedial actions (2)	Little /moderate, to understand how dredging relates to the "big picture".
D Measurement	High, low or unknown accurate indicators are mostly rejected (1/2)	Little, as long technical advisors and public have confidence*.	Little, unless sampling design is considered unrepresentative of personal experience (5)
E Sensitivity	High, low sensitive indicators are mostly rejected (1)	Moderate, to interpret biological and economic importance of change in value (4)	Moderate, to attach meaning to changes in value (3)
F Applicability	Moderate, cross boundary actions increases confidence (5/6)	Moderate, facilitates intercomparisons of results and management (4/5)	Little
G Historical data	High, for estimation reference points and to have confidence in interpretation (2/3)	Little, as long as technical experts and public have confidence*	Little/ moderate/ high depending on amount of context needed to interpret change in values.
Scientific soundness	High, inconsistencies may form (3/4) empirical basis	Little, management generally based on values and performance not ecological theory	Little
Total costs	Little, not their concern	High, managers are budget-conscious.	Moderate/high, value for money.

* The relative importance increases when management has to function without technical support.

More elaborate weighing and scoring techniques have been developed for specific situations (Bocksteller and Giradini, 2003; Scheltinga and Moss, 2007). However, for weighing elements and criteria that mostly lack a quantitative basis such a complex weighing might give a wrong sense of precision. The weighing in table 2 according to three classifications is sufficient and should be carried out interactively and systematically with the client groups involved before the actual screening is carried out.

3.3.3 Scoring

Scoring of the indicator depend both on how good the quality of the information content relative to the criterion is and how the strength of evidence of this information content is judged. The challenge here is that in practice, most candidate indicators often have to be scored in the face of complex dimensionality of the criterion (e.g., criterion "measurement" and underlying the sub-criteria bias, variance, accuracy, precision, repeatability, etc.) while there is a general absence of quantitative measures. As for the weighing, putting too much detail in the ranking gives a wrong sense of discriminating power among the selected indicators.

Following ICES (2001) and OSPAR (2007 and 2009) an ordinal score on a scale of 3 (Rarely, occasionally and usually) may be sufficient (see appendix 3: example of technical evaluation). Underlying the three scales, key dimensions or sub criteria may be included that help the formulation of the criterion ranking. A straight forward ranking of criteria and sub criteria including their information sources based on the work of Rice and Rochet (2005) adapted to the criteria as proposed for technical indicator evaluation used in OSPAR (2009) and Johnson (2008) as an example is given in appendix 3. The scoring process and ranking may differ per indicator. Important here is that as long as the relative position of the indicator is carried forward with regard to their strength of information evidence, subsequent or additional steps can be performed with objectivity.

3.3.4 Screening

Combining the different user groups weighing and the ranking based on the technical evaluation may then be converted to information needed for the final screening and selection. However, a simple computation of the two rankings into a final score will mask certain important shortcomings and is not advisable. For example, averages might conceal severe shortcomings in the indicator design and output. Also, similar scores of complementary indicators may lead to unwanted selection.

Most of the known approaches that have been used to make a final screening possible demonstrated potential flaws (CSAS, 2001, Link et al, 2001), this is because it is difficult to quantify multiple criteria that overlap in information content and vary in importance for different uses.

A proposed method to reduce the amount of information includes the following considerations:

a) If the pressure to the status and trends in the indicator is relatively easy to differentiate from other pressures (natural and anthropogenic) a selection of those indicators that cover most broadly the key system components and multiple uses are preferred.

b) It is necessary to realise whether one is dealing with state, impact or pressure indicators. A Dutch study (Langenberg & Troost, 2008) showed that pressure indicators used to monitor physical and chemical phenomena scored higher, were clearer, and reference levels and limit points may be determined more easily than for biological impact indicators. Also, for these indicators, the time frames for implementation and outcome assessment turned out to be relatively short with acceptable costs.

However, seeing the growing importance of stakeholders in coastal zones involved in sustainable development of this coast and the changing demands of clients, a balanced

suite of indicators for benchmarking the execution process in the context of conservation, protection, and sustainable use is recommended. For the selected suites of indicators this basically means that some are likely to be scientifically specific and designed to further unravel the ecosystem responses to variable human induced impacts, some will have to monitor the main anthropogenic pressures, while others monitor the biological state. The suite of indicators as a whole must perform well on all criteria important for each expected use (see chapter 4: benchmarking for different types of uses), as well as to cover the different objectives set by ecological, social and economic structures.
The reasons for selection based on these considerations should be well documented and retained. When indicators with known shortcomings are retained because they have unique strengths as well, users need to keep these shortcomings in mind when interpreting their values and making decisions.
Subsequently, there is clear risk that the capacity for meaningful dialogue and the processing ability of rule-based decision-making systems such as the proposed FoR become saturated when overloaded with information from too many indicators (see FAO, 2002, 2003; OSPAR 2007). Most seriously, with even modest numbers of indicators, ‘‘current values’’ of different indicators are likely to support arguments for incompatible management actions (chapter 3.2.2.).

3.3.5 Selection

When preselected indicators do not perform well for a given use, then the suite should try to balance the pros and cons, i.e., some indicators in the suite must perform well on each important criterion and elements. Also, when the suite is intended to serve multiple purposes, it should be more effective to select indicators matched well to each intended use, rather than to derive a compromise among uses, not performing particularly well for any of them.
After having provided the definitions, justifications and having evaluated their effectiveness and applicability for compliance with the strategic and operational objectives, ideally a relatively small suite of selected and matching indicators serving all uses can be implemented to form an intrinsic element of the QSC. (As stated in chapter 3.2.2 too large suites of indicators easily overflow the system with too much information often leading to incompatible management actions). Indicator suites' strengths might change over time for different reasons. Time-series data expand continuously, knowledge progresses (biological and dredging impacts), new pressures (natural or anthropogenic) might become important, and societal values could change. All these factors would be the causes to reconsider which indicators to use, or how they are interpreted in practice.
Lastly, retaining the evaluation matrices and the reasons for the selection of indicators allows choices or uses to be adapted without repeating the entire exercise, thus enhancing consistency.

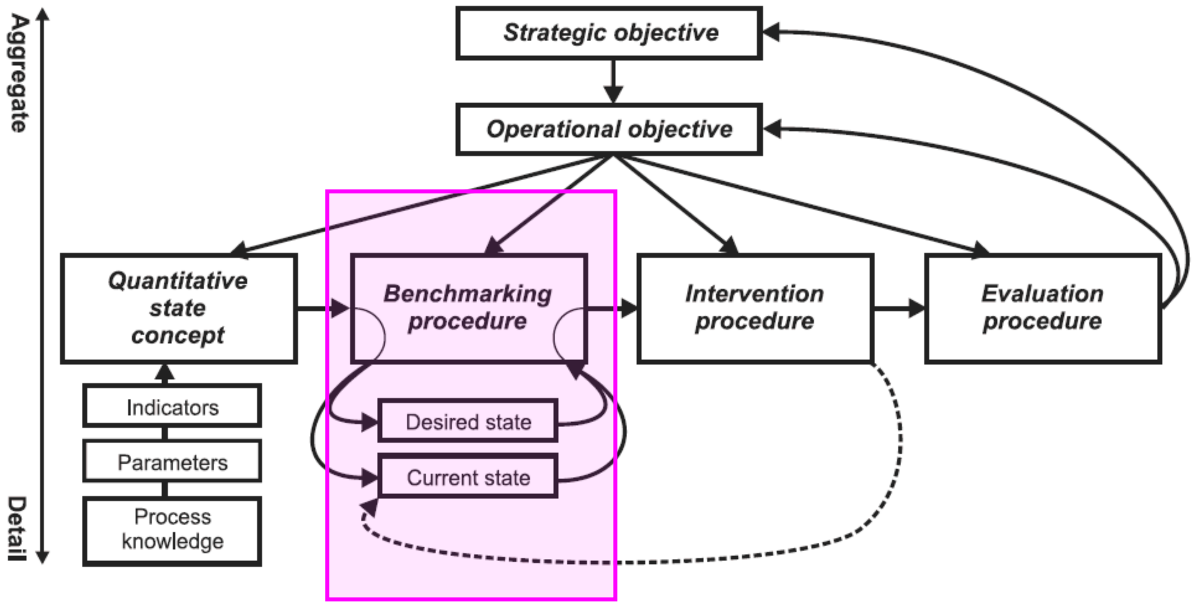
3.3.6 Further considerations

Although selection of indicators continues by consensus and dialogue, the important function of the selection framework also lies in its potential to structure the dialogue and implementation of the indicator as crucial part of the FoR. If all steps are included in the dialogue leading to the selection of the final suite of indicators, most important bottle necks should have been addressed.

Comprehensive indicator evaluations have shown that in practice, the establishment of references, targets or limits needed for useful indicators, seems intricate due to lack of quality data (see Appendix 4). Also, the complex correlations between pressure and impact in time and space are not well understood and hamper the full implementation of indicators. This is commonly the case for indicators for impacted biota, When these type of indicators are implemented they may easily lead to a descriptive and costly monitoring

that only gradually in time may allow one to correlate system responses to other external events or vice versa and derive cause-effect relationships.
It must be noted that during operations there are further analyses needed for the suite's applicability, scientific soundness, practicality and costs involved with future implementation. These retrospective analysis of their performance in supporting the FoR should be fed directly into the evaluation process (See chapter 4 and 6). Only then a flexible inventory-monitoring program can be put in practice that is designed to provide information on individual characteristics of the environment, rather than being based on fixed definitions of resources.

4 Benchmarking



4.1 Introduction

A rigorous benchmarking procedure is necessary, so that we can systematically and objectively determine when to intervene in the system. Intervention is required when a discrepancy between the current system state and a desired or reference system state surpasses some predefined threshold. Implicit differences with the desired system state often generate discussions on what is in the interest of the management objectives and what is not. To facilitate useful discussions, the current as well as the desired state should be made explicit, preferably expressed in terms of the chosen quantitative state concept. This element of the decision recipe often relies on measured or predicted trends in state descriptions, costs and benefits.

For the FoR, monitoring and assessment activities form the main elements for the benchmarking and they are crucial activities in integrating the planning with the intervention procedures. In fact, the benchmarking itself resembles a management practice used to assess the effect of other management practices within the FoR. For more information see also UN/ECE Task Force on Monitoring and Assessment (1993). The integrative benchmarking forms the core of a structured, iterative process of optimal decision making in the face of a mismatch between current and desired environmental state, with an aim to reducing this mismatch or uncertainty over time via concerted monitoring strategies. In this way, the intervention procedure simultaneously optimizes resource and execution objectives. The benchmarking procedure facilitates rigorous corrective actions in the execution that are needed for allowing adaptive management in the FoR. Integrated with QSC and interventions, it also, either passively or actively, accrues information (process knowledge on both hardware and environment) needed to improve the future management of similar projects.

The measuring and predicting of states and the testing of the hypothesis, following the design of the QSC and the specifications of the information needs, require strategies to:

a) design and operate monitoring programmes in such a way that the desired information is obtained.

b) define the approach and the criteria needed for a proper comparison between current and desired state.

4.2 Objectives

Monitoring and assessment can take many forms and realise various objectives before, during, and after any dredging project. This chapter does not provide a comprehensive description of monitoring technology but rather focuses on the importance of implementing sound monitoring en assessment practices as a necessary element in the context of the FoR. Here we introduce guidelines for developing, implementing and assessing cost-efficient monitoring networks or programmes as part of the FoR. The guidelines intend to provide a structure that:

a) clarifies the information needs and underlying monitoring objectives;

b) facilitates the development of monitoring en assessment strategies across scales and across timeframes;

c) facilitates the design and implementation of tailor-made adaptive monitoring programmes; including setting achievable state targets and types of monitoring (end of this chapter);

d) facilitates the management for safeguarding and use of collected data and newly gained knowledge;

e) facilitates the implementation of Quality Assurance management.

4.3 Information needs

The ultimate goal of adaptive monitoring is to provide adequate information needed to answer specific questions in decision-making. Still, many monitoring programmes are characterized by the "data rich, but information poor" syndrome (DRIP-syndrome), therefore, attention should be directed towards the end-product of monitoring, i.e. information. It is Information, not data that facilitates the adaptive process but also informs the stakeholders.
The most critical step in developing a SMART adaptive monitoring programme is the clear definition and specification of monitoring objectives and information needs. Both have to be specified to such an extent that design criteria for the various elements of the benchmarking can be derived.
For practical reasons, the information required for the assessment of the desired and current state should be structured on the basis of the drivers, pressures, state and impact (DPSIR approach see Appendix 1), and the different measures within the FoR. The overview may then follow the operational objectives. More specifically, it allows the needed predefinition of important concerns at hand combined with the possible intervention processes.

4.3.1 Information objectives

Different information objectives can be distinguished, showing the intended use of the information (purpose) and the management concern (e.g. low-impact dredging or protection of sensitive ecotopes). The main information objectives within the benchmarking procedure within the FoR are:

a) Recognition and understanding of environmental issues through in-depth investigations including being well informed on current knowledge.

b) The assessment of the actual status of the system by regular testing for compliance with standards. Standards should be defined for pressures and targets for maintaining the good ecological functioning of the coastal system concerned;

c) Testing for compliance with contractual restrictions;

d) Verification of the effectiveness of impact control strategies (what techniques and approaches are implemented successfully? In what way are these presented to the stakeholders? Are certain targets reached?);

e) Provision of early warning as part of the whole operation. How are the sensitive environments and their people protected during calamities?;

f) To increase knowledge about the environmental conditions and effects of a given dredging process. This knowledge serves as a basis for a better assessment of the environmental effects during future dredging projects.

4.3.2 Specification of information needs

Only specific information needs allow the design of a monitoring and assessment system. Following the information objectives (making clear why and for what this information is gathered), information needs may be better specified. The specified information needs should include the following items:

a) The definition of criteria for the environmental quality assessment. E.g., considerations for the setting of standards or criteria for the choice of alarm conditions for early warning;

b) Select the appropriate monitoring (suites of) indicators according to the Quantitative State Concept (see Chapter 3); they should sufficiently serve specific information needs;

c) Relevant margins have to be specified for each monitoring parameter. What detail is relevant for decision-making? A relevant margin could be defined as the information margin that the user is concerned about;

d) Specify the requirements for reporting and presentation of the Information product (e.g., visualization, the degree of aggregation, indices).

e) The response time should be specified. The response time is the period within which the information is needed. In early-warning procedures, information is needed within hours, whereas for trend detection information is needed within weeks or even months after sampling;

f) It has to be decided what reliability is required. To what extent is inaccurate information allowed? 100% Reliability is impossible or prohibitively expensive. Depending on the consequences, information should be more or less reliable. Together with the relevant margin, this is a determining factor when locations, frequencies and methodologies are chosen in the design of monitoring programmes.

Important notes concerning information needs:
Monitoring is not the only source of information (see Figure 7); often a combination of sources has to be used to meet the information needs.
Information needs are evolving during monitoring due to developments in water management, ecological research and technical progress, attaining of targets or changing policies or clients' wishes. Consequently, monitoring strategies often need to be adjusted over time.
In adaptive monitoring strategies, dynamic information needs require a regular re-thinking (revision) of the information strategy in order to update the concept. However, one should not neglect the need for continuity in time series of measurements. This continuity is necessary to detect significant and reliable trends in coastal ecosystem's characteristics.

4.4 Monitoring and assessment strategies

Following the specification of the information needs, assessment strategies are required to design and operate monitoring programmes in such a way that the desired information is obtained. Strategies define the approach and the criteria needed for a proper design of the monitoring programme and translate the different information needs into operational monitoring networks that will deliver the desired information.
Coastal ecosystems are not closed systems; they exchange materials and energy with their surroundings. Therefore, there is a need to broaden the scope of assessments to the exploration of the linkages and interactions within the ecosystem. A challenge lies in discovering abiotic and biotic factors, as well as the key linkages that provide for the ecosystem integrity, and in maintaining energy, chemical, physical and biological balance in the interlocking ecosystems (see chapter 2 for setting the FoR objectives and appendix 1: the DPSIR context). The movements of substances into and out of the catchment area and the internal dynamics within the catchment area should be known and/or studied.
Modern coastal zone management implies that water resources are managed in an integrated manner on the basis of catchment areas, with the aim of linking social and economic development to the protection of natural ecosystems and of relating coastal resource management to regulatory measures for other environmental media. Such an integrated approach includes humans as a central element in the wellbeing of the system. This implies recognition of social, economic, technical and political factors that affect the ways in which human beings use nature. These factors should be assessed because of their ultimate effect on the coastal integrity.
These integrated approaches, transboundary or not, will influence the way in which monitoring strategies in the FoR are designed and assessments made. Here below, depending on the specific information needs we determined in chapter 2, we elaborate on the most important approaches necessary for subsequent Monitoring and assessment design in the benchmarking.

4.4.1 Harmonised approach

The approach used for environmental impact control for the prediction, detection and control of the pressures caused by dredging or land reclamation, the assessment of the water quality in and around sensitive coastal zones, and the ecological functioning of the coastal ecosystems requires the integration of different types of monitoring:

a) physico-chemical analysis of different environmental compartments (water, suspended matter, sediments and organisms)

b) Ecotoxicological assessment by bioassays and early-warning methods

c) Biological surveys

The combination of the three types above enhances the establishment of the causal linkages between dredging pressures, changes in environmental compartment and bio-availability.

4.4.2 Phased approach

Prior to the implementation of the benchmarking component of the FoR, inventories and preliminary studies must be carried out to set up the benchmarking as effectively and efficiently as possible. The process and indicator knowledge from the Quantitative State Concept (chapter 2) and a screening of information from other knowledge-based systems may form the basis for a comprehensive screening of available information (Figure 7).
However, the general lack of appropriate, consistent, reliable quality data and the non-existence of a baseline against which progress can be measured require additional information. This information must be gathered through different additional monitoring activities ranging, phased from course to fine, from rapid screening tests and simple field surveys to intensified tests (including models) and field variables up to fundamental research
One should realise that as the assessment of environmental quality normally includes different aims (e.g. to signal, control or predict) and as the information needs vary from broad indications to fine-tuned diagnostic figures, the choice of variables and methods (e.g. ecotoxicological indicators) also depends on them. This, in turn, could easily lead to strongly increasing (and unmanageable) information needs and subsequently complex and costly operational monitoring programmes. In this case, a phased approach with stepwise testing strategies from coarse to fine assessments is recommended. Each step should be evaluated and questions like: “is the information obtained sufficient?” Or “is additional research needed?" should be answered rigorously (Figure 7)
Additionally, prioritisation in time is recommended for the introduction of new monitoring strategies, going from labour-intensive to technology-intensive methods. In many cases, the lack of appropriate, consistent and reliable data and the non-existence of an adequate baseline against which progress can be measured make a phased approach a requirement.

4.4.3 Risk assessment approach

A risk assessment approach may help prioritising information needs and monitoring activities. E.g., one can argue that the water quality in a relatively small area in a sparsely populated area is hardly affected by threats, i.e. there is hardly a risk to human health. However, if there are refuse dumps or contaminated sediments, a much higher risk to human and ecosystem health is possible. By using risk assessment, the authorities, clients and project executers can decide which monitoring activities have higher or lower priority. This could be quantified or made visible with the concept of expected damage, i.e.:

1) What goes wrong when insufficient information (because of a lack of monitoring) is available?
2) What is the loss, when suboptimal decisions are made because of this?
3) Will decision-making be hampered due to absence or limited monitoring results?

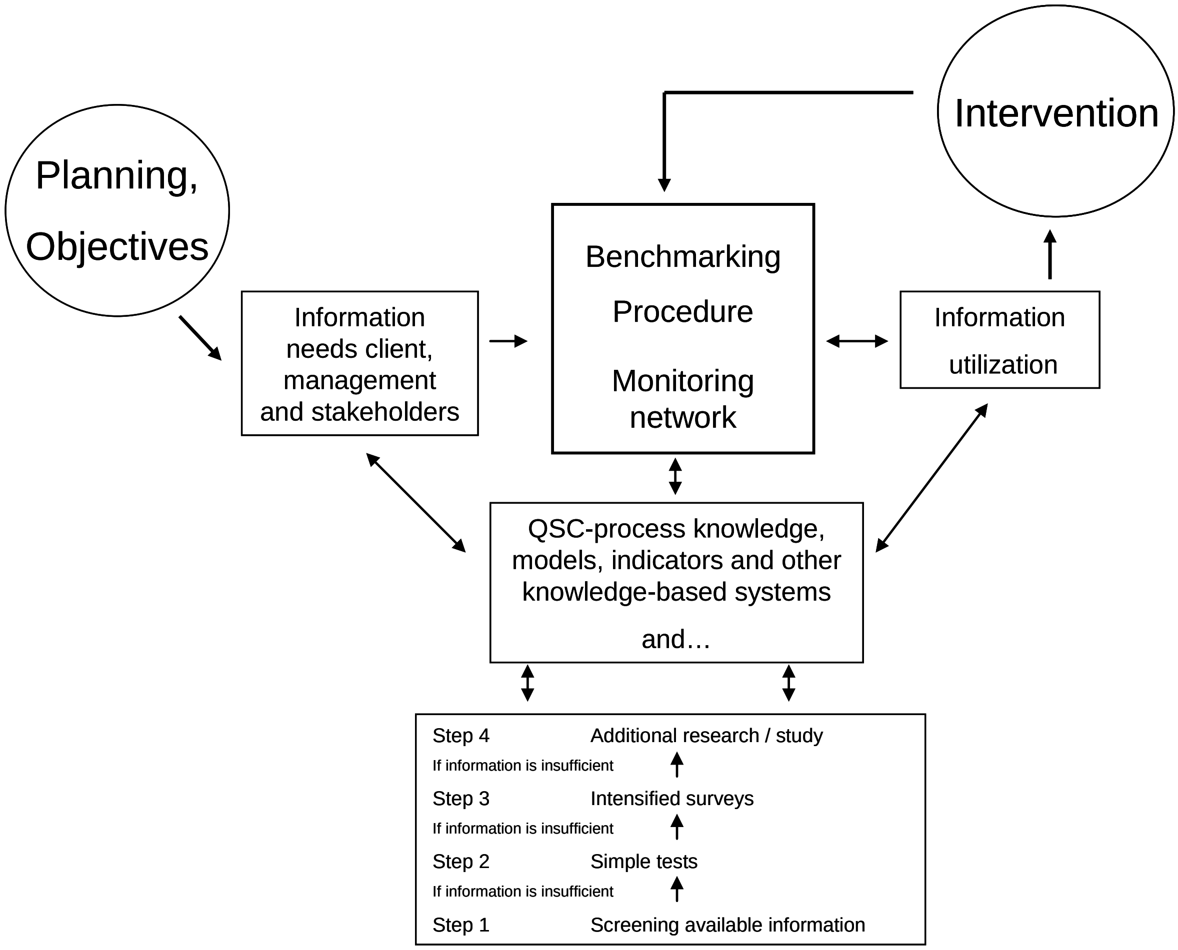


Figure 7. Benchmarking: combining strategies with information flows and intervention. Indicated are the phased approach and different information sources.

The risk assessment is recommended for transboundary monitoring programmes. Predictions can be made regarding the environmental concentrations of chemical and biological constituents that due to proposed activities are produced and emitted into coastal areas. E.g., based on the ratio between predicted concentration levels and expected harmful effects, chemical constituents might be included as variables in the water-quality monitoring programme.

Risk assessment helps setting priorities for establishing health-related monitoring and/or early-warning systems, in general, and in selecting appropriate variables for monitoring, in particular. Although good systems are still to be developed, these will include e.g., hazard identification, dose-effect relationships, exposure assessment and risk characterisation (both qualitative and quantitative).

Obviously, because of limited technical and financial means, not all constituents can be chosen as monitoring variables. Risk assessment should therefore also be used to prioritise specific constituents, based on their physico-chemical properties and toxicity.

4.4.4 Model approach

Models (numerical, analytical or statistical) may play several roles in the monitoring and assessment of dredging impacts in sensitive environments, e.g., they support an integrated assessment of the (transboundary) area, the screening of alternative approaches or policies, the optimisation of monitoring network design, the assessment of the

effectiveness of implemented measures, the determination of the impact on coastal water systems and the risks to human health and the ecosystem.
Hydrodynamic/hydrological computer models of the proposed impacted and the surrounding areas, linked with geo-referenced databases, can be used to analyse the impact of proposed measures, e.g. by simulating the flow and spreading of constituents during dredging or land reclamation. The models may play an important role in early-warning systems (forecasting of constituents dispersal, travel time computations during dredging, etc.). Moreover, integration of observational data and computer models (data assimilation) provides a powerful means to consistently interpolate and extrapolate observations in space and time. Hindcasting techniques aid quantifying the state of the system more completely and help distinguishing human impacts from natural variability. Successful prototype applications of such model-supported monitoring have been applied recently, see e.g., Blaas et al. 2008, 2011, El Serafy et al, 2012. In those applications space-borne remote sensing data have been combined with water quality models and dedicated in situ sampling.
Models can thus be used in addition to monitoring, but also as part of monitoring optimisation programmes. Synoptic area coverage and quasi continuous temporal coverage by models of multiple state variables simultaneously help understand which media should be monitored, when, where, and with what frequency to obtain an optimal representation of the system.
It is important that models should be carefully calibrated and validated on a regular basis (by historical and current data) to avoid unreliable results, which might lead to misunderstandings and erroneous decision-making in benchmarking.
Successful mathematical modelling is possible only if the methodology is properly harmonised and integrated with data collection, data processing and other approaches for the evaluation of the coastal system characteristics.
When riparian states decide on the modelling of a transboundary system, they should realise that the standardisation and the accessibility of data (interfaces to databases and to GIS) are of the utmost importance, rather than the standardisation of software.

4.5 Monitoring programmes

For the design, implementation and operation of monitoring programmes various aspects have to be taking into account (e.g., field measurements, sampling method, pre-treatment, data collection, interfacing data flows, storage, additional analyses, etc.). For good monitoring practices all these aspects must be clarified in monitoring protocols with the appropriate quality assurance. The protocols also elaborate on the selection of variables, locations, sampling frequencies and field measurements.

4.5.1 General design

A. Selection of variables and indicators
As treated in the QSR chapter, the selection of monitoring variables are based on their indicative character (for uses/functioning, issues and impacts), their occurrence and their responsiveness. Any variable must be subject to cost-effectiveness considerations while it is recommended that objectives, references and standards should be selected and or agreed upon by the stakeholders involved in the management of the area in question.

B. Sites selection
It is essential to know what monitoring sites (and consequently the monitoring results) are representative for the assumed impacted area. There are two levels at which a monitoring site can be representative:
• On a macro scale the selection of monitoring sites will be determined by the information objectives (far field representative);

• On a micro scale it is the local circumstances that determine the exact monitoring location (near field representative).
For the combined use of quantity and quality data (e.g. in case of computation of loads), the location of hydrological measurements and of water-quality sampling should be the same as much as possible. Different locations are allowed only if the relationship between the hydrological characteristics of involved sites is unambiguously known.

C. Sampling
Water quantity and quality, sediment characteristics and biota vary over time and space. The objectives of monitoring strongly influence the timescale of interest (e.g. long-term variations for trend detection, short-term changes for plume forecasting and early warning). The required frequencies and methods of sampling (e.g. grab sampling, composite sampling) should be determined on the basis of temporal and spatial variability as well as of the monitoring objectives. As indicated above, numerical model results may provide sampling guidelines as well since they help quantify temporal and spatial variability.

D. Methodology
Joint measurements are recommended to improve the cost-effectiveness and comparability of results. A detailed time schedule of the common measurements and sampling campaigns should explicitly be agreed upon.

4.6 Monitoring categories

The monitoring and assessment must encompass the actual status and trends that are relevant for the functions and uses of coastal systems and thus the local authorities and stakeholders. The needed information is to be provided by ecological, physical and chemical monitoring. The ecological monitoring indicators include presence and trends in different biological variables as being representative for flora and fauna. Physical indicators refer to, e.g., characteristics of the ambient hydrodynamical regimes, bathymetry and sediment characteristics. Also geographical information and habitat factors, such as the presence of wetlands, estuaries, migration routes or spawning grounds, etc. are considered as part of physical indicators. The chemical indicators provide insight in to the chemical status of the different compartments (water, sediment and suspended solids).

Nowadays, increasingly stricter environmental constraints demand different monitoring approaches that improve to understand and adaptively control the main pressures, environmental states and impacts. Seeing the objectives of the FoR set in chapter 4.2, three categories of monitoring are considered in more detail. These are surveillance, compliance and adaptive monitoring. These categories with different characteristics and purposes need to be implemented at the different phases of any dredging activity. For the design of these categories, we elaborate on crucial aspects such as selection of variables and equipment, site selection, sampling frequency and methodology and quality control aspects. Below, we discuss what types of monitoring and monitoring setups are needed to implement a truly adaptive feedback monitoring along a DPSIR chain of reasoning

Following the basic rules and aspects for good monitoring practices we distinguish:

a) Surveillance monitoring. This monitoring aims at sustaining the good ecological status of the coastal zone (low impact) where pressures from planned activities may cause detrimental effects on the ecosystem. The monitoring assesses temporal and spatial changes to selected ecological indicators between the prior condition and the current condition. Following the QSC procedure, a small suite of suitable and best practice environmental state indicators are identified and implemented. The objective of a surveillance monitoring programme is verification of the main hypotheses made during the project preparation. Surveillance Monitoring is usually the responsibility of local and/or central Authorities.

b) Compliance monitoring. This monitoring aims at ensuring that the expected pressures of the dredging execution are in compliance with legal and or contractual restrictions. Restrictions can vary from one project to another depending on the prevailing human and ecological conditions at the site. They can be either physical (e.g., dredging depth, location or transport mode, limitation on turbidity or sedimentation rate at a vulnerable site nearby), seasonally related (e.g., restrictions during certain seasons of biological migrations, breeding but also tourism) or may refer to the quality and quantity of sediment discharges as a function of the dredging execution processes. Compliance Monitoring is normally executed by the Contractor.

c) Feedback monitoring. This monitoring aims of ensuring that signals from a few selected indicators exceeding the environmental criteria can be timely forecast, allowing dredging execution to be adapted accordingly, so costly down-time can be avoided. Adaptive Monitoring encompass fast-reacting and predictable physico-chemical variables that are forecast by (predictive) modelling and then monitored continuously at relatively high frequency during programme execution. Adaptive Monitoring is normally conducted by the project owner or contractor.

4.6.1 Surveillance monitoring

1 Equipment and variable selection

Variables should be indicative of the functions and issues of the targeted area of interest (TAI). For specific human uses, standards should be formulated, making monitoring variables explicit. For ecological functioning, variables are specified by the selected method of assessment (indices, habitat factors) and regional reference communities. The selection of impacting constituents and pollutants as monitoring variables depends on:

a) Impacting, cumulative and persistence characteristics

b) Specific problem substances (produced, released and/or used during dredging process in the TAI)

c) The probability of occurrence; in practice this should be based on results of (site-specific) preliminary surveys.

Nationally and internationally recognised lists of problem constituents and substances may be used as the starting point for the selection of monitoring variables. They draw attention to key variables that are often a problem and that have been politically recognised. The availability of reliable and affordable analytical and measurement methods may restrict the selection of monitoring variables.

In general, EIA studies preceding the dredging work should identify and predict the impact on the relevant variables for the surveillance monitoring programme. These variables should be able to describe changes in the main hydrodynamical, environmental conditions at the TAI and dredging site (e.g., currents, wind, waves, depth, suspended sediments, salinity, existing contamination level, etc.).

Water-quality monitoring should be performed using the most appropriate media for sampling (water, suspended matter, sediments and biota). Many constituents and pollutants can be measured with sufficient accuracy only in one medium, but not in another. The selection of the medium to be examined will be determined largely by the properties of the specific substance, the characteristics of the area involved and the concrete objective of the examination.

2 Sampling Site selection

In general, the selection of sampling sites is based on their representativeness of the TAI concerned. The required distance between sampling locations can be critically evaluated from their degree of correlation by statistical analysis of time-series of variables. However, this is possible only as far as these time series are available.

Sampling in the TAI and in the adjacent areas of confluence is important to show the contribution (e.g. sediment and pollution load) of different adjacent areas. The selection of sampling sites in these areas of confluence should avoid the uncertainties related to incomplete mixing (mixing zones can be several kilometers long).

Considerations of the local representativeness of the sampling point at the TAI are to be based on preliminary surveys or EIAs taking into account the meteorological and environmental regimes at the TAI and dredging site

In general, locations in the main flows of a TAI will be chosen for water and suspended solid sampling. Bottom sediment can best be sampled in regions where the suspended material settles i.e., in the sedimentation area. The number of sampling sites for sediment monitoring strongly depends on the objectives. For trend detection, a low number of sampling sites or mixing samples into composite samples may yield enough information. If spatial information is to be estimated, the number of sampling sites will increase and no composite samples will be used.

3 Sampling frequency

The selection of the sampling frequency should be based on:

a) The variability in parameter values, as related to relevant margins (in practice based on statistical analysis of time series for variables, or representative groups of variables)

b) The statistical significance and accuracy required for specific objectives (trend detection, load calculation, testing of limits and thresholds).

Sampling frequencies for suspended solids are very similar to surface water sample frequencies. For load calculation a higher sampling frequency is recommended when high loads of suspended solids and pollutants are expected. When the temporal variability is rather low, sampling frequencies can be reduced.

Also, the reliability of load estimates and dispersion may be more effectively improved by increasing the sampling frequency than by optimising measurements.

4.6.2 Compliance monitoring

1 Equipment and variable selection

This monitoring type serves to verify whether all the operations related to dredging or dredged material disposal act in accordance with the legal and contractual restrictions. There may be a wide variety of restrictions depending on for example the TAI vulnerability (or specific elements thereof) to natural or biological processes and anthropogenic pressures on the site and in adjacent areas but also the instalment or operational use of certain equipment of a certain quality standard.

The statutory and regulatory requirements of these restrictions normally apply to all communities in and around the TAI. They may be imposed by international law or regional policies and programmes.

Although information from compliance monitoring should basically provide answers on the dredging impact on human and environmental health issues, it is the primary interest

of the contractor to be able to detect and correct violations, provide evidence to support enforcement actions, and evaluate program progress by establishing compliance status.
Consequently, equipment and variable selection will often be limited to those activities of the contractor that may allow him to react swiftly in the event of non-compliance. Monitoring here often relates to physical variables such as spill rates, noise, etc. only.
Normally detailed monitoring requirements (from planning, to measurements, to the definition of thresholds in time and space, and up to the disclosure or reporting of specific pre-defined and agreed-upon information products) are clearly formulated in the contract to minimise confusion and additional costly activities (e.g., extended monitoring campaign and mitigation measures).
It is this critical clarity that allows the contractor to adapt manageable corrective execution measures in the event of non-compliance with the agreed limitations. Priority setting, based on the risk assessment in the selection process for quality variables and accurate objectives, is highly recommended. Existing national or international priority lists of physico-chemical constituents can be helpful. In addition to specific constituents, an increasing emphasis should be placed on aggregate variables.

2 Sampling Site selection

The Environmental Monitoring requirements must be clearly formulated (locations, frequency and duration) to prevent later discussions and confusion. The sites must be chosen in a way that with the pre-described equipment, it generates information relatively fast, allowing corrective measures before calamities take place. Response time for variable output and its sensitivity further define the position of the sites. See sampling frequency of compliance monitoring below for more information on site selection.

3 Sampling frequency

Sampling frequencies and site selection should be based on the amount and variability of the sediment discharged. Pre-investigative surveys (risk assessment) of restricted duration (using continuous or high-frequency sampling) should be performed to gain the required insight into discharge characteristics (e.g. batch processes versus continuous processes). The statistical significance and accuracy required for specific objectives (compliance testing, sediment discharge calculation) and the local regulations (mostly based on previous information) form a basis for the selection of sampling frequencies and sampling methods.

4.6.3 Feedback monitoring

1 Equipment and variable selection

Feedback monitoring encompasses fast-reacting and predictable environmental variables that may be forecast by (predictive) modelling and then monitored continuously at relatively high frequency during dredging execution. The measurement systems consisting of these types of environmental variables must provide input for the forecast modelling exercise. At location, these systems are either substance oriented or effect-oriented.
Physico-chemical analysis screening methods can detect increases in concentrations of specific substances or constituents (e.g., dissolved oxygen, suspended particulate matter, and pollutants). However, only a fraction of the large number of substances or constituents that are expected to occur because of dredging can actually be measured on-line.
Relatively straightforward indicative variables such as dissolved oxygen, Turbidity, pH, underwater light, oil substances or several other constituents can be measured by automatic in situ sensors while biological early-warning systems can detect deterioration in water-quality through the biological effects on fish, shellfish, zoo- and phytoplankton, bacteria, etc.

According to the information objectives and the QSC, constituents and impacts that are most likely to occur while dredging in sensitive coastal regions should be target compounds for the early-warning system.
If the precise detection of specific problematic substances is needed, advanced analytical systems can be used. However, the investment, operating and maintenance costs are higher.
Toxicological effects in organisms on various trophic levels can be measured with automated biological early-warning systems. Early-warning equipment puts high demands on operation characteristics such as speed of analysis, capability of identification and reliability of operation. Characteristics such as the precision and repeatability of the analysis are less critical. (See Appendix 6 for some recent developments).

2 Sampling Site selection
Early warnings should provide enough time for adaptive measures to be taken. Thus, the location of an early-warning station should be determined by the relation between response time (the time interval between moment of sampling until the intervention) and the travel time of the potentially impacting dredging plume (and related effects) in the coastal zone from the early-warning station to the sensitive areas and sites considered for protection.
Local and regional meteorological and hydrodynamical patterns are decisive for the latter. Furthermore, sampling location in time and space should be chosen in such a way that no potentially impacting constituent is missed. This is different from the more randomly chosen location points that form the basis for the statistically sound design used of the monitoring and assessment of impacts in coastal zones, ecoregions or biotopes (e.g., within a surveillance monitoring).

3 Sampling frequency
The measurement frequency should be determined by the expected dimensions of plumes (elapsed time for the plume to pass the station) so that no significant impacting constituent is missed. Dispersion of the plume occurs between the discharge location and the sampling location due to the discharge characteristics of the river. Furthermore, the frequencies should provide sufficient time to take action in the event of an emergency.

4.7 Data quality and sampling control

Data quality and sampling control is a complex and time-consuming activity which must be undertaken regularly to ensure meaningful water quality assessments. This is particularly crucial for some of the physico-chemical analyses carried out on water samples, such as dissolved trace elements, pesticides, nutrients, heavy metals or antifouling compounds. Serious errors may occur in the assessment process.

4.7.1 Quality control of field work

Sampling and measurement precision is key. When sampling, one should follow recommended procedures to avoid collection of unrepresentative samples. Each method, or piece of sampling apparatus, has appropriate procedures which should be followed, accurately and at every sampling occasion. In addition, simple, basic rules such as avoiding disturbance of the site prior to sampling must be followed. Strict observance of the sampling requirements developed for a given site (type of sampler, sensor, sampling depth, cross-sectional samples, etc.) usually enables collection of representative samples. Nevertheless, to assure accuracy, it is recommended that replicate samples be taken occasionally to determine temporal (at one point in a certain time interval) and spatial (simultaneously at different points of the given water body, e.g. cross-section of the targets coasts or region) variability.

Temporal variability is usually determined in preliminary surveys to check seasonal and daily variations, the influence of nearby river inputs, runoff, and monsoons etc. Field analytical operations and sampling handling may comprise numerous steps and must follow predefined requirements and sequence in order to avoid contamination and errors (table 3 for some basic errors and the appropriate actions to correct them). Small deviation from the procedures is possible only when each field operation step is recorded and quality control is ensured

Detailed descriptions of methods and the appropriate recommendations for field work, field sampling, equipment, and analysis and sample handling are given for example in Strickland and parsons (1972) or Crompton (2006).

Table 3. Some possible sources of errors in the water quality assessment process with special reference to physico-chemical methods.

Assessment step	**Operation**	**Possible error**	**Actions**
Monitoring design	Site selection	Station not representative	Preliminary surveys
	Frequency determination	Sample not representative	
Field operations	Sampling	Contamination	Decontaminate
	Filtration	Contamination or loss of sample	Running field blanks
	Field measurement	Un calibrated operations. Inadequate understanding. hydrological regime	Field calibrations. Replicate sampling. Hydrology surveys
Sampling handling	Conservation and identification	Wrong biological and chemical observation. Insufficient cooling. Loss of sample and /or sample ID	Field spiking. Field pre-treatment. Field operator training
Sensor handling	analyses	Contamination. No calibration. Insensitiveness Wrong data report	QA equipment, tests, standards. Control and protocols.
Interpretation	Data interpretation	Lack of basic knowledge. Ignorance of statistical methods. Omission in data report	Appropriate training of experts

4.7.2 Analytical quality control

It is said that 10 to 20 per cent of monitoring resources, including manpower, should be directed towards ensuring the quality of analytical determinations for common water quality variables (WHO, 1996). This percentage may increase when several trace constituents need to be measured.

Unfortunately, on many occasions quality control is not given adequate attention. This results in unreliable data and hence, unsatisfactory containment of the environmental quality status due to dredging and reclamation works. This problem should be addressed by the monitoring programme.

To provide high quality analyses, it is necessary to consider the following basic requirements:

a) The analytical methods should have characteristics (range of measured concentrations, sensitivity, and selectivity) which are adequate for the region and for type of water body being monitored and must pass an calibration test.

b) The instrumental equipment and the available techniques and accessories must correspond to the set of analytical methods chosen.

c) Adequate conditions for the maintenance of analytical instruments must be established.

d) The monitoring and assessment personnel should be sufficiently trained and qualified to carry out the necessary analytical operations properly.

e) A programme of systematic quality control must be organised.

4.8 Data management

Data produced by the monitoring under the benchmarking process should be validated, archived and made accessible for intervention. The actual goal of good data management is to convert the raw data into information that will meet the specified information needs and the associated monitoring objectives allowing the intervention thereafter. Generally, the combined use of data from different sources and sensors demand the implementation of a feasible data exchange and management system.

To safeguard a valuable use of the collected data with the purpose to allow an adaptive monitoring and assessment, several data management steps are required before the information can be properly used:

a) Validate data before entering the data archive and before they are used for decision making (the intervention stage, see chapter 5).

b) Store data necessary for future data exchange.

c) Analyse, interpret and convert data into predefined information forms using appropriate data analysis techniques.

d) Document all datasets (before and after conversion) by means of standardized metadata as part of the data files.

e) Keep track of data file versions e.g. by means of version control software

f) Provide -preferably automated- backup copies of datasets in all critical stages of conversion and processing and manage backups similarly as the originals.

4.9 Validation

Data validation is an intrinsic part of data handling. Such a regular or continuous control of the newly produced data should include the detection of outliers, erroneous values and other obvious mistakes. Computer software facilitates the various control functions, such as correlation analysis and application of limit pairs. Expert judgement and thorough knowledge of the water systems are likewise important for this validation. When the data have been thoroughly checked and the necessary corrections filtered, the data can be approved and made accessible for intervention procedures. Metadata documenting these checks and quality flags need be inseparable parts of the datasets.

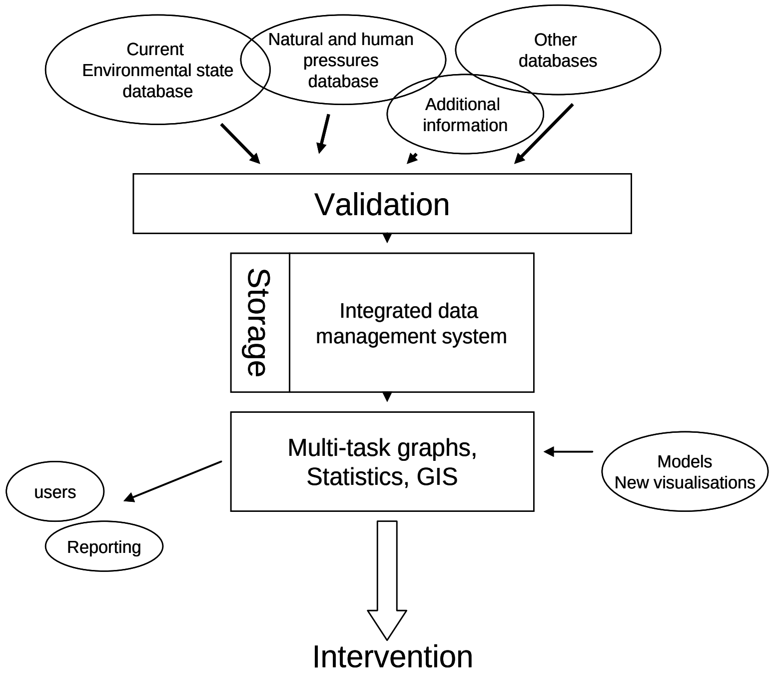


Figure 8. Integrated information system for data management allowing intervention

4.10 Storage

Unfortunately, newly gained data is often not properly stored on durable computer systems. Incomplete and inaccessible quality data bases that are validated may still hamper the intervention or satisfy any information need and consequently adaptive execution.

For efficient use, the data should be stored in such a clear and strict manner that they are accessible and complete with respect to all the conditions and qualifiers pertaining to data collection and analysis. Information on the dimensions and appearance should be stored (e.g. Turbidity in NTU or FTU and SPM in mg/l). Furthermore, a sufficient amount of secondary data (meta-information), which is necessary to interpret the data, has to be stored. Characteristics regarding time and place of sampling, type of sample, preconditioning and analytical techniques are commonly stored. If monitoring is performed in media other than the water phase (e.g. suspended solids, Sediment or biota), relevant meta-information such as total amount of substances in different media, particle size distribution or organic content sediment, etc. should be recorded. It is essential that any database system is safe-guarded against the entering of data without proper meta-information. Any storage system applied should provide backup facilities to safeguard data against loss or corruption. Backups are preferably made automatically on pre-scheduled time intervals on independent storage hardware. Version control systems help storing preceding versions of data files (usually on the same hardware system) whenever files are modified by users.

4.11 Analysis

The conversion of raw data into usable information involves analysis and interpretation. The methods used to analyse the data should ideally be fixed in a protocol. This protocol should comprehensively define the data analysis strategy while taking into account specific characteristics of the data concerned, such as erroneous data, detection limits, censored data, data outliers, non-normality and serial correlation. The adoption of the protocol structures this element of the benchmarking and facilitates the documentation of any encountered changes or adaptation in the analysis procedure.

Preferably, the data analysis, that mostly includes a statistical operation, should be automated. For this the use of tailor-made software is recommended. In case several different data sources are included into the benchmarking, special attention should be paid to the validation and the quality of the process of data collection from all these sources separately.

A clear and comprehensive visualisation system (e.g., GIS, statistical visualisations and multi-task graphs) facilitates the integrated interpretation of data with other information (e.g. spatial mapping, remote sensing imaging, human pressures, but also threshold, limits etc.) that is needed to promptly assess the development of the important water quality variables during execution. Good visualisation systems will allow the production of information products that, if requested, may be adapted to the different stakeholders.

Integrating data originating from different sources into one decision-making system is not trouble-free. It requires data harmonisation up to a necessary level and a standardised interface that interconnects the different data flows.

The data management protocol should comprise procedures for processing the monitoring data in order to meet the specific needs for data interpretation. These procedures should include accepted methods for data interpretation (e.g. calculations based on individual measurement data or running averages, and statistical techniques used to remove non-relevant deterministic influences). Such procedures should also include accepted methods for trend detection, testing for compliance with standards, thresholds, limits and calculations of quality indices.

4.12 Current and desired state.

The final step in the benchmarking procedure is to compare the desired state with the current state. It is highly advisable to clarify the difference between these two states with generic statistical knowledge and tools. The statistical interpretation of the different data sources and sensors with the data on the desired state often involves the development of a null hypothesis in that the assumption is that whatever is desired as state is different from the current state being measured thus allowing adaptations to the execution (i.e., the intervention).

When working from a null hypothesis, two basic forms of error are recognized:

Type I errors where the null hypothesis is falsely rejected giving a "false positive".

Type II errors where the null hypothesis fails to be rejected and an actual similarity between states is missed and consequently costly intervention procedures are carried out.

Occasionally, when the procedures do not give a clear-cut answer, the interpretations often come down to the level of statistical significance applied to the numbers and often refer to the probability of a (p-) value accurately rejecting the null hypothesis. Also, measurement processes during monitoring generating data, are subject to error. Many of these errors are classified as random (noise) or systematic (bias), but other important types of errors (e.g., human blunders, sensor failure) can also be important. Nevertheless, the setting of confidence intervals (90-95%) will allow experts in the FoR to express how closely the desired state matches the current state.

Referring to statistical significance does not necessarily mean that the overall result is relevant in the targeted area. For example, in a large reclamation project it may be shown that the intervention has a statistically significant but very small beneficial effect, such that the adaptation to the execution is unlikely to help to lower the environmental impact.

There are several well-known statistical tests and procedures that may be used to allow the comparison between the data on the two states. A so-called "plausibility test" is adopted within OSPAR (2009) and commonly used by the Data and Information services of the Dutch Ministry of traffic and water affaires. These tools may handle large amounts of data, sets confidence intervals, establishes trends, identifies outliers, may include thresholds and reference levels and visualises the data in relation to the desired levels and thresholds

4.13 Learning aspects

The goal of the guidelines for FoR is to ultimately help manage better the integration of the conservation of sensitive ecosystems and development of cost effective dredging. As pointed out (chapter 1), the need for better management is driven by the facts that projects must take place in complex and dynamic systems in a world that is constantly and unpredictably changing with changing "competitors and clients" adapting even more restrictions while globally coastal ecosystems are generally further degrading by all sorts of other anthropogenic pressures. Therefore, immediate action is required.

Adaptive management takes uncertainty seriously, treating human interventions in natural ecosystems as experimental probes.

Also, when applying the DPSIR chain of reasoning for establishing clear cause and effect, on should realise that there is no such thing as complete information and that there is still a considerable amount of knowledge gap in establishing the exact (as in quantifiable) underlying causal linkages between cause (dredging) and effect (ecological impact).
An important objective of the benchmarking within the FoR is therefore to increase and safeguard knowledge on the ecological impact of the dredging process that will serve as a basis for future low-impact execution projects. This clearly implies the "learning by doing" principle that takes uncertainty seriously, and treat human interventions in natural ecosystems as experimental probes.
However, it should be made clear to project owners, contractors and authorities to what type of learning the different monitoring types in the benchmarking may refer to. For example, a compliance monitoring or an adaptive monitoring type with skewed focus towards the dredging activities (cause) may resemble the characteristics commonly found in so-called Decision Execution Cycles (see for background information Firestone, 2003). These monitoring and management approaches mainly target compliance, are based on fixed, old, knowledge and have clear demand/wishes-thresholds. They are commonly used in process control and adjustments and here the "learning" only involves adjustment of behaviour and do not generate new knowledge that allows us to better understand the relation between dredging pressures and ecological impacts.
On the other hand, if adaptive monitoring targets the cause and effect, the "learning" then means involving adjustment of behaviour based on creative problem-solving resulting in change in the previous knowledge. It is suited for closing the gap to what we know and what we should know and should aim at achieving information production for the integration of different (and growing number) of goals.
The benchmarking transforms comparison into learning, it corrects errors, seeks to improve our imperfect understanding, and allows change in action and plans accordingly.
If embedded properly into dredging operations, it will generate new information that:

a) makes more explicit to stakeholders about what to expect,

b) allows both the contractor and project owner to more easily adapt the execution method or choice of dredging equipment should the project conditions change or if unexpected impacts are detected by the monitoring campaign.

c) helps to further unravel the relation between dredging and its impact on and response of the ecological elements so that new methods and equipment can be designed.

4.14 Resume: elementals for good monitoring and assessment.

a) Define information needs first and then adapt the programme to them and not vice versa (as is too often the case for monitoring).

b) Understand fully the type and nature of the water body (most frequently through preliminary surveys, pilots, models etc.), particularly the spatial and temporal variability within the water body.

c) Set up accountable monitoring programmes.

d) Choose the appropriate compartment or media (water, particulate matter, and biota).

e) Use stepwise approaches for the screening of water, sediments and biota to gain more information at lower cost.

f) With respect to the objectives, choose carefully the variables, type of samples, sampling frequency and station location.

g) Integrate chemical and biological monitoring (including bio-assays) where beneficial.

h) Select the field, analytical equipment and laboratory facilities in relation to the objectives and not vice versa.

i) Use a combination of monitoring and models where beneficial (e.g. correlation models in water-quality assessment, hydrodynamical patterns, and impact forecasting)

j) Establish a comprehensive and operational data treatment scheme and apply a consistent data management strategy and techniques.

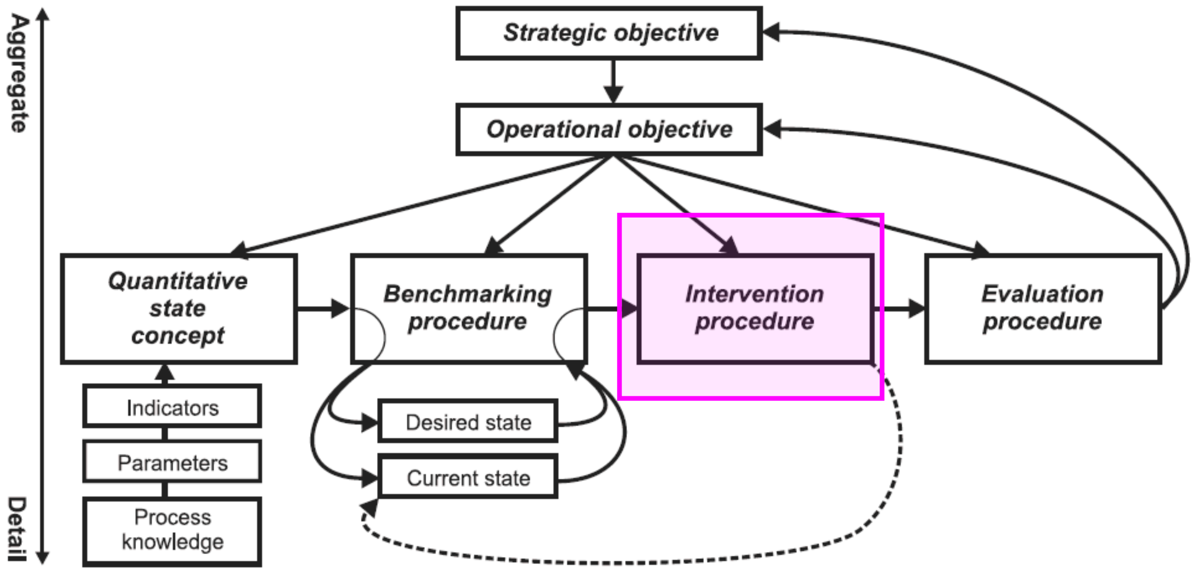
k) Couple the monitoring of the quality of the aquatic environment with the appropriate hydrodynamical, seafloor and coastal monitoring.

l) Check regularly the quality of the data and sampling through quality control.

m) Make information (including recommendations and proposed measures) from interpreted and assessed data available to decisionmakers and actors.

n) Evaluate regularly the performance of the whole programme, especially if the general situation or any particular influence on the environment is changed, either naturally or by measures taken in the targeted area

5 Intervention procedure



5.1 Introduction

After the benchmark which compares the monitored current state with the desired state, the intervention procedure should prescribe whether and what sort of intervention should be carried out. After the difficult, but basically objective comparison of data within the benchmark, now a (subjective) choice needs to be made to intervene in the execution process or not. Also the consecutive steps of the intervening process itself should be prescribed in order to get swiftly into action to assure that the ecosystem does not get over-stressed.

5.2 Intervention need

Within the benchmark procedure, focus was laid on the objective determination of a discrepancy between the current system state and a desired or reference system state. In its most simplified form, the discrepancy is measured clearly. The subjectivity with regards to the intervention need is then limited to the definition of the thresholds that should be adhered to. This is in line with PIANC report 100: *Dredging management practices for the environment: a structured selection approach* (PIANC, 2009). Within this definition process, all sorts of extra safety factors with regards to the allowable discrepancies could be applied. On the one hand this is based on the benchmarking frequency (both temporal and spatial) and on the other hand on the objectives set for the system. Also, the intervention time needed to influence the process might require the application of extra safety margins on the system parameters. If thresholds are thus defined in an earlier stage, during project execution the surpassing of the limit is the clear signal that some kind of intervention is necessary.
However, when seen in line with the benchmarking issues, many uncertainties present at both the current state monitoring and the desired state definition may enlarge the subjectivity in the intervention. Based on these uncertainties it can be rather unfeasible to objectively and scientifically prove that there is any relevant discrepancy between the current state and the desired state, let alone that certainty can be obtained on the surpassing of any threshold.

Although being more subjective, there should still be a procedure to determine whether intervention is necessary or not. In those cases one should predefine the interpretation and management of uncertainties and try to objectify the issues. These (subjective) post-processing tools, reform data that within the benchmark were observed to contain large spreading and uncertainty into clear, comparable decision support parameters. This reduces the problem to the above sketched simple comparison.
As an example, experts have stated that, above a value of 15-20 NTU above background, turbidity has a severe impact on the ecosystem and that the background level varies between 0-10 NTU. The best available measurement tool measures with an accuracy of -2 to +2 NTU. The sensor at the background location indicates 7 NTU and the one in influenced area indicates 23 NTU. Even in this simplified setup it can be defendable both to intervene (because the turbidity in reality can be up to 20 NTU above background) as not to intervene (because it can just as well be less than 15-20 NTU above background). Based on the subjective idea that the measurement values of the sensor most likely represent the actual turbidity value one could determine that the most likely value of the turbidity above background is 16 NTU. Then on the basis of the precautionary approach one could conclude that intervention is necessary here. This example illustrates that only the subjective interpretation of the benchmark leads to intervention or not.

5.3 Traditional management systems

The paragraph above indicated that there is a varying degree of subjectivity in the intervention need. As stated, this subjectivity can be limited to the early stages of the project, by setting up a simple monitoring programme and pre-define the limits as fixed conditions or restraints for the project execution. Within a traditional management system, this method is commonly applied (John et al., 2000).
Although orderly and convenient, this method is sub-optimal for several reasons. On one hand, it requires that in the beginning stage of the project, the work-methods, the impacts on the ecosystem and the ecosystem response are well known, which is often not the case. On the other hand, the system does not allow for flexibility both in execution method as for impact management within later phases, as the focus of the impact reduction is only laid on the predefined impact limits.
When use is made of the commonly accepted precautionary approach, limited knowledge of the ecosystem response would lead to strict limits, which in turn might lead to uneconomic execution practise while it still remains unsure whether the impacted environments are unacceptably impacted or not (see chapter 1 and 2). This can only be prevented by carrying out additional ecological surveys and research before the project can be initiated (see chapter 4). Usually, there is not enough time available to do so. From this it can be seen that there is a necessity to get the project started before detailed information is present that allow for optimal execution, fixed on beforehand.
The lack of flexibility in the traditional management system is also hindering its success in cost effectively reducing the impacts of project developments. As the focus for the impact reduction is pre-defined to be exclusively on several (measurable) parameters, the 'overall' impact might be worse than expected. Furthermore, the execution method cannot be changed too drastically as the monitoring requirements are set for the specific type of project execution.

The abovementioned flaws are often regularly observed in projects in practice. In order to keep the projects running, adjustments are made to make the management system workable and to allow some flexibility in the system. However, these adjustments most often reduce the safety margins applied on impact parameters and should thus be interpreted as the abandoning of the precautionary approach. Basically it includes taking risks on the environmental impact without sufficient scientific background.

5.4 Introducing AMS-principles

When adaptive principles are to be included, the interpretation of the benchmark changes. As the knowledge on both impacts as well as responses is developing, secured and used back into the FoR, the subjective interpretation on intervention need changes over time. This requires that the definitions and the discussion of the interpretation protocol are well documented and communicated in each stage of the project. At least the method of dealing with uncertainties in both current and desired state and of course the implementation of the objectives should be clearly defined and documented (see chapter 4 and PIANC report nr 100). In this way it is possible to reconsider these in later stages/cycles.

With regard to the uncertainties in the desired state, is it necessary that the application of the methodology is clearly defined. Focus should be laid on dealing with the uncertainties within dredging and environmental cause-effect relations, including the distinction between dealing with lethal and sub-lethal effects. As knowledge increases in time, the uncertainty should decrease and the safety margins placed over the desired state could decrease as well.

With respect to the uncertainties in the current state, difference should be made between uncertainties caused by the monitoring characteristics (e.g., as methodological errors and spatial and temporal spreading of monitoring efforts, etc.) and the variance in the TAI characteristics (e.g., external influences and uses, seasonality and other dynamics).

The AMS-principle during the intervention step of the FoR requires that the approach for determining that the current state is 'better' or 'worse' than the desired state is well documented and can be changed according to improved information or when evaluated in light of the overall objectives.

In this way, guidance and structure is added into the process of intervention that facilitates periodic evaluations and consequently adjustments to the whole FoR process.

5.5 The 'traffic light' analogy

With the methods described above, the intervention need can be determined. Due to the subjectivity and the interpretation, it is proposed not only to state whether it is needed to intervene or not, but to adopt a sort of linear scale in intervention need. This is in line with current management practice (Bray, 2008; PIANC, 2009)

One method to intervene in the FoR is to use the analogy of the 'traffic light' analogy. In that case 'green' stands for a situation that is in all kinds acceptable. This means that some increase in impact either by the project or by external influences is allowable and acceptable by the stakeholders. 'Yellow' stands for a situation that still is OK, but that some limits are approached so that any increase in impact will lead to unacceptable ecosystem impact. The 'red' situation stands for a situation where the impact already is unacceptable so that direct intervention is needed to reduce the impact on the system. Of course the method does not have to be defined in a three stage manner, but a continuous transition from green to red or any other convenient discretization is possible.

Within the 'green' (or the more greener) situations, the environmental impact of the works do not require action by itself, but it might be useful to look at optimization possibilities within the execution method, that might have a larger impact. For instance in the beginning of a project, it would be advisable from the precautionary approach to start at a less vulnerable location and decide on the basis of the 'green' information on the monitoring status move towards more vulnerable location as long as the season/situation allows for it.

Within the 'yellow' (or more yellow) situations, one should proceed with caution as the limits are being approached. This means that especially trends and cumulative effects are studied and that plans of action need to be draft to intervene in case the upward trend does continue. When a project is working continuously in the more yellow situations, it is recommended to study the long-term effects of the impact on the ecosystem further (see chapter 4 and 6). Only then a long-term cause-effect relation may be established. As the limits are constantly approached these long-term effects might become more appropriate to investigate than the direct effects which may lead to 'red' situations. It should then be agreed upon how much yellow and red in time and space is deemed acceptable by project financers, contractors and owners and clients. The transparency in proactively reporting, connecting to stakeholders and agreed adjustments made during this step is only possible in an adaptive system such as the FoR.

Within the 'red' situations, direct action is needed. Within a well-working system, the situation does not immediately become red, so action plans are defined on forehand. These plans will be implemented and the intervention can directly affect the execution and lower the environmental impact.

5.6 Intervention methods

The intervention method specifies how the benchmarking of the project execution is manipulated in order to bring the ecosystem's current state closer to the desired state. As stated above, with help of the 'traffic light' analogy, the intervention method is designed first and implemented later. For the design of the intervention method it is necessary to know what the impacts of the execution method are and in what way these impacts can be influenced. This requires not only knowledge of the system that is worked in, but also of the impacts of the equipment and methods that will be commissioned. This asks for large involvement of the contractor, as the impacts can be very specific. Some general background on environmental aspects of equipment and management practices is provided in literature, for instance in Pennekamp et al. (1996), Bray (2008) or PIANC (2009).

In short, intervention can be divided into two main groups: adjustments of the work method and mitigating measures.

When the reasons for unacceptable impact are understood, the way of intervention may be easily determined for tackling them. Adjustments in specific elements of the work methodology may, for example, consist of changes in dredging intensity, dumping location (with a different hydrodynamical regime). Reduction of impacts by slowing down the execution process is generally not seen as a highly effective method, since the exact underlying cause that gave rise to the impact is not tackled. Stoppage of the work (at parts of the location) should therefore only be considered a temporary measure to immediately reduce the impact while searching for a more well-considered alteration of the work method (see also PIANC, 2009).

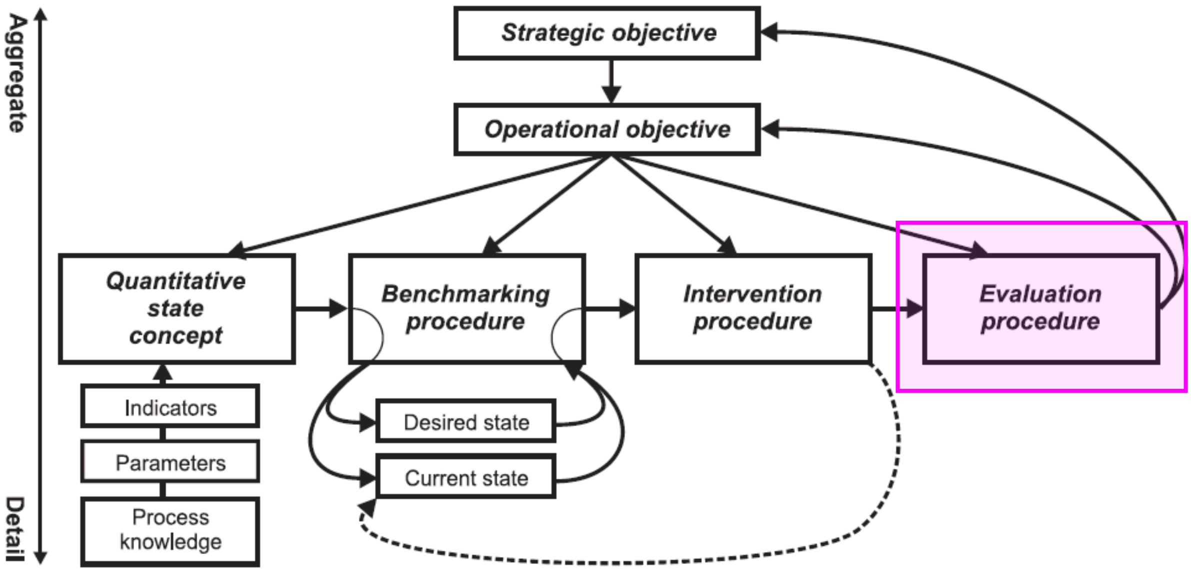
When alterations in the work method seem insufficient in reducing the impact on the ecosystem, mitigation measures may be considered. Mitigating measures are defined as all measures taken specifically to reduce the impact of the project execution on the ecosystem. The most well known option is the implementation of physical barriers to prevent the spread of suspended matter (mostly sediments). The implementation of mitigating measures also puts requirements on the execution operations and is often a limiting factor for productions. Furthermore, deployment, maintenance and repair of mitigating devices require both attention and costs. For that reason mitigation measures must only be considered when specific sensitive parts of the ecosystem cannot be managed by controlling the general execution methods (see also Bray, 2008).

5.7 Planning intervention

From the abovementioned sources, it is possible to create several options for interventions. It would however be highly inefficient if the most optimal intervention method could only be discovered on a trial-and-error basis. Therefore, the interventions should preferably be tested on the basis of modeling effort. Whereas the experiences of the involved parties from previous projects could also form the basis for the planning of the intervention (see Pennekamp et al., 2008).

For the dispersal of constituents in water, such as suspended sediments, dissolved matter and specific pollutants, 2DH modeling is mostly sufficient in modeling the spread of the material (see also Whiteside et al., 1995). This water quality and transport model can be used in the early stages of the project to estimate the expected sediment spread during operations. When the project commences, this model can than be calibrated further and diverse options to intervene can, even before intervention is necessary, be considered.
During the execution of marine infrastructure works, the exact input parameters of releases of the modeling may prove to be problematic (Burt and Hayes, 2005). During dredging, the re-suspended sediment may load into specific layers of the vertical water column structure hindering a realistic determination of the plumes fate and thus impact. Several models are currently in development that may calculate the internal water column sediment loads (e.g., John et al., 2000). Within the context of Building with Nature research, the TASS model, which considers the near-field of re-suspension by Trailing Suction Hopper Dredgers, is further investigated and validated (Aarninkhof et al., 2009).
These tools do make it possible to model impacts and thus design the most optimal intervention strategy.

6 Evaluation



6.1 Introduction

Periodic monitoring and evaluation[3] of all interrelated elements of the FoR are crucial steps towards the proper functioning of a full adaptive approach. It is highly recommended that along the design of the separate elements a clear, comprehensive and detailed plan must be prepared to provide guidance and structure of the evaluation. Previously, an evaluation of the efficiency of a project management approach based on a clear compliance monitoring containing clear objectives and environmental targets could be a rather straight-forward exercise.

Contrary, to evaluate the adaptive execution within a FoR environment is no business as usual. As stated in the first chapters, this is mainly due to the ambitious overarching objectives of establishing dredging projects with no unacceptable environmental impact in a larger context with generally more stakeholders, issues and functions in and around the TAI. Consequently, with the more complex and dynamic settings of the adaptive nature of the FoR, the targets, approach and even operational objectives may be adjusted during the course of the project. For this reason the proposed learning-by-doing becomes an important objective for evaluation as well.

In chapter 1 to 5 and associated appendixes we have provide guidelines to help design and structure the FoR elements and processes. We summarised generic steps to be taken and elaborated e.g., on basic requirements, information needs, elementals for good monitoring, quality assurance system, data management and indicator criteria.

As part of the evaluation plan, indicators could now be easily designed and implemented for assessing the different FoR elements. These basics alone would already greatly improve common approaches to managing key assets of dredging activities in coastal zones. Here we are less concerned by these indicators; they are important points of attention of which most should be tackled when setting up the FoR.

[3] Normally, process or whole project evaluation includes monitoring and possibly indicators. Clearly, the meaning of monitoring as part of the evaluation process is different than the DPSIR monitoring meant as core element of the benchmarking.

In this chapter we present background information and highlight key issues that help to understand what other overarching objectives of monitoring and evaluation process should be concretized and implemented.

6.2 Evaluation objectives

The overarching objectives of the adaptive character of the FoR are learning-by-doing and the adjustments of a project or system towards a new innovative system. There are also other objectives targeted by the evaluation. Put together, the evaluation objectives are foremost:

a) To Learn. For tackling this objective you need information on the project progress on, unwanted and needed effects, developments and bottlenecks in the TAI and project environment. It should then be assessed whether this information is used to reflect on (and adapt) the pre-set assumptions of the problem, and to find solutions for the knowledge gaps. The people directly involved in the execution of the project are here the most important.

b) To have accountability. Here the primary responsibility is to reach the pre-set goals with an efficient use of (financial) resources. The most important stakeholders here are those that financed the projects.

c) To Intervene and adapt. In what way have the interventions and adjustments changed the FoR for the good, e.g., in terms of activities and targeted stakeholders? Important here are stakeholders and programme management. However, interventions may also be the result of conclusions from the project owner and financers on whether budgets are wisely spend. Then these become equally important stakeholders.

d) To inspire and disclosing new knowledge. Inspiring and bringing new knowledge across may help to improve legitimation and support for the introduced innovations. The important stakeholders groups here consist of the project owner, team innovators, possible future financers and insurers, regulators and a broader community.

6.3 Friction

There is often friction between evaluating the "learning and adjusting" and evaluating for compliance or accountability. This is often expressed in flexible versus rigid targets and results (Table 4). Briefly, the learning target of the adaptive approaches demands transparency on failures, flaws and unexpected results, while with a clear target-driven system the focus is on accomplished successes. Furthermore, for the learning processes detailed information is needed on the approach and project/programme progress, while the compliance targets are mostly best served with general information on budgets, planning and results. Limited budgets immediately pressure the intent of combining both objectives.

Finally, the assessment of the acceptable environmental impact on short and long term implies that the improved success of the FoR can only be established beyond project execution. It is important that the evaluation is able to pick up the earliest signals and to be conclusive.

Table 4. Monitoring and evaluating of adaptive system innovations as described above is not the same as the familiar approaches to monitoring and evaluation. A summary of the key features of the most common three are presented here. Based on work of Arkestijn et al. (2007) and van Mierlo et al. (2010).

	Results oriented	*Constructivist*	*Reflexive*
Goal	Accountability and steering	Learning and making adjustments to activities	Learning how to contribute to system innovation
Paradigm	Reality can be defined objectively	Reality is constructed by interaction and negotiations	A new reality has to be defined
Focus	Predefined objectives	Meaning and values based on negotiations	Putting the prevailing values and institutional settings up for discussion

It should be realised that the FoR entails the combination of both the results-oriented and reflexive approaches, and aims at moving whole operations towards a more constructive approach where controlled adaptations are guiding (Table 4). It is therefore of crucial importance to follow a predefined set of results and a project structure for control while allowing room for adaptations and the evaluation of them.

Frequent deliberations between project owner and contractor on monitoring en evaluation objectives are important. Sometimes a set of questions and indicators may assess both the learning and accountability aspects of a project. If this is not the case, then it is advisable to start monitoring and evaluating the learning process first to obtain a clear insight in the developments and results of the project. Based on these insights, additional monitoring and evaluation of accountability may then commence.

6.4 Approach to monitoring and evaluation

Evaluators can choose from, and skill themselves in, a wide range of available methods and techniques. However, what if the problems to be addressed, and the corresponding FoR elements to be evaluated, are very complex and contain uncertainties? What if problem definitions are contested, such as is the case in discussions around ecosystem health, or mitigation efficiency, or sustainable development? What if intervention programs are more comparable to complex and experimental interaction processes between actors from different institutions than to linear processes of problem formulation, project design, and implementation?

It is important to realise that the monitoring and evaluation of the project in these more complex settings should address the objectives of the evaluation as stated in chapter 6.3. This implies that also more traditional ways of the monitoring and evaluation of the project's processes may become very useful to structure the final evaluation approach (see also Regeer et al., 2009).

The following steps are important in determining your direction of evaluating:

a) Clarify and prioritise objectives, questions and target groups for monitoring and evaluation. This allows the evaluator to gain focus. See chapter 2 on evaluation objectives

b) Concretise what the project or programme envisage to accomplish. Important questions are, e.g.: In what system do we define the objectives? What is significantly different from the situation before? What has been done to reach the new situation? How do the interventions contribute to the system innovation, what could be good markers for the monitoring and evaluation approach

c) Translate the choices made into indicators.

6.5 Indicators for evaluation

There are different types of indicators; the answers to the question here above may facilitate the selection of the most suitable ones.

a) Process indicators, e.g.: changes in behaviour, perceptions, and attitudes of the people involved; the composition of the network, the development of new networks or relations; convergence of different visions

b) Early signals of system innovation, e.g.: the extent of the use of new technologies; number of innovative experiments; the developments of new routines and standards

c) Traditional sustainability indicators. For profit, e.g., economical indicators like productivity, efficiency and profit; For planet, e.g., CO_2 emissions, concentration of pollutants, biodiversity parameters For people, e.g., social indicators like well being, income, employment etc.

6.6 Communication

Operating in a more complex project environment requires more from the manner important issues are being communicated. This is often the case on the interface between experts and users of expert knowledge. Suggested causes for the recurring miscommunication range from unclear problem formulation to problems with research management and communication of results (cf. Mulder et al., 2001; EU, 1999; Capobianco, 1999). It may easily lead to:

a) Unused advice describing the wrong phenomenon
b) Advice on the right phenomenon but expressed in the wrong parameters
c) Expert reports that remain unread because the amount of detail makes them unreadable
d) Perfectly good advice that was ignored in the decision process
e) Failure to establish integration between disciplines within complex projects
f) Study or research projects that pursue personal academic interests rather than the practical problems indicated by the contractors or project owner
g) Science-driven projects having problems in translating the research findings to potential end users
h) New findings taking too long to become implemented
i) New findings that are applied too soon to situations for which they were not designed

Monitoring and evaluation is carried out by humans and between humans. In particular, inefficient interactions and knowledge exchange between people are hard to eliminate from any project. Fortunately, many can be sustainably tackled if project design and its periodic evaluation pay attention to the most common flaws in the operation of complex frameworks such as:

a) Little coordination (lack of structuring the uncertainties in approaches)

b) No shared mission/objectives (falling back to familiar practices)
c) Lack of assessments (unaware of project insights and functioning)
d) Few or too many adjustments (loss of project control)
e) Weak chain linkages (this involves qualified "bilingual" people able to link)
f) No continuity (only short term goals are of interest)
g) Normative commitment (outsourcing FoR elements without assimilating them)

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8 Appendices

8.1 Appendix 1: The DPSIR concept (Drivers-Pressure-State-Impact-Response)

A useful analysis of the role of indicators by the World Resources Institute (Hammond et al., 1995) recognized the widely used pressure–state–response framework for environmental indicators that has arisen from a simple set of questions:

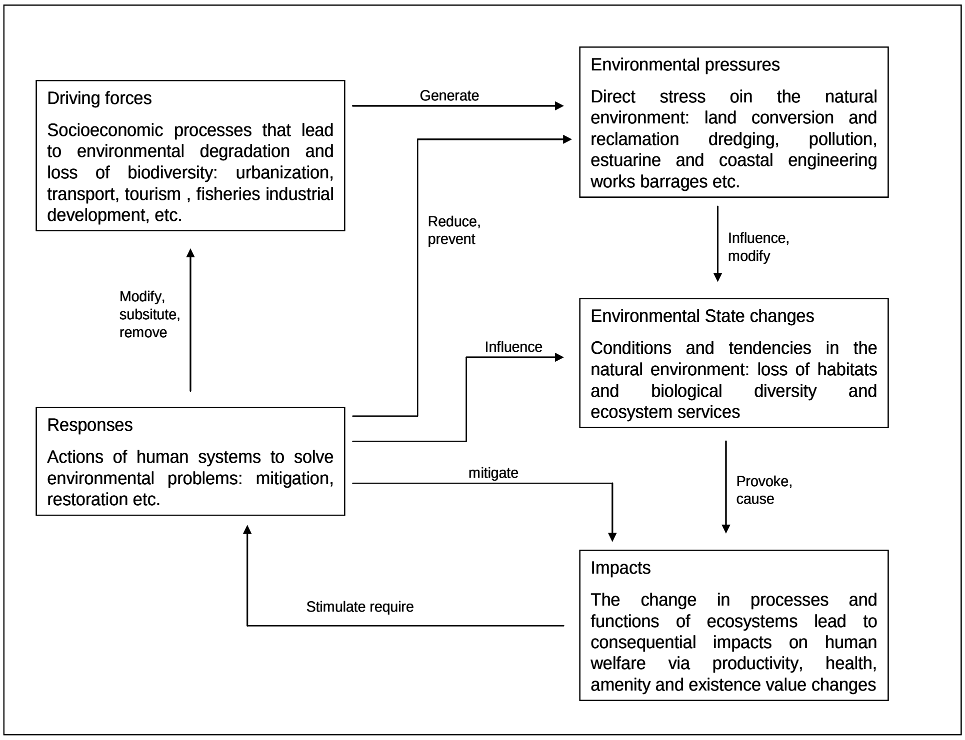
1) What is happening to the state of the environment or natural resources?
2) Why is it happening?
3) What are we doing about it?
4) What can we do about it?

Originally developed by the OECD (1993), based on the work by the Canadian Government and following a cause–effect social response logic, a modification of this framework includes the identification of the driving force for any threat and consequential impact. Thus, the driving forces-pressure-state-impact-response framework (DPSIR), has provided the basis for many national and international initiatives (e.g. EEA, 1999; to select indicators for evaluating the implementation EU environmental policies).

The DPSIR framework is well suited to take different cultural, social, economic, institutional, industrial, political, and environmental aspects into account. The idea of the framework was originally derived from social studies and only then widely applied internationally, in particular for organising systems of indicators in the context of environment and, later, sustainable development.

The DPSIR framework is structured to follow causal chains from an indirect root cause ('driving forces'—D) to a direct pressure and finally a management response (R) between interacting components of social, economic, and environmental systems;

DPSIR model for managing human pressures on the environment.

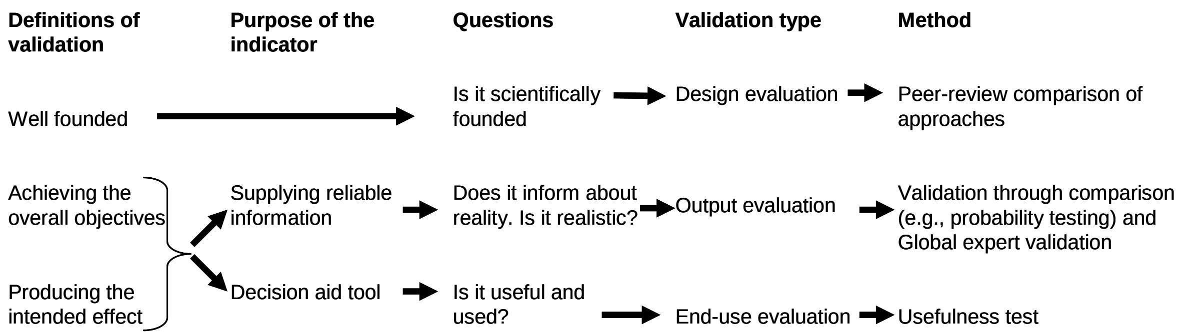


Common analyses include the collection of data and information on all the different elements in the DPSIR chain. Then, possible connections between these different aspects are postulated. The sequence presupposes substantial understanding of the underlying causal relationships between human activities and impacts on ecosystems, coastal economies and communities, and human response mechanisms. Through the use of the DPSIR modelling framework, it is possible to gauge the effectiveness of responses put into place.

Note:
Although the DPSIR, as an elaboration of the PSR (pressure, state, response) model, is useful for visualizing the various parts in the chain of causes, effects and possible responses it can complicate matters and frequently appears to cause confusion, especially when applied to biotic components. This is mainly due to the fact that the distinction between driver and pressure indicators as well as that between state and impact can be difficult to establish. For example biodiversity can be both an aspect of the 'state' of the ecosystem and the 'impact' which managers are intended to address. When the same factor may relate to different indicator categories or suites, it is advisable to precisely define the questions that form the basis for the assessment of the respective DPSIR elements.

8.2 Appendix 2: A general framework for the validation of indicators

From the definition given in the Oxford dictionary, something is validated if: "it is well founded and it achieves the overall objectives or it produces the intended effects". For indicators, the former aspect of the definition implies the assessment of the scientific quality of the construction or design of a given tool. We will call this step a "design validation" (Gilmour, 1973). The latter two aspects of the definition refer to the soundness of the indicator output and to the usefulness of an indicator for potential users. This can be referred to as "output validation" (Gilmour, 1973) and "end-use validation" (Girardin et al., 1999), respectively. Thus, an indicator will be validated if it is scientifically designed, if the information it supplies is relevant, if it is useful and used by the end users. Three types of indicator validation correspond to these three conditions below.



8.3 Appendix 3: Turbidity

An evaluation of the suitability of turbidity indicators for ecological impacts and underlying background information.

a Criteria	Background information and status
Relatively easy to understand by non-scientists and those who will decide on their use	Yes, there seems to be a growing awareness about the importance of turbidity levels and their related effects in ecosystems (Turbidity and related SPM and sedimentation are key variables determining dredging intensity).
Sensitive to a manageable human activity (in relation to measures)	Yes, the underlying mechanisms and variables for turbidity are interrelated, following a cause/effect relationship where the cause is linked to anthropogenic inputs of SPM due to dredging. Since other environmental factors and human activities may contribute to the response as well, the risk of misinterpretation of this cause/effect relationship is substantially reduced when a coherent monitoring is performed of all relevant parameters involved (at pressure and impact level).
Relatively tightly linked in time to that activity (in relation to measures)	Likely. The response is more direct and more tightly linked for the direct effect variables (through reduced light availability or production rates phototrophic biota). The links between increased turbidity and direct and indirect effects of reduced light availability may, however, be spatially and temporally separated through transboundary effects and basin characteristics. Ecosystem or environmental factors (e.g. hydrodynamics, eutrophication) may cause time lags.
Easily and accurately measured, with a low error rate (monitoring)	Likely, the needed elements seem to be part of many operational monitoring programmes accompanying dredging operations. Guidance is available for accurate measurement, including monitoring of the relevant supporting environmental factors (such as salinity, and temperature). There is a wide variety of methodologies and equipment to determine the re-suspended matter through dredging. Variables such as TSS (Total Suspended Solids), SPM (Suspended Particulate Matter) and turbidity (in NTU or FTU) are not the same but they all affect the underwater light availability and do occasionally correlate. Also, there are differences in analytical methods (filtering, drying, optical, fluorescence, etc) one should be aware of. Monitoring of direct and indirect effects should be performed in a coherent way, and with appropriate frequency and area coverage.
Responsive primarily to a human activity but low responsiveness to other causes of change (in relation to measures)	Occasionally, whereby an integrated monitoring and assessment of the cause/effect related parameters is needed in order to relate the (species depended) response to dredging, taking into account environmental factors (weather, turbulence) and (local) ecosystem (run-off characteristics and basin properties (transport, recreation, bottom fisheries).
Measurable over a large proportion of the area to which the classification is to apply	Yes, all variables for turbidity metrics are measurable in all areas. Ample knowledge and assessment and monitoring methodologies are readily available with quality assurance mechanisms implemented.
Based on an existing body or time series of data to allow a realistic setting of objectives (monitoring)	Occasionally. Long-standing time-series are often not available. For most areas, there is insufficient information on the variables for determining turbidity levels, SPM concentrations, column turbulence, seafloor critical shear stress, light attenuation and changes/kills in

		phytobenthos, corals and SAV. Furthermore, frequency and spatial coverage of monitoring may be very low but depending on project size improving.
b	Ecological relevance/basis for the metrics	Both approaches and underlying knowledge is adoptable, the ecological relevance is high.
c	Current and historic levels (including geographic areas)	Rarely. Some recent region specific levels are available through seemingly ad hoc monitoring programmes and other sources of information. Historic levels on most of the elements are not available for most regions.
d	Reference level (= area-specific background concentrations)	Rarely, few area-specific reference values have been derived, on the basis of historic levels and offshore levels. More data is available on SPM or sedimentation rates. The setting of area specific reference levels are needed for comprehensive analyses allowing project management.
e	Limit points (area-specific assessment levels)	Kills of zoobenthos and the demise of SAV are ultimate “limit points” and there is physiological basis for the limit for sedimentation. Zoobenthos status ranges are not clear. Detrimental impact is to be expected from SPM, decreased light availability and sedimentation rates. *Light availability:* Critical light level thresholds for coral and coral reefs worldwide have been estimated to range from 0,2 to 60% of surface irradiance (Jaap and Hallock, 1990; Achituve and Dubinsky, 1990). *Total SPM*: Critical thresholds total SPM for coral reefs worldwide have been estimated to range from 3,3 to 165 mg/l (Bell, 1990; Bogers and Garnder, 2004; Rice and Hunter, 1992) *Sedimentation rates*: Critical thresholds of sedimentation for corals have been estimated to range from 10 to 300 mg/cm2/day (Rogers, 1990; Bak and Elgershuizen, 1976). *Justification* Coral reefs are of crucial importance for a variety of reasons. They harbour a wealth of organisms, provide food and materials for coastal populations, protect vulnerable coastal zones, and sequestrate a significant amount CO_2 a year. High turbidity harms the whole reef biology by shading and burial or may increased availability of sediment related pollutants. *For SAV spatial coverage* one may apply ranges: High: ≥50 and ≤100%, Medium: ≥25% but <50%, Low: ≥1% but <25% and Very low: ≥0 but <10% *Justification* Submerged vascular plants play a vital role in the ecology of nearshore environments These plants attenuate variable inputs of nutrients and sediment, and are thought to be invaluable nursery areas. In relatively pristine waterbodies, SAV thrive while die-off and absence of SAV is generally believed to be (next to an eutrophic condition), associated with high turbidity (Orth and Moore, 1984; Stevenson et al., 1993; Boynton et al., 1996).
f	Time frames	Monitoring frequencies are preferably high due to the dynamics of the variable and underlying mechanisms. However, there is still need to investigate the TAI’s habitat community types’ sensitivity to the dominant pressures. This requires a greater monitoring effort.
g	Monitoring regimes	Monitoring of turbidity is occasionally established in

		operational Monitoring Programmes but mostly on short term projects for control purposes. Monitoring must include estuaries, coastal and offshore areas and other TAIs, and has therefore a broader scope. For most (sub) areas, spatial and temporal coverage should be improved.
h	Management measures to achieve lower turbidity for shorter periods	Although the underlying knowledge is complex in nature, turbidity is an relatively easily interpretable parameter, suitable for fast diagnostic tools, and can be readily evaluated. As such, the variable remains visible and editable for the purpose of management priorities. This allows a transparent assessment method and for any deviation of the overall ecological quality ratio from the reference condition the underlying responsible causes can be easily traced back and evaluated individually. Turbidity resembles an important constituent affecting the environment on different scale and may at least be treated as for example a chemical compound. A further development and implementation of the methodologies in measuring turbidity for assessing the impact on benthic communities and their habitats seems needed for establishing background as well as limit levels.

8.4 Appendix 4: lesson learned

Lessons learned (adapted from UN/ECE, 1993; OECD, 1998 and 2003; FAO, 2002 and 2003)

Developing indicators and monitoring is not an easy task. Before starting this process, the following lessons and general notions may be of help.

On questions:

1. Start at the end. What are the aims of the stakeholders and actors?

2. A proper indicator starts with a proper question. If the question is not well formulated, the corresponding indicator will not provide the intended answer. Because indicators and monitoring are costly, think twice before you choose.

3. Not all questions are to be answered by indicators. Actually many questions can be answered by one-off information (e.g. statistics) or are of narrative character (see also Appendix 1). Besides, monitoring budgets are limited, so balance cost and benefits before deciding establishing an indicator.

On indicators:

1. Indicators are the "eyes and ears" of society, similar to a cockpit for a pilot. They are a prerequisite for adaptive and cost-effective policies.

2. The "keep it simple" principle is applied (KIS); indicators need to be well understood by policy makers and the public.

3. A scientifically perfect indicator does not exist, a politically useful one does.

4. Indicators are not good or bad as such; the suitability of an indicator depends on the purpose it is used for.

5. Choosing indicators is the art of measuring as little as possible with the highest possible policy significance. It is not only a scientific exercise but also a matter of art.

6. Choosing indicators is a cooperative exercise between policy makers and scientists. This guarantees that indicators are policy relevant (targets, baseline choice), affordable, monitorable, ecosystem relevant, linkable with socio-economic scenarios (modelling response-pressures-effect relationships) and reliable.

7. Consultation with stakeholders enlists their participation and consequently increases the effectiveness of indicators as policy and management tool.

8. Biodiversity cannot be measured by a single variable or even a composite indicator. A multi-indicator approach consisting of a few complementary indicators is advisable in order to show the various aspects of biodiversity. Such an approach is also common practise in the socio-economic field. The same applies to pressures, uses and responses.

9. The number of indicators is limited, arbitrary choices are inevitable:

a) Biodiversity is too extensive to measure all its components. Only a smart, representative subset of indicators in a limited number of sample areas can be and needs to be to be measured.
b) This selection problem is similar to that for economic indicators, such as the retail price index: out of millions of products only a representative selection is monitored in a subset of stores - the so called “shopping bag” - to measure inflation.

10. Choosing indicators is not just a matter of science but also a matter of feeling and weighting different factors. The number of indicators is a balance between costs and information needs. This is not a linear relationship. Furthermore, factors other than cost and benefit might play a role, e.g. existing monitoring schemes and institutional partnerships.

11. Be pragmatic:

a) Get started, learn by doing;
b) Do not get stuck in concepts like indicator value, key-stone species, habitat classification systems, etc. They are no goals but just means to help choosing a representative set of indicators. Do not let them keep you from actually doing the work;
c) Do not complain on the lack of data but start with the information and indicators you already have;
d) Indicators do not have to meet all criteria;
e) Aim at a few, simple and feasible indicators on the short term (1-5 years); if possible undergo a gradual development and improvement on the long term (15 years); Rome has not been built in one day either;
f) Aim at an accuracy that corresponds with the necessity of policy making (is money well spent?), not to write scientific articles;
g) Be problem-oriented; focus on human-caused changes, not on natural fluctuations;
h) Develop indicators which are flexible and can be used on different scales for multiple purposes, e.g. useful for national use, international reporting obligations, possibly site management, sustainability assessment, etc. However, indicators for

national policy making tend to be of a different character and scale than those required for site management;

i) Common species are much easier and cheaper to monitor than rare species and may provide equally important information;

12. Indicators can be single variable or highly aggregated composite indicators. They have different features and serve different users and goals:

a) Single indicators provide detailed information, often useful for management questions. They may also the building bricks for composite indicators.
b) Composite indicators provide general overviews often useful for policy making and communication with the public.

On indicator use:

1. The maximum number of indicators one person can simultaneously perceive is around 15.

2. To underpin interventions and adaptations, decision makers are more interested in change than in the state of an entity.

3. Indicator values are just means, not the final goal. The final goal is to implement effective sector and conservation measures.

4. To assess improvement or deterioration of the status of biodiversity, a baseline and policy objectives are needed against which current and expected future state can be compared;

5. Assessments can be made from different points of view, e.g. (i) the more species the better; (ii) the less human-affected the better; (iii) the more self-organizing the better; (iv) the more productive the better; or (v) the lower the risk of extinction the better, etc.

6. If chosen carefully, indicators give suitable direction to monitoring and research programmes.

On monitoring

1. A strong ownership is of great importance of the continuity and quality of monitoring.

2. Monitoring intervals and locations and the corresponding levels of confidence can be determined through statistical analyses.

3. Rules of thumb can sometimes provide an alternative to complex statistical solutions.

8.5 Appendix 5: Scoring of (sub)criteria

Scoring of indicator sub criteria and elements (see chapter 3.3.1 for explanations). Proposed are different information sources for evaluation. Indicated are the scoring (H, High; M, Moderate; L, Low) for the main constituents determining the strength of an indicator and the methods by which the evaluation could be conducted. Stars on items labelled H and L indicate that, if the consideration (or method of evaluation) is relevant, scoring High there is of great importance, and scoring Low is a nearly fatal flaw, respectively. Methods of evaluation presented include PRR (robust conclusive Peer-Reviewed Research), MIP (Multiple Independent Publications providing consistent findings), FDS (Formal Designed Surveys), MIM (Multiple Independent Models producing consistent results), ICE (Interdisciplinary Consensus of weight of Evidence) and EXP (expert judgement).

Criterion/ elements	*Sub criteria and suggested scoring*	*Method evaluation*
A Understandable	Concrete property of physical/biological world (H), or abstract concept (L)?	FDS; ICE; EXP
	Units measurable in the real world (H), or arbitrary scaling factor (L)?	ICE; EXP
	Direct observations (H), or interpretation through model (L)?	ICE; EXP
	Is it a property with a high (H) or low (L) public awareness outside the use as an indicator?	FDS*; ICE; EXP
	Does public understanding correspond well (H) or poorly (L) with technical meaning of indicator?	FDS; ICE; EXP
	If awareness high, is public likely to demand action that is: (i) proportional to indicator value (H); (ii) disproportionately severe (M); (iii) largely indifferent (L)	FDS; ICE; EXP
	Does the nature of what constitutes ‘‘serious harm’’ (used to define a limit point) depend on values that are widely shared (H) or vary widely across stake holders (L)?	FDS; ICE; EXP
	Internationally binding agreements, national or regional legislation require that a specific indicator be reported at regular intervals (H), to agreements/legislation require environmental status reporting, but indicator not specified (M) to no such requirements (L)	ICE; EXP (when indicator not specified in legislation)
B Responsiveness	The indicator changes within hours (H), days, weeks of implementation of measures, to indicator only reflects system responses to management on decadal scales or longer (L)	PRR; MIP; MIM; ICE; EXP
C Specificity	Is impact of environmental forcing on indicator known and small (H) or strong (L)?	PRR; MIP; MIM; ICE; EXP
	If environmental forcing affects indicator, effect systematic and known (H), to irregular or poorly understood (L)	PRR; MIP; MIM; ICE; EXP
	Relative to other factors, indicator is unresponsive (H); responds to specific factors in known ways (M); or responds unclearly to many factors (L)	PRR; MIP; MIM; ICE; EXP
D Measurement	Can variance and bias of indicator be estimated? Yes (H); No (L)	MIP; MIM; ICE; EXP
	Is variance low (H) to high (L)?	MIP; ICE; EXP

	Is bias low (H) to high (L)?	MIP; ICE; EXP
	Does indicator over- (H), or underestimate risk (L)	MIP; MIM; ICE; EXP
	Are both variance and bias been consistent over time (H), or have they varied substantially (L)	MIP; MIM; ICE; EXP
	Probability that indicator value exceeds reference point can be estimated with accuracy and precision (H), to coarsely or not at all (L)	MIM; ICE; EXP
	Indicator comprises techniques with known accuracy and precision (H), to unknown or poor/ inconsistent (L)	MIP; MIM; ICE; EXP
	The indicator is unaffected by sampling gear (H), to sampling methods can be calibrated (M), to calibration difficult or not done (L)	PRR; MIP; ICE; EXP
	Seasonal variation unlikely or highly systematic (H) to irregular (L)	PRR; MIP; MIM; ICE; EXP
	Geographic variation irrelevant or stable and well quantified (H), through random (M) to systematic on scales inconsistent with feasible sampling (L)**	PRR; MIP; ICE; EXP
	Indicator reflects status of all taxa sampled/modelled (H), through ecologically predictable subset of species (M), to only specific species with no identifiable pattern of representativeness (L)	PRR; MIP; ICE; EXP
E Sensitivity	Indicator response to specific dredging pressures is: smooth, monotonic, and with high slope (H), to unreliable, insensitive or irregular, where magnitude of response does not depend on magnitude of pressure signal (L)	PRR; MIP; MIM; ICE; EXP
F Applicability	Indicator metric is applicable across regions and habitats (H) to limited, local and specific indicator employment (L).	PRR; MIP; MIM; ICE; EXP
G Historical data	Data are available for of several decades (H) to years (M), to hardly available (L)	MIP; ICE; EXP
	Data are from the full area of interest (H), to restricted but consistent sampling sites (M), to inconsistent sources, or none (L)	MIP; ICE; EXP
	Data have high contrast, including periods of harm and recovery (H), to high contrast but without known periods of harm and recovery (M), to uninformative about range of variation expected (L)	MIP; ICE; EXP
	Data quality and management is known and good (H), to data scattered with reliability but not systematically certified, and archives not maintained or none (L)	MIP; ICE; EXP
	Data freely available to research community (H), to private or commercial holdings (L)	EXP
Scientific soundness	Basis credible, little debate. Can account for patterns in many data sets (H); to credible, but competing theories with mixed empirical support (M); to key components untested or generally not accepted (L)	MIP, PRR, MIM; ICE; EXP
	Indicator concepts readily reconciled with established theory (H); to concepts not inconsistent with, but not accounted for by, ecological theory (M); to concepts difficult to reconcile with ecological theory (L)	PRR; MIP; MIM; ICE; EXP MIP; MIM; ICE, EXP

	Theory allows calculation of limit point (H)	
Total costs	Proven measurement tools are widely available and inexpensive to use (H), to new, costly, dedicated, and complex instrumentation (L)	ICE; EXP
	Monitoring forms integral continuous element of FoR (H), to ad hoc employment of externally obtainable techniques (L)	ICE; EXP
	Newly gained process knowledge is evaluated and used for sustainable system intervention (H) to no use and fall back to daily routines (L)	EXP

8.6 Appendix 6: Examples biosensors

Some modern examples of on-line and in situ biosensors for monitoring environmental stress and chemical pollutants for use in adaptive monitoring activities of the FoR.

1 Available methods and new initiatives

Several terms for on-line and in situ methods are presently in use, among them real time biomarkers, biosensors, bioelectronic systems and instrumented (sentinel) animals. Several current and new, application-driven on-line methods are described below. These include physiological responses in crab and mussel (measured by respectively heart beat rate and valve movement/shell opening) as global stress indicators. Some of these methods could be potentially applied to any marine invertebrate with a neurogenic heart or, in the case of valve movement, any sensitive bivalve species. This summary gives an account of some of these technologies that may be incorporated into environmental monitoring and management programs of the FoR. The examples are by no means exhaustive. Nonetheless, the use of in situ and on-line biosensors may foster application in BwN adaptive monitoring strategies and activities.

2 General real time stress indicators- heart beat sensors

2.1 Off-shore monitoring environmental monitoring technology

This method is developed and currently in use by IRIS–Biomiljø and BiotaGuard company in Stavanger. The background for the off-shore monitoring initiative is that there are increasing off-shore operations in remote areas as well as sub-sea and unmanned operations. It is a need to bring biomonitoring into the Control Room of Integrated Operations for which real time monitoring is required. To facilitate this, a real time environmental effect monitoring system called "BiotaGuard" has been developed. It is based on known methods of cardiac activity and valve gape behaviour in blue mussels (*Mytilus edulis*). Conventional chemical/physical sensors and passive samplers are integrated in the system. "Passive" (not instrumented) mussels are also exposed and can be collected as needed as basis for more detailed laboratory analysis of mussel health conditions. The system can also accommodate other biosensors to represent specific marine conditions in other regions and water depths where such organisms are pre-sent. Further development of the system for application in Arctic oil fields is presently being initiated, financed by oil companies and the Research Council of Norway. Three field tests with the mussel based prototype have already been conducted, including an off shore test in a North Sea oil field in parallel to the Water Column Monitoring program (Norwegian Oil Industry Association) which is based on bio-marker measurements in caged mussels and cod. A long term field validation outside an oil refinery will be conducted this year, which may provide data for evaluation of the system.

2.2 Safeguarding drinking water quality for Ecological Safety.

The background for this initiative is that immediate responses are needed if unwanted chemicals enter drinking water supplies, and real time monitor-ing is therefore required. The method is based on cardiac activity measurements in the freshwater crayfish *Pontastacus leptodactilus* (Kholodkevich et al. 2007). Stress responses are observed based on “pul-sometric” analysis. Responses measured in test situations demonstrate that the method can be regarded as a general, real-time, stress indicator. The method is currently applied industrially in several water supply stations in St. Petersburg. The method is a further development of a method developed at the University of Plymouth (Bamber & Depledge, 1997).

2.3 Heartbeat sensors assessing hyperbaric physiology

Non-invasive heartbeat sensors to measure the cardiac activity of crustaceans have been adapted for use under hyperbaric conditions. Able to record data continuously over long timescales, these sensors can collect high-resolution data on the physiological state of an organism up to a tested limit of 300 atm. Using this technique, heart rate was recorded in a juvenile of the sublittoral spider crab, *Maja brachydactyla* (Decapoda: Majidae), when subjected to hydrostatic pressures of 1, 50, 100, and 150 atm for periods of 30 min. Heart rate increases with pressure until 100 atm. However, the significant decrease in the mean heart rate from 137.07 bpm at 100 atm to 118.40 bpm at 150 atm indicates a mechanistic limit in the cardiac response of this species to pressures beyond 100 atm. This method could be potentially applied to any marine invertebrate with a neurogenic heart (Robinson et al., 2009).

3 General real time stress indicators- Bivalve monitors

3.1 Mussel monitor

The Musselmonitor II (originally in Dutch: Mosselmonitor®) is a biological sensor for continuous on-line monitoring of surface waters, effluents, drinking water intakes, and of seawater. This system will evaluate the water quality also for compounds that are not tested through routine chemical analyses. Therefore, it is a broad spectrum sensor that operates unattended for weeks, 24 hours per day. At the occurrence of sudden pollution, the system will generate within minutes an alarm signal, which may induce automated sampling.

A remarkable feature of the Mussel monitor is, that eight living organisms (bivalves) are used as sensors. Under normal conditions the shells of mussels are open to allow respiration and feeding. Under adverse environmental conditions the valves will close: the organisms are hiding from the hostile environment (escape behaviour). This valve movement is used as a biological effect parameter.

Bivalves used include the freshwater zebra mussel (Dreissena polymorpha) and the marine blue mussel (Mytilus edulis), but also other mussels, clams and oysters are used successfully. E.g., currently (i.e., 2010), IMARES is developing a biosensor using Ensis for application in the Dutch coastal zone.

The Mussel monitor comes in two different forms: an in situ version that can be employed directly in the aquatic environment and a flow-through version, for installation inside a monitoring station, laboratory. For more technical details and sales or leasing: contact the producer Delta Consult at www.mosselmonitor.com. For an illustration of the system, employed at a drinking water application (see Mermayde and http://www.mermayde.nl/mosselmonitor.html for more information).

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