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Environmental Planning for Risk Reduction in China: A seven-step framework

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Preface

The seven-step framework described in this report has been developed jointly by Chinese Academy of Environmental Planning (CAEP), Vista Analysis and CICERO. It has been thoroughly tested by departments of environmental planning and emergency response in Jiangsu Province and Guizhou Province, and the cities of Tongling (Anhui Province) and Anshun (Guizhou Province). The framework has also benefitted from suggestions by the Ministry of Environmental Protection, China (Planning Division and Emergency Response Center) and from discussions at University of California, Berkeley, University of San Francisco and Norwegian School of Economics (NHH), as well as the authors' institutions CICERO, CAEP and Vista Analysis. A special thanks goes to Professor Hans Martin Seip, Department of Chemistry, University of Oslo for valuable contributions to the project. The Sino-Norwegian cooperation project "Planning for cost-effective environmental risk reduction" began in 2013 and ends in 2016.

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Content

Executive summary

We present a framework for assessing and managing acute and accumulated environmental risk in China's provinces and cities.

China needs a framework for assessing and managing environmental risk

In August 2015 an explosion of environmental toxics at the port of Tianjin left more than 150 people dead. Many were firemen who were unaware that dangerous chemicals were stored on the site and used water to extinguish the fire, thereby contributing to worsening the outcome. More than 3000 tons of dangerous chemicals were released into the air.

The Tianjin incident was one of the most serious environmental incidents in China in recent years. But it is not alone. Unexpected discharges and releases of environmental pollutants happen every year, illustrating the acute environmental risks in the country. Moreover, China faces accumulated risks in the form of chronic bad air quality, polluted waterways and lakes and contamination of soil.

Since "environmental risk prevention" was included among the main tasks in China's national 12th Five-year Plan for environmental protection, China has done a lot in the field of environmental risk assessment, including the formulation of the tentative Guidelines on Environmental Risk Assessment in Enterprises which links environmental risk assessment in an enterprise to the corporate environmental emergency plan, and the requirement in the Administrative Measures for Contingency Plan for Environmental Emergencies for corporate and regional environmental risk assessment. As a result of the stepwise progress of corporate environmental risk assessment and the reflection on the typical accidents in recent years, research and administrative personnel have gained an increasingly thorough awareness about environmental risks.

Yet, the system is not perfect and some problems remain. Working together with environmental planners in pilot provinces and cities, researchers from Chinese Academy of Environmental Planning (CAEP) of China, Vista Analysis of Norway and CICERO of Norway in this document propose a framework for assessing and managing acute and accumulated environmental risk at the province and city level. We call it the Seven-steps framework.

Why it is necessary to assess environmental risk at the province and city level

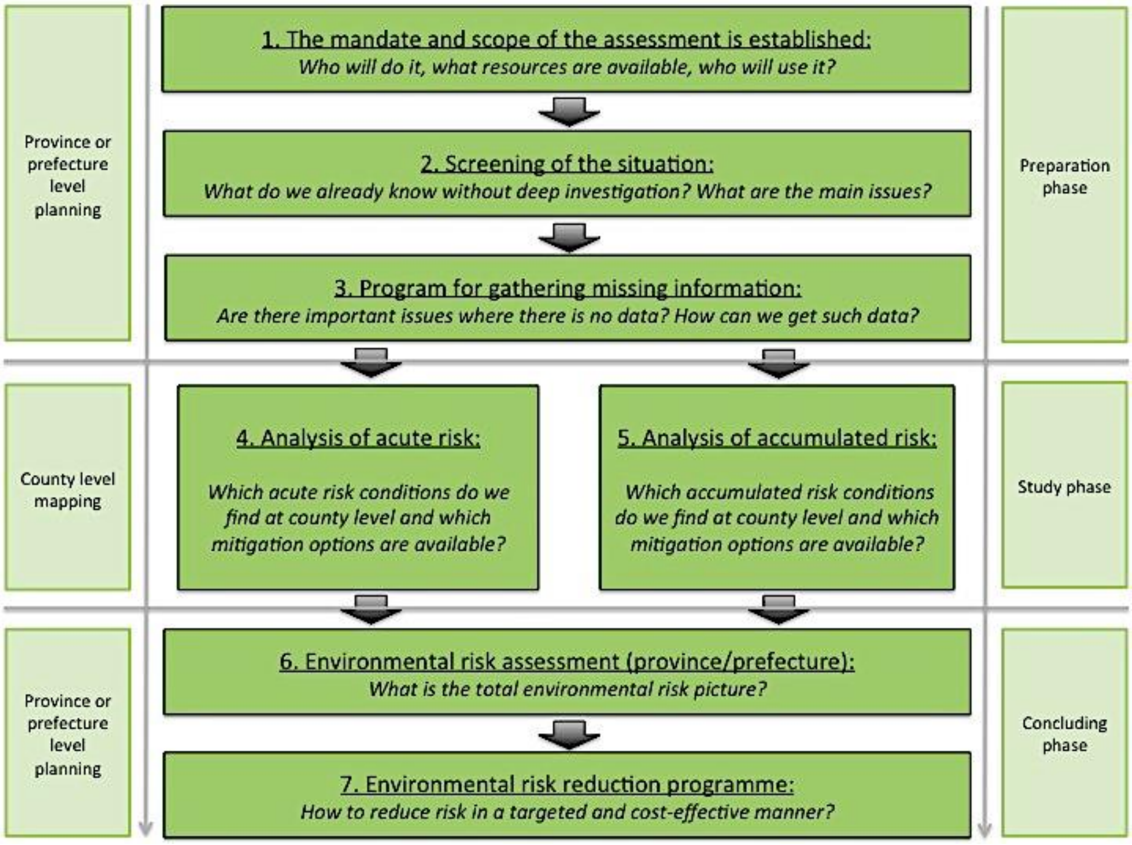
While the end objective of the Seven-step framework is to improve management of environmental risk the initial focus in six of the steps is on *assessment* of risk. The basic premise is that there can be no sound management without a systematic assessment. Assessment is the first part of any management strategy.

More specifically, environmental risk assessment has four functions: first, it provides *diagnosis*, that is, the assessment provides systematic analysis and identification of the type, distribution and degree of environmental risk; second, it enables *optimized decision making*, that is, the assessment offers advice on environmental risk prevention and control for decision makers to implement priority managements; third, it gives *guidance*, that is, the horizontal and vertical comparison of assessment results may guide the reduction of environmental risk level in high-risk areas; fourth, it provides *knowledge*, that is, the assessment may lead to improved awareness of environmental risks, environmental risk problems and knowledge gaps can be identified and the capability of environmental risk management can be improved through the assessment.

Structure of the Seven-step Framework

The structure of the Seven-step Framework is illustrated in figure S.1.

Figure S.1 Step-wise approach for environmental risk assessment



Source: Vista Analysis

There are three phases in the Seven-step Framework: a preparation phase, a study phase and a concluding phase. As the name implies the preparation phase is for preparing and setting up the assessment. It will be a prefecture/city or a province that prepares and carries out the assessment. Any successful assessment and management plan requires the institutional backing of relevant government agencies and a position in the routines of government. In other words, there needs to be a demand for environmental risk assessment and management.

The study phase, which is next, is carried out at a lower administrative level than the prefecture or province. If a prefecture is responsible the study phase is carried out at the county level. If a province is responsible the study phase is carried out at the county level, or prefecture level if that is deemed more practical. In the study phase the framework suggests a detailed, numerical indicator system of environmental risk that requires collection of primary data. The guiding idea behind the system is that environmental risk is a function of sources of risk (S), vulnerability to risk (V) and management capacity (M).

In the concluding phase the information from counties is assembled and synthesized to an overall assessment of environmental risk at the prefecture and province level. Having identified pressing environmental risks at the prefecture and provincial level cost-benefit analysis is used to formulate a targeted risk-reduction program. With this step the framework moves from assessment to management and action.

Time-line

The Seven-step Framework is designed to be carried out over a period of about six months. As underlying conditions change and efforts to reduce environmental risk eventually pays off the steps of the framework should be repeated at regular intervals. The authors believe every 3-5 years is appropriate.

The future

The Seven-steps Framework has so far been tested and applied in two provinces and two individual prefectures/cities. It is possible to scale up the application to any province and any prefecture/city in China that is interested in managing its environmental risks. If the framework eventually is applied in all prefectures in a province and all provinces in the country, it will be possible to compare localities in many interesting ways. Provinces may be compared, prefectures of similar size and dimension may be compared, specific aspects of environmental risk may be compared across the country etc. By comparing provinces and prefectures to each other it will be possible to single out and reward provinces and prefectures that have done a particularly good job in controlling environmental risk. A healthy competition to reduce environmental risk may stimulate prudent, sustainable development in China.

Part A

Seven steps for regional environmental risk assessment

1. Introduction

1.1 Background and purpose

This document provides a general framework for environmental risk prevention planning in China. The basic unit of analysis is the county level. Prefectures may aggregate information from its county level divisions. Provinces may aggregate information from prefectures and individual counties. The national level may aggregate information from provinces, prefectures and counties. The framework provides a step-wise approach and functions as an overall and easily applicable manual for handling environmental issues at a province and prefecture level.

This part of the framework (Part A) is supplemented by four other documents. Two of these documents specify in more detail how to go about assessing acute environmental risk (ref. Framework part B) and accumulated environmental risk (ref. Framework part C). A third document explains the principles, approaches and methods for environmental risk assessment (ref. Framework part D). A fourth document explains what it means to evaluate projects and policies using cost-benefit analysis, and gives examples (ref. Framework part E). The documents draw on international best practice related to environmental risk assessment, environmental impacts assessment and strategic environmental assessment, while adapting them to a Chinese context.

Table 1.1: Definitions of key concepts.

Definitions of key concepts	
Environmental risk	*Actual or potential threat of adverse effects on living organisms and the environment by effluents, emissions, wastes, resource depletion, and similar activities. Usually thought to consist of probability (of adverse consequence) times extent of adverse consequence.*
Environmental risk assessment	*The use of risk assessment methods to identify and respond to ecological, social and economic issues associated with a specific activity, a specific project, a specific plan, or the general development of a specific area.*
Stressor	*A stressor is a physical, chemical or biological agent, environmental condition, or an event that causes stress to human beings or ecological receptors. Examples of a stressor are toxic components such as the classical pollutants and flammable, reactive, explosive, or radioactive hazards.*
Ecological receptor	*Ecological receptors include any living organisms other than humans, the habitat which supports such organisms, or natural resources that could be adversely affected by stressors resulting by a release at or migration from a site.*

Endpoint (biological)	*Final stage of a process from which an adverse effect is observed; a biological endpoint is used for indicating the health effect(s) of an exposure to one or more stressors.*
Ecological risk	*Actual or potential threat of adverse effects on ecological receptors, especially protected areas and drinking water sources.*
Health risk	*Actual or potential threat of adverse effects on (human) health, as shown in endpoints such as, e.g., premature death.*
Acute risk	*Risk of injury or damage to humans or ecological receptors as a result of an instantaneous or short-term enhanced exposure to one or more stressor(s).*
Accumulated risk	*Risk from long-term exposure to one or more stressor(s).*
Regional risk assessment	*Risk assessment that deals with a spatial scale that contains multiple habitats with multiple sources of stressors affecting multiple endpoints.*
Provincial level	*PR China administers 33 provincial-level divisions, including 22 provinces, 5 autonomous regions, four municipalities, and 2 special administrative regions.*
Prefecture level	*In China, a prefecture level city or municipality is an administrative division ranking below a province and above a county. A prefectural level city is often not a city in the strict sense, but an administrative unit comprising a main central urban area and a larger surrounding rural area containing many smaller cities, towns and villages.*
County level	*In China, Counties are at the third level of the administrative hierarchy in provinces and autonomous regions. The county level contains (proper) counties, autonomous counties, county-level cities, banners, autonomous banners, and city districts.*

The framework can be used for generic environmental risk assessment and prevention (covering all types of environmental risk) at regular intervals, for instance every 3 or 5 years. The framework can also be used in a narrower manner according to different and specific requirements, such as environmental risk related to air or water pollution; or the change in risk brought about by a risk reduction programme.

1.2 Principles for successful environmental risk assessment and planning

A high quality environmental risk assessment has the following overall characteristics:

- *Sustainability*: It should enable identification of available options and proposals for sustainable development.

- *Focused*: It should concentrate on key issues, and provide information that is sufficient, reliable, and useful for planning and the decision making process. It should be tailor-made to the needs of planners and politicians, and at the same time it should be cost- and time-effective.
- *Accountable*: It should be performed based on a professional, accurate, responsible and transparent process. Different issues and interests should be reasonably balanced. The responsibility for the environmental risk assessment should lie with the authority responsible for environmental risk prevention and planning.
- *Participative*: It should inform and involve public and governmental stakeholders throughout the process.
- *Iterative*: It should be performed in a stepwise process, where results from the different steps are made available to relevant stakeholders as early as possible.
- *Integrated*: It should ensure that all strategic decisions that influence environmental risk are assessed in a consistent manner, assessing environmental, social and economic aspects in an integrated manner.

1.3 The structure of the Seven-step framework

Preparation phase (province and prefecture level)

- Step 1: The mandate and scope of the assessment and plan
- Step 2: First screening (mapping) of the situation
- Step 3: Program for gathering information that is lacking

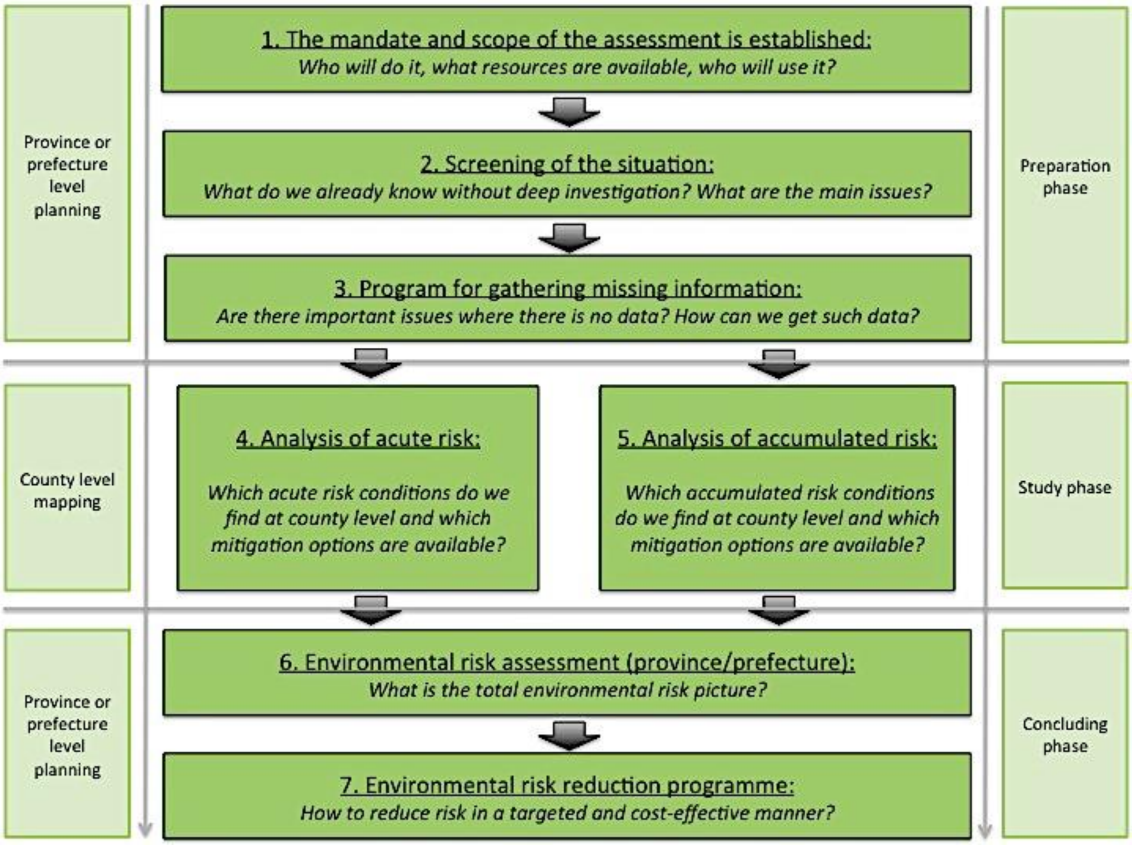
Study phase (county level investigation)

- Step 4: Analysis of acute risk conditions
- Step 5: Analysis of accumulated risk conditions

Concluding phase (provincial and prefecture level)

- Step 6: Environmental risk assessment
- Step 7: Environmental risk reduction programme

Figure 1.1 Step-wise approach for environmental risk assessment



Source: Vista Analysis

Note that different steps require work of EPBs or other relevant institutions at different levels. In the preparation phase, work is mainly carried out (led) by prefecture and province EPBs (ref. Figure 1.1). In the study phase, work is carried out by EPBs at the prefecture and provincial level in cooperation with EPBs and/or other relevant institutions at the county levels. In the concluding phase, work is mainly carried out (led) by prefecture and province EPBs.

Note that the first time the assessment is carried out data will likely be lacking on many of the issues. This is in itself an important finding and measures to ensure that such data can become available in the future should be included in the environmental risk reduction programme. If one chooses to carry out a seven-step assessment on a regular basis (for instance every 3 or 5 years), the data situation will improve each time. The first time will be the most difficult.

A manual/step-wise approach for the work in the study phase (step 4 and step 5), is described in more detail in two separate documents (ref. Framework part B and Framework part C) treating in more detail how to assess acute risk and accumulated risk, respectively. More background on principles, approaches and methods is also found in a separate document (ref. Framework part D). To guide the preparation of the Environmental Risk Reduction Programme (step 7) an explanation of cost-benefit analysis is provided in a separate document (ref. Framework part E). We shall in the following describe the step-wise approach in the preparation phase (step 1-3) and concluding phase (step 6-7) in more detail.

Chapter 3 provides guidance for the implementation of the steps, in the form of tables with a total of 50 guiding questions and suggested actions.

2. Overview of Seven-steps framework

This chapter provides an overview of the Seven-steps.

2.1 The step-wise approach of the preparation phase

Step 1: The scope and mandate of the assessment

When a process is started in which provincial or prefecture EPBs are to apply this framework and carry out an environmental risk assessment, the process must first be anchored formally in the respective institutions. We call this a top-down initiative. The government should issue a mandate and the implementing agency should develop a work plan, which is approved by the government.

The mandate and work plan should include a description of

- the objective
- the process to be carried out (for instance this document)
- specification of who will be responsible for carrying it out (the EPB or similar institution) and a request for other relevant agencies to support the process (for instance through providing access to relevant data, participating in meetings etc.)
- the resources available
- a timeline (for instance 3-6 months)
- outputs (specified below)
- policy objectives that the assessment and plan is related to
- how the assessment and plan will be useful for achieving these objectives
- which planning processes the assessment is relevant for and how
- which institutions should use the assessment when it has been done

Output: Formal decision at provincial, prefecture and/or county level including the points mentioned above.

Table 2.1 Example of a 6-month timeline for implementation of the seven steps

	Month 1		Month 2		Month 3		Month 4		Month 5		Month 6	
Step 1	x											
Step 2		x	x									
Step 3			x									
Step 4				x	x	x	x	x				
Step 5				x	x	x	x	x				
Step 6									x	x		
Step 7											x	x

As an alternative to the top-down initiative it is possible for an institution other than government to initiate an environmental risk assessment on its own. We call this a bottom-up initiative. A bottom-up initiative will benefit from following this framework, more or less like as a top-down initiative will do.

Chapter 3 provides a table with questions that may guide the planning and specification of the assessment (step 1).

Step 2: First screening of the environmental risk situation

Step 2 consists of a first screening of the situation. The first activity is to assess what data exists that indicates the environmental risk situation, where to get the data and how to get the data. All relevant data that can be collected at a short notice shall be collected and formal processes shall be started to get data (for instance from other institutions) that it will require time to get access to.

The output of the first screening is a document that should give the currently available and relevant information about overall environmental risk in the counties of the prefecture (and at the province level, the prefectures of the province). More will be learnt about the risk during the course of the investigation, but from experience the initial screening is useful for forming tentative hypotheses that guide the investigation.

The first screening should include:

- Assessment of existing data and availability of data.
- Quick assessment of main stressors and endpoints.
- Assessment of the relevant socio-political context, incl. relevant political goals.
- Statement of data that is missing and that it will need special efforts to obtain.
- Summary.

The sub-titles and content of the screening document should be similar to the sub-titles and content of chapters of the final assessment (step 6 below). This will save time. A list of sub-titles, guiding questions and suggestions for data and data sources is provided in chapter 3.

Step 3: Design program for gathering missing data

The screening process has likely revealed that there are some issues related to environmental risk where data is lacking, for instance due to lack of measurements of important parameters. If this is the case, efforts should be initiated to ensure that necessary data becomes available for the investigation. More will be learnt about data that is lacking during the investigation, but from experience it is useful to identify at an early stage, areas where important data is obviously lacking and early in the process initiate measures to compensate for this.

In many cases the program will include the following actions:

- Examination of statistical yearbooks at the county, city, province and national levels
- Examination of plan and policy documents such as provincial, city and county five year plans etc.
- Examination of databases existing at the county, city and province level.
- Consultation with relevant departments, organisations and institutions, such as Department of Safety Production, Department of Transport, Department of Construction, Center for Disease Control (CDC), Environmental Monitoring Center etc.
- Collection of primary data through surveys of enterprises, industrial parks, residents etc.

2.2 The step-wise approach of the study phase

Step 4: Analysis of acute risk conditions (at county level)

Step 4 involves listing conditions that create the potential for injury or damage to occur to humans (endpoints) or ecological receptors as a result of an instantaneous or short duration exposure to the effects of an (often accidental) release. The conditions are related to risk *source*, risk *vulnerability* and risk *management* capacity. A prefecture will do the mapping at the county level and should also describe how risk sources within the county may have effects outside of the county. A province may use a combination of county and prefecture level data at this stage.

The output should be a report our chapter in report per county (or in the case of provincial assessment, per county and/or prefecture level city) with environmental rank score, as well as a list and assessment of acute environmental risk sources, pathways and possible mitigation options (with cost estimates if possible).

A step-wise approach on how to do this is provided in more detail in a separate document (ref. Framework part B).

Step 5: Analysis of accumulated risk conditions (at county level)

Step 5 involves an analysis of risk from long-term exposure to one or more pollution agent(s) or stressor(s), typically risk to human health and/or ecology from long-term exposure to enhanced levels of pollutants in air, water or soil. The risk is related to risk *source*, risk *vulnerability* and risk *management* capacity. The mapping will be done at county level and should also describe how sources of accumulated risk within the county may have effects outside of the county.

The output should be a report or chapter in a report per county (or in the case of provincial assessment, per county and/or prefecture level city) with environmental rank score, as well as a list and assessment of accumulated environmental risk sources, and possible mitigation options (with cost estimates if possible).

A step-wise approach on how to do this is provided in more detail in a separate document (ref. Framework part C).

2.3 The step-wise approach of the concluding phase

The preparation phase and the study phase have generated an initial risk screening and brought forward a risk assessment as well as risk reduction measures at the county level. Now this data must be subject to an integrated regional analysis at the prefecture/province level, where the findings of step 4 and step 5 are considered together. Step 6 concerns risk assessment and step 7 concerns risk reduction measures.

Step 6: Risk assessment at prefecture and provincial levels

The aim of the risk assessment is to clarify environmental risk from the perspective of a higher geographical level (prefecture and/or province), in order to understand the overall dynamics and level of environmental risk, how it is spread and how risk factors as well as cost-effective measures are interrelated. Several of the chapters of the prefecture/provincial risk assessment are the same as in step 2 (screening report), but are now updated and more detailed. The risk assessment should include:

- A description of main pollutants/stressors, endpoints and ecological receptors on a regional scale.
- An assessment of the relevant socio-political situation.
- A description of data that is lacking.
- Summaries of county risk evaluations in the form of coloured maps. The colour given to a county indicates its level of risk (green, yellow, red).
- Other figures, tables, maps as appropriate.
- Conclusions and recommendations.
- Eventually, as data from more county risk evaluations becomes available, the risk assessment could also include summaries of county risk evaluations in the form of ranks (eg. County x is no y; county x is no y among counties of less than 10,000 inhabitants etc.).

The output of the provincial risk assessment is a document with tables, maps, figures and recommendations for further investigation and study.

Note that when aggregating county data, a mix of quantitative and qualitative methods must be used, as more data and/or different types of data will often be available in one county than in another. It should be made clear in the report for which counties data is considered robust and which counties where the ranking is a result of quantitative data and qualitative assessments, including the degree of uncertainty related to the assessment. Uncertainty can be described in a three-tier scale; low uncertainty, medium uncertainty, high uncertainty. If the seven-step assessment is conducted at regular intervals (for instance every 3-5 years), improved data should contribute to reducing uncertainty in county assessments.

Chapter 3 provides a table with questions that may guide the development of the regional environmental risk assessment. Chapter 3 also contains some examples.

Step 7: Environmental risk reduction programme at prefecture and province levels

The risk assessment will have revealed the most pressing challenges with respect to environmental risk across the prefecture/province. The county analyses have brought forward suggestions for interventions to reduce risk. It is now necessary to identify the issues that need to be dealt with at prefecture/provincial level and to design a cost-effective program of action, and recommend policies and actions, constituting a provincial risk reduction programme.

Chapter 3 provides a table questions that may guide the development of the risk reduction programme.

3. Guidance to Seven-steps framework

In this chapter we provide 50 guiding questions that may guide the implementation of the seven steps.

3.1 Step 1: Scope and mandate

In addition to the points already mentioned in chapter 2.1, the following questions may guide the process of planning and defining the mandate and scope of the assessment (step 1).

Table 3.1.: Guiding questions for defining mandate and scope (step 1)

	Guiding question	Action
1	In the government, who is responsible for environmental risk issues and should provide a mandate for this regional environmental risk assessment?	Provide information about the need for and methodology of regional environmental risk assessment to relevant political bodies.
2	Which institutions are stakeholders and have relevant data?	Map relevant institutions.
3	What will it require to get access to relevant data from other institutions?	Assess which formal processes and other considerations that are necessary to get access to relevant data from other institutions.
4	Which political goals will improved environmental risk management contribute to?	Identify the relevant policy goals.
5	Which political process could benefit from input about environmental risk?	Identify the relevant political processes.
6	What resources are available for the assessment and who should do it?	Assess available manpower and funds, identify a project team with a project leader and give them mandate to operate.
7	What should the end product look like?	Determine with stakeholders what the end product should look like to be useful.
8	Who should use the results?	Determine who should use the results and secure their backing at an early stage.

3.2 Step 2: First screening

In addition to the points already mentioned in chapter 2.2, the following questions may guide the process of conducting the first screening (step 2).

Answering the questions in table 3.2. will undoubtedly be easier after the county level investigations (in step 4 and step 5), but it is recommended to write down what is known – even if it may be very rudimentary – before the investigations. On this basis, one may then update and further develop the screening document when producing the regional environmental risk assessment (step 6). Please note that the questions are guiding and should be used in light of what is considered useful; it may not be feasible to follow up on all the suggested topics (at least not the first time a seven-step assessment is carried out).

Table 3.2.: Guiding questions for first screening (step 2)

	Guiding question	Action
	Stressors and endpoints	
9	What are the main data sources describing stressors and endpoints?	Make a list of the data sources.
10	Where are the environmental risk sources (stressors) located in the counties/prefecture/province?	Gather existing knowledge of all major environmental risk sources
11	Which pollutants/stressors are known to be more dangerous?	Gather existing knowledge of the damage potential of different pollutants/stressors
12	Where are people mostly exposed to such pollutants/stressors?	Gather information about where people are mostly exposed to pollutants/stressors. Describe in figure and/or table if viable.
13	Where is ecology and drinking water sources mostly exposed to such pollutants/stressors?	Gather information about where ecology (especially Protected Areas) and drinking water sources are mostly exposed to such pollutants/stressors. Describe in figure and/or table if viable.
14	Where are the hotspots in terms of sources and impacts (ecological receptors and endpoints)?	Plot environmental risk sources and impacts in GIS and highlight areas i) with a cluster of risk sources and ii) where high impact overlaps with high ecological values, drinking water sources or high population.
15	What do we know about costs for risk mitigation options related to major environmental risk sources?	Gather available information about costs of possible mitigation options.
16	In which cases do we know about environmental risk sources but not about the impact of these sources, or impact without sources?	Here more data is needed. Assess how crucial it is to get such data and the possibilities to

		get necessary data in a cost-effective manner.
17	How many and what kind of environmental incidents have occurred over the last year? Five years?	Gather available information about environmental incidents in recent years.
18	How many and what kind of environmental complaints have been registered over the last year? Five years?	Gather available information about environmental complaints in recent years.
19	What is the situation with regards to environmental risk sources, ecological receptors and endpoints in the province?	Summarize the points above in a reader-friendly chapter.
	Socio-political context	
20	Which environmental policy goals, standards and regulations are relevant for the environmental risk assessment?	List and describe the relevant policy goals, standards and regulations
21	Is there a gap between political goals, standards, regulations, and the actual situation with respect to environmental risk?	Describe the possible gaps between goals, standards, regulations, and the actual situation.
22	Are current legal requirements sufficient to reduce environmental risk to sustainable levels?	Assess whether full implementation of legal requirements are sufficient to reduce environmental risk to a sustainable level.
23	Are economic incentives such as levies and fees being used and are they currently sufficient to reduce risk to sustainable levels?	Assess whether full implementation of current economic incentives are sufficient to reduce environmental risk to a sustainable level.
24	To what extent are legal requirements to reduce environmental risk implemented and what are the main reasons if legal requirements are not fully implemented?	Assess the degree to which legal requirements are implemented by the relevant organisations and, if not fully implemented, the main reasons for this.
25	To what extent are economic incentives to reduce environmental risk implemented and what are the main reasons if economic incentives are not fully implemented?	Assess the degree to which economic incentives are implemented by the relevant organisations and, if not fully implemented, the main reasons for this.
26	Which institutions are related to the major environmental risk sources?	Describe which organisations are related to major environmental risk sources. (Examples are industrial firms, public

		institutions in charge of wastewater or waste, or transport)
27	What institutional capacity is needed, and to what extent is needed capacity in place, in order to manage environmental risk at the level considered necessary?	Describe capacity needs and status (gap analysis).
28	With the current economic development and political plans, how will the environmental risk picture in the province develop over the next 5-10 years?	Assess the development of the environmental risk picture in a baseline scenario
29	What is the situation with regards to the socio-political context of environmental risk in the province?	Summarize points above in a reader-friendly chapter.
	Missing data	
30	What is required to obtain the data that is lacking, - e.g. money, training, new formal requirements, formal inquiries by the proper authority, further cooperation between public departments, etc.?	Explore whether the required factors can be provided and initiate action to get missing data when required conditions can be met.
31	What data can be realistically be provided within six months?	List data that can be provided within six months and the conditions required to provide the data.
32	What data can be provided within two years?	List data that can be provided within two years and the conditions required to provide the data.
33	What data can be provided in a time perspective longer than 2-3 years?	List data that can be provided in a time perspective of more than 2-3 years and the conditions required to provide the data.
	Summary	
34	What is the situation with regards to environmental risk in the province?	Summarize the main points related to pollutants/stressors, ecological receptors and endpoints, as well as socio-political context.
35	What are the most pressing challenges related to environmental risk?	Draw out and highlight the most pressing and urgent challenges in the summary document. Examples: Areas of high risk, sectors of high risk, lack of preparedness, etc.

3.3 Step 3: Program for missing data

In addition to the points already mentioned in chapter 2.3 and questions 30-33 in table 3.2 above, the following questions may guide the process of initiating efforts to collect data that is missing (step 3).

Table 3.3.: Guiding questions for developing a program to collect missing data (step 3)

	Guiding question	Action
36	Which resources (manpower, funds) do we have available for initiatives to get missing data?	List available manpower, find out what funds may be available.
37	What are the most important data that is missing?	Distinguish between data that is of the type "need to know" (absolutely necessary) and data of the type "nice to know" (not absolutely necessary to know).
38	What is the most cost-effective program to get missing data that is considered to be absolutely necessary to know?	Identify and initiate selected activities to get missing data. Some suggestions are offered in the main text.

3.4 Step 4: Analysis of acute risk at the county level

See separate document (Framework part B) with detailed guidance.

3.5 Step 5: Analysis of accumulated risk at the county level

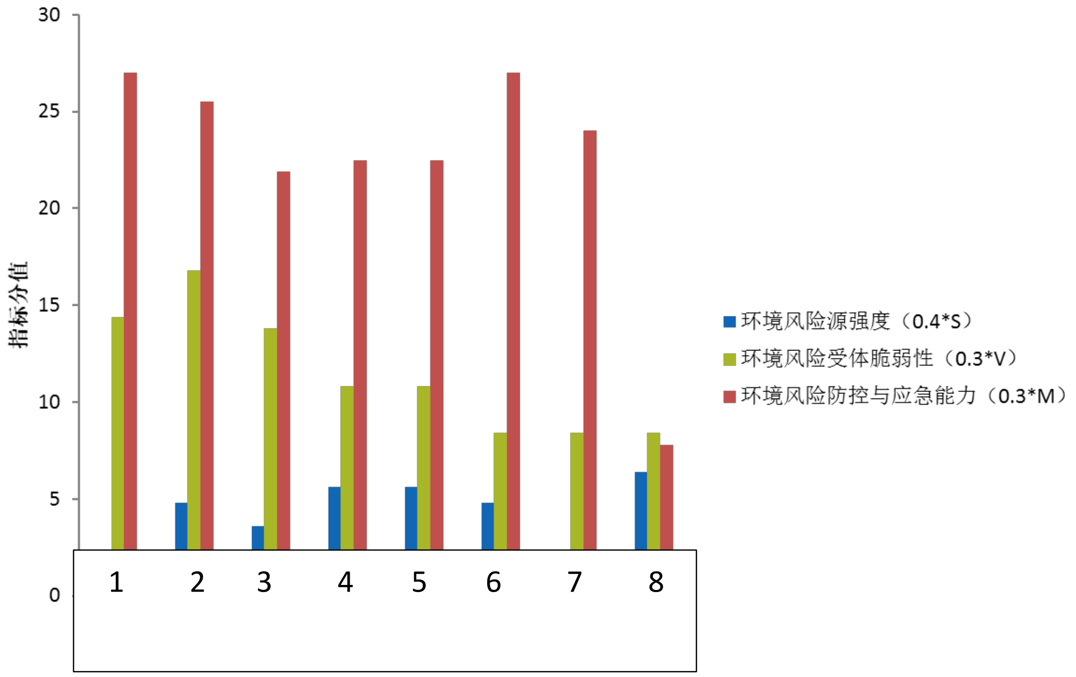
See separate document (Framework part C) with detailed guidance.

3.6 Step 6: Risk assessment at province/ prefecture level

The regional risk assessment document is an update and further elaboration of the screening document of step 2. In addition to the points made in chapter 2.6, the same guiding questions listed for step 2 (see table 3.2 above) are relevant for step 6.

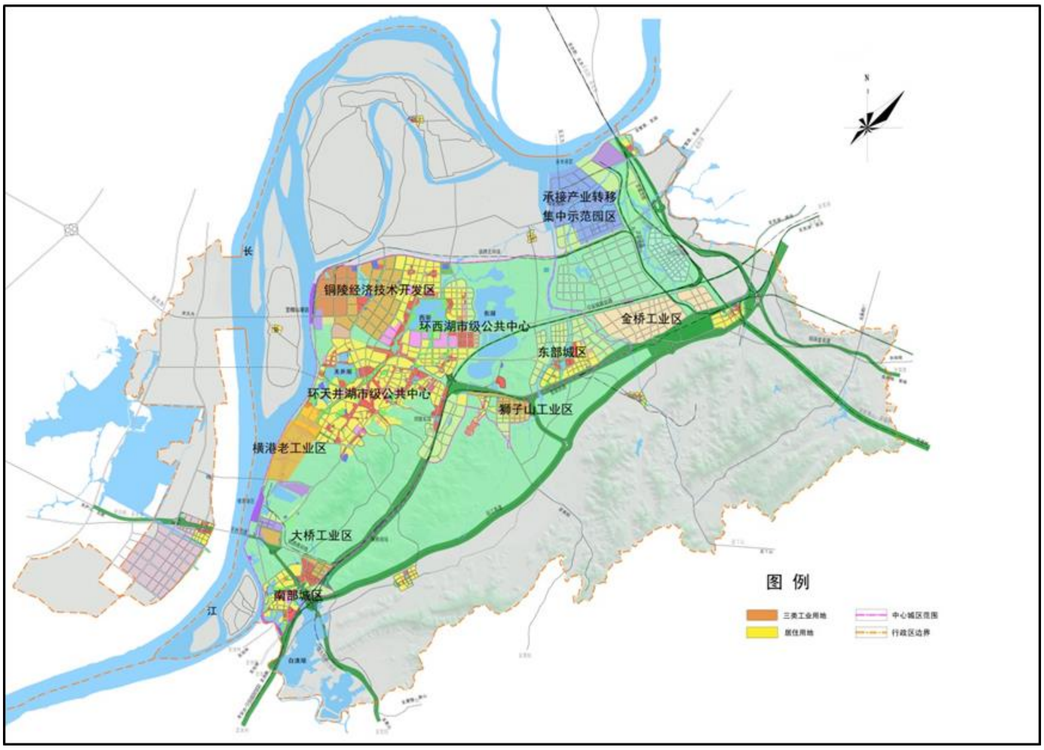
When summarizing county level environmental risk, figures and maps can often be used to good effect. The figure below shows acute environmental risk by source and county. It is clear from the figure that a lack of environmental management capacity is the main source of acute risk in the city.

Figure 3.1 Example of using a histogram to illustrate the importance of management capacity as a source of risk. County 1-8.



The figures and maps used do not necessarily need to follow the county borders. Sometimes it is illustrating to show figures and maps of the situation at large. The map below was used to show the overlap of industrial and residential areas in the city. This overlap is obviously a source of environmental risk.

Figure 3.2 Example of using a map to illustrate in a visual way a source of environmental risk (overlap of industrial and residential areas)



The regional risk assessment document should *not* merely summarize the county scores, but provide an overall assessment. In addition to the county scores, the overall assessment may include observations on

- Aspects of city level risk that are not well represented by the indicators (step 4&5)
- Risk hotspots that are not well covered by the indicators
- Consideration of industrial parks, which may present high environmental risk from a source perspective, but lower risk from a vulnerability perspective (if the location of parks is well chosen) and low risk from a management perspective (if management and monitoring are advanced)
- Consideration of how risk sources (sometimes also vulnerability and management) in counties influence each other
- Other observations as relevant

3.7 Step 7: Risk reduction programme at province/prefecture level

In addition to the points made in chapter 2.7, the following guiding questions are relevant when designing the risk reduction programme (step 7). Please note that the questions are guiding and should be used in light of what is considered useful; it may not be feasible to follow up on all the suggested topics (at least not the first time a seven-step assessment is carried out). Please see separate document (Framework part E) with detailed guidance on cost and benefit estimation.

Table 3.4.: Guiding questions for developing a risk reduction programme (step 7)

	Guiding question	Action
39	How large a reduction of stressors will be necessary to reduce the environmental risk to a sustainable level?	Estimate the required reduction of stressors.
40	Can we by assessing the pollution pathways, pinpoint where environmental pressure must be reduced (and how much) in order to reduce the risk sufficiently?	Assess how the necessary reduction of (potential) pollution should be allocated to upstream sources.
41	Which measures seem the most promising interventions for reducing environmental risk at the prefecture (province) level?	Identify interventions that have prefecture (province) wide effect and/or cost, and should be implemented at that level.
42	Which measures seem the most cost-effective interventions for reducing acute environmental risk at the county level, after the measures identified above (ref. question 41) have been implemented?	Identify interventions that seem to have good effect, are low cost, and possible/easy to implement in the short run. Also identify interventions for the long run.
43	Should emergency and response systems and capacity be upgraded at the provincial and prefecture levels in order to reduce acute risks, and how can this be done efficiently?	Assess need for improving emergency response systems and capacity, and estimate costs of different options.
44	Are additional measures related to monitoring necessary to understand the integrated environmental risk dynamics at the prefecture and provincial levels, and how could this be done efficiently?	Assess the extent to which a sufficient understanding of pollution pathways is present and suggest, if necessary, an improved monitoring system, including cost estimations of different options.
45	Are there other interventions actions that should be implemented at the prefecture or provincial level rather than the county level?	Assess whether there are other intervention actions that should be implemented from i) the prefecture and ii) provincial level, and make a list of all such actions with cost estimates of different options.
46	Which institutions should be responsible for implementing the most promising interventions? What kind of preparation is needed?	Identify the appropriate institutions and list the main acts of preparation
47	What is likely to be the effect in terms of lower environmental risk, as well as	Estimate, to the best of your ability, the effect of the preferred

	cost of the most promising interventions?	interventions on environmental risk, and the cost of the interventions.
48	How can we reduce environmental risk at the prefecture and provincial level in the most cost-effective manner?	Apply cost-benefit analysis to different measures and design a recommended program of action incorporating all actions deemed necessary, incl. a list of costs (having selected the most cost-effective options).[1]
49	How do we finance the risk reduction program?	Investigate funding options and present a viable suggestion for finance.
50	To what degree and how should the public be included in the implementation of the risk reduction programme?	Identify the role of the public in implementing different types of measures and include activities in the program that facilitates information to the public and facilitates public involvement where this is relevant.

[1] Besides the Framework Document Part E, guidance for the use of Cost-Benefit Analysis (CBA) is available in the publication (in Chinese) by Zhao Xuetao et al. (2012): ”Application of SEA and CBA methodologies in environmental planning”, China Environmental Science Press.

Part B

Method for acute environmental risk assessment at the county level

1. Introduction

This part of the framework, the method for acute environmental risk assessment, refers to step 4 in the seven-step framework and gives detailed guidance about this step.

Acute environmental risk assessment method at county level is based on the quantification of intensity of environmental risk source (S), vulnerability of environmental risk receptor (V), and environmental emergency response capacity (M). It uses the index method to assess the acute environmental risk at county level. Figure 1.1 shows the assessment procedure, and Table 1.1 shows the assessment index. The purpose of the method and procedure described below is to enable calculation the acute environmental risk index and rank counties according to their index value.

Figure 1.1 Procedure of acute environmental risk assessment

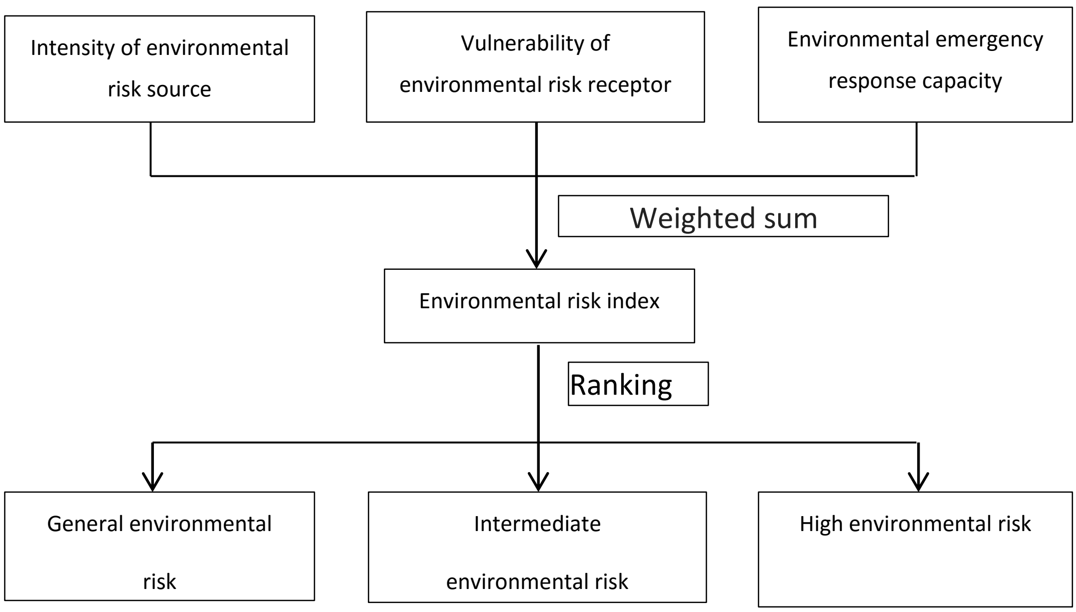


Table 1.1 Evaluation indicators of acute environmental risk at county level

Evaluation indicators		
Intensity of environmental risk source within county(S) (6)	Intensity of acute environmental risk in environmental risk enterprises (4)	Number of enterprises
		Ratio of stock to critical mass of environmental risk materials per unit area
		Percentage of enterprises belonging to key industries
		Number of environmental accidents in enterprises within the administrative region in the last 5 years
	Intensity of acute environmental risk at ports and docks （3）	Number of ports and docks within the administrative region
		Throughput of hazardous chemicals at ports and docks per year within the administrative region
		Number of environmental accidents at ports and docks within the administrative region in the last 5 years
	Intensity of acute environmental risk in terrestrial transport（2）	Quantity of environmental risk materials (include transit capacity) by terrestrial transport per year within the administrative region
		Number of environmental accidents in terrestrial transport within the administrative region in the last 5 years
	Intensity of acute environmental risk in inland waterway transport（2）	Quantity of environmental risk materials by inland waterway transport (include transit capacity) per year within the administrative region
		Number of environmental accidents in inland waterway transport within the administrative region in the last 5 years
	Intensity of acute （2） environmental risk of tailings	Number of tailings above 4 scale rank I
		Number of environmental accidents in tailing ponds within the administrative region in the last 5 years
	Intensity of acute environmental risk of oil and gas pipeline（2）	The condition of oil and gas pipeline across the region within the administrative region
		Number of environmental accidents in oil and gas pipeline within the administrative region in the last 5 years
		Level of flow channels of major water bodies

vulnerability of environmental risk receptor within administrative region（V）(3)	Environmental risk exposure pathway(3)	Coverage of water within administrative region
		Residential wind frequency of pollution
	Vulnerability of environmental risk receptor(4)	Number of population per unit area
		Number of environmentally sensitive targets per unit area
		Number of protected areas of drinking water sources at towns and city level
		Number of population served by drinking water sources in towns and above
	Restorability of environmental risk receptor (1)	Per-capita GDP
Administrative regional environmental emergency response capacity (M)(2)	Administrative regional environmental risk prevention and control capacity(2)	Monitoring and warning capacity
		Administrative regional pollutant intercepting capacity
	Administrative regional environmental emergency response capacity(7)	Establishment of administrative regional environmental emergency plan
		Proportion of enterprise environmental emergency professional team construction
		Reserve of administrative regional emergency materials and equipment
		Environmental emergency decision-making support system
		Emergency monitoring capacity
		Emergency rescue capacity of administrative regional medical institutions
		Capital investment in administrative regional environmental emergency capacity building

2. Intensity of environmental risk source （S）

Use scoring method to evaluate the indicators of environmental risk enterprises, environmental risk materials ports and docks, terrestrial transport, water transport, tailing ponds, oil and gas pipeline. Then calculate the intensity of environmental risk source.

2.1 Intensity of acute environmental risk in key industries

List the number of environmental risk enterprises, number of key industry environmental risk enterprises (number of higher and major environmental risk enterprises), number of environmental risk materials, and number of environmental accidents in environmental risk enterprises. Use Table 2.1 to calculate intensity of acute environmental risk in key industry.

Table 2.1 Intensity of acute environmental risk in key industries

Evaluation indicator	Data resource	Indicator explanation	Indicator value	score
Number of environmental risk key industries enterprises (Nos)	Local EPB	the number of environmental risk enterprises of administrative region	＞500	10
			100-500	8
			50-100	4
			＜50	0
Ratio of stock to critical mass of environmental risk materials per unit area（1/km²）	Local EPB	mass of environmental risk materials divided by area	＞50	10
			(20,50]	8
			（10，20]	4
			≤10	0
Percentage of environmental risk enterprises under key industries（%）	Local EPB or Bureau of industry and information technology.	ratio of the number of environmental risk enterprises involving with petroleum processing and coking, chemical raw materials and chemical products manufacturing and medicine manufacturing, to the number of all	≥80	15
			（40-80]	10
			（20-40]	5
			≤20	0

		environmental risk enterprises in administrative region		
Number of environmental accidents in environmental risk enterprises in the last 5 years	Local EPB	the number of environmental accidents in all environmental risk enterprises within the administrative region in the last 5 years (environmental accidents are caused by natural disasters, illegal sewage, unsafe production, transportation and other causes of environmental pollution incidents)	≥10	10
			5-9	8
			3-4	4
			≤2	0

2.2 Intensity of acute environmental risk at ports and docks

List number of environmental risk materials ports and docks, throughput of hazardous chemicals at ports and docks per year, number of environmental accidents at ports and docks within the administrative region in the last 5 years. Use Table 2.2 to calculate intensity of acute environmental risk at ports and docks.

Table 2.2 Intensity of acute environmental risk at ports and docks

Evaluation indicators	Data resource	Indicator explanation	Indicator Unit	score
Number of ports and docks within the administrative region	Local EPB	within the evaluation region, the number of ports and docks involving loading and unloading and storing of environmental risk materials.	> 2	5
			2	3
			1	1
			0	0
Throughput of hazardous chemicals at ports and docks per year	Local port authority	/	> 50	5
			(30,50]	3
			(10,30]	1

within the administrative region (10000 tons)			≤10	0
Number of environmental accidents at ports and docks within the administrative region in the last 5 years	Local port authority	/	≥5	5
			3-4	3
			1-2	1
			0	0

2.3 Intensity of acute environmental risk in terrestrial transport

List the quantity of environmental risk materials by terrestrial transport per year, number of environmental accidents in terrestrial transport in the last 5 years. Use Table 2.3 to calculate intensity of acute environmental risk in terrestrial transport.

Table 2.3 Intensity of acute environmental risk in terrestrial transport

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Quantity of environmental risk materials(include transit capacity) by terrestrial transport per year within the administrative region (10000 tons)	Local bureau of transport	/	over 4000	5
			(2000,4000]	3
			(1000,2000]	1
			Less than 1000	0
Number of environmental accidents in terrestrial transport within the administrative region in the last 5 years	Local EPB	/	≥10	5
			5-9	3
			3-4	1
			≤2	0

2.4 Intensity of acute environmental risk in inland waterway transport

List quantity of environmental risk materials by inland waterway transport per year, number of environmental accidents in inland waterway transport in the last 5 years. Use Table 2.4 to calculate intensity of acute environmental risk in inland waterway.

Table 2.4 Intensity of acute environmental risk in inland waterway transport

Evaluation indicators	Data resource	Indicator explanation	Indicator Unit	Score
Quantity of environmental risk materials by inland waterway transport (include transit capacity) per year within the administrative region (10000 tons)	Local bureau of maritime safety	/	>800	5
			(400,800]	4
			(200,400]	3
			(1200,200]	2
			(50 , 100]	1
			< 50	0
Number of environmental accidents in inland waterway transport within the administrative region in the last 5 years	Local EPB	/	≥5	5
			3-4	3
			2	1
			≤1	0

2.5 Intensity of acute environmental risk of tailing ponds

List number of tailings above 4 scale level, number of environmental accidents in tailings in the last 5 years. Use Table 2.5 to calculate intensity of acute environmental risk of tailing ponds.

Table 2.5 Intensity of acute environmental risk of tailing ponds

Evaluation indicators	Data resource	Indicator explanation	Scenarios	Score
Number of tailing ponds above 4 scale level within	Local bureau of work safety	depending on the scale rank in "Tailings safety supervision and management	Over 10	5
			6-9	3
			3-5	1

the administrative region		regulations", the number of tailings above 4 scale level	Less than 2	0
Number of environmental accidents in tailing ponds within the administrative region in the last 5 years	Local EPB	/	≥5	5
			3-4	3
			2	1
			≤1	0

2.6 Intensity of acute environmental risk of oil and gas pipeline

List the location of oil and gas pipelines, number of environmental accidents in oil and gas pipeline in the last 5 years. Use Table 2.6 to calculate intensity of acute environmental risk of oil and gas pipeline.

Table 2.6 Intensity of acute environmental risk of oil and gas pipeline

Evaluation indicators	Data resource	Indicator explanation	Indicator unit	Score
The location of oil and gas pipelines within the administrative region	Local bureau of work safety	Whether or not the oil and gas pipeline cross the residential area, the source of drinking water in towns and above, farmland and aquaculture and other important environmental risk receptors	Across the residential area and national nature reserve	5
			Across the source of drinking water in towns and above	3
			Across farmland and aquaculture	1
			Not across air, water or soil and other environmental risk receptors.	0
Number of environmental accidents in oil and gas pipeline within the administrative region in the last 5 years	Local EPB	/	≥5	5
			3-4	3
			2	1
			≤1	0

3. Vulnerability of environmental risk receptor within administrative region（V）

List vulnerability of environmental risk receptor within administrative region, from environmental exposures way, vulnerability of environmental risk receptor, and restorative capacity of environmental risk receptor.

3.1 Environmental risk exposure pathway

List the function of flow channels of important water bodies, coverage of water within administrative region, residential wind frequency of pollution. Use Table 3.1 to calculate environmental risk related to exposure pathway.

Table 3.1 Environmental risk exposure pathway

Evaluation indicators	Data resource	Indicator explanation	Indicator unit	Score
The function of flow channels of important water bodies	Local bureau of water resource, local EPB and bureau of agriculture	The category of flow channels, such as drinking water sources, wild fauna and flora reserve, livestock and poultry breeding area, agricultural irrigation area	Drinking water sources	12
			Wild fauna and flora reserve	8
			Livestock and poultry breeding area	4
			Agricultural irrigation area	2
			Others	0
Coverage of water within administrative region	Local EPB	/	Over 5%	12
			(3%-5%)	8
			(1-3%]	4
			Less than 1%	0
Residential wind frequency of pollution	Local bureau of meteorological	the wind frequency of residential area whose upwind is industrial area, for example, a residential area is in the northwest of the industrial area, if the wind rose shows the frequency of southeast wind is 20%	Over 20%	12
			(10%-20%]	8
			(5-10%]	4
			Less than 5%	0

3.2 Vulnerability of environmental risk receptor

List the number of permanent population per unit area, number of environmentally sensitive targets per unit area, number of protected areas of drinking water at towns and city level, number of population served by drinking water sources in towns and above. Use Table 3.2 to calculate vulnerability of environmental risk receptor.

Table 3.2 Vulnerability of environmental risk receptor

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Population density (Number of permanent population per unit area (persons/km²)	Local bureau of statistics and bureau of land and resources	Ratio of number of permanent population in the evaluated administrative region to the total area of the administration region	>1000	12
			(800-1000]	8
			(500-800]	4
			>1000	12
Number of environmentally sensitive targets per unit area (Nos)	Local EPB or bureau of land and resources	Number of national environmentally sensitive targets in the total area of the administrative region	Over 3	12
			2	8
			1	4
			0	0
Number of protected areas of drinking water sources at towns and city level	Local EPB	/	>2	12
			2	8
			1	4
			0	0
Number of population served by drinking water sources in towns and above	Local government	number of population who get water from water sources in towns and above	over 100000	16
			70000-100000	12
			30000-70000	8
			Less than 30000	0

3.3 Restorability of environmental risk receptor

List per-capita GDP and use Table 3.3 to calculate restorability of environmental risk receptors.

Table 3.3 Restorability of environmental risk receptor

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Per-capita GDP (dollars)	Local bureau of statistical	the ratio of GDP to number of population	≤1000	12
			(1000,3000]	10
			(3000,7000]	9
			(7000,10000]	6
			(10000,13000]	3
			> 13000	0

4. Administrative regional environmental emergency response capacity (M)

Use scoring method to evaluate the environmental risk prevention and control capacity and environmental emergency response capacity.

4.1 Administrative regional environmental risk prevention and control capacity

List the administrative regional monitoring and warning capacity, administrative regional pollutant intercepting capacity, and use Table 4.1 to calculate environmental risk prevention and control capacity at administrative regional level.

Table 4.1 Administrative regional environmental risk prevention and control

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Monitoring and warning capacity	Local EPB	Capacity of the evaluated administrative region for prediction and warning of water and air accidents by setting monitoring site	No emergency monitoring points are set up; no environmental quality monitoring points are set up.	10
			Environmental quality monitoring points are set up; no monitoring point of environmental emergency are set up	7
			Emergency monitoring points are set up, with the ability to monitor the atmosphere, water and soil conventional pollutants	3
			Emergency monitoring points are set up and equipped with air, water and soil related characteristics of pollutants and biological monitoring capabilities	0
Administrative regional pollutant	Local EPB	Capacity for intercepting the pollutants in the region through	Pollutants cannot be intercepted through damming, river diversion, interception, and chemical dosing, etc	10

intercepting capacity		damming, river diversion and chemical dosing when environmental accidents occur	More than 30% pollutants can be intercepted within the region through damming, river diversion, interception, and chemical dosing, etc.	8
			More than 50% pollutants can be intercepted in the region through damming, river diversion, interception, and chemical dosing, etc	4
			Pollutants can be intercepted in the region through damming, river diversion, interception, and chemical dosing, etc	0

4.2 Environmental emergency response capacity

List the establishment of administrative regional environmental emergency plan, proportion of enterprise environmental emergency professional team, reserve of administrative regional emergency materials and equipment, environmental emergency decision-making support system, emergency monitoring capacity, emergency rescue capacity of regional medical institutions, capital investment in administrative regional environmental emergency response capacity building. Use Table 4.2 to calculate environmental emergency response capacity.

Table 4.2 Environmental emergency plan management

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Establishment of administrative regional environmental emergency plan	Local EPB	whether the evaluated administrative region has established a emergency plan, and whether it is operable and perfect.	No emergency plan	15
			Preliminary plan	10
			Better plan	5
			Comprehensive plan including regular updates	0
Proportion of enterprise environmental	Local EPB	the ratio of the percentage of enterprise	< 30%	10
			(30%,50%]	8

emergency professional team		which has a full-time, part-time or third party of the emergency professional team	(50%,70%]	4
			> 70%	0
Reserve of administrative regional emergency materials and equipment	Local center of environmental emergency and accident investigation	Whether the reserved emergency materials and equipment can meet the needs of the environmental emergency plan	Cannot meet the needs of emergency response plan, and invoked materials cannot be put into emergency within 24 hours	15
			Cannot meet the needs of emergency response plan, and invoked materials can be put into emergency within 12 hours	10
			Cannot meet the needs of emergency response plan, and materials can be invoked from neighboring municipalities and provinces within 6hours	5
			Can basically meet the needs of emergency response plan, and it is not necessary to invoke materials from other municipalities and provinces.	0
Environmental emergency decision-	Local center of environmental emergency and	Whether the evaluated administrative region has been equipped	No administrative regional environmental emergency decision-making	10

making support system	accident investigation	with a command and schedule platform for environmental emergency, which can analyze event impact, as well as dispatch emergency capacity and deploy emergency work, in order to improve the capacity of the administrative region for risk prevention and emergency respond	support system has been built	
			An administrative regional environmental emergency decision-making support system has been built, which allows emergency capacity dispatch and emergency task deployment	5
			An administrative regional environmental emergency decision-making support system has been built, which allows consequence analysis of the environmental accidents as well as emergency capacity dispatch and emergency task deployment	0
Emergency monitoring capacity	Local center of environmental emergency and accident investigation	Whether the general monitoring capacity can meet the needs of emergency, and whether it is necessary to dispatch monitoring forces from neighboring municipalities and provinces to conduct emergency monitoring	Necessary to dispatch monitoring forces from neighboring municipalities and provinces to conduct emergency monitoring	10
			Relying on monitoring forces within the region to conduct emergency monitoring	0

Emergency treatment capacity of regional medical institutions(number of ward beds per capita)	Local bureau of health	Ratio of the total number of the ward beds in the medical institution of the administrative region to the number of the permanent population in the administrative region	<0.008	10
			[0.008-0.03)	8
			[0.03-0.05)	4
			>0.05	0
Capital investment in administrative regional environmental emergency capacity building	Local center of environmental emergency and accident investigation	Capital investment for building environmental emergency system, regulating environmental emergency teams, equipping emergency materials and improving emergency response capacity	Less than 1 million yuan	10
			1-3 million yuan	8
			3-5 million yuan	4
			Over 5 million yuan	0

5. Comprehensive index of administrative regional environmental emergency risk

Calculate intensity of environmental risk source(s), vulnerability of environmental risk receptor within administrative region(V), environmental emergency response capacity within administrative region(M), and use the formula to calculate the Acute environmental risk index at county level(R).

$R=0.4S+0.3V+0.3M$

Depending on the value of R, the comprehensive risk can be divided into general risk, intermediate risk and high risk.

Table 5.1 Comprehensive grade of administrative regional environmental emergency risk

R	Risk grade
≥60	High environmental risk
[40,60)	Intermediate environmental risk
< 40	General environmental risk

Part C

Method for accumulated environmental risk assessment at the county level

1. Introduction

This part of the framework, the method for acute environmental risk assessment, refers to step 5 in the seven-step framework and gives detailed guidance about this step. This assessment method aims to quantitatively assess indicators of a given administrative region, including the intensity of environmental risk sources (S), pathways and vulnerability of environmental risk receptors (V), and the administrative environmental management capacity (M). Assessment procedure and indicator system are shown in Figure 1.1 and Table 1.1, respectively. Accumulated environmental risk index and grade at county level can be calculated by employing this approach.

Figure 1.1 Assessment procedure of accumulated environmental risk of an administrative region

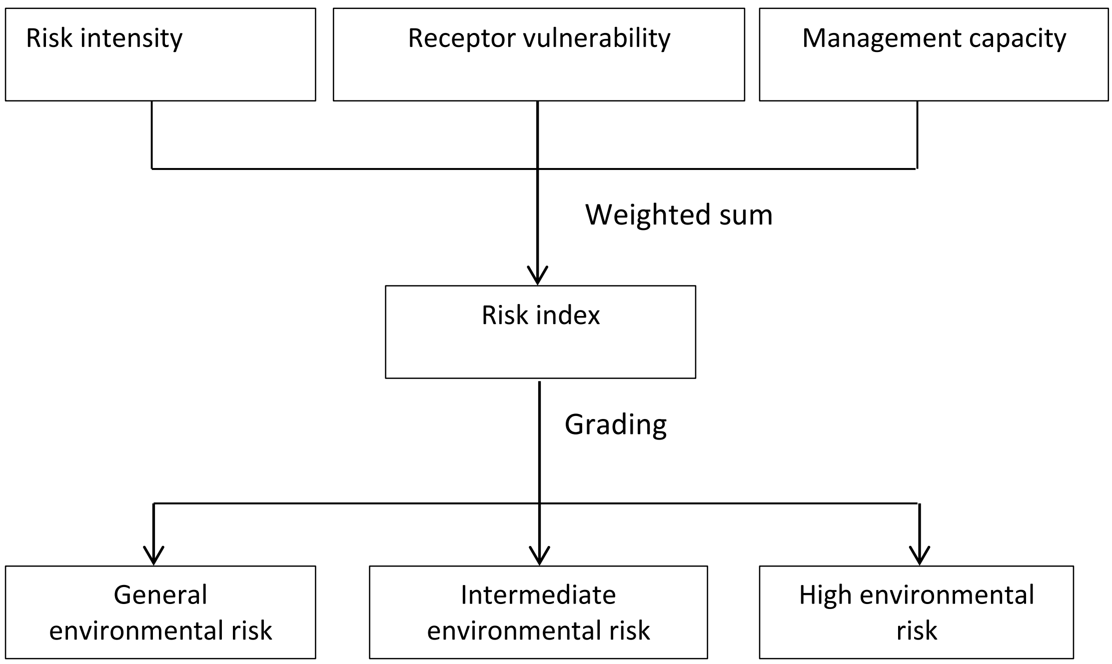


Table 1.1 Evaluation indicators of accumulated environmental risk at county level

Evaluation indicators		
Intensity of environmental risk source within county(S) (3)	Intensity of accumulate environmental risk from environmental risk enterprises（7）	SO_2 emission density
		NO_X emission density
		COD emission density
		NH3-N emission density
		Fees of pollution-discharge
		Heavy metal pollution prevention and control key area
		The number of environmental complaints within 5 years
	Intensity of accumulate environmental risk from farming（3）	The amount of fertilizer used per unit area within the farming region
		The amount of pesticide used per unit area within the farming region
		Proportion of irrigated land with waste water
	Intensity of accumulate environmental risk from households（2）	Daily output of solid waste per capita within the region
		Daily output of waste water per capita within the region
Pathways and vulnerability of environmental risk receptor within administrative region（V）(2)	Environmental risk exposure pathway(5)	Air quality compliance rate within the region
		The proportion of surface water coverage within the region
		Percentage of people having access to treated tap water in the region
		Urban water quality compliance rate of water function zone within the region
		Water quality compliance rate of drinking water source within the region
	Vulnerability of environmental risk receptor(5)	Ecological red line protection area proportion of land area
		The number of species to the total area in the region
		Population density in this region
		Percentage of children and the elderly to the total population in this region
		The proportion of population with chronic disease to the total population in the region

Administrative regional environmental management capacity (M)(1)	Administrative regional environmental risk prevention and control capacity(4)	The number of staff in environmental management per enterprise in the region
		Number of hospital beds per thousand people in medical institutions in the region
		Annual input funds for environmental pollution control per capita

2. Intensity of environmental risk source within a county (S)

Intensity indicators in various aspects, such as industry, agriculture, and daily life, are assigned with scores to assess and summarize environmental risk, further determining the risk intensity of this administrative region.

2.1 Industry

Focused on the industrial emission of administration region, calculate the intensity of accumulate environmental risk from environmental risk enterprises using Table 2.1.

Table 2.1 Intensity of accumulate environmental risk in environmental risk enterprises

Evaluation indicators	Data resource	Indicator explanation	Indicator value	Score
SO_2 emission density	Local EPB	Ratio of SO_2 annual emissions to administrative area	> 20	5
			(10 , 20]	4
			(1 , 10]	3
			[0 , 1]	1
NO_X emission density	Local EPB	Ratio of NO_X annual emissions to administrative area	> 20	5
			(10 , 20]	4
			(1 , 10]	3
			[0 , 1]	1
COD emission density	Local EPB	Ratio of COD annual emissions to administrative area	> 20	5
			(10 , 20]	4
			(1 , 10]	3
			[0 , 1]	1
NH_3-N emission density	Local EPB	Ratio of NH_3-N annual emissions to administrative area	> 2	5
			(1 , 2]	4
			(0.2 , 1]	3
			[0 , 0.2]	1

Heavy metal pollution prevention and control key area	Comprehensive prevention and control of heavy metal pollution "Twelfth Five Year Plan"	To determine whether the region is the key areas of heavy metal pollution prevention and control	Yes	5
			No	0
Fees of pollution-discharge	Local EPB	As there are too many kinds for pollutants, so it is difficult to measure the total discharge of them using one or two indicators. The pollution-discharge fee can reflect the pollutants discharged to some extent Ratio of annual fees of pollution-discharge to administrative area	>4000	10
			(2000,4000]	8
			(1000,2000]	4
			[0,1000]	2
The number of environmental complaints within 5 years	Local EPB	/	>50000	10
			(25000,50000]	8
			(5000,25000]	4
			[0,5000]	2

2.2 Agriculture

Focused on the farming emission of the administration region, calculate the intensity of accumulate environmental risk from farming using Table 2.2.

Table 2.2 Intensity of accumulate environmental risk in farming

Evaluation indicator	Data resource	Indicator explanation	Indicator value	Score
The amount of fertilizer used per unit area within the farming region. (kg/km^2)	The agricultural year book	Ratio of annual fertilizer used to administrative area	> 80000	10
			(50000 , 80000]	8
			(20000 , 50000]	4

			[0，20000]	2
The amount of pesticide used per unit area within the farming region.(kg/km²)	The agricultural year book	Ratio of annual pesticide used to administrative area	＞4000	10
			(2000，4000]	8
			(500，2000]	4
			[0，500]	2
Proportion of irrigated land with waste water(%)	Local agricultural bureau	Ratio of irrigated land area to administrative area	＞10	10
			(5，10]	8
			(1，5]	4
			[0，1]	2

2.3 Households

Focused on the daily-life emission of administration region, calculate the intensity of accumulate environmental risk from households using Table 2.3.

Table 2.3 Intensity of accumulate environmental risk from households

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Daily output of solid waste per capita within the region. (kg per capita)	The year book		[0，50]	10
			(50，70]	8
			(70，90]	4
			(90，100]	2
Daily output of waste water per capita within the region. (kg per capita)	The year book		[0，50]	10
			(50，70]	8
			(70，90]	4
			(90，100]	2

3. Pathways and vulnerability of environmental risk receptor

Listing the pathways and vulnerability status, and assessing the risk with scoring method.

3.1 Exposure pathways

Listing indicators and assessing the exposure pathways of atmospheric and aquatic risk field with Table 5. Calculate the environmental risk exposure pathway using Table 3.1.

Table 3.1 Environmental risk exposure pathway

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Air quality compliance rate within the region. (%)	The year book	Percentage of population living in areas where the air quality is complying with AQS.	[0，30]	10
			(30，60]	8
			(60，90]	4
			(90，100]	2
The proportion of surface water coverage within the region. (%)	Local EPB	The areas of surface water divided by the total area in the region	(75，100]	10
			(50，75]	8
			(25，50]	4
			[0，25]	2
Percentage of people having access to treated tap water	The year book	.	[0，50]	10
			(50，75]	8
			(75，90]	4
			(90，100]	2
Urban water quality compliance rate of water function zone within the region	The year book	/	[0，50]	10
			(50，75]	8
			(75，90]	4
			(90，100]	2

Water quality compliance rate of drinking water source within the region	Local EPB	/	[0，50]	10
			(50，75]	8
			(75，90]	4
			(90，100]	2

3.2 Vulnerability of risk receptor

Calculate the vulnerability of environmental risk receptor using Table 3.2.

Table 3.2 Vulnerability of environmental risk receptor

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
Ecological red line protection area proportion of land area	The year book	The ratio of the ecological red line protection area of administrative region	＞30	12.5
			[20,30)	9
			[10,20)	6
			＜10	2
The number of species to the total area in the region	Local EPB	technical guidelines for ecological environmental assessment (for Trial Implementation) (HJ/T192-2006)	（0，35]	12.5
			（35，55]	9
			（55，75]	6
			＞75	2
Population density in this region	Statistical bureau	The ratio of population to Administrative Region	＞1000	12.5
			（500，1000]	9
			（100，500]	6
			（0，100]	2
The proportion of population with chronic disease to the total population in the region. (%)	The year book	Statistical data can be found on websites of provincial/ municipal commission of population and family planning, or the National Health and Family Planning Commission: http://www.nhfpc.gov.cn/zwgkzt/pwstj/list.shtml	（25，100]	12.5
			（15，25]	9
			（5，15]	6
			[0，5]	2

4. Risk management capacity (M)

Calculate the risk management capacity using Table 4.1.

Table 4.1 Administrative regional environmental risk prevention and control

Evaluation indicators	Data resource	Indicator explanation	SIndicator Unit	Score
The number of staff in environmental management per enterprise in the region	Local EPB	Number of persons; the smaller number of it, the higher assignment of evaluation index This includes local environmental protection administration, environmental management office and staff in consulting and service agencies related to environmental management.	(0 , 0.5]	30
			(0.5 , 1]	20
			(1 , 2]	10
			> 2	5
Number of hospital beds per 1000 capita in medical institutions in the region	Department of health	ratio of the total number of the ward beds in the medical institution of the administrative region to the number of the permanent population in the administrative region	(0 , 4]	30
			(4 , 5]	20
			(5 , 6]	10
			> 6	5
Annual input funds for environmental pollution control per capita	The year book	Yuan per capita; the smaller number of it, the higher assignment of evaluation index	[0 , 200]	40
			(200 , 500]	30
			(500 , 1000]	20
			> 1000	10

5. Risk index of accumulated environmental risk at county level

Calculating the county-level environmental risk source (S), the county-level environmental risk receptor vulnerability (V), the county-level environmental risk prevention and emergency response capability index (M). The accumulated environmental risk index (R) is calculated according to the formula below.

$$R=0.4S+0.4V+0.2M$$

According to the accumulated environmental risk index (R), we can classify the risk into high, intermediate and general levels.

Table 5.1 Classification of Accumulated Environmental Risk

Accumulated environmental risk index (R)	Level of accumulated environmental risk
≥60	High
[40,60)	Intermediate
< 40	General

Part D

Environmental risk assessment from principles to policy

1. Introduction

This document is a part of the framework for environmental risk prevention planning in China at provincial, prefecture and city levels produced by CAEP, Vista Analysis and CICERO. In particular its function is to support and complement Part A “7 Steps for Regional Risk Assessment”. Part A mainly explains the *process* of conducting a risk reduction assessment or plan. Other documents under the general framework explain *methods* to use for assessment of regional risk. This document explains *principles, priorities, approaches, models and policy instruments* available for environmental risk assessment. The document draws on international best practice related to environmental risk assessment while adapting it to a Chinese context.

Our intention in this document is to guide the environmental planner who wishes to understand the background for the proposed process and methods, or a planner who faces problems of environmental risk that require modified or new methods. The process and methods presented in the other documents are in many ways like a recipe. In a similar fashion this document gives a meta-recipe, a recipe for making recipes. As most planners eventually face problems of environmental risk that require modified or new methods we believe that this document is a useful component of the framework.

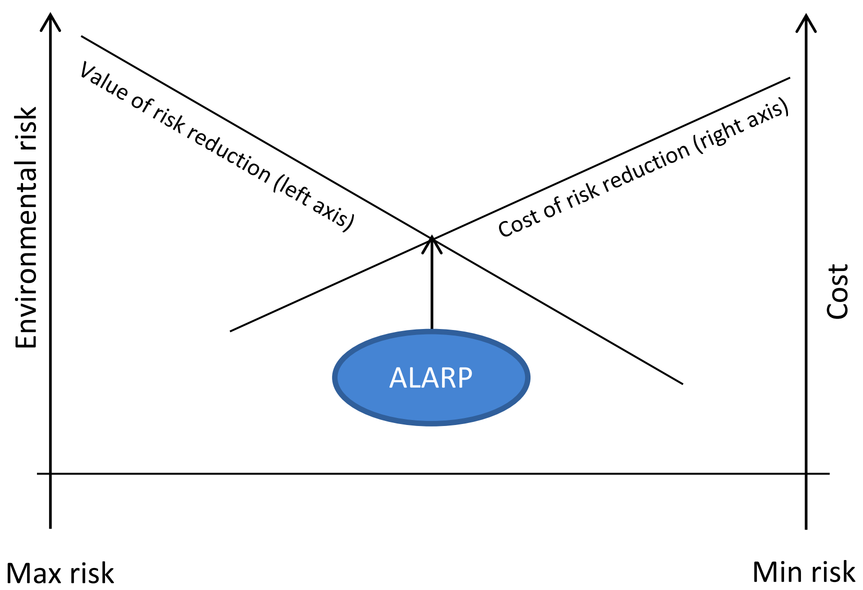
2. Principles of environmental risk management

In risk management we ask the question *Does the benefit in terms of risk reduction outweigh the cost?* Examples of actions are "an intervention to prevent or mitigate risk" or a "new transport corridor" or "current industrial activity". In the case of a new transport corridor or current industrial activity the benefit often is an income gain, and risk increase is the cost. The same risk management principles apply to actions that increase and decrease risk.

2.1 Cost-benefit

The **cost benefit principle** says to carry out an action if the value of environmental risk reduction (= benefit) is greater than the cost. This leads to the concept of "as low as reasonably practicable" environmental risk, abbreviated ALARP.[1] See Figure 2.1.

Figure 2.1 "As low as reasonably practicable" risk balances benefit and cost



In Figure 2.1 ALARP is defined as the marginal remaining risk following all actions that are worth doing because they are "reasonably practicable". Environmental risk decreases from left to right. The biggest risks to the left are important to do away with (value of risk reduction is high) and they are usually easy to reduce (cost is low). The last grains of risk to the right are expensive to eliminate (cost is high), and usually not so important to eliminate either (value of risk reduction is low). ALARP characterizes risks that are tolerable in light of cost and benefit considerations.

ALARP is different from risk minimization, because ALARP does not advocate doing everything to reduce risk, which is necessary if risk really is to be minimized. ALARP advocates doing what is "reasonably practicable" to reduce risk. Some actions are

[1] The term ALARP arises from UK legislation, particularly the Health and Safety at Work etc. Act of 1974. It is now used in various countries in Europe.

reasonably practicable, others are not because they are too expensive or require too much change in society. In other words, one has to compare the risk reduction gained to the resources and services lost. This is the essence of the cost-benefit approach. If done properly and competently this approach produces an optimal risk level, ALARP, that generally is different from the minimal risk level.

Obviously ALARP is influenced by social factors such as

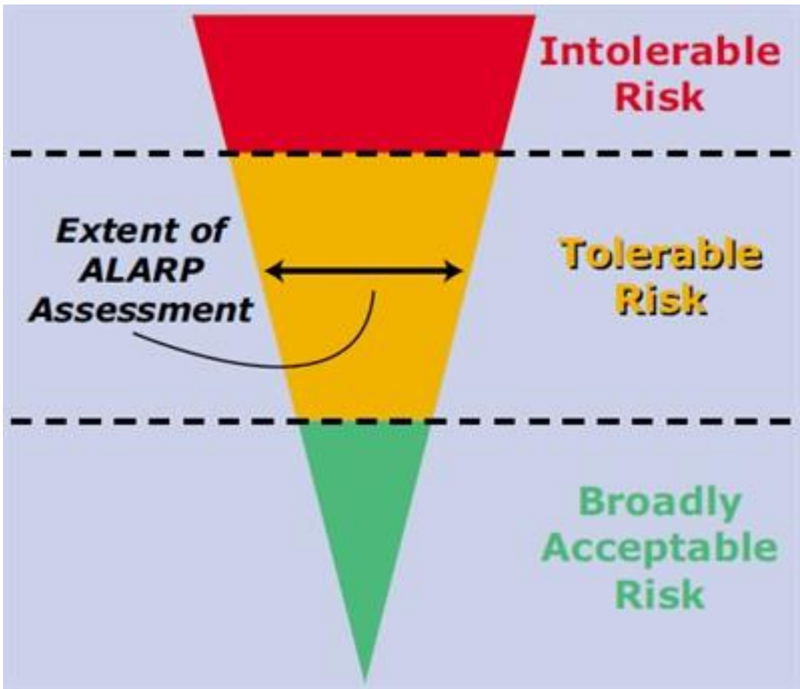
- Scientific knowledge of risk
- Public understanding of risk
- Aversion to risk
- Habitual tolerance to risk
- Time until consequences are experienced
- Time since similar accidents have occurred
- Innovations in control technologies

For these and other reasons ALARP changes over time.

2.2 The ALARP wedge

The cost-benefit principle leading to ALARP can be expressed as a wedge or carrot, see Figure 2.2. Figure 2.2 recognizes that ALARP may depend on circumstances and it may change over time. Importantly it is usually quite difficult to measure and assess environmental risk precisely. For these reasons it is common to distinguish an ALARP *region* rather than an ALARP *point*.

Figure 2.2 The ALARP Wedge

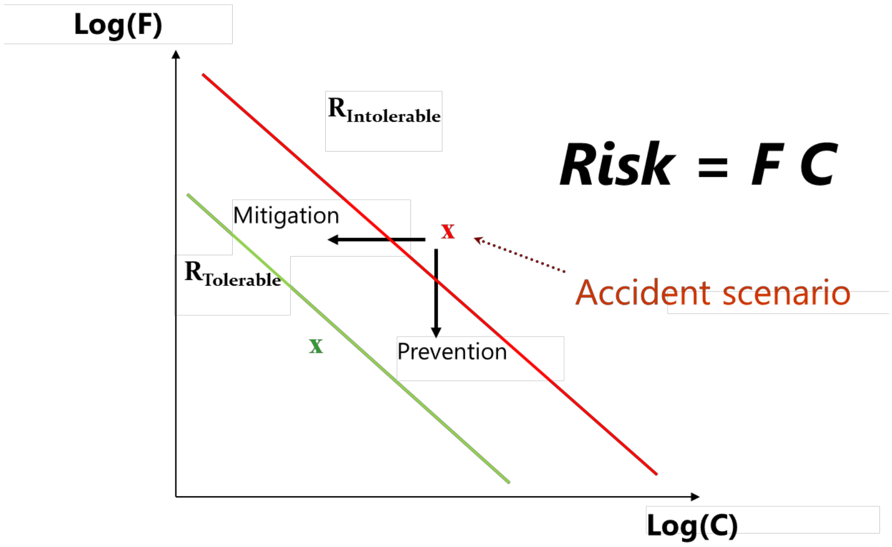


The ALARP region is bounded above by intolerable risks, and bounded below by broadly acceptable risk. In Figure 2.1 intolerable risk is to the left and broadly acceptable risk is to the right of the ALARP "point". What Figure 2.2 does, is to extend the ALARP point to an ALARP region.

2.3 ALARP, risk prevention and risk mitigation

Here is another figure that illustrates the ALARP concept and interventions that reduce risk. Risk is often defined as probability times consequence. With probability indicated by frequency this becomes Risk = FC. Simple math tells us that Log (Risk) = Log (F) + Log (C), which is linear in a figure that has Log (F) and Log (C) on the axes.[1] The ALARP border between tolerable and intolerable risk is one specific risk level. It is the straight red line that denotes combinations of F and C that produce this risk level. The ALARP border between tolerable and broadly acceptable risk is the straight green line.

Figure 2.3 Mitigation and prevention to reduce risk



An intervention that mitigates environmental risk will reduce consequences of an incident and move x horizontally to the left (lower consequence, constant probability). An intervention that prevents environmental risk will reduce the probability of an incident happening and move x vertically down (lower probability, constant consequence).

In order to assess whether it is worthwhile mitigating or preventing x one should also consider cost, but the implicit assumption in many applications is that intolerable risk by assumption should be eliminated, i.e. it is worth more to eliminate it than to save the cost. If this is the case x is worth carrying out by assumption.

Sometimes an incident may have several consequences, each with assigned probabilities. This leads to the generalized risk equation

Environmental risk = $\sum_i F_i C_i$.

[1] This is true whatever the base of the log is.

Some readers will recognize this equation as an (empirical version of) the expectance operator, in other words, expected risk.

Several principles and approaches in environmental risk management deal with the problem that neither probability nor consequence, the two terms of environmental risk, are precisely known. Next we present some of these principles and approaches.

2.4 The precautionary principle

The Rio Declaration on Environment and Development from 1992 states in §15: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". This has come to be known as the precautionary principle. In terms of the concepts we introduced above, the precautionary principle says that if the consequences (C) are serious, lack of certainty about probability (F) shall not be used as an excuse for inaction. Lack of certainty about probability might mean that the probability is between 0 and some upper probability *f*. The precautionary principle says to act as if the probability is close to the upper probability *f*. (Since higher F leads to more action). If, in addition, different risks are assumed to have the same upper probability *f* the risks will be ranked based on their consequence. This way of thinking leads to the consequentialist approach, see below.[1]

More generally the precautionary principle allows more risk reducing actions to pass the cost-benefit test than if one assumed a low probability. The precautionary principle is not an exact law, but it gives support to precaution and has been found useful in decision making. In terms of the ALARP triangle more risk is intolerable in light of the precautionary principle (the bar is moved down).

2.5 The substitution principle

The substitution principle states that a safer substance should replace a harmful substance if the safer substance is technically and economically feasible. If no safer substance exists, the company must try to find one. The substitution principle for instance guides the REACH regulation of harmful substances in Europe. It is mostly applied towards hazardous or unknown chemical substances, and to a lesser extent applied towards classical pollutants.

If a substance is just as good, less harmful and does not cost more, then it is obviously better and should replace existing substances. If the substance is not quite as good and does cost more the question is what is meant by "technically and economically feasible" in the definition above. The substitution principle is formally silent on what is meant by technically and economically feasible, but gives credence to regulators' demands for replacing a substance for another even if it is more costly and not exactly as good. It is also useful that companies should continuously work to find safer alternatives, as this

[1] An example of the benefit of a precautionary approach is chlorofluorocarbons (freons) that have low toxicity and were thought to be ideal for many purposes, refrigerators, spray cans etc. Much later their effect on the ozone layer was detected.

suggests a dynamic process towards lower environmental risk. The question of what constitutes a technically and feasible alternative is similar to ALARP and the cost-benefit question.

2.6 The right to information

Many people will argue that a concept like ALARP is not objectively determined, but rather it is the outcome of society's conversation on what constitutes a reasonable level of environmental risk. For public participation in this conversation to be meaningful and comprehensive citizens should have access to relevant information. The right to information is also essential in order for citizens to make informed choices about their own lives in relation to environmental risk – such as where to live and work etc.

The right to information is guaranteed in China by means two measures released by the MEP, in 2004 and again in 2014.[1] In Europe it is secured by law in the EU and is for instance referred to in the preamble of the Seveso directives of Europe.

2.7 Other principles

There are several other principles underlying environmental risk management in most countries. The *polluter-pays-principle* says that the polluter should pay for the damage caused by his emissions. This has to do with fairness and incentives. For one thing, it is considered fair that a company or person that caused the problem pays for the damage, especially since the company or person often has made money on the activity causing the problem and the damage. Moreover, the payment for pollution is an incentive directed at the one who is closest to the problem. With payment the company or person will want to do something about the pollution.

The *principle of subsidiarity* has become important in the EU. It states that decisions should be made by the level of government that is the closest to the citizens affected by the decisions. It can be defended by reference to fairness (why should others decide over those who are the most affected?), information (those closest to the citizens presumably know the issues best), incentives (those closest to the citizens can presumably do more about it and will benefit directly from actions being taken), avoiding external effects (decisions should be made by the body that best represents the affected citizens), etc.

Fairness is a fundamental principle underlying much of what has been said about the polluter-pays-principle, the right to information etc., just as *efficiency* is a fundamental principle underlying cost-benefit and ALARP. In some cases fairness makes it reasonable to spend more resources on reducing one environmental risk than on another - for instance if the citizens subject to risk bear a disproportionate amount of other burdens as well, or if the risk has emerged as a consequence of an unfair act by someone. Spending unequal amounts of resources violates efficiency, but it may be considered fair and right anyhow.

[1] In 2004 MEP released 'Measures on Environmental Information Publicity (Trial)', and in 2014, MEP released 'Measures on Environmental Information Publicity of Enterprises'. Environmental authorities and enterprises are required to disclose certain information.

3. Priorities

When confronting environmental risks there are many important tasks. Where to begin? This chapter outlines environmental problems and indicators that are associated with significant risk. It should be emphasized, however, that conditions differ and what is a serious risk in a heavily populated, industrial area may turn out to be an insignificant risk in a sparsely populated, rural setting. The consequences of an incident are location specific, and the probability/frequency is also location specific.

To help set priorities this chapter has sections on the consequence of emitting or discharging pollutants (**Feil! Fant ikke referansekilden.** - 3.3) and the frequency of hazardous chemical accidents (3.4). These correspond to the two analytical elements of environmental risk. The chapter also refers to prioritization of certain industries (3.5).

3.1 Consequences and importance of emissions to air, classical pollutants

The classical pollutants to air are particulate matter (PM), sulfur dioxide (SO_2), non-methane volatile organic compounds (nmVOC), and nitrogen oxides (NO_X). With respect to the mass based concentration in air, PM is considered the most risky, but as gases like SO_2 and NO_x may be converted to PM once emitted, the gases contribute to PM risks as well. It is well documented that PM causes significant danger to health. Exposure to PM has been shown to increase the risk of several health conditions, from coughing and sneezing to asthma, chronic bronchitis, chronic pulmonary disease (COPD), and heart attacks and other cardiovascular diseases. The risk of premature death from COPD and a range of other diseases is also higher.

Small particles are more risky for health than relatively bigger particles, because small particles can penetrate deeper into the lung. Focus is on particles smaller than 2.5 µm in diameter, denoted $PM_{2.5}$. The association between $PM_{2.5}$ exposure and health risk is well established in a variety of urban and rural setting, although the quantification varies considerably. Large health effects of PM have been shown for Chinese cities where the air may be highly polluted. However, even in cities with much lower pollution levels, as in many European cities, health effects of PM are documented. Thus, reduced PM exposure is beneficial both in highly polluted and less polluted environments. For some health effects, relatively large reductions in exposure levels are needed to obtain a significant health benefit in case the starting point is a very polluted environment. This is because the empirical relationship between exposure and effect seems to flatten off at high pollution levels. A threshold level under which PM exposure is safe, has not been detected.

So far, one has not been able to establish whether the sources and composition of $PM_{2.5}$ are of major importance for the health risk. In rural areas many people get most of their exposure indoors due to high levels of $PM_{2.5}$ from cooking and heating with solid fuels. Indoor air pollution is an important, and often overlooked, source of environmental health risk in China. The world health organization (WHO) conducts regular assessments of the main health risks across the world. For 2012, it was found that household air pollution from solid fuel use is the largest environmental risk factor globally, higher than ambient air pollution and much higher than unimproved drinking water[1]. In China, ambient air pollution and indoor household pollution are, respectively, the fourth and fifth largest risk factor for premature death, responsible for, respectively, 1.2 and 1.0 million deaths annually in 2010[2]. Combining the indoor and outdoor component, air pollution is the top health risk factor in China.

Recently the attention to $PM_{2.5}$ has increased in China, but historically PM has ranked behind SO_2 and NO_X in terms of policy and regulation. As mentioned, SO_2 and NO_X may form $PM_{2.5}$ in the atmosphere. Ammonia emission from agriculture is also suspected of being of importance for increasing PM pollution in China. The complexity of PM pollution calls for a comprehensive and multi-component approach to PM reduction policies, and such an approach was recently proposed in the Air Pollution Prevention and Control Plan, issued by the Chinese Government in 2013.

Next to PM, ground level ozone is the main environmental health risk associated with classical pollutants. Ground level ozone is formed by NO_X, VOC and sunlight. Ozone monitoring has only quite recently started up in Chinese cities, and there is still very little data on pollution levels in rural areas. The latter is of importance as some major agricultural crops are highly sensitive to ozone.

3.2 The consequence of a kilogram of emission, other compounds

Besides the classical pollutants there are thousands of chemical substances emitted to the environment through production, consumption and waste handling.

China's guidance

In the MEP 'Guideline for Risk Assessment of Environmental Accidents of Enterprises(Trial)' (2014), there is a list of the names and thresholds of 310 kinds of substances, which is based on 'Identification of major hazard installations for dangerous chemicals (GB18218-2009)' and the Seveso Directives.

In the MEP 'List of Hazardous Chemicals for Prioritized Environmental Management' (2014) there are 84 chemicals listed. All 84 chemicals are also included in the list of 310 substances.

International experience

The most comprehensive comparison of these substances that we are aware of is conducted in the field of life cycle assessments. In order to compare across products and technologies a life cycle assessment attaches weights to the respective discharges and emissions to different receptors. The International Reference Life Cycle Data System

[1] The WHO Global Health Observatory. Available at: http://www.who.int/gho/phe/en/

[2] Global Burden of Disease Data Visualizations. Available at: http://www.healthdata.org/gbd/data-visualizations

(ILCD) is a recent attempt at standardizing methods and weights used in life cycle analysis.[1]

The ILCD evaluates the consequence of emitting or discharging one kilogram of each of 40353 pollutant-receptor combinations. It is the consequence of emitting a given quantity that is focused. Consequence is only one component of environmental risk. However, the consequence of emitting a given quantity is by itself a statement about the probability of exposure, times consequence should exposure occur. In this way the ILCD ranking can be interpreted as a statement about environmental risk conditioned on an emission amount.

The ILCD ranking evaluates the pollutant-receptor combinations for their impact on

- Human toxicity, further split on cancer and non-cancer effects
- Ionizing radiation
- Acidification
- Eutrophication, aquatic and terrestrial
- Ecotoxity, aquatic and terrestrial

In addition, respiratory symptoms associated with PM, and photochemical ground level ozone are indicated. Climate change impacts and impacts on stratospheric ozone depletion are also included. Finally the resource categories land use and resource depletion are included.[2]

Table 3.1 indicates the ten worst substances, according to the ILCD, in terms of impact per kilogram (or gram) emitted or discharged.

Table 3.1 The ten worst substances per kilogram emitted or discharged according to ILCD

Rank (worst = 1 etc)	Human toxicity, cancer	Human toxicity, non-cancer	Ecotoxicity, freshwater	Eutrophication, freshwater
1	2,3,7,8-tetrachlorodibenzo-p-dioxin to water	PCB-1254 to water	2,3,7,8-tetrachlorodibenzo-p-dioxin	Phosphorus, total
2	2,3,7,8-tetrachlorodibenzo-p-dioxin to air	Mercury to soil	1,2,3,7,8-pentachloribenzo-p-dioxin	Phosphoric acid

[1] An accessible explanation of the ILCD work is Hauschild et al. (2013).

[2] More information about the ambitious attempt of life cycle analysis at prioritization between substances can be found on the web page ILCD handbook of the Joint Research Centre of the European Union, available here: http://eplca.jrc.ec.europa.eu/?page_id=86. The actual weights, called characterization factors, are in a zipped file for download from the page.

3	2,3,7,8-tetrachlorodibenzo-p-dioxin to soil	Mercury to air	Cyfluthrin	Phospate
4	Photomirex to water	PCB-1254 to air	Estradiol	
5	PCB-1260 to water	PCB-1016 to water	beta-cypermethrin isomer	
6	Heptachlor epoxide to water	PCB-1254 to soil	Cyhalothrin	
7	PCB-1254 to water	Cadmium to soil	Fenpropathrin	
8	DDD to water	Beryllium to air	Antimycin A	
9	Aflatoxin B1 to water	Hydramethylnon to water	Cypermethrin	
10	Toxaphene to water	PCB-1016 to water	Alpha-cypermethrin	

Source: Adapted from *ILCD2011-LCIA-method-documentation-FILE-1-final_v1.0.4_September2012-clean.xls* and *ILCD2011-LCIA-method-documentation-FILE-2-final_v1.0.5_February2013.xls* via the ILCD website http://eplca.jrc.ec.europa.eu/. Endpoint values used where available.

The ILCD ranking finds dioxin to be the most dangerous pollutant causing cancer risk. On non-cancer health risk the PCBs come up the highest, with mercury another important substance. On ecotoxity and eutrophication risk substances like cyfluthrin, estradiol and antimycin A also rank high.[1] Phosphate and phosphoric acid are the most important for fresh water eutrophication. In marine and terrestrial systems nitrogen compounds are important.

The list goes on until all 40353 pollutant-receptor combinations are covered (although not all combinations are relevant for all impacts). Combining information about the damage per kilogram emitted with regular or irregular emission quantities, one obtains a useful first indication of the severity of environmental risk.

Despite the good effort of the ILCD, uncertainty and scientific disagreement remains about the relative risk of pollutants. Factors to look for when assessing the environmental risk of an accidental or "normal" emission or discharge include

- Persistence (how slowly the compound degrades)
- Bioaccumulation (whether organisms accumulate the compound in relatively high concentrations either directly from the environment (e.g., water) or through the food chain)
- Toxicity (whether the compound is toxic or toxic species are formed by reaction with other compounds or by degradation)
- Some compounds cause special environmental problems, e.g, reduction of stratospheric ozone, or climate change.

[1] On human toxicity and eco-toxicity the ILCD relies heavily on USEtox, which is a scientific consensus model on toxicity. It is available here: http://www.usetox.org/.

3.3 The impact pathway as a tool for setting priorities

The rankings from LCIA and other sources inform us how dangerous a pollutant is, other things equal, once it is released on a regular or irregular basis. The danger of a pollutant may depend on the circumstances and safeguards taken. However, some conclusions carry over to almost any circumstance. For instance, the consequence of a dioxin emission of some magnitude is universally high.

Some other fairly robust observations are

- The consequence of a high dose over a short period is often more serious than the consequence of a low dose over a longer period. It should be a priority to have **thorough procedures for avoiding acute environmental emissions and discharges**, especially of the acute toxic pollutants.
- In the cases of water and soil pollution it is possible for individuals to avoid exposure if appropriate measures are taken (drink bottled water, avoid eating food from contaminated land). The options are fewer in the case of air pollution since we all need to breathe. It should be a priority to take steps to **avoid exposure to water and soil pollutants in addition to reducing the pollution itself**. For air pollutants the priority is **reduction of emissions**.
- The poor have fewer possibilities for taking measures to avoid exposure to water and soil pollution. It should be a priority to **reduce discharges to water and soil in rural areas**.
- Emissions to ambient air in urban areas affect a larger number of people than similar emissions in rural areas. Emission of household air pollution, which is more common in rural areas, result in a much higher exposure dose for those affected than the dose resulting from emissions to ambient air. It should be a priority to **avoid urban emissions to ambient air and to avoid household air pollution**.
- Experience show that it often takes a long time after new chemical substances are introduced to the environment till comprehensive knowledge about any adverse effects are gained. It should be a priority to **use a precautionary approach**.

3.4 The frequency of hazardous chemical accidents in China

Academic studies have analyzed the frequency of hazardous chemical accidents in China. These studies indicate the China-wide probability of accidental emission and discharges. As such, they complement knowledge of consequences of emissions and discharges.

Local conditions may vary and general knowledge cannot substitute for detailed local experience and knowledge. Still the China-wide frequencies give interesting background, and of course, local conditions cannot be too far off the China average in *all* cases. We describe the analysis of Zhang and Zheng (2012) and Li et al. (2014). A Chinese-language article that covers some of this material is Zhang and Liu (2012).

Conflicting evidence about accidents in fixed facilities versus accidents during transport: Using data on 1632 hazardous chemical accidents 2006-2010 reported by the State Work Accident Briefing System (SWAB) and the Chemical Accidents Communications (SAWS). Zhang and Zheng (2012) found that accidents in fixed facilities were more frequent than accidents during transport. 67% of accidents happened in fixed facilities, 33% happened during transport.

However, Li et al. (2014) used data on 1400 sudden chemicals leakage accidents from the National Registation Center for Chemicals (NRCC), which is a department of SWAB. Of the 1400 accidents, 666 were singled out for study since there was no or little damage from the others. Li et al (2014) found that accidents during transportation were the most common, accounting for 60% of all cases. These two sources thus give conflicting evidence about the importance of transportation versus fixed sources. The authors do not comment on why their results differ.

Accidents in the form of releases are the most important: Zhang and Zheng (2012) found that eight out of ten accidents during transport are releases, but remember they found half as many accidents in transport as in fixed facilities. Four out of ten at fixed facilities are releases, and hence four out of ten overall. In fixed facilities, explosions are also common (half of fixed facility accidents). Fires are much rarer in both transportation and fixed facilities.

Releases may lead to domino effects: In about ten per cent of all cases, Zhang and Zheng (2012) found that domino effects occurred. Most of these were releases followed by explosion. The authors explain that “when the cumulative amount of release exceeds the threshold, certain trigger factors (e.g., static electricity, light switches, cell phones) may cause the release to ignite.”

Flammable liquid is the most common hazardous chemical in accidents. Li et al. (2014) analyzed which type of hazardous chemical is the most common, and found that it is flammable liquid, followed by corrosive gases. Together these two categories make up 60% of the total. The main pollutants were petroleum including crude oil, heavy oil, gasoline etc., followed by acid base (sulfuric acid, hydrochloric acid, sodium hydroxide etc.).

Safety management systems were not in place: Li et al. (2014) found that overlapping functions between departments cause conflicts of interest and reduce administrative efficiency. As a result some enterprises ignore the qualification requirement and do not implement the national hazardous chemical safety management regulations.

Employees and managers lack qualifications: Li et al. (2014) also found that training of drivers is not good enough and drivers do not have the necessary qualification to transport hazardous chemicals. Drivers and guards have too little safety awareness and are not competent to deal with emergencies. Overloading, overspeeding, modification of dangerous chemical storage containers, and illegal operations do occur.

Defect equipment is a problem: The third cause of sudden chemical leakages identified by Li et al. (2014) is defect equipment. Ignoring daily maintenance, examination and management of transport vehicles and equipment may cause corrosion and ageing to go undetected.

Internal corporate management failure is behind the immediate causes: Zhang and Zheng (2012) comment that behind the rule-breaking behavior is found faulty procedures, poor training, and persistent use of too long shifts. These problems indicate internal corporate management failure as the root cause. An article by He et al (2014) suggests the "strong economic ties between local county governments and chemical small and medium enterprises (SMEs)" as a root cause.

According to Zhang and Zheng (2012) Jiangsu Province is the province in China with the highest number of hazardous chemical accidents in the period 2006-2010. Li et al (2014) have Zhejiang Province as the province with most accidents. In their analysis, Jiangsu Province is no. five.

3.5 The prioritization of certain industries

In China, some industries have been pointed out as high environmental risk ones. For example, the 12th 5 year Plan for Environmental Risk Prevention and Control of Chemicals, listed 7 key industries including petroleum processing, chemical raw materials and chemical products manufacturing, pharmaceutical manufacturing, non-ferrous metal smelting and textiles anchoring.

'Guidance for Implementing Pilot Work of Environmental Liability Insurance' (MEP, 2013) listed 5 industries: non-ferrous metal mining, non-ferrous metal smelting, lead acid battery manufacturing, leather and leather products, chemical raw materials and chemical products manufacturing.

An explicit priority of industries is less common in Europe and the US, but regulations like the EU Industrial Emissions Directive and the Seveso Directive do in practice emphasize the chemical industry and other industries likely to have many high-risk establishments.

4. Approaches

Part A of this framework suggests a seven step framework to approach environmental risk. Following a preamble that defines scope etc., the seven step approach emphasizes screening, study and gathering of information; assessment; and a risk-reduction program. These are steps and types of steps found in other guidance documents as well, e.g., guidance documents for Strategic Environmental Assessment. More concretely, the following themes are found in most approaches to managing environmental risk:

- Monitoring, inspections and procedures e.g, in enterprises with the purpose of *bringing forward information* about environmental risk
- Evaluations and assessments, sometimes based on models with the purpose of *determining acceptable* environmental risk.
- Plans and procedures including early warning systems with the purpose of *reducing environmental* risk to the acceptable level.

A successful approach to managing environmental risk also requires a *legal framework* and *institutions* with designated responsibilities. Further, it requires *implementation* of plans and procedures, which for instance requires an approach to funding. The legal basis, institutions and issues of implementation are not discussed here.

Approach to bringing forward information about risk

There are several hundred thousand industrial chemicals surrounding us. There are also several hundred thousand species in the ecosystem. For any industrial process there are a thousand things that can go wrong. In short, the management of environmental risk is cursed by dimensionality and only a few of the substance-process-receptor combinations are properly understood. Hence we should expect that there are many risks that nobody knows about. In addition, it is common for the regulated enterprise to have more information about risk than the regulator, and/or such information is easier for the enterprise to obtain. In such cases (nobody knows, and only the enterprise knows) an important part of any approach to environmental risk is bring forward information to the regulator and to society.

For instance, the Seveso Directives of the EU require enterprises to notify authorities about the amount of dangerous substances at their premises. Enterprises are required to prepare a major accident prevention policy, and regulators perform inspections to see that rules are followed. High risk enterprises are required to have additional safeguards: They should also write safety reports, prepare emergency plans, and they should make sure to inform the public about their practice.

These plans often rely on scenarios to understand what can go wrong and how to minimize consequences if something goes wrong. If an accident or near-miss has occured, regulators and the enterprises themselves will go through the chronology of events in minute detail, trying to learn from the experience.

The REACH Directive in Europe on hazardous chemicals gives the enterprises the burden of proof to convince regulators that environmental risks of the chemicals can be properly handled.

Sharing of information and the participation of the public, NGOs and the media are other aspects of the process to accumulate information about environmental risks – and also to discuss at the societal level the acceptable level of environmental risk.

Note that several of the approaches for bringing forward information are procedural in nature.

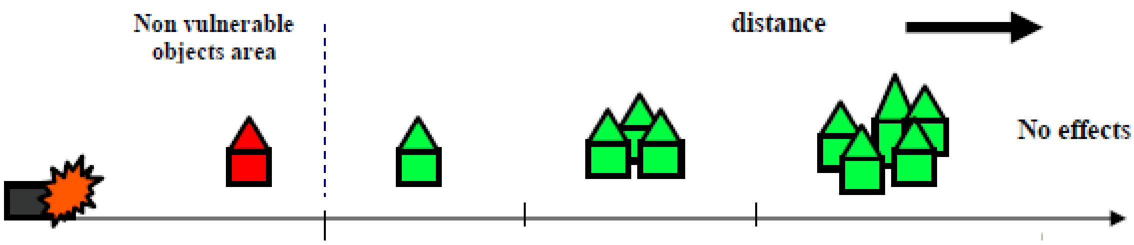
Approach to determining acceptable environmental risk

Arguably, the most advanced approach to assessing and determining environmental risk is found in the case of classical pollutants to air. Air quality guidelines for classical pollutants are based on the impact pathway approach. The impact pathway approach allows an estimate of environmental damage associated with exposure and also reduced damage (= benefits) from reduced exposure. Models help to translate air quality guidelines into emission ceilings in different regions. In Europe these regions are countries.

For hazardous chemicals the approach is cruder. In Europe the REACH directive specifies "substances of high concern". For these substances the process of REACH (registration, evaluation, authorization, restriction and enforcing) is particularly strict. Hazardous chemicals are also regulated in other ways: Some are prohibited, others are restricted to certain usage and/or regulated at the level of discharge. Regulators try to get at these substances during each step of their life cycle.[1]

Zoning is another approached that often is used. One example of zoning (though it is not always presented as such) is the concept of safe distance in the Seveso Directives. The idea is that there should be a safe distance surrounding high risk enterprises. The zoning requirement will be different for different land use purposes, see Figure 4.1.

Figure 4.1 The practice of safe distance, or zoning, in the Seveso Directives



Source: Basta et al. (2008).

Here zoning is related to the individual risk if there is a release from the plant. Typically housing development is not allowed if the risk of dying from exposure to the release is higher than one per million. Other installations such as parking lots and some commercial activities may be allowed. As distance increases the release disperses and the individual risk reduces.

To set safety distances it is common to use a consequentialist approach, in which the probability or frequency of incidents is ignored and one focuses on the consequence of

[1] The full story is told in chapter 3.4 of the International Experiences Report

the worst scenarios for incidents. This is the approach of Figure 4.1 since it focuses on consequences given a release. It is also possible to use a proper risk based approach. The consequentialist or risk based approach is sometimes carried out in an informal manner that relies on tradition and experience.

In Europe zoning is also used in quite different contexts. The Water Framework Directive determines water quality zones for different part of the water body. The OSPAR convention establishes marine protected areas. The Habitats Directive relies on a network of protected sites. It is as if these directives determine that the environmental risk either is present or not present in different areas. If it is present a protection zone is established. This either-or approach is crude, but it may be the only feasible approach in practice. To alleviate the crudeness regulators sometimes determine intermediate zones as well. In intermediate zones some commercial and industrial activities are allowed, and other activities are prohibited. The class I-V surface water categories in China arguably serve a similar purpose.

Approach to reducing environmental risk to an acceptable level

Emergency response plans are designed to reduce consequences in case an acute incident occurs. The incident may be the result of a hazardous chemical accident or it may be the result of unfavorable environmental conditions, as in cases of acute particulate matter pollution. An emergency plan may include elements of “early warning”, which are actions to be taken if there emerge signs of an imminent incident.

For emergency response plans including early warning one needs monitoring networks, a data management system for collecting and summarizing monitoring data, a public alert system using radio/tv, text messages, social media etc., lists of what-to-do tasks for different stakeholders (such as the public including hospitals, schools, enterprises and homes; and government agencies including transport). One also needs depots (regularly maintained and checked) with equipment of various sorts. It is necessary to perform drills and learn from the experience during drills.

Societal plans that are not of the emergency type are designed to reduce the probability (and sometimes consequences) of acute risk; and the probability and consequences of accumulated risk. These plans are often tightly related to the determination of acceptable risk. A river management plan will for instance include zones for acceptable water quality.

5. Models and tools

Several models and tools are available to support the management of environmental risk. Some are free and others are proprietary. Often it will be necessary to tailor the existing model to Chinese data and the Chinese situation more generally.

In many cases the tool takes the form of a procedure. For instance, the Industrial Emissions Directive, the Water Framework Directive, the REACH Directive and the Seveso Directives all specify procedures for managing environmental risk. The EU Eco-management tool EMAS is another example of a tool that specifies a procedure. ISO certification 14001 requires procedures, etc. Such procedural tools are similar to approaches and are not discussed in this chapter. We focus on tools in the form of lists and models that may have transfer value. Our survey is not exhaustive, but based on tools discussed in the International Experiences Report.

Tools in the form of lists

In several cases the European and international approach to managing environmental risks come down to lists of relevant issues. Several of these may be an inspiration for regulators in China. New knowledge tends to become available very quickly and one should not entirely rely on old lists. Lists that are updated regularly, usually offer the best advice. Some lists of interest are:

- Best available technique reference documents (BREF)[1] for determining what constitutes a best available technology (BAT) in a large number of industrial sectors. Environmental regulation often requires BAT.
- A list of 33 priority substances and 8 other pollutants[2] that define Good Chemical Status of a water body. Good Chemical Status is a concept of the Water Framework Directive.
- Annex XIV of the REACH Regulation lists Substances of Very High Concern (SVHC). This Authorization list, as it is called, contains substances that require authorization from the European Chemical Agency. The list currently contains 31

[1] BREFs can be found at http://eippcb.jrc.ec.europa.eu/reference/

[2] The list can be found at http://ec.europa.eu/environment/water/water-framework/priority_substances.htm. The EU Commission has proposed a new directive (COM (2011) 876) amending the current list of priority substances and other pollutants. The proposal includes a revised list of priority substances and provisions to improve the functioning of the legislation. The main features are: 15 additional priority substances (6 of them priority hazardous substances), stricter environmental quality standards for four existing priority substances, designation of two existing priority substances and priority hazardous substances, introduction of biota standards for several substances and provisions to improve the efficiency of monitoring. The proposal as well as background reports can be downloaded here: http://ec.europa.eu/environment/water/water-dangersub/lib_pri_substances.htm#prop_2011_docs

substances.[1] A second list contains candidate SVHCs. It currently contains 155 substances.[2] A third list contains substances (from the candidate list) recommended for inclusion in the authorization list. This list currently contains 22 substances.[3]

- As mentioned above there exists lists of the relative importance, per unit discharge, of thousands of discharge-receptor combinations.
- The Habitats Directive in Europe contains several lists of potential interest. Annex I is a list of natural habitat types that requires conservation in designated areas. Annex II is a list of animal and plant species that require protection within areas of conservation. Annex IV is a list of animals and plant species that need strict protection (in other words, a sub-set of list II). Annex V is a list of animals and plant species that may not be hunted or collected at will.[4]
- Most countries in Asia base their air quality standards on the WHO Air Quality Guidelines, US EPA National Ambient Air Quality Standards (NAAQS), and the European Union (EU) Air Quality Standards (AQS).[5]

Models and methods

Besides lists of issues of relevance there exist useful decision tools for different aspects of environmental risk management. Some are mentioned here.

Acute environmental risk and emergency response

- MEP 'Guidelines for Environmental risk assessment of Construction Projects' (2004) gives recommended models and methodologies on how to calculate the amount and rate of accidental leakage, such as hazardous substances diffused in water and air, oil slick, etc.[6]

- The ALOHA (Areal Location of Hazardous Atmospheres) is a program of the US EPA designed to model chemical releases for emergency responders and planners. It can estimate how a toxic cloud might disperse after a chemical release and also features several fires and explosions scenarios. ALOHA displays its estimate as a threat zone, which is an area where a hazard (such as toxicity,

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[1] The list can be found at http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list.

[2] The list can be found at http://echa.europa.eu/web/guest/candidate-list-table.

[3] The list can be found at http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list.

[4] The directive including annexes can be found at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:01992L0043-20070101. Choose from different languages.

[5] An entry point for air quality standards is available at http://cleanairinitiative.org/portal/airqualitystandards. Current EU standards can be found at http://ec.europa.eu/environment/air/quality/standards.htm

[6] The guideline is available at http://kjs.mep.gov.cn/hjbhbz/bzwb/other/pjjsdz/200412/W020110127329297430823.pdf.

flammability, thermal radiation, or damaging overpressure) has exceeded a user-specified Level of Concern (LOC). Other models with a similar purpose include the Phast model of DNV GL (proprietary) and the ADAM tool of the European Commission.[1]

- AirNow is another system developed by the US EPA and partners. Its intention is to forecast air quality based on data assembled by a large number of air quality agencies (more than 130 in number). They feed into the same system in order to construct reliable and fast air quality information to the public. The model also gives information to other systems, e.g., for emergency response. Versions of the model have been tested in Shanghai, Jiangsu and Zheijiang provinces of China.[2]
- APELL tools are provided by the UNEP/OCHA Environmental Emergency Centre[3]. A training kit, handbooks, the "Flash emergency assessment tool" and much more are offered.

Accumulated risk, water

- The WISER database contains information about the national assessment methods used to classify the ecological status of rivers, lakes, coastal and transitional waters. Member States of the European Union apply these methods in their monitoring programmes according to the EU Water Framework Directive.[4]
- The MONERIS (Modelling Nutrient Emission in River Systems) model is an emission model for point and diffuse sources of nutrients into a river stream, but it can also be adapted in order to deal with heavy metals and some priority substances. MONERIS will estimate the loads emitted from each point source (direct discharges, waste water treatment plant effluents), and through a series of diffuse pathways. MONERIS estimates the annual nutrient load in the river including hot spots. Management scenarios can also be modelled.[5]

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[1] The Aloha model is available at http://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/response-tools/aloha.html. The Phast model is available at http://www.dnv.com/services/software/products/phast_safeti/phast/. We have not been able to find a designated web page for the ADAM model.

[2] The AirNow model is available at http://www.airnow.gov/. AirNow International is available at http://www.airnow.gov/index.cfm?action=airnow.intlpartners.

[3] http://www.eecentre.org/About-EEC.aspx/lan/en-US

[4] More than 300 ecological assessment methods have been developed in Europe. The database is available here: http://www.wiser.eu/results/method-database/

[5] The MONERIS model is found at http://moneris.igb-berlin.de/index.php/model-structure.html.

Accumulated risk, air

- For simulation of air pollution and air quality MEP recommend models like SCREEN3, AERMOD, ADMS and CALPUFF.[1]

- Some models analyze the implications of economic activity for environmental performance and environmental risk. Computable General Equilibrium (CGE) models aim to explain economic activity and the influence on economic and environmental activity of policies such as energy levies. They can for instance account for rebound effects. The model GAINS (Greenhouse gas – Air pollution interactions and synergies) treats economic activity as a mostly independent (exogenous) driver, but models emission scenarios and emission control in detail. GAINS China is a model of China that is available for download.[2] MARKAL and its successor TIMES are energy sector models that have been used in China by the Energy Research Institute and others. The PRIMES model is another energy sector model.[3]

- The AIRQUIS model of the Norwegian Institute of Air Research is an air quality management model and database at the urban scale. It helps trace the emission pathway of pollution and warns about exposure risk. AIRQUIS is used in several cities of China.
- The US-EPA also has available tools and resources for tracing the emission pathway of pollutants, including emission modelling tools, a Greenhouse Gas Equivalencies Calculator, air quality models (like the Community Multi-scale Air Quality (CMAQ) model), the Benefits Mapping and Analysis Program (BenMAP) (a tool for estimating the health impacts and associated economic values), and the Hazardous Air Pollutant Exposure Model (HAPEM) (a screening-level exposure model appropriate for assessing average long-term inhalation exposures).[4]

[1] MEP provides explanations and auxiliary files that can are available at http://www.lem.org.cn/air/index.jhtml.

[2] The model also includes a valuable database. The GAINS China model is available at http://gains.iiasa.ac.at/gains/EAN/index.login.

[3] MARKAL and TIMES are available at http://www.iea-etsap.org/web/Markal.asp. The PRIMES model is available at http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=category&id=35:primes&Itemid=80&layout=default&lang=en

[4] CMAQ is found at http://www.epa.gov/AMD/Research/RIA/cmaq.html. BenMAP is found at http://www.epa.gov/air/benmap/. HAPEM is at http://www2.epa.gov/fera/human-exposure-modeling-hazardous-air-pollutant-exposure-model-hapem.

Accumulated risk, hazardous chemicals

- The EU Commission supports businesses affected by REACH as well as other programmes (OECD HPV, EU Biocides and others) by handing out (free of charge) the software application IUCLID, which simplifies capturing, managing, submitting and exchanging data on chemical substances.[1]
- The USEtox database is a scientific consensus database, endorsed by UNEP, for characterizing human and ecotoxicological impacts of chemicals.[2]

Other

- The US EPA runs a Risk Assessment web page, with a link to models, databases and guidance documents. 24 models for different purposes are listed (mostly different from those mentioned above).[3]
- For each site protected by the EU Habitats Directive national authorities have submitted a Standard Data Form (SDF) that contains a template for an extensive description of the site and its ecology.[4]

[1] The current version is IUCLID 5. It can be found at http://iuclid.eu/.

[2] USEtox can be found at http://www.usetox.org/.

[3] The Environmental Risk webpage can be found at http://www.epa.gov/riskassessment/. Click on models in right column to find the models.

[4] The Standard Data Form Resource page can be found at http://bd.eionet.europa.eu/activities/Natura_2000/reference_portal. The form itself is contained in the Commission Implementing Decision of 11 July 2011 (click on the html-version). Explanatory notes to the form are found at http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/standarddataforms/notes_en.pdf.

6. Policy and regulatory instruments

At a basic level policy instruments may be divided into incentive based or economic instruments on the one hand, and administrative command-and-control instruments on the other hand. Institutions and a legal basis underpin the instruments, but in this document we do not consider them instruments as such. Also, we do not discuss implementation issues. The effectiveness of any policy instrument is obviously reduced if it is not implemented.

Command and control instruments tell enterprises and the public what to do: Which technology to use, which substances not to use etc. This is both their strength and their weakness. It is a strength in the sense that authorities can be fairly certain of the outcome. Enterprises will use best available technology, nobody will use the prohibited substances etc. But this strength is also a weakness since there could have been smarter and less costly ways to obtain the same - or better - environmental outcomes in the receptor. To overcome the weakness it is not uncommon to grant exceptions to the general regulation, e.g. in certain areas the regulation is weakened, for enterprises of a certain age or size the regulation is weakened, etc. This encourages lobbying from regulated enterprises and may lead to web of quite complicated and detailed regulations that basically requires the regulator to think through a great number of circumstances. Examples of command-and-control instruments are required abatement equipment such as mandatory flue gas desulphurization (FGD) in power plants, required best available technology (BAT) in enterprises, regulation of pollution content in the waste stream.

With economic instruments the situation is the opposite. Economic instruments give enterprises and the public the flexibility to take characteristics like age, size and location into account. For instance, a large enterprise may have economics of scale that lead it to react differently to incentives than a small enterprise. On the other hand, the regulator cannot be certain of the outcome since it is up to the enterprises and the public how they will respond. Examples of economic instruments are emission levies, energy taxes and levies, deposit-refund systems.

Some current command-and-control instruments are designed to give enterprises a degree of flexibility. A ceiling on total emissions from an enterprise gives some flexibility and may be more efficient than requiring the use of a certain technology. At the same time, some economic instruments come with guaranteed environmental outcome. An emission trading system fixes total emissions in an area, for example. In these cases the distinction between command-and-control instruments and economic instruments become blurred. Besides, some environmental outcomes are difficult or expensive to monitor properly and it is better after all to regulate something that is easily visible, like best available technology. In general regulation should strive to give flexibility of response to the regulated party while paying attention to the possible difficulty of monitoring.

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Part E

Cost-Benefit Analysis of Environmental Risk Management Measures

TRIAL VERSION

1. Introduction

This article constitutes a part of the general framework of Chinese provincial, county-level and municipal plans for environmental risk prevention (jointly formulated by the Chinese Academy for Environmental Planning (CAEP) under the Ministry of Environmental Protection of PRC, Vista Analysis and the Center for International Climate and Environmental Research-Oslo (CICERO)), and aims mainly to improve and support steps 6 and 7 in the "Seven-step Method of Regional Risk Assessment" as explained in Part A.

Part A describes the *process* of risk assessment and reduction. Other documents under this general framework introduce some regional risk assessment methods. This document presents *some methods and models,* which can *serve the cost-benefit analysis of environmental risk management measures*, and intends to facilitate the operation of such methods as much as possible when ensuring that these methods are scientific and complete. It may provide guidance for those employees who want to understand the background knowledge of this process and methods or those who desire to improve and update the used risk assessment methods.

2. Methodology overview of environmental risk management measures

Environmental risk levels are determined by hazardous source, environmental risks receptor vulnerability and environmental risk prevention and emergency response capacity. Thus, to take proper measures, we can consider prevention from risk sources, risk receptors protection and risk prevention and emergency response capabilities.

Acute risk management

Currently, some regions suffer from improper layout and structure problems with high environmental risk level. In detail, there are many types of environmental risk enterprises, ports for transportation of dangerous chemicals, as well as tailings and other sources of risk. Also, the high water network density and the residential area located at the downwind of industrial area bring more problems. Moreover, there are important drinking water source protection areas, cross-sectional areas or population centers and other sensitive receptors; regional pollutants interception, environmental emergency monitoring and early warning systems. However, the decision making and rescue capacity is relatively weak.

To solve the above problem, measures can be taken regarding prevention and control of environmental risk sources, risk receptors protection as well as enhancement of risk prevention and emergency response capabilities, which are shown in Table 2.1.

Table 2.1 Control Measures for Regional Sudden Environmental Risk Control

Type	Name	Content
Prevention and control of environmental risk source	Adjustment of industrial structure and layout	In high environmental risk areas, eliminate the backward technology factory, shut down and ban access of enterprises that do not meet the industrial standards
	Strengthening environmental supervision of stationary sources	Urge the enterprises to acknowledge the responsibility for the prevention and control of environmental risk and carry out assessment among environmental ventures, tailings, oil and gas facilities, environmental ports as well as carry out emergency plans and emergency drills
	Strengthening mobile sources risk management	Urge enterprises involving dangerous chemicals transportation to carry out regular inspections of transport equipment maintenance, report dangerous chemicals transport routes and install GPS positioning system
Environmental risks receptor	Risk assessment of drinking water sources	Consider drinking water sources pollutant emissions, the total waterway transport of dangerous chemicals, population served by

protection		drinking water sources in terms of risk assessment and risk ranking.
	Environmental risk management of drinking water sources	For drinking water sources with higher environmental risks: by strengthening the upstream environmental risk investigation, strengthening water quality monitoring and setting up alternative water sources, etc., we can strengthen the management
	Setting up of safety distances and buffer zones	In strict accordance with the requirements of health protection, it is necessary to carry out adjustment of risk source layout and the relocation of receptors and require new businesses to follow the requirements of the safety distance. For the buildings that have been put into the industry area but do not meet the requirements of the safety distance, by reducing environmental risk materials volume or setting a buffer, we can reduce the impact of environmental emergencies on the risk receptors
Environmental risk prevention and control capacity building	Emergency monitoring capacity building	Carry out regular monitoring, configurating data collection and equipment maintenance for important sources of environmental risk, industrial parks and environmentally sensitive receptors
	Pollutant interception capacity building	Considering topography, hydrology and other factors to have a proper rational distribution and regulation of river gates, dams, diversion ditches and pollutant dosing points so as to lower the impact of the accidents
	Regional environmental emergency plan and exercises	Strengthen the planning and response to sudden accidents in industrial parks and administration regions, especially for vulnerable receptors
	Environmental emergencies early warning and emergency command platform	Establish early warning and emergency command platform to carry out concentration monitoring for priority sources and sensitive receptors; establish and improve the communication system that can send warning messages in time to emergency response agencies and experts
	Professional emergency rescue team building and emergency supplies configuration	Work agencies of environment, public security, fire, health and other institutions should establish regional environmental emergency rescue team; according to the regional environmental emergency types, prepare emergency supplies and carry out regular updates, maintenance, rotation

	Emergency funding	According to regional environmental risk levels, support appropriate funds for professional training of the emergency response team, environmental emergency expert database construction and maintenance, etc.

Accumulated risk management

Nowadays, the accumulated risk is relatively high. To be detailed, there are large amounts of industrial and transport pollution and of use of chemical fertilizers. Also, garbage and sewage treatment rates are low, resulting in decline in environmental quality. The high water network density as well as poor air quality and water quality result in several environmental exposure pathways. The large area of nature reserves and the large population of the elderly and children in the region make environmental risks receptor fragile. Moreover, there are low environmental pollution control investments, not enough environmental management and low levels of medical and health relief.

To solve the problems, we can take measures in terms of source risk prevention, risk receptors protection as well as enhancement of risk prevention and emergency response capabilities, which are shown in Table 2.2.

Table 2.2 Control Measures for Regional Accumulative Risk Management

Type	Name	Content
Prevention and control of environmental risk source	Control on the total amount of industrial and transport pollutant emissions	Reduce the emissions of SO_2, NO_x and particulates, and monitor the specific pollutant emissions in major industries and industrial zones
	Management of agricultural pollution	According to soil fertility, crop type, climatic conditions, carry out reasonable use plans of pesticides and chemical fertilizers and strictly control the sources of agricultural fertilizers to avoid excessive application
	Management of domestic pollution	Increase the treatment rate of domestic garbage and sewage; carry out classification and centralized treatment of garbage and sewage
Environmental risk receptor protection	Strengthen protection of ecological environment	Strengthen regional water system construction and comprehensive renovation of urban water to eliminate the phenomenon of black-odor
	Strengthen environmental protection publicity and education	Raise public awareness of environmental protection, especially in terms of heavily polluted air and water

Environmental risk prevention and control capacity building	Strengthen information disclosure and public participation	Strengthen regional environmental contingency plans, information disclosure and environmental impact assessment; actively explore the use of internet, wechat and other platforms to encourage public reporting of surrounding environmental pollution incidents
	Improve environmental monitoring and health care processes	Identify degradation of the environment in time by using data from national, provincial and local level and carry out management accordingly; carry out health care for residents near mining and industrial zones
	Environmental capital investment	According to regional environmental risk level, support funding for environmental protection environmental publicity and education, as well as for dealing with environmental disputes

3. Cost-Benefit Analysis Methods

Analysis Procedure

Breakdown of CBA procedure involves 7 steps: 1) Identifying the possible plans and approaches in problem solving; 2) Description of reference scenario (i.e., the trend under the current conditions) to compare the result after implementing those approaches; 3) Identifying associated impacts of different approaches, through methods like experts insights and on-site investigation; 4) Monetizing the impacts in terms of the costs and benefits of each approach, and it is important to properly considerate the starting point and discount rate; 5) Comparing the costs and benefits. However, the approach or plan of the best CBA does not necessarily count as the most favourable one, and the best option depends on the priority of different factors to the decision maker, such as cost, benefit, and time frame; 6) Based on objective analysis and the consideration of feasibility, conducting sensitivity and uncertainty analysis to fully uncover any potential risks in implementing the plan or project; 7) Recommending one or more projects and making suggestions based on the result of the analysis.

Though costs can be normally denoted in currency value, benefits, especially environmental and social benefits, are sometimes hard to quantify in currency value. If the major benefits lack currency value, it is recommended to employ cost-effect analysis or cost-impact analysis to conduct the assessment.

Overview of Valuation Methods

Methods of cost-benefit analysis of environmental risk management measures include the market value or productivity method, the alternative market method, the investigation and assessment method, and the recovery and preventive method. Key techniques and application examples of a variety of methods are shown in Table 3-1 (Liu Yonghong, 2013).

Table 3.1 Key Techniques and Application Examples of Cost-Benefit Analysis

Type	Analysis and Assessment Technique	Application Example
Market value or productivity method	Simple market price or productivity method Human capital method or income loss method Opportunity cost method or preset income method	A rise in crop value and a fall in health risk due to air pollution control; Income lost due to a rise in disease and death (an increase in health risk) by water pollution; Economic loss due to farmland occupancy by garbage or waste

Alternative market method	Property value method Wage difference method Travel cost method	A fall in residential property value due to air pollution; Some wages that workers are willing to lose to improve environmental quality; Entertainment benefit assessment for opening or preserving parks.
Investigation and assessment method	Bidding games Weighing game method Costless choice method Priority assessment method Delphi method	Willingness to pay for water quality; River suitability assessment; Hypothetical application of water pollution; Assessment of desire to pay for water quality improvement.
Recovery and preventive method	Virtual treatment method	Farmland governance cost as the benefit of farmland pollution control

Cost-Benefit Comparison

Net present value of the difference between benefits and costs of environmental risk management measures can be used to indicate the actual effectiveness of the approaches and projects. The formula is listed as follows.

$$NB = TB - TC$$

Where *NB* indicates the present value of net benefits of environmental risk management measures;

TB indicates the present value of benefits of environmental risk management measures;

TC indicates the present value of costs of environmental risk management measures;

The net present value approach aims to compare the net value of benefits and costs, and one certain plan is favourable when $NB \geq 0$, otherwise it is not. If alternative plans or measures are analysed, the plan/measure with the highest *NB* value should be chosen.

4. Building of Cost-benefit Function of Regional Environmental Risk Management

Building of Cost Function of Regional Environmental Risk Management

According to Section 2, the regional environmental risk management measures can be roughly divided into acute environmental risk management and accumulative environmental risk management measures. In detail, this includes the prevention and control of environmental risk sources, environmental risks receptor protection, environmental risk prevention and control capacity-building and other categories. In specific analysis, we list separately the acute and accumulative environmental risk management measures in each category and the specific measures, content, the main responsibility, quantities of engineering, estimated serving years and the impact from the measures. For the calculation of the cost of environmental risk management, you can use direct market method, which calculate the actual cost of inputs. In the monetization process, the need to consider the time of measure implementation and the discount rate (Zhang Mei, 2005).

Table 4.1 Types of Cost from Regional Environmental Risk Management Measures

Type of environmental risk	Type of measures	Name	Content	Estimated quantity of engineering	Years of implementation	Impact
Acute						
Accumulated						

Cost of regional environmental risk management=Cost of risk source prevention and control+Cost of environmental risk receptor protection+Cost of environmental risk control capacity construction.

Building of Benefit Function of Regional Environmental Risk Management

After the environmental pollution incident, if no emergency response measures are taken, there will be adverse effects to surrounding water, air, soil and ecosystems, and it will impact the surrounding residents' daily life and production. If we take effective risk prevention and emergency response, we will be able to reduce and avoid significant environmental, social and economic impacts. Therefore, we can take the cost from not taking any risk prevention and emergency response actions as the environmental risk management measure benefits. However, one single risk management measure will not eliminate all costs from not taking action. The contribution of each measure should be assessed clearly.

Avoid personal injury

It means the benefits from avoiding the unfavorable change of environment that leads to adverse impacts to human life, health, physical suffering, human illness, disability, death or mental state.

Avoid property loss

The benefit gained from avoiding property loss or value reduction due to environmental pollution or ecological damage, and the necessary proper cost of protection against the damage.

Cost from dealing with emergency

During the period of dealing with environmental emergency, the government and related institutions pay for the measures that help avoid or control the damage to public health, property and the ecological environment. This term represents the benefit brought by this.

Avoid ecological damage

The benefit from avoiding environmental pollution from observable or measurable adverse change from direct or indirect physical, chemical or biological change, and from damage of ecological system service ability.

Table 4.2Terms of regional environmental risk management cost

Terms	Contents
Avoid personal injury	The benefits from avoiding the unfavorable change of environment that leads to adverse impacts to human life, health, physical suffering, human illness, disability, death or mental state
Avoid property loss	The benefit gained from avoiding property loss or value reduction due to environmental pollution or ecological damage, and the necessary proper cost for protection against the damage.
Cost from dealing with emergency	The benefit from dealing with environmental emergency when the government and related institutions pay for the measures that help avoid or control the damage to public health, property and the ecological environment.
Avoid ecological damage	The benefit from avoiding environmental pollution from observable or measurable adverse change from direct or indirect physical, chemical or biological change, and from damage of ecological system service ability.

We calculate the cost from environmental damage without proper control measures and take part of it as the benefit from regional environmental risk management. The environmental damage includes personal injury, property loss, ecological environment damage and the cost from responding to emergencies. For the detailed amount, there are references like «Recommended Methods for Environmental Emergency Disposal and Environmental Damage Assessment», «Recommended Methods for Environmental Damage Identification and Evaluation (2nd Edition)», «Interpretation on the Trial of Personal Injury Compensation by Supreme Court», «Explanation on Responsibility of Mental Damage by Supreme Court» and so on.

Benefit from “maximal” environmental risk control=Cost from environmental damage=Cost from personal injury+Property loss+Cost from ecological environment damage+Cost from emergency response

5. Case Study of Cost-benefit Analysis on Environmental Risk Management Measures[1]

In this section, we introduce the framework of cost-benefit analysis for major environmental pollution incidents and emergency control plans as well as case studies of water quality within a basin.

5.1 Framework of Cost-benefit Analysis for Major Environmental Pollution Incidents and Emergency Control Plans

Major environmental pollution accident prevention and emergency prevention cost components include input costs and contingency costs of inputs. The former includes major environmental risk sources, forecasting, major environmental risk source database construction, environmental pollution on-line monitoring system construction, corporate environmental emergency plan, corporate safety and environmental awareness training, alternate water sources and alternate facilities; the latter including emergency monitoring system construction, emergency materials and equipment construction, emergency rescue, command, information release system construction, emergency specialist library building, emergency training and drills. Cost can be calculated with direct market method.

Major environmental pollution accident prevention and emergency benefits include environmental benefits, social and economic benefits. Environmental benefits are the reduction of the degree of environmental pollution and the impact of the pollution scope and duration; Economic benefits are the reduction of pollution control fees and environmental pollution accident emergency funding input; Social benefits are the avoidance of mass incidents and public fears caused by the environmental pollution. Compared to economic benefits, environmental and social benefits are not easy to calculate. The economic benefits can be calculated using the cost from the emergency plan or in the absence of risk prevention and control situation. Economic losses can be divided into direct and indirect economic losses. The former include property damage, loss of environmental resources, casualty losses, fisheries losses, emergency disposal costs; indirect economic loss includes loss in industry, agriculture and livestock breeding, the tertiary industry, restoration ecology, environmental resources, payment due to an accident, and other expenses of adding new employees, lost wages, reduced work efficiency and corporate reputation decline. When calculating direct and indirect costs it is important to avoid double counting. Various types of losses can be calculated by the method of direct marketing method, human capital approach, willingness-to-pay method and other methods.

[1] Based on Xie Donghai (2006).

Case Study of Cost-benefit Analysis of Major Environmental Pollution Incident in a Certain River Basin

The main river of a basin has a length of more than 600 km and it flows across City A, B, C and D before entering the Yangtze River. The area of the river basin is 27 thousand square kilometers. On Feb. 25, 2004, a chemical company caused an acute water pollution incident by discharging a large amount of wastewater that did not meet the water quality standards, due to equipment failure. According to the estimation by environmental agencies, the nitrogen ammonia concentration was 400~4000mg/L, which was far above the standard in GWPB (≤60mg/L). According to the examination results of Feb. 27 to March 2 at Jianyangshiqiao Plant, the concentration of ammonia nitrogen of the water source and the effluent are 16.35~33.27mg/L and 17.30~34.32mg/L respectively, which are more than the GB3838-2002 standard for surface water type III (ammonia nitrogen ≤1.0mg/L); the nitrite concentrations are 1.20~3.00mg/L and 0.70~2.80mg/L, far above the WHO guideline (0.2mg/L); Nitrate concentrations are 15.50~18.26mg/L and 16.98~19.50mg/L, below the standard by the guideline of drinking water (2001) (≤20mg/L). After the pollution accidents occurred, the departments of health, water conservancy and environmental protection took immediate action and the pollution sources were cut on March 2. Water was let out from the upstream reservoir drain to flush out pollutants. The ammonia nitrogen source was effectively controlled within 11 days. Other affected sections came back to the normal state 11 days and 25 days after the accident. The accident caused a total emission of about 1,600 tons of ammonia, and seriously polluted normal life and production downstream and other places along the sides. This affected a population of nearly 1.2 million and caused serious economic losses in agriculture, fisheries, food and beverage industry and so on. According to the estimation by civil affairs department, statistical departments and environmental protection departments, the direct economic losses caused by the pollution incident was 219 million yuan, and indirect economic losses of about 500 million yuan.

Calculation of Economic Losses from the Accident

The watershed environmental pollution accident caused huge economic losses to agriculture, fisheries, food and beverage industry and other industries, which mainly include the following parts.

Without considering the basin ammonia background value, in accordance with the principle of mass conservation, the watershed will have 1.07 billion tons of water over IV class water standards. However, when considering the water purification, there were 800 million tons of sewage. According to the Statistical Yearbook, the water needs from agricultural, industrial and domestic water distribution obeyed the ration of 4:1.8:1. Thus, there were 470 million tons of agricultural water, 212 million tons of industrial water and 118 million tons of domestic water.

Losses of water resource

According to the (2003)43 document of City A, the price for domestic water is 1.68 yuan/t. Assuming that the domestic water and industrial water has the same price, and the adjusting coefficient is 0.05 due to the fact that not all the water is sewage, which means that there are n tons of polluted living water, but due to the purification effect of water treatment plants, as well as the public choose bottle water or other water as living water, the real loss of living water loss in only 0.05×n tons. Under this assumption the loss of water resource is V_w=0.05×3.3×1.68×10=22720 thousand yuan.

Industrial loss

According to the water resource report in 2004, the industrial output of per ton industrial water was 41 yuan. Assuming the adjusting coefficient of 0.05, the industrial loss would be L_2=0.05×2.12×41×100=434.6 million yuan.

Agricultural loss

The agriculture loss is mainly due to the reduction in production due to irrigation sewage and the lowering of quality. In this case, the main pollutant is the ammonia nitrogen, which has no standard in the GB5084-92 in terms of agricultural irrigation water. There is only a limitation of the Kjeldahl nitrogen (water farming: 12mg/L; dry farming: 30 mg/L; vegetable ： 30 mg/L). The amount of polluted water is 23.5 million ton, and the irrigation area is 4400 mu. According to the research results by the agricultural environment research center, the reduction of production in the sewage irrigation area is 14 kg/mu. Assume that the price of the crop is 1.8 yuan/kg. By using the market price method we get the agricultural loss Vb=14×4400×1.8×10≈110 thousand yuan.

Losses in fishery

According to the Ministry of Agriculture’s water pollution accident loss calculation method of fishing regulations, the pollution accidents caused economic losses of 11 million yuan.It’s the loss of wild and farmed fish death caused by water pollution.

Losses from human sickness and casualty

Because after the occurrence of pollution accidents, the domestic water supply cut-off was just in time, the accident caused no casualties and health coverage staff. Therefore, this loss is zero.

Other maintenance and propaganda cost

According to the input after the pollution, if the cost of environmental accidents information publication by newspaper, radio and TV is 6 million yuan, the cost for backup water source is 3 million yuan and the artificial rainfall to wash away the pollution is 1 million yuan, the water flow is about 10 million yuan, then the total cost will be L_4=600+100+300+1000=20 million yuan.

All the economic losses and the total loss are listed in Table 5.1. We can see that the calculated economic loss is more than the direct economic loss of 21.9 billion yuan estimated by the statistic bureau. This is because we fully consider the direct and indirect losses.

Table 5.1 Economic Losses

Terms	Losses (million yuan)
Losses of water resource	22.72
Industrial losses	434.6

Agricultural losses	0.11
Losses in fishery	11
Losses from human sickness and casualty	0
Other maintenance and propaganda cost	20
Total	488.43

Cost Analysis of Environmental Risk Management

If the basin strengthens prevention and response and timely implementation of emergency plans, it will effectively prevent and reduce the occurrence of major environmental pollution accident and reduce economic losses. According to the aforementioned major environmental pollution accident prevention and emergency investment analysis, watershed contingency inputs are shown in Table 5.2.

Table 5.2 Cost Analysis

Terms	Cost (million yuan)
Major environmental risk source database building	0.3
Environmental emergency monitoring system	10
Online monitoring system for major environmental risk source	30
Emergency rescue command system	5
Emergency specialist library construction	0.5
Input for emergency measures	8
Total	53.8

Benefit Analysis for Environmental Risk Management

(1) The development of contingency plans will consist of major hazard database construction, emergency monitoring system, major hazard line monitoring system, emergency rescue command system and emergency measures. This will be totally 53.8 million yuan.

These investments will effectively guarantee that when the accident occur, we can make the fastest, most accurate response, to develop the best treatment options so as to reduce the economic loss of accidents to a minimum. Measures of risk management can avoid domestic water loss, industrial loss, agricultural loss, loss of fisheries, other protective and promotional and other expenses of totaling 488.43 million yuan. The net benefit=total benefit-input=488.43-53.8=454.63 million yuan.

(2) Emergency plans and environmental risk control measures have certain social benefits, whose value is difficult to measure in monetary value. Panic of emergence among residents in severely affected areas and even the local social disorder caused by unrest and a series of social problems can be avoided or controlled with environmental risk management measures, resulting in corresponding social benefits.

(3) Implementation of environmental risk management measures also has some environmental benefits. For example, the development of contingency plans before the major pollution accident can change the route of the waterflow and reduce the polluted area by introducing the pollutants into other tributaries of land followed by treatment processes, which bring great benefit for the basin's ecological environment.

References to Part E

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