

Cranfield University

Brian MacGillivray

Benchmarking risk management practice within the water utility sector

School of Applied Sciences

PhD

Cranfield University

School of Applied Sciences

PhD

2006

Brian MacGillivray

Benchmarking risk management practice within the water utility sector

Supervisors: Professors Simon Pollard and John Strutt

December 2006

©Cranfield University 2006. All rights reserved. No part of the document may be reproduced without the written permission of the copyright owner.

This thesis is submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

## ABSTRACT

Explicit approaches to risk analysis within the water utility sector, traditionally applied to occupational health and safety and public health protection, are now seeing broader application in contexts including corporate level decision making, asset management, watershed protection and network reliability. Our research suggested that neither the development of novel risk analysis techniques nor the refinement of existing ones was of paramount importance in improving the capabilities of water utilities to manage risk. It was thought that a more fruitful approach would be to focus on the implementation of risk management rather than the techniques employed *per se*.

Thus, we developed a prescriptive capability maturity model for benchmarking the maturity of implementation of water utility risk management practice, and applied it to the sector via case study and benchmarking survey. We observed risk management practices ranging from the application of hazard and operability studies, to the use of scenario planning in guiding organisational restructuring programmes. We observed methods for their institutionalisation, including the use of initiation criteria for applying risk analysis techniques; the adoption of formalised procedures to guide their application; and auditing and peer reviews to ensure procedural compliance and provide quality assurance.

We then built upon this research to develop a descriptive<sup>1</sup> capability maturity model of utility risk analysis and risk based decision making practice, and described its case study application. The contribution to knowledge of this stage of the research was three-fold, we: synthesized empirical observations with behavioral and normative

---

<sup>1</sup> Although the model retained its normative character, in the sense that it distinguished between high and low maturity risk management, it was rooted in firmer empirical grounds. We emphasise its descriptive nature, as scholarly work of this nature is lacking in risk management, as we shall highlight later.

theories to codify the processes of risk analysis and risk based decision making; placed these processes within a maturity framework which distinguishes their relative maturity of implementation from *ad hoc* to adaptive; and provided a comparative analysis of risk analysis and risk based decision making practices, and their maturity of implementation, across a range of utility functions.

The research provides utility managers, technical staff, project managers and chief finance officers with a *practical* and systematic understanding of how to implement and improve risk management, and offers preliminary guidance to regulators concerning how improved water utility governance can be made real.

## **ACKNOWLEDGEMENTS**

The work contained in this thesis was kindly sponsored by the UK Engineering and Physical Sciences Research Council (EPSRC), the American Water Works Association Research Foundation (AWWARF), and a consortium of international water utilities, without whom this project would not have been possible.

Thanks go to my supervisors John Strutt and especially Simon Pollard for support and encouragement, and to Paul Hamilton for advice along the way.

Also, thanks to my family and friends, you know who you are (at least I hope the former do anyway).

# TABLE OF CONTENTS

	<b>Page</b>
<b>ABSTRACT</b>	iii
<b>ACKNOWLEDGEMENTS</b>	v
<b>TABLE OF CONTENTS</b>	vi
<b>LIST OF FIGURES</b>	xi
<b>LIST OF TABLES</b>	xiii
<b>Chapter 1 Critical overview of thesis</b>	1
<b>1.1 INTRODUCTION</b>	2
<b>1.2 LITERATURE REVIEW</b>	4
<b>1.3 RESEARCH AIM AND OBJECTIVES</b>	5
<b>1.4 DEVELOPMENT OF RISK MANAGEMENT CAPABILITY MATURITY MODEL</b>	6
<b>1.5 APPLICATION OF RISK MANAGEMENT CAPABILITY MATURITY MODEL</b>	12
<b>1.5.1 Industrial case study</b>	12
<b>1.5.2 Benchmarking survey</b>	13
<b>1.5.3 Summary of findings</b>	13
<b>1.5.4 Limitations and their implications for subsequent research</b>	14
<b>1.6 DESIGN AND APPLICATION OF CAPABILITY MATURITY MODEL FOR BENCHMARKING RISK ANALYSIS AND RISK BASED DECISION MAKING PRACTICE</b>	16
<b>1.6.1 Re-conceptualisation of risk management</b>	16
<b>1.6.2 Research methods for design and application of revised maturity model</b>	18
<b>1.6.3 Architecture of capability maturity model for benchmarking risk analysis and risk based decision making practice</b>	21
<b>1.6.4 Summary of the distinctions between the RM-CMM and the revised capability maturity model</b>	30
<i>1.6.4.1 Changes in the selection of processes</i>	30
<i>1.6.4.2 Changes in the selection of practices</i>	33
<i>1.6.4.3 Changes in the selection of attributes which define process maturity</i>	33
<i>1.6.4.4 Changes in the distinctions between maturity levels</i>	34
	vi

1.6.4.5 <i>Changes in the approach to evaluating process maturity</i>	35
1.6.5 <b>Research findings</b>	35
<b>1.7 CONTRIBUTION TO KNOWLEDGE</b>	36
1.7.1 <b>Design and application of RM-CMM</b>	36
1.7.2 <b>Design and application of capability maturity model for benchmarking risk analysis and risk based decision making practice</b>	37
1.7.2.1 <i>Novelty in coding of risk analysis</i>	38
1.7.2.2 <i>Novelty in coding of risk based decision making</i>	40
1.7.2.3 <i>Novelty in coding of maturity hierarchy</i>	43
1.7.2.4 <i>Utility of capability maturity model for benchmarking risk analysis and risk based decision making practice</i>	46
1.7.2.5 <i>Novelty in empirical findings</i>	47
<b>1.8 CONCLUSIONS</b>	48
<b>1.9 FUTURE RESEARCH</b>	50
<b>1.10 REFERENCES</b>	51
<b>Chapter 2 Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making</b>	59
<b>2.1 INTRODUCTION</b>	61
2.1.1 <b>Background</b>	61
2.1.2 <b>Risk analysis and decision-making</b>	63
2.1.3 <b>The risk hierarchy</b>	65
<b>2.2 STRATEGIC RISK ANALYSIS</b>	66
2.2.1 <b>Regulatory risk</b>	68
2.2.2 <b>Competition risks</b>	71
2.2.2.1 <i>Comparative competition</i>	71
2.2.2.2 <i>Capital market competition</i>	72
2.2.2.3 <i>Competition for the market</i>	74
2.2.2.4 <i>Product market competition</i>	75
2.2.3 <b>Business process re-engineering risks</b>	77
2.2.4 <b>Technological risk</b>	80
2.2.5 <b>Outsourcing risks</b>	85
2.2.6 <b>Employee retention</b>	86
2.2.7 <b>Assessing investment risks</b>	89
2.2.7.1 <i>Assets-in-place</i>	90

2.2.7.2 <i>Opportunities</i>	93
2.2.7.3 <i>Joint-ventures</i>	94
<b>2.3 PROGRAMME RISK ANALYSIS</b>	<b>95</b>
<b>2.3.1 Asset management</b>	<b>96</b>
2.3.1.1 <i>Spatial context of risk</i>	104
<b>2.3.2 Catchment management</b>	<b>106</b>
<b>2.3.3 Network analysis</b>	<b>113</b>
<b>2.3.4 Vulnerability assessments</b>	<b>116</b>
<b>2.4 OPERATIONAL RISK ANALYSIS</b>	<b>118</b>
<b>2.4.1 Public health and compliance risk</b>	<b>118</b>
<b>2.4.2 Reliability analysis</b>	<b>123</b>
<b>2.5 CONCLUSION</b>	<b>127</b>
<b>2.6 REFERENCES</b>	<b>129</b>
<b>Chapter 3 Benchmarking risk management within the international water utility sector. Part I: design of a capability maturity methodology</b>	<b>146</b>
<b>3.1 INTRODUCTION</b>	<b>148</b>
<b>3.2 RISK MANAGEMENT IN THE WATER SECTOR</b>	<b>150</b>
<b>3.3 OVERVIEW OF CAPABILITY MATURITY MODELLING</b>	<b>151</b>
<b>3.4 RATIONALE OF RESEARCH METHODOLOGY</b>	<b>153</b>
<b>3.5 RISK MANAGEMENT CAPABILITY MATURITY MODEL</b>	<b>155</b>
3.5.1 <i>Model overview</i>	155
3.5.2 <i>Risk management maturity levels</i>	156
3.5.3 <i>Risk management processes</i>	161
3.5.4 <i>Attributes</i>	165
3.5.5 <i>Internal structure of process assessment framework</i>	167
3.5.6 <i>Internal structure of process improvement framework</i>	168
<b>3.6 ILLUSTRATING THE RM-CMM</b>	<b>170</b>
<b>3.7 MODEL APPLICATION</b>	<b>172</b>
<b>3.8 CONCLUSIONS</b>	<b>173</b>
<b>3.9 REFERENCES</b>	<b>173</b>
<b>Chapter 4 Implementing risk management: a study of</b>	<b>178</b>



<b>improving performance within a water utility</b>	
<b>4.1 INTRODUCTION</b>	180
<b>4.2 METHODS</b>	180
<b>4.3 RESULTS AND DISCUSSION</b>	184
<b>4.4 CONCLUSIONS</b>	189
<b>4.5 REFERENCES</b>	189
<b>Chapter 5 Benchmarking risk management within the international water utility sector Part II: a survey of eight water utilities</b>	192
<b>5.1 INTRODUCTION</b>	194
5.1.1 Risk management in the water utility sector	194
5.1.2 Risk management capability maturity model (RM-CMM)	195
<b>5.2 METHODOLOGY</b>	198
<b>5.3 RESULTS AND DISCUSSION</b>	200
5.3.1 Strategic risk planning	203
5.3.2 Establishing risk acceptance criteria	203
5.3.3 Risk analysis	205
5.3.4 Risk based decision making and review	209
5.3.5 Risk response	210
5.3.6 Risk monitoring	211
5.3.7 Integrating risk management	213
5.3.8 Supply chain risk management	214
5.3.9 Change risk management	215
5.3.10 Education and training in risk management	216
5.3.11 Risk knowledge management	218
<b>5.4 CONCLUSIONS</b>	219
<b>5.5 REFERENCES</b>	220
<b>Chapter 6 Benchmarking risk analysis practice in the international water sector</b>	223
<b>6.1 INTRODUCTION</b>	225
<b>6.2 RESEARCH SCOPE</b>	226
<b>6.3 METHODS – RISK MANAGEMENT CAPABILITY MATURITY MODEL</b>	227

<b>6.4 RESULTS AND DISCUSSION</b>	229
<b>6.4.1 Process engineering</b>	229
<b>6.4.2 Business planning</b>	230
<b>6.4.3 Asset management</b>	231
<b>6.4.4 Drinking water quality management</b>	232
<b>6.5 THE PRACTICAL LESSONS</b>	234
<b>6.6 CONCLUSIONS</b>	235
<b>6.7 REFERENCES</b>	236
<b>Chapter 7 A capability model for benchmarking risk analysis and risk based decision making practice, with case study application to the water sector</b>	238
<b>7.1 INTRODUCTION</b>	240
<b>7.2 RESEARCH SCOPE</b>	241
<b>7.3 A CAPABILITY MATURITY MODEL FOR RISK ANALYSIS AND RISK BASED DECISION MAKING</b>	242
<b>7.4 RESEARCH METHODS</b>	252
<b>7.5 RESULTS AND DISCUSSION</b>	254
<b>7.5.1 Risk analysis: observed practices</b>	254
7.5.1.1 <i>Hazard identification</i>	257
7.5.1.2 <i>Hazard precursor identification</i>	258
7.5.1.3 <i>Consequence evaluation</i>	259
7.5.1.4 <i>Likelihood evaluation</i>	262
<b>7.5.2 Risk analysis: maturity of implementation</b>	264
7.5.2.1 <i>Procedures</i>	266
7.5.2.2 <i>Initiation criteria</i>	267
7.5.2.3 <i>Stakeholder engagement</i>	269
7.5.2.4 <i>Input data management</i>	269
7.5.2.5 <i>Competence</i>	270
7.5.2.6 <i>Verification: procedural compliance</i>	271
7.5.2.7 <i>Verification: quality control</i>	272
<b>7.5.3 Risk based decision making: observed practices</b>	273
7.5.3.1 <i>Establish criteria for evaluating alternative risk reduction options</i>	276
7.5.3.2 <i>Identify risk reduction options</i>	277
7.5.3.3 <i>Evaluate options</i>	279

<b>7.5.1 Risk based decision making: maturity of implementation</b>	280
<b>7.6 CONCLUSIONS</b>	281
<b>7.7 REFERENCES</b>	282
<b>Appendices</b>	

## LIST OF FIGURES

	<b>Page</b>
<i>Figure 1.1 Re-conceptualisation of a priori risk management processes.</i>	18
<i>Figure 1.2 Basic illustration of the progression from the RM-CMM to the revised capability maturity model for benchmarking risk analysis and risk based decision making practice.</i>	20
<i>Figure 1.3 Flow charts of the practices which comprise the risk analysis process (left) and the risk based decision making process (right). Those encased are considered key rather than critical practices, an important distinction in evaluating process maturity.</i>	23
<i>Figure 2.1 Decision Framework for the Offshore Oil Industry (UK Oil Operators Association, 1999 with permission).</i>	64
<i>Figure 2.2 The risk hierarchy (adapted from Prime Minister's Strategy Unit, 2002).</i>	66
<i>Figure 2.3 Technology risk algorithm (Hartmann and Lakatos, 1998).</i>	84
<i>Figure 2.4 Illustrative fault tree for turbidity non-compliance (after Demotier et al., 2002).</i>	102
<i>Figure 2.5 Reliability block diagrams (after Cyna, 1997).</i>	103
<i>Figure 2.6 Risk-based workforce planning (after Pollard et al., 2002).</i>	108
<i>Figure 2.7 Methodology for reliability analysis of a water treatment plant (after Cyna, 1997).</i>	127
<i>Figure 3.1 The risk hierarchy (adapted from Prime Minister's Strategy Unit, 2002).</i>	151
<i>Figure 3.2 Research methodology for design of RM-CMM.</i>	154
<i>Figure 3.3 Overview of the RM-CMM (after Strutt et al., 2005).</i>	156
<i>Figure 4.1 Structure of risk management capability maturity model.</i>	183
<i>Figure 4.2 The case study utility's risk management maturity profile by self-assessment.</i>	184
<i>Figure 5.1 Overview of the RM-CMM (after Strutt et al., 2005).</i>	196
<i>Figure 5.2 Boxplot of the sample risk management process maturity by self-assessment.</i>	201
<i>Figure 5.3 Spider diagrams of organisational maturity by self-assessment.</i>	202
<i>Figure 6.1 The risk hierarchy (adapted from Prime Minister's Strategy Unit,</i>	225

2002).

- Figure 7.1 Flow chart of the practices which comprise the risk analysis process. Those encased are considered key rather than critical practices, an important distinction in evaluating process maturity.* 245
- Figure 7.2 Flow chart of the practices which comprise the risk based decision making process. Those encased are considered key rather than critical practices, an important distinction in evaluating process maturity.* 246
- Figure 7.3 The reciprocal correlation between consequence severities and their forecast cumulative likelihoods of occurrence for a given adverse event (e.g. the release of hazardous chemicals to the environment due to a deviation from design intention in process engineering).* 261
- Figure 7.4 Spider diagram illustrating the maturity of implementation of risk analysis (left) and risk based decision making (right) within the sub-sample (insufficient data was obtained to evaluate risk based decision making within engineering).* 265

## LIST OF TABLES

	<b>Page</b>
<i>Table 1.1 Descriptions of the RM-CMM processes, their related practices, and their rationale for inclusion within the model.</i>	8
<i>Table 1.2 The attributes characterising process maturity within the RM-CMM, and how they are described at L3 and L4 in risk analysis.</i>	11
<i>Table 1.3 Descriptions of the risk analysis practices and of the rationale for their inclusion in our revised model.</i>	24
<i>Table 1.4 Descriptions of the risk based decision making practices and of the rationale for their inclusion in our revised model.</i>	25
<i>Table 1.5 Descriptions of the risk analysis process maturity hierarchy within our revised model, from ad hoc to adaptive.</i>	26
<i>Table 1.6 Descriptions of the risk analysis process maturity attributes and their rationale for inclusion within our revised model.</i>	27
<i>Table 2.1 Strategic level risk portfolio.</i>	67
<i>Table 2.2 BPR risk matrix (after Remenyi and Heafield, 1996).</i>	80
<i>Table 2.3 Program level risk portfolio.</i>	96
<i>Table 2.4 Component FMEA for chlorine cylinder and outlet valve (Egerton, 2004, with permission).</i>	100
<i>Table 2.5 Operational level risk portfolio.</i>	118
<i>Table 3.1 L3 and L4 process maturity in risk analysis.</i>	169
<i>Table 3.2 Steps for progressing between levels 3 and 4 in risk analysis.</i>	170
<i>Table 4.1 Generalised description of the five maturity levels.</i>	182
<i>Table 4.2 Description of the RM-CMM processes and of the relevant practices observed within the utility.</i>	185
<i>Table 5.1 Generalised representation of the process maturity hierarchy.</i>	197
<i>Table 5.2 Sample characteristics.</i>	198
<i>Table 6.1 Basic descriptions of the attributes characterising risk analysis maturity.</i>	228
<i>Table 7.1 Descriptions of the risk analysis practices and of the rationale for their inclusion in our model.</i>	247
<i>Table 7.2 Descriptions of the risk based decision making practices and of the</i>	248

*rationale for their inclusion in our model.*

*Table 7.3 Descriptions of the risk analysis process maturity hierarchy, from ad hoc to adaptive.* 249

*Table 7.4 Descriptions of the risk analysis process maturity attributes and their rationale for inclusion within our model.* 250

*Table 7.5 Summary of the undertaking of each risk analysis practice within the sub-sample.* 255

*Table 7.6 Summary of the undertaking of each risk based decision making practice within the sub-sample.* 274

# **Chapter 1**

## **Critical overview of thesis**



# 1. Critical overview of thesis

## 1.1 INTRODUCTION

The provision of safe, reliable drinking water, the overarching goal of the international water utility sector (AWWA *et al.* 2001), is within the bounds of the developed world's science, technology, and financial resources. Nevertheless, a nagging prevalence of water quality related outbreaks remains in the developed world, with "causes" ranging from technical failures through to institutional lapses and rarely, in the extreme, negligence on the part of operating and managerial staff (*e.g.* Hrudey and Hrudey, 2004). Regardless of the particular manifestation of these incidents, they all derive from limited organisational capacities, or appetites, to learn how to prevent failures, in other words, to manage risk. Conventionally, utilities manage risk implicitly through codifying their basis for safe operations within standard design and operating procedures. The drivers of said procedures' evolution are two-fold: the introduction of improved methods and technologies (*e.g.* novel treatment processes); and experiences gained from reflecting on past mishaps. From a risk management perspective, we<sup>2</sup> are principally concerned with the latter.

This latter cycle begins with a contamination event or near miss, following which incident analysis is undertaken to determine its primary or root cause, and ends with a technical, operational or administrative solution (*e.g.* adapting design standards or operating procedures) designed to prevent its recurrence. This cycle exists at both the utility and sector level, the latter being reflected in changes to national or industry-wide codes, standards or regulations where learnings are considered generalisable. As Lee

---

<sup>2</sup> Throughout the thesis, we refer to multiple authors to maintain consistency, as the published chapters were lead rather than sole-authored by the PhD recipient.

(1998) notes, whilst this retrospective approach to managing risk is necessary, it is a mistake to consider it sufficient. Procedures, guidelines and regulations can proliferate to the point where they become incomprehensible, and, absurdly yet predictably, resources are diverted towards preventing the incidents that have happened, rather than those most likely to happen (Lee, 1998). Furthermore, a reliance on learning by trial and error in isolation from more proactive strategies is arguably unsound where public health is at stake (*i.e.* if it is not too little, it is certainly too late). Although illustrated in a distinct water quality context, these concepts are generalisable to all aspects of the design, operation and management of water supply systems (*e.g.* from process engineering to occupational health and safety management).

Recognition of the limitations of *post-hoc* analysis has brought a paradigm shift within the water sector from reactive to proactive risk management, wherein utilities have sought to identify potential weaknesses and eliminate root causes of problems before they cause a failure (as reviewed in MacGillivray *et al.*, 2006; Hamilton *et al.*, 2006a,b; Pollard *et al.*, 2004). This shift is being driven by the introduction of water safety plans, codes of good corporate governance, the debate on self-regulation and, more broadly, a growing recognition that the provision of safe drinking water deserves to be treated as a “high reliability” societal service, subject to the rigours and controls inherent to the nuclear, offshore and aerospace industries (Pollard *et al.*, 2005). It is this changing landscape that drives the need for a method for benchmarking and improving organisational competencies in risk management, and for empirical observations of utility risk management to bridge the gap between theory and practice.

## 1.2 LITERATURE REVIEW (CHAPTER 2)<sup>3</sup>

The author's research began with a comprehensive review of risk analysis strategies and techniques for application in the water utility sector at the strategic, programme, and operational levels of decision making. This served to identify the breadth and rigour of existing risk analysis techniques, paying particular attention to the decision contexts of their application, *i.e.* how they informed decision making. We observed that explicit approaches to risk analysis, traditionally applied to occupational health and safety and public health protection, were now seeing broader application in contexts including corporate level decision making, asset management (Booth and Rogers, 2001; Lifton and Smeaton, 2003), watershed protection (IMPRESS Management, 2002; Lloyd and Abell, 2005; WHO, 2004) and network reliability (Stevens and Lloyd, 2004; Stahl and Elliott, 1999). The review suggested that neither the development of novel risk analysis techniques nor the refinement of existing ones was of paramount importance in improving the capabilities of water utilities to manage the plethora of risks to which they are exposed. It was thought that a more fruitful approach would be to focus on the implementation of risk management rather than the techniques employed *per se*, *i.e.* to focus on the institutional capacities of utilities to employ risk analysis and management techniques for more credible, optimal decision making. Here, the field of capability maturity modelling showed great promise.

A capability maturity model (CMM) (Paulk *et al.*, 1993) is a simplified representation of an organisational discipline (*e.g.* software engineering, risk management) which codifies industry practice within a process-based framework.

---

<sup>3</sup> Note that as the research progressed, a broader range of literature was reviewed, including: risk analysis and management frameworks, both within and beyond the sector, decision theory and its application to risk based decision making, capability maturity modelling, and quality management principles. This research is discussed throughout the thesis.

These models are constructed according to maturity levels characterised by the extent to which each process is repeatable, defined, controlled and optimising (although the terminology varies). In essence, they allow distinctions to be made between organisational capabilities based not on the specific practices adopted to, in our case, manage risk, but rather with reference to the maturity of the processes within which those practices are applied (*i.e.* their degree of institutionalisation). The capability maturity modelling concept is finding increasing acceptance in industry and academia. Notable applications include software and systems engineering (Paulk *et al.*, 1993; Software Engineering Institute, 2002a), workforce development and management (Software Engineering Institute, 2002b), offshore design safety (Sharp *et al.*, 2002), reliability engineering (Strutt, 2003), and construction (Sarshar *et al.*, 2000). Capability models enable organisations to establish their current level of process maturity and identify the steps necessary to progress to a higher level, building on their strengths and improving on their weaknesses. Their primary applications are for benchmarking purposes, enabling organisations to compare themselves against other companies in their sector and beyond, or simply as reference models for developing process improvement plans.

### **1.3 RESEARCH AIM AND OBJECTIVES**

The aim of the research was to develop and apply a capability maturity model for benchmarking risk management practice within the water utility sector. An alternative benchmarking approach, the development of a performance measurement framework for water utility risk management, was initiated but subsequently discontinued (Appendix A). The objectives were:

- 1: Develop a prescriptive capability maturity model for benchmarking risk management practice within the water utility sector.
- 2: Apply the prescriptive model to the sector *via* a case study and benchmarking survey, with the purpose of deriving empirical observations of utility risk management practices and their methods for institutionalisation.
- 3: Refine the model from a prescriptive to descriptive state based on the data obtained from its application.
- 4: Apply the revised, descriptive model within a second case study, again with the purpose of deriving empirical observations of utility risk management practices and their methods for institutionalisation.

## **1.4 DEVELOPMENT OF RISK MANAGEMENT CAPABILITY**

### **MATURITY MODEL (CHAPTER 3)**

Chapter 3 describes our development of a risk management capability maturity model (RM-CMM) for the water utility sector. The model was a prescriptive codification of water sector risk management practice, within a process-based maturity hierarchy. It was developed by abstracting the principles of capability maturity modelling observed in other disciplines, including software and systems engineering (Paulk *et al.*, 1993; Software Engineering Institute, 2002a), workforce development and management (Software Engineering Institute, 2002b), offshore design safety (Sharp *et al.*, 2002), reliability engineering (Strutt, 2003), and construction (Sarshar *et al.*, 2000). This was achieved through literature reviews (MacGillivray *et al.*, 2006; Pollard *et al.*, 2004; Hamilton *et al.*, 2006b), scoping interviews with water utility managers, and

prior knowledge of maturity modelling in similar utility sectors. The model was composed of eleven risk management processes, themselves comprised of practices (Table 1.1). These processes were separated into five maturity levels, from learner to best practice. These maturity levels, characterised by reference to attributes (Table 1.2), reflected the extent to which each process is repeatable, defined, controlled and optimising (*i.e.* their maturity of implementation, or degree of institutionalisation). It is important to understand what these levels represent in practice as this was crucial to assessing the maturity of an organisation. Whilst the precise definition of the maturity hierarchy was process specific, levels 3 and 4 in risk analysis are displayed in Table 1.2. The descriptions of the full maturity hierarchy for each process are found in Appendix B.

Table 1.1 Descriptions of the RM-CMM processes, their related practices, and their rationale for inclusion within the model

Process	Description*	Practices	Rationale for inclusion
SRP	The process by which the Board, the executive and senior management set out their overarching framework for corporate risk management.	<ol style="list-style-type: none"> <li>1. Develop a corporate vision for risk management.</li> <li>2. Establish a risk management framework setting out the core roles, responsibilities, accountabilities and mechanisms for risk management throughout the organisation.</li> <li>3. Identify key risk and opportunity elements at the strategic level.</li> <li>4. Develop corporate strategy to manage identified risk and opportunity elements.</li> <li>5. Allocate resources for implementing corporate risk management strategy.</li> <li>6. Establish risk policies and guidelines to inform operational procedures.</li> <li>7. Develop criteria indicating how success and failure in risk management will be measured at the corporate level.</li> </ol>	Hamilton <i>et al.</i> (2006b) describe how these frameworks can introduce greater rigour, consistency and standardisation to the discipline. The researchers further note their potential for adaptation to suit “user needs.” This final point is crucial, as our scoping interviews suggested that risk management frameworks were not simply shoehorned within utilities.
ERAC	The process by which the utility establishes criteria for evaluating the significance and acceptability of risk.	<ol style="list-style-type: none"> <li>1. Define high level risk areas for the business and assets.</li> <li>2. Define the level of risk that is acceptable to the various stakeholders across key risk categories (<i>e.g.</i> financial risk thresholds, technical requirements for safety and reliability, ALARP, <i>etc.</i>).</li> <li>3. Allocate risk acceptance criteria to key components of the business and assets.</li> </ol>	Criteria for evaluating the significance of risk are required to establish their relative priority during risk analysis, whilst criteria for evaluating their acceptability are required to inform decisions as to whether they should be mitigated or accepted.
RA	The identification and assessment of risk.	<ol style="list-style-type: none"> <li>1. Identify risks inherent in business and technical operations. A range of techniques are available for this purpose (<i>e.g.</i> what-if analysis, scenario planning, HAZOP, HACCP, <i>etc.</i>). This task should be informed by a risk register, which is continually updated.</li> <li>2. Assess risks for likelihood of occurrence, likelihood of consequences and overall impact on the utility’s corporate objectives. A range of techniques are available for this purpose (<i>e.g.</i> FMEA, FMECA, NPV-based analyses, compliance assessments, pollutant modelling tools, <i>etc.</i>)</li> <li>3. Evaluate assessed risks with respect to defined acceptance criteria.</li> </ol>	Risks left unidentified are excluded from explicit management. Their assessment is required to understand the mechanisms through which they arise (and so inform measures for their reduction) and to establish their relative priority (and so allocate resources optimally).
RBDM	The identification and evaluation of options to manage risks.	<ol style="list-style-type: none"> <li>1. Select risk response strategies based on output from risk analysis (<i>e.g.</i> avoid, retain, reduce, transfer, exploit).</li> <li>2. Develop selected response strategies according to context and situation (<i>e.g.</i> a selected strategy of reducing currency risk may be developed into a complex hedging strategy).</li> <li>3. Establish indicators to track the progress and effectiveness of risk response strategies.</li> </ol>	Risk analyses that do not inform decision making are mere exercises in compliance and creating the illusion of good governance.

		4. Review risk response strategies in light of risk monitoring output.	
RR	Implementing the selected risk management option(s).	<ol style="list-style-type: none"> <li>1. Define roles, responsibilities and timescales for implementing risk response strategies.</li> <li>2. Prioritise and allocate resourcing for the implementation of risk response strategies.</li> <li>3. Implement risk response strategies.</li> </ol>	Risk based decisions are hollow gestures if left unimplemented.
RM	Reviewing and updating risk analyses.	<ol style="list-style-type: none"> <li>1. Define criteria for risk monitoring activities (<i>i.e.</i> detailing when, what and how to monitor).</li> <li>2. Collect and update data relating to the evolution of watched and mitigated risks.</li> <li>3. Compile and analyse data for watched and mitigated risks to enable evaluation of the progress and effectiveness of risk response strategies.</li> </ol>	Risks are not static, but evolve over time, both objectively ( <i>e.g.</i> real changes in risk) and subjectively ( <i>e.g.</i> as greater information becomes available, their analysis should be updated).
IRM	The integration of risk management process interfaces; the cross-functional integration of risk management; integration of risk management with broader business operations.	<ol style="list-style-type: none"> <li>1. Define and integrate the risk management process interfaces (<i>e.g.</i> ensure that the outputs of the risk monitoring process are sufficient to inform a review of risk response strategies). Techniques for this purpose include technical exchange, peer reviews, <i>etc.</i></li> <li>2. Define and implement the desired level of cross-functional integration for risk management (<i>i.e.</i> the extent to which risk should be managed with respect to functional vs. organisational considerations). Integration is achieved through the establishment and utilisation of methods for cross-functional co-ordination, solution building, conflict resolution, <i>etc.</i></li> <li>3. Integrate the process of risk management within broader business operations (<i>e.g.</i> through establishing initiation procedures, reward and accountability mechanisms, <i>etc.</i>).</li> </ol>	Risk management process interfaces should be integrated to ensure the whole is greater than the sum of its parts. Cross-functional integration of risk management activities is required because managing risk in organisational “silos,” is ineffective as risks are highly interdependent and cannot be segmented and managed by entirely independent units. Integration with broader business operations is required to ensure risk management is an integral part of organisational activities, rather than a “bolt on.”
SCRM	Two aspects: (i) product supply risk management: addressing the way utilities obtain the raw components required to develop a product; (ii) service supply risk management: managing services provided by other organisations throughout the supply chain – <i>e.g.</i> outsourcing agreements.	<ol style="list-style-type: none"> <li>1. Identify and define the risk interfaces between the organisation and suppliers of services and products.</li> <li>2. Establish (risk-based) pre-qualification, selection and retention criteria for work performed by contractors, suppliers and others.</li> <li>3. Establish (risk-based) deliverables and performance standards for suppliers of products and services (<i>e.g.</i> requirements for reliability, safety and technical competence).</li> <li>4. Communicate the benefits of active risk management processes to supplier organisations.</li> </ol>	Many organisational failures can be traced back to minor and apparently insignificant services <i>and</i> components sourced from suppliers.
CRM	Managing the risk implications of business ( <i>e.g.</i>	1. Define and implement an organisational strategy for the management of technical and business change.	A range of factors ( <i>e.g.</i> globalisation, regulatory and market restructuring, novel technologies) are serving to fundamentally



	re-engineering) and technical (e.g. changes in design or technology) change.	<ol style="list-style-type: none"> <li>2. Establish (risk-based) criteria for acting upon change opportunities.</li> <li>3. Identify and define the risk implications of changes in the operating, regulatory and market environment (e.g. novel treatment technologies, alterations in compliance levels, evolving market structures, emerging competition, etc.).</li> <li>4. Develop and execute plans to manage the risk implications of technical and business change.</li> </ol>	alter the context in which water utilities operate.
E&T	Development of the skills and knowledge that enable staff to perform their risk management roles.	<ol style="list-style-type: none"> <li>1. Define education and training requirements for effective risk management (i.e. competency requirements).</li> <li>2. Design education programmes and training vehicles to impart the required knowledge.</li> <li>3. Track the progress and effectiveness of education and training in risk management.</li> <li>4. Define and implement development opportunities for staff (i.e. education and training opportunities that extend beyond their role requirements) to optimise risk management across the organisation.</li> </ol>	Regardless of the technical complexity of the methods employed, risk management remains in many respects an expert discipline, and so the development of competencies is required for its optimal implementation.
RKM	The collection, storage and access of input <i>and</i> output risk data.	<ol style="list-style-type: none"> <li>1. Define data / information requirements for effective risk management.</li> <li>2. Design, develop and implement knowledge management systems and infrastructure to capture, compile and analyse the required data / information.</li> </ol>	We include the former aspect on the premise that in the absence of pre-defined data requirements, risk data collection is likely to be <i>ad hoc</i> and largely restricted to the needs of business as usual. The latter aspect is drawn from discussions of various risk communication and reporting protocols and the use of databases for storing risk assessment outputs.

\*NB: “Utility friendly” examples of these process descriptions were used in the questionnaire application of the RM-CMM (Appendix C).

Key: Strategic risk planning (SRP); Establishing risk acceptance criteria (ERAC); Risk analysis (RA); Risk based decision making and review (RBDM); Risk response (RR); Risk monitoring (RM); Integrating risk management (IRM); Supply chain risk management (SCRM); Change risk management (CRM); Education and training in risk management (E&T); Risk knowledge management (RKM).

*Table 1.2 The attributes characterising process maturity within the RM-CMM, and how they are described at L3 and L4 in risk analysis*

<b>Attribute</b>	<b>Attribute description</b>	<b>Attribute at level 3: Risk analysis</b>	<b>Attribute at level 4: Risk analysis</b>
Scope	The execution of key practices, and the breadth of process implementation across the organisation.	A defined, documented process is in place containing criteria, methods and guidelines for the identification, assessment and evaluation (with respect to acceptance criteria) of a broad range of risks across core business areas, guided by a risk register. The organisation is conversant with and goes beyond the regulatory requirements for risk analysis.	A controlled process is in place containing detailed criteria, methods and guidelines to manage the identification, assessment, evaluation (with respect to acceptance criteria), establishment of causality and linking (common cause and dependent) of risks at all levels of the company and across all functional boundaries of the business, guided by a company-specific risk register.
Integration	The level of process embedment within the organisation.	Procedures are in place to initiate risk analysis processes.	Risk analysis is initiated automatically as part of core business processes (e.g. periodic business risk assessments).
Verification and Validation	Verification refers to ensuring that the process is being performed correctly, validation refers to ensuring that the correct process is being performed.	Basic mechanisms are in place to verify that risk analysis is performed as required, largely reliant on lagging indicators. The expertise for validation is generally lacking.	Verification and validation systems are in place to verify the efficiency of risk analysis activities and to validate their expediency (e.g. the organisation tracks that tools and techniques are being used correctly and that the correct tools and techniques are being used).
Feedback and Organisational Learning	The manner in which feedback, both internally and externally sourced, is collected and used to question and revise processes.	The risk analysis tool suite is reviewed and modified on an event-driven basis.	Feedback is actively used to improve the execution of risk analysis (e.g. gaps identified and risk analysis tools and techniques improved in response).
Stakeholder Engagement	The process of engaging stakeholders, both internal and external, with the purpose of leveraging the process.	Risk analysis processes generally reside within the responsible unit, with limited cross-functional or external consultation.	Risk analysis processes generally reside within affected disciplines, and stakeholders work together to define and implement an integrated approach to risk analysis, capitalising on synergies and collective knowledge.
Competence	The organisational qualities and abilities, both implicit and explicit, which influence process performance.	Detailed knowledge of risk analysis resides only within the responsible unit.	Most involved staff exhibit a good level of competence in the selection and application of risk analysis tools and techniques, and have access to support from internal or external expert risk practitioners.
Resources	Extent and use of resources (e.g. people, pounds and tools)	Adequate resources are provided in support of risk analysis, with both qualitative and quantitative tools and techniques available.	Sufficient resources are provided in support of risk analysis, a portion of which is made available for R + D for risk assessment. A broad range of qualitative and quantitative tools and techniques are available and applied, including methodologies for aggregating and comparing risks.
Documentation and Reporting	Documentation and reporting of risk information.	Risk analysis outputs are compiled and disseminated in a format that supports decision-making.	Risk analysis outputs are compiled and disseminated in a clear, concise and actionable format that supports real-time decision-making, and their reporting is co-ordinated with other risk reporting mechanisms (e.g. risk status updates).

## **1.5 APPLICATION OF RISK MANAGEMENT CAPABILITY MATURITY MODEL (CHAPTERS 4, 5 AND 6)**

### **1.5.1 Industrial case study (Chapter 4)**

Our RM-CMM was prescriptive, being derived by abstracting the overarching principles of capability maturity modelling to fit the context of risk management within the water sector, rather than descriptive (*i.e.* empirically derived). In our view, it was important to move beyond the rhetoric on risk management, whether academic or practitioner, in order to improve practice on the ground. And so this stage of our research was concerned with the case study application of the model within a water and wastewater utility, in order to derive empirical observations of both utility risk management practices (*e.g.* what steps were involved in the application of risk analysis, one process of risk management) and of their methods for institutionalisation (*e.g.* how was risk analysis institutionalised as a process). We consider this extension of the model's application beyond its immediate target context (*i.e.* the water utility sector) both necessary (given the organisational structure of the case study utility) and more importantly valid, as the underlying principles of risk management and capability maturity modelling should remain constant regardless of the utility sector to which they are applied (of course, the model's application to, say, a financial organisation would be more questionable). The research methods informing the model's application included questionnaire, interview and document analysis (see Appendix D for a sample interview transcript; company documents used are not made available due to confidentiality issues).

### **1.5.2 Benchmarking survey (Chapter 5)**

Given the inherent limitations of case study research in terms of generalisability, a survey based application of the RM-CMM was the next logical step in our quest for empirical data. Eight water utilities from the UK, Australia and the USA participated in the study. This was supplemented by the participation of an electricity utility regarded as best practice in risk management. The sample was intended to reflect good risk management practice; hence we do not suggest that our analysis was representative of the sector as a whole. The scope of analysis varied by utility, and included organisational, business unit, and functional perspectives, although was predominantly the former. A survey-type research design was adopted, whilst the research methods included questionnaire, interview and document analysis (see Appendix E for a sample interview transcript, Appendix C for a sample questionnaire response).

### **1.5.3 Summary of findings**

The research findings may be placed into two groups. Firstly, we derived empirical observations reflecting our prescriptive codification of risk management processes, ranging from the application of classical risk assessment methodologies such as hazard and operability studies, to the use of scenario planning in guiding organisational restructuring programmes. Secondly, we derived empirical observations reflecting how those processes may be institutionalised with reference to our maturity hierarchy, including the use of initiation criteria for applying risk analysis techniques, the adoption of formalised procedures to guide their application, and auditing and peer reviews to ensure procedural compliance and provide quality assurance.

The findings provide utility managers, technical staff, project managers and chief finance officers with a *practical* and systematic understanding of how to implement and improve risk management, and offer preliminary guidance to regulators concerning how improved water utility governance can be made real. Further, through seeking to align risk management practice on the ground with our prescriptive model, the research provided the required empirical basis for evolving our model from a prescriptive to a descriptive state.

#### **1.5.4 Limitations and their implications for subsequent research**

One key insight emerging from the application of the RM-CMM was that risk management was best treated not as an overarching discipline, but rather as one which takes discrete forms in varying functional contexts (*i.e.* that explicitly considering the context within which risk management was applied was critical, and that this was best done at the functional level). And so a view formed that adopting a functional, rather than organisational, approach to evaluating risk management capabilities was justified. This shift in focus is illustrated in Chapter 6, where we place the findings of our benchmarking survey (in relation to the risk analysis process) within the context of specific water utility functions (*e.g.* asset management, process engineering).

The research was further limited by, on reflection, inadequate effort by the author to relate the empirical findings to the broader literature. This was supported by correspondence with a utility asset manager in response to preliminary findings, who stated: *“it seems to me that your report is focusing on the quality management...aspects as applied to risk management. I don't see that you have considered the effectiveness of risk management as actually applied to assets. The focus appears to be on making sure everything is well documented – rather than*

*making sure what [is being done] is actually worth documenting.*” Whilst an exaggerated concern in the sense that the concepts underlying capability maturity modelling go beyond simply “document what you do and do what you document,” the common yet misplaced critique of quality management principles, the underlying truth was that greater effort was required to draw upon the broader literature to evaluate the strengths and limitations of the risk management practices observed (*e.g.* the application of hazard and operability studies, one observed risk analysis practice) and their methods for institutionalisation (*i.e.* the attributes defining process maturity, such as initiation criteria guiding the application of hazard and operability studies).

Finally, the research was limited by the prescriptive nature of our model. Whilst we found empirical support for our process descriptions and maturity hierarchy, challenges to its design, of both a theoretical and empirical nature, were encountered. These can be placed into five principal categories, those relating to: the selection of processes; the selection of practices which comprised the processes; the selection of attributes which defined process maturity; the distinctions between maturity levels; and the approach to evaluating maturity. We return to these later. Understanding the implications of all of this for our model required a return to first principles, beginning with a more critical evaluation of what risk management *is*, and therefore what the scope of the author’s research was.

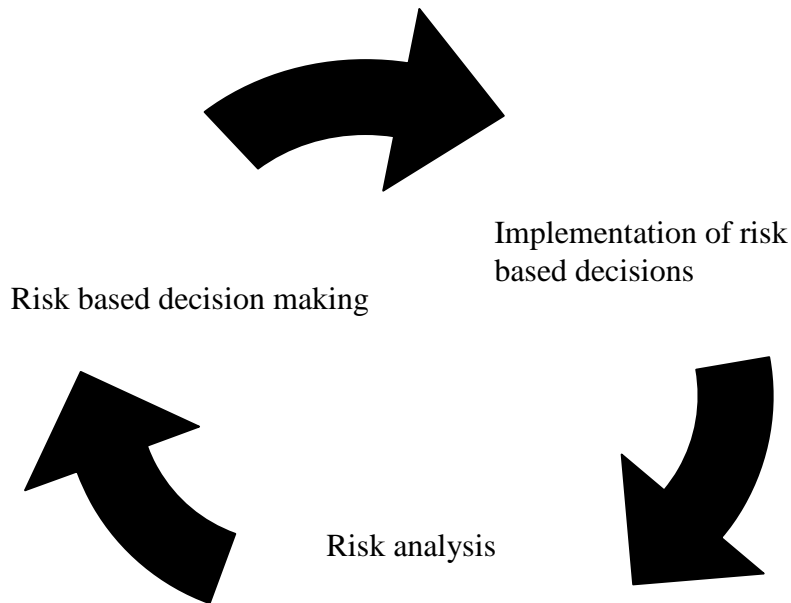
## **1.6 DESIGN AND APPLICATION OF CAPABILITY MATURITY MODEL FOR BENCHMARKING RISK ANALYSIS AND RISK BASED DECISION MAKING PRACTICE (CHAPTER 7)**

### **1.6.1 Re-conceptualisation of risk management**

Before outlining the revised model, and the rationale for the changes adopted, it is important to describe our re-conceptualisation of risk management. The lexicon of risk is at times bewildering, and there are myriad definitions of risk management. Previously, we had deferred from explicitly defining risk management in the context of our development of the RM-CMM, on the premise that its essential meaning was *prima facie* evident – namely, the management of risk – and that engaging in semantics would divert time and resources from the research problem (*i.e.* the meaning was constant, regardless of its articulation). However, the prior applications of the RM-CMM suggested a need to re-define the scope of the research, the starting point of which was a re-examination of the meaning and purpose of risk management itself. A view formed in the authors' minds that many existing definitions of risk management appeared to suffer from the tyranny of consensus, being chosen not so much to elucidate a truth, but instead to be so broad and abstract as to satisfy all stakeholders that their own particular view of risk management was a subset within, so placing them beyond reasonable critique. Of course, one should not disregard the past too readily, and the underlying philosophy and practical utility of the discipline can be found within the literature when one looks beyond this tendency to connote rather than denote. That is, namely, that risk management is concerned with preventing failures.

However, what was needed was not simply a definition of risk management, but rather a deeper conceptualisation. Failures are prevented by understanding how they may arise, and adapting behaviour to prevent their occurrence. In other words, risk management is concerned with “learning how to prevent failures.” Drawing upon Confucius, we conceptualise three means by which water utilities learn to prevent failures, through (i) reflecting on their past mishaps, which is bitterest; (ii) reflecting on those of other utilities, which is easiest; and (iii) *a priori*, using foresight to reflect on potential future mishaps, which is noblest. Our subsequent research addresses the final means on the premise that prevention is better than cure (hence noblest). We consider this final means, *a priori* or proactive risk management, to be comprised of three processes: risk analysis; risk based decision making; and implementation of risk based decisions (Figure 1.1). In short, risk analysis looks to the future to determine what can go wrong, the potential consequences and their relative likelihood, and the overall level of risk. Risk analysis informs risk based decision making, which involves the identification and evaluation of risk reduction options and, where deemed necessary (*i.e.* where the risk is considered unacceptable), selection of the optimal option(s). Of course, fine decisions are hollow gestures if left unimplemented, and so implementation of risk based decisions completes the cycle.





*Figure 1.1 Re-conceptualisation of a priori risk management processes*

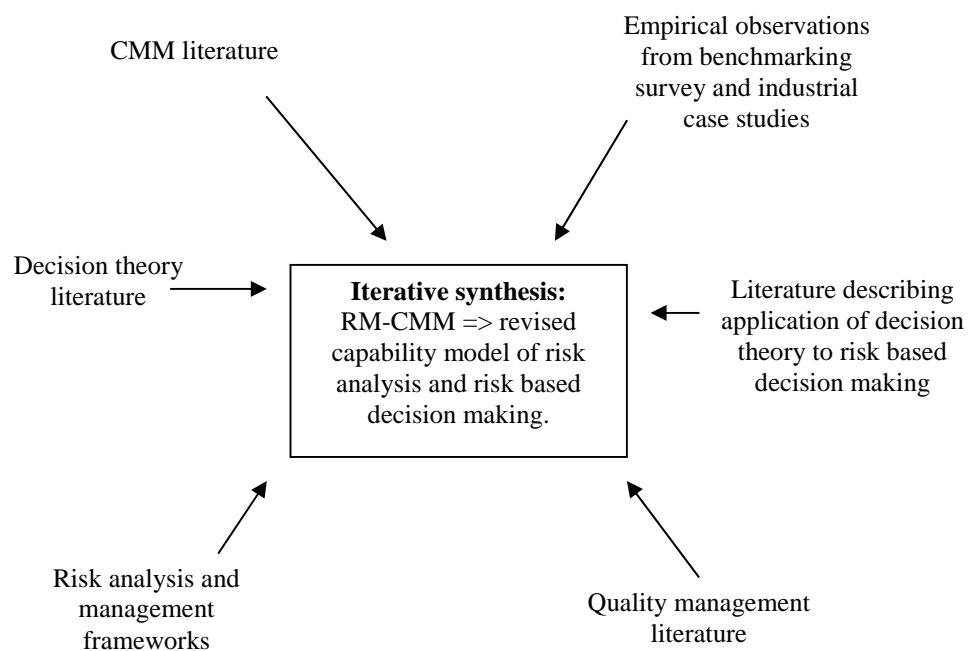
### **1.6.2 Research methods for design and application of revised maturity model**

The initial objectives had been to revise the RM-CMM based on the empirical findings from its prior applications, before testing the revised version within a final industrial case study. However, given the broad nature of the empirical and theoretical challenges to the RM-CMM design, derived from its initial applications and a return to the literature respectively, the grounded theory methodology (Glaser and Strauss, 1967; Straus and Corbin, 1994) was adopted for the final case study. Under this approach (Figure 1.2) data collection, analysis and conceptualisation (*i.e.* the re-coding of processes, practices, maturity attributes and maturity levels within the model) were not undertaken sequentially, but instead iteratively until a point of saturation was reached, which culminated in the revised model. In essence, this meant that the model was both adapted and applied within the final case study.

In brief, we revised the prescriptive RM-CMM model towards a *descriptive* maturity model of risk analysis and risk based decision making through an iterative synthesis of: the capability maturity modelling literature (Paulk *et al.*, 1993; SEI, 2002a/b; Sharp *et al.*, 2002; Strutt *et al.*, 2006; Sarshar *et al.*, 2000); risk analysis and management frameworks, both specific to the sector (NZMOH, 2001; NHMRC, 2001, 2004; WHO, 2002, 2004) and beyond (AS/NZS, 1999, 2004; COSO, 2004; UKOOA, 1999; FERMA, 2003; NIST, 2002; MHU, 2003; Joy and Griffiths, 2005; NEA/CSNI, 1999); decision theory (Slovic *et al.*, 1977; Clemen, 1996; Watson and Buede, 1987) and its application to risk based decision making (Aven *et al.*, 2006; Rosness, 1998; Arvai *et al.*, 2001; Aven and Kørte, 2003; Bohneblust and Slovic, 1998; Amendola, 2001; Renn, 1999); quality management principles (Crosby, 1979, 1996; Hoyle, 2001; ISO, 2000); and empirical observations derived from our prior benchmarking survey and initial case study (Chapters 4, 5 and 6), and, critically, those observations derived from the final, in-depth case study.

One utility responsible for the provision of water and wastewater services participated in this final case study. The sample comprised of seven utility functions: engineering; project management; drinking water quality management; network planning; asset management; emergency management; and occupational health and safety management. The empirical observations were derived from interview and document analysis (see Appendices F and G for sample interview transcripts). Of the sample of seven functions, emergency planning was removed from the analysis due to contradictions in the data and the limited sample of interviewees (two, compared to a minimum of three elsewhere), whilst network planning was discounted owing to limited documentation obtained. Although the focus of our research was on water supply, by the very nature of the utility's organisational design it extended to embrace

aspects of their wastewater services (as, for example, the project management and engineering functions deliver both water and wastewater system designs and projects). Again, we consider this a valid extension, as the underlying principles of risk analysis, decision theory, and capability maturity modelling remain constant.



*Figure 1.2 Basic illustration of the progression from the RM-CMM to the revised capability maturity model for benchmarking risk analysis and risk based decision making practice*

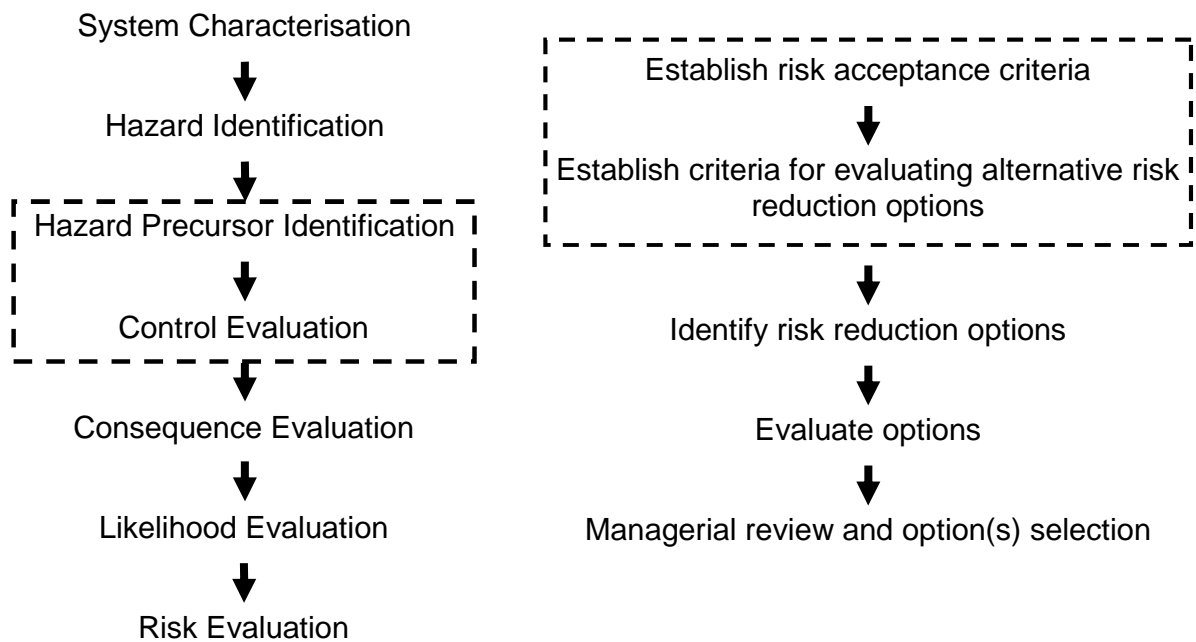
NB: The role of these various inputs in informing the coding of the revised model are evidenced in: Tables 1.3, 1.4, and 1.6, which show the theoretical basis for the coding of risk analysis and risk based decision making and those attributes which define their maturity of implementation; and Tables 7.5, 7.6 and Appendix H which show the empirical observations derived from the final case study. See also section 1.64 for a discussion of the progression from the RM-CMM to the revised model.

### **1.6.3 Architecture of capability maturity model for benchmarking risk analysis and risk based decision making practice.**

The revised model incorporates the processes of risk analysis and risk based decision making. These are considered two of the three *a priori* risk management processes under our re-conceptualisation (Figure 1.1). The implementation of risk based decisions process was not included due to data limitations which were compounded by the fact that implementation mechanisms can be expected, indeed were observed, to vary markedly depending on the nature of the decision to be implemented (*i.e.* operational vs. capital vs. procedural, *etc.*). As noted, this model differs in a variety of ways from its precursor, the RM-CMM. These changes, along with their justification, are summarised in section 1.64. However, the author's adoption of this revised model does not simply reflect a shift in focus from the prior research, it also amounts to a recanting of the RM-CMM (again, see the rationale for this in section 1.64).

Within the model, risk analysis and risk based decision making are composed of a series of practices. These practices, taken together, map out each process flow (whereas in our prior model, the practices were, in essence, elements of each process flow, rather than their totality). Risk analysis (Figure 1.3; Table 1.3) comprises system characterisation, hazard identification, hazard precursor identification, control evaluation, consequence evaluation, likelihood evaluation, and risk evaluation. Risk analysis is always part of a decision context (Aven and Kørte, 2003). Thus, risk based decision making (Figure 1.3; Table 1.4) is concerned with the identification and evaluation of risk reduction alternatives, followed by the application of managerial review prior to selecting the optimal risk reduction measure(s). These are informed by criteria establishing the acceptability of risk and setting out stakeholder values and

concerns used to assess the relative merit of alternative risk reduction options. Both processes are separated into five maturity levels, from *ad hoc* to adaptive. These levels (Table 1.5), characterised in terms of the practices undertaken and attributes reflecting their maturity of implementation (Table 1.6), codify the extent to which each process is repeatable, defined, controlled and adaptive (*i.e.* maturity of implementation, or degree of institutionalisation). Whilst the characterisations of the maturity levels (Table 1.5) and the process maturity attributes (Table 1.6) provided are specific to risk analysis, the same principles apply to risk based decision making (see Appendices I and J for the characterisations of the maturity levels and process maturity attributes relating to risk based decision making, respectively). The theoretical basis for the model's development is summarised in the aforementioned Tables; regarding its empirical basis, refer to Tables 7.5 and 7.6 for observations relating to the undertaking of each risk analysis and risk based decision making practice across a range of the final case study utility's functions, and Appendix H for observations of the process maturity attributes relating to risk analysis from this same case study.



*Figure 1.3 Flow charts of the practices which comprise the risk analysis process (left) and the risk based decision making process (right). Those encased are considered key rather than critical practices, an important distinction in evaluating process maturity*

*Table 1.3 Descriptions of the risk analysis practices and of the rationale for their inclusion in our revised model*

<b>Risk analysis practice</b>	<b>Description</b>	<b>Rationale</b>
System characterisation	To establish and describe the system with which risk analysis is concerned ( <i>e.g.</i> workplace, engineering process, project).	A comprehensive system understanding is a <i>sine qua non</i> for generating risk analysis outcomes that are valid and accepted by stakeholders.
Hazard identification	Identifying situations, events, or substances with the potential for causing adverse consequences, <i>i.e.</i> sources of harm or threats to the system.	A hazard left unidentified is excluded from subsequent analysis.
Hazard precursor identification	Whilst hazard identification is concerned with <i>what</i> can go wrong, precursor identification focuses on <i>how</i> and <i>why</i> things can go wrong, in other words identifying possible routes to and causes of failure.	The potential existence of a hazard does not in itself constitute a risk, as each hazard requires a process or pathway (precursor) to lead to its realisation. Thus, the value of this practice lies in both confirming the existence of pathways to failure (and therefore that a risk exists) and informing the development of risk reduction options focussed at root causes.
Control evaluation	The identification and assessment of existing technical, physical and administrative controls which may either reduce the likelihood of a hazardous event occurring, or serve to mitigate its severity of consequences. Assessment should address both the criticality of the controls ( <i>e.g.</i> based on their inherent capacity to reduce risk, whether they are proactive or reactive, <i>etc.</i> ) and their adequacy of design, management and operation.	An evaluation of existing controls: informs the evaluation of associated risk levels; serves to inform the development of risk reduction options through identifying latent and active control weaknesses ( <i>i.e.</i> through serving as a gap analysis of existing risk reduction measures); and captures the historic basis for safe, reliable system operation.
Consequence evaluation	Identifying the nature of the consequences of a hazardous event occurring ( <i>e.g.</i> financial, environmental) and assessing their severity of impact.	Deriving and combining measures of consequence and likelihood are required to establish the overall level of risk associated with a given hazard, so that management resources may be allocated accordingly and to assess the desirability of potential risk reduction measures ( <i>e.g.</i> to see if they satisfy the ALARP criteria).
Likelihood evaluation	The evaluation of the likelihood ( <i>i.e.</i> frequency or probability) that a hazardous event will occur and lead to a defined severity of consequence.	
Risk evaluation	Combining measures of likelihood and consequence severity to derive an overall measure of risk, either qualitative ( <i>e.g.</i> high, low) or quantitative ( <i>e.g.</i> expected loss of life, value at risk).	

*Table 1.4 Descriptions of the risk based decision making practices and of the rationale for their inclusion in our revised model*

<b>Risk based decision making practice</b>	<b>Description</b>	<b>Rationale</b>
Establish risk acceptance criteria	Establishing criteria for evaluating the acceptability of risk.	In the absence of such criteria, on what basis are decisions taken on whether to mitigate or accept risk?
Establish criteria for evaluating alternative risk reduction options	Establishing criteria used to evaluate the relative merit of alternative risk reduction options ( <i>e.g.</i> forecast risk reduction, technical feasibility, cost of implementation, latency of effects, environmental impacts, <i>etc.</i> ) and, where deemed appropriate ( <i>e.g.</i> where multi-attribute analysis is subsequently undertaken), weightings to establish their relative importance.	A range of risk reduction options may be considered for a particular decision context; the decision as to which is considered the best option is influenced by many factors. Different concerns and values often need to be considered simultaneously, and their relative importance may be valued differently by various stakeholders (Faber and Stewart, 2003). Making this explicit in the form of criteria can improve the credibility and defensibility of decision making, minimise the possibility that decisions will be second guessed or that their rationale be forgotten, remove barriers to stakeholder buy-in, and ensure the existence of an audit trail (SEI, 2002). More broadly, it enables value rather than “alternative focussed” decision making, the latter being characterised by the selection of an “optimal” option from a set of implied or poorly defined criteria (Arvai <i>et al.</i> , 2001).
Identify risk reduction options	Generating alternative solutions for the decision problem.	Options not generated are excluded from subsequent evaluation and, ultimately, implementation.
Evaluate options	There are three elements to this: forecasting the impact of each option against the individual evaluation criteria, determining the cumulative “goodness” of each option ( <i>e.g.</i> via cost-benefit analysis, multi-attribute analysis); and determining risk acceptability.	Systematically evaluating the individual and cumulative merits of alternative options should provide for more credible, defensible and rational risk based decision making. Determining risk acceptability follows as it is risk reduction options, not risks, which are unacceptable or acceptable (Fischhoff <i>et al.</i> , 1981), <i>i.e.</i> the acceptability of risk cannot be determined without considering the costs and benefits of maintaining vs. reducing current risk levels.
Managerial review and option(s) selection	The application of managerial judgement in reviewing the premises, assumptions, and limitations of analyses, prior to the final decision (after Aven <i>et al.</i> , 2006).	In line with Mintzberg (1994), we consider that decision analysis should compliment, but not replace, the knowledge, intuitions and judgement of decision makers, and further, that risk based decisions should not reflect theoretically or analytically derived perspectives that run counter to sound professional judgement (Hrudey and Hrudey, 2003). More specifically, given that risk is, at a fundamental level, an expression of uncertainty, and that the analysis of risk and decision alternatives is further subject to aleatory, epistemic and operational uncertainty (Amendola, 2001), the outputs must be treated diagnostically rather than deterministically, <i>i.e.</i> , they should provide decision support, not decisions.



Table 1.5 Descriptions of the risk analysis process maturity hierarchy within our revised model, from ad hoc to adaptive

<b>LEVEL 5:</b> <i>Adaptive</i>	Validation	A broad range of mechanisms are in place to capture feedback potentially challenging the validity of the risk analysis process (e.g. benchmarking surveys, professional networks, external peer reviews, mathematical validation of technical methodologies).
	Organisational learning	Norms and assumptions underpinning the design of the risk analysis process are openly questioned, critically evaluated and, where appropriate, revised in light of validation findings (i.e. double loop learning).
<b>LEVEL 4:</b> <i>Controlled</i>	Verification	Verification extends beyond rigorous mechanisms to ensure procedural compliance (e.g. sign offs supplemented by in-depth audits) to provide formal quality control of risk analyses (e.g. peer reviews, challenge procedures, external facilitation, Delphi technique, etc.).
	Organisational learning	Root and common causes of errors in the execution of risk analysis (e.g. deficient communication, overly complex procedures, lack of education and training) are identified and resolved. Modifications to the design of the process are identified, evaluated and implemented within periodic and event-driven reviews, but remain largely reactive and externally driven (i.e. mirroring changes to codes, standards, guidelines, etc.).
<b>LEVEL 3:</b> <i>Defined</i>	<b>The critical and key risk analysis practices are explicitly undertaken.</b>	
	Procedures	Procedures exist to guide the execution of risk analysis, with an appropriate degree of standardisation, detail, and complexity.
	Roles and responsibilities	Risk analysis roles and responsibilities are allocated with sufficient regard for staff competencies and authorities.
	Initiation Criteria	Cyclical and event-based criteria are in place to guide the initiation of risk analyses.
	Resource management	The requisite monetary, human and technical resources are identified, acquired and deployed in support of risk analysis.
	Input data management	The requisite data inputs are identified, acquired and deployed in support of risk analysis.
	Output data management	Risk analysis outputs are collected, stored and disseminated in a manner that supports decision-making, satisfies audit requirements, and facilitates organisational learning.
	Verification	Basic mechanisms are in place to ensure compliance with risk analysis procedures, focussing on outputs rather than tasks performed (e.g. sign offs on receipt of completed risk analyses).
	Validation	The validity of the risk analysis process is questioned in light of changes to regulations, codes and standards.
	Organisational learning	Non-compliances with risk analysis procedures are resolved on a case by case basis (i.e. treated as isolated errors requiring sanction to prevent their recurrence). Improvements to the design of the risk analysis process are implemented in a reactive, <i>ad hoc</i> manner (e.g. in response to changes in codes or regulations).
	Stakeholder engagement	A broad cross section of internal and external knowledge, experience, skills and perspectives is reflected within risk analysis, based on explicit guidelines or criteria for stakeholder engagement.
Competence	Staff exhibit adequate knowledge, skills and experience in risk analysis. Education and training in risk analysis is planned and executed based on established competency requirements.	
<b>LEVEL 2:</b> <i>Repeatable</i>	<b>The critical risk analysis practices are explicitly undertaken.</b>	
<b>LEVEL 1:</b> <i>Ad hoc</i>	<b>Risk analysis is absent; or the critical practices are implicitly or incompletely performed.</b>	

Table 1.6 Descriptions of the risk analysis process maturity attributes and their rationale for inclusion within our revised model

Attribute	Description	Rationale	Key aspects
Procedures	The rules guiding the execution of risk analysis.	Procedures serve to capture and disseminate knowledge of the optimal conduct of risk analysis so that it is maintained within the organisational memory rather than as hidden expert knowledge (NEA/CSNI, 1999), and so ensure its consistent, efficient conduct.	Appropriate standardisation and formalisation of procedures taking into account personnel experience and knowledge; participation of end users (e.g. risk analysts) in their development; matching detail with complexity of work; making explicit the rationale for conducting risk analyses; being based on an analysis of the tasks required (NEA/CSNI, 1999; Health and Safety Laboratory, 2003).
Roles and responsibilities	Assignment of personnel to risk analysis roles and responsibilities.	To avoid the “not my job” phenomenon (Joy and Griffiths, 2005), and ensure risk analysis receives appropriate focus and resource allocations.	Matching role descriptions and assignment of responsibilities with personnel competencies and authorities (NEA/CSNI, 1999). Supporting well meaning statements that “risk management is everyone’s job” with specific requirements.
Initiation criteria	Stages or conditions which initiate risk analysis.	To ensure risk analyses is undertaken as required, rather than being initiated on an <i>ad hoc</i> , over zealous, or reactive basis, or marginalised as “make work.”	Identifying where risk analysis is necessary vs. where adherence to codes and standards can be said to discharge the duty (Health and Safety Laboratory, 2003; UKOOA, 1999), and making this explicit in cyclical and event-based criteria.
Resource management	The planning, acquisition, and deployment of funds, techniques and staff in support of risk analysis.	Resourcing of risk analysis is particularly critical during periods of reduced budgets and downsizing, which may bring an emphasis on economic rather than safe operation (NEA/CSNI, 1999).	Sufficiency and availability of financial resources; access to sufficiently competent human resources; and a range of risk analysis techniques which reflect the complexity of the organisation’s activities and working environment (Health and Safety Laboratory, 2003).
Input data management	The identification, collection, and storage of risk analysis data inputs.	The systematic identification and capture of data requirements serves to ensure analyses are underpinned by objective data evaluation, rather than reflecting best guesses in the guise of “expert judgement.”	The definition of data requirements / data sources for risk analysis, either at the process level or, where not practical, on a case by case basis, and mapping these to data collection and storage systems.
Output data management	The collection, storage and dissemination of risk analysis	Risk analysis outputs must be systematically recorded to inform decision makers, for audit and training	Documenting in-depth the risk analysis outcomes, not simply the overall level of risk (e.g. sources of data, assumptions used, methods followed,

	outputs.	purposes, and to facilitate future reviews (COSO, 2004; CSA, 2004). Further, this ensures staff have current knowledge of the human, technical, organisational and environmental factors that govern system safety (Reason, 1997).	<i>etc.</i> ). Although in theory the storage media is unimportant as long as the outputs are easily retrievable (Health and Safety Laboratory, 2003), IT-based data systems (risk registers) have significant advantages, particularly in facilitating information flow between and across layers and boundaries of the organisation (COSO, 2004).
Verification	Ensuring compliance with risk analysis procedures, and providing quality control of the execution of risk analysis.	The mere existence of procedures is not in itself enough to ensure that staff actions will be consistent with them (Hoyle, 2001; ISO, 2000). Errors of omission or commission ( <i>e.g.</i> due to misunderstanding instructions, carelessness, fatigue or management override), may cause deviations. Similarly, procedural compliance does not ensure the quality of execution of risk analysis.	Implementation of mechanisms to ensure adherence to procedures ( <i>e.g.</i> auditing, “sign offs”) and to sanction non-compliance. Quality control mechanisms ( <i>e.g.</i> peer reviews, Delphi panels) should be implemented with explicit methods for controlling ( <i>e.g.</i> establishing group consensus iteratively) or evaluating ( <i>e.g.</i> quality criteria) the quality of analyses. An appropriate balance between the resources required, the constraints of bureaucracy, and the benefits of process control should be struck.
Validation	Assessing the fundamental correctness of the risk analysis process design ( <i>e.g.</i> that the correct techniques are being applied, that the correct initiation criteria are in place).	The willingness and means to question the validity of current risk analysis practices is required to show due diligence and ensure that current practices are legitimate, and is further a prerequisite to the continual improvement of risk analysis.	Formalised approaches to validation include: statistical or mathematical approaches to validating technical methodologies, independent peer reviews, and benchmarking surveys; and informally may draw upon: professional networks, trade and scientific literature, <i>etc.</i>
Organisational learning	The manner in which the organisation identifies, evaluates and implements improvements to the design and execution of risk analysis.	Mechanisms for verification and validation are mere panaceas if their findings are not acted upon, <i>i.e.</i> , if they are not used to rectify deficiencies in the design and execution of risk analysis.	Reviews should: be undertaken at specified intervals and on an event driven-basis; consider a broad range of internal and external feedback; focus on improving the validity of the risk analysis process and the effectiveness of its execution, not on ensuring it complies with a given standard; treat errors of omission or commission in the execution of risk analysis not as isolated lapses requiring sanction to prevent their re-occurrence, but as opportunities to identify and resolve root and common

			causes of error; and be supported by a learning culture, wherein current methods and approaches to risk analysis, and their underlying assumptions, are open to question and critical evaluation.
Stakeholder engagement	The engagement of stakeholders, both internal and external to the utility, for the purpose of harnessing a broad range of perspectives, knowledge, skills and experience.	The legitimacy of risk analysis outputs depends upon appropriately broad stakeholder engagement, as risk is an intrinsically multi-faceted construct, whose comprehensive understanding is often beyond the capabilities of individuals or small groups.	A team approach to risk analysis which pools the knowledge, skills, expertise and experience of a range of perspectives is preferable (Health and Safety Laboratory, 2003; MHU, 2003; Joy and Griffiths, 2005). External stakeholders may be engaged to: capture expertise ( <i>e.g.</i> consultants); confer additional legitimacy on the analyses; communicate due diligence ( <i>e.g.</i> regulators); and capture community values and ensure they are incorporated within the analysis.
Competence	The ability to demonstrate knowledge, skills, and experience in risk analysis to the level required (Health and Safety Laboratory, 2003).	The legitimacy of risk analyses outcomes depends to a large extent on the capacity of staff to critically evaluate available information and to supplement it with their own knowledge and plausible assumptions (Rosness, 1998) , <i>i.e.</i> on staff competencies.	Definition of required staff competencies in risk analysis; evaluation and implementation of appropriate education and training vehicles to develop / maintain those competencies ( <i>e.g.</i> class room learning, external workshops); providing “on the job” training under adequate supervision; designing and implementing methods for evaluating the efficacy of educating and training ( <i>e.g.</i> for measuring that the required competencies have been imparted).

#### **1.6.4 Summary of the distinctions between the RM-CMM and the revised capability maturity model**

Our revised capability maturity model differs in a variety of ways from its precursor, the RM-CMM. Aside from the general progression from prescriptive to descriptive, these changes can be placed into five principal categories, relating to: the selection of processes; the selection of practices which comprised each process; the selection of attributes which define process maturity; the distinctions between maturity levels; and the approach to evaluating process maturity. We summarise these in turn.

##### *1.6.4.1 Changes in the selection of processes*

Firstly, the models' are distinct in terms of the processes included: the revised model incorporates the processes of risk analysis and risk based decision making. These are considered two of the three *a priori* risk management processes under our reconceptualisation (Figure 1.1). The implementation of risk based decisions process ("risk response" in the language of the RM-CMM) was not included due to data limitations which were compounded by the fact that implementation mechanisms can be expected, indeed were observed, to vary markedly depending on the nature of the decision to be implemented (*i.e.* operational vs. capital vs. procedural, *etc.*). This contrasts with the RM-CMM, which considered risk management to be comprised of eleven processes (which included the three discussed above). Therefore, a relevant question to ask here is: what happened to the other eight processes? There are three categories of reasoning for their exclusion from our revised model: processes removed as the initial rationale for their inclusion was considered invalid; processes re-incorporated within the maturity hierarchy (*i.e.* re-formulated as attributes defining process maturity) or within the retained processes; and processes removed as they were

simply redundant. We describe these in turn (although in some cases, combinations of these reasons were applied).

In the first category, the processes of supply chain risk management and change risk management were removed as, with our revised view that risk management is not an overarching discipline, but rather one taking discrete forms which vary according to the functional context of its application, they became simply the application of risk management to supply chain and change management functions, rather than distinct risk management processes. Strategic risk planning was removed because, whilst it centred on the development of the risk management framework, the practices included were a scatter gun of strategic requirements rather than a discrete process, some of which were redundant as they were incorporated within the maturity hierarchy (*e.g.* allocate resources for implementing corporate risk management strategy). Integrating risk management was removed as the three practices it considered were either: redundant (the institutionalisation aspect, which is at the core of the maturity hierarchy concept); no longer considered valid (cross-functional integration, as we now consider that the form of risk management should be fit for purpose, *i.e.* tailored to fit the functional context in which it is applied, rather than being normalised across the organisation to fit a common format); or had found no meaningful empirical support through the RM-CMM's application and so presumed irrelevant (the integration of risk management process interfaces).

The establishing risk acceptance criteria process was reformulated on the basis that the two aspects it addressed were, theoretically and empirically, unrelated. To explain, the development of criteria for evaluating the significance of risk, observed in practice to involve the development of risk ranking techniques (intended to normalise, *e.g.*, environmental and financial risks to a common denominator), was quite distinct

from developing criteria for evaluating the acceptability of risk (e.g. the ALARP principle, cost-benefit principle). They are theoretically distinct in that the determination of whether a risk is acceptable cannot be based purely on its evaluated significance, *i.e.* the acceptability of risk cannot be determined without considering the costs and benefits of maintaining vs. reducing current risk levels. And so the latter aspect is now coded within the risk based decision making process of our revised model as a practice, whilst the former is one element of resourcing, an attribute defining the maturity of implementation of risk analysis (in terms of sufficiency of techniques available). Risk monitoring was no longer considered as a discrete process, but rather as the revision of existing risk analyses, and so is represented within the revised maturity hierarchy of risk analysis (*i.e.* that criteria for initiating risk analyses should be both cyclical and event-based). Risk knowledge management, or the collection and storage of input and output risk management data, is similarly now incorporated within the revised maturity hierarchy (*i.e.* the attributes of input and output data management). Finally, education and training in risk management, *i.e.* the development and maintenance of staff competencies in risk management, is also incorporated within the revised maturity hierarchy (as seen in the characterisation of the maturity attribute competence at L3 for risk analysis and risk based decision making). This reflects: that the limited nature of education and training in risk management observed within our research suggests it would be counter-intuitive to consider it as an independent and therefore critical process; and that competencies in risk management is a somewhat abstract concept, as compared to competencies in risk analysis or risk based decision making, which is more tangible.

An important point to recall is that numerous standpoints could be taken advocating the inclusion of process x or y within our re-conceptualisation of risk

management, as numerous activities central to the management of risk could be formulated as processes. The *reductio ad absurdum* of which is that the allocation of roles and responsibilities in risk analysis could be viewed as a distinct process. This is, strictly speaking, true, however, our re-conceptualisation of risk management explicitly considers only three processes – those considered critical – one of which, implementation of risk based decisions, is not included in our revised model, for reasons discussed above.

#### *1.6.4.2 Changes in the selection of practices*

There were also changes in the practices which comprised the processes of risk analysis and risk based decision making. Within the revised model, risk analysis and risk based decision making are composed of a series of practices. These practices, taken together (Figure 1.3), explicitly map out each process flow (whereas in our prior model, the practices were, in essence, elements of each process flow, rather than their totality). The substantive nature of the changes renders their complete discussion inappropriate. Instead the reader is referred to Chapter 7 for a discussion of the risk analysis and risk based decision making practices coded within the revised model, and of their theoretical and empirical basis.

#### *1.6.4.3 Changes in the selection of attributes which define process maturity*

We now turn to distinctions relating to the selection of attributes which define process maturity. The RM-CMM considered eight attributes to define process maturity, whilst the revised model considers eleven. Note that many of the attributes in the final model were simply extensions, clarifications or adaptations of the prior attributes, whilst others were reformulated from processes now removed (*e.g.* input and output



data management, two maturity attributes of the revised model, were reformulated from the risk knowledge management process of the RM-CMM). This progression was informed by our empirical observations, in particular from the final case study (as evidenced in Appendix H) and a return to the literature (as evidenced in Table 7.4 and Appendix J). Importantly, the revised attributes and their rationale for inclusion were more explicitly defined, information was provided on their key aspects, and their definitions were more closely related to their descriptions within the maturity hierarchy (*i.e.* the coding was tightened, see Table 7.3 and Appendix I).

#### *1.6.4.4 Changes in the distinctions between maturity levels*

The final category of changes relates to how we have defined the distinctions between maturity levels (*i.e.* how L1 is distinguished from L2, from L3, *etc.*). As an exhaustive description of these changes would be banal, we note only those prominent changes. The revised model explicitly considers completeness of process execution as one aspect characterising process maturity. Specifically, to reach L2 maturity in risk analysis or risk based decision making, those practices designated as critical must be explicitly undertaken; to reach L3 maturity, one requirement is that both the critical and key practices are undertaken. The distinction between key and critical practices is somewhat arbitrary, but is based on the premise that the key practices are non-essential (yet valuable) components of each process, whilst the critical practices are essential. A further change may be categorised as general refinements in the maturity hierarchy. Here, the maturity hierarchy was refined based on the revised attributes, and re-scaled in terms of their manner of representation within the hierarchy (*i.e.* how the attributes were characterised at each maturity level).

#### *1.6.4.5 Changes in the approach to evaluating process maturity*

The final category of changes relates to the approach to evaluating process maturity. The revised model requires that in order to achieve a given maturity level, all positive requirements of that level and those preceding levels must be satisfied. This contrasts with the approach to evaluating process maturity adopted in our application of the RM-CMM, which was based on the “highest degree of fit.” This revised approach is more in line with the traditional approach to process maturity evaluations in the CMM field, and emphasises that the weakest link can be the lowest common denominator in determining the value derived from a process.

#### **1.6.5 Research findings**

Here, we focus on the empirical data derived from the revised model’s application within the final industrial case study. In this regard, the research findings may be summarised as: juxtaposing empirical observations on the practices which constitute the processes of risk analysis and risk based decision making across a range of utility functions; providing a comparative analysis of the strengths and limitations of said practices with reference to the broader literature (*e.g.* the strengths and limitations of checklist-based approaches to hazard identification in occupational health and safety management); empirical observations on the steps required for the mature implementation of those practices across a range of functions (*e.g.* relating to how risk analysis may be initiated within engineering, and quality control achieved within project risk analysis); and evaluating the implications of the presence or absence of those maturity characteristics with reference to the broader literature (*e.g.* discussing the implications of the lack of a defined framework for risk based decision making). Whilst the generalisability of the empirical findings is naturally a concern given the

limited sample, the effort taken in setting the findings within the context of the broader literature ameliorated this in part. More broadly, concerns relating to the generalisability of the model must be balanced with the knowledge that whilst this final case study did inform its development, so to did: the empirical findings from the prior benchmarking survey and initial industrial case study; the capability maturity literature; risk analysis and management frameworks; decision theory and its application to risk based decision making; and quality management principles (Figure 1.2).

## **1.7 CONTRIBUTION TO KNOWLEDGE**

### **1.7.1 Design and application of RM-CMM**

In light of our recanting of the RM-CMM, its contribution is best viewed as a vehicle for obtaining the empirical observations derived from its application in the initial case study and subsequent benchmarking survey, and as a precursor to the final model. Note that our recanting does not invalidate those empirical observations; it simply means that they were imperfectly coded. To recap, we methodically derived a portfolio of observations on water utility risk management practices, and their relative maturity of implementation. The novelty of these findings are striking, given that whilst the premise that institutional capacities rather than technical aspects are a fundamental limiting factor in implementing risk management has many proponents (*e.g.* Garrick, 1988; Luehrman, 1997; Strutt, 2006), there is a dearth of descriptive research on both the practical form of risk management within the water and related utility sectors and how it may be institutionalised, and those that exist tend towards the anecdotal rather than analytical (*e.g.* Dalglish and Cooper, 2005; Aabo *et al.*, 2005).

Here, we are compelled to address the recent development of a selection of risk management capability maturity models (*e.g.* IACCM, 2003; RMRDP, 2002). We believe that these models insufficiently reflect the basic principles of capability maturity modelling. The most critical point is that they are not explicitly process-centred. Furthermore, they do not closely reflect the clear distinctions between maturity levels as set out by the Software Engineering Institute and developed further by subsequent researchers (Paulk *et al.*, 1993; SEI, 2002a/b; Sharp *et al.*, 2002; Strutt *et al.*, 2006; Sarshar *et al.*, 2000), instead characterising risk management maturity on a graded scale of good-to-bad practice. Of course, the CMM approach is not the sole means for improving risk management, and these critiqued models have found support within industry. Thus, we do not imply that the IACCM and RMRDP models are without value, indeed their simplicity and modest time demands may prove attractive to many organisations. However, our research was not an extension of these models, but rather a novel application of capability maturity modelling to the discipline of risk management as applied within the water utility sector.

### **1.7.2 Design and application of capability maturity model for benchmarking risk analysis and risk based decision making practice**

Naturally, we focus on the contributions of our revised model and its application, which were three-fold. We have: synthesized empirical observations with behavioral and normative theories to codify the processes of risk analysis and risk based decision making; placed these processes within a maturity framework which distinguishes their relative maturity of implementation from *ad hoc* to adaptive; and provided a comparative analysis of the risk analysis and risk based decision making practices, and

their maturity of implementation, across a range of water and wastewater utility functions.

We begin by discussing the contribution to knowledge regarding the revised model itself, before considering the empirical observations derived from its application. In essence, the model is composed of two elements: practices which together constitute the process flows for risk analysis and risk based decision making (*i.e.* the codification of risk analysis and risk based decision making); and maturity levels, characterised with reference to attributes, which describe their relative maturity of implementation (*i.e.* degree of institutionalisation). Novelty is found within these elements independently, and in their synthesis, as we outline below.

#### *1.7.2.1 Novelty in coding of risk analysis*

We begin by discussing our codification of risk analysis (Figure 1.3; Table 1.3), whose contribution and novelty is best described with regard to prominent risk management frameworks which adopt a strategic, organisation-wide focus (*e.g.* COSO, 2004; AS/NZS, 1999, 2004; FERMA, 2003) and those frameworks for drinking water quality management which adopt a risk-based approach (NZMOH, 2001; NHMRC, 2001, 2004; WHO, 2002, 2004). Consider first our initial practice, system characterisation. This practice is concerned with establishing and describing the system with which risk analysis is concerned, and is included as we propose that a comprehensive system understanding is a *sine qua non* for generating risk analysis outcomes that are valid and accepted by stakeholders. Analogous steps are found in those strategic risk management frameworks (*e.g.* AS/NZS: establish the context; COSO: internal environment), however ours diverges due to its intended functional focus. In other words, those steps in the aforementioned strategic frameworks are

concerned with establishing the organisational context for risk analysis (*e.g.* establishing the organisation's strengths, weaknesses, opportunities, and threats; the organisation's wider goals and capabilities, *etc.*), whilst our model, being intended for application within a functional context, adopts an altogether more operational focus to system characterisation (*e.g.* characterising the workplace, engineering process, or project with which risk analysis is concerned). This practice, when applied to a drinking water quality management function, is analogous to "system assessment and design stage" and "water supply system analysis," elements of WHO's water safety plan approach and the NHMRC framework for drinking water quality management, respectively, although of course these latter frameworks focus only in part on the application of risk analysis to drinking water quality hazards (being concerned with broader aspects of drinking water quality management, such as operational procedures, monitoring, and verification of drinking water quality).

Similarly, our inclusion of the practice hazard precursor identification, is distinct in that those strategic risk management frameworks tend to focus on hazard identification (*i.e.* finding sources of potential harm), rather than the exploration of how and why hazardous events may occur (*i.e.* examining underlying processes or pathways – precursors – through which hazardous events may arise). This is an important observation in that an inability to capture causal pathways to failure significantly impedes the development of risk reduction measures targeted at their root causes. Consider now our practice control evaluation. This involves the identification and assessment of existing technical, physical and administrative controls which may either reduce the likelihood of a hazardous event occurring, or serve to mitigate its severity of consequences. Whilst not in itself novel (*e.g.* AS/NZS, 1999, 2004), our treatment of the practice diverges in that we consider this assessment should address both the

criticality of the controls (*e.g.* based on their inherent capacity to reduce risk, whether they are proactive or reactive, *etc.*) and their adequacy of design, management and operation. In doing so, we abstract principles relating to the control of drinking water quality hazards from those frameworks for drinking water quality management which adopt a risk-based approach (NZMOH, 2001; NHMRC, 2001, 2004; WHO, 2002, 2004).

Finally, our coding of risk analysis places consequence evaluation prior to likelihood evaluation, as opposed to the majority of frameworks which consider the order in which they are performed to be interchangeable, or at least make no explicit reference to their ordering (*e.g.* COSO, 2004; AS/NZS, 1999, 2004; FERMA, 2003). Our reasoning is simple: risk assessment (*i.e.* the combined steps of consequence and likelihood evaluation) involves determining the likelihoods of a range of potential outcomes, or the likelihood of one potential outcome. Thus, the outcome(s) should be defined prior to any evaluation of its (their) likelihood of occurrence. If these steps are performed in reverse, likelihood evaluation will inevitably be concerned with the likelihood of a hazardous event occurring (*e.g.* the probability of asset failure), rather than with the likelihood of an event occurring *and* leading to a defined outcome (*e.g.* the probability of an asset failing and leading to a given environmental impact). The former approach overestimates risk.

#### *1.7.2.2 Novelty in coding of risk based decision making*

We now turn to our coding of the risk based decision making process (Figure 1.3; Table 1.4). It is notable that strategic risk management frameworks (*e.g.* COSO, 2004; AS/NZS, 1999, 2004; FERMA, 2003) conventionally treat risk based decision making, namely the identification, evaluation and selection of options to reduce risks, in a

somewhat cursory manner. This perhaps reflects a prevailing view that values the judgement, intuition, and inherent need for creativity of decision makers, over any perceived moves towards prescription. However, decision making frameworks, including ours, are intended to guide, not prescribe, decision making, with the objective of ensuring a level of consistency, credibility, and confidence in achieving desirable outcomes. This is supported by a wealth of empirical evidence suggesting that, in the absence of a clear framework, people struggle to identify their full range of values and concerns in a given decision context, and are ill-equipped to make those complex trade-offs common to risk based decision making (Arvai *et al.*, 2001; Slovic *et al.*, 1977; Payne *et al.*, 1992; Slovic, 1995; Matheson and Matheson, 1998). This is manifested in the selection of sub-optimal risk reduction options; sub-optimal, as they fail to address the full range of stakeholder concerns and values (Bohneblust and Slovic, 1998).

And so the contribution and novelty of our coding is best illustrated not by its comparison to existing risk management frameworks, but rather to the literature on decision theory (particularly regarding decision analysis and the construction of preferences) and its application to risk based decision making. Through this comparison, novelty is found, particularly, in two aspects. Firstly, in our designation of establish risk acceptance criteria as the initial practice, which refers to the development of criteria for evaluating the acceptability of risk (*e.g.* life safety criteria, as low as reasonably practicable (ALARP) criteria, and the *de minimis* risk concept), as in the absence of such criteria, on what basis are decisions taken whether to accept or reduce risk? Secondly, novelty is seen in our separation of the evaluate options practice into three elements: forecasting the impact of each option against the individual evaluation criteria (*e.g.* engineering studies to evaluate the technical feasibility of an option), determining the cumulative “goodness” of each option (*e.g.* via cost-benefit analysis,



multi-attribute analysis); and determining risk acceptability (*e.g.* applying the results of the cost-benefit analysis to the ALARP criteria). Determining risk acceptability is the final of these elements as it is risk reduction options, not risks, which are unacceptable or acceptable (Fischhoff *et al.*, 1981), *i.e.* the acceptability of risk cannot be determined without considering the costs and benefits of maintaining vs. reducing current risk levels.

Finally, we highlight our inclusion of the practice managerial review and option selection, which is concerned with the application of managerial judgement in reviewing the premises, assumptions, and limitations of analyses, prior to the final decision (*i.e.* selection of risk reduction option). Whilst not novel (after Aven *et al.*, 2006), it is crucial as it highlights our view that decision analysis should compliment, but not replace, the knowledge, intuitions and judgement of decision makers (Mintzberg, 1994), and further, that risk based decisions should not reflect theoretically or analytically derived perspectives that run counter to sound professional judgement (Hrudey and Hrudey, 2003). More specifically, it emphasises that as risk is, at a fundamental level, an expression of uncertainty, and that the analysis of risk and decision alternatives is further subject to aleatory, epistemic and operational uncertainty (Amendola, 2001), then the outputs of decision analysis must be treated diagnostically rather than deterministically, *i.e.*, they should provide decision support, not decisions. This final point is critical, as there is an understandable tendency for decision making frameworks to embrace determinism, given that, at a psychological level, the mind prefers certainty to truth, and often mistakes the former for the latter. Whilst our model seeks to explicitly avoid this, one can question whether the roles of judgement, experience, bias, power structures, *etc.*, would be best incorporated within each process step (*i.e.* practice) of risk based decision making, rather than it being appended as the

last practice in the process. This is because all of these aspects inevitably influence each preceding practice (*e.g.* bias influences the selection of evaluation criteria, *etc.*).

### 1.7.2.3 Novelty in coding of maturity hierarchy

We now turn to the novelty of our revised maturity levels, characterised with reference to attributes, which describe the relative maturity of implementation of the processes of risk analysis and risk based decision making (Table 1.5; Table 1.6). Here, novelty is inherent as, to our knowledge, it is the first detailed application of CMM principles to the processes of risk analysis and risk based decision making (excluding the RM-CMM). Thus, we focus on novelty in comparison to CMMs designed for other disciplines (*e.g.* software engineering, construction management, reliability engineering, *etc.*). In this regard, novelty is found in both the attributes selected and, less importantly, in their manner of representation within the maturity hierarchy (*i.e.* what distinguishes one level from another). We restrict our discussion to the former. Many of the attributes can be traced back to the prior literature on capability maturity modelling and quality management (specifically: procedures, roles and responsibilities, resource management, input data management, output data management, verification, and competence; see *e.g.* Crosby, 1979, 1996; Hoyle, 2001; ISO, 2000; Paulk *et al.*, 1993; SEI, 2002a/b; Sharp *et al.*, 2002; Strutt *et al.*, 2006; Sarshar *et al.*, 2000), however we have built upon this prior art through both refining and adapting our descriptions of these attributes to fit the context of risk analysis and risk based decision making, a task informed by our empirical observations and the broader literature (*e.g.*, see Table 1.6, and Appendices H and J).

This extension of the prior art is shown in our treatment of competence, which, in the case of its application to risk analysis, is defined as the ability of staff to

demonstrate knowledge, skills, and experience in risk analysis to the level required, an attribute included as the legitimacy of risk analyses depends largely on the capacity of staff to critically evaluate available information and to supplement it with their own knowledge and plausible assumptions (Rosness, 1998), *i.e.* on staff competencies. Key issues here include the definition of required staff competencies in risk analysis; the evaluation and implementation of appropriate education and training vehicles to develop / maintain those competencies (*e.g.* classroom learning, external workshops); providing “on the job” training under adequate supervision; and designing and implementing methods for evaluating the efficacy of educating and training (*e.g.* for measuring that the required competencies have been imparted).

We now turn to those attributes which are particularly distinctive in comparison to the prior CMM literature. We illustrate these with reference to the risk analysis process, although their application to risk based decision making is broadly similar. One of these is initiation criteria, which refers to predefined stages or conditions which initiate risk analysis, included to ensure that risk analysis is undertaken as required, rather than being initiated on an *ad hoc*, over zealous, or reactive basis, or marginalised as “make work.” Key issues here include identifying where risk analysis is necessary vs. where adherence to codes and standards can be said to discharge the duty (Health and Safety Laboratory, 2003; UKOOA, 1999), and making this explicit in cyclical and event-based criteria. Another novel attribute is stakeholder engagement, which deals with the engagement of stakeholders, both internal and external to the utility, for the purpose of harnessing a broad range of perspectives, knowledge, skills and experience within risk analysis, on the basis that risk is an intrinsically multi-faceted construct, whose comprehensive understanding is often beyond the capabilities of individuals or small groups.

Consider also our treatment of validation as an attribute, which is concerned with evaluating the fundamental correctness of the risk analysis process design (*e.g.* that the correct techniques are being applied, that the correct initiation criteria are in place), and included because the willingness and means to question the validity of current practices is required to show due diligence and ensure that current practices are legitimate, and is further a prerequisite to their continual improvement. Formalised approaches to validation include: statistical or mathematical approaches to validating technical methodologies, independent peer reviews, and benchmarking surveys; and informally may draw upon: professional networks, trade and scientific literature, *etc.*

Finally consider our inclusion of organisational learning as an attribute, which addresses the manner in which the organisation identifies, evaluates and implements improvements to the design and execution of risk analysis, and is based on part upon the concepts of single and double-loop learning (Argyris and Schön, 1978). It is included because mechanisms for verification and validation of risk analysis are mere panaceas if their findings are not acted upon, *i.e.*, if they are not used to rectify deficiencies in the design and execution of risk analysis. Key issues here are that associated reviews should be: undertaken at specified intervals and on an event driven-basis; consider a broad range of internal and external feedback; focus on improving the validity of the risk analysis process and the effectiveness of its execution, not on ensuring it complies with a given standard; treat errors of omission or commission in the execution of risk analysis not as isolated lapses requiring sanction to prevent their re-occurrence, but as opportunities to identify and resolve root and common causes of error; and be supported by a learning culture, wherein current methods and approaches to risk analysis, and their underlying assumptions, are open to question and critical evaluation.

#### *1.7.2.4 Utility of capability maturity model for benchmarking risk analysis and risk based decision making practice*

We now consider the contribution of the synthesis of our coding of risk analysis and risk based decision making within a process maturity hierarchy in terms of the utility of the revised model; specifically, who will use it and what will it enable them to do that they were previously unable to? From an internal organisational perspective, there are three principal uses of the model: for benchmarking purposes, enabling utility functions to compare themselves against others in their sector and beyond; as a reference model for developing plans to improve capabilities in risk analysis and risk based decision making; or to drive improvements in the capabilities of key suppliers and partners (*e.g.* by using maturity in risk analysis or risk based decision making as a criteria in supplier selection). From an external perspective, the model is of potential use to standards agencies within the water and related utility sectors. It satisfies a key requirement of being both empirically and theoretically grounded, and is distinct from existing standards in terms of: its proven generalisability to a range of utility functions; its detailed treatment of risk based decision making, in particular the inclusion of the principles of decision theory; and its placement of risk analysis and risk based decision making within a maturity framework which allows distinctions to be made between organisational capabilities based on their relative maturity of implementation. Furthermore, the model has potential utility from a regulatory perspective, specifically in facilitating a step-change in the approach to regulating risk management within the water sector from its current synthesis of reactive, outcome based approaches (*e.g.* water quality standards) and prescriptions (*e.g.* codes and regulations), towards a proactive, capability based approach. Finally, the model has potential value to the

research community, as a framework for conducting further descriptive research into utility risk management practices and their methods of institutionalisation.

#### *1.7.2.5 Novelty in empirical findings*

Finally, we consider the contribution of our empirical findings. As noted, these may be summarised as: juxtaposing empirical observations on the practices which constitute risk analysis and risk based decision making across a range of water utility functions; providing a comparative analysis of the strengths and limitations of said practices with reference to the broader literature (*e.g.* the strengths and limitations of checklist-based approaches to hazard identification in occupational health and safety); empirical observations on the steps required for the mature implementation of those practices across a range of functions (*e.g.* relating to how risk analysis may be initiated within engineering, and quality control achieved within project risk analysis); and evaluating the implications of the presence or absence of those maturity characteristics with reference to the broader literature (*e.g.* discussing the implications of the lack of a defined framework for risk based decision making).

As we have noted, the novelty of this is pronounced given the lack of descriptive research of an analytical nature on risk management within water utilities. Indeed, this novelty extends beyond the water sector, as academic treatments of risk analysis and risk based decision making, particularly the former, tend to focus on their technical and normative aspects (*e.g.* focusing on the technical aspects of applying risk or decision analysis techniques), rather than their institutional, behavioural, or descriptive aspects (*e.g.* how risk analysis and risk based decision making can be embedded within organizations, or case study research exploring how they are applied in practice).

Furthermore, our function-specific approach counters the concept of “enterprise wide risk management,” which, anecdotally, appears to have created a majority opinion amongst practitioners where risk management is viewed as an over-arching, strategic discipline (*i.e.* taking broadly similar forms in strategic planning, business planning and project management), as opposed to the minority brief, to which the author subscribes, which, whilst recognising that the underlying theoretical basis of risk analysis and risk based decision making remain largely constant, views the variations and nuances of their application to particular utility functions as critical (*i.e.* we consider that the form of risk analysis and risk based decision making should be fit for purpose, rather than being normalised across the organisation to fit a common format).

## **1.8 CONCLUSIONS**

The research was based on the premise that the most fruitful approach to improving water utility risk management practice on the ground would be to focus on the implementation of risk management rather than the techniques employed *per se*, *i.e.* to focus on the institutional capacities of utilities to employ risk analysis and management techniques for more credible, optimal decision making. Here, the field of capability maturity modelling showed great promise. Thus, the research began with the development of a risk management capability maturity model (RM-CMM) for the water utility sector. The model was a prescriptive codification of water sector risk management practice, within a process-based hierarchy which distinguished the relative maturity of implementation of risk management. The model was then applied to the sector via case study and benchmarking survey. Given our subsequent revision of the model, its contribution is best viewed as a precursor to the revised model, and as a

vehicle for capturing empirical observations reflecting our prescriptive codification of risk management processes and their methods for institutionalisation.

We revised the prescriptive RM-CMM model towards a *descriptive* capability maturity model of risk analysis and risk based decision making practice. We illustrated the application of this revised model to a cross-section of water and wastewater utility functions. The contribution to knowledge of this stage of the research was three-fold, we: synthesized empirical observations with behavioral and normative theories to codify the processes of risk analysis and risk based decision making; placed these processes within a maturity framework which distinguishes their relative maturity of implementation from *ad hoc* to adaptive; and provided a comparative analysis of the risk analysis and risk based decision making practices, and their maturity of implementation, across a range of water and wastewater utility functions.

This research is particularly timely, given that whilst the premise that institutional capacities rather than technical aspects are a fundamental limiting factor in implementing risk management has many proponents (*e.g.* Garrick, 1988; Luehrman, 1997; Strutt, 2006), there is a dearth of descriptive research on both the practical form of risk management within the water and related utility sectors and how it may be institutionalised, and those that exist tend towards the anecdotal rather than analytical (*e.g.* Dalgleish and Cooper, 2005; Aabo *et al.*, 2005). In summary, the research provides utility managers, technical staff, project managers and chief finance officers with a *practical* and systematic understanding of how to implement and improve risk management, and offer preliminary guidance to regulators concerning how improved water utility governance can be made real. This latter point is particularly pertinent, given the revised model's potential for facilitating a step-change in the approach to regulating risk management within the water sector from its current synthesis of



reactive, outcome based approaches (*e.g.* water quality standards) and prescriptions (*e.g.* codes and regulations), towards a proactive, capability based approach.

## 1.9 FUTURE RESEARCH

Finally, we present suggestions for future research:

- 1: Apply the revised model to benchmark the risk analysis and risk based decision making capabilities of a representative sample of the international water utility sector. This would reveal the general strengths and weaknesses of the sector as a whole, and so inform the targeting of regulatory, industrial and scholarly resources to ameliorate the latter. The assessment methodology should depart from that adopted in the thesis in two principal ways. The first concerns the sampling design, which was devised to capture “best practice” utilities throughout this thesis, rather than to reflect the sectors’ capabilities as a whole. The second concerns the approach to determining process maturity. Although we do not anticipate a deterministic assessment approach (*i.e.* there would remain a role for expert judgement in interpreting the data), we feel that in order to enhance the reliability and validity of the maturity profiles that would be obtained, clear criteria should be established as to what constitutes valid *evidence* for attaining each maturity level (*e.g.* what *specific* documentary, observational or anecdotal evidence would correlate with the guideline statement characterising stakeholder engagement at L3 maturity in risk analysis).
- 2: Establish the correlation between maturity in risk analysis and risk based decision making and utility performance in managing risk. This is crucial, as there is a regrettable tendency within the social sciences to judge the value of

tools and policies based on their intentions, rather than the consequences which they generate. However, if industrial take up of the model is desired, empirical evidence of the (presumed) benefits that derive from implementing the model would be crucial (*e.g.* characterising the expected reduction in water quality contamination events from an enhancement of maturity in risk analysis). This work could proceed in concert with the above suggestion, with performance in risk management perhaps measured by the framework presented in Appendix A, and conventional statistical methods used to determine both the nature and extent of the correlation.

- 3: Apply the model to related industry sectors considered at the cutting edge of risk management (*e.g.* nuclear, offshore oil and gas, chemical process). This is because we feel that there is considerable opportunity for cross-fertilisation of knowledge from those sectors who have been experimenting longer with risk management.

## **1.10 REFERENCES**

- Aabo, T., Fraser, J. and Simkins, B., The rise and evolution of the chief risk officer: enterprise risk management at Hydro One, *Journal of Applied Corporate Finance*, *17*(3):62, 2005.
- Amendola, A., Recent paradigms for risk informed decision making, *Safety Sci.*, **40**:17, 2001.
- Argyris, C. and Schön, D., *Organizational learning: A theory of action perspective*, Reading, Mass: Addison Wesley, 1978.

- Arvai, J.L., Gregory, R., and McDaniels, T.L., Testing a structured decision approach: value-focused thinking for deliberative risk communication, *Risk Anal.*, **21**(6): 1065, 2001.
- AS/NZS (Australian/New Zealand Standard). *AS/NZS 4360:1999 Risk management*, Strathfield: Standards Association of Australia, 1999.
- AS/NZS (Australian/New Zealand Standard). *AS/NZS 4360:2004 Risk management*, Strathfield: Standards Association of Australia, 2004.
- Aven, T., Vinnem, J.E. and Wiencke, H.S., A decision framework for risk management, with application to the offshore oil and gas industry, *Reliab Eng Syst Safe.*, In press; 2006; available at: <http://www.sciencedirect.com/science/article/B6V4T-4J9MSSC-2/2/5ad5d7aeb729a6d0d3cd0c93373fde01>
- Aven, T. and Kørte, J., On the use of risk and decision analysis to support decision-making, *Reliab Eng Syst Safe.*, **79**:289, 2003.
- AWWA, EUREAU, WSAA and DVGW, *Bonn Workshop 2001 – Key principles in establishing a framework for assuring the quality of drinking water: a summary*, AWWA, Denver, CO., 2001.
- Bohneblust, H. and Slovic, P., Integrating technical analysis and public values in risk-based decision making, *Reliab Eng Syst Safe.*, **59**:151, 1998.
- Booth, R. and Rogers, J., Using GIS technology to manage infrastructure capital assets, *J. AWWA*, **93**(11): 62, 2001.
- Clemen, R.T., *Making hard decisions*, 2<sup>nd</sup> Ed, New York: Duxbury Press, 1996.
- COSO (Committee of Sponsoring Organizations of the Treadway Commission). *Enterprise risk management – integrated framework*, COSO, 2004.
- Crosby, P.B., *Quality is free*, New York: McGraw-Hill, 1979.
- Crosby, P.B., *Quality is still free*, New York: McGraw-Hill, 1996.

- Dalglish, F. and Cooper, B.J., Risk management: developing a framework for a water authority, *Int. J. Manage. Environ. Qual.*, **16**(3): 235, 2005.
- Faber, M.H. and Stewart, M.G., Risk assessment for civil engineering facilities: critical overview and discussion, *Reliab Eng Syst Safe.*, **80**:173, 2003.
- FERMA (Federation of European risk management associations), *A risk management standard*, FERMA, 2003. (website: <http://www.ferma-asso.org/tabid/195/Default.aspx>).
- Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S., and Keeney R., *Acceptable risk*, New York: Cambridge University Press, 1981.
- Garrick, B.J., The approach to risk analysis in three industries: nuclear power, space systems, and chemical process, *Reliab Eng Syst Safe.*, **23**:195, 1988.
- Glaser, B.G and Strauss, A.L., *The discovery of grounded theory*, New York, Aldine, 1967.
- Hamilton, P.D., Gale, P., and Pollard, S.J.T., A commentary on recent water safety initiatives in the context of water utility risk management. *Environ Int.* **32**:958-966; 2006a.
- Hamilton, P.D., Pollard, S.J.T., Hrudey, S.E., and MacGillivray, B.H., Risk management frameworks for the water sector – a review, at review, 2006b.
- Health and Safety Laboratory, *Good practice and pitfalls in risk assessment*, Health and Safety Executive, research report 151, 2003. (website: <http://www.hse.gov.uk/research/rrhtm/rr151.htm>).
- Hoyle, D., *ISO 9000 Quality systems handbook*, 4<sup>th</sup> edition, Butterworth-Heinemann, 2001.
- Hrudey S.E. and Hrudey E.J., Correspondence, *Reliab Eng Syst Safe.* **82**:343, 2003.

- Hrudey S.E. and Hrudey E.J., *Safe drinking water—lessons from recent outbreaks in affluent nations*, London: IWA Publishing, 2004.
- IMPRESS Management, *IMPRESS Guidance, guidance for the analysis of pressures and impacts in accordance with the water framework directive*, Draft 5.2, European Commission, Brussels, 2002.
- IACCM, *Organisational maturity in risk management: The IACCM business risk management maturity model (BRM3)*, 2003 (website: <http://www.risk-doctor.com/pdf-files/brm1202.pdf>).
- ISO (International Organization for Standardization), *ISO 9001 Quality management systems – requirements*, Geneva: ISO, 2000.
- Joy, J. and Griffiths, D., *National minerals industry safety and health risk assessment guideline*, Minerals Council of Australia, Version 4, January 2005. (website: <http://www.mishc.uq.edu.au/rag/index.asp>).
- Lee, T., Assessment of safety culture at a nuclear reprocessing plant, *Work Stress*, **12**(3):217, 1998.
- Lifton, G. and Smeaton, P., Asset risk management in Scottish Water. *Proc. of the ICE/CIWEM Conference: Risk and reward in asset management delivery – who is best prepared for the challenges ahead?*, 14<sup>th</sup> November, 2003, London, UK.
- Lloyd, R. and Abell, P., Capital maintenance in Yorkshire Water’s water business unit, *Proc. of Risk analysis strategies for better and more credible decision making*, 6-8<sup>th</sup> April, 2005, Banff, Canada.
- Luehrman, T.A., What’s it worth? A general manager’s guide to valuation, *Harvard Business Review*, **75**(3), 132, 1997.

- MacGillivray, B.H, Hamilton, P.D., Strutt, J.E., and Pollard, S.J.T., Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making, *Crit Rev Env Sci Tec.*, **36**: 85, 2006.
- Matheson, D. and Matheson, J., *The “smart” organization: Creating value through strategic R&D*, Cambridge, MA, Harvard Business School Press, 1998.
- MHU (Major Hazards Unit), *Hazard identification, risk assessment and risk control*, New South Wales Department of Urban and Transport Planning, Advisory paper no. 3, consultation draft, version A, 2003. (website: <http://www.planning.nsw.gov.au/plansforaction/mihaps-docs/mihaps-docs.html>).
- Mintzberg, H., *The rise and fall of strategic planning*, Prentice Hall, New York, 1994.
- NIST (National Institute of Standards and Technology), *Risk management guide for information technology systems*, NIST special publication 800-30, US Department of Commerce, 2002. (website: <http://csrc.nist.gov/publications/nistpubs/800-30/sp800-30.pdf>).
- NHMRC, *Australian drinking water guidelines*, Canberra: NHMRC, 2004. (website: [www.health.gov.au/nhmrc/publications/synopses/eh19syn.htm](http://www.health.gov.au/nhmrc/publications/synopses/eh19syn.htm)).
- NHMRC, *Framework for management of drinking water quality*, Canberra: NHMRC, 2001.
- NEA/CSNI (Nuclear Energy Agency/Committee on the Safety of Nuclear Organisations), *Identification and assessment of organisational factors related to the safety of NPPs: state-of-the-art-report*, OECD, Report 21(2), 1999. (website: <http://www.nea.fr/html/nsd/docs/1998/csni-r98-17-vol1.pdf>).
- NZMOH (New Zealand Ministry of Health), *How to prepare and develop public health risk management plans for drinking-water supplies*, Wellington: Ministry of Health, 2001. (website: [www.moh.govt.nz/moh.nsf](http://www.moh.govt.nz/moh.nsf)).

- Paulk, M.C., Curtis, B., Chrissis, M.B., and Weber, C.V., Capability maturity model, version 1.1, *IEEE Software*, **10**(4):18, 1993.
- Payne, J.W., Bettman, J.R., and Johnson, E.J., Behavioural decision research: A constructive processing perspective, *Annu Rev Psychol.*, **43**:87, 1992.
- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Hamilton, P.D. and Hrudey, S.E. Risk analysis and management in the water utility sector – a review of drivers, tools and techniques, *Trans. IChemE, Part B: Proc. Safety Environ.*, **82**(B6): 1, 2004.
- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Sharp, J.V., Hrudey, S.E. and Hamilton, P.D., Risk management capabilities – towards ‘mindfulness’ for the international water utility sector, *Proc. of the DWI Conference: Water Contamination Emergencies: Enhancing our Response*, 12-15<sup>th</sup> June 2005, Manchester, UK.
- Reason, J., *Managing the risks of organizational accidents*, Ashgate, Aldershot, UK, 1997.
- Renn, O., A model for an analytic-deliberative process in risk management, *Environ Sci Technol.*, **33**(18):3049, 1999.
- RMRDP, *Risk management maturity level development*, 2002. (website: <http://www.risksig.com/Articles/rm%20report%20final%20version%2012.doc>).
- Rosness, R., Risk influence analysis: a methodology for identification and assessment of risk reduction strategies, *Reliab Eng Syst Safe*, **60**:153, 1998.
- Sarshar, M., Haigh, R., Finnemore, M., Aouad, G., Barrett, P., Baldry, D., and Sexton, M., SPICE: a business process diagnostics tool for construction projects, *Engineering, Construction and Architectural Management*, **7**(3):241, 2000.

- Sharp, J.V., Strutt, J.E., Busby, J., and Terry, E., Measurement of organizational maturity in designing safe offshore installations, *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering*, **2**:383, 2002.
- Slovic, P., Fischhoff, B., and Lichtenstein, S., Behavioural decision theory, *Annu Rev Psychol*, **28**:1, 1977.
- Slovic, P., The construction of preference, *American Psychologist*, **50**:364, 1995.
- SEI (Software Engineering Institute), *CMMI for systems engineering / software engineering / integrated product development / supplier sourcing, version 1.1*, 2002a. (website: <http://www.sei.cmu.edu/>).
- SEI (Software Engineering Institute). *People capability maturity model, version 2.0*, 2002b. (website: <http://www.sei.cmu.edu/>).
- Stahl, G.R. and Elliott, J.C., 'New generation' computer models for risk-based planning and management, *Water Supply (Australia)*, **17**(3/4): 289, 1999.
- Stevens, I.M. and Lloyd, R.I., *Water resources: Sustainable optimisation and security of supply, a proven example*, A paper presented to the 2004 Water sources conference and exposition, Jan 11-14th, 2004, Austin, Texas.
- Strauss, A.L. and Corbin, J., Grounded theory methodology: an overview, in N.K. Denzin and Y.S. Lincoln (Eds.), *Handbook of qualitative research*, Thousand Oaks, CA:Sage, 1994.
- Strutt, J.E., *Reliability capability maturity briefing document*, Report No. R-03/2/1, Cranfield University, 2003.
- Strutt, J.E., Sharp, J.V., Terry, E., and Miles, R., Capability maturity models for offshore organisational management, *Environ Int.*, **32**:1094, 2006.
- UKOOA (UK Offshore Oil Operators Association), *Industry guidelines on a framework for risk related decision support*, London: UKOOA, 1999.



Watson, S.R. and Buede; D.M., *Decision synthesis*, New York: Cambridge University Press, 1987.

WHO (World Health Organisation), *Water safety plans (revised draft)*, Report publication WHO/SDE/WSH/02.09, WHO, 2002.

WHO (World Health Organisation), *Guidelines for drinking water quality*, 3<sup>rd</sup> edition, Geneva: WHO, 2004. (website: [www.who.int/water\\_sanitation\\_health/dwq/en/](http://www.who.int/water_sanitation_health/dwq/en/)).

## **Chapter 2**

### **Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making**

Published in *Critical Reviews in Environmental Science and Technology* (2006), **36:85**.

## **2. Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making**

B.H. MacGillivray, P.D. Hamilton, J.E. Strutt and Pollard, S.J.T.

*School of Water Sciences, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK.*

### **ABSTRACT**

Financial pressures, regulatory reform and sectoral restructuring are requiring water utilities to move from technically inclined, risk-averse management approaches toward more commercial, business-oriented practices. Risk analysis strategies and techniques traditionally applied to public health protection are now seeing broader application for asset management, assessing competition risks and potential threats to the security of supplies. Water utility managers have to consider these risks alongside one another and employ a range of techniques and devise business plans that prioritise resources on the basis of risk. We present a comprehensive review of risk analysis and management strategies for application in the water utility sector at the strategic, programme, and operational levels of decision making.

**KEYWORDS:** decision making, risk analysis, utilities, water safety plans

## 2.1 INTRODUCTION

### 2.1.1 Background

Providing wholesome, affordable and safe drinking water that has the trust of customers are the overarching goals of the water utility sector. The sector has publicly stated (AWWA *et al.*, 2001) that achieving this requires, at a minimum, that water is safe in microbiological and chemical terms; that it is acceptable to consumers in terms of taste, odour and appearance; and that the supply is reliable in terms of quality and quantity. Delivering these objectives in the context of an increasingly demanding consumer and regulatory environment, under constraints imposed by ageing infrastructure and the trend towards financial self-sufficiency is challenging. Many within the industry, spurred on by developments in international regulation and guidance, are now promoting a business-wide approach to risk management as a means to ease and exploit this transition (*e.g.* Lifton and Smeaton, 2003). In practice, water quality managers and internal audit functions within the sector are working more closely to address issues of business risk and many of the larger international water companies now have “group risk managers” in place to manage business and consumer risks within a single portfolio. Implementation of this business-wide approach to risk management is not straightforward, however - it requires (Pollard *et al.*, 2004):

- (i) integrated frameworks for the management of internal risks (*e.g.* from ageing infrastructure) and external risks (*e.g.* from “competitor” actions) to the utility;
- (ii) the support of Board level, executive management and operational staff as well as that of external stakeholders; and

- (iii) the effective communication of risk and engagement within decision-making processes both within companies and with external stakeholders.

Furthermore, as illustrated in this review, there are potential tensions between managing the risks of a commercial water business and the overarching public health goal of the water industry, stated above. Critically in this regard, the transition to an explicit risk management philosophy within the water utility sector is now reflected in recent revisions to the World Health Organisation's (WHO) Guidelines for Drinking Water Quality (WHO, 2002, 2003; Fewtrell and Bartram, 2001). This is placing an emphasis on the development and implementation of "water safety plans" for water quality management and, within these, the application of risk frameworks and risk tools such as the "hazard analysis and critical control points" (HACCP) (Dewettinck *et al.*, 2001; Hellier, 2000) approach as a basis for prioritising risk management measures within the water supply chain from catchment to tap. The risk management approach is becoming increasingly embedded within utilities and with it a maturing view of risk analysis, shifting from that of a one-off technique to "placate" regulators towards that of a practical methodology to facilitate process control, optimisation and corporate decision-making within a cost-effective framework. Despite a growing consensus, there remain significant barriers to the implementation of risk management within utilities. These can be categorised as business-related, the challenge of integrating risk management within organisational cultures and decision-making processes (*e.g.* Pollard *et al.*, 2004); and technical, relating to the selection and application of risk analysis tools. One of the key difficulties all organisations face in implementing risk management is managing the interfaces between high level corporate objectives, business plans and operational reality. Here then, we critically review the risk analysis

strategies and tools and techniques available for risk analysis within the sector, with particular emphasis on decision-making at the corporate (strategic), business (programme level) and operational levels in water utilities. Necessarily the discussion requires excursions into the management and technical environmental literature. However, we view the juxtaposition of these aspects of risk management as central to providing a well-round examination of the prior art in the current context of its application within the sector.

### **2.1.2 Risk analysis and decision-making**

Before entering a discussion on risk analysis, we must be clear in our terminology. In simple terms, risk is widely accepted to consist of a combination of probabilities and consequences. However, further clarity is required. Adapting Hrudey's (2000) elaboration, we consider the notion of risk to be a prediction or expectation that involves:

- an agent with the potential to cause either harm and/or benefit (*e.g.* a chemical contaminant, or an investment opportunity);
- uncertainty of occurrence and outcomes (expressed by the probability or likelihood of occurrence);
- consequences (the possible outcomes);
- a specified time frame.

The exploration of these facets provides us with an analysis of risk (note that the authors consider the terms risk assessment and risk analysis to be interchangeable). Risk is inextricably linked to uncertainty. Thus uncertainty analysis plays a prominent role in many risk analysis strategies. Finally, and in a distinct business context, we

consider risk management as the sum of the constituent sets of socio-technical decisions and actions taken by staff to optimise their organisation's exposure to risk.

Risk analysis plays a role alongside other decision tools for risk management (Pollard *et al.*, 2004). Detailed risk analysis is not a prerequisite for effective risk management. In many industries there are accepted standards of performance and codes of practice (*e.g.* engineering standards; accepted best practice; Figure 2.1) that, if adhered to, provide high degrees of control. These are applied in familiar and well-characterised situations where uncertainties and system vulnerabilities are well understood.

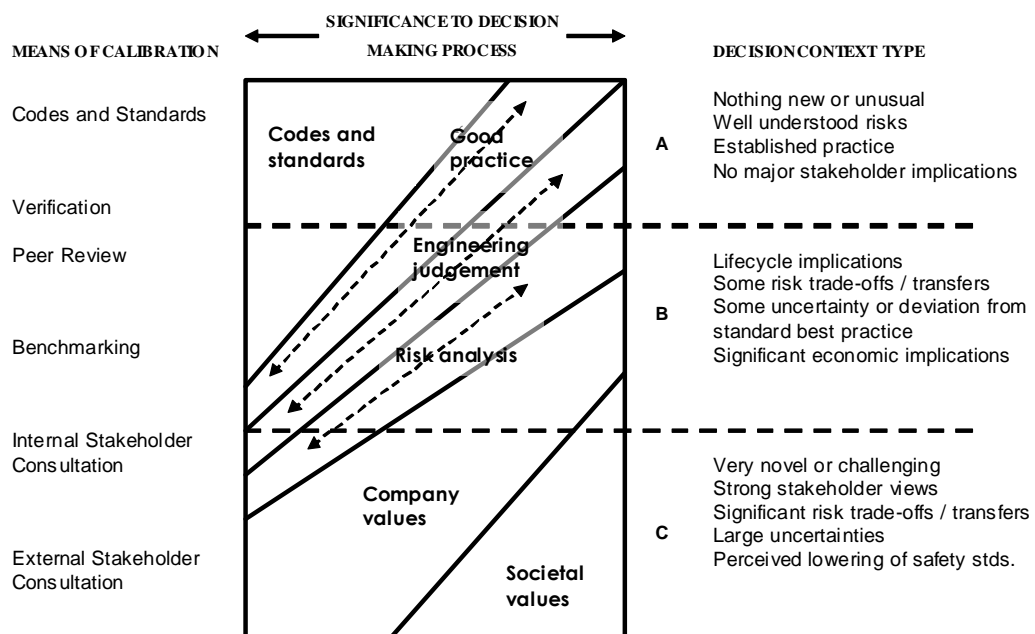


Figure 2.1 Decision Framework for the Offshore Oil Industry (UK Oil Operators Association, 1999, with permission)

However, complex, uncertain and novel systems, that deviate from routine operation, may require risk analysis, so as to better understand what drives the risk from or to the plant, process or operation, thereby allowing management measures for the reduction of unacceptable risks to be targeted for greatest effect (Pollard *et al.*,

2004). This principle extends beyond the operation of technical systems to embrace all aspects of managing a business. This said, risk analysis is, in many respects, a practitioner-driven discipline. Its application within water utilities has its roots firmly in the protection of public health from pathogens afforded by the multiple barrier approach to raw water treatment. Whilst the extension of risk analysis to asset management, water supply security and catchment (watershed) management is clearly evident, these applications and the use of risk-based techniques for optimising treatment plant performance, on-site energy use, maintenance programmes and compliance monitoring regimes can inadvertently but easily detract from and confuse the principal purpose of the water supply industry – to provide wholesome, affordable and safe drinking water that has the trust of customers. In all these applications this goal must remain paramount.

### **2.1.3 The risk hierarchy**

The organisational hierarchy that exists even within “flat” organisations requires that risks are actively managed at the strategic, programme and operational levels of an organisation (Figure 2.2). Typically, there are split accountabilities for these risks such that the chief financial officer / financial director and Board have overall responsibility, supported by an internal audit or control function for the management of strategic risks; executive and senior management address programme level risks (*e.g.* asset management, maintenance planning); and operational (*e.g.* site) managers bear responsibility for operational risks (*e.g.* treatment plant performance) (Pollard *et al.*, 2004).





Figure 2.2 The risk hierarchy (adapted from Prime Minister’s Strategy Unit, 2002)

A range of strategies exist for assessing and managing these risks in a business context. The focus in this review is sector-specific, addressing “process” risk analysis (*i.e.* risks at the operational and programme level), but in establishing a business-wide context for this activity we also draw upon the experiences of organisations assessing risk at the strategic level.

## 2.2 STRATEGIC RISK ANALYSIS

Within an overarching context of public health protection and the maintenance of process reliability, utility managers are increasingly concerned with managing the risks inherent to corporate level decision-making. Critical issues include decisions on outsourcing asset maintenance, billing and monitoring, the management of change, staff retention, the long-term viability of investment decisions, and the management of external interfaces with regulators and “competing” utilities. Risk analysis tools are available to inform decisions on these issues (Table 2.1).

Table 2.1 Strategic level risk portfolio

Context	Tool / Technique	Application	Reference
Regulatory risk	<i>Ex-post</i> modelling	Interpreting / evaluating the relationship between stock risk and regulatory events	Buckland and Fraser (2001), Morana and Sawkins (2000).
	<i>Ex-ante</i> modelling	Modelling evolution of regulatory environment	Larssen and Bunn (1999), Bunn <i>et al.</i> (1997).
Competition risks			
1) Comparative	Competitor analysis	Reducing price review uncertainty (and conventional benefits)	Drohan and O' Connor (1998), Rothschild (1979).
2) Capital market	Screening	Tracking take-over risk	
	Investment analysis	Evaluating take-over opportunity	Thomas (1983).
3) For the market	Investment analysis	Evaluating joint venture	Ranasinghe (1999), Grimsey and Lewis (2002).
4) Product market	Competitor identification / analysis	Minimising competitive threats	Rothschild (1979), Drohan and O' Connor (1998).
	Investment analysis	Evaluating <i>de facto</i> take-over	
BPR risks	Scenario planning	Exploring potential BPR outcomes	Clemons (1995).
	Quantitative 'risk of failure'	Evaluating success likelihood of BPR efforts	Crowe <i>et al.</i> (2002).
	Risk matrix	Appraising and comparing risks of BPR strategies	Remeyi and Heafield (1996).
New technology	Risk matrix	Appraising and comparing risks of new technology projects	McGaughey <i>et al.</i> (1994).
	Risk algorithm	Characterising risk of new technology 'problems'	Hartmann and Lakatos (1998).
	Checklist	Minimising risk of new technology introduction	Hartmann and Lakatos (1998).
	Profile	Guiding strategic technology planning	Wildemann (1986).
Outsourcing	Outsourcing decision models	Evaluating core competencies and appraising market opportunities for outsourcing candidates	Quélin and Duhamel (2003), Lonsdale (1999).
	Scenario planning	Exploring 'what-if' scenarios	Zsidisin <i>et al.</i> (2000).
Employee retention	OCP	Evaluating 'cultural fit' of prospective employees	Sheridan (1992), O'Reilly <i>et al.</i> (1991).
	Early warning system	Identification of 'at-risk' employee groups	McNally (2001).
	Gap analysis	To assess employee development and benefit schemes	
	Checklist	Informal assessment of retention risk	Anon (2001).
Investment analysis			
1) Assets-in-place	NPV / IRR	Valuation of an ongoing business or some part of one	Barriex <i>et al.</i> (2003), Mosca <i>et al.</i> (2001), ADB (2001), Burchett and Tummala (1998), Luehrman (1997), Thomas (1983).
	Strategic portfolio planning	Creating a balanced utility investment portfolio	Rothstein and Kiyosaki (2003).
2) Opportunities	Option pricing theory	Valuation of possible future operations	Luehrman (1997), Black and Scholes (1973).
3) Joint Ventures	NPV / IRR	Valuation of prospective partnerships, strategic alliances	Grimsey and Lewis (2002), Ranasinghe (1999), Luehrman (1997).

### **2.2.1 Regulatory risk**

Throughout the 20<sup>th</sup> Century, the central role of water quality to the protection and preservation of public health encouraged governments to manage utilities within the public sector (Seidenstat, 2000). Regulation was historically self-imposed and limited in scope, and, by extension, posed relatively low risk to municipalities and utilities (in terms of both the likelihood of non-compliance and the associated penalties). In contrast, more recent (since the 1980s) regulatory pressures and drives to impose market discipline on the sector, whether directly (privatisation) or by proxy (*e.g.* corporatisation or required self-sufficiency), have externalised and broadened the role of regulatory scrutiny and intervention. Here our discussion is largely restricted to economic regulation.

A concept of regulatory risk is difficult to grasp. Parker (1998, 2003) contends that it arises from the nature of the regulatory rules and practices, with rules determining the extent to which interventions are discretionary, and practices relating to the interpretation the regulators and others (particularly government) place on the rules. Kilpatrick and Lapsley (1996) consider regulatory risk as the uncertain impact of regulatory decisions on regulated companies. Regulatory risk may best be considered as a combination of the above interpretations, encompassing both the uncertainty of the decision-making process and of its impact on utilities.

The core issues of regulatory risk are: regulatory independence; regulatory discretion; transparency and accountability. Independence is critical to minimising the risk of political interference in a regulatory regime. For example, in England and Wales, the economic regulator (the Office of Water Services; Ofwat), acting in the public interest, is vested with a high degree of autonomy from central government, ensuring that the regulatory process is not subject to direct political interference. In

contrast, in South Australia (SA), the state government directly controls the tariff setting process, and as the dividend from SA Water is a significant contributor to the state budget, there is the danger that political considerations, as well as commercial ones, might be perceived to influence regulatory pricing (ADB, 2001).

Regulatory discretion refers to the freedom afforded to regulators to interpret the importance of set duties and objectives and to determine how best to accomplish them (Kilpatrick and Lapsley, 1996; Parker, 2003). In the UK, Ofwat's Director General is free to identify and change the importance attached to set objectives within the regulatory system, within broadly defined constraints (Parker, 2003). Arguably, the greater the discretion afforded to the regulator, the greater the uncertainty related to future regulatory decisions. Ofwat's regulatory practices are characterised by high levels of transparency and accountability. In practice, utilities are fully engaged in regulatory decision-making, with avenues for consultation and appeal established should companies wish to challenge the outcome. Similarly, the New Jersey Board of Public Utilities, which regulates all investor-owned utilities in the State, publishes reports on its activities and is transparent and accountable in its decisions and processes (ADB, 2001). These arrangements compare to the German system. Water and sewerage in Germany is the responsibility of the municipalities and the municipalities regulate and manage the water supply based on European, national, state and municipal legislation. Though many are satisfied with these relationships, there has been criticism in a recent report (ADB, 2001), where regulatory decisions were viewed as being taken in a closed fashion with little clear accountability.

The nature of a regulatory system (*i.e.* its objectives and the systems in place for their achievement) represents a core strategic risk for water utilities. For example, in many developing countries, regulatory scrutiny is largely confined to ensuring a safe,

secure water supply (ADB, 2001), which, whilst introducing inherent operational risks, does not invoke strategic uncertainty. In contrast, a main goal of Ofwat is to facilitate competition within the sector, an objective that introduces utilities to a range of hitherto unknown risks.

Quantitative treatments of regulatory risk within the literature are restricted to *ex-post* analyses of the relationship between utility share price volatility and the regulatory process. Buckland and Fraser (2001) modelled variations in the systemic (market) risk, using a variable  $\beta$  (which measures the variability in returns of a stock relative to the variability of the broader market), of UK water utilities over time, examining the extent to which observed variations were associated with the regulatory process. A key finding was the surge in the market's assessment of the systemic risk to the industry accompanying the "surprise" result of the 1992 general election. The authors' analysis illustrates the influence of politics in even the most independent of regulatory systems. Similarly, Morana and Sawkins (2000) modelled the London stock market's response to the 1994 "periodic review" of water price setting in the England and Wales utility sector, finding a significant reduction in share price volatility, which they postulated to be a reflection of shareholder confidence in the credibility and sustainability of the settlement.

Ideally, for the active management of regulatory risk, analyses should extend to *ex-ante* treatments of risk. This is of particular relevance to the modern water utility sector, where widespread structural reforms are requiring utilities to operate under rapidly evolving regulatory systems – creating unprecedented uncertainty. In such a market, there has been no historical evolution and the participants, including the regulatory institutions, have a limited understanding of how it will operate in the short term and evolve in the future (Larsen and Bunn, 1999). In such situations, analytical

models may offer value in alerting utilities to unintended consequences of their actions that may trigger the regulator into reaction (Larsen and Bunn, 1999). Larsen and Bunn (1999) argue that system dynamics, which incorporates systems thinking into simulation modelling, is conducive to the dynamic, uncertain and subjective nature of assumptions inherent to strategic analysis. To illustrate, Bunn *et al.* (1997) developed a system dynamics model to simulate regulatory problems in the restructured UK gas and electricity markets. Following problem definition and hypothesis formulation, the authors constructed a simulation model describing the main feedbacks involved in the exercise of “latent” market power. Their analysis explored the relationship between corporate strategies designed to exercise this power and the risk of regulatory scrutiny. The authors concluded that market mechanisms were open to exploitation. Such analysis, and assessments of system sensitivity, could provide utility managers with *a priori* insights into opportunities for exploiting market “imperfections,” thus aiding the development of corporate strategies.

## **2.2.2 Competition risks**

### **2.2.2.1 Comparative *competition***

On account of the water industry’s inherent monopolistic nature, many governments and their regulators have sought to expand the role of sectoral competition. None more prominently perhaps than in the UK, where the concept of comparative competition underpins the regulatory regime (Sawkins, 1995; Saal and Parker, 2001). The theory of comparative, or “yardstick competition” may be traced to the work of Shleifer (1985), who proposed a regime in which the price (or financial rewards) received by a regulated firm depends not on its costs (as in traditional “cost-of-service” or “rate-of-return” regulation), but rather on the costs of “identical” firms

operating within the same sector. Shleifer reasoned that by breaking the dependence between the price a firm received and its own costs, and ensuring that the rewards for a given firm depended on its standing *vis-à-vis* a “shadow firm” (a weighted average of other firms operating within the sector – an idealised benchmark), each firm would be forced to “compete” with its shadow, providing incentives for cost efficiency (widely perceived as lacking from rate of return regulation). In practice, the inherent risks of this “competition by proxy” pale in comparison to those found in fully liberalised markets because market share is not directly threatened.

Techniques for evaluating the “explicit” risks posed by competitors have been well developed in the business and economic literature. A notable example is competitor analysis, with its potential to reduce the uncertainty of the price review process (as price setting is linked to competitor performance). Its application is helped by the tendency for regulatory bodies to disclose company performance data in the interests of transparency. In addition to reducing uncertainty, competitor analysis represents a strategic tool which assists managers in: evaluating competitors’ strengths and weaknesses; identifying sources of competitive advantage; and assessing the implications of competitors’ strategies on both the sector and their own utility (Rothschild, 1979; Drohan and O’Connor, 1998).

#### *2.2.2.2 Capital market competition*

As Cowan (1997) contends, competition in the capital market can be thought of as a private-sector version of yardstick regulation, in that it derives from the ability of investors to make comparisons between different companies in the same sector. Littlechild (1986), in his report to the UK Department of the Environment on the prospects for water privatisation, emphasised that this would be an important incentive

mechanism for utilities, as inefficient firms would be reflected in their share price and be vulnerable to take-over, in addition to facing higher costs of capital. Although Ofwat's restrictions on mergers within the UK water sector, in the interests of maintaining sufficient comparators, act as a constraint on capital market competition (Cowan, 1997), the growing internationalisation of the industry increases the risk of "external" mergers, whilst firms looking to diversify remain a threat to existing utilities.

Furthermore, the quality and quantity of comparative information available under the "yardstick" system assists predators in identifying and assessing potential take-over targets (Sawkins, 2001). Singh and Harianto (1989), in reviewing the acquisition literature, surmised that profitability, size, leverage, and dividends were negatively correlated with the risk of being acquired. In contrast, profitability and liquidity were positively correlated with the probability of a firm acquiring, with leverage and dividends negatively so. In light of this information, the dynamic risk of take-over can be tracked both in real-time (*e.g.* with respect to the transfer of, for example, more than 5% of firm stocks to a potential acquirer and, in the US, the filing of 13D statements indicating investor intent) and pro-actively (by "screening" the external environment for trends and potential hostile bodies). Of further interest to corporate strategists, recent research by Dickerson *et al.* (2003) suggests that acquisition can be used as a strategy to reduce the risk of take-over. The researchers concluded this strategy allows firms to grow quickly, thus protecting them from subsequent take-over. For utilities considering expansion or diversification strategies, take-over represents not just a threat but also an opportunity.



### 2.2.2.3 *Competition for the market*

Another means of fostering competition is to encourage the private sector (perhaps along with the incumbent public utility) to bid competitively for a concession, lease, tender, or management contract (Cowan, 1997). The two key vehicles for doing so are franchising and, more conservatively, contracting out (not involving the transfer of assets). Numerous variants of these processes are adopted internationally, including: build, operate and transfer (BOT) arrangements; finance, operate and own (concession); and operate and provide working capital (*affermage*). The inherent complexity of many of these arrangements, the generally low equity in the project vehicle (Grimsey and Lewis, 2002), and the often significant investment obligations required of the sponsor, create a pressing need for comprehensive risk assessment.

The project and financial risks associated with public-private partnerships have been reviewed by Grimsey and Lewis (2002). Using the financing of Stirling Water, a Scottish design-build-operate contractor as an illustrative example, they discuss the complexity of the contractual arrangements within such partnerships and use a quantitative analysis of returns on investment to characterise the robustness of cash flows from each of the senior lenders to this joint public-private venture. From the procurer's perspective, project risks (*e.g.* delays and claims) are valued and incorporated within the NPV calculation, whilst the impact of financial risks (inflation and interest rate changes) are evaluated through sensitivity analysis. From the sponsor's perspective, risk analysis centres on simulating the effect of the underlying variables (*e.g.* operating performance) upon the equity return. Ranasinghe (1999) uses water supply projects in Sri Lanka to outline a methodology based on financial risk analysis that a government or public utility can use to assess the viability of private sector participation in new infrastructure projects. The author links a commercially

available simulation package to the financial model to analyse the uncertainty associated with the underlying variables (*e.g.* escalation in cost).

#### *2.2.2.4 Product market competition*

The traditional approach to introducing direct product market competition into utility services has been to separate the monopolistic component of the industry and regulate it, and to encourage competition in all other areas, *e.g.* the UK model of separating the gas, electricity and railway networks (monopolistic) from the supply of services over the network (Cowan, 1997). This so-called “vertical disaggregation,” although promoted by the World Bank (1997), has not been widely adopted in the water sector, the implicit assumption being that the industry is naturally monopolistic (Seidenstat, 2000; Cowan, 1997). The UK has led the way in adopting alternative approaches to facilitate product market competition. This can be traced back to the 1991 Water Industry Act, which introduced the concept of “Inset” appointments, whereby a utility can apply for an appointment to provide water to a “large” customer located within the statutory area of an existing company, usually by seeking a bulk supply from the incumbent (Hern, 2001). Sawkins (2001) reports that the first Inset appointment was granted in May 1997, when Anglian replaced Essex and Suffolk Water (ESW) as the supplier to Buxted Chickens Ltd. Company licences were altered and a new pipe constructed linking the site with an Anglian water main.

In practice, various restrictions, recently eased, have meant that this form of competition has been slow to develop (Sawkins, 2001). Similarly, although the 1992 Competition and Service Act allows for cross-border competition, the costs are prohibitive in the majority of cases. Perhaps the most significant recent development has been the introduction of the 1998 Competition Act, which created the possibility for

common carriage agreements, or network sharing, in the water industry. Here, the shared use of an incumbent's infrastructure by a third party enables the latter to provide services within the incumbent's area. To aid this, Ofwat now requires that all water utilities publish "Access Codes" that set out their terms and conditions for common carriage, and has published guidance on this procedure (Ofwat, 2002). Hern (2001) reports that under the Act, utilities risk infringement if they refuse access to any parts of their infrastructure deemed "essential" without objective justification, or if their access terms are considered unreasonable. Although no successful applications for common carriage have resulted to date, the threat alone acts as a catalyst for performance improvements.

The authors were unable to uncover literature quantitatively addressing the risks of product market competition within the water utility sector, a reflection of its nascent development and descriptive nature. It seems appropriate here, however, to introduce an oft-neglected truism: quantitative risk analysis is not a prerequisite of effective risk management. This is apt in addressing the threats introduced by product-market competition, where competitor identification and analysis, in concert with a critical appraisal of self-performance and room for improvement, often provide an appropriate foundation for minimising competitive threats. In contrast, harnessing the opportunities presented by product-market competition requires more detailed analysis, and in the absence of a relevant body of literature, the authors suggest treating what are effectively, at least in the UK model, potential acquisitions of company operations in the manner of strategic investment decisions.

### 2.2.3 Business process re-engineering risks

Our discussion thus far has focused on the strategic approaches to risk management within the sector. The pressures described are having important impacts on the performance of the water sector. Structural changes to utility markets, an increasingly demanding political and consumer environment, and more stringent regulation are requiring utilities to improve financial and operational efficiencies. As Westerhoff (2003) notes, water utilities are responding by rethinking their operations, finding new ways to address problems, and revamping traditional business models – in other words, re-engineering. According to Clemons (1995), major business process re-engineering (BPR) initiatives – which range from the redesign of existing processes for efficiency improvements, to the development of novel processes in support of a new corporate vision – require the commitment of substantial resources and often constitute a lasting legacy. If we define the risk of a project as the deviation in results from the established goals, then there is substantial empirical evidence marking BPR as a high risk endeavour. Many, if not most re-engineering efforts ultimately “fail” (see Crowe *et al.*, 2002; Remenyi and Heafield, 1996). Of particular relevance is the work of Dean *et al.* (1999), whose analysis of change programmes undertaken in the UK water industry suggests that re-engineering efforts, whilst often effective, produce highly variable outcomes. On account of this, project risk analysis should be an integral part of any re-engineering effort.

Clemons (1995) considers the core determinants of the risk profiles associated with large scale BPR efforts to be: (a) functionality risk – the risk of making inadequate or incorrect changes to systems or processes; and (b) political risk – the risk that the organisation will not complete the project, either because of significant internal resistance to the proposed changes or due to a more gradual loss of will. Clemons

promotes scenario planning – a strategic planning tool that embraces uncertainty – as a means for assessing and subsequently managing the risks associated with re-engineering efforts. Rather than determining a single “correct” view of the future with its implicit single response, scenario planning acknowledges the key sources of uncertainty and incorporates these in developing a range of future scenarios and strategic responses for exploration. Clemons argues that its use is suited to the context of re-engineering efforts as it encourages the critical examination of potential futures and strategies, reduces functionality risk and helps ensure the need for change is internally addressed and accepted, thus reducing political risk. Scenario planning has been embraced by the majority of UK water utilities (Phelps *et al.*, 2001). A 2001 study (Phelps *et al.*, 2001) explicitly linked the tool’s use with improved financial performance on the part of utilities, although notably the authors suggest that scenario planning may implicitly encourage firms to focus on financial returns at the expense of customer service levels.

Recent work by Crowe *et al.* (2002) has led to the development of a semi-quantitative tool for estimating the “risk of failure” of companies about to undertake re-engineering efforts. The tool, developed through a survey of BRP-experienced organisations, is based on measures of the core success (*e.g.* egalitarian leadership; collaborative working environment; top management commitment; and change management systems) and failure (middle management fear of losing authority; fear of job loss; scepticism; discomfort of new working environment) factors of implementing change. Raw data is extracted by questionnaire (*e.g.* “do managers usually share vision and information with their subordinates”) is used to mine information on the general leadership style), and refined *via* fuzzy mathematics. Crowe *et al.*’s model is intended to provide companies with an estimate of the likelihood of success or failure

of proposed efforts prior to committing resources and to improve management's *a priori* insights into the potential outcomes of re-engineering. Similarly, Remenyi and Heafield (1996) outline a methodology for evaluating the key risk issues relating to re-engineering efforts. The methodology centres on a risk matrix (Table 2.2) that groups a variety of potential BPR risks under the categories of business risk, financial risk, corporate structure, corporate culture, technology and human. Organisations identify, weight and rank what they consider to be the ten factors most pertinent to their proposed re-engineering efforts. The framework represents a succinct method for appraising and comparing the risks associated with BPR strategies. A perceived failure of much of the BPR literature is the limited emphasis placed on the risks introduced by adopting new technologies, an aspect critical to many re-engineering efforts.

Table 2.2 BPR risk matrix (after Remenyi and Heafield, 1996 )

<i>Indicate the 10 most relevant factors</i>	
FACTORS	FACTORS
<b>BUSINESS RISKS</b>	<b>CORPORATE CULTURE</b>
Change to business scope (e.g. from diversifying)	Staff attitude to technology
Change to market structures	Staff attitude to changes
Change of regulatory relationship	Staff attitude to senior managers
Change of supplier relationship	Managerial style
Impact on (potential) 'competitors'	Positive shared vision
<b>FINANCIAL RISKS</b>	<b>TECHNOLOGY</b>
Funded from current cash flow	Size of project
Funded from new equity	Structuredness of project
Funded from long term debt	Complexity of technology
Funded from short term debt	Complexity of application
	Novelty of technology
<b>CORPORATE STRUCTURE</b>	Novelty of application
Bureaucratic structure	Impact on technical infrastructure
Outsourcing utilisation	
Flexibility of job positions	<b>HUMAN</b>
	Skills base

#### 2.2.4 Technological risk

Clark *et al.* (2000) report that technology adoption is increasingly becoming a concern of strategic planners and policy makers within the water industry. The introduction of novel technology poses risks due to the inherent difficulty of preparing

accurate estimates of the costs, performance and system-wide effects of new components and processes; and the long development cycles required for changes in regulations and consumer demands (Colmer *et al.*, 1999). This has led many researchers to advocate the incorporation of risk management techniques for the effective implementation of new technologies (*e.g.* Colmer *et al.*, 1999; Fitzpatrick, 1995). This is highly relevant to the water sector, where, as Maxwell (2001) notes, the advance of modern technology is illustrated by such trends as the replacement of traditional methods of water treatment with advanced oxidation and other novel physical and mechanical technologies; the broad use of membrane systems to desalinate seawater for human consumption; and the increasingly widespread use of recycling systems and technologies.

McGaughey *et al.* (1994) describe a framework for viewing and comparing the risks inherent in the adoption of new technologies, specifically relating to IT. Initially, proposed projects are assessed, through value chain analysis, in terms of their potential positive and negative outcomes – these are then mapped onto a “speculative” risk matrix to provide management with an initial screening of alternatives. In later stages of planning, specific threats and opportunities associated with the project are identified and ranked, by likelihood and consequence, for prioritisation purposes. Hartmann and Lakatos (1998) drew on case studies monitoring the pace and quality of technology delivery within two product development programmes and generated an algorithm characterising the risk of each technology problem (Figure 2.3). The authors suggest that its use can aid in the refinement of technology development and implementation plans following risk identification. Hartmann and Lakatos define technology problems as those arising:



- from the application of a new process, material or subsystem before fully understanding parameters that control cost, latitudes and failure modes;
- when a previously commercialised technology is extended outside the known domains of the pertinent design rules; and
- from unexpected interactions arising from a new or unique combination of known subsystems of components.

Of further interest, the authors (Hartmann and Lakatos, 1998) developed a checklist to help technology and product developers audit technology progress, which we have adapted to serve as a tool for minimising the risk associated with introducing new technologies (*i.e.* beyond the development stage):

- Implementation goals confirmed
  - validate business assumptions and technology specifications for cost, performance and reliability
- Technology mastery demonstrated
  - critical parameters identified
  - failure modes identified
  - set risk tolerances relating to the critical parameters so as to avoid failure modes and deliver the required performance
  - performance demonstrated using a combination of hardware and mathematical simulation
  - manufacturing feasibility established
- System specifications re-established

- system and subsystem financial and operational performance targets are re-established and re-assessed based on technology specifications
- Additional assessments completed
  - supporting assessments completed, such as safety and environmental impact study
- Contingency planning
  - develop contingency plans should critical risks materialise in spite of control procedures in place

Wildemann (1986) describes a framework for guiding technology planning. Risk profiles are constructed displaying the relative importance of identified threats and opportunities, and thus the inherent “attractiveness” of the technology, complemented by a strengths-weaknesses analysis that estimates the ability of the firm to successfully implement the technology. The author’s aim was to provide an analytical basis upon which strategies may be developed for the introduction of new technologies.

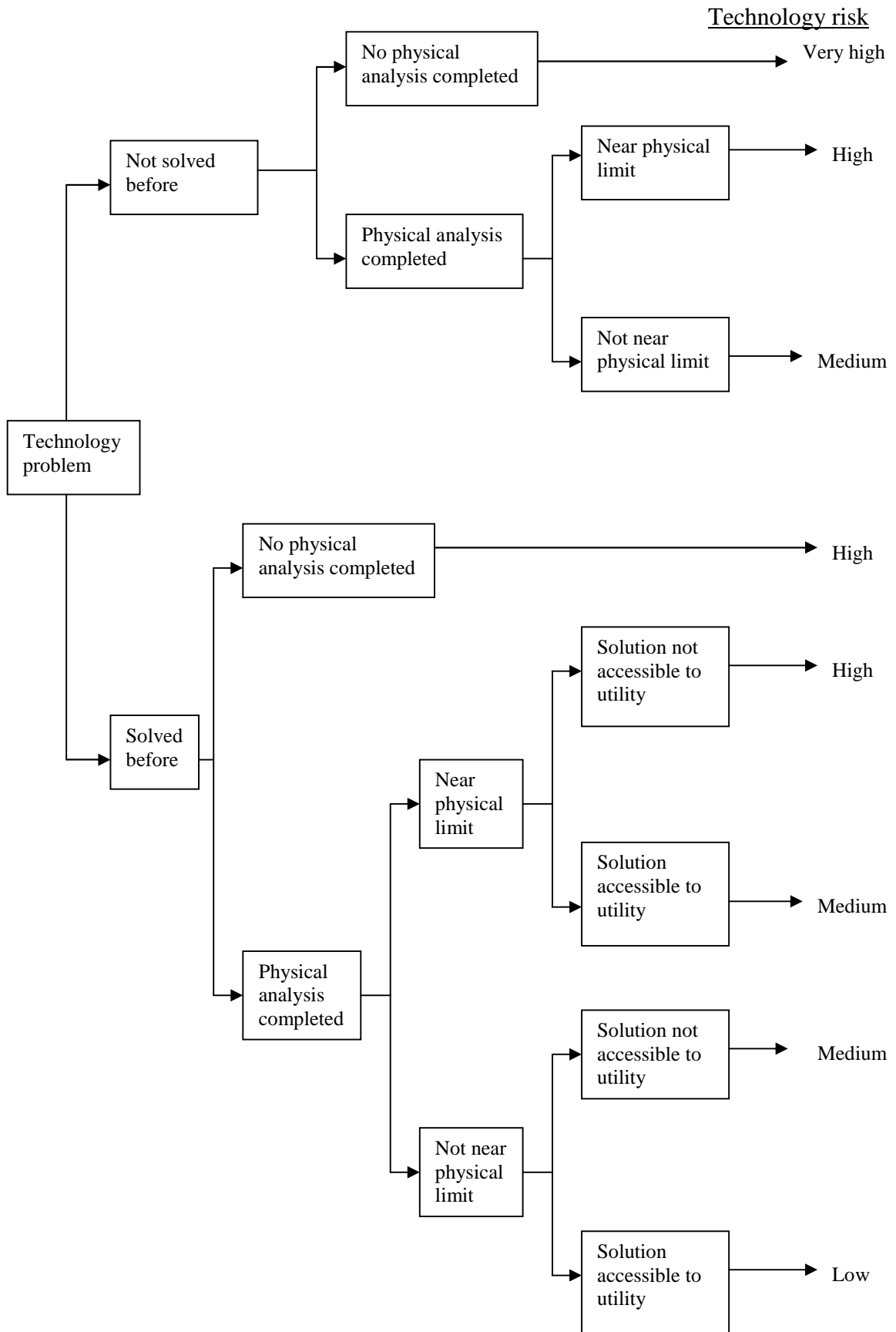


Figure 2.3 Technology risk algorithm (Hartmann and Lakatos, 1998)

### **2.2.5 Outsourcing risks**

Our discussion of risk analysis strategies moves to one of the key features of the international water business – outsourcing. A significant feature of water utility management in recent years has been the growth in outsourcing, defined as the transfer of previously in house activities to a third party. Outsourcing allows utilities to focus on critical functions (core business), access economies of scale, minimise investment, increase quality of service, transfer risk, and reduce administrative burdens including regulatory compliance (Parmelee, 2002; Elias, 2001; Downey, 1995). Common candidates for outsourcing include information technology, maintenance, distribution, manufacturing, and customer care and billing (Parmelee, 2002). A widely held view is that the potential for outsourcing is far from exhausted. A holistic approach to risk being promoted in this review requires that in addition to the traditional review of legal and regulatory responsibilities following contractual agreement, the process of outsourcing should fall within the remit of corporate risk management. That is, outsourcing alters the boundaries of the firm, and the scope of risk analysis and risk management programmes should be extended to reflect this.

Risks are inherent in the process of outsourcing, from the decision to outsource, to the management of agreed contracts. Received wisdom has been that companies should focus on “core competencies” and outsource the remaining parts of the business (although the validity of this distinction has been questioned of late, notably by Heikkilä and Cordon, 2002). The core risks discussed in the literature relating to decisions over what to outsource and who to outsource to include: the loss of key capabilities, developing dependence on the vendor, and risks linked to the service provider’s deficient capabilities. Each decision to outsource must be carefully assessed from a risks and benefits perspective (Downey, 1995). Decision-making frameworks

are available for this purpose. Lonsdale's (1999) decision tree for outsourcing provides a framework for evaluating what constitutes an organisation's core competencies, and analysing market opportunities for outsourcing the remaining parts of the business. The framework seeks to ensure managers retain those resources responsible for competitive advantage, avoid monopolistic or oligopolistic supply markets, and effectively manage the risk of post-contractual dependency. A similar model, although focussed at the policy level, is provided by Quélin and Duhamel (2003). Of course, successful outsourcing further depends on managing supply risks, defined as the transpiration of failures with in-bound goods and services (Zsidisin *et al.*, 2000). Core categories of supply risk discussed in the literature include: the financial stability of the supplier; cost fluctuations; capacity constraints of the market and specific suppliers; variations in quality; the ability of the supplier to adapt to required changes in design or technology; and natural disasters. Two diametrically opposed approaches to managing supply risk are the active management of risk interfaces with the intention of reducing vendor failures (Zsidisin *et al.*, 2000), and the construction of barriers (*e.g.* safety stock, multiple sources) to buffer the effects of inherent uncertainties (Fisher, 1997; Newman *et al.*, 1993). Tools in support of the former approach include qualitative assessments of the financial stability of potential suppliers; formal models for the demonstration of supplier capacity performance; "what-if" scenario planning; and statistical process control to detect deviations from desired quality (Zsidisin *et al.*, 2000).

### **2.2.6 Employee retention**

Retaining valued employees has long been an implicit component of good utility management. The recent emphasis on people as *the* resource, along with the external realities of an increasingly dynamic and pressurised labour market, have led to the

sector embracing employee retention as a critical risk issue – particularly in the technically specialised areas of the water business. This focus is exemplified in recent sectoral research initiatives (e.g. American Water Works Association Research Foundation (AWWARF) project #2850 “Succession planning for a vital workforce in the information age”), and a recent (2001) policy statement from AWWA calling on utilities to establish formal employee retention plans.

Maintaining employee retention, thus managing the risk of losing organisation capacity, begins at the recruitment stage (e.g. Barney, 2002; McNally, 2001; Denton, 1992). Empirical evidence suggests that ensuring a “cultural match” between employees and the organisation plays a critical role in reducing staff turnover (Sheridan, 1992). The tool applied by Sheridan (1992) to “measure” culture (beliefs and values) was the Organisational Culture Profile (OCP) instrument developed by O’Reilly *et al.* (1991). The OCP assesses candidates by encouraging them to sort value statements on: norms regarding the completion of work tasks; norms regarding interpersonal relationships; and norms regarding individual actions. Utilising the OCP as a part of the recruitment process could provide utilities with a proactive tool for minimising staff turnover, by filtering those most likely to leave the organisation early from the selection process. Additionally, it enables the risk-based targeting of retention efforts, for example by focusing efforts on employees hired regardless of “cultural misfit.”

This philosophy is mirrored in the work of McNally (2001), who promotes the use of more traditional tools such as personality assessments at the recruitment stage to ensure “good fits” of personality and work ethic. As Denton (1992) notes, whilst “*good recruitment is certainly important, it is what happens to recruits after joining an organisation that determines whether a company will retain them.*” In relation to this,

McNally (2001) encourages organisations to develop “early warning systems” to identify employees at risk of leaving. Such a system requires the collection and analysis of retention data by subgroup (*e.g.* ethnicity, gender, function, organisational level, *etc.*) to facilitate identification of “at-risk” groups. Following identification, tools such as employee surveys, employee reviews, mentor or manager feedback, local economic trends, head-hunter activity, and, crucially, the exit interview may be used to determine factors driving high rates of defection (McNally, 2001). Adherence to such a system would provide utilities with comprehensive data on who is leaving and why, providing the foundation for developing effective, tailored retention strategies. A recurrent theme of the retention literature is that incentives (*e.g.* salaries and benefits) alone are not enough for achieving high levels of retention, the contention being that retention is related more closely to employee development and intrinsic benefits such as working relationships, job satisfaction and a sense of empowerment (*e.g.* Hagevik, 2001; McNally, 2001; Thompson, 2000; Denton, 1992). Accordingly, utilities may consider undertaking a gap analysis of their employee development schemes (interestingly, Brueck (2002) reports that water utilities spend as little as 1% or less of their labour budget on nonmandatory employee training) and benefit programmes before remedying deficiencies in order to minimise turnover rates. An alternative approach to identifying the level of retention risk is to undertake an informal risk assessment (Anon, 2001) which is essentially a checklist addressing the core issues influencing turnover (*e.g.* employee-manager relationships, communication, job satisfaction, *etc.*).

The negative consequences of employee turnover are clearly emphasised throughout the literature, leading to the implicit assumption that organisations should “pull out all the stops” to minimise defection rates. However, as Sigler (1999) and

Mowday (1984) contend, the costs of reducing retention may, in some cases, exceed the benefits to be derived. It is thus incumbent on organisations to critically analyse the costs and benefits of implementing retention strategies; the cost-benefit analysis approach offers a promising framework for this purpose.

### **2.2.7 Assessing investment risks**

Behind each strategic investment an organisation considers lies some calculation of the move's worth (Luehrman, 1997). Following Rothstein and Kiyosaki (2003), we define strategic investments as those resource allocations that will yield substantial advances toward the achievement of a utility's strategic goals. Whether considering a joint venture, acquisition, or a major extension of an existing facility, how the utility estimates value is a critical determinant of how it allocates its resources, which is in turn a key driver of its overall performance (Luehrman, 1997). Valuation methodologies range from the formal (comprising an appraisal model and a supporting theory) to the informal (based on heuristics) (Luehrman, 1997). However, since the 1970s there has been a trend towards applying valuation methods that are more formal, explicit, and institutionalised (Luehrman, 1997). The most widely adopted framework is the Net Present Value (NPV) model, which estimates value by capitalising (discounting) future streams of cash flow that the investor expects to receive from an asset. The capitalisation rate is the minimum expected rate of return needed to induce an investor to acquire. Capitalisation is comprised of two components, the risk-free rate of return (accounting for the time value of money) and the risk premium (the additional compensation demanded by investors for assuming risk). Although issues have been raised regarding the applicability of conventional appraisal methodologies to the water industry, specifically relating to the long lifespans of many capital projects



and the fact that they often do not generate revenues in the traditional sense (*e.g.* Tebbutt *et al.*, 2001), they remain favoured by academics and industrialists. Our subsequent discussion focuses on three distinct investment problems: valuation of assets-in-place; valuation of “opportunities;” and the valuation of joint ventures.

#### 2.2.7.1 Assets-in-place

The most basic valuation problem is valuing assets-in-place, *i.e.* the valuation of an ongoing business or some part of one, for the purposes of informing decisions ranging from a change in suppliers to an acquisition (Luehrman, 1997). It is for such situations that Discounted Cash Flow (DCF) techniques (methodologies for determining the capitalisation rate) are suited (Luehrman, 1997). In brief, the established DCF methodologies include the weighted-average cost of capital (WACC; Modigliani and Miller, 1958), the capital asset pricing model (CAPM; Sharpe, 1964) and the adjusted present value (APV; Myers, 1974). The WACC, which establishes the risk premium on the basis of the “cost of capital” financing the investment, remains the most commonly practised approach (Luehrman, 1997), though is increasingly criticised in academic circles (*e.g.* Luehrman, 1997; Gregory, 1990). The fundamental idea behind CAPM is to use  $\beta$ , a measure of systemic (market) risk, to adjust cash flows. In contrast, APV seeks to unbundle the various components of value (*i.e.* cash flows), analyse them separately, and then add up the present values. For a fuller discussion of these and other DCF techniques see *e.g.* Modigliani and Miller (1958), Sharpe (1964), Myers (1974), Berry *et al.* (1988), Gregory (1990), Luehrman (1997), and Ye and Tiong (2000).

Regardless of the individual strengths and limitations of the above models, a common deficiency is that there is no indication of the confidence level on the

determined capitalisation rates (Ye and Tiong, 2000). Following on from Hertz (1964), who highlighted the misleading nature of single-point estimates in investment analysis, most researchers advocate the appraisal of investments within a non-deterministic framework; the principle being that investment forecasts are, by definition, uncertain. Reflecting this uncertainty in model outputs lends some assurance to the decision-makers that the available information has been used with maximum efficiency (Hertz, 1964). This is reflected in Guidelines published by the Asian Development Bank (ADB, 1999) on the application of financial evaluation methodologies to water supply projects. Risk analysis, in the form of sensitivity analysis and stochastic simulation, is promoted as a means to examine the influence of changes in key underlying variables on forecast cash flows, and the probability that project NPV will fall below zero. Incorporating these principles, Barriex *et al.* (2003) describe the application of the NPV framework to the proposed restructuring, privatisation and optimisation of water utility operations in Panama. The focus of their study is on the proposed rehabilitation of systems supplying water to Arraijan, Chorrera, Colon and Panama City, a “holistic” programme entailing the upgrading of commercial, technical and operational aspects. Through stochastic simulation and sensitivity analysis of forecast financial returns, the authors confirmed the project’s robustness from a financial standpoint, determining a “zero” probability of negative NPV.

Thomas (1983) uses an illustrative example to examine the role of CAPM in adjusting for the risk inherent to acquisition / diversification appraisals (using internal rate of return (IRR), an appraisal framework similar to NPV). Accounting for the unique nature of acquisition / diversification appraisals, the author provides a methodology for integrating expected financial and operational synergies (*e.g.* derived from financial and operating economies, or the pooling of functional areas) within the

analysis. However, through applying a risk premium to projected cash flows (which by definition accounts for the increased returns investors demand for variable cash flows) and undertaking simulation of the variables influencing future cash flows (thus explicitly modelling the variability of returns), Thomas (1983) is effectively “double counting” for risk, introducing a bias against investment decisions. This criticism is supported in the work of Burchett and Tummala (1998), who apply Monte Carlo simulation to an NPV based appraisal of an infrastructure capital investment decision. These researchers argue that applying specific probability distributions to the relevant variables captures all potential risks relating to the investment, thus negating the requirement for incorporating a risk premium as part of the capitalisation rate.

Although it is widely accepted that a probabilistic approach to investment risk analysis is desirable, problems exist. As Songer *et al.* (1997) assert, the failure to identify all significant risks (*i.e.* to apply appropriate probability distributions to all relevant underlying variables) quickly undermines model validity and output. A further pitfall is identified by Mosca *et al.* (2001), who in applying simulation methodologies to a proposed plant investment, found that the choice of frequency distribution chosen (often arbitrarily) for the independent variables can have a marked effect on the process outcome. These are important observations in that they highlight the biases inherent to all risk models, reminding of us of the need to use risk analysis output diagnostically rather than to over-invest belief in quantitative risk estimates.

In financial circles, recent times have seen an increasing adoption of tools that can perform economic evaluation and modelling on the combined entity of investments (portfolio) as well as for each individual project. This trend extends beyond the financial sphere, as is illustrated in the work of Rothstein and Kiyosaki (2003), who describe the application of portfolio management theory to water utility investment

planning. The philosophy of their approach is to create a portfolio representing a balanced array of investments that mitigate uncertainties and that are likely to realise potential returns. Of particular interest is their use of multi-attribute analysis, which allows the risk-based prioritisation of monetary and non-monetary investment decisions within a single analytical framework.

#### *2.2.7.2 Opportunities*

It is relevant here to further discuss the work of Luehrman (1997), who categorises a second type of valuation problem – the valuation of opportunities (*i.e.* possible future operations) – as distinct from the valuation of operations (assets-in-place). The distinction is that with the former, the decision to invest may be deferred. In opportunity valuation, risk matters in two ways: the risk of the investment, and the risk that circumstances will change before a decision has to be made – such contingencies are not well handled by the traditional DCF approach (Luehrman, 1997). Luehrman (1997) states that a common approach in the valuation of opportunities is simply not to value them formally until they mature to the point where a decision can no longer be deferred, where they can then be valued, in effect, as assets-in-place. Critics have decried this practice, on the premise that it leads companies to undervalue the future and hence underinvest (Luehrman, 1997). In response, Luehrman (1997) discusses the potential of “option-pricing theory” (Black and Scholes, 1973) - an analytical strategy that allows managers to handle the contingencies created by the time-dependant nature of opportunity valuation - as a supplement, not a replacement, for the valuation method for in place assets.

### 2.2.7.3 *Joint-ventures*

A further category of investment decisions is found where firms participate in joint ventures, partnerships, or strategic alliances. This takes on particular resonance in the water industry, where recent years have seen a proliferation in public / private partnerships. In such cases, where ownership is shared with other parties, managers need to understand both the value of the venture as a whole *and* the value of their company's interest in it (Luehrman, 1997).

The investment risks associated with public-private partnerships have been reviewed by Grimsey and Lewis (2002). Using the financing of Stirling Water, a Scottish design-build-operate contractor as an illustrative example, they apply quantitative analysis of returns on investment from the perspective of the private (sponsor) and public (procurer) sector entities.

A common observation of the risk management literature is an all too obvious gap between theory and practice. Much of the highly theorized investment literature does not reflect standard industry practice, particularly that relating to the application of complex methodologies such as simulation and scenario analysis. The discrepancy is explained, in part, in that such techniques do not fit naturally into most companies' skill sets or capital-budgeting systems (Luehrman, 1997). Despite this, there is a dearth of literature focussing on the practicalities of integrating such tools deep within company structures. To address this issue and as part of the research that has informed this review, the authors will be undertaking a benchmarking of risk management capabilities within the international water utility sector.

## 2.3 PROGRAMME RISK ANALYSIS

We turn to a more familiar discussion of the application of risk analysis to the water utility sector. The revised WHO guidelines (WHO, 2003) are promoting the implementation of water safety plans for water quality management from catchment management, through process control, distribution and on to the tap (UKWIR, 2003). Application of risk analysis to these aspects of the water “supply chain” extends to programmes of work as well as individual plant operations. A discussion of the latter, operational risk analysis follows, but here we are concerned with the analysis of risks associated with programmes of activity that are “rolled-out” across organisations, such as asset management and maintenance planning. Here, managers are responsible for the implementation of strategies across company functions, multiple sites and geographic regions. They are concerned with: evaluating the risks posed by a similar hazard at a variety of locations (*e.g.* mains bursts, network intrusion – in asset management, for example); the risk-based appraisal of operational strategies and long-term planning in relation to the water supply-demand equilibrium; and the wide variety of risks existing within a catchment or watershed. Table 2.3 summarises the portfolio of analysis techniques available at the programme level.

Table 2.3 Program level risk portfolio

Context	Tool / Technique	Application	Reference
Asset management	Risk ranking	Prioritisation of remedial work on infrastructure assets	Kent <i>et al.</i> (2003), Radovanovic and Marlin (2003), Foster <i>et al.</i> (2000).
	FMECA	'Source to tap' risk identification and prioritisation	Lifton and Smeaton (2003).
	Logic models	Evaluating structural failure modes	Gray and Powell (1988), Parr and Cullen (1988).
	GIS risk tracking	Infrastructure risk-tracking, visualisation and communication	Kaufman and Wurtz (1998).
	GIS spatial analysis	Risk-mapping of infrastructure	Doyle and Grabinski (2003), Ta (2001).
	GIS risk simulation	Evaluating degradation risk	Lindley and Buchberger (2002), Besner <i>et al.</i> (2001).
Catchment management	Risk ranking	Prioritisation of monitoring strategies	Dabrowski <i>et al.</i> (2002), Verro <i>et al.</i> (2002), Boak and Packman (2001), Feijtel <i>et al.</i> (1998).
	GIS risk mapping	Mapping areas of catchment critical to water quality	Lytton <i>et al.</i> (2003), Sivertun and Prange (2003), Wickham and Wade (2002), Foster and McDonald (2000), Osowski <i>et al.</i> (1999), Fuest <i>et al.</i> (1998), Lantzy <i>et al.</i> (1998).
	Contaminant flow / transport modelling	Projecting degradation patterns / assessing risk of water quality violation	Anderson and Destouni (2001), Gündüz <i>et al.</i> (1998), Halfacree (1998), Liou and Yeh (1997), Cole <i>et al.</i> (1988)
	Kriging	Projecting degradation patterns with limited sample data ( <i>e.g.</i> groundwater)	Passarella <i>et al.</i> (2001), Wingle <i>et al.</i> (1999), Rautman and Istok (1996).
	GIS risk simulation	Quantified risk mapping over space <i>and</i> time	Dabrowski <i>et al.</i> (2002), Verro <i>et al.</i> (2002), Feijtel <i>et al.</i> (1998).
Network analysis	Network reliability modelling	a) Assess susceptibility to supply-demand scenarios; b) aid development of supply strategies and policies; c) assist design of distribution networks; and d) inform the need for capital expenditure.	Stevens and Lloyd (2004), Lifton and Smeaton, (2003), Wang <i>et al.</i> (2003), Merabtene <i>et al.</i> (2002), Ostfeld (2001), Stahl and Elliot (1999), Zongxue <i>et al.</i> (1998), Andreu <i>et al.</i> (1996), Jinno <i>et al.</i> (1995).
Vulnerability assessment	RAM-W	To assess system vulnerabilities and develop measures to reduce risks of attack.	SNL (2001).
	Questionnaire-based self assessment	As above	NRWA (2002).

### 2.3.1 Asset management

In line with Booth and Rogers (2001), we consider asset management as “*managing infrastructure capital assets to optimise the total cost of owning and operating them while delivering the service levels customers desire.*” Managing risk in the face of limited resources has long been an implicit component of asset management. Within the UK, pressure from the economic regulator has ensured that the explicit incorporation of risk analysis into asset management programmes has taken on added momentum. Water utilities are expected to:

*“demonstrate how the flow of services to customers can be maintained at least cost in terms of both capital maintenance and operating expenditure, recognising the trade off between cost and risk, whilst ensuring compliance with statutory duties” (Ofwat letter MD 161, April, 2000).*

In addition to regulatory pressures, the global trend towards requiring financial self-sufficiency on the part of public and private utilities has created a climate in which management can no longer seek to “over-engineer” facilities with the presumption of screening out technical risk. A recent (2004) report (USGAO, 2004) to the US Senate cites *“mounting evidence suggest[ing] that the integrity of the nation’s [water] infrastructure is at risk without a concerted effort to improve the management of key assets...and a significant investment in maintaining, rehabilitating and replacing these assets.”* The report goes on to explicitly endorse the role of risk analysis in asset management. More than ever, utilities must now seek to balance spending with risk minimisation. A risk-based approach to asset management requires an integrated, systematic process drawing upon a broad range of methodologies for the identification, analysis and prioritisation of assets-at-risk, from the process to the component level (*e.g.* Lifton and Smeaton, 2003; Booth and Rogers, 2001).

On a national scale, the US Natural Resources Defence Council (NRDC, 2003) recently (2003) reported on the risk to drinking water quality from ageing pipes and process plant across the US with individual city “rankings” being informed by water quality data, USEPA compliance records and water utility annual reports. Many water companies have in place risk-ranking procedures to evaluate and rank potential risks across a variety of categories, and thus help inform and prioritise risk management procedures (Pollard *et al.*, 2004). For example, Radovanovic and Marlin (2003)



describe the risk-based approach to water mains asset management in place at Sydney Water (Australia). Budgetary requirements are estimated through the application of KANEW, a statistically based survival model which aids the calculation of pipe rehabilitation and replacement needs for distribution networks. The identification of specific pipes requiring work is external to the model, with separate approaches for trunk and reticulation mains (the latter generally being run to failure). Critical trunk mains are identified by means of a checklist-aided screening approach, wherein preliminary assessments of failure likelihood and consequence are combined to create an overall risk score. This combined risk score is used to identify critical water mains deemed to require more detailed analysis (*e.g.* condition-based assessments). This methodology allows Sydney Water to identify and prioritise water mains in need of rehabilitation / renewal, and to proactively assess budgetary requirements.

Louisville Water Company (Kentucky) apply their Pipe Evaluation Model, which integrates data such as pipe age and maintenance history, as a tool for prioritising pipe and water mains for rehabilitation and replacement (USGAO, 2004). Utility managers report that this model, in combination with wider asset management practices, has helped reduce the frequency of water mains breaks from 26 to 22.7 per hundred miles and the frequency of joint leaks from 8.2 to 5.6 per hundred miles (USGAO, 2004). Seattle Public Utilities adopt a risk-based approach to asset management, considering likelihood and impact of pipe rupture with reference to such factors as age, material, location and historical cost of repair (USGAO, 2004). Drawing upon this analysis, utility officials were able to delineate their pipe network into areas of critical and non-critical risk, and allocate maintenance and rehabilitation resources accordingly. Through adopting this approach, officials believe that they are using staff resources

more efficiently and that, over time, the programme will lead to a reduction in maintenance costs (USGAO, 2004).

Kent *et al.* (2003) describe how risk analysis informs the prioritisation of investment strategies for trunk main maintenance at *Dwr Cymru* Welsh Water. The methodology is based on the available records of asset performance, condition and serviceability, which are stored on the company's WAM (Water Asset Management) database. STRUMAP, a software-based mapping system, allows clustered failures to be considered separately from "random" bursts, a task performed as the former are considered likely to be representative of underlying susceptibilities. For each location where a cluster is identified, specific failure rates are derived. For random bursts, failure data is separated according to pipe material and diameter, with failure likelihood determined by group. STRUMAP further enables consideration of failure consequences, in terms of the number of properties potentially affected by an event, taking into account service reservoir storage. Failure likelihood and consequence are then combined to derive an overall severity score, which in turn informs the derivation of investment requirements. The National Research Council of Canada are currently developing a prototype Water Mains Renewal Planner (WARP; Rajani and Kleiner, 2001), which is aimed at integrating the most promising breakage analysis models into one discrete decision support tool. At present, WARP consists of three modules: a) analysis of water main breakage patterns; b) short-term operational forecasting; and c) long-term renewal planning. A fourth module is to be added to enable prioritisation of individual water mains for renewal.

Foster *et al.* (2000) detail a risk-ranking approach for estimating the relative likelihood of failure of embankment dams by piping. Failure likelihood is assessed by weighting the historical frequency of piping failure with respect to dam zoning, filters,

dam age, core soil types, compaction, foundation geology, dam performance, and monitoring and surveillance. The methodology allows the prioritisation of dams-at-risk for more detailed analysis, and is further offered as a check on traditional event-tree methods (see also Seker *et al.*, 2003).

Failure modes and effects analysis (FMEA), developed by the US military, is an engineering technique that tabulates failure modes of equipment and their effects on a system (American Institute of Chemical Engineers, 1992) (Table 2.4). The failure mode describes how equipment fails (open, closed, on, off, leaks, *etc.*). The failure effect is determined by the system's response to the equipment failure.

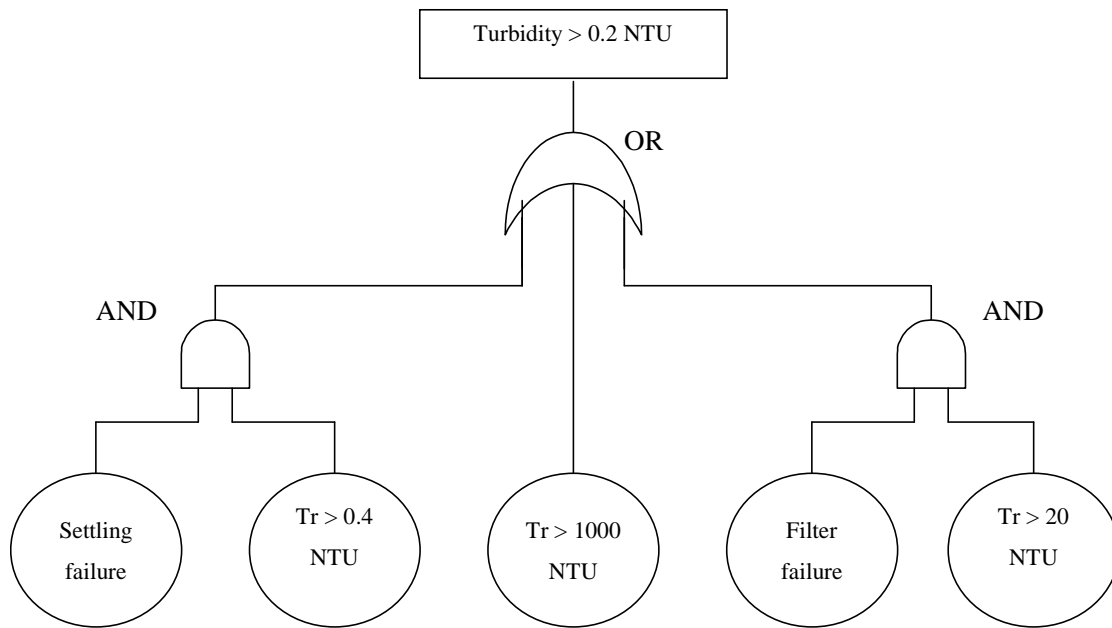
*Table 2.4 Component FMEA for chlorine cylinder and outlet valve (Egerton, 2004, with permission)*

Failure mode	Failure effect on process	Failure effect on system	Methods of Detection	Comments
Fail to open / Reduced output / No output	Loss of adequate chlorination	Non-potable water will leave plant	Changeover should detect loss of supply	System failure would require combination of loss of flow and failure of changeover
Fail to close	None – changeover should transfer to standby cylinders	None	None	
Excess output	Excess chlorination	Possible taste and odour complaints. No serious consequences	Changeover should detect excess chlorine flow	
Outside specification (wrong or contaminated gas)	Outside specification (wrong or contaminated gas)	Non-potable water will leave plant. POTENTIAL FOR MAJOR SAFETY HAZARD	QA checks on delivery. Low chlorine residual readings and alarm	

When FMEA is extended by a criticality analysis, it is known as failure modes, effects and criticality analysis (FMECA). Lifton and Smeaton (2003) detail how Scottish Water apply source-to-tap FMECA studies across their water supply systems as part of their “asset management toolkit.” This allows priority risks to be identified and subsequently compared across the utility portfolio (*e.g.* various mains, raw and treated reservoirs, treatment works *etc.*) in order to focus attention on the most serious

threats to system performance. Infrastructure investment strategies are further informed by the HYSIM-AQUATOR supply-demand model. Of particular interest is their description of the asset risk and criticality scoring system implemented at Scottish Water. The system is designed to assess the relative “total business impact” of asset failures across the company by reference to a “common currency of risk” (one point equates to £1000 of business impact), facilitating a consistent approach to risk scoring across Scottish Water. Additionally, this scoring system guides the prioritisation of reliability studies at the operational level, which further informs asset management strategy.

Given the complexity inherent in describing modes of structural failure and assessing their likelihoods (Gray and Powell, 1988), logic models (visual risk schematics, *e.g.* reliability block diagrams, fault tree analysis (FTA) and event tree analysis (ETA), see Figures 2.4 and 2.5) have found application in support of asset management. Parr and Cullen (1988), through examining the applicability of logic modelling techniques to dam failure analysis, illustrate how such an approach can inform the prioritisation of expenditure on monitoring, maintenance and remedial works. Similarly, Gray and Powell (1988) promote the use of logic diagrams in aiding the development of risk-based strategies for maintaining asset security. The authors model the interactions leading to failure for each class of aqueduct structure. To this, historic data, or where data is deficient, engineering judgement, are applied in order to derive failure probabilities. A cautionary note is sounded by Latiffe (1993), who contends that risk analysis, specifically logic modelling, is not yet effective in modelling dam failure. The author cites insufficient statistical data on the deficiencies of structural components as the core drawback.

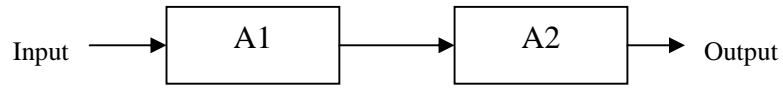


Tr = resource turbidity

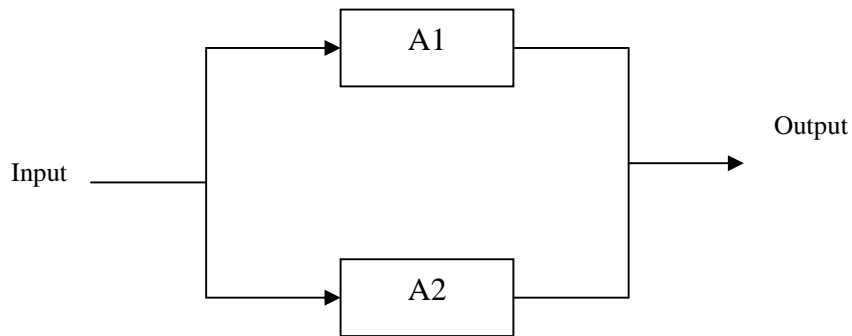
The probability of the top-event may be calculated if the probabilities of the sub-events are known or estimable.

*Figure 2.4 Illustrative fault tree for turbidity non-compliance (after Demotier et al., 2002)*

- a) Series diagram – here, the system / process is working if A1 and A2 are working



- b) Parallel diagram – here, the system / process is working if A1 or A2 are working



- c) Redundancy diagram – here, the system / process is working if at least  $r$  elements among  $n$  are working

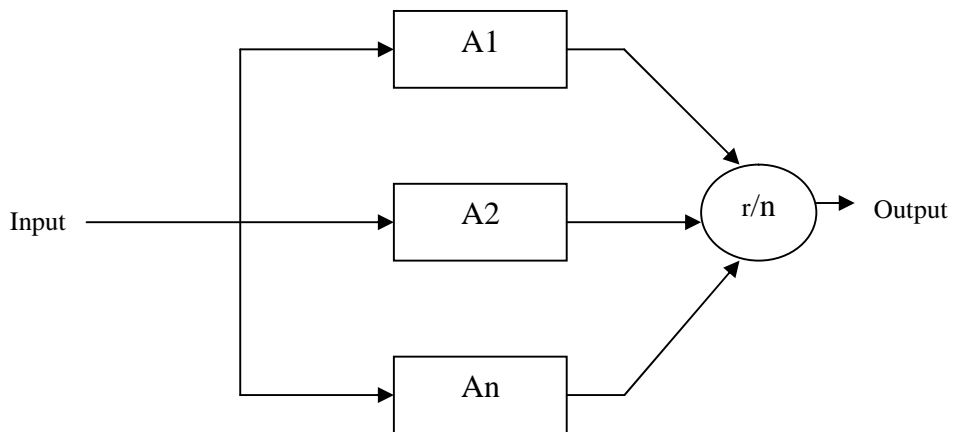


Figure 2.5 Reliability block diagrams (after Cyna, 1997)

### 2.3.1.1 Spatial context of risk

Geographic Information System (GIS) technologies now play a critical role in asset management. At its most basic level, GIS allow utilities to convert data ordinarily displayed on paper maps into one single, easily accessible digital format, representing an excellent method for storing and collating data for future use (Foster and McDonald, 2000). The level of detail (*i.e.* the layers of spatial data) contained within such systems varies widely. Kaufman and Wurtz (1998) describe the evolution of a GIS for a small utility (Beecher Water District, Michigan). An extensive inventory of asset condition records and failure and maintenance data is collated within the system, supporting the risk-based planning of capital improvement and maintenance works. Pertinently, the system took only three months and less than \$3,000 to develop. Similarly, Booth and Rogers (2001) illustrate how the implementation of GIS technologies within an asset management decision support system can allow for the visual tracking of infrastructure assets and their associated risk factors.

Although applications of GIS technologies in support of asset management have proven to be powerful risk-tracking, visualisation and communication tools (Booth and Rogers, 2001), they rarely utilise the capabilities of GIS to spatially analyse data in the classical sense (Foster and McDonald, 2000). Doyle and Grabinski (2003) illustrate these capabilities through quantitatively relating Toronto's infrastructure deterioration to spatially variable corrosion risk factors, providing a basis for the identification of network areas most at risk from external corrosion. Such an approach may allow utility managers to better focus rehabilitation efforts through having a more complete understanding of the causative factors behind water main deterioration. Of further interest is the work of Ta (2001), who describes the application of a probability model for burst risk studies of water mains. Contributing factors (*e.g.* pipe number density,

pipe age, material and diameter, soil corrosivity, *etc.*) are represented as GIS data layers and correlated with past failure data in order to deduce burst probability scores for each water main. The tool, developed for Thames Water Utilities Ltd. (UK), is not intended to predict the likelihood of pipe bursts, rather to aid utilities in sourcing the origin of an area burst (*i.e.* following a pipe burst in the area, the value of probability evaluated for a particular pipe section would indicate the likelihood that the burst actually occurred at that section).

While GIS represent powerful tools for spatial data analysis, their inherent capabilities for complex and dynamic analysis are limited (Sweeney, 1999; Fedra, 1998). In contrast, traditional simulation models are powerful tools for complex and dynamic situations, but often lack the intuitive visualisation and spatial-analysis functions that GIS offers (Sweeney, 1999; Fedra, 1998). Consequently, researchers have sought to couple these systems. Lindley and Buchberger (2002) describe the integration of hydraulic modelling within a GIS for the purpose of assessing intrusion susceptibility in distribution systems. The holistic methodology enables the synthesis of multiple risk factors describing the three key (geographically variable) susceptibility conditions of adverse pressure gradient, intrusion pathway, and contaminant source, thus identifying areas susceptible to intrusion (accidental or intended). Susceptible locations are then prioritised for attention by considering how they are hydraulically connected to local sensitive populations. In addition to informing asset management programmes, this framework may also be applied in a reliability context at the design stage. Similarly, Besner *et al.* (2001) illustrate *via* case study how the coupling of a GIS containing structural, operational and water quality parameters with simulation model EPANET facilitates the identification of key factors responsible for water degradation in the distribution network. Through identifying network areas presenting



the greatest risk, this technique can inform the prioritisation of risk management strategies.

### **2.3.2 Catchment management**

The concept of catchment (or watershed) management has gained widespread international support, representing a shift from the sole reliance on end-of-pipe treatment technologies for point sources towards the watershed-specific prioritisation of water quality problems and their integrated solution (Foran *et al.*, 2000). An outcome of this is that the assessment of hazards to the quality of water resources within a catchment is increasingly subject to formal risk assessment and can be expected as part of routine water safety plans (UKWIR, 2003; Umweltbundesamt, 2003; WHO, 2003). In Europe, the DPSIR approach to identifying key hazards within a watershed, by reference to the driving forces (*e.g.* population growth), pressures (sewer discharge), state (increased nutrient load), impacts (anthropogenic eutrophication) and policy response (discharge control) is being adopted under the European Water Framework Directive (IMPRESS Management, 2002). Here, risk assessments of activities posing an actual or potential threat to the quality of water bodies in “river basin districts” are intended to inform and help prioritise a programme of multi-agency action plans targeted at raising the overall ecological status of the watershed within statutory timescales. Given the plethora of potential catchment management issues in any improvement programme, there is a need to prioritise risk management efforts within the watershed by concentrating on those measures that reduce the significant likelihood of severe impacts being realised. Southern Water (UK) adopt a semi-quantitative ranking scheme in screening their groundwater sources for *Cryptosporidium* contamination risk, as described by Boak and Packman (2001). The methodology

consists of ranking source waters across ten risk categories (*e.g.* land use) using pre-determined scoring hierarchies (*e.g.* occasional livestock grazing: 2), before combining these category rankings into an overall weighted risk score. Through this approach the utility identifies those sources deemed to be at significant risk of oocyst contamination, and which therefore require continuous monitoring (in line with regulations).

Given the improved capabilities and functionality of modern GIS and their inherent ability to map and analyse data that is spatially variable in nature, many catchment-level ranking methodologies have sought to incorporate their benefits. Various authors (Lytton *et al.*, 2003; Sivertun and Prange, 2003; Wickham and Wade, 2002; Foster and McDonald, 2000; Osowski *et al.*, 1999; Fuest *et al.*, 1998) describe the use of map overlay techniques (which essentially combine the attributes of two or more data layers across geographic space) in the identification and mapping of areas critical to catchment water quality. These risk-mapping (essentially spatial risk-ranking) methodologies centre on the analysis of those spatial attributes considered to play a significant role in pollutant transport (*e.g.* geology, rainfall, soil type, agricultural activities *etc.*) according to pre-defined formulae (*e.g.* a weighted runoff-potential index). Their focus may be generic or targeted towards specific hazards (*e.g.* animal feeding operations) or pollutants (*e.g.* through incorporating measures of their leaching potential).

Risk-ranking methods are applied to help target more detailed analysis towards critical risks and to inform the prioritisation of catchment management activities, specifically monitoring programmes. Of course, the potential exists that as the costs of planned monitoring decrease on the one hand, the risks may increase on the other. When designed well, piloted and implemented with feedback, risk-based resourcing strategies (Figure 2.6) can provide a sound basis for distinguishing greater risks from

lesser ones, and for investing resources in risk management that are proportional to the risks posed (Pollard *et al.*, 2002).

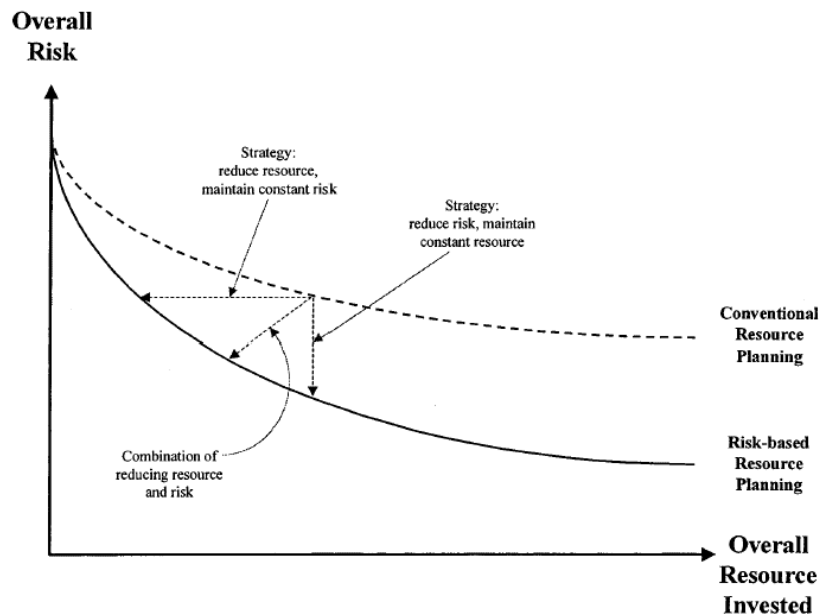


Figure 2.6 Risk-based workforce planning (after Pollard *et al.*, 2002)

Most critically, however, these risk-based optimisation tools, whether intended to drive monitoring regimes, maintenance schedules or workforce planning, may themselves incur significant risk unless the consequences of resource trade-offs are themselves assessed. Consider the actions of the Saskatchewan Department of Environment and Resource Management (SERM) prior to the North Battleford *cryptosporidiosis* outbreak in April 2001 (Pollard *et al.*, 2004). SERM held legislative responsibility for the Saskatchewan drinking water programme and, partly in response to budget cuts in the mid 1990s, drastically reduced the already limited field inspection and enforcement of municipal utilities. This culminated in SERM proposing to eliminate its drinking water programme altogether, a motion tentatively approved by the Treasury Board in 2000/01 and justified as being “risk-based.” The subsequent

North Battleford outbreak, infecting between 5800 to 7100 persons in the immediate community plus a large number of visitors from three other provinces, led to a public inquiry into the outbreak and the provincial drinking water regulatory system. Justice Laing (2002) concluded in his Inquiry report: *“that the current risk-based model employed by SERM since 1996 is arrived at on the basis of economics, and has nothing to do with how best to safeguard the health of the population, all of whom consume water.”* The example aptly illustrates the inappropriate use of risk analysis as a justification for the removal of processes critical to public health protection. Tensions that arise between those seeking economic efficiencies and preservation of the principal goal of providing safe drinking water are often played out in the conflicting expectations and presumed purposes of risk analysis made by different professionals. The real consequences of stripping away levels of safety, precaution and protection using “risk analysis” as a justification can be to render the system as a whole less safe, more precarious and more susceptible to catastrophic failure and so optimisation programmes, maintenance schedules and risk-based monitoring require special scrutiny as to the balance between risk and the full cost of implementing these programmes.

Where more detailed analysis is deemed necessary, a common recourse is to model-based approaches. Water quality and flow / transport models represent core tools for this purpose, due to their combined ability to model the dispersal of pollutants and predict the resultant deterioration of water quality. Aside from the inherent value of fostering an increased understanding of catchment water quality issues, the core benefits of model-based analysis stems from their ability to test management scenarios (through *e.g.* sensitivity and scenario analysis), thus enabling informed decisions on how best to manage the resource. A range of models are available that apply to

catchment risk analysis, from micro to landscape scales, from deterministic to stochastic approaches (Table 2.3).

Common practices of hydrological and water quality modelling have been based mostly on deterministic analysis, producing single point estimates that neglect prediction uncertainty (Andersson and Destouni, 2001). Determinism has been embraced by many risk analysts, for example, Gündüz *et al.* (1998) describe the use of the combined hydrodynamic and water quality model CE-QUAL-W2 in projecting potential water quality degradation patterns under different pollution loads. The tool is intended to aid management in the development of appropriate strategies for the management of water quality. Similarly deterministic approaches to catchment analysis are described by various other researchers (*e.g.* Cole *et al.*, 1988). The limitations of determinism in risk analysis, discussed earlier, are particularly relevant in the context of hydrological and water quality modelling, considering the often scarce or incomplete data available (Mailhot and Villeneuve, 2003). This uncertainty takes on particular importance from the utility standpoint, as their assessments of catchment water quality are performed with regard to set regulatory standards. To illustrate this point, the uncertainties inherent in flow and contaminant transport modelling (from *e.g.* spatial variability, data scarcity, model imperfections) imply that there will always be a risk of exceeding a given standard at some point over space or time following a pollution event, regardless of the estimated single-point (mean) contaminant levels (Andersson and Destouni, 2001).

An argument can thus be forwarded for the explicit consideration of prediction uncertainties in catchment level risk modelling. There exist two dominant approaches towards this task: stochastic modelling; and deterministic modelling allied with uncertainty analysis of the output. Adopting the former approach, Andersson and

Destouni (2001) outline the application of stochastic transport modelling to quantify the risk of exceeding regulatory standards for groundwater at any point on the compliance boundary. This quantification is coupled with an analysis of the abatement costs required to attain an “acceptable” risk level. Halfacree (1998), for example, describes the use of PRAIRIE, an aquatic dispersion modelling tool for assessing chemical pollution risks to water bodies. The main elements are an aquatic dispersion model; hydrological, substance and standards databases; and a tabular / graphical output facility. The model has a deterministic mode used to “screen out” low risk sites, and a probabilistic mode for more detailed analysis of high risk sites. The output results (*e.g.* frequency versus concentration curves) are compared with pre-determined criteria to inform regulatory actions on risk management from hazardous activities within a sensitive catchment. An advantage of the stochastic approach is that uncertainty is interwoven within the model (Zoppou, 2001). However, the solution of stochastic equations is often impractical for complex problems (Li and McLaughlin, 1991). This explains, in part, the preference for deterministic approaches to water quality / hydrological modelling, creating the subsequent need for external consideration of output uncertainty.

In this context, uncertainty analysis is performed to estimate the probability of obtaining a given output value when uncertainties on input variables and parameters are known (Mailhot and Villeneuve, 2003). Liou and Yeh (1997) outline the use of a groundwater transport model in deriving the risk of contaminant concentration exceeding a maximum acceptable upper limit (*e.g.* regulatory standard). The analytical uncertainty of the predicted contaminant concentration is derived by first-order mean-centred uncertainty analysis, prior to the application of Monte Carlo simulation in order to compute the mean risk and associated confidence interval of exceeding standards.

For detailed discussions of the forms of uncertainty in water quality modelling and the techniques for their analysis, see Mailhot and Villeneuve (2003); Portielje *et al.* (2000); and Beck (1997).

In the event of pollution leading to a violation of water quality standards, remediation may be required. Researchers have developed methodologies for optimising remediation strategies (*e.g.* Rogers *et al.*, 1995). However, as Latinopoulos *et al.* (1997) contend, if the inability to meet the constraints of a groundwater quality programme is considered a significant risk, then quantifying the risk of remediation failure in terms of failure to comply with regulatory standards is a primary task. In relation to this, Latinopoulos *et al.* (1997), through coupling stochastic flow and transport simulations with a risk-cost-benefit objective function, have developed a methodology facilitating the risk-based evaluation of remediation strategies (costing the risk of failure in terms of regulatory fines and the need to import / develop alternative supplies).

An alternative approach to characterising the extent and severity of source contamination is that of geostatistical inference (*e.g.* Passarella *et al.*, 2001; Wingle *et al.*, 1999; Rautman and Istok, 1996). These kriging methods – essentially a form of least squares linear regression – focus on providing an estimate of a spatially distributed variable (*e.g.* contaminant concentration) at unsampled locations as a function of a limited set of sample values taken from surrounding locations (Rautman and Istok, 1996). As such, they are ideally suited to groundwater quality issues, where data collection is limited by expense and access. Of particular relevance to risk analysis is the discipline of geostatistical simulation, where multiple, unique estimates of site conditions that mimic the random variability of the parameter(s) of concern are produced (Wingle *et al.*, 1999). Various authors (Passarella *et al.*, 2001; Wingle *et al.*,

1999; Rautman and Istok, 1996) have illustrated how such an approach may answer the following questions: what is the probability that contaminant levels exceed regulatory standards; where are the compliance boundaries (and what is the associated level of confidence); and how much contaminant is present (and hence, how much must be removed)? Although the principles of geostatistical simulation are well established, the technique has yet to be widely applied to problems of groundwater contamination (Rautman and Istok, 1996).

Applications of GIS to catchment risk analysis were discussed earlier in the context of risk-mapping. Although representing efficient risk screening tools, their ability to quantify risk over space *and* time is limited. To counter this, researchers have sought to integrate these systems with simulation models. Feijtel *et al.* (1998) illustrate that the embedding of chemical fate prediction models within a GIS allows for calculation of the distribution of predicted environmental concentrations, both in space and time, of “down-the-drain” chemicals in catchment surface waters. Similar approaches are adopted by Dabrowski *et al.* (2002) and Verro *et al.* (2002) to assess surface water pesticide loading.

### **2.3.3 Network analysis**

A water distribution system may be viewed as an interconnected collection of sources, pipes, and hydraulic control elements (*e.g.* pumps, valves, regulators, tanks) delivering water to consumers in prescribed quantities and at desired pressures (Ostfeld *et al.*, 2002). System behaviour, which is governed by hydraulics, supply, demand, and system layout, may be described mathematically (Ostfeld *et al.*, 2002). This description forms the basis of water supply and distribution modelling (network analysis), a discipline practised in the water industry for many years, particularly to



inform the development of operational strategies (Tanyimboh, 2004; Brammer and Schulte, 1993). Water utilities routinely apply network analysis in order to assess their “security of supply,” defined as the probability of being able to meet consumer demands (*i.e.* network reliability). “Best practice” utilities extend their analysis beyond routine operating conditions to examine network performance under various supply-demand scenarios, thus reflecting the inherent uncertainty of the supply-demand balance. The standard Scottish Water methodology of yield assessment uses the software tool HYSIM-AQUATOR (Lifton and Smeaton, 2003). HYSIM, a hydrological rainfall-runoff simulation model, is used to derive historic inflow series, based on historic rainfall, potential evapotranspiration, and if necessary any artificial influences (*e.g.* abstractions). AQUATOR, a water resource system model, uses the output from HYSIM to simulate reservoir storage based on system demands and compensation flows. The model assists Scottish Water in understanding the level of supply availability risk in the current system and in determining the impact of prospective investment strategies to mitigate this risk.

Stevens and Lloyd (2004) describe the application of the resource modelling package WRAPsim, with reference to the Yorkshire Water (UK) Grid. The model contains over 1200 components including all river and reservoir sources, boreholes, water treatment works, pipelines and demand centres. Through simulation of the conjunctive use of Yorkshire Water’s sources over a given time period, model output provides the decision-maker with an accurate assessment of the behaviour of each source, its ability to meet demand, and the frequency of restrictions that would need to be imposed. Further insights are gleaned through the application of scenario analysis, wherein the supply-demand balance for each zone under variable scenarios (*e.g.* average year, dry year, peak week, *etc.*) allows an assessment of security of supply over

a range of timescales and operating conditions. The authors report that WRAPsim's ability to predict future supply conditions, to optimise allocation of water resources, and to rebalance stocks, has significantly increased the yield and reliability of Yorkshire Water's supply system (Stevens and Lloyd, 2004).

Stahl and Elliott (1999) discuss Essex and Suffolk Water (ESW)'s use of the risk-based resource planning and operational support model DROP (Drought Reliable Output Programme), an adaptation of WRAPsim designed to accommodate the utility's specific technical requirements. The model has been applied in a variety of areas, particularly in support of investment planning and the determination of operational strategies. The authors state that DROP has enabled ESW to improve their understanding of system performance, identify new schemes or short term options to improve reliability of supply, and to more accurately determine future operating costs associated with new developments. Such methodologies, although able to examine system reliability under a range of operating conditions, do not adequately address whether the system is *sufficiently* reliable, as this requires the definition and quantification of appropriate and meaningful reliability measures, a computationally difficult task (Ostfeld, 2001). Harnessing developments in computer processing power and operability, Ostfeld (2001) has developed a methodology for the explicit reliability analysis of water distribution networks, with reliability defined, quantified and measured as the probability of zero annual shortfalls. The methodology, whose development was funded with the intention of practical application by the Israeli Water Commission, is comprised of two interconnected stages: (i) analysis of the storage-conveyance properties of the system; and (ii) implementation of stochastic simulation through use of RAPTOR (Rapid Availability Prototyping for Testing Operational Readiness) software.

However, researchers in the field of network analysis are increasingly aware of the need to take account of both the frequency and severity of modelled failures, and as a result analyses are often suggested to extend beyond measures of reliability to incorporate resiliency (*e.g.* the capacity of a system to recover to a satisfactory state from a state of failure) and vulnerability (*e.g.* a measure of failure significance) (Wang *et al.*, 2003; Jinno *et al.*, 1995). Adopting this paradigm, Zongxue *et al.* (1998) describe the coupling of a risk model (comprising measures of reliability, resiliency and vulnerability), which incorporates predictions of water demand, with a traditional network simulation model. The approach aids the identification of operational strategies of minimum risk under given supply and demand scenarios, and is illustrated by application to Fukuoka Water Supply System, Japan (see also Jinno *et al.*, 1995). Similar methodologies are described by Wang *et al.* (2003); Merabtene *et al.* (2002); and Andreu *et al.* (1996) – though supplemented with formal optimisation procedures to assist derivation of the most appropriate operational policies of minimum risk.

To summarise, network analysis can: (a) allow utilities to assess their susceptibility to various supply-demand scenarios (*e.g.* drought or increases in demand); (b) aid decision-makers in determining “optimal” supply strategies and policies; (c) assist in the design phase of distribution networks; and (d) inform the need for capital expenditure.

#### **2.3.4 Vulnerability assessments**

Operational disruptions are the inevitable result of large-scale disasters (*e.g.* flooding, drought, earthquakes, terrorism). To minimise the risks posed by such “uncontrollable” events, utilities must seek to eliminate or reduce their potential consequences – this is best achieved through contingency and emergency planning

(Shimoda, 1994). The role of formal risk analysis in emergency planning, long restricted to drought management, is now being widely adopted to address security risks. This is largely in response to the events of September 11<sup>th</sup>, 2001. In relation to this, a methodology for vulnerability assessments has been developed by Sandia National Laboratories (SNL) – known as Risk Assessment Methodology for Water Utilities (RAM-W). The methodology allows utilities to conduct a detailed assessment of their system vulnerabilities and to develop measures to reduce the risks and mitigate the consequences of terrorist or other criminal attacks (SNL, 2001). The assessment comprises three steps (SNL, 2001):

- 1) determine how well the system detects a problem, which involves surveying all security and monitoring features (*e.g.* how quickly could it detect an undesired chemical being introduced to the supply);
- 2) measure delay capabilities in order to determine how well a system can stop undesired events (*e.g.* security in place, length of storage time); and
- 3) measure the capacity of private guard forces and local, state and federal authorities to respond to an event.

Perhaps a more pragmatic approach, particularly for smaller utilities, is found in the questionnaire-based self-assessment developed by the National Rural Water Association (NRWA, 2002).

## **2.4 OPERATIONAL RISK ANALYSIS**

Our review now progresses to the analysis of individual plant. Operational risk managers are responsible for the risks associated with specific operations at plant level

– for example, the risk of failure of a device or process component, or the risk of exceeding a particular water quality standard and they are increasingly responsible for the health and safety of plant operatives. Analysis at this level is largely concerned with the “classic” risk analysis methodologies developed and established within other process industries, most notably the oil and chemical sectors (Table 2.5).

*Table 2.5 Operational level risk portfolio*

Context	Tool / Technique	Application	Reference
Compliance risk	Risk ranking	Prioritisation of plant contamination risks	Egerton (2004).
	QMRA	Assessing public health risk from microbial source contamination	Medema <i>et al.</i> (2003), Masago <i>et al.</i> (2000), Teunis <i>et al.</i> (1997).
	End-of-pipe compliance models	Assessing risk of exceeding water quality standards	Demotier <i>et al.</i> , (2002), Haas and Trussell (1998).
	GIS simulation	Assessing risk of distribution system water quality degradation	Lindley and Buchberger (2002), Besner <i>et al.</i> (2001).
Reliability analysis	HACCP	Identifying ‘critical control points’	Mullenger <i>et al.</i> (2002), Dewettinck <i>et al.</i> (2001), Hellier (2000).
	HAZOP	Evaluating deviations from design intent	US Department of Energy (1993), Khan and Abassi (2000).
	FMECA	Evaluating component failures	Lifton and Smeaton (2003), Cyna (1997).
	Logic modelling	Modelling process risk interactions	Demotier <i>et al.</i> (2002) Cyna. (1997).
	Multiple barrier approach	Assessing the reliability of multiple barrier treatment processes	Demotier <i>et al.</i> (2002), Eisenberg <i>et al.</i> (2001), Haas and Trussell (1998).

#### **2.4.1 Public health and compliance risk**

Here, we are primarily concerned with the risk posed by specific contaminants at the plant and distribution system level, particularly relating to the hazards posed to human health and the related risk of exceeding regulatory standards. The multiple barrier approach to water treatment has been the central tenet of modern water treatment systems and relies upon the use of “in-series” water treatment processes to remove hazardous agents from the public water supply. Failure or inadequacy of the treatment and distribution process can result in an interruption of supply and / or derogation in water quality (microbiological or chemical) with potential impacts on

public health. The underlying causes may include source contamination, human error, mechanical failure or network intrusion. The consequences of process failure can be immediate, there is very little time if any to reduce exposure because of the lag in securing monitoring data and the impacts can affect a large number of people simultaneously (Pollard *et al.*, 2004). Beyond the paramount impacts on public health through the direct ingestion of contaminated drinking water, financial and consumer confidence impacts invariably ensue. The financial costs to the community of the fatal Walkerton outbreak for example, were in excess of Cdn\$65 million, with one time costs to Ontario estimated at more than Cdn\$100 million (O'Connor, 2002). Compounding this, the loss of consumer confidence following disease outbreaks is often enormous (Hrudey and Leiss, 2003). Even when there is no legislation covering certain aspects there can be claims of negligence against operating companies. Litigation for civil damages have been prominent features following both the Walkerton outbreak (settled out of court) and the Sydney Water crisis (largely dismissed, costs still incurred) (Pollard *et al.*, 2004).

Conventionally, the public health impacts of drinking water consumption have been assessed retrospectively using epidemiological studies (Hunter *et al.*, 2002). Recognition of the need for a preventative approach to managing risk and providing safe drinking water, however, has driven international interest in the application of risk assessment methodologies within the sector, for both chemical and microbiological hazards (Ashbolt, 2004; Haas *et al.*, 1999). The generic approach is based on the risk assessment framework developed by the National Academy of Sciences (NAS, 1983),<sup>103</sup> which consists of four key steps (Haas *et al.*, 1999):

- problem formulation and hazard identification – to describe the human health effects derived from any particular hazard (*e.g.* infection, carcinogenicity, *etc.*);

- exposure assessment – to determine the size and characteristics of the population exposed and the route, amount, and duration of exposure;
- dose-response assessment – to characterize the relationship between the dose exposure and the incidence of the health effects;
- risk characterization – to integrate the information from exposure, dose-response, and health interventions in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty.

Several substantive differences exist between assessment of risk of microbial agents and assessment of risk of chemicals (Haas, 2002). Accordingly, the NAS approach has been adapted to account for the dynamic and epidemiologic characteristics of infectious disease processes (Fewtrell and Bartram, 2001), to form what is known as quantitative microbial risk assessment (QMRA). The application of these models has long been the basis for the derivation of water quality guidelines for drinking water (WHO, 2002). The substance-specific health risk assessments that have historically informed the guidelines may, however, be somewhat distanced from the immediate operational context of individual utilities (Pollard *et al.*, 2004). However, recent work has extended the application of these models to the operational (plant-specific) context. For example, Medema *et al.* (2003), Masago *et al.* (2002), and Teunis *et al.* (1997) describe the application of QMRA in determining the public health risks posed by the presence of microbial contaminants in treated water. The first step in the process is to define the relationship between measured pathogen source levels and the consumed dose (incorporating analytical detection levels, treatment removal efficiencies, drinking water consumption), followed by the construction of a deterministic model mathematically describing this relationship. Monte Carlo

simulation (a method of uncertainty analysis) is then applied to the output of the deterministic model to determine the distribution of the daily consumed dose, to which the relevant dose response relationship is applied in order to determine the cumulative distribution of the probability of infection. From this, the mean annual individual risk of infection may be determined. Such approaches are of particular relevance in areas, such as the Netherlands, where water supply legislation expresses acceptable health risks in terms of infections per year (Medema *et al.*, 2003). Of course, core microbial standards generally refer to a maximum level of organisms in the treated water, and so consideration of consumption levels and the dose-response relationship is superfluous to compliance risk assessment. The approach perhaps has most utility in “what-if” mode to answer questions such as: “*what are the public health implications of a failure of part of the treatment process or of a re-designing of the treatment process*” (Gale, 2001).

Tools are available to assess the risk of exceeding water quality standards relating to physical or chemical parameters. For example, Demotier *et al.* (2002) describe an integrated FTA / FMEA approach to determining the risk of producing non-compliant drinking water across a range of parameters, taking into account the quality parameters of raw water and the removal efficiencies and reliability of the full set of treatment processes. Similar methodologies are described by Eisenberg *et al.* (2001) and Haas and Trussell (1998) in assessing the reliability of multiple, independent barriers in water treatment. These three pieces of research explicitly consider the performance variability of individual processes along the treatment line, an approach rarely described in operational QMRA. Not only does this offer a more realistic appraisal of compliance risk, it is in line with recent proposals from regulatory bodies (*e.g.* National Health and Medical Research Council (NHMRC, 2001)) calling on utilities to formally



adopt the multiple barrier approach to risk management to ensure multiple levels of protection are afforded against specific contamination threats (see Rizak *et al.*, 2003).

Of course, limitations in resources (human and financial) and in the data to underpin such sophisticated analyses often restrict the practical application of these more advanced methodologies within the sector. A more pragmatic analysis of the risks of process failure is commonly undertaken using a semi-quantitative risk-ranking of hazards according to their likelihood and consequence. Egerton (2004) describes the application of ranking techniques for the prioritisation of contamination risks at a water treatment plant. Risks are scored according to the frequency with which they may occur, the ability to take action to contain the event, and the consequence of subsequent contamination. The methodology is intended to aid the targeting and prioritisation of remedial actions. Such approaches rely heavily on the experience and judgement of the assessment team, and depending on the level of guidance provided for scoring within these criteria, remain open to bias especially from unforeseen circumstances that often fall beyond the process boundary, *e.g.* deliberate or accidental human error.

Finished water can undergo a variety of physical, chemical, and biological changes during transportation through a distribution system (Besner *et al.*, 2001). Understanding the nature and likelihood of these risks has become a priority for water producers (Besner *et al.*, 2001), in part due to research linking such degradation to the incidence of gastrointestinal illnesses (*e.g.* Payment *et al.*, 1991). Application of the methodologies developed by Lindley and Buchberger (2002) and Besner *et al.* (2001), described earlier (see *Asset management*), would provide utilities with a means to distinguish areas of the distribution system at greatest risk of degradation, providing a framework for prioritising risk management activities.

### 2.4.2 Reliability analysis

It is implicit in the planning, design and operation of water utilities that risk analysis is a qualitative component of the intellectual process of the experienced engineer / operator. Reliability analysis seeks to formalise, systemise, and, where necessary, quantify this process. Assessments of operational reliability range from component (*e.g.* risk of valve failure), process (*e.g.* risk of failure of treatment step) to network (*e.g.* network reliability under drought conditions, see *Network analysis*) level analysis. Regardless of focus, the aim is to identify the potential failures that may occur in a system, their effects and their likelihood, thus aiding the identification of critical components and processes where design and operational changes are required to meet safety and / or production targets (Strutt, 2004). Analysis may be summarised as follows (Strutt, 2004):

- system definition – defining the level of analysis;
- failure identification – identifying potential hazards (*e.g.* HACCP, hazard and operability studies, FMEA / FMECA);
- reliability modelling – to describe failure behaviour of system as a whole (*e.g.* FTA, ETA, reliability block diagrams); and
- sensitivity analysis.

The National Health and Medical Research Council (NHMRC), the body responsible for issuing drinking water guidelines to Australian water utilities, in their “Framework for Management of Drinking Water Quality” (Rizak *et al.*, 2003; NHMRC, 2001) advocated the application of a HACCP (hazard analysis critical control points) methodology, namely the determination of “critical control points” whereupon

risks can be monitored and reduced (Codex Alimentarius, 1993). Hellier (2000) describes the implementation of this approach within Melbourne Water (Australia). The process begins with the division of the water system into four discrete subsystems: catchment, treatment, distribution and customer premises. Across each subsystem (*e.g.* catchment) the sources of risk to water quality (*e.g.* native animals) and the associated hazards (*e.g.* bacteria, viruses) are identified and plotted on a simple risk matrix; those risks deemed to be significant are evaluated further for their critical control points. Assessors then identify the critical limits, monitoring systems and corrective actions for each CCP. The application of HACCP to South East Water Ltd.'s (Australia) distribution and reticulation systems is described in Mullenger *et al.* (2002). Through implementing their HACCP plan, the company has developed a greater understanding of water quality issues, refined and optimised operating procedures, and observed a net decrease in customer complaints. These benefits stem from an increased knowledge and understanding of the water supply system and an improved ability to identify potential risks to water supply / quality (Mullenger *et al.*, 2002). Beyond managing existing process control, HACCP may also be used to assess and manage the risks from proposed operational changes, such as the integration of treated domestic wastewater to an existing potable production process (*e.g.* Dewettinck *et al.*, 2001).

HAZOP (hazard and operability study), a technique developed by Imperial Chemical Industries Ltd., systematically evaluates the process and engineering intentions of new or existing facilities in order to identify the hazards that may arise due to deviations from design specifications (American Institute of Chemical Engineers, 1992). Typically, a carefully selected team examines a process (*e.g.* disinfection) subdivided into "nodes," at each node, the team applies guidewords (*e.g.* low) to process parameters (*e.g.* ozone levels) to identify ways in which the process may

deviate from its design intention, before evaluating the causes and consequences of the deviation. A technical document published by the US Department of Energy (1993) describes the undertaking of a HAZOP study on the partially installed chlorination process of a water treatment facility. The analysis, conducted in response to regulatory requirements, identified the key areas of uncertainty (*e.g.* chlorine cylinder received overfilled). “Action items” and recommendations were formulated to clarify these uncertainties and to verify process conditions (*e.g.* check pressure potential from the chlorine cylinder and the system response).

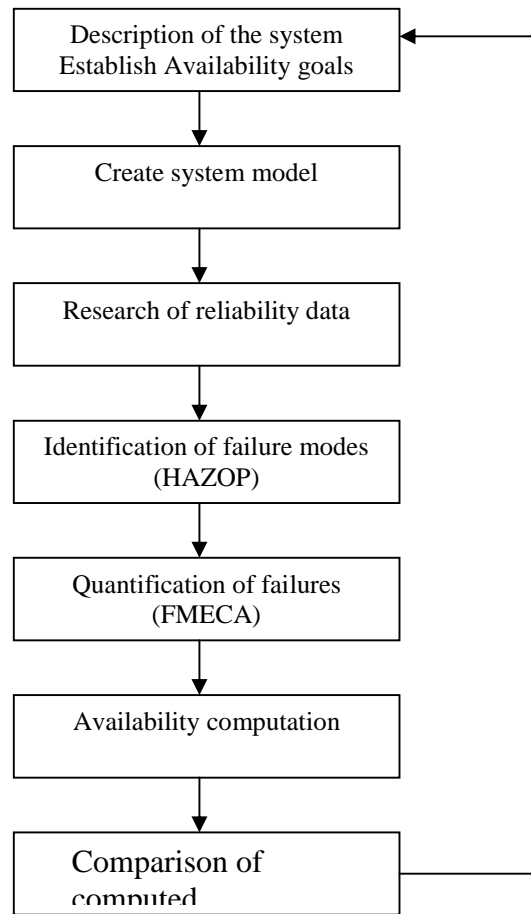
The practical implementation of many of these techniques is often constrained by the institutional capacity of organisations and the skill sets available at the operational level. Risk analysis remains an expert discipline and many organisations are more comfortable with the historic and proven implicit approach to risk management. Nevertheless, we are witnessing a growing number of utilities making their analysis more explicit and using these tools for better decision-making, identifying risk issues early rather than later, when their ability to respond may be compromised. At Scottish Water, for example, FMECA-based studies are performed at the operational level. Targeted by a risk criticality scoring system, the analysis systematically considers various components of the water supply system and their respective failure modes (Lifton and Smeaton, 2003). As the scoring system is “pseudo-economic,” decision-makers are empowered to assess the costs and benefits in terms of risk reduction per pound of mitigation efforts through undertaking simple scenario modelling (Lifton and Smeaton, 2003). Where identified failure modes are traced to specific mechanical or electrical equipment, the equipment is subject to reliability centred maintenance – the risk-based prioritisation of maintenance activities. In recognition of the dangers of ill-informed risk-based resourcing, select critical-risk assets undergo formal optimisation

of maintenance task cost-risk-performance using a suite of asset performance tools (APT).

These methodologies represent an informed and structured, if time-consuming, framework for pinpointing weaknesses in utility design and operation. Applied effectively using personnel with appropriate skills, experience and resources, they provide operational management with a basis for improving process reliability and identifying issues early. Ineffectively applied, they become little more than acronyms for complacency. As discussed, reliability analysis may require a quantitative treatment of the effect of identified risks at the system level. The importance and complexity of this task has increased in recent years, due in part to the increased range of available technologies and the tighter operational margins imposed by regulators (Eisenberg *et al.*, 2001).

For unreliable or heavily used equipment, an analysis of historic data may be sufficient for this purpose. In the absence of such data, there is a requirement for the formal modelling of risk consequences. There exist a range of techniques for this task, including logic modelling (*e.g.* Demotier *et al.*, 2002; Cyna, 1997), “quantitative” FMECA (*e.g.* Cyna, 1997), and multiple barrier approaches to treatment reliability (*e.g.* Demotier *et al.*, 2002; Eisenberg *et al.*, 2001; Haas and Trussell, 1998). An illustration of an integrated approach to evaluating plant reliability is provided by Cyna (1997), who describes the methodology developed and applied by the *Compagnie Generale des Eaux* (France) (Figure 2.7). Following system definition and modelling (*via* reliability block diagrams), risks are identified and classified using HAZOP. Risk consequences are subsequently quantified *via* FMECA, allowing the computation of system availability (the probability of the system to be found operative at a given time). Cyna (1997) describes how the methodology was applied to a proposed post-chlorination

system in *Neuilly-sur-Marne* plant, arguing that its employment helped conceive a reliable system and verified the adequacy of plant availability. The author concludes that reliability analysis is an essential tool at “conception,” which allows the adjustment of project design, and thus cost, to the level of reliability required, and, when associated with maintenance procedures, can provide insurance of design quality.



*Figure 2.7 Methodology for reliability analysis of a water treatment plant (after Cyna, 1997)*

## 2.5 CONCLUSION

Risk management for water utilities is fast becoming an explicitly-stated paradigm, recognising the implicit approach performed over the last 150 years. With

increasing globalisation, outsourcing and increased regulation of the industry, tools that allow system vulnerabilities to be identified before failures occur are essential. In many ways, however, the industry is discovering risk analysis afresh and there is a learning curve to climb in terms of the capabilities and limitations of these tools and techniques. The international water sector has helpfully restated its overarching goal reminding us that even in the face of rationalisation and economic pressure, public health protection is the principal business of the water industry. Risk analysis has a part to play in focussing effort in the right places, but should not be treated as a panacea or substitute for managing risk and neither allowed to dictate the outcome of decisions without recourse to the fundamental goal of the business. Flexibility of approach is key to the successful application of these tools, as is their appropriate selection within the organisational context and legal framework. For large multi-utilities, one can expect high developed business risk capabilities, whereas for smaller and single utilities, an approach based on accepted codes and standards may be more suitable. Our analysis provide a comprehensive inventory of the current state-of-the-art as a reference for developing a risk analysis strategy that is fit for purpose.

### *Acknowledgements*

This work has been funded by the American Water Works Association Research Foundation (AWWARF project RFP2939), Yorkshire Water Services, the Canadian Water Network and a consortium of international water utility companies and organisations. The comments and views herein are the authors' alone. Brian MacGillivray is co-funded on a UK Engineering and Physical Sciences Research Council Doctoral Training Account.

## 2.6 REFERENCES

- American Institute of Chemical Engineers, *Guidelines for Hazard Evaluation Procedures*, 2<sup>nd</sup> Edition, American Institute of Chemical Engineers, New York, 1992, 64-67
- Andersson, C. and Destouni, G., Risk-cost analysis in ground water contaminant transport: the role of random spatial variability and sorption kinetics, *Ground Water*, **39**(1), 35, 2001.
- Andreu, J., Capilla, J. and Sanchis, E., AQUATOOL, a generalized decision-support system for water resources planning and operational management, *J. Hydrol.*, **177**, 269, 1996.
- Anon., Retention risk assessment, *Incentive*, **175**(2), 68, 2001.
- Ashbolt, N.J., Risk analysis of drinking water microbial contamination versus disinfection by-products (DBPs), *Toxicology*, **198**, 255, 2004.
- Asian Development Bank (ADB), *Handbook for the Economic Analysis of Water Supply Projects*, ADB, 1999. (website: [http://www.adb.org/Documents/Handbooks/Water\\_Supply\\_Projects/default.asp](http://www.adb.org/Documents/Handbooks/Water_Supply_Projects/default.asp))
- Asian Development Bank (ADB), *Proceedings of the regional forum on regulatory systems and networking of water utilities and regulatory bodies*, ADB, 2001. (website: [http://www.adb.org/Documents/Conference/Water\\_Uilities/default.asp](http://www.adb.org/Documents/Conference/Water_Uilities/default.asp)).
- AWWA, EUREAU, WSAA and DVGW, *Bonn Workshop 2001 – Key principles in establishing a framework for assuring the quality of drinking water: a summary*, AWWA, Denver, CO., 2001.
- Barney, S.M., Retaining our workforce, regaining our potential, *J. Healthcare Manage.*, **47**(5), 291, 2002.



- Barreix, A., Jenkins, G.P. and Marchesini, M., *Case 1. Restructuring the water and sewer utility in Panama*, World Bank, 2003. (website: [http://130.15.74.22/publications/panama\\_water.pdf](http://130.15.74.22/publications/panama_water.pdf)).
- Beck, M.B., Applying systems analysis in managing the water environment: towards a new agenda, *Wat. Sci. Tech.*, **36**(5), 1, 1997.
- Berry, M.A., Burmeister, E. and McElroy, M.B., Sorting out risks using known APT factors, *Financial Analysts J.*, **44**(2), 29, 1988.
- Besner, M-C., Gauthier, V., Barbeau, B. and Millette, R., Understanding distribution system water quality, *J. AWWA*, **93**(7), 101, 2001.
- Black, F. and Scholes, M., The pricing of options and corporate liabilities, *J. Politic. Econ.*, **81**(3), 637, 1973.
- Boak, R.A. and Packman, M.J., A methodology for the assessment of risk of *Cryptosporidium* contamination of groundwater, *Quarterly J. Engg. Geol. Hydrogeol.*, **34**(2), 187, 2001.
- Booth, R. and Rogers, J., Using GIS technology to manage infrastructure capital assets, *J. AWWA*, **93**(11), 62, 2001.
- Brammer, L.F. and Schulte, A.M., A joint US and UK approach to water supply and distribution modelling, *J. IWEM*, **7**, 471, 1993.
- Brueck, T., Facing the workforce reality: making more out of less, *J. AWWA*, **94**(6), 34, 2002.
- Buckland, R. and Fraser, P., Political and regulatory risk in water utilities: Beta sensitivity in the United Kingdom, *Journal of Business Financing and Accounting*, **28**(7/8), 877, 2001.
- Bunn, D.W., Dyner, U. and Larsen, E.R., Modelling latent market power across gas and electricity markets, *Syst. Dynam. Rev.*, **13**, 271, 1997.

- Burchett, J.F. and Tummala, V.M.R., The application of risk management process in capital investment decisions for EHV transmission line projects, *Constr. Manage. Econ.*, **16**, 235, 1998.
- Clark, T., Jeffrey, P. and Stephenson, T., Complex agendas for new technology adoption in the UK water industry, *Technovation*, **20**, 247, 2000.
- Clemons, E.K., Using scenario analysis to manage the strategic risks of reengineering, *Sloan Manage. Rev.*, **36**(4), 61, 1995.
- Codex Alimentarius, *Guidelines for the Application of the Hazard Analysis and Critical Control Point (HACCP) System*, ALINORM 93 / 13A, Appendix 2, WHO, Geneva, 1993.
- Cole, J.A., Hawker, P.J., Lawson, J.D. and Montgomery, H.A.C., Pollution risks and countermeasures for surface water intakes, *J. IWEM*, **2**, 603, 1988.
- Colmer, G., Dunkley, M., Gray, K., Pugh, P. and Williamson, A., Estimating the cost of new technology products, *Intl. J. Technol. Manage.*, **17**(7/8), 840, 1999.
- Cowan, S., Competition in the water industry, *Oxford Rev. of Econ. Policy*, **13**(1), 83, 1997.
- Crowe, T.J., Fong, P.M., Bauman, T.A. and Zayas-Castro, J.L., Quantitative risk level estimation of business process reengineering efforts, *Business Proc. Manage. J.*, **8**(5), 490, 2002.
- Cyna, B., Reliability analyses of water treatment plants, *Water Supply (Amsterdam)*, **15**(2), 65, 1997.
- Dabrowski, J.M., Peall, S.K.C., Van Niekerk, A., Reinecke, A.J., Day, J.A. and Schulz, R., Predicting runoff-induced pesticide input in agricultural sub-catchment surface waters: linking catchment variables and contamination, *Wat. Res.*, **36**, 4975, 2002.

- Dean, A., Carlisle, Y. and Baden-Fuller, C., Punctuated and continuous change: the UK water industry, *Brit. J. Manage.*, **10**, S3, 1999.
- Demotier, S., Odeh, K., Schon, W., Charles, P., Fotoohi, F. and Allieux, J-F., *Risk assessment for drinking water production process*, 2002. (website: <http://www.hds.utc.fr/~tdenoeux/sime/publis/esrel2002.pdf>).
- Denton, D.K., Keeping employees: the Federal Express approach, *S.A.M. Adv. Manage. J.*, **57**(3), 10, 1992.
- Dewettinck, T., Van Houtte, E., Geenens, D., Van Gege, K. and Verstraete, W., HACCP (Hazard Analysis and Critical Control Points) to guarantee safe water reuse and drinking water production – a case study, *Water Science and Technology*, **43**(12), 31, 2001.
- Dickerson, A.P., Gibson, H.D. and Tsakalotos, E., Is attack the best form of defence? A competing risk analysis of acquisition activity in the UK, *Cambridge J. Econ.*, **27**(3), 337, 2003.
- Downey, J.M., Risks of outsourcing – applying risk management techniques to staffing methods, *Facilities*, **13**(9/10), 38, 1995.
- Doyle G. and Grabinsky, M., Applying GIS to a water main corrosion study. *J. AWWA*, **93**(5), 90, 2003.
- Drohan, W.M. and O'Connor, K., Competitor analysis can give your association the edge, *Association Management*, **50**(1), 103, 1998.
- Egerton, A.J., *FMEA – water flowsheet*, Lectures in risk management for water and wastewater engineers, Egerton Consulting Ltd., 2004.
- Egerton, A.J., Minimising the risk of contamination in water treatment, Lecture given at a Pipeline Industries Guild/Institute of Water Officers meeting, Bristol Water, United Kingdom, 14<sup>th</sup> February, 2004. (website: [www.egertonconsulting.co.uk](http://www.egertonconsulting.co.uk)).

- Eisenberg, D., Soller, J., Sakaji, R. and Olivieri, A., A methodology to evaluate water and wastewater treatment plant reliability, *Wat. Sci. Technol.*, **43**(10), 91, 2001.
- Elias, D., Allocating capital risk: Who should pay?, *Wat. Engg. Manage.*, **148**(5), 61, 2001.
- Fedra, K., Integrated risk assessment and management: overview and state of the art, *J. Haz. Mat.*, **61**, 5, 1998.
- Feijtel, T., Boeije, G., Matthies, M., Young, A., Morris, G., Gandolfi, C., Hansen, B., Fox, K., Matthijs, E., Koch, V., Schroder, R., Cassani, G., Schowanek, D., Rosenblom, J. and Holt, M., Development of a geography-referenced regional exposure assessment tool for European rivers – GREAT-ER, *J. Haz. Mat.*, **61**, 59, 1998.
- Fewtrell L. and Bartram J., *Water quality: guidelines, standards and health – Assessment of risk and risk management for water-related infectious disease*, IWA Publishing, London, 2001.
- Fisher, M.L., What is the right supply chain for your product?, *Harvard Business Review*, **75**(2), 105, 1997.
- Fitzpatrick, E.W., Assessing the worth of new technology, *J. Amer. Soc. of CLU and ChFC*, **49**(4), 37, 1995.
- Foran, J., Brosnan, T., Connor, M., Delfino, K., Depinto, J., Dickson, K., Humphrey, H., Novotny, V., Smith, R., Sobsey, M. and Stehman, S., A framework for comprehensive, integrated, watershed monitoring in New York City. *Environ. Monit. Assess.* **62**, 147, 2000.
- Foster, J.A. and McDonald, A.T., Assessing pollution risks to water supply intakes using geographic information systems (GIS), *Environ. Modelling and Software*, **15**, 225, 2000.

- Foster, M., Fell, R. and Spannagle, M., A method for assessing the relative likelihood of failure of embankment dams by piping, *Can. Geotechn. J.* **37**(5), 1025, 2000.
- Fuest, S., Berlekamp, J., Klein, M. and Matthies, M., Risk hazard mapping of groundwater contamination using long-term monitoring data of shallow drinking water wells, *J. Haz. Mat.*, **61**, 197, 1998.
- Gale, P., Developments in microbiological risk assessment for drinking water, *J. Appl. Microbiology*, **91**, 191, 2001.
- Gray, R.S. and Powell, E., Risk management of major aqueducts, *J. IWEM*, **2**, 594, 1988.
- Gregory, A., The usefulness of Beta in the investment-appraisal process, *Financial Management*, **68**(1), 42, 1990.
- Grimsey, D. and Lewis, M.K., Evaluating the risks of public private partnerships for infrastructure projects, *Int. J. Proj. Manage.*, **20**, 107, 2002.
- Gündüz, O., Soyupak, S. and Yurteri, Development of water quality management strategies for the proposed Isikli Reservoir, *Wat. Sci. Technol.*, **37**(2), 369, 1998.
- Haas, C.N. and Trussell, R.R., Frameworks for assessing reliability of multiple, independent barriers in potable water reuse, *Wat. Sci. Technol.*, **38**(6), 1, 1998.
- Haas, C.N., Progress and data gaps in quantitative microbial risk assessment, *Wat. Sci. Tech.*, **46**(11), 277, 2002.
- Haas, C.N., Rose, J.B., Gerba, C.P., *Quantitative Microbial Risk Assessment*, Wiley, NY, 1999.
- Hagevik, S., What keeps 'em? *J. Environ. Hlth.*, **63**(6), 50, 2001.
- Halfacree, S., Pollution risk management, *Issues in Environ. Sci. Technol.*, **9**, 37, 1998.
- Hartmann, G.C. and Lakatos, A.I., Assessing technology risk – a case study, *Res. Technol. Manage.*, **41**(2), 32, 1998.

- Heikkilä, J. and Cordon, C., Outsourcing: a core or non-core strategic management decision?, *Strategic Change*, **11**, 183, 2002.
- Hellier, K., Hazard analysis and critical control points for water supplies, *Proc. 63<sup>rd</sup> Annual Water Industry Engineers and Operator's Conference*, Warrnambool, 6-7 September, 2000.
- Hern, R., Competition and access pricing in the UK water industry, *Utilities Policy*, **10**, 117, 2001.
- Hertz, D.B., Risk analysis in capital investment, *Harvard Business Review*, **42**(1), 95, 1964.
- Hrudey, S.E. and Leiss, W., Risk management and precaution – insights on the cautious use of evidence, *Environ. Health Persp.*, **111**, 1577, 2003.
- Hrudey, S.E., Limits to Science for Assessing and Managing Environmental Health Risks, *Science, Truth and Justice*, Canadian Institute for the Administration of Justice, Les Éditions Thémis. Faculté de Droit. Université de Montréal, pp. 128-150, 2000.
- Hunter, P.R., Waite, M., Ronchi, E., *Drinking Water and Infectious Disease: Establishing the Links*, IWA Publishing, London, 2002.
- IMPRESS Management, *IMPRESS Guidance*, Guidance for the analysis of pressures and impacts in accordance with the water framework directive, Draft 5.2, European Commission, Brussels, 2002.
- Jinno, K., Zongxue, X., Kawamura, A. and Tajiri, K., Risk assessment of a water supply system during drought, *Wat. Resource Develop.*, **11**(2), 185, 1995.
- Kaufman, M.M. and Wurtz, M., Small system maintenance management using GIS, *J. AWWA*, **90**(8), 70, 1998.
- Kent, N.A., Treece, D. and Davies, M., Asset management through risk assessment for Welsh Water's water trunk mains, *Proc. ICE/CIWEM Conference: Risk and reward in*

- asset management delivery – who is best prepared for the challenges ahead?*, 14<sup>th</sup> November, 2003, London, UK.
- Khan, F.I. and Abbasi, S.A., Towards automation of HAZOP with a new tool EXPERTOP, *Environ. Modelling and Software*, **15**, 67, 2000.
- Kilpatrick, K. and Lapsley, I., “Trust us” – Regulators and the governance of privatized utilities, *Public Money Manage.*, **16**(2), 39, 1996.
- Laing, R.D., *Report of the Commission of Inquiry into matters relating to the safety of the public drinking water in the City of North Battleford, Saskatchewan.*, The Queen's Printer, Regina, Saskatchewan, March 28<sup>th</sup>, 2002. (website: <http://www.northbattlefordwaterinquiry.ca>.)
- Lantzy, R.J., Cichy, P.T. and Leitzinger, A.H., Use of geographical maps to manage risk from groundwater contamination, *Journal of Hazardous Materials*, **61**, 319, 1998.
- Larsen, E.R. and Bunn, D.W., Deregulation in electricity: understanding strategic and regulatory risk, *J. Oper. Res. Soc.*, **50**, 337, 1999.
- Latiffe, R., Probabilistic risk analysis of large dams: its value and limits, *Intl. Wat. Power and Dam Constr.*, **45**(3), 13, 1993.
- Latinopoulos, P., Mylopolous, N. and Mylopoulos, Y., Risk-based decision analysis in the design of water supply projects, *Wat. Resources Manage.*, **11**, 263, 1997.
- Li, S.G. and McLaughlin, D., A nonstationary spectral method for solving stochastic groundwater problems – unconditional analysis, *Wat. Resources Res.*, **27**(7), 1589, 1991.
- Lifton, G. and Smeaton, P., Asset risk management in Scottish Water, *Proc. of the ICE/CIWEM Conference: Risk and reward in asset management delivery – who is best prepared for the challenges ahead?*, 14<sup>th</sup> November, 2003, London, UK.

- Lindley, T.R. and Buchberger, S.G., Assessing intrusion susceptibility in distribution systems, *J. AWWA*, **94**(6), 66, 2002.
- Liou, T-S. and Yeh, H-D., Conditional expectation for evaluation of risk groundwater flow and solute transport: one-dimensional analysis, *J. Hydrol.*, **199**, 378, 1997.
- Littlechild, S.C., *Economic Regulation of Privatised Water Authorities*, London, HMSO, 1986.
- Lonsdale, C., Effectively managing vertical supply relationships: a risk management model for outsourcing, *Supply Chain Manage.*, **4**(4), 176, 1999.
- Luehrman, T.A., What's it worth? A general manager's guide to valuation, *Harvard Business Review*, **75**(3), 132, 1997.
- Lytton, L., Howe, S., Sage, R. and Greenaway, P., Groundwater abstraction pollution risk assessment, *Wat. Sci. Technol.*, **47**(9), 1, 2003.
- Mailhot, A. and Villeneuve, J-P., Mean-value second-order uncertainty analysis method: application to water quality modelling, *Advances in Wat. Resources*, **26**, 491, 2003.
- Masago, Y., Katayama, H., Hashimoto, A., Hirata, T. and Ohgaki, S., Assessment of risk of infection due to *Cryptosporidium parvum* in drinking water, *Wat. Sci. Tech.*, **46**, 319, 2002.
- Maxwell, S., Where are we headed? Ten key trends and developments in the water industry, *J. AWWA*, **93**(4), 114, 2001.
- McGaughey Jr., R.E., Synder, C.A. and Carr, H.H., Implementing information technology for competitive advantage: risk management issues, *Information and Manage.*, **26**, 273, 1994.
- McIntyre, N.R., Wagener, T., Wheeler, H.S. and Chapra, S.C., Risk-based modelling of surface water quality: a case study of the Charles River, Massachusetts, *J. Hydrol.*, **274**, 225, 2003.



- McNally, J.S., Retaining valued employees, *Pennsylvania CPA J.*, **71**(4), 24, 2001.
- Medema, G.J., Hoogenboezem, W., van der Veer, A.J., Ketelaars, H.A.M., Hijnen, W.A.M. and Nobel, P.J., Quantitative risk assessment of *Cryptosporidium* in surface water treatment, *Wat. Sci. Technol.*, **47**(3), 241, 2003.
- Merabtene, T., Kawamura, A., Jinno, K. and Olsson, J., Risk assessment for optimal drought management of an integrated water resources system using a genetic algorithm, *Hydrological Processes*, **16**, 2189, 2002.
- Modigliani and Miller, The cost of capital, corporation finance and the theory of investment, *Amer. Econ. Rev.*, **48**(3), 261, 1958.
- Morana, C. and Sawkins, J.W., Regulatory uncertainty and share price volatility: the English and Welsh water industry's periodic price review, *J. Regul. Econ.*, **17**(1), 87, 2000.
- Mosca, R., Schenone, M. and Bonello, A.F., Risk analysis in the evaluation of plant investments: the contribution of a non-deterministic approach, *Proj. Manage. J.*, **32**(3), 4, 2001.
- Mowday, R.T., Strategies for adapting to high rates of employee turnover, *Human Resource Manage.*, **23**(4), 365, 1984.
- Mullenger, J., Ryan, G., and Hearn, J., A water authority's experience with HACCP, *Wat. Sci. Tech: Wat. Supply*, **2**(5/6), 149, 2002.
- Myers, S.C., Interactions of corporate financing and investment decisions – implications for capital budgeting, *J. Finance*, **29**(1), 1, 1974.
- National Academy of Sciences, *Risk Assessment in the Federal Government: Managing the Process*, National Academy Press, Washington, DC, 1983.

- Newman, W.R., Hanna, M. and Maffei, M.J., Dealing with the uncertainties of manufacturing: flexibility, buffers and integration, *Intl. J. Operations and Production Manage.*, **13**(1), 19, 1993.
- NHMRC, *Framework for Management of Drinking Water Quality*, NHMRC, New Zealand, 2001.
- NRDC, *What's on tap? Grading drinking water in US cities*, Natural Resources Defense Council, Washington DC, 2003. (website: <http://www2.nrdc.org/water/drinking/uscities/pdf>).
- NRWA, Security vulnerability self-assessment guide for small drinking water systems, 2002. (website: <http://www.health.ri.gov/environment/dwq/security/vulnerability.htm>).
- O'Connor D.R., *Report of the Walkerton Inquiry. Part 1. The events of May 2000 and related issues*, The Attorney General of Ontario, Toronto, Canada, 2002.
- O'Reilly, C.A., Chatman, J.A. and Caldwell, D., People and organizational culture: A profile comparison approach to assessing person-organization fit, *Academy of Manage. J.*, **34**(3), 487, 1991.
- Ofwat, *Access codes for common carriage: guidance*, Ofwat, 2002. (website: <http://www.ofwat.gov.uk>).
- Osowski, S.L., Swick Jr, J.D., Carney, G.R., Pena, H.B., Danielson, J.E. and Parrish, D.A., A watershed-based cumulative risk impact analysis: Environmental vulnerability and impact criteria, *Environ. Monit. Assess.*, **66**, 159, 1999.
- Ostfeld, A., Kogan, D. and Shamir, U., Reliability simulation of water distribution systems – single and multiquality, *Urban Water*, **4**, 53, 2002.
- Ostfeld, A., Reliability analysis of regional water distribution systems, *Urban Water*, **3**, 253, 2001.

- Parker, D., Performance, risk and strategy in privatised, regulated industries, *Intl. J. Public Sector Manage.*, **16**(1), 75, 2003.
- Parker, D., Reducing regulatory risk: the case for a new regulatory contract with the privatized utilities, *Public Money Manage.*, **18**(4), 51, 1998.
- Parmelee, M.A., Trends in outsourcing for water utilities, *J. AWWA*, **94**(9), 54, 2002.
- Parr, N.M. and Cullen, N., Risk management and reservoir maintenance, *J. IWEM*, **2**, 587, 1988.
- Passarella, G., Vurro, M., D'Agostino, V., Guiliano, G. and Barcelona, M.J., A probabilistic methodology to assess the risk of groundwater quality degradation, *Environ. Monit. Assess.*, **79**, 57, 2001.
- Payment, P., Richardson, L., Siemiatycki, J., Dewar, R., Edwardes, M. and Franco, E., A randomized trial to evaluate the risk of gastrointestinal disease due to consumption of drinking water meeting currently accepted microbial standards, *Amer. J. Public Hlth.*, **81**(6), 703, 1991.
- Phelps, R., Chan, C., Kapsalis, S.C., Does scenario planning affect performance? Two exploratory studies, *J. Business Res.*, **51**, 223, 2001.
- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Hamilton, P.D. and Hrudey, S.E., Risk analysis and management in the water utility sector – a review of drivers, tools and techniques, *Trans. IChemE, Part B: Proc. Safety Environ.* **82**(B6): 453, 2004
- Pollard, S.J.T., Yearsley, R., Reynard, N., Meadowcroft, I.C., Duarte-Davidson, R. and Duerden, S., Current directions in the practice of environmental risk assessment in the United Kingdom, *Environ. Sci. Technol.*, **36**(4): 530, 2002.
- Portielje, R., Hvitved-Jacobsen, T. and Schaarup-Jensen, K., Risk analysis using stochastic reliability methods applied to two cases of deterministic water quality models, *Wat. Res.*, **34**(1), 153, 2000.

- Prime Minister's Strategy Unit, *Risk: improving Government's capability to handle risk and uncertainty*, The Strategy Unit, London, 2002. (website: <http://www.number-10.gov.uk/SU/RISK/risk/home.html>).
- Quélin, B. and Duhamel, F., Bringing together strategic outsourcing and corporate strategy: outsourcing motives and risks, *Eur. Manage. J.*, **21**(5), 647, 2003.
- Radovanovic, R. and Marlin, A., Critical water mains – the need for risk analysis, *Water (Australia)*, **30** (2), 42, 2003.
- Rajani, B.B. and Kleiner, Y., *WARP – Water Mains Renewal Planner*, National Research Council Canada, 2001. (website: <http://irc.nrc-cnrc.gc.ca/fulltext/nrcc44680/>)
- Ranasinghe, M., Private sector participation in infrastructure projects: a methodology to analyse viability of BOT, *Constr. Manage. Econ.*, **17**, 613, 1999.
- Rautman, C.A. and Istok, J.D., Probabilistic assessment of ground-water contamination: 1. Geostatistical framework, *Ground Water*, **34**(5), 899, 1996.
- Remenyi, D. and Heafield, A., Business process re-engineering: some aspects of how to evaluate and manage the risk exposure, *Intl. J. Proj. Manage.*, **14**(6), 349, 1996.
- Rizak, S., Cunliffe, D., Sinclair, M., Vulcano, R., Howard, J., Hruday, S. and Callan, P., Drinking water quality management: a holistic approach, *Wat. Sci. Tech.*, **47**(9), 31, 2003.
- Rogers, L.L., Dowla, F.U. and Johnson, V.M., Optimal field-scale groundwater remediation using neural networks and the genetic algorithm, *Environ. Sci. Technol.*, **29**, 1145, 1995.
- Rothschild, W.E., Competitor analysis: the missing link in strategy, *The McKinsey Quarterly*, **3**, 42, 1979.
- Rothstein, E. and Kiyosaki, D., Development of a strategic plan: Portfolio management for public utilities, *J. AWWA*, **95**(1), 52, 2003.

Saal, D.S. and Parker, D., Productivity and price performance in the privatized water and sewerage companies of England and Wales, *Journal of Regul. Econ.*, **20**(1), 61, 2001.

Sawkins, J.W., The development of competition in the English and Welsh water and sewerage industry, *Fiscal Studies*, **22**(2), 189, 2001.

Sawkins, J.W., Yardstick competition in the English and Welsh water industry: Fiction or reality?, *Utilities Policy*, **5**(1), 27, 1995.

Seidenstat, P., *Emerging competition in water and wastewater industries*. Universities Council on Water Resources, 2000. (website: [www.ucowr.siu.edu/updates/pdf/V117\\_A2.pdf](http://www.ucowr.siu.edu/updates/pdf/V117_A2.pdf)).

Seker, D.Z., Kadbasli, S. and Rudvan, B., Risk assessment of a dam-break using GIS technology, *Wat. Sci. Technol.*, **48**(10), 89, 2003.

Sharpe, W.F., Capital asset prices: a theory of market equilibrium under conditions of risk, *J. Finance*, **19**(3), 425, 1964.

Sheridan, J.E., Organizational culture and employee retention, *Academy Manage. J.*, **35**(5), 1036, 1992.

Shimoda, T.A., Emergency preparedness and response, *J. AWWA*, **86**, 84, 1994.

Shleifer, A., A theory of yardstick competition, *Rand J. Econ.*, **16**(3), 319, 1985.

Sigler, K.J., Challenges of employee retention, *Manage. Res. News*, **22**(10), 1, 1999.

Singh, H. and Harianto, F., Management-board relationships, takeover risk, and the adoption of golden parachutes, *Academy Manage. J.*, **32**(1), 7, 1989.

Sivertun, A. and Prange, L., Non-point source critical area analysis in the Gisselö watershed using GIS, *Environ. Modelling and Software*, **18**, 887, 2003.

SNL news release, *Sandia develops program to assess water infrastructure vulnerabilities*, October 3<sup>rd</sup>, 2001. (website: <http://www.sandia.gov/media/NewsRel/NR2001/watinfr.htm>).

- Songer, A.D., Diekmann, J. and Pecsok, R.S., Risk analysis for revenue dependent infrastructure projects, *Constr. Manage. Econ.*, **15**, 377, 1997.
- Stahl, G.R. and Elliott, J.C., 'New generation' computer models for risk-based planning and management, *Water Supply (Australia)*, **17**(3/4), 289, 1999.
- Stevens, I.M. and Lloyd, R.I., *Water resources: Sustainable optimisation and security of supply, a proven example*, A paper presented to the 2004 Water sources conference and exposition, Jan 11-14th, 2004, Austin, Texas.
- Strutt, J.E., *Reliability data and sources*, Lectures in risk management for water and wastewater engineers, Cranfield University, Cranfield, UK, 2004.
- Sweeney, M.W., Geographic information systems, *Wat. Environ. Res.*, **71**(5), 551, 1999.
- Ta, C.T., A probability model for burst risk studies of water mains, *Wat. Sci. Technol.: Water Supply*, **2**(4), 29, 2001.
- Tanyimboh, T.T., Availability of water in distribution systems, *Proc. Decision Support in the Water Industry Under Conditions of Uncertainty, ACTUI2004*. 24-25<sup>th</sup> March, 2004, Exeter, UK.
- Tebutt, R.J., Guy, J.A., Gochin, R.J. and Lester, J.N., Requirements of a capital investment appraisal technique for the water industry in England and Wales, *Eur. Wat. Manage.*, **4**(3), 47, 2001.
- Teunis, P.F.M., Medema, G.J, Kruidenier, L. and Havelaar, A.H., Assessment of the risk of infection by *Cryptosporidium* or *Giardia* in drinking water from a surface water source, *Wat. Res.*, **31**(6), 1333, 1997.
- Thomas, H., Risk analysis and the formulation of acquisition / diversification strategies, *Long Range Planning* **16**(2), 28, 1983.
- Thompson, R., Secrets to keeping good employees, *Business Credit*, **102**(1), 68, 2000.

- UK Offshore Oil Operators Association (UKOOA), *Industry guidelines on a framework for risk related decision support*, UKOOA, London, 1999.
- UKWIR, *Managing microbial and chemical risks from source to tap*, Report 03/DW/02/31, UK Water Industry Research Limited, London, 2003.
- Umweltbundesamt, Water safety conference abstracts, Scholl, O. and Chorus, I., Eds., Berlin, 28-30<sup>th</sup> April 2003.
- US Department of Energy (USDOE), *Example process hazard analysis of a department of energy water chlorination process*, USDOE, Washington DC, 1993. (website: [http://tis-hq.eh.doe.gov/chem\\_safety/haz\\_analysis.html](http://tis-hq.eh.doe.gov/chem_safety/haz_analysis.html))
- US General Accounting Office (USGAO), *Water infrastructure: Comprehensive asset management has potential to help utilities better identify needs and plan future investments*, USGAO, 2004. (website: <http://www.gao.gov/new.items/d04461.pdf>).
- Verro, R., Calliera, M., Maffioli, G., Auteri, D., Sala, S., Finizio, A. and Vighi, M., GIS-based system for surface water risk assessment of agricultural chemicals. 1. Methodological approach, *Environ. Sci. Technol.*, **36**, 1532, 2002.
- Wang, J., Yuan, X., Zhang, Y. and Zhang, Y., A reliability and risk analysis system for multipurpose reservoir operation, *Environ. Fluid Mech.*, **3**, 289, 2003.
- Westerhoff, G.P, Pathways to higher performance, *J. AWWA*, **95**(7), 50-57, 2003.
- WHO, *Guidelines for drinking water quality, 3<sup>rd</sup> Edition (draft)*, WHO, 2003. (website: [http://www.who.int/water\\_sanitation\\_health/dwq/guidelines3rd/en/](http://www.who.int/water_sanitation_health/dwq/guidelines3rd/en/)).
- WHO, *Water safety plans (revised draft)*, Report publication WHO/SDE/WSH/02.09, World Health Organisation, 2002.
- Wickham, J.D. and Wade, T.G., Watershed level risk assessment of nitrogen and phosphorus export, *Computers and Electronics in Agriculture*, **37**, 15, 2002.

- Wildemann, H., Justification on strategic planning for new technologies, *Human Syst. Manage.*, **6**, 253, 1986.
- Wingle, W.L., Poeter, E.P. and McKenna, S.A., UNCERT: geostatistics, uncertainty analysis and visualization software applied to groundwater flow and contaminant transport modeling, *Computers and Geosciences*, **25**, 365, 1999.
- World Bank, *Toolkits for private participation in water and sanitation*, World Bank, 1997.  
(website: <http://www.worldbank.org/html/fpd/water/wstoolkits/index.html>).
- Ye, S. and Tiong, R.L.K., NPV-at-risk method in infrastructure project investment valuation, *J. Constr. Engg. Manage.*, **126**(3), 227, 2000.
- Zongxue, X., Jinno, K., Kawamura, A., Takesaki, S. and Ito, K., Performance risk analysis for Fukuoka water supply system, *Wat. Resources Manage.*, **12**, 13, 1998.
- Zoppou, C., Review of urban storm water models, *Environ. Modelling and Software*, **16**, 195, 2001.
- Zsidisin, G.A., Panelli, A. and Upton, R., Purchasing organization involvement in risk assessments, contingency plans, and risk management: an exploratory study, *Supply Chain Manage.*, **5**(4), 187, 2000.



## **Chapter 3**

### **Benchmarking risk management within the international water utility sector. Part I: design of a capability maturity methodology**

*Journal of risk research*, in press.

### **3. Benchmarking risk management within the international water utility sector. Part I: design of a capability maturity methodology**

B.H. MacGillivray, J.V. Sharp, J.E. Strutt, P.D. Hamilton and S.J.T. Pollard

*School of Water Sciences, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK.*

#### **ABSTRACT**

Risk management in the water utility sector is becoming increasingly explicit. However, due to the novelty and complexity of the discipline, utilities are encountering difficulties in institutionalising risk management. In response, the authors have developed a sector specific capability maturity methodology for benchmarking and improving risk management. The research, conducted in consultation with water utility practitioners, has distilled risk management into a coherent, process-based maturity framework. We identified eleven risk management processes, and eight attributes which characterise the extent to which these processes are repeatable, defined, controlled and optimising. Implementation of the model should enable utilities to more effectively employ their portfolio of risk management techniques for optimal, credible and defensible decision making.

**KEYWORDS:** maturity model, risk, analysis, management, water, sector

### 3.1 INTRODUCTION

Financial restrictions, regulatory pressures and sectoral restructuring are encouraging water utilities to move from technically inclined, risk-averse management approaches towards more commercial, business-oriented practices (MacGillivray *et al.*, 2006a). Many within the industry, spurred on by developments in international regulation and guidance, are promoting a business-wide approach to risk management as a means to ease and exploit this transition (*e.g.* Lifton and Smeaton, 2003; Miller, 2005; Lloyd and Abell, 2005). Whilst the sector has made good progress towards setting its stated goal (AWWA *et al.*, 2001) of providing wholesome, safe drinking water that has the trust of customers within a risk-based context (Pollard *et al.*, 2004), there remain barriers to the implementation of risk management. These can be categorised as business-related, the challenge of embedding risk management within organisational cultures and decision-making processes (*e.g.* Pollard *et al.*, 2004; Howard and Lourens, 2005); and technical, relating to the selection and application of risk analysis tools (*e.g.* MacGillivray *et al.*, 2006a). Our research addresses the former; the premise being that the tools and techniques for risk analysis are sufficiently developed, yet lacking is the organisational capacity to employ these methodologies for more optimal, credible, and defensible decision-making.

The authors propose that the dominant cause of this capacity deficiency is the difficulty inherent in institutionalising mature risk management processes. This is perhaps because the sector's approach to implementation has centred on adherence to risk management frameworks. These are essentially standards describing the fundamentals of the prior art and the interrelationships between its core elements (*e.g.* Hamilton *et al.*, 2006). Here, we are not concerned with frameworks for drinking water

quality management (*e.g.* NHMRC, 2001; WHO, 2002), widely accepted and applied within the sector as a means of placing public health protection within a risk-based context, but with those corporate-level frameworks intended to foster an integrated approach to risk management (*e.g.* COSO, 2004; Canadian Standards Association, 1997; Council of Standards of Australia, 1999). These latter frameworks have been instrumental in transforming the discipline from the preserve of engineering and finance functions towards a business-wide paradigm. However, a number of criticisms may be offered. Critically, although they typically embrace the concept that risk management is comprised of processes, their treatment of the discipline focuses on organisational structures and procedures. They often fail to address how the core tasks and activities of risk management may be defined and controlled as processes. Furthermore, although they have evolved beyond prescribing static requirements towards embracing the concept of continuous improvement, too often this is addressed as an afterthought rather than as an explicit component of these frameworks. As such, the water sector has lacked methodologies on which to base risk management improvement initiatives, suggesting that enhancements may often be isolated and that their associated benefits can neither be replicated nor extended throughout organisations. Finally, whilst typically generic in nature, these frameworks are often representative of the large, financially-oriented firms where their application predominates.

To address these shortcomings, the authors have developed a sector-specific risk management capability maturity model (RM-CMM), a vehicle for benchmarking, implementing and improving the *processes* that comprise risk management. In this paper we review the field of capability maturity modelling. We then describe the research methodology adopted in the design of our model, before discussing its

development, structure and practical definition. A companion manuscript (MacGillivray *et al.*, 2006b) describes the model's application in a benchmarking of eight utilities within the international water sector.

### **3.2 RISK MANAGEMENT IN THE WATER SECTOR**

The water industry is undergoing a significant shift in its approach to risk management to one that is increasingly explicit and better integrated with other business processes. Risk management strategies and techniques traditionally applied to occupational health and safety and public health protection are now seeing broader application for asset management (Booth and Rogers, 2001; Lifton and Smeaton, 2003), watershed protection (IMPRESS Management, 2002; NHMRC, 2001; WHO, 2003) and network operation (Stahl and Elliott, 1999; Stevens and Lloyd, 2004). Beyond this operational context, utility managers are increasingly concerned with managing the risks inherent to corporate level decision making. Critical issues include decisions on outsourcing asset maintenance; billing and monitoring; the management of change; staff retention; the long-term viability of investment decisions; and the management of external interfaces with regulators and “competing” utilities (MacGillivray *et al.*, 2006a). Pollard *et al.* (2004) report that the organisational hierarchy that exists even within “flat” utilities requires that these risks are actively managed at strategic, programme and operational levels (Figure 3.1). Typically, there are split accountabilities for these risks such that the chief financial officer / financial director and Board have overall responsibility, supported by an internal audit or control function for the management of strategic risks; executive and senior management address programme level risks (*e.g.* asset management, maintenance planning); and

operational (*e.g.* site) managers bear responsibility for operational risks (*e.g.* treatment plant performance).



Figure 3.1 The risk hierarchy (adapted from Prime Minister's Strategy Unit, 2002)

Water utilities must employ a range of techniques to evaluate and consider these aspects alongside one another, devising business and operating strategies that prioritise resources on the basis of risk. Here tensions may arise from the explicit risk trade-offs inherent to running a commercial water utility, such that the industry's overarching goal of public health protection is placed in conflict with narrower financial interests. Critically in this regard, the transition to an explicit risk management philosophy within the sector is reflected in recent revisions to the World Health Organisation's (WHO, 2003) Guidelines for Drinking Water Quality. It is this overall context that drives the need for an increased capability to manage risk.

### 3.3 OVERVIEW OF CAPABILITY MATURITY MODELLING

A capability maturity model (CMM) is a simplified representation of an organisational discipline (*e.g.* software engineering, risk management) that distils industry practices into a coherent, process-based framework. These models are constructed according to maturity levels, from learner to best practice, which are characterised by the extent to which the processes are repeatable, defined, controlled and optimising (although the terminology varies). The field's origins can be traced to the "quality revolution" of the 1970s (*e.g.* Crosby, 1979) and to the field of management performance measurement. The CMM methodology was first articulated by the Software Engineering Institute (SEI), whose seminal model (Paulk *et al.*, 1993) explored the design capability of software development organisations. The capability maturity modelling concept is finding increasing acceptance in academia and industry. Notable applications include software and systems engineering (Paulk *et al.*, 1993; Software Engineering Institute, 2002a), workforce development and management (Software Engineering Institute, 2002b), offshore design safety (Sharp *et al.*, 2002), reliability engineering (Strutt, 2003), and construction (Sarshar *et al.*, 2000). Capability models enable organisations to establish their current level of process maturity and identify the steps necessary to progress to a higher level, building on their strengths and improving on their weaknesses. They may be used for benchmarking purposes, enabling organisations to compare themselves against other companies in their sector and beyond. This may be done at the corporate, functional or business unit level. Similarly, they may be used to assess the capabilities of key suppliers and partners.

Recently, a selection of risk management capability maturity models (*e.g.* IACCM, 2003; RMRDP, 2002) have been developed. We believe that these models insufficiently reflect the basic principles of capability maturity modelling. The most

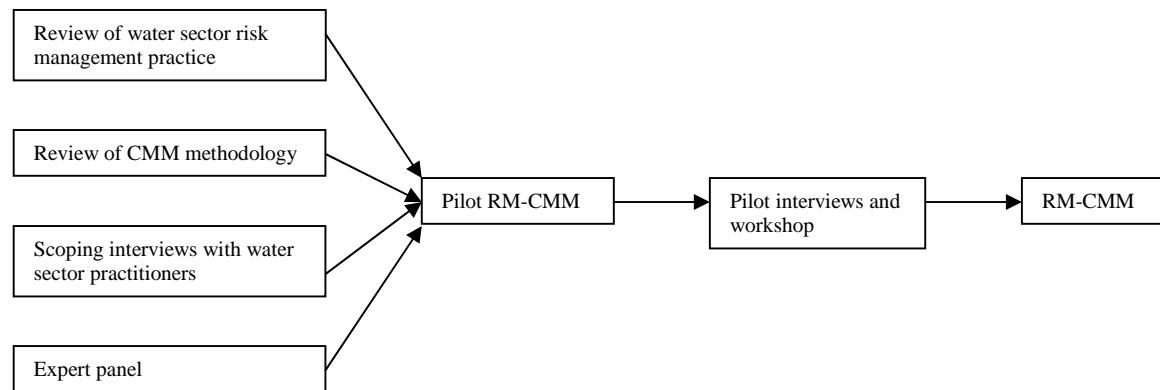
critical point is that they are not explicitly process-centred. Furthermore, they do not closely reflect the clear distinctions between maturity levels as set out by the SEI and developed further by subsequent researchers, instead characterising risk management maturity on a graded scale of good-to-bad practice. Of course, the CMM approach is not the sole means for improving risk management, and these critiqued models have found support within industry. Thus, we do not imply that the IACCM and RMRDP models are without value, indeed their simplicity and modest time demands may prove attractive to many organisations. However, our development of the RM-CMM is not an extension of these models, but rather a novel application of capability maturity modelling to risk management in the water utility sector.

### **3.4 RATIONALE OF RESEARCH METHODOLOGY**

The tailoring of existing maturity models to a new discipline and sector is not a simple mapping exercise (Sarshar *et al.*, 2000). Here, the core principles of maturity modelling were abstracted and recreated in a form specific to risk management within the water utility sector. Design of the research methodology (Figure 3.2) was informed by the authors' previous experience in maturity modelling within similar utility sectors and drew upon the CMM literature, particularly Sarshar *et al.* (2000). The methodology is designated "testing-out research" (Starke, 1995). Here, the aim is to explore the limits of previously proposed generalisations and to specify, modify or clarify their content (Starke, 1995). This form of research must be conducted under real world conditions, where the kind of control present in laboratory conditions is neither feasible nor justifiable. The lead author, in concert with a steering group of four expert practitioners, designed the model in collaboration with partner water utilities. Key development inputs included literature reviews of risk management and capability



maturity modelling, structured scoping interviews with eleven water utility professionals from five countries, prior knowledge of maturity modelling in similar utility sectors, and past experience within the water sector.



*Figure 3.2 Research methodology for design of RM-CMM*

Given the qualitative nature of the research, verification and validation mechanisms were adopted. The purpose of the expert steering group was to verify that the model accurately codified risk management in line with the principles of maturity modelling. Furthermore, feedback was sought from three water utilities to ensure that the model reflected the practical realities of managing risk in the sector. This took the form of one workshop and two interviews conducted after sharing the pilot model. This piloting sought to validate the model's architecture (*e.g.* are the right processes included, are they adequately characterised, are the attributes relevant, *etc.*) and to clarify its terminology. The model remains under research. The authors have recently tested the model through a benchmarking exercise and two industrial case studies. These applications will provide data of intrinsic value to both the industrial and academic communities, and will serve as a means for evolving the model towards a state compatible with industrial ownership.

## **3.5 RISK MANAGEMENT CAPABILITY MATURITY MODEL**

### **3.5.1 Model overview**

The RM-CMM is designed to measure and improve risk management processes. Hence it is process-based rather than focussing on specific outcomes or deliverables. It is increasingly accepted that continuous process improvement is based on a series of small, evolutionary steps, rather than revolutionary measures (Paulk *et al.*, 1993). The RM-CMM organises these steps within evolutionary plateaus, or maturity levels, which lay successive foundations for continual process improvement. Figure 3.3 illustrates the model architecture.

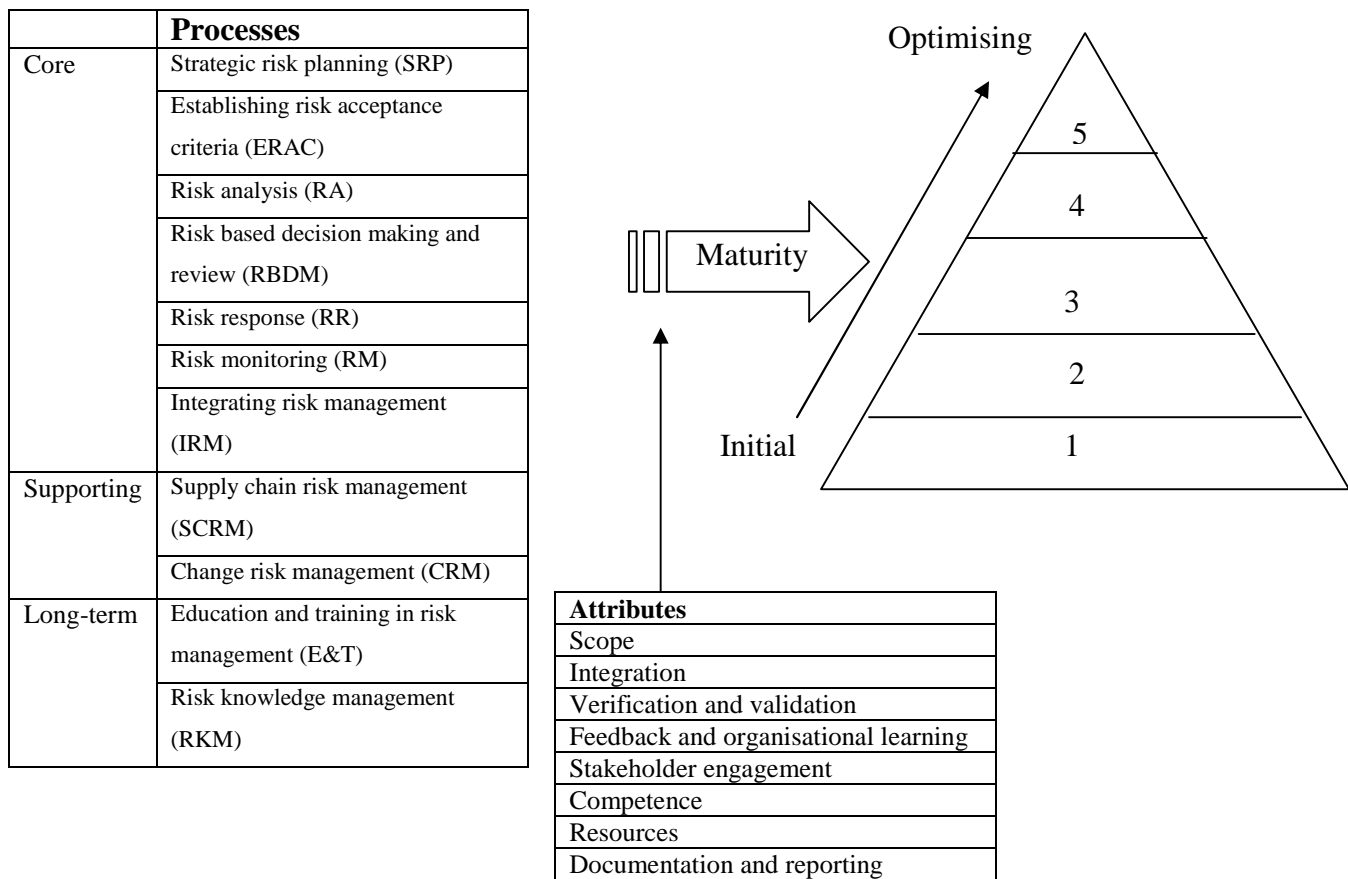


Figure 3.3 Overview of the RM-CMM (after Strutt et al., 2005)

### 3.5.2 Risk management maturity levels

Setting sensible goals for process improvement requires an understanding of the difference between mature and immature organisations (Paulk *et al.*, 1993). We have developed descriptions of five maturity levels that characterise organisational behaviours in both risk management overall and for each constituent process. These levels were derived by abstraction from existing CMMs describing different disciplines (Paulk *et al.*, 1993, Software Engineering Institute, 2002a / 2002b; Sharp *et al.*, 2002; Strutt, 2003; Sarshar *et al.*, 2000), contextualisation of which was supported by reviews

(MacGillivray *et al.*, 2006a, Pollard *et al.*, 2004; Hamilton *et al.*, 2006) and scoping interviews. It is important to understand what these levels represent in practice, as they are central to assessing the maturity of an organisation. Below we describe the overarching maturity hierarchy. Note that at a given level of maturity, the positive characteristics from preceding levels remain.

#### *Level 1 – Initial*

L1 organisations practice a largely *ad hoc* approach to risk management, possessing no formal risk management processes and often exhibiting limited knowledge of relevant standards or regulatory guidelines. Thus, they are largely reliant upon individual heroics for the active management of risk. L1 organisations are likely to be small water providers based in isolated rural areas where resource constraints prevent the staffing of utilities with dedicated water professionals.

#### *Level 2 – The repeatable organisation*

L2 organisations understand that they have risks that require formal management, and have established basic risk management processes for this purpose. However, these processes are ill-defined and poorly institutionalised, limiting their capacity to influence organisational actions. Furthermore, the scope of risk management is narrow, generally restricted to addressing mission-critical risks and areas required by regulation (*e.g.* occupational health and safety, water quality). Hence, at L2 the active management of risk tends to be influenced less by explicit risk management processes than by the repetition of activities and practices that have worked for the organisation before. In a technical context, this places a premium on accepted standards of performance and codes of practice (*e.g.* engineering standards; accepted best practice)

which, if adhered to, provide high degrees of control. This is a pragmatic approach in familiar and well-characterised situations where uncertainties and system vulnerabilities are well understood.

However, this mind set is vulnerable; when mistakes are made they do not learn – failures are repeated as well as success. Whilst L2 organisations often have a reputation for achieving reliable, cost-effective water supply, they are very vulnerable to change, whether organisational, technical or commercial. This, allied with deficient organisational learning, is a common theme across many recent water quality related outbreaks in affluent nations (Hrudey and Hrudey, 2004).

### *Level 3 – The defined organisation*

The key characteristic of the L3 organisation is the definition and implementation of risk management processes across core business areas. This is achieved through establishing process “enablers”. Enablers include the policies, procedures and frameworks that guide risk management activities (*i.e.* who does what and when), and the provision of adequate training, funding and tools in support of these activities. Several scoping interviewees described their recent definition of risk management processes. Drivers for this included: a desire to balance the roles of “*brainstorming*” and “*judgement*” in risk management with more methodological, standardised and objective approaches; the need to “*institutionalise*” risk management; and obligations to exhibit good corporate governance to shareholders and regulators. In essence, definition seeks to formalise existing implicit approaches to risk management. This is most notably illustrated in the sector’s increasing adoption of the “water safety plan” approach, which codifies good practice in the identification, assessment and control of hazards to water quality.

Definition creates an environment in which risks are methodically identified, analysed, responded to and monitored. In a technical context, L3 maturity is required where systems are characterised by greater levels of uncertainty and the potential to deviate from routine operation. This is increasingly common, as the trend towards utility self-sufficiency means that management can no longer seek to “over-engineer” facilities with the presumption of screening out technical risk (MacGillivray *et al.*, 2006a). Here, optimisation of plant, network and process design and operation requires a capacity to assess, understand and respond to what is driving the risk from or to the plant, process or network. However, at L3 the efficiency and quality of risk management processes are variable, stemming from limitations in their verification, validation and feedback mechanisms (the “evaluators”). These limitations restrict organisations’ ability to track and therefore control their risk management processes, which are thus characterised as “open loop.”

#### *Level 4 – The controlled organisation*

The key characteristic of the L4 organisation is a structure which not only enables their risk management processes but also evaluates and ensures their effective execution (closing the open loop of L3). The scope of these processes reach throughout the organisational hierarchy and across all functional boundaries. Evaluating refers to the implementation of verification and validation mechanisms to provide feedback on the status, quality, efficiency and expediency of risk management (*e.g.* ensuring procedural compliance, quality assurance, benchmarking *etc.*). The value of systematic verification was emphasised by one scoping interviewee, who noted that previously, free access to the corporate risk register was combined with an absence of peer review of risk assessments. This had allowed staff to “*over-estimate their own pet concerns*”

and to assign risk reduction actions via the register to other staff “*unbeknownst to them.*” These deficiencies were remedied through the introduction of formal procedures governing access and use of the register and the establishment of challenge procedures to provide quality assurance of risk assessments.

However, the L4 organisation tends to be hardwired and lacking in internal flexibility. This is reflected in that although a learning ethos exists, the manner in which L4 organisations learn is defined as single-loop (Argyris and Schön, 1978). This refers to learning where the emphasis is on improving techniques for executing processes, within the constraints of established process strategies. In other words, learning is directed towards making existing process strategies more effective. Single-loop learning tends to be present in organisations where goals, values, frameworks and strategies are taken for granted. This lack of capacity for deeper learning hampers their ability to make informed risk management decisions in rapidly changing and uncertain contexts. Additionally, L4 organisations are often unable to grasp the soft issues associated with human and organisational behaviour. This is a core weakness.

#### *Level 5 – The optimised organisation*

The key characteristics of the L5 organisation are its adaptability, flexibility and attention to human and organisational behaviour. The L5 mindset is one of deeper understanding, of an adaptive, learning organisation aiming to be best in class and always improving in the long term. Central to this is their capacity for both double (Argyris and Schön, 1978) and triple-loop learning. Double-loop learning involves questioning the norms, values and assumptions underlying the design of risk management processes, and is typically found in organisations where risk information is continually developed through a broad range of channels (*e.g.* experience, R+D,

benchmarking, analysis, simulation, *etc.*). This information is openly shared, communicated and used to publicly test assumptions and beliefs. We define triple-loop learning as questioning and revising *broader* organisational structures and practices to optimise the capability of risk management processes (*e.g.* changing incentive structures to encourage knowledge sharing and collaboration between traditionally competing departments, *etc.*). The core enablers of triple-loop learning are an understanding of how human and organisational behaviour influence process capability, and organisational flexibility. L5 organisations are also actively engaged in the innovation, development and piloting of new ideas and technologies to optimise risk management throughout the organisation. From these efforts, best practices are identified and transferred throughout the organisation. L5 processes are extremely efficient and there is a strong risk management culture, because of the long term investments made in developing processes and in training staff to participate in them.

### **3.5.3 Risk management processes**

Our research identified 11 risk management processes (Figure 3.3). Strategic risk planning centres on developing the corporate framework for risk management. Hamilton *et al.* (2006) describe how these frameworks can introduce greater rigour, consistency and standardisation to the discipline. The researchers further note their potential for adaptation to suit user needs. This final point is crucial, as our scoping interviews suggested that risk management frameworks were not simply shoehorned within utilities. Establishing risk acceptance criteria is perhaps the least understood aspect of risk management. Whilst our scoping interviews implied that internally developed criteria for evaluating the significance of risks were commonplace (risk ranking techniques), prior experience in similar sectors suggests that tolerability criteria



are less prevalent and often externally imposed (*e.g.* ALARP criteria for dam safety). We address both of these aspects in the context of an internal process, as we propose that both are required to develop responses to risks in a consistent, objective and defensible manner. Risk analysis involves the identification and assessment of risk. We have previously reviewed (MacGillivray *et al.*, 2006a) its application in the sector at operational, programme and strategic levels. Here, our focus is not on the methodologies *per se*, but on their application. Supported by initiation criteria and formal procedures, using personnel with appropriate skills, experience, and resources, risk analysis techniques can provide utilities with benefits ranging from an improved understanding of treatment reliability to an explicit appreciation of project financial risks. Applied inappropriately, whether due to ill-defined procedures or deficient institutional capacities, risk analysis is not a subset of risk management but its panacea.

Our inclusion of risk based decision making examines how organisations identify and evaluate solutions to manage individual risks. Clearly, risk analysis is of little use if the outputs are intended to placate regulators rather than inform decision making. Furthermore, one interviewee noted that an absence of criteria to evaluate decisions restricts objectivity (*i.e.* opinions dominate in decision making), and we further propose that it prevents the *ex ante* validation of decisions taken. Risk response is the implementation of risk based decisions. Although an argument may be forwarded that this lies outside the scope of our model as implementation processes are unlikely to be unique to risk based decisions (*i.e.* there will exist models for implementing capital or operational solutions, not models for implementing risk based decisions *per se*), it is included as decisions left unimplemented are hollow gestures. The model's treatment of these latter two processes is particularly relevant as risk management frameworks

have historically focussed on the identification and assessment of risk, effectively marginalising guidance on their practical management.

Risk monitoring involves tracking the evolution of identified risks, and is included in recognition of their dynamic nature. Integration is the current focus of the risk management community. From the literature and our scoping interviews, two aspects were identified: embedding risk management within organisations; and enterprise risk management, where risks are managed with reference to the organisation as a whole, rather than in isolation or in functional silos. Illustrating the latter aspect, Lam (2003) contends that the traditional, fragmented approach, where companies manage risk in organisational “silos,” is ineffective because risks are highly interdependent and cannot be segmented and managed by entirely independent units. As one scoping interviewee stated, *“one of the challenges is...when [staff] are all using discrete [risk] tools which may have different terminologies, scoring systems and ways of presenting the outputs, my role is [to ensure] is a shared understanding and an ability to interpret the results of tools in a business-wide context.”* We introduce a third element of integration by abstraction from the systems engineering CMM (Software Engineering Institute, 2002a): integration of the risk management process interfaces (*e.g.* between risk analysis and risk based decision making).

Supply chain risk management addresses two components: the sourcing of components required to develop a product (*e.g.* chemicals) and the management of services provided by organisations throughout the supply chain. The latter element is of particular significance to the sector owing to the increasing utilisation of outsourcing. However, one pilot interviewee challenged the inclusion of product risk, arguing it is effectively managed through adhering to quality accredited suppliers. However, it was maintained as the authors’ prior research in the oil and gas industry

indicates that many organisational failures can be traced back to minor and apparently insignificant services *and* components sourced from suppliers. Change risk management is abstracted from the reliability engineering CMM (Strutt, 2003), and involves identifying and managing the risk implications of organisational (*e.g.* business process re-engineering) and technical change. We justify its inclusion as a range of factors (*e.g.* globalisation, regulatory and market restructuring, novel technologies) are serving to fundamentally alter the context in which water utilities operate.

Education and training – the development and maintenance of the competencies required to manage risk – is included as our scoping interviews suggested that risk management simply does not fit well into traditional company skill sets. Risk knowledge management may be considered as the collection, storage and access of the data underpinning *and* accumulated from the broader risk management processes, *i.e.* the input and output data. The latter aspect is drawn from our scoping interviews, which discussed various risk communication and reporting protocols and the use of databases for storing risk assessment outputs. We include the former aspect on the premise that in the absence of pre-defined data requirements, risk data collection is likely to be *ad hoc* and largely restricted to the needs of business as usual.

There was some discussion amongst the authors as to whether research and development in risk management merited inclusion as a process. However, the pilot interviewees were resistant to this, with one considering it “*not directly relevant,*” another stating that the tools and techniques of the discipline are sufficiently developed, rendering it a secondary issue. Although their experience within the sector confers validity to their arguments, they may nonetheless be considered somewhat short-sighted. A compromise was found through considering research and development not

as a distinct process but as a defining characteristic of mature risk analysis, risk monitoring and risk knowledge management.

#### **3.5.4 Attributes**

We have identified eight attributes (Figure 3.3) which characterise process maturity. Scope is included as we propose maturity to be correlated with the scope of implementation (*i.e.* a well defined process restricted to engineering does not constitute high *organisational* maturity). Here, integration refers to the existence of initiation criteria and procedures for process execution. Although its treatment as both process and attribute constitutes double-coverage, this was felt appropriate given its prominence in the practitioner and academic literature. Verification mechanisms address procedural compliance and quality assurance of process execution, whilst validation determines whether the process itself is correct. Together, these mechanisms create process control, and provide the primary feedback inputs for organisational learning. The inclusion of organisational learning builds on prior research conducted by the authors in offshore design and safety (Sharp *et al.*, 2002) and reliability engineering (Strutt, 2003), although the underlying principle is drawn from ideas from the *theory of action* and the concept of *single and double loop learning* (Argyris and Schön, 1978). It is best illustrated by paraphrasing Dalrymple (2006), who notes that experience rarely provides lessons directly, but instead requires interpretation through the filter of preconceived theories, values and prejudices. Where these are impregnable, facts are weak things. The capacity to use experience to question and revise these preconceived notions constitutes double loop learning.

We include stakeholder engagement in deference to its prominent representation within risk management frameworks. However, our scoping interviews revealed a

disconnect between academic and industrial perceptions of the appropriate role of *external* stakeholders within risk management, with the latter generally more resistant to their involvement. Explanations to support this stance included the need to preserve commercial confidentiality, concerns over possible conflicting objectives between stakeholders and organisations, and fears that stakeholder representatives may lack specialist knowledge and hence “slow down” risk management. One interviewee described that whilst they developed emergency response plans for water quality incidents in conjunction with the public health regulator, they were resistant to bringing concerns about drinking water safety to the public domain owing to fears of press sensationalism. Another noted that they “*don’t so much consult stakeholders as expose the [risk] governance process to them [e.g. regulators or shareholder representatives] – they form an opinion of [its] adequacy or otherwise.*” That said, there was agreement on the importance of engaging internal stakeholders, on the premise that through engaging other departments, functions, and business units, organisations may avoid the silo mentality which has historically pervaded risk management, thus creating synergies through shared knowledge and expertise, the co-ordination of related work, *etc.* For example, one interviewee described the value of using “networks of participants” to provide input to capital investment decisions. Here, stakeholders have the opportunity to critique proposed options (*e.g.* for constructing a new treatment plant, staff involved in the design, operation and maintenance, costing, *etc.*). The inclusion of competence as an attribute recognises that risk management processes will prove ineffective if their execution lies outwith technical or managerial skill sets. Indeed, many of our interviewees discussed their desire to maintain in-house competencies to manage risk in preference to relying on consultants. Resourcing encompasses the use of monetary, human and technical (*e.g.* analysis methodologies) resources. As one interviewee

noted, “*funding, manpower, and specialists*” are particular constraints to effective risk management in smaller utilities. Process documentation and reporting is the final attribute. Notably, Deloach (2000) reflects that there is often a lack of organisational consistency in reporting formats for risk management, which he perceives as a barrier to “enterprise wide” risk management. More practically, one interviewee argued that in what remains a conservative industry, if risk information is not properly documented and accessible then staff will use this “*as an excuse to ignore risk management.*”

Consideration was afforded to the inclusion of culture as an attribute, given its extensive discussion in the literature and our scoping interviews. However, this was rejected for two reasons. Firstly, culture is a notoriously difficult concept to define, let alone measure. Secondly, overt attempts to change culture, which in this context may be thought of as the values and beliefs held by employees that guide their actions in managing risk, are not only Orwellian, but likely to be ineffectual. Ineffectual, as the authors consider that employee values and beliefs are not intrinsic properties, but rather are conditioned by the environment within which they manage risk (*i.e.* the risk management processes). Thus, culture change is a consequence of process improvement, not a prerequisite.

### **3.5.5 Internal structure of process assessment framework**

At the framework’s core are a series of guideline statements which describe how each process is conducted at each level of maturity with reference to the attributes. In support of this are process descriptions which also outline the practices required to satisfy the process goals. As the guideline statements are largely devolved from the principles contained in the overarching maturity hierarchy, we do not dwell on their

detail. However, by way of illustration, Table 3.1 depicts the assessment framework at levels 3 and 4 for risk analysis.

### **3.5.6 Internal structure of process improvement framework**

This framework outlines the operational steps that utilities may take in order to implement their process improvement priorities as identified from application of the assessment framework. It was developed after receiving feedback that the assessment framework was at a layer of abstraction which restricted its ability to inform the development of improvement plans. The steps are grouped by process and maturity level, and are categorised according to actions to: perform the practices that satisfy the process goals (*i.e.* do the process); establish and define the process (*i.e.* structure the process); and enable and evaluate the process. Table 3.2 depicts the process improvement framework relating to progression from L3 to L4 in risk analysis.

Table 3.1 L3 and L4 process maturity in risk analysis

Attribute	Attribute at level 3: Risk analysis	Attribute at level 4: Risk analysis
Scope	A defined, documented process is in place containing criteria, methods and guidelines for the identification, assessment and evaluation (with respect to acceptance criteria) of a broad range of risks across core business areas, guided by a risk register. The organisation is conversant with and goes beyond the regulatory requirements for risk analysis.	A controlled process is in place containing detailed criteria, methods and guidelines to manage the identification, assessment, evaluation (with respect to acceptance criteria), establishment of causality and linking (common cause and dependent) of risks at all levels of the company and across all functional boundaries of the business, guided by a company-specific risk register.
Integration	Procedures are in place to initiate risk analysis processes.	Risk analysis is initiated automatically as part of core business processes ( <i>e.g.</i> periodic business risk assessments).
Verification and Validation	Basic mechanisms are in place to verify that risk analysis is performed as required, largely reliant on lagging indicators. The expertise for validation is generally lacking.	Verification and validation systems are in place to verify the efficiency of risk analysis activities and to validate their expediency ( <i>e.g.</i> the organisation tracks that tools and techniques are being used correctly and that the correct tools and techniques are being used).
Feedback and Organisational Learning	The risk analysis tool suite is reviewed and modified on an event-driven basis.	Feedback is actively used to improve the execution of risk analysis ( <i>e.g.</i> gaps identified and risk analysis tools and techniques improved in response).
Stakeholder Engagement	Risk analysis processes generally reside within the responsible unit, with limited cross-functional or external consultation.	Risk analysis processes generally reside within affected disciplines, and stakeholders work together to define and implement an integrated approach to risk analysis, capitalising on synergies and collective knowledge.
Competence	Detailed knowledge of risk analysis resides only within the responsible unit.	Most involved staff exhibit a good level of competence in the selection and application of risk analysis tools and techniques, and have access to support from internal or external expert risk practitioners.
Resources	Adequate resources are provided in support of risk analysis, with both qualitative and quantitative tools and techniques available.	Sufficient resources are provided in support of risk analysis, a portion of which is made available for R + D for risk assessment. A broad range of qualitative and quantitative tools and techniques are available and applied, including methodologies for aggregating and comparing risks.
Documentation and Reporting	Risk analysis outputs are compiled and disseminated in a format that supports decision making.	Risk analysis outputs are compiled and disseminated in a clear, concise and actionable format that supports real-time decision making, and their reporting is co-ordinated with other risk reporting mechanisms ( <i>e.g.</i> risk status updates).



Table 3.2 Steps for progressing between levels 3 and 4 in risk analysis

Domain	Improvement step
Process enablement	<ul style="list-style-type: none"> <li>• Identify and allocate sufficient resources in support of risk analysis, updating them as necessary to reflect changing needs.</li> <li>• Identify key internal and external stakeholders (<i>e.g.</i> representatives of different functions or divisions of the business) and define their potential contributions (<i>e.g.</i> synergies from collective knowledge and advice, <i>etc.</i>) and requirements (<i>e.g.</i> involvement in assessing cross business impacts).</li> <li>• Establish mechanisms to involve identified stakeholders (<i>e.g.</i> cross-functional working groups).</li> </ul>
Process evaluation	<ul style="list-style-type: none"> <li>• Establish formal mechanisms (<i>e.g.</i> periodic reviews, audits, status reports, milestones, <i>etc.</i>) to verify that risk analysis adheres to its formal description, policies, and procedures, <b>and</b> is being performed efficiently.</li> <li>• Designate ‘ownership’ of verification to a responsible individual(s). The individual(s) is responsible for ensuring verification is performed, reviewing the findings, and recommending corrective action where necessary. Stakeholders should be involved as appropriate (<i>e.g.</i> staff not conforming to established procedures).</li> <li>• Define and collect measures to support verification of adherence <b>and</b> efficiency (<i>e.g.</i> task and activity checklists, cost of analyses, timeliness of analyses, <i>etc.</i>).</li> <li>• Establish formal mechanisms (<i>e.g.</i> periodic reviews, external advice, status reports, <i>etc.</i>) to validate the process of risk analysis. Candidates for validation include the methods and procedures for risk analysis (<i>e.g.</i> the tools and techniques applied) and the risk analysis outputs (<i>e.g.</i> do the analysis outputs inform decision making).</li> <li>• Designate ‘ownership’ of validation to a responsible individual(s). The individual(s) is responsible for ensuring validation is performed, reviewing the findings, and recommending corrective action where necessary. Stakeholders should be involved as appropriate (<i>e.g.</i> where changes to the tool suite or procedures are recommended, the process ‘owners’ would be involved).</li> <li>• Define and collect measures to support validation of risk analysis (<i>e.g.</i> internal assessments by decision makers of the value of risk analysis outputs, formal validation of risk analysis methodologies, <i>etc.</i>).</li> <li>• Establish mechanisms to compare in-house risk analysis with industry practice, making changes where appropriate (<i>e.g.</i> benchmarking initiatives, strategic information exchange, <i>etc.</i>).</li> </ul>

### 3.6 ILLUSTRATING THE RM-CMM

We have discussed the overarching maturity hierarchy, and introduced the risk management processes and those attributes which define their maturity. Here, we build on these foundations by illustrating what the model practically means within various organisational functions. Consider first risk analysis. The distinction between the initial and the repeatable level is that in the latter, the application of basic techniques by experienced staff creates a degree of stability. In process engineering, this may entail

the execution of hazard and operability studies (HAZOP) to identify and assess the potential for designs to deviate from specifications, whilst at L1 this potential would be addressed implicitly if at all. At L3, initiation points for analyses are defined (*e.g.* at the concept design stage), and formalised procedures detail the tasks, activities, roles and responsibilities for execution, creating a basic infrastructure that maintains the process beyond the tenure of experienced staff (who are depended upon at L2). At L4, verification extends beyond ensuring procedural compliance (L3) to address quality assurance of analyses, for example through technical peer reviews. Questions addressed may include: did the analysts work their way through the HAZOP study systematically, or did they overlook important scenarios, components and process flows; were all stages and operating modes of the process considered (*e.g.* startup, shutdown and transitioning to partial operation); and was adequate time spent on the analysis.

We now consider risk based decision making in the context of occupational health and safety. Here, the initiating point is the receipt of risk analysis outputs (*e.g.* job safety risk analyses, plant hazard evaluations, *etc.*). These outputs, together perhaps with a predefined hierarchy of health and safety risk controls (*e.g.* engineering; administrative; and protective personal equipment) serve as the framework for identifying solutions to manage individual risks. Once identified, these solutions may be evaluated with reference to criteria including: cost, feasibility and risk reduction achieved. In contrast, at L2 maturity, decisions to manage risks are taken in isolation of a clearly defined framework and perhaps even in the absence of risk analysis outputs, and are hence focussed upon replicating historic good practice. Thus, health and safety is under pressure when circumstances change, whether through the introduction of new technical processes or modifications to work practices.

Finally, consider education and training in risk management. Here, a repeatable process may focus on workshops, where the concepts of risk management are introduced to staff on an as required basis, supported by on the job training. Further, there is an absence of clear criteria dictating when and to whom training should be delivered. An additional weakness is the inability to define the required competencies for effective risk management. Without these, on what basis are training programmes designed, how are the appropriate means of delivery selected (*e.g.* classroom training, workshop, on the job, *etc.*), and how can the efficacy of training be evaluated? These weaknesses are remedied at the defined state.

### **3.7 MODEL APPLICATION**

The RM-CMM has a range of potential applications, including:

- Self-assessment or external evaluation (voluntary or audit) of risk management maturity at the corporate, business unit, functional and project level;
- Use by management and technical staff as a reference model for designing and implementing a risk management improvement initiative;
- Evaluation of potential suppliers' / contractors' / partners' risk management maturity prior to selection.

The model can be implemented either as a self-assessment procedure or by external audit using independent verification authorities. It is felt that the latter, in most cases, gives greater credence to the results of an assessment. However, internal assessments are often more useful when using the model as an improvement tool rather than as a measurement tool. The companion paper (MacGillivray *et al.*, 2006b) describes in detail the self-assessment methodology.

### **3.8 CONCLUSIONS**

We have described a risk management capability maturity model, a vehicle for benchmarking and improving risk management within the water sector. We have addressed the model's theoretical and empirical foundations, overviewed its architecture, and illustrated its practical definition. Implementation of the model should assist utilities to more effectively employ their portfolio of risk analysis and management techniques for optimal, credible, defensible decision making. A companion paper describes its application to benchmark eight utilities within the international water sector.

#### *Acknowledgements*

This work has been funded by the American Water Works Association Research Foundation (AWWARF project RFP2939) and a consortium of international water utility companies. The comments and views herein are the authors' alone. BM is co-funded on a UK Engineering and Physical Sciences Research Council (EPSRC) Doctoral training account.

### **3.9 REFERENCES**

- Argyris, C. and Schön, D., *Organizational learning: A theory of action perspective*, Reading, Mass: Addison Wesley, 1978.
- AWWA, EUREAU, WSAA and DVGW, *Bonn Workshop 2001 – Key principles in establishing a framework for assuring the quality of drinking water: a summary*, AWWA, Denver, CO., 2001.

- Booth, R. and Rogers, J., Using GIS technology to manage infrastructure capital assets, *J. AWWA*, **93**(11): 62, 2001.
- Canadian Standards Association, *Risk management: guidelines for decision makers*. CAN/CSA-Q850-97, 1997.
- COSO, *Enterprise risk management framework - Executive Summary*, 2004 (website: [www.otpp.com](http://www.otpp.com)).
- Council of Standards of Australia, *Australian/New Zealand risk management standard No.4360: 1999*, 1999.
- Crosby, P. B., *Quality is Free*, New York, McGraw-Hill, 1979.
- Dalrymple, T., Less liberté means less égalité, *City Journal*, Winter 2006.
- Deloach, J.W., *Enterprise-wide risk management - strategies for linking risk and opportunity*, Pearson Education Limited, London, 2000.
- Hamilton, P.D., Pollard, S.J.T., Hrudey, S.E. and MacGillivray, B.H, Risk management frameworks for the water sector – a review, *at review*, 2006.
- Howard, J. and Lourens, A., Engaging operational staff in risk management, *Proc. of Risk analysis strategies for better and more credible decision making*, 6-8<sup>th</sup> April, 2005, Banff, Canada.
- Hrudey, S.E. and Hrudey E.J., *Safe drinking water: Lessons from recent outbreaks in affluent nations*, IWA Publishing, 2004.
- IACCM, *Organisational maturity in risk management: The IACCM business risk management maturity model (BRM3)*, 2003 (website: <http://www.risk-doctor.com/pdf-files/brm1202.pdf>).
- IMPRESS Management, *Guidance for the analysis of pressures and impacts in accordance with the water framework directive, Draft 5.2*, European Commission, Brussels, 2002.

- Lam, J., *Enterprise risk management: from incentives to controls*, John Wiley & Sons, Hoboken, New Jersey, 2003.
- Lifton, G. and Smeaton, P., Asset risk management in Scottish Water, *Proc. of the ICE/CIWEM Conference: Risk and reward in asset management delivery – who is best prepared for the challenges ahead?*, 14<sup>th</sup> November, 2003, London, UK.
- Lloyd, R. and Abell, P., Capital maintenance in Yorkshire Water's water business unit, *Proc. of Risk analysis strategies for better and more credible decision making*, 6-8<sup>th</sup> April, 2005, Banff, Canada.
- MacGillivray, B.H., Hamilton, P.D., Strutt, J.E., Pollard, S.J.T., Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making, *Critical Reviews in Environmental Science and Technology*, **36**: 85, 2006a.
- MacGillivray, B.H., Sharp, J.V., Strutt, J.V., Hamilton, P.D. and Pollard, S.J.T., Benchmarking risk management within the international water utility sector. Part II: A survey of eight water utilities, *J. Risk Research*, in press, 2006b.
- Miller, G.A., Risk governance in a water utility, *Proc. of Risk analysis strategies for better and more credible decision making*, 6-8<sup>th</sup> April, 2005, Banff, Canada.
- NHMRC, Framework for management of drinking water quality, NHMRC, New Zealand, 2001.
- Paulk, M.C., Curtis, B., Chrissis, M.B. and Weber, C.V., Capability maturity model, version 1.1, *IEEE Software*, **10**(4): 18, 1993.
- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Hamilton, P.D. and Hrudey, S.E., Risk analysis and management in the water utility sector – a review of drivers, tools and techniques, *Trans. IChemE, Part B: Proc. Safety Environ.*, **82**(B6): 1, 2004.

- Prime Minister's Strategy Unit, *Risk: improving Government's capability to handle risk and uncertainty*, The Strategy Unit, London, 2002. (website: <http://www.number-10.gov.uk/SU/RISK/risk/home.html>).
- RMRDP, *Risk management maturity level development*, 2002. (website: <http://www.risksig.com/Articles/rm%20report%20final%20version%2012.doc>).
- Sarshar, M., Haigh, R., Finnemore, M., Aouad, G., Barrett, P., Baldry, D. and Sexton, M., SPICE: a business process diagnostics tool for construction projects, *Engineering, Construction and Architectural Management*, **7**(3): 241, 2000.
- Sharp, J.V., Strutt, J.E., Busby, J. and Terry, E., Measurement of organizational maturity in designing safe offshore installations, *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering*, **2**: 383, 2002.
- Software Engineering Institute, *CMMI for systems engineering / software engineering / integrated product development / supplier sourcing, version 1.1*, 2002a. (website: <http://www.sei.cmu.edu/>).
- Software Engineering Institute, *People capability maturity model, version 2.0.*, 2002b. (website: <http://www.sei.cmu.edu/>).
- Stahl, G.R. and Elliott, J.C., 'New generation' computer models for risk-based planning and management, *Water Supply (Australia)*, **17**(3/4): 289, 1999.
- Starke, R.E., *The art of case study research*, Sage, Thousand Oaks, CA and London, 1995.
- Stevens, I.M. and Lloyd, R.I., *Water resources: Sustainable optimisation and security of supply, a proven example*, A paper presented to the 2004 Water sources conference and exposition, Jan 11-14th, 2004, Austin, Texas.
- Strutt, J.E., *Reliability capability maturity briefing document*, Report No. R-03/2/1, Cranfield University, 2003.

WHO, *Guidelines for drinking water quality, 3<sup>rd</sup> Edition* (draft), WHO, 2003 (website:  
[http://www.who.int/water\\_sanitation\\_health/dwq/guidelines3rd/en/](http://www.who.int/water_sanitation_health/dwq/guidelines3rd/en/)).

WHO, *Water safety plans (revised draft)*, Report publication WHO/SDE/WSH/02.09,  
World Health Organisation, 2002/



## **Chapter 4**

### **Implementing risk management: a study of improving performance within a water utility**

Submitted to *Journal of Water Supply: Research and Technology – Aqua*

## **4. Implementing risk management: a study of improving performance within a water utility**

B.H. MacGillivray and S.J. T. Pollard

*Centre for Water Science, Sustainable Systems Department, School of Applied Sciences, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK.*

### **ABSTRACT**

We describe application of a model to benchmark utility risk management capability and discuss observed risk management practices and their maturity of implementation within an international water utility. We highlight practices ranging from the application of classical risk assessment methodologies such as hazard and operability studies, to the use of scenario planning in guiding organisational restructuring programmes. We draw general conclusions regarding the presence or absence of attributes which determine the maturity of implementation of these practices, such as governance by procedure and criteria for initiating the application of risk analysis techniques. The findings provide additional insight into what risk management means in practice and how organisational capabilities may be improved.

**KEYWORDS:** benchmarking, risk analysis, risk management, governance, water sector.

## 4.1 INTRODUCTION

Formalised risk management is becoming a central feature within the strategic governance of water and wastewater services because it provides opportunities to identify and prevent potential failures before they occur (AWWA *et al.*, 2001; The Expert Panel on Water and Wastewater Strategy, 2005; Pollard *et al.*, 2005). Its application now extends beyond the preserves of occupational health and safety and public health protection to embrace corporate level decision making, asset management, watershed protection and network reliability analysis (as reviewed in MacGillivray *et al.*, 2006a). Risk management is of little value, however, without implementation (Mosse, 2006). So utilities committed to a more strategic approach to their business have concerned themselves with how to improve their organisational capabilities in managing risk. In support, the American Water Works Association (AWWA) Research Foundation have funded research on risk management maturity and we have published a capability maturity model for benchmarking and improving the processes that comprise utility risk management (MacGillivray *et al.*, 2006b). Here, we discuss its application within a water and wastewater utility.

## 4.2 METHODS

Our risk management capability maturity model (RM-CMM) (MacGillivray *et al.* 2006b; Figure 4.1) presents eleven risk management processes at five maturity levels (1-5) characterised with reference to attributes. These maturity levels reflect the extent to which each process is repeatable, defined, controlled and optimising (Table 4.1). Once a process is enshrined in procedures, with staff trained in their application, roles and responsibilities assigned, the necessary resources secured, and mechanisms in place

to prevent deviations from requirements and to learn from the feedback obtained, implementation of risk management should be of consistent high quality. In this way, the demonstrable maturity of risk management becomes the benchmark of an organisation's capability to manage risk, rather than the presence or absence of frameworks and procedures in isolation, the latter frequently being mistaken for the former.

The utility investigated in this paper is responsible for the management and operation of water and wastewater networks. Our analysis has been informed by questionnaire, interviews and document analysis. The questionnaire, completed by the risk manager, comprised a series of statements characterising the implementation of each risk management process at each maturity level. These were responded to on a four point Likert-type scale (fully agree, generally agree, partially agree, disagree). Process maturity was determined according to the "highest degree of fit," a measure of the level of agreement with the guideline statements at each maturity level for each process. Semi-structured interviews were undertaken with the risk manager, eight senior managers charged with the oversight of the discipline within their business functions (*e.g.* asset management, finance, human resources) and one manager responsible for recent organisational restructuring. These interviews, eight conducted *in situ* and two by 'phone, were transcribed verbatim. Finally, a range of supporting company documentation (*e.g.* policies, procedures, methodologies, process flow diagrams) was obtained and reviewed. We preserved the utility's anonymity, so removing potential conflicts (*e.g.* the utility's potential desire that the findings reflected positively upon themselves). Further, the use of multiple data sources allowed triangulation, wherein the documents, questionnaire responses and interview transcripts

were cross-checked for inconsistencies. Finally, two members of the utility's risk management group reviewed and approved our conclusions.

*Table 4.1 Generalised description of the five maturity levels*

Maturity level	Process characteristics
Optimising (L5)	The process is a continual, explicit component of organisational activities, forming part of the 'culture.' Feedback is actively used to improve both the philosophy and execution of the process, and the adaptation of organisational structures and practices to optimise its ability to undertake the process (double loop learning). Management continually establishes measurable targets for process improvement, with systems in place to verify their achievement and to validate the means through which they are pursued. Active innovation, development and piloting of new ideas and technologies to optimise the process.
Controlled (L4)	Verification mechanisms extend to provide quality assurance, and are supplemented by the capacity for process validation. Feedback is actively used to improve process execution, albeit within the constraints of existing process strategies (single loop learning). Broadly spread competencies enable the process to reside within affected disciplines, although stakeholders work together to achieve an integrated approach, capitalising on synergies and collective knowledge. Sufficient resources are available, with limited internal R&D.
Defined (L3)	Process scope exceeds regulatory requirements, extending across core business areas. Documentation details procedures, criteria, methods and guidelines for process undertaking, whilst basic audit mechanisms verify compliance. Feedback limitations restrict process evolution to learning from 'events' (open loop learning). Processes reside within the responsible unit, with limited cross-functional or external consultation. Adequate resources in place.
Repeatable (L2)	Basic process in place, focused on meeting regulatory requirements and addressing 'mission-critical' risks. Initiated reactively, often in response to an event or situation. Limited capacity to evolve based on experience.
Initial (L1)	No formal process; <i>ad-hoc</i> approach. Reliance on individual heroics. Limited awareness of regulatory requirements or relevant standards.

<b>Processes</b>	
Core	Strategic risk planning (SRP)
	Establishing risk acceptance criteria (ERAC)
	Risk analysis (RA)
	Risk based decision making and review (RBDM)
	Risk response (RR)
	Risk monitoring (RM)
	Integrating risk management (IRM)
Supporting	Supply chain risk management (SCRM)
	Change risk management (CRM)
Long-term	Education and training in risk management (E&T)
	Risk knowledge management (RKM)

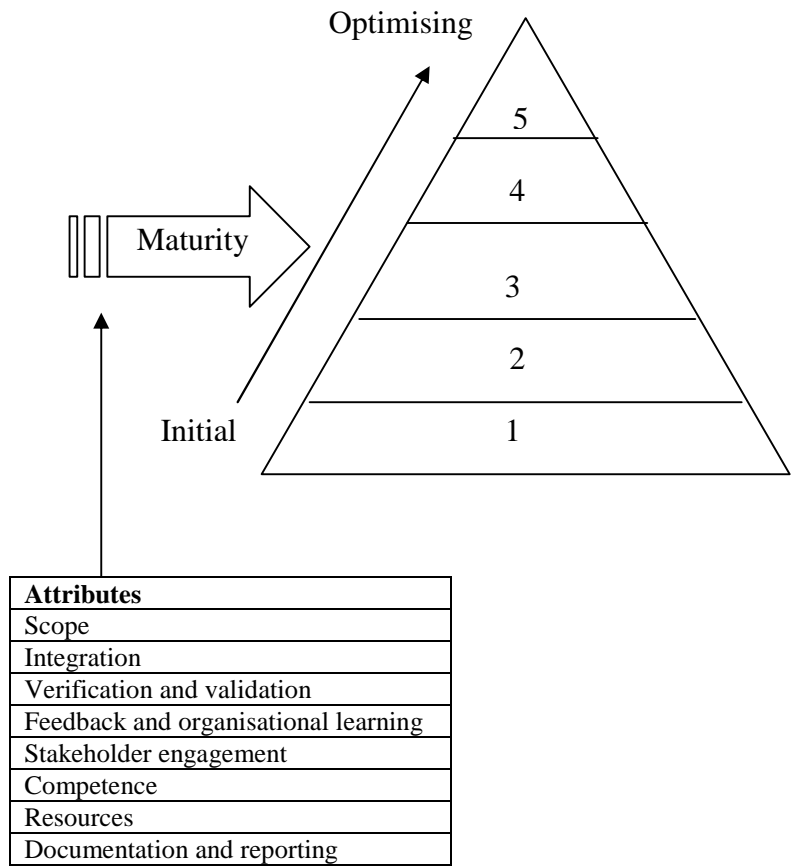
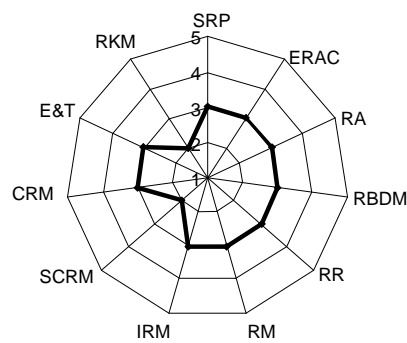


Figure 4.1 Structure of risk management capability maturity model

### 4.3 RESULTS AND DISCUSSION

Figure 4.2 displays the utility's maturity profile by self-assessment. With the exception of supply chain risk management and risk knowledge management (L2), each process was self-assessed at L3, representing process definition. In contrast, L2 processes are generally limited in scope, ill-defined and poorly institutionalised with limited capacity to influence organisational behaviours. Table 4.2 presents the processes included within the RM-CMM, and the related utility practices observed.



*Figure 4.2 The case study utility's risk management maturity profile by self-assessment*

We discuss four processes: (i) risk knowledge management; (ii) change risk management; (iii) education and training in risk management; and (iv) risk analysis. Note that as process maturity is assessed according to the highest degree of fit with a given level, there is scope for discrepancies between, for example, a process evaluated as defined (L3), and a process that may be considered fully defined.

Table 4.2 Description of the RM-CMM processes and of the relevant practices observed within the utility

Process	Description	Observed practices
SRP	The process by which the Board, the executive and senior management set out their overarching framework for corporate risk management.	Risk management policy and framework derived in part from external standards, informed by consultations between the risk management group, senior and executive management and the Board.
ERAC	The process by which the utility establishes criteria for evaluating the significance and acceptability of risk.	Risk ranking technique in place, derived from external standards, which set out criteria for evaluating the consequence, likelihood, strength of existing controls and, combined, the overall significance of strategic risks. However, evaluations as to their acceptability were judgement-based. The acceptable level of operational risk was implicit in asset design and operating standards, at times these were derived with respect to clear criteria ( <i>e.g.</i> ALARP in dam safety, H&S regulations, <i>etc.</i> ), although more often were based on experience, judgement and historic practice.
RA	The identification and assessment of risk.	Two distinct categories of risk analysis: a generic strategic technique applied in business planning and project management; and a series of discrete methods applied operationally. In the former, experience, judgement and the outputs of SWOT and STEEP analyses informed the identification to risks to achieving business plan objectives, which were then assessed via the risk ranking technique. A similar approach was adopted in project management. Operationally, a portfolio of industry standard and best practice risk analysis techniques were applied ( <i>e.g.</i> hazard and operability studies; hazards in construction studies; failure mode, effect and criticality analyses; cryptosporidium risk analysis techniques, Monte Carlo simulation; and dam portfolio analysis).
RBDM	The identification and evaluation of options to manage risks.	No inference possible.
RR	Implementing the selected risk management option(s).	Tasks, responsibilities and accountabilities for implementing risk management options were assigned and logged within the corporate risk register. The nature of the implementation process varied according to the nature of the option ( <i>e.g.</i> operational vs. capital).
RM	Reviewing and updating risk analyses.	Strategic risks (business planning and project management) were informally monitored on an ongoing basis by those assigned responsibility, and formally re-evaluated at periodic intervals.
IRM	The integration of risk management process interfaces; the cross-functional integration of risk management; integration of risk management with broader business operations.	No inference possible.
SCRM	Two aspects: (i) product supply risk management: addressing the way utilities obtain the raw components required to develop a product; (ii) service supply risk management: managing services provided by other organisations throughout the supply chain – <i>e.g.</i> outsourcing agreements.	Broad range of pre-qualification standards / criteria were applied as appropriate ( <i>e.g.</i> all high risk suppliers were evaluated in terms including previous work carried out for the utility; strategic potential; technical competence and experience; financial capacity and stability; health and safety record; quality system; environmental policy). Long term supplier partnerships were established, where appropriate, to optimise value for money <i>and</i> ensure quality and reliability of supply.
CRM	Managing the risk implications of business ( <i>e.g.</i> re-engineering) and technical ( <i>e.g.</i> changes in design or technology) change.	The planning of a recent organisational restructuring was informed by process mapping and scenario planning, which operationalised the broad guidelines for restructuring set at the executive level ( <i>e.g.</i> guidance against processes, organisational structures, commercial approach, <i>etc.</i> ).
E&T	Development of the skills and knowledge that enable staff to perform their risk management roles.	Comprised of a combination of <i>ad hoc</i> attendance of external courses and conferences for key risk management staff; internally delivered training modules wherein the discipline received primary or secondary focus ( <i>e.g.</i> in project management); and “on the job” training, where knowledge transfer occurred through direct participation in the risk management processes ( <i>e.g.</i> risk analysis workshops).
RKM	The collection, storage and access of input <i>and</i> output risk data.	The use of a risk register (IT database) for the collection, storage and access of risk analysis outputs. Pre-defined strategies for collecting the data required to inform risk management appeared restricted to select risks whose management was underpinned by analytical methodologies ( <i>e.g.</i> in reliability modelling, dam safety management).



Consider risk knowledge management. We observed use of a risk register (IT database) for the storage and access of risk analysis and monitoring outputs (catalogued according to level of risk, date of addition, and ownership, *etc.*) from business planning and project management. Formal procedures governed its use, which was overseen by a network of risk co-ordinators and the risk management team, supported by bi-weekly compliance reports on the adequacy of its maintenance. However, a core shortcoming was that a clear understanding of the data required to inform risk management (*i.e.* the input data) proved restricted to select risks whose management was underpinned by analytical methodologies (*e.g.* in reliability modelling, dam safety assessment). This is an important observation because in the absence of predefined requirements, risk data collection is likely to be *ad hoc* and restricted to the familiar requirements of business as usual, leading to an over-reliance on expert judgement in managing risk.

Consider now change risk management, a particularly significant process given the range of factors (*e.g.* globalisation, regulatory and market restructuring, novel technologies; Means *et al.*, 2005) serving to fundamentally alter the context in which the sector operates. Of note was the utility's recent restructuring programme, aimed at improving efficiency, customer service and internal accountability. At the planning stage, process mapping and scenario planning were undertaken to operationalise the restructuring guidelines set by the executive (*e.g.* on processes, organisational structures, commercial approach). Scenario planning acknowledges the key sources of uncertainty and incorporates them into a range of future strategic responses for exploration (Clemons, 1995). As one manager noted "*we got experienced people from within the business to map out [their] processes and, it was in doing that, that we tested the scenarios...the organisational design followed...that was important as there was a great temptation just to jump into [the] re-organisation...but we resisted that, and what*

*it allowed us to do was not only do the scenarios, but also when you come up with the [final plan], it's not as contestable or emotionally charged."* This supports Clemons' (1995) argument that scenario planning reduces the risk of making inadequate changes to organisational structures or processes and, through ensuring the need for change is internally addressed and accepted, reduces the risk that implementation will fail. However, whilst evaluated as closest to L3 maturity, the case study utility's change risk management process cannot be considered fully defined. As one manager offered: *"we don't have a rulebook on organisational change that we pull off the shelf. I think [the process] was [shaped] by a culmination of things...experience, the nature of the team, the leadership, the style of the new managing director... we did run a workshop on lessons learnt before we disbanded [the [restructuring team], but I'm unsure how that finds its way into the corporate rulebook."* This is significant as substantial evidence exists to mark organisational re-engineering a high risk-endeavour, in that whilst often effective, such programmes produce highly variable outcomes (e.g. Remenyi and Heafield, 1996; Crowe *et al.*, 2002; Dean *et al.*, 1999).

Consider now the utility's education and training in risk management process, comprised of a combination of *ad hoc* attendance of external courses and conferences for risk management practitioners; internally delivered training modules (e.g. in project management); and informal "on the job" training. However, once again, as one manager stated, it was *"not yet a formally documented process;"* nor had the required staff competencies been defined. This latter point is key, as without defined competency requirements and methods for determining whether competencies exist or have been imparted (e.g. assessment matrices), the value of training can not be quantified.

In light of this, a pressing question for utility managers is: what practical steps are required to secure fully defined (L3; Table 4.1) risk management processes? To discuss this, we turn to our observations of risk analysis. Within the utility, we observed two categories of risk analysis: a generic strategic technique; and a series of discrete techniques applied in specific operational contexts. The former involved risk ranking to assess and prioritise a broad spectrum of strategic risks (*e.g.* financial, environmental, regulatory, *etc.*) to the delivery of business plans and project objectives. The latter involved a portfolio of industry standard and best practice techniques (*e.g.* hazard and operability studies (HAZOP); hazards in construction studies; failure mode, effect and criticality analyses; *cryptosporidium* risk analysis techniques, Monte Carlo simulation; and dam portfolio analysis). Observed L3 characteristics included procedures and criteria governing the conduct and initiation of these risk analyses. For example, strategic risk analysis was initiated at points in the business planning and project management cycles, whilst HAZOP studies were undertaken at set points in the design stage (*e.g.* during the production of detailed design data). However, even at L3, process execution is variable because of limitations in verification, validation and feedback. For example, whilst the utility had basic mechanisms in place to verify compliance with risk analysis procedures (*e.g.* sign offs, internal audits), it lacked formal, systematic mechanisms to ensure the quality of completed analyses (*e.g.* technical peer reviews, challenge procedures). Nor was a systematic approach to validating the design of the risk analysis process evident (*e.g.* are the risk analysis techniques fit-for-purpose, do the procedures maintain an appropriate balance between standardisation and flexibility, *etc.*). This said, progression to L4, in which these limitations are resolved, is difficult, in part because the measures required are resource

intensive, technically challenging, and may be viewed as introducing unnecessary internal bureaucracy.

#### **4.4 CONCLUSIONS**

Implementing risk management is not straightforward. It requires moving beyond the establishment of frameworks, risk champions and risk management committees and influencing practice on the ground. We therefore anticipate our empirical observations regarding risk management practices and their methods for institutionalisation will be of interest to utility risk managers, asset managers and operational water utility staff, as well as regulators considering how improved water utility governance can be made real.

#### *Acknowledgements*

This work was part funded by the AWWA Research Foundation (RFP2939) and a consortium of international water utilities. The authors are grateful to the case study utility and lead individuals for their contributions, peer review and permission to publish. The comments and views herein are the authors' alone. BHM is co-funded by an EPSRC Doctoral training account.

#### **4.5 REFERENCES**

AWWA, EUREAU, WSAA and DVGW, *Bonn Workshop 2001 – Key principles in establishing a framework for assuring the quality of drinking water: a summary*, AWWA, Denver, CO., 2001.

- Clemons, E.K., Using scenario analysis to manage the strategic risks of reengineering, *Sloan Manage. Rev.*, **36**(4): 61, 1995.
- Crowe, T.J., Fong, P.M., Bauman, T.A., and Zayas-Castro, J.L., Quantitative risk level estimation of business process reengineering efforts, *Business Proc. Manage. J.*, **8**(5): 490, 2002.
- Dean, A., Carlisle, Y., and Baden-Fuller, C., Punctuated and continuous change: The UK water industry, *Br. J. Manage.* **10** (S1): 3, 1999.
- MacGillivray, B.H., Hamilton, P.D., Strutt, J.E., Pollard, S.J.T., Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making, *Critical Reviews in Environmental Science and Technology*, **36**: 85, 2006a.
- MacGillivray, B.H., Strutt, J.E., Sharp, J.V., Hamilton, P.D. and Pollard, S.J.T., Benchmarking risk management within the water utility sector. Part I: Design of a capability maturity methodology, *J. Risk Research*, in press, 2006b.
- Means, E.G. III, Ospina, L. and Patrick, R., Ten primary trends and their implications for water utilities. *JAWWA*, **97**(7): 64, 2005.
- Mosse, P., Implementation - the missing link in water quality, *Waterworks*, June 2006: 3, 2006.
- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Sharp, J.V., Hrudey, S.E., Hamilton, P.D., Risk management capabilities – towards ‘mindfulness’ for the international water utility sector, *Proc. of the DWI Conference: Water Contamination Emergencies: Enhancing our Response*, 12-15<sup>th</sup> June 2005, Manchester, UK.
- Remenyi, D., and Heafield, A., Business process re-engineering: Some aspects of how to evaluate and manage the risk exposure. *Int. J. Proj. Manage.* **14**(6): 349, 1996.

The Expert Panel on Water and Wastewater Strategy, *Watertight: The case for change in Ontario's water and wastewater sector*, Queen's Printer for Ontario, Toronto, 100pp, 2005.

## **Chapter 5**

### **Benchmarking risk management within the international water utility sector. Part II: a survey of eight water utilities**

*Journal of risk research*, in press.

## **5. Benchmarking risk management within the international water utility sector. Part II: a survey of eight water utilities**

B.H. MacGillivray, J.V. Sharp, J.E. Strutt, P.D. Hamilton and S.J.T. Pollard

*School of Water Sciences, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK.*

### **ABSTRACT**

Risk management in the water utility sector is fast becoming explicit. Here, we describe application of a capability model to benchmark the risk management maturity of eight water utilities from the UK, Australia and the USA. Our analysis codifies risk management practice and offers practical guidance as to how utilities may more effectively employ their portfolio of risk management techniques for optimal, credible, and defensible decision making. For risk analysis, observed good practices include the use of initiation criteria for applying risk analysis techniques; the adoption of formalised procedures to guide their application; and auditing and peer reviews to ensure procedural compliance and provide quality assurance. Additionally, we have identified common weaknesses likely to be representative of the sector as a whole, in particular a need for improved risk knowledge management and education and training in the discipline.

**KEYWORDS:** maturity model, risk analysis, risk management, water sector



## 5.1 INTRODUCTION

### 5.1.1 Risk Management in the Water Utility Sector

The water sector is witnessing a significant shift in the approach to managing risk to one that is increasingly explicit and broad in scope. Risk management strategies and techniques traditionally applied to occupational health and safety and public health protection are seeing application to corporate level decision making, asset management (Booth and Rogers, 2001; Lifton and Smeaton, 2003), watershed protection (IMPRESS Management, 2002; Lloyd and Abell, 2005; WHO, 2003) and network reliability (Stevens and Lloyd, 2004; Stahl and Elliott, 1999). This is in large part a response to the corporate governance, asset management, public health and environmental protection agendas, and represents a growing recognition that the provision of safe drinking water deserves to be treated as a “high reliability” societal service, subject to the sectoral and organisational rigours and controls inherent to the nuclear, offshore and aerospace industries (Pollard *et al.*, 2005). However, it is not the presence of risk management *per se* that governs the value derived, but its relative maturity of implementation within a utility. We have developed a capability maturity model for benchmarking and improving the *processes* that comprise risk management (MacGillivray *et al.*, 2006a). Here, we report its application to benchmark within the international water utility sector, the purpose of which was to identify good risk management practices and explore how their mature institutionalisation can be achieved.

### 5.1.2 Risk Management Capability Maturity Model (RM-CMM)

Our companion paper (MacGillivray *et al.*, 2006a) describes the development of a RM-CMM for the water utility sector. The model is a prescriptive codification of water sector risk management practice, within a process-based maturity hierarchy. The model was developed by abstracting the principles of capability maturity modelling observed in other disciplines, including software and systems engineering (Paulk *et al.*, 1993; Software Engineering Institute, 2002a), workforce development and management (Software Engineering Institute, 2002b), offshore design safety (Sharp *et al.*, 2002), reliability engineering (Strutt, 2003), and construction (Sarshar *et al.*, 2000). This was achieved through literature reviews (MacGillivray *et al.*, 2006b; Pollard *et al.*, 2004; Hamilton *et al.*, 2006), structured interviews with water utility managers, and prior knowledge of maturity modelling in similar utility sectors. We identified eleven risk management processes (Figure 5.1). These processes are separated into five maturity levels, from learner to best practice. These maturity levels, characterised by reference to attributes (Figure 5.1), reflect the extent to which each process is repeatable, defined, controlled and optimising. It is important to understand what these levels represent in practice as this is crucial to assessing the maturity of an organisation. Whilst the precise definition of the maturity hierarchy is process specific, a generalised description is provided in Table 5.1.

<b>Processes</b>	
Core	Strategic risk planning (SRP)
	Establishing risk acceptance criteria (ERAC)
	Risk analysis (RA)
	Risk based decision making and review (RBDM)
	Risk response (RR)
	Risk monitoring (RM)
	Integrating risk management (IRM)
Supporting	Supply chain risk management (SCRM)
	Change risk management (CRM)
Long-term	Education and training in risk management (E&T)
	Risk knowledge management (RKM)

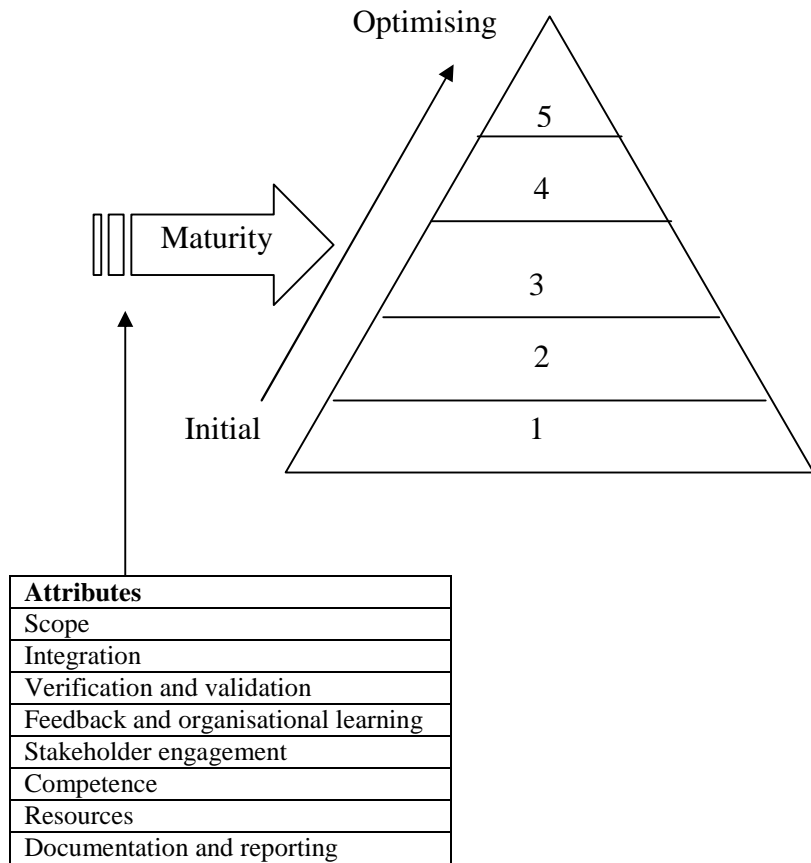


Figure 5.1 Overview of the RM-CMM (after Strutt et al., 2005)

Table 5.1 Generalised representation of the process maturity hierarchy

Maturity level	Process Characteristics
Level 5 – Optimising	The process is a continual, explicit component of organisational activities, forming part of the ‘culture’. Feedback is actively used to improve both the philosophy and execution of the process, and the adaptation of organisational structures and practices to optimise its ability to undertake the process (double loop learning). Management continually establishes measurable targets for process improvement, with systems in place to verify their achievement and to validate the means through which they are pursued. Active innovation, development and piloting of new ideas and technologies to optimise the process.
Level 4 – Controlled	Verification mechanisms extend to provide quality assurance, and are supplemented by the capacity for process validation. Feedback is actively used to improve process execution, albeit within the constraints of existing process strategies (single loop learning). Broadly spread competencies enable the process to reside within affected disciplines, although stakeholders work together to achieve an integrated approach, capitalising on synergies and collective knowledge. Sufficient resources are available, with limited internal R&D.
Level 3 – Defined	Process scope exceeds regulatory requirements, extending across core business areas. Documentation details procedures, criteria, methods and guidelines for process undertaking, whilst basic audit mechanisms verify compliance. Feedback limitations restrict process evolution to learning from ‘events’ (open loop learning). Processes reside within the responsible unit, with limited cross-functional or external consultation. Adequate resources in place.
Level 2 – Repeatable	Basic process in place, focused on meeting regulatory requirements and addressing ‘mission-critical’ risks. Initiated reactively, often in response to an event or situation. Limited capacity to evolve based on experience.
Level 1 – Initial	No formal process; <i>ad-hoc</i> approach. Reliance on individual heroics. Limited awareness of regulatory requirements or relevant standards.

## 5.2 METHODOLOGY

Eight water utilities from the UK, Australia and the USA participated in this study. This was supplemented by the participation of an electricity utility regarded as best practice in risk management. However, an incomplete questionnaire return prevented its maturity assessment, and we restrict its discussion to key observations. The sample is intended to reflect good risk management practice, hence we do not suggest that our analysis is representative of the sector as a whole. The scope of analysis varies by utility, and includes organisational, business unit, and functional perspectives (Table 5.2). Sample selection drew upon existing industrial contacts and was further informed by prior reviews (MacGillivray *et al.*, 2006b; Pollard *et al.*, 2004; Hamilton *et al.*, 2006) of the academic, practitioner and grey literature.

*Table 5.2 Sample characteristics.*

<b>Descriptor</b>	<b>Respondent*</b>	<b>Unit of study</b>	<b>Scope of analysis</b>
Utility A	Corporate risk manager	Corporate	Water supply, sewerage services and electricity distribution
Utility B	Water quality manager	Corporate	Water supply and sewerage services
Utility C	Water quality manager	Corporate	Water supply and sewerage services
Utility D	Corporate risk manager	Corporate	Water supply
Utility E	Asset manager	Corporate	Water supply and sewerage services
Utility F	Corporate risk manager	Corporate	Water supply and sewerage services
Utility G	Asset manager	Business unit	Water supply
Utility H	Water quality manager	Function	Drinking water quality management
Utility I**	Corporate risk manager	Corporate	Electricity transmission and distribution

\* Respondent denotes the interviewee; in most cases, the questionnaire was undertaken in consultation with other staff. \*\* Data limitations prevented the maturity evaluation of Utility I.

A survey-type research design was adopted, whilst the research methods included questionnaire, interview and textual analysis. The questionnaire was comprised of a series of statements characterising the undertaking of each risk management process at each maturity level. These were responded to on a four point scale (fully agree; generally agree; partially agree; and disagree), with space provided for supporting comments. Process maturity was determined according to the highest “degree of fit”; a measure of the average level of agreement with the guideline statements at each maturity level for each process. The interview and textual analysis was concerned with identifying the specific risk management practices undertaken within the sample and correlating these with our model coding (*e.g.* what form does risk analysis take in practice, and how may it be institutionalised as a process). Semi-structured interviews were undertaken with each assessor following receipt of the questionnaire. The interview methodology was developed, tested and refined within a separate industrial case study. Interviews were conducted by 'phone, recorded, and subsequently converted into transcripts. These transcripts were returned to each interviewee, providing them an opportunity to comment. Finally, a range of pertinent supporting company documentation was requested from each participant. Those made available included risk management policies and frameworks, risk analysis procedures and techniques, and water safety plans.

Given the qualitative nature of the research, mechanisms to validate our findings were adopted. This was achieved through sample anonymity and triangulation. Anonymity removed the potential for conflicts with the fundamental goal of adding to the body of knowledge (as opposed, *e.g.*, to the participants' desire that the findings reflected positively upon their organisation). Triangulation sought to balance the lead author's principal analysis of the questionnaires, texts and interview transcripts with a

blind scoping analysis conducted by a co-author. Additionally, each respondent was offered the opportunity to comment on all statements within the paper referring specifically to their utility. Diverging perspectives were resolved through consensus.

### **5.3 RESULTS AND DISCUSSION**

Figures 5.2 and 5.3 illustrate the sample process maturity profiles. Detailed discussion of these levels may be found in our companion paper. Here, we do not dwell on the maturity profiles as our scoring methodology is arbitrarily rather than scientifically derived and the sample is not intended to reflect the sector as a whole. We restrict ourselves to the following observations. The sample profiles are relatively mature for the core and supporting processes of risk management, in contrast to the long-term processes of education and training in risk management and risk knowledge management. Two explanations are offered. Firstly, the attention and resources dedicated to the design and execution of processes is correlated with their perceived criticality. Secondly, the long-term processes receive limited treatment within the academic and practitioner literature, leaving utilities bereft of guidance. The maturity of the supporting processes – supply chain risk management and change risk management – is particularly high. The strength in the former is likely a function of the increasing level of outsourcing within the sector. Similarly, we propose that mature change risk management is driven by evolving regulatory and governance structures and the commonality of internal restructuring.

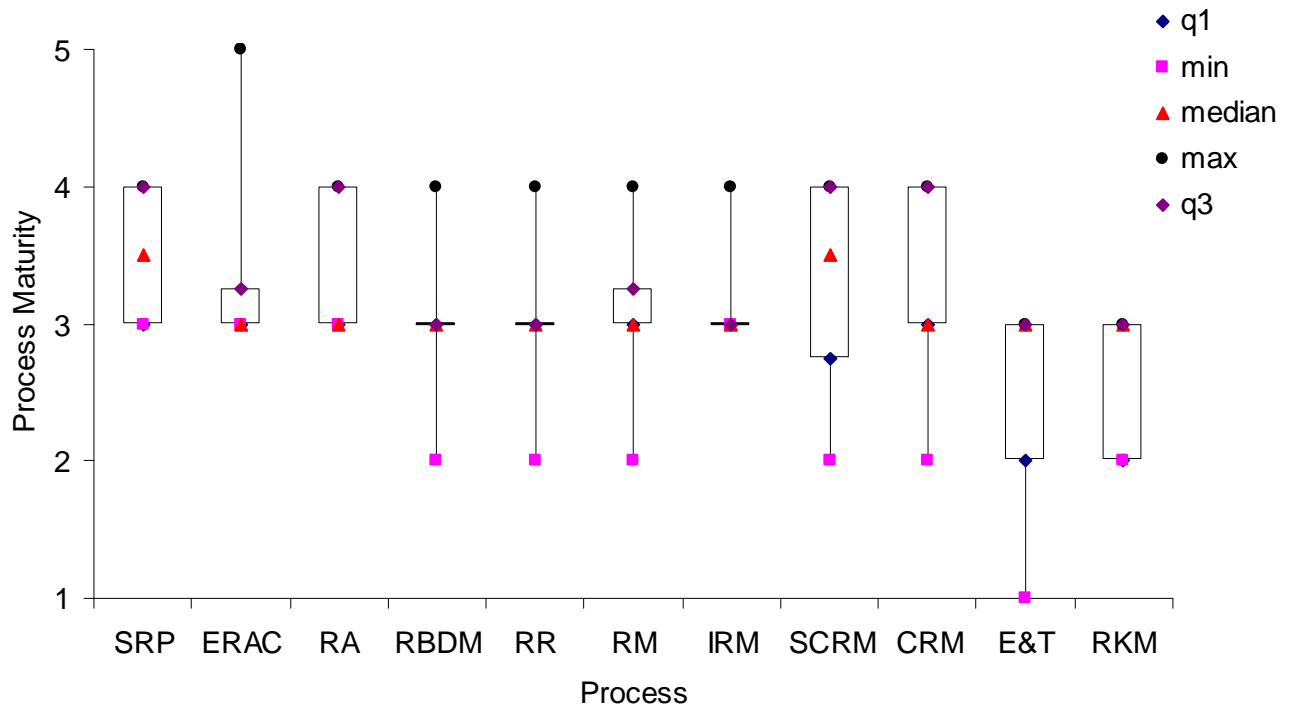
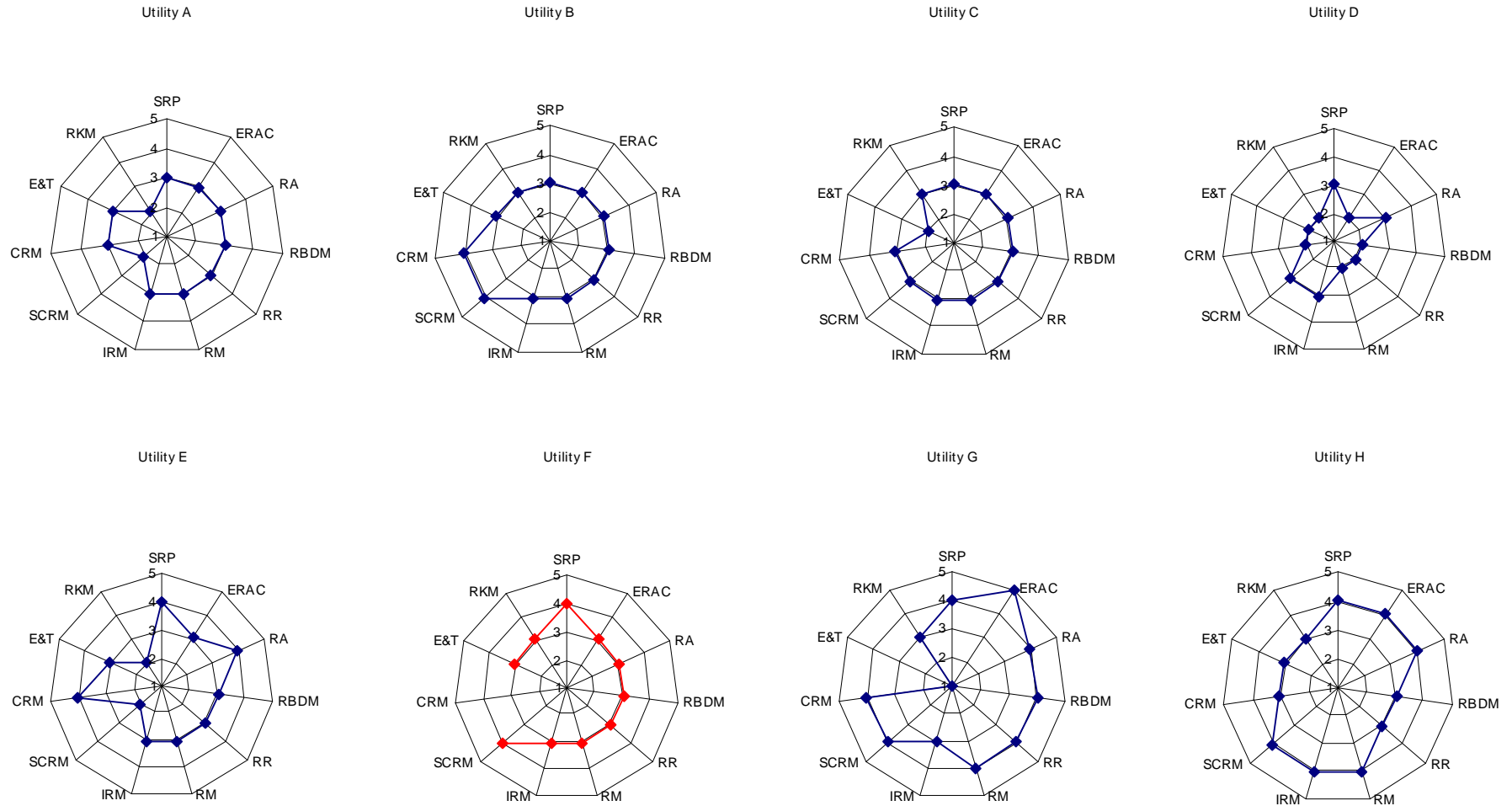


Figure 5.2 Boxplot of the sample risk management process maturity by self-assessment





\* Red indicates uncertainty arising from incomplete questionnaire data.

Figure 5.3 Spider diagrams of organisational maturity by self-assessment

We now discuss the observed risk management practices and their methods for institutionalisation on a process-specific basis.

### **5.3.1 Strategic risk planning**

Here, we observed an even spread of our sample between L3 and L4. Strategic risk planning is primarily concerned with the development of a risk management framework. In essence, these frameworks were observed to set out the rationale, procedures and responsibilities for the discipline. At L3 and L4, we observed that their development may be characterised as the evaluation and adaptation of external risk management standards. For example, one manager described how the forbearer of their corporate-wide risk management framework was an adaptation of an occupational health and safety management system, which has evolved drawing upon the AS/NZS: 4360 (Council of Standards of Australia, 1999) standard and broader experiences of the sector. Another described how they were “*trying to use the rationale, the basis of the COSO (COSO, 2004) standard, but the methodology is one that’s been developed by us.*” We may consider the vetting of these frameworks (*e.g.* by the Board, internal audit, *etc.*) as a form of *output* validation, however, it was unclear whether the *process* by which they are developed, or more precisely adapted, is subject to oversight.

### **5.3.2 Establishing risk acceptance criteria**

This process involves the development of criteria for evaluating the tolerability and significance of risk. Here, we observed five L3 organisations, and one each at L2, L4 and L5. At L2, risk acceptability is largely set with reference to regulations and standards. Expanding on this, the L2 manager stated that “*the corporate risk appetite*

*is primarily perceptual and based upon broad guidelines established by upper management, the Board, external auditors, stakeholders and bond-holders.”*

An observed L3 practice was the allocation of risk tolerability criteria in operational and financial areas. These included design standards informed by hazard and operability (HAZOP) analyses; operating and maintenance practices informed by reliability modelling; as low as reasonably practicable (ALARP) criteria for evaluating dam safety risk; the use of risk-based criteria to determine raw water treatment requirements; and risk-adjusted discount rates applied within financial analysis models to balance investment returns with uncertainty. However, it appeared that the processes through which these criteria are established reside within organisational functions (*e.g.* engineering, finance) and thus lie outside the remit of the corporate risk manager. As one manager noted, tolerability criteria may exist “*within discrete areas of the business...but they exist as islands with no...overlaying risk management policy or strategy.*”

Further, we observed the development of risk ranking techniques which outline the criteria by which organisations assess the significance of risk both at the corporate level and, in some cases, specific to organisational functions such as asset management. Tolerability criteria were often embedded within these techniques (*e.g.* low risk: manage by routine procedures; high risk: management response required). These techniques were typically derived from risk management standards. Observed adaptations included the alignment of consequence criteria with corporate objectives (*e.g.* environmental, financial, *etc.*); the tailoring of impact descriptors; and the assignment of costs to impact categories.

### 5.3.3 Risk analysis

Here, five utilities were evaluated at L3, three at L4. Risk analysis involves the identification and assessment of risk. Our sample indicates two distinct categories of risk analysis: a generic strategic technique; and a series of discrete methods applied in operational areas. The former may be characterised as the application of qualitative risk ranking techniques to analyse the risks inherent to managing a water utility as a business. The latter included a raft of industry standard and best practice tools, both qualitative and quantitative. Those observed included HAZOP studies; hazard analysis and critical control points (HACCP) evaluations; failure mode, effect and criticality analyses (FMECA); and Monte Carlo simulation of financial variables.

A prerequisite for process definition (L3) is that the application of these techniques is guided by formalised procedures – a practice intended to ensure the consistency and rigour of analysis. Regarding strategic risk analysis, best practice may be described with reference to the electricity utility. Here, a range of risk identification techniques are available, and their selection depends upon *“the depth and breadth of activities under review and the extent to which the business context is new.”* Listed techniques include strengths, weaknesses, opportunities and threats (SWOT) analysis; scenario analysis; value chain analysis; benchmarking; control self assessments; audit reports; *etc.* Risk categories are used as a further prompt for identification (strategic, regulatory, financial and operational). It was common practice across our sample to assess strategic risks via a combination of expert judgement and, where available, historic data to determine a range of parameters (*e.g.* probability, consequence, development time, triggers, control design and usage, *etc.*). The electricity utility’s use of the Delphi technique (Dalkey and Helmer, 1963) in risk assessment is notable. Here, facilitated discussions and iterative anonymous voting were applied to generate expert

consensus. The method's explicit recognition of human judgment as a legitimate input is particularly valuable where data is limited. Furthermore, characterised as it is by group participation, anonymity and feedback loops, it minimises bias and dogmatism (*i.e.* reduces the reluctance of staff to abandon previously stated views). A caveat: it appears that in many cases strategic risk analysis tends to be as one manager stated "*shepherded by the corporate risk team*" rather than guided in a mechanistic manner. This contrasts with the more procedural approach adopted operationally (*e.g.* in occupational health and safety), and perhaps reflects the perceived value of creativity in strategic risk analysis.

A further observed L3 characteristic was the use of criteria for the selection *and* application of risk analysis techniques. The strategic risk ranking tools were typically initiated within business and strategic planning as well as on an *ad hoc* basis as new risks arise, whilst various nodes (*e.g.* the concept design stage for application of HAZOP) served as initiating criteria for the various operational methods. Observed selection criteria included the use of financial thresholds to delineate the application of Monte Carlo simulation from simple checklists to evaluate financial risk within programme management. Basic verification mechanisms are a further L3 characteristic. This is reflected in one utility's requirement for supervisors to review risk assessments of minor construction and maintenance works prior to "sign off." Similarly, one manager highlighted the role of their "systems certification process" in ensuring procedural compliance. Here, a taskforce "*conducts certification audits, checking the business practices of each system, making sure that they're in concert with our way of doing business; one element of which is that they're doing risk assessments and that they're doing it properly.*" Another interviewee described a tri-partite approach to auditing. Here, in addition to external auditing by their parent company, "*internal*

*audit come in every year, to check that we're process compliant by drilling down from risk reporting at the highest level, right down through identification, assessment...also as a [risk management] team, we do our own local audits to make sure that people are up to speed...and [we] tackle non compliance."* The importance of such checks and balances was highlighted by one participant's contrasting of the inconsistencies surrounding their locally managed sanitary surveys with the consistency of their centrally managed barrier surveys. Furthermore, several managers related concerns that analyst bias may lead to distortions of risk analysis outputs. Whilst underscoring was the most commonly noted threat, one manager revealed that their adoption of a risk-based capital investment programme has led to a significant likelihood of asset managers "*over-egging*" their analyses to attract greater funding for their regions. To address this, verification should extend to audit the quality of analysis undertaken.

This enhanced role for verification was observed at L4, as reflected in one utility's "quality assurance consistency checks" within asset management. Here, risk analysis outputs and their underpinning assumptions were systematically reviewed and challenged by a multi-disciplinary team of experts. The interviewee noted that the value of this procedure extends beyond quality assurance of analysis outputs to highlighting common errors in applying the methodology itself: "*we've had some problems with people using [the methodology], some were misinterpreting it, we spotted this from the data and [the consistency checks]. Some asset managers score the probability of an asset failing, some score the probability of an asset failing and [leading to a defined] impact; the latter is what we want."* We now highlight the subtle distinction between verification, which seeks to evaluate whether the process has been followed correctly, and validation, which is concerned with whether the process itself is correct (*e.g.* validating the risk analysis techniques). Both of these aspects were

enshrined in one utility's application of a "common sense screen" at the end of their water quality risk analysis process. Here, if analysis outputs appeared at odds with experienced operational knowledge, the reason behind the "false" score was investigated, and the process and score adapted where appropriate.

Although engagement of a broad range of stakeholders is characteristic of L4 maturity, broad internal stakeholder engagement was characteristic of each utility's approach to strategic risk analysis, which was typically conducted within cross-functional forums. However, the engagement of external stakeholders appears to occur on a far more selective basis. One L3 manager commented that there were "*no formal procedures for external risk reporting*" and that, beyond the outcomes of security-related risk assessments, the "*regulator has shown little interest*". Two of the L4 interviewees expressed a greater recognition of the need to engage external actors in risk analysis, both where risks have high external stakeholder implications (*e.g. political or environmental*) and where expert guidance is required. In contrast, one manager explained their reticence to engage external bodies by noting that "*risk assessments are a risk for ourselves, if we identify something as a business risk, particularly if its environmental, hazardous, or regulatory, that's out there, if you don't address that, it's going to come back at you.*"

Finally, the sufficiency of resourcing within each L4 company was evidenced by their active research and development in risk analysis. One was researching the integration of predictive GIS tools with continuous and event-based monitoring data for application in catchment risk analysis. In contrast, one L3 interviewee highlighted resource constraints as a limitation: "*one issue is the complexity of our analyses, we have ten water systems and thirteen catchments [which are] diverse in [size and]*

*nature...for a small organisation that serves only about 15,000 customers, resourcing these sorts of studies is not easy.”*

#### **5.3.4 Risk based decision making and review**

Risk based decision making involves the identification and evaluation of solutions to manage individual risks. Here, six of our sample were evaluated at L3 maturity, with one each at L2 and L4. At L3 maturity, we observed procedures to ensure that risk analysis outputs explicitly inform decision making. These ranged from the integration of the risk analysis and decision making processes within strategic risk management workshops, to the risk analysts’ role of briefing non-technical decision makers in operational areas. We further observed decision making frameworks. This is reflected in one utility’s adoption of a predefined hierarchy of occupational health and safety hazard control measures: elimination (does the work have to be done); substitution (can it be done in a less hazardous way); engineering controls (isolation, containment); administration (procedures, trained staff); personal protective equipment (respirators, helmets); and warning signs. This structures the identification of solutions. In a more generic context, the electricity utility categorizes risks by the extent to which their exposure can be managed: controllable (*e.g.* financial or health and safety risks) and influenceable (*e.g.* competition, regulation). Seven “risk treatment” options are then applied to structure the identification of solutions: retain; retain but change mitigation; increase (risk exposure is increased, for example, where the current controls are not cost-effective); avoid (*e.g.* withdrawal from a business area); reduce likelihood; reduce consequences (*e.g.* through emergency preparedness); and transfer (*e.g.* through insurance or outsourcing). However, inherent in many risk assessment methodologies is a decision making structure. Consider one utility’s catchment to tap methodology.



Here, the assessment links hazard type (*e.g.* physical – turbidity and colour) to their causes (erosion) and to events (landslip, storm). Clearly, by identifying the underlying mechanisms through which hazards are realised, rather than simply evaluating their probabilities and consequences of occurrence, the identification of preventative measures (*e.g.* stabilise gullies, isolate draw-off) is facilitated.

A further L3 characteristic is the establishment of objectives for risk based decisions. However as one manager stated “*with the exception of large projects, the majority of the goal-orientation will focus on cost and physical output*”, rather than risk reduction. In contrast, one L3 utility adopted a goal setting regime for risk reduction at both the asset and strategic level. In the former, asset planners attached cost estimates *and* risk reduction targets to a range of potential capital, operating or maintenance strategies to address risks across their sites, which were then prioritised on the basis of risk reduction per pound spent.

Quality assurance of decisions, whilst characteristic of L4, was observed to an extent within each utility, ranging from the peer review format of cross-functional strategic risk management workshops to more formalised challenge procedures. For example, one manager noted that a central role of their “executive leadership team” – comprised of the president, vice presidents and union leader – and “business owners’ council” – comprised of business unit representatives – was to provide input to and at times critique risk management decisions taken at the corporate and business unit levels respectively.

### **5.3.5 Risk response**

Risk response is the implementation of risk based decisions. Here, six of our sample were evaluated at L3 maturity, with one each at L2 and L4. An L3

characteristic is the systematic allocation of responsibility, tasks, timescales, guidelines and resources for the implementation of risk based decisions; this was observed, *e.g.* within the development of “action plans.” Within the electricity utility, these include a description of the: risks to be mitigated; business objectives threatened; required actions; risk champion; target date of completion; residual risk rating; cost estimate; ease of implementation; and what could go wrong. Returning to a more operational context, we observed emergency management plans detailing the procedures required to minimise the impacts of, for example, plant failure (check component connections, check for blockages, review raw water for turbidity, taste, odour and algae, *etc.*). In practice, we observed that implementation processes were often not unique to risk based decisions, *i.e.* there existed models for implementing capital or operational solutions, not models for implementing risk based decisions *per se*. Indeed, the electricity utility manager emphasised that his role as a risk manager was not to act as a “*central policeman*,” and that implementation was a matter for individual business units and functions.

### **5.3.6 Risk monitoring**

The sample contains one L2, five L3, and two L4 companies in risk monitoring. The L2 interviewee characterised risk monitoring as “*the weaker part of our scheme; we don’t do much beyond the quarterly reviews, the exception being some particularly critical risks.*”

Our sample indicates that risk monitoring may be partitioned into two tiers: the first involving the re-evaluation of risk analyses outputs, the second relating to the tracking of discrete parameters which describe the evolution of risks. The former was observed to occur by procedure at L3 and L4, through both cyclical requirements and

event-driven initiators (*e.g.* changes to technical processes). The importance of such procedures was emphasised by one manager's revelation that prior to their introduction of a central asset risk register with clear requirements for cyclical reviews of analysis outputs, risk analyses were not regularly updated, instead being performed for a specific purpose at decision making points. Good practice was further illustrated in one utility's adoption of reporting protocols for communicating the results of strategic risk re-evaluations; here: co-ordinators reported on the evolution of significant exposures at monthly management meetings; significantly increased risks were escalated to unit directors within thirty six hours; and the risk management function reported to the Board on a monthly basis. We further observed verification of procedural compliance, most commonly achieved through risk register oversight.

One might argue that this first tier of risk monitoring is indistinct as a process from risk analysis, as the revision of previous risk assessments is an element of the feedback loop within the latter process. The distinct second tier was observed to be most prevalent within drinking water quality management and network planning and operation. In the former context, risk monitoring includes both the standard regulatory-driven tracking of primarily lagging water quality parameters (*i.e.* verification of water quality, *e.g.* coliform testing at customer taps), and, where the water safety plan approach is adopted, extends to include leading indicators devised in accordance with the HACCP (Havelaar, 1994; Deere *et al.*, 2001) model (*i.e.* operational parameters describing the effectiveness of control measures designed to mitigate water quality hazards, *e.g.* pH residuals at and post disinfection). It should be noted that HACCP has the inherent characteristics of L4 maturity. To illustrate, within one adopter we observed: weekly reviews supported by in-depth periodic audits to ensure compliance with the established monitoring protocol (*i.e.* verification: ranging from requirements to

review online turbidity data to the calibration of analysis and measurement equipment); formal peer reviews of established operational parameters and their target and action limits (*i.e.* validation: exploring, for example, the rationale behind setting 2000 cells/mL of cyanobacteria as an action limit for controlling taste and odour related hazards); and annual reviews of the protocol taking account of modifications to processes, industry standards, regulatory guidelines and operating licenses (*i.e.* feedback mechanisms).

### **5.3.7 Integrating risk management**

Here, seven of our sample were evaluated at L3, with one at L4 maturity. Our discussion is restricted to one facet of integration: institutionalisation. Our model views institutionalisation as dependant on risk management “enablers” and “evaluators.” Enablers include the provision of guidelines, procedures, systems, tools and training for the discipline (L3), whilst evaluators include verification, validation and feedback mechanisms (L4). We have explored these within the context of the individual processes, here, we seek to evaluate whether this is a sufficient explanation.

Indeed, the influence of culture on institutionalisation, an aspect not explicitly represented within our model, was highlighted by several participants. One noted how staff perceptions ranged from “*those going through the motions, to those more cognisant of how [risk management] supports the broader organisational processes.*” The participant further noted the importance of engaging and empowering operational staff in creating a risk management culture. Here, this took the form of expert practitioners supporting front-line staff to fulfil their risk management obligations (*e.g.* jointly conducted risk assessments) and actively seeking and considering their feedback in revising existing processes (*e.g.* adapting risk evaluation criteria to reflect

operational expertise). We further observed that a prerequisite for cultural change is commitment from executive and senior management, which is often dependent on external events. One manager noted that “*[the risk management team] have finally got the attention of our organisation; early on we couldn’t get much dignity...then a series of events occurred in the [United States] which made risk assessment more important, which resulted notably in the Sarbanes Oxley legislation, we have several members of our board who are very much attuned to that...once we got top level buy in, the rest followed.*” Similarly, one participant reflected that “*Enron, Barings...showed that companies can go under if their controls fail, [whilst] Railtrack showed that companies could lose their [license to operate]. [Another] wake up call was the idea of corporate manslaughter; [this] made us focus our efforts on...assets with low likelihood of failure but high consequence, for example critical reservoirs.*”

### **5.3.8 Supply chain risk management**

This process addresses both the way utilities obtain the raw components required to develop products and the management of services provided by organisations throughout the supply chain (e.g. outsourcing agreements). Here, we observed two L2, two L3, and four L4 utilities. One L2 manager revealed that supply chain risk management was primarily “*left to procurement,*” with formalised approaches to risk management tending to apply only to larger, discrete projects. Similarly, one L3 interviewee stated that risk management was only explicitly involved in supply chain management in relation to products and services critical to their continued operation, further noting that “*although [we] evaluate, qualify and support [our] critical vendors and suppliers, this is not within the context of a formal risk based process.*” In contrast, within one L3 utility risk management was explicitly interwoven within

procurement policies and procedures. Inspection of their contracting and tendering policy revealed that in contrast to the traditional approach of selecting lowest cost suppliers once basic standards are met, a broad range of pre-qualification standards are applied as appropriate, including those that address risk explicitly (*e.g.* occupational health and safety, commercial risk, delivery risk) and implicitly (*e.g.* quality management accreditation). Furthermore, prior to binding acceptance, the probability of failure of the chosen tender to satisfactorily adhere to the contract, and the potential effects of such a failure, were formally assessed and reported.

We obtained limited data on the practices of those L4 utilities, however, we observed that one required all contractors to utilise a formal risk management framework, whilst another adopted criteria to ensure that the “risk attitude” of capital partners aligned with their own.

### **5.3.9 Change risk management**

This process is concerned with identifying and managing the risk implications of organisational (*e.g.* re-engineering) and technical change. Here, we evaluated one utility at L2, and three each at L3 and L4. We observed the expected lack of process definition within the L2 utility, whose respondent noted that where changes to *e.g.* operating or asset standards are considered, “*risk would be part of the decision making process, although the level of formality would vary.*” Regarding organisational change, the interviewee stated that “*whilst the utility has a team dedicated to providing support and education for the implementation of business process improvements, it does not focus on the risk implications of change.*” At L3 and L4, we observed the undertaking of risk analysis to evaluate the expediency of planned technical changes; the use of SWOT analysis to evaluate the “business environment” for changes that may constrain

utility operations and management; application of environmental impact assessments for projects that modify existing processes or introduce new processes, activities or equipment; and regular analyses and reviews of risks and interdependencies within organisational change programmes.

### **5.3.10 Education and training in risk management**

Here, we observed one L1 organisation, two at L2, and five at L3. An *ad hoc* approach was observed within the L1 utility, with no formal process in place to develop or maintain risk management skills and knowledge, and limited cognisance of the required competencies for effective undertaking of the discipline. As the L1 manager noted “*we recognise we have an issue here...we took over one hundred people through risk training in 2000/01, [but we’ve] done nothing since...the next logical step was to cascade it across business...which we haven’t.*” Emphasising the importance of this deficiency, he noted “*we recognise some people have no knowledge of the [risk management] process, yet are expected to prioritise capital investment on the back of it; [but the] only hint of training is when they get shot down at [the consistency checks].*”

The defining characteristic of the L2 organisations was their limited process scope, with limited internal training in risk management (*e.g.* addressing occupational health and safety), supported by attendance of externally delivered courses for key managerial and operating staff (*e.g.* risk management conferences, HACCP training for operating staff). For example, one L2 utility’s site induction procedures sought to ensure that staff understood site-specific hazards and the precautions required to protect their safety and the quality of service. These covered basic issues such as the isolation and lock out procedures required for machinery during maintenance works, site

emergency procedures, confined space entry procedures, and the location of the first aid kit. This was supplemented by video-based training on: risk management planning for drinking water supplies; job safety analysis; and safety leadership. Indeed, this emphasis on “on the job” training was a common theme at L2, the logic perhaps being that staff learn best through real life, hands on examples, rather than lectures and presentations. As the electricity utility interviewee noted, *“most of the education and indoctrination was [achieved] by running [risk management] workshops. At one time my staff were running forty to fifty workshops a year, so all the executives and managers were constantly exposed to this whole methodology of identifying, prioritising and mitigating risk; [towards the end], they’d come and borrow our anonymous voting equipment and run their own workshops.”*

Valuable insights regarding the formalisation of education and training may be gleaned from one L3 utility. Here, two dedicated risk management training packages were observed: an introductory course provided to key strategic members of the business, and a more comprehensive programme delivered to “team leaders.” Of greatest interest is the latter, which was structured around a formal definition of the competencies required for effective risk management, ranging from an understanding of corporate governance to a grasp of the technical aspects of the risk assessment techniques adopted. Both packages were initiated by procedure, with oversight from local management and the risk management team to verify compliance. Furthermore, effective delivery of the process was verified through cyclical evaluations of the ability of staff to act on the training received. These evaluations partly underpinned succession routes, providing a strong catalyst for learning. Supplementing these programmes, *ad hoc* training workshops were provided by risk management staff on request.



In a more operational context, one L3 manager described how in addition to externally delivered HACCP training for key staff, internal training on the fundamentals of drinking water quality management focussed specifically on embedding the risk-based approach inherent in their operating and management principles. Furthermore, their post-incident analyses included an explicit evaluation of the *a priori* risk management strategy, which the interviewee emphasised breeds familiarity with the methodologies and processes of risk management and, by focussing on real examples (or plausible scenarios), highlighted the practical implications of the discipline to front-line staff.

### **5.3.11 Risk knowledge management**

Here, we observed three utilities at L2, and five at L3. Risk knowledge management may be considered as the collection, storage and access of the data underpinning and accumulated from the broader risk management processes, *i.e.* the input and output data. One L2 manager stated that input data requirements for risk management were not well defined, and noted that they “*do not maintain detailed risk information beyond that which is accumulated during risk assessments or that inherent in the normal conduct of business.*” The interviewee assigned this to both a “resource driven inadequacy” and inadvertent constraints imposed by legislation: “*in the public sector...we’re subject to open records request...you don’t want [your risk analyses appearing] in the newspaper the next day, how we store those documents and record our decisions is a strategy in itself, we try to limit circulation, which may be counter-productive to traditional risk management.*”

At L3, we observed procedures governing the use of software packages which serve as tools for the collection, storage and access of output data collected throughout

the life-cycle of risk management. However, pre-defined strategies of input data collection were restricted to select operational risks, particularly those whose management was underpinned by formal analytical methodologies (e.g. reliability modelling), or, as one manager noted, subject to regulatory drivers (e.g. asset management, drinking water quality management). The electricity utility interviewee suggested that this is dictated by pragmatism, as “*raw data requirements are fluid and evolve with the perceptions of management.*” However, we contend that in the absence of predefined requirements, risk data collection is likely to be *ad hoc*, and largely restricted to the requirements of “business as usual.” Indeed, one manager described a reliance on “*expert judgement; without senior experienced people, I’m not sure we have the data to underpin [risk management].*” A further observed L3 characteristic was the lack of expertise for validation (*i.e.* to ensure that the correct data is being collected); to the extent that it is applied, it is informal and *ex-post*.

## **5.4 CONCLUSIONS**

We have described the application of a capability maturity model to benchmark risk management within eight water utilities. The findings provide utility managers, technical staff, chief finance officers and regulatory officials with a systematic understanding of how to implement and improve risk management. This is timely work for a sector grappling to adapt to evolving regulatory and governance arrangements. Furthermore, the research provides a basis for evolving the model from a prescriptive to a descriptive state, which will ultimately render it fit for industrial ownership.

### *Acknowledgements*

This work has been funded by the American Water Works Association Research Foundation (AWWARF project RFP2939) and a consortium of international water utility companies. The comments and views herein are the authors' alone. BM is co-funded on a UK Engineering and Physical Sciences Research Council (EPSRC) Doctoral training account.

## **5.5 REFERENCES**

- Booth, R. and Rogers, J., Using GIS technology to manage infrastructure capital assets, *J. AWWA*, **93**(11): 62, 2001.
- COSO, *Enterprise risk management framework - Executive Summary*, 2004. (website: [www.otpp.com](http://www.otpp.com)).
- Council of Standards of Australia, *Australian/New Zealand risk management standard No.4360: 1999*, 1999.
- Dalkey, M. and Helmer, O., An experimental application of the Delphi method to the use of experts, *Management Science*, **9**(3): 458, 1963.
- Deere, D., Stevens, M., Davison, A., Helm, G. and Dufour A., *Management strategies, Water quality: guidelines, standards and health*, Edited by Fewtrell, L. and Bartram, J., WHO, IWA Publishing, London, 257-288, 2001.
- Hamilton, P.D., Pollard, S.J.T., Hrudey, S.E. and MacGillivray, B.H., Risk management frameworks for the water sector – a review, *at review*, 2006.
- Havelaar, A.H., Application of HACCP to drinking water supply, *Food Control*, **5** (3): 145, 1994.

- IMPRESS Management, *Guidance for the analysis of pressures and impacts in accordance with the water framework directive*, Draft 5.2, European Commission, Brussels, 2002.
- Lifton, G. and Smeaton, P., Asset risk management in Scottish Water, *Proc. of the ICE/CIWEM Conference: Risk and reward in asset management delivery – who is best prepared for the challenges ahead?*, 14<sup>th</sup> November, 2003, London, UK.
- Lloyd, R. and Abell, P., Capital maintenance in Yorkshire Water's water business unit, *Proc. of Risk analysis strategies for better and more credible decision making*, 6-8<sup>th</sup> April, 2005, Banff, Canada.
- MacGillivray, B.H., Strutt, J.E., Sharp, J.V., Hamilton, P.D. and Pollard, S.J.T. Benchmarking risk management within the water utility sector. Part I: Design of a capability maturity methodology, *J. Risk Research*, in press, 2006a.
- MacGillivray, B.H., Hamilton, P.D., Strutt, J.E., Pollard, S.J.T. (2006b) Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making, *Critical Reviews in Environmental Science and Technology*, **36**, 85-139.
- Paulk, M.C., Curtis, B., Chrissis, M.B. and Weber, C.V., Capability maturity model, version 1.1, *IEEE Software*, **10**(4): 18, 1993.
- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Hamilton, P.D. and Hrudey, S.E., Risk analysis and management in the water utility sector – a review of drivers, tools and techniques, *Trans. IChemE, Part B: Proc. Safety Environ.*, **82**(B6): 1, 2004.
- Sarshar, M., Haigh, R., Finnemore, M., Aouad, G., Barrett, P., Baldry, D. and Sexton, M., SPICE: a business process diagnostics tool for construction projects, *Engineering, Construction and Architectural Management*, **7**(3): 241, 2000.

- Sharp, J.V., Strutt, J.E., Busby, J. and Terry, E., Measurement of organizational maturity in designing safe offshore installations, *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering*, **2**: 383, 2002.
- Software Engineering Institute, *CMMI for systems engineering / software engineering / integrated product development / supplier sourcing, version 1.1.*, 2002a. (website: <http://www.sei.cmu.edu/>).
- Software Engineering Institute, *People capability maturity model, version 2.0.*, 2002b. (website: <http://www.sei.cmu.edu/>).
- Stahl, G.R. and Elliott, J.C., 'New generation' computer models for risk-based planning and management, *Water Supply (Australia)*, **17**(3/4): 289, 1999.
- Stevens, I.M. and Lloyd, R.I., *Water resources: Sustainable optimisation and security of supply, a proven example*, Paper presented to the 2004 Water Sources Conference and Exposition, Jan 11-14th, 2004, Austin, Texas.
- Strutt, J.E., *Reliability capability maturity briefing document*, Report No. R-03/2/1, Cranfield University, 2003.
- Strutt, J.E., MacGillivray, B.H., Sharp, J.V., Pollard, S.J.T. and Hamilton, P.D., Measuring risk management capabilities, *Proc. of Risk analysis strategies for better and more credible decision making*, 6-8<sup>th</sup> April, 2005, Banff, Canada.

## **Chapter 6**

# **Benchmarking Risk Analysis Practice in the International Water Sector**

Published in *Water Practice and Technology*, 1(2):1.

## **6. Benchmarking Risk Analysis Practice in the International Water Sector**

B.H. MacGillivray<sup>1</sup>, P.D. Hamilton<sup>1</sup>, S.E. Hrudey<sup>2</sup>, L. Reekie<sup>3</sup> and S.J.T Pollard<sup>1\*</sup>

<sup>1</sup>Department of Sustainable Systems, School of Industrial & Manufacturing Science, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK

<sup>2</sup>Department of Public Health Sciences, University of Alberta, Edmonton, AB, Canada T6G 2G3

<sup>3</sup>American Waterworks Association Research Foundation, 666 West Quincy Avenue, Denver, CO 80235, USA

### **ABSTRACT**

Risk analysis in the water utility sector is fast becoming explicit. Here, we describe application of a capability model to benchmark the risk analysis maturity of a sub-sample of eight water utilities from the USA, the UK and Australia. Our analysis codifies risk analysis practice and offers practical guidance as to how utilities may more effectively employ their portfolio of risk analysis techniques for optimal, credible, and defensible decision making.

**KEYWORDS** analysis, benchmarking, governance, management, risk.

## 6.1 INTRODUCTION

The provision of safe, reliable drinking water, the overarching goal of the international water utility sector (AWWA *et al.*, 2001), is arguably well within the bounds of the developed world's science, technology, and financial resources. Nevertheless, water quality related outbreaks remain depressingly prevalent (*e.g.* Hrudey and Hrudey, 2004), with their causes ranging from technical failures through to lapses or even criminal negligence on the part of operating or managerial staff. Risk analysis can help prevent such failures through proactively identifying and assessing the mechanisms through which they may arise. This concept of *preventing failure through understanding failure* extends beyond the design and operation of a water supply system to encompass the full range of utility functions (*e.g.* from plant operations to strategic investment; Figure 6.1).



Figure 6.1 The risk hierarchy (adapted from Prime Minister's Strategy Unit, 2002)



Indeed, the introduction of water safety plans, codes of good corporate governance and the debate on self-regulation are promoting a shift in the approach to risk analysis to one increasingly explicit and integrated with other business processes. Risk analysis now extends beyond its traditional preserve in occupational health and safety and public health protection to embrace corporate level decision making, asset management (Booth and Rogers, 2001; Lifton and Smeaton, 2003), watershed protection (IMPRESS Management, 2002; WHO, 2003; Lloyd and Abell, 2005) and network reliability (Stahl and Elliott, 1999; Stevens and Lloyd, 2004). When supported by initiation criteria and formal procedures, using personnel with appropriate skills, experience, and resources, risk analysis can provide utilities with benefits ranging from an improved understanding of treatment reliability to an explicit appreciation of project financial risks (MacGillivray *et al.*, 2006a). Applied inappropriately, whether due to ill-defined procedures or deficient institutional capacities, risk analysis is not a subset of risk management but its panacea.

As such, a reasonable research question is: how can we assess and improve organisational competencies in risk analysis? In this paper, we report on the application of a maturity model to benchmark risk management within the international water utility sector, focussing on the findings relating to risk analysis.

## **6.2 RESEARCH SCOPE**

Before proceeding, it is necessary to explain what we mean by risk analysis and risk management. Risk is widely accepted to consist of a combination of probabilities and consequences. A more pragmatic approach is to consider risk as the potential for deviation from desired outcomes (*e.g.* business objectives, design intentions). We consider risk management to be a series of processes for identifying, evaluating and

responding to these uncertainties. Risk analysis involves the identification and assessment of risk. Given the varying contexts within which risk analysis is applied, we view the juxtaposition of both the technical and managerial aspects of the prior art as central to providing a well-rounded examination of its application within the sector.

## **6.3 METHODS - RISK MANAGEMENT CAPABILITY MATURITY**

### **MODEL**

Capability maturity models (Paulk *et al.*, 1993) codify industry practice so distinctions can be made between organisations and improvements made. Our risk management capability maturity model (MacGillivray *et al.*, 2006b) adopts five levels of maturity, from learner to best practice. Its design has drawn on wide-ranging literature reviews, structured interviews with utility managers and prior knowledge of maturity modelling in similar utility sectors. The model includes, in part, an evaluation of the maturity of implementation of risk analysis, one feature of an organisation's capability to manage risk. Attributes describing the maturity of all risk management processes, including risk analysis, and the specific descriptions of maturity levels 3 (L3) and 4 (L4), as they refer to risk analysis, are in Table 6.1.

*Table 6.1 Basic descriptions of the attributes characterising risk analysis maturity*

<b>Attribute</b>	<b>Attribute description</b>	<b>Attribute at level 3: Risk analysis</b>	<b>Attribute at level 4: Risk analysis.</b>
Scope	The execution of key practices, and the breadth of process implementation across the organisation.	A defined, documented process is in place containing criteria, methods and guidelines for the identification, assessment and evaluation (with respect to acceptance criteria) of a broad range of risks across core business areas, guided by a risk register. The organisation is conversant with and goes beyond the regulatory requirements for risk analysis.	A controlled process is in place containing detailed criteria, methods and guidelines to manage the identification, assessment, evaluation (with respect to acceptance criteria), establishment of causality and linking (common cause and dependent) of risks at all levels of the company and across all functional boundaries of the business, guided by a company-specific risk register.
Integration	The level of process embedment within the organisation.	Procedures are in place to initiate risk analysis processes.	Risk analysis is initiated automatically as part of core business processes ( <i>e.g.</i> periodic business risk assessments).
Verification and Validation	Verification refers to ensuring that the process is being performed correctly, validation refers to ensuring that the correct process is being performed.	Basic mechanisms are in place to verify that risk analysis is performed as required, largely reliant on lagging indicators. The expertise for validation is generally lacking.	Verification and validation systems are in place to verify the efficiency of risk analysis activities and to validate their expediency ( <i>e.g.</i> the organisation tracks that tools and techniques are being used correctly and that the correct tools and techniques are being used).
Feedback and Organisational Learning	The manner in which feedback, both internally and externally sourced, is collected and used to question and revise processes.	The risk analysis tool suite is reviewed and modified on an event-driven basis.	Feedback is actively used to improve the execution of risk analysis ( <i>e.g.</i> gaps identified and risk analysis tools and techniques improved in response).
Stakeholder Engagement	The process of engaging stakeholders, both internal and external, with the purpose of leveraging the process.	Risk analysis processes generally reside within the responsible unit, with limited cross-functional or external consultation.	Risk analysis processes generally reside within affected disciplines, and stakeholders work together to define and implement an integrated approach to risk analysis, capitalising on synergies and collective knowledge.
Competence	The organisational qualities and abilities, both implicit and explicit, which influence process performance.	Detailed knowledge of risk analysis resides only within the responsible unit.	Most involved staff exhibit a good level of competence in the selection and application of risk analysis tools and techniques, and have access to support from internal or external expert risk practitioners.
Resources	Extent and use of resources ( <i>e.g.</i> people, pounds and tools)	Adequate resources are provided in support of risk analysis, with both qualitative and quantitative tools and techniques available.	Sufficient resources are provided in support of risk analysis, a portion of which is made available for R + D for risk assessment. A broad range of qualitative and quantitative tools and techniques are available and applied, including methodologies for aggregating and comparing risks.
Documentation and Reporting	Documentation and reporting of risk information.	Risk analysis outputs are compiled and disseminated in a format that supports decision-making.	Risk analysis outputs are compiled and disseminated in a clear, concise and actionable format that supports real-time decision-making, and their reporting is co-ordinated with other risk reporting mechanisms ( <i>e.g.</i> risk status updates).

## **6.4 RESULTS AND DISCUSSION**

We have applied the risk management capability maturity model to the water sector in the US, the UK Canada and Australia and, for a sub-sample of eight utilities providing high quality data, have captured common, good and best practice in risk analysis. Benchmarking comprised three components: self-assessment by questionnaire; semi-structured interviews; and document analysis. With respect to risk analysis, contributors to this sub-sample were described as being at either L3 or L4, though we do not suggest this reflects risk management capability for the sector as a whole. A key finding of our research is that risk analysis is not best viewed as an overarching process, but rather as a series of discrete processes within which distinct analysis methodologies are applied, which themselves reside within organisational functions. We therefore discuss our observations on a function-specific basis.

### **6.4.1 Process engineering**

A prerequisite for process definition (L3) is that the application of risk analysis techniques is guided by formalised procedures – a practice intended to ensure the consistency and rigour of analysis. We observed this within process engineering in one utility, where a technical guideline had recently been devised for the application of hazard and operability studies (HAZOP). HAZOP systematically evaluates the process and engineering intentions of new or existing facilities in order to identify the hazards that may arise due to deviations from design specifications (American Institute of Chemical Engineers, 1992). Typically, a carefully selected team examines a process (*e.g.* disinfection) subdivided into “nodes,” at each node, the team applies guidewords (*e.g.* low) to process parameters (*e.g.* ozone levels) to identify ways in which the

process may deviate from its design intention, before evaluating the causes and consequences of the deviation. The logic of process definition is that specifying the stages in the design process for the application of HAZOP, proceduralising the tasks and activities central to its execution, and providing staff with the requisite expertise (*e.g.* through workshops), creates a process infrastructure that supports its execution beyond the tenure of experienced staff. This is particularly important in an industry characterised by regular restructuring and high levels of staff turnover.

#### **6.4.2 Business planning**

We now turn to discuss the strategic approach to risk analysis which focuses on “business risks”, *i.e.* those primarily non-technical risks with the potential for causing deviation from high-level business objectives. Within one utility, we observed this to be proceduralised within the second of two business planning workshops. The first addressed the market and competitor environment, including: social, technological, environmental, economic and political (STEER) analysis; strengths, weaknesses, opportunities and threats (SWOT) analysis; strategic objectives; and strategic options. From this, the “strategic direction” was set for each business area, which served as the initiation point for the risk analysis workshop. Here, the outputs of the previous workshop, allied with brainstorming and knowledge of historic risk analyses, informed the identification of risks to achieving business objectives (*e.g.* in finance: impact of adoption of International Accounting Standards). A qualitative risk ranking matrix was then applied to assess their potential impact and likelihood of occurrence.

However, in common with the remainder of our sub-sample, this strategic risk analysis tended to rely more upon expert judgement rather than being underpinned by

extensive data analysis. One manager opined that as their strategic risk portfolio tended to evolve over time and with the perceptions of management, a predefined strategy of data collection to support its analysis was not pragmatic. As such, the role of internal audit and the risk management group in facilitating and providing quality assurance (L4) of these workshops, observed within one utility, is critical to ensuring that strategic risk analysis provides utilities with an improved understanding of the risks that they are seeking to manage, rather than simply being an exercise in fortune telling blindly undertaken to satisfy corporate governance regulations. In another utility, quality assurance had historically encompassed the use of a “professional support group” – comprised of experts drawn from multiple disciplines (*e.g.* legal, insurance, finance, environmental and quality, health and safety) who were independent of the risk analysis process – to peer review the strategic risk analysis.

### **6.4.3 Asset management**

Balancing risk and resources has long been an implicit component of asset management, and is becoming increasingly explicit owing to growing pressures for utilities to exhibit financial self-sufficiency, meaning that they can no longer seek to over-engineer facilities with the presumption of screening out technical risk (MacGillivray *et al.*, 2006a). A risk-based approach to asset management requires an integrated, systematic process drawing upon a broad range of methodologies for the identification, analysis and prioritisation of assets-at-risk, from the process to the component level (*e.g.* Booth and Rogers, 2001). Within one utility we observed the undertaking of failure mode, effects and criticality analysis (FMECA) studies across their water supply systems. FMECA is an engineering technique that tabulates failure modes of equipment and their effects on a system (American Institute of Chemical

Engineers, 1992). The failure mode describes how equipment fails (open, closed, on, off, leaks, *etc.*); failure effect is determined by the system's response to the equipment failure. Its application allows the utility to identify and prioritise risks across their asset portfolio (*e.g.* various mains, raw and treated reservoirs, treatment works *etc.*), enabling them to focus attention on the most serious threats to system performance. We observed that their procedures for undertaking and updating FMECA studies were initiated on a cyclical basis. The interviewee highlighted the value of this requirement, noting that prior to its introduction, supported by a central asset risk register, risk analyses were not regularly updated, instead being performed for a specific purpose at decision making points.

We further observed mechanisms for ensuring procedural compliance and proving quality assurance of risk analysis in recognition of its central role in shaping capital investment programmes. This was driven by a desire to ensure consistency in application and to correct for analyst bias. Within one utility, whilst “experts in the field” regarding asset condition principally undertook the analysis, this was supported by a programme of facilitated workshops to ensure consistency. Additionally, the administrator of the asset database conducted spot check audits and was further responsible for the ongoing moderation of analysis outputs.

#### **6.4.4 Drinking water quality management**

The revised WHO guidelines (WHO, 2003) are promoting the implementation of water safety plans for water quality management from catchment management, through treatment, distribution and on to the tap. Central to this is the hazard analysis and critical control points (HACCP) methodology, namely the determination of “critical

control points” whereupon risks can be monitored and reduced (Codex Alimentarius, 1993; Hellier, 2000). We observed the implementation of this approach within our sub-sample. In one utility, the process begins with the division of the water system into subsystems (*e.g.* catchment, treatment, distribution, *etc.*). Across each subsystem (*e.g.* catchment) hazard types (*e.g.* physical: turbidity and colour) and their associated causes (*e.g.* erosion) and driving events (*e.g.* landslip, storm) are identified and rated via a qualitative risk ranking matrix. Those deemed most significant were evaluated further for their critical control points (operational parameters describing the effectiveness of control measures designed to mitigate water quality hazards, *e.g.* ph residuals at and post disinfection). Assessors then identified the critical limits (*e.g.* 2000 cells/mL of cyanobacteria for taste and odour related hazards), monitoring programmes and corrective actions for each CCP.

We now highlight the subtle distinction between verification, which seeks to evaluate whether the process has been followed correctly, and validation (L4), which is concerned with whether the process itself is correct (*e.g.* validating the risk analysis methodologies). Both of these aspects were enshrined in one utility’s application of a “common sense screen” at the end of their HACCP-based process. Here, if analysis outputs appeared at odds with experienced operational knowledge, the reason behind the “false” score was investigated, and either the process and score adapted where appropriate.

## **6.5 THE PRACTICAL LESSONS**

So what does this mean for utility managers? How can they assess their current maturity in risk analysis and identify practical steps to improve? Given that risk



analysis is best treated as a function specific, not overarching discipline, we suggest that they gather representatives from their various functional areas and ask them “the four questions.”

*What methodologies do you apply to identify and assess risks?*

A self-explanatory question, but care should be taken to delve deeply, as the authors have experience of utility engineers viewing risk analysis methodologies as something that “the corporates” apply, neglecting to consider their own use of HAZOP.

*Have you defined how these methodologies are applied and supported?*

Specifically, this seeks to determine whether: initiation criteria are formalised; procedures exist detailing how the methodologies are to be applied; and whether the requisite resources (*e.g.* data inputs, skills) are predefined and available. As we have noted, this creates a process infrastructure which ensures consistency and stability of execution.

*Do you verify that risk analysis is undertaken, and undertaken correctly?*

This seeks to establish whether risk analysis is *controlled* as a process. Ensuring that risk analysis is undertaken as required can be attained through, for example, supervisory “sign off” of completed assessments. Ensuring that risk analysis is undertaken properly (*i.e.* quality assurance) may be achieved through peer reviews. Where HAZOP is applied, for example, questions for the reviewers to pose may include: did the analysts work their way through the HAZOP study systematically, or did they overlook important scenarios, components and process flows; were all stages and operating modes of the process considered (*e.g.* startup, shutdown and transitioning to partial operation); and was adequate time spent on the analysis.

*Do you know whether your risk analysis process is valid?*

In our experience, this is the most difficult question to answer. Regardless, managers should not shy away from examining whether, for example, the application of HACCP within drinking water quality management constitutes good practice, or if recourse to quantitative methodologies is justified. Validation appears a weakness of the sector, and managers should not be distracted by justifications as to why staff *think* that their process is valid, but instead focus on whether objective evidence exists. Methods for validation include external audits, benchmarking, or statistical techniques in the case of quantitative methodologies.

## **6.6 CONCLUSIONS**

Our benchmarking results provide utility managers, chief finance officers and regulatory officials with valuable insights into the developing risk management culture within water utilities and a systematic understanding of good risk analysis practice. Of course, there is a trade off between the investments required to become leading-edge in risk analysis and the benefits to be obtained. Risk analysis remains a largely expert discipline, and many organisations are more comfortable with their historic implicit approaches. However, this does not absolve them of their obligation to understand how mature their risk analysis processes are, and how they may be improved. Only then can the cost-benefit implications of progression up the maturity scale be evaluated.

### *Acknowledgements*

This work has been funded by the American Water Works Association Research Foundation (AWWARF project RFP2939) and a consortium of international water

utility companies. The comments and views herein are the authors' alone. BM is co-funded on a UK Engineering and Physical Sciences Research Council (EPSRC) Doctoral training account.

## 6.7 REFERENCES

- American Institute of Chemical Engineers, *Guidelines for Hazard Evaluation Procedures, 2<sup>nd</sup> Edition*, American Institute of Chemical Engineers, New York, 64-67, 1992.
- AWWA, EUREAU, WSAA and DVGW, *Bonn Workshop 2001 – Key principles in establishing a framework for assuring the quality of drinking water: a summary*, AWWA, Denver, CO., 2001.
- Booth, R. and Rogers, J. Using GIS technology to manage infrastructure capital assets, *J. AWWA*, **93**(11): 62-68, 2001.
- Codex Alimentarius, *Guidelines for the Application of the Hazard Analysis and Critical Control Point (HACCP) System*, ALINORM 93 / 13A, Appendix 2, WHO, Geneva, 1993.
- Hellier, K., Hazard analysis and critical control points for water supplies, *Proc. 63<sup>rd</sup> Annual Water Industry Engineers and Operator's Conference*, Warrnambool, 6-7<sup>th</sup> September, 2000.
- Hrudey, S.E. and Hrudey E.J., *Safe drinking water: Lessons from recent outbreaks in affluent nations*, IWA Publishing, 2004.
- IMPRESS Management, *Guidance for the analysis of pressures and impacts in accordance with the water framework directive*, Draft 5.2, European Commission, Brussels, 2002.

- Lifton, G. and Smeaton, P., Asset risk management in Scottish Water, *Proc. of the ICE/CIWEM Conference: Risk and reward in asset management delivery – who is best prepared for the challenges ahead?*, 14<sup>th</sup> November, 2003, London, UK.
- Lloyd, R. and Abell, P., Capital maintenance in Yorkshire Water's water business unit, *Proc. of Risk analysis strategies for better and more credible decision making*, 6-8<sup>th</sup> April, 2005, Banff, Canada.
- MacGillivray, B.H, Hamilton, P.D., Strutt, J.E., Pollard, S.J.T., Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making, *Critical Reviews in Environmental Science and Technology*, **36**: 85, 2006a.
- MacGillivray, B.H., Strutt, J.E., Sharp, J.V., Hamilton, P.D. and Pollard, S.J.T., Benchmarking risk management within the water utility sector. Part I: Design of a capability maturity methodology, *J. Risk Research*, in press, 2006b.
- Paulk, M.C., Curtis, B., Chrissis, M.B. and Weber, C.V., Capability maturity model, version 1.1, *IEEE Software*, **10**(4): 18, 1993.
- Prime Minister's Strategy Unit (2002) *Risk: improving Government's capability to handle risk and uncertainty*, The Strategy Unit, London, 2002. (website: <http://www.number-10.gov.uk/SU/RISK/risk/home.html>).
- Stahl, G.R. and Elliott, J.C., 'New generation' computer models for risk-based planning and management, *Water Supply (Australia)*, **17**(3/4): 289, 1999.
- Stevens, I.M. and Lloyd, R.I., *Water resources: Sustainable optimisation and security of supply, a proven example*, Paper presented to the 2004 Water Sources Conference and Exposition, Jan 11-14th, 2004, Austin, Texas.
- WHO, *Guidelines for drinking water quality, 3<sup>rd</sup> Edition (draft)*, WHO, 2003. (website: [http://www.who.int/water\\_sanitation\\_health/dwq/guidelines3rd/en/](http://www.who.int/water_sanitation_health/dwq/guidelines3rd/en/)).

## **Chapter 7**

# **A capability model for benchmarking risk analysis and risk based decision making practice, with case study application to the water sector**

Submitted to *Environment International*

## **7. A capability model for benchmarking risk analysis and risk based decision making practice, with case study application to the water sector**

B.H. MacGillivray and S.J.T. Pollard

*Centre for Water Science, Sustainable Systems Department, School of Applied Sciences, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, United Kingdom*

### **ABSTRACT**

We synthesize the principles of risk analysis, decision theory and capability maturity modelling with empirical observations to present a model for benchmarking and improving the processes of risk analysis and risk based decision making. We describe the model's case study application within a water and wastewater utility, providing a comparative analysis of the practices of risk analysis and risk based decision making across a cross-section of organizational functions and, crucially, their maturity of implementation. The findings provide academics, utility professionals, and regulatory officials with a deeper understanding of the practical form and theoretical underpinnings of risk management, and how distinctions can be made between organisational capabilities.

**KEYWORDS:** risk analysis, management, decision theory, benchmarking, water sector.

## 7.1 INTRODUCTION

The provision of safe, reliable drinking water, the overarching goal of the international water utility sector (AWWA *et al.* 2001), is within the bounds of the developed world's science, technology, and financial resources. Nevertheless, a nagging prevalence of water quality-related outbreaks remains in the developed world, with "causes" ranging from technical failures through to institutional lapses and in the extreme, negligence on the part of operating and managerial staff (*e.g.* see Hrudey and Hrudey, 2004). Regardless of the particular manifestation of these incidents, they all derive from limited organisational capacities, or appetites, to learn how to prevent failures, in other words, to manage risk.

Conventionally, utilities manage risk through codifying their basis for safe operations within standard design and operating procedures. These procedures develop with: (i) the introduction of improved methods and technologies (*e.g.* novel treatment processes); and (ii) experiences gained from reflecting on past mishaps. From a risk management perspective, we are concerned with the latter. This begins with a contamination event or near miss, following which incident analysis is undertaken to determine its root cause, and ends with a technical, operational or administrative solution (*e.g.* adapting design standards or operating procedures) designed to prevent its recurrence. This cycle exists at both the utility and sector level, the latter being reflected in changes to national or industry-wide codes, standards or regulations where learnings are generalisable. As Lee (1998) notes, whilst this retrospective approach to managing risk is necessary, it is a mistake to consider it sufficient. Procedures, guidelines and regulations can proliferate to the point where they become incomprehensible and, absurdly yet predictably, resources are diverted towards preventing incidents that have happened, rather than those most likely to happen (Lee,

1998). Furthermore, a reliance on learning by trial and error in isolation of more proactive strategies is arguably unsound where public health is at stake (*i.e.* if it is not too little, it is certainly too late). Although illustrated in a water quality context, this argument is generalisable to all aspects of the design, operation and management of utility systems (*e.g.* from process engineering to occupational health and safety management) and across the utility sectors.

Recognition of the limitations of *post-hoc* analysis has brought a paradigm shift within the water sector from reactive to proactive risk management, wherein utilities have sought to identify potential weaknesses and eliminate root causes of problems before they cause a failure (as reviewed in MacGillivray *et al.*, 2006a; Hamilton *et al.*, 2006a,b; Pollard *et al.*, 2004). This shift is being driven by the introduction of water safety plans, codes of good corporate governance, the debate on self-regulation and, more broadly, a growing recognition that the provision of safe drinking water deserves to be treated as a “high reliability” societal service (Pollard *et al.*, 2005). With this changing landscape in mind, a challenging research question is: how can we assess and improve organisational competencies in risk management? In this paper, we introduce a model for benchmarking and improving the *processes* of risk analysis and risk based decision making, and describe its case study application within a water and wastewater utility.

## **7.2 RESEARCH SCOPE**

As the lexicon of risk is at times bewildering, we now define some key terms and so clarify the scope of our research. A hazard is any situation, event or substance that has the potential to cause harm. Risk is the likelihood of a hazardous event occurring within a specified time period and leading to a defined consequence severity.



We define risk management as “learning how to prevent failures.” Whilst, to our knowledge, a novel definition, the theme underlies the myriad elaborations offered by others, and succinctly captures both the philosophical heart and practical value of the discipline (as learning implies both an improved understanding *and* a change in behaviour). Drawing upon the unlikely source of Confucius, we conceptualise three means by which water utilities learn to prevent failures, through: (i) reflecting on their past mishaps, which is bitterest; (ii) reflecting on those of other utilities, which is easiest; and (iii) *a priori*, using foresight to reflect on potential future mishaps, which is noblest. Our research addresses the latter on a premise that prevention is better than cure. *A priori* or proactive risk management is comprised of three processes: risk analysis; risk based decision making; and implementation of decisions. In short, risk analysis looks to the future to determine what can go wrong, the potential consequences and their relative likelihood, and the overall level of risk. Risk analysis informs risk based decision making, which involves the identification and evaluation of risk reduction options and, where deemed necessary (*i.e.* where the risk is considered unacceptable), selection of the optimal option(s). Of course, fine decisions are hollow gestures if left unimplemented, and so implementation completes the cycle. Our research focuses on risk analysis and risk based decision making.

### **7.3 A CAPABILITY MATURITY MODEL FOR RISK ANALYSIS AND RISK BASED DECISION MAKING**

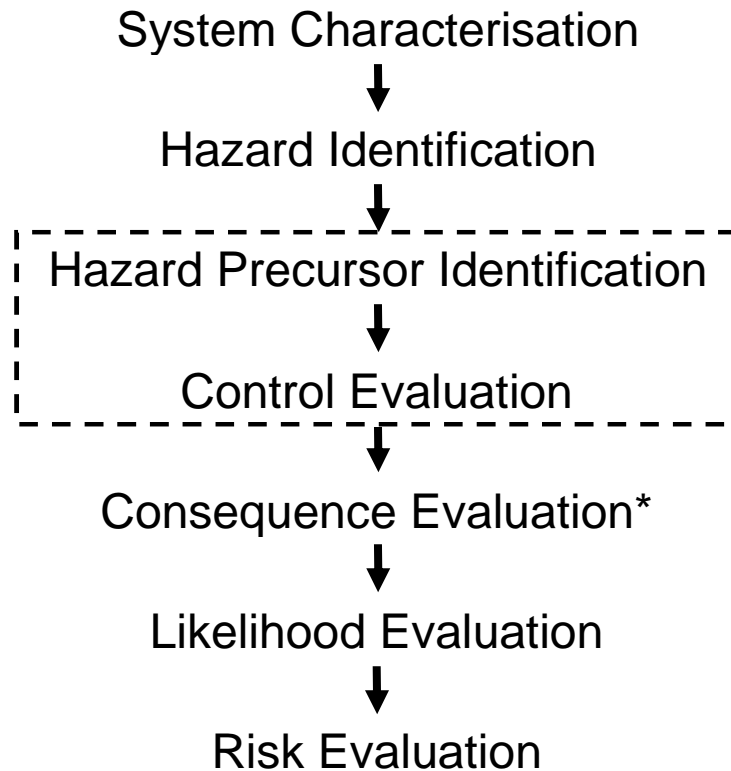
Capability maturity models codify industry practice so distinctions can be made between organisations and improvements made. We have reported the design (MacGillivray *et al.*, 2006b) and application (MacGillivray *et al.*, 2006c) of such a model for benchmarking risk management practice within the water sector. The model

was a *prescriptive* codification of water sector risk management practice, within a process-based maturity hierarchy. Its design drew on wide-ranging literature reviews (MacGillivray *et al.*, 2006a; Pollard *et al.*, 2004; Hamilton *et al.*, 2006b), structured interviews with utility managers, and prior knowledge of maturity modelling in similar utility sectors. We have since substantially revised the model towards a *descriptive* state, through an iterative synthesis of:

- (i) the capability maturity modelling literature (Paulk *et al.*, 1993; SEI, 2002a/b; Sharp *et al.*, 2002; Strutt *et al.*, 2006; Sarshar *et al.*, 2000);
- (ii) risk analysis and management frameworks, specific to the sector (NZMOH, 2001; NHMRC, 2001, 2004; WHO, 2002, 2004) and beyond (AS/NZS, 1999, 2004; COSO, 2004; UKOOA, 1999; FERMA, 2003; NIST, 2002; MHU, 2003; Joy and Griffiths, 2005; NEA/CSNI, 1999);
- (iii) decision theory (Slovic *et al.* 1977; Clemen, 1996; Watson and Buede, 1987) and its application to risk based decision making (Aven *et al.*, 2006; Rosness, 1998; Arvai *et al.*, 2001; Aven and Kørte, 2003, Bohneblust and Slovic, 1998; Amendola, 2001; Renn, 1999);
- (iv) quality management principles (Crosby, 1979, 1996; Hoyle, 2001; ISO, 2000); and
- (v) empirical observations derived from a prior case study and benchmarking study (MacGillivray *et al.*, 2006c) and the case study described in this paper.

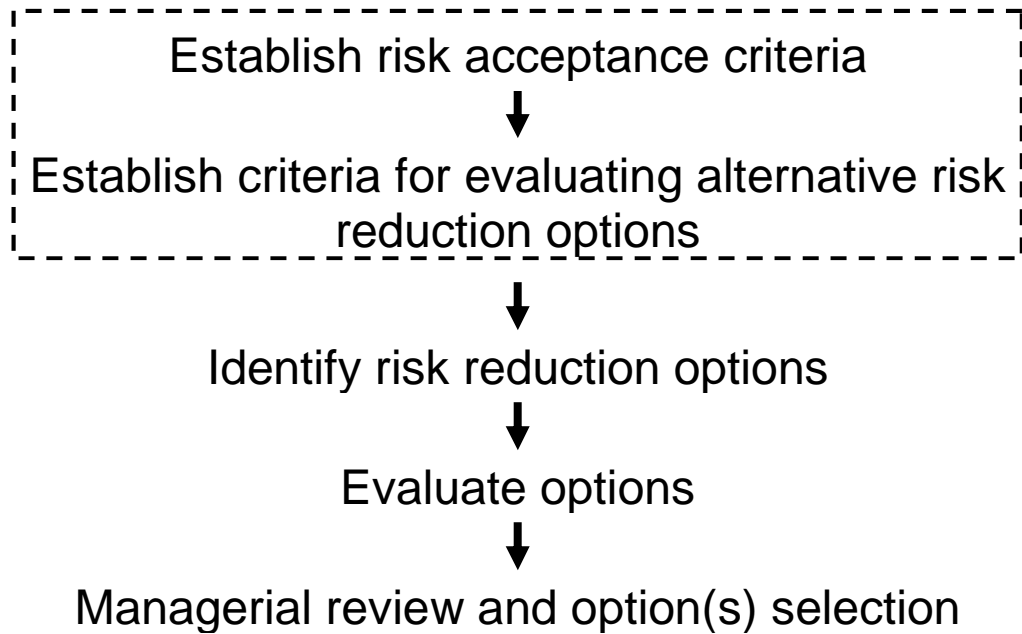
The current model incorporates the processes of risk analysis and risk based decision making. These processes are composed of a series of practices. Risk analysis (Figure 7.1; Table 7.1) comprises system characterisation, hazard identification, hazard precursor identification, control evaluation, consequence evaluation, likelihood

evaluation, and risk evaluation. Risk analysis is always part of a decision context (Aven and Kørte, 2003). Thus, risk based decision making (Figure 7.2; Table 7.2) is concerned with the identification and evaluation of risk reduction alternatives, followed by the application of managerial review prior to selecting the optimal risk reduction measure(s). These are informed by criteria establishing the acceptability of risk and setting out stakeholder values and concerns used to assess the relative merit of alternative risk reduction options. Both processes are separated into five maturity levels, from *ad hoc* to adaptive. These levels (Table 7.3), characterised in terms of the practices undertaken and attributes reflecting their maturity of implementation (Table 7.4), codify the extent to which each process is repeatable, defined, controlled and adaptive. Whilst the characterisations of the maturity levels (Table 7.3) and the process maturity attributes (Table 7.4) provided are specific to risk analysis, the same principles apply to risk based decision making. Note that to achieve a given maturity level, all positive requirements of that level and those preceding levels must be satisfied.



*Figure 7.1 Flow chart of the practices which comprise the risk analysis process. Those encased are considered key rather than critical practices, an important distinction in evaluating process maturity*

\*Note that whilst it is sometimes held that the ordering of consequence and likelihood evaluations is unimportant, we believe it critical that the former precedes the latter. Our reasoning is simple: risk assessment involves determining the likelihoods of a range of potential outcomes, or the likelihood of one potential outcome. Thus, the outcome(s) should be defined prior to any evaluation of its (their) likelihood of occurrence. If these steps are performed in reverse, likelihood evaluation will inevitably be concerned with the likelihood of a hazardous event occurring (e.g. the probability of asset failure), rather than with the likelihood of an event occurring *and* leading to a defined outcome (e.g. the probability of an asset failing and leading to a given environmental impact). The former approach overestimates risk.



*Figure 7.2 Flow chart of the practices which comprise the risk based decision making process. Those encased are considered key rather than critical practices, an important distinction in evaluating process maturity*

*Table 7.1 Descriptions of the risk analysis practices and of the rationale for their inclusion in our model*

<b>Risk analysis practice</b>	<b>Description</b>	<b>Rationale</b>
System characterisation	To establish and describe the system with which risk analysis is concerned ( <i>e.g.</i> workplace, engineering process, project).	A comprehensive system understanding is a <i>sine qua non</i> for generating risk analysis outcomes that are valid and accepted by stakeholders.
Hazard identification	Identifying situations, events, or substances with the potential for causing adverse consequences, <i>i.e.</i> sources of harm or threats to the system.	A hazard left unidentified is excluded from subsequent analysis.
Hazard precursor identification	Whilst hazard identification is concerned with <i>what</i> can go wrong, precursor identification focuses on <i>how</i> and <i>why</i> things can go wrong, in other words identifying possible routes to and causes of failure.	The potential existence of a hazard does not in itself constitute a risk, as each hazard requires a process or pathway (precursor) to lead to its realisation. Thus, the value of this practice lies in both confirming the existence of pathways to failure (and therefore that a risk exists) and informing the development of risk reduction options focussed at root causes.
Control evaluation	The identification and assessment of existing technical, physical and administrative controls which may either reduce the likelihood of a hazardous event occurring, or serve to mitigate its severity of consequences. Assessment should address both the criticality of the controls ( <i>e.g.</i> based on their inherent capacity to reduce risk, whether they are proactive or reactive, <i>etc.</i> ) and their adequacy of design, management and operation.	An evaluation of existing controls: informs the evaluation of associated risk levels; serves to inform the development of risk reduction options through identifying latent and active control weaknesses ( <i>i.e.</i> through serving as a gap analysis of existing risk reduction measures); and captures the historic basis for safe, reliable system operation.
Consequence evaluation	Identifying the nature of the consequences of a hazardous event occurring ( <i>e.g.</i> financial, environmental) and assessing their severity of impact.	Deriving and combining measures of consequence and likelihood are required to establish the overall level of risk associated with a given hazard, so that management resources may be allocated accordingly and to assess the desirability of potential risk reduction measures ( <i>e.g.</i> to see if they satisfy the ALARP criteria).
Likelihood evaluation	The evaluation of the likelihood ( <i>i.e.</i> frequency or probability) that a hazardous event will occur and lead to a defined severity of consequence.	
Risk evaluation	Combining measures of likelihood and consequence severity to derive an overall measure of risk, either qualitative ( <i>e.g.</i> high, low) or quantitative ( <i>e.g.</i> expected loss of life, value at risk).	

*Table 7.2 Descriptions of the risk based decision making practices and of the rationale for their inclusion in our model*

<b>Risk based decision making practice</b>	<b>Description</b>	<b>Rationale</b>
Establish risk acceptance criteria	Establishing criteria for evaluating the acceptability of risk.	In the absence of such criteria, on what basis are decisions taken on whether to mitigate or accept risk?
Establish criteria for evaluating alternative risk reduction options	Establishing criteria used to evaluate the relative merit of alternative risk reduction options ( <i>e.g.</i> forecast risk reduction, technical feasibility, cost of implementation, latency of effects, environmental impacts, <i>etc.</i> ) and, where deemed appropriate ( <i>e.g.</i> where multi-attribute analysis is subsequently undertaken), weightings to establish their relative importance.	A range of risk reduction options may be considered for a particular decision context; the decision as to which is considered the best option is influenced by many factors. Different concerns and values often need to be considered simultaneously, and their relative importance may be valued differently by various stakeholders (Faber and Stewart, 2003). Making this explicit in the form of criteria can improve the credibility and defensibility of decision making, minimise the possibility that decisions will be second guessed or that their rationale be forgotten, remove barriers to stakeholder buy-in, and ensure the existence of an audit trail (SEI, 2002). More broadly, it enables value rather than “alternative focussed” decision making, the latter being characterised by the selection of an “optimal” option from a set of implied or poorly defined criteria (Arvai <i>et al.</i> , 2001).
Identify risk reduction options	Generating alternative solutions for the decision problem.	Options not generated are excluded from subsequent evaluation and, ultimately, implementation.
Evaluate options	There are three elements to this: forecasting the impact of each option against the individual evaluation criteria, determining the cumulative “goodness” of each option ( <i>e.g.</i> via cost-benefit analysis, multi-attribute analysis); and determining risk acceptability.	Systematically evaluating the individual and cumulative merits of alternative options should provide for more credible, defensible and rational risk based decision making. Determining risk acceptability follows as it is risk reduction options, not risks, which are unacceptable or acceptable (Fischhoff <i>et al.</i> , 1981), <i>i.e.</i> the acceptability of risk cannot be determined without considering the costs and benefits of maintaining vs. reducing current risk levels.
Managerial review and option(s) selection	The application of managerial judgement in reviewing the premises, assumptions, and limitations of analyses, prior to the final decision (after Aven <i>et al.</i> , 2006).	In line with Mintzberg (1994), we consider that decision analysis should compliment, but not replace, the knowledge, intuitions and judgement of decision makers, and further, that risk based decisions should not reflect theoretically or analytically derived perspectives that run counter to sound professional judgement (Hrudey and Hrudey, 2003). More specifically, given that risk is, at a fundamental level, an expression of uncertainty, and that the analysis of risk and decision alternatives is further subject to aleatory, epistemic and operational uncertainty (Amendola, 2001), the outputs must be treated diagnostically rather than deterministically, <i>i.e.</i> , they should provide decision support, not decisions.

Table 7.3 Descriptions of the risk analysis process maturity hierarchy, from ad hoc to adaptive

<b>LEVEL 5:</b> <i>Adaptive</i>	Validation	A broad range of mechanisms are in place to capture feedback potentially challenging the validity of the risk analysis process ( <i>e.g.</i> benchmarking surveys, professional networks, external peer reviews, mathematical validation of technical methodologies).
	Organisational learning	Norms and assumptions underpinning the design of the risk analysis process are openly questioned, critically evaluated and, where appropriate, revised in light of validation findings ( <i>i.e.</i> double loop learning).
<b>LEVEL 4:</b> <i>Controlled</i>	Verification	Verification extends beyond rigorous mechanisms to ensure procedural compliance ( <i>e.g.</i> sign offs supplemented by in-depth audits) to provide formal quality control of risk analyses ( <i>e.g.</i> peer reviews, challenge procedures, external facilitation, Delphi technique, <i>etc.</i> ).
	Organisational learning	Root and common causes of errors in the execution of risk analysis ( <i>e.g.</i> deficient communication, overly complex procedures, lack of education and training) are identified and resolved. Modifications to the design of the process are identified, evaluated and implemented within periodic and event-driven reviews, but remain largely reactive and externally driven ( <i>i.e.</i> mirroring changes to codes, standards, guidelines, <i>etc.</i> ).
<b>LEVEL 3:</b> <i>Defined</i>	<b>The critical and key risk analysis practices are explicitly undertaken.</b>	
	Procedures	Procedures exist to guide the execution of risk analysis, with an appropriate degree of standardisation, detail, and complexity.
	Roles and responsibilities	Risk analysis roles and responsibilities are allocated with sufficient regard for staff competencies and authorities.
	Initiation Criteria	Cyclical and event-based criteria are in place to guide the initiation of risk analyses.
	Resource management	The requisite monetary, human and technical resources are identified, acquired and deployed in support of risk analysis.
	Input data management	The requisite data inputs are identified, acquired and deployed in support of risk analysis.
	Output data management	Risk analysis outputs are collected, stored and disseminated in a manner that supports decision-making, satisfies audit requirements, and facilitates organisational learning.
	Verification	Basic mechanisms are in place to ensure compliance with risk analysis procedures, focussing on outputs rather than tasks performed ( <i>e.g.</i> sign offs on receipt of completed risk analyses).
	Validation	The validity of the risk analysis process is questioned in light of changes to regulations, codes and standards.
	Organisational learning	Non-compliances with risk analysis procedures are resolved on a case by case basis ( <i>i.e.</i> treated as isolated errors requiring sanction to prevent their recurrence). Improvements to the design of the risk analysis process are implemented in a reactive, <i>ad hoc</i> manner ( <i>e.g.</i> in response to changes in codes or regulations).
	Stakeholder engagement	A broad cross section of internal and external knowledge, experience, skills and perspectives is reflected within risk analysis, based on explicit guidelines or criteria for stakeholder engagement.
Competence	Staff exhibit adequate knowledge, skills and experience in risk analysis. Education and training in risk analysis is planned and executed based on established competency requirements.	
<b>LEVEL 2:</b> <i>Repeatable</i>	<b>The critical risk analysis practices are explicitly undertaken.</b>	
<b>LEVEL 1:</b> <i>Ad hoc</i>	<b>Risk analysis is absent; or the critical practices are implicitly or incompletely performed.</b>	



Table 7.4 Descriptions of the risk analysis process maturity attributes and their rationale for inclusion within our model

Attribute	Description	Rationale	Key aspects
Procedures	The rules guiding the execution of risk analysis.	Procedures serve to capture and disseminate knowledge of the optimal conduct of risk analysis so that it is maintained within the organisational memory rather than as hidden expert knowledge (NEA/CSNI, 1999), and so ensure its consistent, efficient conduct.	Appropriate standardisation and formalisation of procedures taking into account personnel experience and knowledge; participation of end users ( <i>e.g.</i> risk analysts) in their development; matching detail with complexity of work; making explicit the rationale for conducting risk analyses; being based on an analysis of the tasks required (NEA/CSNI, 1999; Health and Safety Laboratory, 2003).
Roles and responsibilities	Assignment of personnel to risk analysis roles and responsibilities.	To avoid the “not my job” phenomenon (Joy and Griffiths, 2005), and ensure risk analysis receives appropriate focus and resource allocations.	Matching role descriptions and assignment of responsibilities with personnel competencies and authorities (NEA/CSNI, 1999). Supporting well meaning statements that “risk management is everyone’s job” with specific requirements.
Initiation criteria	Stages or conditions which initiate risk analysis.	To ensure risk analyses is undertaken as required, rather than being initiated on an <i>ad hoc</i> , over zealous, or reactive basis, or marginalised as “make work.”	Identifying where risk analysis is necessary vs. where adherence to codes and standards can be said to discharge the duty (Health and Safety Laboratory, 2003; UKOOA, 1999), and making this explicit in cyclical and event-based criteria.
Resource management	The planning, acquisition, and deployment of funds, techniques and staff in support of risk analysis.	Resourcing of risk analysis is particularly critical during periods of reduced budgets and downsizing, which may bring an emphasis on economic rather than safe operation (NEA/CSNI, 1999).	Sufficiency and availability of financial resources; access to sufficiently competent human resources; and a range of risk analysis techniques which reflect the complexity of the organisation’s activities and working environment (Health and Safety Laboratory, 2003).
Input data management	The identification, collection, and storage of risk analysis data inputs.	The systematic identification and capture of data requirements serves to ensure analyses are underpinned by objective data evaluation, rather than reflecting best guesses in the guise of “expert judgement.”	The definition of data requirements / data sources for risk analysis, either at the process level or, where not practical, on a case by case basis, and mapping these to data collection and storage systems.
Output data management	The collection, storage and dissemination of risk analysis outputs.	Risk analysis outputs must be systematically recorded to inform decision makers, for audit and training purposes, and to facilitate future reviews (COSO, 2004; CSA, 2004). Further, this ensures staff have current knowledge of the human, technical, organisational and environmental factors that govern system safety (Reason, 1997).	Documenting in-depth the risk analysis outcomes, not simply the overall level of risk ( <i>e.g.</i> sources of data, assumptions used, methods followed, <i>etc.</i> ). Although in theory the storage media is unimportant as long as the outputs are easily retrievable (Health and Safety Laboratory, 2003), IT-based data systems (risk registers) have significant advantages, particularly in facilitating information flow between and across layers and boundaries of the organisation (COSO, 2004).
Verification	Ensuring compliance with risk analysis procedures, and providing quality control of the execution of risk analysis.	The mere existence of procedures is not in itself enough to ensure that staff actions will be consistent with them (Hoyle, 2001; ISO, 2000). Errors of omission or commission ( <i>e.g.</i> due to	Implementation of mechanisms to ensure adherence to procedures ( <i>e.g.</i> auditing, “sign offs”) and to sanction non-compliance. Quality control mechanisms ( <i>e.g.</i> peer reviews, Delphi panels) should be implemented with explicit methods for

		misunderstanding instructions, carelessness, fatigue or management override), may cause deviations. Similarly, procedural compliance does not ensure the quality of execution of risk analysis.	controlling ( <i>e.g.</i> establishing group consensus iteratively) or evaluating ( <i>e.g.</i> quality criteria) the quality of analyses. An appropriate balance between the resources required, the constraints of bureaucracy, and the benefits of process control should be struck.
Validation	Assessing the fundamental correctness of the risk analysis process design ( <i>e.g.</i> that the correct techniques are being applied, that the correct initiation criteria are in place).	The willingness and means to question the validity of current risk analysis practices is required to show due diligence and ensure that current practices are legitimate, and is further a prerequisite to the continual improvement of risk analysis.	Formalised approaches to validation include: statistical or mathematical approaches to validating technical methodologies, independent peer reviews, and benchmarking surveys; and informally may draw upon: professional networks, trade and scientific literature, <i>etc.</i>
Organisational learning	The manner in which the organisation identifies, evaluates and implements improvements to the design and execution of risk analysis.	Mechanisms for verification and validation are mere panaceas if their findings are not acted upon, <i>i.e.</i> , if they are not used to rectify deficiencies in the design and execution of risk analysis.	Reviews should: be undertaken at specified intervals and on an event driven-basis; consider a broad range of internal and external feedback; focus on improving the validity of the risk analysis process and the effectiveness of its execution, not on ensuring it complies with a given standard; treat errors of omission or commission in the execution of risk analysis not as isolated lapses requiring sanction to prevent their re-occurrence, but as opportunities to identify and resolve root and common causes of error; and be supported by a learning culture, wherein current methods and approaches to risk analysis, and their underlying assumptions, are open to question and critical evaluation.
Stakeholder engagement	The engagement of stakeholders, both internal and external to the utility, for the purpose of harnessing a broad range of perspectives, knowledge, skills and experience.	The legitimacy of risk analysis outputs depends upon appropriately broad stakeholder engagement, as risk is an intrinsically multi-faceted construct, whose comprehensive understanding is often beyond the capabilities of individuals or small groups.	A team approach to risk analysis which pools the knowledge, skills, expertise and experience of a range of perspectives is preferable (Health and Safety Laboratory, 2003; MHU, 2003; Joy and Griffiths, 2005). External stakeholders may be engaged to: capture expertise ( <i>e.g.</i> consultants); confer additional legitimacy on the analyses; communicate due diligence ( <i>e.g.</i> regulators); and capture community values and ensure they are incorporated within the analysis.
Competence	The ability to demonstrate knowledge, skills, and experience in risk analysis to the level required (Health and Safety Laboratory, 2003).	The legitimacy of risk analyses outcomes depends to a large extent on the capacity of staff to critically evaluate available information and to supplement it with their own knowledge and plausible assumptions (Rosness, 1998) , <i>i.e.</i> on staff competencies.	Definition of required staff competencies in risk analysis; evaluation and implementation of appropriate education and training vehicles to develop / maintain those competencies ( <i>e.g.</i> class room learning, external workshops); providing “on the job” training under adequate supervision; designing and implementing methods for evaluating the efficacy of educating and training ( <i>e.g.</i> for measuring that the required competencies have been imparted).

## 7.4 RESEARCH METHODS

One utility responsible for the provision of water and wastewater services participated in this study. The provision of safe, reliable drinking water depends on a range of organisational functions spanning the design, operation and management of water supply systems from catchment to tap. We therefore view the juxtaposition of a cross-section of functional risk analysis and risk based decision making capabilities as central to providing a well-rounded examination of the utility's capacity to protect public health. Although the focus of our research is water supply, by the nature of the utility's organisational design, it extended to embrace aspects of their wastewater services (as, for example, the project management and engineering functions deliver both water and wastewater system designs and projects). We consider this a valid extension, as the underlying principles of risk analysis, decision theory, and capability maturity modelling remain constant regardless of the application context.

The sample comprised of seven organisational functions: engineering; project management; drinking water quality management; network planning; asset management; emergency management; and occupational health and safety management. The research methods included interview and document analysis as described below.

A semi-structured interview template was refined based on our previous research and here adapted on an interview-specific basis to fit the function (*e.g.* asset management) and, where relevant, functional discipline (*e.g.* dam safety management) under examination. The questions were designed to explore the practical form of risk management in each function (*e.g.* "what is the process for identifying health and safety hazards within workplaces?") and the relative maturity of its implementation (*e.g.* "are there mechanisms for quality control of risk analyses?"). Interviews (mean approx. 45

minutes, ranging from 25-85 minutes) were conducted *in situ* (32) and by 'phone (1), recorded, and subsequently converted into verbatim transcripts (with two exceptions, where notes were taken). The transcripts were returned to each interviewee, providing them an opportunity to comment. Finally, a range of pertinent supporting company documentation was obtained from interviewees, the corporate intranet, and the public domain (*e.g.* internet, conference articles). Those obtained included risk management policies and frameworks, risk analysis procedures and methods, accident and incident statistics and reports, water safety plans, risk analysis outputs, *etc.*

Each function's process maturity was determined according to the lead author's judgement based on the data obtained. Recall that to achieve a given maturity level, all positive requirements of that level and those preceding levels must be satisfied. However, caution is required. Whilst effort was expended to clearly define each process maturity characteristic, there remained an element of subjectivity in determining their attainment. Further, the purpose of the case study was to both refine the model and illustrate its application, not to derive a maturity assessment of auditable rigour. Thus, the value of this research lies in its synthesis of normative and behavioural theories with empirical observations to codify the processes of risk analysis and risk based decision making, placing these within a maturity framework that facilitates their assessment and improvement, and then illustrating these aspects with reference to a cross-section of water and wastewater utility functions.

Mechanisms to validate our findings were adopted. This was achieved through sample anonymity and triangulation. Anonymity removed the potential for conflicts with the fundamental goal of adding to the body of knowledge (as opposed, *e.g.*, to the participant's desire that the findings reflected positively upon their organisation). Triangulation was achieved through interviewing a range of representatives from each

function and cross checking for inconsistencies in accounts, cross checking interviewee accounts with documented sources, and providing the interviewees an opportunity to comment on drafts of the research outlined in this paper (and subsequently reflecting those comments in redrafts). Thus, we ensured consistency between interviewees, between interviewees and document sources, and between the researchers' and interviewees' perspectives. Indeed, of the sample of seven functions, emergency planning was removed from the analysis due to contradictions in the data and the limited sample of interviewees (two, compared to a minimum of three elsewhere), whilst network planning was discounted owing to limited documentation obtained.

## **7.5 RESULTS AND DISCUSSION**

We begin by summarising and discussing the sub-sample's risk analysis practices, before evaluating their relative maturity of implementation. We then turn to risk based decision making, where we repeat the same structure of discussion.

### **7.5.1 Risk analysis: observed practices**

Table 7.5 summarises the undertaking of each risk analysis practice within the sub-sample, on a function specific basis.

Table 7.5 Summary of the undertaking of each risk analysis practice within the sub-sample

	Drinking water quality management	Occupational health and safety management	Asset management		Project management	Engineering
			Treatment plants	Major dams*		
System characterisation	Schematics of water supply systems were produced. Data was obtained to characterise the following system elements: catchment ( <i>e.g.</i> geomorphology, climate, land uses); source water ( <i>e.g.</i> surface or ground water, flow and reliability, seasonal changes); storage tanks, reservoirs and intakes ( <i>e.g.</i> detention times, design); treatment and distribution systems ( <i>e.g.</i> processes, configuration, monitoring); current operational procedures; point sources of pollution; and consumers ( <i>e.g.</i> population, demand patterns).	Checklists were used to interrogate characteristics of the work spaces and the type and methods of work to be undertaken ( <i>e.g.</i> existence / location of pits, shafts, ducts, pressure vessels, access and egress routes, ventilation, isolation and lockout procedures, substances used, <i>etc.</i> ).	Plant components were identified, their condition and performance evaluated through asset inspections, and current operating and maintenance regimes detailed.	Engineering assessments of dams were undertaken, drawing on technical reports, site visits, flood and earthquake loadings, dam safety standards, <i>etc.</i>	Project options were characterised through scope development and value management workshops. These detailed the project need and relevant assumptions and constraints, before characterising each option in terms including their: functional specifications, capacities, required inputs and outputs, and relative costs and benefits.	Prior to the application of HAZOP studies, process and instrumentation diagrams – which show the interconnection of process equipment and the instrumentation used for process control – were created.
Hazard identification	Chemical, microbiological, physical and radiological water quality hazards ( <i>e.g.</i> chlorine sensitive pathogens) were identified on a system and sub-system ( <i>e.g.</i> catchment, treatment) specific basis through a checklist-based approach.	Hazards were identified via the use of task, substance and workplace specific checklists. Where deemed relevant, this was supplemented by systems engineering techniques, incident and near miss records, and brainstorming.	A FMECA-type approach linked potential hazards ( <i>e.g.</i> supernatant overflows to surroundings or temporary pipework pumps) to their direct causes ( <i>e.g.</i> not enough capacity to hold or evaporate sludge received) for each component and for the plant as a whole. Informed by site visits, incident records, and feedback from operating and maintenance staff.	Significant failure modes (flood, earthquake, and static loading) were identified.	Hazards threatening the delivery of the project option(s) on time, to budget, and within the required quality parameters, were identified through facilitated brainstorming, structured with reference to generic hazard categories.	HAZOP studies identified potential deviations from process design intent ( <i>i.e.</i> hazards) through the application of guide words ( <i>e.g.</i> low, high, none) to process parameters ( <i>e.g.</i> ozone flow).
Hazard precursor identification	Knowledge of the environmental behaviour of hazards and the system under examination, technical judgement, incident reports, survey maps, and monitoring records were synthesised to link hazards ( <i>e.g.</i> chlorine sensitive pathogens) to their sources ( <i>e.g.</i> dairy farming or grazing) and to the events which may lead to their realisation ( <i>e.g.</i> runoff or percolation from land based activities).	There was an absence of explicit provisions for identifying the precursors to identified hazards, one exception being for hazards arising from manual handling activities, where checklists examined which aspects of the actions and movements, workplace layout, and working posture generated said hazards.		No inference possible.	Hazards ( <i>e.g.</i> aqueduct erosion) were linked to their direct causes ( <i>e.g.</i> major storm runoff; water release from failed stormwater dams).	Engineering judgement was applied to identify potential causes of deviations from design intent ( <i>e.g.</i> human error: acts of omission or commission; equipment failure; and external events).

Control evaluation	Actions, activities and processes applied to mitigate the introduction or transport of hazards from catchment to customer tap (e.g. catchment protection, pre-treatment, ozonation) were identified via a checklist-type approach applied to system schematics. Critical controls were identified via set criteria. Technical data, consultations with operators, and site visits informed survey-based evaluations of their adequacy of design, management and operation with reference to key attributes (e.g. infrastructure; planning, procedures and legislation; monitoring; and auditing).	Health and safety risk controls were identified with reference to a control hierarchy which established their relative criticality: engineering (e.g. substitution, isolation, design modification, guarding), administrative (e.g. training, supervision, procedures), and personal protective equipment. No explicit provision for evaluating their adequacy of design, management or operation.	Not observed to have been explicitly undertaken.	The influence of structural and non-structural (e.g. early warning systems) controls was incorporated within the modelling of failure scenarios (i.e. within event trees, dam break modelling, etc.).	Not observed to have been explicitly undertaken.	Systems or procedures designed to prevent, detect, provide early warning, or mitigate the consequences of a deviation (i.e. safeguards) were identified. No explicit provision for evaluating their adequacy of design, management or operation.
Consequence evaluation	This may be generalised as the judgement-based interpretation of limited data sets describing the nature and severity of consequences of past hazardous events (e.g. in occupational health and safety: cost of claims, lost time due to incidents) to derive a credible evaluation of the potential consequence(s) of uncertain future events. Evaluations were near uniformly characterised with reference to descriptors of the nature (e.g. environmental, financial) and severity of consequences of events enshrined within the utility's portfolio of risk ranking techniques. However, isolated applications of mathematical modelling (e.g. event tree analysis, dam break modelling, inundation mapping, and economic impact evaluations in major dam risk analysis; event tree analysis in one occupational health and safety risk analysis application) were observed.					
Likelihood evaluation	May be generalised as the judgement-based interpretation of data pertaining to the frequency of past hazardous events (e.g. water quality exceedence frequencies) in light of analyst(s) knowledge, experience, and assumptions. Evaluations were near uniformly characterised with reference to likelihood benchmarks within risk ranking techniques. However, isolated applications of mathematical modelling were observed (e.g. in major dam risk analysis, network reliability analysis, etc.).					
Risk evaluation	Outside of isolated risk analyses driven by consultants (e.g. notional costs of risk and statistical lives lost were derived in major dam risk analysis), risk was expressed in qualitative terms (extreme, high, medium or low) derived by combining estimates of consequence severity and likelihood on a risk matrix.					

\* Note that this describes the overarching portfolio risk analysis of major dams, which itself is supplemented by a more detailed risk analysis at the component and sub-component level.

Below, we provide a comparative analysis of the strengths and limitations of a selection of these practices.

#### *7.5.1.1 Hazard identification*

The sub-sample adopted a range of hazard identification methods, each with their own strengths, limitations and application contexts. Consider occupational health and safety management, where hazard identification was concerned with those physical, chemical and biological threats inherent to workplaces and work practices. These were primarily identified *via* checklists linking known hazards with processes, equipment, workplaces, or operations. Checklists are useful means of capturing and passing on the experiences of others, and so their application is most relevant where there is a significant body of knowledge or experience on the range and nature of potential hazards (Joy and Griffiths, 2005). However, they may tend to suppress lateral thinking (MHU, 2003), and hazards not incorporated within them are likely to be excluded from identification (Joy and Griffiths, 2005). As such, occupational health and safety management procedures required that the use of checklists was supplemented with: *“judgement formed from experience and knowledge of the work, past incident records, brainstorming, and system engineering techniques.”* This acknowledges the above limitations and the notion that it is inappropriate to base hazard identification solely on lessons learned from the past, as some hazards may be present that have never been realised, or there may have been changes to workplaces or work practices such that historic data is no longer a valid representation of the hazard potential of the current system (Health and Safety Laboratory, 2003).

In practice, the application of system engineering techniques was the remit of the engineering function. Here, hazard identification was concerned with determining



ways in which engineered systems may fail to operate within design specifications. This was reflected in their use of hazard and operability studies (HAZOP). In brief, analysts examined a process (*e.g.* disinfection) subdivided into nodes, at each node, the analysts applied guidewords (*e.g.* low, high) to process parameters (*e.g.* temperature, pressure, flow) to identify ways in which the process may deviate from its design intention. In contrast, neither prescription nor a definitive methodological structure was evident in project management's approach to hazard identification, which was concerned with threats to the delivery of projects on time, to budget, and within the required quality parameters. Acknowledging that projects and their related hazards are by definition unique, the function adopted facilitated group brainstorming, informed by generic risk categories (*e.g.* economic / business risk: the risk of exceeding project budget due to, for example, the impact of unfavourable exchange rates on the cost of minerals), to stimulate dialogue and encourage a systematic yet creative approach to hazard identification.

#### *7.5.1.2 Hazard precursor identification*

The potential existence of a hazard does not in itself constitute a risk, as each hazard requires a process or pathway (here, termed a precursor) to lead to its realisation. Whilst hazard identification is concerned with *what* can go wrong (*e.g.* introduction of hydrocarbons within a water supply system), precursor identification examines *how* and *why* things can go wrong (*e.g.* off-take water contaminated *via* oil emissions from inadequately maintained pumps or pipes; due to an absence of procedures or inadequate supervision and training of maintenance staff); in other words identifying possible routes to and causes of failure. Consider the drinking water quality management function, wherein risk analysis was based on an adaptation of the hazard

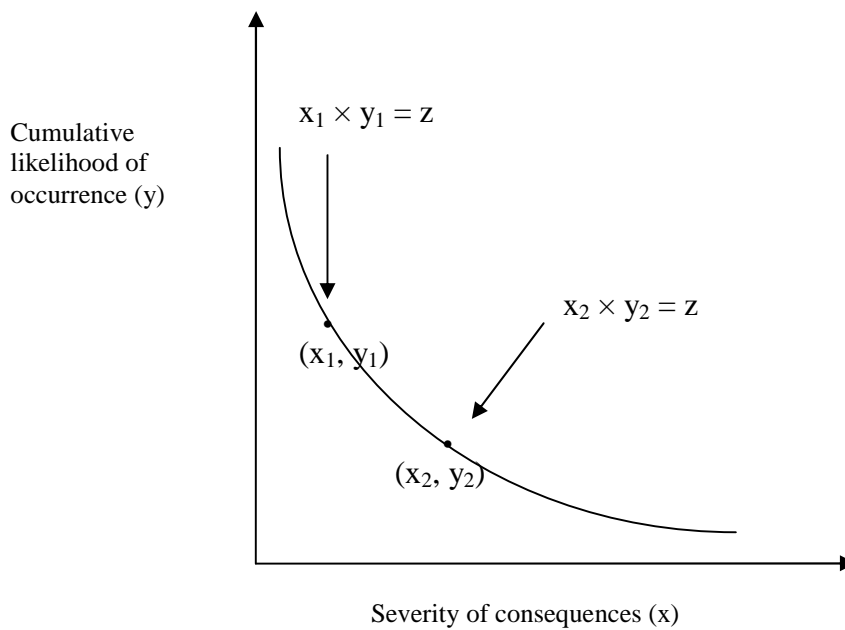
analysis and critical control points (HACCP) methodology. This method seeks to provide a basis for understanding and prioritising health and aesthetic hazards within the water supply chain from catchment to tap (see Deere and Davison, 1998; Deere *et al.*, 2001; Hamilton *et al.*, 2006a). Within the function, knowledge of the environmental behaviour of hazards (*e.g.* transportability) and the system under examination, technical judgement, incident reports, survey maps, and monitoring records were synthesised to link hazards identified within each subsystem (*e.g.* catchment: chlorine sensitive pathogens) to their sources (*e.g.* dairy farming or grazing) and to the events which may lead to their realisation (*e.g.* runoff or percolation from land based activities).

Whilst variable in rigour and method, a common theme was that each function's approach to precursor identification (where evident) tended to focus on how failure events may arise, rather than addressing their in-depth causes and reasons. In other words, they neglected to explore the reasons *why* human or technical systems may fail. This is flawed in that easily predictable causes of failure are often simply specific manifestations of deeper, underlying weaknesses (Reason, 1997). This is an important observation in that an inability to understand causal paths to failure constrains the development of risk reduction options targeted at the root causes of risks.

#### *7.5.1.3 Consequence evaluation*

This practice involves identifying the nature of the consequences of a hazardous event occurring (*e.g.* financial, environmental) and assessing their severity of impact. There are a range of techniques for consequence evaluation, from quantitative modelling to qualitative ranking techniques, the span of which were observed within the sub-sample. However, applications of the former were largely restricted to asset

management (*e.g.* event tree analysis, dam break modelling, inundation mapping, and economic impact evaluations in major dam risk analysis), with the majority of evaluations being single point estimates framed by risk ranking techniques. These ranking techniques separated consequences on one axis according to the nature of their impact (*e.g.* financial, environmental), with the other axis being a graded scale of severity expressed by descriptive benchmarks. Such categorisation can substantially reduce subjectivity in consequence evaluations (Health and Safety Laboratory, 2003). Their practical application within the sub-sample was not typically underpinned by an analytical method *per se*, instead relying upon the interpretation of limited data sets (*e.g.* in occupational health and safety: cost of claims, lost time due to incidents) to derive a *credible* consequence evaluation. We do not consider the subjectivity inherent in this as a limitation, because in principle one single point estimate is as good – or as bad – as another. In other words, as in this case consequence evaluations serve solely to anchor single point estimates of risk at points on implied isocontours, they are required only to be credible (*i.e.* to lie within the curve; Figure 7.3). In contrast, greater accuracy is required of likelihood evaluations, as they are concerned with finding specific points on isocontours (*i.e.* the likelihood of occurrence for a given severity of consequence). This is an important observation as the resource-intensive nature of data collection and analysis dictates that it must be pursued on a rational rather than dogmatic or uninformed basis.



*Figure 7.3 The reciprocal correlation between consequence severities and their forecast cumulative likelihoods of occurrence for a given adverse event (e.g. the release of hazardous chemicals to the environment due to a deviation from design intention in process engineering)*

NB: Cumulative likelihood is the likelihood that the event will occur and lead to a defined consequence severity or greater. A fundamental assumption of single point estimate risk analysis is that the gradient of this relationship, when expressed on  $\log_{10}$  scales, approximates -1. Thus, at any point on the curve, the product of likelihood of occurrence and consequence severity is uniform. Consequently, the location on the curve at which the single point estimate is taken does not influence the risk evaluation. This relationship is sometimes referred to as an “iso-risk contour,” and is often held to characterise the behaviour of most hazards. Whilst intuitively attractive, the authors are unaware of its theoretical underpinning, whilst its empirical basis (e.g. Hirst and Carter, 2002) is to our knowledge limited.

#### 7.5.1.4 Likelihood evaluation

This practice involves evaluating the likelihood that a hazardous event will occur and lead to a defined severity of consequence. Its undertaking within the sub-sample may be generalised as the judgement-based interpretation of data pertaining to the frequency of past hazardous events in light of analyst(s) knowledge, experience, and assumptions. These evaluations were categorised either numerically (probability/frequency gauges) or descriptively (*e.g. “will only occur in exceptional circumstances”*).

Consider first water quality risk analysis, which was concerned with the likelihood that specific hazardous events may occur and cause an exceedence of water quality or operational targets. Here, historic frequencies of exceedence of water quality and operational parameters formed the baseline data inputs (*e.g. turbidity data, e-coli*). Where deemed appropriate, this was supplemented by statistical analysis. For example, an evaluation of the likelihood of climatic and seasonal variations leading to excess levels of suspended solids in source waters was informed by correlating historic loadings of suspended solids with flow and rainfall data. However, whilst comprehensive monitoring of water quality parameters within the catchment, source waters and at the customer tap was routine, the absence of an overarching operational monitoring philosophy at the treatment and disinfection plant level meant that datasets characterising the behaviour of hazards within water supply systems were interspersed with black boxes. As one interviewee noted, *“we do have online monitoring...but traditionally it’s been a fairly ad hoc process...no-one has really taken a holistic view of the whole state and said – I think we should have online monitors here, chlorine residual analysers at these following locations or online pH...or ammonia [monitoring] at the following locations [and] for these reasons.”* This knowledge gap was being

remedied through identifying those operational parameters (*e.g.* free chlorine levels) which described the effectiveness of control measures (*e.g.* maintenance of residual chlorination post disinfection) designed to mitigate water quality hazards (*e.g.* entry or regrowth of chlorine sensitive pathogens within the disinfection system), and integrating them within existing monitoring programmes.

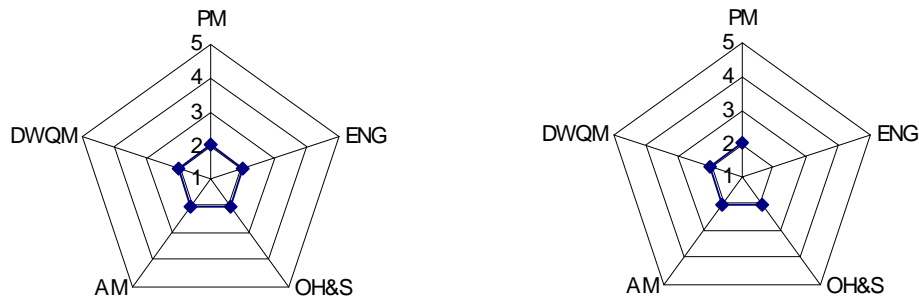
A similar theme emerged from occupational health and safety management, whose risk analysis procedure stated that likelihood evaluations “*may be determined using statistical analysis and calculations,*” but “*where no past data exists or is available, subjective estimates will be required to reflect an individual’s or groups degree of belief*” that a particular severity of consequence will occur. It further specified that incident records, experiments and prototypes, and economic, engineering or other models may be used to minimise subjective bias. However, our research revealed that, in practice, modelling (*e.g.* event tree analysis) was restricted to isolated applications, whilst the availability of historic data (*e.g.* frequency rates by injury type, mechanism of injury, *etc.*) was constrained by the organisation’s good health and safety record: “*the amount of information that we generate doesn’t produce sufficient data for us to analyse...and that’s not necessarily because of a lack of reporting, it’s just that...we actually don’t produce that many incidents.*” This was offset in part by reference to external data sources (*e.g.* national health and safety databases), however, these inevitably failed to reflect the unique nature of the utility’s design, construction, operation, and maintenance practices, and, more broadly, their working culture; and, furthermore, are often skewed by the under-reporting of incidents and near-misses (Health and Safety Laboratory, 2003).

Our final illustration refers to asset management’s application of risk analysis to prioritise replacements of below ground major water mains. All pipeline systems are

subject to an array of internal and external loading conditions (*e.g.* from the soil, ground movement, traffic loads). Additionally, pipe materials degrade due to environmental factors (*e.g.* corrosiveness of ground water in conjunction with soil properties). Thus, the causes and modes of failure can be complex and varied, depending on the pipe material and its operating environment. This complexity, coupled with the relatively high consequence severities of major main failures, provided the rationale for a data-intensive approach to likelihood evaluation. An initial screening evaluation was undertaken using pipe details from the geographic information system to assign each major main a “risk score” based on factors relating to either their likelihood *or* consequence of failure (*e.g.* pipe diameter, material, age, *etc.*). Detailed analysis was then undertaken of high priority main sections. Subsequently, likelihoods of failure were determined through a predefined relationship between pipe material and years of service. Although predefined, this was not prescriptive, being open to adaptation where professional experience, overseas studies, or internal investigations (*e.g.* test coupon, linear polarisation) relating to the failure rates of particular mains questioned its validity.

### **7.5.2 Risk analysis: maturity of implementation**

Having summarised (Table 7.5) and discussed the sub-sample’s risk analysis practices, we now consider their maturity of implementation. Within each function, the requirements of L2 maturity in risk analysis were satisfied (Figure 7.4).



Key: DWQM: drinking water quality management; AM: asset management; OH&S: occupational health and safety management; ENG: engineering; PM: project management.

*Figure 7.4 Spider diagram illustrating the maturity of implementation of risk analysis (left) and risk based decision making (right) within the sub-sample (insufficient data was obtained to evaluate risk based decision making within engineering)*

That is, a *repeatable* process was in place, characterised by the explicit undertaking of the *critical* risk analysis practices. However, L2 is limited in two fundamental ways. One is that the *key* practices of hazard precursor identification and control evaluation may be absent or implicitly undertaken. With the exceptions of engineering and drinking water quality management, this was true across our sub-sample (see Table 7.5). This is a significant observation, as knowledge of the processes or pathways through which hazards are realised, and of the weaknesses in the design, operation and management of existing controls, are prerequisites to developing risk reduction options targeted at common and root causes of failures yet to arise. A further defining L2 characteristic is that the rigour and quality with which those critical



practices are performed depends in large part upon the individuals executing and managing the work, and may vary considerably. In addition, the methods and techniques adopted may be retrospective and historical, regardless of their applicability or currency. This is because they do not fully satisfy the requirements of a defined (L3), controlled (L4) or adaptive (L5) process. However, *fully* is the key word, as we observed each function to exhibit *some* higher level maturity attributes, and so the prior characterisation may be somewhat harsh. We do not dwell on precisely what prevented our sub-sample from attaining higher levels of maturity, given the limited interest to the reader. Instead, we now discuss our most noteworthy observations.

#### 7.5.2.1 Procedures

One L3 requirement is that risk analysis is guided by procedure, making explicit, for example, the tasks, methods and assumptions to be adopted. In our sub-sample, these procedures were observed within project management, asset management, and occupational health and safety management to varying levels of completeness, detail, and prescription. As one interviewee noted, project risk analysis was facilitated by the corporate risk management group rather than being guided by a “*prescribed and definitively defined procedure*,” perhaps an implicit acknowledgement that risk analysis is, as Garrick (1988) suggested, a thinking business which should not be fully prescribed or cook booked. This lay in contrast to the more prescribed approach to risk analysis within occupational health and safety management, perhaps reflecting its inherent potential for standardisation (*i.e.* that it is by nature repetitive), along with the need for legislative compliance. Bureaucracy has negative connotations in today’s world, however one must recognise that procedures do not exist for their own sake, but as a means of capturing organisational experience, guiding staff in process execution,

and of showing due diligence to key stakeholders (e.g. regulators, shareholders). The underlying principle is that as staff accumulate experiences and become more expert in the application of risk analysis, they find better or the best ways of doing so. However, if this hidden knowledge is not made explicit and documented, it will remain within their minds and theirs alone (NEA/CSNI, 1999). This is particularly important during periods of internal restructuring or high employee turnover. The implications of this had not gone unnoticed within the drinking water quality management function: *“I think there is a gap [in process documentation]...obviously you’re aware that we’ve had some recent structural changes and we are sitting in a precarious position where we need to ensure that information is transferred...to ensure that this work continues and [that] we improve on it.”*

#### 7.5.2.2 Initiation criteria

Within many sectors, there are accepted standards of performance and codes of practice that, if adhered to, provide high degrees of control (Pollard *et al.*, 2004). These are applied in familiar and well-characterised situations where uncertainties and system vulnerabilities are well understood. Here, adhering to the historic basis for safe operations can be considered to discharge the risk analysis duty (Health and Safety Laboratory, 2003; UKOOA, 1999). Returning to our sub-sample, this concept was reflected in the electrical engineer’s comments: *“electricity is a dangerous thing, it’s a source of high energy that can be released instantaneously, obviously you need to be in control and protected satisfactorily, to make sure that there’s no risk to personnel or the property...because the technology is very mature...we have our own design guidelines [for electrical engineering] that actually emphasise...issues like lifecycle cost, security of operation, reliability, safety...[and so] I don’t think it is necessary to*

*have a formalised [risk analysis] process [in electrical engineering], because it's part and parcel of the detailed design anyway."*

However, complex, uncertain and novel systems, with the potential to deviate from routine operation, may require risk analysis, so as to better understand what drives the risk from or to the plant, process or operation (Pollard *et al.*, 2004). This principle extends beyond the design and operation of technical systems to embrace all aspects of managing a water utility. As such, an L3 attribute is the existence of initiation criteria: predefined stages or conditions which initiate the application and revision of risk analysis. In a world becoming obsessed with "the risk management of everything" (Power, 2004), the absence of clear criteria may drain resources as staff initiate analysis without first considering whether adherence to good practice would serve as a sufficient proxy for risk management, or at the other extreme, analysis may be applied reactively, perhaps even to provide *ex post* justifications of investment decisions (*e.g.* Health and Safety Laboratory, 2003). To illustrate, initiation criteria observed within our sub-sample included: undertaking project risk analyses prior to full financial approval depending on the cost, complexity and novelty of the project (and updating them at project delivery milestones); undertaking manual handling risk analyses in occupational health and safety management for novel, altered or relocated processes, or in response to high frequency injury records or employee requests; undertaking hazop studies within engineering for complex or costly processes at set stages of design completeness; whilst timescales for revising risk analyses of various asset classes were observed in asset management (though not uniformly). Critically, these criteria acknowledge that risk analysis is not a one off activity, but is instead one requiring regular revision to reflect system changes and the improved understanding of risks that

inevitably develops over time (*e.g.* from monitoring data, increased operator experience).

#### *7.5.2.3 Stakeholder engagement*

A further positive characteristic of the utility's approach to risk analysis was the reflection of a broad spectrum of knowledge, skills, experience, and perspectives within each function's approach to risk analysis. Input from stakeholders with diverse skills and backgrounds serves to minimise analyst bias and creates synergies of knowledge and expertise. Furthermore, one benefit of our sub-sample's primarily qualitative approach to risk analysis was that it ensured that non-technical experts, specifically what one interviewee referred to as "*the people that use the systems, use the equipment and undertake the processes,*" could participate in or critically scrutinise the process. This is key, as engaging those grassroots staff who have practical knowledge of the hazards under examination ensures that they have a sense of ownership and engagement within the process, as opposed to it residing within a core set of experts isolated from operational realities, the latter being a pitfall common to risk analysis (*e.g.* Health and Safety Laboratory, 2003).

#### *7.5.2.4 Input data management*

One notable observation was the general absence of predefined strategies of data collection to inform each function's approach to risk analysis. By this, we mean that, at the process level, risk analysis was not typically informed by a prior consideration of the data requirements and methods of capture; instead, data collection was undertaken on an *ad hoc* or case by case basis, except where analytical methodologies were

applied. By way of practical illustration, consider project management, where one interviewee reflected that the majority of risk evaluations were based on “*the judgement of people*,” although raw data was sourced where deemed appropriate. Illustrating this, he reflected on a project concerned with the construction of a new pipeline, wherein the hazard of striking rock during excavation was identified. As the level of risk associated with this would largely determine the provision of project contingency funds, bore-log samples were undertaken along the planned pipeline route to maximise the accuracy of the analysis. This illustrates that seeking to predefine the data collection strategy for project risk analysis is simply not pragmatic given the inherently unique nature of projects; it is further flawed in that it fails to recognise human judgement as a legitimate input.

#### *7.5.2.5 Competence*

As Rosness (1998) notes, the accuracy of risk analyses depends to a large extent on the competency of analysts to critically evaluate available information and to integrate it with their own knowledge and assumptions. Thus, regardless of the technical complexity of the methods adopted, risk analysis remains in many respects an expert discipline. Reflecting this, and the growth in the application of risk analysis, we observed the recent development of education and training programmes in the discipline within the sub-sample. These ranged from internally delivered training modules within occupational health and safety, comprising an overview of the relevant legislation, the process itself, and practical exercises; to external modules for hazop facilitators and project managers. This is in contrast to a reliance on “on the job” training with asset and drinking water quality management. Nevertheless, the importance of this learning by trial and error should not be marginalised, as competence

is broadly held to be a combination of knowledge, expertise *and* experience (e.g. Health and Safety Laboratory, 2003). However, a broader point is that absent a formal definition of the competencies required of risk analysts within the sub-sample, and of metrics for assessing whether they exist or have been imparted, on what basis is education and training in risk analysis initiated (*i.e.* targeted to areas of greatest need), assessed and improved?

Education and training can further serve to embed a cultural acceptance of risk analysis through tackling residual perceptions of it as make-work, which appeared to persist within the sub-sample, as reflected by one interviewee's comments: "*you could describe [risk management] as something that's in vogue at the moment, it's considered it'll probably be a passing phase, so a lot of people don't get too excited about it.*" This was reflected in the risk manager's planning: "*I'm looking at developing...risk awareness training and risk culture training...[and] that would be aligned with our regulation and governance business plan to get funding...[at present, we're largely restricted to on the job training]...and that's very limited because...[some people] tend to get a psyche that – well [the risk manager has] done the risk assessment, therefore that's it, [and don't recognise their obligation to monitor changes in risks]...what I'm looking for from a cultural point of view...[is] that people view it more as their responsibility.*"

#### 7.5.2.6 Verification: procedural compliance

The mere existence of procedures guiding risk analysis is not in itself enough to ensure that staff actions will be consistent with them, as errors of omission or commission will inevitably arise. Thus, there is a need for verification of procedural compliance, achieved within our sub-sample through means ranging from "sign offs,"

to audits, to expert facilitation of risk analysis workshops. This is crucial in resource-constrained environments where the role of risk analysis can be marginalised by staff seeking to attend to more immediate operational realities, as reflected in one interviewee's comments: "*Operational realities...and financial realities...[mean]that the things that aren't immediately obvious tend to fall off first...[staff] worry about fixing the burst water main and doing [their day] job and then [think], oh, well, [risk analysis], that's paperwork...[so] we've got to try and coerce, employ...whatever [methods] we can to...make sure [that] they're up to date [with their analyses], and of course there's always the stick later on when there are audits.*"

#### *7.5.2.7 Verification: quality control*

One weakness was the limited nature of our sub-sample's risk analysis quality control mechanisms. Quality control of risk analyses is intended to enhance their credibility and accuracy through ameliorating those inherent uncertainties, both epistemic, due to lack of knowledge, and operational, derived from the use of knowledge (*e.g.* analyst bias, judgements, human error; see Faber and Stewart, 2003; Amendola, 2001). For example, peer reviews of risk analysis were observed to be executed in a largely informal and unsystematic manner, rather than being guided by explicit quality evaluation criteria (refer to Joy and Griffiths (2005) for an example of a hazop technical audit, and Rosness (1998) for a more general discussion of quality criteria for risk analyses). In contrast, the use of facilitators within project risk analysis and hazop studies was noteworthy. Our interviews emphasised that their role was *not* to drive any particular outcomes or to provide technical input, but to guide analysts in the application of the methods and to focus on the quality of process execution (*e.g.*

challenging outliers during consequence evaluation, and ensuring all relevant risk categories were considered during hazard identification).

However, as formalised quality control mechanisms were the exception rather than the norm within the sub-sample, there was an implicit reliance on analyst competencies and the perceived validity of the methods adopted. However, we have already noted the limited nature of education and training in risk analysis; furthermore, all risk analysis methods have inherent limitations and are based on assumptions rarely made explicit, whilst their applications are not scientific in the classical sense, instead drawing upon the accumulated experiences, knowledge and bias of analysts (Aven *et al.*, 2006 ). It is in this context that the utility's prior use of the Delphi technique (Dalkey and Helmer, 1963) within project risk analysis is worth noting. Here, facilitated discussions and iterative anonymous voting were applied to generate expert consensus in risk evaluation. The method's explicit recognition of human judgment as a legitimate input was particularly valuable given the often data sparse environment in which project risk analysis was conducted. Furthermore, characterised as it is by group participation, anonymity and feedback loops, it minimises bias and dogmatism (*e.g.* reduces the reluctance of staff to abandon previously stated views). Indeed, one interviewee suggested that since its application had been rescinded, evaluations often reflected the subjective judgement of lone experts, which “*typically went unchallenged.*”

### **7.5.3 Risk based decision making: observed practices**

Table 7.6 summarises the undertaking of each risk based decision making practice within the sub-sample (note that the engineering function was discounted due to limited data).



Table 7.6 Summary of the undertaking of each risk based decision making practice within the sub-sample

	Drinking water quality management	Occupational health and safety management	Asset management	Project management
Establish risk acceptance criteria	Corporate policy was to reduce risks to a level “as low as reasonably practicable (ALARP).” The ALARP principle recognises that it would be possible to spend infinite time, effort and money attempting to reduce a risk to zero, and reflects the idea that the benefits of risk reduction should be balanced with the practicality of implementation. However, ALARP was not referred to within individual functions’ risk management procedures, with the exception of OH&S and in major dam safety management. In the latter, risk acceptability considered three criteria: life safety criteria; ALARP, and the <i>de minimis</i> risk concept, in order of stringency.			
Establish criteria for evaluating alternative risk reduction options	Not explicitly defined. Interviewees referred to cost, time and effort required for implementation; forecast risk reduction; regulatory compliance; risks introduced ( <i>e.g.</i> disinfection by-products); geographical and technical feasibility ( <i>e.g.</i> site constraints); operability; manpower required; and social and political concerns.	Not explicitly defined. Forecast risk reduction, cost of implementation, and technical feasibility were referred to by one interviewee.	Defined for below ground major water mains: qualitative risk reduction, cost of implementation, and latency of effects; for major dams: cost of implementation, and forecast reduction in statistical lives lost and economic losses from dam failure events (weighted to ensure preference for reducing statistical lives lost). Not explicitly defined for wastewater treatment plants.	Not explicitly defined. Note that although project managers were explicitly required to take a cost-benefit approach in evaluating risk reduction options, the scope of these considerations, <i>i.e.</i> the criteria with which costs and benefits were determined with reference to, was not defined.
Identify risk reduction options*	Options ( <i>e.g.</i> infrastructure upgrades, fencing off sensitive catchments, educating and training operators) were generated by groups responsible for the risk analysis of each sub-system ( <i>e.g.</i> catchment) in consultation with relevant specialists ( <i>e.g.</i> engineering, operations).	Options ( <i>e.g.</i> introducing standard work practices) were typically generated in brainstorming sessions involving a broad cross-section of regional / departmental staff, and, where relevant, OH&S staff.	Options ( <i>e.g.</i> for wastewater treatment plants: capital projects, alterations to operating or maintenance regimes, contingency plans; for dams: structural and non structural measures, such as installing external back up seals on concrete faced rockfill dams, or early warning systems, respectively) were generated by those groups responsible for the risk analysis of each asset class in consultation with operating and maintenance staff.	Options were typically generated by the project manager in consultation with relevant stakeholders ( <i>e.g.</i> engineering staff, environmental representatives), or within the risk analysis workshops through group brainstorming. This was informed by predefined measures for: reducing likelihood of occurrence ( <i>e.g.</i> audit and compliance programs, training, preventative maintenance); reducing impact of occurrence ( <i>e.g.</i> contingency planning, engineering and structural barriers, early warning devices); and risk transfer ( <i>e.g.</i> contracts; insurance arrangements).

Evaluate options	The impact of options against individual evaluation criteria	Methods ranged from the application of professional judgement, to the revision of risk analyses ( <i>i.e.</i> to derive the forecast risk reduction), to stakeholder consultations, cost-estimations, and engineering studies ( <i>e.g.</i> feasibility studies in major dam safety management). However, given that in most cases the evaluation criteria were not explicitly defined, the undertaking of this tended towards the informal or implicit.
	The cumulative goodness of each option	Methods for determining the cumulative goodness of each option were again largely informal and judgement-based, although the use of formal cost-benefit analysis was observed within asset management’s approach to prioritising major dam safety upgrades, whilst cost effectiveness evaluations informed prioritisations of the replacement of below ground major water mains. Furthermore, risk reduction options that took the form of capital projects valued in excess of approx. \$150,000 (US) underwent formal cost-benefit analysis as part of the capital approval process.
	The acceptability of risk	Note that cost-benefit analysis of risk reduction options is central to determining whether risks are “as low as reasonably practicable.” However, the limited application of this method in the context of evaluating risk reduction options within the sub-sample meant that the determination of risk acceptability was typically based on judgement rather than data.
Managerial review and option(s) selection	Limited data was obtained characterising this aspect. Thus, whilst our interviewees referred to peer reviews of varying degrees of formality as helping to shape the final option(s) selection across our sub-sample, the data obtained does not allow for a meaningful analysis of the roles of judgement, experience, bias, power structures, <i>etc.</i> in shaping the decision outcomes.	

\*Refer to Table 7.5 for detail on the risk analysis inputs to the identification of risk reduction options. The most relevant practices are: hazard identification, the *sine qua non* for developing risk reduction measures; hazard precursor identification, as an understanding of what drives hazards is key to informing the development of remedial measures; and control evaluation, which identifies where controls are absent and inadequacies in the design, operation and management of existing controls, and so is a crucial input to developing risk reduction options.

Below, we provide a comparative analysis of the strengths and limitations of a selection of these practices.

#### *7.5.3.1. Establish criteria for evaluating alternative risk reduction options*

A range of risk reduction measures may be considered for a particular decision context. Consider drinking water quality management; options for reducing the risk to public health posed by chlorine sensitive pathogens include: enhancing monitoring of indicator organisms in source waters (*e.g.* e-coli), catchment protection measures (*e.g.* fencing, or exclusion zones for livestock), infrastructure upgrades (*e.g.* filtration flow control), and operator training. The objective of each option is to reduce the risk to a level considered acceptable; however, the decision as to which is considered the best option(s) is influenced by many factors. In best practice organisations, these factors are reflected in criteria used to evaluate the relative merit of alternative options.

As cost benefit analysis is closely linked to the determination of whether risks, or, more accurately, risk reduction options satisfy the “as low as reasonably practicable” (ALARP) criteria adopted within the sub-sample, it is tempting to consider the balancing of costs and benefits as their evaluation criterion. However, we propose that cost benefit analysis is best viewed as an evaluation methodology, being in essence a normative theory for measuring the relative utility of an option with respect to various criteria, which it does not presume to define. In this context, it does not prescribe whether one should simply balance the financial expense of implementing an option with the benefits of the qualitative risk reduction forecast, or whether one should incorporate broader, often less tangible, aspects such as technical feasibility, social values, and political concerns. Whilst our research revealed that a broad range of criteria implicitly guided the evaluation of risk reduction options within our sub-

sample, they were only made explicit within asset management's risk-based approach to prioritising major water mains replacements and major dam safety upgrades (Table 7.6). As such, one can expect what Arvai *et al.* (2001) termed "alternative focussed" decision making to predominate within the sub-sample, characterised by first an analysis of available alternatives followed by selection of the "optimal" option from a set of implied or poorly defined criteria. Of course, it is not desirable for a process to dictate or prescribe decisions, as too mechanical an approach to decision making would fail to recognise the important role of management in performing difficult value judgements under uncertainty (Aven *et al.*, 2006). However, expressing the criteria against which those judgements should be taken could improve the credibility and defensibility of decision making, minimise the possibility that decisions will be second guessed or that their rationale be forgotten, remove barriers to stakeholder buy-in, and ensure the existence of an audit trail (SEI, 2002a).

#### 7.5.3.2. *Identify risk reduction options*

This practice is concerned with generating alternative solutions for the decision problem. Within the sub-sample, it was typically undertaken within creative workshops involving a diverse range of stakeholders. The value of this collective brainstorming, which seeks to stimulate innovation through open interaction and feedback, was cited by various interviewees, with one noting that it "*empowers people to think; the worst [thing] that you can do is take away people's creativity.*" Furthermore, engaging stakeholders with diverse skills and backgrounds can help to identify and address those assumptions, constraints and biases which can have a significant influence on the generation of alternatives (Aven and Kørte, 2003). Whilst primarily creative, within some functions this practice was informed by classifications of risk controls or risk

influencing factors, which may be viewed as *de facto* cheat lists for generating risk reduction alternatives. One example was occupational health and safety management's hierarchy of risk controls, which classified: engineering controls for hazard removal (*e.g.* substitution, isolation, modification to design, guarding and mechanical ventilation); administrative controls for preventing the occurrence of hazardous events (*e.g.* safe work practices, or procedures, training, supervision, nominating maximum exposure times); and personal protective equipment for minimising their severity of consequences.

However, perhaps the most important factor was the depth and rigour of the risk analyses themselves. Consider risk analysis within drinking water quality management. Recall that hazards identified within each subsystem (*e.g.* catchment: chlorine sensitive pathogens) were linked to their sources (*e.g.* dairy farming or grazing) and to the events which may lead to their realisation (*e.g.* runoff or percolation from land based activities). Subsequently, detailed surveys were undertaken exploring the adequacy of design, management and operation of those actions, activities and processes applied to mitigate the introduction or transport of said hazards from catchment to customer tap (*e.g.* catchment protection, pre-treatment, ozonation, *etc.*). We propose that systematically identifying the underlying mechanisms through which hazardous events may occur, before evaluating the latent and active weaknesses in their control mechanisms, promoted a rational, evidence-based approach to identifying risk reduction options. This is an important observation as it reminds us that the overarching purpose of risk analysis should be to develop a better understanding of the factors governing system reliability, and should not be treated solely as a “numbers game” (*e.g.* to satisfy quantitative risk acceptance criteria; Faber and Stewart, 2003). It

is in this former guise that risk analysis represents a most efficient tool for improving system safety and performance.

#### 7.5.3.3. Evaluate options

We now turn to the evaluation of risk reduction options. There are three elements to this practice: forecasting the impact of options against each evaluation criteria (*e.g.* technical feasibility), determining the cumulative “goodness” of each option; and determining the acceptability of the risk. Methods for achieving the former included applying professional judgement, revising risk analyses (to derive the forecast risk reduction post-implementation), stakeholder consultations, cost-estimations, and engineering studies (*e.g.* feasibility studies in major dam safety management). That said, recall that in most functions the evaluation criteria were not defined, and so this element often tended towards the informal or implicit.

For the second element, the cost-benefit approach was observed to be a sub-sample-wide guiding principle in measuring the relative utility of alternative risk reduction options. The cost benefit method itself is concerned with assigning financial values to a range of burdens and benefits, and summarising the optimality of alternatives in, for example, the expected Net Present Value of costs and equivalent monetary values of benefits and burdens (Aven and Kørte, 2003). Such an explicitly mathematical analysis was applied to evaluate the cumulative goodness of risk reduction options in isolated cases (*e.g.* in major dam safety management). More commonly, managerial judgement was used to balance their costs and benefits, at times informed by cost-effectiveness evaluations (*e.g.* forecast risk reduction per dollar spent). Thus, the determination of whether risks satisfied the ALARP criteria was typically judgement-based, rather than being informed by an explicit evaluation of the

costs and benefits of reducing vs. maintaining risk levels, the latter being central to the evidence-based determination of whether risks are “as low as reasonably practicable,” because, as Fischhoff *et al.* (1981) noted, it is not risks, but options, which are acceptable or unacceptable.

We present two rational justifications for the variable rigour and formality that characterised this practice: that the resources expended in decision analysis must be justified by the benefit of producing better decisions, and so detailed analysis is neither desirable nor justifiable in every decision context; and that evaluation criteria incorporating intangible dimensions are innately difficult to incorporate within the strictly mathematical framework of cost benefit analysis. However, a more critical analysis would suggest that as the criteria for both evaluating risk reduction options and selecting from the range of evaluation methods (*e.g.* formal cost benefit analysis vs. cost-effectiveness evaluation vs. heuristics or rules of thumb) were typically not explicitly defined, the logical corollary is that option evaluation may be expected to be undertaken in an informal or even *ad hoc* manner.

#### **7.5.4 Risk based decision making: maturity of implementation**

The sub-sample’s risk based decision making profile maturity mirrors that of risk analysis (Figure 7.4). However the decision making processes, or frameworks, were qualitatively less mature, in that they were characterised by a lesser degree of formality. However, rather than focus on findings relating to the individual process maturity attributes, we restrict ourselves to summarising the general implications of this lack of definition. Most critically, we may expect a lesser degree of rigour and formality in risk based decision making. This perhaps reflects an organisational culture that values the judgement, intuition, and inherent need for creativity of decision makers, over any

perceived moves towards prescription. However, our decision making framework is intended to guide, not prescribe, decision making, with the objective of ensuring a level of consistency, credibility, and confidence in achieving desirable outcomes. This is supported by a wealth of empirical evidence suggesting that, in the absence of a clear framework, people struggle to identify their full range of values and concerns in a given decision context, and are ill-equipped to make those complex trade-offs common to risk based decision making (Arvai *et al.*, 2001; Slovic *et al.*, 1977; Payne *et al.*, 1992; Slovic, 1995; Matheson and Matheson, 1998). This is manifested in the selection of sub-optimal risk reduction options; sub-optimal, as they fail to address the full range of stakeholder concerns and values (Bohneblust and Slovic, 1998).

## **7.6 CONCLUSIONS**

In this paper, we presented a capability maturity model for benchmarking and improving risk analysis and risk based decision making, and illustrated its application to a cross-section of water and wastewater utility functions. The contribution to knowledge is three-fold, we have: synthesized empirical observations with behavioral and normative theories to codify the processes of risk analysis and risk based decision making; placed these processes within a maturity framework which distinguishes their relative maturity of implementation from *ad hoc* to adaptive; and provided a comparative analysis of the methods, techniques, and maturity of risk analysis and risk based decision making across a range of water and wastewater utility functions. The findings provide researchers, utility managers, engineers, asset managers, occupational health and safety representatives, public health officials, project managers, chief finance officers and regulatory officials with a deeper understanding of the practical form and theoretical underpinnings of risk management, and how distinctions can be



made between organisational capabilities. This is timely work for a sector grappling to adapt to evolving regulatory and governance arrangements. Of note is the model's potential for facilitating a step-change in the approach to regulating risk management within the water sector from its current synthesis of reactive, outcome based approaches (*e.g.* water quality standards) and prescriptions (*e.g.* codes and regulations), towards a proactive, capability based approach.

### *Acknowledgements*

This work has been part funded by the AWWA Research Foundation (AWWARF project RFP2939) and a consortium of international water utility companies. The authors are particularly grateful to the case study utility and the lead individuals for their contributions, peer review and permission to publish. The comments and views herein, however, are the authors' alone. BHM is co-funded by a UK Engineering and Physical Sciences Research Council (EPSRC) Doctoral training account.

## **7.7 REFERENCES**

Amendola, A., Recent paradigms for risk informed decision making, *Safety Sci.*, **40**:17, 2001.

Arvai, J.L., Gregory, R., and McDaniels, T.L., Testing a structured decision approach: value-focused thinking for deliberative risk communication, *Risk Anal.*, **21**(6): 1065, 2001.

AS/NZS (Australian/New Zealand Standard). *AS/NZS 4360:1999 Risk management*, Strathfield: Standards Association of Australia, 1999.

AS/NZS (Australian/New Zealand Standard). *AS/NZS 4360:2004 Risk management*, Strathfield: Standards Association of Australia, 2004.

- Aven, T., Vinnem, J.E. and Wiencke, H.S., A decision framework for risk management, with application to the offshore oil and gas industry, *Reliab Eng Syst Safe.*, In press; 2006; available at: <http://www.sciencedirect.com/science/article/B6V4T-4J9MSSC-2/2/5ad5d7aeb729a6d0d3cd0c93373fde01>
- Aven, T. and Kørte, J., On the use of risk and decision analysis to support decision-making, *Reliab Eng Syst Safe.*, **79**:289, 2003.
- AWWA, EUREAU, WSAA and DVGW, *Bonn Workshop 2001 – Key principles in establishing a framework for assuring the quality of drinking water: a summary*, AWWA, Denver, CO., 2001.
- Bohneblust, H. and Slovic, P., Integrating technical analysis and public values in risk-based decision making, *Reliab Eng Syst Safe.*, **59**:151, 1998.
- Booth, R. and Rogers, J., Using GIS technology to manage infrastructure capital assets, *J. AWWA*, **93**(11): 62, 2001.
- Clemen, R.T., *Making hard decisions*, 2<sup>nd</sup> Ed, New York: Duxbury Press, 1996.
- COSO (Committee of Sponsoring Organizations of the Treadway Commission). *Enterprise risk management – integrated framework*, COSO, 2004.
- Crosby, P.B., *Quality is free*, New York: McGraw-Hill, 1979.
- Crosby, P.B., *Quality is still free*, New York: McGraw-Hill, 1996.
- Dalkey, M., Helmer, O., An experimental application of the Delphi method to the use of experts, *Manage Sci.* **9**(3): 458, 1963.
- Deere, D., Stevens, M., Davison, A., Helm, G., and Dufour, A., *Management strategies*. In: Fewtrell, L; Bartram, J. editors. *Water quality: guidelines, standards and health*, London: IWA Publishing, 2001, p. 257–88.
- Deere, D. and Davison, A., Safe drinking water — are food guidelines the answer? *Water*, **25**:21, 1998.

- Faber, M.H. and Stewart, M.G., Risk assessment for civil engineering facilities: critical overview and discussion, *Reliab Eng Syst Safe.*, **80**:173, 2003.
- FERMA (Federation of European risk management associations), *A risk management standard*, FERMA, 2003. (website: <http://www.ferma-asso.org/tabid/195/Default.aspx>).
- Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S., and Keeney R., *Acceptable risk*, New York: Cambridge University Press, 1981.
- Garrick, B.J., The approach to risk analysis in three industries: nuclear power, space systems, and chemical process, *Reliab Eng Syst Safe.*, **23**:195, 1988.
- Hamilton, P.D., Gale, P., and Pollard, S.J.T., A commentary on recent water safety initiatives in the context of water utility risk management. *Environ Int.* **32**:958-966; 2006a.
- Hamilton, P.D., Pollard, S.J.T., Hrudey, S.E., and MacGillivray, B.H., Risk management frameworks for the water sector – a review, at review, 2006b.
- Health and Safety Laboratory, *Good practice and pitfalls in risk assessment*, Health and Safety Executive, research report 151, 2003. (website: <http://www.hse.gov.uk/research/rrhtm/rr151.htm>).
- Hirst, I.L. and Carter, D.A., A worst case methodology for obtaining a rough but rapid indication of the societal risk from a major accident hazard installation, *J Hazard Mater.*, **92**(3):223, 2002.
- Hoyle, D., *ISO 9000 Quality systems handbook*, 4<sup>th</sup> edition, Butterworth-Heinemann, 2001.
- Hrudey S.E. and Hrudey E.J., Correspondence, *Reliab Eng Syst Safe.* **82**:343, 2003.
- Hrudey S.E. and Hrudey E.J., *Safe drinking water—lessons from recent outbreaks in affluent nations*, London: IWA Publishing, 2004.

IMPRESS Management, *IMPRESS Guidance, guidance for the analysis of pressures and impacts in accordance with the water framework directive*, Draft 5.2, European Commission, Brussels, 2002.

ISO (International Organization for Standardization), *ISO 9001 Quality management systems – requirements*, Geneva: ISO, 2000.

Joy, J. and Griffiths, D., *National minerals industry safety and health risk assessment guideline*, Minerals Council of Australia, Version 4, January 2005. (website: <http://www.mishc.uq.edu.au/rag/index.asp>).

Lee, T., Assessment of safety culture at a nuclear reprocessing plant, *Work Stress*, **12**(3):217, 1998.

Lifton, G. and Smeaton, P., Asset risk management in Scottish Water. *Proc. of the ICE/CIWEM Conference: Risk and reward in asset management delivery – who is best prepared for the challenges ahead?*, 14<sup>th</sup> November, 2003, London, UK.

MacGillivray, B.H, Hamilton, P.D., Strutt, J.E., and Pollard, S.J.T., Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision-making, *Crit Rev Env Sci Tec.*, **36**: 85, 2006a.

MacGillivray, B.H., Strutt, J.E., Sharp, J.V., Hamilton, P.D., and Pollard, S.J.T., Benchmarking risk management within the international water utility sector. Part I: Design of a capability maturity methodology, *J. Risk Research*, in press, 2006b.

MacGillivray, B.H., Strutt, J.E., Sharp, J.V., Hamilton, P.D., and Pollard, S.J.T. Benchmarking risk management within the international water utility sector. Part II: A survey of eight water utilities, *J. Risk Research*, in press, 2006c.

Matheson, D. and Matheson, J., *The “smart” organization: Creating value through strategic R&D*, Cambridge, MA, Harvard Business School Press, 1998.

- MHU (Major Hazards Unit), *Hazard identification, risk assessment and risk control*, New South Wales Department of Urban and Transport Planning, Advisory paper no. 3, consultation draft, version A, 2003. (website: <http://www.planning.nsw.gov.au/plansforaction/mihaps-docs/mihaps-docs.html>).
- Mintzberg, H., *The rise and fall of strategic planning*, Prentice Hall, New York, 1994.
- NIST (National Institute of Standards and Technology), *Risk management guide for information technology systems*, NIST special publication 800-30, US Department of Commerce, 2002. (website: <http://csrc.nist.gov/publications/nistpubs/800-30/sp800-30.pdf>).
- NHMRC, *Australian drinking water guidelines*, Canberra: NHMRC, 2004. (website: [www.health.gov.au/nhmrc/publications/synopses/eh19syn.htm](http://www.health.gov.au/nhmrc/publications/synopses/eh19syn.htm)).
- NHMRC, *Framework for management of drinking water quality*, Canberra: NHMRC, 2001.
- NEA/CSNI (Nuclear Energy Agency/Committee on the Safety of Nuclear Organisations), *Identification and assessment of organisational factors related to the safety of NPPs: state-of-the-art-report*, OECD, Report 21(2), 1999. (website: <http://www.nea.fr/html/nsd/docs/1998/csni-r98-17-vol1.pdf>).
- NZMOH (New Zealand Ministry of Health), *How to prepare and develop public health risk management plans for drinking-water supplies*, Wellington: Ministry of Health, 2001. (website: [www.moh.govt.nz/moh.nsf](http://www.moh.govt.nz/moh.nsf)).
- Paulk, M.C., Curtis, B., Chrissis, M.B., and Weber, C.V., Capability maturity model, version 1.1, *IEEE Software*, **10**(4):18, 1993.
- Payne, J.W., Bettman, J.R., and Johnson, E.J., Behavioural decision research: A constructive processing perspective, *Annu Rev Psychol.*, **43**:87, 1992.

- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Hamilton, P.D. and Hrudey, S.E. Risk analysis and management in the water utility sector – a review of drivers, tools and techniques, *Trans. IChemE, Part B: Proc. Safety Environ.*, **82**(B6): 1, 2004.
- Pollard, S.J.T., Strutt, J.E., MacGillivray, B.H., Sharp, J.V., Hrudey, S.E. and Hamilton, P.D., Risk management capabilities – towards ‘mindfulness’ for the international water utility sector, *Proc. of the DWI Conference: Water Contamination Emergencies: Enhancing our Response*, 12-15<sup>th</sup> June 2005, Manchester, UK.
- Power, M., *The risk management of everything — rethinking the politics of uncertainty*. London: Demos, 2004.
- Reason, J., *Managing the risks of organizational accidents*, Ashgate, Aldershot, UK, 1997.
- Renn, O., A model for an analytic-deliberative process in risk management, *Environ Sci Technol.*, **33**(18):3049, 1999.
- Rosness, R., Risk influence analysis: a methodology for identification and assessment of risk reduction strategies, *Reliab Eng Syst Safe*, **60**:153, 1998.
- Sarshar, M., Haigh, R., Finnemore, M., Aouad, G., Barrett, P., Baldry, D., and Sexton, M., SPICE: a business process diagnostics tool for construction projects, *Engineering, Construction and Architectural Management*, **7**(3):241, 2000.
- Sharp, J.V., Strutt, J.E., Busby, J., and Terry, E., Measurement of organizational maturity in designing safe offshore installations, *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering*, **2**:383, 2002.
- Slovic, P., Fischhoff, B., and Lichtenstein, S., Behavioural decision theory, *Annu Rev Psychol*, **28**:1, 1977.
- Slovic, P., The construction of preference, *American Psychologist*, **50**:364, 1995.

- SEI (Software Engineering Institute), *CMMI for systems engineering / software engineering / integrated product development / supplier sourcing, version 1.1*, 2002a. (website: <http://www.sei.cmu.edu/>).
- SEI (Software Engineering Institute). *People capability maturity model, version 2.0*, 2002b. (website: <http://www.sei.cmu.edu/>).
- Strutt, J.E., Sharp, J.V., Terry, E., and Miles, R., Capability maturity models for offshore organisational management, *Environ Int.*, **32**:1094, 2006.
- UKOOA (UK Offshore Oil Operators Association), *Industry guidelines on a framework for risk related decision support*, London: UKOOA, 1999.
- Watson, S.R. and Buede; D.M., *Decision synthesis*, New York: Cambridge University Press, 1987.
- WHO (World Health Organisation), *Water safety plans (revised draft)*, Report publication WHO/SDE/WSH/02.09, WHO, 2002.
- WHO (World Health Organisation), *Guidelines for drinking water quality*, 3<sup>rd</sup> edition, Geneva: WHO, 2004. (website: [www.who.int/water\\_sanitation\\_health/dwq/en/](http://www.who.int/water_sanitation_health/dwq/en/)).