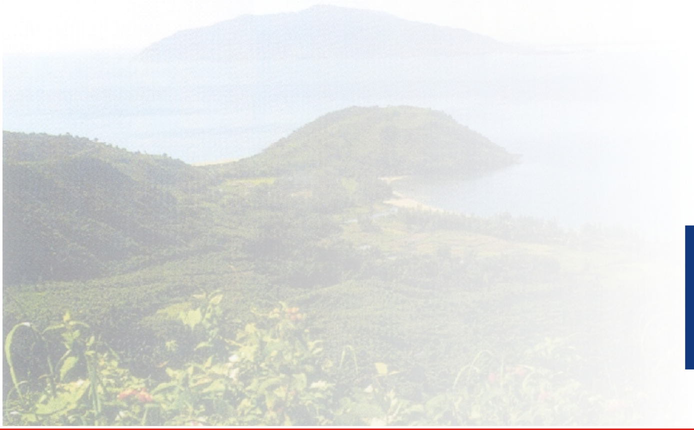

Danang

Initial Risk Assessment

Danang Initial Risk Assessment

Danang People's Committee

GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia

DANANG INITIAL RISK ASSESSMENT

July 2004

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MISSION STATEMENT

The Global Environment Facility/United Nations Development Programme/International Maritime Organization Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) aims to promote a shared vision for the Seas of East Asia:

> "The resource systems of the Seas of East Asia are a natural heritage, safeguarding sustainable and healthy food supplies, livelihood, properties and investments, and social, cultural and ecological values for the people of the region, while contributing to economic prosperity and global markets through safe and efficient maritime trade, thereby promoting a peaceful and harmonious co-existence for present and future generations."

PEMSEA focuses on building intergovernmental, interagency and intersectoral partnerships to strengthen environmental management capabilities at the local, national and regional levels, and develop the collective capacity to implement appropriate strategies and environmental action programs on self-reliant basis. Specifically, PEMSEA will carry out the following:

- build national and regional capacity to implement integrated coastal management programs;
- promote multi-country initiatives in addressing priority transboundary environment issues in sub-regional sea areas and pollution hotspots;
- reinforce and establish a range of functional networks to support environmental management;
- identify environmental investment and financing opportunities and promote mechanisms, such as public-private partnerships, environmental projects for financing and other forms of developmental assistance;
- advance scientific and technical inputs to support decision-making;
- develop integrated information management systems linking selected sites into a regional network for data sharing and technical support;
- establish the enabling environment to reinforce delivery capabilities and advance the concerns of non-government and community-based organizations, environmental journalists, religious groups and other stakeholders;
- strengthen national capacities for developing integrated coastal and marine policies as part of state policies for sustainable socio-economic development; and
- promote regional commitment for implementing international conventions, and strengthening regional and sub-regional cooperation and collaboration using a sustainable regional mechanism.

The twelve participating countries are: Brunei Darussalam, Cambodia, Democratic People's Republic of Korea, Indonesia, Japan, Malaysia, People's Republic of China, Philippines, Republic of Korea, Singapore, Thailand and Vietnam. The collective efforts of these countries in implementing the strategies and activities will result in effective policy and management interventions, and in cumulative global environmental benefits, thereby contributing towards the achievement of the ultimate goal of protecting and sustaining the life-support systems in the coastal and international waters over the long term.

Dr. Chua Thia-Eng
Regional Programme Director
PEMSEA

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List of Abbreviations and Acronyms

ADB	–	Asian Development Bank
ASEAN	–	Association of Southeast Asian Nations
BOD	–	Biochemical oxygen demand
BOF	–	Branch of Forestry
CN	–	Cyanide
CNSN	–	Center of National Science and Nature
COD	–	Chemical Oxygen Demand
CPUE	–	Catch per unit of effort
DAO	–	DENR Administrative Order
DDE	–	Dichlorodiphenyldichloroethylene
DDT	–	Dichlorodiphenyltrichloroethane
DFAF	–	Department of Fishery, Agriculture and Forestry
DNEPA	–	Danang Natural Resources and Environmental Protection Association
DO	–	Dissolved oxygen
DOSTE	–	Department of Science, Technology and Environment (now the Department of Science and Technology or DOST)
DSB	–	Danang Statistic Branch
DU	–	Danang University
EIA	–	Environmental Impact Assessment
ERA	–	Environmental Risk Assessment
GEF	–	Global Environmental Facility
Gm	–	Geometric mean/Geomean
HP	–	Horsepower
HPOI	–	Hai Phong Oceanography Institute
ICM	–	Integrated Coastal Management
IMO	–	International Maritime Organization
IRA	–	Initial Risk Assessment
ISQV	–	Interim sediment quality values of Hong Kong
LC_{50}	–	Lethal concentration that causes death in 50 percent of an exposed population
LOC	–	Level of concern
MEC	–	Measured environmental concentration
MEL	–	Measured environmental levels
MOF	–	Ministry of Fisheries
MOH	–	Ministry of Health
MPN	–	Most probable number
NEA	–	National Environment Agency
NH_3	–	Ammonia
NH_4	–	Ammonium
NH_4-N	–	Nitrogen in the form of ammonium
NO_2	–	Nitrite
NO_2 -N	–	Nitrogen in the form of nitrite
NO_3	–	Nitrate
NO_3-N	–	Nitrogen in the form of nitrate

NOAEL	–	No observed adverse effect level
N_{Total}	–	Total nitrogen
PAH	–	Polycyclic aromatic hydrocarbon
PCB	–	Polychloro biphenyl
PEC	–	Predicted environmental concentration
PEL	–	Predicted environmental levels
PEMSEA	–	Partnerships in Environmental Management for the Seas of East Asia
PMO	–	Project Management Office
PNEC	–	Predicted no-effect concentration
PNEL	–	Predicted no-effect level
PO_4	–	Phosphate
PO_4-P	–	Phosporus in the form of phosphate
ppm	–	parts per million or mg/l
ppt	–	parts per thousand or µg/l
P_{Total}	–	Total phosporus
RPO	–	Regional Programme Office
RQ	–	Risk quotient: MEC (or PEC)/PNEC (or Threshold)
RQ_{Gm}	–	Mean risk quotient: MEC (or PEC)$_{Geo}$/PNEC (or Threshold)
RQ_{Max}	–	Maximum risk quotient: MEC (or PEC)$_{Max}$/PNEC (or Threshold)
RQ_{Min}	–	Minimum risk quotient: MEC (or PEC)$_{Min}$/PNEC
TBT	–	Tributyltin
TDE	–	1,1-dichloro-2,2-bis(4-chlorophenyl)ethane (also known as DDD – dichlorodiphenyldichloroethane)
TDI	–	Tolerable daily intake
TNT	–	Trinitrotoluene
TOC	–	Total organic carbon
TSS	–	Total suspended solids
UNDP	–	United Nations Development Program
URENCO	–	Urban Environmental Company
USEPA	–	United States Environmental Protection Agency
USFDA	–	United States Food and Drug Administration
VCEP	–	Vietnam-Canada Environmental Project
VNS	–	Vietnam National Standards
WWF	–	World Wide Fund for Nature

Preface

Danang is one of the most important economic growth centers of Central Vietnam. While the economic development opportunities are promising, the City is facing a string of environmental problems that impact not only on public health but also on the environment. There is now a growing awareness that management measures must be stepped up to arrest or reverse the declining environmental conditions. The application of management tools, such as risk assessment, where the state of the environmental condition is assessed and areas that require management interventions are identified, is currently gaining wider recognition.

A training course on Environmental Risk Assessment was organized and conducted by GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) on 3-8 December 2001 in Danang as one of the component activities of the Danang National Integrated Coastal Management (ICM) Demonstration Site Project. Members of the Environmental Risk Assessment Team, including representatives of various state management agencies such as environment, fishery, agriculture, forestry and health as well as representatives from key research institutions in Danang, attended the training course. A preliminary risk assessment report was generated at the end of the training course including action plans for completing the Initial Risk Assessment (IRA).

This publication presents the results of the IRA, which was completed based on available scientific information on the marine and coastal resources and environment of Danang City. Priority environmental concerns for management actions were identified, including data gaps and uncertainties that need to be addressed through comprehensive environmental monitoring program. Recommendations were also drawn up focusing on the best management options that would address the identified risks.

This initiative not only emphasized the importance of cross-sectoral and inter-agency collaboration but it also provided essential scientific information for informed decision-making. Hopefully, the body of knowledge generated from this initiative will be put to good use and will also pave the way for more detailed scientific studies for the sustainable development of Danang City.

Mr. Hoang Tuan Anh
Chairman
People's Committee of Danang City

Dr. Nong Thi Ngoc Minh
Vice-Chair
People's Committee of Danang City

Acknowledgments

A Preliminary Risk Assessment report was prepared during the Training Course on Environmental Risk Assessment organized by PEMSEA and held from 3-8 December 2001 in Danang, Vietnam.

Based on the Preliminary Risk Assessment report, the Risk Assessment Team prepared the IRA for the Danang coastal area. The report represents one component activity of the Danang National ICM Demonstration Site Project, which is being implemented in collaboration with several government departments and agencies in Danang. The Danang National ICM Demonstration Site Project and the PEMSEA Regional Programme Office (RPO) jointly coordinated these efforts.

The contributions of the following are deeply appreciated:

Mr. Alexander T. Guintu and Ms. Cristine Ingrid S. Narcise of PEMSEA RPO, the resource persons for the course;

Various offices in Danang City, which provided data to complete the preliminary environmental risk assessment for the Danang coastal area;

The participants to the Training Course on Environmental Risk Assessment: from the Danang Department of Science, Technology and Environment, Mr. Tran Manh Cuong, Ms. Nguyen Thi Kim Ha, Mr. Dang Quang Vinh, Mr. Do Manh Thang, Ms. Pham Thi Chin, and Mr. Nguyen Chuong Duc; from Danang Department of Health, Mr. Nguyen Van Lanh and Mr. Dang Ngoc Hung; from Danang Branch of Statistic, Mr. Nguyen Thanh Su; from Danang Department of Fishery, Forest and Agriculture, Mrs. Le Hoang Thuy, Mr. Phan Van My, Mr. Le Manh Tien, and Mr. Le Duc Dung; from Danang Environmental Protection Center, Mr. Tran Phuoc Cuong and Ms. Nguyen Thi My Linh; from Port Authorities, Mr. Nguyen Truong Binh; from the Danang Environmental Engineering Center, Mr. Phan Nhu Thuc; from Branch of Water Resource Management and Flood Prevention, Mrs. Nguyen Thi Dao; and from the Department of Construction, Mr. Nguyen Van Sy;

The Risk Assessment Team which conducted the initial risk assessment led by Mr. Nguyen Dinh Anh from the Department of Science, Technology and Environment;

Dr. Nguyen Minh Son, Center for Marine Environment Survey, Research and Consultation, for technical assistance during the training and in refining the draft reports.

Dr. Nong Thi Ngoc Minh, former director of the Project Management Office (PMO) and the PMO Staff for technical and administrative support.

The staff of PEMSEA RPO including Ms. Cristine Ingrid S. Narcise and Ms. Nancy Bermas for technical refinements of the document draft; Mr. S. Adrian Ross, Senior Programme Officer and Technical Coordinator for providing guidance throughout the study, and Dr. Jihyun Lee, the Principal Coordinator of the Danang National ICM Demonstration Site Project.

Executive Summary

Potential harm to human and environmental targets may arise from exposure to contaminants in the environment. These contaminants come from activities that bring economic growth and contribute benefits to society. The potential harm to environmental targets may also arise from the indiscriminate extraction of resources and the physical destruction of habitats. The environmental impacts of these activities stem from the loss of ecological functions and consequent disruption of the ecological balance. The impacts may not be as evident as impacts from pollutants, but may be irreversible and may lead to greater losses.

The Environmental Risk Assessment (ERA) estimates the likelihood of harm being done to identified targets because of factors emanating from human activities, but reaching the targets through the environment. This combines knowledge about the factors that bring about hazards, their levels in the environment, and the pathways to the targets.

There can be two approaches to protect the environment and human health. The first approach is to eliminate the contaminant or stop the activities that produce it. Another approach is to prevent the contaminant level from exceeding an allowable level that presents an acceptable risk. The elimination of contamination to zero concentration may require large investments, and discontinuing the economic activities may hinder the delivery of goods and services that contribute to human welfare and economic development.

The second approach, the risk-based methodology, presumes that there are contaminant levels in the environment that present low or acceptable risks to human health and the environment, and that there is not always a need for zero-emission levels. Scientific studies have specified threshold values below which adverse effects are not likely to occur. This implies that economic development activities can be managed at levels that promote human health and environmental protection, yet maintain activities that produce economic benefits. This emphasizes the importance of cost-benefit analyses in sustainable development initiatives.

The risk assessment attempted to answer two questions: "what evidence is there for harm being done to targets in the coastal area?" (Referred to as the Retrospective Risk Assessment) and "what problems might occur as a consequence of conditions known to exist, or possibly exist in the future?" (Referred to as the Prospective Risk Assessment).

To answer these questions, it is necessary to identify appropriate targets, assessment endpoints, and corresponding measurement endpoints. Assessment endpoints are features related to the continued existence and functioning of the identified targets such as community structure or diversity, production, density changes and mortality. These, however, may not be easy or would take much time to measure. Therefore, other features related to the assessment endpoints, and which are easier to measure, are used instead. These are called measurement endpoints. For the earlier mentioned assessment endpoints, the corresponding measurement endpoints are the presence of indicator species (for community structure/diversity), biomass (for production), abundance (for density changes), and LC_{50} or biomarkers (for mortality) (MPP-EAS, 1999a).

The risk assessment of the site was conducted as a preliminary step to a more comprehensive risk assessment in the future. It provides a glimpse of environmental conditions in the coastal zone using available data. It serves as a screening mechanism to identify priority environmental concerns in the coastal zone, identifies data gaps and uncertainties and recommend areas for immediate management intervention or for further assessment. It identifies contaminants that present acceptable risks and hence, may not need further assessment, and highlights contaminants that present risks to the environment and/or to human health. It also identifies resources and habitats that are at risk and recognizes significant causes of risks. The results of the initial risk assessment will be used to formulate an action plan for a more comprehensive risk assessment that is focused on the identified priority areas of concern. Evaluating the results of the initial risk assessment will also facilitate improvement and refinement of the methods used.

The initial risk assessment also draws attention to the importance of collaboration among the different government agencies, universities and scientific and technical research institutions and the roles that these groups may undertake in the risk assessment. The wide range of expertise and knowledge of these different groups would contribute to the efficient conduct and success of the risk assessment. A mechanism to facilitate the sharing of information and the access to existing data should also be put in place.

The results of the risk assessment — what is at risk and how it can be protected against the risk — are essential to ensure its sustainability. Risk assessment as a management tool is expected to play a significant role in strengthening marine pollution risk management.

In risk management, options for addressing priority environmental concerns are identified. The benefits and costs to society of employing the identified management options are considered as well as stakeholder consensus on appropriate management interventions.

In this study, environmental risk assessment was carried out for Danang City's coastal zone which covers six districts: Hai Chau, Thanh Khe, Hoa Vang, Ngu Hanh Son, Lien Chieu and Son Tra, which include watersheds draining to Danang coastal zone from surface water areas such as lakes and rivers – headwaters of rivers from the mountains and hilly areas in Danang City (Appendix 1). The contiguous boundaries of the coastal zone including Quang Nam province and Hue City were also assessed in this report.

Danang City (mainland) is located in the area bounded by coordinates 15°55′15′′ to 16°13′15′′ latitude and 107°49′ to 108°20′18′′ longitude. Thua Thien Hue Province borders the city on the north, Quang Nam Province on the south and the west of the city and East Sea on the east of the city. Hoang Sa Islands border the East Sea, lying inside the coordinates 15°30′ to 17°12′ latitude and 111°30′ to 115°00′ longitude. Danang City is composed of seven districts (Hai Chau, Thanh Khe, Lien Chieu, Son Tra, Ngu Hanh Son, Hoa Vang and Hoang Sa) with 47 communes. The total area of natural land is 1,248.4 km^2, including urban areas (205.87 km^2), rural areas (1,042.5 km^2) and Hoang Sa Islands (305 km^2).

Danang has a coastline of approximately 90 km, of which, more than 30 km are used for tourism activities. The average depth of Danang Bay is from 10 m to 20 m and its slope is very high, from 0.0017 to 0.0083 (HPOI, 1997).

The population of Danang City as of 2001 is approximately 728,823 persons (Yearbook, 2001). Economic activities consist of marine fisheries and aquaculture and various secondary and manufacturing industries.

The results of the retrospective and prospective risk assessments are summarized in the following sections.

RETROSPECTIVE RISK ASSESSMENT

In the retrospective risk assessment, qualitative and quantitative observations on the resources and habitats were assessed in reference to earlier observations to determine if there are significant changes, particularly for declines. Potential agents were identified and the likelihood that these agents caused the impacts on the resources and habitats were determined (Appendix 2).

Data for the retrospective assessment were mostly taken from the *Environmental Profile of Danang City* (DOSTE, 2000), the Annual Reports on Environmental Status (DOSTE, 1994-2001), and the Annual Reports from the Department of Fisheries, Agriculture and Forestry (DFAF, 1997-2001). Other sources of information include some environmental studies on the Danang coastal zone undertaken from 1990 to 1997. The list of information sources for each target is given in Appendix 3.

The resources considered include: 1.) marine fisheries; 2.) aquaculture; and 3.) phytoplankton. For the habitats, the following were assessed: 1.) coral reefs; 2.) seagrasses; 3.) sandy beaches; rocky shores; riverbanks; 4.) wetlands; 5.) soft-bottom; and 6.) forest resources.

Results

Clear evidence of decline was established for aquaculture, sandy beaches, wetlands and forests. For marine fisheries, data on yield or catch per unit of effort (CPUE) were not available to determine decline, but the declining status of marine fisheries was inferred from other related information. For phytoplankton, coral reefs, seagrasses, rocky shores and soft-bottom communities, there was no evidence to indicate decline.

For the decline in aquaculture, the identified primary agents are parameters associated with industrial activities such as dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil and grease, heavy metals, total suspended solids (TSS), nutrients and coliform. Among these agents, low DO was identified as the main agent that caused fish kills in Tram and Mac Lakes. The excessive contamination of the water column with organic substances in aquaculture areas in these lakes has increased the susceptibility of shrimps to diseases. Other causes of decline in aquaculture are extensive farming, lack of technical knowledge, and lack of wastewater treatment facilities.

For sandy beaches, the identified primary agents of decline were reclamation, construction work and forest devastation. Among these agents, construction work along the coastal area was identified as a very likely agent causing the decline of sandy beaches. Reclamation and forest devastation were identified as possible agents.

For forest cover, clearing of land for farming, illegal cutting of trees and tourism development have contributed to the observed decline. For forest fauna, hunting, forest fire and decreasing forest cover were identified as the likely agents causing the decline of species. In addition, unsustainable forest exploitation and toxic chemicals have contributed to serious decline of forest areas as well as the number of valued forest products. The risk assessment of forest resources was conducted to assess the loss of habitats, loss of economically and ecologically valued species, potential effects on the climate through greenhouse effect and potential impacts on ecological balance.

For wetlands, which include lakes, swamps, river shores and tidal flats located along the coasts and river mouths, the destruction of forests in the watersheds and unregulated sand mining along the rivers are identified as agents causing decline of river shores. For some of the lakes in the urban areas, construction activities and the discharge of solid waste into the lakes are considered agents causing the decline of lakes. The consequences of wetland area decline include damages to infrastructure, flooding in low-lying areas of Danang City, loss of valuable habitats, and reduction of the function of river systems and lakes in regeneration of microclimate in urban areas.

For coral reefs, separate surveys in different areas report about declining conditions although no comparative evidence of decline was available for this risk assessment. Potential agents that could cause coral reef decline in the Danang coastal zone were, however, identified. The agents range from chemical to physical and biological, such as TSS, BOD/COD, oil and grease, cyanide, sedimentation, destructive fishing, physical disturbance, illegal exploitation, port dredging, algal overgrowth and predation. A systematic coral reef survey will be needed to establish decline and identify the primary agents. Coral reef decline will lead to loss of biodiversity, decreased fisheries productivity, reduced tourism potential and decrease in physical protection provided by coral reefs to other components of the ecosystem.

For rocky shores, seagrasses, fishery and soft bottom, retrospective risk assessment could not be performed due to lack of information on previous extent of cover and distribution in the Danang coastal zone.

PROSPECTIVE RISK ASSESSMENT

In the prospective risk assessment, the identified potential stressors and the Measured Environmental Concentrations (MECs) are compared with the threshold values or Predicted No-Effect Concentrations (PNECs) to obtain Risk Quotients (RQs). An RQ of less than 1 indicates acceptable risk and suggests little concern, while an RQ greater than 1 signifies cause for concern. The level of concern increases with an increase in RQ.

For the assessment of ecological risk, RQs were obtained using water column data from Danang Bay and South Son Tra - Ngu Hanh Son Coastal Water; Cu De, Phu Loc and Vu Gia rivers; and Rong, Tram, Thac Gian-Vinh Trung and March 29 Park Lakes. For the human health risk assessment, the data from Cau Do River and Green Lake, both sources of water for domestic supply, and ground water (wells) were used.

The primary source of information for the prospective risk assessment was the environmental monitoring data (Danang DOSTE and NEA, 1994-2000). Other references used were the EIA reports, environmental monitoring report of VCEP (1997-1998) and the periodic reports of industries on the environment (1996-2001). A detailed list of the sources of data for each parameter, including descriptions of the data and sampling stations, is given in the respective sections for each parameter. A summary table on sources of data and thresholds applied for all parameters is given in Appendix 3.

Most of the data used were presumed to be accurate and reliable although preliminary screening was done for some data for which ranges of concentrations in different environmental conditions was known.

In Danang City, two environmental monitoring programs have been conducted by DOSTE and NEA since 1994. The activities covered the quarterly monitoring of 26 stations for fresh water column parameters and 6 stations for seawater column parameters. For the sea monitoring stations, there were five near-shore stations and one station at the mouth of Danang Bay. In addition to the periodic monitoring stations, various isolated locations have also been sampled in the water column. There were no available data for fish tissue.

The threshold values or PNECs for water quality were from the Vietnam National Standards for Surface Water Quality (VNS 5942-1995); Coastal Water Quality (VNS 5943-1995); and Ground Water Quality (VNS 5944-1995). Some international criteria or standards were also used to assess water quality, such as the Marine Water Quality Criteria of ASEAN, (ASEAN, 2003) and the Water Quality Criteria for the Philippines (DAO 34, 1990).

The threshold values or PNECs for human health were the Vietnamese Standards of the Ministry of Health (MOH, 505-1995). Seafood consumption rates were available from the Department of Fisheries, Agriculture and Forestry although monitoring data in seafood tissue were not available. The list of Vietnam National Standards is provided in Appendix 4. The list of international criteria and standards is presented in Appendix 5.

Average and worst-case (maximum) risk quotients from water-borne substances were calculated and used for comparative risk assessment. Comparative risk assessment provides a wide perspective through the average RQs and a hotspot perspective through the worst-case RQs. It also shows the relative concern among the different chemical contaminants. This approach is conservative in that the worst-case conditions are presented. It also effectively screens out contaminants when the worst-case concentrations still do not indicate significant cause for concern, and this is the value of the initial risk assessment.

Results

The following are the comparative risk assessment results of both human health and ecological risks. Risk agents are classified either as priority risks or localized risks. Priority risk agents were determined on the basis of RQ_{Gm} exceeding 1. Localized risks were indicated by RQ_{Max} that exceeded 1. The ranking of priority or localized risks was done based on the order of magnitude of RQs as presented in the comparative RA tables. Agents for which risks are acceptable (RQ_{Max} < 1) are also presented.

Human Health Risk

For human health, there is a cause for concern as a consequence of coliform contamination in bathing beaches, rivers and lakes and in fresh surface water and ground water used for domestic water supply (i.e., Cau Do River, Green Lake and wells). Concern associated with levels of nutrients such as nitrogen in the form of ammonia and nitrate (NH_4-N, NO_3-N), certain heavy metals like mercury (Hg), iron (Fe), lead (Pb) and arsenic (As), and cyanide (CN^-) in ground water and surface waters is also evident.

The detailed prioritization of risk agents in waters used for domestic supply is as follows:

RQ	Well Water	Cau Do River	Green Lake
RQ_{Gm} > 1	Coliform > Fe > BOD > As (n = 1)	NH_4-N > NO_2-N, BOD, DO	NH_4-N, Hg (n = 1), DO
RQ_{Max} > 1	NH_4-N, NO_3-N, Pb > CN^-, Hg, SS, Cl^-	Coliform, TSS, COD, Fe	Coliform > NO_3-N, BOD, COD, CN^-
RQ_{Max} < 1	Cu, Zn, Cd	NO_3-N, Hg, Pb	Pb, Fe, Cu, Zn, As (n = 1), Cd (n = 1), Mn (n = 1)

The high levels of coliform in the Danang City wells suggest contamination with human and animal fecal material. The highest measured concentration was 2,200,000 MPN/100 ml, while the geometric mean was 210 MPN/100 ml (n = 74). In well water, Fe, organic load (indicated by BOD) and As (n = 1) were also identified as priority concerns, while nutrients Pb, CN^-, Hg, suspended solids and Chloride (Cl^-) were among the localized concerns.

In surface waters used as sources of domestic water supply, such as Cau Do River and Green Lake, mean RQs for NH_4-N and DO show cause for concern. Nitrogen in the form of nitrite (NO_2-N) and BOD are also priority concerns in Cau Do River, while a single data on Hg in Green Lake shows cause for concern (RQ = 10) and the need to verify levels of Hg in the area. On the basis of maximum RQs, localized risk was shown for coliform in both areas; TSS, COD and Fe in Cau Do River; and NO_3-N, BOD, COD and CN^- in Green Lake. The risk for Hg was acceptable in Cau Do River but CN^- was not assessed due to lack of data.

In sea, river and lake water, coliform has generated the highest mean RQs among all water column parameters assessed for all the areas covered, with the exception of Cu De River where the mean RQ less than 1 indicated localized concern.

The following table shows that among the rivers, the Vu Gia River System gave the highest RQs, while the RQs for Rong Lake showed serious cause for concern and the need for immediate management intervention.

Location	$RQ_{Geomean}$	RQ_{Max}
Seawater		
Danang Bay	15.84	500
South Son Tra - Ngu Hanh Son Coastal Water	6.96	600
River Water		
Cu De River	0.31	24
Phu Loc River	1.57	14
Vu Gia River System	4.14	200
Lake Water		
Rong Lake	164,402	2,800,000
Thac Gian-Vinh Trung Lake	1.75	36
Tram Lake	2.06	800
March 29 Park Lake	1.48	470

Ecological Risk

A separate assessment of ecological risks in coastal waters, rivers and lakes has shown that:

Seawater

For both Danang Bay and South Son Tra - Ngu Hanh Son Coastal Water, zinc (Zn) in the water column is a priority concern. Mercury, cyanide, and oil and grease are also priority concerns in the South Son Tra - Ngu Hanh Son Coastal Water while these are localized concerns in Danang Bay.

Conversely, Fe is a priority risk agent in Danang Bay while it is a localized risk agent in South Son Tra - Ngu Hanh Son Coastal Water. Other localized risk agents are NH_4-N, low DO, CN^- and Pb in both areas and copper (Cu), BOD and TSS in Danang Bay. In the South Son Tra - Ngu Hanh Son Coastal Water, risk is acceptable for TSS and Cu while there was no data on BOD. In addition to potential contamination from sewage and industries along the coast, these contaminants could also be linked to discharges from various rivers and lakes, since the same risk agents found in coastal waters were also found as priority agents in tributary rivers and lakes.

River Water

Oil and grease is a priority concern in Cu De, Phu Loc and Vu Gia Rivers. Other priority risk agents are Hg in Cu De River and phenol, NH_4-N and cyanide in Phu Loc River.

There is localized risk from cyanide in Cu De and Vu Gia Rivers, Hg in Phu Loc and Vu Gia Rivers, and organic load (BOD/COD), nutrients (NH_4-N and/or NO_3-N/NO_2-N) and other heavy metals in all rivers. This shows that the three rivers are, in varying degrees, contaminated with most of the identified risk agents, and point to the probability of similar pollution sources.

Seawater

RQ	Danang Bay	South Son Tra - Ngu Hanh Son Coastal Water
$RQ_{Gm} > 1$	Fe > Zn	Hg and cyanide > oil and grease and Zn
$RQ_{Max} > 1$	Hg, NH_4-N > oil and grease, TSS, DO, BOD, cyanide, Pb and Cu	Fe, NH_4-N, DO, Pb
$RQ_{Max} < 1$	As and Cd	TSS, Cu, As (n = 1) and Cd (n = 1)

River Water

RQ	Cu De River	Phu Loc River	Vu Gia River System
$RQ_{Gm} > 1$	Hg > oil and grease	Phenol (n = 1) > NH_4-N, cyanide, oil and grease	Oil and grease
$RQ_{Max} > 1$	NH_4-N, NO_3-N > cyanide, BOD, COD, As	Hg > Cd > COD, BOD, NO_3-N, TSS, Fe, As	Hg, CN^- > Cd > Fe, Cu, Pb, NH_4-N, NO_3-N, NO_2-N, BOD, COD, TSS, Mn
$RQ_{Max} < 1$	NO_2-N, DO, TSS, Phenol, Pb, Fe, Cu, Mn and Cr	DO, Pb, Cu, Zn, Mn (n = 1) and Cr (n = 1)	DO, Phenol, Zn, As, Cr, DDT and Total Pesticides

Lake Water

RQ	Rong Lake	Thac Gian-Vinh Trung Lake	Tram Lake	March 29 Park Lake
$RQ_{Gm} > 1$	Oil and grease, NH_4-N, DO > BOD, COD	NH_4-N, NO_2-N (n = 1) > BOD, COD, Oil and grease (n = 1)	Oil and grease, CN^- > Hg, COD, BOD	NH_4-N, Oil and grease > NO_2-N, COD, CN^-, Hg
$RQ_{Max} > 1$	CN^-, NO_3-N, TSS, Hg, Pb	Pb, Fe, TSS	NO_3-N, TSS, DO, Cd, Fe	DO, BOD, TSS, Pb
$RQ_{Max} < 1$	NO_2-N, Fe, Cu, Zn, As, Mn, Cr^{+6}	NO_3-N, DO, CN^- (n = 1), Hg (n = 1), Zn (n = 1), As (n = 1), Mn (n = 1), Cr^{+6} (n = 1)	NO_2-N, Pb, Cu, Zn, As (n = 1), Mn (n = 1), Cr^{+6} (n = 1)	NO_3-N, Fe, Cu, Zn, As (n = 1), Mn, Cd

<u>Lake Water</u>

All the lakes assessed are in polluted states. Oil and grease, organic load (BOD/COD) and nutrients (NH_4-N/NO_3-N) are priority ecological concerns in most if not all of the four lakes. Cyanide and Hg are also priority concerns in Tram and March 29 Park Lakes while these are localized concerns in Rong Lake. Other localized risk agents are TSS in all lakes and Pb in all lakes except Tram Lake. Acceptable risk was found for most other heavy metals although limited data were used in the assessment.

There is acceptable risk from heavy metals such as As and cadmium (Cd) in seawater; from pesticides, phenol, manganese (Mn), hexavalent chromium (Cr^{+6}) and Zn in river water; from Cu, Zn, Mn, As and Cr^{+6} in lake water; and from Cu, Zn and Cd in ground water.

Risk assessment for other potentially important parameters in the different bodies of water was not conducted because of lack or inadequacy of MECs and/or PNECs.

SUMMARY OF RISK ASSESSMENT RESULTS

The chief human health concern is drinking water from wells that are contaminated with coliform. This is followed by wells contaminated with Fe, BOD/COD and As. In surface waters, the concerns are nutrients and organic matter. Contamination of water in wells and in Green Lake with Hg and CN^-, even though localized, should also be a cause for concern since it puts human health, in specific locations, at risk.

For sea, river and lake waters, human health risk associated with bathing or direct contact with the water came out as the topmost concern in all areas assessed, with the exception of Cu De River where it is a localized concern.

Ecologically, oil and grease is a priority concern in all areas except in Danang Bay where the concern is localized. The relative prioritization of other risk agents, such as nutrients, organic matter (BOD/COD), Hg, CN, other specific heavy metals and TSS varies but the level of concern are higher in lakes than in rivers and coastal waters.

Decline in fisheries and aquaculture and degradation of coastal and marine habitats also provide cause for concern. Erosion of coasts threaten tourism through loss of sandy beaches. Erosion of riverbanks has contributed to the threat posed by floods and storms.

Water pollution, as well as the natural resources degradation, can be attributed to various human activities that directly or indirectly affect the aquatic environment (i.e., domestic, industrial, agricultural, commercial, fishery, aquaculture, forestry, mining, engineering works, tourism, etc.) and it indicates the limited effectiveness of current control measures to protect the environment.

At present, most of the industry and hospitals in the province do not have proper wastewater and/or hazardous waste treatment facilities, and the receiving areas are the drainage system and rivers. Inhabitants and small-scale enterprises along the rivers and coasts normally discharge domestic waste directly into the water. The drainage system of Danang City needs to be upgraded and wastes need to be treated. Fertilizers and pesticides used in agriculture are transported to coastal waters through run-off and the canal and river systems, and the dumping site in Danang is overloaded and has exceeded safety limits.

Concern has also been raised about the development of some small and medium-sized industries, which are not equipped with proper waste treatment facilities, and in residential areas. Expansion of land used for residential and industrial purposes, which impact on areas that have potential for tourism, is another issue; as is the concern for the conversion of wetlands for aquaculture purposes, which affect ecological balance and reduce natural protection. Finally, illegal forest exploitation, such as timber cutting and burning for land cultivation, and conflicting uses of land, sea coasts and river sides arising from the urbanization and economic developments in Danang are matters requiring management intervention.

The identified environmental concerns have had implications on the suitability of some of the waters for supporting aquatic life, agriculture, and domestic activities, and the severity of damages occurring from natural factors (e.g., floods and typhoons), with consequent ecological, social and economic losses. In particular, the contamination of ground water with the same pollutants that were found in surface waters suggests the need for immediate management interventions to prevent adverse effects to human health.

A case in point is Tram Lake, which receives discharges from adjacent industrial zones. RQ_{Gm} exceeded 1 for coliform, BOD, COD, oil and grease, cyanide and Hg, while RQ_{Max} exceeded 1 for NO_3, DO, TSS, Cd and Fe. A previous study (VCEP, 1998b) has linked the pollution of the entire lake with the discharges from the industries. The water in the lake, however, is also used for aquaculture and agriculture, and adverse effects such as fish kills and low crop yields were linked with the degraded state of the lake. Some wells were also found unsuitable for domestic use in the areas surrounding the lake, and potential linkages with the pollution of the lake water have been hypothesized. This demonstrates the seriousness of ecological and human health risks that may arise from the discharge of untreated wastes into the environment, and the likelihood that this condition exists or may arise in other similar settings is not unlikely.

Even activities in the watershed areas could contribute to pollution in the downstream areas. Gold mining activities in the mountains have been identified as one of the potential sources of cyanide and Hg that are elevated in most of the assessed water bodies.

With Danang City's orientation towards further economic development, the likelihood that environmental problems will intensify and pose further ecological and human health risks may increase unless environmental protection activities are well managed to assure sustainable development. Addressing all known environmental problems can be difficult, complicated and costly. This risk assessment, therefore, provides a systematic approach of determining priorities and developing recommendations for environmental management to ensure cost-effective utilization of resources and increase the benefits that can be derived from environmental management efforts.

Data Gaps

The risk assessment, aside from highlighting areas of concern, also identified the following potentially important data gaps:

1. For marine fisheries, there is a need to gather more information on CPUE for fishery, aquaculture yield, local consumption, and the shellfish industry in the Danang coastal zone.

2. More information on plankton, seaweed, seagrasses, rocky shores, and coral reefs.

3. For forests, there is a need to supplement information on the forest area at the watersheds and the annual forest productivity for every type of forest. There is also a need to gather more information on valuable species of animals and plants in the Danang coastal zone.

4. More information on phosphate in the water column, heavy metals, pesticides, cyanide, phenol and other toxic and persistent chemicals in the water column, fish tissue and sediment. Data on fecal coliform should also be collected.

5. Suitable threshold values for each target, especially threshold values on toxicity for human health and ecology. Lack of threshold values for PO_4-P, total N, total P and individual pesticides, for which measured concentrations were available, did not permit the assessment of risks from these parameters.

Sources of Uncertainty

1. MECs and PNECs

The risk quotients obtained and the conclusions drawn depend largely on the accuracy of the measured concentrations as well as the suitability of the threshold values that were used in calculating the risk quotients.

Considerable effort has been put to evaluate the reliability of the data used in the risk assessment although for some parameters, which had very few data, the risk assessment was done using the available data.

For the threshold values, uncertainty may arise from the use of criteria or standards that were specified for temperate regions or other locations. The suitability of these values in the tropics, particularly in the Danang coastal zone, still has to be verified.

2. Limited Data

The limited number of monitoring stations for all the parameters does not allow area-wide generalizations to be made. It would be safe to apply the statements only to the areas where measurements were taken.

3. Spatial and Temporal Variations

Worst-case conditions indicate potential hotspots. This would require analysis of spatial variability. Contaminant levels may also be affected seasonally so temporal variability should also be assessed.

The initial risk assessment was based on average and worst-case conditions. More detailed uncertainty analyses would be needed to clarify some of the assessments. Consideration of spatial and temporal variability in the data would enable more detailed and specific assessments to be made, such as determination of relationships between predominant human activities and levels of contaminants. This would be particularly useful in the identification of contaminant sources and setting up of interventions.

At this point, it would be wise to reiterate that the results of the risk assessment are not always representative of the entire water body. For some of the parameters, the data represented only certain areas within the site. A more in-depth analysis of the data in a refined risk assessment may be able to address this.

SUMMARY OF RECOMMENDATIONS

Various ecological and human health risk agents were identified through the risk assessment. Decline in marine resources and habitats have also been observed and linked to some specific human activities and parameters. Further consideration of various contaminant pathways needs to be undertaken to strengthen recommendations concerning immediate management interventions.

Nonetheless, the preliminary recommendations and action plans based on the results of the initial risk assessment are presented and discussed in the section on Recommendations and Proposed Actions.

The recommendations, in brief, are as follows:

On Human Health Risks

1. Prioritize the management of contaminants that present human health risks such as:

   a.) Coliform in Danang Bay, South Son Tra - Ngu Hanh Son Coastal Water, Phu Loc, Vu Gia and Cu De Rivers, Rong, Thac Gian – Vinh Trung, Tram, and March 29 Park Lakes

   Immediate risk reduction measures are a necessity for Rong Lake (RQ_{Gm} = 164,402)

   b.) Contaminants in well water column
   Priority ($RQ_{Gm} > 1$): Coliform > Fe > 1 BOD > As (n = 1)
   Localized ($RQ_{Max} > 1$): NH_4, NO_3, Pb > CN^-, Hg, TSS, Cl^-

   c.) Contaminants in surface water for domestic supply

   Cau Do River:
   Priority ($RQ_{Gm} > 1$): NH_4 > NO_2, BOD, DO
   Localized ($RQ_{Max} > 1$): Coliform, TSS, COD, Fe

Green Lake water column:
Priority (RQ_{Gm} > 1): NH_4, Hg (n = 1), DO
Localized (RQ_{Max} > 1): Coliform>
CN^-, NO_3, BOD, COD

In spite of the lesser concern that is usually attached for contaminants for which RQ_{Max} > 1, the toxicity of parameters such as Hg, CN^-, and Pb that are present in some sources of water used for human consumption (particularly wells) necessitates immediate actions to identify and prevent further use of the affected areas.

Risks to human health from coliform contamination

2. Confirm baseline information on the impact of sewage discharges into freshwater, South Son Tra - Ngu Hanh Son Coastal Water or Danang Bay.

    a.) Collect and analyze information on morbidity and mortality rate regarding water-borne diseases in communities in the Danang coastal zone.

    b.) Gather more data on coliform contamination or coliform loadings, including fecal coliform, for all main water sources.

3. Undertake measures to prevent human health problems arising from coliform contamination of coastal waters, rivers, lakes, and wells. Short-term recommendations include:

    a.) Control fish and shellfish supply from contaminated sources and regulate the use of contaminated beaches and bathing stations.

    b.) Conduct communication campaigns on the results of monitoring and establish other measures to prevent possible human impacts caused by contaminated waters and food.

The following management recommendations are designed to address the root cause of water contamination in the Danang coastal zone. These recommendations will be part of the risk management program.

a.) Accelerate sewage collection and treatment programs in the entire watershed particularly in urban and industrial areas.
b.) Eliminate direct and indirect discharges of untreated sewage into receiving waters.

c.) Gather more data on coliform contamination or coliform loadings, including fecal coliform, for all main water sources; conduct routine monitoring of water and shellfish in aquaculture areas, fish and shellfish sold in market places, and waters in beaches or contact recreation areas.

d.) Perform benefit-cost analysis to identify appropriate interventions.

Risks to human health from heavy metals and cyanide

4. Identify specific areas, particularly wells, where there is concern for heavy metal and cyanide levels in order to prevent further use of contaminated water and protect the users, and to facilitate the identification of contaminant sources.

5. Set up a properly designed long-term environmental monitoring program for heavy metals, cyanide and pesticides in

marine water, sediment and seafood tissue, fresh surface water, and ground water.

6. Assess the impact of land-based wastewater discharges, specifically industrial waste and run-off from gold mining activities, on the quality of ground water.

7. In conjunction with relevant health agencies, assess the impact of human exposure to heavy metals, and cyanide and other contaminants in ground water as well as the effectiveness of health and environmental control measures being implemented by the government, through:

   a.) Analysis of morbidity and mortality statistics in identified areas of concern and other areas close to industrial zones, landfills, gold mining activities, and other potential sources of heavy metals and cyanide;

   b.) Surveys and/or interviews in communities on adverse effects to human health that could potentially be linked to the use of contaminated ground water;

   c.) Epidemiological survey to determine how communities are exposed to various pollutants and the duration of exposure; and

   d.) Biomarker study to establish the concentration level of metals and cyanide in humans.

Other recommendations to protect human health from coliform, heavy metals, cyanide and other risk agents in the aquatic environment include:

8. Eliminate direct discharges (i.e., no treatment) of domestic, industrial, agricultural and hospital waste, including septic or sludge disposal to the Danang coastal zone and rivers by:

   a.) Improving the city drainage and wastewater treatment system; and

   b.) Investing in wastewater treatment facilities for industries, hospitals, hotels, restaurants, other commercial ventures, and agricultural projects.

9. Implement control programs for indirect discharges such as agricultural, mining, upland and urban run-off to Danang coastal zone and the rivers.

10. Improve current solid waste management and treatment methods to prevent contamination of surface and ground waters from dumpsite leachates.

11. Provide potable water for households.

12. Improve coordination and cooperation of relevant agencies in monitoring industrial discharges and compliance with standards for waste discharge.

13. Work out an incentive/disincentive system to encourage industries to improve the quality of wastewater discharges and enforce penalties and/or long-term corrective measures on violators.

14. Support research and development efforts to fill in information gaps such as:

   a.) Concentrations of contaminants in various media especially in tissue;

   b.) Tolerable daily intake values (TDI) of various contaminants and fish/shellfish consumption rates for various age groups for human health risk assessment; and

c.) Transport, distribution and fate of contaminant in the environment and exposure pathways for ecological and human targets.

On Ecological Risks

15. Prioritize the identified ecological contaminants for risk management, i.e.,

Seawater column:

Danang Bay: Fe > Zn

South Son Tra - Ngu Hanh Son Coastal Water: Hg and CN^-> Oil and grease and Zn

River water column:

Cu De River: Hg > oil and grease

Phu Loc River: Phenol (n = 1) > NH_4-N, CN^-, Oil and grease

Vu Gia River: Oil and grease

Lake water column:

Rong Lake: Oil and grease, NH_4-N, DO > BOD, COD

Tram Lake: Oil and grease, CN^- > Hg, COD, BOD

March 29 Park Lake: NH_4-N, Oil and grease > NO_2-N, COD, CN^-, Hg

Thac Gian-Vinh Trung Lake: NH_4-N, NO_2-N (n = 1) > BOD, COD, Oil and grease

Cost-effective risk management measures to decrease the concentrations of these risk agents in the environment should be identified and prioritized.

16. Identify major sources of oil and grease, nutrients, organic load, heavy metals, pesticides, cyanide, phenol and TSS into the aquatic environment and estimate the contributions of these sources to contaminant loading.

17. Develop and implement management plans to control direct and indirect discharge of untreated wastes to the environment.

18. Set up an appropriately designed long-term monitoring program for contaminants especially oil and grease, nutrients, organic load, heavy metals, pesticides, cyanide, phenol and TSS in the water column and sediments.

19. Based on existing activities in Danang, determine the importance of parameters identified as data gaps in the risk assessment for inclusion in the environmental monitoring program.

20. Establish appropriate threshold values for parameters for which monitoring data are being collected, such as PO_4-P, total N, total P, and individual pesticides, to allow evaluation of the ecological risks posed by these parameters.

21. Develop predictive models on contaminant concentrations and transport that can be used to support management decisions.

On Habitats

22. Conduct benefit-cost analysis of restoration of wetlands and protection of corals as part of an overall Danang Coastal Strategy Implementation Plan. This analysis should incorporate the social, economic and ecological benefits and costs. The question that needs to be addressed is "Are these habitats worth restoring considering other existing and potential economic activities in the Danang coastal zone?"

23. Require benefit-cost analysis of reclamation, mining, logging, construction and development projects along the coasts and rivers as part of the government approval process, considering direct/indirect and short-term/long-term impacts on the marine and aquatic environment (i.e., habitat loss/ alteration, sedimentation, erosion, flooding, etc.)

24. As part of the Danang Coastal Strategy Implementation Plan, develop an integrated land- and water-use plan that is aimed at ensuring appropriate balance between the resources and habitats and the economic activities.

25. Strengthen the implementation of laws and regulations on zoning and resource use.

26. Support research and development efforts aimed at addressing the identified data gaps on resources and habitats:

    a.) For coral reefs and other resources and habitats, a systematic survey is necessary in order to establish plans for resource and ecosystem protection;

    b.) Coordination with ongoing pollution monitoring programs will enhance understanding of linkages between ecological conditions and physical, chemical and biological factors; and

    c.) For forests, there is a need for more information on forest areas and watersheds, on annual productivity per district, as well as information on exploitation of important animal species.

27. Monitor areas that are vulnerable to erosion and flooding, and develop measures to control erosion and prevent damages to lives and properties.

28. For comprehensive and cost-effective resource management, promote coordination and cooperation among related organizations to improve the implementation of common activities. For forest management specifically, collaborative efforts are necessary between organizations responsible for activities related to tourism development, the prevention of hunting, and slash burning for land cultivation.

On Resources

29. Strengthen enforcement of existing laws and regulations on utilization of fisheries resources and assess their effectiveness and relevance for present conditions.

30. Develop plans to improve fisheries management, such as an offshore fishing program aimed at reducing the pressure on nearshore fisheries by limiting nearshore fishing activities and preventing overfishing and destructive fishing.

31. Promote public awareness on the declining condition of local fisheries, causes of decline, long-term adverse impacts of destructive fishing practices, efforts to improve fisheries management and expected long-term benefits, and the important roles that they need to perform to ensure sustainability of fisheries resources.

32. Develop management plans for protection of fisheries/shellfisheries resources from discharges of untreated wastewater, particularly from point sources, i.e., industries, release of solid wastes and other polluting substances, and other activities that

compromise the integrity of the resources and the environment.

33. Apart from assessing adverse conditions in aquaculture areas due to contaminant discharges from land-based and other sea-based activities, evaluate adverse conditions arising from existing aquaculture practices, and support the application of environmentally sound aquaculture practices.

34. Formulate measures to prevent degradation of mangrove forests, coral reefs and other coastal habitats, and promote rehabilitation efforts.

35. Reinforce legal frameworks and regulations and provide a clear policy for sustainable fisheries management.

36. Support efforts to gather more information for future risk assessment such as:

    a.) Information on CPUE for marine fisheries and aquaculture production that can be used to establish changes in these resources;

    b.) Data on contaminant levels in fish and shellfish tissue to determine fitness for human consumption;

    c.) Information on cause-effect relationships between targets and agents to further strengthen evidence on causes of decline.

Taking into consideration the various recommendations on resource conservation and coastal and marine environment protection, the following activities are considered as important in managing environmental concerns in the Danang coastal zone.

Integrated Land- and Water-Use Zoning

37. Some of the problems on utilization of resources and habitats and identified ecological and human health risks are linked with current land and water uses in Danang, particularly as a result of recent economic developments. With Danang's potential for further development, it is recommended that an integrated land and water use zoning scheme with associated institutional arrangements be developed to reduce conflicting uses of land and water resources, promote uses based on the potential of each area, and prevent adverse effects to the ecosystem and human health.

Integrated Environmental Monitoring Program

38. The initial risk assessment has shown priority areas of concern and data gaps with regard to resources, habitats, and potentially important risk agents, and the need for further monitoring to evaluate the environmental impacts of human activities and the effectiveness of management actions to control these adverse impacts. It is recommended that a systematic, cost-effective and coordinated environmental monitoring program be developed, which will be aimed at:

    a.) Addressing the priority concerns and data gaps identified in the risk assessment;

    b.) Pooling the efforts and resources of relevant agencies through an operational monitoring network;

    c.) Enhancing exchange and integration of information through an information-sharing network;

    d.) Enhancing local technical capability with regard to field and analytical tools and human resources; and e.) Strengthening the linkage between environmental monitoring and environmental management through application of the risk assessment/risk management framework.

This long-term program should integrate the monitoring of priority pollutants, human health, and resource and habitat conditions. Other important components to be included are industrial wastewater monitoring at source, and ground water quality monitoring in areas close to industrial zones.

Environmental Investments

39. The results of the risk assessment show the need to develop long-term strategies and programs of actions to address environmental problems caused by the discharge of untreated sewage, solid wastes and industrial and hazardous wastes, and emphasize the need for environmental services and facilities, including clean technologies, in order to allow economic growth without sacrificing the environment.

The environmental facilities necessary for sustainable management of the environment in Danang include industrial wastewater treatment, hazardous waste management facilities, integrated solid waste management, and a municipal sewerage system. In addition to ensuring sustainable management of the environment, these projects also provide investment opportunities that create income, employment and livelihood. These, however, require large financial investments and technological resources, and need innovative approaches that facilitate the participation of various sectors in coastal and marine pollution prevention and resource conservation.

Benefit-Cost Analysis

40. The development of management programs should involve the quantification of costs and benefits from alternative management strategies and from the activities that may be associated with environmental impacts. This is an important consideration for environmental managers in reviewing new projects and programmes in the Danang coastal zone.

Collaboration and Institutional Arrangements

41. Partnerships between different government agencies, universities and scientific and technical research institutions, local government units, communities, non-governmental organizations, and the private sector are vital to the development and sustainability of environmental management programs for the Danang area and should be promoted. In particular, institutional arrangements for multi-agency and cross-sectoral undertakings, such as the integrated land and water use zoning, integrated environmental monitoring program, and environmental investments will be necessary to ensure sustainability of these undertakings. Evaluation and strengthening of policies, rules and regulations, implementation frameworks and enforcement capabilities on resource utilization and environmental protection also require collaborative efforts.

Background

The Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) has identified Danang City as one of the ICM demonstration sites in the region to demonstrate the viability and effectiveness of multi-stakeholder partnerships at the local level through the implementation of the ICM program.

Risk assessment is used in a wide range of professions and disciplines and is now increasingly being used in examining environmental problems. Environmental risk assessment (ERA) uses scientific and technical assessments of available information to determine the significance of risk posed by various factors emanating from human activities on human health and the ecosystem.

The gradual shift in environmental policy and regulation from hazard-based to risk-based approaches was partly due to the recognition that "zero discharge" objectives are unobtainable and that there are levels of contaminants in the environment that present "acceptable" risks (Fairman et al., 2001). Aiming for "zero discharge" levels or using the best available technology may not be cost-effective and could result in excessive economic burdens to society and adversely affect the provision of goods and services that contribute to human welfare. Risk assessment is a systematic and transparent process that provides comprehensive and logical information to environmental managers and decision-makers for identifying rational management options. Identifying areas of concern through the risk assessment also prevents the pitfalls of wasting effort and resources on minor concerns.

Various methodologies and techniques for ERA have been developed and different organizations are presently involved in further improving this management tool (ADB, 1990; UNEP-IE, 1995; UNEP-IETC, 1996; Fairman et al., 2001). The approach adopted by PEMSEA is based on the risk quotient (RQ) approach. It starts by simply using worst-case and average scenarios and progresses if the results show the need for more refined and more sophisticated ways of assessing and addressing the uncertainties associated with the RQ technique. The initial risk assessment of the site is a preliminary step to identify priority environmental concerns that will be the focus of a more comprehensive refined risk assessment.

The initial risk assessment of Danang was initiated during the Training Course on Environmental Risk Assessment held from 3-8 December 2001 in Danang City.

Objectives

The objective of the study is to conduct an initial environmental risk assessment of the Danang coastal zone using available information to determine the effects of factors derived from human activities on human and ecological targets.

Specifically, it aims to:

1. Evaluate the impacts of various pollutants in the Danang coastal zone on human and ecological targets and identify the priority environmental concerns;

2. Identify activities that contribute to pollution in the site;

3. Identify gaps and uncertainties that will need more effort in future environmental monitoring and risk assessment activities;

4. Make recommendations for an integrated risk assessment and environmental monitoring program that is focused on the identified areas of concern;

5. Identify agencies and institutions that can play significant roles in the integrated risk assessment and environmental monitoring program and in the long-term management of the Danang coastal area; and

6. Identify priority concerns to be addressed under risk management.

SOURCES OF INFORMATION

Data used for the retrospective assessment were taken from Danang City's Environmental Profile (DOSTE, 2000) and the Annual Reports of the Department of Fisheries, Agriculture and Forestry (DFAF, 1997-2001). In addition, results from national research programs on the marine environment of Danang or the coastal area of Quang Nam Province were used for the retrospective analysis.

Data used for the prospective assessment were taken from local monitoring programs (DOSTE, 1994-2001); national monitoring programs of Danang City (NEA, 1995-2001); Vietnam-Canada Environment Project (VCEP, 1996-2000), and the EIA report of Danang City's Sanitation Project (URENCO, 1997). Other data were also collected from the periodical reports on environment of enterprises or industries in the Danang coastal zone from 1997 to 2001. The list of information sources is given in Appendix 3.

Most of the data used were presumed to be accurate and reliable, although preliminary screening was done for some data in which ranges of concentrations in different environmental conditions were known. Ideally, the reliability of data should be more systematically assessed based on the sampling design and laboratory techniques used to produce the data, as well as the period when these were obtained. A more thorough assessment of data should be made in the refined risk assessment.

DEFINITION OF KEY TERMS

The following are key terms used in risk assessment. A more comprehensive list of terms, as modified from U.S. EPA (1997), U.S. EPA (1998) and IUPAC (1993), is found in the Glossary.

Effects assessment – The component of a risk analysis concerned with quantifying the manner in which the frequency and intensity of effects increase with increasing exposure to substance.

Exposure assessment – The component of a risk analysis that estimates the emissions, pathways and rates of movement of a chemical in the environment, and its transformation or degradation, in order to estimate the concentrations/doses to which the system of interest may be exposed.

Hazard identification – Identification of the adverse effects that a substance has an inherent capacity to cause, or in certain cases, the assessment of a particular effect. It includes the identification of the target populations and conditions of exposure.

Risk – The probability of an adverse effect on humans or the environment resulting from a given exposure to a substance. It is usually expressed as the probability of an adverse effect occurring, e.g., the expected ratio between the number of individuals that would experience an adverse effect in a given time and the total number of individuals exposed to the risk factor.

Risk assessment – A process, which entails some or all of the following elements: hazard identification, effects assessment, exposure assessment, and risk characterization. It is the identification and quantification of the risk resulting from a specific use or occurrence of a chemical including the determination of exposure/dose-response relationships and the identification of target populations. It may range from largely qualitative (for situations in which data are limited) to quantitative (when enough information is available so the probabilities can be calculated).

Risk characterization – The step in the risk assessment process where the results of the exposure assessment (e.g., PEC, daily intake) and the effects assessment (e.g., PNEC, NOAEL) are compared. If possible, an uncertainty analysis is carried out, which, if it results in a quantifiable overall uncertainty, produces an estimation of the risk.

Risk classification – The weighting of risks in order to decide whether risk reduction is required. It includes the study of risk perception and the balancing of perceived risks and perceived benefits.

Description of Danang City

The Danang coastal zone consists of the mainland area (6 districts) and sea area of the city from the coast up to a depth of about 50 m. Figure 1 shows the administrative boundary of the Danang coastal area.

The mainland is located within the coordinates 15°55′15′′ to 16°13′15′′ latitude and 107°49′ to 108°20′18′′ longitude. It is bordered at the north by Thua Thien Hue Province, at the south and west by Quang Nam Province, and at the east by the East Sea. Hoang Sa Islands border the East Sea and are located within the coordinates 15°30′ to 17°12′ latitude and 111°30′ to 115°00′ longitude. Danang is composed of seven districts (i.e., Hai Chau, Thanh Khe, Lien Chieu, Son Tra, Ngu Hanh Son, Hoa Vang and Hoang Sa) with 47 communes. The total land area of the mainland is 1,248.4 km^2 (including total land area of Hoang Sa Islands**)** where 205.87 km^2 are urban areas and 1,042.5 km^2 are rural areas. The Hoang Sa Islands are estimated to have a total land area of 305 km^2.

Danang lies in a tropical zone influenced by monsoon, with a stable mean temperature. Annually, the coastal zone receives an average of 2,000 mm of rainwater, although rainfall is distributed unevenly throughout the year, and the rainy season from August to December contributes significantly to the average figure. The northeast monsoon usually brings with it destructive typhoons while the southwest monsoon brings about squalls, gales, and sometimes whirlwind and hails.

The two main river systems, the Cu De River and the Han River originate from the west-northwest of the city and Quang Nam Province in the south, respectively. Cu De River in the north has a length of 38 km and a watershed area of 426 km^2. Han River in the south, which originates from the Cai headwater and the watershed of Giao Thuy, Quang Nam Province, has a length of 204 km and an area of 5,180 km^2.

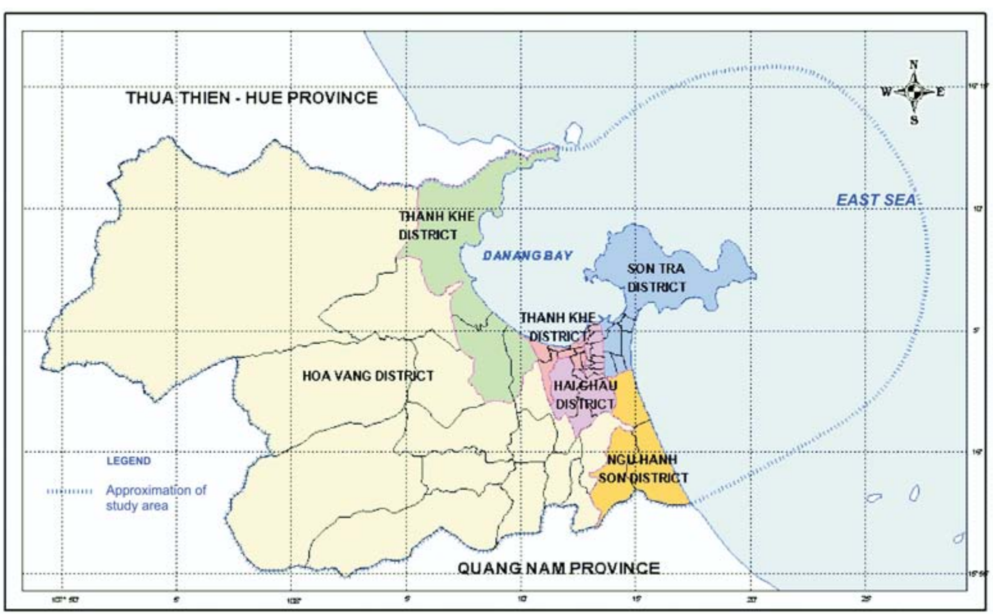

Figure 1. The Administrative Boundary of the Danang Coastal Area.

Danang is influenced by an irregular semi-diurnal tide regime. The tide oscillation is not large such that the difference between the low and high water marks is not big. Hydrographic phenomena, such as large waves and increasing water level sometimes reaching over 1 m, characterize the sea area particularly during the occurrence of storms.

Geophysically, Danang is classified into four main groups consisting of mountainous areas, hilly areas, deltas, dales and estuaries with 16 different geo-environment types. Each geophysical group has some specific problems, such as:

- Mountainous areas: danger of fall, erosion, and strong slips.
- Hilly areas: erosion, strong slips.
- Deltas: erosion, sand and dust, subsidence, fall, environmental pollution.
- Dales and estuaries: floods, erosion, deposition, saltwater intrusion.

For the marine resources, there are 58 plankton species belonging to 34 genera, 25 families, 7 groups and 4 phyla; 120 species of benthic organisms belonging to 88 genera, 66 families, 6 classes and 4 phyla; 55 species of hard corals distributed in the northern part of Danang Bay, in the southern and northern parts of Son Tra Peninsula, and more than 500 species of fish where over 30 species are of high economic value. Annual production of seafood species is estimated to reach 113,000 tons where about 70,000 tons are surface species and 30,000 tons are bottom species including shrimps and squids.

Forested areas cover 67,148.35 ha (as of 2000), of which, 63 percent are specific forests and protective forests. Popular wood species belong to the chestnut family. Some valued wood species include Lau and Mat sindora. Some of the associated fauna that are considered important are the Vooc Va gibbon, *Pheinardia ocellata* and the blue-indigo pheasant.

For the water resources, an average of 8 billion m^3 of water drain into the Han and Cu De Rivers every year, a significant quantity of which is contributed by rainfall during the rainy season. The estimated ground water potential in the west, AVuong fracture layer at Ngu Hanh Son, and Lien Chieu was estimated to be about 85,000 m^3 per day. Other potential sources of water are being explored.

Danang also has abundant mineral resources including industrial white sand, as well as building materials such as stone, sand, gravel, and clay. Other metals include tin and gold.

For tourism, Danang has a coastline of over 90 km, 30 km of which is slated for tourism development. Seventeen communes are located along the coast which is dotted with numerous beaches such as those found in My Khe, Bac My An, Non Nuoc, Nam O, Xuan Thieu, Thanh Binh and Son Tra. Aside from the beaches, there are also well-known landscapes and seascapes such as Ba Na-Nui Chua tourism resort, Son Tra Peninsula, Hai Van Pass and Ngu Hanh Son making Danang a popular tourism area.

Based on the 2001 Yearbook, the population of Danang is recorded at 728,823 persons. The urban population is 78.6 percent with females comprising 50.9 percent. The Kinh people make up 99.6 percent of the population and the remaining are the ethnic minorities such as Han, Ka-Tu, etc. The average population density is 573 persons/km^2, although in urban areas, the average population density is 2,698 persons/km^2. The labor force makes up 58.8 percent of the total population.

The economic structure of Danang in the past years was focused on industry, service, tourism, fisheries, agriculture, and forestry. The rate of GDP averaged 9.8 percent per year in 2000, which is higher than the mean level of the country (8.2

percent) for the same period, while from 1997 up to the present GDP is computed to be about 10 percent per year. The economic structure is aimed at decreasing the ratio of agriculture and services while increasing the ratio of industry. For industrial fuel, production fields comprised a high ratio (over 90 percent). Growth rate of services was slow, which was at 8.7 percent in 1998. The economic structure of agriculture changed from development of fisheries and agricultural production to urban services, industrial zones and export production.

The total inland area of Danang City is 943.4 km^2, comprising of 128.37 km^2 of agricultural land (13.61 percent of total land area), 617.76 km^2 of forest land (65.48 percent of land area), 72.82 km^2 of land for special uses (7.72 percent of land area), 21.07 km^2 of residential areas (2.23 percent of land area) and 103.35 km^2 of unused land (10.96 percent of land area). Pedagogically, some of the soil types in the coastal zone are characterized as red-yellow, light yellow, brown-yellow, humus-yellow, rock-ascent, sand bank, sand beach, some alluvial lands, and salt land.

The Risk Assessment Approach

Risk is the probability of an adverse effect on humans or the environment resulting from a given exposure to a substance. It can be carried out as a retrospective risk assessment or a prospective risk assessment. For the retrospective risk assessment, the fundamental question concerns the extent to which conditions are likely to have caused adverse effects observed in specific targets. Prospective risk assessment considers the extent to which current conditions, and/or those likely to pertain to the future due to new development, would likely cause harm. Both can be used as a basis for environmental management and imply the desire to control activities and conditions to levels that do not cause harm and which are likely to be nonzero. In the Danang coastal zone, a combination of retrospective and prospective approaches is used. A retrospective approach is applied to explain observed deterioration in ecological targets and/or the occurrence of human health problems in terms of likely exposure levels and their causes. A prospective approach is applied to consider and compare the likely adverse effects emanating from observed environmental concentrations of chemicals. The approaches converge to indicate the relative importance of different adverse effects and their causes. This should lead to appropriate, cost-effective management programs.

The fundamental features of both retrospective and prospective risk assessments are that they identify problems and their causes based on systematic and transparent principles that can be justified in public and can be revisited as more information and understanding become available. The key concept for risk assessment is the comparison between environmental conditions (e.g., environmental concentrations of chemicals) and threshold values likely to cause adverse effects in the targets under consideration. In a prospective risk assessment, this is made explicit as a risk quotient (RQ), derived from the ratio of an environmental concentration that is either predicted (PEC) or measured (MEC) with a predicted no-effect concentration (PNEC) for the target of concern (RQ = P (MEC/PNEC). An RQ < 1 indicates a low and thus acceptable risk, and an RQ ≥ 1 indicates a level of concern and possibly the implementation of appropriate management programs.

The basic principles and techniques for both retrospective and prospective risk assessment are described in *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems* (MPP-EAS, 1999a).

To elaborate on the interrelatedness of agents and targets, a simplified risk pathway (Figure 2) was used. Figure 2 shows the agents that present potential adverse effects to human health and the coastal and terrestrial environment, as well as effects on the ecosystem. It also shows the relationships between these harmful agents and the various social and economic activities, and presents potentially important concerns for management of activities that could cause adverse effects to human health and environment.

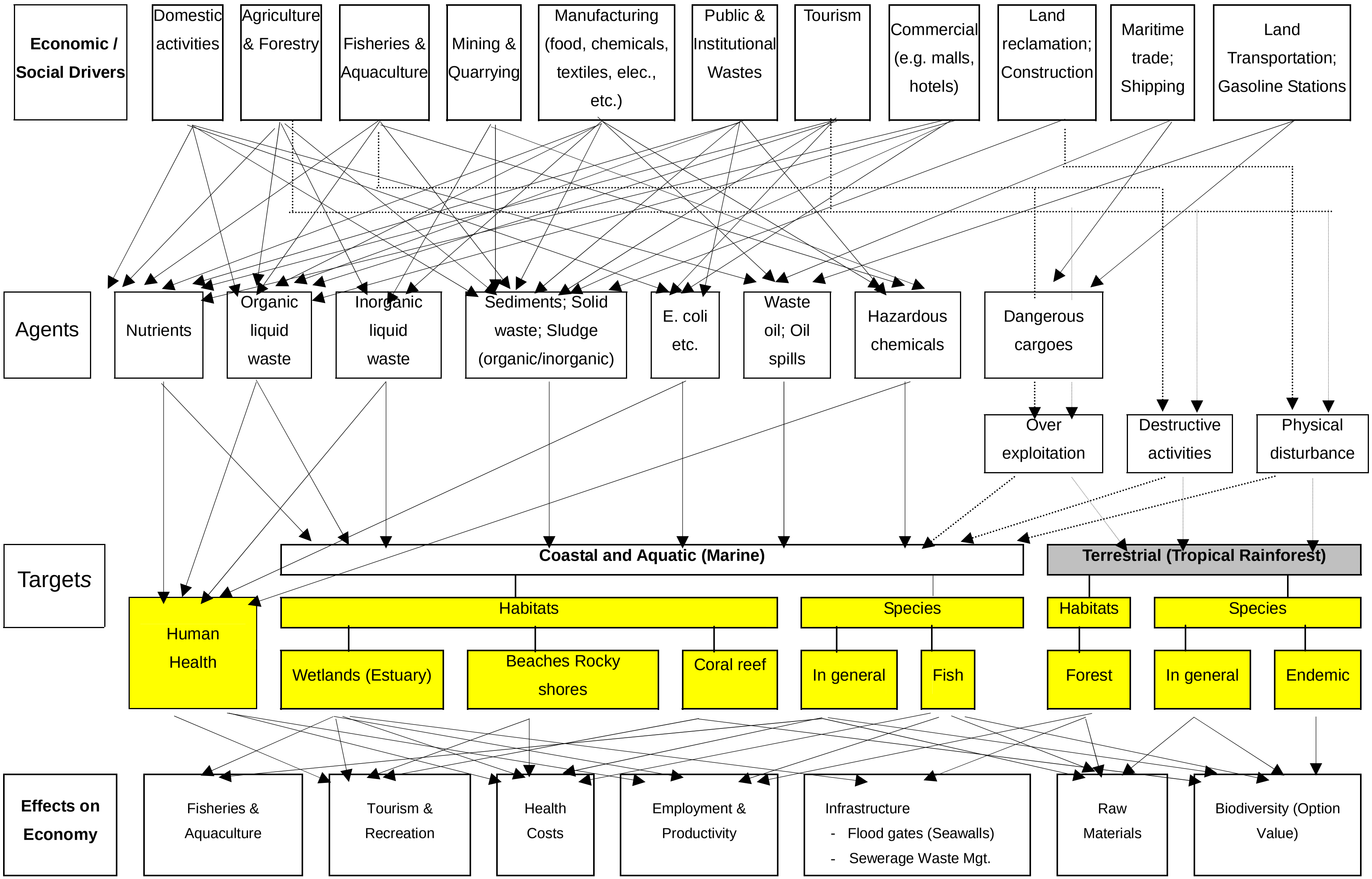

Figure 2. Simplified Risk Pathways for the Danang Coastal Zone

Retrospective Risk Assessment

Introduction

Retrospective risk assessment is an evaluation of the causal linkages between observed ecological effects and stressor(s) in the environment. It addresses risks from actions that began in the past and can therefore be assessed based on measurements of the environment's state (Suter, 1998). It attempts to answer the question: "What evidence is there for harm being done to targets in the coastal zone?" (MPP–EAS, 1999b). In retrospective studies, it is important to identify significant effects (targets and endpoints) and ascribe causation. The approach involves making inferences about the causes of observed effects (Suter, 1998) and this often requires temporal and spatial series of data for comparative purposes. Comparison facilitates the ascribing of risks to a particular source.

The retrospective approach employed for the Danang coastal zone was of the "effects-driven assessment" type that addresses apparent ecological effects that have uncertain causes (Suter, 1998). Under this perspective, risk is viewed as the likelihood that current impacts are occurring and the demonstration of these existing impacts confirms that a risk exists. It is important to note that impacts have primary or secondary effects, as these may cause direct or indirect changes in identified targets.

Methodology

A considerable volume of materials on the Danang coastal zone, from various studies, reports, and projects, were reviewed and relevant data on identified targets (habitats and resources) in the coastal zone were put together for the retrospective risk assessment. Steps prescribed in the *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems* (MPP-EAS, 1999a) were, likewise, applied.

Problem Formulation

The problem formulation phase involved defining the target and the way it is impaired by recognizing that an undesirable effect on an ecological system or human population has already occurred, identifying suspected (or known) agents, and considering the links between the agents and the adverse effects on the targets, with an aim to eventually manage these agents to reduce harm.

It is also important to determine the assessment and measurement endpoints in the targets. Assessment endpoints are features related to the continued existence and functioning of the identified targets (e.g., production, density changes and mortality), which may not be easy or would take much time to measure. So measurement endpoints, which are features related to the assessment endpoints but are easier to measure, such as biomass (for production), abundance (for density changes) and LC_{50} or biomarkers (for mortality), are used instead.

The suspected agents responsible for the decline of the different resources and habitats include: 1.) nutrients; 2.) DO/BOD/COD; 3.) TSS; 4.) coliform; 5.) pesticides; 6.) cyanide; 7.) phenol; 8.) heavy metals; 9.) oil and grease; 10.) pollutants; 11.) untreated waste; 12.) overfishing; 13.) destruction of habitats and watershed; 14.) destructive catching; 15.) physical disturbance; 16.) illegal exploitation; 17.) reclamation; 18.) construction works; 19.) forest devastation; 20.) sand mining; 21.) sedimentation; 22.) tourism development; 23.) forest fire; 24.) illegal cutting of trees; and 25.) clearing of land for farming.

The identified targets for resources include: 1.) marine fisheries; 2.) aquaculture; and 3.) phytoplankton. The identified targets for habitats were: 1.) coral reefs; 2.) seagrasses; 3.) sandy beaches; 4.) rocky shores; 5.) wetlands; 6.) soft-bottom communities; and 7.) forest resources.

Retrospective Risk Assessment

Under the retrospective risk assessment phase, a set of questions, answerable by yes (Y), no (N), maybe (M), or no data (?), not relevant (NR) was formulated in order to establish evidences of decline, and the causes and consequences of the decline. The following questions were adapted from the *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems* (MPP-EAS, 1999a).

a.) Is the target exposed to any of the agents?

b.) Was there any loss/es that occurred following exposure? Was there any loss/es correlated through space?

c.) Does the exposure concentration exceed the threshold where adverse effects start to happen?

d.) Do the results from controlled exposure in field experiments lead to the same effect? Will removal of the agent lead to amelioration?

e.) Is there specific evidence in the target as a result of exposure to the agent?

f.) Does it make sense (logically and scientifically)?

In order to facilitate the assessment, all the above-mentioned questions were tabulated in a matrix where each of the targets was subjected to the series of questions. The answers to the questions were based on available information on

Decision Criteria for Determining the Likelihood of Harm:

Case	Result Decision Tables	Conclusion
A	No 1 & 2 = unlikely (U)	No correlation
B	Yes 1 & 2, ND for 3 – 6 = possibly (P)	Just correlation
C	Yes 1 & 2, but no 3 = unlikely (U)	Correlation but negative evidence for cause-effect
D	Yes 1 & 2, but no 6 = unlikely (U)	Spurious correlation
E	Yes 1, 2, & 3 = likely (L)	Correlation with some evidence of cause-effect
F	Yes 1, 2, & 3, but no 4a = unlikely/possibly (U/P)	Correlation but negative evidence for cause-effect; if good experimental design (e.g., low Type II error = unlikely), with poor experimental design (e.g., high Type II error) = possibly.
G	Yes 1, 2, & 3, ND for 4a, but no 4b = possibly (P)	Correlation but lack of evidence for cause-effect
H	Yes, 1, 2, 3, & 4a, but no 4b = likely (L)	Correlation with evidence for cause-effect and recovery does not always occur
I	Yes, 1, 2, 3, 4a, & 5 = very likely (VL)	Correlation with strong evidence for cause-effect
J	Yes, 1, 2, 3, & 4a, but no 5 = likely (L)	Correlation with evidence for cause-effect (a lack of biomarker response is inconclusive evidence)
K	Yes, 1, 2, 3, 4a, 5, & 6 = very likely (VL)	Correlation with very strong evidence for cause-effect
L	Yes, 1, 2, 3, but maybe 6 = possibly (P)	Correlation but scientific/logical justification lacking
M	Yes 6 but no data for 1 & 2 = don't know (DK)	Cause-effect relationship known to be possible in principle, but no evidence in this case
N	Yes 1, but no 2	Target is exposed but there is no evidence for decline; if there is good evidence for no decline then there is no need to take the risk assessment further; if evidence for no decline is weak or questionable, seek more evidence

the targets and agents. The matrices are termed here as "decision tables." Using these tables, agents that were likely to have caused adverse effects have been systematically screened.

The different categories of likelihood of harm are as follows:

a.) Very Likely;
b.) Likely;
c.) Maybe;
d.) Possibly;
e.) Unlikely; and
f.) Unknown.

Upon screening, summaries of the likelihood for agents to have caused the decline in resources and habitats (see Appendix 2) were prepared and were made part of the basis for the results of the retrospective risk assessment. It is important to note that the summaries of likelihood were established on the basis of the retrospective analyses (decision tables) and on the prospective risk assessments for different agents summarized in the Comparative Risk Assessment section.

After establishing evidences of decline in the resources and habitats, the ecological, economic, and social consequences of decline were evaluated.

RESOURCES

Marine Fisheries

Evidence of Decline

There was no evidence of decline in marine fisheries in the Danang coastal area since information on fish catch or catch per unit effort were not available for the risk assessment. Related information, however, such as number of boats and ships and evidences of illegal fishing activities, were used to infer the status of marine fisheries in Danang. These data were taken from the Danang City Environmental Profile (DOSTE, 2000) and reports from the Department of Fisheries, Agriculture and Forestry (DFAF, 1997-2001).

Since decline in marine fisheries was not clearly established, there was no point in proceeding with the detailed retrospective risk assessment to identify significant causes for the decline in fisheries. Table 1, instead, presents the information that might be relevant to the assessment of the status of fisheries in Danang.

Reports on fishery activities show that the number of boats operating inshore decreased by 67 units while the number of boats operating

Table 1. Summary of Information for the Retrospective Risk Assessment for Fisheries.

Resource type	Areal extent	Information
Fisheries	Large	Port activities: – Increase in boat/ship arrivals from 860 to 1,509 from 1994 to 1999 – Increase in number of oil ships from 133 to 342 from 1994 to 1999
		Fishing activities: – Decrease in number of near-shore boats by 67 from 1997 to 2001 – Increase in number of boats with over 45 HP (for off-shore operation) by 85 from 1997 to 2001
		Destructive fishing activities: – Confiscation of 29 electrical pulse tools, 1,799 kg of trinitrotoluene (TNT), 212 detonators, 15.6 meters of delay igniters in 2000

Sources: DFAF (2000a and b); DOSTE (2000).

Table 2. Summary of the Retrospective Risk Assessment for Aquaculture.

Resource type	Areal extent	Results		
		Observed changes	Identified agents	Impacts
Aquaculture	Small	Decrease of aquaculture area in Tram Lake by 30 ha. Fish kills: – Tram Lake: 15,466 kg in 1996 and 982 kg in 2000. – Mac Lake: unknown quantity in 2000. Dead shrimps at Hoa Hiep commune, unknown quantity in 1998 and in 1999.	Very likely: – DO Possibly: – Oil and grease – Heavy metal – BOD, COD-TSS – Coliform – Nutrients	– Economic damage – Loss of local species – Effects on human health

Source: DFAF (1997-2001); DOSTE (2000).

offshore increased by 85 units. The decrease in the number of small-capacity boats might be indicating the need to go farther offshore to fish, potentially signifying decline in near-shore fish resources.

In 2000, some gears and supplies used in destructive fishing methods were confiscated, which include 29 electrical pulse tools, 1,799 kg of trinitrotoluene (TNT) for dynamites, 212 detonators and 15.6 meters of delay igniters. The adverse ecological impacts of destructive fishing methods are well recognized, and evidences that these are being practiced in Danang create concern for the state of resources and habitats in the area.

From 1994 to 1999, the number of boats and ships arriving in Danang increased from 860 to 1,509, and this includes small and medium-sized oil ships, which increased in number from 133 to 342 during the same period. The increase in port activities demonstrates the potential for increasing adverse ecological impacts from stressors associated with shipping activities and port operations such as oil and grease, suspended solids and physical disturbance, among others.

Although data on the status of marine fisheries had not been available for the risk assessment, these related information provide a view on pressure being exerted on the marine ecosystem that might have potential adverse effects on marine fisheries. This assessment also points to the need for studies and monitoring programs, which can provide information on changes occurring in marine fisheries and be used to support fisheries management in Danang. Attention should also be directed to determine the effects of overfishing, destruction of habitats, and water pollution on fisheries productivity and contamination of fish tissue.

Aquaculture

Evidence of decline

Data for aquaculture were taken from the *Environmental Profile of Danang City* (DOSTE, 2000) and reports from DFAF (1997-2001). Table 2 shows the results of the retrospective risk assessment for aquaculture in the Danang coastal area.

In Danang coastal zone, about 1,000 ha of water surface could be developed for aquaculture where over 50 percent is freshwater and the remaining is brackish water. The water surface currently used for aquaculture is 420 ha with an annual productivity of 273 tons/year. Half of the 60 ha used for aquaculture in the Tram Lake area had been reduced due to pollution from industrial wastes and fish kills had been reported in 1996 and 2000. Fish kills were also recorded in Mac Lake due to oily wastes from industrial establishments. In 1998 and 1999, a series of shrimp deaths occurred in the shrimp ponds in Hoa Hiep commune.

Attributed Causes

The parameters that were considered in the retrospective risk assessment for aquaculture include oxygen demand parameters (DO, BOD and COD), oil and grease, heavy metals, TSS, nutrients and coliform. Table 3 presents the retrospective risk assessment for aquaculture.

Table 3 shows DO as a very likely agent for the observed decline in aquaculture. Low DO, in particular, had been identified as the main factor that caused the fish kills in Tram and Mac Lakes because the concentration of dissolved oxygen in the water was below the threshold value for aquaculture (Mien, 1997). Depletion of DO can be caused by conditions that enhance demand for dissolved oxygen like high organic loading and occurrences of algal blooms, as well as conditions that inhibit water circulation.

The decline cannot be linked to the other agents with certainty but in the prospective risk assessment, all these agents were shown to have exceeded specified threshold levels in Tram Lake. Risk assessment was not performed for Mac Lake. Although correlation between the decline and the agents was not established, and other evidences to show the adverse effects of the agents on aquaculture were not available, there is still a

Table 3. Detailed Risk Assessment for Aquaculture.

Aquaculture	DO	Oil and grease	Heavy metals	BOD, COD	TSS	Coliform	Nutrients
1. Is the target exposed to any of the agents?	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	M	M	M	M	M	M
2b. Was there any loss/es correlated through space?	M	M	M	M	M	M	M
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field or laboratory experiments lead to the same effect?	Y	?	?	?	?	?	?
4b. Will removal of the agent lead to amelioration?	?	?	?	?	?	?	?
5. Is there an effect in the target that is known to be specifically caused by the agent (e.g., a contaminant-specific biomarker response)?	Y	?	?	?	?	?	?
6. Does it make sense (logically and scientifically)?	Y	Y	Y	?	?	Y	?
Likelihood	**VL**	**P**	**P**	**P**	**P**	**P**	**P**

Legend: Y – Yes; M – Maybe; ? – No data; VL – Very Likely; P – Possibly possibility that these agents might have contributed to the decline in aquaculture due to their elevated concentrations.

BOD and COD are indices of organic loading that can adversely affect aquatic organisms by using up dissolved oxygen in the water column for the decomposition of organic materials. High organic loading may be one of the main factors that caused the death of shrimps in Hoa Hiep commune. Nutrients are not toxic to aquatic organisms but at elevated levels, and in combination with other factors, can lead to proliferation of algae and affect dissolved oxygen levels. TSS can make the water turbid, reduce light penetration, and enhance low DO conditions as well as affect primary productivity and food supply for aquatic organisms. Oil, grease and heavy metals can affect the physiological and reproductive processes of aquatic organisms, as well as their fitness for human consumption. Coliform is not toxic to aquatic organisms but can affect the quality of aquatic food products for human consumption.

The decline of aquaculture can be attributed to the uses of freshwater in the Danang coastal area. Some of the lakes, such as Tram Lake, have become the receiving areas for untreated industrial wastewater. On the other hand, the freshwater areas are also used for different purposes such as aquaculture and irrigation, and the discharge of untreated wastewater conflicts with these uses. Results of monitoring programs have actually shown that these areas are highly polluted (DOSTE, 1999).

The possibility that aquaculture itself might be contributing to decline in environmental quality due to intensive aquaculture practices and application of insufficient technologies should also be considered. Efforts to improve production might be causing conditions that can lead to depletion of DO or the outbreak of diseases, and bring about significant economic losses.

Consequences

The decline of aquaculture has resulted in the decrease of fresh and brackish water available for aquaculture. Aquaculture areas in Tram Lake decreased by 30 ha in 1998, while shrimp farming areas in the Han estuary that were badly affected by environmental pollution had to be abandoned.

The decline of aquaculture has led to the loss of local species and financial losses for shrimp pond owners and has indirectly affected the socioeconomic condition of Danang City.

Phytoplankton

Evidence of Decline

There are no available information to show the decline of phytoplankton in Danang coastal

Table 4. Summary of Information for the Retrospective Risk Assessment for Phytoplankton.

Resource type	Areal extent	Information
Phytoplankton	Large	• 154 species of phytoplankton were found in the marine coastal area of Quang Nam - Danang Province. • The density of phytoplankton is similar in the surface and bottom of the water column. In a year, the average density of phytoplankton was about 120,000 cells/m^3, the maximum number was 200,000 cells/m^3 in October, and the minimum number was 39,000 cells/m^3 in May.

Sources: CMH (1990); DOSTE (1990).

area. Although surveys on phytoplankton have been carried out in 1989 and 1996, only information on the number of species, distribution and density were obtained.

Since decline in phytoplankton was not established, the detailed retrospective risk assessment, which aims to identify potential causes for observed decline, was not conducted anymore, but information from the previous surveys will still be presented.

Table 4 shows the available information for phytoplankton in the Danang coastal zone.

Although the decline of phytoplankton was not established, the potential impacts of suspended solids and pollutants in the water on primary productivity should be considered. High density of suspended solids in the water will decrease primary productivity, and the reduction or inhibition of primary productivity will have a chain effect on succeeding trophic levels. The ecological importance of this resource, therefore, makes it as valuable as the other resources dependent on it in the food chain.

HABITAT

Coral Reefs

Evidence of Decline

Data used for the retrospective assessment were taken from WWF (1994), HPOI (1997) and Tuan, Vo Sy (2000). Results of researches show that coral reefs exist at the southern part of Hai Van Pass and at the northern and southern parts of Son Tra Peninsula (Figure 3).

Fifty-five species of hard corals were recorded while no species of soft corals were found. The most common genera are *Montipora*, *Acropora* and *Porites*. At Son Tra, coral reefs exist at a depth of 12 m and extend down to 200 m.

The coral reef surveys, however, were conducted in different sites, such that the information collected could not be used to establish changes for the retrospective risk assessment. Available information for coral reefs in the Danang coastal zone are presented in Table 5.

Table 5. Summary of Information for the Retrospective Risk Assessment for Coral Reefs.

Resource type	Areal extent	Information
Coral Reef	Medium	• Coral reefs are distributed in the hard-bottom of the northern part of Danang Bay and in the southern and northern parts of Son Tra Peninsula – 55 species of hard corals; no species of soft corals • At the southern part of Son Tra Peninsula, coral reefs extend down to 200 m from a depth of 12 m – Survey point no. 1 • Dead cover: 16.49 percent • Live cover: 27.03 percent • Dominant genera: *Montipora*, *Goniopora*, *Porites* – Survey Point No. 2: • Dead cover: 23.08 percent • Live cover: 19.23 percent • Dominant genera: *Porites*, *Acropora*, *Favia*

Sources: WWF (1994); HPOI (1997); Tuan Vo Sy (2000).

Attributed Causes

Although there is no definite evidence of coral reef decline in the Danang coastal zone, TSS, BOD/COD, sedimentation, oil and grease, destructive fishing, physical disturbance, cyanide, and illegal exploitation are identified as potential agents that may cause the decline.

According to a research report prepared by Nha Trang Oceanography Institute, entitled *Environmental Characterizations and Possible Relationships in the Decline of Coral Reefs in Nha Trang Bay* (Pham Van Thom – Vo Sy Tuan, 1998), there is evidence that chemical environmental parameters such as TSS, BOD, COD, etc., were the causes of coral reef decline.

Table 6. Summary of Information for the Retrospective Risk Assessment for Seagrasses.

Resource type	Areal extent	Information
Seagrasses	Large	Species: – *Halophila beccarri* Asch – *H. ovalis* Hooker – *Zostera marina* L – *Enhalus acoroides* Royle – *Cymodocea rotundata* her. Et hemp Area: 260.17 ha; coverage: 50-90 percent in coastal areas with sandy-muddy substrate at depths less than 6 m, and estuaries such as Han and Cu De Rivers

Sources: Thanh Tran Duc, et al. (1998) and Tien Nguyen Van (1998).

Consequences

Decline in coral cover impairs important ecological functions provided by coral reefs such as breeding, spawning and nursery grounds for important species, natural protection from wave action and protection from coastal erosion. Fish productivity of the reefs can also be adversely affected. Reduced fish productivity ultimately affects the economy and the people particularly the small-scale fishers who are dependent on fishing for livelihood. The loss of natural coastal protection also affects the safety of coastal communities from flooding particularly during typhoons.

Seagrasses

Evidence of Decline

Data for seagrasses were taken from Thanh Tran Duc, et al. (1998) and Tien Nguyen Van (1998). Available information provided a general description of species composition, distribution and occurrence of seagrasses in the Danang coastal area. There were no information on the decline of seagrasses and associated flora and fauna.

The summary of information on seagrasses in the Danang coastal area is given in Table 6. Available information indicated that seagrasses are distributed along the estuaries and sea areas with sandy-muddy substrate. The spatial and temporal distribution, however, were not determined.

Agents that can potentially affect seagrasses include sedimentation and the conversion of seagrass areas for aquaculture activities. Seagrasses serve as habitat and nursery grounds for various marine life, provide detrital matter, stabilize the substrate, and protect the coast from erosion. Comparative information will be important to be able to monitor and evaluate the conditions of seagrasses in the Danang coastal area, determine changes, and prevent possible decline.

Sandy Beaches

Evidence of Decline

Documents used for the assessment include the *Environmental Profile of Danang City* (DOSTE, 2000), *Reports of the Project on Mitigating Flood Impact on Environment and Reinforced Capacity to Cope with Flood in Danang City* (MOSTE, 2000), *Summary*

Record of Reference on Information Needs for Integrated Coastal Management in Danang City (HPOI, 1997) and *Environmental Protection Strategy of Danang City up to the Year 2010* (DOSTE, 2001a).

Table 7 shows the evidence of decline for sandy beaches in the Danang coastal zone.

There are evidences of decline of sandy beaches in Danang Bay and the South Son Tra - Ngu Hanh Son Coastal Water such as Nam O, Xuan Ha, Thuan Phuoc, My Khe, Bac My An and Non Nuoc. The rate of inland erosion has been estimated at 5 to 10 meters a year. Erosion of sandy beaches at Nam O can threaten the wharf of Hai Van Cement Joint-Venture Company. The erosion at My Khe, on the other hand, had exposed the oil line of a petrol company.

Attributed Causes

Causes of shoreline changes could be attributed to natural factors as well as human activities. Human activities in Danang that have high potential in causing the decline in beaches include reclamation, construction works along the coastal area such as sea walls, wharf construction, and devastation of forested areas in the upstream and along the watershed. These activities can contribute to decline in beaches by altering the water flow and movement of sediments along the coast.

Table 8 presents the detailed retrospective analysis for sandy beaches in Danang coastal zone.

The results show that construction works along the coastal area is a very likely cause for the decline of beach areas in Danang, while reclamation and devastation of forests in the watersheds were identified as possible causes. Erosions of the beach at Nam O were observed following the construction of a wharf in 1996. Sea walls in the mouth of Han River and sand mining in the upstream have altered the flow of Han River into Danang Bay. Construction along the coast and deforestation were recognized as factors that influence movement of sediments in coastal areas, although for this risk assessment, more information is required to determine the contribution of these activities

Table 7. Summary of Information for the Retrospective Risk Assessment for Sandy Beaches.

Resource type	Areal extent	Result		
		Observed changes	Identified agents	Impact
Sandy Beaches	Small	The benthos consists of: • Himantopus • Mollusca • Mussel • Crabs • Starfish Occurrences of beach erosion: • Nam O, Xuan Hoa and Thuan Phuoc (Danang Bay), My Khe, Bac My An and Non Nuoc (South Son Tra - Ngu Hanh Son Coastal Water) Rate of erosion at some places: • 5 to 10 meters inland per year	Very likely: • Reclamation Possible: • Construction works along the coast • Deforestation	• Reduction or loss of habitat • Destruction of properties and infrastructure along the coast • Economic losses

Sources: DOSTE (2000) ; DOSTE (2001a); HPOI (1997) ; MOSTE (2000).

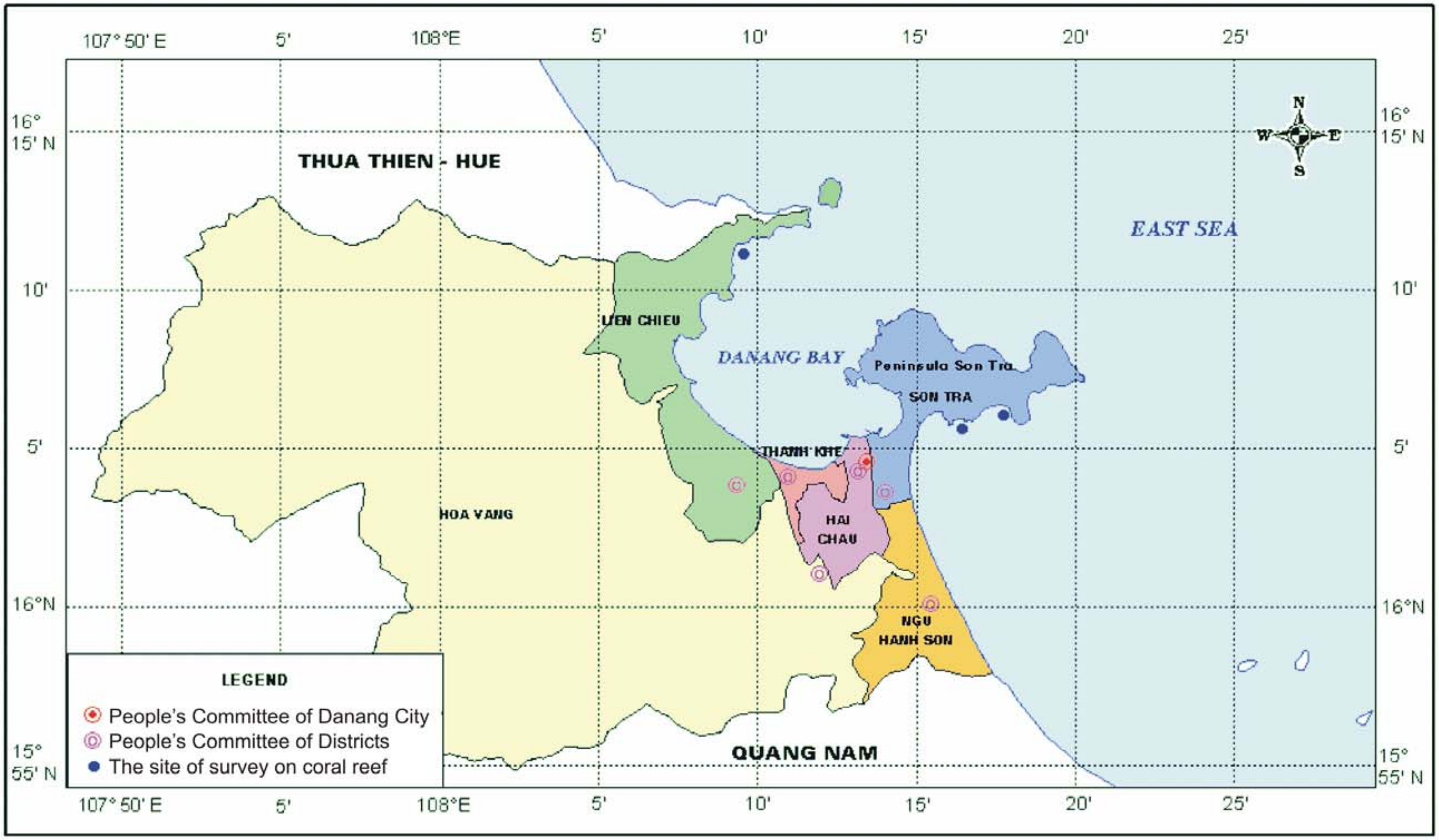

Figure 3. Location of Sampling Stations for the Investigation of Biological Resources in the Danang Coastal Zone.

Table 8. Detailed Retrospective Risk Assessment for Sandy Beaches.

Sandy Beaches	Reclamation	Construction Works	Deforestation
1. Is the target exposed to any of the agents?	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	M	Y	M
2b. Was there any loss/es correlated through space?	M	Y	M
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	M	Y	M
4a. Do the results from controlled exposure in field or laboratory experiments lead to the same effect?	M	M	M
4b. Will removal of the agent lead to amelioration?	?	?	?
5. Is there an effect in the target that is known to be specifically caused by the agent (e.g., a contaminant-specific biomarker response)?	?	?	?
6. Does it make sense (logically and scientifically)?	?	Y	?
Likelihood	**P**	**VL**	**P**

Legend: Y – Yes; M – Maybe; ? – No data; VL – Very Likely; P – Possibly

to the observed changes in the beach areas. The possibility of reduced shoreline protection due to decline in ecosystem components that provide natural protection to the coast, such as seagrasses, coral reefs and mangroves, should also be considered.

Consequences

The decline of beaches has led to many adverse effects such as loss of habitat, reduction of tourism activity, and destruction of infrastructure along the coast including properties and structures built for shoreline protection, and has contributed to economic losses in Danang.

Rocky Shores

Evidence of Decline

No evidence of decline in the rocky shores of the Danang coastal area was observed. Baseline information (HPOI, 1997) indicated that there are two rocky shores at Son Tra Peninsula and at the southern part of Hai Van Pass, having a total length of 56 km. Comparative information is not available to determine changes in rocky shores. Information on location and associated fauna is shown in Table 9.

Common benthic species recorded in the rocky shores include shipworm, oysters, mussels, crabs and starfishes. Detailed information on the distribution and abundance of benthos in the rocky shores in the Danang coastal area are not available.

Table 9. Summary of Information for the Retrospective Risk Assessment for Rocky Shores.

Habitat type	Areal extent	Information
Rocky Shores	Large	Distributed in the southern part of Hai Van Pass and around Son Tra Peninsula Benthos consist of: • Shipworm (*Balanus*) • Oyster • Mussel • Crabs • Starfish

Source: HPOI (1997).

Wetlands

Evidence of Decline

Evidences of decline for wetlands are given in Table 10.

Wetlands in the Danang coastal area include lakes, swamps, river shores and tidal flats located along the coasts and river mouths. Wetlands contribute significantly to the socioeconomic development of Danang.

There are some evidences of river shore decline in the midlands and lowlands of Vu Gia and Cu De Rivers, as well as in some riverside swamps and lakes in Danang urban areas.

Attributed Causes

The retrospective risk assessment shows that reclamation, sand mining, deforestation in the watersheds, and pollution are very likely causes of decline in the wetland areas.

Unregulated sand mining activities have caused serious erosion in some riverbank sections. Some riverside swamps had also been lost due to reclamation activities and areas of some lakes in Danang urban areas had been reduced due to development projects located near the lakes.

Decline in riverbanks are also attributed to the exploitation of forest areas along the watersheds, although the adverse effects occur gradually and are not as apparent as the impacts of reclamation and sand mining. Watershed deforestation, however, has long-term effects such as flooding, erosion and sedimentation. Decline in environmental quality are also observed in the rivers and lakes in Danang due to discharges of untreated wastes from nearby establishments. The results of the prospective risk assessment show that most of the lakes and rivers in Danang have exceeded the threshold levels of various contaminants in the water column, and fish kill incidents in rivers and lakes have been associated with the degraded environment.

Consequences

The decline of wetlands greatly affects development along the riversides and causes flooding of low-lying city areas. It also causes loss of habitats, affects biodiversity and fisheries, and decreases the regeneration of microclimate in rivers and pond systems in the urban areas.

Table 10. Summary of Information for the Retrospective Risk Assessment for Wetlands.

Habitat type	Areal extent	Results		
		Change/ time	Identified agent	Impacts
Wetlands	Large	• Total length of eroded river shore was 32,920 m (Cu De, Han, Vinh Dien, Yen, Cau Do, Qua Giang and Tuy Loan Rivers) • Loss of riverside swamps • Reduction in lake areas. • Degradation of water quality	• Sand mining in rivers • Reclamation • Untreated wastes • Forest devastation at the watersheds	• Loss of habitat • Destruction of infrastructure and properties • Flooding in low-lying areas • Reduced tourism potential of the city • Decrease of the regulation of microclimate

Sources: DOI (2000); DOSTE (2001b and 2001c).

Table 11. Detailed Retrospective Risk Assessment for Wetlands.

Wetlands	Reclamation	Sand Mining	Deforestation	Pollutant
1. Is the target exposed to any of the agents?	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	NR	NR	NR	Y
4a. Do the results from controlled exposure in field or laboratory experiments lead to the same effect?	NR	NR	NR	NR
4b. Will removal of the agent lead to amelioration?	?	?	?	?
5. Is there an effect in the target that is known to be specifically caused by the agent?	Y (reduced area)	Y (loss of sand and erosion)	?	?
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y
Likelihood	**VL**	**VL**	**VL**	**VL**

Legend: Y – Yes; M – Maybe;? – No data; NR – not relevant; VL – Very Likely

Soft-bottom Communities

Evidence of Decline

The Hai Phong Oceanography Institute (HPOI) investigated on the soft-bottom communities and benthos at the Danang coastal zone in 1997. Due to lack of comparative information, however, changes in the soft-bottom communities have not been established. Table 12 presents the available information on soft-bottom communities.

Soft-bottom communities which are predominantly sandy-muddy with high organic humus content (i.e., 6.35 - 15.5 percent) occur in the Danang coastal area in a depth of 6 to 20 m. Common benthos recorded were Nephthys malnegreni (*Stemapis sculate, Cirrulatus filipormis*), holothurians (*Molpadia roeti*) and starfish (*Astropecten* sp., *Paraheteromastus* sp.).

Human activities that potentially affect soft-bottom communities adversely include the use of trawls and pushnets for fishing and other activities that disturb the substrate. Heavy sedimentation arising from development activities along the coast and watershed areas can also bring unfavorable effects to benthic communities. Pollution and high organic loading can also affect benthic organisms, particularly in low dissolved oxygen conditions. A decline in soft-bottom communities can have adverse effects on fisheries, biodiversity and the regulation of organic loading.

Table 12. Summary of Information for the Retrospective Risk Assessment for Soft-bottom Communities.

Habitat type	Areal extent	Information
Soft-bottom	Large	Distribution: at coastal areas in a depth of 6 to 20 m Substrate: sandy-muddy with high organic humus content, 6.35 - 15.5 percent. Benthos: • Nephthys malnegreni (*Stemapis sculate, Cirrulatus filipormis*) • Holothurians (*Molpadia roeti*) • Starfish (*Astropecten* sp., *Paraheteromastus* sp.)

Source: HPOI (1997).

Forest Resources

Evidence of Decline

Sources of information for the assessment include the Annual Report of DFAF from 1990 to 2000, *Feasibility Study on Environment and Culture of the Southern Area of the Hai Van Mountain* (BOF, 1990), *Theme of Environmental Status and Environmental Protection Solutions for Ba Na Tourist Resort* (DOSTE, 2001d), *Ba Na-Nui Chua Natural Conservation Zone Project* (DFAF, 1997), *Investigation Report on the Fauna and Flora of Son Tra Peninsula Natural Conservation Zone* (DU, 1997) and *Theoretical Facts on Economy and Technology for Son Tra Peninsula Natural Conservation Zone* (BOF, 1986).

Table 13. Summary of Information for the Retrospective Risk Assessment for Forests.

Habitat/ Resource type	Areal extent	Results		
		Observed changes	Identified agents	Impacts
Forest cover	Large	Decline of forest area • Increase of 6000 ha of barren lands from 1975-1990. • A large part of the forest cannot be rehabilitated due to soil infertility. • Natural forest of Son Tra was reduced by 107 ha from 1992-1996 and 12 ha in 1998-2000. • 15 cases of forest fires recorded in the south of Hai Van from 1992-1994. • Forest cover of the south of Hai Van decreased by 40 percent from 1974-1990. • Plantation forest in Son Tra Peninsula decreased by 92 ha from 1992-1996. • Decline of Ba Na forest: big decrease of the quantities of *Sindora tonkinensis* Ahev and peck-wood.	• Clearing land for farming • Illegal land exploitation • Hazardous war substances • Forest fires • Development of tourism	• Loss of habitat • Reduced carbon storage • Loss of economically and ecologically-important species • Disruption of ecological balance
Forest fauna	Large	• 800 snakes were reintroduced into the forest in 2000 which affected forest diversity • Three species of primates were reduced. • Langur macaque monkey, small loris species, *Macaca fascicularis* and deers are in danger of extinction in Son Tra Peninsula. • 9 species of animals, 3 species of birds, 2 species of reptiles are in danger of extinction: Cha Va (*Pygathrix nemaeus nemacus*), gibbon (*Hylopates concluor gabrillac*), Malayan bear (*Helaretos malayanus*), tibetan bear (*Selennaretos thibetanus*), tiger (*Panthera tigris*), panther (*Panthera pardus*)	• Wild animal hunting • Decreasing forest cover • Introduction of other animals • Forest fires	• Loss of habitat • Loss of economically and ecologically-important species • Disruption of ecological balance

Sources: BOF (1986 and 1990); DFAF (1990 – 2000); DOSTE (2001a); DU (1997).

Table 14. Detailed Retrospective Risk Assessment for Forest Cover.

Forest Cover	Clearing of Land for Farming	Illegal Cutting of Trees	Forest Fires	Tourism Development
1. Is the target exposed to any of the agents?	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	NR	NR	NR	NR
4a. Do the results from controlled exposure in field or laboratory experiments lead to the same effect?	NR	NR	NR	NR
4b. Will removal of the agent lead to amelioration?	?	M	?	?
5. Is there an effect in the target that is known to be specifically caused by the agent?	Y	Y	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y
Likelihood	**VL**	**VL**	**VL**	**VL**

Legend: Y – Yes; M – Maybe; ? – No data; NR – not relevant; VL – Very Likely

The targets of the risk assessment are forest cover and associated fauna.

The natural forest areas of Son Tra Peninsula decreased by 107 ha from 1992-1996 and another 12 ha were lost from 1998-2000. Even the plantation forest in Son Tra Peninsula decreased by 92 ha from 1992-1996. In Hai Van forest, fifteen cases of forest fires were recorded from 1992 to1994. The forest cover of the southern part of Hai Van decreased by 40 percent from 1974-1990. The decline of the Ba Na Forest was also reported. The area of barren land in Danang increased by 6,000 ha from 1975 to 1990 and a large part of the forest could not be rehabilitated due to soil infertility.

In the coastal forests located at the Son Tra and Hai Van mountains, three species of primates have disappeared in the past 10 years (1990-2000). The Team of Forest Investigation reported that in 1988, there were about 50 to 60 primates spotted at Son Tra. In 1989, the number of Vooc Va, a species of primate (*Pygathrix nemaeus*), was estimated at 350 to 400 individuals. In 1997, this number was significantly reduced to 30-40 Vooc Va. The reduction in the number of Vooc Va and other animals in the past eight years can be attributed to illegal hunting. In 1983, a herd of 14 Vooc Va was shot dead. Other records of decline show that 13 langurs were shot dead in 1988 in one day, while 11 were shot dead in 1987.

Table 13 shows the results of the retrospective risk assessment of forest cover in Danang.

Attributed Causes

Factors that were considered to have caused the forest cover decline in Danang include land clearing for farming, illegal forest exploitation, exposure to hazardous war substances, forest fires and tourism development. Table 14 presents the retrospective risk assessment for forest cover.

For the decline in wild animals, potential causes include illegal hunting, forest fires, release of non-endemic species and decrease in forest cover. Table 15 presents the retrospective risk assessment for forest fauna.

Table 15. Detailed Retrospective Risk Assessment for Forest Fauna.

Forest Fauna	Hunting	Forest Fire	Decreasing Forest Cover	Release of other animals
1. Is the target exposed to any of the agents?	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	M
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	NR	NR	NR	NR
4a. Do the results from controlled exposure in field or laboratory experiments lead to the same effect?	NR	NR	NR	NR
4b. Will removal of the agent lead to amelioration?	Y	M	M	M
5. Is there an effect in the target that is known to be specifically caused by the agent (e.g., a contaminant-specific biomarker response)?	?	?	?	?
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y
Likelihood	**L**	**L**	**L**	**P**

Legend: Y – Yes; M – Maybe; ? – No data; NR – not relevant; L – Likely; P – Possibly

The retrospective risk assessment for forest cover shows that clearing of land for farming, illegal forest exploitation, forest fires associated with human activities, and tourism development are all very likely causes of forest cover decline in Danang. The relative contributions of these activities to forest cover decline, however, still need to be determined to be able to develop appropriate measures to mitigate the decline.

Based on the retrospective risk assessment for selected forest fauna, hunting, forest fires (associated either with human activities such as farming or with natural causes) and decrease in forest cover or degradation of habitat are all significant causes of decline, although hunting could be considered as the main reason leading to the decline of forest fauna. Continuous illegal hunting could lead to rapid decline in the number of wild animals. In addition to these agents, the release of a large number of species not endemic to the place such as the 800 snakes introduced into the forest might have also adversely affected the existing forest fauna. More information is needed to validate this assumption.

Consequences

The decline in forest cover will lead to loss of habitat that can adversely affect associated flora and fauna, and lead to loss of species with economic and/or ecological values. This can also have potential adverse effects on climate conditions due to reduced carbon sequestration to regulate the greenhouse effect and lead to changes in ecological balance.

Continuous hunting of wild animals and other detrimental activities can also lead to potentially irreversible loss of economically and ecologically important species and disrupt the balance of the ecological system.

SUMMARY OF RISK ASSESSMENT

Resources

Data for marine fisheries and aquaculture, were taken from the *Environmental Profile of Danang City* (DOSTE, 2000) and *Reports of Fisheries* from the Department of Fisheries, Agriculture and Forestry (DFAF, 1997-2001). No data showing the decline of marine fisheries were found. Available documents, however, (DOSTE, 2000; Reports from DFAF, 2001) put forward information on activities with potential adverse impacts on fisheries which include the confiscation of 29 electrical pulses, 1,799 kg of dynamites, 212 detonators and 15.6 m of delay igniters.

Data for phytoplankton were taken from the *Special Report on the Variation in Phytoplankton Species, Density and Biomass in the Marine Coastal Area of Quang Nam-Danang Province, 1989-1990* (DOSTE, 1990) and the Center of Marine Hydrometeorology *Special Report on Component, Distribution and Changing of Living Mass of Phytoplankton in the Central Coastal Area of Vietnam and Quang Nam-Danang Province* (CMH, 1990)

Table 16 shows the assessment of decline evidences, scope of impact and consequences of the decline of different resources on the ecological system, economy and society in Danang coastal zone.

Habitats

Data used for coral reef were taken from WWF (1994), HPOI (1997) and Tuan, Vo Sy (2000).

Data for seagrasses, rocky shores and soft-bottom communities were taken from the *Summary Record of Reference on the Information Needs for Integrated Coastal Management in Danang City* (HPOI, 1997).

Data for sandy beaches were taken from *Environmental Protection Strategy of Danang City up to the year 2010* (DOSTE, 2001), *Summary Record of Reference on the Information needs for Integrated Coastal Management in Danang City* (HPOI, 1997),

Table 16. Summary of Evidences, Areal Extent and Consequences of Resource Decline.

Resources	Evidences	Areal extent	Consequences		
			Ecology	Economy	Society
Marine fisheries	Not enough	**	**	***	***
Aquaculture	Enough	***	***	***	***
Phytoplankton	Unclear	***	**	Unclear	Unclear

Note: (*) – Small; (**) – Medium; (***) – Large

Table 17. Summary of Evidences, Areal Extent and Consequences of Habitat Decline.

Habitats	Evidences	Areal extent	Consequences		
			Ecology	Economy	Society
Coral reefs	Few	***	***	**	**
Seagrasses	Few	**	***	**	*
Sandy beaches	Few	*	*	***	***
Rocky shores	Not enough	Unknown	Unknown	Unknown	Unknown
Wetlands	Enough	***	**	**	**
Soft-bottom communities	Not enough	Unknown	Unknown	Unknown	Unknown
Forest resources	Not enough	***	***	***	***

Note: (*) – Small; (**) – Medium; (***) – Large

Environmental Profile of Danang City (DOSTE, 2000), and the *Reports of the Project on Mitigating Flood Impact on Environment and Reinforced Capacity to Cope with Flood in Danang City* (MOSTE, 2000).

Data for wetlands were taken from *Reports of Environmental Status, 1994-2001* (DOSTE, 2001b), *Planning for River-sand Exploitation in Danang* (DOI, 2000), and *Theme on Planning for Using Lakes in Urban Areas of Danang City* (DOSTE, 2001c).

Sources of information for the forest resource include the *Annual Reports of DFAF from 1990 to 2000, Feasibility Study on Environment, Culture of the Southern Area of Hai Van Mountain* (BOF, 1990), *Theme of Environmental Status and Environmental Protection Solutions for Ba Na Tourist Resort* (DOSTE, 2001d), *Ba Na-Nui Chua Natural Conservation Zone Project* (DFAF, 1997), *Investigation Report on the Fauna and Flora of Son Tra Peninsula Natural Conservation Zone* (DU, 1997) and *Theoretical Facts on Economy and Technology for Son Tra Peninsula Natural Conservation Zone* (BOF, 1986).

There were no evidence of decline for coral reefs, seagrasses, rocky shores and soft-bottom communities in the Danang coastal zone. Table 17 shows the evaluation of the evidences of decline, scope of impact and consequences of each habitat decline on ecology, economy and society.

Prospective Risk Assessment

Introduction

A prospective risk assessment aims to determine if measured or predicted levels of environmental parameters are likely to cause harm to targets of interest. This is accomplished by identifying the likely targets then comparing the measured or predicted environmental concentrations (MECs or PECs) with appropriate threshold values (PNECs) to get risk quotients (RQs). For human health, risk through seafood ingestion is estimated by comparing measured or predicted environmental levels (MELs or PELs) with levels of concern (LOCs) as PNECs.

In an ecological point of view, different thresholds should be specified for different targets, and if these are not available, as is often the case, ecotoxicological endpoints can be extrapolated to ecosystem endpoints using appropriate application factors (MPP-EAS, 1999a).

For the Danang coastal zone, a simplified ecological risk assessment was carried out using standards and criteria values from the Vietnam National Standards and the literature as thresholds to estimate the risk to the entire ecosystem. The principles and techniques applied are described in MPP-EAS (1999a).

For the ecological risk assessment, RQs are the ratios of MECs (or PECs) and PNECs. For human health, RQs are the ratios of MELs (or PELs) and LOCs. LOCs are obtained by dividing the tolerable daily intakes (TDIs) by the consumption rates. When an RQ is less than 1, it is presumed that the likelihood of adverse effects is low. When an RQ is greater than 1, there is a likelihood of adverse effects the magnitude of which increases with RQ increase.

For ecological risk assessment:

$$RQ = \frac{MEC\ (or\ PEC)}{PNEC}$$

For human health:

$$RQ = \frac{MEC\ (or\ PEL)}{LOC}$$

Where	RQ	< 1	Low risk
		≥ 1	High risk

The reliability of the assessment depends largely on the quality of the data used as MECs and on the quality and relevance of the threshold values used as PNECs. Although there may be uncertainties associated with the MECs and PNECs used in the risk assessment, the utility of the RQs in signaling potential areas of concern is significant. The uncertainties can be minimized through the careful selection of good quality data and relevant thresholds; these can be described so that future use of the results of the risk assessment would take the possible effects of the uncertainties into consideration.

Uncertainties can also arise from the variability in the RQs obtained. An initial measure of uncertainty was obtained by taking the average and worst-case (maximum) RQs. A more quantitative measure of uncertainty can be carried out using the Monte Carlo simulation, a re-sampling technique that randomly re-samples pairs of MECs and PNECs to come up with the percentage of the measured values exceeding the threshold.

Data for the initial risk assessment of the site came primarily from the local environmental monitoring program (DOSTE, 1994-2001), national

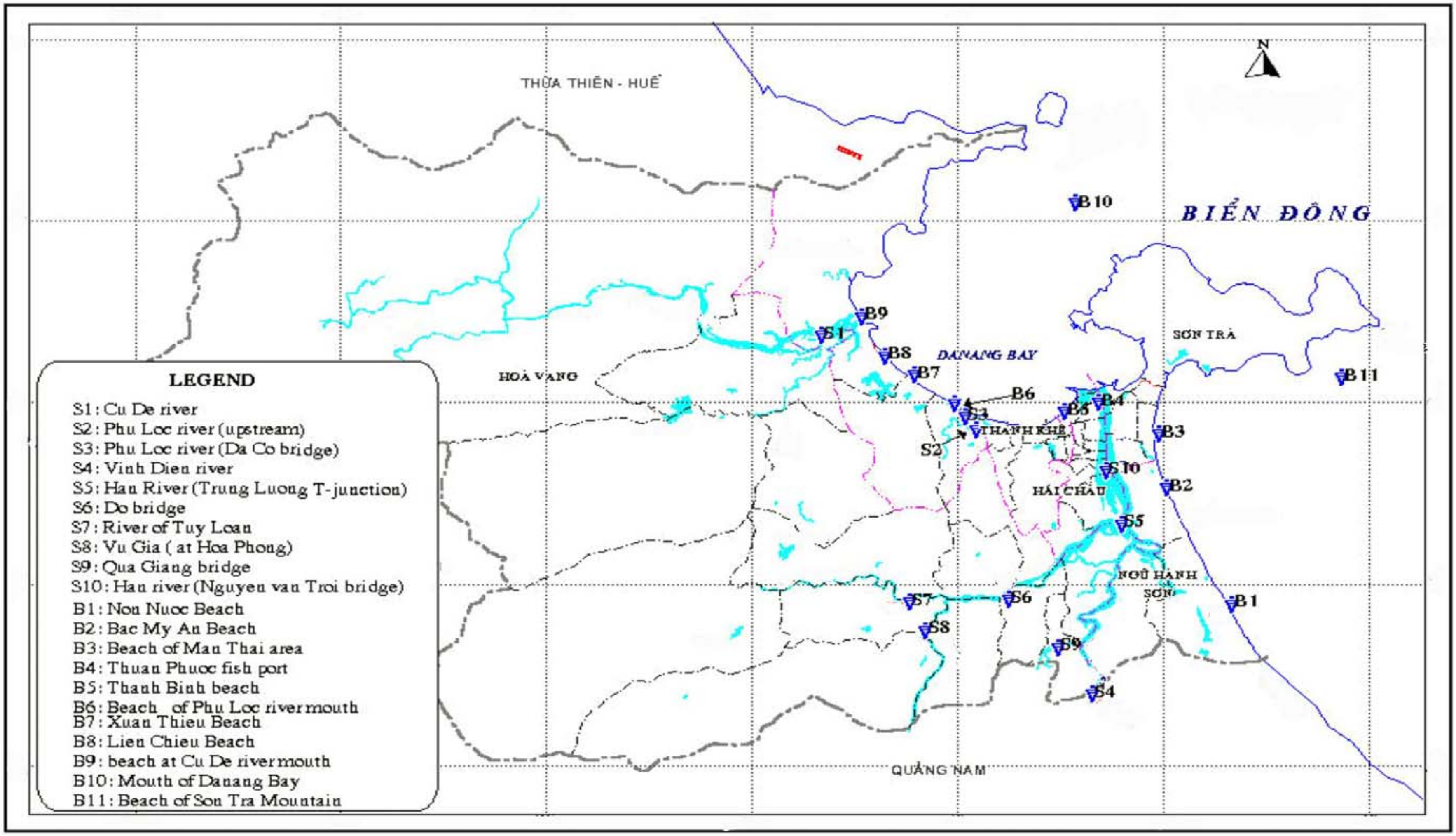

Figure 4. Location of Monitoring Stations along the Rivers and Sea in Danang.

environmental monitoring program at the site (DOSTE-NEA,1994-2001), and from several environmental projects at the coastal zone such as Vietnam-Canada Environment Project (VCEP, 1996-2000), and the Danang City's Sanitation Project (URENCO, 1997). The data includes measurements in marine water, rivers, lakes, well and ground water (Figure 4). In addition, some information from the environmental monitoring data of business enterprises and industrial companies in the coastal zone were also used for the assessment.

The threshold values, used as PNECs, came from various sources (Appendix 3) and will be detailed in the discussion for each parameter. The primary source of PNECs was the Vietnam National Standards (MOSTE, 1995a to d) which includes standards for coastal water quality (VNS 5943-1995), surface water quality (VNS 5942-1995) and ground water quality (VNS 5944-1995). The Ministry of Health also has specified standards on provisional hygiene criteria (MOH 505-1995). For parameters for which local standards were not available, other threshold values from the region and outside the region were applied such as the Philippine Water Quality Criteria (DENR Administrative Order No. 34 or DAO 34, 1990), the ASEAN Marine Water Quality Criteria (ASEAN, 2003) and the National Standards of P.R. China (1995). These criteria values were also used to compare RQs obtained using VNS standards and other threshold values.

Water classification according to the Water Quality Standard for freshwaters, ground waters and coastal waters in Vietnam was promulgated by the Ministry of Science, Technology and Environment (MOSTE, 1995a to d).

The Water Quality Standard for surface water is applied to control the quality of surface water sources. In this Standard, there are two limitation values, A and B. Values in column A are applied to the surface water used as source of domestic water supply with appropriate treatment. Values in column B are applied to the surface water used for purposes other than domestic water supply. For aquaculture life, there are some criteria of water quality in VNS 5943-1995.

The Water Quality Standard for ground water is applied to evaluate the quality of a ground water source and to monitor the pollution status of the ground water in a specific area. In this standard, there is only one limitation value.

The Water Quality Standard for marine water is applied to evaluate the quality of a coastal water resource. In this standard, there are three limitation values for different purposes. This standard's first value class is applied for bathing and recreation areas, the second one is applied for aquatic cultivation areas, and the third one is applied for other purposes.

The DAO 34 was based on background levels and criteria limits of other jurisdictions, and were specified for different water classifications of freshwaters and coastal and marine waters based on current best beneficial use. The ASEAN Marine Water Quality Criteria was based on a comprehensive evaluation of toxicological data for a minimum of six tropical marine species and concentration levels prevailing in tropical environments.

Nutrients

<u>Water Column</u>

The data for nutrients in seawater, lake water, river water, and ground water were taken from the annual reports of the local monitoring program (DOSTE, 1995-2001), *Annual Reports of the national monitoring program in Danang* (DOSTE-NEA, 1994-2001), *Results of Danang Bay Environment Monitoring* and *Results of Tram Lake and Cu De River*

Environmental Monitoring (VCEP, 1998a and c), and the *EIA Report of Danang City's Sanitation Project* (URENCO, 1997). The data includes results of environmental monitoring undertaken two to six times a year for seawater, lake water, river water and ground water. The sampling frequency was two times a year from 1995 to 1997, four times a year from 1998 to 2000, and six times a year from 2001 up to the present for seawater, lake water, river water and ground water. The monitoring stations in Danang Bay consist of Lien Chieu, Xuan Ha, Xuan Thieu, Thanh Binh, Thuan Phuoc and the mouths of the Cu De, Han and Phu Loc Rivers, and the mouth of Danang Bay. The monitoring stations at the South Son Tra - Ngu Hanh Son Coastal Water consist of Tho Quang, Man Thai, Bac My An and Non Nuoc beaches. Corresponding threshold values for seawater, fresh water and ground water were applied.

For ammonium in seawater, the threshold value used in the risk assessment was the standard for aquaculture cultivation areas in the Vietnam National Standards for coastal water quality (VNS 5943-1995). For nitrite, nitrate and phosphate in seawater, the threshold values used in the risk assessment were from the ASEAN Criteria. There are no data on total nitrogen and threshold values for total nitrogen and total phosphorus.

For nutrients in freshwater, the threshold values used in the prospective risk assessment were the standards for aquaculture areas in the Vietnam National Standards for surface water quality (VNS 5942-1995). At Cau Do, however, the VNS 5942-1995 standards for surface water used as source of domestic water supply (with appropriate treatment) were used.

For human health, the threshold values used in the prospective risk assessment for nutrients in well water was the Vietnam National Standard (MOH 505-1995).

There were no data for nutrients in sediment and fishery tissue. There were no data and PNECs for total nitrogen and no PNECs for total phosphorus in seawater column. Table 18 presents the RQs for nutrients in seawater column.

Ecologically, there is cause for concern for the levels of nitrate and phosphate in seawater as indicated by the maximum and geomean RQs which are greater than 1, especially for NO_3-N (RQ_{Max} = 26; RQ_{Gm} = 1.05). RQ_{Max} for NO_{2-}-N and NH_4-N are greater than 1, but the RQ_{Gm} are less than 1.

The maximum MECs for nutrients were sampled at stations in Danang Bay near the mouth of Cu De, Han and Phu Loc Rivers.

Table 18. RQs for Nutrients in Seawater Column.

Nutrients	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	VNS			ASEAN criteria		
			PNEC (mg/l)	RQ_{Max}	RQ_{Gm}	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Danang Bay								
NO_2-N (n = 125)	0.86	0.01				0.06	15.64	0.17
NH_4-N (n = 193)	6.30	0.09	0.50	12.60	0.18			
NO_3-N (n = 181)	1.56	0.06				0.06	26.00	1.05
PO_4-P (n = 70)	0.18	0.01			0.02	12.20	0.84	
South Son Tra - Ngu Hanh Son Coastal Water								
NH_4-N (n = 30)	0.80	0.06	0.50	1.60	0.12			
NO_3-N (n = 1)	3.00	3.00				0.06	50.00	50.00

Source for MECs: DOSTE (2001b)
Sources for PNECs: VNS 5943-1995 and ASEAN Marine Water Quality Criteria (ASEAN, 2003).

Nutrients are required for primary productivity but elevated concentrations may cause eutrophication and may trigger phytoplankton blooms. This can lead to low dissolved oxygen levels in the seawater column and eventually affect the benthos and other sessile organisms.

Table 19 presents the RQs for nutrients in river water column.

Ecologically, there is cause for concern for the nitrogen levels in the river water column because, except for nitrite in Cu De River, all maximum RQs for nitrite, ammonium and nitrate in Cu De, Phu Loc and Vu Gia Rivers are greater than 1. The highest RQ_{Max} is for ammonium in Cu De River (RQ_{Max}= 10.44). RQ_{Gm} for nutrients, however, except for ammonium in Phu Loc River, are all less than 1. RQ_{Max} for phosphate in the Vu Gia River System is also less than 1. There are no data on phosphate for the other rivers.

For Cau Do River, a source of domestic water supply, maximum and mean RQs for nitrite and ammonium indicate cause for human health concern. The RQ_{Max} for ammonium in Cau Do River is particularly high (RQ_{Max}= 122).

Table 20 shows the MECs and RQs for lakes in Danang.

Ammonium (NH_4-N) is a main concern for all lakes, including Green Lake which is a source of domestic water supply, with RQ_{Max} and RQ_{Gm} greater than 1, with the highest RQ_{Max} of 44 coming from Rong Lake. Maximum and geomean RQs for NO_2-N in March 29 Park Lake and Thac Gian-

Table 19. RQs for Nutrients in River Water Column.

Nutrients	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	VNS			DAO 34		
			PNEC (mg/l)	RQ_{Max}	RQ_{Gm}	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Cu De River								
NO_2-N (n = 4)	0.034	0.012	0.05	0.68	0.25			
NH_4-N (n = 13)	10.440	0.359	1.00	10.44	0.36			
NO_3-N (n = 15)	140.000	1.488	15.00	9.33	0.10	10.00	14.00	0.15
Phu Loc River								
NO_2-N (n = 5)	0.160	0.031	0.05	3.20	0.62			
NH_4-N (n = 21)	9.600	1.053	1.00	9.60	1.05			
NO_3-N (n = 28)	38.300	1.744	15.00	2.55	0.12	10.00	3.83	0.17
Vu Gia River System								
NO_2-N (n = 70)	0.190	0.011	0.05	3.80	0.23			
NH_4-N (n = 155)	6.100	0.075	1.00	6.10	0.07			
NO_3-N (n = 165)	26.000	0.213	15.00	1.73	0.01	10.00	2.60	0.02
PO_4-P (n = 68)	0.190	0.060				0.40	0.48	0.15
Cau Do River								
N_{Total} (n = 0)								
NO_2-N (n = 12)	0.080	0.012	0.010	8.00	1.24			
NH_4-N (n = 26)	6.100	0.055	0.050	122.00	1.11			
NO_3- N (n = 27)	0.530	0.158	10.000	0.05	0.02			
P_{Total} (n = 11)	0.130	0.043						
PO_4-P (n = 14)	0.160	0.057						

Source for MECs: DOSTE (2001b)
Sources for PNECs: VNS 5942-1995: Class (A) for Cau Do River and Class (B) for other river; DAO 34 (1990).

Vinh Trung Lake are greater than 1. For Rong, Tram, and Green Lakes, maximum RQs for NO_3-N are greater than 1 although geomean RQs are still less than 1. There are no data for PO_4-P and there are no standards in the VNS 5942-1995 for PO_4-P and total phosphate.

The high concentration of ammonium in lake water column is the main cause for the unpleasant smell in the residential areas close to the lakes. The high concentration of nutrients in the water column of the lakes also caused eutrophication and triggered phytoplankton blooms in March 29 Park Lake.

Table 21 presents the RQs for nutrients in well and ground water column.

Table 20. RQs for Nutrients in Lake Water Column.

Agents	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Rong Lake					
N_{Total} (n = 2)	32.000	26.533			
NO_2-N (n = 8)	0.024	0.014	0.050	0.48	0.29
NH_4-N (n = 40)	44.000	19.560	1.000	44.00	19.56
NO_3- N (n = 24)	33.900	2.317	15.000	2.26	0.15
P_{Total} (n = 6)	11.050	3.867			
Thac Gian-Vinh Trung Lake					
NO_2-N (n = 1)	1.470	1.470	0.050	29.40	29.40
NH_4-N (n = 7)	32.500	16.531	1.000	32.50	16.53
NO_3- N (n = 7)	12.500	2.751	15.000	0.83	0.18
Tram Lake					
N_{Total} (n = 0)					
NO_2-N (n = 2)	0.045	0.035	0.050	0.90	0.71
NO_3- N (n = 11)	112.400	2.442	15.000	7.49	0.16
P_{Total} (n = 1)	29.000	29.000			
PO_4-P (n = 0)					
March 29 Park Lake					
N_{Total} (n = 1)	6.000	6.000			
NO_2-N (n = 5)	0.492	0.085	0.050	9.84	1.70
NH_4-N (n = 12)	19.000	1.198	1.000	19.00	1.20
NO_3- N (n = 17)	9.600	2.780	15.000	0.64	0.19
P_{Total} (n = 4)	4.700	1.554			
PO_4-P (n = 0)					
Green Lake					
N_{Total} (n = 0)					
NO_2-N (n = 0)					
NH_4-N (n = 7)	0.390	0.075	0.050	7.80	1.50
NO_3- N (n = 7)	69.400	0.893	10.000	6.94	0.09
P_{Total} (n = 1)	6.700	6.700			
PO_4-P (n = 0)					

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Source of PNEC: VNS 5942-1995, Class A for Green Lake and Class B for other lakes.

Maximum RQs of ammonium and nitrate in well water are greater than 1 (RQ_{Max} of NH_4-N = 30.60; RQ_{Max} of NO_3-N = 22.15), but geomean RQs are less than 1. This shows that human health risk is associated with ammonia and nitrate levels in water from certain wells in the study area. For ground water, maximum and geomean RQs for nitrate are less than 1 while no threshold values for nitrite, ammonia and phosphate are available from VNS 5944-1995.

The high maximum MECs of ammonium and nitrate were sampled at sites near the factories and in the residential areas

The high nitrate concentration in well water or ground water presents risks to human health. According to the national primary drinking water regulations of the USEPA, infants below six months of age who drink water containing nitrate and nitrite in excess of the specified maximum contaminant levels (10 mg/l for NO_3–N and 1 mg/l for NO_2-N) could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome (USEPA, 2001).

The possible sources of nutrients in the Danang coastal zone, rivers, lakes, wells and ground water are domestic/commercial/institutional waste and sewage, untreated or partially treated industrial effluents and agricultural discharge or run-off. Possible sources of phosphate may be attributed to the extensive use of feeds, fertilizers and detergents with high phosphate contents. Leaching from septic tanks and erosion of natural deposits also contribute to well and ground water contamination.

Uncertainty Analysis

The risk assessment results highly depend on the MECs and PNECs employed in the calculations. For some nutrients for which local standards were not available, thresholds from the ASEAN and Philippines were used to compute for RQs. With regard to the MECs, the maximum RQs that were obtained using the highest measured nutrient value will be useful in identifying environmental hotspots, but there will still be a need for a more detailed analysis of the spatial and temporal distribution of risks to identify potential impacts to the ecosystem and human health. Nutrient contributions from natural sources also need to be separated from those contributed by human activities.

Table 21. RQs for Nutrients in Well and Ground Water Column.

Nutrients	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Well water					
N_{Total} (n = 6)	3.23	0.76			
NO_2-N (n = 65)	4.94	0.06			
NH_4-N (n = 89)	91.80	0.12	3.00	30.60	0.04
NO_3-N (n = 121)	221.50	3.46	10.00	22.15	0.35
P_{Total} (n = 17)	10.05	0.13			
PO_4-P (n = 2)	0.29	0.28			
Ground water					
NO_2-N (n = 9)	4.12	1.95			
NH_4-N (n = 21)	4.50	0.29			
NO_3-N (n = 20)	8.60	2.64	45.00	0.19	0.06
PO_4-P (n = 11)	4.15	0.15			

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Sources for PNECs: MOH 505-1995 for well water and VNS 5944-1995 for ground water.

DO, BOD, COD

Water column

Table 22 describes the data used in the risk assessment for DO, BOD and COD in marine, river and lake water column. The data for BOD, COD and DO in seawater, lake water, river water, and well water were taken from the report of the local monitoring program (DOSTE, 1996-2001), reports from the national monitoring program in Danang (DOSTE-NEA, 1995-2001), the environmental monitoring reports of the VCEP project (1998a to c), and the *EIA Report of Danang City's Sanitation Project* (URENCO, 1997).

The PNECs for seawater were taken from the Vietnam National Standards for coastal water quality (VNS 5943-1995) and the Chinese standards for different water classifications, while the PNECs for river and lake water were from the Vietnam National Standards for surface water quality (VNS 5942-1995) and the PNECs for well water were from MOH 505-1995.

For dissolved oxygen, unlike other parameters, concentrations lower than the threshold value signal deteriorating environmental conditions. RQ, therefore, is not the ratio of MECs and PNECs, but the reciprocal of the ratio, and the worst-case RQ or RQ_{Max} is obtained by using the lowest MEC.

The environmental monitoring program was implemented with sampling frequencies that ranged from two to six times a year. Sampling frequency was two times a year from 1995 to1997, four times a year from 1998 to 2000, and six times a year from 2001

Table 22. Summary of Information for the Prospective Risk Assessment for DO/BOD/COD (Sea/Lake/River).

Agent	Compartment	Description of data	Location	References
DO, BOD, COD	Water column (sea, lakes, rivers and wells)	– Danang Bay: 272 samples for DO, 128 for BOD and 208 for COD (1994-2001). – South Son Tra - Ngu Hanh Son Coastal Water: 38 samples for DO, 31 for BOD and 2 for COD (1994-2001). – Rivers: 138 samples for DO, 128 for BOD and 171 for COD (1995-2001). – Lakes: 12 positions at 5 lakes with 76 samples for DO, 132 for BOD and 123 for COD (1994-2001). – Wells: 53 samples for DO, 34 for BOD and 21 for COD	– Danang Bay (5 stations) and South Son Tra - Ngu Hanh Son Coastal Water (2 stations). – 3 rivers: Cu De, Phu Loc and Vu Gia River system. – 5 lakes: (29 March, Public Garden, Green, Rong, Thac Gian-Vinh Trung and Tram). – Wells in Danang City	– Annual Environmental Monitoring Reports in Danang City (DOSTE-NEA, 1994-2001). – EIA Reports of Danang City's Sanitation Project (URENCO, 1997). – Environmental Monitoring Reports of Tram Lake (VCEP, 1998b). – Environmental Monitoring Reports of Danang Bay (VCEP, 1998a).

up to the present for seawater, lake water, river water and ground water. There are two environmental monitoring programs in the Danang coastal zone, each conducted by the National Environmental Agency and by Danang DOSTE.

The possible sources of organic load that increase the BOD and COD levels and decrease DO levels in the water column of the study area are domestic/commercial/institutional waste and sewage, untreated or partially treated industrial effluents and agricultural discharge or run-off. The following are the results of the assessment for BOD, COD, and DO in water column.

The average and maximum RQs for BOD, COD and DO in seawater column are given in Table 23.

The maximum RQs for DO in Danang Bay and the South Son Tra - Ngu Hanh Son Coastal Water are both greater than 1 (RQ_{Max} = 1.47 in Danang Bay and RQ_{Max} = 1.32 in the South Son Tra - Ngu Hanh Son Coastal Water), while the geomean RQs are both less than 1. For BOD in seawater column, RQ_{max} exceeded one in Danang Bay (RQ_{Max} = 1.316), but is less than 1 in the South Son Tra - Ngu Hanh Son Coastal Water (RQ_{Max} = 0.9). The geomean RQ_s for BOD in seawater column for both bodies of water are less than 1. COD data are available for Danang Bay and the South Son Tra - Ngu Hanh Son Coastal Water but the threshold value is not available. Use of the Chinese standard for COD shows cause for concern for COD in the water column in both areas, with the maximum and geomean RQs exceeding 1. It should be noted, however, that in the National Standards of P.R. China, the standard for COD (5 mg/l for Class IV) is greater than the standard for BOD (4 mg/l for Class IV), whereas the Vietnam National Standard for BOD is 10 mg/l. This has implications on the relative comparability of RQs for BOD and COD.

Table 23. RQs for BOD, COD, DO in Seawater Column.

BOD, COD, DO	MEC (mg/l)			VNS			Chinese Standard		
	Max	Min	Gm	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Danang Bay									
DO (n = 268)	9.700	3.40	6.307	5.000	1.471	0.793			
BOD (n = 161)	13.000	0.06	2.479	10.000	1.300	0.248			
COD (n = 199)	47.000	0.55	10.455				5.000	9.400	2.091
South Son Tra - Ngu Hanh Son Coastal Water									
DO (n = 55)	11.100	3.90	6.085	5.000	1.316	0.822			
BOD (n = 31)	9.000	1.00	3.574	10.000	0.900	0.357			
COD (n = 24)	35.700	8.90	19.593				5.000	7.140	3.919

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Sources for PNECs: VNS 5943-1995, for aquatic cultivation area; Chinese Standard, Class IV.

The high concentration of organic matters in seawater can cause depletion of dissolved oxygen and affect benthos and sessile organisms.

Average and maximum RQs for BOD, COD and DO in water column of rivers are given in Table 24.

Using VNS Class A (VNS 5942-1995) for Cau Do River, geomean RQs for DO and BOD are all equal to or greater than 1. Maximum RQ for COD is greater than 1 (RQ_{Max} = 2.2) although geomean RQ is less than 1. These results indicate potential concern for levels of organic matter in Cau Do River. It should be noted that levels of DO, BOD and COD in this river are less than or within the range of concentrations in the other rivers. The use of Cau Do River as source of domestic water supply, however, requires better water quality and application of more stringent standards.

Using VNS Class B (VNS 5942-1995), maximum RQs for BOD and COD for river water column are all greater than 1. The highest RQs for BOD and COD were obtained in Phu Loc River (RQ_{Max} = 2.4 for BOD; and RQ_{Max} = 4.83 for COD). Average RQs for BOD and COD, however, are less than 1

Table 24. RQs for BOD, COD, DO in River Water Column.

BOD, COD, DO	MEC (mg/l)			VNS		
	Max	Min	Gm	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Cu De River						
DO (n = 19)	7.300	4.180	5.602	2.000	0.478	0.357
BOD (n = 15)	44.800	1.000	8.899	25.000	1.792	0.356
COD (n = 16)	57.600	1.000	11.643	35.000	1.646	0.333
Phu Loc River						
DO (n = 29)	7.600	2.340	3.929	2.000	0.855	0.509
BOD (n = 25)	60.090	3.000	12.673	25.000	2.404	0.507
COD (n = 24)	169.000	1.700	26.242	35.000	4.829	0.750
Vu Gia River System						
DO (n = 179)	8.400	3.900	5.869	2.000	0.513	0.341
BOD (n = 127)	33.000	1.000	5.472	25.000	1.320	0.219
COD (n = 169)	81.300	0.500	9.357	35.000	2.323	0.267
Cau Do River						
DO (n = 29)	8.000	4.400	6.019	6.000	1.360	1.000
BOD (n = 19)	10.000	3.000	5.558	4.000	2.500	1.390
COD (n = 30)	22.000	2.800	8.591	10.000	2.200	0.860

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Source for PNECs: VNS 5942-1995, Class A for Cau Do river and Class B for other rivers.

(RQ_{Gm} = 0.31 for BOD and 0.52 for COD, for all data). The threshold value for DO in aquaculture areas (2 mg/l) was also not exceeded and maximum RQs for all sites are less than 1. These results show localized concerns with regard to organic matter levels in river waters. The results further show that these rivers, which drain in Danang Bay, are potential contributors to organic loading in the coastal waters. Specific areas of concern along the rivers need to be identified for the formulation of appropriate management interventions.

In the risk assessment for lakes, threshold values from the VNS 5942-1995 Class B for aquaculture were applied for DO, BOD and COD for all the lakes except Green Lake in which Class A limits for domestic water supply were used. Maximum MECs for DO exceeded in all sites except Thac Gian-Vinh Trung Lake and the highest RQ_{Max} (66.67) was obtained at Rong Lake. Geomean RQs for DO exceeded 1 in Rong Lake (RQ_{Gm} = 3.13) and Green Lake (RQ_{Gm} = 1.39). The maximum and geomean RQs for BOD and COD exceeded 1 in all sites except for BOD in March 29 Park Lake and BOD and COD in Green Lake. The highest RQ_{Max} for BOD and COD were obtained at Green Lake (RQ_{Max} = 7.05) and Tram Lake (RQ_{Max} = 7.86), respectively.

Tram, Rong, and Thac Gian-Vinh Trung Lakes are areas that receive untreated or partially treated wastewater from most of the activities in the Hai Chau, Thanh Khe and Lien Chieu Districts.

The high concentration of BOD and COD and the low concentration of DO in lake water column may have already caused serious ecological changes in these lakes.

The average and maximum RQs for BOD in well water column are given in Table 26. There were no PNEC for DO and COD in MOH 505-1995.

In the risk assessment for wells, threshold values from MOH 505-1995 were applied for BOD. The maximum and geomean RQs for BOD exceeded 1 in well water column (RQ_{Max} = 15.0, RQ_{Gm} = 2.18).

With regard to human health, risks are associated with the levels of organic matter, as indicated by BOD, in well water. Risks from levels of BOD, COD and DO are also associated with certain areas in Green Lake, a source of domestic water supply, as indicated by RQ_{Max} values greater than 1.

Table 25. RQs for BOD, COD, DO in Lake Column.

BOD, COD, DO		MEC_{Max}	MEC_{Gm}	PNEC (mg/l)	RQ_{Max} (mg/l)	RQ_{Gm} (mg/l)
Rong Lake	DO (n = 86)	0.030(*)	0.639	2.000	66.667	3.131
	BOD (n = 143)	128.000	35.856	25.000	5.120	1.434
	COD (n = 134)	223.000	78.896	35.000	6.371	2.254
Thac Gian-Vinh Trung Lake	DO (n = 86)	2.900(*)	3.360	2.000	0.690	0.595
	BOD (n = 143)	61.000	36.054	25.000	2.440	1.442
	COD (n = 134)	205.000	75.280	35.000	5.857	2.151
Tram Lake	DO (n = 86)	0.800(*)	2.660	2.000	2.500	0.752
	BOD (n = 143)	111.000	31.192	25.000	4.440	1.248
	COD (n = 134)	275.000	70.948	35.000	7.857	2.027
March 29 Park Lake	DO (n = 86)	0.700(*)	4.471	2.000	2.857	0.447
	BOD (n = 143)	46.000	15.068	25.000	1.840	0.603
	COD (n = 134)	140.000	57.917	35.000	4.000	1.655
Green Lake	DO (n = 86)	3.800(*)	4.314	6.000	1.579	1.391
	BOD (n = 143)	28.200	2.619	4.000	7.050	0.655
	COD (n = 134)	28.000	3.844	10.000	2.800	0.384

Note: The values having sign (*) mean MEC_{min} (mg/l) of DO.
Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Source of PNECs: VNS 5942-1995 class A for water supply (for Green Lake) and class B for aquaculture.

Uncertainty Analysis

For data in which RQ_{Max} is greater than 1 but RQ_{Gm} is less than 1, the Monte Carlo simulation was used to determine the probability that RQs will exceed 1. The result shows that the probability that RQs for DO in sea water will be greater than 1 is about 7.4 percent (SD = 0.914) for Danang Bay water, 20.7 percent (SD = 1.24) for the South Son Tra - Ngu Hanh Son Coastal Water, 55.2 percent (SD = 2.639) for Tram Lake water and 99.4 percent (SD = 0.45) for Green Lake water. It is important, therefore, to analyze spatial and temporal distribution of risk from low DO, to determine marine areas with low DO concentration, as well as the low DO contributors, to adequately identify impacts of DO to various ecological components.

Table 26. RQs for BOD, COD, DO in Well Water Column.

Agents	MEC (mg/l)			MOH 505-1995		
	Max	Min	Gm	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
DO (n = 53)	5.400	0.700	3.057	No data		
BOD (n = 34)	30.000	0.300	4.353	2.000	15.00	2.18
COD (n = 21)	64.000	0.020	5.131	No data		

Total Suspended Solids (TSS)

Water Column

Similar to the data for BOD/COD/DO, the data for TSS was extracted from Danang DOSTE (national and local environmental monitoring programs in Danang City, from 1995 to 2001), the Environmental Monitoring Reports of the VCEP Project (1998a to c), and the EIA Report of Danang City's Sanitation Project (URENCO, 1997). The PNECs for seawater were taken from the Vietnam National Standards for coastal water quality (VNS 5943-1995; for bathing and aquaculture). The PNECs for freshwater were taken from the Vietnam National Standard for surface water quality (VNS 5942-1995, column B for aquaculture).

The environmental monitoring program was implemented with sampling frequencies that ranged from two to six times a year. The sampling frequency was two times a year from 1995 to 1997, four times a year from 1998 to 2000, and six times a year from 2001 up to the present for seawater, lake water, river water and ground water. There are two

Table 27. Summary of Information for the Prospective Risk Assessment for TSS in Water Column.

Agent	Compartment	Description of data	Location	References
TSS	Water column (seas, lakes, rivers and wells)	– Danang Bay: 250 samples (1994-2001) – South Son Tra - Ngu Hanh Son Coastal Water: 27 samples (1994-2001) – River water with 16 stations and 166 samples (1996-2001) – Water column of lakes with 12 stations and 124 samples (1994-2001) – Well water: 80 samples (1995-2001)	– Danang Bay and South Son Tra - Ngu Hanh Son Coastal Water – Cu De, Phu Loc and Vu Gia Rivers. – 29 March, Public Garden, Green, Rong, Thac Gian-Vinh Trung and Tram Lakes.	– Annual Environmental Monitoring Reports of Danang City (NEA and Danang DOSTE, 1994- 2001) – EIA Reports of Danang City's Sanitation Project (URENCO, 1997) – Environmental Monitoring Reports of Tram Lake (VCEP, 1998b) – Environmental Monitoring Reports of Danang Bay (VCEP, 1998a)

Table 28. RQs for TSS in Seawater Column.

TSS	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Danang Bay					
Hon Cho SS (n = 12)	47.200	36.078	50.000	0.944	0.722
Kim Lien SS (n = 12)	41.700	34.336	50.000	0.834	0.687
Cu De SS (n = 16)	37.100	25.061	50.000	0.742	0.501
Xuan Thieu SS (n = 37)	163.000	21.226	25.000	6.520	0.849
Phu Loc SS (n = 18)	34.200	20.082	50.000	0.684	0.402
Xuan Hoa SS (n = 12)	55.900	35.384	50.000	1.118	0.708
Thanh Binh SS (n = 40)	161.000	27.058	50.000	3.220	0.541
Thuan Phuoc SS (n = 38)	160.000	23.390	50.000	3.200	0.468
Mouth of Danang Bay SS (n = 67)	20.000	8.134	50.000	0.400	0.163
Tien Sa SS (n = 12)	49.200	33.382	50.000	0.984	0.668
South Son Tra - Ngu Hanh Son Coastal Water					
Tho Quang SS (n = 6)	19.000	9.500	50.000	0.380	0.190
Man Thai SS (n = 6)	21.000	14.167	25.000	0.840	0.567
Bac My An SS (n = 6)	24.000	17.333	25.000	0.960	0.693
Non Nuoc SS (n = 17)	41.000	16.812	25.000	1.640	0.672

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Source for PNECs: VNS 5943-1995 (Column A for bathing (25 mg/l) and column B for aquaculture (50 mg/l)).

Table 29. RQs for TSS in River Water Column and Well Water Column.

TSS	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Cu De River					
SS (n = 12)	44.00	9.960	80.00	0.55	0.12
Vu Gia River					
Hoa Phong (n = 28)	164.00	18.440	80.00	2.05	0.23
Cau Do (n = 29)	166.00	15.520	20.00	8.30	0.78
Hoa Tho (n = 29)	168.00	11.640	80.00	2.10	0.15
Qua Giang (n = 28)	167.00	17.030	80.00	2.09	0.21
Tuyen Son (n = 6)	36.00	17.230	80.00	0.45	0.22
Nguyen Van Troi Bridge (n = 27)	164.00	17.100	80.00	2.05	0.21
Thuan Phuoc (n = 8)	58.00	12.040	80.00	0.73	0.15
Phu Loc River					
SS (n = 20)	124.00	17.490	80.00	1.55	0.22
Vinh Dien River					
SS (n = 16)	208.20	20.390	80.00	2.60	0.25
Well water column (n = 80)	1056.40	6.399	500.00	2.11	0.01

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Sources for PNECs: VNS 5942-1995 (Class A for domestic water supply and class B for aquaculture); MOH 505-1995 for well water column

environmental monitoring programs in the Danang coastal zone, each conducted by the National Environmental Agency and by Danang DOSTE.

Table 28 shows the RQs for TSS in seawater column.

Table 28 shows that, among the four bathing stations, cause for concern for TSS levels were found in Xuan Thieu (RQ_{Max} = 6.52) and Non Nuoc (RQ_{Max} = 1.64). For the other stations, concern for levels of TSS for aquaculture was identified at three stations in Danang Bay, with maximum RQs of 3.2 at Thanh Binh and Thuan Phuoc.

Table 29 shows the results of the prospective risk assessment for TSS in river water column and well water column.

Most of the data used for calculating RQs are the results of the annual environmental monitoring program in Danang City. A part of the data was sampled and analyzed by Danang DOSTE and the rest by NEA.

There are hotspots for TSS in the water column at the Vu Gia, Phu Loc, Vinh Dien Rivers and at certain wells as shown by maximum RQs that exceeded 1. The highest maximum RQ was found in Cau Do River, a source for drinking water in Danang City. Corresponding geomean RQs were all less than 1.

Table 30 shows the RQs for TSS in lake water column. The five lakes named are the lakes that had environmental monitoring stations. Green Lake is being used for domestic water supply.

All RQ_{Max} of TSS in lake water column exceeded the threshold value, except for Green Lake, and RQ_{Gm} of TSS in all the lakes are less than 1.

Suspended solids refer to organic and inorganic fine solid particles suspended in the seawater and their size is lower than 0.45 μm. Natural sources of suspended solids include eroded soil and rocks. Suspended solids can also come from various land-use practices in the watersheds and the coast like land reclamation projects, mining activities, aquaculture and agricultural activities; from coastal erosion as a consequence of habitat destruction and sea level rise; and from re-suspension of bottom sediments as a consequence of dredging, trawling and natural mixing. Suspended solids in seawater, river water and lake water can also come from domestic, commercial and institutional waste and sewage, and untreated or partially treated industrial effluent discharges and run-off.

Suspended solids in the water column may reduce light penetration and visibility. The resultant turbidity might lead to decrease in primary productivity and decrease in food supply for different trophic levels. The solids also serve as surfaces on which oil and other toxic pollutants can be adsorbed and transported to the bottom sediments. Suspended solids may also be deposited on coral reefs, in effect causing their suffocation and deterioration.

Table 30. RQs for TSS in Lake Water Column.

TSS	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Rong Lake (n = 52)	90.00	27.23	80.00	1.13	0.34
Thac Gian-Vinh Trung Lake (n = 7)	100.00	39.59	80.00	1.25	0.49
Tram Lake (n = 48)	634.00	68.40	80.00	7.93	0.86
March 29 Park Lake (n = 20)	149.20	32.90	80.00	1.87	0.41
Green Lake (n = 7)	12.00	5.33	20.00	0.60	0.27

Sources for MECs: NEA (1995-20010; DOSTE (2001b)
Source for PNECs: VNS 5942-1995 (Column A for domestic water supply and Column B for aquaculture).

Uncertainty Analysis

The threshold values used to calculate the RQs for TSS were specific values from the Vietnam National Standards. The application of general standards or specific values to assess risks from TSS for various locations is, however, not totally appropriate, because these can not accurately reflect the changes in TSS caused by natural stream flow and the ecological impact thresholds for marine

Table 31. Summary of Information for Total Coliform in Water Column.

Agent	Compartment	Description of data	Location	References
Coliform	Water (seas, lakes, rivers and wells)	– Danang Bay: 170 samples (1994-2001) – South Son Tra - Ngu Hanh Son Coastal Water: 33 samples (1994-2001) – Lake water: 120 samples (1996-2001). – Rivers: 211 samples (1995-2001). – Wells: 74 samples (1995-2001)	– Danang Bay – South Son Tra - Ngu Hanh Son Coastal Water – 5 lake water – 3 rivers – wells in Danang City	– Annual Environmental Monitoring Reports of Danang City (NEA and Danang DOSTE, 1994- 2001). – EIA Reports of Danang City's Sanitation Project (URENCO, 1997. – Environmental Monitoring Reports of Tram Lake (VCEP, 1998b). – Environmental Monitoring Reports of Danang Bay (VCEP, 1998a).

communities such as coral reefs and seagrasses. There is a need, therefore, to find more suitable threshold values for TSS that will protect various ecological components in the area, particularly the bottom-dwelling species.

Coliform

Water Column

The data for coliform were taken from national and local environmental monitoring programs from 1994 to 2001 including some records of environmental monitoring of VCEP Project (1998a to c) and Danang City's Sanitation Project (URENCO, 1997). There are 14 marine environmental monitoring stations, 15 fresh water environmental monitoring (10 stations for river water column and 5 for ground water) in Danang City. There are no data for fecal coliform in water column in Danang coastal zone.

RQs for coliform in seawater column are given in Table 32.

Table 32. RQs for Total Coliform in Seawater Column.

Coliform	MEC_{Max} (MPN/100ml)	MEC_{Gm} (MPN/100 ml)	PNEC (MPN/100 ml)	RQ_{Max}	RQ_{Gm}
Danang Bay					
Tien Sa (n = 12)	500,000	12,170	1000	500.00	12.17
Thanh Binh (n = 40)	31,000	2,868	1000	31.00	2.87
Xuan Thieu (n = 37)	110,000	7,562	1000	110.00	7.56
Kim Lien (n = 12)	240,000	23,365	1000	240.00	23.37
Cu De (n = 16)	1,400	1,400	1000	1.40	1.40
Phu Loc (n = 18)	120,000	24,805	1000	120.00	24.81
Xuan Hoa (n = 12)	24,000	12,750	1000	24.00	12.75
Thuan Phuoc (n = 38)	11,000	723	1000	11.00	0.72
Mouth of Danang Bay (n = 67)	160,000	4,881	1000	160.00	4.88
South Son Tra - Ngu Hanh Son Coastal Water					
Bac My An (n = 6)	17	7	1000	0.02	0.01
Man Thai (n = 6)	500,000	101,747	1000	500.00	101.75
Non Nuoc (n = 17)	14,635	873	1000	14.64	0.87
Tho Quang (n = 6)	26	13	1000	0.03	0.01

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Source for PNECs: VNS 5943-1995 for aquaculture.

Table 32 shows that there is cause for concern for coliform in seawater column for all stations in Danang Bay and some stations in the South Son Tra - Ngu Hanh Son Coastal Water. Only Bac My An and Tho Quang in the South Son Tra - Ngu Hanh Son Coastal Water have maximum RQs that are less than 1.

The high bacterial load may be attributed mainly to voluminous sewage and domestic wastes generated from households that discharge directly to Danang Bay or to the South Son Tra - Ngu Hanh Son Coastal Water. Other sources include commercial and agricultural establishments such as slaughterhouses, markets, livestock farms, hospitals, and topsoil run-offs.

Results of analysis show that there is cause for concern for coliform in river water column at Thuan Phuoc, Phu Loc and Vinh Dien where maximum and geomean RQs exceeded 1. There are hotspots for coliform in river water column at other sites.

The main sources of coliform in river water column can be the untreated waste effluent discharges or run-off from agriculture and domestic areas.

With regard to human health, risk is associated with activities that involve contact with the water or consumption of food harvested from the rivers.

For well water, since there is no standard in MOH 505-1995 for coliform so the threshold in the Vietnam National Standards for ground water quality (VNS 5944-1995) was used. For drinking water, standards for total coliform (including fecal coliform and *E. coli*) are usually equal to zero (USEPA, 2001). The high maximum and mean RQs (RQ_{Max} = 733,333 and RQ_{Gm} = 70) provide cause for concern for human health from bathing in and ingestion of coliform-contaminated well water.

Contamination of the underground water table may be due to ground seepage from agricultural and domestic discharges, as well as from leaking septic tanks.

Contaminated wells should be identified and sources of contamination should be determined and addressed. Communities should also be informed about the potential human health risks of using water from the contaminated wells.

Results of the analysis show that maximum and geometric mean RQs for total coliforms have exceeded the threshold value (10,000) at all of the lakes monitored. Specifically, the mean RQ for Rong Lake (RQ_{Gm} = 1,644,023) presents serious cause for concern and calls for immediate management intervention. There is also a hotspot

Table 33. RQs for Total Coliform in River Water Column and Well Water Column.

Coliform	MEC_{Max} (MPN/100ml)	MEC_{Gm} (MPN/100 ml)	PNEC (MPN/100 ml)	RQ_{Max}	RQ_{Gm}
Cu De (n = 16)	240,000	3,078.680	10,000	24	0.31
Hoa Phong (n = 28)	46,000	4,283.790	10,000	4.6	0.43
Hoa Tho (n = 28)	31,000	5,521.250	10,000	3.1	0.55
Qua Giang (n = 28)	240,000	7,136.150	10,000	24	0.71
Cau Do (n = 28)	40,000	4,518.220	5,000	8	0.90
Tuyen Son (n = 6)	20,000	3,922.660	10,000	2	0.39
Nguyen Van Troi Bridge (n = 29)	50,000	7,957.300	10,000	5	0.80
Thuan Phuoc (n = 10)	2,000,000	30,158.820	10,000	200	3.02
Phu Loc (n = 22)	140,000	15,730.320	10,000	14	1.57
Vinh Dien (n = 16)	1,700,000	14,194.460	10,000	170	1.42
At well water column (n = 74)	2,200,000	209.636	3	733,333	70.00

Note: Cau Do is a source of water for domestic water supply in Danang City. No PNEC in MOH 505-1995 for well water column. Ground water standard from VNS 5944-1995 was used.
Sources for MECs: NEA (1995-2001); DOSTE (2001b).
Source for PNECs: VNS 5942-1995 (Column A for water supply and Column B for aquaculture).

Table 34. RQs for Total Coliform in Lake Water Column.

Coliform	MEC_{Max} (MPN/100ml)	MEC_{Gm} (MPN/100 ml)	PNEC (MPN/100 ml)	RQ_{Max}	RQ_{Gm}
Rong Lake (n = 51)	28,000,000,000	1,644,023,298.00	10,000	2,800,000.0	1,644,023.00
Thac Gian-Vinh Trung (n = 7)	360,000	17,526.64	10,000	36.0	1.75
Tram Lake (n = 36)	8,000,000	20,636.37	10,000	800.0	2.06
March 29 Park Lake (n = 19)	4,700,000	14,849.47	10,000	470.0	1.48
Green Lake (n = 6)	53,000	171.05	5,000	10.6	0.1

Sources for MECs: NEA (1995-2001); DOSTE (2001b)
Source for PNECs: VNS 5942-1995 (Column A for domestic water supply and column B for aquaculture).

for coliform in the water column at Green Lake, which needs to be identified.

Except for Green Lake, all these lakes receive untreated or partially treated wastewater from domestic, commercial, and institutional activities as well as run-off from land.

The high concentration of coliform in water at the lakes can cause adverse effects on human health.

Uncertainty Analysis

The initial risk assessment done on the water column was mainly based on data from the inshore section, and there were few records for the offshore section. The results of the risk assessment, therefore, represent only the inshore area, and cannot be generalized for the whole coastal zone. Data from other areas of the Danang coastal zone should be gathered for a more refined risk assessment.

For the lake water column, the risk assessment done was based on data from some lakes that were sampled. Additional data will have to be collected from other areas for a more detailed risk assessment.

RQs for coliform in marine, river and lake water were all very high, indicating high risk to human health. Information on occurrences of diseases related to exposure to coliform-contaminated waters should also be collected. Areas where the high coliform concentrations were measured should be identified and sources of coliform should be determined.

The risk assessment was performed using data for total coliform only. Data on fecal coliform should also be collected.

Pesticides

Water Column

Data on pesticides were taken from the NEA *Annual Reports of the National Environment Monitoring Program* (1998-2000) and all these records were observed at Vu Gia River system. There were no other information for pesticides in seawater, sediment or seafood tissue. Table 35 shows the data used in the risk assessment.

In the National Environmental Monitoring Program, there are two locations (i.e., Hoa Phong and Hoa Tho) at the Vu Gia River that were

Table 35. Summary of Information for the Prospective Risk Assessment for Pesticides.

Agent	Compartment	Description of data	Location	References
Pesticides	Water column of rivers.	– Data from the Vu Gia River System (1998-2000), which include: – BHC: 14 samples – Aldrin: 14 samples – DDE: 14 samples – Endrin: 14 samples – Dieldrin: 13 samples – TDE: 14 samples – DDT: 14 samples	– Vu Gia River	– Annual Reports of the National Environmental Monitoring Program (1998-2000)

Table 36. RQs for Pesticides in River Water Column.

Pesticides	MEC_{Max} (ppt)	MEC_{Gm} (ppt)	PNEC (ppm)	RQ_{Max}	RQ_{Gm}
DDT (n = 14)	312.0	98	0.01	0.03120	0.00982
Total pesticides (n = 14)	143.5	4	0.15	0.00096	0.00003

Source for MECs: NEA (1998-2000)
Source for PNEC: VNS 5942-1995.

sampled for pesticides. From 1998 to 2000, sampling for pesticides was done four times a year. In the other environmental monitoring programs, pesticides in river water were not sampled.

In the VNS 5942-1995, threshold values are given only for DDT and total pesticides (except DDT). In the computation of RQs, MECs for total pesticides were taken as the sum of the values of the six pesticides that include aldrin, BHA, DDE, dieldrin, endrin and TDE. Average and maximum RQs for pesticides in river water column are given in Table 36.

Table 36 shows that there is no cause for concern for pesticides in river water as shown by the maximum RQs for DDT and the total of pesticides that are much less than 1.

Uncertainty Analysis

There were very limited data for pesticides for detailed assessment. More information in the water column, sediment and seafood tissue should be gathered, specifically in areas where there are agricultural activities. In addition, more suitable criteria values for the assessment of each pesticide should be developed.

Cyanide

Water Column

Data on cyanide in marine, river and lake waters were taken from NEA and Danang DOSTE (2001b) and the *EIA Report for Danang City's Sanitation Project* (URENCO, 1997). There were few data on cyanide in the water column,

Table 37. Summary of Information for the Prospective Risk Assessment for Cyanide.

Agent	Compartment	Description of data	Location	References
Cyanide	Water column (Sea/lake/river/well)	• Danang Bay: 19 samples (1999-2000) • South Son Tra - Ngu Hanh Son Coastal Water: 3 samples (1997)	• Danang Bay	– Annual Reports of the National Environmental Monitoring Program of Danang City (1994-2001). – Annual Reports of Danang City's Environmental Monitoring Program (DOSTE, 2001b) – EIA Reports of Danang City's Sanitation Project (URENCO, 1997).
		• River water column: 10 samples (1995-2001) – 3 samples in Cu De River – 2 samples in Phu Loc River – 5 samples in Vu Gia River	• Cu De, Phu Loc, and Vu Gia Rivers.	
		• Lake water column: 39 samples (1994 to 2001) – 3 samples in March 29 Park Lake – 1 sample in Green Lake – 3 samples in Rong Lake – 1 sample in Thac Gian-Vinh Trung Lake – 31 samples in Tram Lake.	• March 29 Park, Green, Rong, Thac Gian – Vinh Trung and Tram lakes	
		• Well water column: 3 samples (1997-2001)	• Wells in Danang City	

Table 38. RQs for Cyanide in Water Column.

Cyanide	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Seawater (n = 22)					
Danang Bay (n = 19)	0.0162	0.0085	0.0100	1.62	0.85
South Son Tra - Ngu Hanh Son Coastal Water (n = 3)	0.3120	0.0315	0.0100	31.20	3.15
River water (n = 10)					
Cu De River (n = 3)	0.1400	0.0131	0.0500	2.80	0.26
Phu Loc River (n = 2)	0.3900	0.1396	0.0500	7.80	2.79
Vu Gia River (n = 5)	1.4600	0.0365	0.0500	29.20	0.73
Lake water (n = 39)					
Rong Lake (n = 3)	0.1800	0.0378	0.0500	3.60	0.76
Thac Gian-Vinh Trung Lake (n = 1)	0.0100	0.0500	0.2000		
Tram Lake (n = 31)	0.7900	0.1835	0.0500	15.80	3.67
March 29 Park Lake (n = 3)	0.2600	0.0618	0.0500	5.20	1.24
Green Lake (n = 1)	0.0100	0.0100	1.0000		
Well water (n = 3)	0.7500	0.0750	0.1000	7.50	0.75

Sources for MECs: NEA and Danang DOSTE: in seawater (1999-2001); in river water (1996-1997); in lake water (1997-1998, 2000); and in well water (1997-2001).
Sources for PNEC: VNS 5942-1995 (Class A for Green Lake, Class B for other rivers and lakes); VNS 5943-1995 (for aquaculture) for seawater; and MOH 505-1995 for well water column.

especially in seawater and river water. There were no records of cyanide in sediment and seafood tissue. The criteria used for calculating RQs are VNS 5943-1995 for seawater and VNS 5942-1995, class B for aquaculture, and for river and lake water.

The data used in the risk assessment of cyanide are described in Table 37. There were very few data on cyanide in water column of rivers and lakes. Table 38 shows the RQs for cyanide in surface water resources.

The result of the risk assessment show significant risk from cyanide in water column of the South Son Tra - Ngu Hanh Son Coastal Water (RQ_{Max} equal to 31.20 and RQ_{Gm} equal to 3.15), in water column of Phu Loc River (RQ_{Max} equal to 7.80 and RQ_{Gm} equal to 2.79) and in water column of some lakes such as Tram (RQ_{Max} equal to 15.80 and RQ_{Gm} equal to 3.67) and March 29 Park Lakes (RQ_{Max} equal to 5.20 and RQ_{Gm} equal to 1.24). Except for Thac Gian-Vinh Trung Lake, RQ_{Max} in the other areas also exceeded 1.

The gold mining activities in some upland districts has been identified as the primary cause of cyanide pollution in the downstream regions particularly during the rainy season. Other potential sources of cyanide are discharges from steel/metal, plastic and fertilizer factories.

Uncertainty Analysis

The risk assessment conducted for different bodies of water in Danang provides useful information on potential areas of concern and sources of cyanide entering the coastal areas, although the limited number of data used does not allow general statements to be made for each water body assessed. More extensive data will be required to come up with a detailed assessment of risks associated with cyanide in the water column.

Phenol

Water Column

Data used for the risk assessment were taken from the *EIA Report of Danang City's Sanitation Project* (URENCO, 1997). There were very few useful data, mostly from Phu Loc, Vu Gia and Cu De Rivers. There were no records on phenol in seawater, ground water, sediment, and seafood tissue.

The criteria values used were from the Vietnam Criteria for aquaculture that was published in 1995 (VNS 5942-1995).

Table 39 describes the data used in the assessment.

Phenol was sampled only in 1997 at three stations in Vu Gia River, two stations in Cu De River, and one station in Phu Loc River. The data on phenol was used for preparing the *EIA Report of Danang City's Sanitation Project* in 1997.

Table 40 presents the results of the risk assessment for phenol in water column.

Although there is only one record of phenol in the water column of Phu Loc River, RQ for phenol exceeded 1, showing that phenol is a potential agent of concern in the river. Maximum RQs were less than 1 for both Cu De and Vu Gia Rivers.

Phenol may be associated with human activities in urban areas as shown by the lower RQs for phenol at Vu Gia River compared to RQs at Cu De and Phu Loc Rivers. Paper processing may be one of the sources of phenol.

Phenol is colorless or, when it is pure, a white solid. However, it is usually sold and used as a liquid. It is very soluble in water and is flammable. Phenol is primarily used in the production of phenolic resins, which are used in plywood, construction, automotive, and appliance industries. Phenol is also used in the production of caprolactam and bisphenol A, which are intermediates in the manufacture of nylon and epoxy resins, respectively. Other phenol uses are as slimicide, as disinfectant, and in medicinal products such as ear and nose drops, throat lozenges, and mouthwashes.

Uncertainty Analysis

The risk assessment was conducted using very limited data (one sample for Phu Loc River, two for Cu De River, and three for Vu Gia River System) obtained from a single station for each of the rivers in 1997 for Cu De and Phu Loc Rivers and 1996-1997 for Vu Gia River. This does not represent the actual conditions for these rivers. However, it provides a signal that phenol is a potential agent of concern in river water and that further work should be done to verify the risk presented by phenol in the rivers, as well as in coastal areas including identifying significant sources of this agent.

Table 39. Summary of Information for the Prospective Risk Assessment for Phenol.

Agent	Compartment	Description of data	Location	References
Phenol	Water column (River)	Water column of rivers: • 1 sample (Phu Loc River, 1997) • 3 samples (Vu Gia River System, 1996-1997) • 2 samples (Cu De River, 1997)	• Phu Loc River (at Da Co bridge) • Vu Gia River (at Nguyen Van Troi bridge) • Cu De River (at Nam O bridge)	– EIA report of Danang City sanitation project (URENCO, 1997)

Table 40. RQs for Phenol in Water Column.

Phenol	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Seawater (n = 0)	No data		0.0010		
River water (n = 6)					
Cu De River (n = 2)	0.0030	0.0024	0.0200	0.15	0.12
Phu Loc River (n = 1)	0.0300		0.0200	1.50	
Vu Gia River (n = 3)	0.0010	0.0010	0.0200	0.05	0.05
Lake water (n = 0)	No data		0.0200		
Well water (n = 0)	No data				

Source for MECs: URENCO, 1997.
Source for PNEC: VNS 5942-1995; VNS 5943-1995.

Heavy Metals

Water column

The data for heavy metals in seawater, lake water and river water were taken from the annual reports of the local monitoring program (DOSTE, 1995-2001), annual reports of the national monitoring program in Danang (DOSTE-NEA, 1995-2001), the results of Danang Bay environmental monitoring and Tram environmental monitoring (VCEP, 1998b), and the *EIA Report of Danang City's Sanitation Project* (URENCO, 1997). The data includes results of environmental monitoring undertaken every year. From 1995-1997, sampling frequency was two times/year; from 1998-2000, it was three to four times/year; and since 2001, frequency increased to six times a year, for seawater, lake water and river water. There were no data on heavy metals in sediment and seafood tissue. The threshold values used for the risk assessment were from the Vietnam National Standards (1995). Detailed information on the heavy metals data used in the risk assessment are presented in Table 41.

Geomean and maximum RQs for heavy metals in seawater column are given in Table 42. These were obtained using PNECs from the Vietnam National Standards for marine waters (VNS 5943-1995).

In Danang Bay, maximum and geomean RQs for Zn and Fe in seawater column exceeded 1. Maximum RQs for mercury, lead and copper are greater than 1 but the RQ_{Gm} are less than 1. The chief concern, based on the RQs, appears to be iron (RQ_{Max} = 22 and RQ_{Gm} = 1.05).

In the South Son Tra - Ngu Hanh Son Coastal Water, maximum and geomean RQs exceeded 1for Hg and Zn in the water column, showing cause for concern particularly for mercury (RQ_{Max} = 58 and RQ_{Gm} = 2.34). RQ_{Max} for Pb and Fe are greater than 1 but the RQ_{Gm} are both less than 1.

RQs for heavy metals in river water column are given in Table 43.

At Cu De River, the RQs show cause for concern for levels of mercury (RQ_{Max}= 29 and RQ_{Gm} = 1.37). The maximum RQ for arsenic in water column exceeded 1 (RQ_{Max} = 1.41) but geomean RQ was less than 1 (RQ_{Gm} = 0.03). For other heavy metals, RQs were all less than 1. At Phu Loc River, the maximum RQs exceeded 1 for mercury, iron, arsenic and cadmium, but geomean RQs were all less than 1. At Vu Gia River, the maximum RQs for mercury, lead, iron, copper, cadmium and manganese in the water column were greater than or equal to 1 but geomean RQs were less than 1.

At Cau Do River, maximum RQ for Fe exceeded 1, but maximum RQs for Hg and Pb were

Table 41. Summary of Information for the Prospective Risk Assessment for Heavy Metals.

Agent	Compartment	Description of data	Location	References
Heavy metals	Water column (sea, lakes, rivers and wells)	– At Danang Bay there were 117 samples for Fe, 37 samples for Cu, 39 samples for Zn, 39 samples for As, 38 sample for Cd, 132 samples for Pb and 114 samples for Hg (1994-2001). – At the South Son Tra - Ngu Hanh Son Coastal Water there were 25 samples for Fe, 2 samples for Cu, 2 samples for Zn, 1 sample for As, 1 sample for Cd, 21 samples for Pb and 10 samples for Hg (1994-2001).	– Danang Bay and South Son Tra - Ngu Hanh Son Coastal Water.	– Annual Environmental Monitoring Reports of Danang City (NEA and Danang DOSTE, 1994-2001). – EIA Reports of Danang City's Sanitation Project (URENCO, 1997). – Environmental Monitoring Reports of Tram Lake (VCEP, 1998b). – Report on Environmental Monitoring for Danang Bay (1997-1998)
		– At Cu De River there were 9 samples for Fe, 2 samples for Cu, 3 samples for As, 2 samples for Mn, 2 samples for Cr^{+6}, 9 samples for Pb and 3 samples for Hg (1997-2001). – At Phu Loc River there were 13 samples for Fe, 14 samples for Cu, 3 samples for Zn, 2 samples for As, 13 samples for Cd, 1 sample for Mn, 1 samples for Cr^{+6}, 13 samples for Pb and 5 samples for Hg (1997-2001). – At Vu Gia River: 158 samples for Fe, 17 samples for Cu, 10 samples for Zn, 3 samples for As, 9 samples for Cd, 3 samples for Mn, 3 samples for Cr^{+6}, 124 samples for Pb and 89 samples for Hg (1995-2001).	– Cu De, Phu Loc and Vu Gia River systems	
		– At Green Lake there were 5 samples for Fe, 5 for Cu, 5 for Zn, 1 for As, 1 for Cd, 1 for Mn, 1 for Cr^{+6}, 5 for Pb, 1 for Hg. (2000-2001). – At other lakes there were 27 samples for Fe, 60 for Cu, 39 for Zn, 4 for As, 25 for Cd, 4 for Mn, 4 for Cr^{+6}, 77 for Pb, 49 for Hg. (1994-2001).	– Green Lake (Source of drinking water supply) – March 29 Park, Rong, Thac Gian-Vinh Trung, and Tram Lakes	
		– Well water: there were 5 samples for Hg, 43 for Pb, 68 for Fe, 31 for Cu, 28 for Zn, 1 for As and 2 for Cd (1997-2001).	– In Danang City	

Table 42. RQs for Heavy Metals in Seawater Column.

Heavy Metals	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Danang Bay					
Hg (n = 114)	0.0870	0.0000	0.0050	17.40	0.00
Pb (n = 132)	0.0520	0.0000	0.0500	1.04	0.00
Fe (n = 117)	2.2000	0.1046	0.1000	22.00	1.05
Cu (n = 37)	0.0157	0.0043	0.0100	1.57	0.43
Zn (n = 39)	0.0560	0.0167	0.0100	5.60	1.67
As (n = 39)	0.0044	0.0017	0.0100	0.44	0.17
Cd (n = 38)	0.0006	0.0002	0.0050	0.12	0.05
Mn (n = 0)	No data		0.1000		
Cr^{+6} (n = 0)	No data		0.0500		
South Son Tra - Ngu Hanh Son Coastal Water					
Hg (n = 10)	0.2900	0.0117	0.0050	58.00	2.34
Pb (n = 21)	0.0880	0.0024	0.0500	1.76	0.05
Fe (n = 25)	0.3600	0.0486	0.1000	3.60	0.49
Cu (n = 2)	0.0060	0.0049	0.0100	0.60	0.49
Zn (n = 2)	0.0220	0.0133	0.0100	2.20	1.33
As (n = 1)	0.0021		0.0100	0.21	
Cd (n = 1)	0.0010		0.0050	0.20	
Mn (n = 0)	No data		0.1000		
Cr^{+6} (n = 0)	No data		0.0500		

Sources for MECs: NEA and Danang DOSTE, 1996-2001.
Source for PNEC: VNS 5943-1995 for aquaculture.

less than 1. Cau Do River is a source of water for domestic supply and high levels of Fe in drinking water may present risk to human health.

RQs for heavy metals in well water column are given in the Table 44.

In well water column, the RQs show cause for concern for levels of iron (RQ_{Max} = 633.3 and RQ_{Gm} = 1.34). For Hg and Pb, the maximum RQs are greater than 1, however geomean RQs were all less than 1. For other heavy metals, RQs were all less than 1. The elevated levels of Fe in most wells and the Pb and Hg in some wells present causes for concern for human health. Specific wells, for which RQs for these metals exceeded 1, should be identified and sources of these heavy metals should be determined, including potential erosion of natural deposits, corrosion of pipes, and run-off or seepage from agricultural and/or industrial activities.

RQs for heavy metal in lake water column are given in the Table 45. RQ_{Max} for Hg in Green Lake water column exceeded 1 (RQ_{Max} = 10.00) but it is only one data, while RQ_{Max} and RQ_{Gm} for other heavy metals in the lake were all less than 1. In Rong Lake, RQ_{Max} for mercury and lead were greater than and equal to 1, respectively, but RQ_{Gm} were less than 1. In Thac Gian-Vinh Trung Lake, RQ_{Max} for iron and lead exceeded 1 while RQ_{Gm} were less than 1. In Tram Lake, RQ_{Max} and RQ_{Gm} for Hg were greater than 1 and RQ_{Max} for iron and cadmium exceeded 1 but RQ_{Gm} were less than 1. In March 29 Park Lake, there was an area of concern for mercury (RQ_{Max} = 6.0 and RQ_{Gm} = 1.01) and a hotspot for lead (RQ_{Max} = 1.90 and RQ_{Gm} = 0.15) in the water column.

In almost all lakes, including Green Lake, a source of domestic water supply, Hg appears as an important concern in certain hotspots. In Tram Lake and March 29 Park Lakes, the RQ_{Gm} exceeding 1 for Hg indicate wider concern. Pb and Fe also present some concern, with maximum RQs exceeding 1 or approaching 1 in some lakes. The potential risk posed by Hg to aquatic organisms, as well as humans warrant careful consideration of potential sources with a view to controlling discharges at acceptable levels. Potential sources of mercury may include discharges from refineries and factories, run-off from croplands, dumpsites or landfills, and erosion of natural deposits. The presence of these activities around the lakes should be confirmed; the potential that these are indeed contributing to Hg in lake waters and the extent of contribution should be determined.

Uncertainty Analysis

Although there were areas of concern and hotspots for heavy metals in the water column, results cannot be generalized for the whole Danang City coastal zone because of the limited data for heavy metals that were used in the risk assessment. There is a need, therefore, to collect more data on heavy metals in the Danang coastal zone, especially in the sediment and seafood tissue.

Oil and Grease

Water Column

Oil and grease comprise very complex mixtures of thousands of organic compounds with different behaviors and, hence, different possible effects on marine life and, ultimately, on human health. Once released into the environment, all of these compounds are subject to continuous and variable changes due to biological degradation, and other processes.

Data for oil and grease in seawater, lake water and river water were taken from the Report of the Danang Monitoring Program (DOSTE, 1996-2001), reports from the national monitoring program in Danang (DOSTE, 2001b), results of environmental monitoring at Tram and Danang Bay (VCEP, 1998a and b), and *EIA Report of Danang City's Sanitation Project* (URENCO, 1997). The data includes results of environmental monitoring undertaken every year. From 1995-1997, sampling frequency was two times/year, from 1998-2000, it was three to four

Table 43. RQs for Heavy Metals in River Water Column.

Heavy Metals	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Cu De River					
Hg (n = 3)	0.05800	0.00270	0.0020	29.000	1.37
Pb (n = 9)	0.04000	0.00950	0.1000	0.400	0.09
Fe (n = 9)	0.80000	0.11110	2.0000	0.400	0.06
Cu (n = 2)	0.00300	0.00230	1.0000	0.000	0.00
Zn (n = 0)			2.0000		
As (n = 3)	0.14100	0.00290	0.1000	1.410	0.03
Cd (n = 0)			0.0200		
Mn (n = 2)	0.06000	0.05480	0.8000	0.075	0.07
Cr^{+6} (n = 2)	0.00980	0.00560	0.0500	0.200	0.11
Phu Loc River					
Hg (n = 5)	0.04200	0.00020	0.0020	21.000	0.10
Pb (n = 13)	0.05100	0.01300	0.1000	0.510	0.13
Fe (n = 13)	2.80000	1.24810	2.0000	1.400	0.62
Cu (n = 14)	0.45000	0.01140	1.0000	0.450	.0.01
Zn (n = 13)	0.40000	0.02620	2.0000	0.200	0.01
As (n = 2)	0.26600	0.01820	0.1000	2.660	0.18
Cd (n = 12)	0.20000	0.00200	0.0200	10.000	0.10
Mn (n = 1)	0.04000		0.8000	0.050	
Cr^{+6} (n = 1)	0.00720		0.0500	0.140	
Vu Gia River					
Hg (n = 89)	0.04000	0.00040	0.0010	40.000	0.35
Pb (n = 124)	0.11000	0.00540	0.0500	2.200	0.11
Fe (n = 158)	9.00000	0.50210	1.0000	9.000	0.50
Cu (n = 17)	0.48100	0.01070	0.1000	4.810	0.11
Zn (n = 10)	0.19500	0.02340	1.0000	0.200	0.02
As (n = 3)	0.00280	0.00230	0.0500	0.060	0.05
Cd (n = 9)	0.10000	0.00140	0.0100	10.000	0.14
Mn (n = 3)	0.10000	0.06500	0.1000	1.000	0.65
Cr^{+6} (n = 3)	0.01000	0.00530	0.0500	0.200	0.11
Cau Do River					
Hg (n = 16)	0.00082	0.00033	0.001	0.820	0.33
Pb (n = 21)	0.01000	0.00500	0.05	0.200	0.10
Fe (n = 29)	4.20000	0.67800	1.00	4.200	0.68

Source for MECs: DOSTE (2001b).
Source for PNEC: VNS 5942-1995: Class A for Vu Gia River and Cau Do River, and Class B for other rivers.

Table 44. RQs for Heavy Metals in Well Water Column.

Agents	MEC (mg/l)			MOH 505-1995		
	Max	Min	Gm	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Hg (n = 5)	0.005	0.000	0.001	0.001	4.50	0.75
Pb (n = 43)	0.925	0.001	0.006	0.050	18.50	0.12
Fe (n = 68)	190.000	0.010	0.401	0.300	633.33	1.34
Cu (n = 31)	0.939	0.001	0.009	1.000	0.94	0.01
Zn (n = 28)	0.977	0.011	0.055	5.000	0.20	0.01
As (n = 1)	0.281			0.050	5.62	
Cd (n = 2)	0.002	0.000	0.000	0.005	0.38	0.08

Source for MECs: DOSTE (2001b).
Source for PNEC: MOH 505-1995.

times/year, and since 2001, sampling frequency increased to six times a year, for seawater, lake water and river water.

The threshold values used for the risk assessment were from the Vietnam National Standards (1995) and the ASEAN Marine Water Quality Criteria (ASEAN, 2003).

A summary of the information used for the assessment of oil and grease in the water column is shown in Table 46.

RQs for oil and grease in the water column are given in Table 47.

Based on the RQs generated using the VNS, RQ_{Max} for oil and grease in the coastal areas, rivers and lakes all exceeded 1. Except Danang Bay, all the other marine, river and lake water areas gave RQ_{Gm} values that were also greater than 1. There were no data available for Green Lake. The lake for which the highest RQs were obtained was Rong Lake (RQ_{Max}= 36.83 and RQ_{Gm} = 11.19) while for the rivers, the highest RQ was obtained from Vu Gia River (RQ_{Max}= 36.66 and RQ_{Gm} = 2.22). The results show that there is risk associated with oil and grease in the Danang coastal area.

Some studies on toxicities of various petroleum products to aquatic organisms have shown that concentrations as low as 0.1 mg/l, particularly of the water-soluble compounds, had been lethal to aquatic organisms, particularly to marine larvae. Long-term sub-lethal effects on growth, respiration, feeding and reproduction of organisms had also been shown to result from petroleum product concentrations as low as 10 to 100 µg/l (Tong, et al., 1997).

Uncertainty Analysis

A potential source of uncertainty in the oil and grease risk assessment is the comparability of their measured environmental concentrations with the chosen predicted no-effect concentrations, owing to the potential differences in analytical methods employed and to the variability of their reported threshold values. The differences in critical values may arise from the use of different test organisms in the toxicity tests from which the critical values were derived. This shows that more consideration should be given to the choice of criteria for oil and grease, ensuring that this value is protective of the sensitive organisms in the area and the beneficial water uses.

Table 45. RQs for Heavy Metals in Lake Water Column.

Compartment	Heavy Metals	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Rong Lake	Hg (n = 8)	0.00280	0.000455	0.0020	1.4000	0.2277
	Pb (n = 12)	0.10000	0.012696	0.1000	1.0000	0.1270
	Fe (n = 11)	1.32000	0.348154	2.0000	0.6600	0.1741
	Cu (n = 5)	0.05000	0.003701	1.0000	0.0500	0.0037
	Zn (n = 1)	0.10000	0.100000	2.0000	0.0500	0.0500
	As (n = 1)	0.00217	0.002170	0.1000	0.0217	0.0217
	Mn (n = 1)	0.18000	0.180000	0.8000	0.2250	0.2250
	Cr+6 (n = 1)	0.00880	0.008800	0.0500	0.1760	0.1760
Thac Gian-Vinh Trung Lake	Hg (n = 1)	0.00020		0.0020	0.1100	
	Pb (n = 7)	0.30000	0.026500	0.1000	3.0000	0.2700
	Fe (n = 7)	2.48000	0.553000	2.0000	1.2400	0.2800
	Zn (n = 1)	0.25000		2.0000	0.1300	
	As (n = 1)	0.00220		0.1000	0.0200	
	Mn (n = 1)	0.23000		0.8000	0.2900	
	Cr^{+6} (n = 1)	0.00480		0.0500	0.1000	
Tram Lake	Hg (n = 34)	0.01400	0.002500	0.0020	7.0000	1.2500
	Pb (n = 55)	0.09400	0.004700	0.1000	0.9400	0.0500
	Fe (n = 9)	2.83000	0.201400	2.0000	1.4200	0.1000
	Cu (n = 52)	0.03000	0.001400	1.0000	0.0300	0.0010
	Zn (n = 37)	0.60230	0.058900	2.0000	0.3000	0.0300
	As (n = 1)	0.00010		0.1000	0.0000	
	Cd (n = 12)	0.09000	0.000400	0.0200	4.5000	0.0200
	Mn (n = 1)	0.05500		0.8000	0.0700	
	Cr^{+6} (n = 1)	0.00640		0.0500	0.1300	
March 29 Park Lake	Hg (n = 6)	0.01200	0.002000	0.0020	6.0000	1.0100
	Pb (n = 11)	0.19000	0.014700	0.1000	1.9000	0.1500
	Fe (n = 8)	1.80000	0.335600	2.0000	0.9000	0.1700
	Cu (n = 4)	0.01300	0.004000	1.0000	0.0100	0.0040
	Zn (n = 2)	0.01200	0.006600	2.0000	0.0100	0.0030
	As (n = 1)	0.00260		0.1000	0.0300	
	Cd (n = 2)	0.00100	0.000800	0.0200	0.0500	0.0400
	Mn (n = 1)	0.05000		0.8000	0.0600	
	Cr^{+6} (n = 1)	0.01000		0.0500	0.2000	
Green Lake	Hg (n = 1)	0.01000		0.0010	10.0000	
	Pb (n = 5)	0.01900	0.003000	0.0500	0.3800	0.0600
	Fe (n = 7)	0.40000	0.130600	1.0000	0.4000	0.1300
	Cu (n = 7)	0.03000	0.005800	0.1000	0.3000	0.0600
	Zn (n = 6)	0.12000	0.022600	1.0000	0.1200	0.0200
	As (n = 1)	0.00310		0.0500	0.0600	
	Cd (n = 1)	0.00100		0.0100	0.1000	
	Mn (n = 1)	0.05000		0.1000	0.5000	
	Cr^{+6} (n = 1)	0.01000		0.0500	0.2000	

Source for MECs: DOSTE (2001b).
Source for PNEC: VNS 5942-1995: Class A for Green Lake and Class B for other lakes.

Table 46. Summary of Information for the Prospective Risk Assessment for Oil and Grease.

Agent	Compartment	Description of data	Location	References
Oil and grease	Water column (sea, lake, river)	Danang Bay: 76 samples (1994-2001) South Son Tra - Ngu Hanh Son Coastal Water: 15 samples (1994-2001)	Danang Bay and South Son Tra - Ngu Hanh Son Coastal Water	• Annual Environmental Monitoring Reports of Danang City (NEA and Danang DOSTE, 1994-2001). • EIA Reports of Danang City's Sanitation Project (URENCO, 1997).
		Rivers (3 river systems): 16 locations and 18 samples (1996-1998)	Cu De, Phu Loc and Vu Gia Rivers	
		Lakes: 42 samples (1996-1998, 2001).	March 29 Park, Green, Rong, Thac Gian-Vinh Trung and Tram Lakes	

Table 47. RQs for Oil and Grease in Seawater, Rivers and Lakes.

Oil and Grease (mg/l)	MEC_{Max} (mg/l)	MEC_{Gm} (mg/l)	PNEC	RQ_{Max}	RQ_{Gm}
Sea					
Danang Bay (n = 76)	3.9000	0.2933	1.0000	3.90	0.29
South Son Tra - Ngu Hanh Son Coastal Water (n = 15)	3.1000	1.2769	1.0000	3.10	1.28
Rivers					
Cu De River (n = 4)	1.4000	0.9649	0.3000	4.66	3.21
Phu Loc River (n = 3)	2.0000	0.3900	0.3000	6.66	1.30
Vu Gia River (n = 11)	11.0000	0.6681	0.3000	36.66	2.22
Cau Do River (n = 1)	0.1200	0.1200	0		
Lakes					
Rong Lake (n = 8)	11.0500	3.3556	0.3000	36.83	11.19
Thac Gian-Vinh Trung Lake (n = 1)	0.7000		0.3000	2.33	
Tram Lake (n = 29)	4.0000	0.6537	0.3000	13.33	2.18
March 29 Park Lake (n = 4)	3.5000	2.0812	0.3000	11.67	6.94
Green Lake (n = 0)			0		

Sources for MECs: NEA and DOSTE (1994-2001); URENCO (1997).
Source for PNECs: VNS 5943-1995 (for aquaculture) for seawater; VNS 5942-1995: Class A for Cau Do River and Green Lake, Class B for other rivers and lakes.

Comparative Risk and Uncertainty Assessment

Introduction

Comparative risk assessments for the range of agents considered of potential concern for the Danang coastal zone have been carried out separately for water columns of marine areas, rivers, lakes and wells. The results of these analyses are summarized in the following tables. An initial indication of uncertainty in the risk assessments is provided by comparing differences between average and worst-case (i.e., maximum MECs) conditions. The comparative risk assessment also provides a wide perspective through the average RQs and a hotspot perspective through the worst-case RQs. In addition, the comparative risk assessments highlight data gaps, both in terms of lack of MECs and lack of criteria.

For all targets, average and maximum MECs for the range of agents are shown. Average MECs were calculated as geometric means since data of this kind often follow a lognormal distribution, and, in such cases, the geometric mean will provide a less biased measure of the average than will the arithmetic mean.

Comparative Assessment of Risks to the Ecology of Danang Coastal Zone from Water-borne Substances

Tables 48-53 present the summary of RQs for seawater, river water and lake water. Tables 54-59 show the comparative risks across contaminants for all the sites assessed using the RQ_{Gm} and RQ_{Max} (lower-end and upper-end of the bars) respectively.

Table 54 shows that of all contaminants with available seawater column data, only coliform, Fe, Zn, oil and grease and cyanide have geomean RQs exceeding the critical threshold of one. In addition to these contaminants, NH_4, BOD, TSS, Pb, Cu, CN and DO have maximum RQs that exceed 1. There were no MECs available for seawater column concentration of N_{Total}, P_{Total}, tributyltin (TBT), polycyclic aromatic hydrocarbons (PAHs), polychloro biphenyl (PCB), phenol, aldrin, DDE, Endrin, Dieldrin, TDE and DDT. No criteria were available for COD, NO_3 and PO_4 for which MECs were available.

From Tables 55, 56, 57, it is clear that of all contaminants with available river water column data, the following agents have geomean RQs exceeding the critical threshold of one: coliform, oil and grease and Hg in Cu De River, NH_4-N, coliform, CN, phenol and oil and grease in Phu Loc River and coliform and oil and grease in Vu Gia River. In addition to these contaminants, NH_4-N, NO_3-N, NO_2-N, BOD, Hg and CN have maximum RQs that exceed 1 in the three rivers while TSS, Fe, Cu, As, Cd, Pb and Mn have maximum RQs that exceed 1 in at least one river.

Tables 58 and 59 show that there is risk in lake water column from coliform, BOD, COD and oil and grease which have geomean RQs exceeding the critical threshold of one in the four lakes, and NH_4-N, NO_2-N, CN and Hg in two to three lakes. In addition, DO, NO_3, TSS, Pb, Fe, As, Cd and Cr have maximum RQs that exceed 1. There were no MECs available for lake water column concentration of PO_4-P, TBT, PAHs, PCB, phenol, aldrine, DDE, Endrine, Diedrine, TDE and DDT. Except for DDT, no criteria were available for the aforementioned contaminants and for N_{Total}, P_{Total} for which MECs were available.

Table 48. Initial Risk Assessment Summary for Seawater.

Agents	MEC			VNS 5943-1995		
	Max	Min	Gm	PNEC	RQ_{Max}	RQ_{Gm}
Danang Bay						
N_{Total} (n = 0)						
NO_2-N (n = 125)	0.8600	0.0003	0.0092			
NH_4-N (n = 193)	6.3000	0.0100	0.0889	0.5000	12.60	0.18
NO_3-N (n = 181)	1.5600	0.0030	0.0631			
P_{Total} (n = 48)	0.5300	0.0100	0.0627			
PO_4-P (n = 70)	0.1830	0.0010	0.0126			
DO (n = 268)	9.7000	3.4000	6.3072	5.0000	1.47	0.79
BOD (n = 161)	13.0000	0.0600	2.4791	10.0000	1.30	0.25
COD (n = 199)	47.0000	0.5500	10.4546			
TSS (n = 290)	164.0000	1.0000	21.4363	50.0000	3.28	0.43
Coliform (n = 170)	500,000.0000	3.0000	15,844.8400	1,000.0000	500.00	15.84
Oil and grease (n = 76)	3.9000	0.0520	0.2939	1.0000	3.90	0.29
CN (n = 19)	0.0162	0.0020	0.0085	0.0100	1.62	0.85
Hg (n = 114)	0.0870	0.0000	0.0000	0.0500	17.40	0.00
Pb (n = 132)	0.0520	0.0003	0.0000	0.0500	1.04	0.00
Fe (n = 117)	2.2000	0.0100	0.1046	0.1000	22.00	1.05
Cu (n = 37)	0.0157	0.0016	0.0043	0.0100	1.57	0.43
Zn (n = 39)	0.0560	0.0062	0.0167	0.0100	5.60	1.67
As (n = 39)	0.0044	0.0008	0.0017	0.0100	0.44	0.17
Cd (n = 38)	0.0006	0.0001	0.0002	0.0050	0.12	0.05
Pesticides (n = 0)						
South Son Tra - Ngu Hanh Son Coastal Water						
N_{Total} (n = 0)						
NO_2-N (n = 0)						
NH_4-N (n = 30)	0.8000	0.0100	0.0590	0.5000	1.60	0.12
NO_3-N (n = 1)	3.0000	3.0000	3.0000			
P_{Total} (n = 0)						
PO_4-P (n = 0)						
DO (n = 55)	11.1000	3.8000	6.0848	5.0000	1.32	0.82
BOD5 (n = 31)	9.0000	1.0000	3.5739	10.0000	0.90	0.36
COD (n = 24)	35.7000	8.9000	19.5929			
TSS (n = 35)	41.0000	1.0000	15.1943	50.0000	0.82	0.30
Coliform (n = 34)	500,000.0000	1.0000	6,964.3200	1,000.0000	500.00	6.96
Oil and grease (n = 15)	3.1000	0.3000	1.2769	1.0000	3.10	1.28
CN (n = 3)	0.3120	0.0100	0.0315	0.0100	31.20	3.15
Hg (n = 10)	0.2900	0.0000	0.0117	0.0500	58.00	2.34
Pb (n = 21)	0.0880	0.0009	0.0024	0.0500	1.76	0.05
Fe (n = 25)	0.3600	0.0200	0.0480	0.1000	3.60	0.49
Cu (n = 2)	0.0060	0.0040	0.0049	0.0100	0.60	0.49
Zn (n = 2)	0.0220	0.0080	0.0133	0.0100	2.20	1.33
As (n = 1)	0.0021	0.0021	0.0021	0.0100	0.21	0.21
Cd (n = 1)	0.0010	0.0010	0.0010	0.0050	0.20	0.20
Pesticides (n = 0)						

Nutrients

Seawater

For seawater column, monitoring results in some areas of Danang Bay and the South Son Tra - Ngu Hanh Son Coastal Water were available. Except for NH_4-N, there were no Vietnamese threshold values available to compute for the RQs of other nutrients such as NO_3-N, NO_2-N and PO_4-P. The prospective risk assessment shows that NH_4-N in seawater column gave maximum RQs that exceed 1. Standards and criteria from other countries were used to compute for the RQs of the other nutrients, and the results indicate cause for concern for levels of NO_3-N, NO_2-N and PO_4-P in seawater. These results, however, are not included in the comparative RA tables.

Lake Water

The results of RQ computation show that NH_4-N in water column of all lakes have geomean RQ exceeding 1. In addition, NO_2-N at Thac Gian-Vinh Trung Lake and March 29 Park Lake has geomean RQs that exceed 1. Thus, attention should be paid on more detailed assessment of nutrients in lake water column. Monitoring and calculation of nutrient concentration/load from major sources should also be undertaken.

Table 49. Initial Risk Assessment Summary for Cu De River.

Agents	MEC			VNS 5942-1995 (class B)		
	Max	Min	Gm	PNEC	RQ_{Max}	RQ_{Gm}
N_{Total} (n = 0)						
NO_2-N (n = 4)	0.034	0.003	0.012	0.050	0.680	0.2500
NH_4-N (n = 13)	10.440	0.020	0.359	1.000	10.440	0.3600
NO_3- N (n = 15)	140.000	0.010	1.488	15.000	9.330	0.1000
P_{Total} (n = 0)						
PO_4-P (n = 0)						
DO (n = 19)	7.300	4.180	5.602	2.000	0.480	0.3600
BOD (n = 15)	44.800	1.000	8.899	25.000	1.790	0.3600
COD (n = 16)	57.600	1.000	11.643	35.000	1.650	0.3300
TSS (n = 12)	44.000	2.000	9.961	80.000	0.550	0.1200
Coliform (n = 16)	240,000.000	20.000	3,078.680	10,000.000	24.000	0.3100
Oil and grease (n = 4)	1.400	0.600	0.965	0.300	4.670	3.2100
CN- (n = 3)	0.140	0.004	0.013	0.050	2.800	0.2600
Phenol (n = 2)	0.003	0.002	0.002	0.020	0.150	0.1200
Hg (n = 3)	0.058	0.000	0.003	0.002	29.000	1.3700
Pb (n = 9)	0.040	0.001	0.009	0.100	0.400	0.0900
Fe (n = 9)	0.800	0.030	0.111	2.000	0.400	0.0600
Cu (n = 2)	0.003	0.002	0.002	1.000	0.000	0.0000
Zn (n = 0)						
As (n = 3)	0.141	0.000	0.003	0.100	1.410	0.0300
Cd (n = 0)						
Mn (n = 2)	0.060	0.050	0.055	0.800	0.075	0.0685
Cr (n = 2)	0.010	0.003	0.006	0.050	0.200	0.1100
DDT (n = 0)						
Total pesticides (n = 0)						

River Water

The results of the assessment show that in the river, there is risk from NH_4-N in the Phu Loc River as shown by the geomean RQ exceeding one. In addition, NH_4-N, NO_3-N, NO_2-N in water column of all rivers have maximum RQs that exceed 1. There were no MECs and PNECs available for river water column concentration of N_{Total}, P_{Total} and PO_4.

DO, BOD, COD

Seawater

The RQs in seawater column show that there are risks associated with levels of DO and BOD in Danang Bay and DO in the South Son Tra - Ngu Hanh Son Coastal Water in certain locations. Maximum RQs of DO and BOD exceed 1 but the geomean RQs are less than 1. There was no threshold value for COD in seawater column, thus the RQ value for this parameter was not calculated.

Table 50. Initial Risk Assessment Summary for Phu Loc River.

Agents	MEC			VNS 5942-1995 (class B)		
	Max	Min	Gm	PNEC	RQ_{Max}	RQ_{Gm}
N_{Total} (n = 0)						
NO_2-N (n = 5)	0.160	0.005	0.031	0.050	3.20	0.62
NH_4-N (n = 21)	9.600	0.010	1.053	1.000	9.60	1.05
NO_3- N (n = 28)	38.300	0.050	1.744	15.000	2.55	0.12
P_{Total} (n = 0)						
PO_4-P (n = 0)						
DO (n = 29)	7.600	2.340	3.929	2.000	0.85	0.51
BOD (n = 25)	60.090	3.000	12.673	25.000	2.40	0.51
COD (n = 24)	169.000	1.700	26.242	35.000	4.83	0.75
TSS (n = 20)	124.000	2.000	17.485	80.000	1.55	0.22
Coliform (n = 22)	140,000.000	400.000	15,730.320	10,000.000	14.00	1.57
Oil and grease (n = 3)	2.000	0.050	0.391	0.300	6.67	1.30
CN- (n = 2)	0.390	0.050	0.140	0.050	7.80	2.79
Phenol (n = 1)	0.030	0.030	0.030	0.002	15.00	15.00
Hg (n = 5)	0.042	0.000	0.000	0.002	21.00	0.10
Pb (n = 13)	0.051	0.003	0.013	0.100	0.51	0.13
Fe (n = 13)	2.800	0.640	1.248	2.000	1.40	0.62
Cu (n = 14)	0.450	0.002	0.011	1.000	0.45	0.01
Zn (n = 13)	0.400	0.001	0.026	2.000	0.20	0.01
As (n = 2)	0.266	0.001	0.018	0.100	2.66	0.18
Cd (n = 12)	0.200	0.000	0.002	0.020	10.00	0.10
Mn (n = 1)	0.040	0.040	0.040	0.800	0.05	0.05
Cr (n = 1)	0.007	0.007	0.007	0.050	0.14	0.14
DDT (n = 0)						
Total pesticides (n = 0)						

Lake Water

The results of comparative assessment for DO, BOD, COD at the lake water column show that there is risk from BOD and COD in Rong, Thac Gian- Vinh Trung, Tram and March 29 Park Lakes. Except for BOD in March 29 Park Lake for which only RQ_{Max} exceeded 1, all RQ_{Gm} for BOD and COD exceeded 1e in all lakes. In Rong Lake, RQ_{Gm} for DO also exceeded 1 indicating wide concern for DO while in Tram and March 29 Park Lakes, only RQ_{Max} for DO exceeded one indicating localized concern.

River Water

For river water column, there is no risk from DO at all rivers (RQMax < 1) but risk is associated with BOD and COD at certain locations, which gave maximum RQs that exceed 1 in all rivers. BOD and COD are, therefore, localized concerns in river water column.

Table 51. Initial Risk Assessment Summary for Vu Gia River System.

Agents	MEC(mg/l)			VNS 5943-1995 (Class B)		
	Max	Min	Gm	PNEC	RQ_{Max}	RQ_{Gm}
N_{Total} (n = 0)						
NO_2-N (n = 70)	0.190	0.001	0.011	0.050	3.80	0.23
NH_4-N (n = 155)	6.100	0.001	0.075	1.000	6.10	0.07
NO_3- N (n = 165)	26.000	0.010	0.213	15.000	1.73	0.01
P_{Total} (n = 61)	7.400	0.002	0.049			
PO_4-P (n = 68)	0.190	0.010	0.060			
DO (n = 179)	8.400	3.900	5.869	2.000	0.51	0.34
BOD (n = 127)	33.000	1.000	5.472	25.000	1.32	0.22
COD (n = 169)	81.300	0.500	9.357	35.000	2.32	0.27
TSS (n = 166)	208.200	2.000	16.155	80.000	2.60	0.20
Coliform (n = 174)	2,000,000.000	20.000	41,404.000	10,000.000	200.00	4.14
Oil and grease (n = 11)	11.000	0.080	0.668	0.300	36.67	2.22
CN- (n = 5)	1.460	0.005	0.037	0.050	29.20	0.73
Phenol (n = 3)	0.001	0.001	0.001	0.020	0.05	0.05
Hg (n = 89)	0.040	0.000	0.000	0.001	40.00	0.35
Pb (n = 124)	0.110	0.001	0.005	0.050	2.20	0.11
Fe (n = 158)	9.000	0.010	0.502	1.000	9.00	0.50
Cu (n = 17)	0.481	0.001	0.011	0.100	4.81	0.11
Zn (n = 10)	0.195	0.007	0.023	1.000	0.20	0.02
As (n = 3)	0.003	0.002	0.002	0.050	0.06	0.05
Cd (n = 9)	0.100	0.000	0.001	0.010	10.00	0.14
Mn (n = 3)	0.100	0.050	0.065	0.100	1.00	0.65
Cr (n = 3)	0.010	0.002	0.005	0.050	0.20	0.11
DDT (n = 15)	312.000	4.900	98.000	10,000.000	0.03	0.01
Total of pesticides (n = 14)	143.500	0.600	4.392	150,000.000	0.00	0.00

Note: For DDT and total of pesticides, the units of MECs and PNEC are ppt.

TSS

There is no risk from TSS at the South Son Tra - Ngu Hanh Son Coastal Water and Cu De River. In other monitoring stations such as Danang Bay, Vu Gia and Phu Loc Rivers and Rong, Tram, Thac Gian-Vinh Trung and March 29 Park Lakes, TSS has maximum RQ exceeding 1.

Coliform

The risk assessment done for the water column was based only on some points in the area, and therefore, it is not representative of the whole coastal area. Data from the other areas of the Danang coastal zone should be gathered for a more refined risk assessment.

There is risk from coliform at Danang Bay, South Son Tra - Ngu Hanh Son Coastal Water, Cu De, Phu Loc and Vu Gia Rivers and Rong, Tram, Thac Gian and March 29 Park Lakes. The geomean RQs of coliform in water column are very high, especially at Rong, Tram, and Thac Gian Lakes. Maximum and geomean RQ for 74 wells in Danang are also higher than 1.

Coliform, therefore, is one of the priority concerns that need immediate attention. There is a need to identify specific areas affected and identify major sources of discharge to the coastal areas, rivers, and lakes, through more detailed data analysis, to develop appropriate management actions.

The risk assessment was performed using data for total coliform only. Data on fecal coliform should also be collected.

Pesticides

There was very limited data on pesticides for detailed assessment. There were only few data on DDT and total pesticides at Vu Gia River. According to comparative results, there is no risk for DDT and total pesticides at Vu Gia River.

More information in the water column and seafood tissue should be gathered, specifically in areas where there are nearby agricultural activities.

Heavy Metals

The RQs for heavy metals indicate a concern for these types of contaminants although limited data were used for the risk assessment. There is a need, therefore, to verify these results, especially when more recent data becomes available. There should also be monitoring for heavy metals in sediment and seafood tissues.

Seawater

In Danang Bay, the results show that there are risks from Fe and Zn in seawater column as shown by the geomean RQs that exceed 1. In addition, maximum RQs of other heavy metals such as Pb and Cu also exceed 1.

There are risks from Cu and Zn at the water column of the South Son Tra - Ngu Hanh Son Coastal Water indicated by the geomean RQ that exceed 1. Some heavy metals such as Pb and Fe also have maximum RQs that exceed 1.

Lake Water

The results of comparative assessment show that there is localized risk for mercury at Rong Lake (RQ_{Max} < 1) and wider risk at Tram and March 29 Park Lakes (RQ_{Gm} > 1); there is localized risk for lead at Rong, Thac Gian-Vinh Trung and March 29 Park Lakes; and there is localized risk for Fe at Thac Gian-Vinh Trung and Tram Lakes.

Table 52. Initial Risk Assessment Summary for Rong and Thac Gian-Vinh Trung Lakes.

Agents	MEC_{MAx} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Rong Lake					
N_{Total} (n = 2)	32.0000	26.533			
NO_2-N (n = 8)	0.0240	0.014	0.0500	0.480	0.290
NH_4-N (n = 40)	44.0000	19.560	1.0000	44.000	19.560
NO_3- N (n = 24)	33.9000	2.317	15.0000	2.260	0.150
P_{Total} (n = 6)	11.0500	3.867			
DO (n = 86)	0.0300(*)	0.639	2.0000	66.670	3.130
BOD (n = 143)	128.0000	35.856	25.0000	5.120	1.430
COD (n = 134)	223.0000	78.896	35.0000	6.370	2.250
TSS (n = 52)	90.0000	27.231	80.0000	1.130	0.340
Coliform (n = 51)	28,000,000,000.0000	1,644,023,298.8	10,000.0000	2,800,000.000	164,402.330
Oil and grease (n = 8)	11.0500	3.3556	0.3000	36.830	11.190
CN (n = 3)	0.1800	0.0378	0.0500	3.600	0.760
Hg (n = 8)	0.0028	0.0005	0.0020	1.400	0.230
Pb (n = 12)	0.1000	0.0127	0.1000	1.000	0.130
Fe (n = 11)	1.3200	0.3482	2.0000	0.660	0.170
Cu (n = 5)	0.0500	0.0037	1.0000	0.050	0.000
Zn (n = 1)	0.1000	0.1000	2.0000	0.050	0.050
As (n = 1)	0.0022	0.0022	0.1000	0.020	0.020
Mn (n = 1)	0.1800	0.1800	0.8000	0.230	0.230
Cr^{+6} (n = 1)	0.0088	0.0088	0.0500	0.180	0.180
Thac Gian -Vinh Trung Lake					
NO_2-N (n = 1)	1.4700	1.4700	0.0500	29.400	29.400
NH_4-N (n = 7)	32.5000	16.5310	1.0000	32.500	16.530
NO_3- N (n = 7)	12.5000	2.7510	15.0000	0.830	0.180
DO (n = 86)	2.9000(*)	3.3600	2.0000	0.690	0.600
BOD (n = 143)	61.0000	36.0540	25.0000	2.440	1.440
COD (n = 134)	205.0000	75.3000	35.0000	5.860	2.150
TSS (n = 7)	100.0000	39.5880	80.0000	1.250	0.490
Coliform (n = 7)	360,000.0000	17,526.6000	10,000.0000	36.000	1.753
Oil and grease (n = 1)	0.7000	0.7000	0.3000	2.330	2.330
CN (n = 1)	0.0100	0.0100	0.0500	0.200	0.200
Hg (n = 1)	0.0002	0.0002	0.0020	0.110	0.110
Pb (n = 7)	0.3000	0.0265	0.1000	3.000	0.270
Fe (n = 7)	2.4800	0.5530	2.0000	1.240	0.280
Zn (n = 1)	0.2500	0.2500	2.0000	0.130	0.130
As (n = 1)	0.0022	0.0022	0.1000	0.020	0.020
Mn (n = 1)	0.2300	0.2300	0.8000	0.290	0.290
Cr^{+6} (n = 1)	0.0048	0.0048	0.0500	0.100	0.100

Note: The values having sign (*) mean MEC_{min} (mg/l) of DO.

Table 53. Initial Risk Assessment Summary for Tram and March 29 Park Lakes.

Agents	MEC_{MAx} (mg/l)	MEC_{Gm} (mg/l)	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Tram Lake					
N_{Total} (n = 0)					
NO_2-N (n = 2)	0.0450	0.0350	0.0500	0.900	0.710
NO_3- N (n = 11)	112.4000	2.4420	15.0000	7.490	0.160
P_{Total} (n = 1)	29.0000	29.0000			
PO_4-P (n = 0)					
DO (n = 86)	0.8000(*)	2.6600	2.0000	2.500	0.750
BOD (n = 143)	111.0000	31.1920	25.0000	4.440	1.248
COD (n = 134)	275.0000	70.9480	35.0000	7.860	2.030
TSS (n = 48)	634.0000	68.4010	80.0000	7.930	0.860
Coliform (n = 36)	8,000,000.0000	20,636.4000	10,000.0000	800.000	2.064
Oil and grease (n = 29)	4.0000	0.6537	0.3000	13.330	2.180
CN- (n = 31)	0.7900	0.1835	0.0500	15.800	3.670
Hg (n = 34)	0.0140	0.0025	0.0020	7.000	1.250
Pb (n = 55)	0.0940	0.0047	0.1000	0.940	0.050
Fe (n = 9)	2.8300	0.2014	2.0000	1.420	0.100
Cu (n = 52)	0.0300	0.0014	1.0000	0.030	0.000
Zn (n = 37)	0.6023	0.0589	2.0000	0.300	0.030
As (n = 1)	0.0001	0.0001	0.1000	0.000	0.000
Cd (n = 12)	0.0900	0.0004	0.0200	4.500	0.020
Mn (n = 1)	0.0550	0.0550	0.8000	0.070	0.070
Cr^{+6} (n = 1)	0.0064	0.0064	0.0500	0.130	0.130
March 29 Park Lake					
N_{Total} (n = 1)	6.0000	6.0000			
NO_2-N (n = 5)	0.4920	0.0850	0.0500	9.840	1.700
NH_4-N (n = 12)	19.0000	1.1980	1.0000	19.000	1.200
NO_3- N (n = 17)	9.6000	2.7800	15.0000	0.640	0.190
P_{Total} (n = 4)	4.7000	1.5540			
PO_4-P (n = 0)					
DO (n = 86)	0.7000(*)	4.4710	2.0000	2.860	0.450
BOD (n = 143)	46.0000	15.0680	25.0000	1.840	0.603
COD (n = 134)	140.0000	57.9170	35.0000	4.000	1.650
TSS (n = 20)	149.2000	32.9030	80.0000	1.870	0.410
Coliform (n = 19)	4,700,000.0000	14,849.5000	10,000.0000	470.000	1.485
Oil and grease (n = 4)	3.5000	2.0812	0.3000	11.670	6.940
CN- (n = 3)	0.2600	0.0618	0.0500	5.200	1.240
Hg (n = 6)	0.0120	0.0020	0.0020	6.000	1.010
Pb (n = 11)	0.1900	0.0147	0.1000	1.900	0.150
Fe (n = 8)	1.8000	0.3356	2.0000	0.900	0.170
Cu (n = 4)	0.0130	0.0040	1.0000	0.010	0.000
Zn (n = 2)	0.0120	0.0066	2.0000	0.010	0.000
As (n = 1)	0.0026	0.0026	0.1000	0.030	0.030
Cd (n = 2)	0.0010	0.0008	0.0200	0.050	0.040
Mn (n = 1)	0.0500	0.0500	0.8000	0.060	0.060
Cr^{+6} (n = 1)	0.0100	0.0100	0.0500	0.200	0.200

Note: The values having sign (*) mean MEC_{min} (mg/l) of DO.

River Water

The result of comparative assessment shows that at Cu De River, mercury has geomean RQ that exceeds 1.

At Phu Loc River, there is risk from Hg, As, Cd and Fe, which have maximum RQs that exceed 1.

At Vu Gia River, Hg, Pb, Fe, Cu and Cd have maximum RQs exceeding 1.

Oil and Grease

The results of comparative risk assessment show that there are risks from oil and grease at seawater column (South Son Tra - Ngu Hanh Son Coastal Water), all rivers (Cu De, Phu Loc and Vu Gia) and all lakes (Rong, Thac Gian-Vinh Trung, Tram and March 29 Park) based on geomean RQs exceeding one.

There was no data on the organic constituents of oil and grease in the site. The complex mixture of organic compounds in oil and grease may have different adverse effects on marine life, particularly shellfisheries and benthos organisms. Identification of these various organic constituents will enable the determination of eco-toxicological risks that these compounds present to the ecosystem.

Cyanide

There was no risk from cyanide in the water column at Thac Gian-Vinh Trung Lake.

At the South Son Tra - Ngu Hanh Son Coastal Water, Phu Loc River, Tram and March 29 Park Lake, geomean RQs exceed 1.

At Danang Bay, Cu De and Vu Gia Rivers, and Rong Lake, maximum RQs for cyanide exceed 1.

Phenol

Results of the comparative risk assessment show risk from phenol at Phu Loc River although only one data was used in the assessment.

Risk assessment of phenol for other rivers has not been defined yet because of lack of data. There is no data on phenol for lake water column. One recommendation is the collection of more data for further assessment.

COMPARATIVE ASSESSMENT OF RISKS TO HUMAN HEALTH

The risk assessment for human health consists of RQs generated using levels of contaminants in ground water (wells) and surface waters (Cau Do River and Green Lake) that are used as sources of domestic water supply. Appropriate threshold values for the protection of human health were applied to get the RQs.

Tables 60 to 63 show that there is risk associated with levels of some contaminants in Green Lake, Cau Do River, and well water column. For Green Lake, geomean RQs for NH_4, DO, Hg and cyanide exceed 1 while maximum RQs for NO_3, BOD and COD also exceed 1. In Cau Do River, geomean RQs for coliform, NH_4, NO_2, BOD and DO, and maximum RQs for TSS, coliform, COD, Hg and Fe are greater than 1. In ground water, geomean RQs for Fe, BOD and As exceed the critical threshold of one, while maximum RQs for NH_4, NO_3, Pb, Hg, cyanide and suspended solids also exceed 1. There were no PNECs available for N_{Total}, P_{Total}, NO_2-N, PO_4-P, DO, COD and coliform in ground water, and N_{Total}, P_{Total}, NO_2-N, PO_4-P, and oil and grease in fresh surface waters.

Table 54. Comparative Risk Assessment for Seawater.

Agents	RQs				
	<1	1-10	10-100	100-1000	>1000
Danang Bay					
N_{Total} (n = 0)	No data				
NO_2-N (n = 125)	No PNEC				
NH_4-N (n = 193)	—	—	—		
NO_3-N (n = 181)	No PNEC				
P_{Total} (n = 48)	No PNEC				
PO_4-P (n = 70)	No PNEC				
DO (n = 268)	—	—			
BOD (n = 161)	—	—			
COD (n = 199)	No PNEC				
TSS (n = 290)	—	—			
Coliform (n = 170)			—	—	
Oil and grease (n = 76)	—	—			
CN (n = 19)	—	—			
Hg (n = 114)	—	—	—		
Pb (n = 132)	—	—			
Fe (n = 117)	—	—	—		
Cu (n = 37)	—	—			
Zn (n = 39)		—			
As (n = 39)	—				
Cd (n = 38)	—				
Pesticides (n = 0)	No data				
South Son Tra - Ngu Hanh Son Coastal Water					
N_{Total} (n = 0)	No data				
NO_2-N (n = 0)	No data				
NH_4-N (n = 30)	—	—			
NO_3-N (n = 1)	No PNEC				
P_{Total} (n = 0)	No data				
PO_4-P (n = 0)	No data				
DO (n = 55)	—	—			
BOD (n = 31)	—				
COD (n = 24)	No PNEC				
TSS (n = 35)	—				
Coliform (n = 34)		—	—	—	
Oil and grease (n = 15)		—			
CN (n = 3)		—	—		
Hg (n = 10)		—	—		
Pb (n = 21)	—	—			
Fe (n = 25)	—	—			
Cu (n = 2)	—				
Zn (n = 2)		—			
As (n = 1)	●				
Cd (n = 1)	●				
Pesticides (n = 0)	No data				

Table 55. Comparative Risk Assessment for Cu De River.

Agents	RQs				
	<1	1-10	10-100	100-1000	>1000
Cu De River					
N_{Total} (n = 0)	No data				
NO_2-N (n = 4)					
NH_4-N (n = 13)					
NO_3-N (n = 15)					
P_{Total} (n = 0)	No data				
PO_4-P (n = 0)	No data				
DO (n = 19)					
BOD (n = 15)					
COD (n = 16)					
TSS (n = 12)					
Coliform (n = 16)					
Oil and grease (n = 4)					
CN (n = 3)					
Phenol (n = 2)					
Hg (n = 3)					
Pb (n = 9)					
Fe (n = 9)					
Cu (n = 2)					
Zn (n = 0)	No data				
As (n = 3)					
Cd (n = 0)	No data				
Mn (n = 2)					
Cr (n = 2)					
DDT (n = 0)	No data				
Total pesticides (n = 0)	No data				

Table 56. Comparative Risk Assessment for Phu Loc River.

Agents	RQs				
	<1	1-10	10-100	100-1000	>1000
Phu Loc River					
N_{Total} (n = 0)	No data				
NO_2-N (n = 5)	—	—			
NH_4-N (n = 21)		—			
NO_3-N (n = 28)	—	—			
P_{Total} (n = 0)	No data				
PO_4-P (n = 0)	No data				
DO (n = 29)	—				
BOD (n = 25)	—	—			
COD (n = 24)	—	—			
TSS (n = 20)	—	—			
Coliform (n = 22)		—	—		
Oil and grease (n = 3)		—			
CN (n = 2)		—			
Phenol (n = 1)			●		
Hg (n = 5)	—	—	—		
Pb (n = 13)	—				
Fe (n = 13)	—	—			
Cu (n = 14)	—				
Zn (n = 13)	—				
As (n = 2)	—	—			
Cd (n = 12)	—	—			
Mn (n = 1)	●				
Cr (n = 1)	●				
DDT (n = 0)	No data				
Total pesticides (n = 0)	No data				

Table 57. Comparative Risk Assessment for Vu Gia River System.

Agents	RQs				
	<1	1-10	10-100	100-1000	>1000
Vu Gia River System					
N_{Total} (n = 0)	No data				
NO_2-N (n = 70)	—	—			
NH_4-N (n = 155)	—	—			
NO_3-N (n = 165)	—	—			
P_{Total} (n = 61)	No PNEC				
PO_4-P (n = 68)	No PNEC				
DO (n = 179)	—				
BOD (n = 127)	—	—			
COD (n = 169)	—	—			
TSS (n = 166)	—	—			
Coliform (n = 174)		—	—	—	
Oil and grease (n = 11)		—	—		
CN (n = 5)	—	—	—		
Phenol (n = 3)	—				
Hg (n = 89)	—	—	—		
Pb (n = 124)	—	—			
Fe (n = 158)	—	—			
Cu (n = 17)	—	—			
Zn (n = 10)	—				
As (n = 3)	—				
Cd (n = 9)	—	—			
Mn (n = 3)	—				
Cr (n = 3)	—				
DDT (n = 15)	—				
Total pesticides (n = 14)	—				

Table 58. Comparative Risk Assessment for Rong and Thac Gian-Vinh Trung Lakes.

Agents	RQs				
	<1	1-10	10-100	100-1000	>1000
Rong Lake					
N_{Total} (n = 2)	No PNEC				
NO_2-N (n = 8)	—				
NH_4-N (n = 40)			—		
NO_3-N (n = 24)	—	—			
P_{Total} (n = 6)	No PNEC				
DO (n = 86)		—	—		
BOD (n = 143)		—			
COD (n = 134)		—			
TSS (n = 52)	—	—			
Coliform (n = 51)					—
Oil and grease (n = 8)		—			
CN (n = 3)	—	—			
Hg (n = 8)	—	—			
Pb (n = 12)	—				
Fe (n = 11)	—				
Cu (n = 5)	—				
Zn (n = 1)	●				
As (n = 1)	●				
Mn (n = 1)	●				
Cr^{+6} (n = 1)	●				
Thac Gian-Vinh Trung Lake					
NO_2-N (n = 1)			●		
NH_4-N (n = 7)			—		
NO_3-N (n = 7)	—				
DO (n = 86)	—				
BOD (n = 143)		—			
COD (n = 134)		—			
TSS (n = 7)	—	—			
Coliform (n = 7)		—	—		
Oil and grease (n = 1)		●			
CN (n = 1)	●				
Hg (n = 1)	●				
Pb (n = 7)	—	—			
Fe (n = 7)	—	—			
Zn (n = 1)	●				
As (n = 1)	●				
Mn (n = 1)	●				
Cr^{+6} (n = 1)	●				

Table 59. Comparative Risk Assessment for Tram and March 29 Park Lakes.

Agents	RQs				
	<1	1-10	10-100	100-1000	>1000
Tram Lake					
N_{Total} (n = 0)	No data				
NO_2-N (n = 2)					
NO_3-N (n = 11)					
P_{Total} (n = 1)	No PNEC				
PO_4-P (n = 0)	No data				
DO (n = 86)					
BOD (n = 143)					
COD (n = 134)					
TSS (n = 48)					
Coliform (n = 36)					
Oil and grease (n = 29)					
CN (n = 31)					
Phenol (n = 0)	No data				
Hg (n = 34)					
Pb (n = 55)					
Fe (n = 9)					
Cu (n = 52)					
Zn (n = 37)					
As (n = 1)					
Cd (n = 12)					
Mn (n = 1)					
Cr^{+6} (n = 1)					
March 29 Park Lake					
N_{Total} (n = 1)	No PNEC				
NO_2-N (n = 5)					
NH_4-N (n = 12)					
NO_3-N (n = 17)					
P_{Total} (n = 4)	No PNEC				
PO_4-P (n = 0)	No data				
DO (n = 86)					
BOD (n = 143)					
COD (n = 134)					
TSS (n = 20)					
Coliform (n = 19)					
Oil and grease (n = 4)					
CN (n = 3)					
Phenol (n = 0)	No data				
Hg (n = 6)					
Pb (n = 11)					
Fe (n = 8)					
Cu (n = 4)					
Zn (n = 2)					
As (n = 1)					
Cd (n = 2)					
Mn (n = 1)					
Cr^{+6} (n = 1)					

Table 60. Initial Risk Assessment Summary for Surface Waters for Domestic Water Supply.

Agents	MEC (mg/l)			VNS 5942 (A)-1995		
	Max	Min	Gm	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
Cau Do River						
N_{Total} (n = 0)						
NO_2-N (n = 12)	0.08000	0.0010	0.01200	0.0100	8.00	1.24
NH_4-N (n = 26)	6.10000	0.0010	0.05500	0.0500	122.00	1.11
NO_3- N (n = 27)	0.53000	0.0600	0.15800	10.0000	0.05	0.02
P_{Total} (n = 11)	0.13000	0.0030	0.04300			
PO_4-P (n = 14)	0.16000	0.0100	0.05700			
DO (n = 29)	8.00000	4.4000	6.01900	6.0000	1.36	1.00
BOD (n = 19)	10.00000	3.0000	5.55800	4.0000	2.50	1.39
COD (n = 30)	22.00000	2.8000	8.59100	10.0000	2.20	0.86
TSS (n = 29)	166.00000	3.0000	15.52300	20.0000	8.30	0.78
Coliform (n = 28)	40,000.00000	100.0000	4,518.22300	5,000.0000	8.00	0.90
Oil and grease (n = 1)	0.12000	0.1200	0.12000	0.0000		
CN^- (n = 0)						
Phenol (n = 0)						
Hg (n = 16)	0.00082	0.0000	0.00033	0.0010	0.82	0.33
Pb (n = 21)	0.01000	0.0010	0.00500	0.0500	0.20	0.10
Fe (n = 29)	4.20000	0.1100	0.67800	1.0000	4.20	0.68
Total of pesticides (n = 0)						
Green Lake						
N_{Total} (n = 0)						
NO_2-N (n = 0)						
NH_4-N (n = 7)	0.39000	0.0100	0.07500	0.0500	7.80	1.50
NO_3- N (n = 7)	69.40000	0.0180	0.89300	10.0000	6.94	0.09
P_{Total} (n = 1)	6.70000	6.7000	6.70000			
PO_4-P (n = 0)						
DO (n = 86)	5.10000	3.8000	4.31400	6.0000	1.58	1.39
BOD (n = 143)	28.20000	1.0000	2.61900	4.0000	7.05	0.65
COD (n = 134)	28.00000	1.0000	3.84400	10.0000	2.80	0.38
TSS (n = 7)	12.00000	2.0000	5.32800	20.0000	0.60	0.27
Coliform (n = 6)	53,000.00000	3.0000	171.04600	5,000.0000	10.60	0.03
Oil and grease (n = 0)						
CN^- (n = 3)	0.01000	0.0100	0.01000	0.0100	1.00	1.00
Phenol (n = 0)						
Hg (n = 1)	0.01000	0.0100	0.01000	0.0010	10.00	10.00
Pb (n = 5)	0.01900	0.0010	0.00300	0.0500	0.38	0.06
Fe (n = 7)	0.40000	0.0300	0.13060	1.0000	0.40	0.13
Cu (n = 7)	0.03000	0.0010	0.00580	0.1000	0.30	0.06
Zn (n = 6)	0.12000	0.0010	0.02260	1.0000	0.12	0.02
As (n = 1)	0.00310	0.0031	0.00310	0.0500	0.06	0.06
Cd (n = 1)	0.00100	0.0010	0.00100	0.0100	0.10	0.10
Mn (n = 1)	0.05000	0.0500	0.05000	0.1000	0.50	0.50
Cr^{+6} (n = 1)	0.01000	0.0100	0.01000	0.0500	0.20	0.20

Table 61. Initial Risk Assessment Summary for Well Water Column.

Agents	MEC (mg/l)			DOH 505-1995		
Well Water	Max	Min	Gm	PNEC (mg/l)	RQ_{Max}	RQ_{Gm}
N_{Total} (n = 6)	3.230	0.070	0.760			
NO_2-N (n = 74)	4.935	0.010	0.092			
NH_4-N (n = 110)	91.800	0.010	0.146	3.000	30.60	0.05
NO_3-N (n = 141)	221.500	0.010	3.331	10.000	22.15	0.33
P_{Total} (n = 17)	10.050	0.010	0.131			
PO_4-P (n = 13)	4.150	0.050	0.170			
DO (n = 53)	5.400	0.700	3.057	No data		
BOD (n = 34)	30.000	0.300	4.353	2.000	15.00	2.18
COD (n = 21)	64.000	0.020	5.131	No data		
SS (n = 80)	1,056.400	0.100	6.399	500.000	2.11	0.01
Coliform (n = 74)	2,200,000.000	2.000	209.636	3.000*	733,333.00	69.9
CN (n = 3)	0.750	0.001	0.075	0.100	7.50	0.75
Hg (n = 5)	0.005	0.000	0.001	0.001	4.50	0.75
Pb (n = 43)	0.925	0.001	0.006	0.050	18.50	0.12
Fe (n = 68)	190.000	0.010	0.401	0.300	633.33	1.34
Cu (n = 31)	0.939	0.001	0.009	1.000	0.94	0.01
Zn (n = 28)	0.977	0.011	0.055	5.000	0.20	0.01
As (n = 1)	0.281			0.050	5.62	
Cd (n = 2)	0.002	0.000	0.000	0.005	0.38	0.08
Phenol (n = 0)						
Chloride (n = 19)	638.810	0.610	54.173	250.000	2.56	0.22
Hardness (n = 60)	1,039.500	0.670	50.505	500.000	2.08	0.10

* Used standard for ground water from VNS 5944-1995

Table 62. Comparative Risk Assessment for Surface Waters for Domestic Water Supply.

Agents	RQs				
	<1	1-10	10-100	100-1000	>1000
Cau Do River					
N_{Total} (n = 0)	No data				
NO_2-N (n = 12)					
NH_4-N (n = 26)					
NO_3-N (n = 27)					
P_{Total} (n = 11)	No PNEC				
PO_4-P (n = 14)	No PNEC				
DO (n = 29)					
BOD (n = 19)					
COD (n = 30)					
TSS (n = 29)					
Coliform (n = 28)					
Oil and grease (n = 1)	No PNEC				
CN (n = 0)	No data				
Phenol (n = 0)	No data				
Hg (n = 16)					
Pb (n = 21)					
Fe (n = 29)					
Total of pesticides (n = 0)	No data				
Green Lake					
N_{Total} (n = 0)	No data				
NO_2-N (n = 0)	No data				
NH_4-N (n = 7)					
NO_3-N (n = 7)					
P_{Total} (n = 1)	No PNEC				
PO_4-P (n = 0)	No data				
DO (n = 86)					
BOD (n = 143)					
COD (n = 134)					
TSS (n = 7)					
Coliform (n = 6)					
Oil and grease (n = 0)	No data				
CN (n = 3)					
Phenol (n = 0)	No data				
Hg (n = 1)					
Pb (n = 5)					
Fe (n = 7)					
Cu (n = 7)					
Zn (n = 6)					
As (n = 1)					
Cd (n = 1)					
Mn (n = 1)					

Table 63. Comparative Risk Assessment for Well Water Column.

Agents	RQs				
Well Water	**<1**	**1-10**	**10-100**	**100-1000**	**>1000**
N_{Total} (n = 6)	No PNEC				
NO_2-N (n = 74)	No PNEC				
NH_4-N (n = 110)	—	—	—		
NO_3-N (n = 141)	—	—	—		
P_{Total} (n = 17)	No PNEC				
PO_4-P (n = 13)	No PNEC				
DO (n = 53)	No PNEC				
BOD (n = 34)		—	—		
COD (n = 21)	No PNEC				
SS (n = 80)	—	—			
Coliform (n = 74)			—	—	—
CN (n = 3)	—	—			
Hg (n = 5)	—	—			
Pb (n = 43)	—	—	—		
Fe (n = 68)		—	—	—	
Cu (n = 31)	—				
Zn (n = 28)	—				
As (n = 1)		●			
Cd (n = 2)	—				
Phenol (n = 0)	No data				
Chloride (n = 19)	—	—			
Hardness (n = 60)	—	—			

Conclusions, Data Gaps and Uncertainties

Retrospective Risk Assessment

Although data on the status of marine fisheries has not been available for the risk assessment, related information provide a view on the pressure exerted on the marine ecosystem that might have potential adverse effects on marine fisheries. Attention should also be directed to determine the effects of overfishing, destruction of habitats, and water pollution on fisheries productivity and contamination of fishery tissue. There is a need to collect more information on marine fisheries such as catch per unit of effort (CPUE) to identify evidences of decline of marine fisheries in Danang coastal zone.

For aquaculture, DO is identified as very likely agent, oil and grease, heavy metals, BOD, COD, TSS, coliform, nutrients are identified as possible agents. Results of monitoring programs in lakes, where aquaculture decline was observed, have shown that these areas are highly polluted. These lakes have been used as receiving areas for untreated industrial wastes.

Although the decline of phytoplankton was not established, the potential impacts of suspended solids and pollutants in the water on primary productivity should be considered.

For habitats, there was no evidence of decline for coral reefs in the coastal zone due to lack of baseline data for comparison. Separate surveys in different areas, however, reported declining conditions. Potential agents that may cause coral reef decline were, therefore, identified. The agents range from chemical to physical and biological such as TSS, BOD/COD, oil and grease, cyanide, sedimentation, destructive fishing, physical disturbance, illegal exploitation, port dredging, and algal overgrowth and predation. A systematic coral reef survey will be needed to establish decline and identify the primary agents. Decline of coral reefs will have large ecological consequences due to the loss of their ecological functions as breeding, spawning and nursery grounds for various marine life.

For seagrasses, rocky shores and soft-bottom communities, there was no available information for risk assessment. There is a need to collect information for these targets for future assessment.

For sandy beaches, decline was established based on information on coastal erosion in specific areas. Construction work is identified as very likely agent, while reclamation and deforestation were identified as possible agents that can cause decline.

For wetlands, reclamation, deforestation, sand mining, and pollution were identified as very likely agents that can cause decline.

For forest cover, it is shown that land clearing for farming, illegal cutting of trees for conversion to coal and other uses, forest fires associated with human activities and tourism development are very likely causes of decline. For forest fauna, forest fires, forest cover reduction and illegal hunting were identified as likely agents that can cause decline.

PROSPECTIVE RISK ASSESSMENT

The following are the comparative risk assessment results for both human health and ecological risks. Risk agents are classified either as priority risks or localized risks. Priority risk agents were determined on the basis of RQ_{Gm} exceeding 1. Localized risks were indicated by RQ_{Max} that exceeded 1. The ranking of priority or localized risks was done based on the order of magnitude of RQs as presented in the comparative RA tables. Agents for which risks are acceptable (RQ_{Max} < 1) are also presented.

Human Health Risk

Analysis shows that for human health, there is cause for concern from bathing in coastal areas, rivers and lakes as a consequence of coliform contamination. Among all the agents, the highest RQs were obtained for coliform in areas for bathing as well as aquaculture. Although no data on seafood tissue were available for the risk assessment, cause for concern can also be associated with consumption of seafood grown in areas contaminated with coliform and pollutants such as heavy metals, oil and grease or cyanide.

The table shows that among the rivers, the Vu Gia River System gave the highest RQs for coliform, while the RQs for coliform in Rong Lake showed serious cause for concern and need for immediate management intervention.

Location	RQ_{Gm}	RQ_{Max}
Seawater		
Danang Bay	15.84	500
South Son Tra - Ngu Hanh Son Coastal Water	6.96	600
River water		
Cu De River	0.31	24
Phu Loc River	1.57	14
Vu Gia River System	4.14	200
Lake water		
Rong Lake	164,402.00	2,800,000
Thac Gian-Vinh Trung Lake	1.75	36
Tram Lake	2.06	800
March 29 Park Lake	1.48	470

With regard to concern on human health associated with sources of domestic water supply, the highest RQ values were obtained for coliform levels in well water, NH_4-N levels in river water (Cau Do), and coliform levels in lake water (Green Lake).

High levels of coliform in the wells in Danang City suggest contamination with human or animal fecal material. The highest measured concentration was 2,200,000 MPN/100 ml while the geometric mean was 210 MPN/100 ml (n = 74). In well water, Fe, organic load (indicated by BOD) and As (n = 1) were also identified as priority concerns while nutrients, Pb, CN^-, Hg, suspended solids and Cl^- are among the localized concerns.

In surface waters used as sources of domestic water supply such as Cau Do River and Green Lake, mean RQs for NH_4-N and DO show cause for concern. NO_2-N and BOD are also priority concerns in Cau Do River while a single data on Hg in Green Lake shows cause for concern (RQ = 10) and the need to verify levels of Hg in the area. On the basis of maximum RQs, localized risk was shown for coliform in both areas: TSS, COD and Fe in Cau Do River; and NO_3-N, BOD, COD and CN^- in Green Lake. The risk for Hg was acceptable in Cau Do River but CN^- was not assessed due to lack of data.

Detailed Prioritization of Risk Agents:

RQ	*Well Water*	*Cau Do River*	*Green Lake*
$RQ_{Gm} > 1$	Coliform > Fe > BOD > As (n = 1)	NH_4-N > NO_2-N, BOD, DO	NH_4-N, Hg (n = 1), DO
$RQ_{Max} > 1$	NH_4-N, NO_3-N, Pb > CN^-, Hg, SS, Cl^-	Coliform, TSS, COD, Fe	Coliform > NO_3-N, BOD, COD, CN^-
$RQ_{Max} < 1$	Cu, Zn, Cd	NO_3-N, Hg, Pb	Pb, Fe, Cu, Zn, As (n = 1), Cd (n = 1), Mn (n = 1)

Ecological Risk

Ecologically, oil and grease, nutrients (NH_4, NO_2 and NO_3), organic load (BOD and COD), DO, cyanide, certain heavy metals (Hg, Cd, As, Fe, Pb, Zn and Cu) and TSS are, in varying degrees, contaminants of concern in various water columns in Danang. The highest RQ values obtained for the different bodies of water were for Fe levels in seawater column, Hg levels in river water column, and ammonium levels in lake water column.

The separate assessment of ecological risks in coastal waters, rivers and lakes are presented in the following sections.

Seawater

For both Danang Bay and the South Son Tra - Ngu Hanh Son Coastal Water, Zn is a priority concern. Mercury, cyanide, and oil and grease are also priority concerns in the South Son Tra - Ngu Hanh Son Coastal Water while these are localized concerns in Danang Bay. Conversely, Fe is a priority risk agent in Danang Bay while it is a localized risk agent in the South Son Tra - Ngu Hanh Son Coastal Water. Other localized risk agents are NH_4-N, low DO, CN^- and Pb in both areas and Cu, BOD and TSS in Danang Bay. In the South Son Tra - Ngu Hanh Son Coastal Water, risk is acceptable for TSS and Cu, while there was no data on BOD.

In addition to potential contamination from direct discharges from industries, establishments and households along the coast, these contaminants could also be linked to discharges received by various rivers and lakes since the risk agents found in coastal waters have also been found as priority agents in tributary rivers and lakes.

River Water

Oil and grease is a priority concern in Cu De, Phu Loc and Vu Gia Rivers. Other priority risk agents are Hg in Cu De River and phenol, NH_4-N and cyanide in Phu Loc River. There is localized

Seawater

RQ	Danang Bay	South Son Tra - Ngu Hanh Son Coastal Water
$RQ_{Gm} > 1$	Fe > Zn	Hg and cyanide > oil and grease and Zn
$RQ_{Max} > 1$	Hg, NH_4-N > oil and grease, TSS, DO, BOD, cyanide, Pb and Cu	Fe, NH_4-N, DO, Pb
$RQ_{Max} < 1$	As and Cd	TSS, Cu, As (n = 1) and Cd (n = 1)

River Water

RQ	Cu De River	Phu Loc River	Vu Gia River System
$RQ_{Gm} > 1$	Hg > oil and grease	Phenol (n = 1) > NH_4-N, cyanide, oil and grease	Oil and grease
$RQ_{Max} > 1$	NH_4-N, NO_3-N > cyanide, BOD, COD, As	Hg > Cd > COD, BOD, NO_3-N, TSS, Fe, As	Hg, CN^- > Cd > Fe, Cu, Pb, NH_4-N, NO_3-N, NO_2-N, BOD, COD, TSS, Mn
$RQ_{Max} < 1$	NO_2-N, DO, TSS, Phenol, Pb, Fe, Cu, Mn and Cr	DO, Pb, Cu, Zn, Mn (n = 1) and Cr (n = 1)	DO, Phenol, Zn, As, Cr, DDT and Total pesticides

risk from cyanide in Cu De and Vu Gia Rivers, Hg in Phu Loc and Vu Gia Rivers, and organic load (BOD/COD), nutrients (NH_4-N and/or NO_3-N/NO_2-N) and other heavy metals in all rivers.

This shows that the three rivers are, in varying degrees, contaminated with most of the identified risk agents, and point to the probability of similar pollution sources.

Lake Water

All the lakes assessed are in a polluted state. Oil and grease, organic load (BOD/COD) and nutrients (NH_4-N/NO_3-N) are priority concerns in most, if not all of the four lakes. Cyanide and Hg are also priority concerns in Tram and March 29 Park Lakes while these are localized concerns in Rong Lake. Other localized risk agents are TSS in all lakes and Pb in all lakes except Tram Lake. Acceptable risk was found for most other heavy metals although limited data were used in the assessment.

There is acceptable risk from heavy metals such as As and Cd in seawater; from pesticides, phenol, Mn, Cr^{+6} and Zn in river water; from Cu, Zn, Mn, As and Cr^{+6} in lake water; and from Cu, Zn and Cd in ground water.

There are, however, few studies on heavy metals in seawater, river water and lake water and new data may be unavailable, so further monitoring for heavy metals in water column may be necessary. The initial risk assessment suggests that levels of metals such as mercury, zinc, arsenic, lead and cadmium in the water column need to be verified.

Risk assessment for other potentially important parameters in the different bodies of water was not permitted by the lack or inadequacy of MECs and/or PNECs. Pesticides and heavy metals in sediment and seafood tissues will be assessed in future risk assessments when data become available.

DATA GAPS

Retrospective risk assessment was not carried out for some resources and habitats due to lack of comparative information. The initial risk assessment has also identified other data that would be necessary as starting points for resources and habitats management in the coastal zone.

1. For marine fisheries, there is need to gather more information on CPUE and aquaculture

Lake Water

RQ	Rong Lake	Thac Gian – Vinh Trung Lake	Tram Lake	March 29 Park Lake
$RQ_{Gm} > 1$	Oil and grease, NH_4-N, DO > BOD, COD	NH_4-N, NO_2-N (n = 1) > BOD, COD, Oil and grease (n = 1)	Oil and grease, CN^- > Hg, COD, BOD	NH_4-N, Oil and grease > NO_2-N, COD, CN^-, Hg
$RQ_{Max} > 1$	CN^-, NO_3-N, TSS, Hg, Pb	Pb, Fe, TSS	NO_3-N, TSS, DO, Cd, Fe	DO, BOD, TSS, Pb
$RQ_{Max} < 1$	NO_2-N, Fe, Cu, Zn, As, Mn, Cr^{+6}	NO_3-N, DO, CN^- (n = 1), Hg (n = 1), Zn (n = 1), As (n = 1), Mn (n = 1), Cr^{+6}(n = 1)	NO_2-N, Pb, Cu, Zn, As (n = 1), Mn (n = 1), Cr^{+6} (n = 1)	NO_3-N, Fe, Cu, Zn, As (n = 1), Mn, Cd

yield, to establish the decline of these resources.

2. For phytoplankton, since there were very few information available, more data should be gathered on phytoplankton density and biomass, specifically on the kinds of toxic algae potentially present in the coastal zone.

3. For coral reefs, seagrasses, rocky shores and soft-bottom communities, more data on distribution and cover are required to establish decline.

4. For forest resources, there is a need to supplement information on forest areas at watersheds and annual forest productivity for every district. There is a need to gather more information on exploitation of important animal species.

5. For aquaculture, there is a need to collect information on water, sediment, and fish and shellfish tissue quality.

Prospective risk assessment was not carried out for some parameters due to lack of measured concentrations or lack of threshold values. The following potentially important data gaps were identified in the initial risk assessment and would need further effort in a refined risk assessment.

1. For water column, there were no data for fecal coliform, total organic carbon (TOC), PAHs, PCBs and other organic chemicals and limited information on heavy metals, pesticides, *E. coli*, and nutrients.

2. For sediments, there were limited data in Danang coastal zone.

3. For tissues, there was no record of any agents in the site.

4. There was lack of appropriate criteria in the VNS for nutrients and COD in seawater; N_{Total}, P_{Total}, and PO_4 in river, lake and ground water; DO and COD in ground water; and fecal coliform and individual pesticides for all bodies of water.

5. In terms of human health risks, there was lack of data for pesticides and heavy metals in fishery tissue. There were few TDIs for pesticides, no TDIs for essential metals, and no criteria for total coliforms in shellfish and fishery tissues.

Recommendations and Proposed Actions

Various ecological and human health risk agents have been identified through the risk assessment. Decline in marine resources and habitats have also been observed and linked to some specific human activities and parameters. Further consideration of various contaminant pathways needs to be undertaken to strengthen recommendations concerning immediate management interventions.

The following sections provide preliminary recommendations and action plans based on the results of the initial risk assessment.

On Resources and Habitats

Fisheries and Aquaculture

Destructive fishing caused decline in fisheries at the inshore areas. There were no data on catch yield and productivity to assess exploitation of fish in the Danang coastal zone. Decline of fisheries has led to reduced fish biodiversity, loss of economically important species, reduced fish yield, and consequent ecological, economic and social losses.

For shellfisheries, decline in aquaculture was attributed to contaminants that led to low DO levels and to conditions favorable for diseases. These contaminants were linked with industrial and domestic discharges in the areas where aquaculture activities are also undertaken. Measures for controlling discharge of untreated wastes from these activities need to be put in place.

To enhance the risk assessment, there is a need to gather more information on CPUE for marine fisheries and aquaculture production that can be used to establish adverse changes in these resources. Data on contaminant levels in fish and shellfish tissues also need to be collected to determine decline with regard to fitness for human consumption. Additional information on cause-effect relationships between the targets and agents will also be useful to further strengthen the ascribing of causation for the observed decline.

Recommendations for management of fisheries and shellfisheries should be focused on the following:

1. Strengthening enforcement of existing laws and regulations on utilization of fisheries resources and assessing their effectiveness and relevance for present conditions.

2. Developing plans to improve fisheries management such as an offshore fishing program aimed at reducing the pressure on near-shore fisheries by limiting near-shore fishing activities and preventing overfishing and destructive fishing.

3. Promoting public awareness on the declining condition of local fisheries, causes of decline, long-term adverse impacts of destructive fishing practices, efforts to improve fisheries management and expected long-term benefits, and the important roles that they need to perform to ensure sustainability of fisheries resources.

4. Developing management plans for protection of fisheries/shellfisheries resources from discharges of untreated wastewater, particularly from point-sources,

i.e., industries, release of solid wastes and other polluting substances, and other activities that compromise the integrity of the resources and environment.

5. Apart from assessing adverse conditions in aquaculture areas due to contaminant discharges from land-based and other sea-based activities, evaluate adverse conditions arising from existing aquaculture practices, and support the application of environmentally sound aquaculture practices.

6. Formulating measures to prevent degradation of mangrove forests, coral reefs and other coastal habitats, and promote rehabilitation efforts.

7. Reinforcing legal frameworks and regulations and providing clear policy for sustainable fisheries management.

Habitats

The results of the initial risk assessment have shown that sandy beaches, and wetlands are at risk in the Danang coastal zone. Erosion of coastal and river shores had been attributed to unregulated sand mining, reclamation, construction works and deforestation. Decline in environmental quality in rivers and lakes were attributed to the discharge of untreated wastes from nearby industries, establishments and communities. Available information was insufficient to assess the conditions of coral reefs, seagrasses and soft-bottom communities.

The recommendations to address the identified concerns include:

1. Conduct benefit-cost analysis of restoration of wetlands and protection of corals be conducted as part of an overall Danang Coastal Strategy Implementation Plan. This analysis should incorporate the social, economic and ecological benefits and costs. The question that needs to be addressed is "Are these habitats worth restoring considering other existing and potential economic activities in Danang coastal zone?"

2. Require benefit-cost analysis of reclamation, mining, logging, construction and development projects along the coasts and rivers as part of government approval process, considering direct and indirect and short-term and long-term impacts on the marine and aquatic environment (i.e., habitat loss/alteration, sedimentation, erosion, flooding, etc.).

3. As part of Danang Coastal Strategy Implementation Plan, develop an integrated land- and water-use plan that is aimed at ensuring appropriate balance between the resources and habitats and economic activities.

4. Strengthen the implementation of laws and regulations on zoning and resource use.

5. Support research and development efforts aimed at addressing the identified data gaps on resources and habitats.

   a. For coral reefs and other resources and habitats, a systematic survey is necessary in order to establish plans for resource and ecosystem protection.

b. Coordination with ongoing pollution monitoring programs is necessary to enhance understanding of linkages between ecological conditions and physical, chemical and biological factors.

c. For forests, there is a need for more information on forest areas at watersheds and annual productivity per district as well as information on exploitation of important animal species.

6. Monitor areas that are vulnerable to erosion and flooding, and develop measures to control erosion and prevent damages to lives and properties.

7. For a comprehensive and cost-effective resource management, promote coordination and cooperation among related organizations in order to improve the implementation of common activities. For forest management, specifically, collaborative efforts are necessary between organizations responsible for activities related to tourism development and prevention of hunting and burning for land cultivation.

ON HUMAN HEALTH RISKS

There is a need to prioritize the management of contaminants that present human health risks such as:

1. Coliform in Danang Bay, South Son Tra - Ngu Hanh Son Coastal Water, Phu Loc, Vu Gia and Cu De Rivers, Rong, Thac Gian – Vinh Trung, Tram, and March 29 Park Lakes

   Immediate risk reduction measures are a necessity for Rong Lake (RQ_{Gm} = 164,402).

2. Contaminants in well water column

   Priority ($RQ_{Gm} > 1$):
   Coliform > Fe > BOD > As (n = 1)
   Localized ($RQ_{Max} > 1$):
   NH_4, NO_3, Pb > CN, Hg, SS, Cl^-

3. Contaminants in surface water for domestic supply

   Cau Do River:
   Priority ($RQ_{Gm} > 1$): $NH_4 > NO_2$, BOD, DO
   Localized ($RQ_{Max} > 1$): Coliform, TSS, COD, Fe

   Green Lake water column:
   Priority ($RQ_{Gm} > 1$): NH_4, Hg (n = 1), DO
   Localized ($RQ_{Max} > 1$):
   Coliform> CN^-, NO_3, BOD, COD

In spite of the lesser concern that is usually associated for contaminants for which $RQ_{Max} > 1$, the toxicity of parameters such as Hg, CN^-, and Pb that are present in some sources of water used for human consumption (particularly wells) necessitates immediate actions to identify and prevent further use of the affected areas.

Risks to Human Health from Coliform Contamination

Human health risk arises from coliform contamination in the water column. The high bacterial load is mainly attributed to sewage generated from households and commercial, agricultural, institutional and industrial establishments that discharge into the lakes and rivers or directly into Danang Bay and the South Son Tra - Ngu Hanh Son Coastal Water.

The following short-term recommendations are designed to confirm baseline information on the impact of sewage discharges into freshwater, South Son Tra - Ngu Hanh Son Coastal Water or Danang Bay.

1. Collect, analyze information on morbidity and mortality rate regarding water-borne diseases in communities in Danang.

2. Gather more data on coliform contamination or coliform loadings, including fecal coliform, for all main water sources.

Short-term management recommendations to prevent human health problems arising from coliform contamination of coastal waters, rivers, lakes, and wells include:

3. Control fish and shellfish supply from contaminated sources and reduce waste load discharging into the contaminated beaches and bathing stations.

4. Conduct information and education campaigns on the results of monitoring to inform the public of the adverse effects of bathing in and, more importantly, ingesting water and seafood from coliform-contaminated waters, and establish other measures to prevent possible human impacts caused by contaminated waters and food.

The following management recommendations are designed to address the root cause of water contamination in the Danang coastal zone. These recommendations will be part of the risk management program.

5. Accelerate sewage collection and treatment programs in watershed areas.

6. Eliminate direct and indirect discharges of untreated sewage into receiving waters.

7. Gather more data on coliform contamination or coliform loadings, including fecal coliform, for all main water sources; and conduct routine monitoring of water and shellfish in aquaculture areas, fish and shellfish sold in market places, and waters in beaches or contact recreation areas.

8. Perform benefit-cost analysis to identify appropriate interventions.

Risks to Human Health from Heavy Metals and Cyanide

On the basis of RQ_{Gm} exceeding 1, human health is at risk from Fe and As in well water in Danang City. Localized risks (RQ_{Max} > 1) are associated with Hg, Pb and CN^- in wells; Hg and Fe in the water column of Cau Do River; and CN^- in Green Lake. A single data on Hg in Green Lake generated an RQ equal to 10, indicating the need for further verification.

Specific areas, particularly for wells, for which RQs for these metals and CN^- exceeded 1 should be determined in order to:

1. Prevent further use of contaminated wells and protect the users; and

2. Facilitate identification of contaminant sources.

For heavy metal contamination of ground water, sources may include erosion of natural deposits, corrosion of pipes, and run-off or seepage from agricultural or industrial activities or landfills. For cyanide contamination, potential sources are the gold mining activities in the upland areas and potential discharges from steel/metal, plastic and fertilizer factories. Identification of primary sources of contaminants will aid in designing appropriate measures to control direct as well as indirect discharges of these contaminants.

There was no information on pesticides but considering the extensive agricultural activities in the area, this is also a potentially important risk agent.

In view of the risks from heavy metals and cyanide associated with domestic water supply, seawater, rivers and lakes, and the scarcity of information on cyanide and pesticides, it is recommended that:

1. A properly designed long-term environmental monitoring program for heavy metals, cyanide and pesticides in marine water, sediment and seafood tissue, fresh surface water, and ground water be set up. Efforts to determine exposure levels to these heavy metals could also be supplemented by the conduct of rapid appraisal of heavy metals and cyanide loadings into rivers, lakes and coastal areas.

2. An assessment of the impact of land-based wastewater discharges and/or contaminated surface waters on the quality of ground water be conducted.

3. An assessment of the impact of human exposure to heavy metals, cyanide and other contaminants in ground water be carried out, in conjunction with relevant health agencies, through:

   a. Analysis of morbidity and mortality statistics in identified areas of concern and other areas close to industrial zones, landfills, gold mining activities, and other potential sources of heavy metals and cyanide;

   b. Surveys and/or interviews in communities on adverse effects to human health that could potentially be linked to the use of contaminated ground water;

   c. Epidemiological survey to determine how the communities are exposed to pollutants and the duration of exposure; and

   d. Biomarker study to establish the concentration level of metals and cyanide in humans.

Such information can also be considered as a tool in assessing the effectivity of health and environmental control measures being implemented by the government.

Other recommendations to protect human health from coliform, heavy metals, cyanide and other risk agents in the aquatic environment include:

4. Eliminate direct discharges (i.e., no treatment) of domestic, industrial, agricultural and hospital waste, including septic or sludge disposal to the Danang coastal zone and rivers by:

   a. Improving the city drainage and wastewater treatment system; and

   b. Investing in wastewater treatment facilities for industries, hospitals, hotels, restaurants, other commercial ventures, and agricultural projects.

5. Implement control programs for indirect discharges such as agricultural, mining, upland and urban run-off to the Danang coastal zone and rivers.

6. Improve current solid waste management and treatment methods to prevent contamination of surface and ground waters from dumpsite leachates.

7. Provide clean water for households.

8. Improve coordination and cooperation of relevant agencies in monitoring industrial discharges and compliance with standards for waste discharge.

9. Work out an incentive/disincentive system to encourage industries to improve the quality of wastewater discharges and enforce penalties and/or long-term corrective measures on violators.

10. Support research and development efforts to fill in information gaps such as:

    a. Concentrations of contaminants in various media especially in tissue;

    b. Tolerable daily intake values (TDI) of various contaminants and fish/ shellfish consumption rates for various age groups for human health risk assessment; and

    c. Transport, distribution and fate of contaminants in the environment and exposure pathways for ecological and human targets.

ON ECOLOGICAL RISKS

There is a need to prioritize the identified ecological contaminants (RQ_{Gm} > 1) for risk management such as:

Seawater column:
Danang Bay: Fe > Zn
South Son Tra - Ngu Hanh Son Coastal Water: Hg and CN^-> Oil and grease and Zn

River water column:
Cu De River: Hg > oil and grease
Phu Loc River: Phenol (n = 1) > NH_4-N, CN, Oil and grease
Vu Gia River: Oil and grease

Lake water column:
Rong Lake: Oil and grease, NH_4-N, DO > BOD, COD
Tram Lake: Oil and grease, CN^- > Hg, COD, BOD
March 29 Park Lake: NH_4-N, Oil and grease > NO_2-N, COD, CN^-, Hg
Thac Gian-Vinh Trung Lake: NH_4-N, NO_2-N (n = 1) > BOD, COD, Oil and grease

Cost-effective risk management measures to decrease the concentrations of these risk agents in the environment should be identified and prioritized.

The following actions are recommended to deal with the identified priority contaminants:

1. Identify major sources of oil and grease, nutrients, organic load, heavy metals, pesticides, cyanide phenol and TSS into the aquatic environment and estimate the contributions of these sources to contaminant loading.

Assessment of contaminant loading from activities that use and discharge these substances is important to be able to prioritize management measures.

2. Develop and implement management plans to control direct and indirect discharge of untreated wastes to the environment.

   Industrial, domestic, institutional (e.g., hospital), commercial, agricultural, aquaculture activities as well as sea-based and upland activities are likely to be implicated in the levels of various priority contaminants in Danang waters. Discharges could either be direct such as untreated industrial wastes released directly to receiving waters or indirect such as cyanide or mercury from gold mining activities or pesticides from agriculture that are transported to water bodies via rainfall.

   There is a need to reinforce control measures for direct and indirect pollution discharges to the environment, such as requiring industries, hospitals, hotels, restaurants, other commercial ventures, and agricultural projects to have adequate wastewater treatment facilities; setting up central wastewater treatment stations in industrial zones; improving sewage collection and treatment systems; improving solid waste management and treatment methods; employing environmentally-friendly aquaculture practices; and implementing control programs to minimize impacts of contaminants from agricultural, mining and other upland activities.

   Existing laws and regulations should be enforced and/or strengthened and policies that could encourage various sectors to adopt environmentally sound practices should be formulated.

3. Set up an appropriately designed long-term monitoring program for contaminants.

   A continuous monitoring program that can keep track of changes in environmental levels of priority contaminants and detect emerging contaminants should be set up. Risk assessment requires the use of reliable, accurate and comparable data. Adequate information to evaluate spatial and temporal distribution of risks would also enhance the value of risk assessment as a management tool. The monitoring program should be designed in agreement with the data requirements for risk assessment that will allow generation of purposeful information to provide recommendations for environmental management actions. The monitoring program should ensure the generation of accurate data through the application of adequate quality assurance and quality control practices in sampling and analysis.

4. Based on existing activities in Danang, determine the importance of parameters identified as data gaps in the risk assessment for inclusion in the environmental monitoring program.

   There were no data for fecal coliform, PAHs, PCBs and other organic chemicals and limited information on heavy metals, pesticides, cyanide and phenol. There were also no data on contaminants in sediments and tissue. Based on existing activities (i.e., potential contaminant sources) in the site, the value of monitoring these parameters need to be assessed and the strategic sampling locations, environmental compartments (i.e., water, sediment, tissue) and monitoring tools need to be identified. The inclusion in the monitoring program of other potentially important agents such as organotins and substances that exhibit endocrine-disrupting effects also need to be evaluated. The need for more information to establish linkages between nutrient concentrations, phytoplankton blooms and low DO levels in specific areas also has to be considered.

5. Establish appropriate threshold values based on scientific data.

   Risk assessment was not conducted for some parameters for which data were available due to the absence of threshold values. There was a lack of appropriate threshold values in the VNS for nutrients and COD in seawater; N_{Total}, P_{Total}, and PO_4 in river, lake and ground water; DO and COD in ground water; and fecal coliform and individual pesticides for all bodies of water. There was also no threshold value for coliform in well water in the MOH 505-1995. For NO_2, NO_3 and PO_4 in seawater, values from the ASEAN Marine Water Quality Criteria were used. Appropriate threshold values need to be established to allow suitable evaluation of the ecological risks posed by these parameters. Adequacy of threshold values of various parameters in sediments also needs to be determined for future risk assessment, when data becomes available.

6. Develop predictive models on contaminant concentrations and transport that can be used to support management decisions.

   In view of the limited data available on heavy metals and cyanide and lack of data on pesticides and phenol, it may be necessary to develop models that give some predicted environmental concentrations so that management programs can be developed. For oil and grease, a simple model may be developed to determine the likely contribution from land-based and sea-based sources. A model for nutrient and organic loading and potential impacts on DO levels could also be developed.

   Predictive models could be used to identify significant sources of nutrient discharges, evaluate levels of contaminants resulting from different control scenarios, or assess contaminant levels arising from proposed projects.

   Rapid appraisal using data on contaminant releases and eco-toxicological properties could also be done to estimate environmental risk.

Taking into consideration the various recommendations on resource conservation and coastal and marine environment protection, the following activities are considered as important in managing environmental concerns in the Danang Coastal Zone.

INTEGRATED LAND- AND WATER-USE ZONING

Some of the problems on utilization of resources and habitats and identified ecological and human health risks are linked with current land and water uses in Danang, particularly as a result of recent economic developments. With Danang's potential for further development, it is recommended that an integrated land and water use zoning scheme with associated institutional arrangements be developed to reduce conflicting uses of land and water resources, promote uses based on the potential of each area, and prevent adverse effects to ecosystem and human health.

INTEGRATED ENVIRONMENTAL MONITORING PROGRAM

The initial risk assessment has shown the priority environmental concerns and data gaps with regard to resources, habitats, and potentially important risk agents, and the need for further monitoring to evaluate the environmental impacts of human activities and the effectiveness of management actions to control these adverse impacts. It is recommended that a systematic, cost-effective and coordinated environmental monitoring program be developed, which will be aimed at:

1. Addressing the priority concerns and data gaps identified in the risk assessment;
2. Pooling the efforts and resources of relevant agencies through an operational monitoring network;
3. Enhancing exchange and integration of information through an information-sharing network;
4. Enhancing local technical capability with regard to field and analytical tools and human resources; and
5. Strengthening the linkage between environmental monitoring and environmental management through application of the risk assessment/risk management framework.

This long-term program should integrate the monitoring of priority pollutants, human health, and resource and habitat conditions. Other important components to be included are industrial wastewater monitoring at source, and ground water quality monitoring in areas close to industrial zones.

ENVIRONMENTAL INVESTMENTS

The results of the risk assessment show the need to develop long-term strategies and programs of actions to address environmental issues problems caused by the discharge of untreated sewage, solid waste and industrial and hazardous wastes, and emphasize the need for environmental services and facilities, including clean technologies, in order to allow economic growth without sacrificing the environment.

The environmental facilities necessary for sustainable management of the environment in Danang include industrial wastewater treatment, hazardous waste management facilities, integrated solid waste management, and a municipal sewerage system. In addition to ensuring sustainable management of the environment, these projects also provide investment opportunities that create income, employment and livelihood. These, however, require large financial investments and technological resources, and need innovative approaches that facilitate the participation of various sectors in coastal and marine pollution prevention and resource conservation.

BENEFIT-COST ANALYSIS

The development of management programs should involve the quantification of costs and benefits from alternative management strategies and from the activities that may be associated with environmental impacts. This is an important consideration for environmental managers in reviewing new projects and programmes in the Danang coastal zone.

COLLABORATION AND INSTITUTIONAL ARRANGEMENTS

Partnerships between different government agencies, universities and scientific and technical research institutions, local government units, communities, non-governmental organizations, and the private sector are vital to the development and sustainability of environmental management programs for the Danang area and should be promoted. In particular, institutional arrangements for multi-agency and cross-sectoral undertakings, such as the integrated land and water use zoning, integrated environmental monitoring program, and environmental investments will be necessary to ensure sustainability of these undertakings. Evaluation and strengthening of policies, rules and regulations, implementation frameworks, and enforcement capabilities on resource utilization and environmental protection also require collaborative efforts.

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Glossary

Accuracy. The degree to which a measurement reflects the true value of a variable.

Adverse ecological effects. Changes that are considered undesirable because they alter valued structural or functional characteristics of ecosystems or their components. An evaluation of adversity may consider the type, intensity, and scale of the effect as well as the potential for recovery.

Agent. Any physical, chemical, or biological entity that can induce an adverse response (synonymous with stressor).

Assessment endpoint. An explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes.

Attribute. A quality or characteristic of an ecological entity. An attribute is one component of an assessment endpoint.

Benthic community. The community of organisms dwelling at the bottom of a pond, river, lake, or ocean.

Bioaccumulation. General term describing a process by which chemicals are taken up by an organism either directly from exposure to a contaminated medium or by consumption of food containing the chemical.

Bioconcentration. A process by which there is a net accumulation of a chemical directly from an exposure medium into an organism.

Community. An assemblage of populations of different species within a specified location and time.

Comparative risk assessment. A process that generally uses a professional judgment approach to evaluate the relative magnitude of effects and set priorities among a wide range of environmental problems.

Concentration. The relative amount of a substance in an environmental medium, expressed by relative mass (e.g., mg/kg), volume (ml/L), or number of units (e.g., parts per million).

Contaminant of concern. A substance detected at a hazardous waste site that has the potential to affect ecological receptors adversely due to its concentration, distribution, and mode of toxicity.

Correlation. An estimate of the degree to which two sets of variables vary together, with no distinction between dependent and independent variables.

Degradation. Conversion of an organic compound to one containing a smaller number of carbon atoms.

Disturbance. Any event or series of events that disrupts the ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.

Ecosystem. The biotic community and biotic environment within a specified location and time, including the chemical, physical, and biological relationships among the biotic and abiotic components.

Effects assessment. The component of a risk analysis concerned with quantifying the manner in which the frequency and intensity of effects increase with an increasing exposure to the substance.

Environmental risk assessment. The likelihood that an environmental condition caused by human activity will cause harm to a target. It involves estimating the likelihood of harm being done to human health and/or ecosystems through factors emanating from human activities that reach their natural targets via the natural environment.

Exposure. Co-occurrence of or contact between a stressor and an ecological component. The contact reaction between a chemical and a biological system or organism.

Exposure assessment. The component of a risk analysis that estimates the emissions, pathways and rates of movement of a chemical in the environment, and its transformation or degradation, in order to estimate the concentrations/doses to which the system of interest may be exposed.

Fate. Disposition of a material in various environmental compartments (e.g., soil or sediment, water, air, biota) as a result of transport, transformation, and degradation.

Food-chain transfer. A process by which substances in the tissues of lower-trophic-level organisms are transferred to the higher-trophic-level organisms that feed on them.

Habitat. Place where a plant or animal lives, often characterized by a dominant plant form and physical characteristics.

Hazard. The likelihood that a substance will cause an injury or adverse effect under specified conditions.

Hazard identification. Identification of the adverse effects that a substance has an inherent capacity to cause, or in certain cases, the assessment of a particular effect. It includes the identification of the target populations and conditions of exposure.

Ingestion rate. The rate at which an organism consumes food, water, or other materials (e.g., soil, sediment). Ingestion rate usually is expressed in terms of unit of mass or volume per unit of time (e.g., kg/day, L/day).

LC_{50}. A statistically or graphically estimated concentration that is expected to be lethal to 50 percent of a group of organisms under specified conditions.

Lowest-observable-adverse-effect level (LOAEL). The lowest level of a stressor evaluated in a toxicity test or biological field survey that has a statistically significant adverse effect on the exposed organisms compared with unexposed organisms in a control or reference site.

Measurement endpoint. A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint. Measurement endpoints often are expressed as the statistical or arithmetic summaries of the observations that make up the measurement. Measurement endpoints can include measures of effect and measures of exposure.

Population. An aggregate of individuals of a species within a specified location in space and time.

Precision. A measure of the closeness of agreement among individual measurements.

Predicted or estimated environmental concentration (EC). The concentration of a material predicted/estimated as being likely to occur in environmental media to which organisms are exposed.

Primary effect. An effect where the stressor acts on the ecological component of interest itself, not through effects on other components of the ecosystem (synonymous with direct effect; compare with definition for secondary effect).

Prospective risk assessment. An evaluation of the future risks of a stressor(s) not yet released into the environment or of future conditions resulting from an existing stressor(s).

Reference site. A relatively uncontaminated site used for comparison to contaminated sites in environmental monitoring studies, often incorrectly referred to as a control.

Representative samples. Serving as a typical or characteristic sample; should provide analytical results that correspond with actual environmental quality or the condition experienced by the contaminant receptor.

Retrospective risk assessment. An evaluation of the causal linkages between observed ecological effects and stressor(s) in the environment.

Risk. The probability of an adverse effect on humans or the environment resulting from a given exposure to a substance. It is usually expressed as the probability of an adverse effect occurring, e.g., the expected ratio between the number of individuals that would experience an adverse effect in a given time and the total number of individuals exposed to the risk factor.

Risk assessment. A process, which entails some or all of the following elements: hazard identification, effects assessment, exposure assessment and risk characterization. It is the identification and quantification of the risk resulting from a specific use of occurrence of a chemical including the determination of exposure/dose-response relationships and the identification of target populations. It may range from largely qualitative (for situations in which data are limited) to fully quantitative (when enough information is available so the probabilities can be calculated).

Risk characterization. The step in the risk assessment process where the results of the exposure assessment (e.g., PEC, daily intake) and the effects assessment (e.g., PNEC, NOAEL) are compared. If possible, an uncertainty analysis is carried out, which, if it results in a quantifiable overall uncertainty, produces an estimation of the risk.

Risk classification. The weighting of risks in order to decide whether risk reduction is required. It includes the study of risk perception and the balancing of perceived risks and perceived benefits.

Risk Pathways (Exposure Pathways). A diagrammatic representation of the course that all agents take from a source to exposed organisms (target) (Modified from EPA). In the diagram, each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, transport/exposure media (i.e., air, water) are also included. For the particular use of the report, the major categories found in the diagram include economic/social drivers (sources), hazards, resources and habitats (targets), and the effects on the economy. It may also sometimes be referred to as the *conceptual model* that describes an ecosystem or ecosystem components potentially at risk, and the relationships between measurement and assessment endpoints and exposure scenarios.

Sample. Fraction of a material tested or analyzed; a selection or collection from a larger collection.

Secondary effect. An effect where the stressor acts on supporting components of the ecosystem, which in turn have an effect on the ecological component of interest (synonymous with indirect effects; compare with definition for primary effect).

Sediment. Particulate material lying below water.

Source. An entity or action that releases to the environment or imposes on the environment a chemical, physical, or biological stressor or stressors.

Species. A group of organisms that actually or potentially interbreed and are reproductively isolated from all other such groups; a taxonomic grouping of morphologically similar individuals; the category below genus.

Stressor. Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).

Threshold concentration. A concentration above which some effect (or response) will be produced and below which it will not.

Tolerable daily intake (TDI). Regulatory value equivalent to the acceptable daily intake established relevant regulatory bodies and agencies, e.g., US Food and Drug Administration, World Health Organization, and the European Commission Scientific Committee on Food. It is expressed in mg/person, assuming a body weight of 60 kg. And is normally used for food contaminants.

Trophic level. A functional classification of taxa within a community that is based on feeding relationships (e.g., aquatic and terrestrial plants make up the first trophic level, and herbivores make up the second).

Uncertainty. Imperfect knowledge concerning the present or future state of the system under consideration; a component of risk resulting from imperfect knowledge of the degree of hazard or of its spatial and temporal distribution.

Uptake. A process by which materials are transferred into or onto an organism.

APPENDICES

Appendix 1. List of Seas, Lakes and Rivers in Danang.

Sea:
• Danang Bay
• South Son Tra - Ngu Hanh Son Coastal Water
Lakes:
• March 29 Park
• Green
• Rong
• Thac Gian - Vinh Trung
• Tram
Rivers:
• Cu De
• Han
• Phu Loc
• Vu Gia

Appendix 2. Retrospective Risk Assessment: Summary of Likelihood.

Summary of likelihood of some identified agents causing decline in resources.

Resources	Very likely	Likely	Possibly	Unlikely	Unknown
Aquaculture	– DO		– Oil and grease – Heavy metals – Coliform – BOD, COD – TSS – Nutrients		
Forest Animals		– Hunting – Forest fires – Decreasing forest cover – Release of other animals			

Summary of likelihood of some identified agents causing decline in habitats.

Resources	Very likely	Likely	Possibly	Unlikely	Unknown
Sand beaches	– Construction works		– Reclamation – Deforestation		
Wetlands	– Reclamation – Sand mining – Deforestation – Pollution				
Forest cover	– Clearing of land for farming – Illegal cutting of trees – Forest fires – Tourism development				

Categories defined as follows:

Likely (L) – based on knowledge of exposure to the agent and either established effect concentrations (i.e., criteria used in prospective analyses) or other evidence (such as knowledge about intentional harvesting, field observations (e.g., of infestation), the agent is considered to be a likely cause of area-wide decline in the resource.

Possibly (P) – based on available information about exposure and effect levels, this agent cannot be excluded as a cause of area-wide decline in the resource.

Unlikely (UL) – based on available information about exposure and effect levels, this agent is unlikely to have caused area-wide decline in the resource. However, agents in this category may have indirect effects on the resource. For example, nutrients, themselves, would not have a negative effect on benthos (defined here as unlikely), but by enhancing primary productivity (algal blooms), increased nutrients could lead to lowered DO, which is likely to have a negative impact on benthos.

Unknown (?) – there is not enough information available on exposure and/or effect levels to assess whether agents in this category have led to area-wide decline in the resource.

These summaries of likelihood were established on the basis of the retrospective analyses (decision tables), on the prospective risk assessments for different agents summarized in the Comparative Risk Assessment section (for water and sediment), on direct field observations (e.g., insect infestation in mangroves) and on information about levels of intentional human activity (e.g., harvesting, clearance). For fisheries, shellfisheries, benthos, seagrass and seaweeds/algae exposure via both water and sediment were assumed. For mangroves, exposure was assumed to occur primarily from sediment; for coral reefs and phytoplankton, exposure was assumed to occur primarily from water.

Appendix 3. List of Data Sources for the Initial Risk Assessment of Danang.

Retrospective Risk Assessment

Resource/Habitat	References
Marine fisheries Aquaculture	• Environmental Profile of Danang City (DOSTE, 2000)· • Reports from the Department of Fisheries, Agriculture and Forestry (DFAF, 1997-2001).
Phytoplankton	• Special report on changing of phytoplankton species, density and biomass in the marine coastal area of Quang Nam-Danang Province (DOSTE, 1990).
Coral reefs	• WWF (1994) • Summary record of references on the need of information for integrated coastal management at Danang City (HPOI, 1997) and· • Sketchy knowledge about coral reef at coastal area of Danang City (Tuan Vo Sy, 2000)
Seagrasses Rocky shores Soft-bottom communities	• Summary record of reference on the needs of information for integrated coastal management at Danang City (HPOI, 1997) ·
Sandy beaches	• Environmental Profile of Danang City (DOSTE, 2000),· • Reports of Project for Mitigating Flood Impact on Environment and Reinforced Capacity to Cope with Flood in Danang City (MOSTE, 2000),· • Summary record of reference on the needs for information for integrated coastal management at Danang city (HPO, 1997), and · • Environmental Protection Strategy of Danang City up to the year 2010 (DOSTE, 2001a).
Wetlands	• Reports of Environmental Status (1995-2001) (DOSTE, 2001b)· • Planning for river-sand exploitation in Danang. (DOI, 2000)· • Theme on planning for using lakes in urban areas of Danang City (DOSTE, 2001c)
Forest	• Annual Report of DFAF from 1990 to 2000· • Feasibility Study on Environment and Culture of the Southern Area of Hai Van mountain (BOF, 1990)· • Theme of Environmental Status and Environmental Protection Solutions for Ba Na Tourism Resort (DOSTE, 2001d)· • Ba Na-Nui Chua Natural Conservation Zone Project (DFAF, 1997)· • Investigation Report on Fauna and Flora of Son Tra Peninsula Natural Conservation Zone (DU, 1997)· • Theoretical Facts on Economy and technology for Son Tra Peninsula Natural Conservation Zone (BOF, 1986).

Prospective Risk Assessment

Parameter		Source of MECs	Source of PNECs
Nutrients	Seawater	NEA and Danang DOSTE, 1995-2001. VCEP, 1997-1998a	VNS 5943-1995; ASEAN Marine Water Quality Criteria (ASEAN, 2003)
	River water	NEA and Danang DOSTE, 1995-2001 VCEP, 1998-1999c	VNS 5942-1995; DAO 34 Philippines
	Lake water	Danang DOSTE, 1995-2001 VCEP, 1997-1998b	VNS 5942-1995; DAO 34 Philippines
	Ground water	Danang DOSTE, 1995-2001	VNS 505-1995 for well water; VNS 5944-1995 for ground water
DO/BOD/ COD	Seawater	NEA and DOSTE, 1995-2001 VCEP, 1997-1998a	VNS 5943-1995 for aquaculture Chinese Standard, Class IV
	River water	NEA and DOSTE, 1995-2001 URENCO, 1997; VCEP, 1998-1999c	VNS 5942-1995, Class B
	Lake water	Danang DOSTE, 1995-2001. VCEP, 1997-1998b	VNS 5942-1995 Class B, Class A for Green Lake
TSS	Seawater	NEA and Danang DOSTE, 1995-2001. VCEP, 1997-1998a	VNS 5943-1995 for bathing and for aquaculture
	River water	NEA and Danang DOSTE, 1995-2001. URENCO, 1997; VCEP, 1998-1999c	VNS 5942-1995, Class A & Class B
	Lake water	Danang DOSTE, 1995-2001 VCEP, 1997-1998b	VNS 5942-1995, Class A & Class B
Coliform	Seawater	NEA and Danang DOSTE, 1995-2001; VCEP, 1997-1998a	VNS 5943-1995, for aquaculture
	River water	NEA and Danang DOSTE, 1995-2001. URENCO, 1997; VCEP, 1998-1999c	VNS 5942-1995, Class A & Class B
	Lake water	Danang DOSTE, 1995-2001; VCEP, 1997-1998b	VNS 5942-1995, Class A & Class B
Pesticides	River water	NEA, 1998-2000	VNS 5942-1995
Cyanide	Seawater	NEA and Danang DOSTE, 1999-2001	VNS 5943-1995, for aquaculture
	River water	NEA and Danang DOSTE, 1996-1997	VNS 5942-1995 Class B
	Lake water	Danang DOSTE (1997-1998, 2000)	VNS 5942-1995, Class A for Green Lake, Class B for other lakes
Phenol	River water	URENCO, 1997	VNS 5942-1995
Heavy metals	Seawater	NEA and Danang DOSTE, 1996-2001; VCEP, 1997-1998a	VNS 5943-1995 for aquaculture
	River water	NEA and Danang DOSTE, 1995-2001; URENCO, 1997	VNS 5942-1995, Class A for Vu Gia River, and Class B for other rivers
	Lake water	Danang DOSTE, 1995-2001; VCEP, 1997-1998b	VNS 5942-1995, Class A for Green Lake and Class B for other lakes
Oil and grease	Seawater, river, lake water	NEA and DOSTE, 1994-2001 URENCO, 1997	VNS 5943-1995, for aquaculture (seawater). VNS 5942-1995, Class B (river and lake water)

Note: Danang DOSTE, 1995-2001 – annual reports of the local monitoring program
NEA, 1995-2001 – annual reports of the national monitoring program in Danang
VCEP, 1997-1998a – The environmental monitoring reports at Danang Bay
VCEP, 1997-1998b – The environmental monitoring reports at Tram Lake
VCEP, 1998-1999c – The environmental monitoring program at Cu De River
URENCO, 1997 – EIA report of Danang City's sanitation project

Appendix 4. Vietnam National Criteria/Standards for Water Quality.

Vietnam National Criteria/Standards (VNS 5942-1995) for Surface Water Quality

No	Parameter and pollutant	Unit	Limitation value	
			A	B
1	pH	-	6 to 8.5	5.5 to 9
2	BOD (20^{o}C)	mg/l	< 4	< 25
3	COD	mg/l	>10	> 35
4	DO	mg/l	> 6	> 2
5	TSS	mg/l	20.000	80.000
6	As	mg/l	0.050	0.100
7	Ba	mg/l	1.000	4.000
8	Cadmium	mg/l	0.010	0.020
9	Lead	mg/l	0.050	0.100
10	Crom (VI)	mg/l	0.050	0.050
11	Crom (III)	mg/l	0.100	1.000
12	Copper	mg/l	0.100	1.000
13	Zinc	mg/l	1.000	2.000
14	Manganese	mg/l	0.100	0.800
15	Niken	mg/l	0.100	1.000
16	Iron	mg/l	1.000	2.000
17	Mercury	mg/l	0.001	0.002
18	Tin	mg/l	1.000	2.000
19	Ammonia (as N)	mg/l	0.050	1.000
20	Florua	mg/l	1.000	1.500
21	Nitrate (as N)	mg/l	10.000	15.000
22	Nitrite (as N)	mg/l	0.010	0.050
23	Cyanide	mg/l	0.010	0.050
24	Phenol (Total)	mg/l	0.001	0.020
25	Oil, grease	mg/l	None	0.300
26	Detergent materials	mg/l	0.500	0.500
27	Coliform	MPN/100ml	5,000.000	10,000.000
28	Total of pesticides (except DDT)	mg/l	0.150	0.150
29	DDT	mg/l	0.010	0.010
30	Gross- activities- alpha	Bq/l	0.100	0.100
31	Gross- activities- beta	Bq/l	1.000	1.000

Values in column A are applied to surface water used as source of domestic water supply with appropriate treatments.

Values in column B are applied to surface water used for purposes other than domestic water supply; quality criteria of water for aquatic life are specified on a separate standard.

Vietnam National Criteria/Standards (VNS 5943-1995) for Coastal Water Quality.

No	Parameter and pollutant	Unit	Limitation value		
			Bathing	Aquaculture Area	Other Areas
1	Temperature	^oC	30.000	-	-
2	Smell		indisposed	-	-
3	pH		6.5 to 8.5	6.5 to 8.5	6.5 to 8.5
4	DO	mg/l	$\geq$ 4	$\geq$ 5	$\geq$ 4
5	BOD (20^{o}C)	mg/l	< 20	< 10	< 20
6	TSS	mg/l	25.000	50.000	200.000
7	As	mg/l	0.050	0.010	0.050
8	NH_4	mg/l	0.100	0.500	0.500
9	Cadmium	mg/l	0.005	0.005	0.010
10	Lead	mg/l	0.100	0.050	0.100
11	Cr (VI)	mg/l	0.050	0.050	0.050
12	Cr (III)	mg/l	0.100	0.100	0.200
13	Chloride	mg/l	-	0.010	-
14	Copper	mg/l	0.020	0.010	0.020
15	F	mg/l	1.500	1.500	1.500
16	Zinc	mg/l	0.100	0.010	0.100
17	Manganese	mg/l	0.100	0.100	0.100
18	Iron	mg/l	0.100	0.100	0.300
19	Mercury	mg/l	0.005	0.005	0.010
20	SO_3	mg/l	0.010	0.005	0.010
21	Cyanide	mg/l	0.010	0.010	0.020
22	Phenol (total)	mg/l	0.001	0.001	0.002
23	Slightly oil-grease	mg/l	None	None	0.300
24	Oil, grease	mg/l	2.000	1.000	5.000
25	Total pesticides	mg/l	0.050	0.010	0.050
26	Coliform	MPN/100ml	1,000.000	1,000.000	1,000.000

Vietnam National Criteria/Standards (VNS 5944-1995) for Ground Water Quality.

No	Parameter and pollutant	Unit	Limitation value
1	pH value		6.5 – 8.5
2	Color	Pt - Co	5 – 50
3	Hardness (as $CaCO_3$)	mg/l	300 - 500
4	Total solids	mg/l	750 - 1500
5	Arsenic	mg/l	0.050
6	Cadmium	mg/l	0.010
7	Chloride	mg/l	200 - 600
8	Lead	mg/l	0.050
9	Chromium (VI)	mg/l	0.050
10	Cyanide	mg/l	0.010
11	Copper	mg/l	1.000
12	Fluoride	mg/l	1.000
13	Zinc	mg/l	5.000
14	Manganese	mg/l	0.1 – 0.5
15	Nitrate	mg/l	45.000
16	Phenol compound	mg/l	0.001
17	Iron	mg/l	1 – 5
18	SO_4	mg/l	200 - 400
19	Mercury	mg/l	0.001
20	Selenium	mg/l	0.010
21	Fecal coliform	MPN/100 ml	Not detectable
22	Coliform	MPN/100 ml	3.000

Vietnam National Criteria/Standards (TCVN 5945-1995) for Industrial Wastewater Discharge.

No	Parameter and pollutant	Unit	Limitation Value		
			A	B	C
1	Temperature	^{o}C	40.000	40.000	45.00
2	pH value		6 - 9	5.5 - 9	5 - 9
3	BOD (20^{o}C)	mg/l	20.000	50.000	100.00
4	COD	mg/l	50.000	100.000	400.00
5	Suspended solids	mg/l	50.000	100.000	200.00
6	Arsenic	mg/l	0.050	0.100	0.50
7	Cadmium	mg/l	0.010	0.020	0.50
8	Lead	mg/l	0.100	0.500	1.00
9	Residual Chlorine	mg/l	1.000	2.000	2.00
10	Chromium (VI)	mg/l	0.050	0.100	0.50
11	Chromium (III)	mg/l	0.200	1.000	2.00
12	Mineral oil and fat	mg/l	Not detectable	1.000	5.00
13	Animal-vegetable fat and oil	mg/l	5.000	10.000	30.00
14	Copper	mg/l	0.200	1.000	5.00
15	Zinc	mg/l	1.000	2.000	5.00
16	Manganese	mg/l	0.200	1.000	5.00
17	Nickel	mg/l	0.200	1.000	2.00
18	Organic phosphorous	mg/l	0.200	0.500	1.00
19	Total phosphorous	mg/l	4.000	6.000	8.00
20	Iron	mg/l	1.000	5.000	10.00
21	Tetrachlorethylene	mg/l	0.020	0.100	0.10
22	Tin	mg/l	0.200	1.000	5.00
23	Mercury	mg/l	0.005	0.005	0.01
24	Total nitrogen	mg/l	30.000	60.000	60.00
25	Trichlorethylene	mg/l	0.050	0.300	0.30
26	Ammonia (as N)	mg/l	0.100	1.000	10.00
27	Fluoride	mg/l	1.000	2.000	5.00
28	Phenol	mg/l	0.001	0.050	1.00
29	Sulfide	mg/l	0.200	0.500	1.00
30	Cyanide	mg/l	0.050	0.100	0.20
31	Coliform	MPN/100 ml	5,000.000	10,000.000	-
32	Gross - activity	Bg/l	0.100	0.100	-
33	Gross - activity	Bq/l	1.000	1.000	-

Ministry of Health

Standards on Provisional Hygiene Criteria

(Attached Decision No. 505 of Ministry of Health)

Parameter	Unit	For urban areas	For single station or rural areas
Transparent	Cm	> 30	> 25
Color (Co)	Degree	< 10	< 10
Odor (after boiling at 50-60°C)	Marks	0.000	0.000
Undissolved solid	mg/l	5.000	20.000
Total of dry solid	mg/l	500.000	1000.000
pH		6.5-8.5	6.5-8.5
Hardness ($CaCO_3$)	mg/l	500.000	500.000
NaCl for coastal areas	mg/l	400.000	500.000
NaCl for inland areas	mg/l	250.000	250.000
BOD	mg/l	0.5-2.0	2.0-4.0
NH_4 in surface water	mg/l	0.000	0.000
NH_4 in ground water	mg/l	3.000	3.000
NO_2	mg/l	0.000	0.000
NO_3	mg/l	10.000	10.000
Al	mg/l	0.200	0.200
Cu	mg/l	1.000	1.000
Fe	mg/l	0.300	0.500
Mn	mg/l	0.100	0.100
Na	mg/l	200.000	200.00
SO_4	mg/l	400.000	400.00
Zn	mg/l	5.000	5.000
Hydrogen sulfide	mg/l	0.000	0.000
Chlorobenzen and Chlorophenol	mg/l	0.000	0.000
Detergents	mg/l	0.000	0.000
As	mg/l	0.050	0.050
Cd	mg/l	0.005	0.005
Cr	mg/l	0.050	0.050
CN	mg/l	0.100	0.100
F	mg/l	1.500	1.500
Pb	mg/l	0.050	0.050
Hg	mg/l	0.001	0.001
Selenate	mg/l	0.010	0.010
Aldrin and Dieldrin	µg/l	0.030	0.030
Benzene	µg/l	10.000	10.000
Benzo (a) pyrene	µg/l	0.010	0.010
Carbon tetrachloride	µg/l	3.000	3.000
Chlordane	µg/l	0.300	0.300

Parameter	Unit	For urban areas	For single station or rural areas
Chloroform	µg/l	30.000	30.000
2, 4D	µg/l	100.000	100.000
DDT	µg/l	1.000	1.000
1, 2- Dichloroethane	µg/l	10.000	10.000
1, 1- Dichloroethane	µg/l	0.300	0.300
Heptachlor epoxide	µg/l	0.100	0.100
Gamma-HCH (Lindane)	µg/l	3.000	3.000
Hexachlorobenzene	µg/l	0.010	0.010
Methoxychlor	µg/l	30.000	30.000
Pentachloro phenol	µg/l	10.000	10.000
Terachloroethene	µg/l	10.000	10.000
Trichloroethene	µg/l	30.000	30.000
2, 4, 6 Trichlorophenol	µg/l	10.000	10.000
Trihalomethene	µg/l	30.000	30.000
Total of radian activity (µ)	Bg/l	0.100	0.100
Total of radian activity (b)	Bq/l	1.000	1.000

Appendix 5. International Criteria and Standards.

Water Quality Criteria

	U.S. EPA Quality Criteria for water for regulatory purposes (USEPA, 2000)		Water Quality Criteria for coastal and marine waters in the Philippines (DAO 34, 1990)				ASEAN Marine water quality criteria (ASEAN, 2003)	Chinese Standards for different classifications (National Standards of PR China, 1995)			
	Marine acute criteria	Marine chronic criteria	Classes					Classes			
			SA	SB	SC	SD		I	II	III	IV
Physico-chemical parameters											
DO (mg/l)			5	5	5	2	4.000	6	5	4	3
COD (mg/l)								2	3	4	5
BOD5 (mg/l)			3	5	7	-		1	2	3	4
Nitrate (mg/l)							0.060				
Nitrite (mg/l)							0.055				
Phosphate (mg/l)							0.015-0.045 (coastal - estuaries)				
TSS (mg/l)							50.000 (Malaysia)				
Cyanide (ug/l)	1	1	50	50	50	-	7.000	5	5	100	200
Ammonia (ug/l)							70.000 (unionized)				
Heavy Metals (µg/l)											
Cadmium	43.0	9.300	10	10	10	-	10.00	1	5	10	10
Copper	2.9	2.900	-	20	50	-	8.00	5	10	50	50
Lead	140.0	5.600	50	50	50	-	8.50	1	5	10	50
Mercury	2.1	0.025	2	2	2	-	0.16	0.05	0.2	0.2	0.5
Nickel	75.0	8.300						5	10	20	50
Chromium	1,100.0	50.000	50	100	100	- (VI)	50.00 (VI)	50	100	200	500
Silver	2.3	-									
Zinc	95.0	55.000					50.00	20	50	100	500
Arsenic	69.0 (Tri)	36.000 (Tri)	50	50	50	-	120.00	20	30	50	50
Selenium	410.0	54						10	20	20	50

Water Quality Criteria

	U.S. EPA Quality Criteria for water for regulatory purposes (USEPA, 2000)		Water Quality Criteria for coastal and marine waters in the Philippines (DAO 34, 1990)				ASEAN Marine water quality criteria (ASEAN, 2003)	Chinese Standards for different classifications (National Standards of PR China, 1995)			
	Marine acute criteria	Marine chronic criteria	Classes					Classes			
			SA	SB	SC	SD		I	II	III	IV
Trace Organics (ug/l)											
Chlordane	0.090	0.0040	3	-	-	-					
DDT	0.130	0.0010	50	-	-	-		0.05	0.1	0.1	0.1
Malathion	-	0.1000						0.5	1	1	1
Endosulfan	0.034	0.0067									
Pentachlorophenol	13.000	7.9000									
Heptachlor	0.053	0.0035			-						
Endrin	0.037	0.0023			-						
Aldrin	1.300	-	1	-	-	-					
Dieldrin	0.710	0.0019	1	-	-	-					
Lindane			4	-	-	-					
Toxaphane			5	-	-	-					
Methoxychlor	-	0.0300	100	-	-	-					
Benzene	5,100.000	700.0000									
Phenol							120				
PCBs	10.000	0.0300	1	-	-	-					
PAHs	300.000	-									
Benzo[a]pyrene								2.5	2.5	2.5	2.5
HCHs								1	2	3	5
Organometallics											
TBT (ug/l)							0.01				
Oil & grease(mg/l)	0.09	0.004	1	2	3	5	0.14	0.05	0.05	0.3	0.5
			(Petroleum ether extract)				(Water soluble fraction)				

Sediment Quality Criteria

Heavy Metals	HK-ISQVs (mg/kg) (EVS, 1996)		CANADA (mg/kg) Environment Canada, 1995)		NOAA (mg/kg) Long, et al., 1995)		NETHERLANDS (mg/kg) (MTPW, 1991)	
	Contamination Classification		Threshold/Probable Effects Level		Effects Range		Provisional Test/ Warning Value	
	Lower limit	x	Threshold	Probable	Low	Median	Test	Warning
Cadmium	1.50	9.60	[0.68]	4.21	1.20	9.60	7.5	30
Copper	65.00	270.00	[18.70]	108.00	34.00	270.00	90.0	400
Lead	75.00	218.00	30.20	112.00	46.70	218.00	530.0	1,000
Mercury	0.28	1.00	0.13	0.70	0.15	0.71	1.6	15
Nickel	40.00	N/A	[15.90]	42.80	20.90	51.60	45.0	200
Chromium	80.00	370.00	52.30	160.00	81.00	370.00	480.0	1,000
Silver	1.00	3.70	[0.73]	[1.77]	1.00	3.70	-	-
Zinc	200.00	410.00	124.00	271.00	150.00	410.00	1,000.0	2,500
Arsenic	8.20	70.00	7.24	[41.60]	8.20	70.00	85.0	150

Sediment Quality Criteria

Organics	HK-ISQVs (μg/kg) (EVS, 1996)		CANADA (μg/kg) Environment Canada, 1995)		NOAA (μg/kg) Long, et al., 1995)		NETHERLANDS (μg/kg) (MTPW, 1991)	
	Contamination Classification		Threshold/Probable Effects Level		Effects Range		Provisional Test/ Warning Value	
	Lower limit	x	Threshold	Probable	Low	Median	Test	Warning
Acenaphthene	16.00	500	[6.71]	[88.90]	16.00	500.0	-	-
Acenaphthylene	44.00	640	[5.87]	[245.00]	44.00	1,100.0	-	300
Anthracene	85.30	1,100	[46.90]	[128.00]	85.30	640.0	80	-
Fluorene	19.00	540	21.20	[144.00]	[19.00]	540.0	-	-
Naphthalene	160.00	2,100	34.60	[391.00]	160.00	2,100.0	-	-
Phenanthrene	240.00	1,500	86.70	544.00	240.00	1,500.0	[80]	[300]
Low mol. wt. PAHs	552.00	3,160	-	-	552.00	3,160.0	-	-
Benzo[a] anthracene	261.00	1,600	[74.80]	693.00	261.00	1,600.0	80	[300]
Benzo[a]pyrene	430.00	1,600	88.80	763.00	430.00	1,600.0	80	[300]
Chrysene	384.00	2,800	108.00	846.00	384.00	2,800.0	[80]	[300]
Dibenzo[a,h] anthracene	63.40	260	[6.22]	[135.00]	63.40	260.0	80	300
Fluoranthene	600.00	5,100	[113.00]	1,494.00	600.00	5,100.0	200	[700]
Pyrene	665.00	2,600	153.00	1,398.00	665.00	2,600.0	[80]	[300]
High mol. wt. PAHs	1,700.00	9,600	-	-	1,700.00	9,600.0	-	-
Total PAHs	4,022.00	44,792	-	-	4,022.00	44,792.0	[460]	[1,700]
Total PCBs	22.70	ns	21.50	189.00	22.70	180.0	[20]	[40]
p,p′-DDE (4,4′-DDE)	2.20	ns	[2.07]	374.00	2.20	[27.0]	-	-
Total DDT	1.58	ns	3.89	51.70	[1.58]	[46.1]	2	50
Bis(2-ethylhexyl) phthalate			182.00	2,647.00				
Chlordane			2.26	4.79				
Lindane			[0.32]	0.99				
Organometallics								
TBT in interstitial water (μg/l)	0.15	not stated						

Human Health Guidelines

Heavy metals	TDI in µg/person/day (mostly from FDA, USA) (MPP-EAS, 1999b)
Arsenic	130
Cadmium	55
Chromium	200
Copper	400 (1-10yr) 2,000 (adults)
Iron	8,000 (1-10 yr) 14,000 (adults)
Mercury	16
Manganese	1,000 (1-10 yr)
	2,500 (adults)
Nickel	1,200
Lead	6 (0-6 yr) 15 (7-adults) 25 (pregnant women) 75 (adults)
Zinc	5,000 (1-10 yr) 15,000 (adults)

Human Health Guidelines

	TDI in µg/person/day (mostly from FDA, USA) (MPP-EAS, 1999b)
Pesticides	
Chlordane	
DDT/DDE	80
Endosulfan Heptachlor	4.8 4.8
Endrin	4.8
Aldrin	4.8
Dieldrin	4.8
Lindane	1.6-8

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