RISK-BASED DECISION MAKING FRAMEWORK FOR THE INTEGRATED ENVIRONMENTAL MANAGEMENT OF DREDGING SEDIMENTS

A thesis submitted to Imperial College London for the degree of Doctor of Philosophy

By

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October 2013

DECLARATION OF OWN WORK

I declare that this thesis 'Risk-based decision making framework for the integrated environmental management of dredging sediments' is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

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ABSTRACT

Many environmental management tools have been developed aiming to reduce the impacts of dredging and protect the environment. As this has typically not been done in an integrated way that takes into account the socio-economic, environmental, technical and managerial aspects of dredging, there is a need to develop an integrated decision making tool to manage the impacts of dredging and help decision makers make sustainable decisions concerning dredging.

The aim of this study was to develop a risk-based decision making framework for the integrated environmental management of dredging sediments in order to reduce the impacts of dredging and to lower the cost of environmental quality analysis and management. Selection of the best sediment management option using the risk-based approach of integrated environmental management has the potential to help effectively balance and prioritize the various socio-economic, environmental, technical and managerial aspects of dredging. The proposed framework will therefore utilize this concept throughout its six developmental steps. The first step reviews the literature on the impact of dredging and the two main factors that determine its magnitude, namely sediments and dredging technology.

In order to manage the impacts of dredging efficiently, the relationship between scientific evidence and dredging activities will be assessed in the second developmental step. This step evaluates historical evidence from three dredging projects undertaken between 2006 and 2008 on the rivers of Sungai Sitiawan and Sungai Dinding, Perak, Malaysia. Monitoring and fish toxicological data from these projects are analyzed to determine their relationship with dredging activities performed in these rivers, with Geographic Information System (GIS) software used to illustrate the relationships found.
The third developmental step assesses dredging problems other than the environmental impacts using Driving force-Pressure-State-Impact-Response (DPSIR) analysis, an IEM-based tool. This tool was employed in Malaysia's dredging industry using interviews and a questionnaire-based survey. Dredging experts, including representatives from port operators, manufacturing companies and dredging contractors, were interviewed in 2008, with the socio-economy and management being found as the main drivers, together with environmental impacts, affecting dredging stakeholders in Malaysia. In 2010, further dredging experts (including marine ecologists, registered chemists, professional and chartered engineers, environmental consultants, university professors and environmental analysts) responded to the questionnaire, with results suggesting that governance of dredging in Malaysia is weak and that it is essential for Malaysia to review its current dredging environmental management tools and practices.

The fourth developmental step develops the first stage (screening) of the proposed framework based on understanding provided by the three steps developed previously and demonstrated using Malaysia as a case study. This screening stage utilizes the historical dredging monitoring data and the contamination level in media data into Ecological Risk Assessment (ERA) phases, which have been adjusted for benefits in cost, time and simplicity. Using case studies from Malaysia, the fifth developmental step (Tier 1) shows how Multi-Criteria Decision Analysis (MCDA) can be used to analyze and prioritize dredging areas based on environmental, socio-economic and managerial criteria and is demonstrated for the Tier 1 stage. The results from MCDA will be integrated into Ecological Risk Assessment (ERA) to characterize the degree of contamination found in the areas. Priority areas, their degree of contamination and other concerns are then identified and brought forward to the sixth developmental step (Tier 2 stage). The Tier 2 stage is demonstrated using previous findings and analyzed using MCDA, in order to identify the best sediment management option, accounting for the economic, environmental and technical aspects of dredging.

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge and extend my heartfelt gratitude to my supervisors, Dr. Nick Voulvoulis and Dr. Norzima Zulkifli for their support and encouragement during the completion of this interesting research. I believe that without their guidance, this research would not be as comprehensive as it is. Many thanks also to John Skolout, Dr Dieudonné-Guy Ohandja, Claire Hunt, Eleni Iacovidou, Prof. Nigel Bell, Prof. Maimon Abdullah and Prof. Jane Plant for their constructive criticism, which enabled me to improve my writing and research skills.

I would also like to thank YM Raja Zainal Abidin Raja Hussin, Dato' Dr. Ir. Nik Mohd Kamel Nik Hassan, Ir.Eddy Daud, En. Mohd Affandi Abdullah, Ir. Mohd Radzi Mustaffa, En.Budiman Ahmad, Puan Murni Ahmad, Ir. Faizah Kamel and Ir.Juzailan Zainal for their faith in my ability and their continuous support ever since I joined the dredging industry ten years ago. I hope this research brings a new perspective on how we dredge and hopefully it opens up opportunities for us to do research together in the future.

There are too many of my friends to name individually, however special thanks are given to Kak Nita, Zita, Mie, Gunjai, Dahlia, Huzaina, Shamsiah, Amnor, Mahib, Samia, Janet, Carmina, Ho-shik, Young, Aisha, Alex, Maria, Khareen, Aida, James, Danelle, Sally, Nick, Yas, Mishuari and Faiz for the prayers and support given. You guys hold a special place in my heart.

I am forever grateful for the care, prayers and support given by my parents and siblings all these years. I hope this success will be the start of many more successful stories to come. I am also forever grateful to be loved by Iman, who reminded me on a daily basis of how important it was to successfully complete this research, regardless of the long distance between us.

Last but not least, my heartfelt gratitude is extended to the sponsor of this research - Department of Higher Education Malaysia and Universiti Tun Hussein Onn Malaysia. Thank you.

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ABBREVIATIONS

API	Air Pollution Index
Al	Aluminium
NH_3- *N*	Ammonia-nitrogen
AHP	Analytical hierarchy process
L	Annual load of pollutant
VR	Annual runoff depth
As	Arsenic
D	Average annual rainfall
R	Average annual runoff depth
BOD	Biochemical oxygen demand
B	Boron
Cd	Cadmium
A	Catchment area
COD	Chemical oxygen demand
Cr	Chromium
Co	Cobalt
CIDB	Construction Industry Development Board
Cu	Copper
CSD	Cutter Suction Dredger
DOE	Department of Environment, Malaysia
DO	Dissolved oxygen
DPSIR	Driving-force-Pressure-State-Impact-Response
ERA	Ecological Risk Analysis
ECOTOX	ECOTOXicology database
EA	Environmental Assessment

EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EMS	Environmental Monitoring System
EQA	Environmental Quality Act 1974
EQS	Environmental Quality Standards
EEA	European Environmental Agency
EU	European Union
EMC	Event Mean Concentration
C	Event Mean Concentration pollutant
GIS	Geographic Information System
GEODE	Groupe d'Etude et d'Observation sur le Dragage et
ha	Hectare
HHM	Hierarchical Holographic Modelling
ICM	Integrated Coastal Management
ICZM	Integrated Coastal Zone Management
IEM	Integrated Environmental Management
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
Fe	Iron
KSIS	Keep Sediment in the System'
Pb	Lead
LCA	Life Cycle Analysis
Mg	Magnesium
MSMA	Malaysia's Urban Storm water Management Manual
Mn	Manganese
MWQSC	Marine Water Quality Standard and Characterization
Hg	Mercury
MAUT	Multi-attribute utility theory
MCDA	Multi-criteria Decision Analysia

NGRDWQ	National Guidelines for Raw Drinking Water Quality
Ni	Nickel
NO_3^-	Nitrates
N	Nitrogen
NGO	Non-government Organisation
NA	Not applicable
OHSAS	Occupation Health and Safety Assessment Series
P	Phosphorus
PCB	Polychlorobiphenyls
PAH	Polycyclic aromatic hydrocarbons
RA	Risk Analysis
SQ	Sediment Quality
SQG	Sediment Quality Guidelines
Ag	Silver
SIBOD	Sub-index BOD
SICOD	Sub-index COD
SIDO	Sub-index DO
SIAN	Sub-index NH3-N
SIpH	Sub-index pH
SISS	Sub-index SS
S^{2-}	Sulphide
USACE	The U.S. Army Corps of Engineers
UK	The United Kingdom
US	The United States
US EPA	The United States Environmental Protection Agency
Sn	Tin
TKN	Total kjeldahl nitrogen
TOC	Total Organic Content
Y	Total risk ratio

TSS	Total suspended solids
TELK	Traditional Eco-Livelihood Knowledge
TK	Traditional Knowledge
THSD	Trailer Hopper Suction Dredger
WFD	Water Framework Directive
WGV	Water Guideline Values
WQ	Water Quality
WQI	Water Quality Index
CV	Weighted average annual runoff coefficient
Zn	Zinc

1 INTRODUCTION

Dredging is a process that removes sediments from river and sea beds mainly to aid ship navigation, and was first used more than a thousand years ago by the peoples who lived on the banks of the Tigris and Euphrates to deepen sea channels (Shankland 1931, Herbich 1975, Montgomery 1984).

In addition, other purposes of dredging have historically included extraction of sediments for the construction and agricultural industries, removal of sediments for wharf expansion, protection of coastal areas through land reclamation, environmental improvement in the form of flood prevention or contamination remediation, and infrastructure purposes such as underwater cabling and pipelines (Sheehan, Harrington et al. 2010b, Orosz, Bierbauer 1994, Blazquez, Adams et al. 2001, Gurfinkel, Shepsis 1993). There are two main types of dredging. ***Capital dredging*** occurs in previously undisturbed areas, and ***Maintenance dredging*** takes place to sustain areas adequately deepened (Montgomery 1984, Yell, Riddell 1995).

In recent years, the growing need to perform extensive maintenance dredging has been due to ships growing in size and numbers due to increased maritime trading activities. Capital dredging has been needed to build or extend wharfs and ports, with a number of mega dredging projects currently in progress, including one on the River Scheldt and another as part of the expansion of the Panama Canal (Schexnayder 2010, Krizner 2010). In addition, there is an emerging demand for dredging in developing countries due to growing global trade, with India estimated to become the largest dredging market, in light of the large number of dredging projects planned there (George 2011, Thacker 2007)**.**

Through such increasing demand, it is more critical to understand the environmental impacts of dredging. The magnitude of dredging impacts varies according to a number of factors, one of which is sediment characteristics. Sediments are considered an important habitat within water ecosystems, both for aquatic flora and fauna (Bridge, Demicco 2008, Nittrouer, Austin Jr. et al. 2007, Riley, Chester

1971, Stolzenbach, Adams 1998). Dredging can, therefore, negatively affect them by disturbing sediments and releasing contaminants into the water column (Riley, Chester 1971, Turekian, Steele et al. 2010, Office of Naval Research 2008, Zockler, Lysenko 2000).

As can be expected, dredging has been shown to increase the contaminant content of the water column when conducted in highly polluted areas, thus having the potential to harm aquatic ecosystems (Groote, Dumon et al. 1998). On the other hand, when conducted in areas of low contamination, dredging has been shown to have no major toxic effects (Groote, Dumon et al. 1998, Otto 1996, Su 2002).

Another key factor is the technology used for dredging. From trailer hopper suction dredgers to pit excavators, for example, the use of technology can have a significant impact in reducing environmental effects. Booms and silt curtains can further reduce such impacts and protect sensitive environments (Su 2002, Newell, Hitchcock et al. 1999).

Although much work has been conducted to date assessing the impacts of dredging and the factors for it, most of this has been purely scientifically focused, failing to relate these impacts to wider dredging environmental management and decision making. This thesis thus aims to develop a risk-based decision making framework for the integrated environmental management of dredging sediments in order to reduce the impacts of dredging and to lower the cost for environmental quality analysis and management.

2 BACKGROUND

2.1 Dredging problems

Dredging has been largely perceived in a negative light due to its adverse environmental impacts (Tables 2-1 to 2-6). For example, the high turbidity levels that occur during dredging have always been a key problem debated by the public (Aarninkhof 2008). Previous research has established, however, that the rise of turbidity levels caused by dredging is a temporary effect. Furthermore, other research has suggested that the re-suspension of fine sediments during storms, as well as during other human activities such as fishing and ship manoeuvring, can cause similar impacts to dredging (Hamburger 2003). While it is correct to point out the rise and fall in chemical, physical and biological parameter values and the ecosystem equilibrium disturbance that occurs during dredging (as listed in Tables 2-1 to 2-6), it should be noted that the negative perception of dredging cannot be generalised, but rather understood and managed accordingly on a site by site case.

Table 2-1 Physical impacts of maintenance dredging

Parameter	During Dredging		After Dredging	
	Increase	Decrease	Increase	Decrease
Turbidity	[1] √			[1] √
Light penetration				[2,3] √
Coastal erosion and wave action			[4] √	
Sand resource for land and beach				[4] √
Loss of habitat for benthic life			[5] √	

* Number of reference √, *1*=(Balchand, Rasheed 2000)*, 2*=(Munawar 1989)*, 3*=(Douvere, Ehler 2009)*, 4*=(Messieh, Rowell et al. 1991)*, 5*=(Padmalal 2008)

Table 2-2 Chemical impacts of maintenance dredging

	During dredging		**During disposal**		**After dredging**	
Parameter	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**
Hg, Ni, Zn, Cu, Fe, Mn, Pb, Cr and Al ^{S}	[1] √$_{I,III}$					
Cd ^{S}	[1] √$_{I,III}$				[3,4] √	
Al ^{W}	[1] √$_{II}$	[1] √$_{I, III}$	[1] √$_{I, II, III}$		[1] √$_{II,III}$	[1] √$_{I}$
Fe ^{W}	[1] √$_{I, II}$	[1] √$_{III}$	[1] √$_{I, II, III}$		[1] √$_{II,III}$	[1,3] √$_{III}$
Cu ^{W}	[1] √$_{I}$		[1] √$_{III}$		[3,4] √	[1] √$_{I}$
Cr ^{W}	[1] √$_{I, II}$		[1] √$_{III}$			
Mn ^{W}	[1] √$_{II}$	[1] √$_{III}$	[1] √$_{III}$			[1] √$_{III}$
Pb ^{W}	[1] √$_{II}$		[1] √$_{I, III}$		[2,4] √	
Zn ^{W}	[1] √$_{II}$		[1,2] √$_{III}$			
Hg ^{W}					[2] √	
P ^{W}	[1] √$_{II}$	[1] √$_{I}$	[1] √$_{III}$		[2] √	[1] √$_{III}$
Ag, Ni and Cu ^{W}					[4] √	
Alkalinity	[1] √$_{II, III}$	[1] √$_{I}$			[1] √	[1] √$_{III}$
Oxygen production				[3] √		
Oxygen demand					[5] √	
Toxicity ^{S}					[2] √	
Total organic carbon						[3,6] √

* [Number of reference] √$_{\text{Dredging episode (I,II or III)}}$, ^{S} =Sediments, ^{W} =Water, *1*=(Munawar 1989)*, 2*=(Ponti, Pasteris et al. 2009)*, 3*=(Toes 2008)*,4*=(Mackie 2007)*, 5*=(Messieh, Rowell et al. 1991) *,6*=(Piou 2009)

Table 2-3 Biological impacts of maintenance dredging

Parameter	During Disposal		After Dredging	
	Increase	**Decrease**	**Increase**	**Decrease**
Flora				
Phytoplankton species-*Chrysophyceae*			[1] √$_{II}$	
Phytoplankton species-*Cryptomonas erosa Ehrenberg*	[1] √$_{II}$			
Phytoplankton species-*Phytoflagellates*	[1] √$_{III}$			
Fauna				
Macrofauna				[3] √
Meiofauna				[3] √
Macrobenthos community structure at 6 metre				[3] √$_{D}$
Macrobenthos and meoibenthos at 18 metre-abundance, number of taxa, diversity				[3] √
Macrobenthos at 18 metre-polychaetes with verniform shape, without external protection, and carnivory			[3] √	
Animals with scales or chitinous bodies, vermiform shape, absence of external protection and deposit-feeding mode				[3] √
Polychaeta species- *Streblospioshrubsolii*			[4] √$_{D}$	[4] √$_{C}$
Polychaeta spesies-*Capitella capitatawas*				[4] √$_{CD}$
Amphipod species-*Carophium insidiosum*			[4] √$_{D}$	
Corals				[5] √
Scallop-filter feeding fauna				[5] √
Juvenile fauna				[5] √
Loss of abundance and biodiversity of benthic life			[6] √	

* [Number of reference] √$_{\text{Impact location}}$, $_{D}$=*Dredged site*, $_{C}$=*Control site*, *1*=(Munawar 1989), *2*=(Toes 2008), *3*=(Constantino 2009), *4*=(Ponti, Pasteris et al. 2009), *5*=(Balchand, Rasheed 2000), *6*=(Ser 1991)

Table 2-4 Chemical impacts of capital dredging

Parameter	During dredging		After Dredging	
	Increase	Decrease	Increase	Decrease
PCB concentration on water inside silt curtain	[1] √			
PCB concentration on water outside silt curtain	[1] √			
PCB concentrations in sediments at a depth of 2-3 inch thick			[1] √	
PCB concentrations in sediments at a depth of 4-7 inch thick				[1] √
PAH on sediments			[1] √	
P release from sediment into water				[2] √

* Number of reference √, *1*=(Thibodeaux, Duckworth 2001), *2*=(Shigaki, Kleinman et al. 2008)

Table 2-5 Physical impacts of capital dredging

Parameter	After Dredging	
	Increase	Decrease
Turbidity	[1] $\surd_{D}$	
Transparency		[2] $\surd_{DC}$
Bed roughness	[3] √	
Velocity	[3] √	
Sediment accumulation		[4] √
Accretion process in the bay head		[4] √
Size of accretion bar		[4] √
Natural sediment nourishment of the sand bar		[4] √
Erosion of the coast	[4] √	

* Number of reference $\surd_{D}$=*Dredged site,* $_{C}$=*Control Site, 1*=(Su 2002)*, 2*=(Bonvicini Pagliai, Cognetti Varriale et al. 1985)*, 3*=(Ellery, McCarthy 1998)*, 4*=(Sergeev 2009)

Table 2-6 Biological impacts of capital dredging

Parameter	**After Dredging**	
	Increase	**Decrease**
Crab body burden	[1] √	
Benthic diversity and number of individual	[2] √$_D$	
In-channel flora		[3] √
Channel vegetation		[3] √$_D$
Caged fish-(compared with before silt curtain removal)		[4] √

* Number of reference √$_D$=*Dredged site, 1*=(Su 2002)*, 2*=(Bonvicini Pagliai, Cognetti Varriale et al. 1985)*, 3*=(Ellery, McCarthy 1998)*, 4*=(Thibodeaux, Duckworth 2001)

There are many examples of legislative actions (Table 2-7) taken aimed at preserving the environment, which could have implications for dredging. In the UK, for example, the Water Framework Directive (WFD), which was transposed into national law in 2003, calls for good ecological status to be achieved in water bodies, allowing only a slight reduction of water quality in comparison to an unmodified natural water body (European Sediment Research Network 2004, Mink, Dirks et al. 2006). Furthermore, the WFD calls for Sediment Environmental Quality Standards (EQS) to be derived for the monitoring and regulation of sediment contamination. The mandatory pass/fail nature of these standards, which additionally depend on suspended sediment as sampling medium, has fallen under criticism from within the dredging related industries (Mark 2003, European Parliament 2000).

This is due to the fact that, if dredging operations were to be restricted in line with the implementation of this directive, not only would merchants and fishermen with deep draught ships be negatively affected, but also port and harbour operators, due to lost transactions. This is because an unmaintained seabed level would obstruct the pathway of container ships entering ports and harbours for mooring, thus preventing the unloading of goods and raw materials. It will also force container ship operators to use facilities at other deeper ports and harbours, even if this involves a significant deviation from their normal route.

In the United States, sediment quality standards similar to EQS were also proposed by the US Environment Protection Agency (US EPA) to characterise dredged sediments for remediation. The US Army Corps of Engineers and the US dredging industry, however, strongly resisted the proposal, arguing that there is insufficient scientific data to produce a reliable sediment quality standard and that it could lead to a disproportionately high cost for sediment remediation. Moreover, threshold limit values of sediments are variable and site-specific, it is therefore doubtful that these values will be applicable to national or wide geographical areas. The limitations of sediment quality standards, including frequent false positive or negative predictions, chemical specificity, and the risk that the values may not apply to larger-grained sediments, have limited their use in dredging operations (Burton 2002). In contrast, Water Guideline Value (WGV) is considered more consistent and useful as better indicators of environmental change (Pan 2009). Despite the limitations of sediment quality standards, it is important not to neglect sediment characteristics as one of the important factors determining the impacts of dredging.

The cost of dredging varies according to the results of environmental quality analysis and management that determine the technology and equipment used, volume of dredged sediments, distance from excavation to disposal site, and disposal method. The high cost of environmental quality analysis and management has always been the main problem for port operators, who are responsible for dredging and maintaining deep channels, but also need to spend funds to expand or build new terminals in order to cater for growing trade activities (Anderson, Barkdoll 2010, Williams 2008). Although costs are perceived as the biggest problem by a number of dredging stakeholders, only few papers have discussed or analysed the cost of dredging. For example, Lee (2011) attempted to create a framework for dredging cost, analysing the construction operation process, type of river section, and the combination of equipment employed for river dredging. This analysis was based on historical data of river dredging projects conducted in South Korea (Lee, Lee et al. 2011).

Table 2-7 Dredging related rules and regulations in nations and their problems

Criteria	The US	The UK	France	Malaysia
Dredging related rules and regulations	- Water Resources Development Act (WRDA), 1986 - Harbour Maintenance Act of 1986 - Water Resources Development Act of 1996 - Clean Water Act (Gibb 1997)	- Water Framework Directive - Marine and Coastal Access Act 2009 (Transitional Provisions) Order 2012 - Food and Environmental Protection Act 1985 - London Convention 1972 and - OSPAR Convention for licensing of dredged material disposal - Harbour Act - Coast Protection Act 1949 - Merchant Shipping Act - Environmental Impact Assessment Directive - Habitats Directive - Birds Directive - The Town and Country Planning Act 1971 - Control of Pollution Act (Part 2) 1984 - Coast Protection Act 1949 (Bray, Bates et al. 1979)(Eisma 2006)	- Prevention and repression of marine pollution by immersion (Law n°76 599 of July, 7, 1976) - Require licence of immersion and public investigation (Decree n°82°842 of September, 29, 1982) - Environmental protection and integration of environmental problem in all public or private activities likely to have environmental impacts (Law n°76 629 of July, 10, 1976) - Procedures of authorization and declaration (Law n°92 3 of January, 1992 Decree n°93 742 of mars, 29, 1993 and Decree n°93 742 of mars, 29, 1993) - GEODE thresholds (Decree of June, 14, 2000) (Abriak, Junqua et al. 2006) - EIA (OSPAR Commision 2009)	- EIA 1987 Order, 11(c) Mining (Government of Malaysia 5th November 1987) - Occupational Safety and Health Act 1994 - Factories and Machineries Act 1967 - Wildlife Act 1972 - Fisheries Act 1985 - Guidelines on Erosion Control for Development Projects in the Coastal Zone - Environmental Impact Assessment Guidance Document for Sand Mining/Dredging Activities (Department of Irrigation and Drainage Malaysia 1197)(Department of Environment Malaysia 2007)

Criteria	The US	The UK	France	Malaysia
Dredging problems	**Economic and environmental problems:** - Trends in the shipping industry toward larger vessels requiring deeper draughts - The result of years of dismissing environmental problems as irrelevant - High cost of sediment remediation (Gibb 1997) **Managerial problem** - Confliction between stakeholders from federal, state and local political leadership during dredging	**Environmental problem** - Loss of natural habitat - The deteriorating water quality - Polluted dredged material - Beneficial use of dredged material (Vellinga 2002) - Conflicts on defining what constitutes waste to describe dredged sediments (Mink, Dirks et al. 2006) **Managerial problem** - Potential friction between EU Directives and international conventions - Other Directives on environmental protection, including Habitats and Birds Directives and Waste Framework Directive, lead to delays or cancellation of projects and to increase costs (Mink, Dirks et al. 2006)	**Environmental problem:** - Harbour sites are located in sheltered zones where tides, streams, swell, and wind cause the trapping of sediments that becomes an obstacle for the access of ships to the harbour infrastructures **Social problem:** - Dredging involves many stakeholders including the community and each stakeholder has a view and some interests can diverge - The late involvement of environmental protection is responsible for blockings, loss of money and loss of time - No public inquiry procedure while applications are being considered (Gac, Chiffoleau et al. 2011)	**Social and economic problem:** - Public participation (Emang 2006) - Economic vs the Environment (Briffett, Obbard et al. 2004) **Managerial and environmental problem:** - Conflict of power distribution (State vs Federal) that cause delays (Staerdahl, Schroll et al. 2004) - No mandatory action for monitoring (Briffett, Obbard et al. 2004) - No incentives for mitigation measures (Briffett, Obbard et al. 2004) - Difficult to enforce EIA 1987 Order (Emang 2006) - Lack of cumulative impact analysis (Briffett, Obbard et al. 2004) - Illegal sand dredging - Environment aspect was not included during pre-planning stage (Briffett, Obbard et al. 2004) - Lack of baseline data/evidence based documents (Briffett, Obbard et al. 2004)

2.2 Risk-based approach

Risk-based approach is any decision-making or management approach that is based on principles of Risk Assessment and Risk Management. Examples of risk-based decision-making framework are illustrated in Figures 2-1 to 2-3.

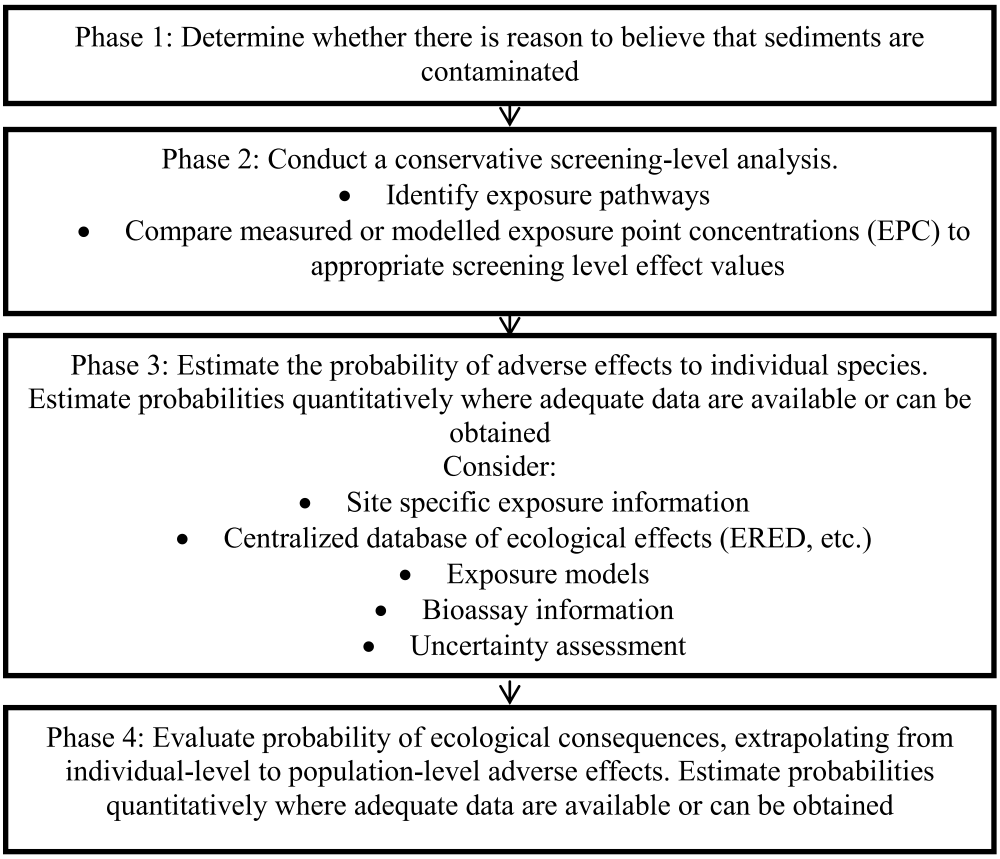


Figure 2-1 Risk-based decision framework for dredged material management for USACE (Moore, David 1998)

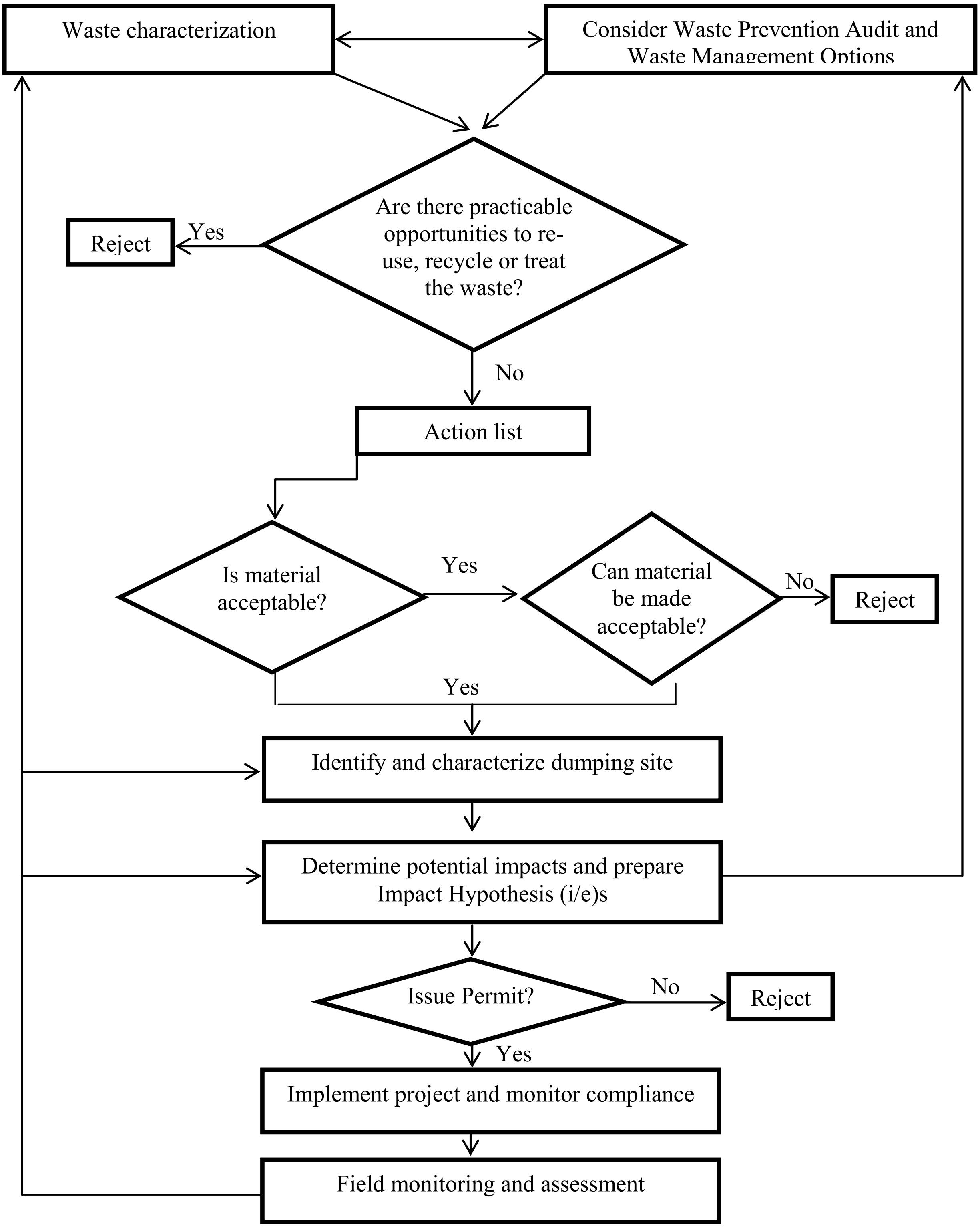


Figure 2-2 Assessment framework for the London Convention and Protocol (The National Oceanic and Atmospheric Administration (NOAA) 2006)

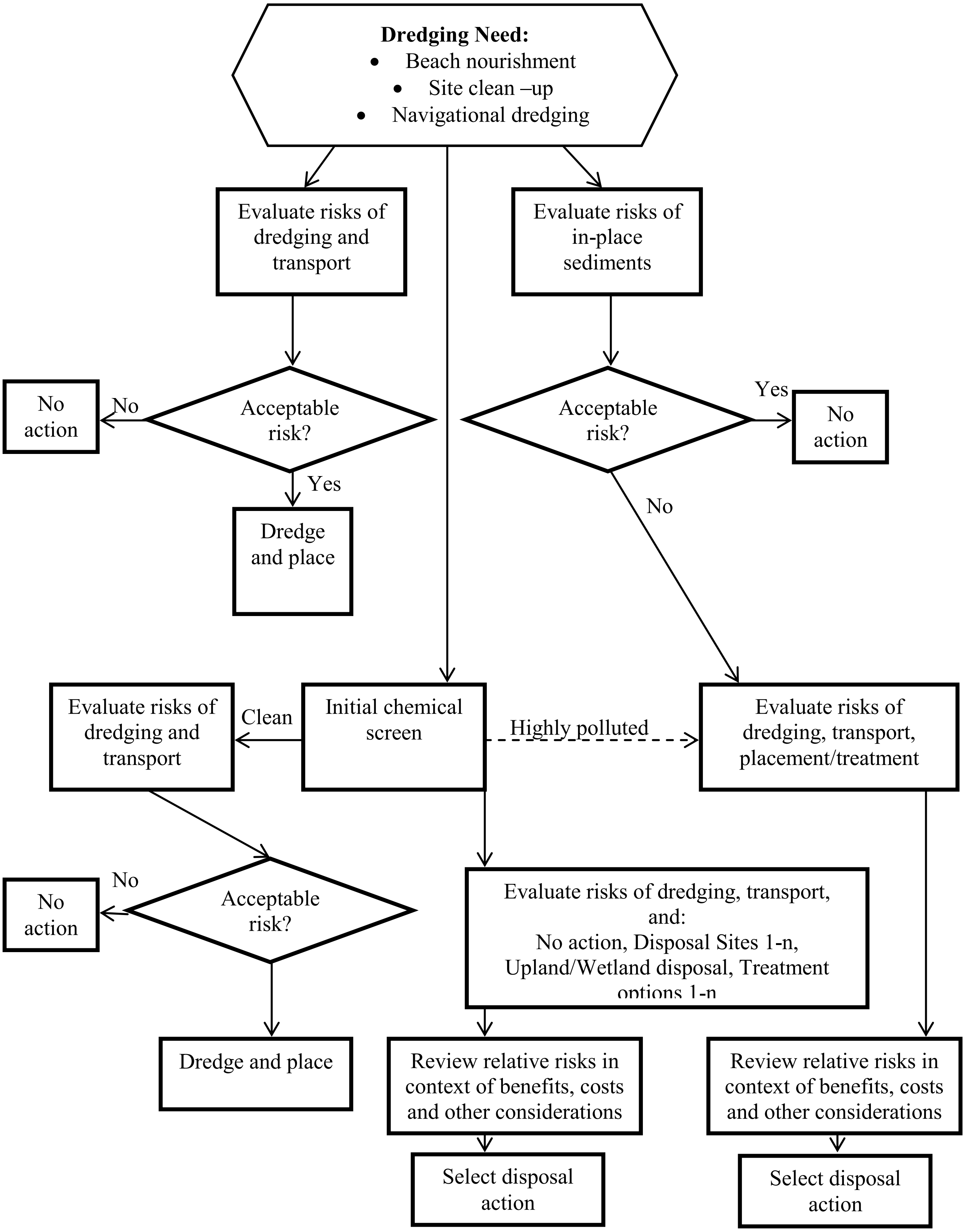


Figure 2-3 Risk-based decision tree proposed for US federal practices (Munns, Wayne 2002)

The presence of linkage between source, pathway and receptor during dredging constitutes a risk of dredging impact. Therefore, the sources, pathways and targets should be taken into consideration when identifying measures for reducing dredging impacts (Eisma 2006, Vellinga 2002, Oste, Hin 2010, Raaymakers 1994). Source-pathway-target linkages offer different opportunities for reducing, avoiding or mitigating environmental impacts. These measures can be applied by controlling the levels of contaminants from point and diffuse sources, managing the pathways by using appropriate, environmentally friendly technologies, or by avoiding environmentally sensitive habitats. It is critical to employ a tool for environmental management that relates these choices to the wider problems of dredging.

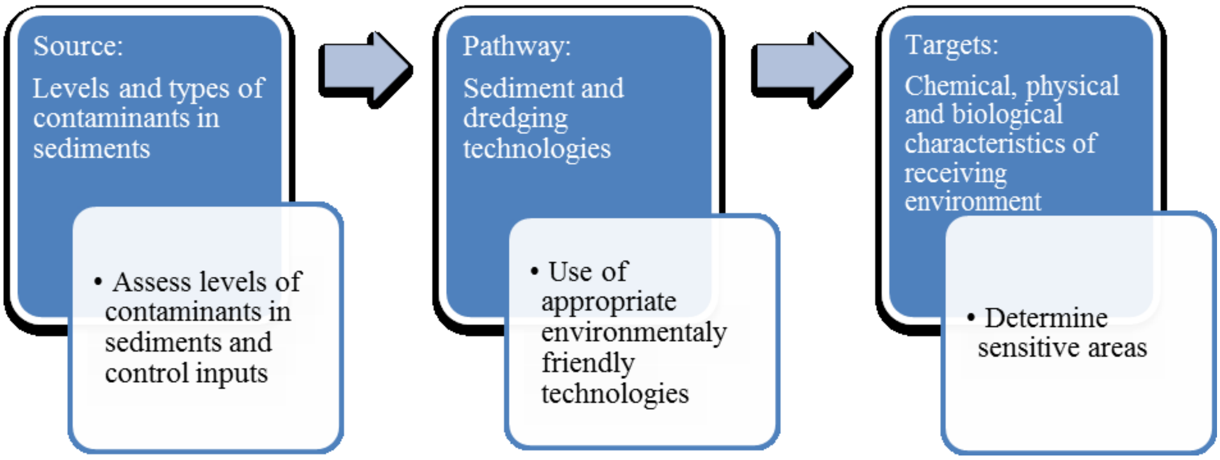


Figure 2-4 Source-Pathway-Target opportunities to reduce environmental impacts of dredging

2.3 Integrated environmental management

A combination of environmental management tools is gaining support as an integrated environmental management (IEM) that aims to achieve sustainable development and maximise benefits for society, the economy, and ecosystems by integrating and balancing the problems of resource exploitation, social, economic and the environmental preservation (Wang 2006).

Environmental management tools that have previously been applied in the dredging industry are outlined in Table 2-8. These include tools for auditing and monitoring, data collection, and strategic monitoring and planning (Barrow 2005, Bartelmus 1986). Examples of tools used for auditing and monitoring include Environmental Impact Assessment (EIA), Life Cycle Analysis (LCA) and risk assessment analysis (Staerdahl, Schroll et al. 2004, Morrisey 1993, Guinée, Heijungs 2000, Horne 2009, Kiker 2007, Linkov, Seager 2011). Another set of environmental management tools focus on data collection, with one example being the use of Geographical Information System (GIS). A number of applications of integrated tools have also been developed, usually coupled with multi–criteria decision analysis (MCDA), which aims to create structured and defendable decisions (Kiker 2007).

Table 2-8 Environmental management tools and their application in dredging industry

Environmental management tools		Applications in dredging industry	Strengths and/or weaknesses
Auditing and monitoring	Environmental Impact Assessment (EIA)	Used globally (i.e. in Malaysia that stipulating dredging in the Environmental Impact Assessment Order of 1987) [1]	Reducing the unexpected impacts and providing an advance warning of environmental problems (Barrow 2005). However, it can involve minimal public participation (i.e. in Malaysia) and can be excessively time consuming and costly (Staerdahl, Schroll et al. 2004, Barrow 2005, Morrisey 1993)
	Life Cycle Analysis (LCA)	To support the choice of different sediment management options by compiling and evaluating the environmental consequences of each choice [2]	It can be a very data-intensive analysis that is complex, time consuming and costly (White 1993)
	Risk assessment analysis	Examples: dredging risk assessment model applications (DRAMA), risk-based environmental windows, comparative risk assessment, water quality, sediment quality, and ecological risk assessment [3]	Its weakness associated with its dual nature of accounting for both probability and severity (Pan 2009)
Data collection	Geographical Information System (GIS)	Examples: GIS-based dredging model system and geostatical GIS model to identify cadmium and zinc contamination areas in sediments [4]	Substituting conventional maps and card indexes to display information

Environmental management tools		Applications in dredging industry	Strengths and/or weaknesses
Strategic monitoring and planning	Integrated environmental management (IEM)	Examples: comparative risk assessment and MCDA, coupling of comparative risk assessment, MCDA, and adaptive management, coupling of MCDA, LCA and risk assessment analysis, harmonized framework for ecological risk assessment of sediments, evaluation of the Norwegian management system for contaminated sediments, Driving force-Pressure-State-Impact-Response (DPSIR) in Malaysia's dredging industry, and decision analysis approach to dredged material management [5]	A combination of many environmental tools providing a holistic analysis

Reference: [1]=(Government of Malaysia 5th November 1987, Briffett, Obbard et al. 2004), [2]=(Vestola 2009, International Organization for Standardization 1997), [3]=(Suedel, Kim et al. 2008, Deliman, Ruiz et al. 2002, Agius, Porebski 2008, Liu A.J., Kong F.X., Wang D. 2006, Alvarez Guerra, Viguri et al. 2007, Zeman, Patterson et al. 2006), [4]=(Howlett, Galagan et al. 2000, Vianna, L. F. de N. 2004), [5]=(European Environment Agency 2003, Ness, Anderberg et al. 2010, Maxim, Spangenberg et al. 2009, Langmead, McQuatters Gollop et al. 2009)

The concept of IEM could provide a structured framework to accommodate different views of stakeholders, and identifies the most suited scale of actions towards addressing multi-criteria and conflicting problems, as faced by many countries as detailed in Table 2-7 (Antunes, Santos 1999). Successful applications of this concept have been seen in the Integrated Coastal Management (ICM) and the Integrated Coastal Zone Management (ICZM), which is among the tools of the IEM (Antunes, Santos 1999, Pacheco, Carrasco et al. 2007).

The use of integrated environmental management has also gained support within the dredging industry (Abriak, Junqua et al. 2006, Agius, Porebski 2008, Wang, Feng 2007). Coupling qualitative (for example public perception) with quantitative (for example sediment quality) measurements for the characterisation of dredged sites could further lessen the dependency on scientific measurements, including sediments characterization, in the dredging decision making process, thus making it more holistic, integrated and sustainable.

One of the most notable attempts on this was the methodology for dredging developed at the Port of Dunkirk, France as illustrated in Figure 2-5 (Abriak, Junqua et al. 2006, Junqua, Abriak et al. 2006). In the figure, it has indicated different environmental management tools (shown in different colours) as to their potential use within this methodology. Its steps include characterising dredged sites according to the types of sediments and sources of pollution, developing waste improvement options, and determining the most relevant management scenario. Through the active participation of dredging professionals, researchers and local communities, this methodology follows an integrated environmental management, making use of risk assessment and MCDA (Kiker 2007).

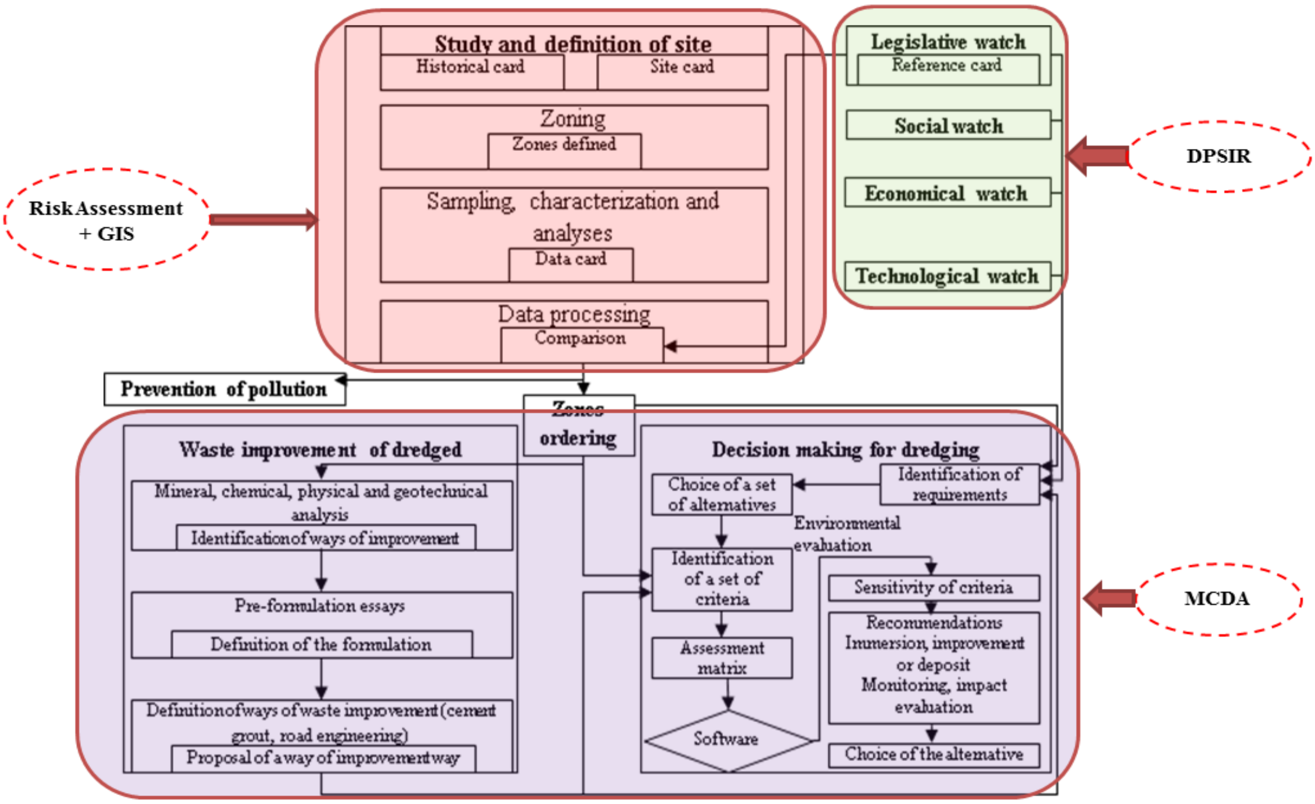


Figure 2-5 Methodology for dredging at Port of Dunkirk, France (Abriak, Junqua et al. 2006)

Environmental management for developing countries

Developing countries have an opportunity and a duty to review and learn from practices in order to sustain growth without causing significant damage to their environment. Despite the fact that developing countries were estimated to become the largest dredging markets in the world over the next few years, stiff competition from foreign dredging contractors heightens the need to lower costs for local dredging contractors (George 2011, Thacker 2007). This, together with poor facilities and limited dredging and environmental expertise, increases the risk of environmental negligence in developing countries. In addition to the problems faced in developed countries, dredging operators in developing countries, for example Malaysia, face an even greater challenge of limited funds (Barrow 2005, Bartelmus 1986). Although the maritime industry in Malaysia has been treated as a priority by its government (Ministry of Finance Malaysia 2010, Tun Abdul Razak 2010, Mohamad 2010), this nation is facing a challenge in effectively monitoring the impacts of dredging. The sensitivity of its environment, which is deteriorating, makes it more critical to investigate the impacts of dredging (Spalding 2001).

A significant body of research has reviewed the environmental impacts of dredging, and many environmental management tools have been identified attempting to control its adverse effects. Nevertheless, the focus of research has generally been on developed countries, with fewer attempts made addressing how these tools can be applied in developing countries. Therefore, further research balancing the problems of dredging particularly for emerging economies such as Malaysia is a necessity. A variation to the Port of Dunkirk methodology (Figure 2-5) and various international frameworks (Figures 2-1 to 2-3), which requires costly data collection and hard to implement (Choueri, Cesar et al. 2010), might be more appropriate for developing nations.

Developed and developing countries have very different primary concerns. In developing countries, the desire for economic growth and development often takes precedence over environmental problems and concerns, while developed countries often have the economic strength to put greater emphasis on environmental concerns. Despite this, the development of any nation, regardless of economic status, should be balanced with the need to preserve the environment.

Malaysia is used here as an example of a developing country. It is among the most richly diverse regions for coral reefs, of which 91% are at risk due to anthropogenic activities, such as dredging (Spalding 2001). In addition, Malaysia houses a number of tropical islands which are the habitat of abundant and exotic wildlife. It was also noted that the number of fisherman in Malaysia increased 3% in 2010 from the previous year, showing a growing dependence on the fishing industry (Department of Fisheries Malaysia 2010, Omar 2011). Furthermore, Malaysia is currently undergoing major economic development as part of a government plan to become a fully developed country by 2020. To that end, much effort has been made to increase the economic wellbeing and quality of life of its people (Mohamad 2010). This has included the government's provision of USD 250 million over the years 2006 to 2009 to build and extend ports, and to ensure the safety of ship navigation for the fishing industry (Ministry of Finance Malaysia 2010). Dredging is a major component of this, and it has been noted in previous research that Malaysia is facing difficulties in effectively monitoring the impacts of dredging (Manap, Voulvoulis et al. 2012), making even greater the need for this country to develop an effective environment management tool for dredging to avoid further environmental deterioration.

3 AIM AND OBJECTIVES

3.1 Aim

The aim of this thesis is to develop a risk-based decision-making framework for the integrated environmental management of dredging sediments in order to reduce dredging impacts and to lower the cost for environmental quality analysis and management.

3.2 Objectives

In order to develop this framework, the following objectives need to be met:

1. Assessment of dredging environmental impacts and the relevant factors that determine the magnitude of impact (dredging technology and sediment characteristic) through a review of the relevant literature
2. Analysis of dredging environmental impacts and factors using historical dredging monitoring data
3. Analysis of dredging problems other than environmental impacts using an IEM tool, the Driving force-Pressure-State-Impact-Response (DPSIR)
4. Development of the screening stage of the proposed framework within the context of Malaysia using publicly accessible data and historical dredging monitoring data
5. Development of the Tier 1 stage of the proposed framework within the context of Malaysia in order to prioritize dredging areas and determine their degree of contamination and concern for further investigation
6. Development of the Tier 2 stage of the proposed framework in the context of Malaysia to select the best sediment management option
7. Proposal of a risk-based decision-making framework for integrated environmental management of dredging sediments that integrates the three stages (screening, Tier 1 and Tier 2) developed previously
8. Policy analysis and implications of the proposed framework and discussion of limitations and recommendations for future research

3.3 Thesis structure

The thesis has been structured so as to demonstrate how the framework was developed. The introduction and rationale for the research herein, accompanied by a brief overview on the research topic, is presented in **Chapter 1 and 2**. The overall aim and objectives of this thesis and its contribution to the science are clearly defined in **Chapter 3**.

The first developmental step of the proposed framework is presented in **Chapter 4**, which assesses dredging environmental impacts and the two relevant factors (dredging technology and sediment characteristics) that determine the magnitude of impacts, using a literature review. The impacts and factors determined in this chapter will serve as the basis for the proposed framework.

As presented in **Chapter 5**, the second developmental step of the proposed framework further analyses the environmental impacts of dredging and its factors using Malaysia's historical dredging monitoring data in order to manage dredging impacts efficiently. In this chapter, an evaluation is performed and discussed of historical evidence from three dredging projects undertaken between 2006 and 2008 on the rivers of Sungai Sitiawan and Sungai Dinding, Perak, Malaysia. Monitoring results and fish toxicological data from these projects are subjected to descriptive analysis. The data's relationship to dredging projects performed in these rivers is illustrated using GIS software, ArcMap 10. Dredging impacts and factors based on historical evidence are discussed at the end of this chapter.

The third developmental step of the proposed framework is to analyse dredging problems other than dredging environmental impacts using DPSIR, as presented in **Chapter 6**. This is in order to develop an integrated and holistic framework, which focuses not only on scientific evidence. Interviews and an online questionnaire survey with Malaysia's dredging experts (including marine ecologists, registered chemists, professional and chartered engineers, environmental consultants, university professors and environmental analysts) are performed and discussed in this chapter. Using the survey findings, a DPSIR framework that highlight main dredging problems affecting dredging stakeholders in Malaysia is developed at the end of this chapter.

On the basis of understanding of these three developmental steps, which cover dredging impacts and relevant factors, the fourth step is as in **Chapter 7** that develops the first stage of the proposed framework (screening stage) in Malaysia's context to identify areas that requires high environmental protection using a newly developed method that integrates publicly accessed data and historical dredging monitoring data into a variation of standard ERA phases. It is demonstrated using historical dredging monitoring data from twelve maintenance dredging projects performed between 2005 and 2010 in Peninsular Malaysia. The degree of contamination in dredging locations determined from this screening stage is discussed at the end of this chapter.

The development of the second stage (Tier 1) of the proposed framework in Malaysia's context is the fifth step and as presented in **Chapter 8**. The Tier 1 stage is developed to prioritize sensitive areas and determine their degree of contamination and concern for further investigation using a newly developed method that integrates MCDA and ERA. This stage is demonstrated using monitoring and fish toxicological data from three dredging projects undertaken between 2006 and 2008 on the rivers of Sungai Sitiawan and Sungai Dinding, Perak, Malaysia. Prioritized areas and their degree of contamination and concern are discussed at the end of this chapter.

The sixth step is as presented in **Chapter 9** that develops the third stage (Tier 2) of the proposed framework within the context of Malaysia to select best sediment management option using a newly developed method that balances multiple criteria using MCDA. This stage utilized findings from the Tier 1 stage, as discussed in the previous chapter, in order to demonstrate the application of this stage. The best sediment management option for the rivers of Sungai Sitiawan and Sungai Dinding, Perak, Malaysia is discussed at the end of this chapter.

Chapter 10 presents a risk-based decision-making framework for the integrated environmental management of dredging sediments, which integrates six previously developed steps into three framework stages (screening, Tier 1 and Tier 2) in order to reduce the environmental impacts of dredging and to lower the cost of environmental quality analysis and management. The aim, function and benefits of the proposed framework for dredging stakeholders are also discussed in this chapter.

Chapter 11 analyses current policy and the implications of the proposed framework through discussion of national and international policy contexts, research limitations and recommendations for future research, followed by the conclusion in **the final chapter**.

The remainder of this thesis includes the list of references and the appendices, which provide supplementary data associated with the development of the findings presented in the chapters.

3.4 Significance of the work

This work identifies issues to be examined before and during dredging and will be helpful to dredging stakeholders, especially government agencies charged with overseeing dredging projects. The significance of this work also rests in its highly applicable framework that assists dredging contractors to select best sediment management option. This newly developed framework of dredging decision-making tool, which avoids the likelihood of disproportionately high costs of sediment remediation by balancing conflicting problems of socio-economic, environmental, managerial and technical aspects, helps dredging decision makers to make a sustainable decision. The novelty of this research lays in the newly developed methodologies in the framework's three distinct stages that screens degree of contamination in dredging areas, prioritizes dredging areas and subsequently selects the best sediment management option in a newly developed framework that is integrated and holistic. This highly applicable framework to dredge sediments in a sustainable manner has been proven beneficial through its demonstration in a developing country of Malaysia.

Most of the chapters in this thesis have been prepared for publication and already been published or submitted for consideration for publication to various international journals, thus reflecting the originality of this research.

Publications

Manap, N.B., Zulkifli, N.B. & Voulvoulis, N. Manap, N.B.. The application of Driving force-Pressure-State-Impact-Response (DPSIR) in Malaysia's dredging industry. *International Journal of Food, Agriculture and Environment in January 2012.*

Manap, N. & Voulvoulis, N. (*submitted*). Dredging sediments: the need for integrated environmental management. *Marine Pollution Bulletin*.

Manap, N. & Voulvoulis, N. (*submitted*). Establishing best practices for dredging: the case study of Malaysia.

Manap, N. & Voulvoulis, N. (*submitted*). The application of Risk Assessment and Multi-criteria decision analysis in dredging and sediment management.

Manap, N. & Voulvoulis, N. (*submitted*). The application of Multi-criteria decision analysis to select best sediment management option.

Manap, N. & Voulvoulis, N. (*submitted*). Integrated Environmental Management (IEM) framework for dredged sediments.

Conference proceedings

Manap, N.B., Zulkifli, N.B. & Voulvoulis, N. (2011). Implementation of Environmental Impact Assessment in Malaysia: Dredging problems as indicators. *Proceedings of the 2011 International Conference on Technological Advancements in Civil Engineering (ICTACE), Chennai, India, 19-20 February 2011.*

Manap, N.B. (2011). A talent in Integrated Environmental Management (IEM), sediments and dredging. *Proceedings of the 2011 Talent Management Symposium (TMS2011), Imperial College London, United Kingdom, 18-20 July 2011.*

4 ENVIRONMENTAL IMPACTS OF DREDGING

4.1 Dredging technologies

The first developmental step of the proposed framework is presented in this chapter where it assesses dredging environmental impacts and its two important factors (dredging technology and sediment characteristic) that determine the magnitude of impacts through literature review. The impacts and its factors determined in this chapter will be the basis of the proposed framework.

Excavation, transport and disposal of sediments are the three main stages of dredging activities (Figure 4-1). These are successively repeated until a target quantity of sediments is dredged (Thorn 1975), with each stage requiring different technologies. Historically, and as the dredging industry has developed, technologies have improved, and today different types of dredgers are available to be utilised for different applications.

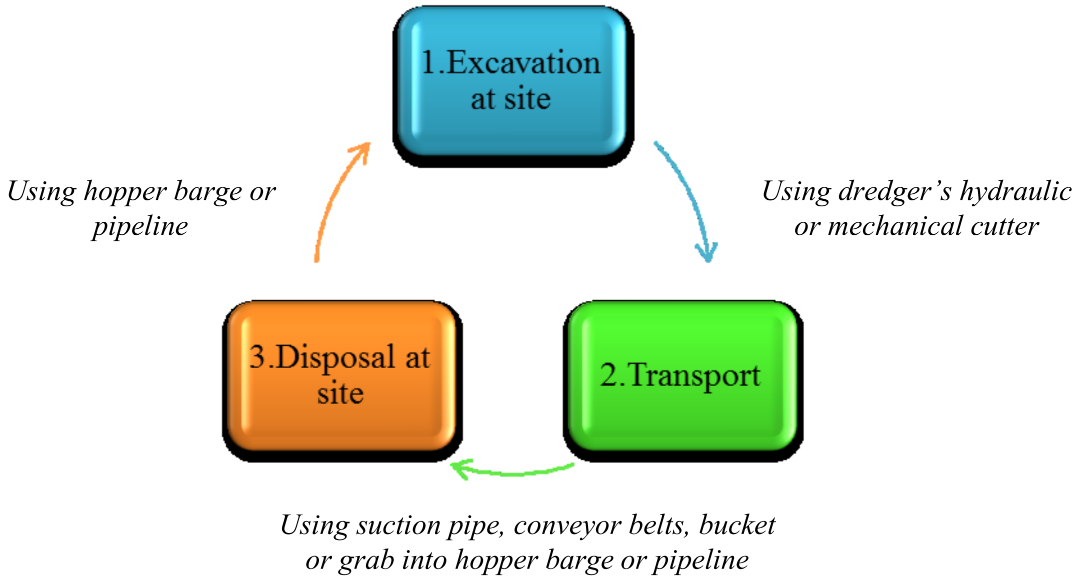


Figure 4-1 Stages of dredging (Verbeek 1984, Highley, Hetherington et al. 2007)

Dredging starts with the excavation of sediments at a site with a hydraulic and/or mechanical cutter (Du Yuhai, Li Hongwei 2010, Antipov, Antipov Yu et al. 2006, Klein 1998, Honmagumi KK, Chiyoda Kenki KK 1995). Different types of dredgers are required for different sediments and depths, but similar extraction methods may be required for both capital and maintenance dredging, whether through suction or grab (Den Herder 2010, Fujimoto, Tadasu 1998). Trailer dredgers are commonly used at sea, and deepen by dragging their cutter along the seabed, extracting loose sediments until the hopper is full and ready for disposal (Messieh, Rowell et al. 1991, Gubbay 2005). Conversely, anchor dredgers are generally confined to small areas such as lakes and port basins, and move by anchor and/or hydraulic spud: a part of dredger that penetrated into the sea or river beds to retain stability while dredging (Reba BV 1975, Quimby 1914, Mostafa 2012). Pit excavators and bar skimmers, on the other hand, are commonly used to extract sediments from riverbeds (Padmalal 2008, Highley, Hetherington et al. 2007, Ge, Sun et al. 1999). Backhoe dredgers, trailing suction hopper dredgers and cutter suction dredgers are among the other types of dredgers frequently used to date (Lefever, Van Wellen 2011, Guo 2011, Tack 2010, Lin, Liu et al. 2010, Tashiro 2009, Liu 2005, Ikeda, Nomoto 1999).

Dredged sediments are then transferred (Figure 4-1) into hopper barges or pipelines using suction pipes, conveyor belts, bucket or grab (Duran Neira 2011a, Nippon 1996, Schnell 1984). The hopper barges or pipelines then transport the dredged sediments to the intended disposal site. Dredging often still takes place during transport when the practice of excess dredging is applied, which involves the continuation of dredging after the hopper is full, with the surplus volume discharged over the hopper weirs (Thorn 1975, Highley, Hetherington et al. 2007, Van Nieuwenhuijzen, Van Den Broeck 2011).

Finally, the dredged sediments are disposed at a selected site. Several methods are available for this, including agitation dumping, side casting, dumping in rehandling basins, sump rehandling operations, or direct pumping ashore. Open water disposal is the most economical and widely used method, with hopper barges as the usual means of transport (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al.

2009, Krishnappan 1975, Saxena, Vaidyaraman et al. 1975). During open disposal, the dredged sediments are barged to the designated dumping site and disposed through its bottom gate (Thorn 1975, Krishnappan 1975). Another technique is the use of pipelines to pump the dredged sediments onto land. This process includes loading sediments into the hopper, transporting them through pipelines; and then pumping them ashore (Welte 1975).

During open disposal, either silt curtains or booms may be used to contain suspended sediments in order to prevent diffusion and help sedimentation (Elander, Hammar 1998). A boom is a heavy structure comprising a plastic cover, connectors, skirt, tension member and ballast weight which is hooked to an air or solid float (Dreyer 2006). A submerged or floating silt curtain consists of a tension member, ballast weight, anchor and curtain (Dreyer 2006, Ueno Y 2010, Ishizaki, Rikitake 2010, Guo, He et al. 2009, Otoyo 2003, Sawaragi 1995, Trang, Keat 2010). However, there is concern regarding their use due to the risk of contamination leakages (Su 2002, Thibodeaux, Duckworth 2001, Morton 2001).

Open disposal is generally not permitted when handling highly contaminated sediments (Krizek, Giger et al. 1975). Contaminated dredged sediments often require remediation, for example through mechanical mixing and aeration (Kim 2004, Toyo Kensetsu KK, Daiichi Kogyo Seiyaku Co LTD et al. 1994). Other remediation techniques include sequential extraction techniques, pre-treatment, physical separation processes, containment, washing, thermal extraction, bioremediation, electro kinetics, solidification/stabilization, vitrification, and chemical oxidation (Pensaert, Dor et al. 2008, Mulligan, Yong et al. 2001, Morinaga Kumi KK, Trade Service KK et al. 1997).

4.2 The influence of sediments characteristics

Sediment characteristics refer to the role of sediments as a contaminant source. Sediments act as a sink in that they adsorb and retain contaminants that have settled on the bottom of rivers and marine waters, coming from both point and diffuse sources (Riley, Chester 1971, European Sediment

Research Network 2004, Burton 2002, Rothwell, Dise et al. 2010, US Geological Survey 2004). Point sources, defined as identifiable sources, include waste dumps, direct effluent from industry and household effluent (Office of Naval Research 2008, European Sediment Research Network 2004, Zühlke 1994). Conversely, examples of diffuse sources, defined as undetermined sources, include weathering, atmospheric deposition, erosion, sewer system sediments and mining traces (European Sediment Research Network 2004, Parkhill 2002).

Sediments also retain nutrients, including N and P (Moss, Madgwick et al. 1996). The natural source of these nutrients is from the microbial processes of microorganisms, homogeneous reactions and equilibrium reactions (Stolzenbach, Adams 1998). However, the level of nutrients can increase as a result of human activities, such as through the release of fertilizer-borne nutrients used in agriculture (European Sediment Research Network 2004, Lair 2009). Along with nutrients, sediments also retain and transport metals including Zn, Hg, Cd, As, Pb, Cu and Ni. Among the sources of these metals are weathered sedimentary rocks and underwater volcanic actions. The use of chemicals in various industries, including pharmaceutical, textiles and agriculture also results in the release of volatile and soluble organic compounds into the environment, which at the same time shows that human activities can artificially increase metal and organic concentrations (Garrett 2000, Holt 2000).

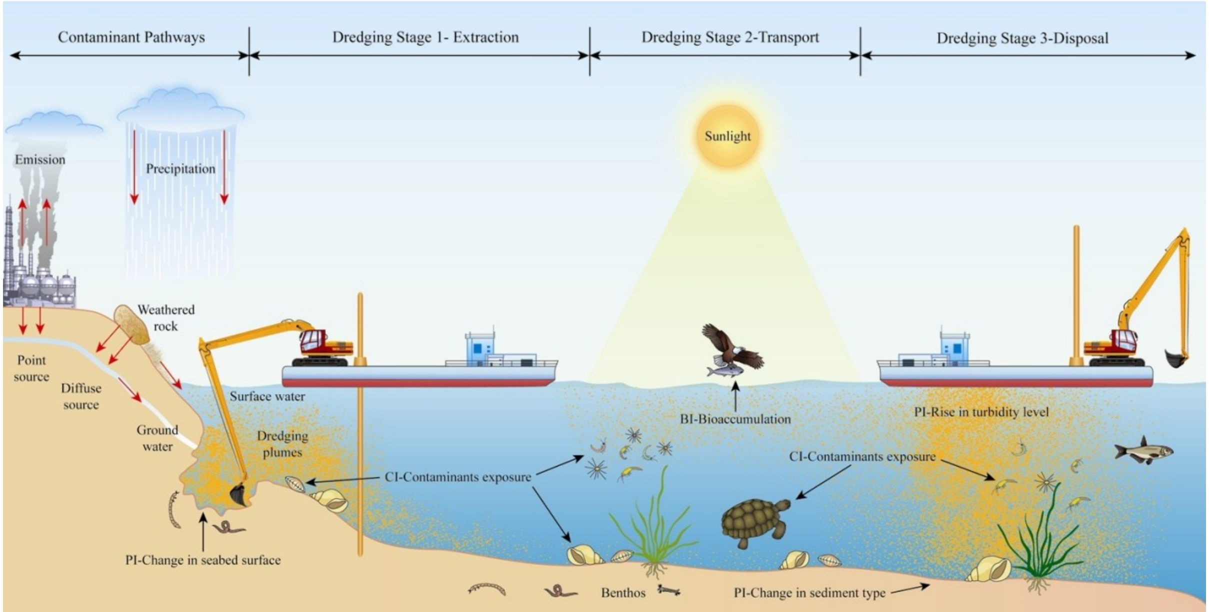
Sediments can therefore also release contaminants into the environment, as contaminants bound on sediment particle surfaces and interior matrices can be released when sediments are disturbed (European Sediment Research Network 2004, Burton 2002, Garrett 2000, Fluck, Chevre et al. 2010). Transportation of contaminants by sediments is dependent on several factors, primarily particle size (Jain, Ram 1997). Sediment particles are classified into different sizes, namely fine particle size up to 2µm (clay), particle size up to 16µm (silt), particle size between 63µm to 64mm (sand and gravel), and particle size more than 64mm (rock) (Nittrouer, Austin Jr. et al. 2007, Verbeek 1984, Tsinker 2004). Furthermore, contaminants in sediments may be transported in different forms, whether in dry gaseous state, dry particulate or wet deposition (Lair 2009). Ocean and wetland systems, tides, currents and waves can be attributed to sediment transportation (Office of Naval Research 2008, Nielsen 2009).

Sediment Quality Guidelines (SQGs) have been used to screen potentially contaminated sediments before dredging, even though this is not a regulatory requirement (Burton 2002, Wenning 2005). Currently in the US, Ireland, the UK, Belgium and Canada, SQGs are used to determine the sediments' level of contamination at a dredging site, although still not because of regulatory requirements (Pan 2009, Suedel, Kim et al. 2008, The National Oceanic and Atmospheric Administration (NOAA) 2006, Praveena 2008). SQGs are utilised to evaluate the quality of dredged sediments in order to help protect both the environment and humans from contamination exposure (Burton 2002). This means that if the sediments exceed the guideline values, it becomes necessary to consider an alternative technological means to handle them (O'Connor 1998).

Along with SQGs, Water Guideline Values (WGVs) are used to monitor the chemical parameters of the water column affected by dredging operations. WGVs can be determined from two perspectives: water quality in aquatic water systems; and quality of water intended for potable use (MacGillivray, Kayes 1994). They are usually derived from either studies on humans or animal toxicity, but the latter is more widely used.

4.3 Dredging impacts and its factors

The easiest way to understand the environmental impacts of dredging is through a traditional source-pathway-target assessment of risks. With the sources covered under sediments characteristics earlier, and with pathways of contaminants mainly associated with transport of sediments and therefore dependent on dredging technologies, a conceptual model illustrating source, pathway and target linkages is presented in Figure 4-2.



PI=Physical impacts, CI=Chemical impacts, BI=Biological impacts

Figure 4-2 Source-Pathway-Target linkages: conceptual model for assessing dredging impacts

Understanding the nature and extent of sediment contamination requires investigating the sources of pollution. Industrial effluents and sedimentary rocks represent point and diffuse sources for contaminated sediments, respectively. From such sources, contaminants can dissipate into groundwater, be released through precipitation, or be transported by sediments into surface water, and finally adsorbed and retained in sediments on sea or river beds (Moss, Madgwick et al. 1996, Jain, Ram 1997, De Nobili, Francaviglia et al. 2002). Similarly, contaminant pathways into the environment are through media including sediments, air, groundwater, surface and marine water. Through contaminant precipitation, absorption or direct influent from point and diffuse sources into the media, contaminants are retained or transported directly into surface and marine water (Moss, Madgwick et al. 1996, Jain, Ram 1997). This can be followed by bioaccumulation in food web communities triggered by the disturbance of sediments, including from dredging activities (Figure 4-3) (Moss, Madgwick et al. 1996, De Nobili, Francaviglia et al. 2002).

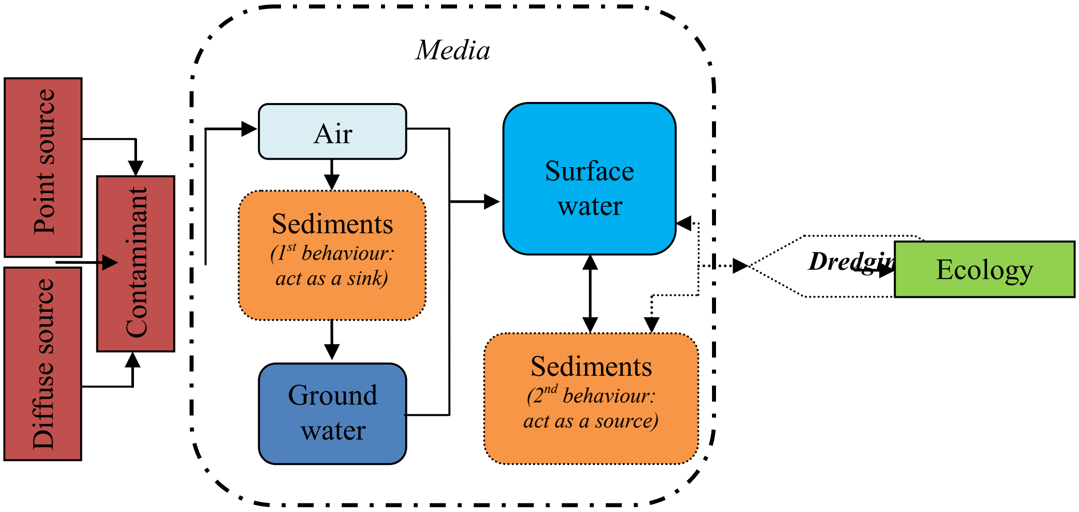


Figure 4-3 Contaminant pathways

Figure 4-1 illustrates that environmental impacts of dredging can take place during extraction, followed by transport and disposal of dredged sediments. Sediment extraction causes a variety of impacts, including dispersal of contaminants from sediments into the water, change in seabed surface, formation of dredging plumes and exposure of benthos and fishes to contamination. The dredged sediments are then transported to designated disposal sites. The impacts of these two stages can include bioaccumulation, contamination exposure, change of sediment type and rise in turbidity level.

Contaminant pathways including dredging technologies and sediments have been highlighted in Figure 4-3. Examples of environmental impacts associated with these pathways are summarised in Table 4-1. It was found that a low environmental risk according to biological parameters is normally associated with low contamination. Additionally, mechanical dredgers (including mechanical shovel and clamshell) posed a lower environmental risk than hydraulic dredgers (cutter suction dredger). Nevertheless, the environmental risk according to chemical parameters remained high at both site categories, regardless of the technology used.

Table 4-1 The risk of different technology and level of contamination

Dredging technology and (level of contamination at dredged site)	Environmental risk	Reference
Cutter suction dredger with cutter crown and sweep head (low)	*38% biological, 54% chemical,	(Groote, Dumon et al. 1998)
Mechanical shovel (low)	29% chemical	(Piou 2009)
Clamshell (low)	0% biological	(Su 2002)
Dragline and excavators (high)	55% biological, 67% chemical	(Ponti, Pasteris et al. 2009)
Mechanical shovel and bunds (high)	86% biological	(Ellery, McCarthy 1998)
Backhoe equipped with sieve bucket, excavator, auger dredger, silt curtains and oil boom (high)	80% biological	(Thibodeaux, Duckworth 2001)

*The percentage represents the likelihood of the environmental parameter to degrade. It is calculated based on the number of times negative impact occurred in each research compared to 'positive' and 'no effect' impacts.

The impacts of dredging vary according to chemical, biological and physical parameters of the aquatic environment. Further descriptions of dredging impacts and parameters that have been monitored can be found in Table 4-2 and in Appendix A. Whether these parameters increased or decreased as a result of dredging has been indicated with a mark (√) and numbered to show its reference in Table 4-2.

Table 4-2 Impacts of dredging (Further details in Appendix A)

	During dredging		After dredging		During disposal		After disposal	
Parameter	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**
Chemical impacts:								
Organic compound in sediments and water			$\surd_{1,2,3,22,18}$	$\surd_{5,11}$	$\surd_{21,22}$			
Inorganic compound in sediments and water	$\surd_{10}$		$\surd_{10}$					
Oxygen demand			$\surd_{4}$					
Biological impacts:								
Benthic fauna			$\surd_{1,2,7,13,18}$	$\surd_{8,19,20}$		$\surd_{23,24}$	$\surd_{27}$	$\surd_{25,26}$
Benthic flora			$\surd_{6}$	$\surd_{14}$				
Fishes				$\surd_{15}$				
Physical impacts								
Turbidity			$\surd_{12,4}$					
Transparency				$\surd_{13}$				
Bed roughness			$\surd_{16}$					
Erosion of the coastal area			$\surd_{17}$					
Recovery rate after 2 years							$\surd_{26}$	
Sand percentage							$\surd_{27}$	

* √ Number of reference : 1=(Ponti, Pasteris et al. 2009), 2=(Toes 2008), 3=(Mackie 2007), 4=(Messieh, Rowell et al. 1991), 5=(Piou 2009), 6=(Munawar 1989), 7=(Constantino 2009), 8=(Balchand, Rasheed 2000), 9=(Douvere, Ehler 2009), 10=(Thibodeaux, Duckworth 2001), 11=(Shigaki, Kleinman et al. 2008), 12=(Su 2002), 13=(Bonvicini Pagliai, Cognetti Varriale et al. 1985), 14=(Ellery, McCarthy 1998), 15=(Thibodeaux, Duckworth 2001), 16=(Ellery, McCarthy 1998), 17=(Sergeev 2009), 18=(Rasheed, Balchand 2001), 19=(Padmalal 2008), 20=(Kenny, Rees 1996), 21=(Ljung 2010), 22=(Cappuyns 2006), 23=(Ware, Bolam et al. 2010), 24=(Crowe, Gayes et al. 2010), 25=(Cruz-Motta, Collins 2004), 26=(Powilleit, Kleine et al. 2006), 27=(Wilber, Clarke et al. 2007)

A number of possible factors for dredging impacts, as illustrated in the conceptual model, are presented in Table 4-3. The table shows that impacts of dredging are highly dependent on the levels of contamination of dredged sites and technologies used. Furthermore, the increase in chemical parameters that occurs during dredging and disposal shows that the disturbance of sediments exposes the ecosystem to contaminants. Increases in the levels of organic and inorganic compounds heighten the risk of contaminant exposure that can negatively affect flora and fauna. The change in physical parameters further reinforces this point. While it has been noted that some positive changes can occur during the various stages of dredging, this review treats those more as anecdotal and suggests that the impacts are largely detrimental to the environment.

Table 4-3 The environmental impacts and possible factors

Environmental Impact	Possible factor	Remarks
Increase of chemical content in sediments and the water after dredging (Munawar 1989)	Dispersal of contaminants into the water due to excavation Contaminants previously dispersed deposited back into sediments after dredging Excavation exposes new layer of sediments with higher value of contaminants	Silt curtain may not fully contain dispersal due to leakage (Thibodeaux, Duckworth 2001)
Increase of oxygen demand (Messieh, Rowell et al. 1991)	Increase of aquatic fauna Chemical pollutants maximise the need for oxygen to decompose	NA
Increase in number of polychaeta (Ponti, Pasteris et al. 2009)	Excavation exposes sources of food	Exposure of food sources attracts other polychaeta species, creates competition and congests the dredged site resulting in decrease of weaker species (Ponti, Pasteris et al. 2009)
Decrease in number of polychaeta (Ponti, Pasteris et al. 2009)	Excavation removes polychaeta from their habitat	Recovery rate is between 1 to 2 years (Kenny, Rees 1996, Powilleit, Kleine et al. 2006)
Decrease of light penetration (Munawar 1989, Douvere, Ehler 2009)	Dredging stages cause high level of turbidity	High level of turbidity is temporarary (Messieh, Rowell et al. 1991, Herbich, Brahme 1991)

Environmental Impact	Possible factor	Remarks
Increment of chemical body burden in crab (Su 2002)	Dispersal of chemicals leads to bioaccumulation	NA
Habitat change (Padmalal 2008)	Excavation changes sediment type and forces polychaeta species to change their habitat	NA

4.4 Conclusion

This chapter presented the first developmental step of the proposed framework where it reviewed the literature for dredging environmental impacts and its two important factors (dredging technology and sediment characteristic) that determine the magnitude of impacts. The Source-Pathway-Target linkages that have been highlighted in this chapter will be the basis of the proposed framework.

5 ENVIRONMENTAL IMPACTS OF DREDGING: THE MALAYSIA'S CASE STUDY

5.0 Introduction

This chapter presents the second developmental step of the proposed framework that further analyses the dredging environmental impacts and its factors using Malaysia's historical dredging monitoring data in order to manage dredging impacts efficiently.

Dredging has multiple uses, including to aid ship navigation and to expand ports and harbours. Each of dredging's three main stages (extraction, transport and disposal) requires the use of different technologies. Different types of dredgers can be used during the extraction and transport stages, ranging from cutter suction dredgers to trailer hopper suction dredgers (Lefever, Van Wellen 2011, Hongqi, Ning et al. 2010, Duran Neira 2011b). During disposal, uncontaminated dredged materials are frequently dumped offshore or recycled for beneficial use, while contaminated dredged materials require different disposal methods. These include the use of silt curtains, oil booms, or special remediation techniques (Su 2002, Newell, Hitchcock et al. 1999, Kim 2004, Toyo Kensetsu KK, Daiichi Kogyo Seiyaku Co LTD et al. 1994).

Many dredging projects have been undertaken, the construction of Panama Canal being one example (Schexnayder 2010). There is also a high demand for dredging in developing countries due to growing maritime trade. In fact, given the number of dredging projects proposed in India, it has been estimated that this nation will be the largest dredging market in the world within a few years (George 2011, Thacker 2007).

Much research has been undertaken to identify dredging impacts, as can be found in Tables 5-1 and 5-2. It has been considered good dredging practice to use sediment quality guidelines to characterise the levels of contamination in dredged sites in developed countries like the United States. Nevertheless, its use to determine contamination level of a dredging site has also received much criticism due to its potential for causing disproportionate sediment remediation costs (Mark 2003, European Parliament 2000, Burton 2002). In the United Kingdom (UK) for example, the Water Framework Directive (2000/60/EC), which was transposed into UK national law in 2003, calls for good ecological status to be achieved in water bodies, allowing only a slight reduction of water quality in comparison to an unmodified natural water body (Mark 2003, European Parliament 2000). This Directive also calls for Sediment Environmental Quality Standards (EQS) to be derived for the monitoring and regulation of sediment contamination. The mandatory pass/fail nature of these standards, which additionally depend on suspended sediment as a sampling medium, has fallen under criticism from within the dredging industry (Burton 2002).

In addition, developing countries like Malaysia may not have the economic capability to prioritise environmental problems such as through costly sediment remediation techniques, making environmental negligence, for instance towards the use of sediment quality guidelines as good dredging practice, a concern. Thus, it is important to holistically assess dredging impacts and its factors in one particular location such as Malaysia, so that decisions to perform dredging in a more sustainable manner in this location can be taken.

This chapter aims to present the second developmental step of the proposed framework that further analyses the dredging environmental impacts and its factors using Malaysia's historical dredging monitoring data in order to manage dredging impacts efficiently. Historical scientific evidence will be assessed in order to determine dredging impacts and its factors using three dredging projects in Malaysia that extracted sediments amounting to 3 million meter^3 over a period of 3 years were assessed. Water and sediment quality and a fatal incident at an aquaculture farm adjacent to a dredging site were assessed holistically in order to establish their relationships with dredging.

Table 5-1 Dredging impacts on water

Indicator	Impact	Stage	Causal factor	Reference
P, Al, Cr, Fe, Mn, Pb, Zn and alkalinity	Increased 3 weeks later but not to eco-toxic level	During dredging	-	(Munawar 1989)(Clément, Vaille et al. 2010)
PCB concentrations on water while boulder removal and during dredging	Exceeded reference values	During dredging	-	(Thibodeaux, Duckworth 2001)
Nitrate concentration at dredged area	Constantly high at bottom water depths; Increased at non-dredged area during pre-monsoon season	During dredging	Nutrient release	(Rasheed, Balchand 2001)
PCB concentrations in the water measured outside the curtain	Higher for the upstream samples than those downstream	After dredging	-	(Thibodeaux, Duckworth 2001)
Organic pesticides	Traced	After dredging	-	(Munawar 1989)
Al, Fe, Mn, Cr, Pb, Zn, P and Cu	Increased immediately	After disposal	-	(Munawar 1989)
Fe, Ni and As	High concentration	After disposal	-	(Ljung 2010)
Turbidity	Increased while dredging; Decreased after dredging stopped; Caused sediment plumes; Increased but then decreased to baseline in 24-48 hours; Higher turbidity in surface waters at both non-dredged and dredged during monsoon season; Increased at dredged site as depth increased during post monsoon season, with maximum at 8-10 meter depth	During and after dredging	Caused by dragging, scooping or dumping actions that clog membranes of filter-feeding fauna like shellfish; High level of sediment disturbance; High turbid freshwater inflow (typical for tropical estuaries)	(Balchand, Rasheed 2000)(Su 2002)(Messieh, Rowell et al. 1991)(Wu, de Leeuw et al. 2007)(Clément, Vaille et al. 2010)

Table 5-2 Dredging impacts on various indicators

Indicator	Impact	Stage	Causal factor	Reference
PAH on soil	Available at northern end of the dredged area where the cap was in place	Excavation	Dredging and capping were operating simultaneously for a time	(Thibodeaux, Duckworth 2001)
Phosphorus release to flowing water	Reduced	Excavation	Sediment with high P content dredged/disposed	(Shigaki, Kleinman et al. 2008)
PCB concentrations on 1995 on sediment at 4 inch thick	Reduced by 94%	Excavation	-	(Thibodeaux, Duckworth 2001)
PCB concentrations on 1997 on sediment at 3 inch thick	Higher 257% than pre-dredge	Excavation	-	(Thibodeaux, Duckworth 2001)
PCB concentrations on 1995 on sediment at 6-7 inch thick composites	Lower 45% than pre-dredge	Excavation	-	(Thibodeaux, Duckworth 2001)
PCB levels at 2 inch surficial sediment	Increased	Excavation	Exposure of sediment with higher PCB concentrations	(Thibodeaux, Duckworth 2001)
Total organic carbon (TOC) decreased	Decreased along time	Disposal	Mineralization by aerobic microorganisms	(Piou 2009)
Sediment toxicity, Sediment's P, Pb, Zn and Hg	Increased at control sites and exceed guidelines-4 days after dredging	Disposal	Increased oxygenation of bottom sediments and less contaminated by trace metals than removed sediments	(Ponti, Pasteris et al. 2009)
Cu, Cd and Fe concentration	Elevated	Disposal	Microbial oxidation of contaminated organics at the sediment surface; Could be caused by the anaerobic reduction of heavy-metal-containing iron-(hydr)oxides; The site is located in the vicinity of an industrial wharf	(Toes 2008)
As, Zn, Cd and Pb	Increased	Disposal	-	(Lions 2010)

5.1 Methodology

5.1.1 Case studies

Malaysia serves as another example of a developing country with a high demand for dredging. At the same time, this nation is known as being one of the most diverse regions for coral reefs in the world (Spalding 2001), further heightening the need for it to protect its aquatic ecosystems. It has also been noted that its dependence on the fisheries industry has been growing, thus intensifying the demand for dredging to aid vessel navigation (Department of Fisheries Malaysia 2010, Omar 2011). In parallel to this, the government of Malaysia was reported to have spent USD250 million between 2006 and 2009 for port expansion and ship navigation, including dredging, this in line with the nation's vision to become a developed country by 2020 (Ministry of Finance Malaysia 2010, Tun Abdul Razak 2010, Mohamad 2010). However, the dredging industry in Malaysia is facing a number of challenges, including in socio-economic, environmental and managerial criteria which could cause detrimental impacts of dredging (Manap, Voulvoulis et al. 2012). Taking this into consideration, dredging practices in Malaysia were assessed in order to determine dredging impact factors by investigating three dredging projects performed in between 2006 to 2008.

Sungai Dinding river, 2006 and 2008

Two dredging projects along this river were performed between 2006 and 2008 using trailer hopper suction dredger (THSD). The total amount of sand, silt and clay (Figure C-13 in Appendix C) extracted from this river was 2.0 million meter^3, for a seabed depth of 10 meters.

Sungai Sitiawan river, 2007

Sungai Sitiawan river was dredged to a depth of 8 meters, and a total of 1.0 million meter^3 of sand, clay, silt and gravel were extracted using THSD starting in 2007. In addition, an incident affecting a fish farm at this river was assessed, where in 2008 fish in an aquaculture farm adjacent to the dredging project were killed, with a financial loss of nearly USD 0.3 million.

5.1.2 Data sources

Dredging data was collected from the dredging contractor who performed these three projects. A summary of environmental, socio-economic, technical and managerial data can be found in Subsections C-4 to C-8 in Appendix C. A dredging database consisting of water and sediment quality status data was then developed using Microsoft Excel and Geographical Information System (GIS) software ArcMap 10. Spatial data for ArcMap 10 was collected from the Federal Department of Town and Country Planning for Peninsular Malaysia and the Department of Irrigation and Drainage Malaysia. In addition, a toxicological report based on an investigation by the Aquatic Toxicological Centre at the Fisheries Research Institute of Malaysia conducted two days after the fish farm incident was assessed in order to ascertain the relationship to dredging performed nearby.

5.1.3 Data monitoring

Data monitoring covered all dredging stages, before, during and after dredging (Figure C-2 in Appendix C). The monitoring frequency varied according to regulatory requirements, in accordance with Malaysia's Environmental Impact Assessment Order 1987 (Government of Malaysia 5th November 1987). More than twenty indicators of water and sediment quality status were monitored as can be found in Table 5-3. However, not all dredging projects were required to monitor every one of these indicators; the minimum number of indicators monitored for a sample was eleven, and the maximum twenty eight.

5.1.4 Data analysis

Dredging data was analysed and presented using descriptive statistics in Microsoft Excel and sample locations were illustrated using ArcMap10. Marine Water Quality Standard and Characterization (MWQSC) values (Figure C-9 in Appendix C), developed by the Malaysian Department of

Environment (DOE), were used as reference values. Data on Water Quality Index (WQI) from Annual River Quality Status between 2006 and 2010, reported by the DOE, were analysed to determine the water quality status of rivers upstream from the dredging site (Department of Environment 2006, Department of Environment 2007, Department of Environment 2008, Department of Environment 2009, Department of Environment 2010). It should be noted that Malaysia has not established its own reference values for sediment quality, so reference values used in other countries including Ireland, the United Kingdom, Belgium and Canada were applied for the sake of comparison (The National Oceanic and Atmospheric Administration (NOAA) 2006, Praveena 2008, Pan 2010). It is also important to note that all analysis in this chapter related to duration was based on the date of first monitoring until completion of dredging at the location, ranging from 1 to 32 months.

Table 5-3 Indicators monitored and not monitored in three case studies discussed in this chapter

* Ri	Water quality																				Sediment quality								
	pH	**BOD**	**COD**	**NH_3-N**	**TSS**	**DO**	**S**	**Fe**	**B**	**Hg**	**Cd**	**Zn**	**Tin**	**As**	**Pb**	**Cu**	**Mn**	**E-coli**	***Tur**	***Temp**	**TOC**	**Mn**	**Pb**	**Fe**	**Cu**	**Cd**	**Cr**	**As**	**Zn**
^A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	x	√	√	√	√	√	√	√	√	√	√
^B	√	√	x	x	√	√	x	√	√	√	√	√	√	√	√	√	√	√	√	√	x	x	x	x	x	x	x	x	x
^C	√	√	√	x	√	x	x	x	x	√	√	x	x	√	√	√	x	√	x	√	x	x	x	x	x	x	x	x	x

√ = *Indicator monitored*
x = *Indicator not monitored*
**Ri=River name*
**Tur=Turbidity*
**Temp=Temperature*
^ *A= Sungai Dinding river, 2006*
^ *B= Sungai Sitiawan river, 2007*
^ *C= Sungai Dinding river, 2008*

5.2 Results

5.2.1 Sungai Dinding river, 2006 and 2008

The quality of this river was monitored from 1st March 2006 to 1st December 2008. Sediment quality analysis was made prior to both dredging projects and taken from four sampling locations (represented by triangles in the Figure 5-1 below).

In addition, 42 water quality analysis samples (represented by circles in the Figure 5-1 below) were taken on different monitoring dates. As the sampling points for water quality analysis were scattered, they were divided into four areas (Areas S1, S2, S3 and S4) adjacent to four sediment sampling point locations. Results of monitoring are illustrated in Figure 5-1.

5.2.2 Sungai Sitiawan river, 2007

Monitoring in this river was performed from 29th November 2007 to 30th November 2008. No sediment quality analysis was made prior dredging; however 33 water samples were monitored before, during and after dredging. Water quality indicator levels are illustrated in Figures 5-2 to 5-4.

Data related to two rivers located upstream, Sungai Deralik and Sungai Wangi, was also collected. It was reported by the DOE that the WQI of Sungai Deralik decreased, being found to have a 'polluted' status in one of the years. Similarly, the WQI of Sungai Wangi was reported to have decreased, but did retain a status of 'slightly polluted' (Department of Environment 2006, Department of Environment 2007, Department of Environment 2008, Department of Environment 2009, Department of Environment 2010).

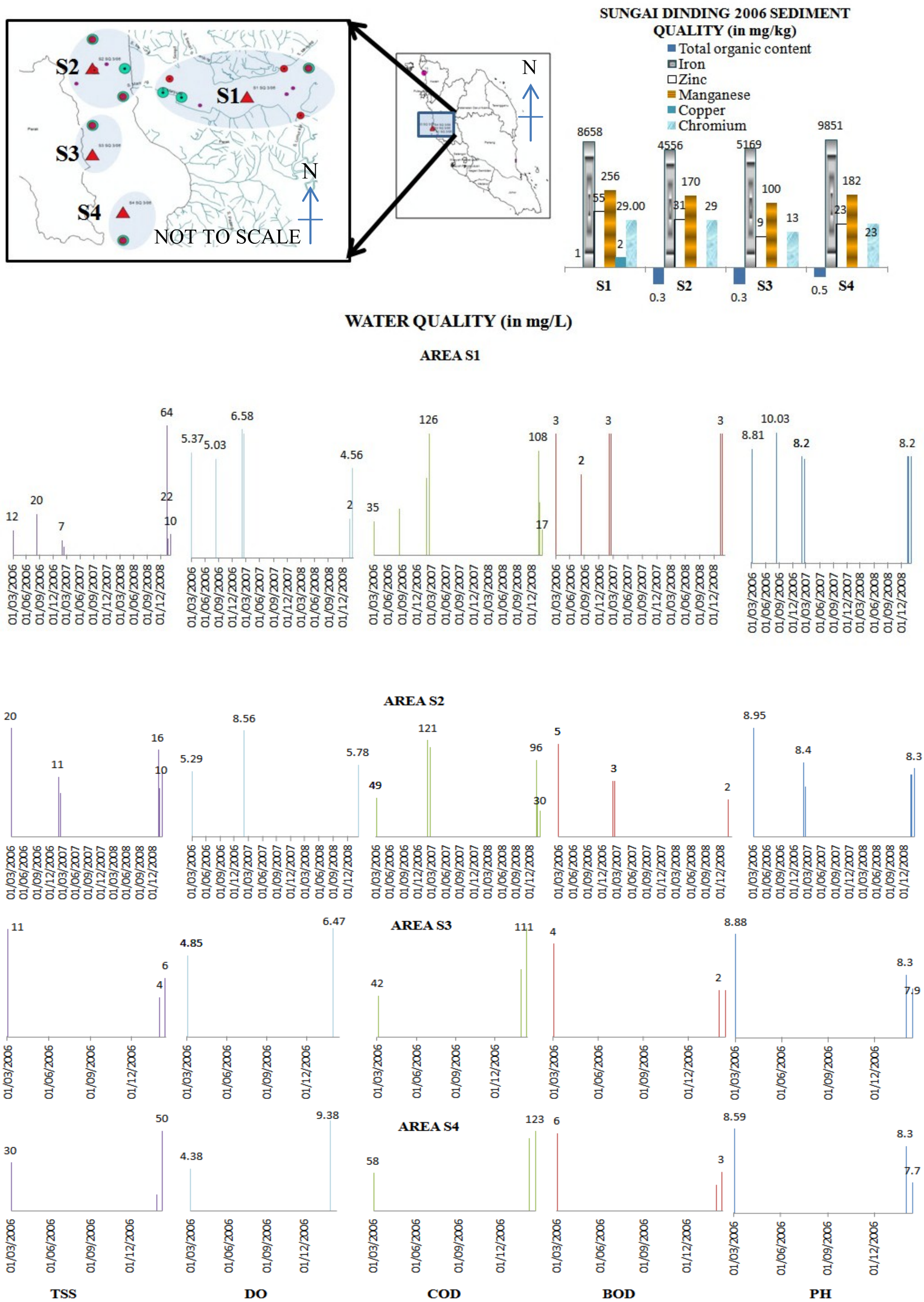


Figure 5-1 Indicator levels monitored during dredging projects in Sungai Dinding in 2006 and 2008

Impacts of dredging on caged fish at Sungai Sitiawan river

Analysis was performed on an incident fatally affecting fish at an aquaculture farm on 6th October 2008. On the same day as this incident, it was reported that a THSD (located in site 4, 1.6 km upstream of the aquaculture farm) was commencing dredging during low tide. The location of the THSD and aquaculture farm is illustrated in Figure 5-2. Toxicological analysis reported that caged fish in the aquaculture farm died mainly due to a reduced oxygen level in the water. It was also reported that levels of boron, copper, iron and zinc were high in the skin cells of the caged fish. In order to determine the relationship between the fatal incident and dredging operations adjacent to the aquaculture farm, a total of 92 water samples from three dredging projects were assessed. Locations and indicators shown to be above reference values (MWQSC as Figure C-9 in Appendix C) are illustrated in Figure 5-2.

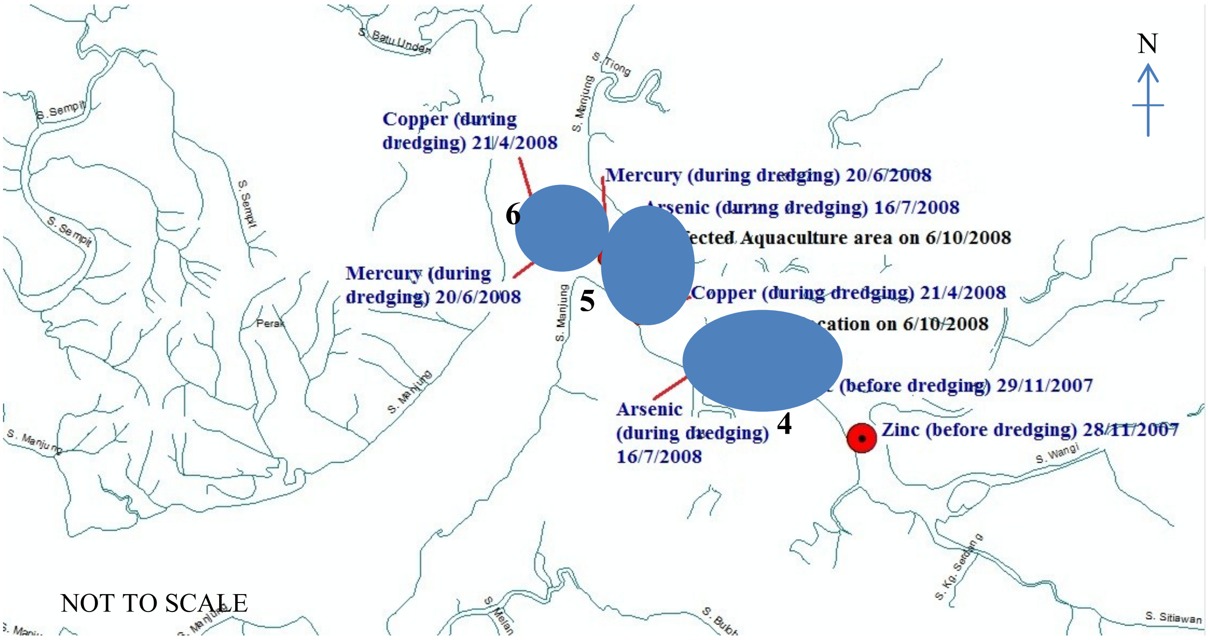


Figure 5-2 Location of affected aquaculture farm and dredger on 6/10/2008, and of sites with metals above standard values

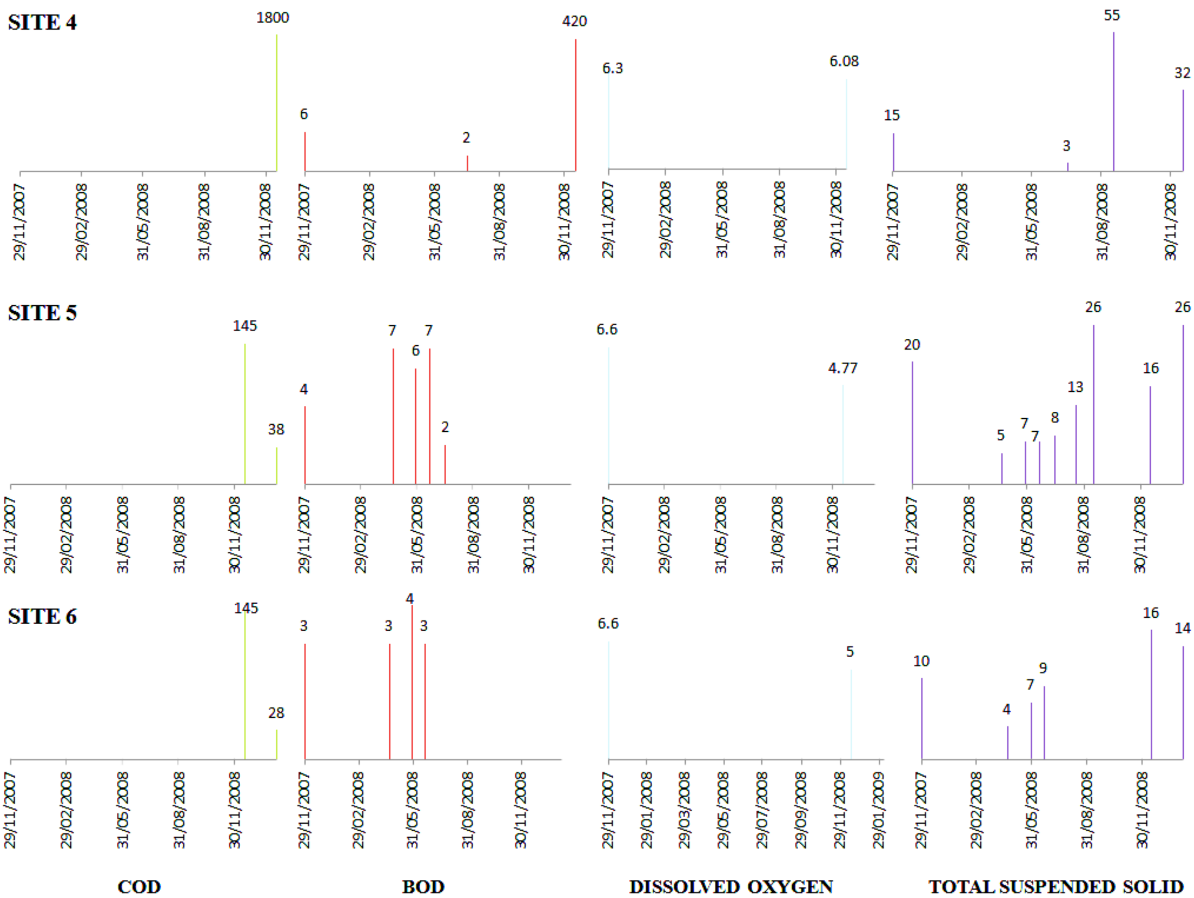


Figure 5-3 Physical water quality indicators at different sites at Sungai Sitiawan river, derived from 33 water samples (in mg/L)

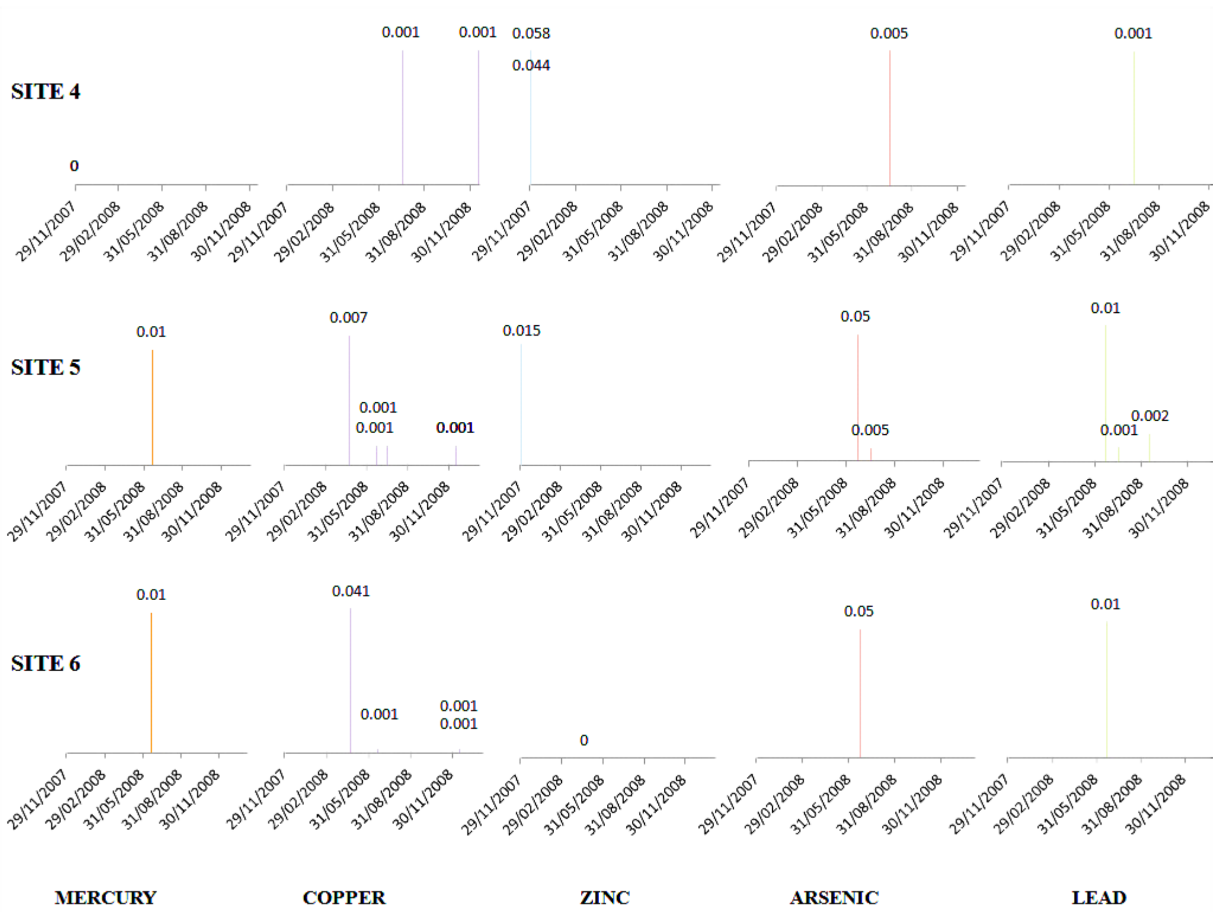


Figure 5-4 Metals at 3 sites at Sungai Sitiawan river, derived from 33 water samples (in mg/L)

5.3 Discussion

This chapter presented the third developmental step of the proposed framework that further analyses the dredging environmental impacts and its factors, as discussed in subsequent subsections, using Malaysia's historical dredging monitoring data in order to manage dredging impacts efficiently.

5.3.1 Relationship between levels of contamination in sediments and pattern of changes in water quality at Sungai Dinding 2006 and 2008

Two dredging projects undertaken at different locations were assessed, identifying four main conclusions.

Firstly, more significant changes in water quality occurred in the highly contaminated area than in the less contaminated area. A high level of iron and manganese in sediments was identified at all locations in the sediment quality analysis. It was noted that area S1 had the highest level of manganese (256 mg/L), zinc (55 mg/kg), total organic content (1 mg/kg), copper (2 mg/kg) and chromium (29 mg/kg), while area S4 has the highest level of iron (9851 mg/kg). Relatively low levels of contamination were found at S3 and S4. Nevertheless, zinc, copper and chromium levels in the sediments did not exceed the lower benchmark values of Ireland, the United Kingdom, Belgium and Canada (The National Oceanic and Atmospheric Administration (NOAA) 2006, Praveena 2008, Pan 2010) in any of these areas, meaning that the sediments of this river would be classified as uncontaminated. In spite of this, it should be emphasized that, while sediment values did not exceed benchmark values, the high levels of metals found could adversely affect DO levels in certain areas (refer Subsection C-1 in Appendix C).

It can be observed that DO levels at S2, S3 and S4 increased, with increases ranging between 9% and 114%. This shows that dredging led to an improvement in DO levels in all areas, except in area S1. This could be attributed to the fact that S1 had the highest levels of metals in sediments of these areas. This is in line with research by Ponti et al (2009) which showed that the use of dragline and excavator at highly contaminated sites poses a high risk of degradation in terms of chemical parameters of the environment (Ellery, McCarthy 1998). This further shows the prominence of sediment contamination levels as a factor affecting water quality after dredging. This is reinforced by the fact that, during dredging, the pH level in area S1 exceeded the reference values for Class E (mangroves, estuarine and river mouth water) of Malaysia's MWQCS (Figure C-9 in Appendix C). It is worth noting that at the same time as when the pH in area S1 exceeded the reference values, no monitoring was conducted at the other areas, meaning that no comparison can be made between the pH values in area S1 and the values at other areas. It can be noted, however, that the pH levels decreased in all areas, though maintaining an alkaline state. Therefore, it can be concluded that more substantial decreases in water quality occurred at the highly contaminated S1 area than in the less contaminated areas of S2, S3 and S4.

Secondly, a month was required for the water quality in this river to improve after the disturbance caused by dredging. After 31 months since the first monitoring, TSS levels increased in areas S1 (433%) and S4 (67%) when compared to levels monitored before dredging, while TSS levels in other areas decreased. However, at area S1, TSS levels decreased by 84% in the 32nd month, reaching a level below that before dredging, indicating an overall improvement. No monitoring of TSS levels was conducted at S3 and S4 over a comparable interval, but a similar pattern of decrease was found in area S2. This analysis indicates that TSS levels can recover within one month.

Thirdly, DO levels showed a negative linear relationship with TSS and COD levels, i.e. when either of these levels increase, DO levels decrease. TSS levels demonstrated a negative linear relationship with DO levels in areas S1, S2, and S3. For example, in area S1, when TSS reached their peak, DO levels decreased to their lowest level. This means contaminants that dispersed with TSS deleteriously consumed DO levels.

Fourthly, similar patterns of changes were identified with regard to TSS and COD. TSS and COD levels demonstrated a direct relationship meaning that when TSS levels increase, so do COD levels. Moreover, COD levels increased in all areas, ranging from 98% to 208% compared to the levels monitored before dredging and representing a negative change. This is likely due to the fact that all areas were noted to have high levels of heavy metal contamination. Additionally, area S1 recorded the highest COD level out of the areas monitored, with an increase of 260% found about a year after the first monitoring, likely due to the fact that the area was heavily contaminated with organic compounds.

It has been shown in previous research by Thebedaux and Duckworth (2001) that the levels of organic compounds, including polychlorinated biphenyl (PCB) and polynuclear aromatic hydrocarbons (PAH), increased during and after dredging (Thibodeaux, Duckworth 2001). Nevertheless, COD levels soon recovered, as after a month levels in this area and in S2 were found to be lower that the levels before dredging. At the same time, BOD levels at all areas remained at a similar level or slightly decreased when compared to levels before dredging.

5.3.2 Pattern of changes in water quality and its impacts on caged fish at Sungai Sitiawan river, 2007

A dredging project undertaken at Sungai Sitiawan river was assessed, identifying five main conclusions.

Firstly, COD and BOD levels at Site 4 were heavily affected by dredging and by the deterioration of water quality in the rivers upstream, Sungai Deralik and Sungai Wangi. This shows that the deterioration of water quality status upstream, affected by adjacent on-land activities, can worsen the impacts of dredging. It was also noted that the dredging sites were situated adjacent to an industrial compound containing an active fabrication yard for the oil and gas industry. However, no sediment analysis was made prior to dredging to ascertain the level of sediment contamination. Nevertheless, physical indicators of water quality were monitored, comprising COD, BOD, DO and TSS, though COD levels were not monitored before dredging at any of the sites.

More dramatic changes were observed at Site 4 than at other sites, which is the location where dredging was commenced during low tide on 6th October 2008. At this site, it was noted that COD and BOD levels were extremely high in the samples taken 2 months after the incident, with the COD level being 1800 mg/L and the BOD level 420 mg/L. The true severity of these levels is made clear when they are compared to the levels monitored at other locations in the rivers of Sungai Sitiawan and Sungai Dinding. They were plotted in Figure 5-5, derived from 92 water samples, with 2 bubble graphs illustrating COD and BOD levels against their longitudes and latitudes. These graphs demonstrate that COD and BOD levels at Site 4 were much higher than at the other sites. This could be attributed to increases of organic and inorganic levels at this site.

As mentioned previously, the water quality of rivers situated upstream of dredged sites, including Sungai Deralik and Sungai Wangi, had deteriorated. Thus, it is logical to conclude that their deterioration dramatically affected the water quality at the nearest monitoring site, which in this case was Site 4. Although no sediment quality analysis was undertaken prior to dredging, the high levels of COD and BOD levels detected during dredging indicate that these dredging sites were highly contaminated. In addition, it was previously noted that the level of contamination in sediments sampled further downstream from these sites was extremely high. It was evident that the TSS level at Site 4 was the highest among the sites (55 mg/L) within the month prior to the incident, further worsening the water quality. However, despite the fact that this site faced the greatest deterioration of water quality in terms of TSS, COD and BOD, DO levels at this site were peculiarly seen to decrease only slightly to 3% a year after the first monitoring.

Figure 5-5 The COD and BOD levels of 92 water samples

Secondly, the worst affected sites when it comes to DO levels were Site 5 (the location of the aquaculture farm) and 6, which had a significantly higher level of deterioration than at Site 4. This was monitored by comparing the levels before dredging with the levels two months after the fatal incident, and may have been due to the fact that Site 5 and 6 were located downstream of Site 4. The relatively low DO levels found at Site 4 could be explained by higher levels of oxidation that would occur as a result of the high BOD and COD levels, as previously discussed. Furthermore, the high levels of heavy metals found at these sites would cause further deterioration in DO levels.

Thirdly, it took approximately five months for signs of recovery to be seen at Site 5, where the aquaculture farm was located. The pattern of changes monitored at this site was similar to that of Site 4, albeit not as dramatic; COD levels at this site were not as high as the levels in the site upstream.

Five months after the incident, COD levels had decreased 74%, a positive sign which indicates that the site had begun to recover within this period.

Fourthly, the water quality had begun deteriorating before the incident occurred, and did not recover during the following two months, a scenario seen at Sites 5 and 6. At Site 5, DO levels showed a significant decrease of 28%, comparing levels monitored before dredging with levels two months after the incident. This comes in parallel to the investigation report from the Aquatic Toxicological Centre, stating that the fatal incident was caused by reduced oxygen. As the fish were caged, thereby limiting their mobility, the reduced oxygen level led to their death. Moreover, the decrease in DO levels was detected 2 months after the incident, indicating that more than two months is required for the water quality to recover. It appears that approximately 3 months before the incident, BOD levels at Site 5 decreased to half the level before dredging. In addition, TSS levels at this site consistently increased from before dredging until 3 months before the incident. This shows that the water quality had begun deteriorating before the incident took place. At the same time, at Site 6, COD levels were 81% lower 5 months after the incident, a positive indication. The change in BOD levels before dredging and three months before the incident was negligible. This could be due to the fact that Site 6 was located furthest from the deteriorated water quality of upstream rivers and dredged sites. A similar pattern of changes occurred at this site as with Site 5, with DO levels decreasing 24%, comparing levels before dredging with levels two months after the incident. This further demonstrates that water quality at this site failed to begin recovering even two months after the incident.

Fifthly, it can be concluded that metal levels increased during dredging, that the time needed for water quality to begin recovering from the disturbance of dredging was less than a year, and that the dispersal of contaminants creates a risk of bioaccumulation. Figure 5-4 illustrates metal levels in the water, including mercury, copper, zinc, arsenic and lead. It was found that, before dredging, metals were at undetectable levels at almost all sites. Nevertheless, it can be seen that their levels increased mid-way through the monitoring, but decreased towards the end. Thus, it shows that dredging, being the prime source of sediment disturbance during the duration monitored, negatively affected the levels of contamination at most of the sites. This further demonstrates that during the extraction stage of dredging, the disturbance of sediments caused the release of contaminants from sediments into the water, thus affecting levels of contamination. In addition, the levels decreased towards the end of the monitoring duration, showing that the period needed for recovery to begin from the disturbance of metals was within a year.

5.3.3 Overall discussion

Data obtained in previous studies (Tables 5-1, 5-2 and Appendix E) indicate how dredging adversely impacts the environment. According to Ponti et al (2009) and Thibodeaux and Duckworth (2001), levels of organic and inorganic compounds in sediments and water increased after dredging (Ponti, Pasteris et al. 2009, Thibodeaux, Duckworth 2001). This was blamed on high levels of sediment contamination.

Developing countries especially may neglect the importance of sediment quality analysis as part of good dredging management. This is shown in the case of Malaysia, presented here and in Subsection C.1 in Appendix C. This nation is an especially good example among developing countries given its active dredging industry and its critically important environmental assets, which are reportedly deteriorating (Spalding 2001). In addition, this country has had difficulties in effectively monitoring the impacts of dredging (Manap, Voulvoulis et al. 2012). In light of this, our study assessed how Malaysia monitors dredging impacts. For this chapter, three dredging projects undertaken in Perak, Malaysia were analysed to identify vital dredging impact factors in order to develop a decision making framework to help dredging stakeholders to make a sustainable decision when selecting sediment management option.

This study indicates that, in Malaysia, the negative impacts of dredging results from the fact that sediment quality analysis is often neglected and misleading and water quality is not properly monitored. Additionally, this study highlighted that dredging causes contaminants to disperse from sediments, thereby negatively affecting the water quality of the river. Furthermore, dredging has been shown to negatively impact the environment by causing bioaccumulation and a lack of dissolved oxygen, as can be seen from the incident that occurred at Sungai Sitiawan river which fatally affected a fish farm.

Dredging at Sungai Sitiawan and Dinding rivers caused critical changes of indicators and most of their water quality values during dredging exceeded national reference values. Additionally, it was found that the contamination level in neighbouring area, assessed through WQI of upstream rivers, was deteriorating, and this could lead to accumulation of contaminants in sediments and fishes that located at downstream river. However, the environmental risk of dredging in these areas has not been assessed prior to dredging. Even though sediment quality analysis had already been performed, showing that they were uncontaminated according to selected sediment international reference values (The National Oceanic and Atmospheric Administration (NOAA) 2006, Praveena 2008, Pan 2010), it is important to note that contaminants in sediments, which are dispersed by dredging, will consume dissolved oxygen through oxidation. This will eventually lower the level of dissolved oxygen available for caged fish and benthos, potentially resulting in their death.

In fact, reference values found in sediment quality guidelines used in developed countries, like those for instance used in the UK (Department for environment, food and rural affairs (DEFRA) 2007); only take into consideration priority substances that are carcinogenic, and overlook other substances like iron and manganese. This contrasts with the findings of this study, which shows that high levels of iron and manganese in sediments can fatally affect caged fish due to lack of oxygen. Thus, levels of non-priority substances also need to be taken into account when deciding the levels of contamination in an area, bearing the level of DO in mind.

Moreover, the non-existence of Malaysia's sediment quality reference values forced this study to use international reference values. It should be highlighted that the use of nationalized sediment quality guidelines has been contended in developed countries due to the threshold limit values of sediments that are variable and site-specific, it is therefore doubtful that these values will be applicable to national or wide geographical areas (Burton 2002). Therefore, there remains a need for this country to develop its own sediment quality reference values on a case by case basis, in order to help prevent the impacts of dredging.

Nevertheless, all metals monitored in the water at the location of case studies were compared to MWQSC values (Figure C-9 in Appendix C). It was noted that most metal values monitored in the water exceeded the reference values. In addition, it shows that Site 5, where the aquaculture farm was situated, had the highest number of metals in the water exceeding reference values: mercury, arsenic and copper. Furthermore, this occurred as early as 6 months before the incident, which could easily have led to the bioaccumulation of metals in the caged fish. This was confirmed by the toxicological report, where it was reported that the skin cells of caged fish contained high levels of metals, including copper, iron, zinc and boron, signalling that bioaccumulation was occurring prior to the incident.

This study underlined the vital dredging impact factors that must be considered prior to dredging, namely **contamination levels of sediment and of neighbouring area**. In addition, it has also indicated the need for an environmental management tool to help assess these vital dredging impact factors (contamination level of sediment and neighbouring area) when dealing with sensitive and highly contaminated areas.

IEM tool that illustrated by Abriak et al. (2006) has been seen as one such potential tool (Abriak, Junqua et al. 2006). It uses a strategic approach that covers cumulative effects from adjacent areas and sediment contamination levels. The adaptation of this tool into a scenario of developing nation such as Malaysia that often stressed upon economic benefit has been seen as necessary. This holistic approach would help to better anticipate the impacts of dredging, and allow for suitable mitigation measures to be identified, subsequently proposing a sustainable decision for dredging practices.

However, some limitations are worth noting. Although this study was supported statistically, it was not possible to identify the exact time and date of commencement and cessation of dredging operations. Therefore, future work should attempt to take into consideration the exact time and duration of dredging in order to anticipate the impact factors more accurately.

More importantly, the use of IEM approach in country such as Malaysia requires further research and development, focussing on integrating conflicting factors of socio-economic, environmental and management and of dredging impacts and its factors (as highlighted in this chapter) using a newly developed decision making framework that has been tapped into the scenario of developing nation.

5.4 Conclusion

This chapter presented the second developmental step of the proposed framework that further analyses the dredging environmental impacts and its factors using Malaysia's historical dredging monitoring data in order to manage dredging impacts efficiently. It was found that, in virtually all cases, the impacts of dredging were associated with these factors: levels of contamination in sediments and neighbouring area. The findings of this study therefore underline the importance of sediment quality analysis and analysis of contamination level in neighbouring area as the main factors that need to be performed prior dredging. Above all, this chapter provides compelling evidence for the use of IEM in a location such as Malaysia to improve its practices of dredging while maintaining its navigational benefits by integrating the conflicting problems of environmental, socio-economic, and managerial towards achieving a sustainable decision.

6 OTHER PROBLEMS RELATED TO DREDGING

6.1 Introduction

The third developmental step of the proposed framework is presented in this chapter that aims to analyse dredging problems other than dredging environmental impacts using DPSIR. This is in order to develop an integrated and holistic framework that not only focusses on scientific evidence.

Malaysia is rich with natural resources, one of which, historically speaking, is tin. In 1850, it was mined by labourers and exported to foreign countries. Due to the high demand for it, dredging was introduced to Malaysia by Europeans in 1910 (Gubbay 2005, Hennart 1986, Netzband, Adnitt 2009).

In recent years, dredging has been performed in many projects in Malaysia. For example in 2000, intensive dredging, the cost of which amounted to USD 1.0 billion, was performed for the first phase of port development at Tanjung Pelepas, Johor (Renkema, Kinlan 2000, The Institution of Engineers Malaysia 1999), and USD 13 million were allocated for dredging works to alleviate flood problems in Selangor under the 10th Malaysia Plan in 2010 (Bernama.com 2010). However, numerous researchers have scientifically established the environmental impacts of dredging (Messieh, Rowell et al. 1991, Sergeev 2009). They have prominently characterized dredging as a disturbance of nature.

Environmental preservation in Malaysia was first established in 1971 with the formation of the National Forestry Council. This was followed by an enactment of the Protection of Wildlife Act and the Environmental Quality Act in 1972 and 1974, respectively. In addition, on 1st April 1988 the Environmental Impact Assessment (EIA) Order of 1987 was enacted, requiring 19 categories of activities to perform EIA (Government of Malaysia 5th November 1987, Briffett, Obbard et al. 2004, Hezri, Hasan 2006).

One of the categories of activities under the EIA Order 1987 was mining. The requirement of EIA submission under the mining category covered a number of activities, namely the mining of minerals in new areas where the mining lease covered a total area in excess of 250 hectares; ore processing, including concentrating for aluminium, copper, gold or tantalum; and sand dredging involving areas of 50 hectares or more. The latter requirement of EIA is the closest in relation to the recent application and is widely applied for dredging in Malaysia. This means that any dredging works involving sand as their dredged material and covering an area of less than 50 hectares are excluded from performing the EIA.

In addition to EIA Order 1987, several other guidelines pertaining to dredging have been developed by government departments. These include 'Guidelines on Erosion Control for Development Projects in the Coastal Zone' developed by the Department of Irrigation and Drainage Malaysia, and 'Environmental Impact Assessment Guidance Document for Sand Mining/Dredging Activities' developed by the Department of Environment Malaysia (Department of Environment Malaysia 2007, Department of Irrigation and Drainage Malaysia 1997, Department of Environment 2007). Moreover, the Environmental Impact Assessment (EIA) Procedures and Requirements, published by the Department of Environment Malaysia, states that the formal procedure of EIA under EIA Order 1987 consists of three steps, namely preliminary assessment, detailed assessment and review (Department of Environment, Ministry of Science, Technology and the Environment Malaysia 1993, Legal Research Board 2005).

As stated above, the EIA Order 1987 was transposed into Malaysia's legislation over 20 years ago to prevent environmental damage (Government of Malaysia 5th November 1987). Although this Act has been applied for almost 3 decades, to date its effect is debatable (Emang 2006, Staerdahl, Schroll et al. 2004). In fact, looking at global opinions, many researchers have suggested that the EIA system is ineffective especially in developing nations (Rajaram, Das 2008, Ahammed, Harvey 2004, Tang, Tang et al. 2005, Jou, Liaw 2006, Tortajada 2000, Alshuwaikat, Rahman et al. 2007, Jain 1999, Kolhoff, Runhaar et al. 2009).

Nevertheless, Malaysia has put a plan in place to achieve fully developed status by 2020 (Mohamad 2010). In order to achieve this, without neglecting the environmental aspect, it is crucial to establish Malaysia's environmental problems (for example dredging problems) and to convey them to Malaysia's government in order for the necessary action to be taken. One of the options for doing this is to investigate the problems faced by Malaysia's dredging industry by employing an interview and questionnaire-based survey with its stakeholders as the respondents.

The European Environmental Agency (EEA) has referred to the requirement of this type of investigation in their report which states: *"Together they should develop what is here called "the story": a description of the stakeholders' view on the issue and the ways they see it solved. The "story" focuses and frames the issue. It is here that the understanding of the DPSIR framework and its dynamics enters the process. Driving force-Pressure-State-Impact-Response (DPSIR)-thinking helps to systematize the causes of a problem and the various responses"* (European Environment Agency 2003).

DPSIR is a tool of Integrated Environmental Management (IEM) that integrates the environmental and socio-economic impacts for a basis of detail analysis (Pacheco, Carrasco et al. 2007, Beliaeff, Pelletire 2011). It is developed to give a better understanding, in a politically meaningful way, of an environmental problem on multiple levels and at large scale (Ness, Anderberg et al. 2010, Maxim, Spangenberg et al. 2009, Langmead, McQuatters Gollop et al. 2009, Pacheco, Carrasco et al. 2007, Bidone, Lacerda 2004, Carr, Wingard et al. 2007). DPSIR also defines and develops environmental indicators in relation to anthropogenic activities (Maxim, Spangenberg et al. 2009, Pacheco, Carrasco et al. 2007, Beliaeff, Pelletire 2011). Furthermore, it has been utilized to identify pressures and impacts under the Water Framework Directive (Kagalou 2010).

DPSIR produces a framework which creates the description of an environmental problem by defining the relationship between the anthropogenic activities and the environment using indicators that integrate the socio-economic and environmental impacts resulting from related human activities. Pacheco and Carrasco (2007) have described the processes to implement this tool as: "*the environmental issues and solutions are simplified into indicators that clarify the cause and effect relationships between anthropogenic activities that generate pressures on the environment (pressure), the condition of the environment (state), and society's response to these conditions (response)*" (Pacheco, Carrasco et al. 2007).

The evolution of the DPSIR framework started in the late 1970s with the Stress-Response model by Rapport and Friends, followed by the Pressure-State-Response model by Organisation for Economic Cooperation and Development, and the Driver-Pressure-Response model by the United Nations Commission on Sustainable Development (Ness, Anderberg et al. 2010, Carr, Wingard et al. 2007). The EEA adapted these models and developed the DPSIR framework in 1999 (Carr, Wingard et al. 2007).

A clear cause-effect relationship of environmental problems, which appeals to policy makers, is one of the advantages of this framework. In addition, this framework integrates and structures different indicators (including environmental, social and economic ones), which in turn leads to proposals for relevant political objectives (Maxim, Spangenberg et al. 2009, Pacheco, Carrasco et al. 2007). Nevertheless, this framework also has certain flaws. Simplicity and linearity, which potentially defy the reliability of analysis, are the common flaws for this framework (Ness, Anderberg et al. 2010, Maxim, Spangenberg et al. 2009, Langmead, McQuatters Gollop et al. 2009).

This chapter presents the third developmental step of the proposed framework to analyse dredging problems other than dredging environmental impacts using DPSIR. This is in order to develop an integrated and holistic framework that not only focusses on scientific evidence.

6.2 Methodology

Face-to-face interview sessions were held in 2008 with members of both upper and middle management to identify problems faced by Malaysia's dredging stakeholders. The details of the interviewees are listed in Table 6-1. Interview data was analyzed using Microsoft Excel, where the pools of data were characterized into different themes of problems (driver), pressure and state. In order to avoid bias issue, the characterization of themes is based on the collective agreement of stakeholders from different positions, ranks and departments. These categories are then further grouped into three broader classifications, namely environment, socio-economic and management.

Table 6-1 Interview respondents

Stakeholder		Representative's position rank
Client	Port administrator	General Manager
		Head of Environment Section
		Senior Executive of Corporate Communications
	Manufacturing company	Assistant Manager for Health, Security, Safety and Environment Department
		Assistant Manager of Civil Department
	Government of Malaysia	Marine Officer
Contractor	Contractor A	Assistant Manager
	Contractor B	Senior Project Manager
	Contractor C	Project Manager
Public	Environmentalist	Corporate Executive
	Public	Head village

A questionnaire, the main questions of which are as presented in Table 6-2, was developed and distributed in 2010 in order to collect information on current practices and problems relating to dredging in Malaysia. The rest of the results of this questionnaire are as in Appendix B. A total of 282 invitations were distributed via email. A list of registered environmental consultants under Malaysia's Department of Environment has drawn from a wide range of specialized areas including: general environmental management; coastal zone management; maritime; and mining. The questionnaire was also distributed to registered contractors, in dredging-related industries listed in the Construction Industry Development Board (CIDB) and Malaysia's Contractor Service Centre. Fifty professionals, including marine ecologists, registered chemists, professional and chartered engineers, environmental consultants, university professors and environmental analysts responded. A list of local experts that responded to this questionnaire can be found in Table B-1 in Appendix B.

Table 6-2 The main questions in the questionnaire

No	Questions
1.	Do you agree that existing environmental legislation for dredging in Malaysia is adequate?
2.	Do you agree that Malaysia's current environmental legislations and guidelines for dredging works are not strictly affixed, especially for monitoring aspects?
3.	Do you agree that Malaysia's existing environmental management tools and practices for dredging works are efficient?
4.	Do you agree that Malaysia's dredging industry lacks the guidance necessary to implement efficient environmental management tools and practices?

Figure 6-1 shows the percentages of respondents from different organizations. The majority of them are environmental consultants and 26% of the respondents are from other organizations that include academic, concessionaires, civil and structural consultants, and safety consultants. Only 3% of respondents are from government sectors and 6% are contractors.

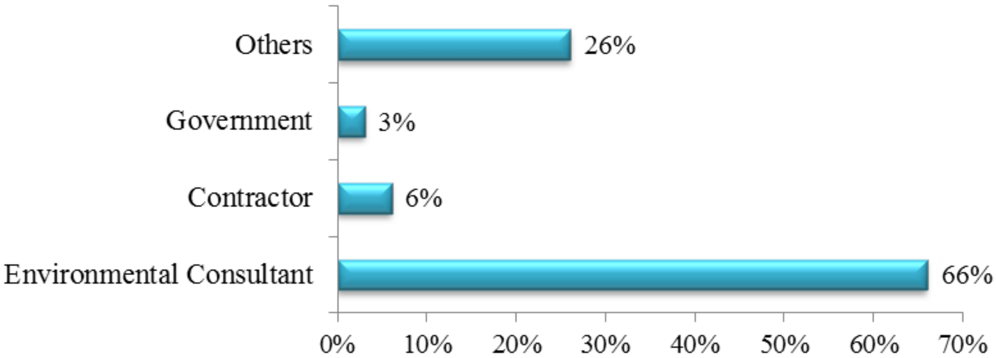


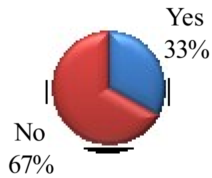
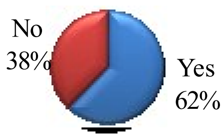
Figure 6-1 The percentage of questionnaire survey respondents

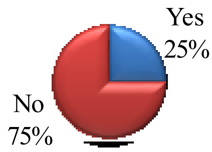
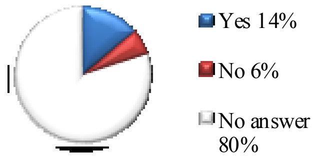
6.3 Results

6.3.1 The questionnaire results

The results of questionnaire survey are as detailed in Table 6-3 and as per Appendix B. The result suggests that the environmental legislation for dredging in Malaysia is weak and that efficient environmental management tools and practices are required for it to be strengthened.

Table 6-3 Questionnaire results

Questions	Answer
Do you agree that existing environmental legislation for dredging in Malaysia is adequate?	
Do you agree that Malaysia's current environmental legislations and guidelines for dredging works are not strictly affixed, especially for monitoring aspects?	

Do you agree that Malaysia's existing environmental management tools and practices for dredging works are efficient?	
Do you agree that Malaysia's dredging industry lacks the guidance necessary to implement efficient environmental management tools and practices?	

6.3.2 The interview results

The results of the interview sessions are as detailed in Table 6-4, Table 6-5 and Table 6-6, which were structured according to the DPSIR framework. It is found that socio-economic, the environment and management are the drivers which result in relevant pressures and impacts onto Malaysia's dredging stakeholders. All respondents have demanded that actions be taken by the relevant parties, which in their view were responsible of the problems they faced.

Table 6-4 Interview result: Socio-economic as a driver

Driver (D)	Pressure (P)	State (S)	Impacts (I)	Response (R)	
				Action	Responsibility
Socio-economy	Compensation cost for local communities	High	Financial burden	Build apartment for illegal residents on gazette area and sell to local communities at a low price	Client
				Give compensation based on social obligation	Client
				Strict regulation of government gazette area	Client (Government)
				Government bodies (i.e. Fisheries Department) to set a guideline for fishermen in dredged areas	Client (Government)
				Forums to be held with neighbour and authority parties (i.e. Fisheries Development Authority of Malaysia) on dredging benefits	Client
	Cost of environmental monitoring, mitigation measures and remediation	High	Financial burden, Environmental negligence	Negotiation with neighbouring industry, who exhibited a low standard of waste management	Client and Contractor
				Identify source of effluent containing contaminants and suggest ways for improvement	Client and Contractor
				Engage with good manufacturing factory for technology transfer	Client (Government)
				Allocate funds for environmental monitoring	Client
	Research cost	High	Environmental negligence	Joint venture with dredging stakeholders	Environmentalist and Client
				Adopt nearest island	Environmentalist and Client

Table 6-5 Interview result: Environment as a driver

Driver (D)	Pressure (P)	State (S)	Impacts (I)	Response (R)	
				Action	**Responsibility**
Environment	Flood and erosion	Happened after dredging	Public complaint	Investigate source of flood	Client and Contractor
	Dredging operation	Noisy	Public complaint	Follow Department of Environment's rules	Client and Contractor
	Turbidity	High level	Public complaint	Build bund or use silt curtain	Contractor
				Recycle dredged material by filling on nearest swamp	Contractor
	Marine traffic	Increased	Public complaint	Close one lane of traffic to not disturb current vessel operation	Client and Contractor
				Analyze existing marine traffic from local maritime or river authority	Client and Contractor
				Re-route existing local traffic	Client and Contractor
	Marine life	Disturbed	Public complaint, Fisherman income depleted	Upgrade dredging technology towards environmental friendly	Client and Contractor
				Consider vessel type during pre-tender process	Client and Contractor
				Replant sea grass and mangrove on an adopted island	Client, Contractor and Environmentalist
				Set environment procedure to be followed	Client (Government)
				Provide dustbin on vessel	Contractor
				Establish and implement environment preservation with Europeans as a benchmark	Client (Government)
				Regular water monitoring for contamination trend	Client, Contractor and Environmentalist
				Good environmental control measures applied since the beginning	Client and Contractor
				Set up perimeter bund at diesel tank	Contractor
				Strict law enforcement on vessel permit	Client (Government)

Table 6-6 Interview result: Management as a driver

Driver (D)	**Pressure (P)**	**State (S)**	**Impacts (I)**	**Response (R)**	
				Action	**Responsibility**
Management	Project information	Not channeled to public	Public complaint	Announcement and discussion through 'Opening Ceremony' prior to the commencement of the dredging project	Client and Contractor
	Monitoring personnel	Inexperience and not enough manpower	Project delayed, High cost, Environment negligence, Dispute	Contractor to make sure the Spoil Monitoring system is functioning well	Contractor
				Regular briefing and site visits of local authority for exposure	Client
				Malaysian environmental policy and enforcement should be strengthened	Client (Government)
				Send monthly report and minutes of meeting to relevant government representatives	Contractor
				Payment certificate not to be endorsed unless the subcontractors have successfully performed their work	Client
				Deduction on payment if work quality is low	Client
				Apply liquidated damages for delayed project	Client
				Engage a licensed hydrographical surveyor to confirm contractor's work	Client
	Agreements	Obscure clauses	Dispute	Proper agreement sealed after meetings	Client and Contractor
	Vessel maintenance cost	High	Machine clog	Use appropriate types of dredgers. i.e. excavator is more efficient than CSD due to less clogging	Client and Contractor
	Government feedback	Too slow	Project delayed	Speed up government feedback	Client (Government)
				Fast feedback	Client (Government)
				Less politic interference	Client (Government)

(continued..)

Driver (D)	**Pressure (P)**	**State (S)**	**Impacts (I)**	**Response (R)**	
				Action	**Responsibility**
Management	Government requirement	Strict guidelines, quality standards and conditions	Project delayed	Flexibility in dredging and slope shape tolerance	Client (Government)
	Coordination by Government representative	None during pre-tendering process	Dispute, Project delayed	Government representative (i.e. DOE) involve in pre-tendering process to avoid coordination problem	Client (Government)
				Monthly meeting between client and contractor	Client and Contractor
				To provide environmental specification in pre-tender process	Client (Government)
	Management of dredging	Inexperience	Project delayed, High cost, Environmental negligence, Dispute	Hire experienced environmental contractor and consultant	Client
				ISO 14001, ISO 9002 and OHSAS 18001 certified	Client and Contractor
				Benchmarking	Client and Contractor
				Perform site visit to determine surrounding activity	Client and Contractor
				Safety meeting every 3 months	Client and Contractor
				Awareness meeting with contractor weekly	Client
	Monitoring personnel	Inexperience and not enough manpower	Project delayed, High cost, Environmental negligence, Dispute	Contractor to make sure Spoil Monitoring system is functioning well	Contractor
				Regular briefing and site visits of local authority for exposure	Client
				Malaysian environmental policy and enforcement should be strengthen	Client (Government)
				Send monthly report and minutes of meeting to relevant government representative	Contractor

6.4 Discussion

The third developmental step of the proposed framework is presented in this chapter to analyse dredging problems other than dredging environmental impacts using DPSIR. This is in order to develop an integrated and holistic framework that not only focusses on scientific evidence.

Fifty participants responded to a questionnaire and the results suggested that efficient environmental management tools and practices are required to aid current Malaysian environmental legislation in relation to dredging. In addition, eleven members from a variety of dredging stakeholder groups were interviewed and Figure 6-2, Figure 6-3 and Figure 6-4 give a summary of the interview results, which were grouped into different drivers (socio-economic, the environment and management) using the DPSIR framework.

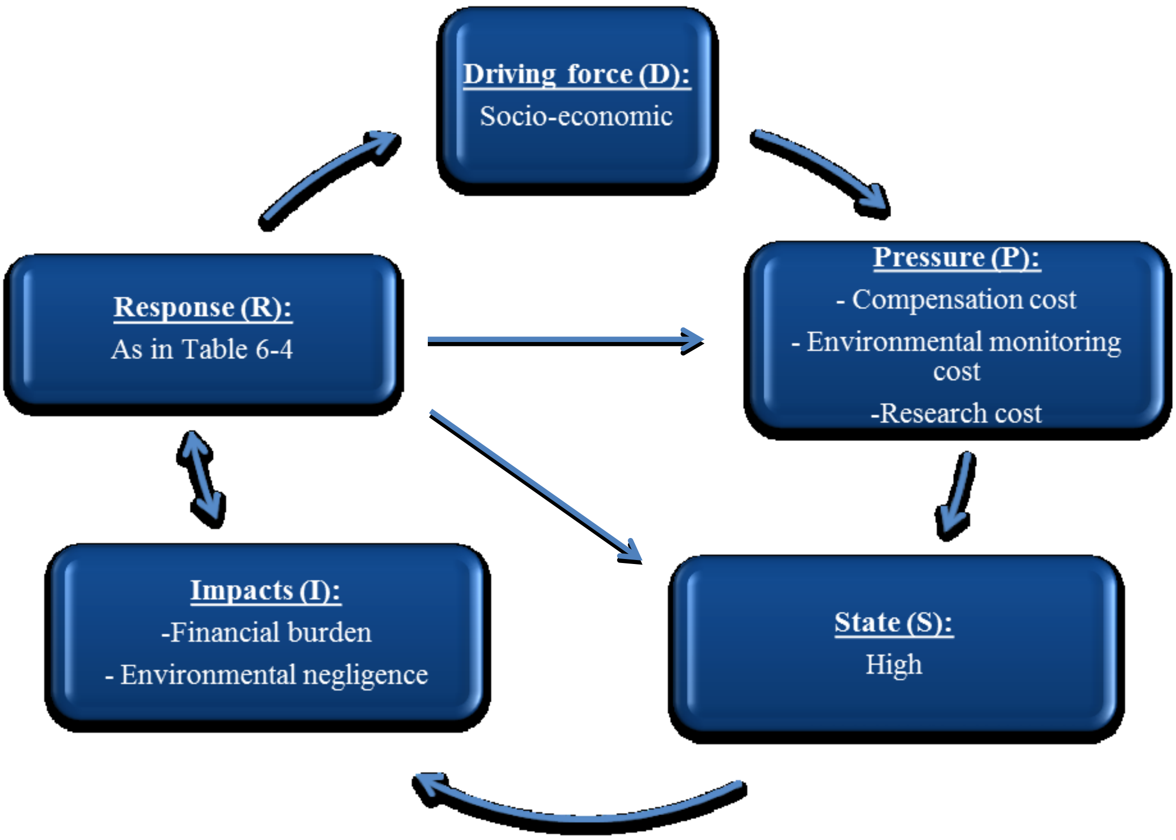


Figure 6-2 DPSIR Framework with socio-economy as the driver

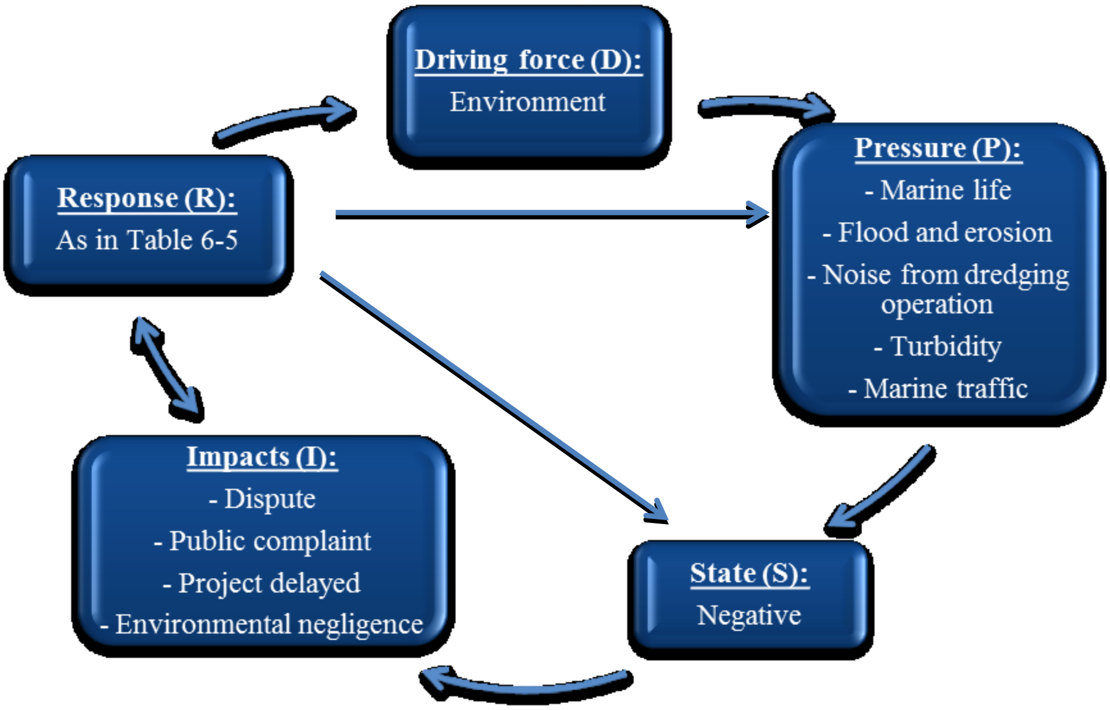


Figure 6-3 DPSIR Framework with environment as the driver

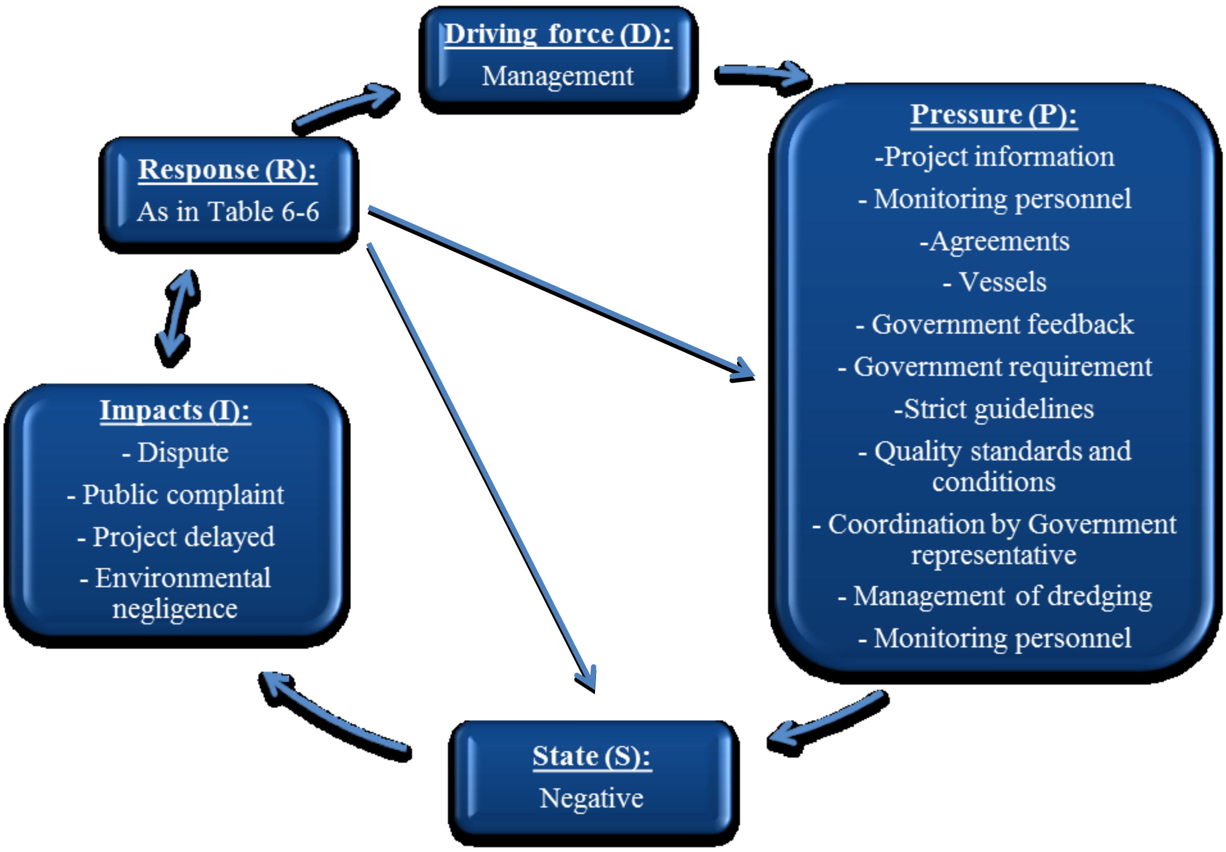


Figure 6-4 DPSIR Framework with management as the driver

These findings virtually suggest that governance is required. Governance is defined as the establishment of policies by the members of the governing body, which in this case is the Government of Malaysia (BusinessDictionary.com 2011). The DPSIR Framework, an example derived from this study as illustrated in Figure 6-5, is an IEM tool that conveyed the needs to integrate the views of multiple stakeholders in order to address the complex problems in dredging. By using the DPSIR framework, this proposal can help policy makers look at the problems in a more simplified form.

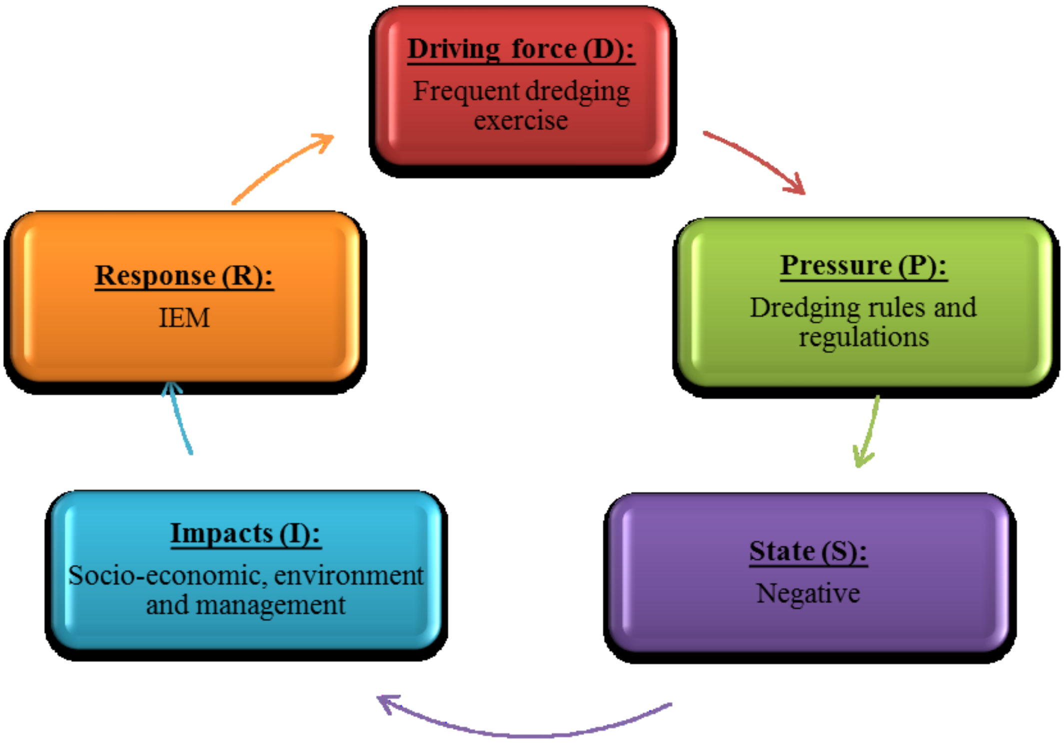


Figure 6-5 A proposal of DPSIR Framework for Malaysia's dredging industry

In order to support the establishment of new and effective dredging rules and regulations by the Malaysian government, IEM, as opposed to other conventional environmental management tools, is suggested because of its benefits that allow it to achieve sustainable development and provide a structured framework that accommodates all stakeholders' views.

The number of respondents in this study is small, so its results may create validity issue; however this is uncommon due to its qualitative nature. This is supported by previous research using only a limited number of respondents: 9 respondents by Utne in 2008; 12 respondents by Nielsen and Mathiesen in 2006; and 18 respondents by Mawapanga and Debertin in 1996 (Innes, Pascoe 2010, Utne 2008, Raakjaer Nielsen 2006, Mawapanga 1996). Nevertheless, this chapter has highlighted the requirement to demonstrate a risk-based decision making framework using Malaysia's case studies in order to support the governance of dredging in this country.

6.5 Conclusion

This chapter presented the third developmental step of the proposed framework in order to analyse dredging problems other than dredging environmental impacts using DPSIR. This is in order to develop an integrated and holistic framework that is not only focusses on scientific evidence. Through DPSIR analysis, it described that socio-economic and managerial problems can be affected by dredging and together with environmental problems, they became the main barriers to reduce its impacts. This was blamed on the inefficacy of EIA Order 1987 in Malaysia's dredging industry and the failure to integrate these conflicting problems demonstrates that an integrated environmental management approach is beneficial to aid the environmental preservation efforts of a nation such as Malaysia to protect its sensitive environment in a sustainable manner. Interviews and an online questionnaire survey with Malaysia's dredging experts (including marine ecologists, registered chemist, professional and chartered engineers, environmental consultants, university professors and environmental analysts) were performed and discussed in this chapter. Using the survey findings, DPSIR frameworks that highlighted main dredging problems affecting dredging stakeholders in Malaysia is developed at the end of this chapter.

7 FRAMEWORK STAGE 1: SCREENING

7.1 Introduction

On the basis of understanding of the three developmental steps that cover dredging impacts and its important factors as discussed in Chapters 4, 5 and 6, this chapter develops the fourth step of the proposed framework (screening stage) in Malaysia's context to identify sensitive areas that require high environmental protection using a newly developed method that integrates publicly accessed data and historical dredging monitoring data into a variation of standard ERA phases.

Malaysia performs dredging on a regular basis and simultaneously, this nation faces socio-economic, environmental, and managerial problems (Manap, Voulvoulis et al. 2012). The proposed framework has the potential to integrate and balance these conflicting problems of dredging. Its 3 stages - screening, Tier 1 and Tier 2 stages - allow for the decomposition of each problem into easy and manageable parts, so that the risks can be assessed individually and be integrated with other conflicting criteria in order to make a sustainable decision.

Dredging, which is performed in a highly contaminated site, but has not been identified as a risk, could prove fatal for biological resources (Su 2002, Toes 2008, Guerra, Pasteris et al. 2009a). Such cases have been observed in the developing country of Malaysia as discussed in Chapter 5. This could be due to the fact that assessing environmental risks and providing mitigation measures is costly, which is a discouraging factor for many developing countries such as Malaysia to use the already developed tools and assessments (Burton 2002, Morrisey 1993, Choueri, Cesar et al. 2010). Moreover, current understanding of low number of contaminated sites owing to its slower development rate in comparison to countries like the US and the UK that their contaminated land requires strict environmental rules and regulations, could worsen the state (Yi, Talib 2006). In fact, the DPSIR analysis, which explored dredging problems in the developing country of Malaysia, confirmed that it lacks efficient tools and practices to assess the environmental risks of dredging (Manap, Voulvoulis et al. 2012). Therefore, the need remains for an efficient tool or assessment, which takes into account a country's economic capability, to be developed in order to identify possible risks of dredging.

Ecological Risk Assessment (ERA) has been widely used to assess impacts of chemical exposure on endangered biological resources (Pekey, Karakaş et al. 2004b, U.S. Environmental Protection Agency 1998, Pekey, Karakaş et al. 2004a). This analysis involves simplistic phases of risk assessment, compared to the analysis of chemical risk on humans which was developed by the U.S. National Research Council (National Research Council 1983). Three phases of ERA have been suggested by the US EPA (1998): problem formulation, extent of impacts from exposure to chemicals over toxicity levels, and characterization of risk (U.S. Environmental Protection Agency 1998).

The ecological impacts caused by exposure to contaminated sediments have generated considerable research interest in the US and the UK and many frameworks have been developed in order to characterize the risks of the presence of contaminated sediments for biological resources, including assessment of ecotoxicological risks related to the depositing of dredged materials on soil and assessment of ecological risks of sediments dredged from ports and estuarine zones (Choueri, Cesar et al. 2010, Perrodin, Babut et al. 2006). Unfortunately, these can be time-consuming and are often difficult to perform, which could be unfavourable to middle income countries such as Malaysia, which are currently in the state of rapid development (Choueri, Cesar et al. 2010). Therefore, an alternative approach that is easy to perform and not time-consuming is a necessity.

This chapter develops the fourth step of the proposed framework (screening stage) in Malaysia's context to identify sensitive areas that requires high environmental protection using a newly developed method that integrates publicly accessed data and historical dredging monitoring data into a variation of standard ERA phases. This newly developed method benefits parties that place an emphasis on cost, time and simplicity in their efforts to protect sensitive environment whilst striving for economic strength.

7.2 Methodology

A new methodology employed in the screening stage to initially identify the degree of contamination in dredging areas is illustrated in Figure 7-1. This stage is specifically designed for maintenance dredging due to the fact that capital dredging could involve a higher risk of impact than maintenance (Gupta, Gupta et al. 2005); therefore, capital dredging should be automatically forwarded to the Tier 1 stage, avoiding this screening stage. Additionally, if the degree of contamination in the area of concern, where maintenance dredging will be performed, was specified as low during the screening stage, Tier 1 can be avoided. This is in order to ensure that resources can be allocated to areas of higher risk.

This method makes use of three steps; identifying historical dredging risk values, assessing and quantifying the contamination level in media, and combining results obtained from previous steps for a total risk value.

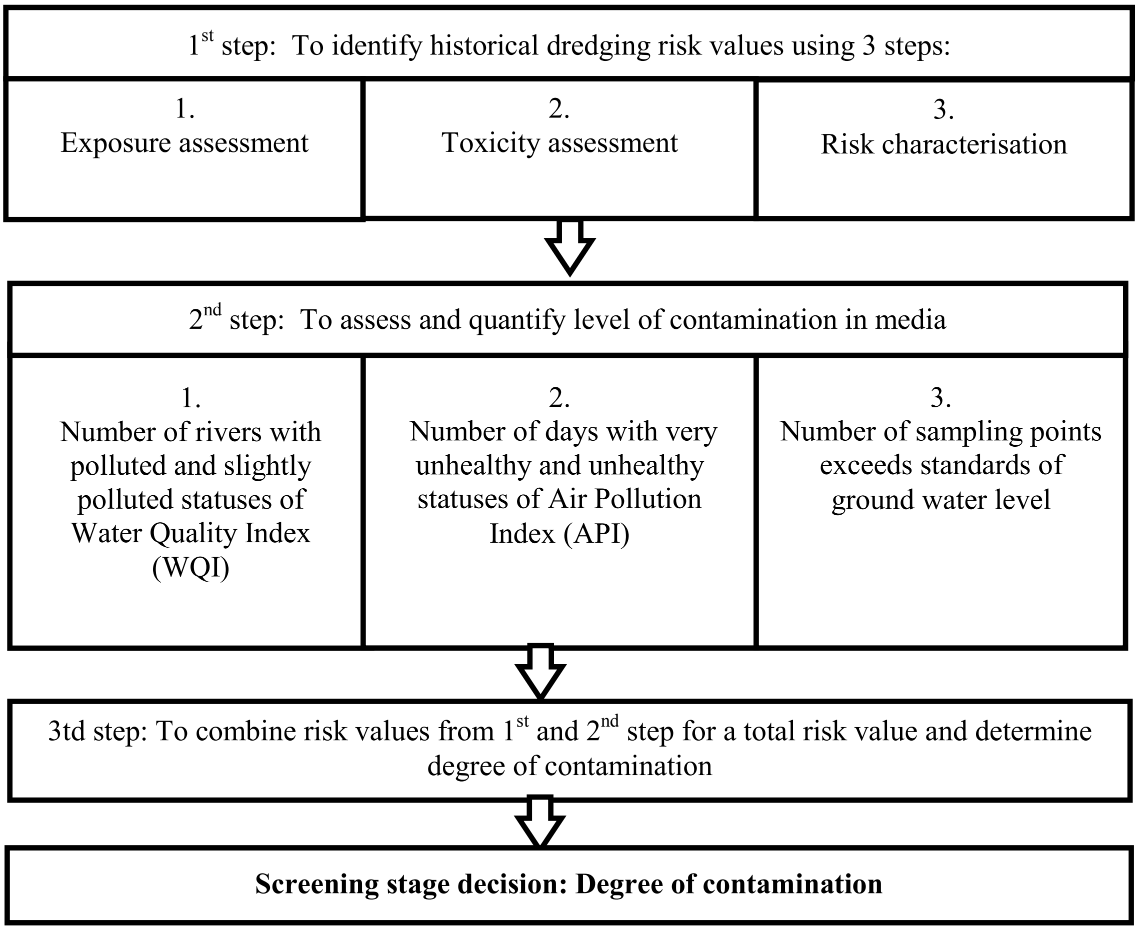


Figure 7-1 Method for screening stage

7.2.1 1st step

The objective of this first step of the screening method is to identify historical dredging risk values through three distinct stages; assessment of exposure level from historical dredging, assessment of toxicity level associated with exposed substances, and characterisation of the risks found. The execution of this step can circumvent the unnecessary sediment analysis, which can often be costly.

The reason for using historical dredging data lays in the fact that previous research indicates that concentration levels of metals in sediments increased after dredging. This means that contaminants dispersed by dredging are deposited back onto the new layer of sediments, exposed after excavation

(Munawar 1989, Piou 2009, Ware, Bolam et al. 2010). This creates a potential for future dredging to disperse the contaminants that have been re-deposited. Additionally, critical changes in indicators, monitored after historical dredging in an area, indicated its high contamination levels, which could have been initially caused by contaminants inputs from neighbouring land. Therefore, it is vital to analyse the behaviour of contaminants and the risk of re-contamination from adjacent land and therefore utilized in this step.

7.2.2 2nd step

The objective of this second step is to assess and quantify contamination level in media as a total risk value using three types of data, namely number of rivers with polluted and slightly polluted status of WQI, number of days with very unhealthy and unhealthy status of API and number of sampling points exceeding the standards of groundwater levels.

The reason behind the selection of this data to screen for ecological risks lays within the contaminants pathways as have been discussed in Chapter 2. The contaminant originates from point and diffuse sources and penetrates sediments, which are about to be dredged, through precipitation, emission and dissipation from various media, including air, groundwater, and surface and marine water (Moss, Madgwick et al. 1996, Jain, Ram 1997, De Nobili, Francaviglia et al. 2002). Therefore, it is necessary to assess these media (air, groundwater, and surface and marine water) to indicate its quality that determines the degree of contamination in an area.

The Water Quality Index (WQI), Air Pollution Index (API) and groundwater level that have been monitored annually on a national level, can be good indicators of the quality of media (Department of Environment 2006, Department of Environment 2007, Department of Environment 2008, Department of Environment 2009, Department of Environment 2010). Moreover, the utilization of this publicly accessible data can save cost and time to screen the dredging risks for the environment. Quantification of these indicators can be used in accordance to their indexes, however it should be noted that the lower the WQI becomes, the worse the water quality is. This is in contrast to the API, which denotes that the risk increases, as the index itself increases. A stable quantification of risk is required to relate these indexes, which can signify the environmental risks. Therefore, it is suggested that the number of rivers in the river basin of the area to be dredged, that have a polluted and slightly polluted status of WQI, the number of days in the area, which have a very unhealthy and unhealthy status of API and the number of sampling points, which exceed standards of groundwater levels in the area, should be used for this step of the screening. It should be noted that the duration of data monitoring depends on data availability; however the monitoring should have a similar duration in each location in order to ensure a fair comparison between areas.

7.2.3 3^{td} step

The final step of this screening stage is to combine risk values found in previous steps for a total risk value and to determine the degree of contamination of an area. The terminology for the degree of contamination can be found in Table 7-1 (Pekey, Karakaş et al. 2004a, Hakanson 1980). Terminology for degree of contamination is subject to the governance of dredging that set by policy makers using scientific evidence. Therefore, the terminology for degree of contamination as utilized by this study provides an ample space for future research.

Table 7-1 Degree of contamination

Total risk ratio (Y)	Degree of contamination
Y<7	Low
7<Y<14	Moderate
14<Y<28	Considerable
Y>28	Very high

7.2.4 Case studies: Dredging in Peninsular Malaysia

Twelve maintenance dredging projects (Figure 7-2) performed between 2005 and 2010 in Peninsular Malaysia were selected as the case studies for this chapter.

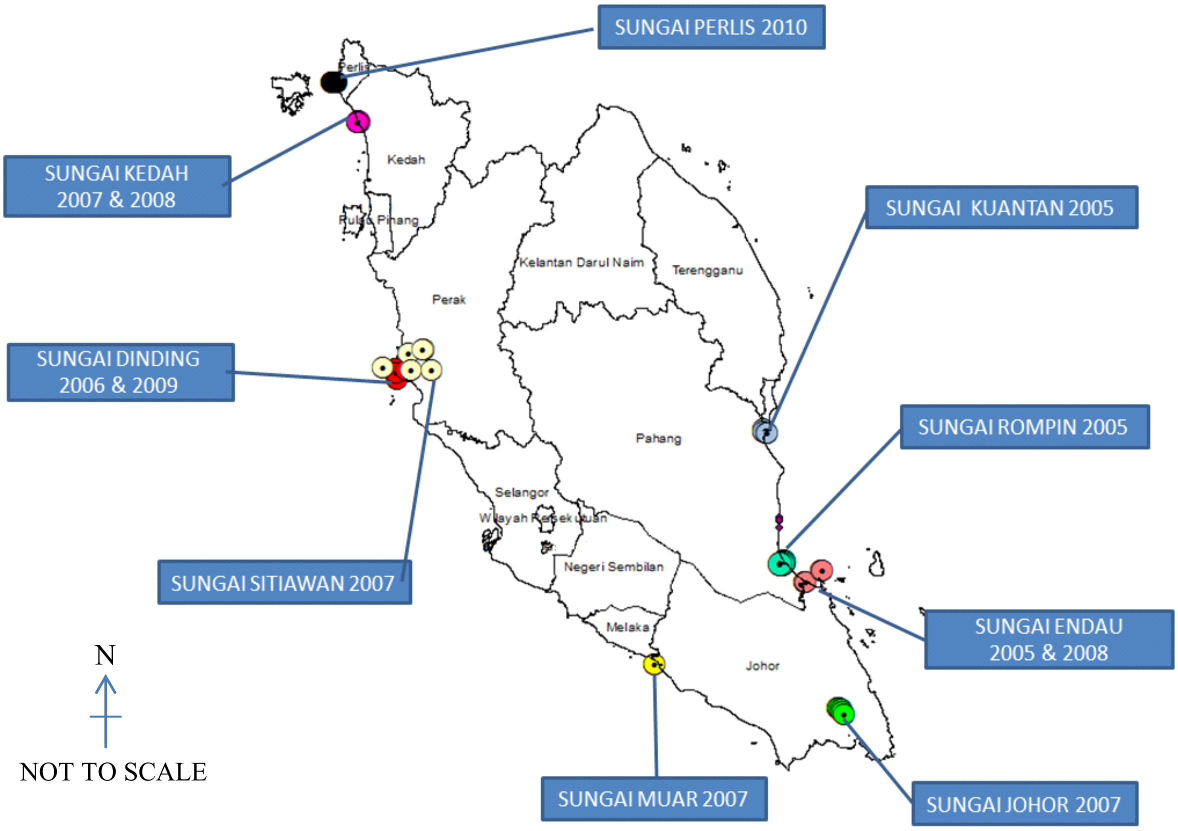


Figure 7-2 Dredging locations in Peninsular Malaysia and the year it performed, as discussed in this study

7.3 Result

7.3.1 1st step results

The first stage of this step, exposure assessment, has already been explored and illustrated using the GIS application in Chapter 5 and in Subsection C-1 in Appendix C. The water quality status from historical dredging monitoring data was selected for this first stage because it is a good initial indicator of the contamination level of the area that is about to be dredged, prior to the costly assessment of sediment (Pan 2009). MWQSC (Figure C-9 in Appendix C) or NWQS (Figure C-10 in Appendix C) values (which depend on the location of sampling points of the case studies, whether in a river or sea) were used as toxicity levels. In this chapter, risk value is the ratio of exposure data over toxicity data.

Results of historical dredging risk values in the locations of the case studies can be found in Table 7-2, which subsequently proposes an average total risk value of each area. Sungai Perlis river has been found to have the highest average total risk value of historical dredging (Figure 7-3), compared to other locations. Additionally, it has been found that this river has very high risk values of Pb and Cu. Nevertheless, it should be noted that not all substances and indicators were monitored for each river. This explains the unavailable data in this table, for which the symbol of (-) was used. It should be stressed that the unavailability of this data does not necessarily mean that the risk of exposure to these substances is non-existent.

Table 7-2 Historical dredging risk value at the location of case studies

Indicator	Sungai Kedah	Sungai Johor	Sungai Muar	Sungai Perlis	Sungai Dinding and Sitiawan	Sungai Kuantan	Sungai Endau	Sungai Rompin
BOD	-	-	-	-	1.17	9.9	6.67	-
COD	-	-	-	-	-	0.2	-	-
TSS	48.66	93.34	33.07	10.74	12.04	1.48	5.27	2.44
Hg	-	-	-	-	190	-	-	-
Cd	-	-	-	-	1.33	-	0.67	-
As	-	-	-	-	43.33	-	-	-
Pb	122.35			311.76	5.41	-	1.41	-
Cu	0.15	13.89	217.24	103.45	45.77	-	4.14	-
Zn	3.8	-	-	9.09	3.68	-	-	-
NH_3-N	100.29	-	-	-	-	-	2.86	20
DO	-	-	3.05	10.72	7.08	1.33	-	-
Total risk value (Y_H)	275.25	107.23	253	446	310	12.91	21	22
Number of monitoring points (X)	44	72	40	15	92	14	44	20
Average Y_H per point (Y_H/X)	**6.3**	**1.5**	**6.3**	**29.73**	**3.4**	**0.9**	**0.5**	**1.1**

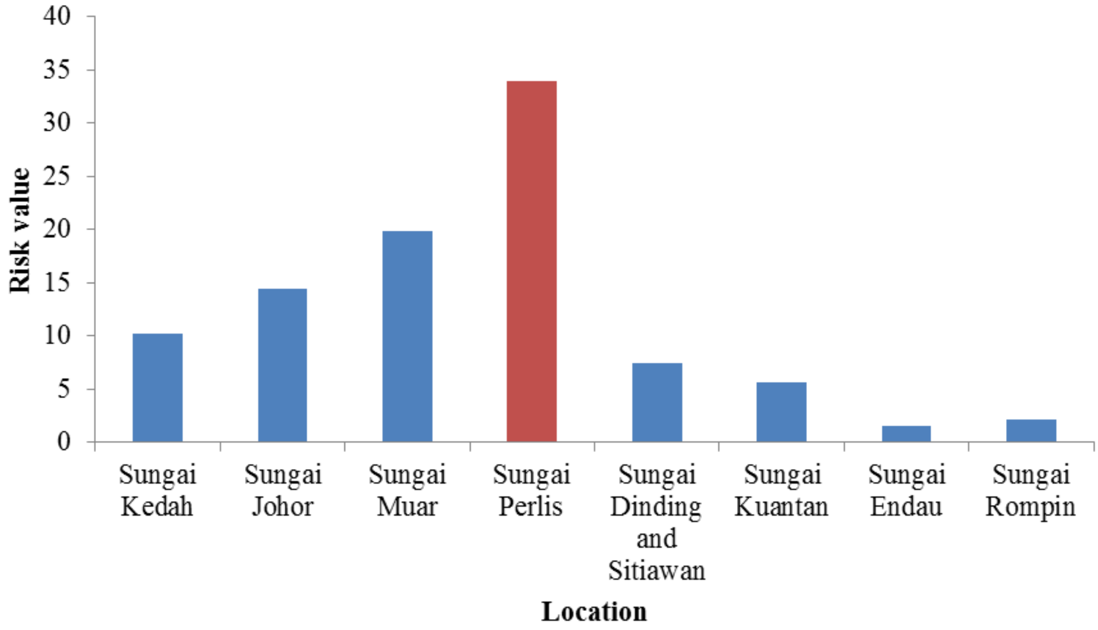


Figure 7-3 Average of total historical dredging risk value at location of case studies

7.3.2 2nd step results

The results for the second step in the screening stage can be found in Table 7-3 (and Appendix D) which shows media risk values for each case study location. These results were illustrated in Figure 7-4, which shows that Sungai Muar has the highest average total risk value in media.

Table 7-3 Media risk value at the location of case studies

Media	Sungai Kedah	Sungai Johor	Sungai Muar	Sungai Perlis	Sungai Dinding and Sitiawan	Sungai Kuantan	Sungai Endau	Sungai Rompin
Number of rivers with polluted and slightly polluted WQI status in between 2005-2011	14	63	63	28	26	26	None recorded	None recorded
Number of days according to very unhealthy and unhealthy API status in	6	21	25	None recorded	None recorded	None recorded	None recorded	None recorded

Media	Sungai Kedah	Sungai Johor	Sungai Muar	Sungai Perlis	Sungai Dinding and Sitiawan	Sungai Kuantan	Sungai Endau	Sungai Rompin
between 2005-2011								
Number of sampling points exceeds standards of ground water level in between 2005-2011*	*1	1	1	1	1	1	1	1
Total risk value (Y_C)	21	85	89	29	27	27	1	1
Duration of monitoring in years (X)	7	7	7	7	7	7	7	7
Average Y_C per year (Y_C/X)	**3**	**12.14**	**12.71**	**4.14**	**3.86**	**3.86**	**0.14**	**0.14**

**Unavailable data but the value of one is allocated to symbolize the relevance of groundwater as a risk into an area*

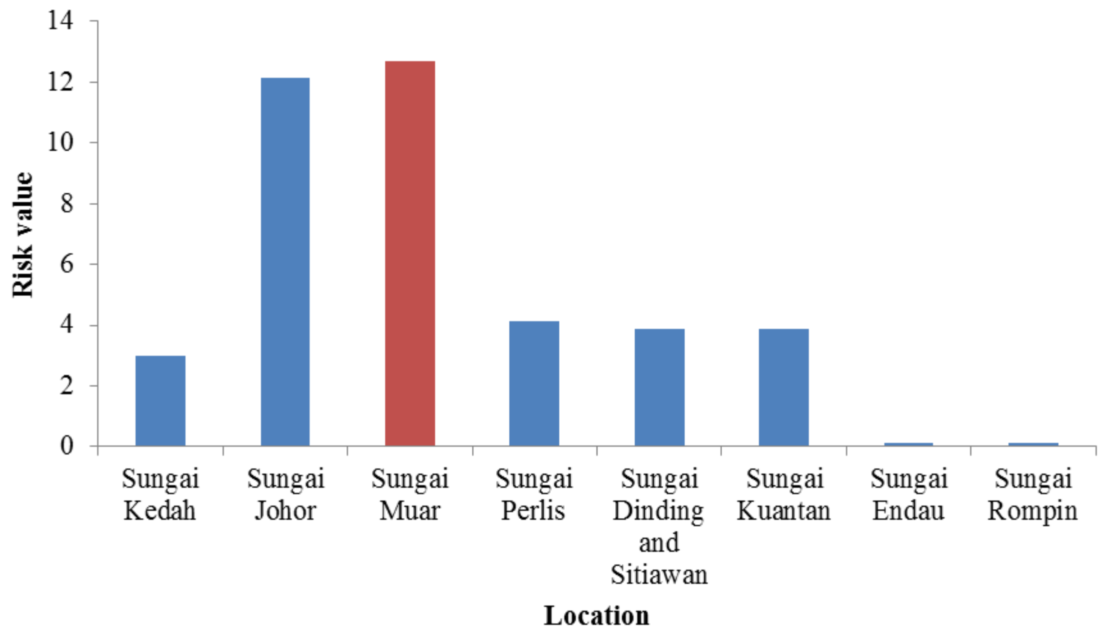


Figure 7-4 Average of total media risk value at the location of case studies

7.3.3 3rd step results

Results for this step combining average total risk values from previous steps can be found in Table 7-4, which shows the rivers, their individual risk values, their total risk values and their degrees of contamination. The results have been illustrated in Figure 7-5. It was found that the river, which has a very high degree of contamination, was Sungai Perlis.

Table 7-4 Results for total risk value at locations of case studies

River name	Historical dredging average total risk value	Media average total risk value	Total risk value	Degree of contamination
Sungai Kedah	6.3	3	**9.3**	Moderate
Sungai Johor	1.5	12.14	**13.64**	Moderate
Sungai Muar	6.3	12.71	**19.01**	Considerable
Sungai Perlis	29	4.14	**33.14**	Very high
Sungai Dinding and Sitiawan	3.4	3.86	**7.26**	Moderate
Sungai Kuantan	1.0	3.86	**4.86**	Low
Sungai Endau	0.5	0.14	**0.64**	Low
Sungai Rompin	1.1	0.14	**1.24**	Low

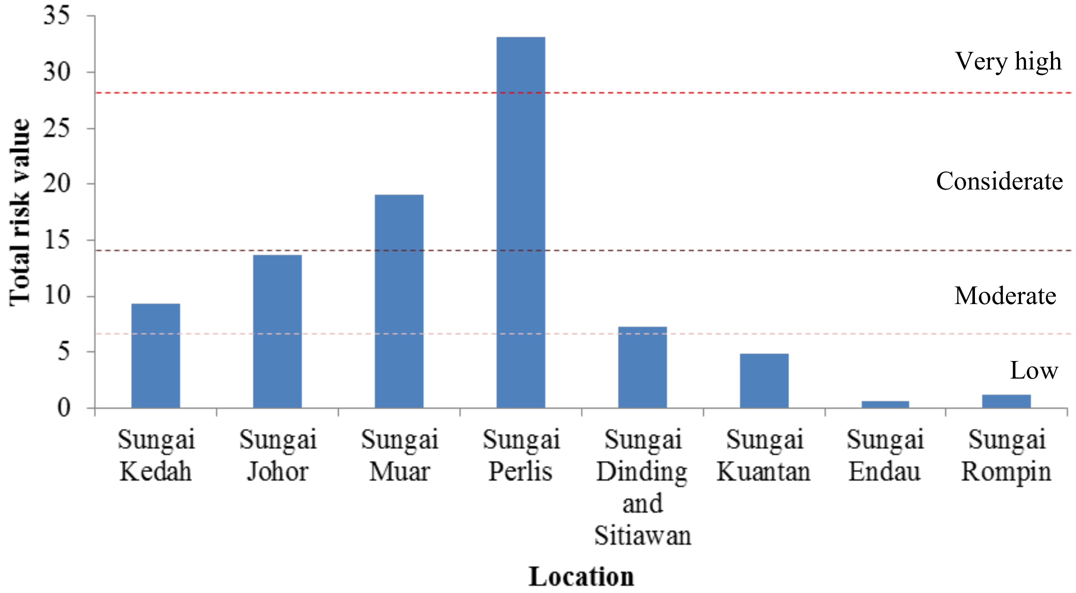


Figure 7-5 Results of screening stage

7.4 Discussion

Prior work highlighted the environmental impacts of dredging and many tools and assessments to identify dredging risks have been developed, but remain difficult to utilise, costly and time-consuming. This becomes the discouraging factor to use them by party that seeks for economic, simplicity and time benefits. In this chapter, it developed the fourth step of the proposed framework (screening stage) in Malaysia’s context to identify sensitive areas that requires high environmental protection using a newly developed method that integrates publicly accessed data and historical dredging monitoring data into a variation of standard ERA phases. This method corroborated the ERA phases suggested by US EPA (1998), well matched to the behaviour of indicators, when being dredged by utilizing historical dredging monitoring data, and well suited to the contaminant pathways into sediments, when using media contamination level data.

This method was demonstrated in Malaysia using twelve case studies and it was found that the Sungai Perlis river has a very high degree of contamination. It was also found that this location has high historical dredging risk values of Pb and Cu, while simultaneously having a not-significant risk value of contamination in media. This could stem from the fact that there was inadequate monitored data in national level for groundwater to be retrieved prior the execution of this study. This highlights the insufficiency of monitoring of this vital environmental indicator on a national level in this country. At the same time, this becomes a good indicator, demonstrating how this country deals with the problem of contaminated land. It should be stressed that contamination from point and diffuse sources can dissipate into groundwater and be transferred from one area to another (Lions 2010, Cantwell, Burgess 2004, Li 2009). Therefore, the lack of monitoring on a national level for this vital media shows that the problem of contaminated land has not been recognized in Malaysia.

Nevertheless, it should be highlighted that ERA was initially suggested to protect endangered species and there can be tolerance for its risk values, only if they do not affect the entirety of populations and communities (Pan 2010). For example, Sungai Perlis has been characterized as having a very high degree of contamination, but if its biodiversity is not endangered and is highly mobile, the very high degree of contamination of this area can be tolerated with caution.

As discussed in Chapter 5, fatality, which could be due in large part to dredging activity, has been seen at the Sungai Sitiawan river when it was dredged in 2008. However, no fatality was reported when dredging was performed at the Sungai Perlis river in 2010. This may be due to the fact that when dredging at Sungai Perlis was performed, it was not monitored for indicators of the detrimental impacts of dredging, like the Sungai Sitiawan river, where incidentally there was an aquaculture farm. Fish in the farm were immobile and could not escape from the conditions - lack of dissolved oxygen and high metal concentrations. There is a danger that this entrapment is also faced by organisms that have limited or no mobility, such as shellfish and coral. This study also highlighted the fact that every location of case studies in this chapter shows that their risk values of TSS are not low, which means immobile organisms can be smothered due to this, as noted by previous research (Messieh, Rowell et al. 1991, European Sediment Research Network 2004, Trimarchi, Keane 2007, Hill 2009).

As countries like Malaysia are well-known for their biodiversity, which has become one of its sources of income, proactive action towards protecting them from the harmful effects of dredging is strongly needed. The results from this study should be looked upon as an opportunity for countries like Malaysia to improve their efforts to protect their environment from harmful dredging impacts. Thus, screening of biodiversity composition and its mobility should be executed in the future.

This screening method enables an accurate initial prediction of environmental dredging risks and it is straightforward and efficient in terms of time and cost. This could encourage parties that stress upon benefits in cost, simplicity and time, like Malaysia, to take proactive actions toward protecting their environment, whilst increasing their economic strength.

7.5 Conclusion

Dredging has been proven to have an impact on the environment and many tools and assessments have been developed. However these are difficult to perform, costly and time-consuming. This chapter developed the fourth step of the proposed framework (screening stage) in Malaysia's context to identify areas that requires high environmental protection using a newly developed method that integrates publicly accessed data and historical dredging monitoring data into a variation of standard ERA phases. This method was demonstrated in a scenario of a developing country, Malaysia, where economic aspect has been a concern and it was found that one its rivers had a very high degree of contamination. This also highlighted many insufficiencies of environmental monitoring in this country, where this method could provide an opportunity to improve current efforts to prevent environmental damage due to dredging. This improvement should be reflected in future projects, when this method is used, in order to benefit from its low cost, time efficiency and straightforwardness. Additionally, the results and implications of this study will be used in a more stringent analysis of the proposed framework, the Tier 1 stage.

8 FRAMEWORK STAGE 2 (TIER 1): SENSITIVE AREAS

8.1 Introduction

The development of the fifth step (Tier 1 stage) of the proposed framework in Malaysia's context is presented in this chapter. The Tier 1 stage is developed to prioritize dredging areas and determine their degree of contamination and concern for further investigation using a newly developed method that integrates MCDA and ERA.

Scientific research has characterized the effects of dredging, an underwater excavation process for navigational purposes or material extraction, and has shown its association with a number of chemical, physical and biological impacts. Among these are the decrease of invertebrate species due to sediment change, increase of oxygen demand due to re-suspension of sediments that also affects lighting intensity, and increase of turbidity levels caused by plumes, which can be triggered by dragging, scooping and dumping acts while dredging (Balchand, Rasheed 2000, Crowe, Gayes et al. 2010, de Leeuw 2010).

Besides the environmental impacts, conflicting problems including cost, rules and regulations, socio-economic and managerial aspects of dredging have received excessive consideration over the last few years. This comes from the fact that dredging has increased in demand due to numerous projects, from the decrease of the seabed of River Scheldt and the expansion of Panama Canal to the development of projects in India for the construction of ports due to increased waterborne transportation (Schexnayder 2010, Krizner 2010, George 2011, Thacker 2007). Dialogues over the sustainability of dredging practices have risen together with its popularity, highlighting the need for research in assessing its sustainability based on its conflicting problems including from environmental, socio-economic and managerial aspects. However, this kind of research in the dredging industry has fallen short.

Furthermore, different types of decision makers including idealists, politicians or environmentalists can greatly influence decision-making processes of dredging industry, and often, contradictory views are expressed during negotiations and investigations concerning dredging (Alvarez-Guerra, Canis et al. 2010). In other industries, many development projects have benefitted from strategic environmental management that offers holistic analysis by integrating different environmental management tools in order to achieve a balanced and sustainable decision (Abriak, Junqua et al. 2006, Agius, Porebski 2008, Wang, Feng 2007). Multi Criteria Decision Analysis (MCDA) has been widely used to rank options based on the assessment of different criteria (Balasubramaniam 2005, Alvarez Guerra, Viguri et al. 2009). This tool has previously been applied together with comparative risk assessment, adaptive management, life cycle analysis and risk assessment analysis (European Environment Agency 2003, Ness, Anderberg et al. 2010, Maxim, Spangenberg et al. 2009, Langmead, McQuatters Gollop et al. 2009).

The human brain is a powerful decision-making tool and it has taken on-going research to imitate the complexity of a human brain when it comes to structuring a good decision-making method, with Weight of Evidence as an example (Linkov, Cormier et al. 2012). Moreover, many evaluations have already been completed on the likelihood of adverse ecological effects occurring from contaminant exposure through Ecological Risk Assessment (ERA) (Olsen, Christensen et al. 2001, Jones, Stauber et al. 2005). Examples include, open disposal impacts of contaminated mud, DRAMA for evaluation of dredging impacts, screening and prioritization of chemical risks from metal mining operations, and copper and cadmium ecological risk assessment (ERA) (Deliman, Ruiz et al. 2002, Agius, Porebski 2008, Alvarez Guerra, Viguri et al. 2007, Zeman, Patterson et al. 2006, Pan 2010, Clarke, Jackson et al. 2000, Hall, Scott et al. 1998). However, potentially disproportionate costs caused by considering one aspect alone, such as using sediment quality analysis alone to characterize contamination level in a dredging area, in dredging decision-making have created waves of worry among dredging stakeholders (Burton 2002). Thus, development of a sustainable decision-making method like IEM for dredging is a necessity.

The aim of this work is to develop the fifth step (Tier 1 stage) of the proposed framework in Malaysia's context in order to prioritize dredging areas and determine their degree of contamination and concern for further investigation using a newly developed method that integrates MCDA and ERA. Dredging monitoring and toxicological data from three dredging projects performed at the rivers of Sungai Sitiawan and Dinding, Perak, Malaysia were collected and analysed in order to help stakeholders to make informed decisions on dredging processes by considering environmental, socio-economic and management aspects.

8.2 Contaminant pathways

As discussed in Chapter 4, contaminants originate from two major sources: diffuse and point sources. Point sources may include industry, waste dumps, and households of which effluents are discharged into surface waters leading to contamination (Office of Naval Research 2008, European Sediment Research Network 2004, Zühlke 1994). Traffic activities, atmospheric deposition, grassland and woodland, agriculture, mining wastes, recreational activities, groundwater, and building materials are examples of diffuse sources (Chon, Ohandja et al. 2012). Contaminants enter the surface water through precipitation and adsorption that involve air, sediments and groundwater. Anthropogenic activities like dredging have proven to change the equilibrium of this system and affect the ecology (Figure 8-1).

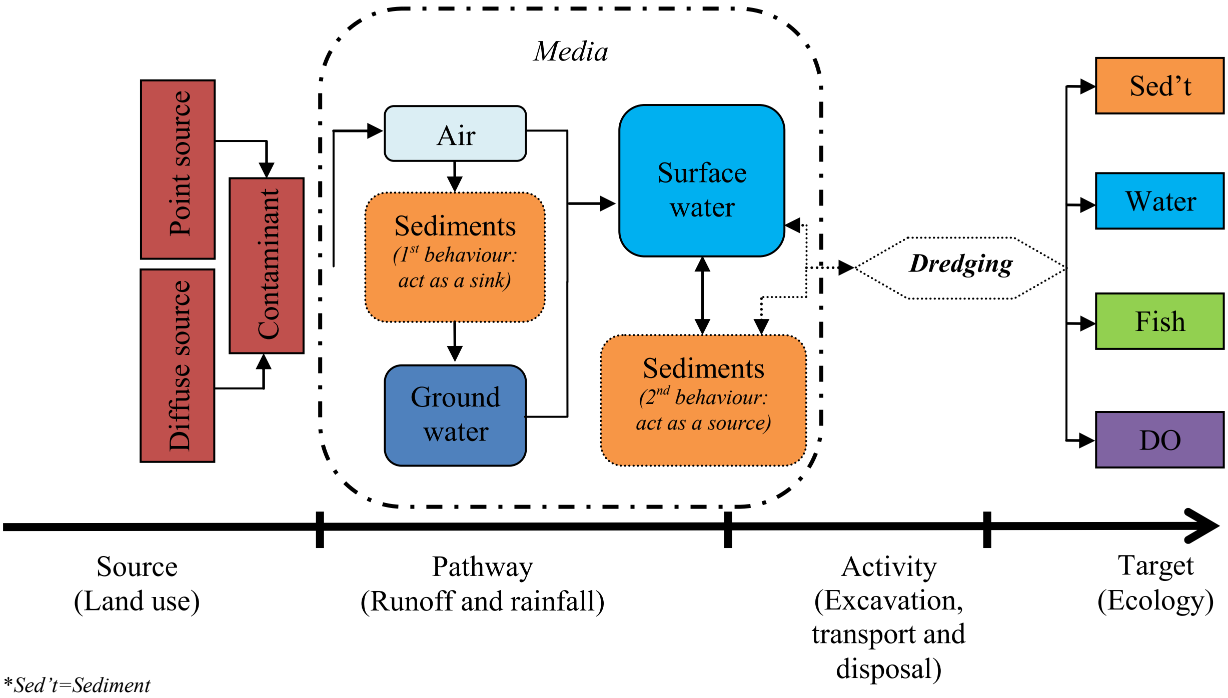


Figure 8-1 Contamination pathways and impacts of dredging to the ecology

8.3 Case study: The rivers of Sungai Sitiawan and Dinding, Perak, Malaysia

Due to data limitation in Sungai Perlis (that has been characterized as having a very high degree of contamination in Chapter 7), case studies with a complete data has to be chosen in its stead. Therefore, dredging performed in between 2006 and 2008 along the rivers of Sungai Sitiawan and Dinding, Perak, Malaysia was chosen for this chapter. For the purpose of this chapter, environmental, technical, financial, toxicological and soil investigation reports of these rivers were collected from a dredging contractor (summarized in Sub-sections C-4 to C-8 in Appendix C). Data extracted from these reports were disseminated and interpreted using ArcMap 10, an application of Geographic Information System (GIS). In these rivers, types of sediments consisting of sand, silt and clay (as in Figure C-13 of Appendix C) amounting to 1.0 million cubic meters were dredged from a seabed depth of 8 meters.

As discussed in Chapter 6, opinions on dredging problems in Malaysia from sixty-one dredging experts of varying expertise have been collected between 2008 and 2010. Marine ecologists, registered chemists, professional and chartered engineers, environmental consultants, university professors, environmental analyst, and a head villager are among respondents involved (Manap, Voulvoulis et al. 2012). The results of Chapter 6 presented three problems of dredging that became the criteria which will be discussed in this chapter namely the environment, socio-economic and management (Figures 8-2 to 8-4). As can be seen in these figures, the pressures that triggered these problems are varied, however for the purpose of this chapter; one pressure per criteria will be selected as sub-criteria for discussion.

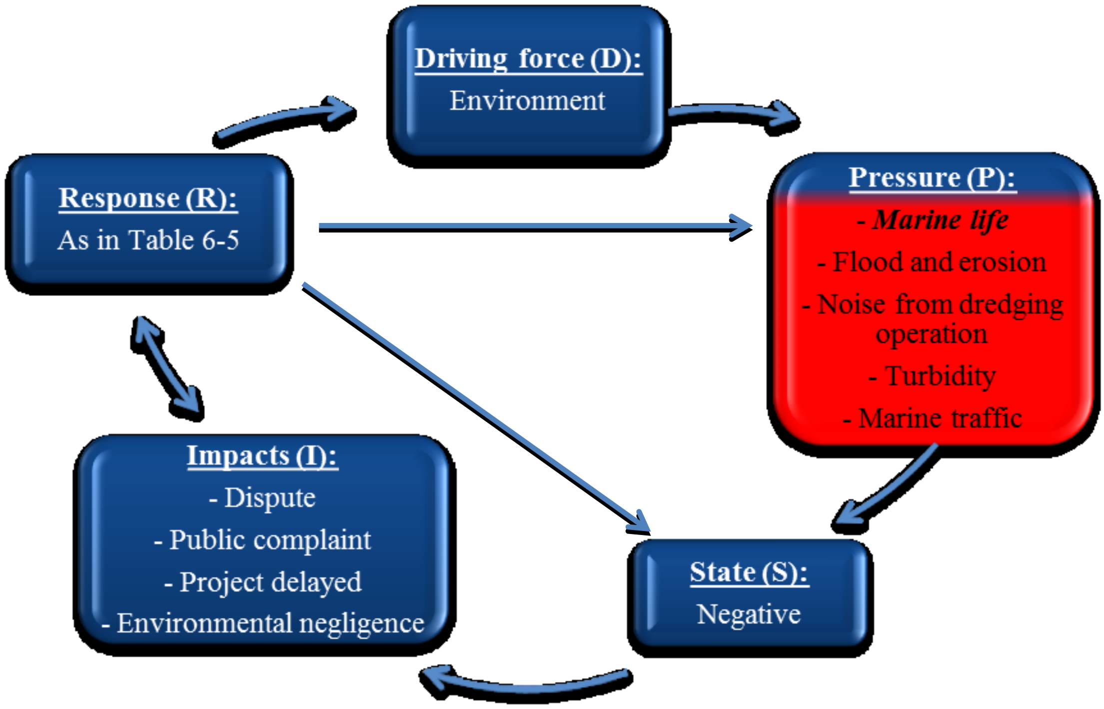


Figure 8-2 DPSIR Framework with Environment as the criteria and Marine life as sub-criteria to be assessed in this chapter

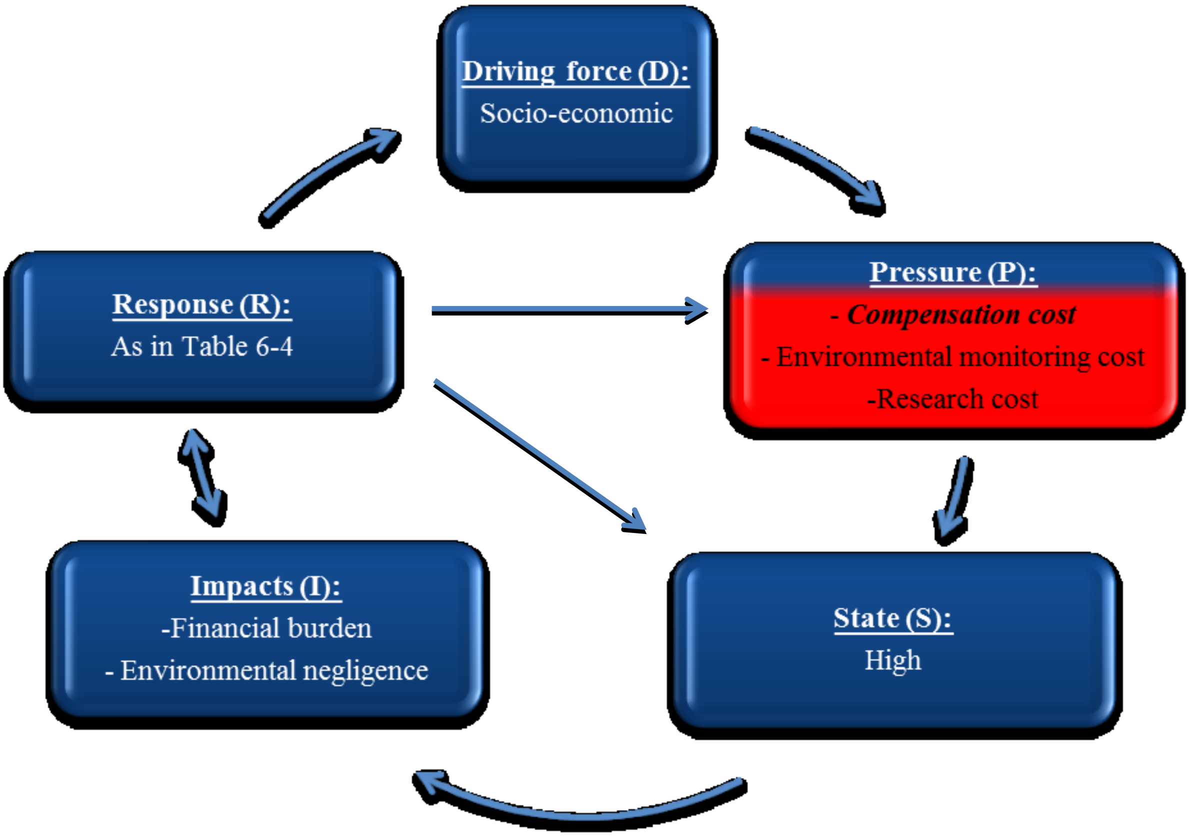


Figure 8-3 DPSIR Framework with Socio-economy as the criteria and Compensation cost as the sub-criteria to be assessed in this chapter

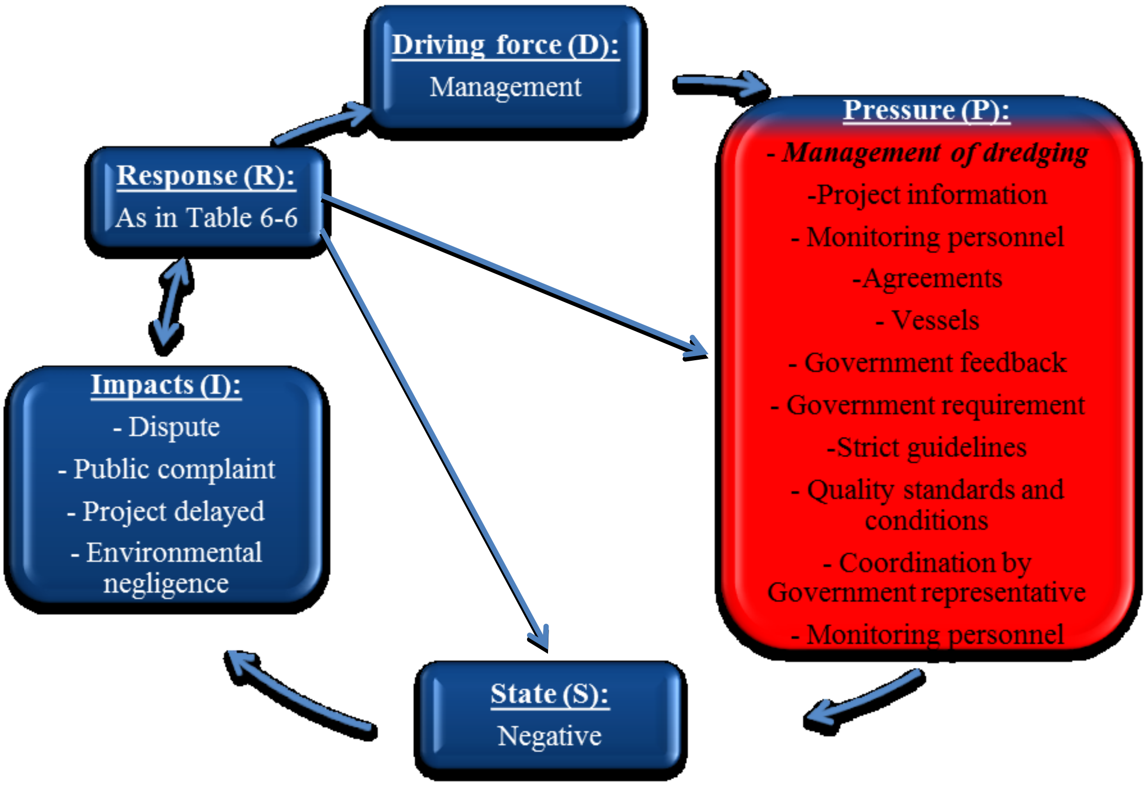


Figure 8-4 DPSIR Framework with Management as the criteria and Management of dredging as the sub-criteria to be assessed in this chapter

8.4 Methodology

In order to minimize the cost of environmental decisions and to optimize dredging benefits, prioritization of dredging areas is important. This is where MCDA plays an essential role, and is often practiced in remediation of contaminated sediments and aquatic ecosystems by USACE, for example in the context of making decisions about the disposal of dredged materials (Linkov, Satterstrom et al. 2006a). MCDA is a prevalent tool for decision-making because of its ability to incorporate contradictory facets and its functionality, which considers both qualitative and quantitative measures (Sparrevik, Barton et al. 2011).

Weighted Summation method (applying Multi-attribute utility theory (MAUT)), Analytical hierarchy process (AHP) and outranking, are among some of the methods of MCDA (Kiker 2005). Weighted

Summation method and AHP are compensatory optimization approaches of MCDA. Weighted Summation method selects an option that has the highest performance expressed in a single and non-monetary number. Pairwise comparisons between options are the main element in AHP that depends on human judgment to decide the highest importance between options. On the other hand, the outranking method selects a prevailing option that outperformed other options in at least one criterion (Linkov, Satterstrom et al. 2006b). This chapter benefits from the ease of comparison between scores that are expressed as single numbers, using the Weighted Summation method. Steps taken in MCDA for the purpose of this chapter were of three kinds. Firstly, delimitating management units that define prioritized areas was required and secondly, the ranking of available decision options occurred and finally is analysing the sensitivity of the results achieved (Alvarez Guerra, Viguri et al. 2009).

The integration of different environmental management tools provides a holistic analysis. For this reason, the results of MCDA will be further evaluated using ERA (Laws 2012). The objective of ERA is to determine the degree of contaminants dispersed by dredging that affected the sediments, the water, fish and level of dissolved oxygen, and to determine the receptor of concern, dredging phase of concern and dredging activity of concern. In order to achieve this, five steps will be applied in ERA namely conceptual modelling, hazard identification, exposure assessment, toxicity assessment and risk characterisation.

A method for the Tier 1 stage, which ties in socio-economic, environmental and managerial criteria (as discussed in Chapter 6) and dredging impacts and its relevant factors (as discussed in Chapters 4 and 5), is illustrated in Figure 8-5. This stage will analyse areas where capital dredging and maintenance dredging (where the degree of contamination has been specified as very high, considerable or moderate) will be performed. This is in order to ensure that resources are allocated to those areas, which pose the highest risks. After deliberation in this Tier 1 stage, areas with very high degrees of contamination should be considered unsuitable to be dredged and this information should be communicated to relevant agencies, i.e. the government. Options, other than dredging should be explored. This includes auto-flushing, soft-sediment engineering and Keep Sediment in the System (Kirby 2012).

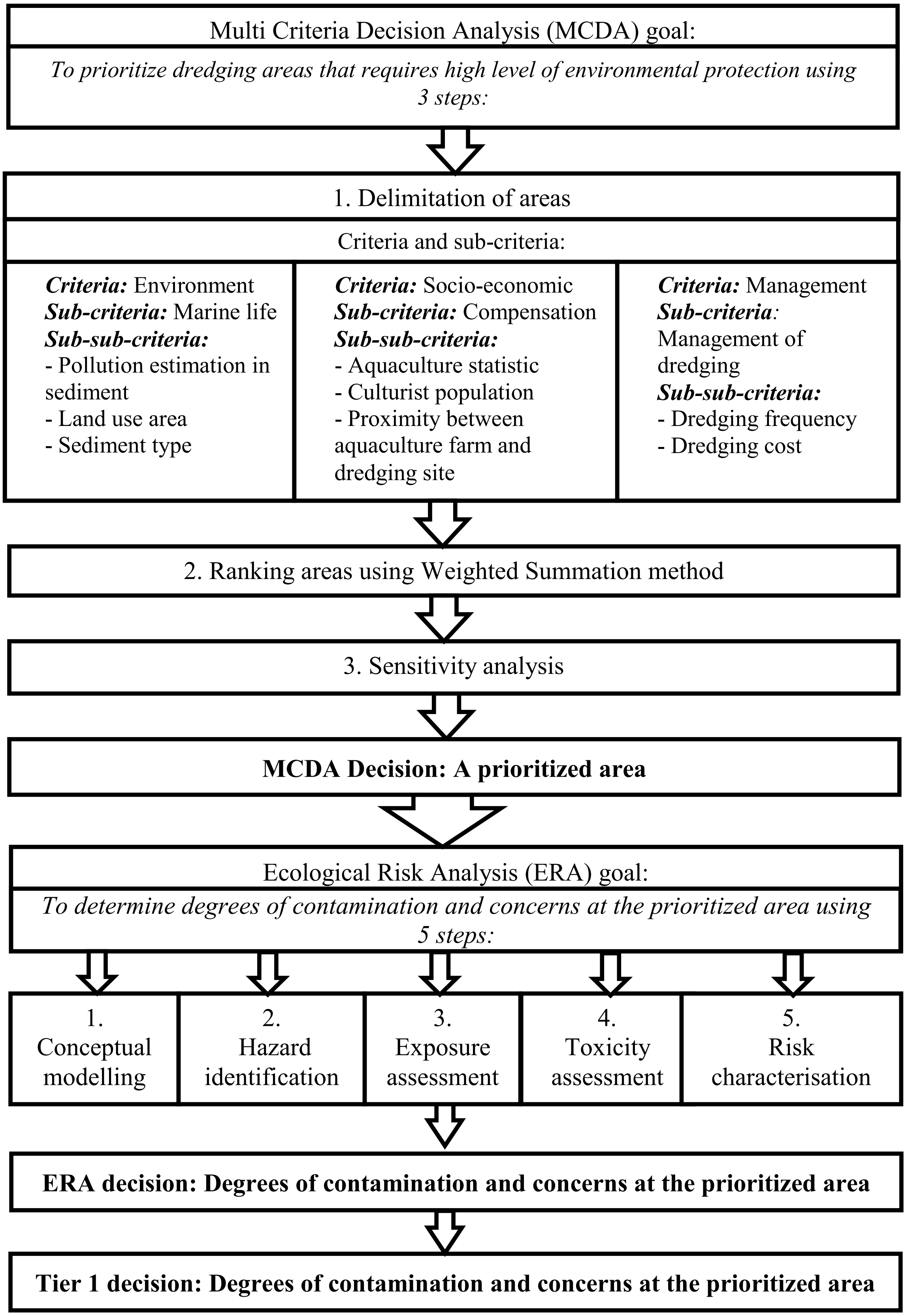


Figure 8-5 Method for Tier 1 stage

8.4.1 Multi-criteria Decision Analysis (MCDA)

The objective of this analysis is to prioritize areas that require high level of environmental protection based on environment (**sediment characteristics and neighbouring land as discussed in Chapters 4 and 5**), socio-economic and management criteria (**as discussed in Chapter 6**).

A decision support software package, DEFINITE 3.1, is useful that can help to achieve this objective. Manual calculation using Microsoft Excel can also be performed to achieve this objective; however the time to analyse and human error are a concern. In fact, variation of weightings can easily be incorporated for sensitivity analysis using the software package to compare to using this conventional method. Sensitivity analysis is performed in order to examine the robustness of the results from methodology that have been developed. This analysis can help decision makers to see the variations of ranking of the areas if they change the weightings of criteria and sub-criteria. Area that is sensitive to changes of weightings but not having highest overall score should also be considered as a priority.

The ***initial stage*** of MCDA is to select the areas that are going to be assessed and prioritised based on land uses and river catchments of Sungai Sitiawan and Dinding rivers. Five areas (Area 1, Area 2, Area 3, Area 4 and Area 5) have been identified and shown in Figure 8-6. As discussed in Sub-section 8.3, the environmental, socio-economic, and management aspects were the criteria to be analysed, whereas marine life, compensation cost and management of dredging were selected as sub-criteria (details are as in Figures 8-2 to 8-4).

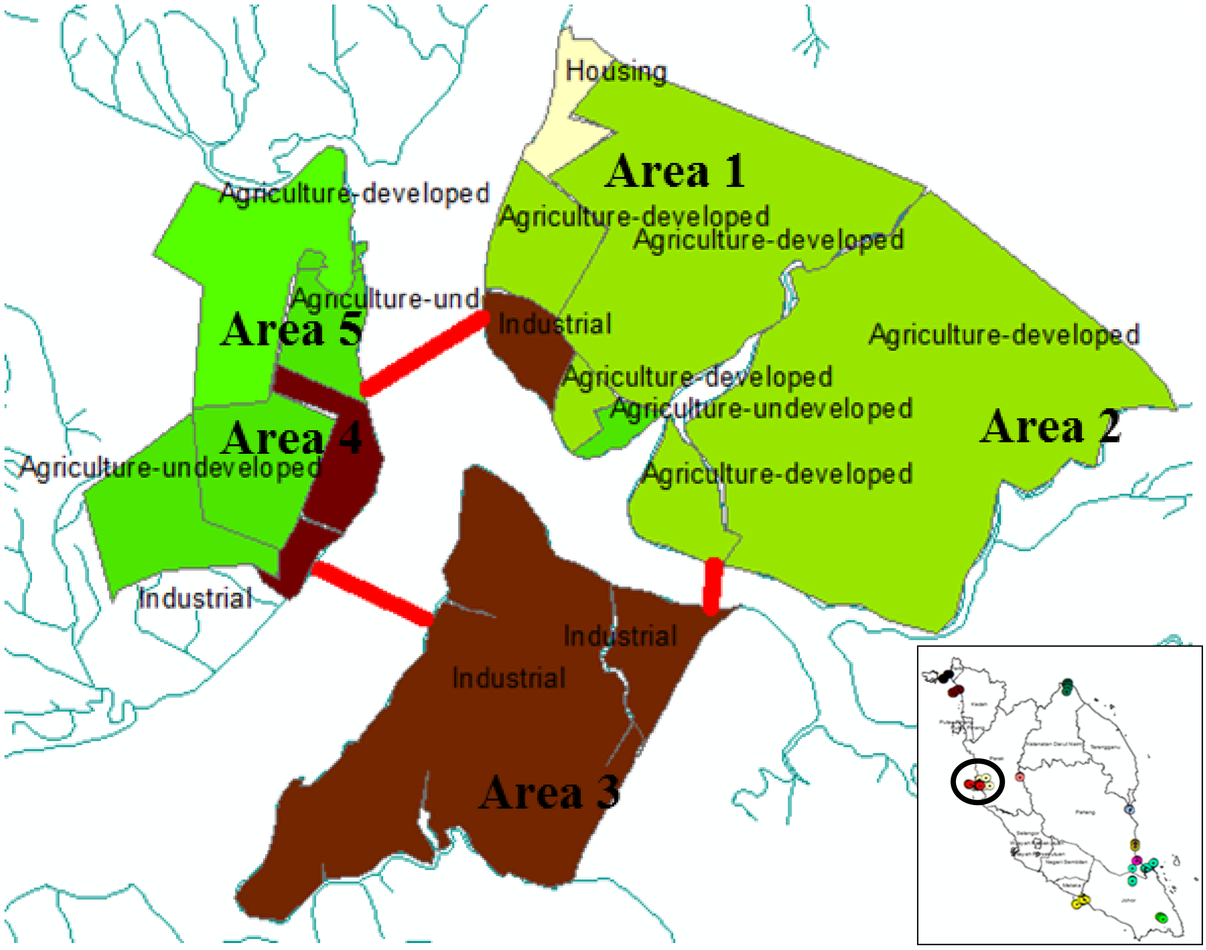


Figure 8-6 Areas of concerned

In order to further analyse the sub-criteria, sub-sub-criteria were selected and discussed as per explanations below.

Pollution estimation in sediment

The pathway of contaminants (Figure 8-1) during dredging can lead to disturbance of marine lives (Figure 8-2). This indicates the importance of estimating **the contamination level of dredging areas and neighbouring land uses** in order to protect the environment while dredging (as discussed in Chapter 5).

In this chapter, sediment contaminations were estimated using the Event Mean Concentration (EMC) method due to its practicality and ease of use. Similar methods have been suggested by the Department of Irrigation and Drainage Malaysia, as described in Malaysia's Urban Storm water Management Manual (MSMA) (Department of Irrigation and Drainage Malaysia 2001b, Zakaria, Ghani et al. 2004, Department of Irrigation and Drainage Malaysia 2001a). Calculation of the annual load of pollutant in sediment is achieved using Equation [1]. In parallel with MSMA suggestions, the value of EMC for rural grazing is 500 mg/L and the value for industry is 200 mg/L. Additionally, the calculation of the annual runoff depth (Vr) is done using Equation [2], in which annual rainfall depth was 2,224.5mm (Department of Statistics Malaysia 2009). In addition, the weighted average annual runoff coefficient was assumed as 0.7, which was considered as the worst-case value suggested by MSMA.

$L = 10-4 \ x \ C \ x \ V_R \ x \ A$ ……………………………………………………………………Equation [1]

Where,

L = Annual load of pollutant (kg)
C = Event Mean Concentration (EMC) of pollutant (mg/l)
V_R = Annual runoff depth (mm)
A = Catchment area (ha)

$R = D \ x \ Cv$………………………………………………………………………………..Equation [2]

Where,

R = Average annual runoff depth (mm)
D = Average annual rainfall depth (mm)
C_v = Weighted average annual runoff coefficient

Sediment characteristics

Sediment characteristics are important because their types and sizes determine the rate of contaminant's adsorption (Pekey, Karakaş et al. 2004a, Glasby, Szefer et al. 2004). The smaller the sediment particle size, the higher the contaminant absorption rate and the higher the risk of contamination of an area (Jain, Ram 1997). In light of this, sediment characteristics in dredging areas that were analysed prior to dredging were evaluated on a qualitative scale, which +++ allocated for silt and ++ allocated for sand.

Aquaculture farm

Avoidance of high compensation costs for local communities as mentioned by dredging stakeholders in Figure 8-3 is feasible by considering the sensitivity of a dredged area prior to commencement of dredging. Moreover, the production value of aquaculture farms in the rivers of Sungai Sitiawan and Sungai Dinding is high; therefore, areas that contain these farms are sensitive. Area 1 is highly sensitive as it contains an aquaculture farm that is located in the river and a value of +++ allocated for this area. However, area 2 contains aquaculture farms that are far from dredging area and are split by mangroves between the farms and the river. A value of ++ is allocated for this area as it is categorized as medium sensitive. Areas 3, 4 and 5 does not have aquaculture farms adjacent to dredging areas, so these areas are treated as if they have low sensitivity and given a value of +.

Aquaculture production

The rivers of Sungai Sitiawan and Dinding are an important resource for culturists. The value of aquaculture production during 2008 in Perak where these rivers are situated was USD 110 million, the second highest compared to other states in Malaysia (Suedel, Kim et al. 2008, Department of Fisheries Malaysia 2008). Fish and shrimps that are cultivated in, or near this river were the products that generated this high income. Therefore, dredging along this river may compromise the revenue of the culturists; thus particular attention is necessary to acknowledge the expected revenue generated by culturists along the river before commencement of dredging. The higher the value, the higher the level of importance to remediate the sediments or to provide technology that can control damage due to dredging. In this study, the estimated production values were projected from the total value of aquaculture production in Perak in 2008 and it was found that the production values in Areas 1 to 5 were USD14.8 million, USD18.6 million, USD 14 million, USD 6.5 million and USD 5.6 million, respectively.

Culturist population

As mentioned, the rivers of Sungai Sitiawan and Dinding are an important resource that in total amounts to 1833 freshwater and brackish water culturists administering 3,250 hectares of aquaculture farms in Perak, Malaysia. These figures highlighted Perak as the state that has the highest number of culturists in Peninsular Malaysia in 2008 (Suedel, Kim et al. 2008, Department of Fisheries Malaysia 2008). Two thirds of the culturists are located in Sungai Sitiawan and Dinding rivers, specifying that these rivers are an important commercial area. Dredging stakeholders in Malaysia mentioned the risks of flooding and erosion happened after dredging as can be seen in Figure 8-2. Thus, it is important to consider the potential number of culturists affected by dredging. In this chapter, the number of culturists per area was projected from the total number of culturists in Perak and there were 693, 869, 660, 303 and 263 potentially affected culturists in Areas 1 to 5, respectively.

Dredging frequency

Capital or initial dredging presents a higher risk of the dispersal of fine grain sediments compared to maintenance or continual dredging (Gupta, Gupta et al. 2005). As fine grain sediments are more likely to absorb contaminants due to its larger surface area (Jain, Ram 1997), it is important to establish the type of dredging in order to anticipate the level of risk. In consideration of this and the fact that the case study is maintenance dredging, a qualitative scale of ++ was allocated to all areas.

The dredging project will cover 35 hectares of dredged area with a total dredged quantity of 1,002,730.00 m3. Projection of dredged material quantities has been made for each catchment area and for Areas 1 to 5; the quantities are 144,215.4 m^3, 147,177.7 m^3, 580,477 m^3, 97,493.9 m^3 and 20,865.4 m^3, respectively. An assumption made for the purpose of this chapter is that the contaminants from on land activities dispersed equally on the surface of the riverbed. The contractor who performed the dredging at this area has completed a design of the channel that is illustrated in Figure 8-7. Areas in the channel were based on adjacency of these areas with the five areas previously mentioned (Areas 1, 2, 3, 4 and 5).

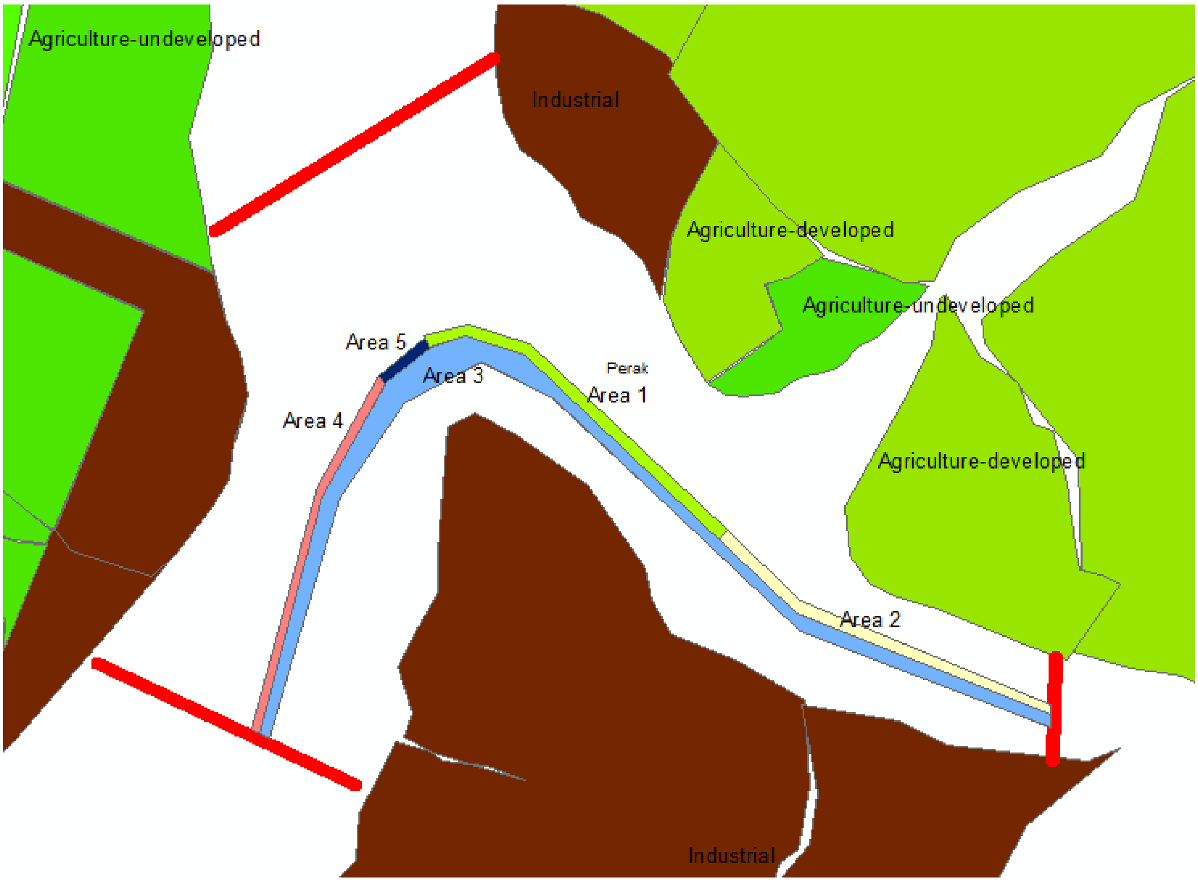


Figure 8-7 Channel to be dredged in the rivers of Sungai Sitiawan and Dinding, Perak

Dredging cost

Operational costs of dredging are the biggest problem perceived by a number of dredging stakeholders. The costs depend on multiple factors including technology applied, types of dredged material, volumes to dredge and methods of disposal (Anderson, Barkdoll 2010, Williams 2008). It is important to analyse the initial cost of dredging for this river using historical dredging cost data, in order to acknowledge to what extent the environment and social-economic traits can be put into context. The contractor who performed dredging at Sungai Sitiawan and Dinding rivers, Perak provided costing data for these projects; however, due to its confidentiality, the breakdown of the costs cannot be revealed. Only an estimate value which ranges between USD 0.4 million to USD 0.97 million, was given for the use of this chapter.

The ***second step*** for MCDA is ranking of the areas. In order to do this, the weighted summation method is applied, which is an easy to use method (Alvarez Guerra, Viguri et al. 2009, Chon, Ohandja et al. 2012). In this study, the prioritized area is the one with the highest standardised weighted score.

The ***third step*** of MCDA is sensitivity analysis. Robustness of the results from MCDA will be examined using this analysis through application of weights on sub-criteria, as in Table 8-1, to observe the changes of rankings. An assumption that decision makers would attach a balanced level of importance to the environment, socio-economic and management aspects was made and the criteria were considered of equal weighting.

Table 8-1 Assignment of weights

Criteria	Sub-criteria	Weights	Individual weights (%)
Environment	Pollution estimation	1/3	11.11
	Land use area	1/3	11.11
	Sediment type	1/3	11.11
Socio-economic	Approximation between aquaculture farm and dredging site	1/3	11.11
	Population of culturists	1/3	11.11
	Aquaculture statistic	1/3	11.11
Management	Dredging frequency	1/2	16.67
	Dredging cost	1/2	16.67

The ***decision from MCDA***, the prioritized area, will be brought forward for Ecological Risk Assessment (ERA).

8.4.2 Ecological Risk Assessment (ERA)

The objective of this analysis is to determine degrees of contamination and concerns at the prioritized areas. Five steps as discussed below will be followed in order to achieve this objective.

Development of a conceptual model

The ***first step*** of ERA is to develop a conceptual model that represents the stages of dredging and how they affect the ecology. Projection of a conceptual model in the prioritized areas was made in order to identify sources, pathways and receptors of risks that were involved during dredging.

Identification of Hazard

The ***second step*** for ERA is identification of hazard. Hazard identification will provide results on receptors of concern, dredging of concern and dredging activity of concern. These results inform dredging stakeholders on when to take precautionary measures during what phase and activity of dredging in order to minimize its impacts. The conceptual models developed during the first step of ERA were analysed to find the sources of risk during dredging. In this step, three stages were taken in order to understand the sources and pathways of contaminants, the related dredging activities that caused the impacts and the target of ecological parameters that were affected by dredging.

Stage 1: The Framework of Hierarchical Holographic Modelling (HHM)

HHM is a system decomposition method and was developed to understand the link between dredging activities and the ecological receptors. Construction of HHM framework as in Figure 8-8 was made using multiple headings and sub-headings. As can be seen in this figure, the sources of risks are listed under three different headings; namely excavation, disposal, and phases of dredging. The headings further decomposed to their lower hierarchal structure, the sub-headings. For example, activities during excavation done using a trailer hopper suction dredger (THSD) could trigger different environmental risks onto multiple receptors during various phases. The activities include lowering down the dredgehead (A1), injection of air into sediment to loosen them (A2), dragging the dredge head along channel (A3), suction of dredged material into barge (A4), and lifting the dredge head to surface area (A5) (Pan 2009). The water, sediments, fish/benthos and dissolved oxygen (DO) are the potential receptors (D1 to D4), whereas the phases include before, during and after dredging and disposal (C1 to C5).

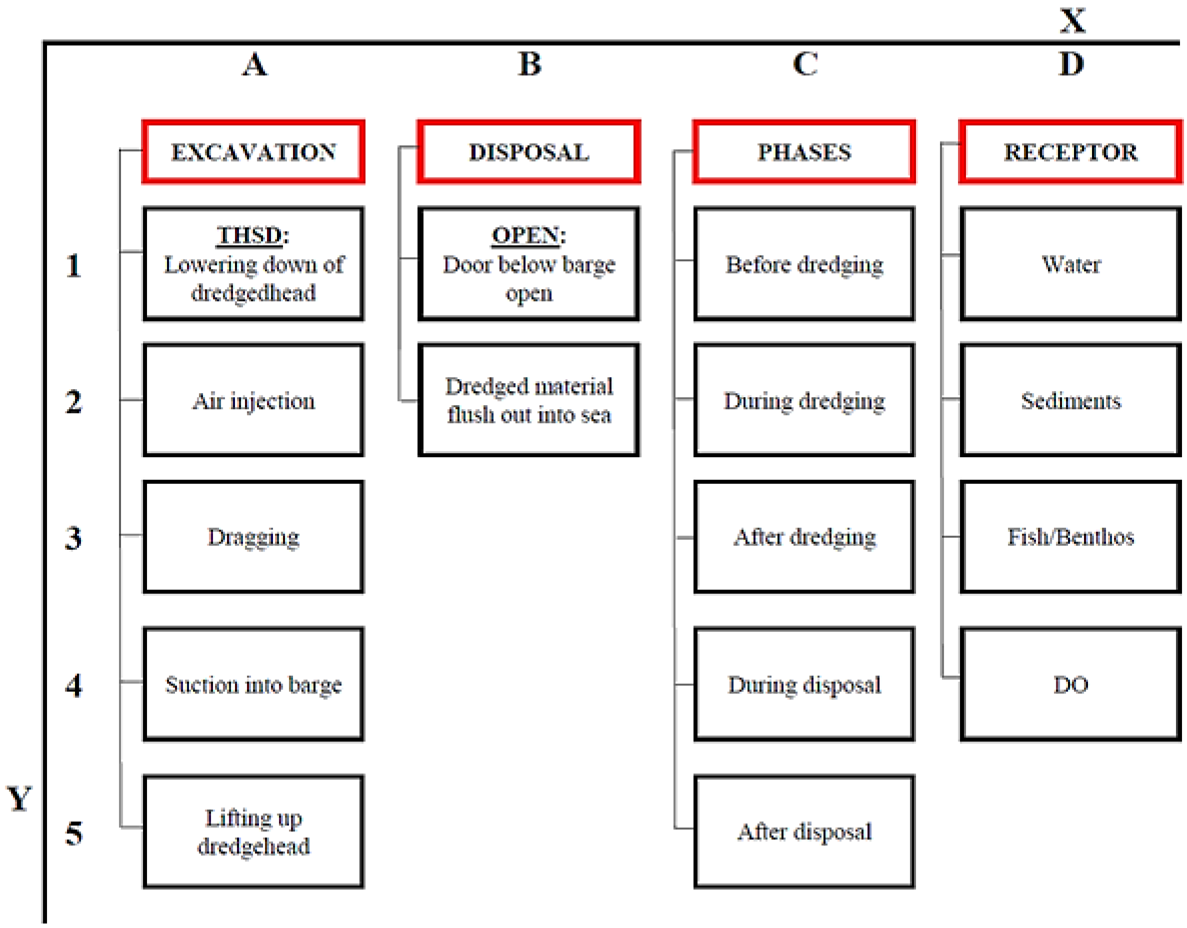


Figure 8-8 HHM Master List for dredging

Stage 2: Scenario filtering

Decisions in this stage are taken based on the interests and needs of individual risk manager or decision maker (Pan 2009). In this chapter, 269 multiple risks (as in Appendix E) were found from the literature and examples can be found in Tables 8-2 and 8-3.

Table 8-2 Assessment of local ecological component

Issue	Source of impact	Impact/ Species	Location	Reference
Impacts of water pollution on invertebrate larvae	Copper and cadmium in water	Sea urchin, oyster and mud crab	Pulau Payar Marine Park	(Ramachandran, Patel et al. 1997)
Hydrocarbon pollution	Oil pollution	Aquaculture fish-Red fish, grouper, tiger grouper and pomfret	Straits of Malacca	(Manan, Raza et al. 2011)
Fisherman income depleted	Reclamation	Fish	Bandar Hilir, Melaka, Malaysia	(Jusoh 2013)
Death of sea life	-	Dugong	Langkawi	(Bernama 2007)
High Polycyclic Aromatic Hydrocarbons (PAHs) content	Crude oil, used crankcase oil and input from street dust and traffic sources	Sediment	estuarine along the Klang Estuary, West Coast, inshore off Klang Estuary, and offshore in the Straits of Malacca	(Zakaria, Takada et al. 2002)
Tar-balls	Spills from offshore oil platforms, transported via currents from east cost to the Straits of Malacca, discharged ballast water and tank washings during delivery and loading ports transit, accidental spills from tanker, and oilfields and refineries along eastern shores of Sumatra	Applications of PAH and hopanes as biomarkers to identify source of oil pollution	West and East coast of Peninsular Malaysia	(Zakaria, Okuda et al. 2001)(Zakaria, Okuda et al. 2001)(Zakaria, Takada et al. 2002)
Detected persistent organic pollutants	-	Turtle eggs	Markets in Kota Bharu, Kuantan,	(Merwe, Hodge et

Issue	Source of impact	Impact/ Species	Location	Reference
(POPs)—such as organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs)—and heavy metals in turtle eggs that are sold to customers			Kuala Lumpur, Johor Bahru	al. 2009)
High metals concentrations-Pb, Cd, Cu and Zn	Polluted sediment and water, industrial and agricultural activities, use of paints by fishermen and boating activities	fiddler and hermit crabs	Kuala Perlis, Kuala Kedah, Kuala Sala, Kuala Merbok, Kuala Prai and Kuala Juru	(Ismail, Badri et al. 1991)
Slow rate of restoration and rehabilitation of reef	Boat activities, discharge from resorts	Artificial reef	Tioman Island	(M., Ang et al. 2013)
Declines in coral calcification rate over 31 year period	Higher thermal threshold	Porites coral	Pulau Payar and Port Dickson	(Tanzil, Brown et al. 2013)
Low number of dugongs and rare sightings	Entanglement in nets, and blast fishing, illegal trade, limited implementation of conservation	Dugong dugon	Tanjung Inaruntung, Sabah	(Rajamani 2013)
no specific legislation establishing dugong sanctuaries and policy is yet to be developed for managing the Malaysian dugong population	Dugong hunting, incidental catch from fishing activities, habitat loss including loss from land reclamation, and pollution from palm oil plantations and sedimentation	Dugong dugon	Johor Straits, Langkawi Island, Kudat, Sandakan, Semporna	(Marsh, Penrose et al. 2002)
Declining number of river terrapins	Poaching of adults and the extensive collection of their eggs	river terrapins	Kedah, Perak and Terengganu	(Khan, Elagupillay et al. 1982)

Stage 3: Bi-criteria filtering and ranking

In this stage, quantification was made only in chemical and biological risks using the U.S. Air Force Risk Matrix methodology, as explained in detail by Pan (2009). Different levels of frequency, severity and risk were allocated to the prioritized areas. As shown in Table 8-2, the literature highlighted that concentration of lead and zinc in sandy sediment increased (Ponti, Pasteris et al. 2009). This happened when the dredge head was dragged (A3) during dredging (C2), causing impacts on sediments (D2). This risk was 'likely' to happen in Area 1 and was allocated the frequency of four. In the meanwhile, quantification of severity of this risk is according to their ranking during MCDA. The severity of four was allocated for the risk of increased lead and zinc on sediments because Area 1 ranked as the second prioritized area. The frequency and severity allocated for the risk were then fitted into an environmental risk matrix and it was found that the quantification of risk was three; therefore, Area 1 is categorized as a 'high risk' area. Area 2 is categorized as the utmost prioritized area, therefore quantification of risk as mentioned in Table 8-4 for this area was four and is categorized as an 'extremely high risk' area. In addition, Table 8-5 shows examples of impacts on fish and level of dissolved oxygen when exposed to high concentration of different contaminants during related risks.

Assessment of Exposure

The ***third step*** of ERA is assessment of exposure. In order to quantify the risks at the prioritized areas, assessment was made on toxicological data prepared by the Fisheries Research Institute of Malaysia. In this chapter, the exposure data is the concentration of contaminants that were exposed to receptors. This includes levels of heavy metals found in sediments, in the water and in the tissues of fish. However, the only area that was analysed for exposure of heavy metals in tissues of fish was Area 1, as there were no aquaculture farms in Area 2.

Assessment of Toxicity

The ***forth step*** of ERA is assessment of toxicity. A wide range of toxicity data from different resources was applied in this study. This includes the marine screening benchmark values as listed in ECOTOX prepared by the US Environmental Protection Agency (US Environmental Protection Agency 2012b), the water reference values of the river mouth as listed in Marine Water Quality Criteria and Standard (MWQCS) prepared by Department of Environment Malaysia (Department of Environment 2009), and the toxicological data obtained from the literature.

Table 8-3 Example of multiple risks from the literature

Indicator	Impact	Stage	Causal	Reference
Concentrations of dissolved metals	Higher concentration	After dredging	Sewage is discharged from a treatment plant that located near the sampling site and may elevate dissolved metals	(Mackie 2007)
Coastal erosion, wave action, physical disturbance from ship waves, wave regime and river flow	Increased	After dredging	No aquatic plants; Elimination of this vegetation as the nick point advances reduces the roughness; Increasing flow velocity	(Messieh, Rowell et al. 1991, Ellery, McCarthy 1998, Sergeev 2009)
Surface salinity	Decreased and lower value than bottom water	After dredging	Proximity of stations close to bar-mouth and depth factors	(Messieh, Rowell et al. 1991, Vivier, Cyrus 1999)
Phosphate concentration	Decreased as season advances at dredged sites	After dredging	-	(Rasheed, Balchand 2001)
Phosphate concentration	Increased at non-dredged sites n decrease, increase gradually at surface at dredged n non-dredged location during monsoonal season	After dredging	Sharp reduction after monsoon due to consumption by way of enhanced productivity; Inputs into the estuaries via rivers; Higher local inputs from municipal sewage or industrial wastes	(Rasheed, Balchand 2001)
P, Al, Cr, Cu, Fe, Mn, Pb, Zn and pH	Decreased-60 minute after disposal	Disposal	-	(Munawar 1989, Clément, Vaille et al. 2010)
Benthic diversity	Migrated upstream for a distance of 10.5 km, deterioration incurred by advance of the nick point	Excavation, Disposal	Head-ward erosion of the nick point creates a narrow channel which concentrates flow and steepens the gradient; Presence of in-channel vegetation; Oxidation of deposited sediment	(Ellery, McCarthy 1998, Ljung 2010)

Sediment transport	Destabilized, increased	Excavation	Active dredging in the near shore zone; Dredging has destabilized the seabed sediment such that the local tide and wave conditions are now capable of transporting sediment which otherwise would have remained stationary	(Sergeev 2009, Kenny, Rees 1996)
Topography	Disturbed with large furrows	Excavation	Sediment transport was larger led to a significant erosion of these furrows and still visible after three years.	(Desprez 2000)(Desprez, 2000)
Bacteria-Cu resistant	Vast quantity	Disposal	Bioturbation; Grazing pressure or light conditions	(Toes 2008)
Dredge track/furrow	Further eroded; Well-defined created after dredging	Excavation	Increased wave action over the winter months and prevailing tidal currents increased sediment transport; Due to equipment used that create shallow furrow or large pits	(Messieh, Rowell et al. 1991, Kenny, Rees 1996, Kenny, Rees 1994)
Colonial of new benthic fauna	Increased at southern dredged channel, decreased at northern dredged channel	Disposal	New sediment type n exposure of beneath original layer	(Messieh, Rowell et al. 1991, Ponti, Pasteris et al. 2009)
pH	Increased	After disposal	Acidity of the soils does not seem to be transported into the nearby canals	(Ljung 2010, Clément, Vaille et al. 2010)

Table 8-4 Examples of decomposition analysis using HHM

Area	Description	Excavation	Phases	Receptor	Frequency	Severity	Risk	Reference
Area 1	Increase of Lead and Zinc in sandy sediment	A3	C2	D2	4	4	3	(Ponti, Pasteris et al. 2009)
Area 2	Deformation ranging from crooked spines and backbones to missing fins of fishes due to increase in metals	A3	C3	D3	5	5	4	(Thibodeaux, Duckworth 2001)

Table 8-5 Risk of exposure to different contaminants

Sulphide	Cd	Hg	As	Ammonia	Fe	B	DO
- Sulphide oxidation that was stimulated by suspended particles causing oxygen in the water depleted to undetectable levels (Jørgensen 1991)	- Total meiofauna abundance found to be lower (Ser 1991) - Alterations in Cd storage and reductions in prey capture found in the grass shrimp (Wallace 2000)	- Cardiovascular function and renal structures affected in rats (M. Astruc, J.N. Lester 1988) - Bivalve immune functions affected in contaminated areas (Gagnaire, Thomas-Guyon et al. 2004)	- Growth of plankton and macro algae affected (Phillips 1990)	- Gills of fish damaged (Lease 2003)	- Fish distributions affected on the long term by reducing aerobic scope and altering competitive strength (Verberk 2012) - Immune system compromised and reduced the resistance of fish to diseases (Kiron 2012) - Accumulation of iron found on the gill and caused gill damage. Respiratory disruption due to this is suggested as a possible mechanism for iron toxicosis in fish. The higher iron diet suppressed growth of juvenile catfish (National Research Council (US). Committee on Minerals 2005)	- Reduced growth in *C. mrigala* caused by an impairment of normal physiological functions (Adhikari, Mohanty 2012) - Fish are not especially sensitive to boron as borate or boric acid. Studies shows water containing a variety of boron concentrations showed no adverse effects on embryo-larval stages of rainbow trout (National Research Council (US). Committee on Minerals 2005)	- Prolonged anoxia may cause the animals to advance onset of reproduction (U.S. Environmental Protection Agency 2000, Philipp, Wessels et al. 2012) - Hydrogen sulphide toxicity happened after severe hypoxia and total lack of oxygen (anoxia) causing severe mortality to marine organisms (Vaquer Sunyer 2008)(Vaquer Sunyer 2008)

Characterisation of Risk

The ***final step*** of ERA is characterisation of risk. A risk ratio of a contaminant was obtained by dividing exposure data by toxicology data. If the ratio exceeds one (1), ecological risk in an area was confirmed to exist and the higher the ratio, the larger the anticipated risk (Hall, Scott et al. 1998). The sum of risk ratios for substances found in an area signified the degree of contamination and the terminologies of different degrees of contamination are as per detailed in Table 8-6 (Pekey, Karakaş et al. 2004a, Hakanson 1980).

Table 8-6 Degree of contamination

Total risk ratio (Y)	Degree of contamination
Y<7	Low
7<Y<14	Moderate
14<Y<28	Considerable
Y>28	Very high

8.5 Result

8.5.1 Site prioritization using Multi-Criteria Decision Analysis (MCDA)

The matrix of MCDA as shown in Table 8-7 consists of scores for different areas (Areas 1 to 5) and this matrix will be analysed using weighted summation to rank the areas. The result of ranking is as in Figure 8-9 that exhibited Area 2 as the area with highest overall weighted scores. Robustness of this result was verified using sensitivity analysis and the results are as in Figures 8-10 to 8-12 and in Appendix E (Figures E-1 to E-8). It has been shown from this analysis that the ranking of Area 1 is sensitive to the changes of weights in Socio-economic criteria (as in Figures 8-10 to 8-12). Therefore, for the sake of comparison and allowing for the fact that Area 1 is treated as an environmentally sensitive area because it consists of an aquaculture farm, ERA of this area has also been performed, along with Area 2.

Table 8-7 MCDA Matrix

Criteria	**Area**	**Environment**			**Socio-economy**			**Management**	
		Pollution estimation		Sediment	Aquaculture farm	Social	Economic	Dredging project	
Sub-criteria		Pollution estimation	Land use area	Sediment type	Approximate between aquaculture farm and dredging site	Population of culturists in 2008	Aqua -culture statistic	Dredging frequency	Dredging cost
Unit		Kilogram	Hectare	+/+++ (qualitative)	+/+++ (qualitative)	Number of person	USD (in million)	+/+++ (qualitative)	USD (in million)
Option	Area 1	49,050	630	++	+++	693	14.8	++	0.95
	Area 2	61,507	790	+++	-	869	18.6	++	0.97
	Area 3	24,603	600	++	-	660	14	++	3.82
	Area 4	46,715	275	+++	-	303	6.5	++	0.64
	Area 5	18,608	239	++	-	263	5.6	++	0.14

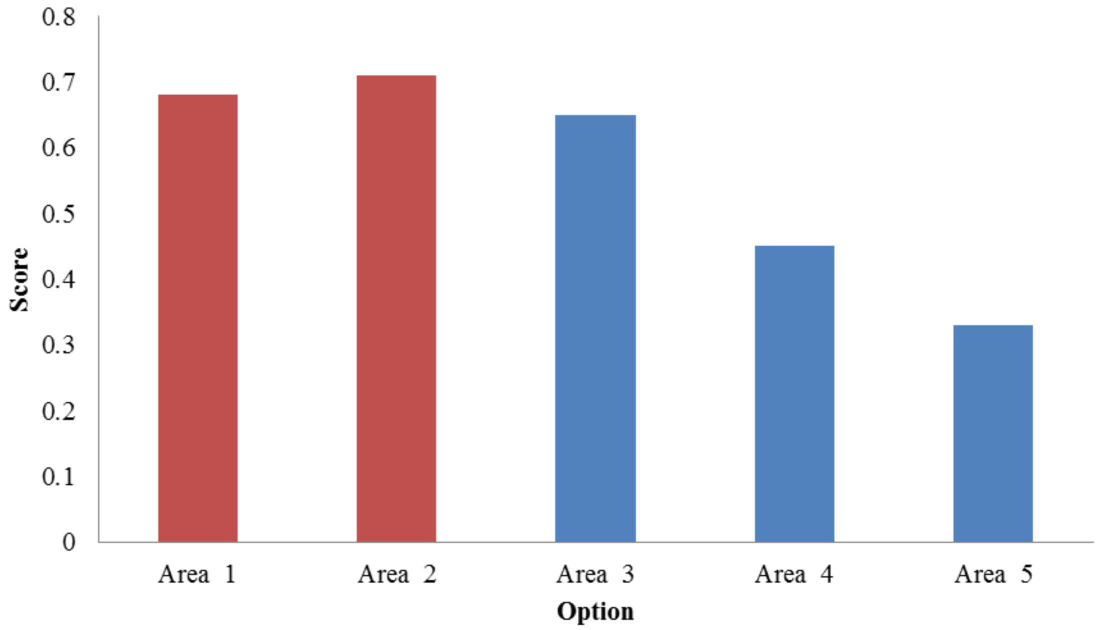


Figure 8-9 MCDA overall scores, with Areas 1 and 2 that will be forwarded for ERA

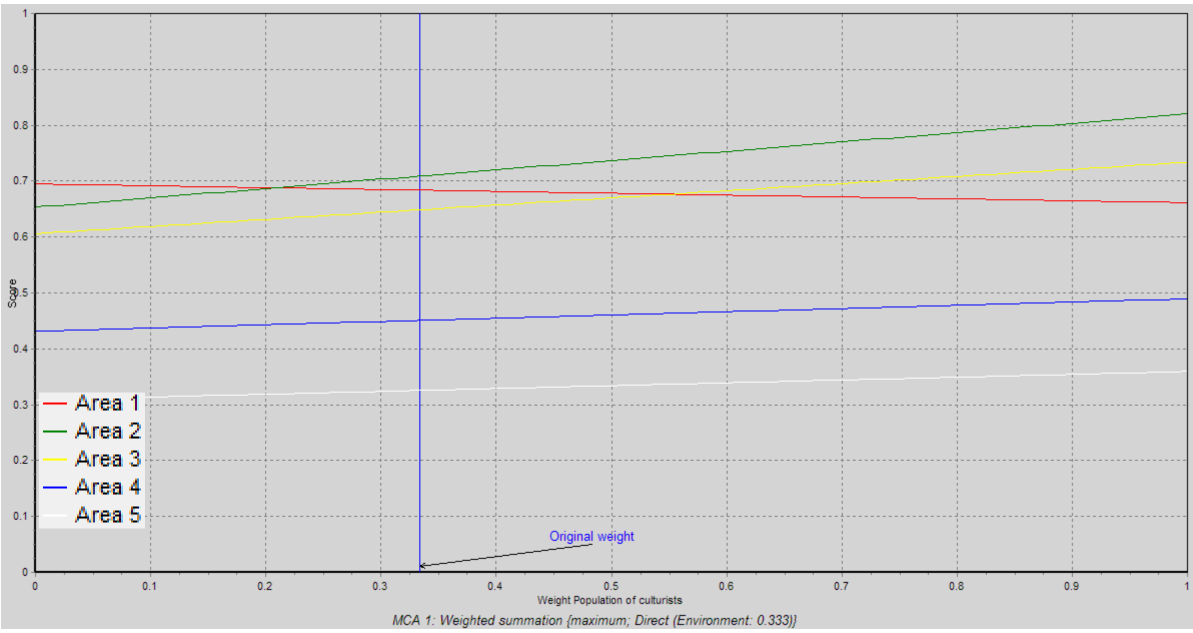


Figure 8-10 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Population of culturists

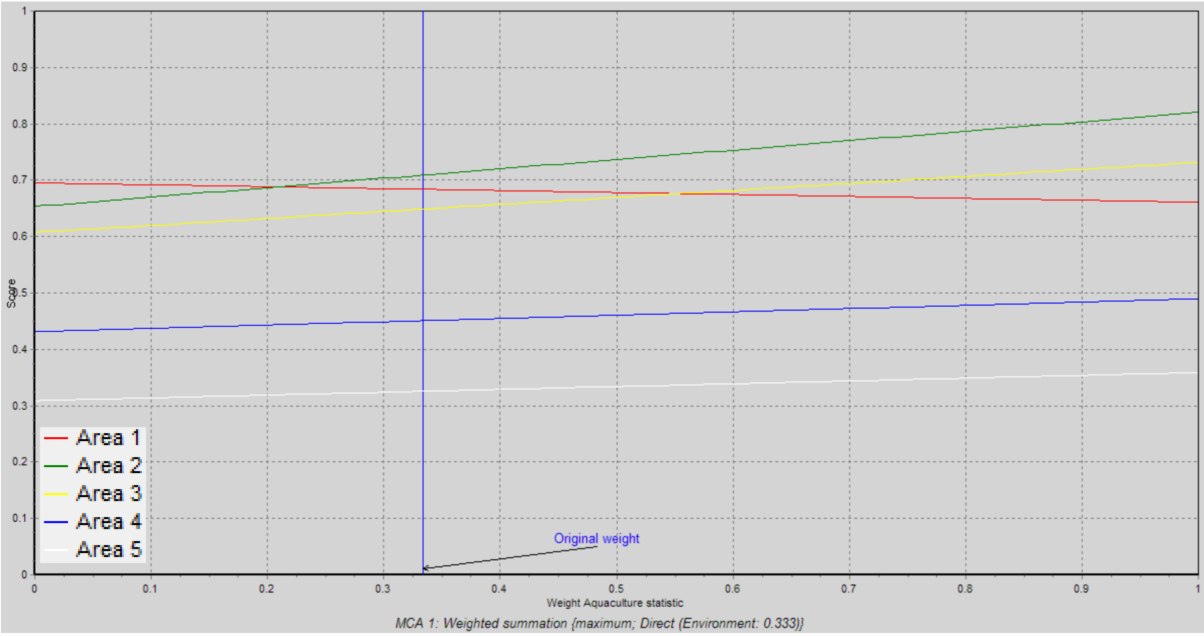


Figure 8-11 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Aquaculture statistic

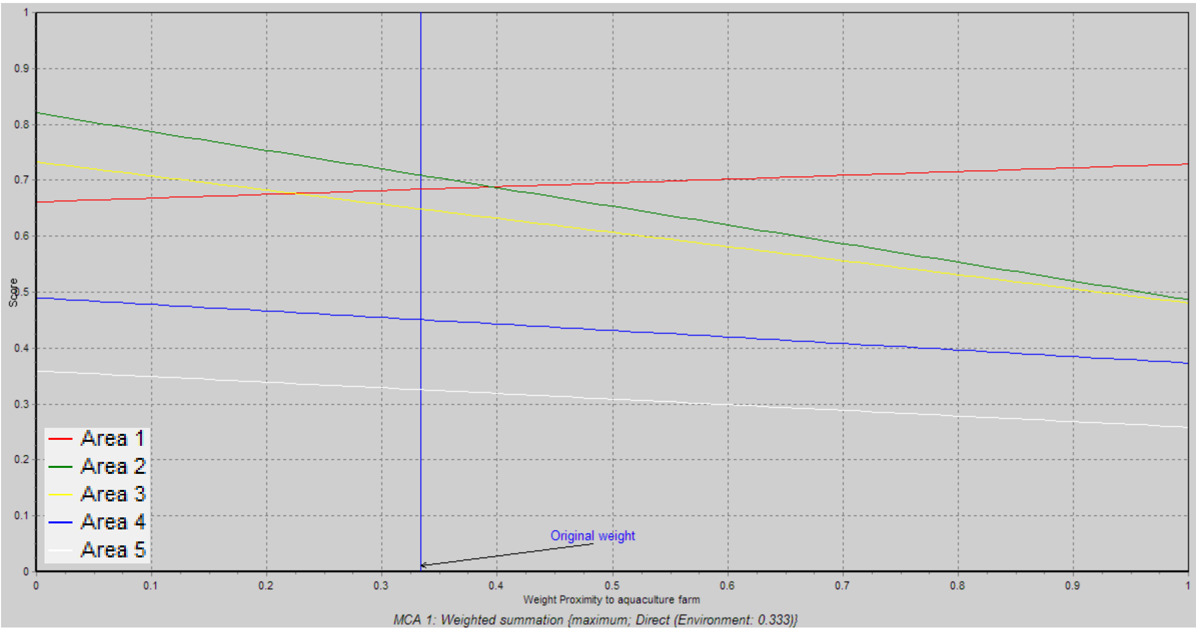


Figure 8-12 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Proximity to aquaculture farm

8.5.2 Risk characterization using Environmental Risk Assessment (ERA)

Contaminants of concern

Area 1

An aquaculture farm that breeds brown-marbled grouper (*Epinephelus fuscoguttatus*) is located in the river of Sungai Sitiawan. This species has been classified as near-threatened by the International Union for Conservation of Nature (IUCN), and is a large-bodied, long-lived, late-maturing and slow-growing coral reef grouper (Aquaculture Department Southeast Asian Fisheries Development Center Tigbauan, Iloilo, Philippines 2001, IUCN 2012, Rhodes 2012, Census of Marine Life, UNESCO 2012). Because it is environmentally and socio-economically sensitive, analysis on the dredging area near to this aquaculture is a necessity. It should be noted that no toxicity data has been researched specifically for the type of fish that was bred in this area, therefore toxicity level of other types of fish (*Cyprinus carpio*) from the literature needs to be used (Eisler 1993, Ghanmi, Rouabhia et al. 1989).

Figure 8-13 shows the conceptual framework for Area 1 and the exposure and toxicity values are shown in Table 8-10. Area 1 was found to have a very high degree of contamination in the water and in the tissues of the fish. In addition, it was found that sulphide, mercury and cadmium are the contaminants of concern as they have very high-risk ratios (Table 8-9 and Figure 8-14).

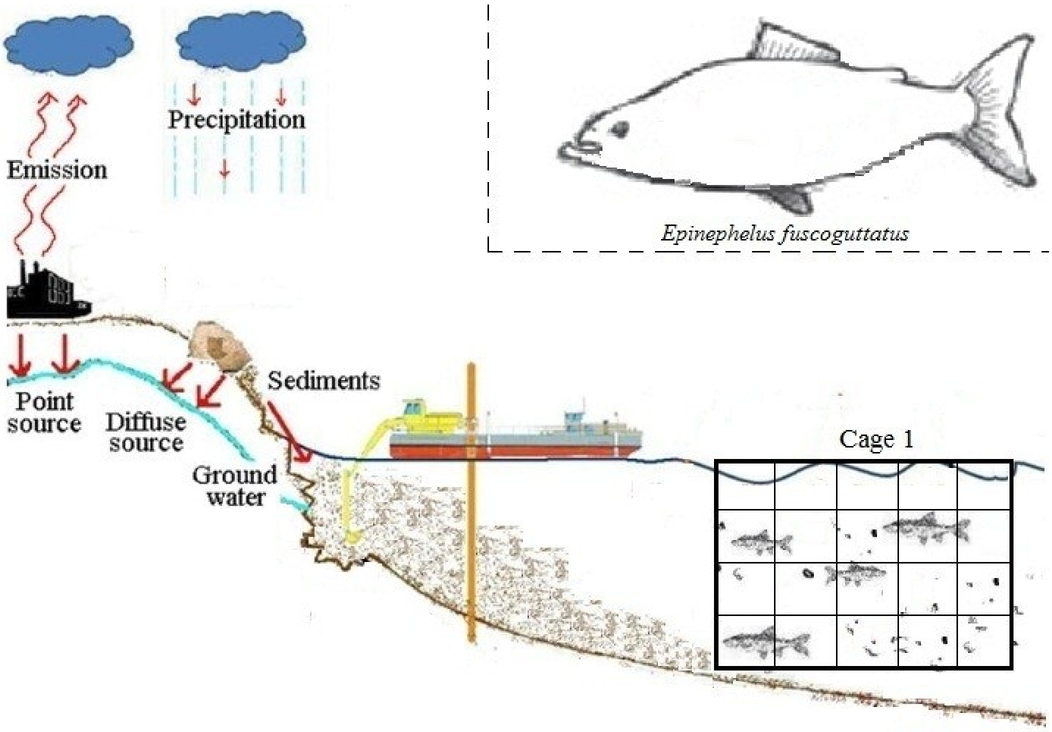


Figure 8-13 Conceptual model for Area 1

Table 8-8 Results of Tier 1 stage that indicate risk ratios and degree of contamination in Area 1 after ERA

Receptor	B	Zn	NH_3-N	Cd	S^{2-}	Hg	As	Cu	Fe	Total	Degree of contamination
Water	5	1	88	1,000	1,500	625	17	2	-	3,238	Very high
Sediment	-	3	-	-	-	-	-	-	-	3	Low
Fish	356	8	-	-	-	-	-	-	220	584	Very high
Dissolved oxygen (DO)					3					3	Low

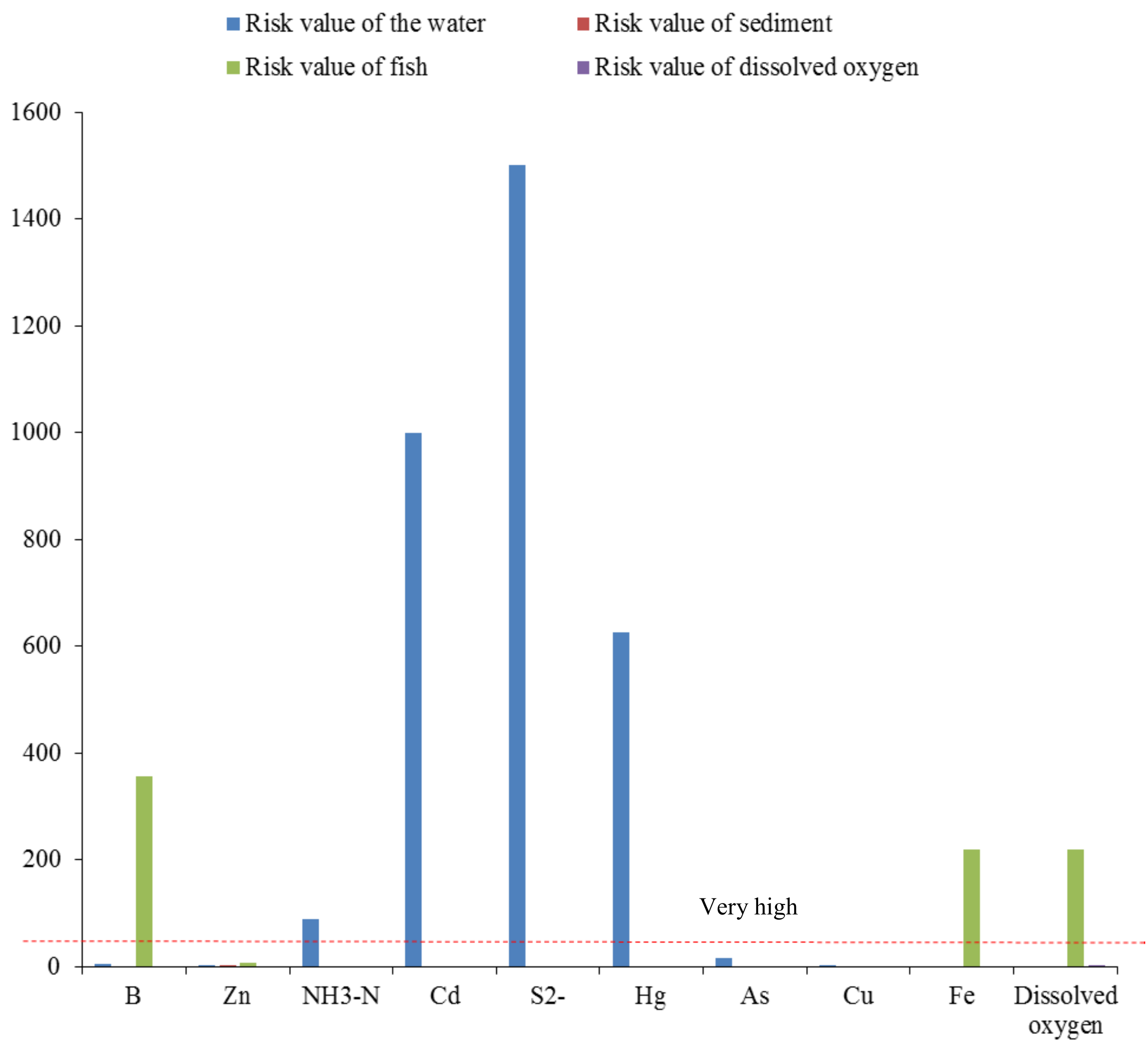


Figure 8-14 Illustration of Tier 1 results derived from ERA for Area 1

Area 2

Conceptual framework for Area 2 is as shown in Figure 8-14 and the exposure and toxicity values are as listed in Table 8-11. Analysis of ERA in this area indicated that it has a low degree of contamination (Table 8-9 and Figure 8-16).

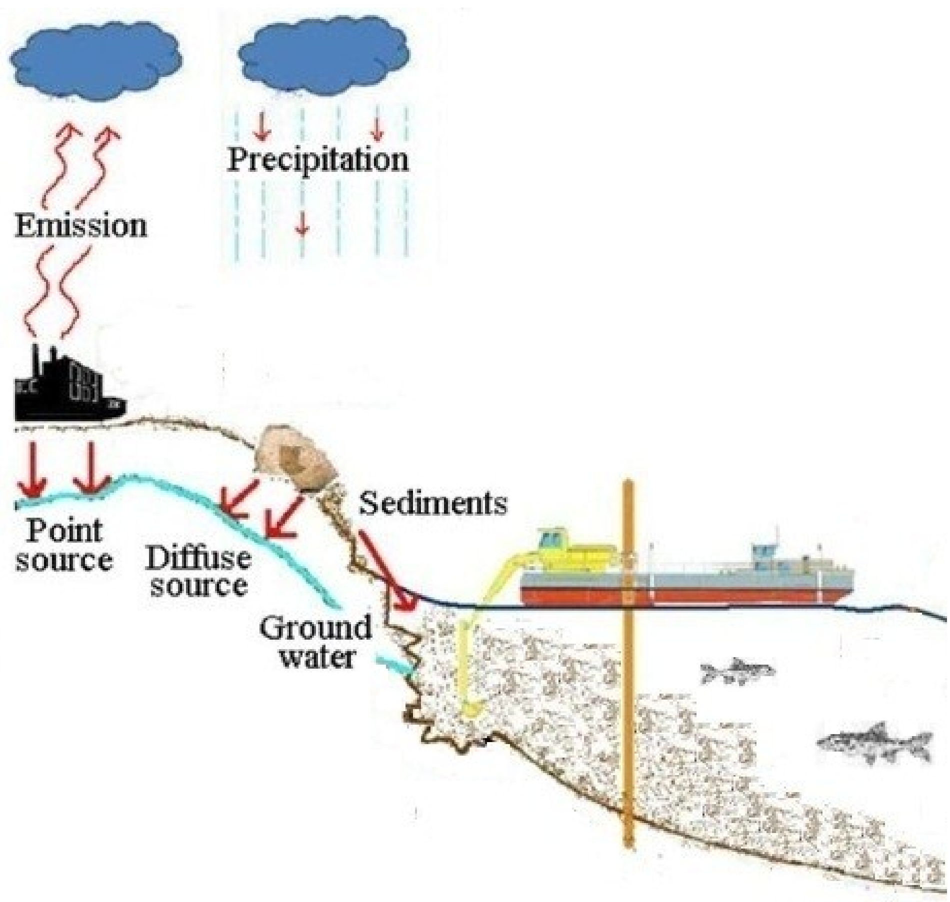


Figure 8-15 Conceptual model for Area 2

Table 8-9 Results of Tier 1 stage that indicate risk ratios and degree of contamination in Area 2

Receptor	Zn	Mn	As	Cu	Fe	Total	Degree of contamination
Water	1.2	-	1.7	0.34	-	3.24	Low
Sediment	2	0.1	-	-	0.35	2.45	Low
Dissolved oxygen (DO)			2.7			2.7	Low

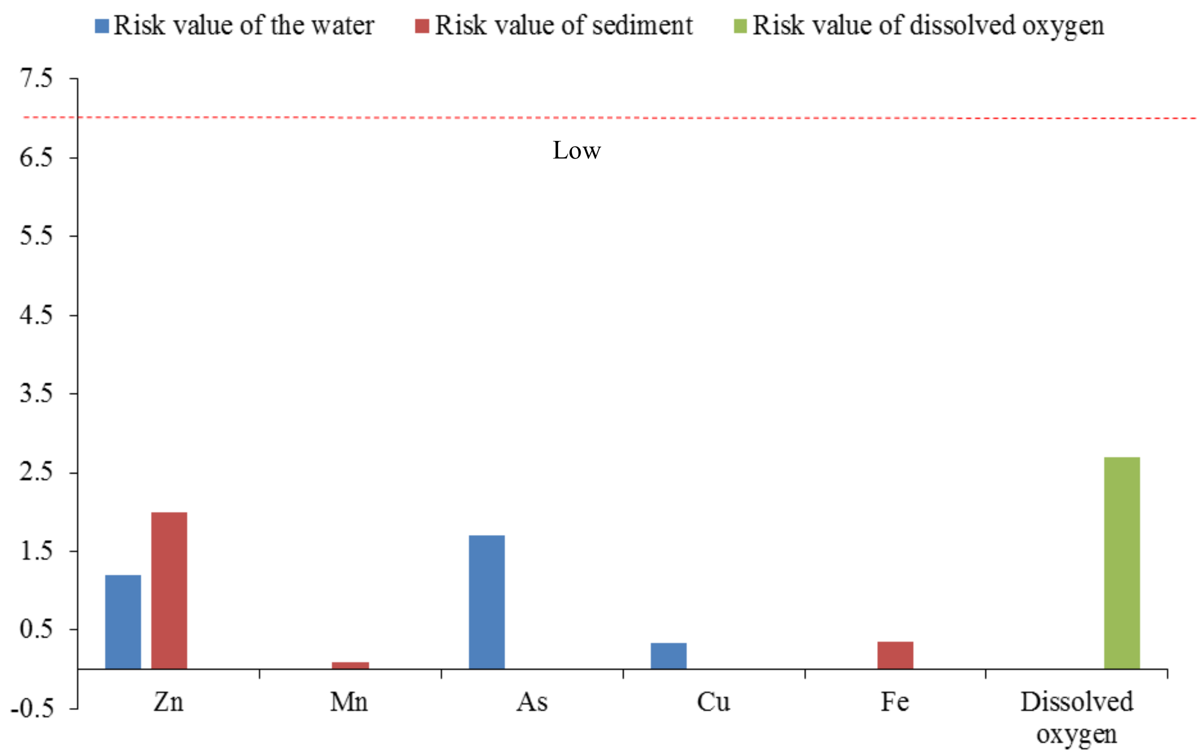


Figure 8-16 Illustration of Tier 1 results derived from ERA for Area 2

Table 8-10 Exposure and toxicity values at Area 1

	Fe		B		Mn		Zn		Cd		Amm		Sulfide		Hg		As		Cu		DO	
	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*
Water (in mg/l)			4.8	1[a]			0.03	0.05[b]	0.12	0.00012[c]	0.34	0.07[d]	3	0.002[e]	0.01	0.00001[f]	0.05	0.003[g]	0.007	0.0029[h]		
Fish (in mg/kg)	11	0.05[i]	3.2	0.009[j]			5.3	0.65[k]														
Sediment (in mg/kg)	19,0000	20,000[l]			80	460[m]	80	11.5[n]														
Dissolved oxygen (in mg/l)																					5.25	2.3[o]

[*] Exp =Exposure, Tox=Toxicity
[a] ECOTOX Marine screening benchmarks value=1000 ug/l=1 mg/l (US Environmental Protection Agency 2012b)
[b] MWQCS River mouth water=0.5 ug/l= 0.0005 mg/l (Department of Environment 2009)
[c] ECOTOX Marine screening benchmarks value=0.12 ug/l= 0.00012mg/l (US Environmental Protection Agency 2012b)
[d] MWQCS River mouth water=70 ug/l= 0.07mg/l (Department of Environment 2009)
[e] ECOTOX Marine screening benchmarks value=2 ug/l = 0.002 mg/l (US Environmental Protection Agency 2012b)
[f] ECOTOX Marine screening benchmarks value= 0.016 ug/l= 0.000016 mg/l (US Environmental Protection Agency 2012b)
[g] MWQCS River mouth water=3 ug/l= 0.003 mg/l (Department of Environment 2009)
[h] MWQCS River mouth water=2.9 ug/l= 0.0029 mg/l (Department of Environment 2009)
[i] 96 hour LC_{50} of Brown trout : 0.05 mg soluble iron/L (iron (III) sulfate liquor= 28mg/L) (National Research Council (US). Committee on Minerals 2005)
[j] Acute: Maximum tolerable levels for early life stages of rainbow trout:0.009 to 0.103 mgBoron/L (National Research Council (US). Committee on Minerals 2005)
[k] Toxicity value of Cyprinus carpio = 650 µg=0.65 mg/l (Eisler 1993)(Ghanmi, Rouabhia et al. 1989)
[l] ECOTOX Freshwater sediment screening benchmarks value= 20,000 mg/kg (US Environmental Protection Agency 2012a)(US Environmental Protection Agency 2012c)*(No guidelines for marine, as stated in reference, use freshwater value)
[m] ECOTOX Freshwater sediment screening benchmarks value= 460 mg/kg (US Environmental Protection Agency 2012a)(US Environmental Protection Agency 2012c) *(No guidelines for marine, as stated in reference, use freshwater value)
[n] Criteria values to evaluate dredged material disposal option: 11.5mg/kg (Finley, Su 2000)
[o] Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater)= 2.3 mg/l (U.S. Environmental Protection Agency 2000)

Table 8-11 Exposure and toxicity values at Area 2

	Fe		B		Mn		Zn		Cd		Amm		Sulfide		Hg		As		Cu		DO	
	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*	Exp*	Tox*
Water (in mg/l)			2.35	1 a			0.058	0.05 [b]									0.005	0.003 [c]	0.001	0.0029 [d]		
Sediment (in mg/kg)	70,000	20,000 [e]			60	460 [f]	40	11.5 [g]														
Dissolved oxygen (in mg/l)																					6.3	2.3 [h]

[*] Exp =Exposure, Tox=Toxicity
[a] ECOTOX Marine screening benchmarks value=1000 ug/l=1 mg/l (US Environmental Protection Agency 2012b)
[b] MWQCS River mouth water=0.5 ug/l= 0.0005 mg/l (Department of Environment 2009)
[c] MWQCS River mouth water=3 ug/l= 0.003 mg/l (Department of Environment 2009)
[d] MWQCS River mouth water=2.9 ug/l= 0.0029 mg/l (Department of Environment 2009)
e ECOTOX Freshwater sediment screening benchmarks value= 20,000 mg/kg (US Environmental Protection Agency 2012a)(US Environmental Protection Agency 2012c)*(No guidelines for marine, as stated in reference, use freshwater value)
[f] ECOTOX Freshwater sediment screening benchmarks value= 460 mg/kg (US Environmental Protection Agency 2012a)(US Environmental Protection Agency 2012c) *(No guidelines for marine, as stated in reference, use freshwater value)
[g] Criteria values to evaluate dredged material disposal option=11.5mg/kg (Finley, Su 2000)
[h] Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater)=2.3 mg/l (U.S. Environmental Protection Agency 2000)

Receptor of concern, dredging phase of concern and dredging activity of concern

The literature has highlighted various risks in different receptors, phases and activities (Table 8-12). The receptor that is affected by a high number of risks is fish/benthos, whereas after dredging, it is the dredging phase and disposal activity that was found to have the highest number of risks.

Table 8-12 Results of Tier 1 stage-Number of risks for receptor, dredging phase and dredging activity of concern found from literature

Concern	No. of risks	Reference
Receptor (D1-D7) :		
Water	54	(Balchand, Rasheed 2000, Munawar 1989, Messieh, Rowell et al. 1991, Mackie 2007, Thibodeaux, Duckworth 2001, Bonvicini Pagliai, Cognetti Varriale et al. 1985, Ellery, McCarthy 1998, Sergeev 2009, Ljung 2010, Wu, de Leeuw et al. 2007, Perrodin, Babut et al. 2006, Vivier, Cyrus 1999)
Sediment	97	(Munawar 1989, Messieh, Rowell et al. 1991, Padmalal 2008, Toes 2008, Mackie 2007, Piou 2009, Constantino 2009, Thibodeaux, Duckworth 2001, Ellery, McCarthy 1998, Sergeev 2009, Kenny, Rees 1996, Ljung 2010, Cappuyns 2006, Wilber, Clarke et al. 2007, Lions 2010, Perrodin, Babut et al. 2006, de Leeuw 2010, Alvarez Guerra, Viguri et al. 2009, Desprez 2000, Kenny, Rees 1994, Cooper, Barrio Froján et al. 2008)
Fish/Benthos	***112***	(Su 2002, Balchand, Rasheed 2000, Munawar 1989, Messieh, Rowell et al. 1991, Padmalal 2008, Toes 2008, Constantino 2009, Thibodeaux, Duckworth 2001, Bonvicini Pagliai, Cognetti Varriale et al. 1985, Ellery, McCarthy 1998, Rasheed, Balchand 2001, Kenny, Rees 1996, Ware, Bolam et al. 2010, Crowe, Gayes et al. 2010, Cruz-Motta, Collins 2004, Powilleit, Kleine et al. 2006, Wilber, Clarke et al. 2007, de Leeuw 2010, Vivier, Cyrus 1999, Kenny, Rees 1994, Cooper, Barrio Froján et al. 2008, van den Hurk, Eertman et al. 1997)
Dissolved oxygen	7	(Messieh, Rowell et al. 1991, Toes 2008, Perrodin, Babut et al. 2006)
Dredging phases (C1-C5):		
Before dredging	1	(Rasheed, Balchand 2001)
During dredging	21	(Balchand, Rasheed 2000, Munawar 1989, Thibodeaux, Duckworth 2001, Bonvicini Pagliai, Cognetti Varriale et al. 1985, Rasheed, Balchand 2001, de Leeuw 2010)

After dredging	***176***	(Su 2002, Balchand, Rasheed 2000, Munawar 1989, Messieh, Rowell et al. 1991, Padmalal 2008, Toes 2008, Mackie 2007, Mackie 2007, Piou 2009, Constantino 2009, Thibodeaux, Duckworth 2001, Thibodeaux, Duckworth 2001, Shigaki, Kleinman et al. 2008, Ellery, McCarthy 1998, Sergeev 2009, Alvarez Guerra, Viguri et al. 2007, Rasheed, Balchand 2001, Kenny, Rees 1996, Wu, de Leeuw et al. 2007, de Leeuw 2010, Desprez 2000, Kenny, Rees 1994, Cooper, Barrio Froján et al. 2008, Guerra, Pasteris et al. 2009b)
During disposal	0	-
After disposal	71	(Balchand, Rasheed 2000, Munawar 1989, Messieh, Rowell et al. 1991, Toes 2008, Ljung 2010, Ware, Bolam et al. 2010, Crowe, Gayes et al. 2010, Cruz-Motta, Collins 2004, Powilleit, Kleine et al. 2006, Wilber, Clarke et al. 2007, Lions 2010, Perrodin, Babut et al. 2006, Vivier, Cyrus 1999, van den Hurk, Eertman et al. 1997)
Dredging activity :		
Excavation (A1-A5)	119	(Su 2002, Balchand, Rasheed 2000, Munawar 1989, Messieh, Rowell et al. 1991, Padmalal 2008, Thibodeaux, Duckworth 2001, Bonvicini Pagliai, Cognetti Varriale et al. 1985, Ellery, McCarthy 1998, Ellery, McCarthy 1998, Sergeev 2009, Rasheed, Balchand 2001, Kenny, Rees 1996, de Leeuw 2010, Desprez 2000, Kenny, Rees 1994, Cooper, Barrio Froján et al. 2008)
Disposal (B1-B2)	***149***	(Balchand, Rasheed 2000, Munawar 1989, Messieh, Rowell et al. 1991, Ponti, Pasteris et al. 2009, Toes 2008, Toes 2008, Mackie 2007, Piou 2009, Sergeev 2009, Ljung 2010, Cappuyns 2006, Ware, Bolam et al. 2010, Crowe, Gayes et al. 2010, Cruz-Motta, Collins 2004, Powilleit, Kleine et al. 2006, Wilber, Clarke et al. 2007, Lions 2010, Perrodin, Babut et al. 2006, Alvarez Guerra, Viguri et al. 2009, Vivier, Cyrus 1999, van den Hurk, Eertman et al. 1997)

8.6 Discussion

Scientific research has proven the detrimental impacts of dredging towards ecology, particularly in highly contaminated areas. Sediment quality analysis was proven to help minimize the risks; however, the decision to use this analysis alone in determining dredging decisions may cause disproportionate costs for remediation action. Thus, a sustainable dredging decision making method is necessary. This chapter presented the fifth step (Tier 1 stage) of the proposed framework in Malaysia's context. The

Tier 1 stage is developed to prioritize dredging areas and determine their degree of contamination and concern for further investigation using a newly developed method that integrates MCDA and ERA.

The evaluation of dredging areas undertaken using MCDA enabled the identification of Area 1 and Area 2 as the prioritized areas that require high level of environmental protection, based on environmental, socio-economic and managerial criteria. The degree of contamination in Area 1 was found to be very high in the water and fish tissues, and signs of depletion of dissolved oxygen were also recorded.

However, it must be highlighted that the results of this study were highly dependent on data extracted from the reports collected, and assumptions made due to lack of data. It has been found that Area 2 has an extremely high risk (risk value of four) compared to Area 1(risk value of three). Even though the degree of contamination in Area 2 was found to be lower than that in Area 1, it has been discussed in Subsection 5.4.2 of Chapter 5 highlighting that more dramatic changes were observed at Site 4 (as adjacent to Area 2 of this chapter) than at other sites. Area 2 (as Site 4 in Chapter 5) is the location where dredging was commenced during low tide on 6th October 2008 that detrimentally affected fishes in the nearby aquaculture farm. This may a result of the fact that data collected in Area 2 was not enough for a thorough analysis of contamination degree in this chapter. This contradiction of results has proven that the meticulousness of hazard identification of this newly developed method helps providing a thorough analysis.

Furthermore, the delimitation of areas made in MCDA was based on data that was not well presented the land use of each area. Thus, it should be noted in future studies that more contaminant information and detailed land use data for each area are required in order to identify the type of contaminant and its sources so that better results can be achieved.

The decision-making method that was developed will help dredging industry to make decisions that are sustainable. The integration of MCDA and ERA in this study avoids the likelihood of disproportionately high costs of sediment remediation, by not using sediment analysis alone in making decisions. This method can be used to determine which areas that can be considered as contaminated through the analysis of environmental, socio-economic and management criteria. In addition, the identification of risk in prioritized areas helps decision makers to give attention to these areas when making decisions prior dredging.

8.7 Conclusion

Research into sustainability in the dredging industry has fallen short and as such, this chapter presented the fifth step (Tier 1 stage) of the proposed framework in Malaysia's context. The Tier 1 stage was developed to prioritize dredging areas and determine their degree of contamination and concern for further investigation using a new methodology that prioritized dredging areas using MCDA and identified the degree of contamination in prioritized areas using ERA. In addition, this chapter highlighted contaminants, and dredging phases and activity of concern from the available literature. The case study of this chapter was three dredging projects performed at the rivers of Sungai Sitiawan and Dinding, Perak, Malaysia. The results of MCDA that took into account the environment, management and socio-economic factors found that Area 1 and Area 2 were the prioritized areas and should be brought forward for ERA. ERA determined that the degree of contamination in Area 1 was very high, and this was imposed on the area by multiple contaminants of concern including sulphide, cadmium and mercury that can potentially cause mortality of caged fish. It has also been found that Area 2 has a lower degree of contamination than Area 1. However, this result was disputed due to the exposure data's inadequacy, and the many assumptions being made. This method, however, has taken into account multiple conflicting criteria that could be a good model for decision-making in dredging industry. Further to this study, an informed decision during selection of technology and method for dredging can be made, but only in conjunction with a detailed land-use data and complete contaminant information.

9 FRAMEWORK STAGE 3 (TIER 2): SELECTION OF SEDIMENT MANAGEMENT OPTION

9.1 Introduction

This chapter develops the sixth step (Tier 2 stage) of the proposed framework in Malaysia's context to select best sediment management option using a newly developed method that balances multiple criteria using MCDA. This stage utilized findings from the Tier 1 stage as discussed in previous chapter in order to demonstrate the application of this stage.

Sediment management has been performed worldwide for a variety of reasons; for example, to ensure the safety of navigation for waterborne transportation, or to avoid the dispersal of contaminants from sediments. Currently, many types of sediment management have been utilized and this includes 'Keep Sediment in the System' (KSIS) (Kirby 2012) and dredging. The latter is an age-old technology to compare to others and commonly used. During sediment management, hazardous contaminants that have accumulated on a sediments surface matrix will be exposed; therefore strict supervision is required when dealing with highly contaminated sediment in order to avoid detrimental consequences.

Typically, decisions concerning which sediment management option to use, and the level of supervision needed are highly dependent on the types of decision makers involved in the decision making process. These decision makers include port administrators, representatives of the government (including members of the departments of environment and finance), environmental consultants, environmentalists, dredging contractors and the public. Each of these decision makers have different styles, opinions and interests, which are shaped by their skills, knowledge, experience, intelligence, judgment, attitude, character and drive (Michaels 1942). A decision maker can be considered as an idealist, a politician, an environmentalist, an economist or balanced during his or her engagement in the sediment management decision-making process (Alvarez-Guerra, Canis et al. 2010). Due to these differences, conflicts may arise. In order to avoid this, tools are developed to help structure decision-making processes and methods, so that the decisions can be streamlined as required.

In line with this, much research has been conducted, including ones which have imitated the sophistication of the human brain to aid the decision making process (Linkov, Cormier et al. 2012). The Sediment Quality Triad is one of the major breakthroughs that have been applied in sediment management. Its application involves using three types of data to describe and interpret environmental risks; namely benthic alteration, toxicity and chemistry (Perrodin, Babut et al. 2006, Pinto, Patrício et al. 2009, Chapman, Ho et al. 2002). However, not much research has been focused on sustainable decision making methods that combine this scientific evidence with socio-economic or other qualitative criteria, to interpret environmental risks due to anthropogenic activities such as dredging (Apits, White 2003).

In addition to the types of decision makers involved, the environmental stresses, technology available, economic restraint and the level of managerial or operational skills may also affect decisions in selecting a sediment management option (Bray, Bates et al. 1979). In developing countries, economic constraint can often drive the selection of options rather than environmental aspects, but this is not necessarily the case in developed nations where they have greater purchasing power. Nevertheless, it is important to consider the environmental aspect when making decisions in sediment management, in order to avoid social costs including loss of income for fishermen.

Therefore, a decision making method that can balance multiple drivers in selecting sediment management options is essential. The method must be able to decompose the drivers structurally. In addition, the criteria for selection should be quantifiable, either in a quantitative sense or a qualitative one. Furthermore, defendable decisions are required so that the method can be adapted or changed over time. The method should also allow decision makers to situate and change the priorities of each driver, so that it can be made flexible and applicable to many scenarios. In relation to this, Multiple-criteria Decision Analysis (MCDA) is a potential method of making a sound, defendable and balanced decision which could be subjected to multiple and conflicting elements (Linkov, Satterstrom et al. 2006a). Unfortunately, not many methods like this have been developed in the sediment management industry.

Decisions that are biased towards scientific evidence in sediment management may divert objectives. As mentioned, developing nations may have different perspectives when it comes to selecting their sediment management options. This could cause economic burden, which is unfavourable to these countries. However, not many papers have discussed case studies in countries that typically stress economic aspects over other criteria.

Thus, this chapter aims to develop the sixth step (Tier 2 stage) of the proposed framework in Malaysia's context to select best sediment management option using a newly developed method that balances multiple criteria (namely environmental, technical and economic) using MCDA. This stage utilized findings from the Tier 1 stage as discussed in previous chapter in order to demonstrate the application of this stage. Dredging data of the rivers of Sungai Sitiawan and Sungai Dinding, Perak was used as the case study to demonstrate the Tier 2 stage of the proposed framework.

9.2 Criteria, sub-criteria and options of sediment management

Technical, socio-economic and environmental (as in Table 9-1) are among the criteria that affect decision making processes in sediment management, and available options of sediment management range from excavation to no dredging can be found in Table 9-2.

Table 9-1 Criteria and sub-criteria in sediment management decision-making process

Technical	Socio-economic	Environmental
Energy and raw materials consumption, water required, and final solid residuals produced (Alvarez-Guerra, Canis et al. 2010)	Quantity of dredged sediments, the cost of dredging equipment and construction cost of facilities required (Lee, Lee et al. 2011)	Noise pollution, level of tourism quality, navigation condition, cultural and economic activities (Garmendia, Gamboa 2012)
Soil characteristic, the requirements of dredging work, logistics, site conditions and environmental and legal limitations such as noise and pollution (Training Institute for Dredging 2002b)	Cost for mobilisation and demobilisation of dredger (Training Institute for Dredging 2002a)	Impact on habitat, marshes, reed beds, sandbanks, birds, shellfish and invasive species proliferation (Garmendia, Gamboa 2012)
Process of organic amelioration and pH adjustment of dewatering and desalination	Cost of equipment, materials, consumables and work force (Training Institute for Dredging 2002a)	Reversibility, Maintain the potential of the area for the future, Respect the dynamics of the river, Encourage a long term orientation for reaching an equilibrium (Garmendia, Gamboa 2012)
-	Overhead cost including communication and logistics (Training Institute for Dredging 2002a)	Ecological risk and human health risk (Linkov, Satterstrom et al. 2006b)
-	Financing and insurance cost (Training Institute for Dredging 2002a)	Transport emissions of CO2 (Sheehan, Harrington et al. 2010c)
-	Taxes and dues (Training Institute for Dredging 2002a)	Level of risk reduction (Sheehan, Harrington et al. 2010c)
-	Cost for subcontractors and agents (Training Institute for Dredging 2002a)	Duration for environmental protection to be effective (Sheehan, Harrington et al. 2010c)
-	Requirements by clients (Training Institute for Dredging 2002a)	Implementability of environmental protection, level of experience, degree in which type and level of contamination are conducive for the option, degree in which sediment characteristics are conducive for the option (Sheehan, Harrington et al. 2010c)

Technical	Socio-economic	Environmental
-	Contingency costs (Training Institute for Dredging 2002a)	PAH Content in Marine Sediment of Kuala Perlis, Malaysia (235)
-	Cost and initial investment (Alvarez-Guerra, Canis et al. 2010)	Sensitivity analysis on transport emissions, The capacity of the hopper/barge used for transport, The distance from the production site to the quay/couple site, Power consumption during dredging, Distance from source of organic material (Sheehan, Harrington et al. 2010c)
-	Public acceptability (Linkov, Satterstrom et al. 2006b) (Alvarez-Guerra, Canis et al. 2010)	

Table 9-2 Options in sediment management decision making

Excavation	Transport	Disposal	Beneficial use	Remediation	No dredging
Drilling pontoon (Bray, Bates et al. 1979)	Hopper barges (Duran Neira 2011a, Nippon 1996, Schnell 1984)	Agitation dumping (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al. 2009, Krishnappan 1975, Saxena, Vaidyaraman et al. 1975, Welte 1975)	Road construction (Breugelmans 2012)	Monitored natural recovery (Alvarez-Guerra, Canis et al. 2010)	Auto-flushing systems(Kirby 2012)
Dipper dredger (Bray, Bates et al. 1979)	Pipe lines (Duran Neira 2011a, Nippon 1996, Schnell 1984).	Side casting (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al. 2009, Krishnappan 1975, Saxena, Vaidyaraman et al. 1975, Welte 1975)	Landfill closure (Envisan Environmental Technologies, Jan De Nul Group, Sedival-Moen 2012)	Sediment washing (Alvarez-Guerra, Canis et al. 2010)	Soft-sediment engineering(Kirby 2012)
Backhoe dredger (Bray, Bates et al. 1979)	-	Dumping in re-handling basins (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al. 2009, Krishnappan 1975, Saxena, Vaidyaraman et al. 1975, Welte 1975)	Construction of a sediment treatment plant (Envisan Environmental Technologies, Jan De Nul Group, Sedival-Moen 2012)	Bioreactor (Alvarez-Guerra, Canis et al. 2010)	Open basins- self-cleansing (Kirby 2012)
Bucket dredger (Bray, Bates et al. 1979)	-	Sump re-handling operations (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al. 2009, Krishnappan 1975, Saxena,	Retaining structures, river embankments, beach reinforcement, sludge factory (Pensaert, Dor et al. 2008)	Solidification/stabilization (Alvarez-Guerra, Canis et al. 2010)	Keep Sediment in the System (KSIS) (Kirby 2012)

Excavation	Transport	Disposal	Beneficial use	Remediation	No dredging
		Vaidyaraman et al. 1975, Welte 1975)			
Grab dredger (Bray, Bates et al. 1979)	-	Direct pumping ashore (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al. 2009, Krishnappan 1975, Saxena, Vaidyaraman et al. 1975, Welte 1975)	Brick production (Ramli, Jumali et al. 2013, Sheehan, Harrington 2012)	Upland confined disposal facility (Alvarez-Guerra, Canis et al. 2010)	-
Cutter suction dredger (Bray, Bates et al. 1979)	-	Open water disposal (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al. 2009, Krishnappan 1975, Saxena, Vaidyaraman et al. 1975, Welte 1975)	Ceramic production (Sheehan, Harrington 2012, Baruzzo, Minichelli et al. 2006)	Capping (Sheehan, Harrington 2012)	-
Trailer hopper Suction Dredger (Bray, Bates et al. 1979)	-	-	Structural fill material (Sheehan, Harrington 2012, Beeghly, Schrock 2010)	-	-
Dustpan (Bray, Bates et al. 1979)	-	-	Topsoil (Sheehan, Harrington et al. 2010a, Sheehan, Harrington et al. 2010d)	-	-
Backhoe dredger with eco-bucket (Sheehan, Harrington 2012)	-	-	Lightweight aggregate (Wang 2009, Wang, Tsai 2006)	-	-
-	-	-	Land reclamation (Sheehan, Harrington 2012)	-	-

9.3 Methodology

9.3.1 Multi-criteria decision analysis (MCDA)

MCDA has many advantages, including the incorporation of qualitative and conflicting factors, the creation of adaptable and replicable results, and the aggregation of data without monetization (Sparrevik, Barton et al. 2011). However, the process is time-consuming, and the high subjectivity of this analysis has limited its benefits (Linkov, Cormier et al. 2012, Linkov, Satterstrom et al. 2007, Paquette, Lowry 2003).

Nevertheless, MCDA has already been widely applied in the sediment management industry. This includes in the choosing of remedial action options, in remediating contaminated aquatic ecosystems, in the area of selecting technological options for sediment management, and in identifying clean-up activities (Linkov, Satterstrom et al. 2006a).

The above was implemented through various approaches of MCDA, which have been well represented by Kiker (Kiker 2005). Two well-defined approaches of MCDA include Weighted Summation method (applying Multi-attribute utility theory (MAUT)) and Analytical Hierarchy Process (AHP).

In Weighted Summation method and AHP, multiple criteria are joined as a single optimization function for deliberation. The decision to select the optimum single function is made by using two different approaches, whether through pair-wise comparison (AHP) or through the highest performance of a non-monetary number (Weighted Summation method). If the criteria are incomparable, outranking approaches can be used to investigate the relative magnitude of each criterion, taking into consideration not only optimum but also inferior values (Alvarez-Guerra, Canis et al. 2010, Linkov, Satterstrom et al. 2006a).

In MCDA, different processes can be used depending on the objectives. For example, Alvarez listed a process for prioritizing a contaminated site using MCDA. The steps of this process include delimitating management units, defining the prioritized areas and ranking available decision options (Alvarez Guerra, Viguri et al. 2009). In addition, Sparrevik et al. listed multiple steps for supporting the sustainable management of contaminated sediments, that included objectives formulation, option generation, criteria and metrics development, performance measurement, weighting, and information synthesis and sensitivity analysis (Sparrevik, Barton et al. 2011).

9.3.2 Method for Tier 2 stage

Method for Tier 2 stage which selects the best sediment management option for the rivers of Sungai Sitiawan and Sungai Dinding, Perak, Malaysia is as per Figure 9-1. Areas that will be performed capital dredging and maintenance dredging with low, moderate and considerate degrees of contamination determined from previous stages will be brought forward in this Tier 2 stage. In this stage, sediments with beneficial use and remediation options will be further analysed before deliberation to choose technology options for each dredging stage (excavation, transport and disposal) are made and one sediment management option will be selected afterwards. Permit to dredge can then be issued and dredging project can be implemented using the option that has been selected. The framework has been designed to be dynamic and transparent that its users can review their decisions and compliance to the steps can be monitored.

Options and **S*ub-criteria*** that will be analysed in this chapter are further detailed in subsequent subsections.

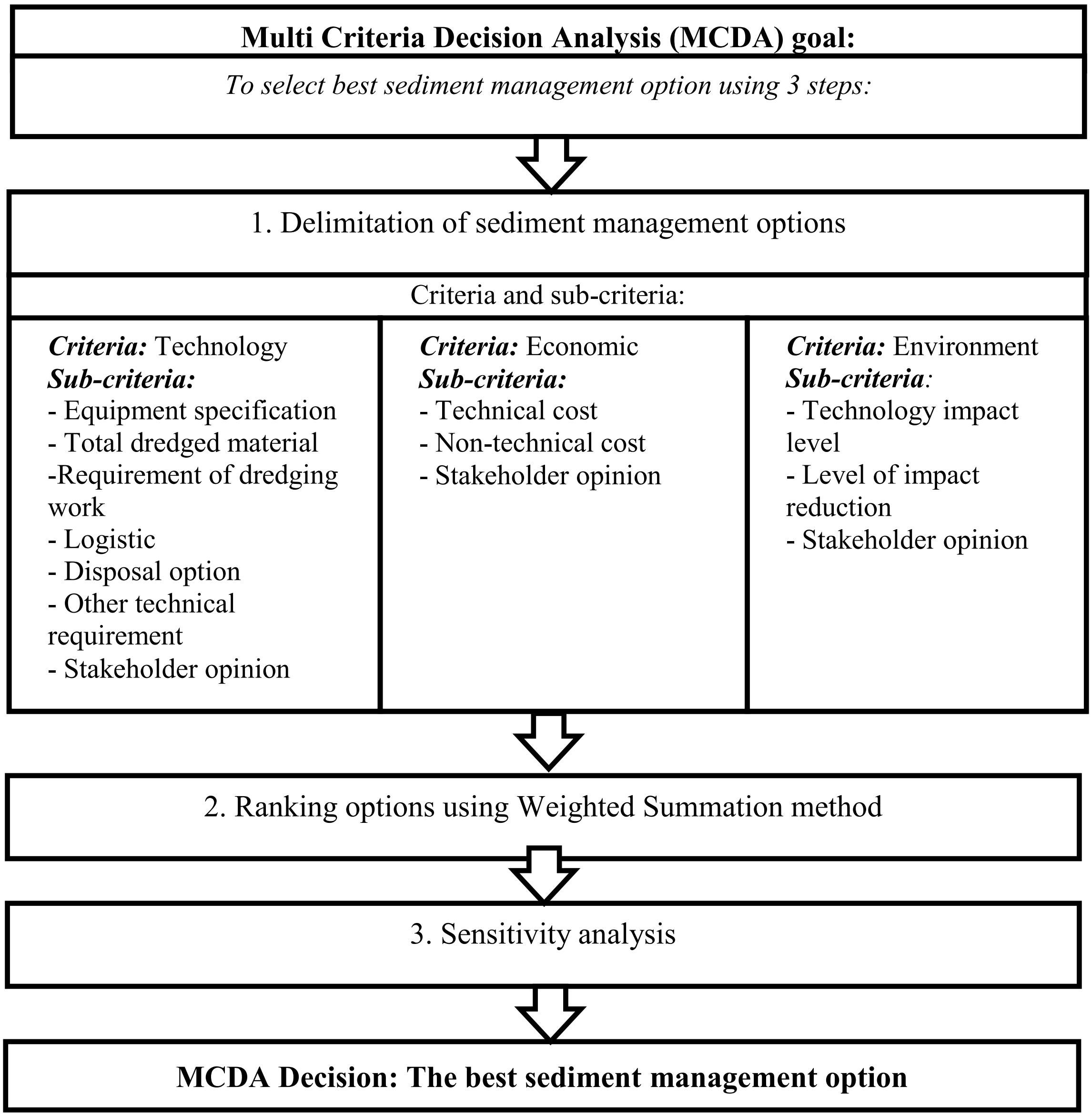


Figure 9-1 Method for Tier 2 stage

9.3.3 The case study of Sungai Sitiawan and Dinding rivers, Perak, Malaysia

The main selection criterion for case studies in this thesis is the availability of dredging data executed in river systems of a developing country. The three sample reports (similar to case studies as used in Chapters 5 and 8) used in the Tier 2 stage of this framework fitted into this main selection criteria. The case studies are also suitable due to the fact that there were two other dredging activities executed during two different intervals, which is adjacent to an incident affecting caged fish at Sungai Sitiawan river which has been properly documented.

Data was collected from a company that performed dredging in 2008 at the rivers of Sungai Sitiawan and Sungai Dinding, Perak, Malaysia (Figure 9-2). This company has also performed many dredging projects locally and internationally that qualify them as an expert in dredging. An analysis on nine other dredging projects performed by this company in Peninsular Malaysia can be found in Sub-section C.1 in Appendix C.

In this chapter, selection of the best sediment management option was based on a combination of multiple data. This includes data from the interview and questionnaire-based survey in Chapter 4, and data from environmental, toxicological, soil investigation, technical and financial reports that were collected from the company as discussed in Chapter 5 and Chapter 8.

In order to select the best sediment management option for this river, the data was analysed for multiple purposes, including dredging cost per meter cube, aquaculture production values, environmental risk value, and for soil characteristics. It was also analysed to discern contaminants' behaviour, historical problems, prioritized contaminated areas, the degree of contamination, the identification of multiple concerns, and also for dredgers' technical specifications, for water quality status, and for toxicological analysis.

In addition to a number of factors that have been outlined in Table 9-1 and Table 9-2, it is imperative to consider local factors affecting the MCDA for selecting the best sediment management tool for these rivers. In this chapter, local factors determining the selection of sediment management option include data limitation, the most common practice of sediment management in any given locality, available technology, and economic restraint.

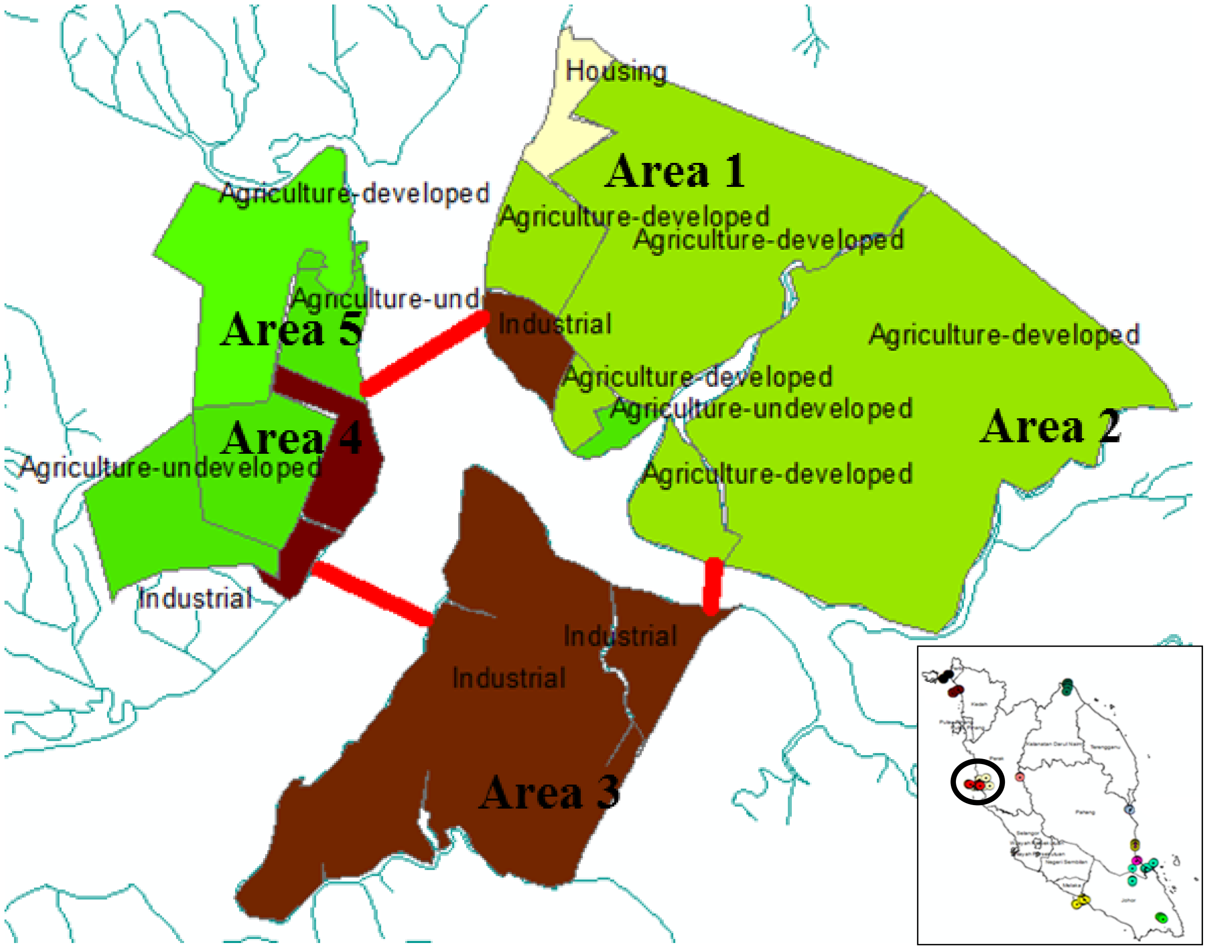


Figure 9-2 The location of the river of Sungai Sitiawan, Perak, Malaysia

9.3.4 Options

Sediment management options for the rivers of Sungai Sitiawan and Dinding, Perak, Malaysia as discussed in this chapter are as illustrated in Figures 9-3 to 9-5.

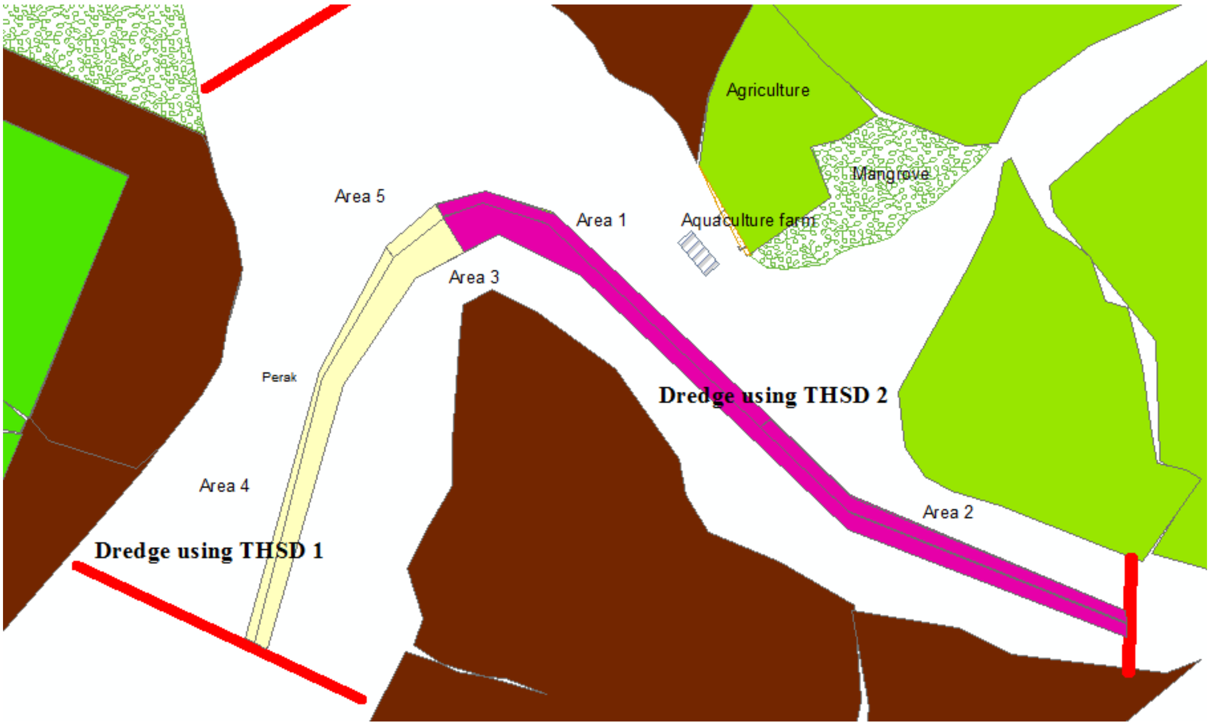


Figure 9-3 Option 1 – Two THSDs and dredged sediments to be dumped offshore

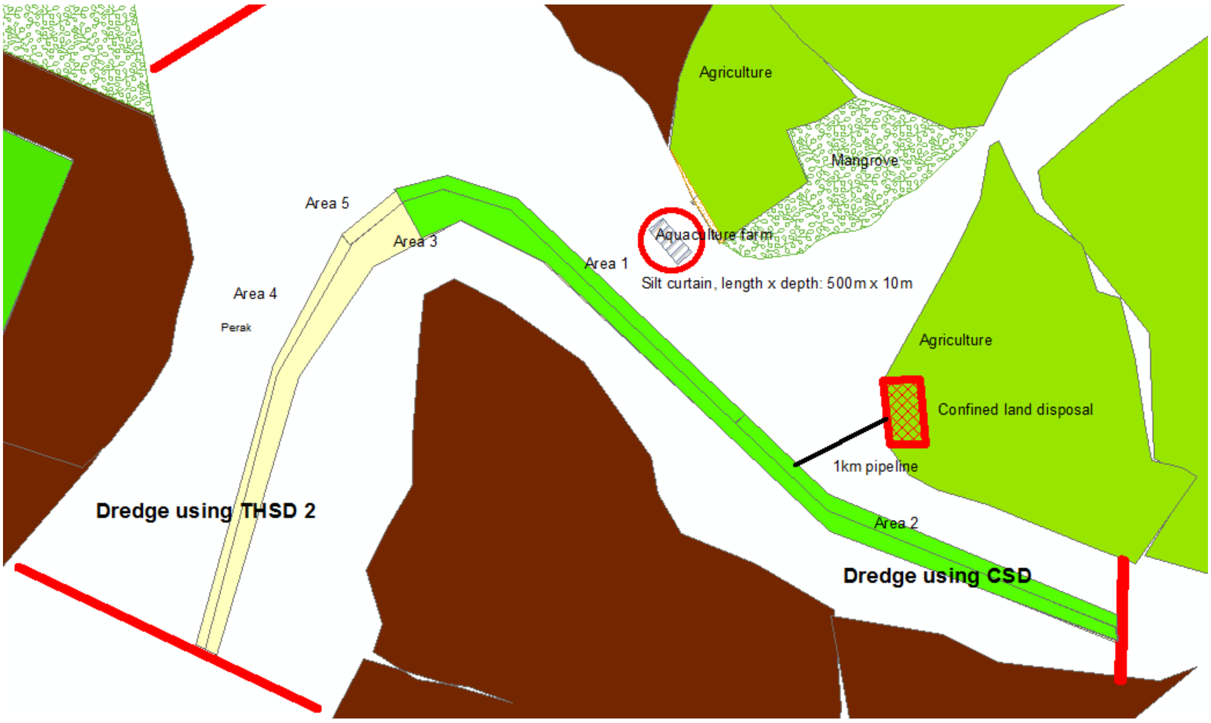


Figure 9-4 Option 2 – One THSD, one CSD, silt curtain and dredged sediments to be dumped at a confined land disposal and at offshore, and to be used as top soil

Figure 9-5 Option 3 – No dredging

9.3.5 Sub-criteria

Accumulated fuel consumption

Fuel consumption of machinery depends on its efficacy and working hours, which directly affect the cost of dredging. The higher the consumption levels, the higher the cost of dredging. For this chapter, calculations were made as in Table 9-3 for fuel consumption, based on the specifications of dredgers and expert opinion.

Table 9-3 Calculation made for accumulated fuel consumption

Option 1	Option 2		Option 3
THSD No.1 and No.2	**THSD No.2**	**CSD**	**No dredging**
15,790kg	9,990kg	Fuel consumption of dredge pump=202 g/kWhour	-
		Power at shaft=922kW	-
		Total fuel consumption of dredged pump=0.202kg/kWhour x 922kW=186kg/hour	-
		Total fuel consumption of dredge pump=186kg x 8 hours=1,488kg/day	-
		Fuel consumption of auxiliary power=206g/kWhour	-
		Caterpillar power=345 kW	-
		Total fuel consumption for auxiliary power=0.206kg/kWhour x 345kW=71kg/hour	-
		Total fuel consumption of auxiliary power=71kg x 8 hours=567kg/day	-
		Fuel consumption of cutter=202g/kWhour	-
		Power at shaft=170kW	-
		Total fuel consumption for cutter=0.202kg/kWhour x 170kW=34kg/hour	-
		Total fuel consumption=34kg x 8 hours=275kg	-
		Accumulated fuel consumption of CSD= 1,488kg + 567kg + 275kg=2,330kg	-

Accumulated sailing speed

THSDs have different sailing speeds that depend on their technical specifications. This, however, was not applied to CSD, as it has a different method of handling. Nevertheless, the faster the sailing speed of a THSD, the sooner dredging finishes, and therefore, a smaller quantity of fuel will be consumed.

Accumulated dredging speed

Similar to sailing speed, THSDs have different dredging speeds that depend on their engine capacity and efficacy. The speed during excavation is much lesser than it would be when sailing with an emptied barge to a new dredge area after disposal. The sailing and dredging speed as in this discussion was based on expert opinion.

Accumulated pump capacity

The pumping capacity of a dredger is important because it determines the time it takes to fill up barges with dredged sediments to be disposed of. Its efficacy depends on soil characteristics and the overall state of a dredger. The higher the pumping capacity, the faster dredged sediments can be transferred into barges, and the sooner dredging finishes.

Accumulated hopper capacity

Dredgers and barges have different sizes of hopper capacity, and this should be taken into consideration because the higher the capacity, the more dredged sediments can be transported, and so it would take less time to finish the dredging works.

Accumulated dredging depth and length of a dredger's arm

A suitable length for the arm of a dredger is required in order to dredge accordingly to meet a client's requirement. The deeper the dredging depth, the longer a dredger's arm needs to be. This has a tendency to affect the size of a dredger and its fuel consumption.

Overall length of pontoons and accumulated breadth

This is important when mobilizing and demobilizing dredgers using land transportation like trucks, because this will affect the size of the area needed for the dredgers to be assembled. The larger the dredger, the more space it consumes.

Accumulated draught

Draught of a dredger is an important consideration when trying to avoid a dredger becoming trapped during low tide, because it will become entrenched even more deeply when the hopper is full of dredged sediments and ready to be transported to a disposal site. The draught of a dredger typically depends on the hopper's capacity. The higher the capacity, the higher the draught of the dredger becomes.

Total dredged sediments

Total dredged sediments will affect the number of days required for dredging works and the size of dredgers that will be used.

Type of dredging work

A higher level of management is required for capital dredging, considering the fact that this type of dredging handles sediments that have never been dredged before, which may contain high level of contamination. In this chapter, a similar qualitative measure ++ was allocated, as both Options 1 and 2 require a similar type of dredging, the maintenance dredging.

Duration to dredge

It is essential to consider the duration of dredging because this relates to the cost of dredging. Furthermore, monsoon season highly affects the time taken to dredge in Malaysia. The longer it takes to dredge, the higher the dredging cost, and the higher the possibility of re-sedimentation. Calculation of dredge duration for this chapter is as per detailed in Table 9-4.

Table 9-4 Calculations for duration to dredge

Parameter	Unit	Scenario 1		Scenario 2		Scenario 3
		THSD No.1	THSD No.2	THSD No.2	CSD	No dredging
Dredging speed	minutes/ km	4.6	3.2	3.2	3.2	-
Sailing speed	minutes/ km	3.2	2.4	2.4	3.6	-
Distance from dredged site to disposal	km	22	25.4	25.4	1.5	-
Dredged material loading time	minutes	30	30	30	30	-
Time sailing to disposal site	minutes	22.9 x 4.6=106	25.4 x 3.2=81.28	25.4 x 3.2=81.28	1.5 x 3.2=4.8	-
Disposal time	minutes	5	5	5	5	-
Duration to sail empty to a new dredged site	minutes	22.9 x 3.2=74.2	25.4 x 2.4=60.96	25.4 x 2.4=60.96	1.5 x 2.4=3.6	-
Duration for 1 cycle	minutes	30+106=5=74.2= 215.2	30+81.28+5+60.96= 177.24	30+81.28+28.5+60.96=1 77.24	30+4.8+5+3.6= 43.4	-
Total cycles	cycles/ day	480/215.2=2	480/177.24=3	480/177.24=3	CSD pump output=5520m3/day Total cycles for barge to dispose=5520/1000= 6	-
Capacity of THSD/barge	m3	1000	2500	2500	Barge capacity=1000	-

Total dredged material disposed	m3	2 x 1000=2000	3 x 2500=7500	3x 2500=7500	5520	-
Total dredged material	m3	Area 4=97,493.9 Area 5=33,366 Area 3=275,607.2 *Total = 353,901.21*	Area 1=144,215.4 Area 2=147,177.7 Area 3=357,453.7 *Total = 648,828.79*	Area 4=97,493.9 Area 5=33,366 Area 3=223,041.31 *Total = 353,901.21*	Area 1=144,215.4 Area 2=147,177.7 Area 3=357,453.69 *Total = 648,828.79*	-
Number of days to finish dredging	days	353,901.21/2000= 177	648,828.79/7500= 87	353,901.21/7500= 47	648,828.79/5520= 118	-
Number of months to finish dredging	months	177/30= 6	87/30= 3	47/30= 1.6	118/30= 3.9	-

Open disposal

Open disposal is the most economic (Kizyaev, Golubev et al. 2011, Katsiri, Pantazidou et al. 2009, Krishnappan 1975, Saxena, Vaidyaraman et al. 1975) and commonly carried out practice in Malaysia. However, it is good dredging practice to choose disposal options based on the environmental risk associated with the disposal of the dredged sediments (Burton 2002, Wenning 2005). If the dredged sediments are highly contaminated, then open disposal should not be chosen. Risk values for this river ranged between high risk and extremely high risk; therefore, the implementation of open disposal was considered as detrimental. In this paper, a qualitative measure has been used and this disposal option was given the highest rank, +++.

Confined on-land disposal

If the dredged sediments are highly contaminated, then this is among facilities that should be considered in order to avoid environmental damage. This facility will require a permanent structure to be built on-land which necessitates a high level of management if it has never been performed before, and thus involves a high handling cost. This option has been used by the United States since the 1970's in order to avoid the disposal of contaminated sediments offshore (Great Lakes and Ohio River Division U.S. Army Corps of Engineers 2010). This type of disposal is still being used today, which shows that it can be considered as efficient when trying to control the impacts of contaminated sediments as compared to open disposal method. In this paper, the qualitative measure of + was allocated for Option 2.

Size of silt curtain

If dredged sediments are suspected to be highly contaminated but dredging must be performed, then mitigation measures through the use of a silt curtain must be considered (Su 2002). Silt curtains are utilized in order to contain contaminants. The size of the silt curtain depends on the size of area that needs to be contained. The type of silt curtain used must be suitable for the conditions of the dredged area in order to avoid the risk of leaking.

Number of split hopper barge and loading barge

This depends on the availability of the split hopper barge, and the condition of marine traffic at the dredged area. The higher the number utilized, the denser the traffic becomes (Rao, Rao et al. 2008); but a higher total of dredged materials can be transported, and fewer days will be required to finish the dredging project.

Total dredged quantity for confined land disposal

The total dredged quantity will affect the size of the area allocated and the structure that needs to be built for the on-land confined disposal facility. This facility is built to process sediments from maintenance dredging performed in this river over twenty years. This chapter utilizes a similar design of on-land confined disposal facility at the Great Lakes. The longer the time projected, the higher the quantities of dredged materials that need to be processed, and the bigger the area that needs to be allocated (Great Lakes and Ohio River Division U.S. Army Corps of Engineers 2010).

Total dredged sediments quantity for beneficial use

This depends on a variety of factors, including the characteristic of dredged sediments and the efficiency of the processing facility in preparing the dredged sediments for beneficial use. It is important to consider this because the higher the total useable quantity, the higher the profits.

Vessel maintenance cost

A dredger can depreciate in parallel to its age, which causes inefficiency; thus, it is important to consider the age of a dredger that will be utilized in a dredging project. In addition, the wear and tear costs for dredgers are typically high. In this chapter, expert opinion has been sought on this, and both options were labelled ++.

Government requirements

It is important to consider this because this affects the duration of a dredging project. The stricter the requirement, the longer it takes to finish the dredging works (Staerdahl, Schroll et al. 2004). Option 1 is the common sediment management method implemented in Malaysia; therefore, Option 1 was allocated a qualitative measure that weighs +. In contrast, Option 2 required the building of a new permanent structure that lasted for over 20 years, and therefore, deliberations had to be made on a variety of aspects, and many requirements were expected to be complied with. In consideration of the levels of complexity involved in Option 2, a qualitative measure of +++ was allocated.

Management of dredging

Inexperienced personnel from the government may implement stricter and inappropriate requirements that can cause delays in a dredging project (Manap, Voulvoulis et al. 2012). The higher the experience level of the personnel involved, the lower the possibility of dredging impacts, and the shorter the amount of time needed to finish the dredging work. A qualitative measure was allocated to imply the level of experience of personnel in handling both options. As the government of Malaysia has already applied Option 1 in prior dredging projects, + was allocated to Option 1. Option 2 was allocated +++ to symbolize the inexperience of personnel when performing this option.

Total fuel price

Fuel price depends on a dredger's fuel consumption, and the price of world crude oil. It is important to consider this because it greatly affects the cost of dredging. The higher the total fuel price, the higher the cost of a dredging project. Fuel price per litre on January 2013 was USD 94 (Oil-price.net 2013). The calculation for total fuel cost and fuel cost per meter^3 is explained below.

Total fuel cost = Fuel cost per day x Number of days to finish dredging

Fuel cost per meter^3 *= Total fuel cost/total dredged quantity*

Total rental rate

Some dredging contractors may not have a suitable dredger so they have to rent dredgers from other sources (Sheehan, Harrington et al. 2010c), and therefore, they have to pay the rent. The rent may include the fuel price, wages, wear and tear cost or food supply. It is important to consider this, as the total rent can account for a bulk of the total dredging cost.

Total cost for silt curtain

The cost depends on the availability of the silt curtain and the location of its manufacturer. In some cases, the silt curtain has to be imported from overseas, which involves a high cost. In addition, the properties of a silt curtain need to be custom made according to where it will be used. This chapter has utilized the cost of a silt curtain as given by the manufacturer in China (Laiwu Starring Trading Co. Ltd. 2013).

Total cost for construction of confined land disposal

A country's lack of experience in building a confined land disposal unit for dredged material could affect its construction cost. In this chapter, a recent construction of confined land disposal at the Great Lakes was taken as an example (Great Lakes and Ohio River Division U.S. Army Corps of Engineers 2010).

Total profits from beneficial use

Monetary and environmental profits from the beneficial use of dredged sediments (for example, bricks, top soil productions and bird sanctuary) can cover the high cost of the construction of confined land disposal. This chapter has considered research by Sheehan et.al (2010) on topsoil production and its total profit (Sheehan, Harrington et al. 2010a).

Total technical cost

Total technical cost is the sum of total fuel cost, rental rate, total cost for the silt curtain, total cost for confined land disposal and total profits from beneficial use.

Preliminary costs including insurances, taxes and levy

This cost is usually a requirement of the clients in order to protect their investment, workers and the equipment used in a dredging project. Insurances, taxes and levy, including port taxes and land removal may be required prior dredging (Newman 2003). In addition, if a dredging project is performed in a foreign country, the currency exchange needs to be considered during costing. The higher the preliminary cost, the higher the dredging cost.

Hydro graphic survey cost

It is very important to allocate this cost, because survey activities will determine how much dredged sediment needs to be dredged, and also how much has already been dredged (Thibodeaux, Duckworth 2001). The more frequently the survey needs to be done, the higher the costs allocated.

Soil investigation cost

The rate of dredging will typically depends on the characteristics of the sediments. If rocks need to be dredged, the rate may be higher than the rate of dredging fine grains (Training Institute for Dredging 2002c). This is because different types of dredge heads are required to dredge rocks. It is also important to allocate this cost in order to project the quantity of dredged material for beneficial use. This activity can be performed by using a vibro-corer machine, Machintosh probe or any drilling machines suitable for soil investigation. The cost depends on the number of boreholes that need to be drilled, and the types of analysis that are required. The more boreholes required, the higher the cost.

Engineering services cost

Before dredging is performed, the channel's width, length and side slope have to be designed, taking into account many engineering factors including sediment transportation and wave generation. This requires a specialist to analyse and project the behaviour of sediments after dredging, in order to avoid physical impacts, such as knick points that caused erosion at upstream (Padmalal 2008).. Thus, it is important to allocate this cost in order to help environmental monitoring.

Provisional cost

It is important to allocate this cost in order to cater for the difference in dredged quantity between preliminary and post hydro graphic surveys. Typically, if the dredged quantity from a post hydro graphic survey is lesser than the preliminary survey, then this cost has to be returned back to the client.

Total non- technical cost

The total non-technical cost is the sum of the cost of preliminaries, the hydro graphic survey cost, soil investigation cost, engineering services cost and the provisional cost.

Compensation cost for local communities

This cost is allocated in order to avoid negative perceptions from the public towards dredging activities. This cost is beneficial if dredging requires on-land disposal that requires the demolishing of residents' houses situated in government-gazetted areas. In addition, compensation cost needs to be allocated for fishermen who lose their incomes due to dredging (Manap, Voulvoulis et al. 2012). The higher the impact of dredging, the more residents that will be impacted and the higher the costs that needs to be allocated. A qualitative measure was used in this sub-criteria, whereby +++ was given to Option 1, in accordance with a historical event where an aquaculture farm was fatally affected due to the performance of an option used in a previous dredging process similar to Option 1. Option 2 will use a silt curtain in order to keep this effect to a minimum level, and the building of the on-land confined disposal area requires no demolishing of houses. Thus, a qualitative measure of + was allocated.

Loss due to un-dredged channel

Unmaintained channels will affect fisheries and manufacturing industries. These industries will not be able to transfer their catch or merchandise for import and export activities, as an unmaintained sea or river bed can increase the risk of ships being trapped during low tide. Furthermore, contaminants from highly contaminated sediments can be dispersed downstream through the act of bio-sedimentation, waves or engine disturbance (Hamburger 2003). The lower the frequency of dredging, the higher the risks mentioned above. Both Options 1 and 2 were not given any qualitative measures due to the fact that the sediments will be dredged. However, a qualitative measure of +++ was allocated for Option 3, because of its possible impact on the economic activity of this river.

Cost for environmental monitoring, mitigation measure and remediation

As mentioned, compensation costs for residents and fishermen could be higher due to environmental damage caused by dredging; thus, it is important for the environment to be monitored. The higher the impacts anticipated, the higher the costs of mitigation measures allocated should be. A qualitative measure was used when an allocation of +++ was given to Option 2, because this option has never been performed in Malaysia. For Option 1, the research cost was allocated +, because the cost was anticipated not to be as high as Option 2.

Research cost

In order to avoid damage due to dredging, research needs to be performed, and it has been previously acknowledged that scientific research is costly. Option 2 was allocated a qualitative measure of +++ after considering the fact that this option has never been performed in Malaysia, and Option 1 was allocated + as the research cost was expected to be much lower than Option 2.

Reduction of impact level

The impact level of dredging in prioritized areas can be reduced using appropriate dredging technology. Therefore, it is important to consider the degree of contamination and its risk value in an area using ERA as discussed in Chapter 8. As Option 1 utilizes conventional dredging that proven to damage the environment during historical dredging activities (as discussed in Chapter 5), a qualitative measurement of (+) was given to this option. Option 2 utilizes dredging technology that has been proven beneficial (Great Lakes and Ohio River Division U.S. Army Corps of Engineers 2010), therefore allocated a qualitative measurement of (+++).

Dissolved oxygen impact

The oxidation of contaminants can lower the dissolved oxygen level of a dredged area; therefore, it is important to determine the level of dissolved oxygen, especially if the dredged area is sensitive. The lower the level of dissolved oxygen, the higher the impact level on fish/benthos. Impacts are highly dependent on the contamination level of the dredged area, and the technology used. As per detailed in Subsection C-1 in Appendix C, THSD was proven to have lesser impacts on TSS levels compared to CSD and excavators on pontoons, but was also proven to be the cause of low levels of dissolved oxygen. Furthermore, Area 1 was considered a priority due to its high level of contamination and its proximity to an aquaculture farm. Therefore, Option 1 (which utilized THSD in this area) was allocated +++, while Option 2 (which utilized CSD in this area) was allocated ++.

Total suspended sediment (TSS) impact

High levels of TSS block the sun light and prevent the production of dissolved oxygen. The higher the TSS level, the higher the environmental impact on fish or benthos (Trimarchi, Keane 2007). As detailed in Subsection C-1 in Appendix C, THSD caused lesser impacts on TSS level as compared to CSD, but triggered impacts on dissolved oxygen levels. Based on these facts, a qualitative measure of ++ was allocated for Option 1, and +++ for Option 2.

Total useable sediments quantity

The quantity of total useable sediments depends on soil properties, and this is an important consideration because it determines the profits from beneficial use, and processing costs (Sheehan, Harrington et al. 2010c). The percentage of gravel and sand affects the quantity of total useable sediments, so the higher the percentage, the higher the benefits will be. The processing costs of beneficial sediment need to be considered too which the higher the total useable sediments, the higher the processing costs involved.

Flood and erosion after dredging

It is important to consider this because it will affect the income and daily activities of residents adjacent to dredging areas. But investigation needs to be done in order to confirm that this is really caused by dredging activities alone, and not by any other adjacent activities, which highlights the importance of Cumulative Impact Analysis (Bérubeacute, 2007, Cooper, Boyd et al. 2007, Cooper, Sheate 2004, Xue, Hong et al. 2004) prior to dredging. The higher the risk of this, the higher the cost of compensation that needs to be allocated. A qualitative measure of + was allocated for Option 2, because the construction of a permanent structure may affect the area, which could lead to flooding. No qualitative measure was allocated for Option 1 due to the fact that no on land disposal will be made under this option.

Noise from dredging

This is an important element to be considered, because noise from dredging that using heavy machinery will affect the livelihoods of people adjacent to dredging areas. In addition, research has shown that dredging causes the migration of porpoise due to noisy operation (de Leeuw 2010). Heavier, noisier machinery has a greater impact therefore, + was given to Option 1 and ++ was given to Option 2.

Level of turbidity

Turbidity affects lighting intensity and the aesthetic value of a river or sea (Wu, de Leeuw et al. 2007). In addition, turbidity can lead to the dispersal of contaminants from sediments into the water, thus affecting its quality. The higher the level of turbidity, the higher the level of environmental and aesthetic impacts will be. As explained in Subsection C-1 in Appendix C, THSD caused less total suspended solid (TSS) than CSD and excavators on pontoons, but at the same time, it has been proven to cause low levels of dissolved oxygen. Based on these facts, ++ was allocated for Option 1 and +++ for Option 2.

Marine traffic

Dredgers and hoppers affect existing marine traffic in a dredged channel or basin (Rao, Rao et al. 2008), so it is important to consider this element. Density increases as more machinery is used. As the level of machineries used is higher for Option 2, +++ was allocated for Option 2 and + allocated for Option 1.

Level of disturbance to marine life

It is important to consider this element because dredging will affect the level of water quality and numbers of fish/benthos. The higher the contamination level, the higher the risk of contaminant dispersal and bioaccumulation. In this chapter, the qualitative measure +++ was given to both options 1 and 2, due to the similar dredged areas involved. However, a lower degree of disturbance was expected in Option 3, and so the label + was allocated.

MCDA Matrix

The matrix for MCDA that displaying scores for sub-criteria discussed above can be found in tabular format as Table 9-5.

Table 9-5 MCDA Matrix to select best sediment management for the rivers of Sungai Sitiawan and Dinding, Perak, Malaysia

Criteria	Sub-criteria group	Sub-criteria	Unit	Data source	Option 1	Option 2	Option 3
Technology	Equipment specification	Accumulated fuel consumption	litre/day	Calculation as in Table 9-3	15,790	12,320	-
		Accumulated sailing speed	knots	Expert opinion	23	13	-
		Accumulated dredging speed	knots	Expert opinion	17	10	-
		Accumulated pump capacity	m^3/hour	Expert opinion	7,500	3,190	-
		Accumulated hopper capacity	m^3	Technical specification	3,500	2,500	-
		Accumulated dredging depth	meter	Technical specification	35	34	-
		Overall length	meter	Technical specification	159	120	-
		Accumulated breadth	meter	Technical specification	30	24	-
		Accumulated draught	meter	Technical specification	13	9	-
		Length over pontoons	meter	Technical specification	-	22	-
		Length of dredger's arm	meter	Technical specification	-	2	-
	Dredged material	Total dredged sediments	m^3	Expert opinion	1,002,730	1,002,730	-
	Requirement of dredging work	Type of dredging work (maintenance or capital)	+/+++	Expert opinion	++	++	-
		Duration to dredge	month	Calculation as in Table 9-4	9	5.5	-
	Disposal option	Open disposal	+/+++	Expert opinion	+++	+++	-
		Confined land disposal	+/+++	Expert opinion	-	+	-
	Other	Size of silt curtain	$meter^2$	Expert opinion	-	5,000	-

Criteria	Sub-criteria group	Sub-criteria	Unit	Data source	Option 1	Option 2	Option 3
	technical requirement	Number of loading barge	number	Expert opinion	-	1	-
		Number of split hopper barge	number	Expert opinion	-	1	-
		Pipeline	km	Expert opinion	-	1	-
		Total dredged quantity for confined land disposal (Great Lakes and Ohio River Division U.S. Army Corps of Engineers 2010)	m^3	Literature	-	3,672,000	-
		Total dredged material for beneficial use	m^3	Expert opinion	-	294,594	-
	Stakeholder opinion	Vessel maintenance cost	+/+++	Expert opinion	++	++	-
		Government requirement	+/+++	Expert opinion	+	+++	-
		Management of dredging-Inexperience	+/+++	Expert opinion	+	+++	-
Economy	Technical cost	Total fuel price	USD	Calculation	1,115,363	278,202	-
		Rental rate	USD	Expert opinion	4,865,237	4,621,892	-
		Total cost for silt curtain (Laiwu Starring Trading Co. Ltd. 2013)	USD	Expert opinion	-	22,500	-
		Total cost for confined land disposal (Great Lakes and Ohio River Division U.S. Army Corps of Engineers 2010)	USD	Literature	-	29,000,000	-
		Total profits for beneficial use (Sheehan, Harrington et al. 2010a)	USD	Literature	-	9,752,650	-
		Total technical cost	USD	Calculation	5,980,599	24,147,443	-
	Non-technical cost	Preliminary cost including insurances, taxes, levis, client's requirements	USD	Expert opinion	340,894	1,376,404	-
		Hydro graphic survey costs	USD	Expert opinion	119,612	482,949	-
		Soil investigation costs	USD	Expert opinion	25,119	101,419	-
		Engineering services costs	USD	Expert opinion	109,445	441,898	-
		Provisional sum	USD	Expert opinion	49,639	200,424	-
		Total non-technical cost	USD	Calculation	644,709	2,603,094	-

Criteria	Sub-criteria group	Sub-criteria	Unit	Data source	Option 1	Option 2	Option 3
	Stakeholder opinion	Compensation cost for local communities	+/+++	Expert opinion	+++	+	-
		Loss due to un-dredged material	+/+++	Expert opinion	-	-	+++
		Cost for environmental monitoring, mitigation measure and remediation	+/+++	Expert opinion	+	+++	-
		Research cost	+/+++	Expert opinion	+	+++	-
Environment	Reduction of impact level	Value according to ERA	+/+++	Expert opinion	+	+++	-
	Technology impact level	Dissolved oxygen impact	+/+++	Expert opinion	+++	++	-
		Total suspended solid impact	+/+++	Expert opinion	++	+++	-
	Sediment characteristic	Total useable sediments quantity	m^3	Expert opinion	-	294,594	-
	Stakeholders' opinion	Flood and erosion - Happened after dredging	+/+++	Expert opinion	-	+	-
		Noise from dredging operation	+/+++	Expert opinion	+	++	-
		Turbidity impact	+/+++	Expert opinion	++	+++	-
		Marine traffic impact	+/+++	Expert opinion	+	+++	-
		Marine life impact	+/+++	Expert opinion	+++	+++	+

9.3.6 Weights

Weights are important for increasing the subjectivity of an option, and in this chapter, it was carried out using the weighted summation method. Sensitivity analysis was performed using different weights (as in Table 9-6) in order to ensure the robustness of the results and to observe the changes in rankings if weightings were changed. In this chapter both analyses of MCDA and sensitivity were performed using Microsoft Excel.

Table 9-6 Sustainable weights applied on MCDA matrix

Criteria	Number of Sub-criteria	Weights	Individual weights (%)
Technology	17	1/17	1.94
Economy	18	1/18	1.83
Environment	8	1/8	4.13

9.4 Result

Deliberation to select the best sediment management option for Sungai Sitiawan and Dinding rivers, Perak, Malaysia showed that Option 2 (which used one THSD, one CSD, a silt curtain, disposed of dredged sediments on confined land and offshore, and also created top soil) has the highest overall scores and suggested that it is the best sediment management option, compared to the others (Figure 9-6). Sensitivity analysis has been performed and its results showed that compensation cost for local community is the most sensitive among other sub-criteria when weightings were changed. As can be seen in Figure 9-7, Option 1 was ranked first when weight is slightly above 0.02, which outdone Option 2. This means that careful deliberation should be made when assigning weights for this sub-criteria in order to ensure the quality of selection of best sediment management. The results of other sub-criteria can be found in Appendix F.

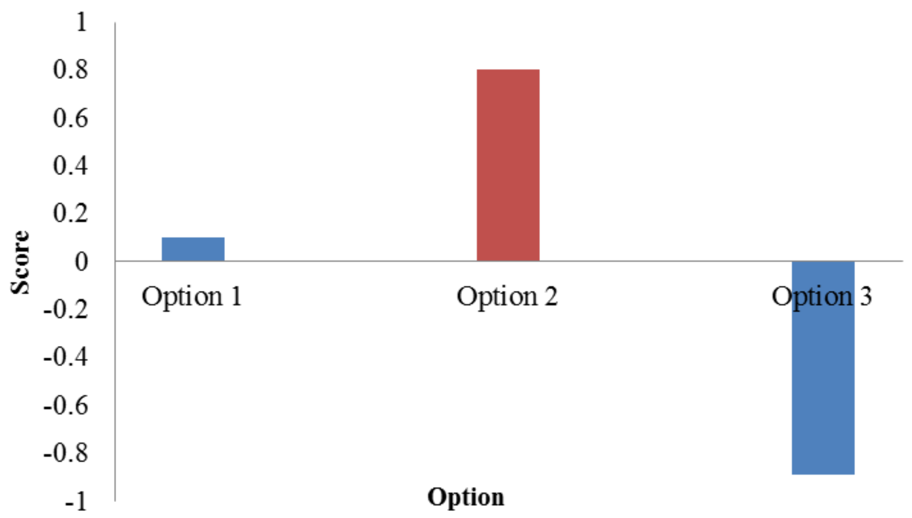


Figure 9-6 Results of Tier 2 stage

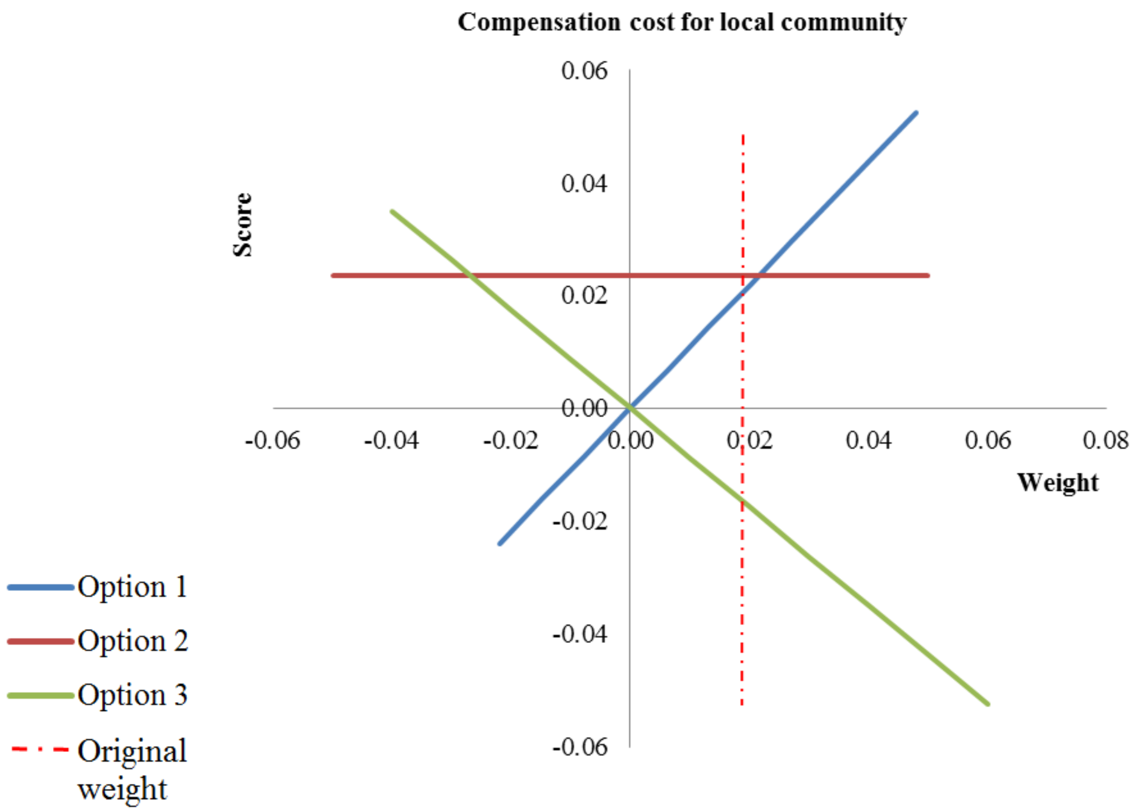


Figure 9-7 Sensitivity analysis results showing rankings of the options after variations of weights assign to sub-criteria of Compensation cost for local community

9.5 Discussion

The aim of this chapter was to develop the sixth step (Tier 2 stage) of the proposed framework in Malaysia's context to select best sediment management option using a newly developed method that balances multiple criteria. MCDA was utilized in order to achieve this aim, due to its practicality and simplicity. The demonstration of this stage showed that Option 2 was the best sediment management option for the rivers of Sungai Sitiawan and Sungai Dinding, Perak. Option 2 consisted of the use of one THSD, one CSD, a silt curtain, the disposal of dredged sediments at a confined land disposal and offshore, and the beneficial use of sediments as top soil. This demonstration was supported by the application of Weighted Summation method and sensitivity analysis, showing that Option 2 is clearly the best option.

However, the limitation of this methodology is the use of many expert opinions in its sub-criteria weightings. This occurred due to the unavailability of evidence-based documents specifically for these rivers. Nevertheless, this chapter has taken into account more than forty sub-criteria which covered many aspects including technology, economics and the environment. This makes the methodology proposed in this chapter adaptable to many scenarios. In the future, it would be advisable to utilize this framework with more options in order to improve the validity of the chosen option.

9.6 Conclusion

Much research on decision making methods has been performed; however, management tools that can balance economic, environmental and technical aspects are still being sought in the dredging industry. Therefore, this chapter developed the sixth step (Tier 2 stage) of the proposed framework in Malaysia's context to select best sediment management option using a newly developed method that balances multiple criteria using MCDA. This stage utilized findings from the Tier 1 stage as discussed in previous chapter in order to demonstrate the application of this stage. The rivers of Sungai Sitiawan and Sungai Dinding, Perak, Malaysia was chosen as the case studies. After much deliberation that using an extensive list of over forty sub-criteria that holistically analysed technical, economic and environmental criteria that were integrated in MCDA, we found an option that is the best for this particular location. This chapter also highlighted the importance of Malaysia gaining more evidence based documents in order to develop efficient tools to preserve its environment, especially during dredging.

10 THE PROPOSED FRAMEWORK

10.1 The Framework

This chapter presents a risk-based decision-making framework for the integrated environmental management of dredging sediments.

This framework was designed following a **risk-based approach** focusing on Source-Pathway-Target linkages (as illustrated in Figure 10-1) that were used to evaluate dredging impacts for all dredging stages (extraction, transport and disposal as illustrated I Figure 10-2). The framework was designed as a risk-based in order to enable the allocation of resources to high priority risks, which would increase cost effectiveness. It is a justified decision-making process and improved efficacy of environmental protection during sediment management. As the framework is tiered and transparent, users of this framework are able to review their decisions, resulting in a dynamic and reliable decision-making process.

The framework serves as **integrated environmental management** tools (as illustrated in Figure 10-3) that aim to add environmental, socio-economic, managerial and technical aspects of dredging during deliberation of selecting best sediment management option. It therefore delivers an integrative and holistic methodology for a sustainable dredging. Its benefits lie in its capability to decompose complex systems of dredging, its flexibility to quantify criteria and sub-criteria in qualitative and quantitative measurements and its ability to balance multiple criteria during decision-making make this framework applicable in many sediment management situations.

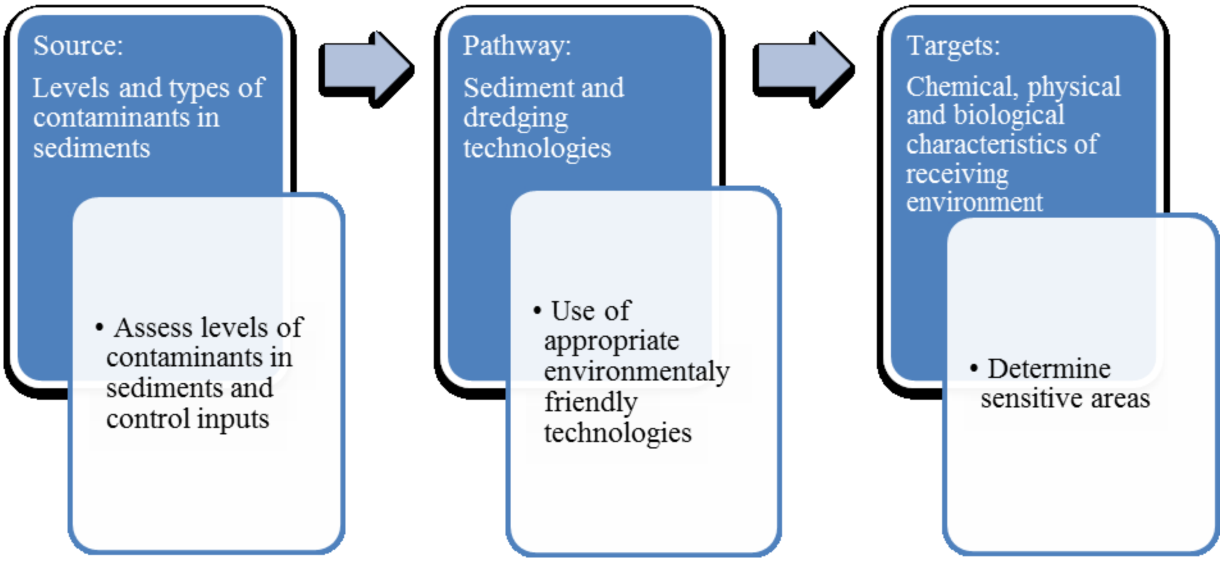
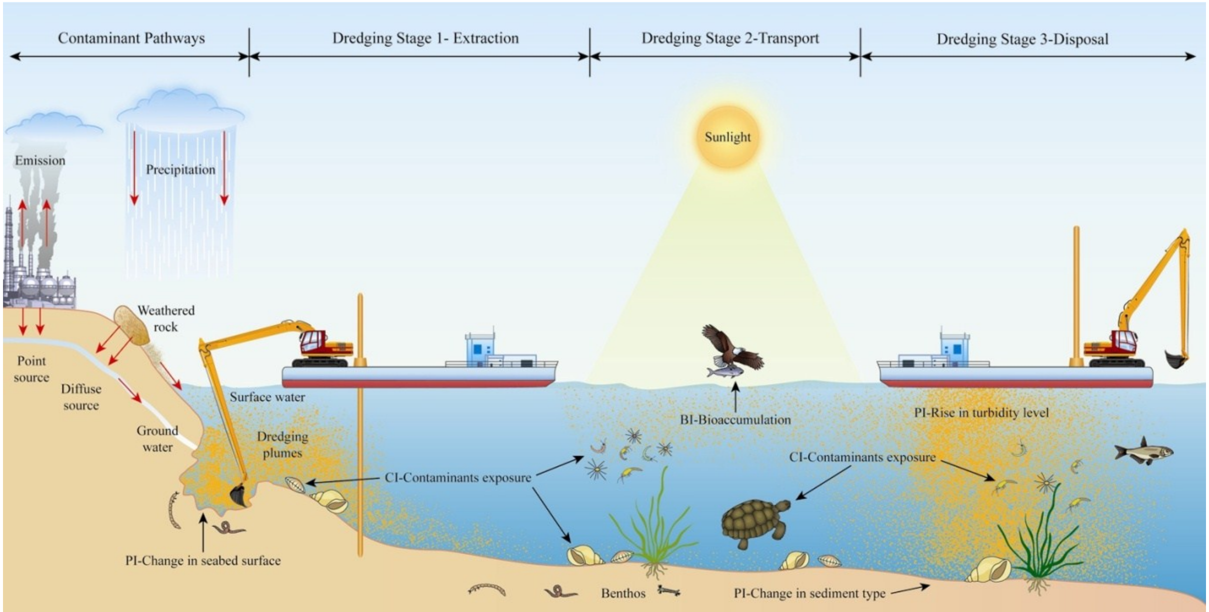


Figure 10-1 Risk-based approach: Source-Pathway-Target linkages



PI=Physical impacts, CI=Chemical impacts, BI=Biological impacts

Figure 10-2 Risk-based approach: Source-Pathway-Target linkages conceptual model for assessing dredging impacts

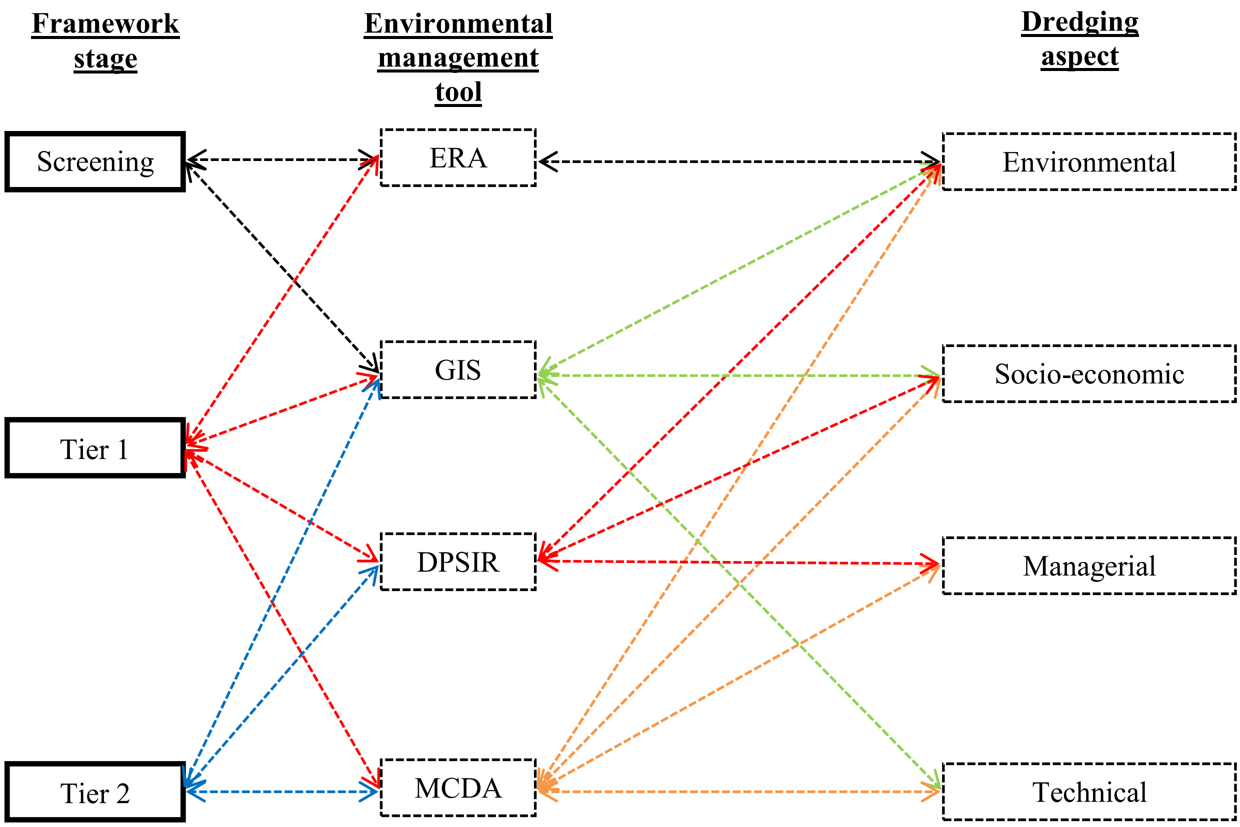


Figure 10-3 Integrated environmental management concept

Figure 10-4 combines the six steps developed in previous chapters into three stages of framework. The first stage of this framework is screening, and its objective is to identify areas that require high level of environmental protection. The next stage is the Tier 1 stage and its objectives are to prioritize dredging areas that are in need of strict environmental preservation and to determine the degree of contamination and level of concern in areas identified during the screening stage as having a very high, considerate or moderate degree of contamination. The last stage is the Tier 2 stage and its objective is to determine the best sediment management option for the location that will be dredged.

The function of this framework is to reduce dredging impacts and to lower the cost of environmental quality analysis and management. The benefits of this decision-making framework lie in its risk-based approach, which communicates to the audience a complex set of dredging problems, provides defendable decisions which lead to better environmental preservation, and allows resources to be targeted to high priority risks (as illustrated in Figure 10-5). This can be achieved due to the fact that the framework is staged so that its objectives can be reviewed and therefore the amount of money spent on environmental quality analysis and management can be minimized.

This framework is beneficial to dredging stakeholders including government representatives, dredging companies, environmental consultants and the public. Additionally, it is highly suitable for countries like Malaysia which put an emphasis on fast and accurate results but also relatively low costs for environmental quality analysis and management during the selection of best sediment management option.

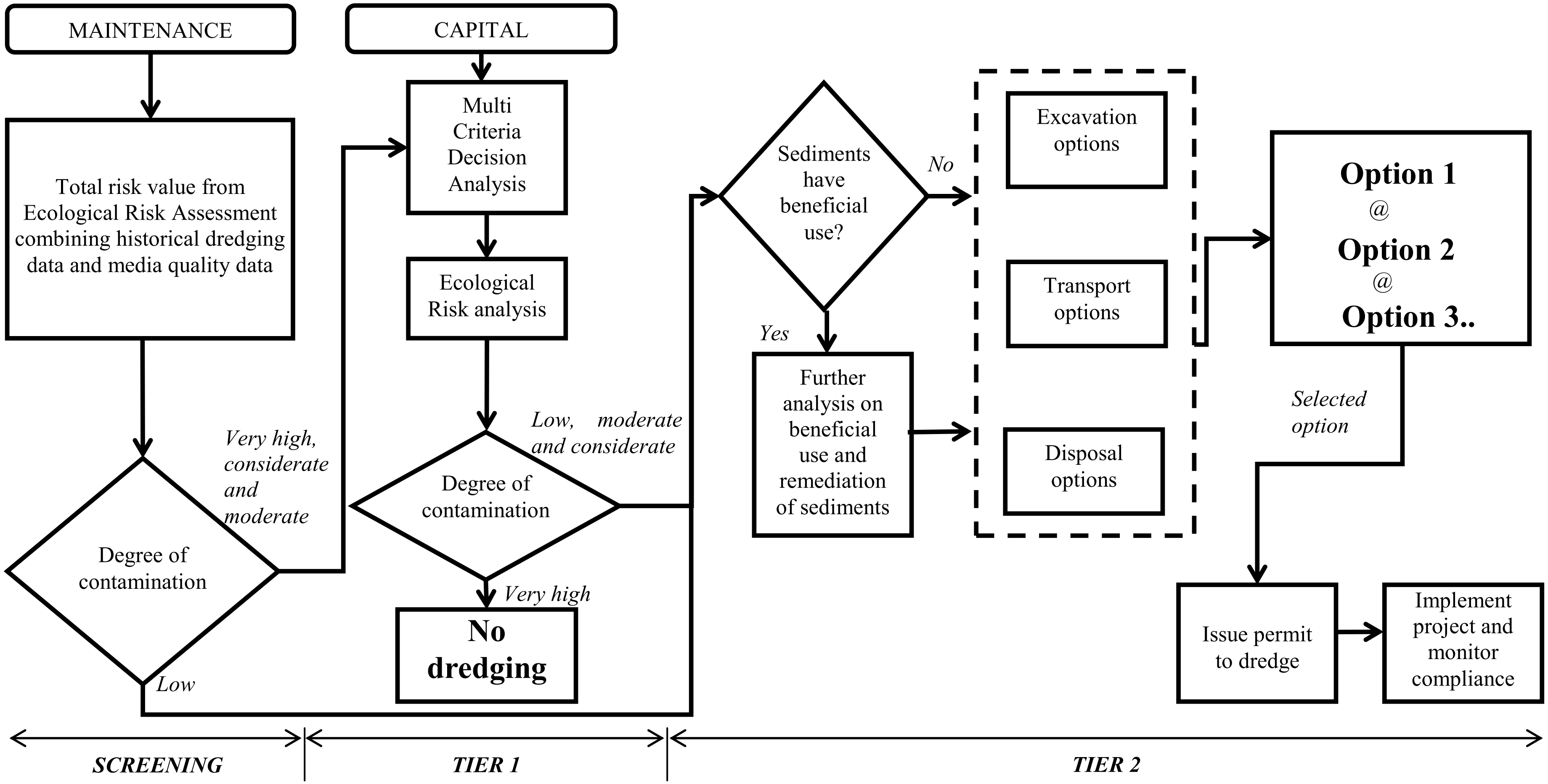


Figure 10-4 The risk-based decision making framework for an integrated environmental management of dredging sediments

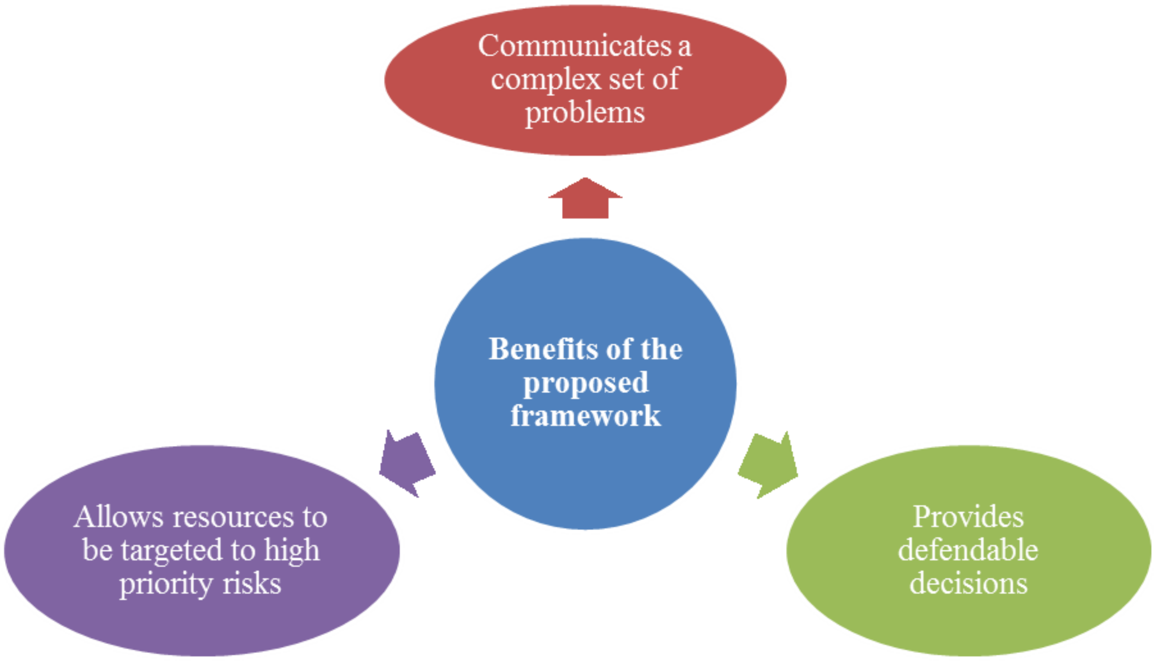


Figure 10-5 Benefits of the proposed framework

This framework is transparent and efficient for communicating the risks of dredging to different stakeholders. This is due to its staged nature involving subsequent steps; therefore, care must be taken if a step has been skipped.

Specifically, this framework applies when the government of a country has found that it is necessary to dredge an area, and communicated its intention to a dredging company. After receiving a formal instruction from the government, the dredging company should then identify the types of dredging required in the area concerned. Based on the fact that there are two distinctive types of dredging (maintenance and capital) and the fact that capital dredging could trigger a higher risk of dredging impact than maintenance (Gupta, Gupta et al. 2005), capital dredging should be automatically forwarded to Tier 1 stage. Whenever maintenance dredging is involved, three steps need to be followed by the dredging company in the screening stage (as illustrated in Figure 10-6 and discussed in Chapter 7).

The ***first step*** of this stage is to identify risk value using historical dredging monitoring data available from dredging contractors who previously performed dredging in the same area or from government records. The identification of risk value can be achieved through a variation of standard Ecological Risk Assessment (ERA) utilizing the historical dredging data, as well as through Geographical Information System (GIS) to illustrate the relationships found. ERA requires characterisation of risk, and a risk ratio of a contaminant can be obtained by dividing exposure data by toxicological data. If the ratio exceeds one (1), ecological risk in an area is confirmed to exist, and the higher the ratio, the larger the anticipated risk (Hall, Scott et al. 1998). At the end of this first step, the dredging company should identify an average total risk for each area to signify its degree of contamination and to be brought forward to the second step of this stage. The degree of contamination of the area in concern should be characterised according to this terminology: very high, considerate, moderate and low (Pekey, Karakaş et al. 2004a, Hakanson 1980).

The ***second step*** of the screening stage to be followed by the dredging company is to determine and quantify contamination level of media as a risk value. In consideration of Source-Pathway-Target of contaminants during dredging, it is suggested to use the average number of rivers having polluted and slightly polluted Water Quality Index (WQI) statuses per year, the average number of days maintaining very unhealthy and unhealthy Air Pollution Index statuses per year, and groundwater quality data. This data can be obtained from government agencies (Department of Environment 2006, Department of Environment 2007, Department of Environment 2008, Department of Environment 2010, Department of Environment 2011, Department of Environment Malaysia 2009b, Department of Environment 2005).

The ***third step*** of this stage is to combine the risk values from previous steps for a total value of risk. If the value is found to be very high, considerate or moderate, dredging should be considered to have high potential for negatively affecting the well-being of an area, and therefore further analyses should be performed as underlined in the Tier 1 stage.

However, if the values in this screening stage show that the degree of contamination is low, then Tier 1 can automatically be avoided. The reason behind this is to minimize irrelevant analyses which could be costly and time-consuming.

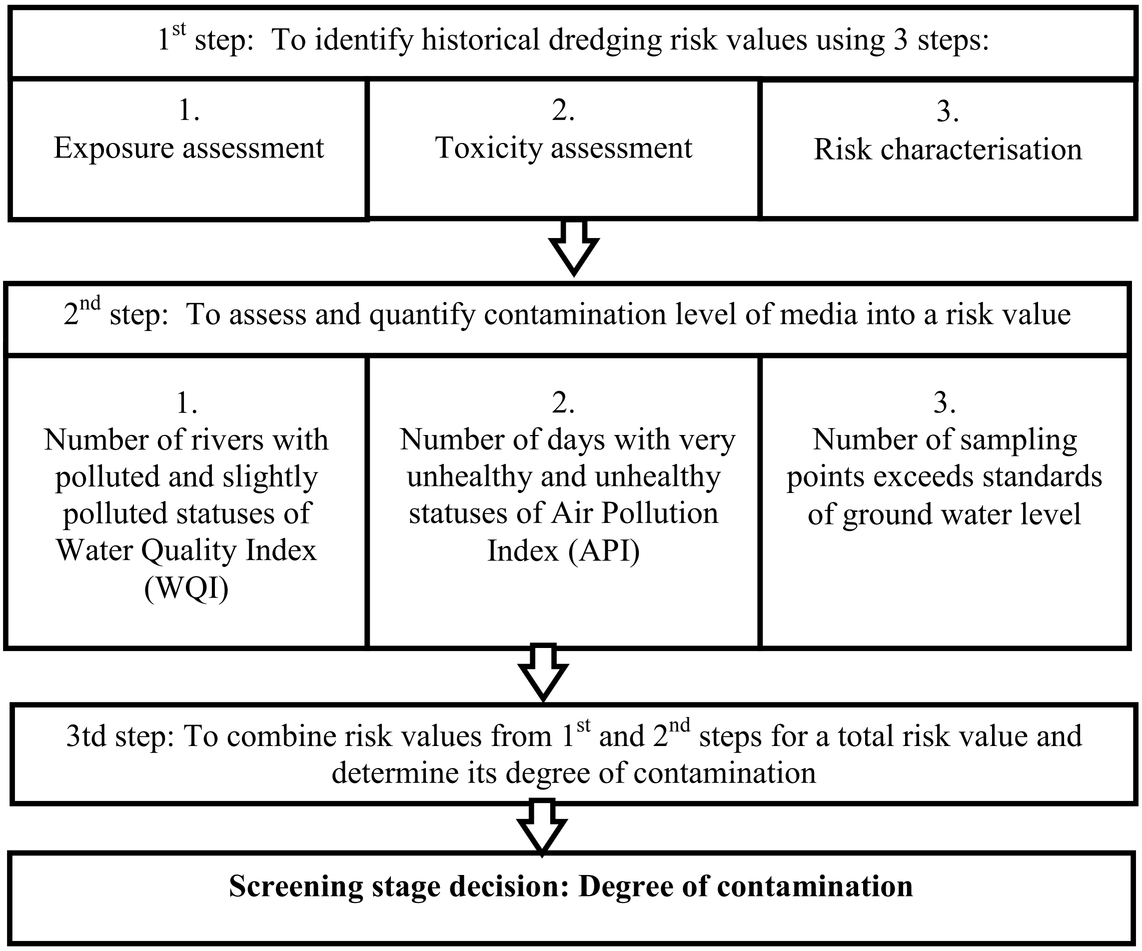


Figure 10-6 Method for screening stage

As mentioned, if the dredging company found that the area in concern has a very high, considerate or moderate degree of contamination, the Tier 1 stage should be performed in the area. The method developed for this stage is illustrated in Figure 10-7 and previously discussed in Chapter 8. The ***first step*** of the Tier 1 stage should be performed by the dredging company, which is to prioritize dredging areas that require a high level of environmental protection in order to minimize the cost of environmental decisions and to optimize dredging benefits. MCDA will be utilized in this stage to assess and integrate multiple criteria, including environmental, socio-economic and managerial. MCDA is a commonly-used tool for decision-making because of its ability to incorporate contradictory facets and its functionality, which considers both qualitative and quantitative measures (Sparrevik, Barton et al. 2011). It has often been practiced in contaminated sediments and aquatic ecosystems by USACE, for example in the context of making decisions about the disposal of dredged materials (Linkov, Satterstrom et al. 2006a). This step requires three stages: delimiting areas, ranking areas using the weighted summation method and performing sensitivity analysis.

After the prioritized areas have been determined, the ***second step*** of this stage should be followed by the dredging company, the objective of which is to determine degree of contamination using ERA utilizing current environmental data including the statuses of sediment quality and water quality and the health of biological indicators of an area, including fishes. This data can be obtained through standard environmental sampling practices and involves the hiring of environmental consultants specialized in collecting the required data. This data will be analyzed for degree of contamination, which, if it found to be low, moderate or considerate, will mean that the area in question will be brought forward to the Tier 2 stage. However, if the degree of contamination was found to be very high, the dredging company should consider the option of no dredging in the area concerned and communicate this information to the government agency.

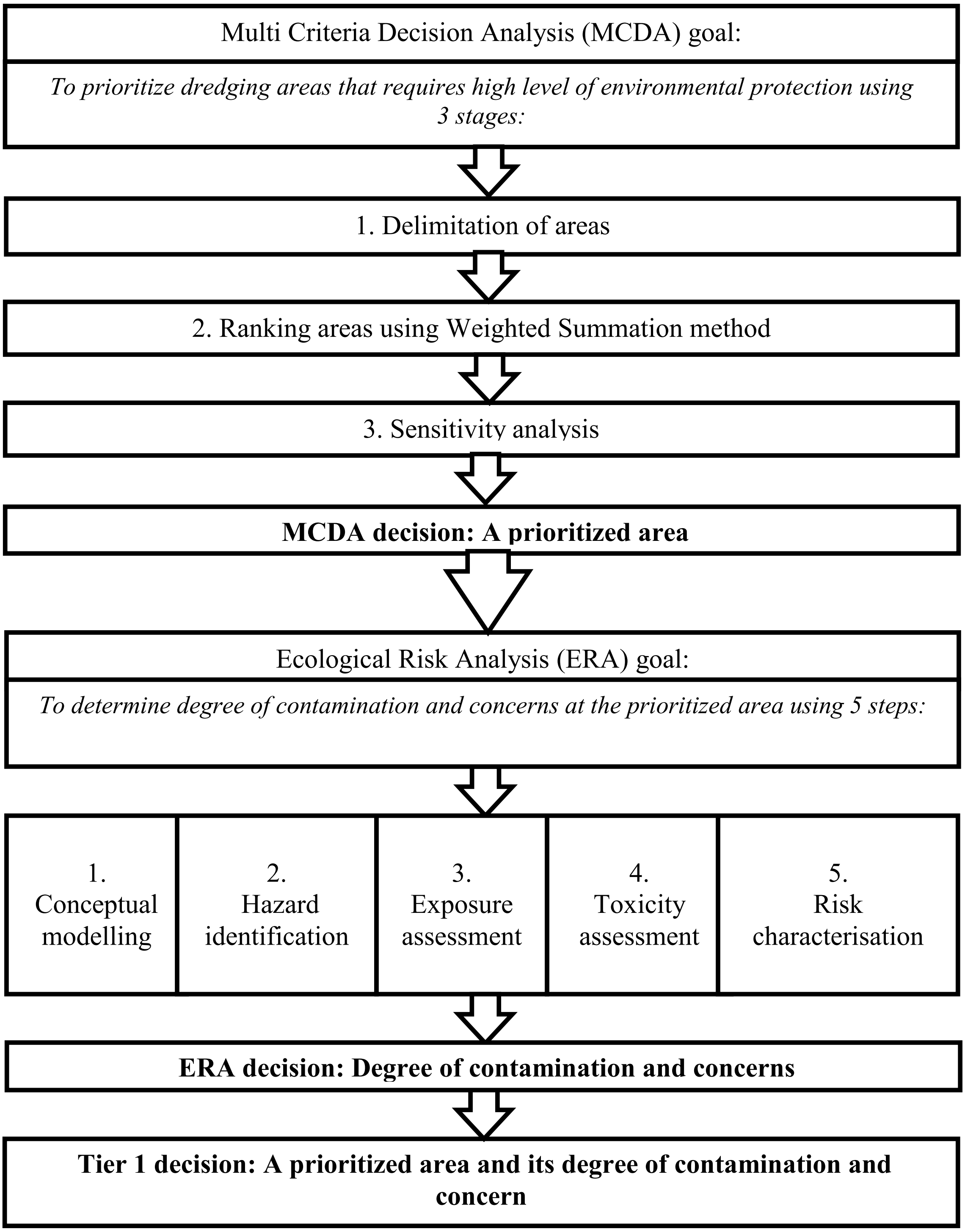


Figure 10-7 Method for Tier 1 stage

Areas that have been determined their degrees of contamination from previous stages should be brought forward to Tier 2 stage (as illustrated in Figure 10-8 and discussed in Chapter 9). In this stage, dredging company should identify whether the sediments have beneficial use in order to gain profit to cover the cost of dredging. If the sediments are suitable for beneficial use, analysis on beneficial use and remediation of sediments should be performed. Deliberation of technology options for each dredging stage (excavation, transport and disposal) should be made afterwards. One sediment management option should be selected after the deliberation has been made. Permit to dredge can then be issued and dredging project can be implemented using the option that has been selected. The framework was designed to be dynamic and transparent which means that its users can review their decisions and therefore, compliance to the steps suggested in this framework can be monitored.

Selection of best sediment management option in Tier 2 stage requires three steps, namely delimitation of sediment management options, ranking options using weighted summation method and execution of sensitivity analysis. This stage also requires inputs from different stakeholders including government representatives, the dredging company, environmental consultants, environmentalists and the public. As this stage involves many stakeholders, MCDA is a suitable tool for use in that multiple criteria can be considered, including technological, economic and environmental.

A meeting should be called between all stakeholders to collect data from different views in order to select the best sediment management option for the area in concern. This data can be acquired from personal experience of the stakeholders, historical dredging data and the literature review. In the meeting, the ***first step*** should be taken, which is to delimit sediment management options. This can be achieved by exploring the available sediment remediation and technology control options during the meeting. Selection of this depends on degree of contamination determined during the previous stages. Dredged sediments should be further analyzed in order to determine their suitability for beneficial use. If found that the sediments are suitable, further cost-benefit analysis should be performed. High profitability can be expected for sediments found not to be contaminated and which avoided the Tier 1 stage. Deliberation should be made to select the sediment improvement, excavation, transport and disposal options. These will be brought forward in concert (as Option 1, Option 2, Option 3 and so on) to the second step.

The ***second step*** during the meeting is to rank the options (as Option 1, Option 2, Option 3 and so on) using the weighted summation method. ***Finally***, sensitivity analysis in order to determine the robustness of the results from this stage should be performed in the meeting. After the best sediment management option has been determined, a license to implement dredging in the area of concern can be issued. It should be noted that if there were archaeological findings found during dredging, they should belong to the government and be treated as national heritage.

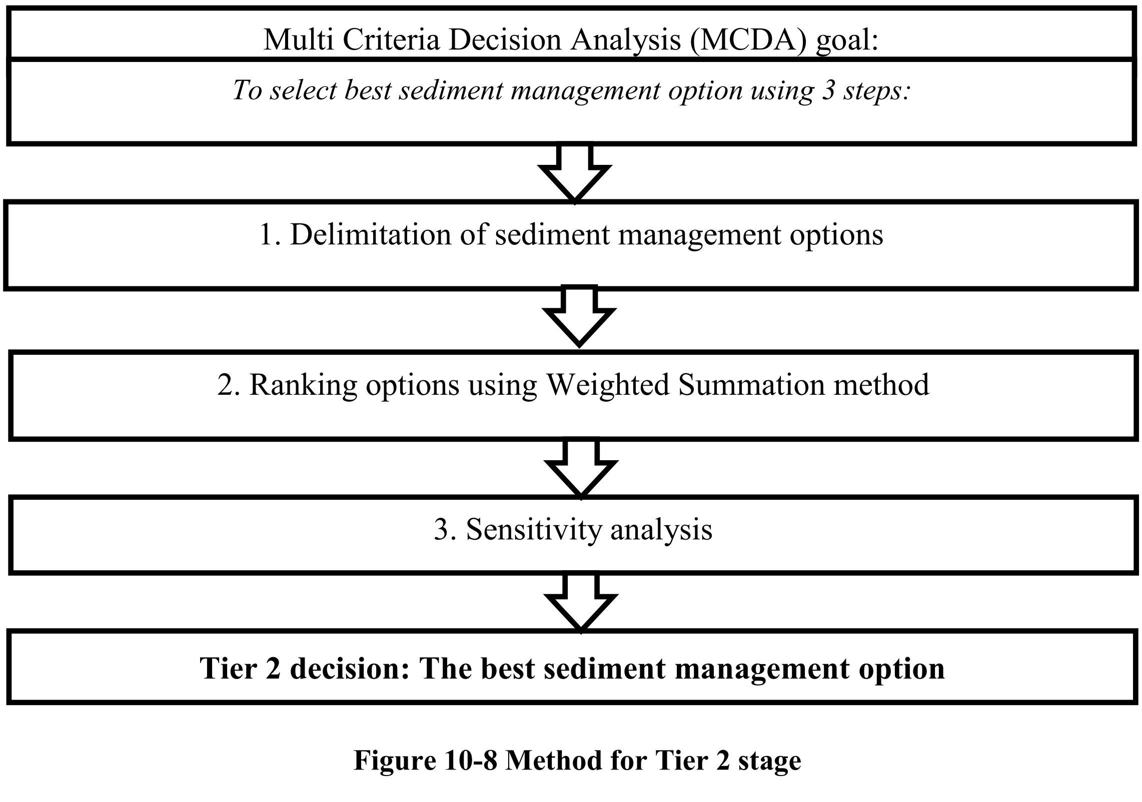


Figure 10-8 Method for Tier 2 stage

10.2 Conclusion

This chapter presented a risk-based decision-making framework for integrated environmental management of dredging sediments in order to reduce the impacts of dredging and lower the cost of environmental quality analysis and management. This framework has three distinct stages that should be followed by a dredging company after receiving formal instruction from the government to dredge an area: screening, Tier 1 and Tier 2. The objective of the screening stage is to identify dredging areas that require a high level of environmental protection. This stage has three distinct steps: identifying historical dredging risk values, assessing and quantifying the contamination level of media into a risk value, and combining risk values from the first two steps for a total risk value determining the overall degree of contamination. Dredging locations with high, moderate or considerable degrees of contamination will be forwarded to the next stage of this framework. The next stage is Tier 1, the objective of which is to prioritize dredging areas and determine their degree of contamination and concern for further investigation using a newly developed method that integrates MCDA and ERA. Tier 1 stage utilized three distinct steps of MCDA in order to determine a prioritized area: delimitation of areas, ranking areas using the Weighted Summation method, and sensitivity analysis. The prioritized area will be further investigated using ERA in order to determine its degree of contamination and concern through five steps: conceptual modelling, hazard identification, exposure assessment, toxicity assessment and risk characterization. The option of no dredging should be chosen if the dredging locations are found to have a very high degree of contamination. However, if it is found to be low, moderate or considerable, the area in question will be brought forward to the final stage of the framework that is the Tier 2 stage. The objective of this stage achieved through a meeting with all dredging stakeholders, is to select the best sediment management option that balances economic, environmental and technological aspects using MCDA. This stage utilizes three distinct steps: delimitation of sediment management options, ranking options using the Weighted Summation method, and sensitivity analysis. The decision to apply the best sediment management option that minimizes the impacts of dredging and lowers environmental quality analysis and management costs can be achieved through the implementation of this framework. A dredging permit can be issued to relevant dredging stakeholders to implement a dredging project, in which compliance to environmental rules and regulations can be monitored.

11 OVERALL DISCUSSION

This chapter aims to discuss the overall aim of the thesis, to analyse current policy and the implications of the proposed framework through a discussion of national and international policy contexts, to make recommendations for future research and to identify research limitations.

This thesis presents a risk-based decision making framework for the integrated environmental management of dredging sediments. The Screening, Tier 1 and Tier 2 stages have been incorporated into the framework in order to reduce dredging impacts and lower the cost of environmental quality analysis and management. The benefits of risk-based approach and integrated environmental management are summarized in Figures 11-1 and 11-2.

This framework applies to two types of dredging, capital and maintenance. Maintenance dredging will be analysed in the screening stage and areas with low degrees of contamination will be brought forward to Tier 2 stage, while other degrees of contamination will be analysed further in Tier 1 stage. This is in order to ensure that only high priority risks are considered.

On the other hand, capital dredging handles sediments that have never been dredged before, so the area may be highly contaminated, which could trigger a higher risk of impact than maintenance (Gupta, Gupta et al. 2005). Therefore, based on the same ground to ensure that only high priority risks are considered, this type of dredging will be brought forward to the Tier 1 stage, skipping the screening stage. In the Tier 1 stage, very high degree of contamination areas will not be considered for dredging and options other than dredging should be explored, including auto-flushing, soft-sediment engineering, or Keep Sediment in the System (Kirby 2012). Areas with suitable degrees of contamination will be analysed in the Tier 2 stage in order to select the best sediment management option. The selected option will be implemented after a permit to dredge has been issued.

The framework has been designed to be dynamic and transparent, which means that its users would be able to review their decisions and therefore, compliance to the steps suggested in this framework can be monitored in order for it to achieve its main objectives, which are to reduce the environmental impacts of dredging and to lower the cost of environmental quality analysis and management.

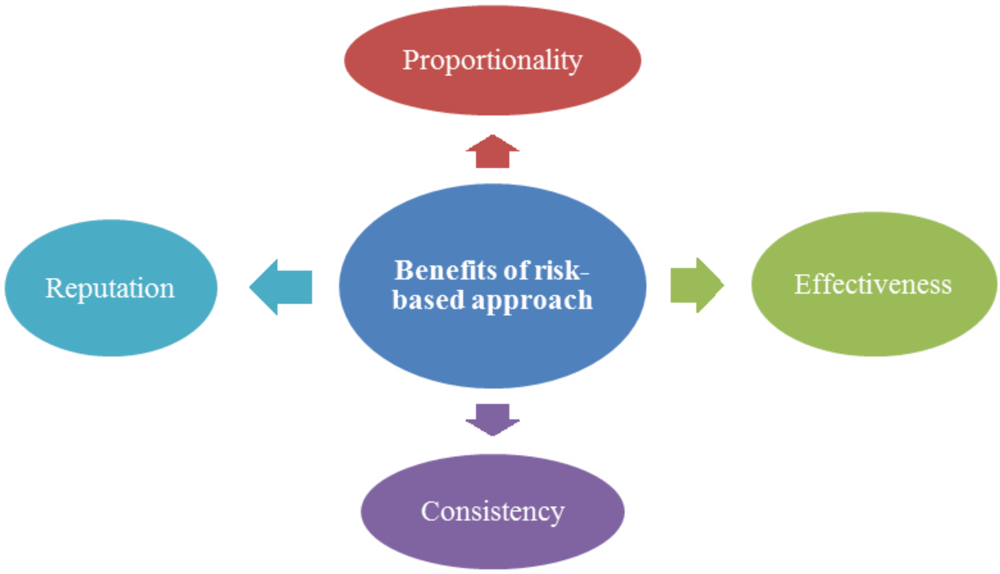


Figure 11-1 Benefits of risk-based approach

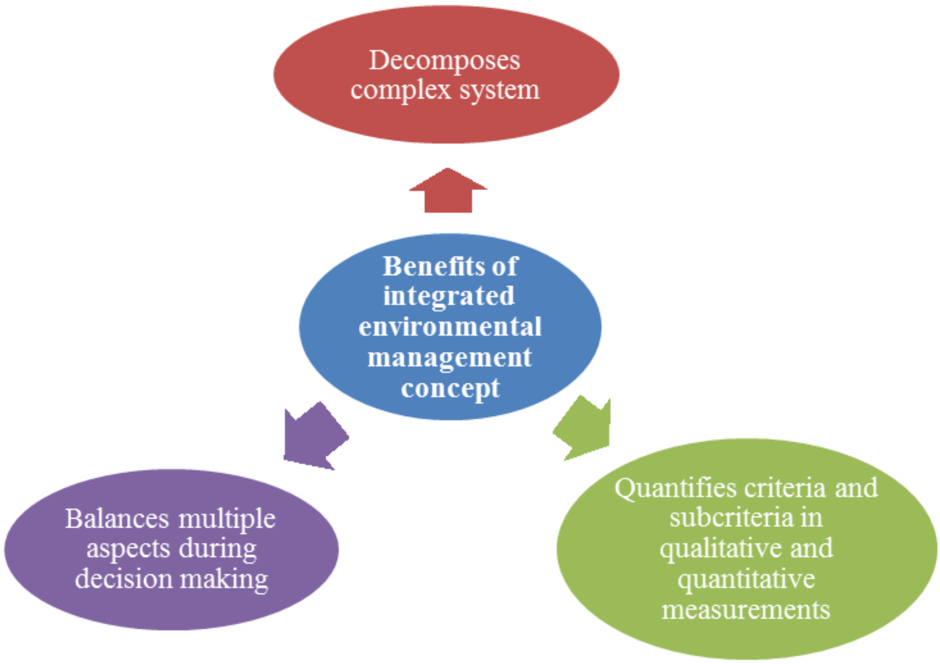


Figure 11-2 Benefits of integrated environmental management

The role of the proposed framework in improving governance of dredging is illustrated in Figure 11-3. This framework can serve as a tool for other countries to ease the governance of dredging by informing policy makers about the problems of dredging, commonly related to ecological, socio-economic, managerial and technical concerns, in order to improve current environmental legislation that stipulates whether to perform or to prohibit dredging. Furthermore, this framework helps decision-makers look at dredging problems from integrative and holistic perspectives, which therefore lead to a sustainable decision.

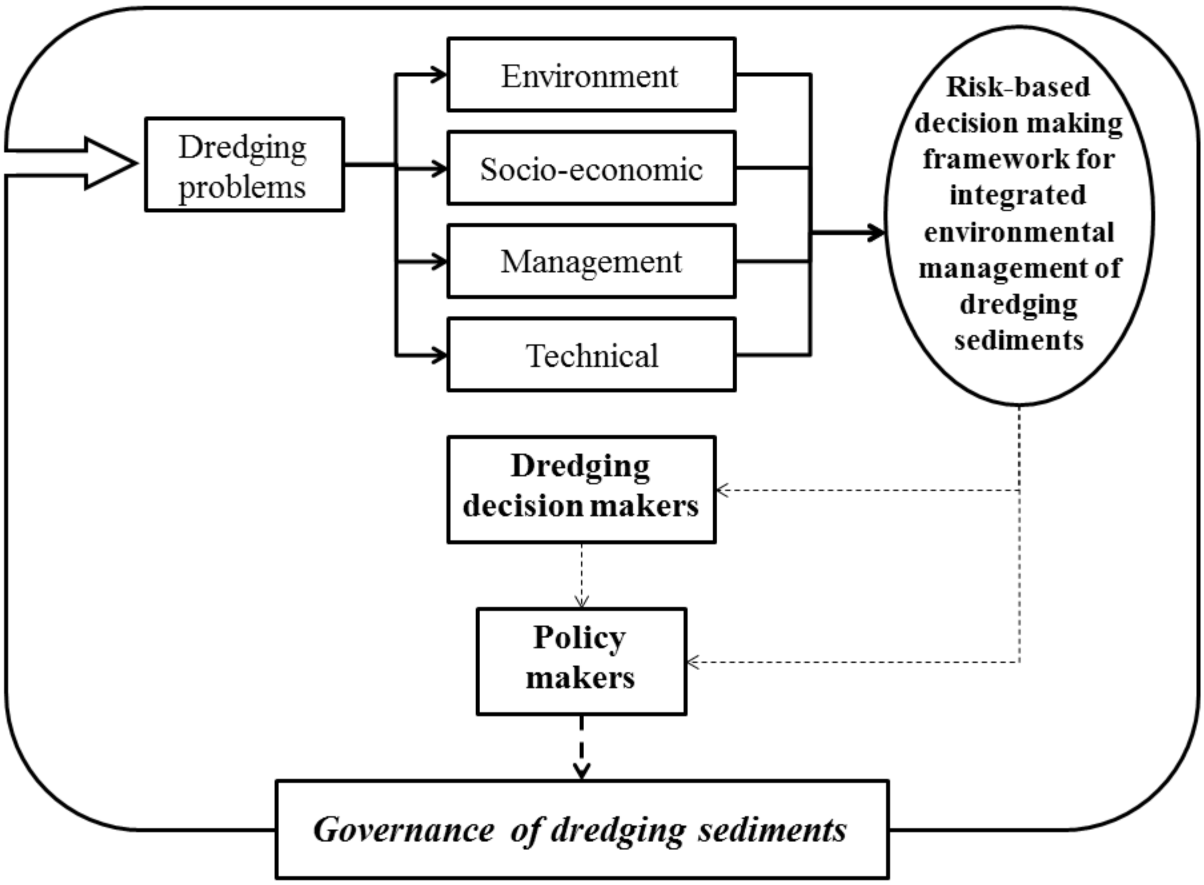


Figure 11-3 The role of the proposed framework in improving governance of dredging

11.1 Implementation to national policy

This research and its development have highlighted many points, which could have implications for current environmental policies, both on the national and international level.

Within a national environmental policy context, this study highlights the inefficacy of IEM Order 1987, which regulated dredging works in Malaysia, limiting their monitoring programme during dredging. It is important to note that their current monitoring programme does not take into consideration the latest research issues in the dredging industry. This includes the restriction on open disposal, the analysis of cumulative impacts, the recycling of dredged materials for beneficial use, the noise at bottom water during extraction, and public engagement.

Additionally, this study stresses the need to develop a sediment quality database that would gather and analyse the levels of tolerable and non-tolerable risk values, which could help to identify the risks of dredging in an area. The database can be integrated into current efforts of river basin management, but it should be made clear that this sediment quality database cannot be implemented on a national level because of differences in characteristics (including geographic and hydrographic, biological sensitivity and contaminant types and their sources) that can be found between areas.

This study emphasized the need to investigate land uses that could cause the decrease of water and sediment quality in areas that will be dredged. Locations, where dredging areas are adjacent to wastewater treatment facilities, combined sewer overflows, storm drains and overland runoff, and solid waste land disposal, could all be considered to pose higher risks (Fredette, Pederson 1998).

Moreover, this study highlights the weaknesses of Malaysia's annual groundwater quality status, which is considered undefined. As this data is paramount especially for the dredging industry, which supports Malaysia's economic development and has a detrimental effect on the environment, it is vital to monitor the status of groundwater as strictly as water and air quality are monitored in this country.

More importantly, this study underlines a problem that still has not been recognised in Malaysia - the problem of contaminated land. After presenting compelling evidence on the impacts of dredging in close proximity to land that should be considered contaminated, this study rejected many opinions to the effect that the rate of development in Malaysia was not as high as the rate of development in developed countries (like the UK and the US) that require strict rules and regulations of contaminated land and dredging permit criteria (Table 11-1).

In Malaysia, a national policy for contaminated sites is considered non-existent (Yi, Talib 2006). Even though guidelines had already been structured in 2006 by their DOE, the findings of this thesis showed that they have not been thoroughly developed. This was proven by the extent of negligence towards contaminated site and dredging impact issues on sensitive biological resources during dredging works in Malaysia in between 2006 to 2011, a topic that has been highlighted by this thesis. Therefore, one of the implications of this study is an increased emphasis on the fact that the time has come for countries such as Malaysia, which is not on the frontline of the industrial arena and presumably has fewer contaminated areas, to pay attention to the problems of environmental impacts from contaminated sites.

Although identifying an area as contaminated can cause land stigmatization and depreciate its economic potential, the risks of abandoning this problem can, however, be far worse and can damage the state of sensitive environmental resources and, what is worse, human health through bioaccumulation.

As countries such as Malaysia strive towards a high income, more development is expected on the way and this strengthens the argument that it is time for them to learn from countries at later stages of development, which are still paying the debt accumulated in the past for the sake of a high income per capita (Stolzenbach, Adams 1998).

11.2 The framework in international context

From an international context, the application of this framework provides good guidance on how to use dredging data as an indicator to show the level of contamination in an area. This will help countries with low to middle incomes, which frequently perform dredging, but lack the scientific evidence to define land as contaminated, in order for them to manage their contaminated land problems in a sustainable manner (Sousa 2001).

In addition, this study stresses that it is important for sediment quality analysis to be considered and supports the developmental efforts of EQS, River Basin Management and the integrated approach to managing dredging impacts (Gac, Chiffoleau et al. 2011). However, more attention should be paid to geographical differences, as well as the high levels of un-prioritized substances, including Mn and Fe, that affect DO levels during dredging.

Furthermore, it is undisputed that the EIA system in developing countries is weak and without neglecting the economic aspect, this risk-based decision making framework offers a holistic and cohesive strategy that can improve environmental preservation in these countries (Rajaram, Das 2008, Ahammed, Harvey 2004, Tang, Tang et al. 2005, Jou, Liaw 2006, Tortajada 2000, Alshuwaikat, Rahman et al. 2007, Jain 1999, Kolhoff, Runhaar et al. 2009).

In addition, the framework presented a detailed, dynamic, systematic and updated decision-making tool in order to protect the environment from harmful dredging impacts and to lower the cost of environmental quality analysis and management. This offers opportunities to parties that previously make use of the existing methodologies and frameworks (as mentioned in the Background), which are outdated, costly and hard to implement (Choueri, Cesar et al. 2010).

11.3 Potential for future research

The results of risk values obtained from the use of this framework undoubtedly are limited by secondary data. However, the aim of this study was to develop a framework that could be used in many cases, and the use of case studies from Malaysia is an exemplification of how this framework can be used. The nature of this dynamic and transparent framework makes it easy for it to be changed in the future to fit different cases. Additionally, the three case studies were used as samples in order to show how the framework was developed and to demonstrate how it can be utilized, not only for Malaysia but for other countries as well.

Countries such as Malaysia should produce more scientific evidence particularly highlighting the environmental impacts of dredging and contaminated sites and the application of this framework can already support this course and should be in parallel with sustained efforts to construct national dredging and contaminated land policies.

In fact, chapter 6 has already highlighted the dredging locations in Malaysia that need stringent environmental protection through the implementation of the proposed screening stage. Therefore, future dredging works should use this framework and its results in order to help decision-making in local dredging and sediment management industries. This can be achieved through Tiers 1 and 2 of this framework, using case studies that have been discussed as examples. In addition, research should be performed to construct an integrated database for contaminant sources, sediment properties and land uses that can help identify the risks of dredging using GIS applications. This framework should be treated dynamically and should be evaluated after it has been applied to actual dredging projects, where changes can be made accordingly.

As dredging usually involves development projects including coastal reclamation, port expansion, and infrastructure and resort development, a wide coverage of EIA study should be performed by a country in order to prevent detrimental impacts of dredging.

This framework can be part of an EIA study for dredging, starting with the interfusion of Stage 1 (Screening) of this framework into preliminary assessment of EIA. The nature of this stage, which is cost and time effective, made it suitable for execution in conjunction with the current EIA. The screening stage, which evaluates initial risks using historical dredging data and media data, made the preliminary assessment focus on prioritized areas, and as a result, resources can be allocated to high priority areas.

The next stages of this framework (Stage 2 and 3) can the detailed assessment of EIA study (Department of Environment, Ministry of Science, Technology and the Environment Malaysia 1993, Legal Research Board 2005). Risk assessment in Stage 2 is able to identify degrees of contamination and concerns at a prioritized area; however, caution should be taken, as the identification of risk values in this thesis was not done using local specimens. This thesis used toxicity values adapted from various resources, including from literature reviews and ECOTOX benchmarks values by the U.S. Environmental Protection Agency (US Environmental Protection Agency 2012b) (Finley, Su 2000) (Eisler 1993) (Ghanmi, Rouabhia et al. 1989).

This thesis used the toxicological data of foreign species in its ERA. This is due to the fact that the use of case studies in this thesis is only for exemplification of how the framework can be used in the future. Undoubtedly, the toxicological research on local species is very limited. Nevertheless, when this framework is used in the future, it should consider local biochemical and molecular markers, especially the top ten marine fish species endemic in this country – Indian mackerel (kembong), round scad (selayang), selar scad (selar kuning), sardine (tamban), threadfin bream (kerisi), longtail tuna (aya/tongkol), anchovy (bilis), hard tail scad (cencaru), drum and croaker (gelama and tengkerong) and ray (pari) (Tan, Yap 2006) - in order to be used for monitoring aquatic environmental health. As dredging is trans-boundary and involves many other types of development including reclamation, a wide range of indicators to indicate dredging impacts should be used in order to anticipate accurately the dredging impacts. This includes effects of leachates on aquatic organisms or effluents on benthos, and mangrove diebacks due to disruption of coastal processes (Zakaria, Okuda et al. 2001)."

It took more than 10 years to plan dredging at Houston River and Boston Harbor because of the environmental impacts it may have posed (Stolzenbach, Adams 1998, The Hudson River Dredging Project 2013). In contrast to dredging practice in Malaysia, environmental aspects has have not always been included in the planning stage, which means that the duration of the dredging assessment study only focuses on technical and financial matters (Briffett, Obbard et al. 2004). Therefore, it shows that the duration of the dredging assessment study in Malaysia is considered short and inadequate to compare to international practice."

Collections of toxicological data may be difficult in terms of cost and monitoring duration, thus data sharing among stakeholders can be an advantage for developing countries like Malaysia. A database that is user-friendly and network-based is necessary, and a good example can be seen on the British Geological Survey website (http://www.bgs.ac.uk/), where data including toxicological is delivered through Geo Information Systems (GIS). This could help stakeholders to keep the environmental monitoring costs to a minimum. A team of experts from multiple disciplines including biologists, chemists and computer programmers, needs to be set up in order to develop this toxicological database."

The demonstration of this framework only focused on chemical and biological impacts of dredging. In the future, in addition to dredging impact factors (sediment characteristics and media quality) research should emphasize dredging impact factors other than the ones that have been explored in this study, in order to grasp the overall benefits of this framework. The dredging impact factors can include transport and deposition of contaminated sediments, organism-sediment-contaminant interaction, contaminant source, exchange of contaminants between sediments and the water column, and physical and hydro graphic setting, as illustrated in Figure 11-4. Although many scientific works have already been published on these factors, attempts to put them into perspective for developing countries can be considered virtually non-existent, which necessitates future research focusing on this particular area.

In addition, after disposal options such as bioremediation of dredged sediments (Table 11- 1) should be considered in addition to what have been discussed in this thesis. The term "bioremediation" describes the process of contaminant degradation in the environment by biological methods, using the metabolic potential of microorganisms to degrade a wide variety of organic compounds.

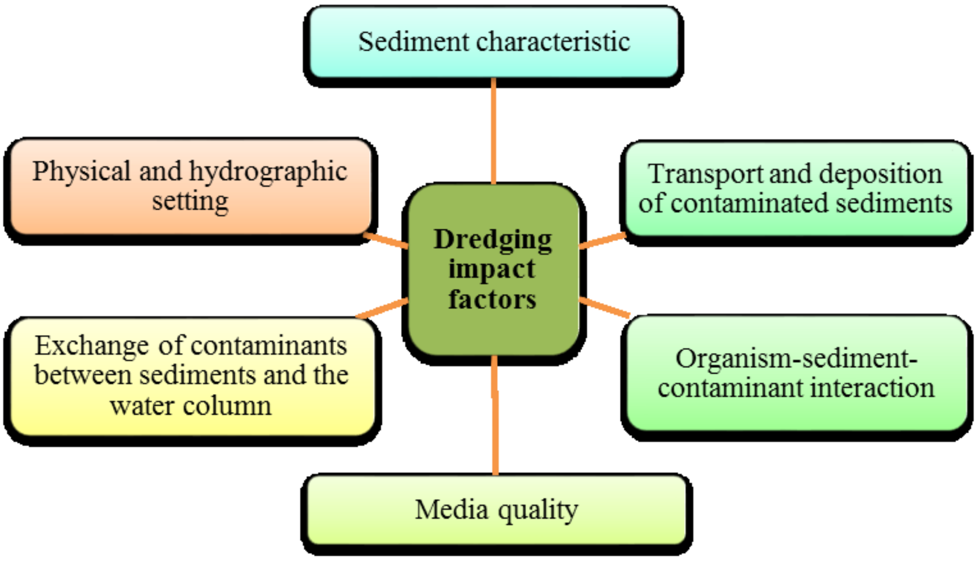


Figure 11-4 Dredging impact factors that included sediment characteristic and media quality as highlighted in this research (Stolzenbach, Adams 1998)

Table 11-1 Bioremediation technique

Option	Reference
Mangrove replanting	(Hashim, Catherine 2013, Peng, Chen et al.)
Natural re-vegetation	(van Rooyen, van Rooyen et al. 2013, Asiedu)
Soft sediment engineering	(Kirby 2012)
Bird sanctuary	(Scarton, Cecconi et al. 2013)
Confined upland disposal (CUD)	(Great Lakes and Ohio River Division U.S. Army Corps of Engineers 2010).
Phytoremediation	(Perelo 2010, King, Royle et al. 2006, King, Royle et al. 2006)

Furthermore, indicators (as listed in Appendices A and E) including detrimental changes in geographic features, due to illegal sand dredging, noise in the water during dredging, and the release of CO2 from dredgers, would also need to be explored in addition to the chemical and biological indicators that have been highlighted in this study. In addition, public participation can be considered minimal during the demonstration of this framework. Traditional Eco-Livelihood Knowledge (TELK) and Traditional Knowledge (TK) are among the option tools available, which could be used to complement the methodology. TK is defined as the knowledge gained from the experience and detailed accounts of local residents, and TELK is defined as the knowledge people possess about their local environment and the ways they derive livelihoods from it (Tamuno, Smith et al. 2009). These forms of knowledge can be obtained through different approaches to stakeholder engagement, including semi-directive interviews, questionnaires, analytical workshops and collaborative fieldwork (Huntington 2000). They can be used for a number of applications, including setting the optimum dredging intervals, to apply environmental windows for dredging, to select dredging techniques, and to treat or dispose dredged material (Talley 2007, Tamuno, Smith et al. 2009).

This thesis recommends combining qualitative assessment e.g. public perception surveys with quantitative assessment in order to reduce dependency on scientific measurements, including sediments characterization, in the dredging decision. A combination of many environmental tools providing a holistic analysis such as those of the Integrated Coastal Management (ICM) and the Integrated Coastal Management (ICZM), harmonized framework for ecological risk assessment of sediments, Driving force-Pressure-State-Impact-Response (DPSIR) in Malaysia’s dredging industry, and decision analysis approach to dredged material management. Utilising an integrated environmental management concept (IEM) that balances multiple criteria using MCDA and ERA could provide a structured framework to accommodate different views of stakeholders, and identifies the most suited scale of actions towards addressing multi-criteria and conflicting problems, to render it more holistic, integrated and sustainable. Such methods can be very useful in practical terms and with appropriate testing and validation could be good decision-making tools.

Table 11-2 Contaminated sites and dredging in the UK, the US, France and Malaysia

Criteria	The UK	The US	France	Malaysia
2012 Gross Domestic Product (GDP)	USD 2.434 trillion (The Central Intelligence Agency 2013)	USD 15.65 trillion (The Central Intelligence Agency 2013)	USD 2.58 trillion (The Central Intelligence Agency 2013)	USD 307.2 billion (The Central Intelligence Agency 2013)
Contaminated site related rules and regulations	1. Health and Safety at Work Act 1974 2. Control of Pollution Act 1974 3. Occupiers Liability Acts 1957 and 1984 4. Building Regulations 1985 5. Collection and Disposal of Waste Regulations 1988 6. Control of Pollution Act 1989 7.Water Act 1989 8. Town and Country Planning Act 1990 9. Environmental Protection Act 1990 10. Controlled Waste Regulations 1991 11.Water Resources Act 1991 12. Environment Act 1995 13. Landfill Tax Contaminated land Order 1996 14. Special Waste Regulations 1996 (Luo, Catney et al. 2009)	1. Comprehensive Environmental Response and Liability Act (CERCLA), 1980 which is commonly known as Superfund, amended and known as Superfund Amendments and Reauthorisation Act (SARA),1986 2. individual State administrations including remediation legislation in Minnesota and Pennsylvania (Martin, Visser et al. 1996)	1. Waste Management Law (1975) and the 2. Industrial Installations Classified for Environmental Protection Law (1976), 3. Classified Industrial Establishment Law (Martin, Visser et al. 1996)	1. Contaminated Land Management Framework 2. Contaminated Land Management and Control Guidelines No.1,2 &3 by DOE (Department of Environment Malaysia 2009b, Department of Environment Malaysia 2009a, Department of Environment Malaysia 2009c) 3. Derelict Land Development Project (Yi, Talib 2006)
Number and area of contaminated site	50,000 to 250,000 registered as contaminated sites (Sousa 2001)(Martin, Visser et al. 1996)	384,000 registered as contaminated sites (Sousa 2001)(Martin, Visser et al. 1996)	700 registered as contaminated sites (Martin, Visser et al. 1996)	>800,000 ha (Yi, Talib 2006)

Criteria	The UK	The US	France	Malaysia
Dredging stakeholders	- Marine Management Organisation (MMO) - Environment Agency, CEFAS, relevant authorities, competent authorities, other berth operators (The UK Marine Management Organisation 2011, The UK Marine Management Organisation 2013)	- Environmental Protection Agency (EPA) - the Corps (USACE) as disposal Licence problemr - State's Department of Environmental Conservation as permit from discharge point problemr	- Client and project manager - Head of the Departmental Maritime Administration - Head of the Mission of Regional Water Management - Head of Regional Environmental Administration - Environmental Department of the Sanitary and Social Administration - Mayors of municipalities concerned - Head of the Laboratory of IFREMER - Associations for Environmental protection (Abriak, Junqua et al. 2006) - Town and country planning, water, coastal authorities (Gac, Chiffoleau et al. 2011) - Centre d'Etudes Techniques Maritimes Et Fluviales (CETMEF) - Groupe d'Etude et d'Observation sur le Dragage et l'Environnement (GEODE) (Gac, Chiffoleau et al. 2011)	- Department of Environment - Ministry of Transport - Department of Irrigation and Drainage - Marine Department - Fisheries Development Authority of Malaysia - Port administrator and companies - Dredging contractors - Specialist consultants

Criteria	The UK	The US	France	Malaysia
Dredging permit criteria	- Contaminants include As, Hg, Cd, Cr, Cu, Ni, Pb, Zn, organotins, PCBs, DDT, Dieldrin - Bioassays, historical data and knowledge regarding the dredging site and the materials characteristics are among weight base evidence that will be used for characterizing dredging areas - Action levels are used to consider whether sediments are suitable for sea disposal, including Below Action Level One, Above Action Level Two and Between Action Levels 1 and 2 - Below Action Level One is contaminant levels are of no concern and are unlikely to influence the licensing decision - Above Action Level Two are contaminant levels that are unsuitable for sea disposal. This most often applies only to a part of a proposed dredging area and so that area can be excluded	- Contaminants include heavy metals, dioxin, PCBs and carcinogenic compounds (Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn, PCb, PAH, DDT as highlighted pollutants for dredging in Boston Harbour) are categorized into Categories 1,2 and 3 - Category I is material that does not cause unacceptable toxicity or bioaccumulation in biological test systems, and is suitable for ocean disposal - Category II is material that cannot be disposed of unrestrictedly in the ocean but does not pose a threat of mortality. (It meets existing federal standards despite showing significant toxicity or bioaccumulation.) It can be disposed of in the ocean if capped, can be disposed of at landfills, or in borrow pits. -Category III consists of material that fails to meet federal Limiting Permissible Concentration Criteria	- Contaminants include As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, PCB, total of the 7 PCBs defined by the ICES, total of the 25 PCBs, PCB 28, PCB 52,PCB 101, PCB 118, PCB 138, PCB 153, PCB 180, TBT, DDT, Dieldrin - The type of sediment, the amount of dredged materials and the distance from shellfish or sea farming areas are among data that will be analysed to categorize a dredging - Contaminants are classified into two levels namely N1 and N2 and consideration to dispose is based on whether the risks can cause physical hazard (H1 to H3), or can be hazardous to human health (H4 to H12), or can be hazardous after disposal (H13), or eco-toxic (H14) * If sediments are not characterised as hazardous waste but cannot be dispersed or dumped, they must be disposed of on land, together with any by-	- Dredged site above 50 hectares require detailed EIA - If dredging area is less than 50 hectares, State's DOE may require EA, EMP, EM or EMnP (Government of Malaysia 5th November 1987) - Contaminants in sediments are categorized according to international standards

Criteria	The UK	The US	France	Malaysia
	from disposal at sea and disposed of by other methods including landfill - Between Action Levels One and Two are contaminant levels that requires further consideration and testing before a decision will be made (The UK Marine Management Organisation 2011, The UK Marine Management Organisation 2013) * No environmental assessment is required for maintenance dredging except disposal of the sediment at sea (Ahammed, Harvey 2004)	established for toxicity and/or bioaccumulation for one or more species (Fredette, Pederson 1998)(Gibb 1997)	products, in conditions that comply with health and environmental regulations (Gac, Chiffoleau et al. 2011)	

The use of exposure and toxicological studies in this thesis may not be accepted in current practice in Malaysia, as it may involve high costs and long-term monitoring for collection of data that is to be used within the developed framework. Apart from this, its full benefits can only be obtained by using local toxicological data. The use of toxicological values in its ERA, which are not originally collected from the ecosystems of Malaysia, will misrepresent the real impact of dredging in the areas of the case studies. Even in big countries like Malaysia, biological resources in the East can be different to resources in the Peninsular. This is due to site specificity (temperature, salinity dll) that can be found in the habitat of a biological resource. It is therefore critical to highlight the importance of establishing local toxicological data in future research (especially by local universities) before the framework as developed in this thesis can be put into practice.

Many good examples of toxicological research that have been performed to find lethal dose (LD), lethal time (LT), lethal concentration (LC) and many more research endpoints have been carried out in the west. This has been performed using sensitive biological resources, and its examples can be found in Table 11-3. Developing countries should have this type of data using their local species in order to predict dredging impacts more accurately.

Table 11-3 Toxicological studies

Substance	Species	Lethal concentration	Reference
(Acetato-kappaO)phenylmercury	Channel catfish (*Ictalurus punctatus*)	360 ug/L	(Clemens, Sneed 1958)
(Acetato-kappaO)phenylmercury	Flatworm	300ug/L	(Siegel, Eshleman et al. 1973)
O,O-Diethyl O-[6-methyl-2-(1-methylethyl)-4-pyrimidinyl] ester phosphorothioic acid	Talapia (*Cichlidae*)	3848.7 ug/L	(Palacio, Henao et al. 2002)
Chromic acid dipotassium salt	Tapah (*Wallago attu*)	42460-59440 ug/L	(Abbasi, Baji et al. 1991)
Phosphorothioic acid, O,O-Diethyl O-(3,5,6-trichloro-2-pyridinyl) ester	Sepat (*Trichogaster pectoralis*)	10 ug/L	(Areekul 1986)
Phosphorodithioic	Puyu (*Anabas*	1500 ug/L	(Bakthavathsalam,

acid, O,O-Diethyl-S-[2-(ethylthio)ethyl] ester	*Testudineus*)	Reddy 1982)

It should be noted that, apart from heavy metals, organic substances including PAHs and PCBs (used for example in ship painting) is detrimental to the environment (Zakaria, Takada et al. 2002, Zakaria, Okuda et al. 2001, Wahid, Salim et al.). Data regarding chemical substances used by ship companies should be collected in order to know the list of substances to be checked for toxicological tests. In addition, mapping of the toxicological data in network-based GIS can complement the initiatives to identify the sources of pollution.

Benthos can be a good indicator for dredging impacts, as it can be an index for levels of pollution in an area. Collection of data in benthos quality (Figure 11-5) can be a good measurement for examining the impacts of dredging. Samples of benthos should be collected within a km range until the quality of benthos (i.e. levels of heavy metals) detected in samples are found to be lowered. When the levels are undetectable, the range of areas where samples have been collected can be identified as zone of dredging impacts. This is beneficial for monitoring dredging impacts as pollution movement due to dredging can be detected. In addition, by having this data collected, prediction of dredging impacts can be made more accurately in the future.

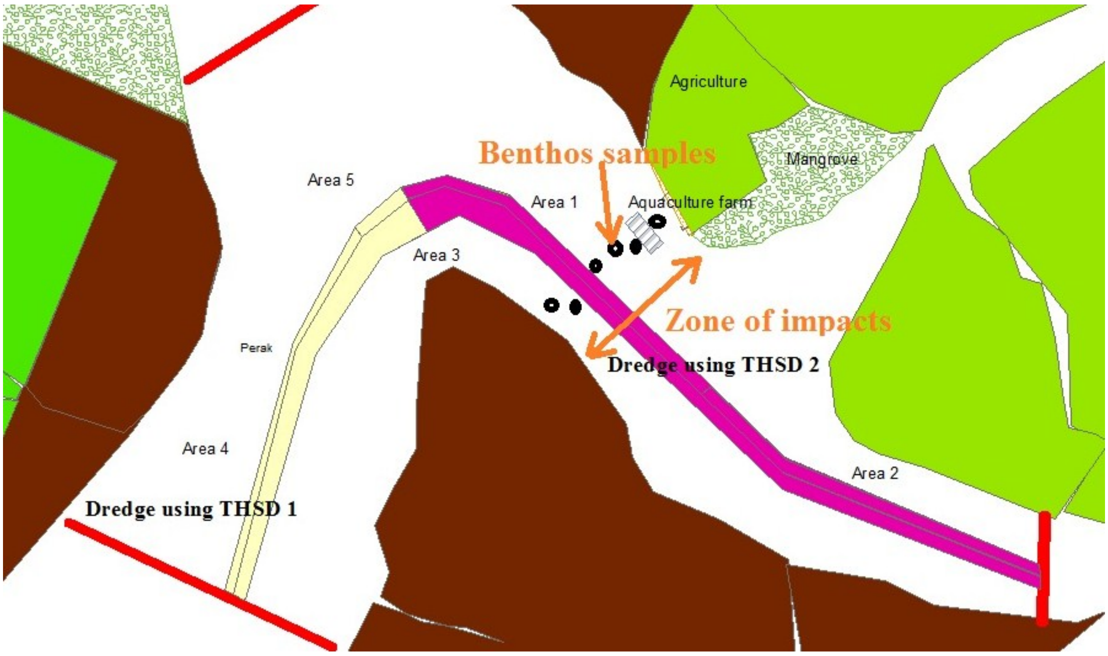


Figure 11-5 Zone of impacts when using benthos as indicator for dredging impacts

Dredging areas that are close to sewerage, poultry and other dairy farms should be considered as high risk areas before dredging commences. This is due to the fact that pollution (that may contain, for example, E-coli) is discharged unfiltered into the water, especially if sewerage management in a country is found to be poor. This becomes a major concern, especially when animal resistance to indicator bacteria E-coli has been found to be raised (van den Bogaard, Stobberingh 2000).

CONCLUSIONS

Dredging has been proven to have negative impacts in previous studies. Important factors that determine the magnitude of dredging impacts include dredging technology and sediment characteristics. Socio-economic and managerial conditions in a location can also be affected by dredging. In addition, there is a need to prioritize environmental quality analysis and management to reduce the impacts of dredging so that analysis can be assigned and resources can be allocated to areas with the highest risk. Therefore, a risk-based decision-making framework for integrated environmental management of dredging sediments has been developed in this research in order to reduce the impacts of dredging and to lower the cost of environmental quality analysis.

Through analysis of historical dredging monitoring data, which has been illustrated using GIS software, the ArcMap 10, it was found that the two vital factors in measuring dredging impact are sediments and neighbouring areas, the contamination levels of which determine the magnitude of impacts.

Moreover, by using DPSIR analysis, which examined data from interviews and an online questionnaire survey, it was found that dredging problems other than the environment include socio-economic and managerial factors.

Based on these findings, the first stage of the proposed framework has been developed to identify prioritized areas that require a high level of environmental protection. A new method has been introduced for this screening stage, utilizing three distinct steps: identifying historical dredging risk values, assessing and quantifying the contamination level of media into a risk value and combining risk values from previous steps for a total risk value, as well as determining the degree of contamination.

Findings from the screening stage have been used in the next stage of the proposed framework, Tier 1. This stage determines the degree of contamination and concern in the prioritized area using a new method, which integrates MCDA and ERA for further investigation. The Tier 1 stage utilized three distinct steps of MCDA in order to determine a prioritized area: delimitation of areas, ranking areas using the Weighted Summation method, and sensitivity analysis. The prioritized area will be further investigated in ERA in order to determine the degree of contamination and concern, using five steps: conceptual modelling, hazard identification, exposure assessment, toxicity assessment and risk characterisation.

Based on findings from the Tier 1 stage, the selection of the best sediment management option has been made in the Tier 2 stage of the proposed framework using a new method, which balances the technological, environmental and economic aspects using MCDA. This stage utilizes three distinct steps: delimitation of sediment management options, ranking options using the Weighted Summation method and sensitivity analysis in order to select the best sediment management option.

A proposal of a risk-based decision-making framework for an integrated environmental management of dredging sediments, which integrated the three stages (screening, Tier 1 and Tier 2) was made in order to reduce the impacts of dredging and to lower the cost of environmental quality analysis. The benefits of this decision-making framework lie in its risk-based approach that communicates to the audience a complex set of dredging problems, provides defendable decisions leading to better environmental preservation and allows resources to be targeted at high priority risks. This benefits many dredging stakeholders, government representatives, non-government organizations, contractors, consultants, environmentalists and the public. This framework is highly suitable for countries such as Malaysia, which prioritise fast and accurate results, but relatively low environmental quality analysis cost during the selection of the best sediment management option.

Current policies and the implications of the proposed framework were discussed focusing on national and international policy contexts. Additionally, the limitations of the research were discussed and recommendations were made for future research. This includes production of more scientific evidence on the environmental impacts of dredging on and adjacent to contaminated land, and construction of an integrated database for contaminant sources, sediment properties and land uses. Preparation, maintenance and updating of sediment quality database should be the responsibility of many integrated stakeholders. As the application of this database is by many stakeholders including DOE, Department of Drainage and Irrigation, Department of Town and Country Planning, Mineral and Geoscience Department, Department of Survey and Mapping Malaysia (JUPEM), Marine Department, and local universities (i.e. Department of Geology and Department of Chemistry, Universiti Malaya), need to have this database incorporated into their existing programme (such as River Basin Management).

This thesis therefore delivers a risk-based decision-making framework for the integrated environmental management of dredging sediments in order to reduce the environmental impacts of dredging and to lower the cost of environmental quality analysis and management.

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APPENDIX A

A.1 Impacts at disposal site

Table A-1 Chemical impacts at disposal site

Parameter	During Disposal	
	Increase	Decrease
Metal concentrations in sediments	[1] √	
Ph soil		[1] √
Fe, Ni and As of water	[1] √	
Ph water	[1] √	
Metal concentration in suspended solid with higher ph	[1] √	
Cd, Zn, Cu concentration levels	[2] √	

* Number of reference √, $_D$=*Dredged site,* $_C$=*Control site, 1*=(Ljung 2010)*, 2*= (Cappuyns 2006)

Table A-2 Biological impacts at disposal site

Parameter	During Disposal		After Disposal	
	Increase	Decrease	Increase	Decrease
Species of bivalve, annelid and invertebrate		[1,2] √		
Change of habitat - Hard bottom reef and bivalve	[1,2] √			
Tropical soft-bottom benthic assemblage				[3] √
Polychaete *N.hombergii*				[4] √
Epibenthic *cumacean D.Rathkei*				[4] √
Recovery rate after 2 years			[4] √	
Sand worm *Oweenid*			[5] √	
Sand worm *Ptychoderid hemichordates*			[5] √	

* Number of reference √, $_D$=*Dredged site,* $_C$=*Control site,1*=(Ware, Bolam et al. 2010)*, 2*=(Crowe, Gayes et al. 2010)*, 3*=(Cruz-Motta, Collins 2004)*, 4*=(Powilleit, Kleine et al. 2006)*, 5*=(Wilber, Clarke et al. 2007)

Table A-3 Physical impacts at disposal site

Parameter	During Disposal		After Disposal	
	Increase	Decrease	Increase	Decrease
Change of sediment type	[1] √			
Sand percentage			[2] √	

* Number of reference √, $_D$=*Dredged site,* $_C$=*Control site, 1*=(Ware, Bolam et al. 2010), *2*=(Wilber, Clarke et al. 2007)

A.4 Impacts of sand and gravel dredging

Table A-4 Chemical impacts of sand and gravel dredging

Parameter	After Dredging	
	Increase	Decrease
Nitrate concentration on pre-monsoon season	[1] √ $_D$	
Phosphate concentration as season advances	[1] √ $_C$	[1] √ $_D$
Surface salinity		[2] √

* Number of reference √ $_{\text{Impact location}}$, $_D$=*Dredged site,* $_C$=*Control site, 1*=(Rasheed, Balchand 2001)*, 2*=(Messieh, Rowell et al. 1991)

Table A-5 Physical impacts of sand and gravel dredging

Parameter	After Dredging	
	Increase	Decrease
Channel width	[1] √	
Change in seabed surface	[2] √	
Casualties of structures including bridges, rural water supply and side protection structures	[2] √	
Transperancy		[3] √$_{DC}$
Turbidity in post-monsoon	[3] √$_D$	
Sediment transport	[4] √	
Sediment particle distribution	[4] √	

* Number of reference √ $_{\text{Impact location}}$, $_D$=*Dredged site,* $_C$=*Control site, 1*=(de Leeuw 2010)*, 2*=(Padmalal 2008)*,* *3*=(Messieh, Rowell et al. 1991)*, 4*= (Kenny, Rees 1996)*()*

Table A-6 Biological impacts of sand and gravel dredging

	After Dredging	
Parameter	**Increase**	**Decrease**
Change of habitat-Benthic fauna	[1] $\surd_D$	
Mobile habitat		[1] $\surd_D$
Riparian and in-stream vegetation		[1] $\surd_D$
Finless porpoise-change of habitat	[2] $\surd_D$	
Bottom fauna-polycheates		[3] $\surd_D$
Bottom fauna-crustaceans	[3] $\surd_D$	
Macrofauna taxa mean density		[4] √
Macrofauna taxa mean density-after 1 year	[4] √	
Species of macrofauna taxa		[4] $\surd_D$
Species of macrofauna taxa-after 1 year	[4] $\surd_D$	

* [Number of reference] $\surd_{\text{Impact location}}$, $_D$=*Dredged site*, $_C$=*Control site*, *1*=(Padmalal 2008), *2*=(de Leeuw 2010), *3*=(Rasheed, Balchand 2001), *4*=(Kenny, Rees 1996)

APPENDIX B

A questionnaire has been developed with the aim of getting information on current practices and problems related to dredging works in Malaysia. A total of two hundred and eighty-two (282) invitations have been distributed via email. A list of registered EIA consultants under the Department of Environment Malaysia has been drawn from wide categories including general environmental management, coastal zone management, maritime and mining. The questionnaire has also been distributed to registered contractors in the Construction Industry Development Board (CIDB) and Malaysia's Contractor Service Centre. Over thirty dredging professionals as in Table B-1 that include marine ecologists, registered chemists, professional and chartered engineer, environmental consultant, university professors and environmental analysts have responded.

Table B-1 Dredging professionals

Name	Dredging experience	Email
Prof. Dr. Ahmad Khairi Abdul Wahab	15 years	dr_khairi@citycampus.utm.my
Dr. Hj. Mohd Zaki Mohd Said	> 10 years	drzaki_ms@yahoo.com
Paul Michael Goldsworthy	15 years	paul.goldsworthy@erm.com
Maimon Abdullah	EIA in dredging works, more than 10 years	maimon@ukm.my
Dr. Tie Yiu Liong	As a Soil Scientist since 1976 but all in dredging works	ecocon@streamyx.com
Ir. Dr. Selamat Aliman	Involved while working as an Inspector of Mines (1985-1993) and as Consulting Mining Engineer (1993-now)	sba2@streamyx.com
Dato' Ir. Dr.Nik Mohamad Kamel Nik Hassan	20 years	irdrnik@gmail.com
Tuan Abdul Majid Hj Rais	Less than a year	majid@marine.gov.my
Tuan Shamsir bin Mohamed	Since 2005	shamsir@marine.gov.my
Prof. Madya Ir. Ahmad	5 years	ahmadmhashim@gmail.c

Name	Dredging experience	Email
Mustafa Hashim		om
Syarifah Noorlia Wan Bujang	3	syarifah.noorlia@worleyparsons.com
Gopinath Nagaraj	14 years	fanlimarine@gmail.com
Nhakhorn Somchit	5	nhakhorn@gmail.com
Ir. C.Kamalesen Chandrasekaran	5 years	kamalesen@gmail.com
Mohd On Basiran	2	ondegreensb@gmail.com
Raveenthar Manivelu	1 year	raveenthar.forthill@gmail.com
Dato' Kapt. Ahmad Othman	15 yrs	ahmad@marine.gov.my
Tuan Mohamad Sayuti Sepeai	15 years	mss@doe.gov.my
Suzanne Mathan	6 mths	suzanne.mathan@erm.com
Ir. Mohd Taufik Salleh	> 10 years	taufiks@iwk.com.my
Abd Hafis Hussin	1 and 1/2 year	hafis@drnik.com.my
Muhammad Zaidy Abu Tamin	6 months	mozad_85@yahoo.com
Ir. Anuar Hamzah	1 tin minng report	anuar_amec@yahoo.com
Mohd Asimi Abu Bakar	1	mohdasimi@gmail.com
Md Zahar Mohamad	10	zaharmzm@yahoo.com
Lee Hwok Lok	2 years	lee.hwok.lok@worleyparsons.com
Mohd Taufiq A.Talib	2 month	tfq@ere.com.my
Mohd Zambri Mohd Akhir	3 years	zam@dhi.com.my
Lee Chan Moi	On and off since 1994	chanmoi@ranhill.com.my
Tuan Noor Suffianhadi Ramly	5	nsr@doe.gov.my
Tuan Mohd Shamsul Farid Mohd Omar	5 years.	msfarid@marine.gov.my
Tuan Hazman Hussein	on project basis only	hazman@marine.gov.my
En.Rosli Abdul Manaf	17 years	ram@doe.gov.my
Tuan Julaidi Rasidi	1	julaidi@doe.gov.my

The demographic questions revealed that forty percent (40%) of the respondents have a bachelor's degree, thirty one percent (31%) have a PhD and twenty eight percent (28%) have a Master's degree. Figure B-1shows the summary of respondents' qualifications.

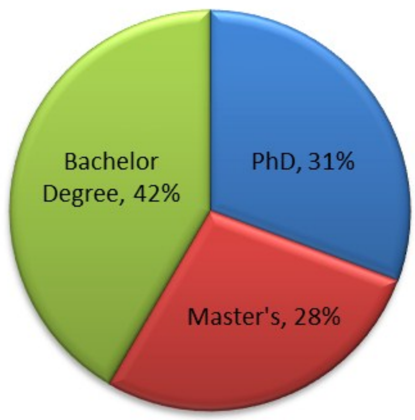


Figure B-1 Respondent Educational Qualification

The respondents have between two (2) years and twenty (20) years experience in the dredging industry and hold various positions at the middle and top management level in their current organisations. The positions they hold in their respective organisations includes; technical specialist (Marine Impact Assessment and Planning), senior environmental consultant, owner and principal of an environmental consulting company, managing director and contracts manager.

Most of the respondents are involved in various kinds of dredging projects. Thirty eight percent (38%) of them are involved in maintenance dredging, sixteen percent (16%) in capital dredging, twenty seven percent (27%) are involved in dredging for the extraction industry including mineral and sand mining and eighteen percent(18%) are involved in other projects, including safety inspection, risk assessment, supervising students, beach nourishment and land reclamation projects. A graphic representation of the results can be found in Figure B-2 below.

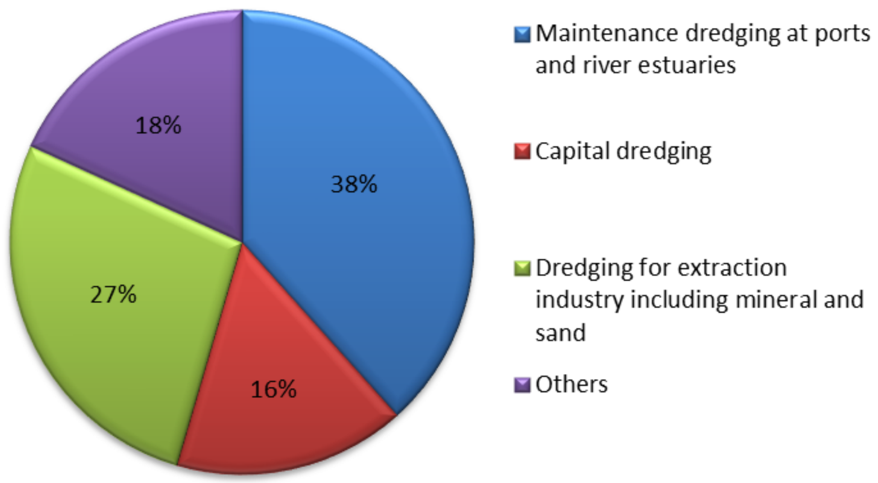


Figure B-2 Types of dredging projects

The organisations they usually dealt with, while engaged in dredging works, include; the Department of Environment, the Marine Parks, dredging companies, developers, Public Work Department, Department of Minerals and Geosciences, port authority, Marine Department and concession holders.

Seventy-three percent (73%) of the respondents acknowledged that the dredging works they have handled were under Malaysia's government Federal Subsidiary Legislation of Environmental Quality (Prescribed Activities)(Environmental Impact Assessment) 1987, under clause 11 of Mining and sub-clause (c) of sand dredging involving an area of fifty (50) hectares or more. While twenty-seven percent (27%) were not acknowledged based on various reasons including: the area of dredging works was less than fifty (50) hectares in size and the dredging works were under the port extension works. The result can be found in Figure B-3 below.

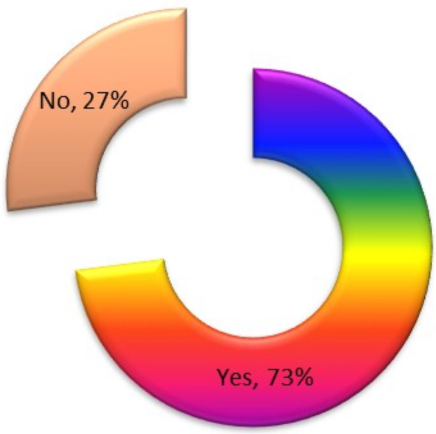


Figure B-3 Acknowledgement of current dredging legislation

Fifty-three percent (53%) of the respondents answered “no” and forty-seven percent (47%) answered “yes” when asked whether any other Malaysian legislation or amendments of existing legislation exist, relating to dredging works that they know of from their previous dredging works. The respondents have listed a number of relevant acts including the Exclusive Economic Zone Act 1984, the Continental Shelf Act 1966, the Mineral Development Act 1994, the State Mineral Enactments, the Local Authority Act and the Building and Drain Act.

Sixty-seven percent (67%) of the respondents believe that the existing environmental legislation for dredging in Malaysia is not congruent enough, based on the dredging works that they have been involved in, while the rest agreed. A graphic representation of the result can be found in Figure B-4 below.

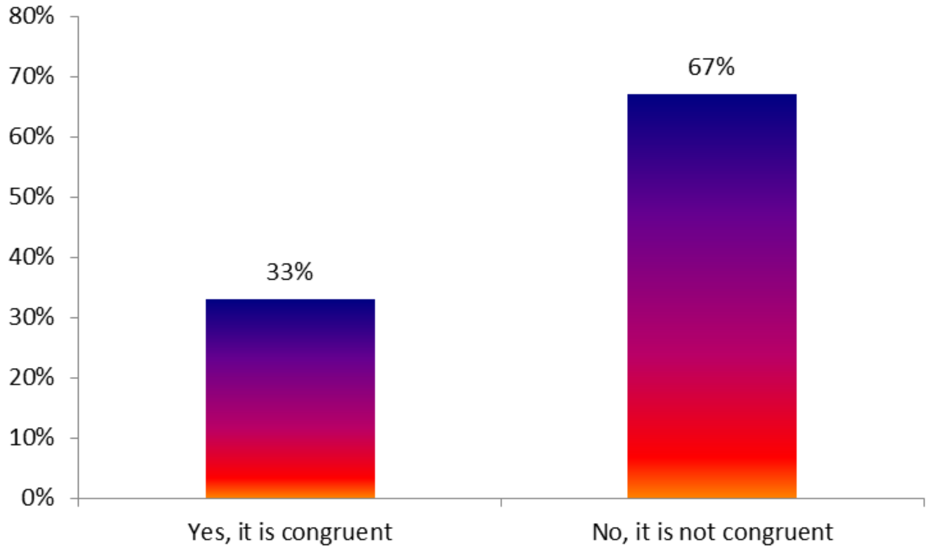


Figure B-4 Respondent perspective on current legislation

The justification of those, who believe that the current legislation was not congruent, includes; the area specified under the existing legislation, as well as the schedule referring to the dredging works that requires EIA, need to be updated. One other respondent has stated that the existing legislation is quite irrelevant for river sand dredging, which he believes has a high impact on the downstream area, but since the legislation requires an area of dredging works of more than fifty (50) hectares to conduct an EIA, then the dredging works, conducted in a smaller area will be easily approved by the District Office, without any environmental consideration.

Other respondents have also justified that the legislation involving dredging works should not only cover the area involved, but also the dredged volume and the adjacent sensitive areas. Other respondents have also specified that emphasis should be put on the disposal of contaminated dredged materials. Other respondents have also commented that the existing legislation have many loopholes; the lack of control parameters on illegal sand mining is one example. One respondent has also commented that suitable enactment should be done on dredging for mining of minerals involving mineral processing on board of the dredger.

Twenty-six percent (26%) of the respondents have performed the preliminary EIA and EMP in dredging works that they were involved in. Twenty four percent (24%) of the respondents have been involved in the preparation of detailed EIA. Thirteen percent (13%) have utilised the Environmental Monitoring System (EMS), three percent (3%) have used the ISO 14000 series, and the remaining eight percent (8%) have used other environmental management tools, including the Environmental Assessment (EA) and tin, silica and sand mining scheme for submission to relevant authorities. The graphic presentation can be found in Figure B-5 below.

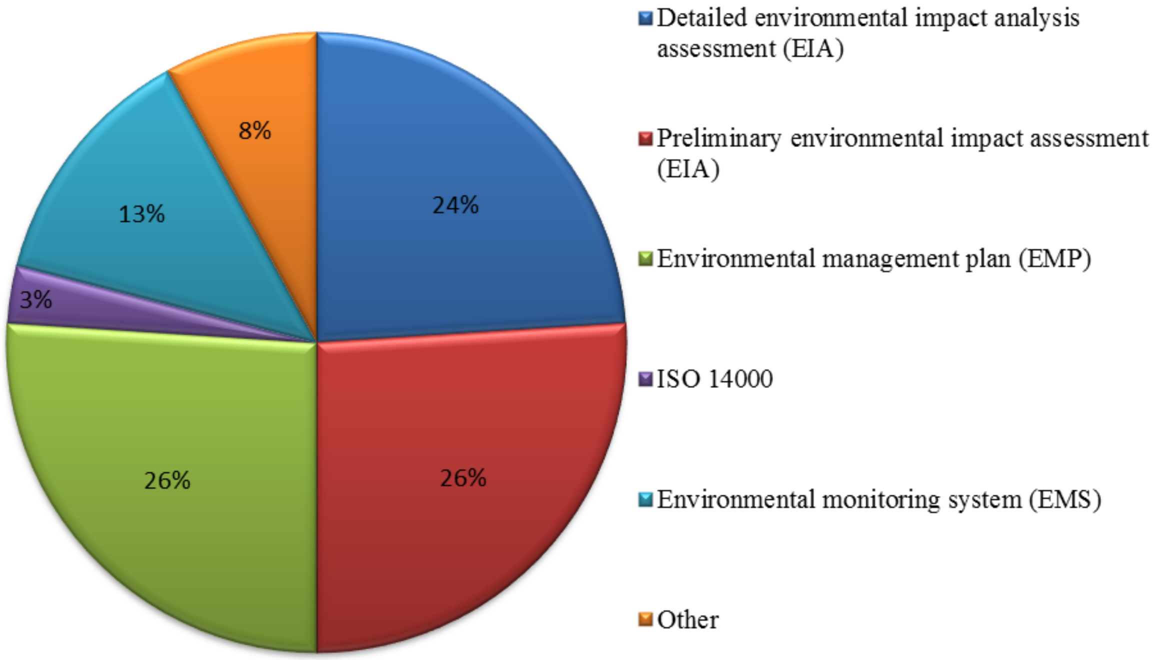


Figure B-5 Types of environmental management relevant to respondents

Each respondent was asked whether the environmental management tools and practices they handled were a necessity, required by the existing legislation or they were based on the best managerial practices. Seventy-one percent (71%) answered that it was necessary, while twenty-nine percent (29%) of respondents took the best managerial practices from other parties. The justifications included: the legislation by itself would not be as effective as compared to the best managerial practices; the requirement depends on the client whether they wish to meet the necessary legislation or go further and incorporate the best management practice; and large international clients will have their own corporate standards or guidelines, which extend beyond local legislative requirements.

Three (3) of the questions were developed with an open structure in order to gauge the respondents' understanding on Malaysia's dredging legislation based on their previous practices. One of the questions is; in the respondents' opinion, which aspects are considered most important by Malaysia's environmental legislation related to dredging works. Table B-2 below shows the answers of the respondents.

Table B-2 Answers of the respondents

No.	Respondent's Comments
1.	1. Justifications on the need for dredging 2. Potential impacts on the environment and socio-economic stakeholders 3. Mitigation plan for any negative impacts 4. Well planned monitoring during and after dredging for immediate, short and long term impacts and residual impacts.
2.	Improving the enforcement and monitoring system, to ensure full compliance and necessary intervention in case adverse effects are detected.
3.	As per requirement stated in the EQA 1974, based on area (number of ha) or by industry/development e.g. new port development, reclamation etc.
4.	1. How to protect or provide natural habitats for the fisheries, because after the dredging works the river becomes a drain, not so much a river or stream. 2. The new alignment of a river, which has been dredged, must not differ from its original shape as it will affect on the whole ecosystem along the river.
5.	EIA and monitoring.
6.	Incorporating best practice for environmental assessment, especially with respect to disposal of dredged material, and monitoring during the dredging operations
7.	EIA Prescribed Activity 11(c): EIA is required for sand dredging of more than 50 ha for the purpose of mining. EIA Prescribed Activity 4: EIA is required for dredging that is integrated with coastal reclamation >50 ha.
8.	1. Judicious monitoring and surveillance. 2. Control illegal mining and sand extraction, both inland waters as well as offshore 3. Prevent corruption by parties with vested interest & political clout.
9.	Mining scheme plan which include planning and environmental control.
10.	1. Impact of aquatic life, especially benthic communities. 2. Stirring up sediment and causing sediment pollution. 3. Disposal of dredged materials. 4. Hydrological changes causing changes to flow, etc.
11.	Putting more emphasis on green management on mining wastes and how to strengthen vector of related diseases control in the project area.

The respondents were asked to explain briefly the environmental management tools and practices that they had used during their previous dredging projects. Table B-3 below shows the answers of the respondents.

Table B-3 The process of relevant environmental management tools and practices

No.	Various respondent's Comments
1.	Planning, design, implementation and control of the whole operation.
2.	1. EIAs predict the impacts of dredging and disposal of spoil material. 2. EMPs are used to manage the dredging operations according to regulatory and best management practices.
3.	1. Conducting a baseline environmental survey to identify sensitive receptors. 2. Undertaking EIA. 3. Provide recommendations for mitigation measures 4. Develop EMP
4.	EIA, EMP and monitoring
5.	1. Providing guidelines which constrain all the necessity action to be taken during dredging work. 2. Submitting a report to Drainage and Irrigation Department or Public Work Department to get approval on method statement and the environmental monitoring procedure. 3. Carrying out the work based on the environmental guidelines. 4. Doing environmental monitoring as per schedule. 5. Doing auditing on environment.
6.	1. Conducting an EIA study based on legal requirements according to the process specified by Department of Environment. 2. Mostly hydraulic studies are used to predict the extent of the plumes from the dredging activity. 3. Mitigation measures are proposed either in the techniques used for dredging or mitigating measures such as sediment nets to manage the impact. 4. All these are specified in the EMP and need to be undertaken by the contractor 5. A monitoring regime/schedule, which is approved by DOE, will be undertaken.
7.	1. Gathering baseline data & information prior to dredging works, which is then compared to post dredging data. 2. Continuous monitoring during dredging. 3. Usage of environmental friendly and properly maintained dredger.
8.	1. Baseline data collection. 2. Impacts studies involving engineering analyses and modelling including optimum dredge methodology and dredge limits. 3. Proposing mitigating and control measures. 4. Proposing EMP and responsible parties.

The respondents were asked to explain briefly the process of the dredging works that they had been involved according to the relevant phase - pre-construction phase, construction phase and post-construction phase. Table B-4 shows the answers of the respondents.

Table B-4 Dredging practice in Malaysia

Pre-Construction	Construction	Post-construction
-Determine site and extent of dredge limit (area and depth), dredge methodology and containment methods	Environmental monitoring (water quality, sediment plume dispersion, hydrodynamic parameters etc.)	continuous monitoring
Survey & Baseline data collection, engineering study and numerical model study	Monitoring & survey	Final survey
Baseline data collection is used to explain the pre-construction environmental conditions. EIA study carried out to include hydraulic modeling for plume as well as other impact studies e.g. marine traffic impact, social impact, fisheries impact studies. Explanation of the methods and equipment to be used by the contractor. From the results, mitigating measures are proposed to ensure that the impact to the environment is kept at an acceptable level. Proposing an environmental management plan and a monitoring plan during construction and post-construction, which will be reported to DOE.	Implement approved EMP to ensure that the mitigating measures are in place and working during this period. Conduct periodic monitoring to ensure that the EMP is working and reducing the environmental impact.	Monitoring of the site post construction based on the approved EMP to see if the site has returned to its normal state based on the EIA and EMP recommendations.
Concept studies and detailed design studies	Emergency preparedness analysis	Sustainability studies
Installation of pump and bund	Pumping into bund and discharge to tailing	Rehabilitation works
1. Planning on the process of dredging activity 2. Create milestone or master schedule 3. Identify access road, where to dump unwanted material	1. Performing dredging activity, transporting material, backfilling, soil reinforcement, bund construction, road construction, earth drain	Monitoring slope protection and river bank protection if it failure or need to enhance. monitoring on water level which is over the design level or not
Site survey to determine existing environment	EMP, monitoring	Monitoring
Environmental baseline	Assessment of potential impacts, recommending mitigation measures, undertaking monitoring - water quality	Undertaking monitoring to assess actual impacts from dredging works, undertaking monitoring to assess recovery of impacted receptors

Pre-Construction	Construction	Post-construction
-Identification of dredging site for borrow/fill material -Sediment/particle size evaluation for suitability -Selection of dredging site based on technical and economic factors	Monitoring of dredging operations (prevent encroachment out of dredging area), Monitoring of spoil disposal operations (prevent unauthorized dumping), Monitoring of sand filling operations by hydraulic pumping (preventing sedimentation of adjacent waters)	Monitoring of dredged pit, Monitoring of reclaimed land
Typical dredging work for sand mining (use of suction/hopper dredger, etc.). Standard process as per manual.	Standard process as per manual.	Standard process as per manual.
Evaluating the ambient environment of the area in consideration for dredging. Evaluating for impacts and mitigation required.	Dredging operations should follow the approved dredging plan using approved dredge and other equipment.	Rehabilitation of the dredge area. To ensure that decommissioning process is adhered to.
Planning (deciding where to dredge, how much, etc.) and mobilisation	Carrying out dredging according to planned specifications and disposing of dredged materials	Tidying up and demobilise
We do health baseline investigation on all sensitive receptors. We also study the surveillance activities that have been carried out by the local health office for the past 6 months. We calculate disease burden of the respective population. Estimation of health risk will be calculated from air or water modelling. All these steps are required in the EIA.	Nothing	Nothing

The respondents were asked whether they had been involved with the public or other environment-related parties including NGO's while engaged in their previous dredging works; half of the respondents answered yes. One respondent explained that the public or NGO's were involved by invitation of the contractors during the EIA review and presentation, while the other respondent said that there was no statutory requirement for involvement by the public or other related parties.

The respondents were also asked to explain in what way the public or related parties participated in the dredging project that they were involved in. One of the respondents explained that the environmental NGO's and local community groups monitored the beach rehabilitation works and provided feedback on water quality and environmental impacts. Another respondent commented that the participation was through involvement in the initial public consultation periods and throughout the project in terms of updated information on progress and any identified impacts. One of the respondents also explained that participation was achieved through public consultation, comments on EIA and direct contact during the EIA preparation.

None of the respondents had ever initiated any works on Cumulative Effects Analysis in their previous dredging works. One of the respondents commented that it was difficult to obtain funding from clients to undertake any additional studies; including the Cumulative Effects Analysis.

The respondents were asked whether they had reused the dredged sediment for any beneficial usage. Sixty-three percent (63%) said yes and the rest said never. They specified the usage which included; reclamation and river dredging works to nourish areas which have been eroded, restoration of wildlife habitats in aquatic wetland areas, using contaminated dredged material for construction of building foundations in industrial port areas, sand for construction material, clay for ceramics or bricks and also rehabilitated paddocks for wildlife habitat. One respondent commented that there was no economic incentive to reuse the dredged sediments; the dredged sediments are classified as spoil (e.g. mud), are not suitable for reuse, and there is no processing centre or operator to receive and handle them.

When asked whether they had ever initiated environmental monitoring during their previous dredging projects, eighty eight percent (88%) answered yes. They explained that the monitoring was done in accordance with DOE regulations, which include parameters such as water quality, sea grass habitat, coral reefs, sedimentation rate, re-suspension of dredged material after disposal in offshore areas, macro benthos community and sediment plume monitoring through aerial surveys.

Other respondents also commented that monitoring of runoff water from hydraulic pumping for transferring sand from dredger to land reclamation area and also monitoring of dredge spoil dewatering pond discharge water has been done on their previous dredging works. Some respondents also stated that they have done monitoring in terms of its adherence to its approved mining scheme. One of the respondents said that monitoring was recommended in the report, but it was not done.

When asked whether any of the respondents or their organizations had ever been penalized for infringement of any Malaysia's environmental legislation on their previous dredging works, none of them had.

Sixty-three percent (63%) of the respondents agreed that the current Malaysian environmental legislation and guidelines for dredging works are not strict enough especially for monitoring aspects, while thirty-eight percent (38%) said otherwise. A graphic representation of the results can be found in Figure B-6 below.

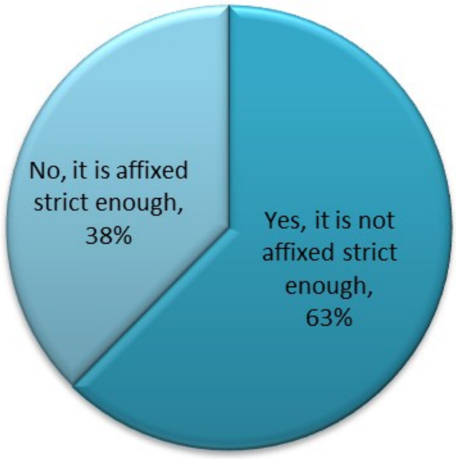


Figure B-6 Perspective on current enforcement especially on monitoring

Respondents, who agreed that current enforcement especially on monitoring aspects was not strict enough, justified this concern with the following factors;

- Manpower shortage
- Inadequate understanding
- Lack of knowledge and understanding on the part of government agencies
- Lack of financial and technical capacity of the contractor to implement proper management and monitoring measures
- Lack of knowledge and understanding among enforcement agencies
- Lack of understanding of dredging impacts
- Lack of enforcement
- It does not cover all types of dredging
- Monitoring by the relevant authorities is very lax.

The respondents concluded that the frequency of monitoring needs to be increased, more stringent guidelines for disposal of dredged material in offshore areas needed to be specified, including mandatory assessment of sediment quality prior to disposal - see Australian National Assessment Guidelines for Dredging and that monitoring was not comprehensive enough. It should cover ecological impacts, and not only water quality per se. The legislation is there. Any shortcomings are mostly in enforcement.

Based on details in Table 3.4: Summary of problems and recommendations, the respondents were asked whether they had experienced any of the stated problems and ranked their frequency as always, sometimes of never encountered. From the highest percentage of environmental concerns ranked as always happened, and also a comment made by a respondent, it can be concluded that a set of environmental concerns as explained below should be prioritized for the proposed framework development.

- Competition for projects among bidders leading to a traded-off of environmental concerns
- No in-house laboratory and expertise to perform environmental analysis
- Noise from dredging operation
- Dredging information not being channeled to the public by government representative
- Raining season delaying the project
- High turbidity parameter
- Disturbance to local aesthetic value
- Environmental specifications are not detailed during the pre-tendering process
- Government representative not involved in pre-tendering process
- Cost for environmental monitoring and mitigation measure not being allocated by client
- High research cost
- Slow feedback from relevant parties
- Flood and erosion
- Sticky clay
- Not involved directly with public
- High project cost due to frequent need for vessel maintenance
- Government feedback is too slow
- Late payment by client
- High cost of vessel maintenance
- Noise from vessel operation
- Disturbance to recreational sailor activities
- Fishermen compensation

The respondents were also asked about their perspectives on the factors that influenced problems related to the environment that they had previously faced with their dredging projects. The answers are given below.

- Inadequate experience and manpower.
- Lack of knowledge and commitments.
- People generally do not value or cherish the environment until or unless something bad happens. NIMBY syndrome -- people don't care unless it directly affects them.
- Economic and financial factors override environmental factors.
- Usually lack of understanding by contractors and or government representatives
- High costs involved
- Lack of awareness and concern by the developers
- Lack of budgeting for environment protection by contractor.
- Lack of enforcement by government authorities.

The respondents were asked for their recommendations to solve the problems and concerns involving dredging projects and the environment. The answers are given below.

- Capacity building; awareness campaign
- To instill a sense of responsibility and commitment to all parties involved through structured courses and awareness initiatives.
- More awareness and education on environmental problems for the public. Stricter enforcement of regulations. Focus on main problems, i.e. habitat conservation, suspended sediment. Implement simple solutions, not necessarily complicated, high-tech methods.
- Establish standard guidelines and/or mandatory process for all dredging. Establish strict permitting system based on volumes to be dredged and/or environmental factors.
- Strict enforcement.
- Engaged quality consultant.
- Update the requirements. Ensure that more experts are called in during the review of the EIA.

- Close cooperation between stakeholders, client should consider compensation to disaffected parties based on measured parameters.

Below are stated the recommendation, which have been supported by a hundred percent vote by the respondents.

- Copy of DOE regulation and guidance to contractor.
- Less political interference.
- Speed up government feedback.
- Upgrade dredging technology towards environmentally friendly methods.
- Strengthen Malaysian environmental policy and enforcement.
- Allocate a budget for environmental monitoring.
- Perform site visit to determine surrounding activity.
- Provide dustbins on vessels.

The respondents were asked whether Malaysia's existing environmental management tools and practices for dredging works were efficient, seventy-five percent (75%) said yes, and the rest said no. The justification given among all was that EIA regulations are not clear enough on which activities require an EIA and that coordination between relevant government authorities in the administration of dredging works needs to be enhanced. A graphic presentation can be found in Figure B-7 below.

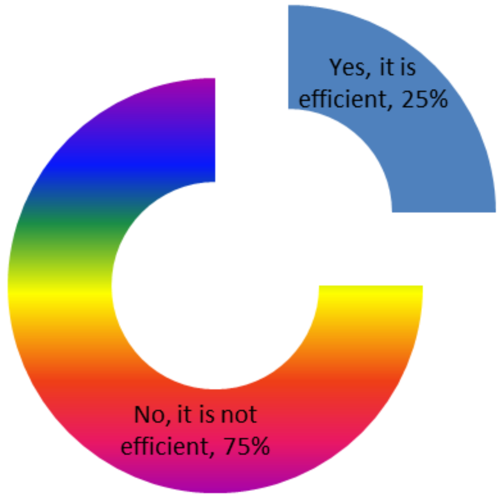


Figure B-7 Perspective on current environmental management

The respondents were also being asked whether they agree that dredging industry in Malaysia lacks guidance to utilise efficient environmental management tools and practices; seventy-five percent (75%) said yes and the rest said no. The justification given among all was that there are available EIA guidelines and the dredging industry can adopt international best practices. Other respondents explained that technical and environmental aspects need to be practically balanced and coordinated.

Seventy-five percent (75%) of the respondents expect research to be done on producing efficient environmental management tools and practices for Malaysia's dredging works through adoption of some benchmarks of developed countries. The justification and comments among all are; it is preferable to observe countries with similar climate and hydrographical conditions and experiences from developed countries need to be tapped and practically adapted locally. One respondent also stated that researching information on the spread of sediment plume from dredge spoil disposal should be done. A graphic representation of the results is provided in Figure B-8 below.

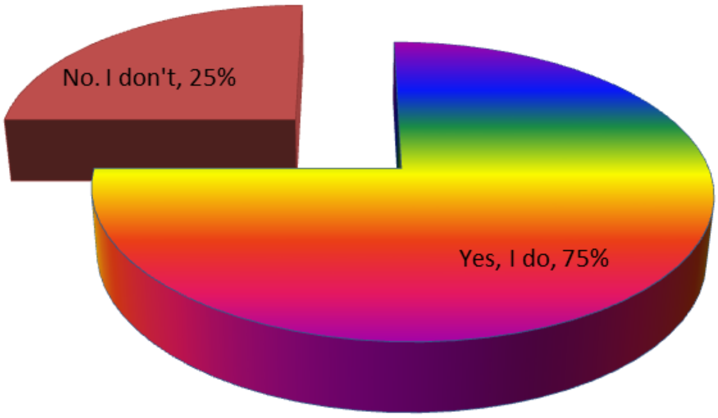


Figure B-8 The need of a research to benchmark developed nation's practice

Three (3) respondents have agreed to supply the researcher with any documents related to the environmental management they have handled. This will be used strictly for academic purposes. Four (4) respondents have agreed to be interviewed for the purpose specified above.

APPENDIX C

C.1 Additional analysis on Dredging Environmental Risk: Malaysia's context

C.1.1 Data sources

A total of 108 dredging reports, including environmental, soil investigation and technical reports were collected from a government appointed dredging contractor (Malaysian Maritime and Dredging Corporation Sdn. Bhd.). The reports relate to twelve maintenance dredging projects undertaken in Malaysia in between 2005 and 2011. From these reports, data from a total of 340 samples of water and sediment quality status were used and analysed an sample locations were illustrated using the Geographical Information System (GIS) software ArcMap 10, as can be seen in Figure C-1. Spatial data for ArcMap 10 was collected from the Government of Malaysia's representative bodies, including the Federal Department of Town and Country Planning for Peninsular Malaysia and the Department of Irrigation and Drainage Malaysia. In this appendix, the four methods of analysis outlined above are further discussed in subsequent subsections. It is worth noting, however that all analysis in this appendix was based on the date of first monitoring until a dredging project completed, ranging in between 1 to 14 months.

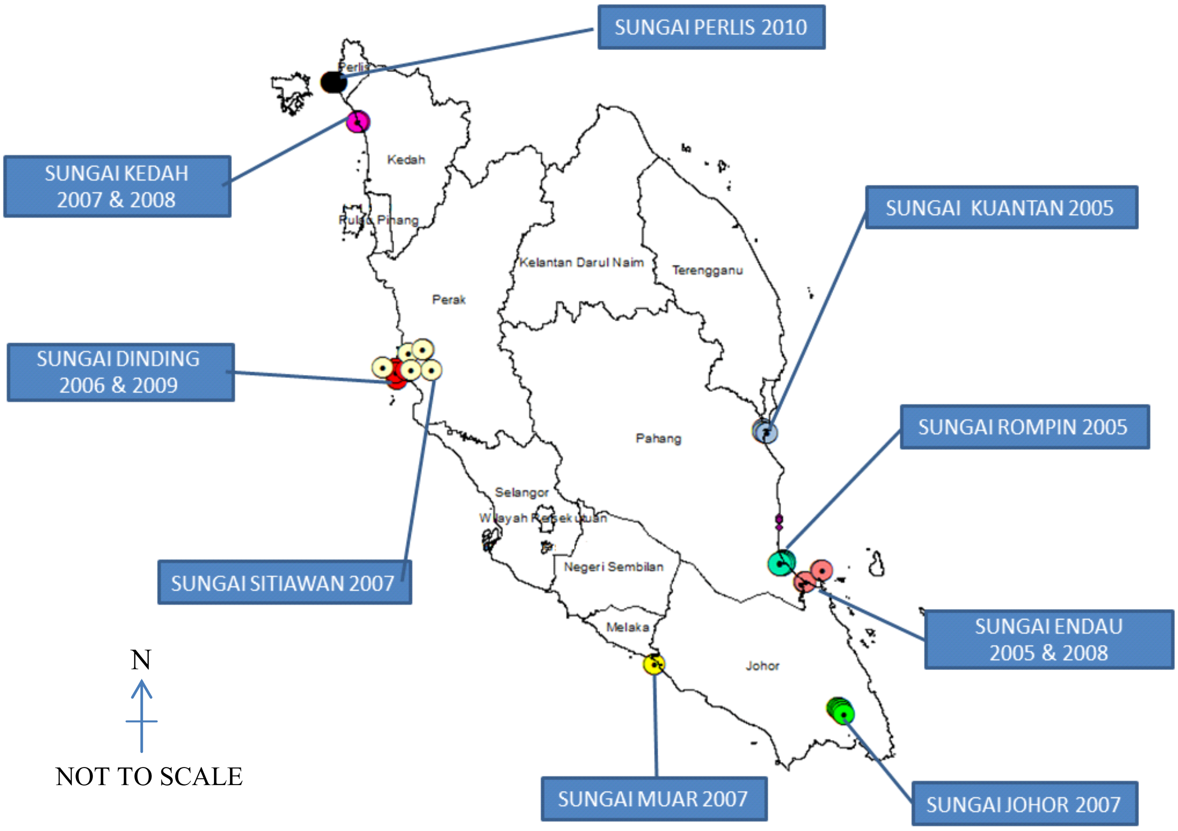


Figure C-1 Map of the dredging locations in Malaysia, as discussed in this study

The environmental reports issued covered all dredging stages, before, during and after dredging (Figure C-2). The issuing frequency of the reports varied according to regulatory requirements, in accordance with Malaysia's Environmental Impact Assessment Order 1987 (Government of Malaysia 5th November 1987). Twenty indicators of water quality status were collected in these reports, including pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Dissolved Oxygen (DO) and concentrations of Hg, Cd, As, Pb, Cu, Mn, Zn and Fe. However, not all dredging projects were required to monitor every one of these indicators; with the minimum number of indicators monitored for a sample being four, and the maximum thirteen. In addition, two dredging projects were required to undertake sediment quality analysis prior to dredging. The indicators used to determine sediment quality status include Total Organic Content (TOC) and concentrations of Mn, Pb, Fe, Cu, Cd, Zn and Cr.

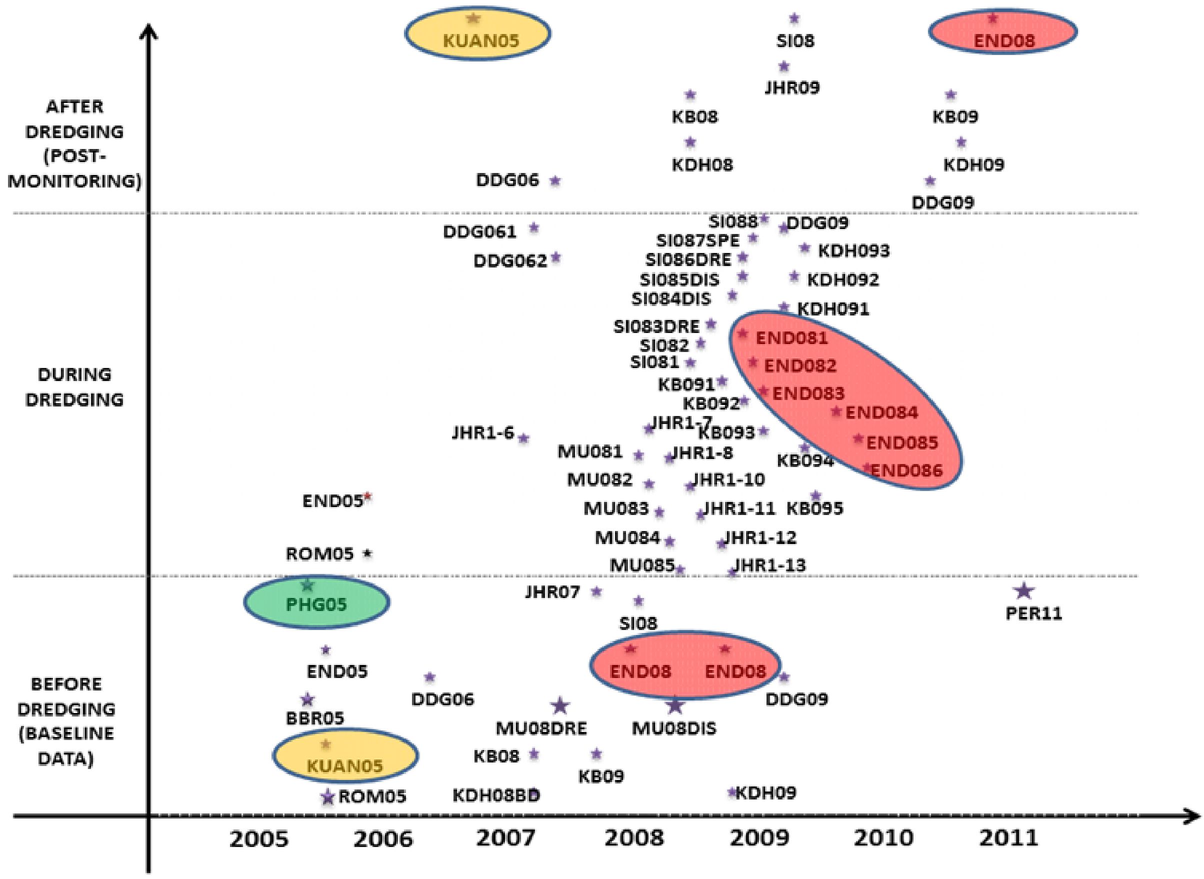


Figure C-2 Frequency of monitoring during the different stages of dredging

C.1.2 Data analysis

Water Quality Index (WQI) is a numeric expression of water quality status, and was first developed by the National Sanitation Foundation (NSF) of the United States (Simões, Moreira et al. 2008). It has since been adapted by the Department of Environment Malaysia to monitor the status of river quality. Since 1978, thousands of monitoring points have been monitored annually, and 6 indicators, including DO, BOD, COD, NH_3-N suspended solid and pH, have been calculated according to Equation [3] to produce a WQI for each river. The WQIs are classified into three index ranges, namely ‘clean’ if the

WQI falls between 81 and 100, 'slightly polluted' if the WQI is between 60 and 80, and 'polluted' if the WQI is between 0 and 59 (Department of Environment 2010). A total of 35 water samples were used to calculate the WQI values in this analysis, in relation to two dredging projects. WQI analysis is clear and can be easily understood by dredging stakeholders, but is by its nature simplistic, leaving a need for a more holistic approach to assess the impacts of dredging.

$$WQI = (0.22*SIDO)+(0.19*SIBOD)+(0.16*SICOD)+(0.15*SIAN)+(0.16*SISS) + (0.12*SIpH)\ldots$$

[Equation 3]

Where;

SIDO = Sub-index DO (% saturation)
SIBOD = Sub-index BOD
SICOD = Sub-index COD
SIAN = Sub-index NH3-N
SISS = Sub-index SS
SIpH = Sub-index pH, $0 \leq WQI \leq 100$

Sediment quality analysis importantly aims to determine the effects of dredging on water quality and how levels of sediment contamination affect this. An analysis based on 42 water samples and 7 sediment samples from five dredging projects was made to determine the pattern of changes in water quality after dredging. Out of these five dredging projects, three were analysed to determine the pattern of changes in water quality and two were analysed to establish the relationship between levels of contamination in sediments and patterns of changes in water quality. It should be noted that Malaysia has not established its own reference values for sediment quality, so reference values used in other countries including Ireland, the United Kingdom, Belgium and Canada were applied for the sake of comparison (The National Oceanic and Atmospheric Administration (NOAA) 2006, Praveena 2008, Pan 2010).

C.1.3 Result

- ***Water Quality Index (WQI)***

It has been concluded that the water quality status improved after dredging at Sungai Kedah, but not at Sungai Kuantan. A striking illustration of this can be seen in Figure C-3, which shows the WQI of these dredging projects at different sampling locations.

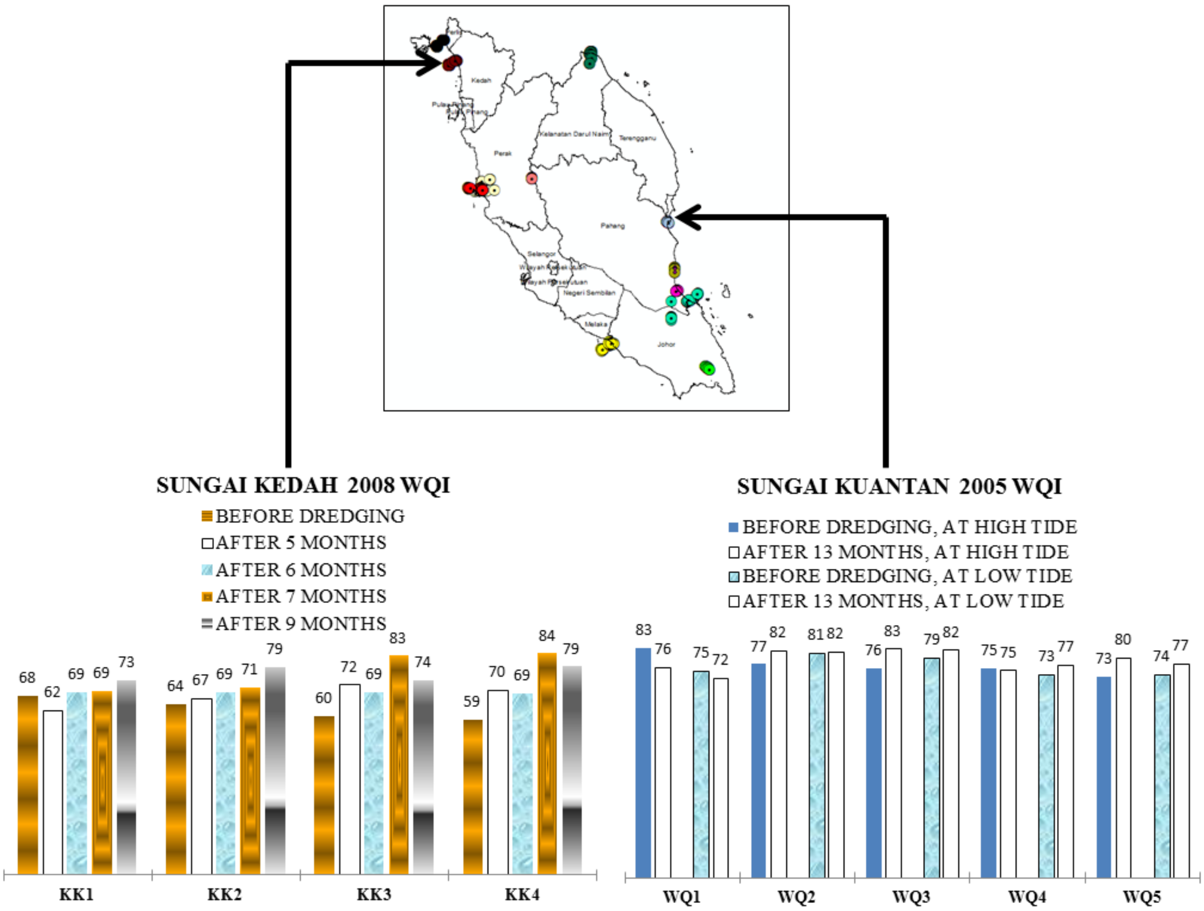


Figure C-3 The Water Quality Index (WQI) of two dredging projects, derived from 35 water samples

Sungai Kedah has the lowest WQI value (59 at KK4), compared with Sungai Kuantan's minimum value of 72 at WQ1, as can be seen in Figure C-3. This means that, before dredging commenced at these locations, Sungai Kedah was categorized as 'polluted' at KK4, and Sungai Kuantan as 'slightly polluted' at WQ1.

In 2008, the river bed at Sungai Kedah was dredged to a depth of 4 meters, with a total of 193,000 cubic meters of silt and clay (Figure C-14) being extracted. It was concluded that dredging improved its water quality, based on the monitoring of WQIs over 9 months at four different locations in this river. This comes from the observation that all samples show significant increases of WQIs after dredging, including at KK4 which was classified as 'polluted' before dredging. Nonetheless, it is worth noting that KK3 and KK4 show decreases of WQIs after 9 months compared to 7 months. Nonetheless, the WQIs at both locations after 9 months were higher than the WQI monitored before dredging. This means that, despite having slight decreases of WQI during later months of monitoring, the water quality of this river improved. The pattern of changes and the relationship between water quality and the level of sediment contamination in this river are further discussed in Subsection 3.2.2.

Sand amounting to 850,000 cubic meters was dredged from Sungai Kuantan in 2005 (Figure C-15), when it was dredged to a depth of 4 meters. It was concluded that dredging did not improve its water quality status, particularly at WQ1, based on monitoring at five different locations over 13 months. It was observed that before dredging, the water quality status during high tide at WQ1 was 'clean', while 'slightly polluted' at WQ2, WQ3, WQ4 and WQ5. However, 13 months after the first monitoring was conducted, the status of WQ1 decreased to 'slightly polluted', both at low tide and high tide, while the other monitoring locations show improvements. The pattern of water quality changes at Sungai Kuantan due to dredging are further explained and holistically discussed in the later part of Subsection 3.2.1.

- ***Pattern of changes in water quality***

The initial part of this subsection discusses the pattern of changes in water quality that occurred in Sungai Kedah in 2007, while the latter discusses the pattern of changes seen at Sungai Kuantan in 2005.

As demonstrated in Figure C-4, it can be concluded that dredging did not improve the water quality at most of the monitoring locations in Sungai Kedah, after dredging in 2007. In line with this fact, this subsection summarizes 5 points regarding the pattern of changes traced during dredging in this area:

1. A significant increase (<1100%) of TSS did not affect DO levels,
2. An extreme increase (>2000%) of TSS slightly affected DO levels, with more than 14 months required to recover,
3. The negative impact of dredging was greater at the river mouth than offshore,
4. Dredging released contaminants from dredged materials, thus affecting DO levels at dredged sites, and
5. The dumping of contaminated dredged materials negatively affected DO and TSS levels at disposal sites.

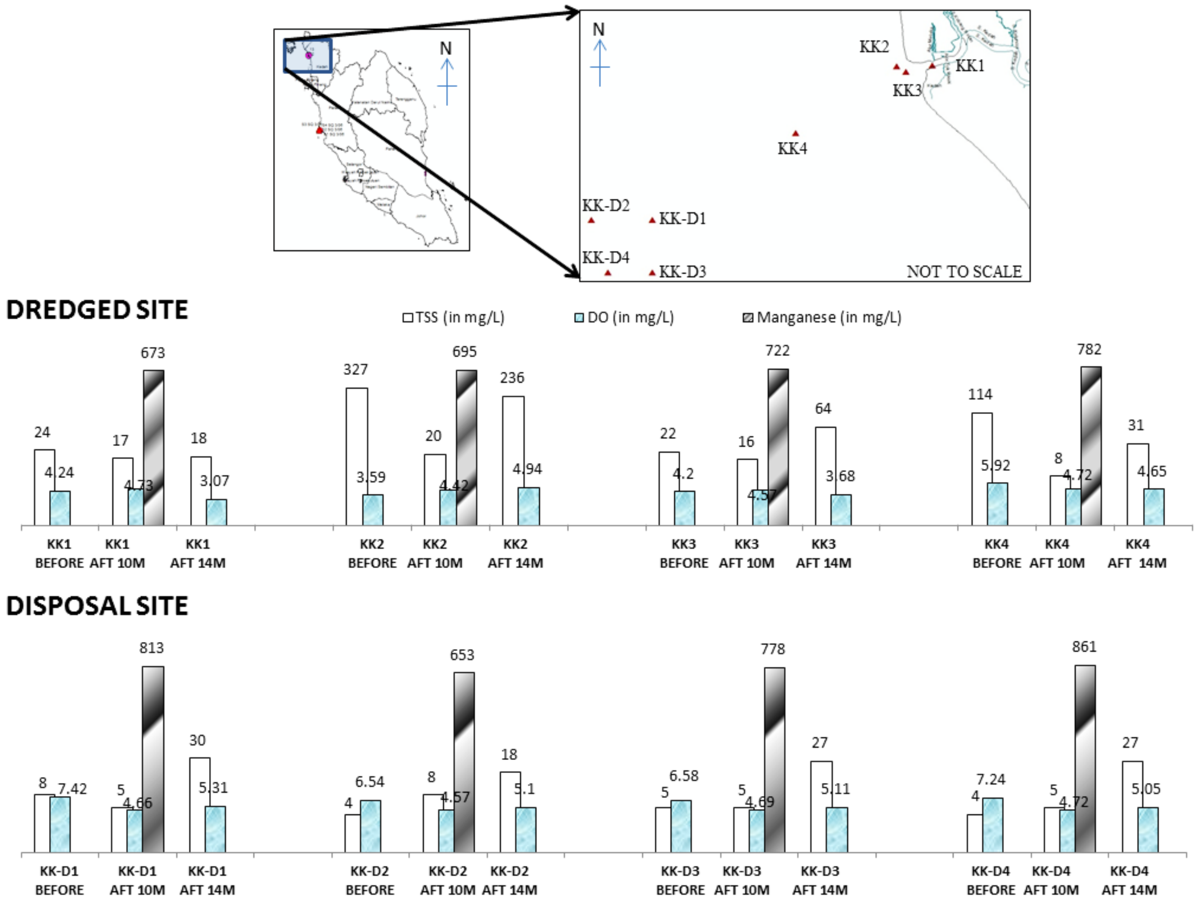


Figure C-4 Water quality status of Sungai Kedah in relation to a dredging project undertaken in 2007, derived from 24 water samples

1.1 million cubic meters of clay and silt were extracted starting at the river mouth and moving offshore at Sungai Kedah during 2007. This project was started a year before another dredging project was undertaken on the same river but further upstream, as discussed in Subsection 3.1. At KK1, CSD was used to dredge this area, while THSD was employed at the rest of the sampling points. The water quality was monitored both at dredged and disposal sites. This was done three times, namely before dredging, and 10 and 14 months after first monitoring. The indicators monitored at these 8 different sampling points included TSS, DO and Mn.

At the dredged site, a significant increase in TSS levels (1080%) at KK2 can be seen. This was noted when a comparison was made between levels found at 10 and 14 months after first monitoring. While a significant increase of TSS levels did occur, there was also an unusual 12% increase in DO levels. A similar pattern can be seen in DO levels when comparing the levels of before dredging with the levels 14 months after first monitoring. Even though this location has faced a significant level of TSS dispersal (which may block out sunlight, hence reducing oxygen production (Munawar 1989, Douvere, Ehler 2009)), it seems that the water quality status at KK2 improved.

However, this pattern was not found to be consistent; at KK3, located only 360 meters away from KK2, DO levels were found to have slightly decreased, comparing levels found before dredging to levels found 14 months after first monitoring. In fact, during the same interval, the most significant decrease of DO levels out of the monitoring locations was detected here at KK3 (12%). In addition, it was the only location to have seen an increase of TSS levels when comparing levels before dredging with levels after 14 months. This may be due to the fact that an extreme increase of TSS levels (2250%) at KK3 occurred between 10 and 14 months after the first monitoring. This increase was double the increase of TSS levels found at KK2 over the same interval. It can be seen that the water quality at KK3 did not improve during the 14 months of monitoring and, with more time apparently required for TSS levels to return to their natural state.

KK1 and KK4 showed a somewhat similar pattern of changes in DO levels when comparing their before dredging and after 14 months, with DO levels decreasing by 28% and 21% at KK1 and KK4, respectively. However, DO levels at 10 months and 14 months were compared, with the decrease of DO levels over this interval higher at KK1 (36%) than at KK4 (1%), indicating that the impacts of dredging were greater inside the river mouth, at KK1, than offshore, at KK4. It can also be seen that during this interval, the TSS levels increased 288% at KK4, but the levels increased only slightly by 6% at KK1. It can also be seen that, while showing only a small increase of TSS, DO levels at the river mouth (KK1) deteriorated most significantly. Based on this, it is evident that the decrease of DO at KK1 was not due to an increase of TSS levels. One possible reason for this is the extreme increase in Mn levels that was detected after 10 months in the dredged sites. This likely resulted from the extraction stage of dredging, which releases contaminants from sediments, whose dispersal consumes DO through oxidation.

A similar occurrence has been observed at disposal sites, where DO levels decreased at levels ranging between 22% and 30%, with dredged materials still being contaminated when they are disposed offshore. In addition, a comparison was made between TSS levels monitored before dredging and after 14 months, showing that they increased at levels ranging between 275% and 575%. Based on this monitoring of TSS and DO levels over 14 months at disposal sites, it is clear that they were negatively affected due to the disposal of contaminated dredged materials.

This part discussed pattern of changes that was seen at Sungai Kuantan in 2005. In addition to describing the pattern of changes at WQ1, this part concludes that it is preferable to conduct dredging during high tide rather than during low tide. Sungai Kuantan was dredged in 2005 using CSD and, as analysed in Subsection 3.1, it was concluded that the water quality of this river at WQ1 did not improve after dredging. Indicative of this, Figure C-5 illustrates the location of dredging, WQIs, and the levels of water quality indicators (including COD, DO, BOD, TSS and Fe) monitored during dredging at this site. Monitoring was conducted twice, before dredging and 13 months after the first monitoring.

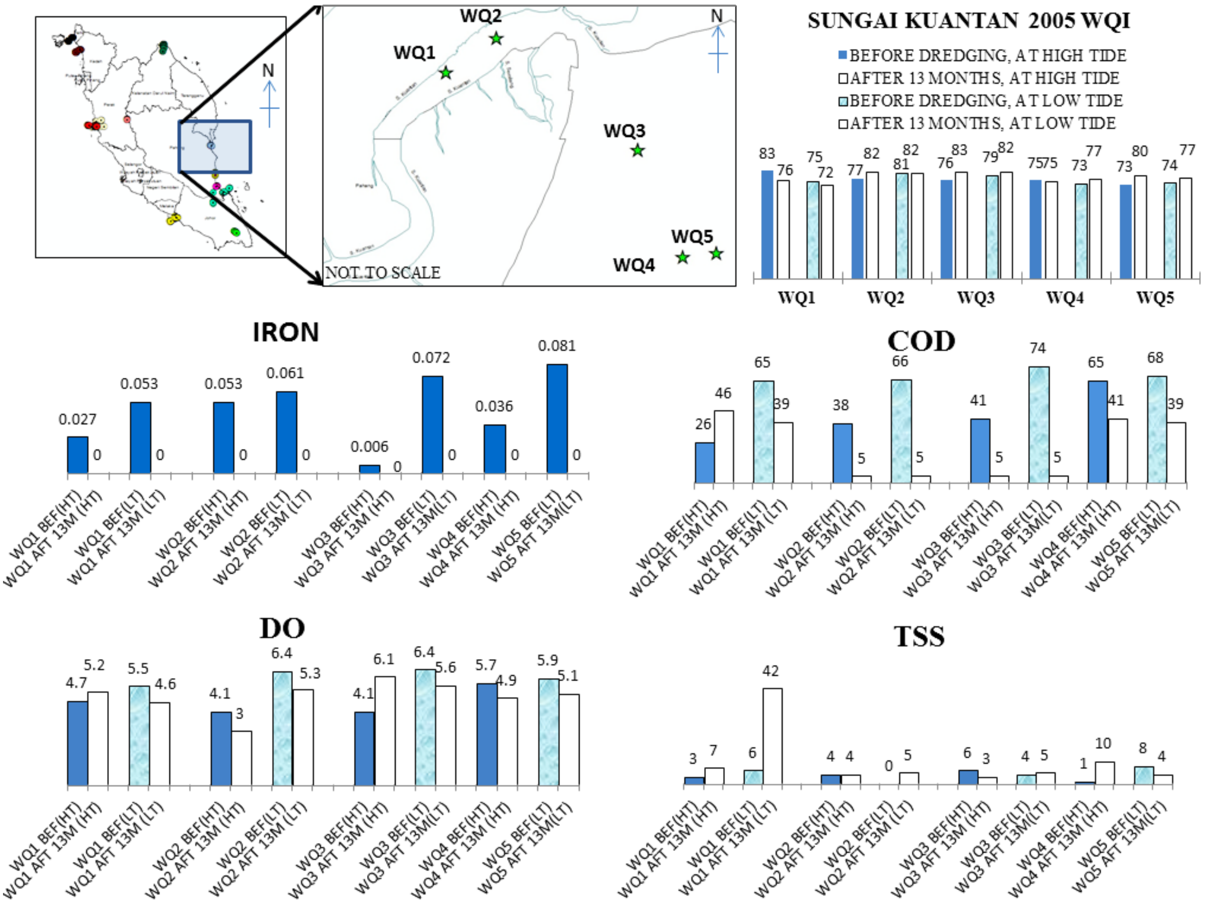


Figure C-5 The location, WQI and water quality indicators (in mg/L) derived from 14 water samples at Sungai Kuantan for dredging project commenced in 2005

During high tide, in addition to an increase of COD levels (77%), TSS levels at WQ1 were shown to increase significantly (133%). Peculiarly, however, its DO levels increased (11%). This may be due to the relatively high volume of water present at high tide, as a higher volume of water increases the space available in the water column for TSS to disperse, hence decreasing its concentration. This would aid the penetration of sunlight after dredging in this area, thus positively affecting DO levels.

Moreover, a greater increase of TSS levels amounting to 600%, representing an extreme, was detected during low tide, with DO levels decreasing 16%. This relationship between DO and TSS levels supports the discussion made with regard to Sungai Kedah 2007 (KK2), concluding that an extreme increase of TSS levels may affect the levels of DO, but that a merely significant increase may not have a similar effect. Nevertheless, a positive change was seen with regard to COD levels, which decreased during low tide. This may be due to the fact that Fe levels decreased during both high and low tide at all monitoring points after 13 months.

However, despite the improvement seen with regard to COD levels, the negative changes in TSS and DO levels seen during low tide lead to the conclusion that, as best practice, dredging should only be undertaken during high tide.

- ***Relationship between levels of contamination in sediments and pattern of changes in water quality***

Dredging impacts at Sungai Kedah in 2008 were analysed and discussed. Two points were concluded, namely that dredging in a river with low levels of sediment contamination did not negatively affect, but rather improved, its water quality, and that dredging was a beneficial intervention when commenced in two consecutive years. In 2008, Sungai Kedah was dredged using THSD, CSD and excavator. Figure C-6 shows the location of dredging sites, levels of heavy metals in sediments, WQIs, and levels of physical and chemical indicators in the water monitored during dredging. The monitoring was conducted five times, before dredging and after the 5^{th}, 6^{th}, 7^{th} and 9^{th} months. Three samples at different locations (represented by circles and numbered as S1, S2 and S3) were taken for sediment analysis before dredging. In addition, water samples were monitored at 4 different locations (represented by stars and numbered as KK1, KK2, KK3 and KK4) to measure heavy metal levels, including Pb, Mn, Zn, Fe and phenol. KK1 was 1.5 km from S1, KK2 was 0.3 km from S2, KK3 was 0.46 km and KK4 was 0.9 km from S3. This dredging project was performed a year after another dredging project was undertaken in 2007, with the more recent project located further upstream.

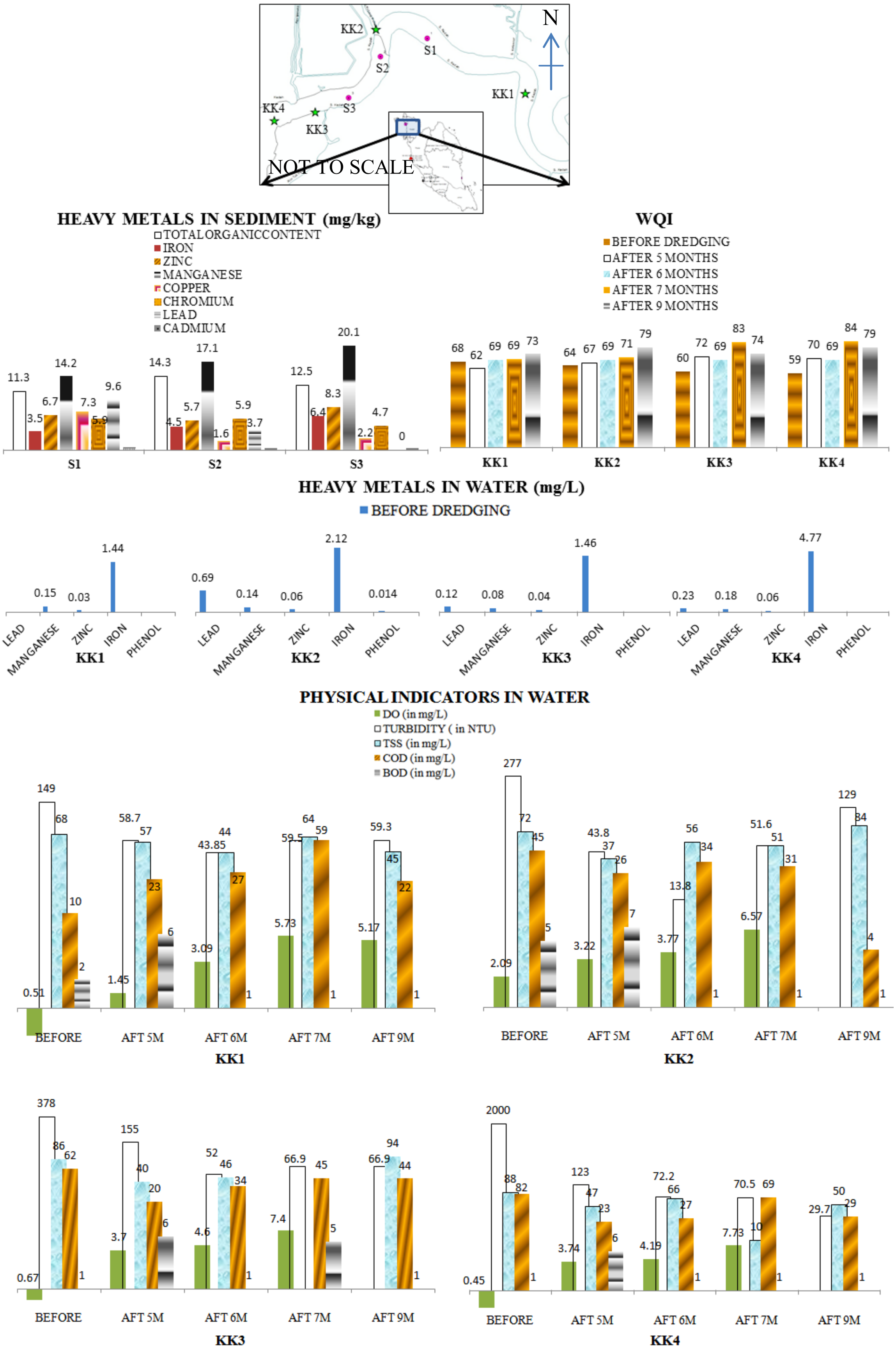


Figure C-6 Sediment and water quality at Sungai Kedah for dredging undertaken in 2008

It can be seen that sediments at all Sungai Kedah monitoring locations had detectable levels of heavy metals, but being very low compared to the levels monitored at Sungai Dinding/Manjung. Nevertheless, all heavy metal levels monitored in sediments at both sites were below the lower benchmark values for Ireland, the United Kingdom, Belgium and Canada (The National Oceanic and Atmospheric Administration (NOAA) 2006, Praveena 2008, Pan 2010). Based on this measure, the sediments were categorized as uncontaminated. Before dredging, all water monitoring locations showed low levels of heavy metals, and in fact it was noted that none of these levels were higher than the standard values Class E (mangroves, estuarine and river mouth water) of Malaysia's Marine Water Quality Criteria and Standards (Department of Environment 2010). In addition, the levels of heavy metals were shown to decrease to non-detectable levels after dredging, thus showing improvement.

This means that dredging undertaken in a river with low sediment contamination can improve its water quality. This might be explained by a number of reasons, including that the layers of sediments with low contamination have been entirely removed and could have lessen the risk of contamination release through bioturbation or many others. A previous study is in relation to this, showing that PCB levels in sediments at a depth of 4-7 inch thick decreased after dredging, compared to its levels at the same area but at the depth of 2-3 inch thick (Thibodeaux, Duckworth 2001).

As previously mentioned, dredging in 2008 commenced further upstream than in 2007. KK1 of the dredging executed in 2007 was located in the river mouth. This point is in close proximity to KK3 (236 meter upstream of KK1) and KK4 (231 meters downstream of KK1) which were both sampled in 2008, as illustrated in Figure C-7. The discussion below focuses on comparing the levels found at these locations.

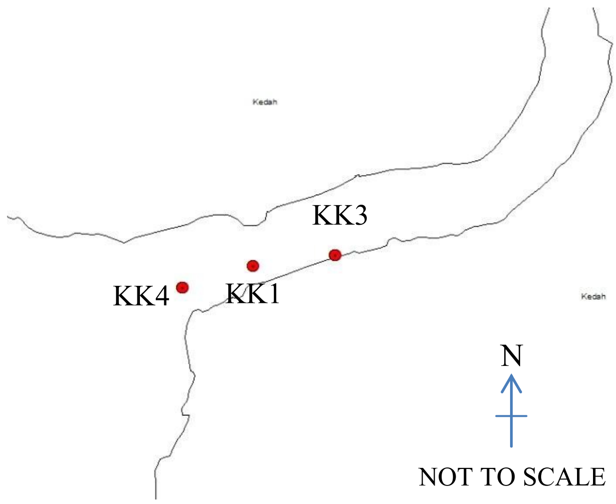


Figure C-7 The locations of KK1, KK3 and KK4

At KK1, it was noted that DO levels were found to be 3.07 mg/L 14 months after first monitoring for the dredging conducted in 2007, while before dredging commenced in 2008, the levels at KK3 and KK4 were only 0.67 mg/L and 0.45 mg/L, respectively. Even though there was no dredging commenced between 2007 and 2008 in this river, DO levels were shown to decrease. At the same time, it was noted that before dredging commenced in 2008, higher values of TSS were monitored at KK3 and KK4 than at KK1. This further explains the deterioration of DO levels at this location in 2008, but dredging cannot be established as the cause. In fact, it can be seen that after dredging was undertaken in 2008, DO and TSS levels changed positively, indicating that dredging improved water quality in this area.

Moreover, during the dredging undertaken in 2007, a high level of Mn in water at KK1 was detected (673 mg/L), before decreasing 4 months after. However, before dredging in 2008, the level was only 0.08 mg/L and 0.18 mg/L at KK3 and KK4, respectively, and these values further decreased to non-detectable levels during the extraction stage. This shows that the level of contamination in this area decreased after dredging in two consecutive years.

➢ ***Dredger type and its relation to TSS and DO levels***

This section discusses an analysis aiming to determine the most damaging types of dredgers, and was based on 182 water samples monitored during dredging. In the dredging projects whose reports were collected as part of this study, three types of dredgers were used. These were trailer hopper suction dredgers (THSD), cutter suction dredgers (CSD), and excavators on pontoons. Both THSDs and CSDs utilise the suction method in their operations, while excavators utilise the grab method. Based on data from the environmental reports, the average differences in TSS and DO levels before and after dredging were calculated, which were then categorized according to the type of dredger used. Average TSS and DO levels were also then calculated, according to the number of months since first monitoring, which ranged from 1 to 13 months.

When seeking to minimise impacts on TSS levels alone, THSD is the preferred type of dredger, but on the other hand is shown to have a major negative impact on DO levels. Two graphs are shown in Figure C-8, demonstrating the average difference in these indicators before and after dredging. These graphs represent the effects dredging had upon natural levels of TSS and DO. As explained in Section 2.2.4, these changes can be broken down according to the type of dredger employed, namely CSD, THSD or excavator. Generally, the graph indicates that all dredgers improved DO levels. This can be seen during the 7th (CSD), 9th (THSD) and 8th (excavator) months. Nevertheless, it shows that the later the monitoring was conducted, the lower the average difference. This indicates that DO levels at dredged sites can recover to natural levels when using most types of dredger, or can even improve as a result of dredging. The use of THSD, however, is an exception to this, as its DO level failed to improve, but in fact decreased even after 14 months. It can, thus, be concluded that that THSD more aggressively impacts DO levels than the other types of dredgers.

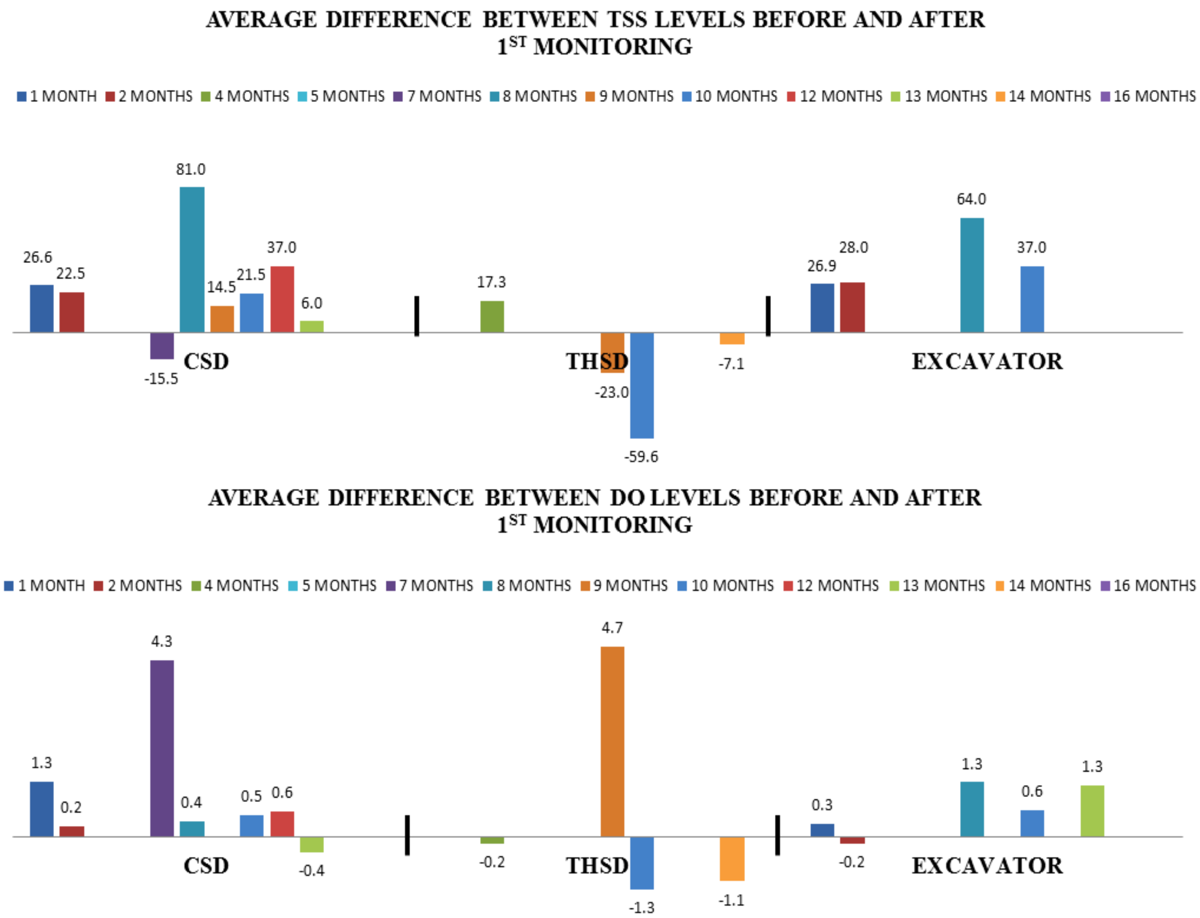


Figure C-8 Average difference of TSS and DO levels derived from 182 water samples according to type of dredger

As can be seen in the graphs, the CSD (using the suction method) shows the greatest increase (81 mg/L) of TSS levels 8 months after the first monitoring but also the greatest decrease of DO levels after 10 months. During the same time period, the increase seen for the excavator (using the grab method) was seen to be slightly lower. Based on this, it can be concluded that dredgers using the suction method, the CSD, more aggressively impacted TSS levels than dredgers using grab method, the excavator. Moreover, the CSD was seen to more aggressively impact TSS levels than the THSD, which also uses the same suction method. At the same time, it was noted that THSD had a larger decrease (-59.6 mg/L) in TSS levels than the other types of dredgers. Despite the fact that the THSD shows marginally greater impacts on DO levels than the other technologies, it is preferable, given that its impact on TSS levels is considerably less than either of the other technologies.

C.2 Malaysia's quality standards

	Parameter	CLASS 1	CLASS 2	CLASS 3	CLASS E
	BENEFICIAL USES	Preservation, marine protected areas, Marine Parks	Marine Life, Fisheries, Coral Reefs, Recreational and Mariculture	Ports, Oil & Gas Fields	Mangroves, Estuarine & River-mouth water
1	Temperature (°C)	≤2 °C increase over maximum ambient	≤2 °C increase over maximum ambient	≤2 °C increase over maximum ambient	≤2 °C increase over maximum ambient
2	Dissolved Oxygen (mg/L)	>80% saturation	5.0	3.0	4.0
3	Total Suspended Solid (mg/L)	25 mg/L or ≤10% increase in seasonal average, whichever is lower	50 mg/L (25 mg/L) or ≤10% increase in seasonal average, whichever is lower	100 mg/L or ≤10% increase in seasonal average, whichever is lower	100 mg/L or ≤30% increase in seasonal average, whichever is lower
4	Oil and Grease (mg/L)	0.01	0.14	5	0.14
5	Mercury* (µg/L)	0.04	0.16 (0.04)	50	0.5
6	Cadmium* (µg/L)	0.5	2(3)	10	2
7	Chromium (VI)(µg/L)	5	10	48	10
8	Copper (µg/L)	1.3	2.9	10	2.9
9	Arsenic (III)* (µg/L)	3	20 (3)	50	20(3)
10	Lead (µg/L)	4.4	8.5	50	8.5
11	Zinc (µg/L)	15	50	100	50
12	Cyanide (µg/L)	2.0	7.0	20	7
13	Ammonia (unionized) (µg/L)	35	70	320	70
14	Nitrite (NO_2) (µg/L)	10	55	1000	55
15	Nitrate (NO_3) (µg/L)	10	60	1000	60
16	Phosphate (µg/L)	5	75	670	75
17	Phenol (µg/L)	1	10	100	10
18	Tributyltin (TBT) (µg/L)	0.001	0.01	0.05	0.01
19	Faecal Coliform (Human health protection for seafood consumption) - (MPN)	70 faecal coliform/100ml *70 E.coli/100 ml*	100 faecal coliform/100ml (70 faecal coliform/100 ml) *100 E.coli/100ml (70 E.coli/100ml)*	200 faecal coliform/ 100ml *200 E.coli/100ml*	100 faecal coliform/100ml (70 faecal coliform/100 ml) *100 E.coli/100ml (70 E.coli/100ml)*
20	Polycyclic Aromatic Hydrocarbon (PAHs) ng/g	100	200	1000	1000

Figure C-9 Malaysia Marine Water Quality Criteria and Standards (MWQCS) (Department of Environment 2010)

PARAMETER	UNIT	CLASS				
		I	IIA/IIB	III*	IV	V
Al	mg/l	NATURAL LEVELS OR ABSENT	-	(0.06)	0.5	LEVELS ABOVE IV
As	mg/l		0.05	0.4 (0.05)	0.1	
Ba	mg/l		1	-	-	
Cd	mg/l		0.01	0.01* (0.001)	0.01	
Cr (VI)	mg/l		0.05	1.4 (0.05)	0.1	
Cr (III)	mg/l		-	2.5	-	
Cu	mg/l		0.02	-	0.2	
Hardness	mg/l		250	-	-	
Ca	mg/l		-	-	-	
Mg	mg/l		-	-	-	
Na	mg/l		-	-	3 SAR	
K	mg/l		-	-	-	
Fe	mg/l		1	1	1 (Leaf) 5 (Others)	
Pb	mg/l		0.05	0.02* (0.01)	5	
Mn	mg/l		0.1	0.1	0.2	
Hg	mg/l		0.001	0.004 (0.0001)	0.002	
Ni	mg/l		0.05	0.9*	0.2	
Se	mg/l		0.01	0.25 (0.04)	0.02	
Ag	mg/l		0.05	0.0002	-	
Sn	mg/l		-	0.004	-	
U	mg/l		-	-	-	
Zn	mg/l		5	0.4*	2	
B	mg/l		1	(3.4)	0.8	
Cl	mg/l		200	-	80	
Cl_2	mg/l		-	(0.02)	-	
CN	mg/l		0.02	0.06 (0.02)	-	
F	mg/l		1.5	10	1	
NO_2	mg/l		0.4	0.4 (0.03)	-	
NO_3	mg/l		7	-	5	
P	mg/l		0.2	0.1	-	
Silica	mg/l		50	-	-	
SO_4	mg/l		250	-	-	
S	mg/l		0.05	(0.001)	-	
CO_2	mg/l		-	-	-	
Gross-α	Bq/l		0.1	-	-	
Gross-β	Bq/l		1	-	-	
Ra-226	Bq/l		< 0.1	-	-	
Sr-90	Bq/l		< 1	-	-	
CCE	µg/l		500	-	-	-
MBAS/BAS	µg/l		500	5000 (200)	-	-
O & G (Mineral)	µg/l		40; N	N	-	-
O & G (Emulsified Edible)	µg/l		7000; N	N	-	-
PCB	µg/l		0.1	6 (0.05)	-	-
Phenol	µg/l		10	-	-	-
Aldrin/Dieldrin	µg/l		0.02	0.2 (0.01)	-	-
BHC	µg/l		2	9 (0.1)	-	-
Chlordane	µg/l		0.08	2 (0.02)	-	-
t-DDT	µg/l		0.1	(1)	-	-
Endosulfan	µg/l		10	-	-	-
Heptachlor/Epoxide	µg/l		0.05	0.9 (0.06)	-	-
Lindane	µg/l		2	3 (0.4)	-	-
2,4-D	µg/l		70	450	-	-
2,4,5-T	µg/l		10	160	-	-
2,4,5-TP	µg/l		4	850	-	-
Paraquat	µg/l		10	1800	-	-

Figure C-10 National Water Quality Standard (NWQS) for Malaysia (Department of Environment 2010)

Parameter	Symbol	Benchmark
Sulphate		
Hardness	SO_4-	250 mg/l
Nitrate	$CaCO_3$	500 mg/l
Coliform	NO_3-	10 mg/l
Manganese	—	Must not be detected in any 100 ml sample
Chromium	Mn	0.1 mg/l
Zinc	Cr	0.05 mg/l
Arsenic	Zn	3 mg/l
Selenium	As	0.01 mg/l
Chloride	Se	0.01 mg/l
Phenolics	Cl	250 mg/l
TDS	—	0.002 mg/l
Iron	—	1000 mg/l
Copper	Fe	0.3 mg/l
Lead	Cu	1.0 mg/l
Cadmium	Pb	0.01 mg/l
Mercury	Cd	0.003 mg/l
	Hg	0.001 mg/l

Source: Ministry of Health, Malaysia

Figure C-11 National Guidelines for Raw Drinking Water Quality (NGRDWQ)

API	AIR QUALITY STATUS
0 – 50	Good
51 – 100	Moderate
101 – 200	Unhealthy
201 – 300	Very Unhealthy
> 300	Hazardous

Figure C-12 API guidelines

Appendix C.3 Soil characteristic maps

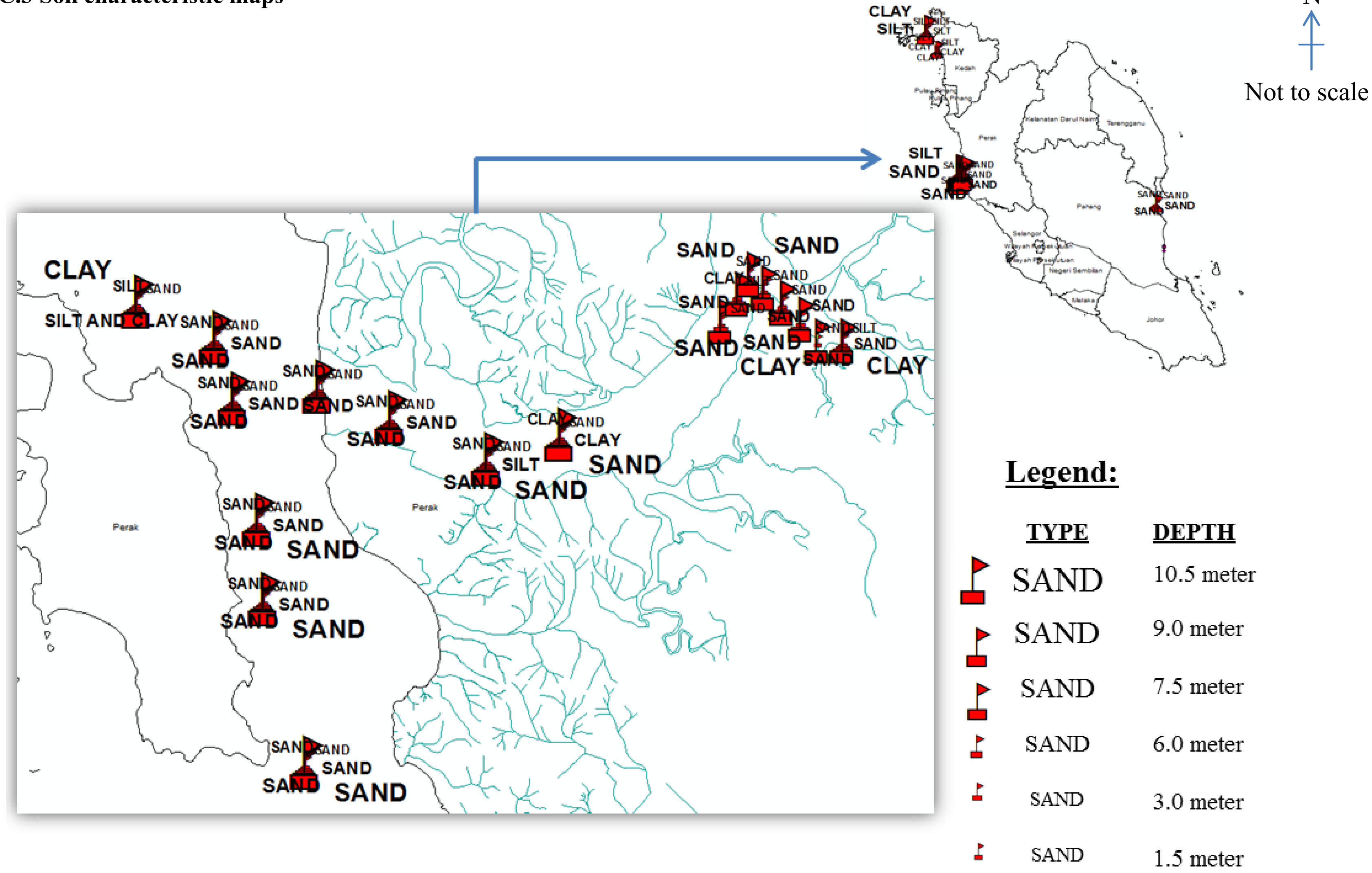


Figure C-13 Soil characteristic map as in 2005 for Sungai Sitiawan and Dinding rivers, Perak Malaysia

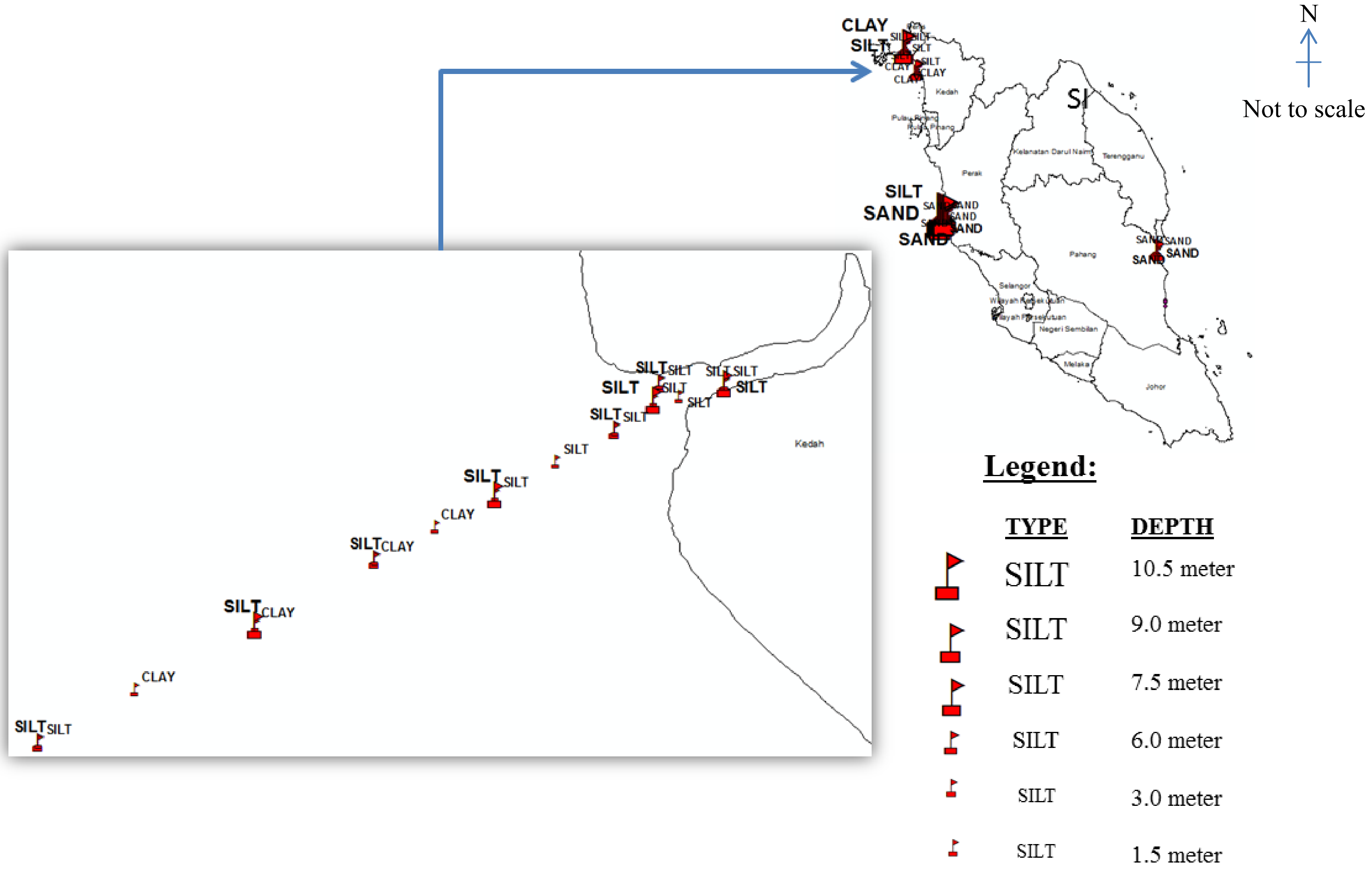


Figure C-14 Soil characteristic map as in 2006 for Sungai Kedah, Kedah Malaysia

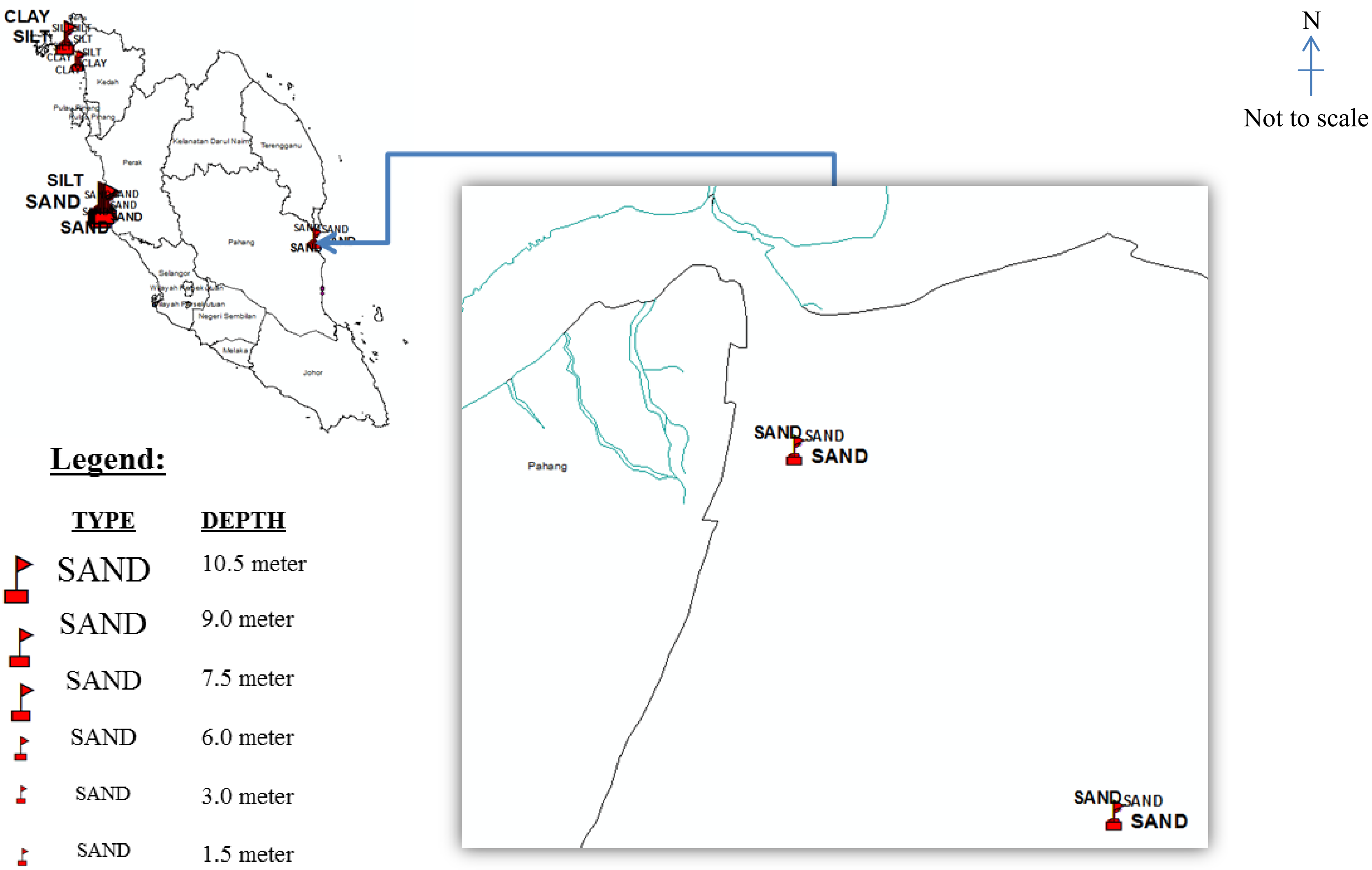


Figure C-15 Soil characteristic map as in 2004 for Sungai Kuantan, Pahang Malaysia

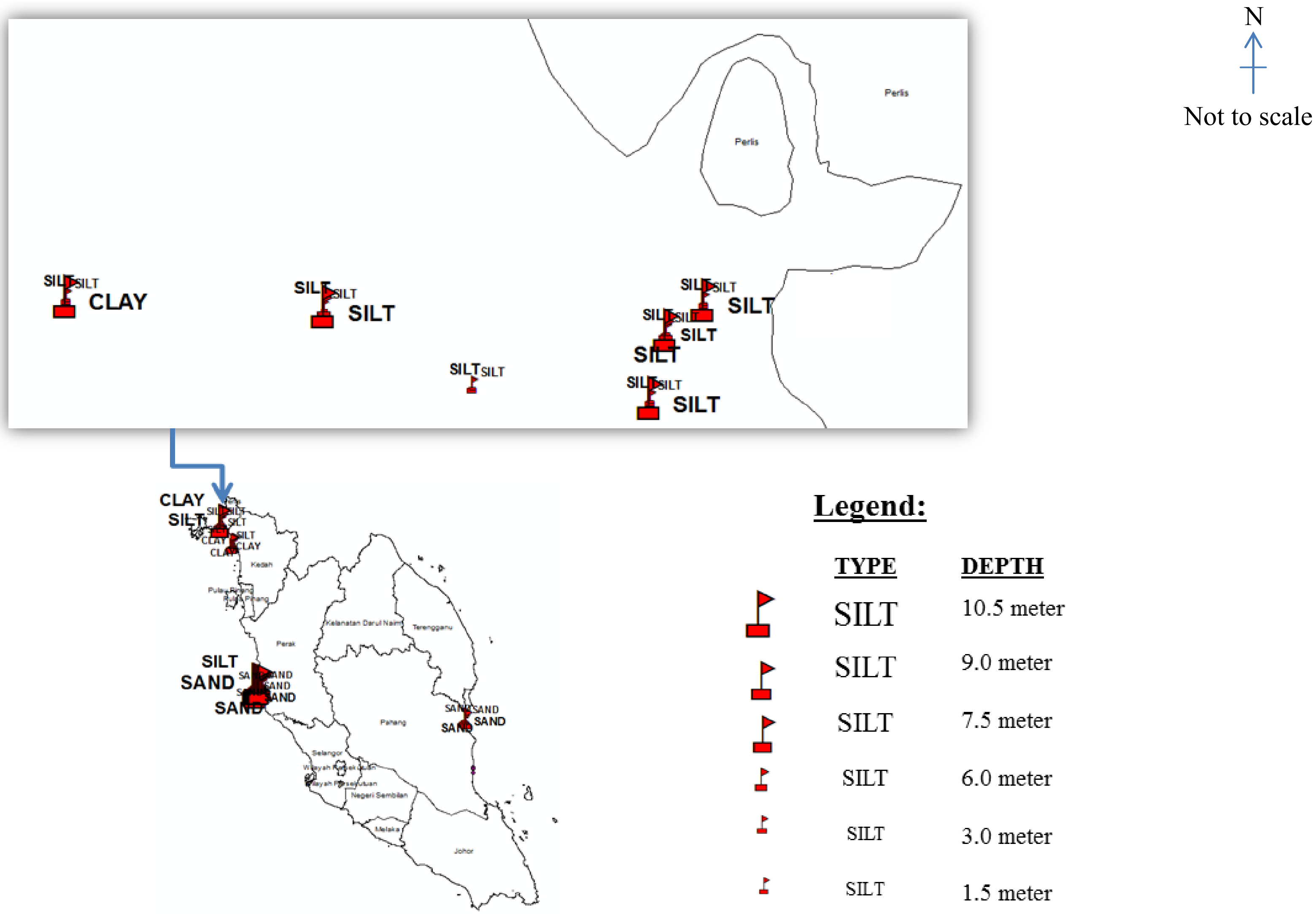


Figure C-16 Soil characteristic map as in 2001 for Sungai Perlis, Perlis, Malaysia

C-4 Data sources for Sungai Sitiawan and Sungai Dinding rivers, Perak, Malaysia

- Data sources for these rivers were extracted from:

1. Environmental Assessment Report for dredging works at Sungai Dinding, Perak, Malaysia, December 2006, written by Dr.Nik & Associates Sdn. Bhd. for Malaysian Maritime & Dredging Corporation Sdn.Bhd. and Marine Department, Peninsular Malaysia
2. Environmental Management Plan for dredging works at Sungai Sitiawan river, Perak, Malaysia, December 2007, written by ZnK Consult Sdn.Bhd. for Malaysian Maritime & Dredging Corporation Sdn.Bhd. and Marine Department, Peninsular Malaysia
3. Environmental Quality Report, 2006 to 2011, written by Department of Environment, Malaysia

C-5 Summary of environmental data

- **Hydro graphic features**

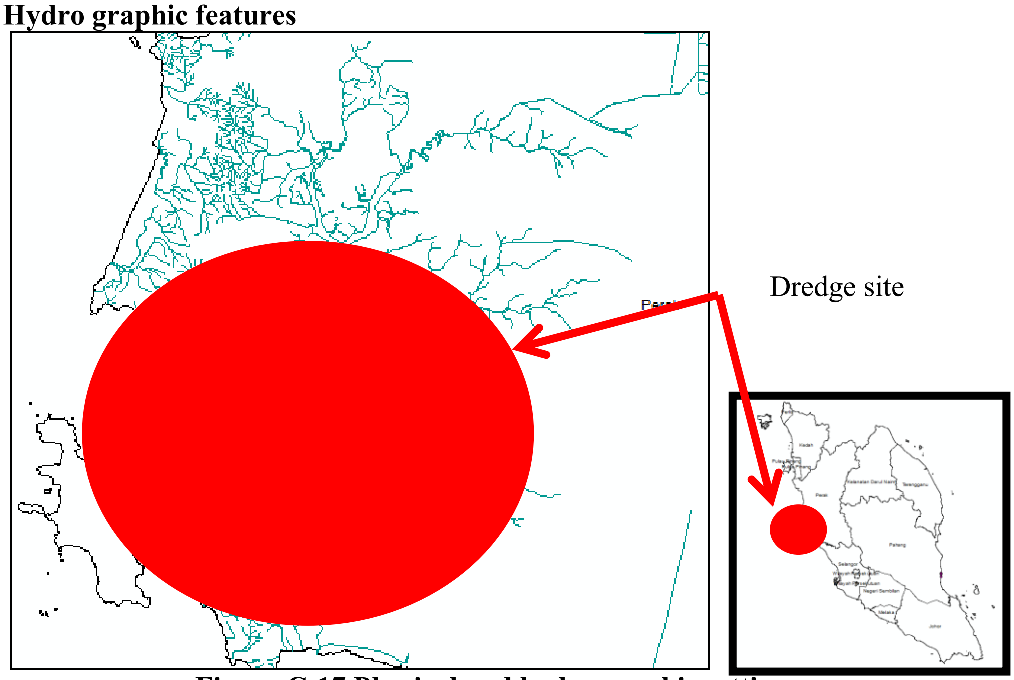


Figure C-17 Physical and hydro graphic setting

➢ **Sources of contamination and types of land use**

Table C-1 Contaminant inputs

Location	Types of land use	Annual WQI status of rivers in river basin			API	Groundwater contaminants and their sources (in brackets) that have high percentage (>80%) of non-compliance to Malaysia's standard values
		Year	Polluted	Slightly polluted		
Sungai Dinding and Sitiawan rivers, Perak, Malaysia *River basin-Raja Hitam and Wangi	- Solid waste disposal with waste load 120-140 tonnes/day - Agriculture - Industrial - Housing	2005	Derhaka, Raja Hitam	-	None	Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills)
		2006	-	Derhaka, Raja Hitam, Deralik, Wangi	None	As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills),
		2007	-	Derhaka, Raja Hitam, Deralik, Wangi	None	Mn (Ex-mining), Fe (Municipal water supply, landfill)
		2008	-	Derhaka, Raja Hitam, Deralik, Wangi	None	Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex - mining), Fe (municipal water supply), As (Ex-mining)
		2009	-	Derhaka, Raja Hitam, Deralik, Wangi	None	Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply)
		2010	Deralik	Raja Hitam, Manjong, Wangi	None	Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas)
		2011	Raja Hitam	Manjong, Deralik, Wangi	None	Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)

- **Physical, chemical and biological indicators**

- Dredged area: Shoreline geomorphology, water quality, sediment quality, air quality and noise quality

- Dumping area:Water quality, phytoplankton (Eighty species found including *Bacillariophyta, Cyanophyta and Pyrrophycophyta*), zooplankton (Thirty two species found), and benthos (*Gastropoda, Bivalvia, Scaphopoda, Crustacea, Annelidia, Oligochaeta*)

- **Tides**

Table C-2 Tide data

Tide levels	Elevations (ACD)
	Bagan Datuk, Perak
Highest Astronomical Tide (HAT)	+3.47 m
Mean High Water Spring (MHWS)	+2.97 m
Mean High Water Neap (MHWN)	+2.26m
Mean Sea Level (MSL)	+1.87 m
Mean Low Water Neap (MLWN)	+1.47 m
Mean Low Water Spring (MLWS)	+0.77 m
Lowest Astronomical Tide (LAT)	+0.00 m

- **Freshwater input**

- Six tributaries (the rivers of Sungai Derhaka, Sungai Manjong, Sungai Nyior, Sungai Raja Hitam, Sungai Deralik and Sungai Wangi)

- **Sensitive areas**

- Mangrove forests at dredged area (Flora: *Avicennia sp., Rhizophora sp., Bruguiera sp,* Fauna: Mudskippers, cockles and crabs)

- Coral reef (Nearest coral reef areas from dumping area are located at Pulau Lalang, Pulau Rumbia and Pulau Buloh)

- Seagrass bed/Meadow (None at dredged and dumping areas)

- Aquaculture areas near dredging area (Visible at upstream rivers with the nearest location is located less than 2 km away from river-mouth of the river of Sungai Dinding)
- Channel users including cruisers, yachts, barges, fishing boats, ferries, cargo vessels, Navy vessels including patrol ships, frigates, patrol boats and submarines

C-6 Summary of political data

- Dredging rules and regulations stipulated under EIA Order 1987

C-7 Summary of socio- economic data

- Population size of Lumut, Perak is 31,882 in 2000 with 1.8% growth by 2015
- Occupation: 2322 Fishermen with 5,716,733 kg of marine livestock landed at the Lumut LKIM jetty in July 2006, amounting to revenue of RM25.2 million
- 8000- 12,500 tourists/week of Pulau Pangkor
- Royal Malaysian Navy (TLDM) Base located at downstream of the river Sungai Dinding

C-8 Summary of technical and managerial data

- Channel dredged in 2006 using trailer hopper suction dredgers with cost amounting RM22 million

APPENDIX D

Table D-1 Initial risk assessment for Sungai Kedah river

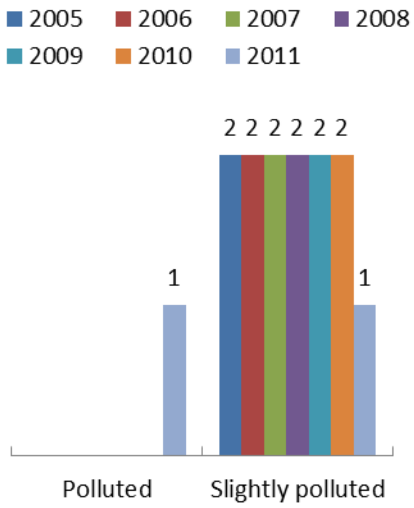
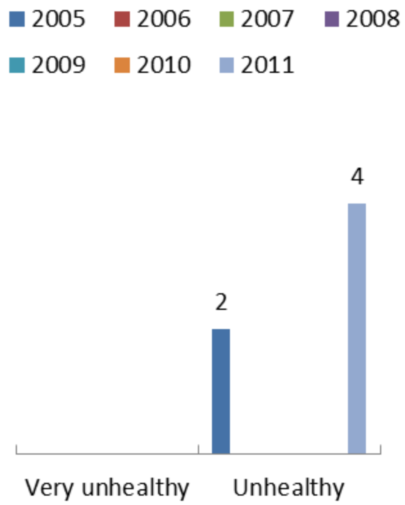
Location	**Number of rivers with polluted and slightly polluted WQI status that located in Kedah river basin**	**Number of days according to very unhealthy and unhealthy API status at Alor Setar, Kedah**	**Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values**	**Dredging concern from historical data**	**Risky?**
1. Sungai Kedah river	 *Polluted rivers:* *Kedah* *Slighted polluted rivers:* *Pendang and Kedah*		Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills) --- As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills) --- Mn (Ex-mining), Fe (Municipal water supply, landfill) --- Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex-mining), Fe (Municipal water supply), As (Ex-mining) --- Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply) --- Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas) --- Fe (Industry, landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)	- Consisting very high (Pb) and considerable (NH_3-N) degrees of contamination - Low DO level during dredging - Type of sediments: Silt and clay (as in Figure C-14 in Appendix C)	**Yes because WQI, API and ground-water statuses and historical dredging concerns show evidence of risk**

Table D-2 Initial risk assessment for Sungai Johor river

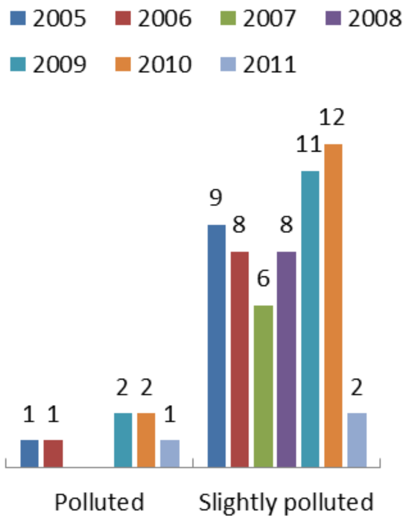
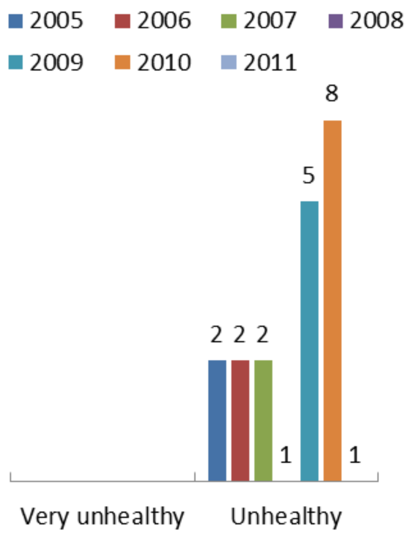
Location	Number of rivers with polluted and slightly polluted WQI status that located in Johor river basin	Number of days according to very unhealthy and unhealthy API status at Pasir Gudang, Johor	Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values	Dredging concern from historical data	Risky?
2. Sungai Johor river	 *<u>Polluted rivers:</u>* *Anak Sungai Sayong and Serai* *<u>Slighted polluted rivers:</u>* *Belitong, Berangan, Bukit Besar, Chemangar, Sebol, Sening, Tiram, Semenchu, Melatai, Mengkibol and Pamol*		Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills)	-Low DO during dredging	**Yes because WQI, API and ground-water statuses and historical dredging concerns show evidence of risk**
			As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills)		
			Mn (Ex-mining), Fe (Municipal water supply, landfill)		
			Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex -mining), Fe (Municipal water supply), As(Ex-mining)		
			Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply)		
			Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas)		
			Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)		

Table D-3 Initial risk assessment for Sungai Muar river

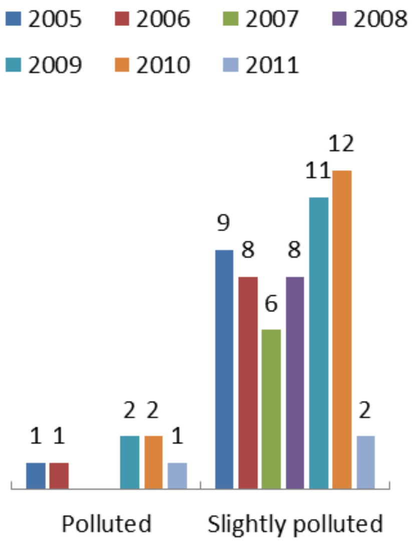
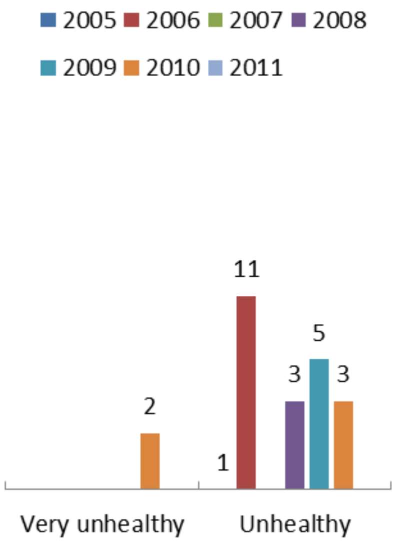
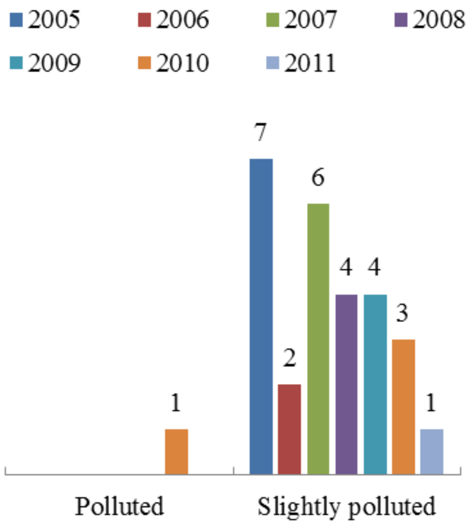
Location	Number of rivers with polluted and slightly polluted WQI status that located in Muar river basin	Number of days according to very unhealthy and unhealthy API status at Muar, Johor	Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values	Dredging concern from historical data	Risky?
3.Sungai Muar river	 *Polluted rivers:* *Senarut, Kelamah, Sarang Buaya and Serom* *Slighted polluted rivers:* *Gemas, Kelamah, Labis, Merlimau, Simpang Loi, Temarong, Tenang, Merbudu, Pulau Mengkuang, Palong, Muar and Segamat*		Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills) As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills), Mn (Ex-mining), Fe (Municipal water supply, landfill) Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex -mining), Fe (Municipal water supply), As (Ex-mining) Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply) Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas) Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)	-Very high degree of contamination (Cu) -Low DO during dredging	**Yes because WQI, API and ground-water statuses and historical dredging concerns show evidence of risk**

Table D-4 Initial risk assessment for Sungai Perlis river

<table>
<tr><th>Location</th><th>Number of rivers with polluted and slightly polluted WQI status that located in Perlis river basin</th><th>Number of days according to very unhealthy and unhealthy API status at Kangar, Sg. Perlis</th><th>Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values</th><th>Dredging concern from historical data</th><th>Risky?</th></tr>
<tr><td rowspan="6">4. Sungai Perlis river</td><td rowspan="6">

<u>Polluted rivers:</u>
Serai

<u>Slighted polluted rivers:</u>
Arau, Jernih, Kok Mak, Ngulang, Perlis, Tasoh, Jarum and Pelarit</td><td rowspan="6">- None recorded</td><td>Fe (Municipal water supply, ex-mining, industrial)
Mn (Radioactive Landfills)</td><td rowspan="6">- Very high degree of contamination (Cu and Pb)
- Low DO during dredging
- Big catchment area
-Silt and clay (Figure C-16 in Appendix C)</td><td rowspan="6">Yes because WQI and ground-water statuses and historical dredging concerns show evidence of risk</td></tr>
<tr><td>As (Radioactive Landfills),
Fe (Radioactive Landfills),
Mn and As (Radioactive Landfills),</td></tr>
<tr><td>Mn (Ex-mining),
Fe (Municipal water supply, landfill)</td></tr>
<tr><td>Cr, Pb, SO_4 (Ex-mining),
Cr, Fe, Pb (Radioactive landfill), Phenol (Ex -mining),
Fe (municipal water supply),
As (Ex-mining)</td></tr>
<tr><td>Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply)</td></tr>
<tr><td>Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas)

Fe (Industry,landfill),
Mn (Rural areas, ex-mining),
Phenol (Landfill)</td></tr>
</table>

Table D-5 Initial risk assessment for Sungai Dinding and Sitiawan rivers

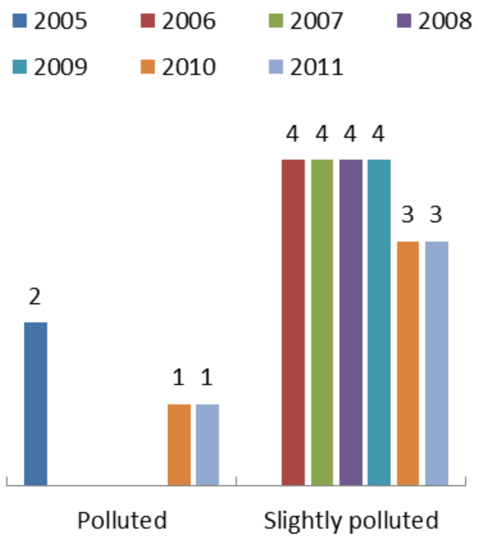
Location	Number of rivers with polluted and slightly polluted WQI status that located in Raja Hitam/Manjong and Wangi river basins	Number of days according to very unhealthy and unhealthy API status at Seri Manjung, Perak	Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values	Dredging concern from historical data	Risky?
5. Sungai Dinding and Sungai Sitiawan rivers	 *<u>Polluted rivers:</u>* *Derhaka, Deralik and Raja Hitam* *<u>Slighted polluted rivers:</u>* *Deralik, Wangi and Manjong*	- None recorded	Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills) --- As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills), --- Mn (Ex-mining), Fe (Municipal water supply, landfill) --- Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex -mining), Fe (municipal water supply), As (Ex-mining) --- Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply) --- Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas) --- Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)	- Considerable and moderate degree of contamination (Hg, Cu and As) -Low DO during dredging - Silt and clay at deeper soil depth (Figure C-13 in Appendix C)	**Yes because WQI and ground-water statuses and historical dredging concerns show evidence of risk**

Table D-6 Initial risk assessment for Sungai Bebar river

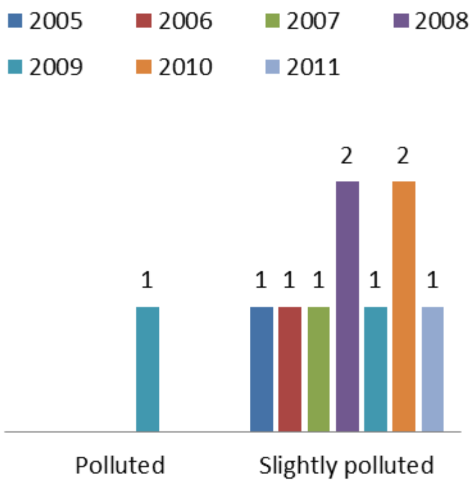
Location	Number of rivers with polluted and slightly polluted WQI status that located in Bebar river basin	Number of days according to very unhealthy and unhealthy API status at Bebar, Pahang	Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values	Dredging concern from historical data	Risky?
6. Sungai Bebar river	 *Polluted rivers:* *Sepayang* *Slighted polluted rivers:* *Bebar, Serai, Bakar, Sepayang, Keratong and Rompin*	- None recorded	Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills)	-	**Yes because WQI and ground-water statuses and historical dredging concerns show evidence of risk**
			As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills),		
			Mn (Ex-mining), Fe (Municipal water supply, landfill)		
			Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex -mining), Fe (Municipal water supply), As (Ex-mining)		
			Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply)		
			Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas)		
			Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)		

Table D-7 Initial risk assessment for Sungai Kuantan river

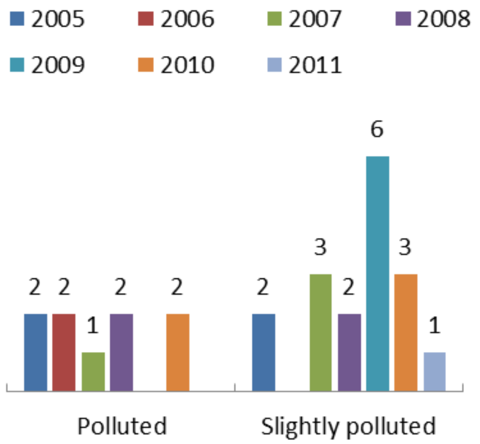
Location	Number of rivers with polluted and slightly polluted WQI status that located in Kuantan river basin	Number of days according to very unhealthy and unhealthy API status at Kuantan, Pahang	Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values	Dredging concern from historical data	Risky?
7. Sungai Kuantan river	 *Polluted rivers:* *Galing Besar, Galing Kecil and Kenau* *Slighted polluted rivers:* *Pandan, Reman, Balok, Riau, Pinang, Talam*	- None recorded	Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills)	- Low DO during dredging	**Yes because WQI and ground-water statuses and historical dredging concerns show evidence of risk**
			As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills),		
			Mn (Ex-mining), Fe (Municipal water supply, landfill)		
			Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex-mining), Fe (municipal water supply), As (Ex-mining)		
			Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply)		
			Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas)		
			Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)		

Table D-8 Initial risk assessment for Sungai Endau river

Location	Number of rivers with polluted and slightly polluted WQI status that located in Anak Endau river basin	Number of days according to very unhealthy and unhealthy API status at Endau, Pahang	Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values	Dredging concern from historical data	Risky?
8. Sungai Endau river	- None recorded	- None recorded	Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills)	-Above standard but low degree of contamination (NH3-N, Cu)	**No because WQI and API statuses not showing evidence of risk**
			As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills)		
			Mn (Ex-mining), Fe(Municipal water supply, landfill)		
			Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex-mining), Fe (Municipal water supply), As (Ex-mining)		
			Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply)		
			Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas)		
			Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)		

Table D-9 Initial risk assessment for Sungai Rompin river

Location	Number of rivers with polluted and slightly polluted WQI status that located in Rompin river basin	Number of days according to very unhealthy and unhealthy API status at Rompin, Pahang	Contaminants and their sources (in brackets) in groundwater that have high percentage (>80%) of non-compliance to Malaysia's standard values	Dredging concern from historical data	Risky?
9. Sungai Rompin river	- None recorded	- None recorded	Fe (Municipal water supply, ex-mining, industrial) Mn (Radioactive Landfills)	-Above standard but low degree of contamination (NH3-N)	**No because WQI and API statuses not showing evidence of risk**
			As (Radioactive Landfills), Fe (Radioactive Landfills), Mn and As (Radioactive Landfills),		
			Mn (Ex-mining), Fe (Municipal water supply, landfill)		
			Cr, Pb, SO_4 (Ex-mining), Cr, Fe, Pb (Radioactive landfill), Phenol (Ex-mining), Fe (Municipal water supply), As (Ex-mining)		
			Fe (Municipal water supply, industrial, landfill, ex-mining), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas, municipal water supply)		
			Fe (Ex-mining, landfill and industrial), Phenol (Industrial, landfills, agriculture, urban/suburban, golf courses, rural areas)		
			Fe (Industry,landfill), Mn (Rural areas, ex-mining), Phenol (Landfill)		

APPENDIX E

E.1 Environmental risks of dredging as found in the literature

Table D.1 Environmental risks of dredging

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
1	Micro plankton/net plankton	Production/ Biomass quotient	Enhanced slightly-during dredging episode 1	Addition of sediment elutriates	C3			G2	H3	(Munawar 1989)
2	Micro plankton/net plankton	Production/ Biomass quotient	Enhanced slightly-during dredging episode 2		C3			G2	H3	(Munawar 1989)
3	Micro plankton/net plankton	Production/ Biomass quotient	Inhibited slightly		C3			G2	H3	(Munawar 1989)
4	Micro plankton/net plankton	Production/ Biomass quotient	Enhanced slightly-during disposal episode 1				E2	G5	H3	(Munawar 1989)
5	Micro plankton/net plankton	Production/ Biomass quotient	Inhibited slightedly-15 minutes and recovered 60 minutes after dredging				E2	G3	H3	(Munawar 1989)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
6	Micro plankton/net plankton	Production/ Biomass quotient	Inhibited slightly-immediately after disposal and remain low 60 minutes after disposal episode 2				E2	G5	H3	(Munawar 1989)
7	Micro plankton/net plankton	Production/ Biomass quotient	Enhanced slightly-immediately after disposal episode 3				E2	G5	H3	(Munawar 1989)
8	Micro plankton/net plankton	Production/ Biomass quotient	Enhanced significantly after 60 minutes disposal episode 3				E2	G5	H3	(Munawar 1989)
9	Ultra plankton	Production/ Biomass quotient	Enhanced significantly-during dredging episode 1 and 15 minutes after dredging	Addition of sediment elutriates	C3			G2	H3	(Munawar 1989)
10	Ultra plankton	Production/ Biomass quotient	Enhanced slightly-15 minutes after dredging episode 2				E2	G3	H3	(Munawar 1989)
11	Ultra plankton	Production/ Biomass quotient	Enhanced slightly-during dredging episode 2		C3			G2	H3	(Munawar 1989)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
12	Ultra plankton	Production/ Biomass quotient	Inhibited slightly-after dredging episode 2				E2	G3	H3	(Munawar 1989)
13	Ultra plankton	Production/ Biomass quotient	Enhanced slightly-during n post dredging		C3			G2	H3	(Munawar 1989)
14	Ultra plankton	Production/ Biomass quotient	Enhanced slightly-during n post dredging				E2	G3	H3	(Munawar 1989)
15	Ultra plankton	Production/ Biomass quotient	Enhanced significantly-immediately after disposal and continued to enhanced 60 minutes after disposal episode 2				E2	G5	H3	(Munawar 1989)
16	Ultra plankton	Production/ Biomass quotient	Inhibited significantly-after disposal				E2	G5	H3	(Munawar 1989)
17	Ultra plankton	Production/ Biomass quotient	Inhibited slightly after 60 minutes disposal episode 3				E2			(Munawar 1989)
18	Species of phytoplankton	Phytoflagell ates	Offshore species did not show much response	Change in sediment type			E2	G3	H3	(Munawar 1989)
19	Macrobenthic assemblages	Abundance of polycheate	Decreased at comtrol site after dredging				E2	G3	H3	(Ponti, Pasteris et al. 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
20	Macro benthic assemblages	Abundance of the polychaete	Reduced at both sites closer to the dredged channel and in control areas				E2	G3	H3	(Ponti, Pasteris et al. 2009)
21	Macro benthic assemblages	Abundance of polychaete	Disappeared from control sites after dredging	Observed changes in sediment catachrestic, contamination and toxicity			E2	G3	H3	(Ponti, Pasteris et al. 2009)
22	Macro benthic assemblages	Species diversity	increase at control site				E2	G3	H3	(Ponti, Pasteris et al. 2009)
23	Macro benthic assemblages	Species diversity	Decrease at dredged sites	Observed changes in sediment catachrestic, contamination and toxicity			E2	G3	H3	(Ponti, Pasteris et al. 2009)
24	Macro benthic assemblages	Species diversity	Reduced at central and northern part of dredged channel in comparison to control site	Observed changes in sediment catachrestic, contamination and toxicity			E2	G3	H3	(Ponti, Pasteris et al. 2009)
25	Macro benthic assemblages	Species diversity	Reduced abundance at impacted area				E2	G3	H3	(Constantino 2009)
26	Macro benthic assemblages	Species diversity	Removal of unidentified *Ophiuroid* from impacted area				E2	G3	H3	(Constantino 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
27	Macro benthos at depth - 18m	Abundance, number of taxa, diversity and species richness patterns	Lower abundance, number of taxa and diversity after dredging at impacted site to compare to control area	Due to the removal of target and non-target species by the gear and/or spatial redistribution of macro benthic fauna in the dredged area, due to the reduction of habitat complexity, resulting from the removal of tubicolous organisms and epibenthic species			E2	G3	H3	(Constantino 2009)
28	Macro benthos at depth - 18m	Abundance, number of taxa, diversity and species richness patterns	Added of unidentified communities after dredging at impacted site	Due to the removal of target and non-target species by the gear and/or spatial redistribution of macro benthic fauna in the dredged area, due to the reduction of habitat complexity, resulting from the removal of tubicolous organisms and epibenthic species			E2	G3	H3	(Constantino 2009)
29	Macro benthos at depth - 18m	Polychaetes with vermiform shape, without external protection, and carnivore were the dominant functional categories	Enhanced	Due to the removal of target and non-target species by the gear and/or spatial redistribution of macro benthic fauna in the dredged area, due to the reduction of habitat complexity, resulting from the removal of tubicolous organisms and epibenthic species			E2	G3	H3	(Constantino 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
30	Macro benthos at depth - 18m	Taxa mostly crustaceans (mainly amphipods) and polychaetes.	Negatively affected	Due to the removal of target and non-target species by the gear and/or spatial redistribution of macro benthic fauna in the dredged area, due to the reduction of habitat complexity, resulting from the removal of tubicolous organisms and epibenthic species			E2	G3	H3	(Constantino 2009)
31	Macro benthos at depth - 18m	Functional categories animals that had scales or chitinous bodies, vermiform shape, absence of external protection and deposit-feeding mode	Negatively affected	Due to the removal of target and non-target species by the gear and/or spatial redistribution of macro benthic fauna in the dredged area, due to the reduction of habitat complexity, resulting from the removal of tubicolous organisms and epibenthic species			E2	G3		(Constantino 2009)
32	Meiobenthos at depth - 18m	Abundance, number of taxa and community structure	Decreased and persisted until 13 to 35 days				E2	G3	H3	(Constantino 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
33	Meiofaunal	Abundance, number of taxa and community structure	Higher sensitivity to dredging impacts; last until 35 days after dredging than macro faunal				E2	G3	H3	(Constantino 2009)
34	Macro faunal	Abundance, number of taxa and community structure	Impacts apparent only right after dredging				E2	G3	H3	(Constantino 2009)
35	Bacteria-Cu resistant	Polluted sediment (HBC)	Sensitive to Cu				E2	G3	H3	(Toes 2008)
36	Bacteria-Cu resistant		Vast quantity of bands and also showed comparable successive changes in the two sandy sediments	These changes might be due to bio-turbation, grazing pressure, or the shift from natural to artificial light conditions			E2	G3	H2	(Toes 2008)
37	Mobile habitat		Destroyed	Release of contaminated sediment			E2	G3	H3	(Messieh, Rowell et al. 1991)
38	Immobile habitants residing along the dredging course		Died	Due to entrapment			E2	G3	H3	(Messieh, Rowell et al. 1991)
39	Bottom fish		Food decline	Due to new benthic fauna			E2	G3	H3	(Messieh,

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
										Rowell et al. 1991)
40	Epifauna and infauna individual number		Decreased	Due to the release of materials from drilling action, release of contaminants and natural reactions of biological and chemical compound			E2	G3	H3	(Messieh, Rowell et al. 1991)
41	Corals		Died	Due to its habitat destructed along the dredging pathway	C3			G2	H3	(Balchand, Rasheed 2000)
42	Filter feeding fauna like scallop		Decreased	Difficult to filter food due to existence of foreign substance	C3			G2	H3	(Balchand, Rasheed 2000)
43	Filter feeding fauna like scallop						E2	G3	H3	(Balchand, Rasheed 2000)
44	Juvenile fauna	Died	Obstruct feeding and respiration process		C3			G2	H3	(Balchand, Rasheed 2000)
45	Juvenile fauna	Died					E2	G3	H3	(Balchand, Rasheed 2000)
46	Cr, Cu and Fe		Increased- During dredging episode 1-		C3			G2	H1	(Munawar 1989)
47	TKN, P, alkalinity, Al, Cr, Fe, Mn, Pb, Zn		Increased- During dredging episode 2-		C3			G2	H1	(Munawar 1989)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
48	Organic pesticides		Traced		C3				H1	(Munawar 1989)
49	NH3, TKN, alkalinity, Al, Cr, Fe, Mn		Decrease- During and post dredging episode 3		C3			G2	H1	(Munawar 1989)
50	Fe and Al		Increase- Post dredged				E2	G3	H1	(Munawar 1989)
51	NH3, TKN, AL, Fe, Mn, Pb, Zn		Increase- Immediately after disposal episode 1				E2	G5	H1	(Munawar 1989)
52	Pb and Cr		Decreased 60 min after disposal episode 1				E2	G5	H1	(Munawar 1989)
53	TKN, Al, Cr and Fe		Increased- immediately after disposal episode 2				E2	G5	H1	(Munawar 1989)
54	Pb		Decreased- immediately after disposal episode 2				E2	G5	H1	(Munawar 1989)
55	TKN, Al, Cr, Fe and Pb		Returned to level or lower				E2		H1	(Munawar 1989)
56	P, Al, Cr, Cu, Fe, Mn, Pb and Zn		Increased- immediately after disposal episode 3				E2	G5	H1	(Munawar 1989)
57	P, Al, Cr, Cu, Fe, Mn, Pb and Zn		Decreased-60 minute after disposal				E2	G5		(Munawar 1989)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
58	Sediment toxicity		Increased at control sites	Possibly related to the increased oxygenation of bottom sediments and equally or less contaminated by trace metals than removed sediments			E2	G3	H2	(Ponti, Pasteris et al. 2009)
59	Sediment's TKN, P, Pb, Zn and Hg		Increased and exceed guidelines-4 days after dredging				E2	G3	H2	(Ponti, Pasteris et al. 2009)
60	Oxygen flux		Stable for the first 3 months				E3	G3	H4	(Toes 2008)
61	Oxygen flux		Increased 5 months later				E4	G3	H4	(Toes 2008)
62	Oxygen production		Declined after deposition of silt on sandy sediment				E2	G5	H4	(Toes 2008)
63	Iron concentration	In polluted sediment	Dominated at first profiles n lowered after 3 months bio-turbation				E2	G3	H2	(Toes 2008)
64	Iron concentration	Homogenized polluted sediment	Dominated at first profiles n lowered after 3 months bio-turbation				E2	G3	H2	(Toes 2008)
65	Iron concentration	Sandy mesocosm	Lower 3-5 times than HB at first profiles n				E2	G3	H2	(Toes 2008)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
			lowered after 3 months bio-turbation							
66	Iron concentration		Lower 3-5 times than HB except detected at 3cm depth--5 months after, n lowered after 3 months bio-turbation				E2	G3	H2	(Toes 2008)
67	Cu and Cd concentration	Sandy sediment with a 3-mm layer of polluted sediment deposited on top (IFD).	Elevated after 5 months	High surface concentrations were probably caused by the microbial oxidation of metal-contaminated organics at the sediment surface. Because oxygen penetration depth varied between different time points, the release of Cu and Cd in the subsurface could also be caused by the anaerobic reduction of heavy-metal-containing iron(hydr)oxides			E2	G3	H2	(Toes 2008)
68	Cu concentration	Sandy sediment with a 3-mm layer of polluted sediment deposited on top	High level after 3 months bio-turbation and until the end, and all metal fluxes subsided after the bio-turbation	This extreme Cu pollution is primarily connected to the fact that dredged site is located in the vicinity of an industrial wharf			E2	G3	H2	(Toes 2008)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
69	Cu concentration	Homogenized polluted sediment	No metal fluxes but metal transport developed after 3months and declined				E2	G3	H2	(Toes 2008)
70	Concentrations of dissolved metals	Dissolved Cd	Two times greater	Sewage is discharged from the North River Sewage Treatment Plant, located near the LHR sampling site, and accordingly may elevate dissolved metals			E2	G3	H1	(Mackie 2007)
71	Concentrations of dissolved metals	Particulate metal levels	High concentration				E2	G3	H1	(Mackie 2007)
72	Concentrations of dissolved metals	Suspended sediments	High concentration	Sewage is discharged from the North River Sewage Treatment Plant, located near the LHR sampling site, and accordingly may elevate dissolved metals			E2	G3	H1	(Mackie 2007)
73	Dissolved and particulate fractions in water leaving FC	Cd	Elevated	Suggesting that Cd extended significantly below 30 cm of depth at the time of dredging, or that dredging resulted in incomplete removal of contaminated sediment from across the hotspot area			E2	G3	H2	(Mackie 2007)
74	Dissolved and particulate fractions in water	Cd	Highest level at un-dredged area				E2	G3	H2	(Mackie 2007)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
75	Suspended particulate load	Co, Cu, Pb, Ni, and Ag	Nominal, but non- significant				E2			(Mackie 2007)
76	Suspended particulate load	Dissolved concentrations of Cd and Ni	Significantly high	Suggesting the effective removal of sources of these metals to water			E2	G3	H2	(Mackie 2007)
77	Suspended particulate load	Ag	14 times greater	Sewage is discharged from the North River Sewage Treatment Plant, located near the sampling site, and accordingly may elevate dissolved metals			E2	G3	H2	(Mackie 2007)
78	Suspended particulate load	Copper	Elevated				E2	G3	H2	(Mackie 2007)
79	Suspended particulate load	Cu	Elevation of Cu	Wastewater effluent or possibly benthic remobilization of contaminated estuarine sediments			E2	G3	H2	(Mackie 2007)
80	Suspended particulate load	Dissolved Pb	High level				E2	G3	H2	(Mackie 2007)
81	Organic matter		Breakdown due to loss of surface sites				E2	G3	H2	(Piou 2009)
82	Cation exchange capacity (CEC) and humidity	After 1.5 years	Higher than year 1 and 2				E2	G3	H2	(Piou 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
83	DOC and Ca2+ values in leachate	After 1.5 years	Lower than year 1 and 2				E2	G3	H2	(Piou 2009)
84	Total organic carbon	After 1.5 years	Decrease along time	Due to a putative mineralization by aerobic microorganisms			E2	G3	H2	(Piou 2009)
85	Oxygen demand	After 1.5 years	Increased	Due to re-suspension of sediment affecting lighting intensity n reduced food resource			E5	G3	H4	(Messieh, Rowell et al. 1991)
86	Coastal erosion and wave action	After 1.5 years	Increased				E2	G3	H1	(Messieh, Rowell et al. 1991)
87	Resource of sand for adjacent land and beach	After 1.5 years	Reduced				E2	G3	H2	
88	Sediment	After 1.5 years	Colonial of new benthic fauna	Due to new sediment type and exposure of new sediment layer			E2	G3	H2	
89	Turbidity	After 1.5 years	Increased while dredging, decreased after dredging stop (temporary)		C3			G2	H1	(Balchand, Rasheed 2000)
90	Turbidity	Sediment organic matter	Increased at southern dredged channel	Observed changes in sediment catachrestic, contamination and toxicity			E2	G3	H2	(Ponti, Pasteris et al. 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
91	Turbidity	Sediment organic matter		Opposite effect of dredging along the channel may be due to the different time passed since intervention, which started from the north side			E2	G3	H2	(Ponti, Pasteris et al. 2009)
92	Turbidity	Sediment organic matter	Decreased at northern dredged channel	Observed changes in sediment catachrestic, contamination and toxicity			E2	G3	H2	(Ponti, Pasteris et al. 2009)
93	Sediment characterization depth - 6m	Grain size	No clear change at control area	This effect might be essentially related with the activity of surface waves on the bot- tom. the most significant changes were related to the more energetic events, sediments were mobile during a large part of the experiment, which may explain the fast recovery recorded for the sediment and for benthic communities			E2		H2	(Constantino 2009)
94	Sediment characterization depth - 6m	Grain size	Decrease in grain size after dredging at dredged area	This effect might be essentially related with the activity of surface waves on the bottom			E2	G3	H2	(Constantino 2009)
95	Sediment characterization depth - 6m	Grain size	Increase slowly and become similar after 17d	This effect might be essentially related with the activity of surface waves on the bottom			E2	G3	H2	(Constantino 2009)
96	Sediment characterization depth - 18m	Grain size	Change to coarse at impacted area after 1 day	This effect might be essentially related with the activity of surface waves on the bottom.			E2	G3	H2	(Constantino 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
			dredged							
97	Sediment characterization depth - 18m	Grain size	Change gradually finer after 13 days dredged	Can be related to an increase in bottom energy levels partially represented in the data and can explain the relative increase in the finer sand fractions			E2	G3	H2	(Constantino 2009)
98	Light penetration	Grain size	Decreased but not a limiting factor for mobile phytoplankton	Increased turbidity			E2	G3	H1	(Munawar 1989)
99	Sediment	Grain size	Colonial of new benthic fauna	Due to new sediment type and exposure of new sediment layer			E2	G3	H2	(Messieh, Rowell et al. 1991)
100	Turbidity level	Grain size	Causing plumes	Caused by dragging n scooping act or dump act that clog membranes of filter feeding fauna like shellfish	C3			G2	H1	(Balchand, Rasheed 2000)
101	Lighting intensity	Grain size	Decreased	Due to turbidity plumes that block the sunlight and causing less dissolved oxygen produced by phytoplankton			E2	G3	H1	(Balchand, Rasheed 2000)
102	Lighting intensity	Grain size	Decreased	Due to turbidity plumes that block the sunlight and causing less dissolved oxygen produced by phytoplankton			E2	G5	H1	(Balchand, Rasheed 2000)
103	Crab body burden	Grain size	Increased until 6 months after dredging works	Increased in chemical content in water	C3			G3	H3	(Su 2002)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
104	Benthic diversity	Number of individuals	Reduction after dredging (2 months)	Action substrates have on larval recruitment and settlement of the benthic fauna, changes from sandy to muddy bottom and suspension of material and its fallout in the benthic environment	C3			G3	H3	(Bonvicini Pagliai, Cognetti Varriale et al. 1985)
105	Benthic diversity	Channel flora	Virtual elimination		C3			G3	H3	(Ellery, McCarthy 1998)
106	Benthic diversity	Terrestrial species	Encroachment of the floodplain		C3			G3	H3	(Ellery, McCarthy 1998)
107	Benthic diversity	Channel vegetation.	Removed		C3			G3	H3	(Ellery, McCarthy 1998)
108	Benthic diversity		Minimal in dredged section		C3			G3	H3	(Ellery, McCarthy 1998)
109	Benthic diversity	No aquatic plants		Deterioration of the floodplain vegetation is due to the presence of cattle in the area	C3			G3	H3	(Ellery, McCarthy 1998)
110	Benthic diversity	Width of former floodplain communities	Reduction		C3			G3	H3	(Ellery, McCarthy 1998)
111	Benthic diversity	Nick point created by dredging	Migrated upstream for a distance of 10.5 km		C3			G3	H2	(Ellery, McCarthy 1998)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
112	Benthic diversity	Channel	Deterioration incurred by advance of the nick point	Head-ward erosion of the nick point creates a narrow channel which concentrates flow and steepens the gradient	C3			G3	H2	(Ellery, McCarthy 1998)
113	Benthic diversity	Bed roughness upstream of the nick point	High value	Presence of in-channel vegetation	C3			G3	H2	(Ellery, McCarthy 1998)
114	Benthic diversity	Velocity	High flow	No aquatic plants, elimination of this vegetation as the nick point advances reduces the roughness, increasing flow velocity	C3			G3	H1	(Ellery, McCarthy 1998)
115	Largemouth bass	Velocity	Deformities, ranging from crooked spines and backbones to missing fins, were harvested	Both dredging and capping were operating simultaneously for a time, causing release of contaminations	C3			G3	H3	(Thibodeaux, Duckworth 2001)
116	Resident fish-small-mouth bass and catfish-body composites	Total Aroclor	Reductions from 1993 to1997		C3			G3	H3	(Thibodeaux, Duckworth 2001)
117	Caged fish and resident fish near dredged area		Concentration after dredge higher than pre-dredge	Enhanced soluble and particulate bound PCB releases from the curtained-off area	C3			G3	H3	(Thibodeaux, Duckworth 2001)
118	Caged fish	In-harbour cages	30-50% reduction but no clear trend in 95-97		C3			G3	H3	(Thibodeaux, Duckworth 2001)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
119	Phosphorus release to flowing water	In-harbour cages	Reduced	Sediment with high P content	C3			G3	H2	(Shigaki, Kleinman et al. 2008)
120	Phosphorus release to flowing water	In-harbour cages	Increased if exposed underlying sediment type (which is coaster and low organic, Al n Fe content) that will lower P the sorption capacity n release more P to the flowing water	Dredged of upper layer that contain more organic and microbial	C3			G3	H2	(Shigaki, Kleinman et al. 2008)
121	Total organic carbon	In-harbour cages	Lower in dredged zone during dredging and not accompanied by increase in neighbouring zones	Mobilization of resources by the dredging operations and their transport to neighbouring area by sediment plume	C3			G2		(Bonvicini Pagliai, Cognetti Varriale et al. 1985)
122	Total organic carbon	In-harbour cages					E2			
123	PCB concentrations on water while boulder removal n	In-harbour cages	Exceed standard values		C3			G2	H1	(Thibodeaux, Duckworth 2001)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
	during dredging									
124	PCB concentrations on 1995 on sediment at 4 inch thick	In-harbour cages	Reduced by 94%		C3			G3	H2	(Thibodeaux, Duckworth 2001)
125	PCB concentrations on 1997 on sediment at 4 inch thick	In-harbour cages	Reduced by 88%		C3			G3	H2	(Thibodeaux, Duckworth 2001)
126	PCB concentrations on 1997 on sediment at 3 inch thick	In-harbour cages	Higher 257% than pre-dredge		C3			G3	H2	(Thibodeaux, Duckworth 2001)
127	PCB concentrations on 1995 on sediment at 6-7 inch thick composites	In-harbour cages	Lower 45% than pre-dredge		C3			G3	H2	(Thibodeaux, Duckworth 2001)
128	PCB concentrations after dredging on sediment at 3 inch thick composites	In-harbour cages	Increased		C3			G3	H2	(Thibodeaux, Duckworth 2001)
129	PCB concentrations in the water	In-harbour cages	Higher during the operation than in the pre-		C3			G3	H1	(Thibodeaux, Duckwort

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
	measured outside the curtain		dredging period							h 2001)
130	PCB levels- the surficial sediment 2 inch surficial sediment	In-harbour cages	Increased based on 1993, 1997, and 1998 sediment surveys based on two-inch surficial grab samples	Removing one to two feet of material resulted in the exposure of sediment with higher than average PCB concentrations	C3			G3	H2	(Thibodeaux, Duckworth 2001)
131	PCB concentration	Upstream water	Higher for the upstream samples than those downstream		C3			G3	H1	(Thibodeaux, Duckworth 2001)
132	PAH on soil	Upstream water	Available at northern end of the dredged area where the cap was in place	Both dredging and capping were operating simultaneously for a time causing release of contaminations	C3			G2	H2	(Thibodeaux, Duckworth 2001)
133	Sediment type	Upstream water	Changed	Dredging exposed coarser sediment	C3			G3	H2	(Shigaki, Kleinman et al. 2008)
134	Surface sediment	Concentrations of chemical	Increased	Disturbance of contaminated sediment	C3			G3	H2	(Su 2002)
135	Turbidity	Concentrations of chemical	Increase but decreased to baseline in 24-48 hours	High level of disturbance	C3			G3	H1	(Su 2002)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
136	Transparency	Concentrations of chemical	Less transparency at dredged area and neighbour during dredging	Increased turbidity	C3			G2	H1	(Bonvicini Pagliai, Cognetti Varriale et al. 1985)
137	Transparency	Width of former floodplain communities	Reduction		C3			G3	H3	(Ellery, McCarthy 1998)
138	Transparency	Nick point created by dredging	Migrated upstream for a distance of 10.5 km		C3			G3	H2	(Ellery, McCarthy 1998)
139	Transparency	In channel	Deterioration incurred by advance of the nick point	Head-ward erosion of the nick point creates a narrow channel (Fig. 13), which concentrates flow and steepens the gradient	C3			G3	H2	(Ellery, McCarthy 1998)
140	Transparency	Bed roughness upstream of the nick point	High value	Presence of in-channel vegetation	C3			G3	H2	(Ellery, McCarthy 1998)
141	Transparency	Velocity	High flow	No aquatic plants, elimination of this vegetation as the nick point advances reduces the roughness, increasing flow velocity	C3			G3	H1	(Ellery, McCarthy 1998)
142	Sea depth	Velocity	Increased		C3			G3	H2	(Sergeev 2009)
143	Sediment transport	Velocity	Destabilization	Active dredging in the near shore zone	C3			G3	H2	(Sergeev 2009)
144	Sediment accumulation	Velocity	Reduction	Active dredging in the near shore zone	C3			G3	H2	(Sergeev 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
145	Accretion processes in the bay head	Velocity	Reduced		C3			G3	H2	(Sergeev 2009)
146	Size of accretion bar	Velocity	Decreased		C3			G3	H2	(Sergeev 2009)
147	Sediment traps	Velocity	Increased	The new ship channels will interrupt sediment transport	C3			G3	H2	(Sergeev 2009)
148	Natural sediment nourishment of the sand bars	Velocity	Reduced		C3			G3	H2	(Sergeev 2009)
149	Erosion of the coasts	Velocity	Increased	Disturbance of natural processes, caused by dredging	C3			G3	H2	(Sergeev 2009)
150	Near shore seabed	Velocity	Increased	Disturbance of natural processes, caused by dredging	C3			G3	H2	(Sergeev 2009)
151	New accretion areas within the ship channels	Velocity	Increased		C3			G3	H2	(Sergeev 2009)
152	Wave regime	Velocity	Change	Relief transformation	C3			G3	H1	(Sergeev 2009)
153	Planned from ship waves,	Velocity	Increased				E2			(Sergeev 2009)
154	Sedimentation conditions in the vicinity of the port	Velocity	Change		C3			G3	H2	(Sergeev 2009)
155	Sediment trap with abnormal accumulation rate		Increased	Artificial bottom depressions such as waterways and submarine carriers	C3			G3	H2	(Sergeev 2009)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
156	Benthic fauna and fishes		Habitat change	Due to disturbance of food resource and damage of hiding and breeding ground caused by scooping act	C3			G3	H3	(Padmalal 2008)
157	Benthic fauna and fishes		Mobile habitat destroyed	Release of contaminants	C3			G3	H3	(Padmalal 2008)
158	Water	Velocity	Decreased	Slumped of riverbank and unplanned road for sand transportation	C3			G3	H3	(Padmalal 2008)
159	Finless porpoise		Habitat change	Due to noise	C1			G2	H3	(de Leeuw 2010)
160	Finless porpoise	Velocity	Habitat change	Due to noise	C3			G2	H3	(de Leeuw 2010)
161	Bottom fauna		New dominant group		C3			G3	H3	(Rasheed, Balchand 2001)
162	Bottom fauna		None observed		C3			G3	H3	(Rasheed, Balchand 2001)
163	Bottom fauna		None observed	Extensive dredging n acute anaerobic bottom conditions in the estuary and due to migration of organisms under unfavourable hydro graphic condition	C3			G3	H3	(Rasheed, Balchand 2001)
164	Bottom fauna		New dominant group	Indicates re-colonisation after substratum failure	C3			G3	H3	(Rasheed, Balchand 2001)
165	Bottom fauna		Crustaceans dominating the bottom fauna		C3			G3	H3	(Rasheed, Balchand 2001)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
166	Bottom fauna		Dredged site showed increase of organisms than non-dredged		C3			G3	H3	(Rasheed, Balchand 2001)
167	Bottom fauna		Maximum benthic growth prior commencement of dredging, repeating the cycle		C3			G1	H3	(Rasheed, Balchand 2001)
168	Rate of recovery	Physical nature of seabed	Not permanently altered				E2			(Cooper, Barrio Froján et al. 2008)
169	Rate of recovery	Macro faunal assemblages	Recovered 1-2 years	Physical change not permanently changed	C3			G3	H3	(Cooper, Barrio Froján et al. 2008)
170	Sediment transport	Macro faunal assemblages	Increased	Dredging has destabilized the seabed sediment such that the local tide and wave conditions are now capable of transporting sediment which otherwise would have remained stationary.	C3			G3	H2	(Kenny, Rees 1996)
171	Biomass	Macro faunal assemblages	Decreased in 24 months after dredging	Sediment disturbance	C3			G3	H3	(Kenny, Rees 1996)
172	Macro benthos	Re-colonization	Rapid		C3			G3	H3	(Kenny, Rees 1996)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
173	Dredge track/furrow	After 2 years	Further eroded	The weathering of dredge tracks may have been due to increased wave action over the winter months which, combined with the prevailing tidal currents, would serve to increase sediment transport at that time	C3			G3	H2	(Kenny, Rees 1996)
174	Sediment particle distribution	At dredged site	Increased coarser sediment	The action of suction-trailer dredging would have resulted in the exposure of gravel 'rich' layer which may account for the increased gravel content at the treatment site post-dredging	C3			G3	H2	(Kenny, Rees 1996)
175	Macro fauna taxa	Mean density	Decreased immediately after post dredging		C3			G3	H3	(Kenny, Rees 1996)
176	Macro fauna taxa	Mean density	Increased after post dredging after 1 year		C3			G3	H3	(Kenny, Rees 1996)
177	Macro fauna taxa	Species at controlled site	Constant number of species for 29 month sampling period		C3			G3	H3	(Kenny, Rees 1996)
178	Macro fauna taxa	Species at treatment side	Decrease immediately after post dredging		C3			G3	H3	(Kenny, Rees 1996)
179	Macrofauna taxa	Species at treatment	Increase a year later onwards				E2			(Kenny, Rees

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
		side								1996)
180	Variety, abundance and biomass of benthic organisms	Species at treatment side	Reduced		C3			G3	H3	(Kenny, Rees 1994)
181	Re-colonization of substrates	Species at treatment side	Rapid but not fully recovered after 7 months		C3			G3	H3	(Kenny, Rees 1994)
182	Furrow		Well-defined created after dredging		C3			G3	H2	(Kenny, Rees 1994)
183	Gravel content		Increase in post dredging than pre-dredged level	Examination of a vibro-core sample taken at the treatment site before dredging indicated that a greater proportion of gravel was present in a layer between 0.05 and 0.7 m deep. The action of suction-trailer dredging would therefore have resulted in exposure of this layer.	C3			G3	H2	(Kenny, Rees 1994)
184	Number of species	Immediately after dredging	Constant at reference site		C3			G3	H3	(Kenny, Rees 1994)
185	Number of species		Decreased at dredged site		C3			G3	H3	(Kenny, Rees 1994)
186	Number of species	After 7 months of post dredging	Increased		C3			G3	H3	(Kenny, Rees 1994)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
189	Biomass data		Reduced immediately after dredging than pre-dredged level at dredged site		C3			G3	H3	(Kenny, Rees 1994)
190	Channel width		Widen that will increase rate of sediment flow and higher erosion rate		C3			G3	H2	(de Leeuw 2010)
191	Seabed level		Fast lowering causing casualties to bridges, rural water n side protection structures		C3			G3	H2	(Padmalal 2008)
192	Seabed level		Perennial walls adjacent dried up				E2	G3	H2	(Padmalal 2008)
193	Seabed surface		Change of seabed surface	Due to equipment used that create shallow furrow and large pits	C3			G3	H2	(Messieh, Rowell et al. 1991)
194	Seabed surface		Effect number of catch				E2	G3	H5	(Messieh, Rowell et al. 1991)
195	Seabed surface		Fisherman's usual gear not fitted anymore				E2	G3	H5	(Messieh, Rowell et al. 1991)
196	Surface salinity		Lower value than bottom	Proximity of stations close to bar-mouth and depth factors	C3			G3	H1	(Messieh, Rowell et al. 1991)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
197	Transparency		Decrease gradually at dredged n non-dredged area throughout the post monsoon season	Light penetration increases as season advances	C3			G3	H1	(Messieh, Rowell et al. 1991)
198	Transparency		High value at both site on pre-monsoon	Increase in turbidity	C3			G3	H1	(Messieh, Rowell et al. 1991)
199	Transparency		Low value	Dredging stop	C3			G3	H1	(Messieh, Rowell et al. 1991)
200	Transparency		Constant during monsoon season	Homogeneity in water transparency	C3					(Messieh, Rowell et al. 1991)
201	Turbidity		Higher turbidity in surface waters at non-dredged and dredged during monsoon	Freshwater inflow - typical for tropical estuaries	C3			G3	H1	(Messieh, Rowell et al. 1991)
202	Turbidity		Increased at dredged site as depth increase on post monsoon season with max at 8-10 meter depth		C3			G3	H1	(Messieh, Rowell et al. 1991)
203	Water turbidity		Increased		C3			G3	H1	(Wu, de Leeuw et al. 2007)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
204	Water turbidity		Increased	Dredging activities	C3			G3	H1	(Wu, de Leeuw et al. 2007)
205	Topo graphy		Disturbed with large furrows	Sediment trans port was larger (presence of sand-ripples), this led to a significant erosion of these furrows, but they were still visible after three years	C3			G3	H2	(Desprez 2000)
206	Sand mega ripples	Big depressions between areas of gravels and shingles	Exist		C3			G3	H2	(Desprez 2000)
207	Nitrate concentration at dredged area		Constantly high at bottom water, increased at non-dredged area while pre-monsoon season	Sediment-water exchange gradient influence by dredging action n turbulent movement in bottom waters which agitate the sediment leading to nutrient release	C3			G2	H1	(Rasheed, Balchand 2001)
208	Phosphate concentration		Decrease as season advances at dredged sites		C3			G3	H1	(Rasheed, Balchand 2001)
209	Phosphate concentration		Increase at non-dredged sites n decrease	Sharp reduction after monsoon due to consumption by way of enhanced productivity	C3			G3	H1	(Rasheed, Balchand 2001)
210	Phosphate concentration		Increase gradually at surface at dredged n non-dredged location	Inputs into the estuaries via rivers	C3			G3	H1	(Rasheed, Balchand 2001)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
			during monsoonal season							
211	Phosphate concentration		Increased largely	Higher local inputs from municipal sewage or industrial wastes	C3			G3	H1	(Rasheed, Balchand 2001)
212	Chlorophyll a concentration		Seasonal monsoon peak in bottom samples occurred	Replenishment of bottom water with benthic micro flora	C3			G3	H3	(Rasheed, Balchand 2001)
213	Chlorophyll b concentration		Monsoonal peak at bottom waters at all dredged stations, greatly affected by dredging		C3			G3	H3	(Rasheed, Balchand 2001)
214	Chlorophyll c concentration		Higher than chlorophyll b, less affected by dredging	Substantial contribution of diatom from flora	C3			G3	H3	(Rasheed, Balchand 2001)
215	Fauna		Decreased	Because sealant of the eggs by deposition of dredged mat at breeding ground			E2	G5	H3	(Messieh, Rowell et al. 1991)
216	Bivalve species		Reduction in number and change of habitat	Due to change of sediment type, from finer to coarser			E2	G5	H3	(Ware, Bolam et al. 2010)
217	Annelid species			Due to abundance of tube dwelling polychaete species at the same site acting as their food resource			E2	G5	H3	(Ware, Bolam et al. 2010)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
218	Other fauna		Reduction	Due to saturation of bivalve and annelid species			E2	G5	H3	(Ware, Bolam et al. 2010)
219	Hard bottom reef habitat		Habitat change from sand to hard bottom reef habitat	Sediment change			E2	G5	H3	(Crowe, Gayes et al. 2010)
220	Invertebrate species		Decreased				E2	G5	H3	(Crowe, Gayes et al. 2010)
221	Tropical soft-bottom benthic assemblage	Abundance of organisms and number of species	Decreased				E2	G5	H3	(Cruz-Motta, Collins 2004)
222	Macro benthic assemblages	Different inside the spoil ground were assemblages outside the spoil ground 3 months after dumping	No different	Respond quickly to the disturbance			E2	G5	H3	(Cruz-Motta, Collins 2004)
223	Abundances of the polychaete		Decreased				E2	G5	H3	(Powilleit, Kleine et al. 2006)
224	Invertebrates		Decreased severely				E2	G5	H3	(Powilleit, Kleine et al. 2006)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
225	Alpha site (August 3 and 14, 1992)	Sand percentage	Increased than pre-disposal and differ from ref site				E2	G5	H2	(Wilber, Clarke et al. 2007)
226	Alpha site (August 3 and 14, 1992)	Taxonomic composition of in faunal	Different from ref site for 6 months after disposal				E2	G5	H3	(Wilber, Clarke et al. 2007)
227	Alpha site (August 3 and 14, 1992)	Sand worms	Increased than pre-disposal August, 1993.	Polychaetes are suspension feeders that construct tubes from sand grains, thus increased sand availability at the Alpha and Delta disposal sites may have favoured their establishment.			E2	G5	H3	(Wilber, Clarke et al. 2007)
228	Beta site (September 26 to October 5, 1992)	Sediment granulo metry	Same with referenced site after disposal				E2	G5	H2	(Wilber, Clarke et al. 2007)
229	Beta site (September 26 to October 5, 1992)	In faunal abundance	Decreased immediately and until 9 months later				E2	G5	H3	(Wilber, Clarke et al. 2007)
230	Beta site (September 26 to October 5, 1992)	Overall in faunal abundance	Fluctuate				E2	G5	H3	(Wilber, Clarke et al. 2007)
231	Beta site (September 26 to October 5, 1992)	community composition	Different from site n ref	Lack of opportunistic polychaetes which raised total abundance at the disposal sites to reference levels within the first six months of recovery			E2	G5	H3	(Wilber, Clarke et al. 2007)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
232	Beta site (September 26 to October 5, 1992)	Taxonomic composition	6 months of recovery time				E2	G5	H3	(Wilber, Clarke et al. 2007)
233	Delta site (May 4 to 25, 1993, approximately 8 months after sediment placement at the Alpha and Beta)	Sediment	Increased in size (coarser)				E2	G5	H2	(Wilber, Clarke et al. 2007)
234	Delta site (May 4 to 25, 1993, approximately 8 months after sediment placement at the Alpha and Beta)	Total in faunal abundance	Increased than reference site after 2 years				E2	G5	H3	(Wilber, Clarke et al. 2007)
235	Delta site (May 4 to 25, 1993, approximately 8 months after sediment placement at the Alpha and Beta)	Abundant of *Amphiurid* brittle stars	Increased for the first 6 months after disposal				E2	G5	H3	(Wilber, Clarke et al. 2007)
236	Overall abundance of		Higher at all disposal sites	Due to fall increases in the abundance of *Oweniid*, more			E2	G5	H3	(Wilber, Clarke et

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
	in fauna		than at the respective reference sites	pronounced at the Alpha and Delta sites where the sand component of the sediments increased following disposal sand worms						al. 2007)
237	Overall recovery of total in faunal abundance	Pre-impact and reference levels	Occurred within 3-10 months				E2	G5	H3	(Wilber, Clarke et al. 2007)
238	Amphipod *B. Sarsi*		Increased in mortality	Organisms that are exposed to sediments which are contaminated with a wide range of chemical compounds may experience negative (or fatal) effects which may be caused by any of these compounds or by specific combinations of compounds.			E2	G5	H3	(van den Hurk, Eertman et al. 1997)
239	Mussel	Tolerance to aerial exposure	Reduced	Organisms that are exposed to sediments which are contaminated with a wide range of chemical compounds may experience negative (or fatal) effects which may be caused by any of these compounds or by specific combinations of compounds.			E2	G5	H3	(van den Hurk, Eertman et al. 1997)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
240	Oyster larvae	Development	Impaired	Organisms that are exposed to sediments which are contaminated with a wide range of chemical compounds may experience negative (or fatal) effects which may be caused by any of these compounds or by specific combinations of compounds.			E2	G5	H3	(van den Hurk, Eertman et al. 1997)
241	Salinity		Decreased				E2	G5	H1	(Vivier, Cyrus 1999)
242	Zoo benthic fauna	Number of taxa, densities and species diversity	Decreased	Sediment spilled on the benthic fauna			E2	G5	H3	(Vivier, Cyrus 1999)
243	Zoo benthic fauna	pH	Low	Oxidation of deposited sediment			E2	G5	H2	(Ljung 2010)
244	Zoo benthic fauna		Potentially toxic elements can continue to leach out of the soil profile with time	Oxidation of deposited sediment			E2	G5	H2	(Ljung 2010)
245	Zoo benthic fauna	Metal mobility	Decreased metal mobility with time after disturbance				E2	G5	H2	(Ljung 2010)
246	Zoo benthic fauna	As, Ni, Cd	Strong correlation	Showing discharge from soil to water environments			E2	G5	H2	(Ljung 2010)
247	Water	Fe, Ni and As	High concentration				E2	G5	H1	(Ljung 2010)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
248	Water	pH	High	Acidity of the soils does not seem to be transported into the nearby canals			E2	G5	H1	(Ljung 2010)
249	Dust fraction of soils with higher pH	Metal	Higher concentrations than original soil	Soil acidity increased			E2	G5	H2	(Ljung 2010)
250	Dust fraction of soils with higher pH	Metal		Affected by acidic sediment deposition			E2	G5	H2	(Ljung 2010)
251	Soil actual heavy metal mobility		Low	A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)
252	Soil actual heavy metal mobility	Cd, Zn and Ni		A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)
253	Soil actual heavy metal mobility	Cd and Zn	Highest potential availability	A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)
254	Soil actual heavy metal mobility	Cu and Ni	Medium potential availability	A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)
255	Soil actual heavy metal mobility	Pb	Not very sensitive to acidification but can be mobilized by complexing substances in the soil	A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)
256	Heavy metal mobility	As and Cr	Long-term availability seems to be very	A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
			low							
257	Soil actual heavy metal mobility	Cd, Zn and Cu	High total concentrations	A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)
258	Soil actual heavy metal mobility	Cd, Zn and Cu	Zn > Cu > Ni > Pb > Cd	A function of pH and organic carbon content			E2	G5	H2	(Cappuyns 2006)
259	As, Zn, Cd, Pb	Level of contamination at 0.5m depth	Highest				E2	G5	H2	(Lions 2010)
260	pH	Day −28 to day 0 but reached similar values, around 7.51±0.04 pH units, in all LGPs	Decreased				E2	G5	H2	(Clément, Vaille et al. 2010)
261	Oxygen content	Between day −20 and day 0. This	Decreased	Due to absence of aeration in the LGPs and increase of oxygen demand of sediment and gravel microbial communities.			E2	G5	H4	(Clément, Vaille et al. 2010)
262	Turbidity		Peaked				E2	G5	H1	(Clément, Vaille et al. 2010)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
263	Conductivity of surface waters	Following sediment addition but stable after 2 weeks for surface water and until day 40 for groundwater	Increased far higher for the treated sediment	Renewal of surface water probably explains its decrease			E2	G5	H1	(Clément, Vaille et al. 2010)
264	pH	Surface water in treated sediment	Increased				E2	G5	H1	(Clément, Vaille et al. 2010)
265	Water oxygen content		Decreased	Addition of raw carbon sediment			E2	G5	H4	(Clément, Vaille et al. 2010)
266	Water above treated sediment		More oxygenated				E2	G5	H1	(Clément, Vaille et al. 2010)
267	Oxygen content	In treated sediment	Increased	Chemical reaction inside water			E2	G5	H4	(Clément, Vaille et al. 2010)
268	Zink	In treated sediment	Delayed release in increase 3 weeks later but not to ecotoxic level				E2	G5	H1	(Clément, Vaille et al. 2010)
269	Chromium	At treated sediment in surface water above treated	High concentration				E2	G5	H1	(Clément, Vaille et al. 2010)

No. of risk	Parameter	Detail parameter	Impact	Factor	Excavation (C1-C5)	Transport (D1-D3)	Disposal (E1-E2)	Phase (G1-G5)	Receptor (H1-H7)	Ref.
		sediment n returned to undetectable value after 2 weeks								

E.1 Sensitivity analysis results for Chapter 6

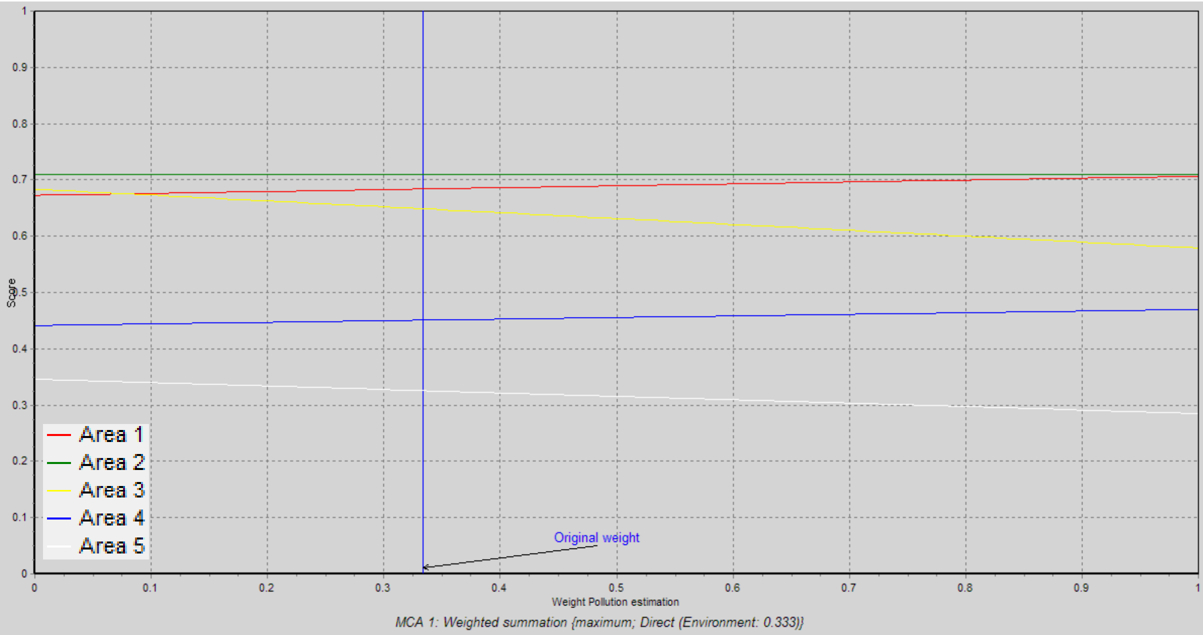


Figure E-1 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Pollution estimation

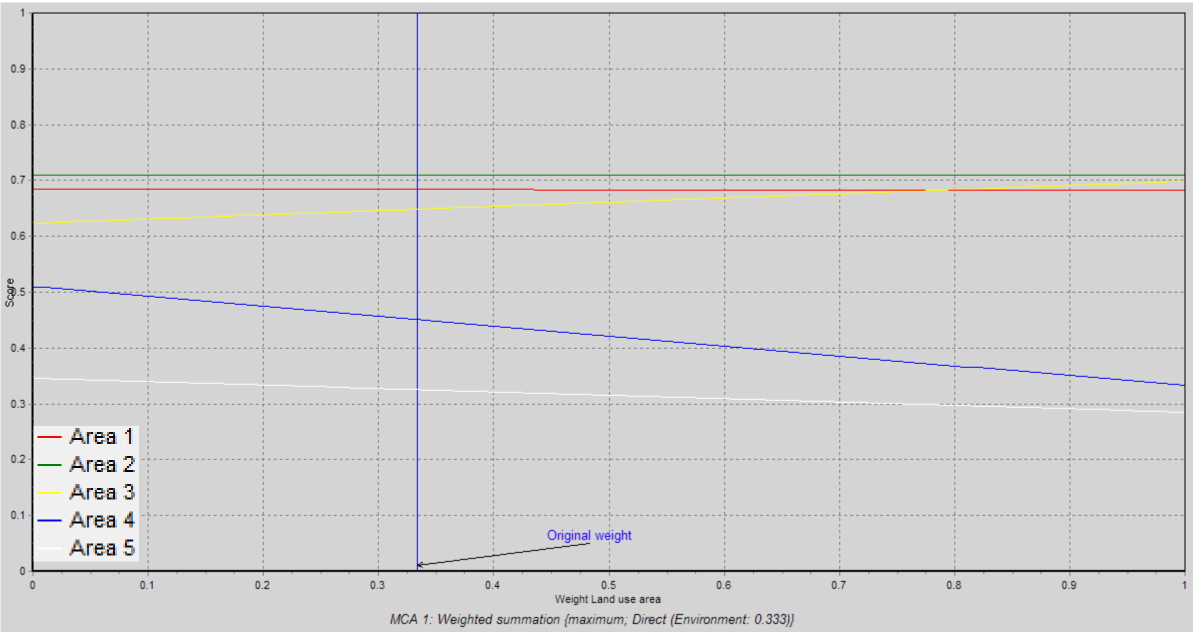


Figure E-2 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Land use area

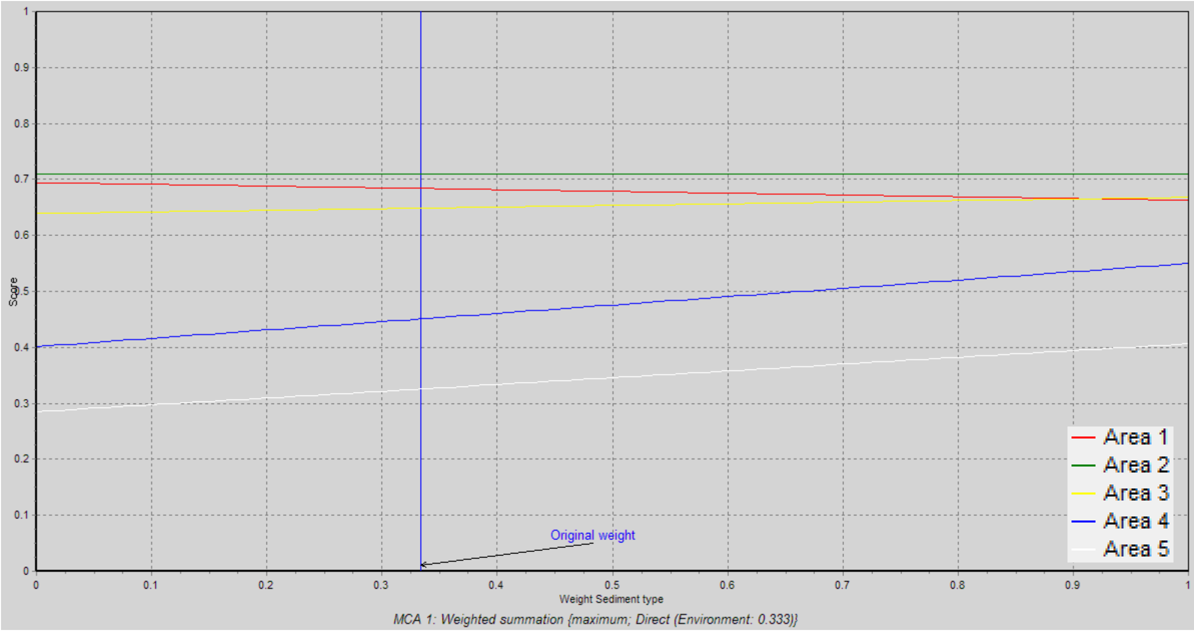


Figure E-3 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Sediment type

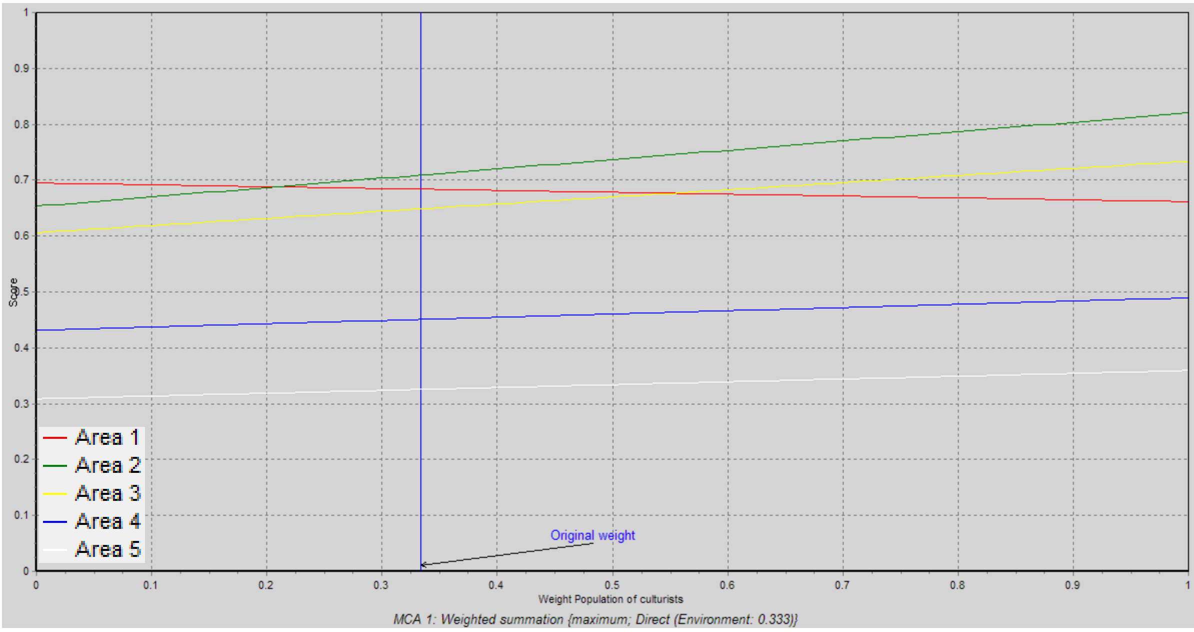


Figure E-4 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Population of culturists

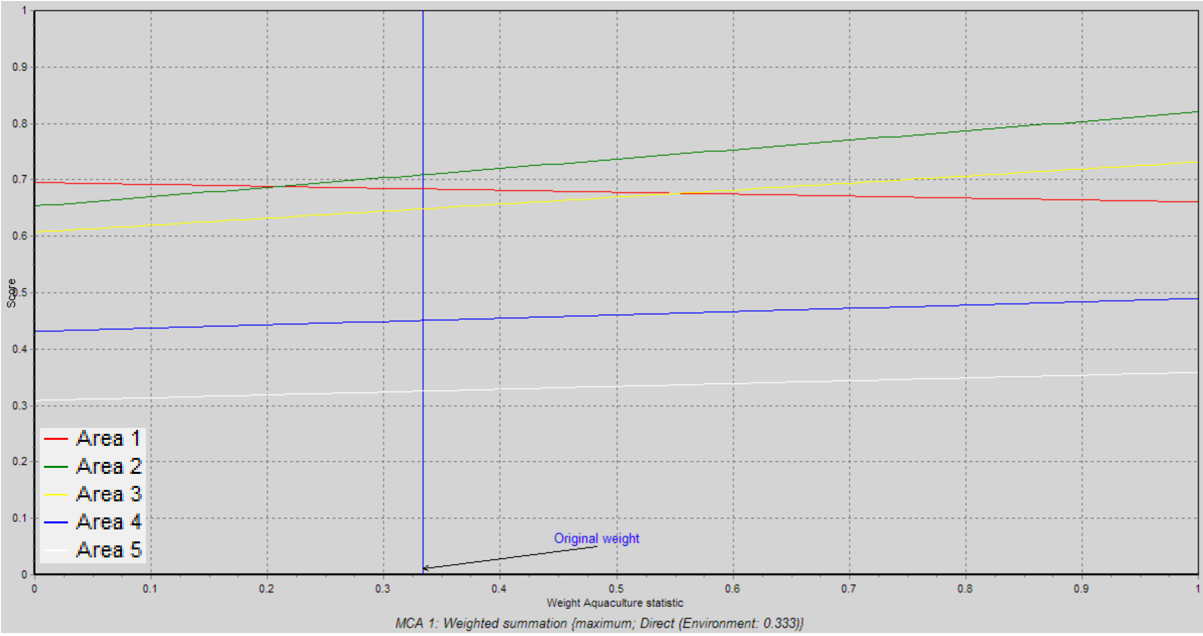


Figure E-5 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Aquaculture statistic

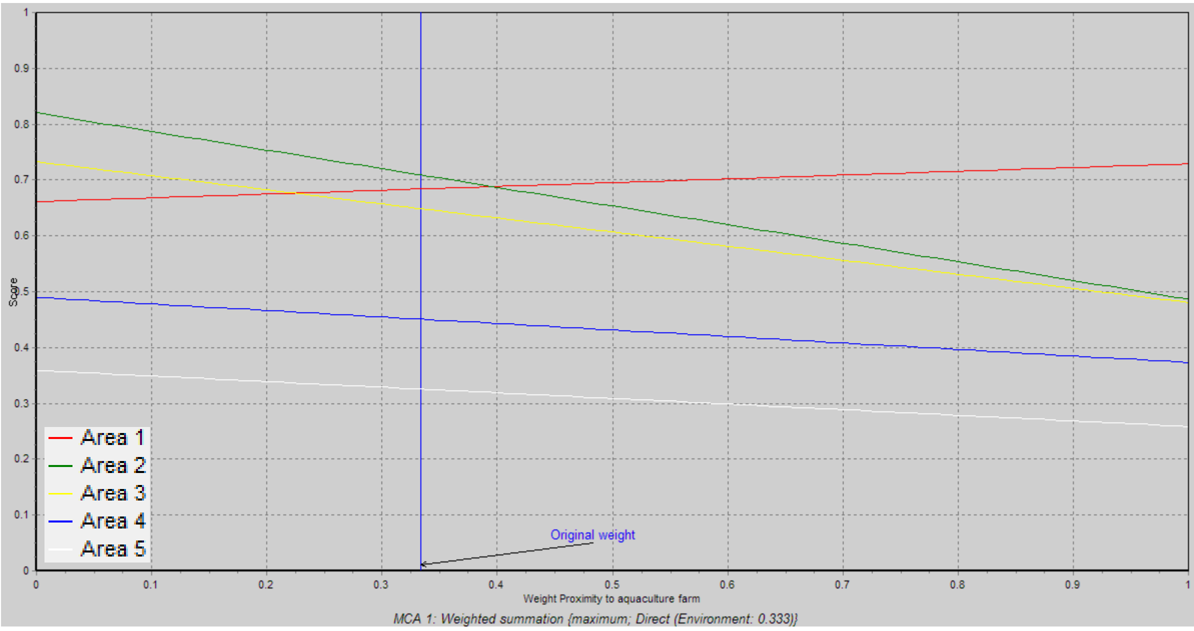


Figure E-6 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Proximity to aquaculture farm

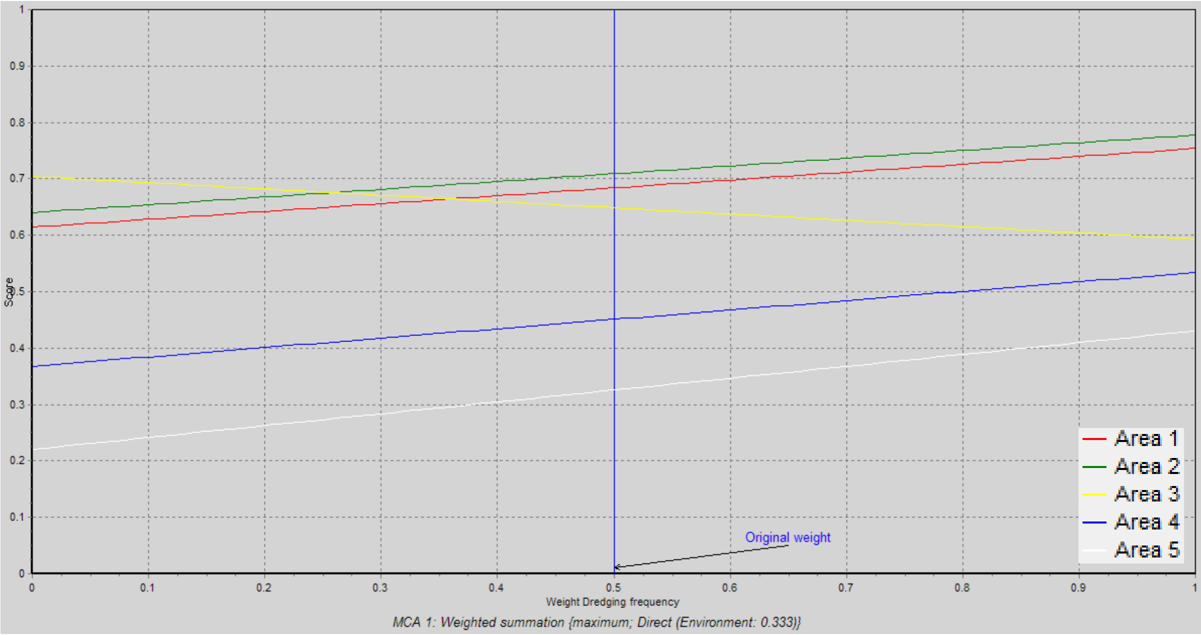


Figure E-7 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Dredging frequency

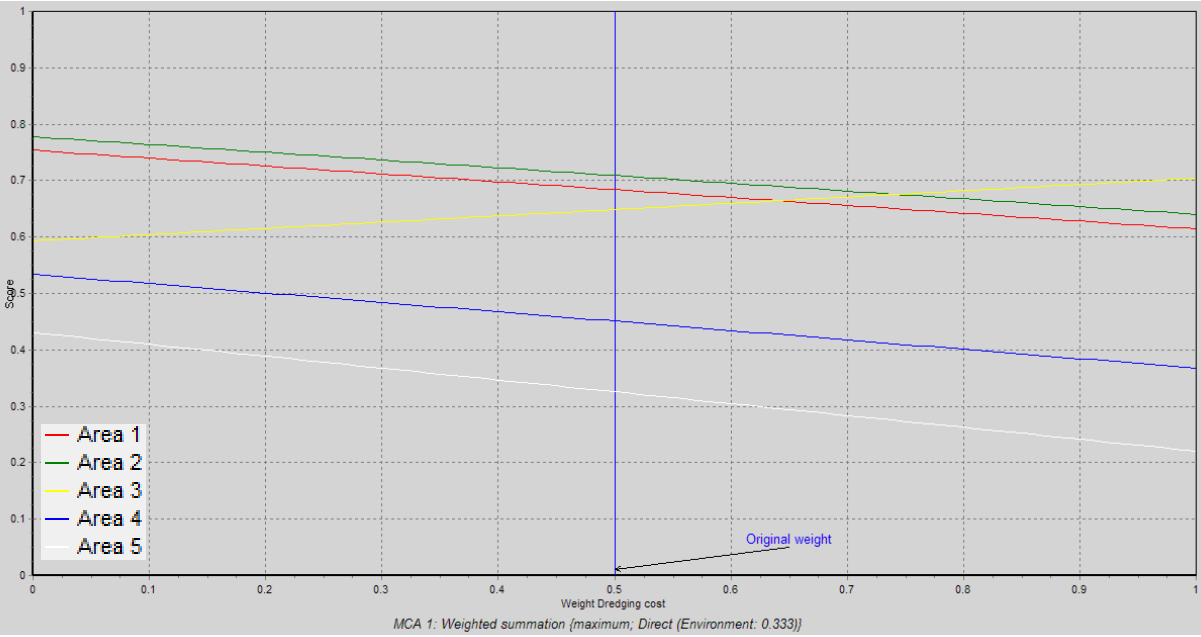


Figure E-8 Results of sensitivity analysis showing rankings of the areas after variations of weights assigned to sub-criteria of Dredging cost

APPENDIX F

F.2 Sensitivity analysis results for Chapter 9

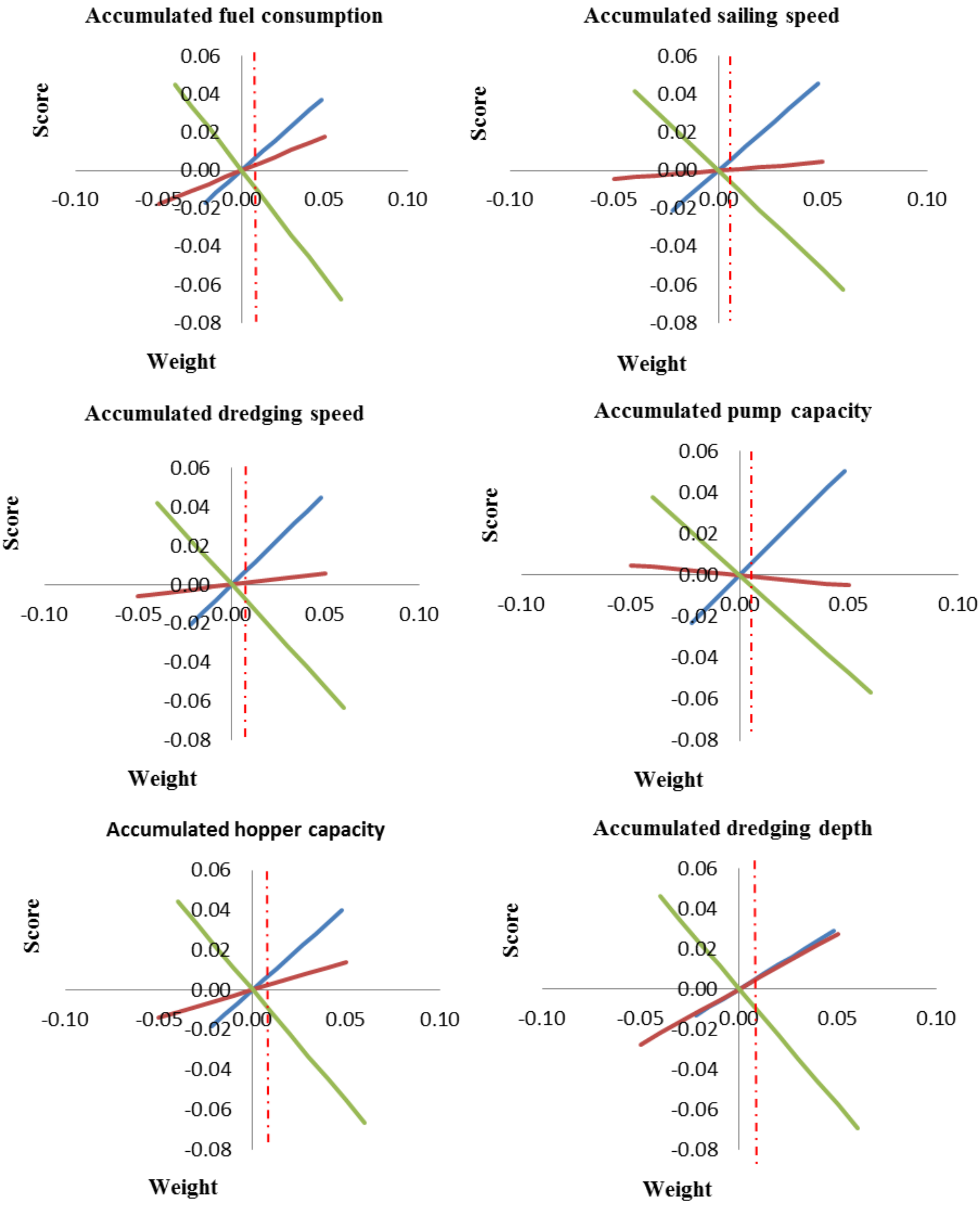


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria

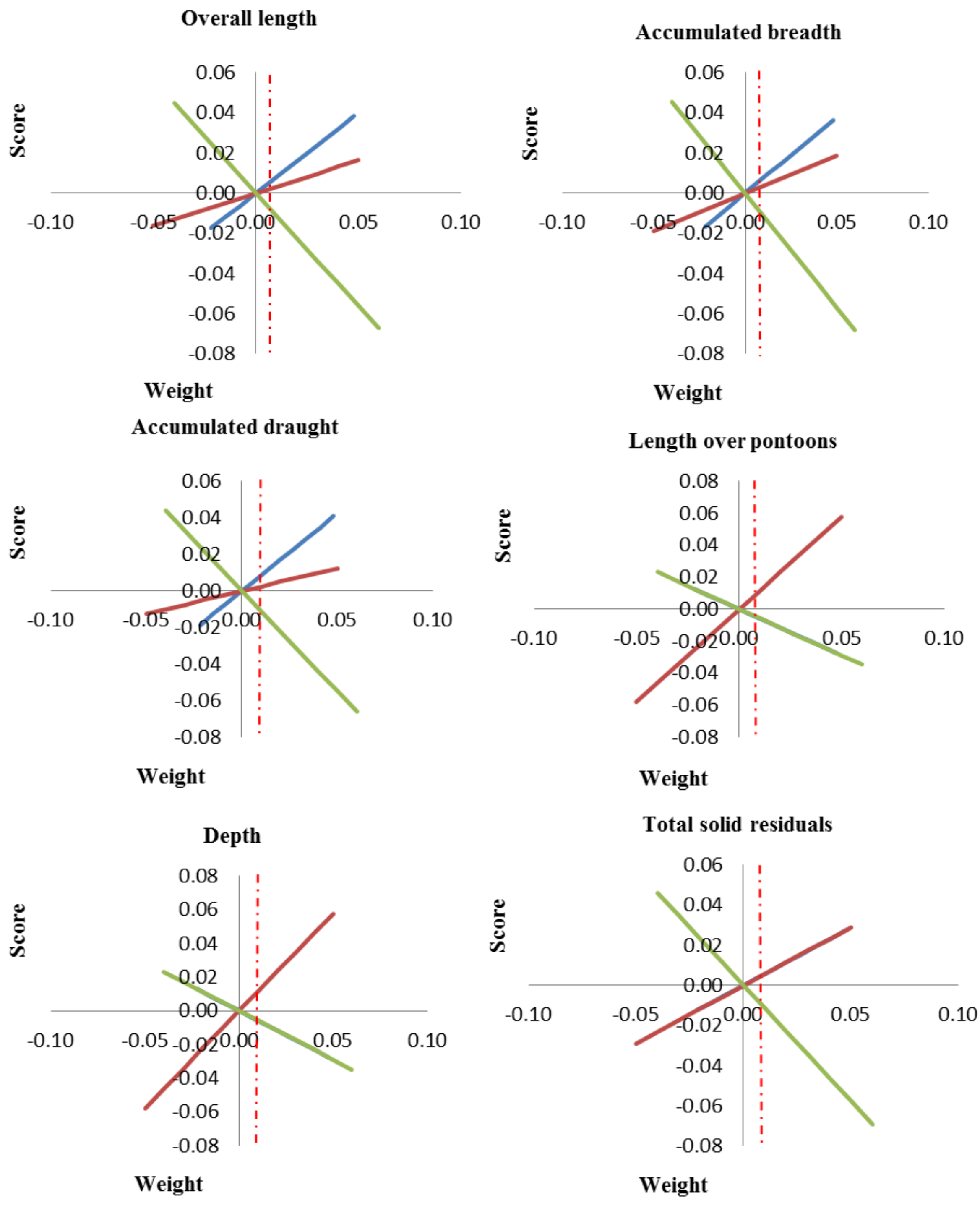


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued*)

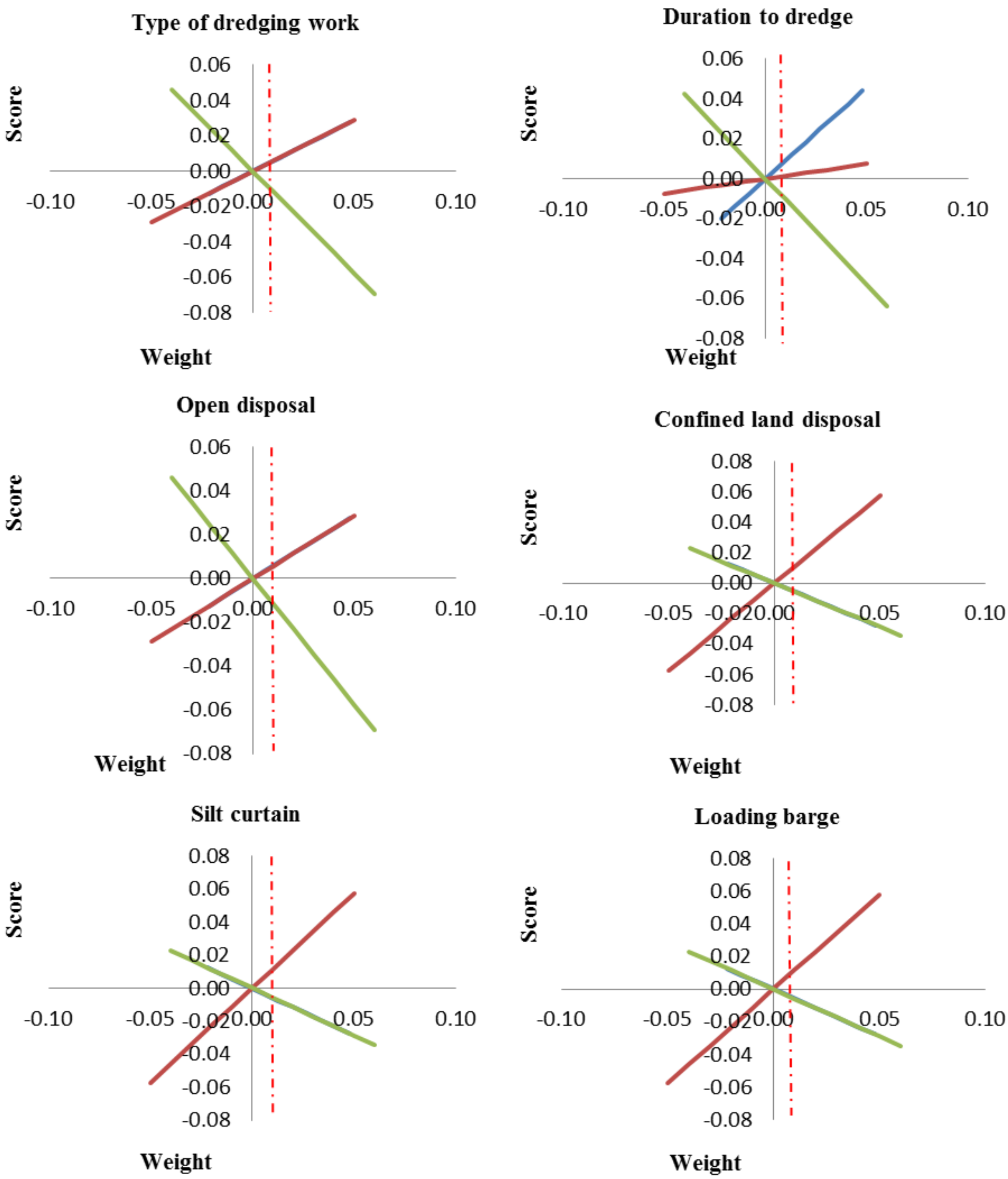


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued)*

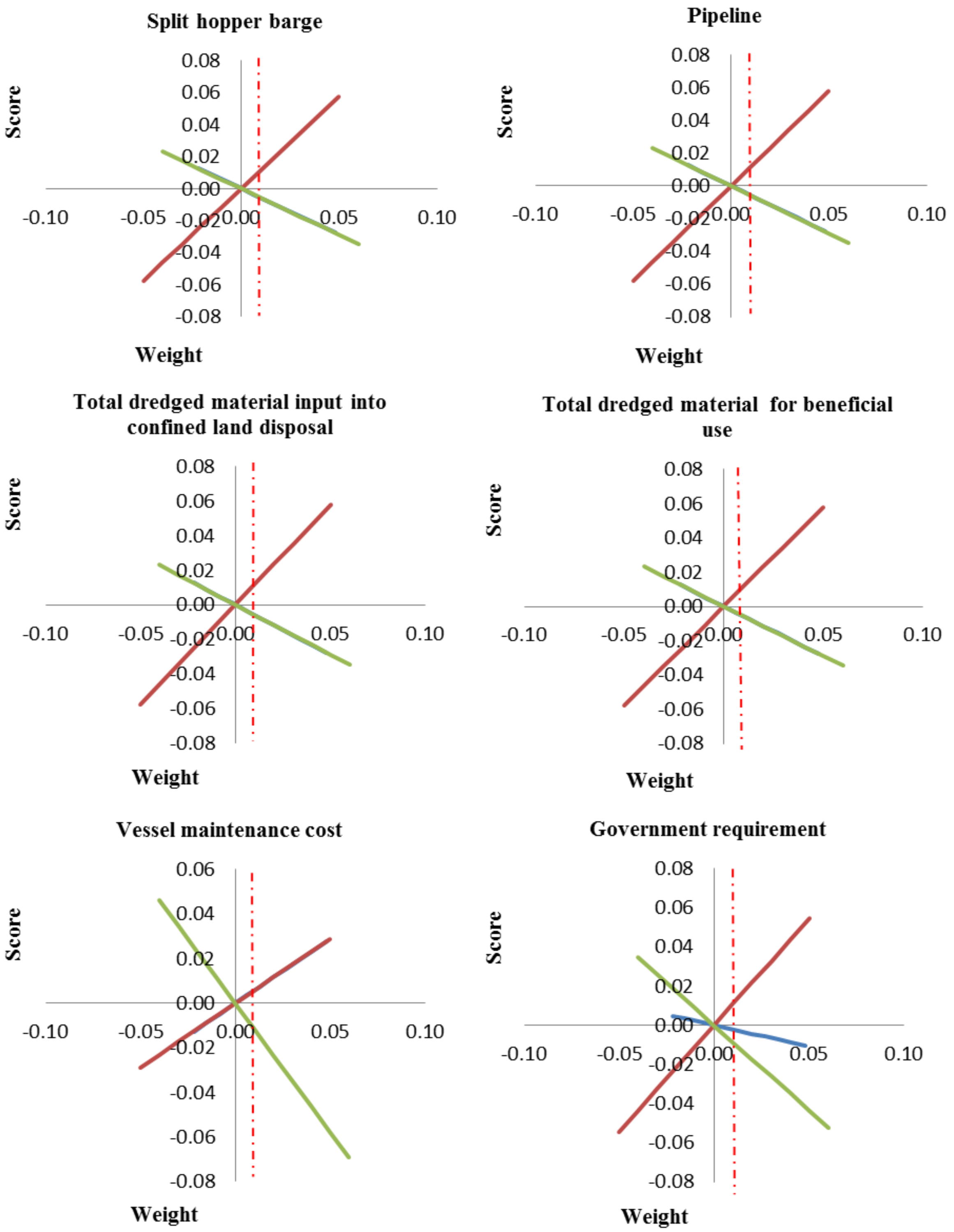


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued)*

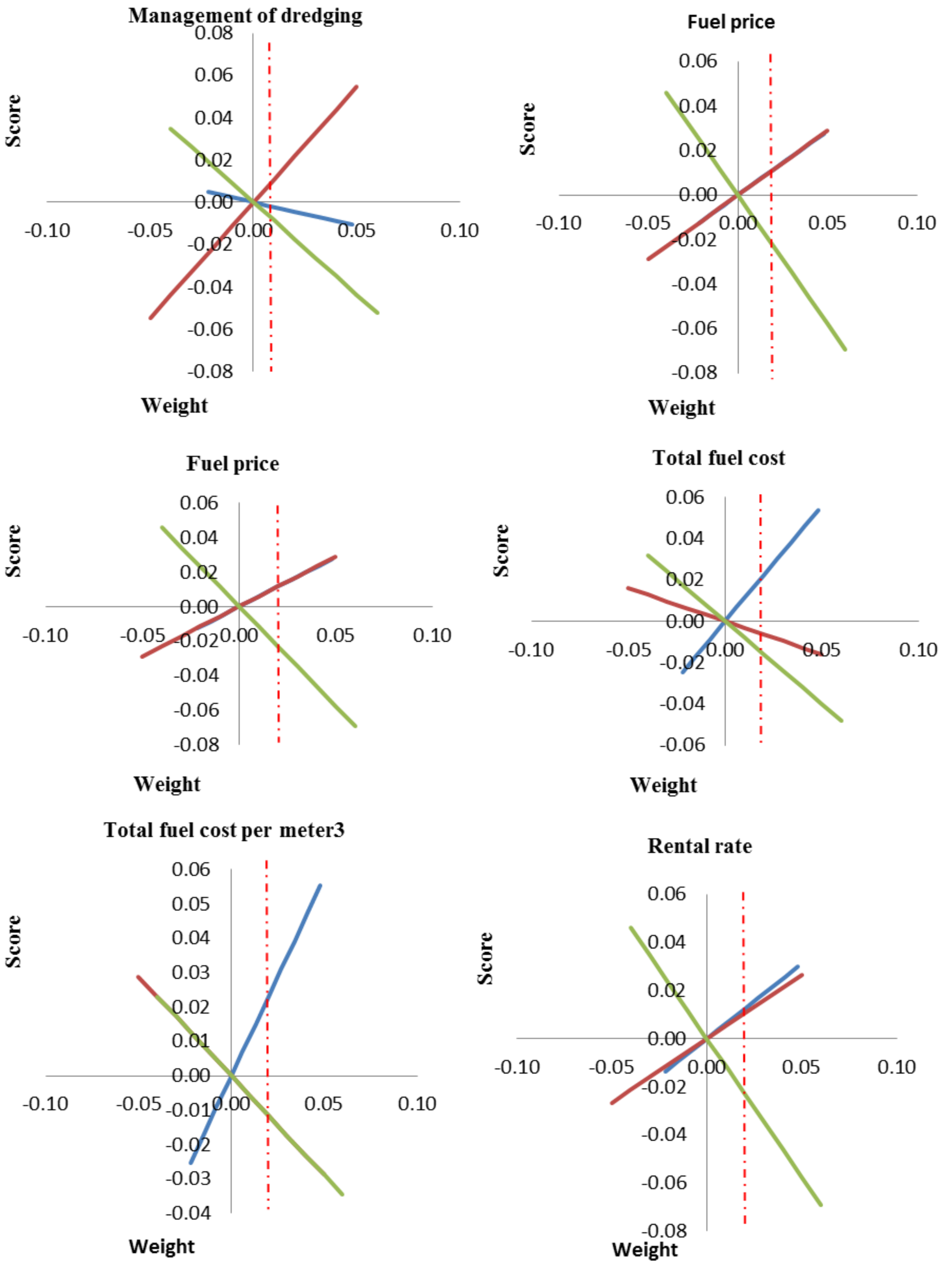


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued)*

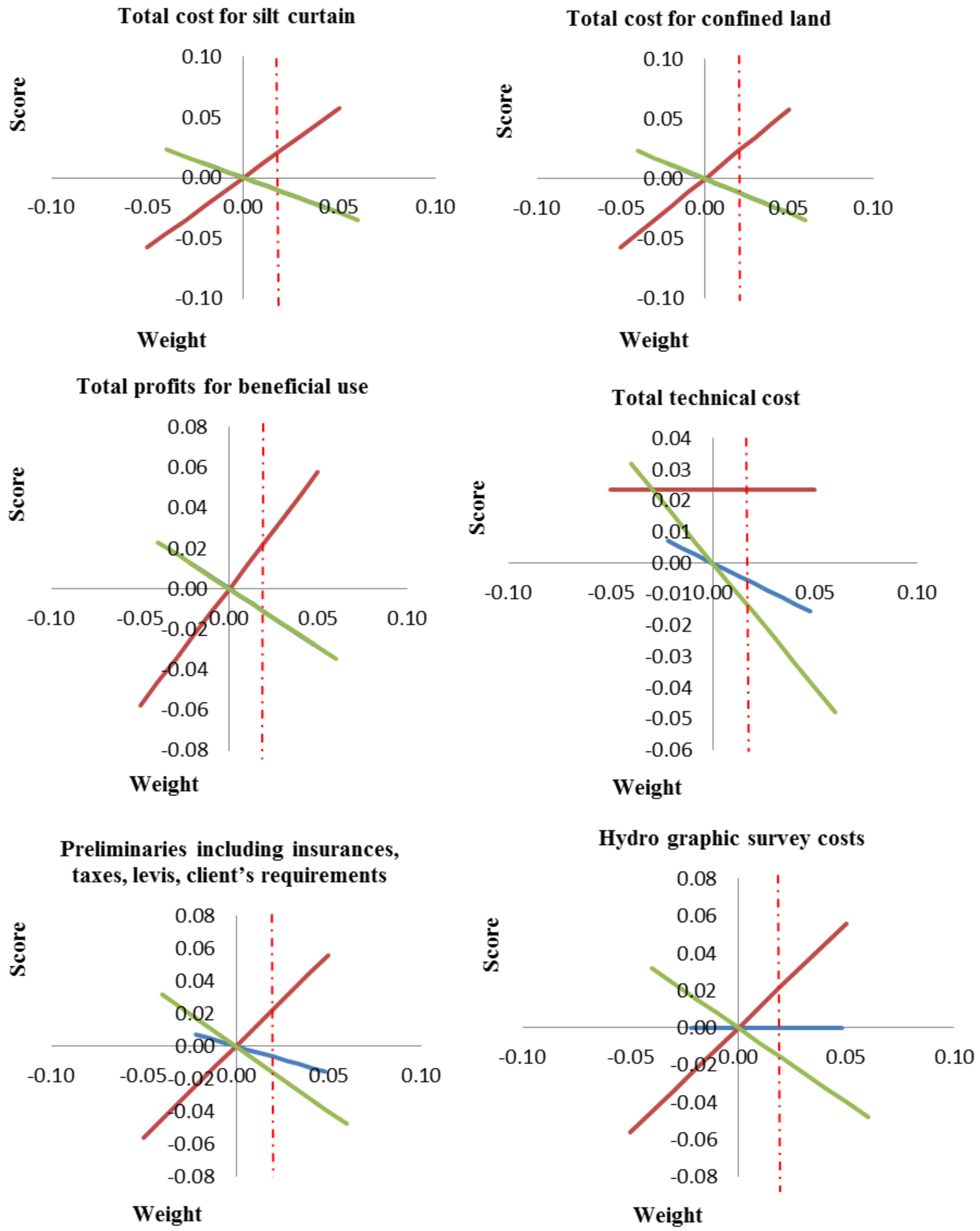


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued)*

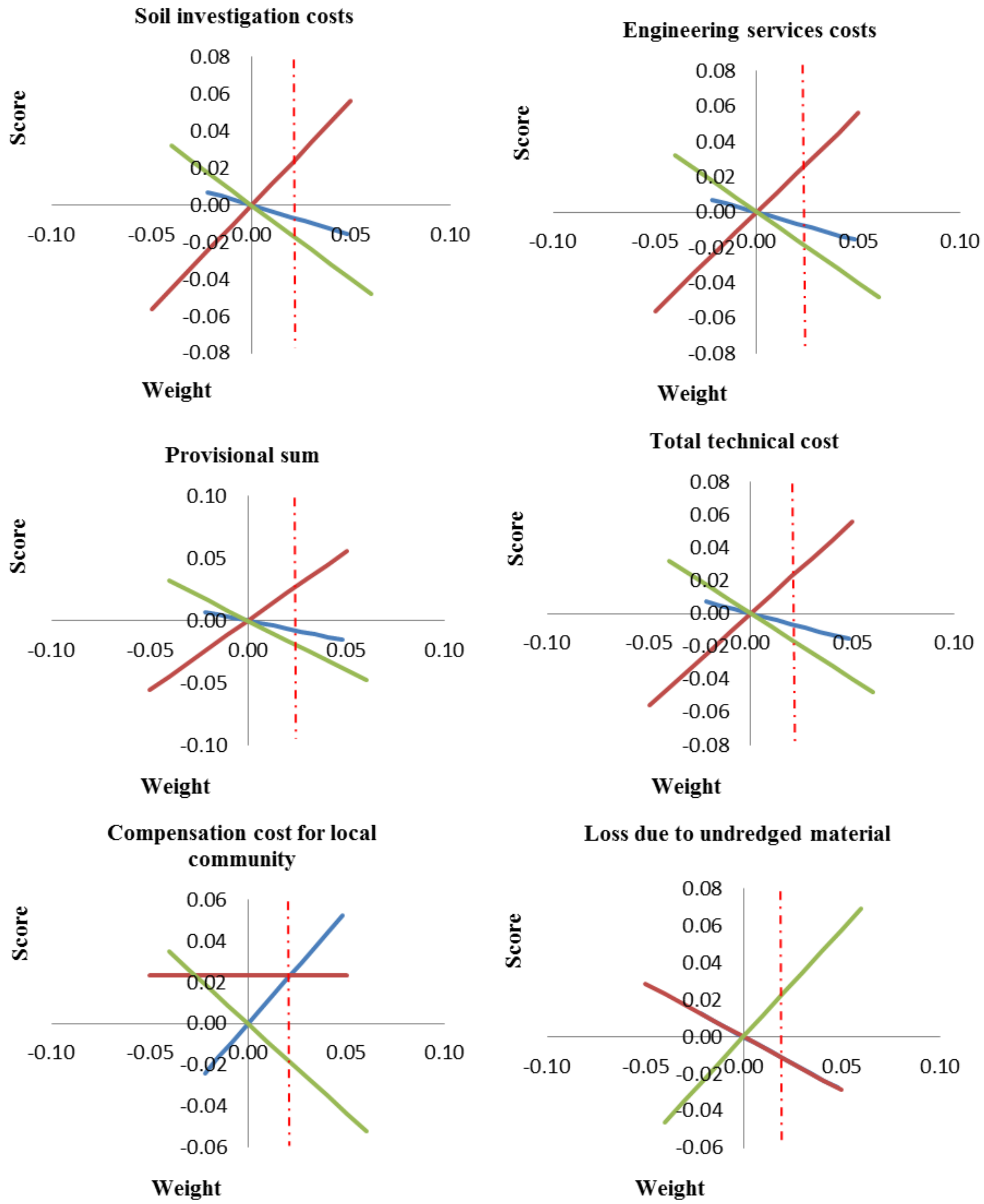


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued)*

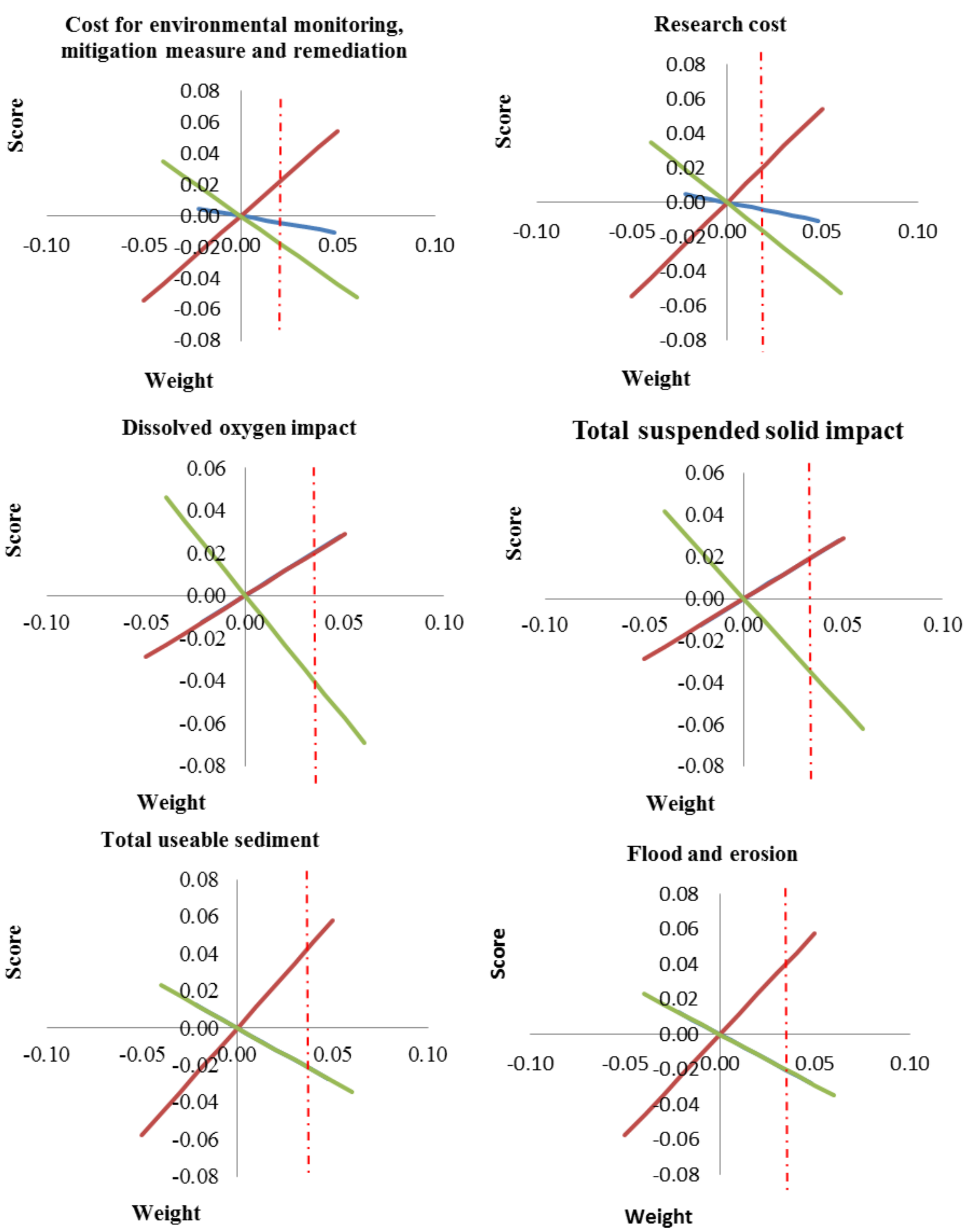


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued)*

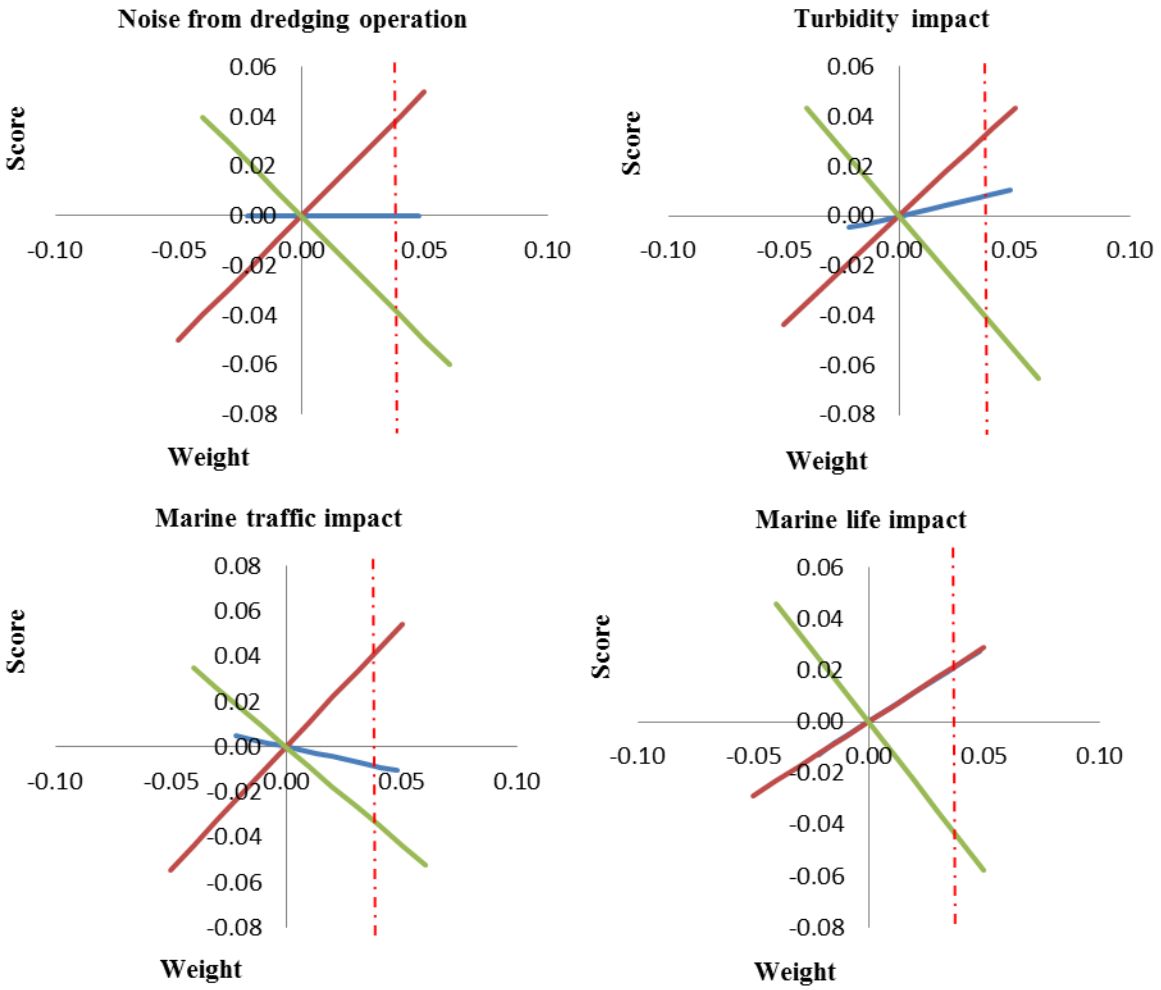


Figure F-9 Results of sensitivity analysis showing rankings of the options after variations of weights assigned to sub-criteria (*continued)*

<u>Legend:</u>