CHAPTER 7

RISK ASSESSMENT FOR ENVIRONMENTAL MANAGEMENT OF THE MARINE ENVIRONMENT

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INTRODUCTION

Planned emissions and unplanned incidents in the marine environment have the potential to result in adverse environmental effects if a discharge of hazardous material or release of energy comes into contact with sensitive receptors. Environmental risk management is the process of systematically identifying credible environmental hazards, analysing the likelihood of occurrence and severity of the potential consequences, and managing the resulting level of risk.

The South-east Regional Marine Plan is primarily concerned with the hazards of anthropogenic activities in the marine environment (Chapters 1–6). A consultative risk assessment approach is necessary to evaluate the scale of environmental impacts from potential ecological and human health hazards. The benefit of risk assessment is to assist the decision making and planning framework for management of the Region.

The evaluation of ecological hazards must fit into decision making when comparisons of risk are necessary for a wide range of human activities and naturally occurring events. The process is not, of course, entirely objective and scientific in nature. Social expectations and the pressures of special interest groups influence perceptions of risk that cannot be ignored.

Decision makers seek to obtain the best possible scientific advice on which to base decisions. The criteria for decision-making is necessarily weighted in favour of consultation with stakeholders on issues of high social significance. The risk management process should be designed to address both the scientific expressions of risk and also deal with perceptions of environmental values which are more subjective and are likely to change with time.

The risk assessment methodology described here is based on the Australian/New Zealand Standard for risk management (AS/NZS 4360:1999; HB 203:2000). Although ecological risk assessment is a relatively new technical discipline, a systematic process has been applied to several proposed industry developments. These early efforts have been used to guide the selection of appropriate management actions, for the protection and enjoyment of the marine environment in Australia.

PRECEDENT FOR ENVIRONMENTAL RISK MANAGEMENT

Environmental risk management has been the subject of Australian government attention related to uranium mining and other resource development projects (Beer and Ziolkowski, 1995), and has been treated as an environmental management imperative by Australian resource industry organisations (Stoklosa, 1997).

Quantitative environmental risk assessment of offshore petroleum development in Australia was first requested in 1996 by the Western Australia Environment Protection Authority (WA EPA), although earlier assessments of produced formation water discharge had been undertaken independently (Terrens and Tait, 1994). Quantitative environmental risk assessment is regarded as an alternative to the problematic application of prescriptive exclusion zones near sensitive marine resources, and is being used as a key element of the environmental approvals process for petroleum and mining industry development projects (WA EPA, 1997a, 1997b; Stoklosa, 1999; Environment Australia, 1999; DEI, 2001). Industry and scientific organisations continue to undertake environmental risk assessments to aid the decision making process for marine management.

Internationally, ecological risk assessments are being undertaken for developments in the North Sea (Sorgard and Jodestol, 1997), the Gulf of Mexico (Neff and Sauer, 1995) and the Australia–Indonesia Zone of Cooperation (Pinceratto and Casey, 1998).

ENVIRONMENTAL RISK MANAGEMENT METHODOLOGY

The methodology for assessing and managing environmental risk follows AS/NZS 4360 for risk management. The risk management process in AS/NZS 4360 is adopted for ecological risk as shown in Figure 1, using the guidelines of HB 203. Within this framework, practitioners must focus on the practical aspects of conducting ecological risk assessment, which is often frustrated by a lack of scientific data or an insufficient understanding of environmental responses in natural systems.

(insert Figure 1 hereabouts)

An important feature of the risk management process is to involve industry, government, special interest groups and community stakeholders in the assessment of activities that may impact the marine environment. In doing so, clear objectives and assessment criteria are adopted from the outset, useful input to identify all potential hazards is gained, and a consultative approach is taken to manage the risks that are assessed.

Risk management is an iterative process. The techniques for identifying and analysing hazards, in particular, clearly expose gaps in the information available on the hazards being assessed. Where information is lacking for hazards perceived to have potentially high impacts, decision makers are alerted to the requirements for data gathering and environmental monitoring activities that would increase confidence in the evaluation of risk.

Many assessments begin with conservative, often qualitative risk analysis to determine whether an identified hazard has the potential to expose the environment to a high level of risk. In cases where conservative approaches suggest that risk may be significant, the aspects of the risk analysis which appear to be the most influential are re-considered in a more rigorous manner, perhaps quantitatively, and a more confident estimation of risk is obtained. Although there are many analysis tools available for risk analysis, it is clearly impractical to select the most rigorous techniques in every case. A balance must be sought to perform risk assessments in the most efficient manner. There is a need to control potentially prohibitive assessment costs and time, while ensuring that uncertainties are understood by decision makers without compromising the integrity of the results.

Risk management is also a continuous process. The estimations of risk to the marine environment should be updated as new information becomes available. The objectives of risk management are also likely to change with time, requiring a re-assessment of risk and management strategies. The changes occur as a result of political imperatives, newly discovered or introduced threats, or the perceived value of particular environmental resources.

The steps in the risk assessment methodology are described in more detail below. In many cases, the experience of a specialist risk assessor is needed to obtain advice for the most appropriate approach.

Formulating the problem

The problem formulation step of the process establishes the context for the strategic and organisational conduct of the overall assessment. This begins with the planning process for the South-east Regional Marine Plan, to develop a shared understanding and appreciation of the area’s unique and valued characteristics. A consultative approach with stakeholders is necessary to establish criteria for characterising the level of risk that might be associated with potential environmental impacts. Such agreed assessment ‘endpoints’ are fundamental for any ecological risk assessment.

It is essential to understand the key concept of assessment and measurement endpoints — the criteria used to judge the significance of potential risks to the environment. Endpoints have the same importance to ecological risk analysis as health standards do to human health risk assessment. Where protocols for human health standards are generally well understood, endpoint criteria for the health of ecological systems have not been universally established or accepted.

An endpoint is a formal expression of the environmental values to be protected. Examples of commonly used endpoints are the lethal concentration for a particular species exposed to a particular chemical for a specified period of time (eg 48-hour LC_{50}), or a specified decrease in the population size of an environmentally sensitive or socially valued species.

Defining meaningful endpoints involves two steps:

1. Identifying the valued attributes of the environment that are considered to be at risk; and
2. Defining these attributes in operational terms – which translates to making a judgement regarding the criteria that will be used to determine when an impact on a valued ecological attribute is deemed to be significant.

The selection of assessment and measurement endpoints may be illustrated in the analysis of produced formation water discharge from offshore platforms, as evident in Terrens and Tait (1994). Decision makers may regard the sustainability of a commercial fishery as the environmental attribute of primary importance. The assessment endpoint might be conveniently selected to be the probability of a five percent reduction in the fin fish population, with any greater impact being unacceptable. However, direct measurement of the assessment endpoint may be problematic if the toxicity of produced formation water to fin fish is unknown. In this case, we might accept that fin fish can simply avoid the immediate vicinity of a discharge plume that is rapidly diluted, questioning the applicability of any laboratory measurements of toxicity to individuals exposed in small tanks. Instead, we might choose the toxicity of produced formation water to the primary (planktonic) food sources for the commercial fishery as the appropriate measurement endpoints for the analysis. The toxicity thresholds measured for significant food sources in the laboratory can be compared to the dilution of produced formation water predicted by fate and transport modelling (and verified by field measurements). In this case, a ‘zone of effect’ was analysed to determine the toxicity of discharge to the endpoint organisms (the plankton food source), as shown conceptually in Figure 2. The significance of the discharge to the food source can be characterised and compared to the potential impact on the commercial fishery. The potential for bio-accumulation of toxic compounds in the food chain and in fin fish was also considered in the effects assessment.

(insert Figure 2 hereabouts)

It is important for government and industry environmental managers to agree on the relationship between the measurement and assessment endpoints. With such agreements in place for specific circumstances, ecological risk assessment can be a valuable tool for environmental management.

Regulatory principles are easy to apply when a potential environmental hazard is shown to be innocuous by inspection, or when a hazard would have obvious unacceptable impacts. However, when the potential effects of an environmental hazard are near the threshold of what might be considered acceptable risk, it becomes necessary to clearly define the expected effect, the threshold of acceptability, and the likelihood that the threshold would be exceeded.

An appraisal of suitable endpoints can be achieved on technical grounds using techniques borrowed from conventional risk assessment practices:

- Creating a matrix of hazards and environmentally sensitive species to evaluate the potential intensity of exposure and effects.
- Performing a qualitative or semi-quantitative exposure assessment to determine the fate and transport of an environmental hazard in various media, and to identify the components of the ecosystem that are likely to be exposed to the altered media.
- Developing trees of causal linkages between hazards and specific environmental consequences, similar to the familiar event tree approach used in process safety risk analysis (an example of the failure of adult species to spawn is presented in Figure 3). An event tree is useful in the context of

the South-east Regional Marine Plan, as this technique assimilates various natural and anthropogenic hazards in the evaluation of suitable endpoints for risk assessment. Event trees cannot yet be analysed in quantitative probabilistic terms, since the probabilities of failure of ecological components are not quantifiable in the same way as mechanical devices at the current level of understanding.

- Reviewing existing data to determine the sensitivity of particular species, habitats or natural processes that are most vulnerable to potential environmental hazards.

Hazard evaluation for screening the potential adverse consequences of environmental hazards can also benefit from mapping and brainstorming exercises.

(Insert Figure 3 hereabouts)

Hazards due to human activities should be expressed in the context of naturally occurring environmental hazards such as extreme meteorological events (eg cyclones), *El Nino* climatic phenomena, and ecological anomalies (eg infrequent but significant events such as coral spawning slicks). The event tree shown in Figure 3 takes these types of natural events into account when evaluating the potential causes for the failure of fish to spawn. Event trees and other methods for appraising suitable endpoints must account for temporal factors. The variability of meteorological conditions (eg temperature, tidal phase, winds, waves and currents) and seasonal events (eg spawning, migration, pupping and nesting) may be critical to the survival of a species or population.

An example of a severe ecological anomaly that had consequences similar to an oil spill occurred in 1989 when a coral spawning slick destroyed corals and other marine animals at Ningaloo Reef, Western Australia. Coral spawning during flood tide conditions (instead of the usual neap ebb tides), and unusual combinations of onshore wind and wave conditions can disrupt the success of spawning and result in the type of natural destruction of coral communities that has been observed at Ningaloo Reef (Simpson et al, 1993). The alteration or destruction of coastal habitats by cyclones could also be used to put the potential effects of human activities in perspective. In the South-east Region, appropriate natural hazards should be identified and considered.

The interpretation of the acceptability of adverse impacts that might occur from human actions must be viewed in the perspective of the naturally occurring variability of ecological systems. While the importance of this perspective is recognised in the scientific community (Beer & Ziolkowski, 1995; Suter, 1993; Bartell et al, 1992) government and the public may be reluctant to accept the potential consequences of marine environmental hazards, even though the relative risks may be demonstrably insignificant compared to the risk of other human enterprises and naturally occurring events. The consequences of natural variability tend to be more acceptable to the public than the potential outrage of human commercial activities, partly because the risks of human activities are not in the direct control of the public.

Social relevance of assessment endpoints is not a constant. Changes in public attitudes toward the valued attributes of the environment serve to alter the acceptability of certain hazards. The past degradation of some wetlands through the use of recreational vehicles and commercial enterprises has given way to an understanding that wetlands are significant ecological settings that require preservation. The protection and rehabilitation of coastal dune systems and rocky reefs are other examples of changes in social attitudes toward conservation of significant coastal resources.

An endpoint relevant to social concerns may not have real ecological significance. The local extinction of a socially valued but otherwise non-threatened species may have no apparent effect on the attributes of the ecosystem as a whole. However, the situation could gain the attention of decision makers who may be persuaded to view the local extinction of the species as unacceptable. Thus, the most relevant types of endpoints have both biological and societal significance to be useful for decision making.

Assessment endpoints should be defined operationally, with a subject environmental attribute (eg endangered species or commercial fish population) and an exposure characteristic of the subject attribute (local extinction or percent reduction of population). The operational definition of the assessment endpoint must be expressed as numerical criteria for judging the significance of potential exposure responses. If a ten percent drop in the harvestable yield of a commercially important fishery is judged to be a significant threshold for adverse impacts, then the assessor may choose to express the endpoint as the probability that a ten percent reduction in yield is likely to occur.

To constructively utilise endpoints in ecological risk assessment, the risk assessor should formally establish the following assessment standards in consultation with environmental managers and decision makers:

- The assessment endpoints – the formal expression of the environmental values to be protected;
- The measurement endpoints – the scientific data that can be obtained from a literature search, testing, monitoring, modelling and other means; and
- The methods that will be used to extrapolate information from the measurement endpoints to the assessment endpoints.

Hazard identification

Environmental hazards in the natural environment include both anthropogenic and natural hazards associated with the area of interest. Hazards considered in the South-east Regional Marine Plan (Chapters 1–6) include the potential impacts of events and activities associated with:

- the introduction of marine species;
- shipping;
- harvesting of commercial fisheries;
- petroleum exploration and production;
- commercial aquaculture; and
- the ocean/land interface.

From the identification of hazards, it is necessary to develop credible hazard scenarios for detailed risk assessment. Credible scenarios should be described in terms of circumstances where accidental or planned emissions to the environment are thought to be most likely to occur, and at locations where the most potential damage might eventuate. Temporal and seasonal factors can also be considered to allow the most severe consequences to occur for the purpose of the assessment (eg unfavourable wind and tide conditions, and coincidence with seasonal spawning, nesting or raising juveniles). Credible hazard scenarios should therefore represent realistic but severe situations for assessing risk. An experienced risk assessor may provide useful advice to ensure that scenarios are developed appropriately for the conditions of the South-east Region.

It is not useful to promote the language of ‘worst case scenarios’ for environmental risk assessment. The responses of natural systems are not well understood, and the gaps in available data lead to some uncertainty in the estimation of risk. The presentation of worst case scenarios to decision makers suggests that the likelihood of an incident or emission and the severity of the consequences is known to produce the worst possible result, which is clearly not the case in environmental systems. The term conceals uncertainty from decision makers, and can lead to unproductive debate over what is the worst, worst case. Credible scenarios overcome this difficulty by clearly defining realistic and severe circumstances for risk assessment, and expressing the uncertainty in the results to allow informed decision making.

Risk analysis

The methodology for risk analysis involves four technical disciplines, as shown in Figure 4. Primary and secondary exposure represent the physics and chemistry of a release of material or energy to the environment, while primary and secondary effects represent the organic response of the environment from exposure. Figure 4 illustrates how information developed at each step is used in a sequential risk analysis process.

(insert Figure 4 hereabouts)

Primary and secondary exposure estimates can generally be estimated quantitatively from probabilities of release associated with the hazard scenario (eg pipeline leak or episodic variation in expected emissions), and the probability of the hazard coming in contact with sensitive receptors.

Primary and secondary effects estimates generally rely on a scientific but qualitative understanding of the mechanism of exposure, and published observations of effects and recovery following exposure.

Risk analysis tends to be the domain of qualified and experienced technical specialists, however it also has the reputation of a ‘black box’ process that produces terse and unrepeatable risk estimates for complex hazard scenarios. Primary and secondary exposure involves the chemistry and physics of the transport and transformation of material from its point of emission to the location of a sensitive receptor (eg transport and weathering of an oil spill from a ship to a distant offshore island, emission and attenuation characteristics of sonar between a ship and migrating cetaceans). The technical approach may involve specialist modelling or data reduction, and it is essential for the risk assessor to explain not only the results of the analysis, but the confidence limits due to uncertainties in available data and limitations in modelling.

An example of primary and secondary exposure is the prediction of an offshore oil spill coming in contact with a sensitive intertidal or coastal habitat. In the case of an accidental spill from a shipping channel or a fixed offshore structure, a sophisticated approach is to use Monte Carlo simulations of the movement of surface waters and spreading of a spill. If sufficient information is available to model current movements during varying wind and tidal conditions, and a sufficient number of random simulations are performed, a probability contour can be developed to show the likelihood of oil contacting areas of interest, as shown in Figure 5. The primary exposure analysis yields an estimate of the volume and duration of a release, and the characteristics of the spilt material as input to the model. The secondary exposure analysis models the transport of the material to sensitive receptor locations such as intertidal reefs and coastlines, and predicts the volume of material stranded and the time taken to reach these locations. The secondary exposure analysis also accounts for the ‘fate’, or weathering behaviour of the material (eg vaporisation, dissolution, dispersion, emulsification, sedimentation, bio-degradation, photo-oxidation, etc).

(insert Figure 5 hereabouts)

Once the exposure analysis is complete, the risk assessor has identified the potentially vulnerable habitats that could be exposed to an environmental hazard, and has determined the mechanism and characteristics of that exposure. This information is the starting point for the analysis of effects to vulnerable marine species.

The analysis of primary and secondary effects may involve specialist evaluation of toxicity or other organic response data. In many cases, data for the species of interest is not available, or must be extrapolated from other studies of similar species. These techniques result in varying levels of uncertainty in the predictions that are made. In the case of fin fish, toxicity data from one related species might be extrapolated to the species of interest with an acceptably high degree of confidence. In the case of invertebrate species, however, data for the species of interest may be limited and extrapolations between species would be very problematic.

There are a number of techniques for specifically assessing the exposure of the natural environment to introduced marine pests, for example (Hayes, 1997). The selection of an appropriate methodology to analyse the effects of exposure to marine pests will entail: a review of available information on the exotic species of concern; its impact to existing marine habitats and species vulnerable to its introduction; its ability to reproduce, compete with other organisms and spread; and its response to various control methods to limit its introduction or reduce its numbers.

If the risk analysis process is organised in terms of the methodology shown in Figure 4, there is a greater opportunity to ensure that a meaningful understanding of ecological risk is achieved through consultation with stakeholders at specific steps of the process. The analysis becomes more transparent and understandable, and decision makers are afforded a better understanding of the predictions made by risk analysts, and the confidence limits that can be placed on those predictions.

Risk characterisation

The likelihood of exposure is expressed in categories from ‘virtually impossible’ to ‘virtually certain’, as shown in an indicative manner in Table 1. The indicative definitions from AS/NZS 4360 are used here for convenience. The adopted definitions for any risk assessment should be subject to consultation and endorsement of stakeholders.

Similarly, the severity of the effects is expressed in categories from ‘negligible’ to ‘disastrous’, as shown in an indicative manner in Table 2. The definitions used here have been published in previous environmental risk assessments (Stoklosa, 1999; DEI, 2001), and should be reviewed and revised for the specific circumstances of the South-east Region of the marine environment. The categories of effects should incorporate the assessment endpoints adopted for the study, and reflect any relevant statutory criteria for environmental management of the marine environment in various jurisdictions.

(insert Table 1 hereabouts)
(insert Table 2 hereabouts)

The results of the exposure and effects analysis outlined in Figure 4 can be used to characterise the level of risk for each of the credible incident scenarios being considered, in accordance with the classification strategy for exposure and effects described above. A matrix of the likelihood of occurrence (primary and secondary exposure) and severity of consequences (primary and secondary effects) is used to describe the relative level of risk for each hazard scenario.

For the purpose of establishing the types of management actions that may be required to reduce risk to acceptable levels, the risk matrix is divided into four regions that represent four categories of overall risk, as illustrated in Figure 6. This type of approach represents the idealised model of how risks should be characterised for decision makers. A useful approach to communicate risk is to name each scenario being assessed and to list each scenario graphically on the matrix in its assessed location (Stoklosa, 1999).

(insert Figure 6 hereabouts)

Risk Management

The four levels of risk defined in Figure 6 each have a corresponding level of risk management objectives, based upon the principle of minimising risk to a level **as low as reasonably practical** (ALARP) (Wiig et al, 1996). The principle of the ALARP approach is to treat, or reduce risks to the environment to an achievable level. Risk has been reduced to ALARP when further treatment measures become unreasonably disproportionate in cost and feasibility to the additional risk reduction obtained. The definitions in Figure 6 show that hazards that represent the highest level of risk may be considered intolerable, not supportable on any grounds without mitigation measures that reduce the likelihood and severity of the risk to acceptable levels.

The ALARP management approach is a recognition of the difficulty of establishing firm criteria for risk to ecological systems, where the natural variability of ecosystems and their ability to recover from exposure may be largely unknown. Consultation to establish assessment endpoints is used to aid decision makers with agreed criteria for judging risk.

RISK ASSESSMENT FOR ENVIRONMENTAL MANAGEMENT

Seeking a balance between the use of natural resources and the preservation of environmental values is not an easy task. It can be suggested that the problem is not in the technical management of risks arising from commercial hazards, but in the fact that the range of environmental values may not be well understood or agreed among government agencies, the public and special interest groups. The development of the South-east Regional Marine Plan will result in a shared understanding and appreciation of the characteristics of the Region, allowing the opportunity for risk assessment to aid informed decision making and management planning. Such an integrated and inclusive approach toward managing risk will assist to identify economic, social and conservation opportunities that can be developed through the management plan.

REFERENCES

AS/NZS 4360:1999—*Risk Management*, Standards Australia and Standards New Zealand.

BARTELL, S.M., GARDNER, R.H. AND O'NEILL, R.V., 1992—*Ecological Risk Estimation*, Lewis Publishers.

BEER, T. AND ZIOLKOWSKI, F., 1995—*Environmental Risk Assessment: An Australian Perspective*. Supervising Scientist Report Number 102, Commonwealth Environment Protection Agency.

DEI, 2001—*Tasmania Natural Gas Project, Stage 1, Public Environment Report (Commonwealth), Environmental Effects Statement (Victoria) and Development Proposal and Environmental Management Plan (Tasmania)*. E-Systems for Hydro Tasmania, on behalf of Duke Energy International.

Environment Australia, 1999—*Best Practice Environmental Management, Environmental Risk Management*.

Hayes, K.R., 1997—*A Review of Ecological Risk Assessment Methodologies*, Centre for Research on Introduced Marine Pests, Technical Report Number 13, CSIRO Division of Marine Research.

HB 203:2000—*Environmental Risk Management—Principles and Process*, Standards Australia and Standards New Zealand.

NEFF, J.M. AND SAUER, T.C. JR, 1995—*An Ecological Risk Assessment for Polycyclic Aromatic Hydrocarbons in Produced Formation Water Discharges to the Western Gulf of Mexico*. Battelle Ocean Sciences Laboratory, Duxbury, Massachusetts. Unpublished.

PINCERATTO, E. AND CASEY, J., 1998—*Environmental Risk Assessment—Case Study of an Offshore Petroleum Development*—SPE 46842. Presented at the 1998 SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Caracas.

SIMPSON, C.J., CARY, J.L. AND MASINI, R.J., 1993—*Destruction of Corals and Other Reef Animals by Coral Spawn Slicks on Ningaloo Reef, Western Australia*. Environmental Protection Authority, Perth.

SORGARD, E., JODESTOL, K., HOELL, E. AND FREDHEIM, B., 1997—*A Stepwise Methodology for Quantitative Environmental Risk Analysis of Offshore Petroleum Activities*—SPE 37851. Presented at the 1997 SPE/OKOOA European Environmental Conference in Aberdeen, Scotland.

STOKLOSA, R.T., 1997—*Environmental Risk Assessment Discussion Paper*. Prepared for the Australian Petroleum Production and Exploration Association. Unpublished.

STOKLOSA, R.T., 1998—*The Relevance of Risk Assessment in Environmental Approvals and Decision Making*. The APPEA Journal, 38 (1), 715-723.

STOKLOSA, R.T., 1999—*Practical Application of Environmental Risk Management—Gorgon LNG Project Case Study*. The APPEA Journal, 39 (1), 606-621.

SUTER, G.W. II, 1993—*Ecological Risk Assessment*, Lewis Publishers.

TERRENS, G.W. AND TAIT, R.D., 1994—*Effects on the Marine Environment of Produced Formation Water Discharges from Offshore Development in Bass Strait, Australia*—SPE 27149. Presented at the 2nd International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Jakarta, Indonesia.

US EPA, 1992—*Framework for Ecological Risk Assessment*—EPA/630/R-94/003. Washington, DC, USA.

WA EPA, 1997a—*Appraisal Drilling Programme for Wonnich Field, South-west of the Montebello Islands, Apache Energy Limited, Report and Recommendations of the Environmental Protection Authority*, Bulletin 853, Perth, Western Australia.

WA EPA, 1997b—*Wonnich Gas Development, South-west of the Montebello Islands, Apache Energy Limited. Report and Recommendations of the Environmental Protection Authority*, Bulletin 856, Perth, Western Australia.

WIIG, E, NESSE, E. AND KITTELSEN, A., 1996—*Environmental Quantitative Risk Assessment (EQRA)*—SPE 35945. Presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana.

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FIGURES

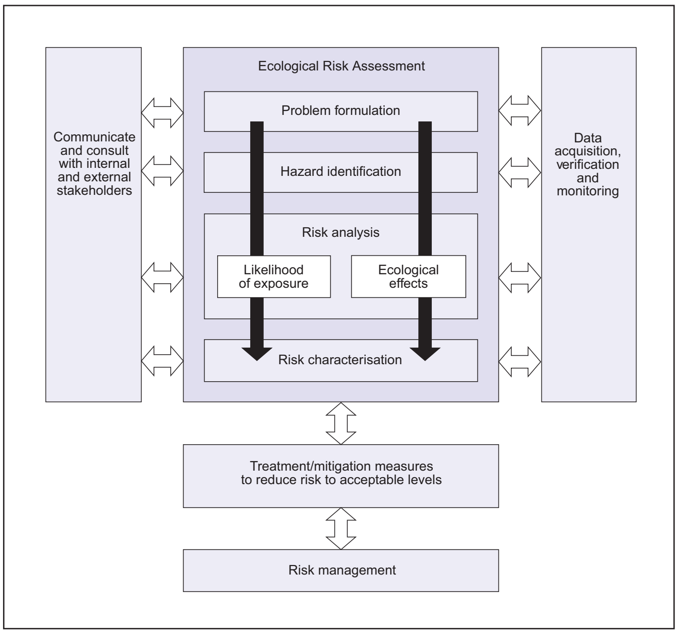

Figure 1. Framework for ecological risk management (after AS/NZS 4360).

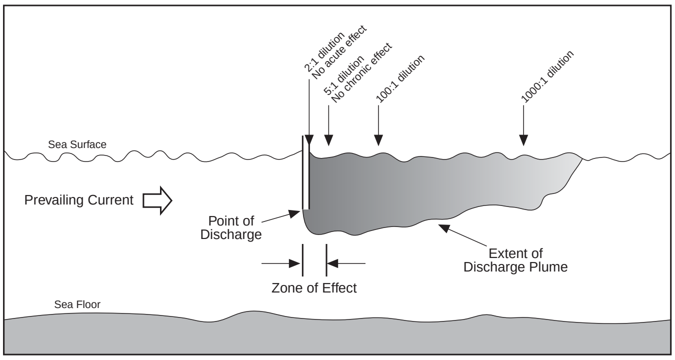

Figure 2. Conceptual representation of the zone of effect for an offshore discharge.

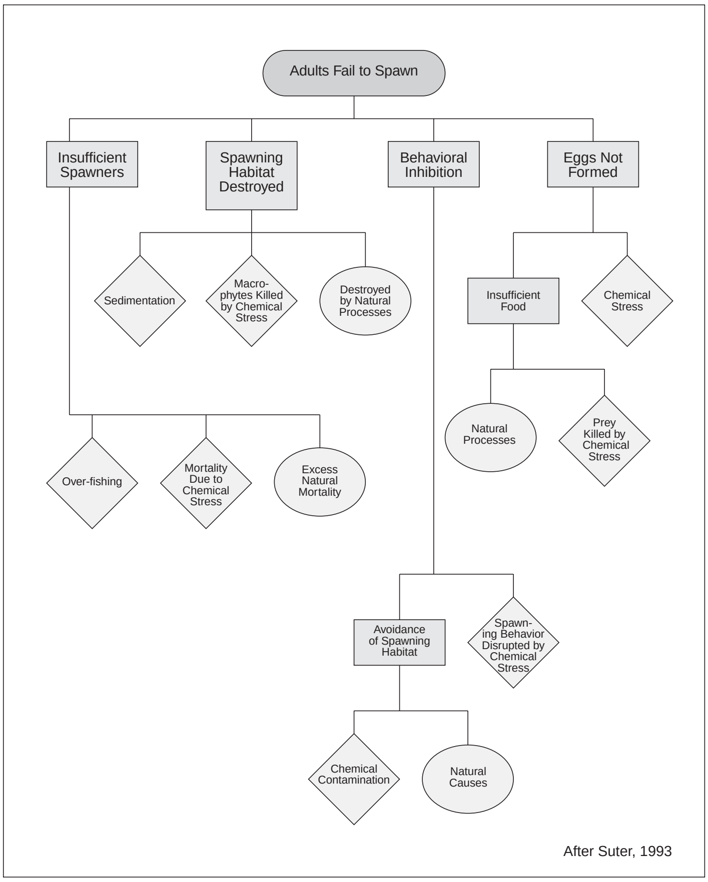

Figure 3. Event tree for the failure of adult fish to spawn.

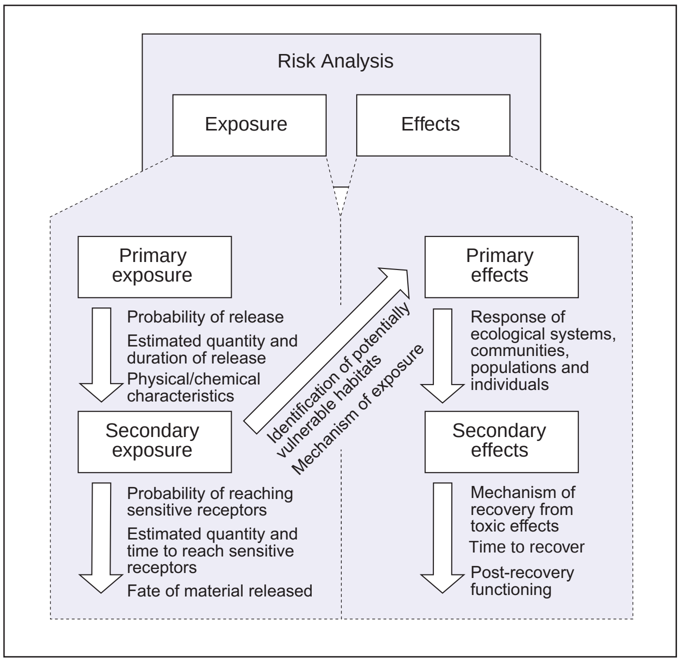

Figure 4. Steps in the ecological risk analysis methodology.

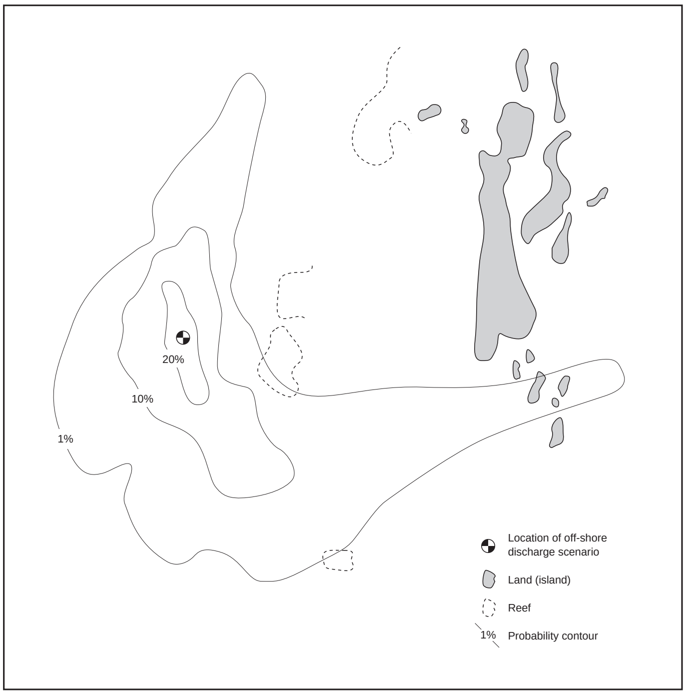

Figure 5. Conceptual result of a Monte Carlo exposure simulation.

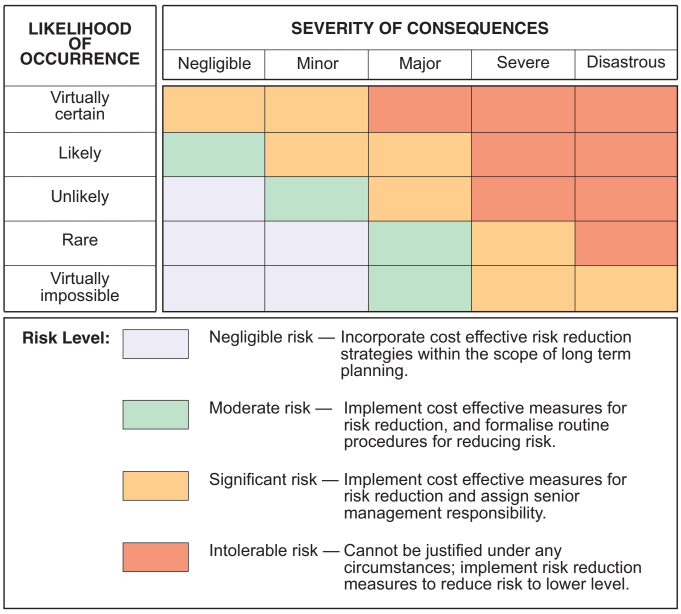

Figure 6. Matrix defining four possible regions of risk levels (after AS/NZS 4360).

TABLES

Table 1. Categories of likelihood for characterising risk (after AS/NZS 4360)

Category of likelihood	Probability and qualitative description
Virtually impossible	$< 10^{-6}$/year; or Once in more than 1 000 000 years This type of event has almost never occurred, but conceivably could.
Rare	$> 10^{-6}$/year and $< 10^{-4}$/year; or Once in 10 000 to 1 000 000 years Such events have occurred on a worldwide basis but only a few times.
Unlikely	$> 10^{-4}$/year and $< 10^{-2}$/year; or Once in 100 to 10 000 years Event occurs, but it is not likely here within the project lifetime.
Likely	$> 10^{-2}$/year and < 1/year; or Once in one to 100 years Event likely to occur during the project lifetime.
Virtually certain	> 1/year; or More than once per year Event can be expected to occur more than once a year, including continuous emissions.

Table 2. Categories of consequences (effects) for characterising risk (after AS/NZS 4360, Stoklosa, 1999 and DEI, 2001)

Category of consequences	Qualitative description
Negligible	▪ No human injuries or health effects. Incidental environmental nuisance. ▪ Possible incidental impacts to flora and fauna in a locally affected environmental setting. No ecological consequences.
Minor	▪ Incidental injury or health effects to persons exposed, up to a requirement for first aid. Minor environmental nuisance to the affected community. ▪ Reduction of the abundance/biomass of flora and fauna in the affected environmental setting. No changes to biodiversity or the exposed ecological system.
Moderate	▪ Injuries or health effects to persons requiring medical treatment. Major environmental nuisance to the affected community. ▪ Reduction of abundance/biomass in the affected environmental setting. Limited impact to local biodiversity without a significant loss of pre-impact ecological functioning.
Severe	▪ Injuries or health effects to persons resulting in prolonged medical care or lost time, or isolated fatality. ▪ Substantial reduction of abundance/biomass in the affected environmental setting. Significant impact to biodiversity and ecological functioning. Eventual recovery of ecological systems possible, but not necessarily to the same pre-impact conditions.
Disastrous	▪ Injuries or health effects resulting in multiple fatalities or severe permanent disabilities to more than one person. ▪ Irreversible/irrecoverable changes to abundance/ biomass in the affected environmental setting. Loss of biodiversity on a regional scale. Loss of ecological functioning with little prospect of recovery to pre-impact conditions.