From Ecological Risk Assessments to Risk Governance. Evaluation of the Norwegian Management System for Contaminated Sediments.

† ‡ Magnus Sparrevik and †§Gijs D. Breedveld

† *Norwegian Geotechnical institute, PO Box 3930 Ullevål Stadion, NO-0806 Oslo, Norway, magnus.sparrevik@ngi.no, gijs.breedveld@ngi.no

‡ Department of Industrial Economics and Technology Management. Norwegian University of Technology, 7491 Trondheim, Norway

§ Department of Geosciences, University of Oslo, P.O. Box 1047, Blindern, 0316 Oslo, Norway.

ABSTRACT

Managing of contaminated sediments is a complex process that will naturally have to balance scientific, political and economic interests. This paper evaluates the Norwegian system for managing contaminated sediments towards a generic system for risk governance encompassing both knowledge, legally prescribed procedures and social values. The review has been performed examining the management plans for 17 prioritised contaminated fjord systems in Norway. The results indicate a strong focus in the Norwegian management system on ecological risk assessment. This facilitates selection of local sustainable remediation measures, but may also complicate the balance towards other relevant interests in a decision making process. The Norwegian system lacks management tools to identify and handle ambiguity through concern assessments and stakeholder involvement, and the decision making process seems to a large extent based on “ad-hoc” decisions making it difficult to incorporate and document multi criteria evaluations into the management process. To develop a sustainable management system, encompassing environmental, economical and social interests, a stronger focus on concern assessment and multi criteria evaluations is required.

KEYWORDS: Risk Governance, Sediment, Management, Sediment Quality Guidelines, Multi criteria decisions

INTRODUCTION

Sediment contamination in a river basin or an urban coastal area is often related to a complex situation of sources contributing to contamination. The sources may have a local origin as effluent releases from present or former industrial sites, whereas other sources are diffuse like urban run-off or long-range transport of pollution. The sediments often act as a sink accumulating contamination from all sources, thus making it likely to find elevated levels of contamination in large areas. Due to the nature of the sediment problem characterised by potentially significant volumes with contamination above background levels, the management of contaminated sediments will naturally have to balance cost, environmental aspects and potentially social conflicting interests. Therefore there exists not one single correct way to address the problem, but the approach should rather be driven by the ecological, political and economic goals of all interested parties (Apitz & Power 2002). The balance between these interests is delicate and involves not only natural science oriented aspects but is also depending on social understanding, risk perception and social acceptance among stakeholder groups and public.

Norway has taken an approach for sediment management decisions based on site-specific risk assessment. Even though this may be a large step towards a sustainable management of contaminated sediments, (Apitz 2008), allowing also in-situ remediation technologies and natural recovery to be used as remediation options, this paper will evaluate the Norwegian management system for contaminated sediments examining the maturity towards a risk governance framework encompassing both knowledge, legally prescribed procedures and social values, and will suggest improvements to guide sediment management in a sustainable direction.

THE NORWEGIAN MANAGEMENT MODEL

Sediment contamination in Norway differs somewhat from the situation in the rest of Europe. The main concern with relation to sediments is not connected to river basins and need for dredging to maintain navigational depth, but to the presence of contamination in the inner parts of the fjords and in harbour areas. Driving forces for management are increased environmental awareness and urban development in these areas.

The process of sediment management in Norway started in the late 1990s by an extensive investigation of contamination in more than 120 locations along the coast. Based on these investigations a system for sediment quality guidelines (SQGs) was developed, classifying the sediment in five classes from background values (Class I) to severe contamination (class V) (SFT 1997). Initially the different classes were set merely by statistical evaluation and expert knowledge, whereas in the in latest revision of the guideline the values are based on eco-toxicological data and derived Probable No effect values (PNEC) using the EU-TGD system (EU 2003). To complement the basic risk assessment based on SQGs, a system for site specific risk assessment was developed allowing a more detailed assessment based on local site conditions. The local assessment considers risk on human health (exposure for contamination), spreading (to water and uptake in marine organisms) and ecological risk (damage on the local ecosystem) for the area of concern. In parallel with this assessment system, health guidelines for oral intake of fish and shellfish have been prepared. These restrictions on intake of fish and shellfish are based on expert judgement as well as direct analysis of biota, and evaluation using a separate set of guideline values. At present stage 32 coastal areas have restrictions to seafood consumption.

Based on the investigations and the risk assessments, a strategy for mitigating sediment contamination has been developed and formalised through preparation of sediment management plans. These management plans are based on national governmental objectives stating that Norway should be a leading nation with respect to a clean marine environment, striving to reduce exposure to harmful chemicals as far as possible. Today, management plans for 29 areas have been prepared, targeting 17 of them for further remedial actions.

The sediment management strategy is formalised through two white papers from the Norwegian Government in 2002 and 2006 (MD 2002; MD 2006).

RISK GOVERNANCE MODELS

One way to expand the process of contaminated sediment management is to incorporate it into a broader risk governance perspective. Risk governance includes the totality of actors, rules, conventions, processes and mechanisms concerned with how relevant risk information is collected, analysed and communicated and how a management decision is taken. One of the main aspects in risk governance is the acceptance and understanding of the duality of risk. In Klinke & Renn (2002) the duality of risk is discussed in the terms of realism versus constructivism. The realists consider risk as a representation of observable hazards predicted by calculations unbiased by human observations. The constructive camp considers risk as a mental model validated towards the logical consistency, cohesion and internal conventions of logical deduction. This mental translation of risk is best described as risk perception and is well documented in the social literature (Slovic 2000). A transparent decision model should try to balance the socio-economic and political considerations with scientific evaluations into a governance framework.

Perhaps the most comprehensive conceptual risk governance framework is described by the International Council of Risk Governance, (IRGC 2007; Renn 2008). In literature there are several descriptions of adaptations of the framework to different applications or development of new models for decision making using the fundamentals of the framework (Pollard et al. 2008; Pollard et al. 2004b; Assmuth & Hilden 2008; Pollard et al. 2004a; Kristensen et al. 2006). This paper however refers to the generic ideas of the four stage risk governance framework as presented by IRGC, Figure 1;

The *pre-assessment* serves as the baseline for the risk assessment and management, giving guidance on both the dimension of the risk, the relevance and interests of the stakeholders and public as well as the existing foundations such as laws, regulations and other relevant guidelines. The framework defines stakeholders as socially organised groups who are or will be either affected by the risk or have strong interests in the issue. Public is defined as individuals, non-organised groups or media that are experiencing the outcome of the event or is a part of the opinion on the issue (Renn 2008). The pre-assessment is important since it allows the duality of risk to be reflected early in the policy making phase.

The second step is *risk appraisal*. This step identifies and assesses important information about the risk to be used in the subsequent characterisation and evaluation steps. The risk appraisal contains both the conventional scientific *risk assessment* based on the identification of hazard, exposure, vulnerability and probability of occurrence. The framework also contains a *concern assessment* which encompasses the associations and the perceived consequence that the stakeholder may associate with the hazard. This assessment will identify the potential bias between the scientific (realistic view) and the perceptive (constructivist view) allowing both sides to be reflected in the evaluation and management of risk.

The third step in the framework consists *of risk characterisation/evaluation*. This step encompasses both the process of characterising the risk according to the findings in the appraisal phase, as well as an evaluation of the tolerability and acceptability. For the scientific evaluation this normally means evaluation towards predefined acceptance criteria, whereas this model also includes an evaluation towards social values based on the result of the concern assessment.

The final stage of the framework is the *risk management phase*. This phase comprises the identification of risk reducing measures and the decision making process as well as the design, implementation and monitoring the effect of these measures. *Communication* is central in the process indicating that communication with stakeholders is required to build trust in all phases of the framework.

One of the main elements in this conceptual governance model is to choose management strategy based on the characteristics of the risk, This system divides the risk into four different classes; *simple, uncertain, complex and ambiguous* depending on the characteristics of the risk. This classification may facilitate both problem framing in the pre-assessment phase as well as the characterisation of risk in the characterisation/evaluation phase and the need for stakeholder involvement in the management phase.

MATERIALS AND METHODS

The evaluation of the Norwegian management system for contaminated sediment has been performed as a case study analysis, adapting the methods described by Eisenhardt (1989). This method is based on analysis of cases to build new theory and to compare it with relevant literature in order to validate the results. The theory building proposed in the result chapter is based on analysing each of the 17 fjord cases prioritised for further actions. The main sources of information for each case are the management plans available at the web page of the State Control Authority Board (www.sft.no). Each of the management plans have been subjected to textual analysis with respect to consensus to requirements for information and with the three elements in the risk governance framework prior to the management phase itself. The following criteria for consistency have been used in the analysis;

Pre-assessment. Has one established and agreed on site specific goals and objectives for the management of sediment contamination?

Risk appraisal. Did the material contain a risk assessment (RA) and was the classification of risk based on general sediment quality guideline values (SQG), or did it contain a site specific RA? Was the probability of occurrence related to spreading of contaminants evaluated? Was there any evidence indicating that risk perception or public opinion had been evaluated in a concern assessment?

Risk characterisation/evaluation. Was the evaluation performed towards predefined ecological risk acceptance criteria? Were qualitative and / or qualitative methods used to evaluate other socio-economical factors towards the ecological criteria, or were management decisions taken using ad-hoc decision methodology?

Information. Have stakeholders been involved in the analysis work and/or in the preparation of the management plans?

The performance of the Norwegian management system, with respect to incorporation of the principles of the risk governance framework, is analysed and the gaps towards the risk government framework are identified. The results are compared and discussed towards relevant literature. The relevance of using risk governance as a generic tool towards sustainable management of sediments is also discussed in the results chapter.

RESULTS

Analysis of the framework

The results from the case study are summarised in Table 1. A positive finding towards the predefined criteria is marked as a positive sign in the table, whereas lack of evidence to agree with the criteria is marked with a negative sign. The analysis shows that all plans have a strong focus on ecological risk assessment and all plans have used site specific sediment investigations and sediment quality guidelines to classify the contamination using ecological acceptance criteria. 64% of the plans have also performed site specific evaluations of ecological risk, but only one of the plans has taken concern assessment into account. Three of the plans have made an evaluation of the probability of occurrence of contamination due to unwanted events. In the Kristiansand and Trondheim management plans, the probability of ship traffic causing sediment mobilisation combined with the SQG were used to assess the risk of contaminant mobilisation. In the Oslo fjord the risk of unwanted incidents during the remediation were assessed by using semi-quantitative risk matrices. However in general the risk assessments are executed by assuming the probability of occurrence of the contaminant releasing processes to be equal to one, i.e. the risk assessment is determining the potential consequence of exposure to contamination using that assumption.

The majority of the plans had incorporated some kind qualitative decision making in the work, but only a few of the objects had used any kind of comparative or multi criteria based decision making. The communication in form of stakeholder involvement and participation is found to be present in approximately 50% of the plans.

Case illustrating ambiguity in sediment management

Sediment management decisions are influenced by many factors and there may be ambiguous characteristics to be considered in the management operations. This is illustrated in the remediation of sediments in the inner Oslo fjord (2006-2009), where perceived risk and social acceptance differs significantly from the risk assessed by the experts.

Due to construction of a new road tunnel in the Oslo harbour area dredging of contaminated sediments was necessary and a remediation project was initiated. The selected disposal method was to place the sediments in a confined aquatic disposal facility (CAD) approximately 3 km from the dredging site. In addition, other contaminated areas in the harbour would be capped with clean material. The solution was selected as the most feasible option compared to other remedial alternatives and documented through an environmental assessment (EIA). This solution was approved by the environmental agency (SFT) and the local city council as an environmental sound project for remediation of the inner Oslo fjord. National and local non-governmental organisations (NGOs) however opposed to the disposal method, trying to stop the project during the implementation phase. The main objection against the project is the concept of using the fjord as a disposal site for contaminated sediments. The case has been highlighted in the media, and a search on Google™ search engine in August 2009 on the combination of "Malmøykalven" (the name of the disposal site) and "gift" (toxin) generates 962 hits. A search on the same keywords in Norwegian published material (TV, radio, web and newspaper) on the Retriever database (www.retriewer-info.com) generates 351 hits. This indicates how the project has been associated with negative perceptive values and socially amplified through media (Kasperson et al. 1988).

Identification of gaps and comparison with literature

Pre-assessment

All work presented in the management plans is governed through the requirements given in the governmental white paper (MD 2002). The white paper gives the framework for the content and delegates the responsibility for the preparation process and management of the plans.

The review of the targeted plans shows that approximately 60% of the management plans were containing accepted site specific environmental targets and goals, whereas other plans were just presenting alternatives allowing the decision to set targets and objectives for the decision makers. The lack of specific goals and targets guiding the management work may have both advantages and disadvantages. The obvious disadvantage is that without clear objectives and targets early in the process the subsequent decision making process will be less structured, possibly leading to more ad-hoc decisions. On the other hand, the advantage is that this open approach may facilitate adaptive management (Linkov et al. 2006a) allowing several remediation alternatives to be evaluated until a more detailed level of understanding of the problem has been achieved.

<u>Risk appraisal (risk assessment and concern assessment)</u>

The analysis show that all plans have used ecologically derived generic sediment quality guidelines (SQG) to evaluate the sediment conditions at the sites. 80% of the plans have also performed site specific ecological risk assessments based on the level of contaminants found in the sediments. Transport of contamination from the sediment out of the affected area has been estimated by flux calculations. Risk of human exposure has been estimated by comparing the potential of exposure to the maximum tolerable dose (MTR) for a lifelong exposure. The ecological risk is assessed by performing site specific calculations of water concentrations derived from the measured sediment concentrations and comparing them with the water quality guidelines (WQG). The work with ecological risk assessments has been performed according to Norwegian guidelines (SFT 2007).

The framework for performing ecological risk assessments (ERA) and establishing SQG which are used in the first phase of the ERA is an extensive process. The process is based on available toxicity data for marine organisms, following a statistical interpretation to determine the water concentrations where 95% of the organisms should be protected giving water quality guidelines (WQG). SQG are then calculated by using the distribution coefficient between sediment and water (K_d-value). There are a number of uncertainties involved in the process. First the calculation is based on toxicity data derived from aquatic species (PNEC values), which by themselves change over time due to increased knowledge and more scientific data. For components where limited toxicity data are available, safety factors are applied in order to be conservative in the estimations (EU-TGD 2003). Secondly the conversion from WQG to SQG using the generic distribution coefficients between sediment and water may significantly underestimate the tolerable sediment concentrations for some components, (Breedveld et al. 2007).

In order to test the robustness of ERA as a framework for decision making, the SQG values for a number of organic and inorganic components for three revisions of the Norwegian SQG (SFT 2007) were compared**.**

Figure 2 shows the standard deviation from a calculated mean value for the three revisions (1997, 2005 and 2007). It can be seen that the deviation is within the order of magnitude of ±10 to 150%, with large differences both in time and between components. All these variation may be well explained from evolving scientific data and better understanding of the ecological and chemical processes in the modelled system. However, for a risk manager or stakeholder who is only presented with the output from the evaluations, the impact on the interpretation may be significant. This highlights the sensitivity of a management system, only relying on the presentation of acceptable contaminant values for single components. This conclusion is in line with the findings by Apitz & Power (2002), where several assessment frameworks were assessed and found useful for flagging potential contaminants in the sediments but less suitable for use as disposal or cleanup criteria.

Efforts to overcome these problems and reduce uncertainties have been undertaken by the standardisation of derivation of SQG from toxicological data through the EU-TGD framework. Another more innovative approach to reduce the sensitivity of variations in the

SQG and the uncertainty in the evaluations is to use unit-less indexes. Apitz et al. (2007) used a weighting method where each component of interest is divided by the contaminant concentration forming a Contaminant/SQG value ratio (HQ) for each component. A mean ratio was also calculated (mHQ) by dividing the sum of all Contaminant/SQG value ratios with the number of components. The system was tested for 19 different SQG from various countries. The results indicated that even if there were differences between the assessments of each component, the indexation gave relatively comparable results between the different set of SQGs.

A similar approach to risk assessment of sediment contamination has been taken in the Norwegian offshore oil industry (Singsaas I et al. 2008). Here the focus has been to assess the impact of cuttings from drilling operations on the environment. The main argument for developing a management system for the drill cuttings has been to assess which components in the drilling fluid that has the greatest impact on environmental risk, and to compare the environmental effect of cuttings in different regional areas in order to be able to prioritise risk mitigation. In this system both toxic stressors, as the chemical components, and non toxic stressors, as for example oxygen depletion, are assessed. The risk is estimated by calculating the ratio between the concentration of the stressor, often referred as predicted environmental concentration (PEC) and corresponding PNEC value. This PEC/PNEC ratio for each component is summarised and the integrated value is forming an environmental impact factor (EIF).

From a risk manager's perspective a transparent system using mHQ or EIF values would be valuable. The unit-less indexes is less sensitive to changes in SQG values since elevated in toxicity for some components may be levelled out by reduction of toxicity for other compounds. A unit less index also makes it easier to assess the overall effect of contamination between different locations or even regions, thus allowing the decision to make prioritise the remedial effort. It is however important to be aware that all weighing methods have limitations since chemical and toxicological data may get lost in the process. The results should be used with care allowing full transparency of the background data, and should be subjected to sensitivity analysis.

Concern assessment is scarcely traceable in the analysis of the remediation plans. Only one of the plans, Grenland fjord, has addressed risk perception by assessing the willingness to pay for remediation of contamination (Navrud & Barton 2006). This result indicate that the part of the risk governance framework relating to the duality of risk and taking the perceptive risk into the management process, is only to a minor degree incorporated in the Norwegian framework for managing contaminated sediments. This observation may have two logical explanations. The first possibility is that risk of contaminated sediments may be defined as a simple, complex or uncertain risk requiring low or no stakeholder involvement. The other possibility is that risk of contaminated sediments may have ambiguous characteristics and indicates a gap between the management system and the framework.

In order to test which of the possibilities that explains the observation, the system for risk classification in the framework was used and adapted to sediment contamination, Table 2.

The review of the Norwegian management model clearly indicates that sediment management in general is not a simple issue, since site specific ecological risk assessments have been widely used to evaluate the risk and prioritize remediation. To some extent one may argue that the problem is complex since there may be multiple sources contributing to the effect of contamination in the ecosystem, including contaminant sources and chemical agents not yet identified to be of environmental concern. The management strategy is addressing these issues in a way that the SQG are reflecting the most predominant contaminants at the time, and site specific ecological risk assessments also recognises that there may other sources contributing to risk.

The main focus in the management strategy is however on uncertainty based management. The use of SQG is a precautionary approach since the same toxicological assessment system is used to evaluate the environmental risk for new substances introduced to the market through the REACH directive, (www.echa.europa.eu). Compared to other risks that people freely are willing to accept like smoking or car driving, the risk from contaminated sediments may seem insignificant. However, by using a precaution-based strategy it is assured that the handling of contaminated sediments is performed in a way not causing additional risk to humans or the ecosystem.

The use of the risk management system for sediment remediation operations has, as described in the analysis chapter, revealed at least one example where perceived risk and social acceptance may differ significantly from the risk assessed by the experts. This indicates that sediment remediation also may have ambiguous characteristics. This is again an evidence of the difference in risk perception between experts and stakeholders. This example emphasise that sediment remediation may be ambiguous, and that concern assessment in these cases should be a part of the management framework.

Risk Characterisation/evaluation

In 70% of the plans the management strategy has been formed by using an ad-hoc process, meaning that recommendations for remedial actions are not based on a systematic evaluation, weighing and prioritization of the obtained data. In four of the plans, Grenland, Oslo, Drammen and Kristiansand there has been an effort to use comparative methods to propose management strategies. Three major strategies have been chosen.

The first method used in the Grenland area focuses on the environmental benefit a remediation may have on lifting the restrictions for consumption of seafood and shellfish, (Saloranta et al. 2008). This method assesses the uptake of contaminants in relevant species from the contaminated sediments with and without remedial actions. The model calculates the time it takes to reach a state of conditions where the consumption restrictions of fish and shellfish may be lifted. Based on the modelling results a study on the willingness to pay to remove consumption restrictions, as well as the preference for different remediation alternatives was initiated. The main conclusion from the study was that the willingness to pay for a remedial action was increasing in the vicinity of the contaminated area and that capping methods were preferred as the remediation method, (Navrud & Barton 2006).

The second strategy used in Drammen and Oslo is based on the contaminant transport from an area before, during and after remediation, comparing it with a reference state. The idea is here to calculate a scoring value (remediation efficiency), comparing the ratio between contaminant flux from a given area during and after remediation with the contaminant flux without remediation. For a given time frame the remediation efficiency should be positive, i.e. indicating that the release of contaminants during and after the remediation should be less or equal to an alternative without remediation, (Eek et al. 2006).

The third strategy used in Kristansand, utilises an efficiency index where the cost is divided with the amount of contamination removed. The site index gives the opportunity to assess the cost of remediation for one unit of contaminant. Even though the methods use different strategies to support a management decision, they are all founded in a physical/chemical model of the fate of the contaminants.

There are however also other methods to facilitate complex decisions associated with sediment management as described in Linkov et al. (2006a) and (2006b). These methods are based on multi criteria decision analysis (MCDA) and may better facilitate the decision making, allowing other factors than the fate of chemicals to influence the decision. Unlike the management decision methods used in the Norwegian sediment management (MCDA) are derived from the general need to solve complicated management problems and therefore neutral in the sense of expert knowledge. The core potential of MCDA is the ability to structure, compare and evaluate complicated management decisions involving both technical data and stakeholder values. The process is interactive where all relevant factors affecting the decision are identified and weighed against each other. There are several examples in the US, where MCDA have been used for management of sediment remediation cases (Kiker et al. 2008; Suedel et al. 2008; Yatsalo et al. 2007).

Although there are substantial advantages to use MCDA in complex decisions there are also difficulties in relation to use the ad-hoc method based on "common sense", (Gamper & Turcanu 2007). One of the disadvantages may be lack of experience with these methods among experts; another may be the need for extensive stakeholder participation and the sharing of knowledge between scientists, managers and other stakeholders.

Communication

The traceability of communication in the management plan varies between the cases, but in 53% of the plans, participation from local problem owners and environmental advisors in the local municipality has been identified. By the definition of Rowe & Frewer (2000) the participation in the work may be classified as citizen/public advisory committee. This way of involvement is characterised with a general moderate degree of representativeness and transparency. The influence is variable from case to case depending on the working process locally. The quality of communication and success of involvement by using this method may therefore be questioned compared to other negotiation based methods.

DISCUSSION AND CONCLUSIONS

The review of the Norwegian management plans indicates that the management is heavily influenced by the system for ecological risk assessments and especially the use of sediment quality guidelines (SQG), Figure 3.

The pre-assessment has been formed over a long time period involving knowledge build up, investigations and policy making. The management system is dominated by the view of regulatory authorities and experts on ecological risk assessments, developing the management system and performing the assessments. This selection of expert competence has framed the system and contributed to encapsulate it from developing into a governance system incorporating the broader picture of risk.

The strong dependence on SQG as management indicators may also be challenging since there are uncertainties in establishing these kinds of criteria and they have been changing over time. It is also evident that the focus on consequence oriented ecological risk assessments may enhance the conservativeness in the management system and limit the practical use as an efficient management tool to reduce risk. To reduce the impact of uncertainties, standardisation in the form of weighing and grouping of environmental indicators may be beneficial in order to increase the transparency and allowing comparison of environmental impact between different locations or even regions. Three major deviations from the risk governance framework are observed in the study;

Primarily, the use of concern assessment is low, mainly explained by the strong focus on uncertainty management. Since the study shows indications of an ambiguity gap between expert judgment and stakeholder perception in at least one of the performed remediation cases, the management decisions may be biased due to the lack of knowledge about the socio-economical concerns related to the remediation operations. A stronger focus on concern assessment earlier in the decision making process will reduce this gap.

Secondly, the decision making process in the management system is weak. Even if the different data to support a structured management decision process are in place, most of the recommendations for implementation of sediment management for the different locations are based on ad-hoc processes. Implementation of a decision analysis framework supporting multi criteria decisions could be beneficial for a more transparent process. This will however require new type of competence in the management process and should be assessed carefully before introduction.

Tertiary, the involvement of stakeholders and decision makers in the analysed management plans, and the communication during the process may be categorised as advisory, mainly influencing the management phase. A stronger involvement earlier in the process will reduce the ambiguity, but will also require a paradigm shift in the regulatory framework.

Finally, it is recommended to direct further research towards methods that may facilitate concern assessment and enhance transparent decision making processes for sediment management. A well functioning system for identification, weighing and prioritisation of environmental indicators encompassing environmental, social and economical factors will contribute to create a sustainable management system for sediment contamination.

REFERENCES

Apitz, S. E. (2008). *Is risk-based, sustainable sediment management consistent with European policy?* Journal of Soils and Sediments, 8, 461-466.

Apitz, S. E., Barbanti, A., Bernstein, A. G., Bocci, M., Delaney, E., and Montobbio, L. (2007). *The assessment of sediment screening risk in Venice lagoon and other coastal areas using international sediment quality guidelines*. Journal of Soils and Sediments, 7, 326-341.

Apitz, S. E. and Power, E. A. (2002). *From Risk Assessment to Sediment Management. An International Perspective*. Journal of Soils and Sediments, 2, 1-5.

Assmuth, T. and Hilden, M. (2008). *The significance of information frameworks in integrated risk assessment and management*. Environmental Science & Policy, 11, 71-86.

Breedveld, G. D., Pelletier, E., St Louis, R., and Cornelissen, G. (2007). *Sorption characteristics of polycyclic aromatic hydrocarbons in aluminum smelter residues*. Environmental Science & Technology, 41, 2542-2547.

Eek, E., Pettersen, A., Hauge, A., Breedveld, G. D., Solberg, A., Heines, S. U. S. K., and Lie S.O. (2006). *Disposal of dredged material in a local confined disposal facility: budgeting and accounting of contaminant transport*. Journal of ASTM International, 3.

Eisenhardt, K. M. (1989). *Building Theories from Case-Study Research*. Academy of Management Review, 14, 532-550.

EU. Technical Guidance Document (TGD) for Risk assessment of new notified and existing chemicals under directive 93/67/EEC and Regulation (EC) No 1488/94. 2003. European Commission Joint Research Center, European Chemicals Burerau, EUR 20418 EN/2.

EU-TGD. Technical guidance document on risk assessment, Part II. 2003. European Commission Joint Research Centre EUR 20418 EN/2.

Gamper, C. D. and Turcanu, C. (2007). *On the governmental use of multi-criteria analysis*. Ecological Economics, 62, 298-307.

IRGC. An introduction to the IRGC risk governance framework. 2007. IRGC, Geneva, Switzerland.

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., Kasperson, J. X., and Ratick, S. (1988). *The Social Amplification of Risk - A Conceptual-Framework*. Risk Analysis, 8, 177-187.

Kiker, G. A., Bridges, T. S., and Kim, J. (2008). *Integrating Comparative Risk Assessment with Multi-Criteria Decision Analysis to Manage Contaminated Sediments: An Example for the New York/New Jersey Harbor*. Human and Ecological Risk Assessment: An International Journal, 14, 495-511.

Klinke, A. and Renn, O. (2002). *A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies*. Risk Analysis, 22, 1071-1094.

Kristensen, V., Aven, T., and Ford, D. (2006). *A new perspective on Renn and Klinke's approach to risk evaluation and management*. Reliability Engineering & System Safety, 91, 421-432.

Linkov, I., Satterstrom, F. K., Kiker, G., Batchelor, C., Bridges, T., and Ferguson, E. (2006a). *From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications*. Environment International, 32, 1072-1093.

Linkov, I., Satterstrom, F. K., Kiker, G., Seager, T. P., Bridges, T., Gardner, K. H., Rogers, S. H., Belluck, D. A., and Meyer, A. (2006b). *Multicriteria decision analysis: A comprehensive decision approach for management of contaminated sediments*. Risk Analysis, 26, 61-78.

MD. White paper 12 "Rent og rikt hav" (In Norwegian). 2002. Norwegian Ministry of Environment.

MD. White paper 14 "Sammen for et giftfritt miljø - forutsetninger for en tryggere fremtid" (In Norwegian). 2006. Norwegian Ministry of Environmwent.

Navrud, S and Barton, D. N. Nytte-kostanalyse av prosjektet "Rein fjord". Rapport til prosjektet rein fjord. Tiltaksplan for forurenset sjøbunn i Telemark - fase 2. Rev 01 (In Norwegian). 2006. Fylkesmannen i Telemark.

Pollard, S., Brookes, A., Earl, N., Lowe, J., Kearney, T., and Nathanail, C. P. (2004a). *Integrating decision tools for the sustainable management of land contamination*. Science of the Total Environment, 325, 15-28.

Pollard, S. J. T., Davies, G. J., Coley, F., and Lemon, M. (2008). *Better environmental decision making - Recent progress and future trends*. Science of the Total Environment, 400, 20-31.

Pollard, S. J. T., Kemp, R. V., Crawford, M., Duarte-Davidson, R., Irwin, J. G., and Yearsley, R. (2004b). *Characterizing environmental harm: Developments in an approach to strategic risk assessment and risk management*. Risk Analysis, 24, 1551-1560.

Renn, O. (2008). *Risk Governance. Coping with uncertainty in a complex world*. Earthscan.

Rowe, G. and Frewer, L. J. (2000). *Public participation methods: A framework for evaluation*. Science Technology & Human Values, 25, 3-29.

Saloranta, T. M., Armitage, J. M., Haario, H., Naes, K., Cousins, I. T., and Barton, D. N. (2008). *Modeling the effects and uncertainties of contaminated sediment remediation scenarios in a Norwegian Fjord by Markov chain Monte Carlo simulation*. Environmental Science & Technology, 42, 200-206.

SFT. Classification of environmental quality in fjords and coastal water. TA-1467/1997, 1-36. 1997. Norwegian State Pollution Control Board (SFT).

SFT. Risk assessment of contaminated sediment. TA-2230. 2007.

Singsaas I, Rye, H., Frost, T. K., Mathijs GD, S., Garpestad, E., Skare, I., Bakke, K., Falcao Veiga, L., Buffagini, M., Follum, O. A., Johnsen, S., Moltu.U.E., and Reed, M. (2008). *Development of a risk-based environmental managment tool for drilling discharges. Summary of a four-year project*. Integrated Environmental Assessment and Management, 4, 171-176.

Slovic, P. (2000). *The perception of risk*. Earthscan Publications Ltd,London and Sterling,VA.

Suedel, B. C., Kim, J., Clarke, D. G., and Linkov, I. (2008). *A risk-informed decision framework for setting environmental windows for dredging projects*. Science of the Total Environment, 403, 1-11.

Yatsalo, B. I., Kiker, G. A., Kim, J., Bridges, T. S., Seager, T. P., Gardner, K., Satterstrom, F. K., and Linkov, I. (2007). *Application of Multicriteria Decision Analysis Tools to Two Contaminated Sediment Case Studies*. Integrated Environmental Assessment and Management, 3, 223-233.

LIST OF TABLES

LIST OF FIGURES