CRANFIELD UNIVERSITY

ANN S PARCHMENT

DEVELOPMENT OF A NOVEL METHOD FOR CROSS-DISCIPLINARY HAZARD IDENTIFICATION

SCHOOL OF APPLIED SCIENCES

PhD

Academic Year: 2012 - 2013

Supervisors: PROFESSOR J OAKEY, DR S ROCKS, DR S JUDE

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ABSTRACT

Hazards and risks are currently identified in generic risk silos using top-down tools and methods which are incorporated into whole system risk management frameworks such as enterprise risk management. The current methods of identification and documentation are linear in approach and presentation. However, the world is multi-dimensional requiring a method of identification which responds to complex non-linear relationships. A method is required to identify cross- disciplinary hazards and formulate a register method to evidence the identified hazards. This study uses expert elicitation, web, survey and case studies to develop a method for cross-disciplinary hazard identification by application of the dimensions of generic, interface, causation and accumulation. The results of the study found many of the tools and methods used for hazard and risk identification such as hazard and operability studies took a top down approach commencing with a known failure and establishing cause and effect. The starting position of a known failure or event precludes identification of new types of failure or events and perpetuates a linear approach to hazard identification. Additionally the linear design of a risk register does not facilitate the presentation of multidimensional hazards. The current methods do not accommodate multiple lifecycles and components within cross discipline relationships. The method was applied to three case studies. The first case study had an existing risk register of 50 risks, post method application an additional 531 hazards were identified; case study (2) a register of 49 hazards and post method application additional hazards of 261; case study (3) an initial register of 45 hazards and an additional 384 hazards after method application. The impact of the method application highlights inconsistencies in the initial risk register and provides a tool which will aid the identification understanding and communication of hazards. Additionally it documents previously unidentified cross-disciplinary hazards and provides a proactive register method for identification and documentation by application of the dimensions of interface, causation and accumulation.

Keywords: Cross-disciplinary hazards, hazard identification, interconnectivity, multidimensional, risk register.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ALARP	As low as reasonably practicable
ANOVA	Analysis of variance
BERR	Department for Business, Enterprise and Regulatory Reform
BIS	Department for Business Innovation and Skills
BRMF	Business Risk Management Framework
BTS	British Tunnelling Society
CAPEX	Capital expenditures
CAS	Casualty Actuarial Society
CCP	Carbon capture plant
CCRA	Climate change risk assessment
CCS	Carbon capture and storage
COMAH	Control of major accident hazards
COSO	Committee of Sponsoring Organizations of the Treadway Commission
CRESTA	Catastrophe Risk Evaluation and Standardising Target Accumulation
Defra	Department for Environment, Food and Rural Affairs
dist	Distribution
DECC	Department of Energy and Climate Change
DOE	Department of Environment
DyPASI	Dynamic Procedure for Atypical Scenarios Identification
ERM	Enterprise risk management
ERMA	European Risk Managers Association
ERO	European Risk Observatory
ETA	Event tree analysis
EU	European Union
EU-OSHA	European Agency for Safety and Health at Work
FEED	Front end engineering
FEP	Features Events and Processes
FMEA	Failure Mode Effects Analysis
FMECA	Failure mode effects and criticality analysis
FCA	Financial Conduct Authority
FTA	Fault tree analysis
GEJE	Great Eastern Japanese Earthquake
GHG	Greenhouse gases
GIS	Geographic information systems
GRAFCET	Functional graph control steps and transitions
HACCP	Hazard analysis and critical control points
HAZOP	Hazard and Operability Studies
HHM	Hierarchical holographic modelling
HMI	Human machine interface
HSE	Health and Safety Executive

HSL	Health and Safety Laboratory
IAIS	International Association of Insurance Supervisors
ID	Identification
IEA	International Energy Authority
IPCC	Intergovernmental Panel on Climate Change
IPCS	International Programme on Chemical Safety
IRM	Institute of risk management
IRMI	International Risk Management and Insurance Institute
ISO	International Organisation for Standardization
KSI	Key strategic intentions
LCA	Lifecycle assessment
LCI	Lifecycle inventory
MAH	Major Accident Hazards
MBCA	Model Business Corporation Act
Natech	Natural hazard event
NGO	Non-governmental organisation
NTS	National technical services (EA)
OGC	Office of Government Commerce
OPEX	Operating expenditure
PHA	Process Hazard Analysis
RA	Reporting authority
RMM	Risk management methodology
SDM	Soil Moisture Deficit
SELL	Economic Level of Leakage
SFAIRP	So Far As Is Reasonably Practicable
SOX	Sarbanes- Oxley Act
SSRS	Strategic risk register system
SSSI	Sites of Special Scientific Interest
SWIFT	Structured What If Technique
UKCCSc	UK Carbon capture and storage community
UKCGC	UK Corporate Governance Code
UKCP09	UK Climate projections 2009
UNISDR	United Nations International Strategy for Disaster Reduction
VaR	Value at risk
WEO	World Economic Organisation

1 THESIS INTRODUCTION

1.1 Introduction

Globalisation and the exponential proliferation of access to a plethora of new technological developments have resulted in a complex web of interconnections and dependency. Additionally this scenario has to operate within the constraints of an increasing demand for the earth's scarce resources (Stern, 2006) and an escalation of the population of 6.5bn in 2005 to 8.5bn in 2030 (IEA, WEO, 2008).This has changed the risk profile and exposures of the current world. At the same time there has also been a move from hazard identification to risk identification and quantification.

The methods and tools to identify hazards and risks have not kept pace with this change and are not able to identify the multidimensional exposures that result from complex interactions in the current environment (Beck and Kropp, 2011). There is recognition of the need for cross-disciplinary risk management which is not focused on quantification or control (Rasmussen, 1997). Hazards are a risk source (Aven, 2011) and if not identified; these hazards and potential risks remain unidentified, un-quantified, unmanaged and unregulated. The result is significant cost to insurers as well as governments as the reinsurer of last resort.

1.2 Aim

The aim of this research project is to identify and investigate (using case studies) why robust and encompassing hazard identification does not occur, particularly in areas where multiple fields overlap; and to design a framework that will address these deficiencies.

The value of this research will be the formulation of a method for cross disciplinary hazard identification and documentation. The resulting identified hazards will provide risk practitioners, insurers and regulators with a repository of cross-disciplinary hazards which can be incorporated into existing risk identification modules of risk management. As a result quantification, management and regulation will benefit from cross-disciplinary identification.

1.3 Research objectives

The objectives for this research are:

- Critically evaluate current approaches to hazard identification and risk management to identify their suitability for the identification of hazards in an interconnected world.
- Define the dimensions of generic, interface, causation and accumulation risk and critically evaluate their application to the identification of hazards.
- Develop and evaluate a model for the identification and documentation of multidimensional attributes of hazards.

1.4 Research rational

Hazards are currently identified in their generic risk silos (Rasmussen, 1997; Ai et al., 2012). While whole system frameworks have been developed with the aim of integrating generic risks for example using enterprise risk management (ERM) (COSO, 2004), this integration at the stage of identification has not occurred (Ai et al., 2012).The development of an understanding of dependency has commenced but this is focused on already identified risk's which is the case with Allen and Yin (2010). To ascertain the unidentified hazards, a method will be developed to embrace the multidimensional attributes of hazards in a number of descriptors. This requires the introduction of new dimensions and the development of an appropriate medium for documenting the identified hazards. The choice of documentation has to be capable of embedding the existing risk management regime within organisations. The method will be developed for the use of organisations concerned with the identification of hazards within the risk management of large infrastructure. The result will be a portfolio of hazards which are multidimensional providing risk professionals with a more holistic overview of their risk profile.

1.5 Thesis structure

The thesis structure and alignment of research objectives are illustrated in Figure 1-1. The figure shows the development of the rationale and evidence for the model in Chapters 1, 2 and 3. The research methodology is outlined in Chapter 4 and the initial results from surveys and questionnaires analysed to support the formulation of the method for hazard identification in Chapter 5. The method for cross-disciplinary hazard identification is presented in Chapter 6, tested and developed by application to three case studies which are presented in Chapters 7, 8 and 9. Each of the case studies test the robustness of the method and adds to its development.

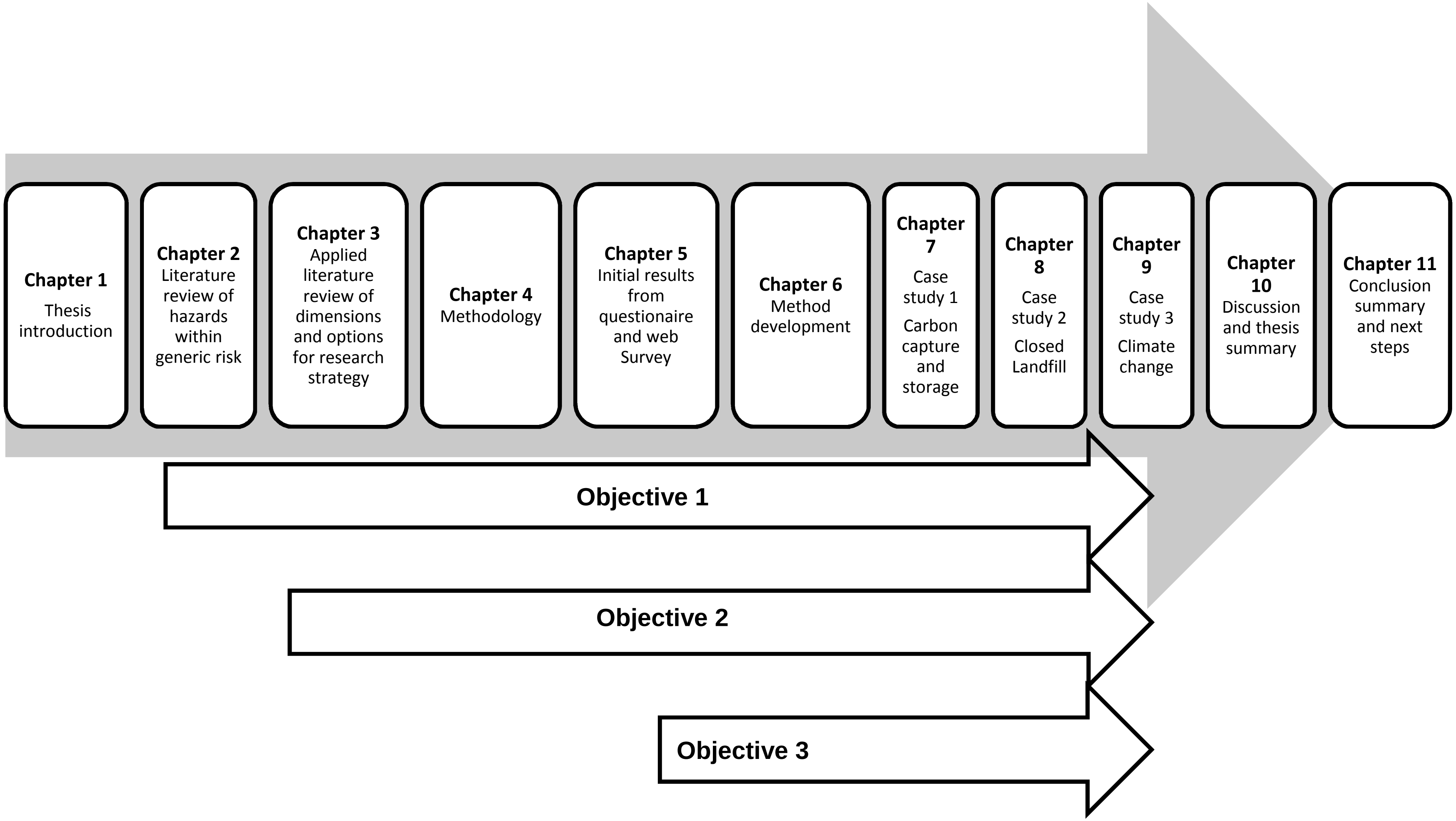

Figure 1-1 Thesis structure alignment and attainment of research objectives

2 PRIOR ART

2.1 Introduction

The world is increasingly complex and interconnected and there is a need to identify and manage the resulting hazards and risks (WEF, 2011). Many of the increasing unanticipated commercial costs of risk are related to incomplete hazard identification (Goh and Chua, 2010). Historically hazards have been identified in generic disciplines such; as health, safety, legal and environmental, however seldom are they identified across disciplines. Technical hazards are identified as part of a process and are usually focused on a single point in time. Methods of identification have not developed to replicate the cross-disciplinary relationships of hazards or the changing profile of a hazard over a lifecycle (Beck and Kropp, 2011).

This chapter delineates the significant factors of hazard identification by investigating the current knowledge surrounding the relationship between hazard, risk and uncertainty. It then explores the landscape of risk identification, within generic risk identification, risk assessment and risk management frameworks.

2.2 Key concepts

This research project aims to develop a methodology to improve the identification of hazards across multiple disciplines. Clarity of the term hazard and its relationship with risk and uncertainty is essential to the identification of hazards.

2.2.1 Hazard

A hazard is defined as a source or cause of; adverse effects, danger, harm, loss, injury, damage, disruption, and degradation (Kaplan and Garrick, 1981; Royal Society, 1992; Sutton, 1992; Fairman et al., 1998; IPCS, 2004; Smith, 2005; IPCS, 2008; HSE, 2011). The diversity of definitions creates uncertainty and does not facilitate effective hazard identification. The following definition will apply in this research:

hazard is defined as a source of danger, damage, harm or loss. Hazards can result from natural phenomena such as, hydrological meteorological, geological, biological or human activity (HSE, 2001; UNISDR, 2009).

Hazards can be latent or immediate, chronic or acute and result from the use, development and decommissioning of technology. Hazards can be identified and characterised; whereas risks are often quantified (Aven, 2010).

2.2.2 Risk

Risks are assessed and managed in numerous contexts and applied to many different aspects of life by various disciplines and professions on a daily basis (Fairman et al., 1998). Risk is a phenomena and concept that requires awareness and management, but risk does not have a commonly accepted definition (Renn, 2011). This is evidenced by the number of harmonisation projects that have taken place and have not resulted in an agreed definition of the phenomena of risk (IPCS, 2004; Aven and Renn, 2009; Redmill, 2002).

Risks are identifiable and measurable (Van der Elst and Van Daelen, 2007).The quantifiable characteristic of risk is a common theme and is expressed as a probability, expected frequency, likelihood, severity, possibility, magnitude or chance (Smith, 1981; March and Shapira, 1987; HSE, 2011).

Risk is defined as the probability of a specific hazard. Risks can be characterised by qualitative descriptions such as significance, severity and magnitude. Qualitative descriptions of risk can be expressed as the potential for danger, damage, or harm and where the likelihood, probability, frequency, severity or deviation can be quantified. Risks can have both positive and negative impacts. Hillson (2002) describes upside risks as opportunities and downside risks as threats. This research focuses on the negative aspects of risk. Uncertainty, exposure and hazard are essential elements of risk (Bedford and Cooke, 2001).

2.2.3 Uncertainty

Uncertainty is identifiable but not measurable (Knight, 2002). Uncertainty can be categorised as aleatory, (systems) uncertainty and epistemic (knowledge based) uncertainty (Bedford and Cook, 2001; Bowden, 2004). The origins of uncertainty can be human, scientific, institutional or policy based (IPCC, 2010).

Uncertainty can arise from incomplete and imperfect knowledge resulting from corrupt data, incomplete information, inconsistency, or information that is complex and misunderstood (Van der Sluijs et al., 2005; Defra, 2011). It may also result from variability in parameters and structural issues with extrapolation (Gallegos and Bonano, 1993) such as the incomplete knowledge of a model, process or system. It can arise from the quality and interpretation of data; result from conflicting evidence, lack of evidence, and validity of evidence. Uncertainty can be the consequence of the balance between objectivity and subjectivity (Bowden, 2004) where uncertainty is the variability of possible outcomes (Hertz and Thomas, 1984; March and Shapira, 1987).

Uncertainty is accommodated in risk analysis and can be expressed as probability distributions, percentages and confidence levels. It is dealt with in two ways by: (1) qualitative methods such as social/ legal assessment with the use of expert opinion; or (2) statistical methods for example probability analysis (Finnveden et al., 2009). Knight (2002) stated that uncertainty cannot be measured but judgments can be made on the probability. However a statistical approach does not remove or reduce uncertainty but formally includes it in the process facilitating uncertainty management (Stenhouse et al, 2009).

2.2.4 Relationship between hazard, risk and uncertainty

Risk is the relationship of uncertain outcomes and incomplete knowledge (Hansson, 2011). It is the product of uncertainty and hazard where the resulting impact may be reduced by mitigation (Kaplan and Garrick, 1981). A hazard is the source of a risk and has to be identified prior to risk identification (Carter and Smith, 2006). The management of risk requires characterisation of hazard, an understanding of the potential variability of outcomes which is expressed either explicitly or implicitly as a probability or likelihood of adverse effect. Risk requires the attributes of hazard, probability exposure and consequence, where all elements have an inherent level of uncertainty.

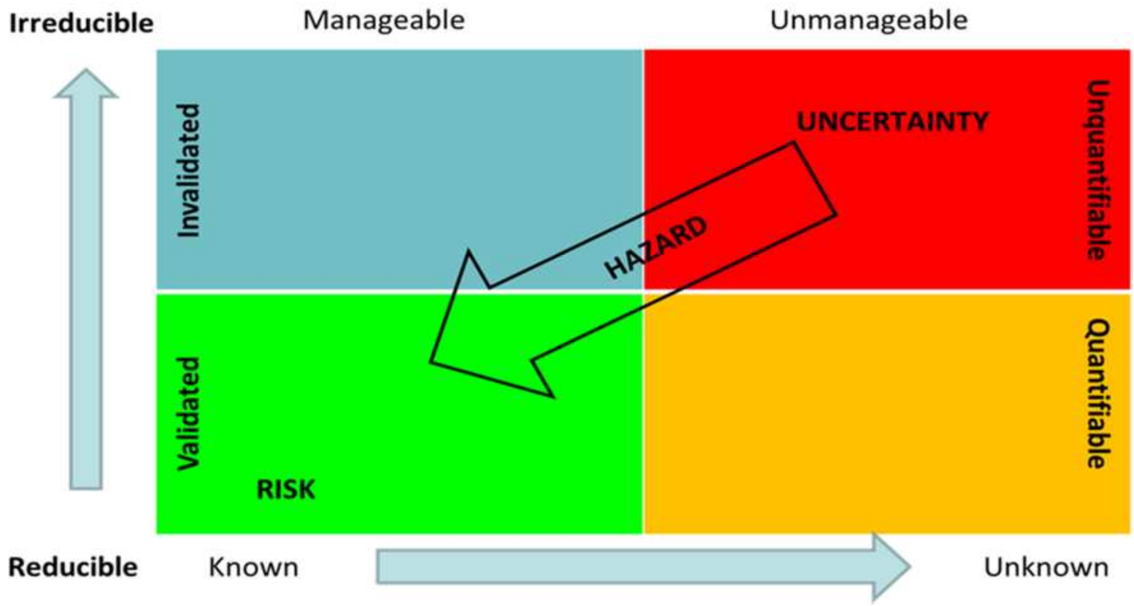

Figure 2-1 Risk attributes matrix which allows the visual positioning of risk (adapted from IPCC, 2000 and Stirling, 2007)

The relationship between risk, hazard and uncertainty is depicted in Figure 2-1. If a hazard is not identified, risks remain unassessed and mitigation cannot be focused to control the unidentified hazard (Carter and Smith, 2006). The result is unmanaged risks. New technologies and increasingly dynamic and interconnected environments require hazard identification methods to evolve reducing uncertainty and improving the management of risk.

2.3 Hazard and risk identification

2.3.1 Hazard identification

Hazard identification involves the identification of the relevant properties that cause adverse effects such as loss, danger, damage or harm and is usually incorporated as part of the risk management framework of generic risks such as health and safety and the environment. There has been a move away from hazard-based management to risk-based management (Fairman et al., 1998).This approach may not facilitate a holistic vision of the dynamic profile of hazards and risks in the current world (Beck and Kropp, 2011). This is due to the underlying source of risk not being identified. Risk management frameworks are comprised of a number of stages; risk identification, risk assessment, risk analysis and risk treatment (ISO 31000, 2009).

2.3.2 Risk identification

2.3.2.1 Linear risk identification

Risk identification developed initially from characterising a risk and defining the qualitative attributes, for example categorisation in generic silos such as safety risk and market risk (Kaplan and Garrick, 1981). The qualitative characteristics of risk are based on what is intended, the current information and the gaps in knowledge about what is intended (Kaplan and Garrick, 1981). This translates as the context, attributes and impact of a risk. As a result the unknown element or gap in knowledge equates to the uncertainty element of risk.

2.3.2.2 Quantitative attributes of risk

The characterisation of risk has developed to include the quantification of risk. This development resulted in what is commonly called the “triplet idea” (Kaplan and Garrick, 1981). The triplet idea was expressed as Risk = (S_i $P_{i,}$ X_i) and required identifying the different outcomes or sources of harm (S_i), the likelihood of the outcomes occurring (P_i) and the resulting consequences (X_i) (Kaplan and Garrick, 1981). This quantification of a hazard can only occur if qualitative identification takes place (Fairman et al., 1998). It is the identification of S_i which is the focus of this research.

2.3.2.3 Third development of risk identification

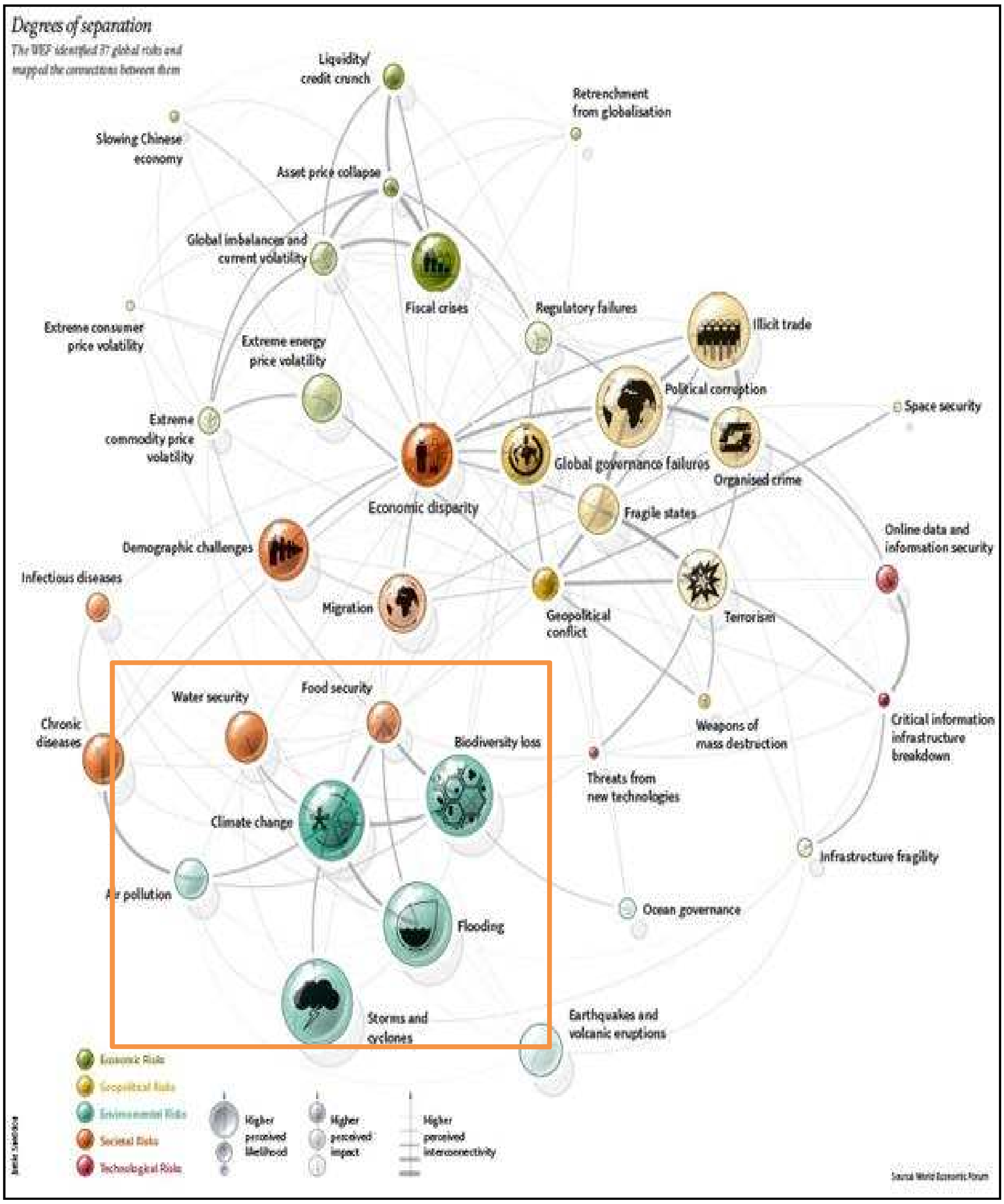

Figure 2-2 Interconnectivity of world events (after World Economic Forum 2011)

Recent events in the world have shown that the interaction of different risks brings a third stage to the development of risk which should take into account risk connectivity (Allan and Yin, 2010), the complexity of these interactions are illustrated in Figure 2-2. The different interactions across disciplines result in hazards which are not identified by current generic risk methods. For example in Figure 2-2 the orange box shows the immediate interconnections of climate change which include; biodiversity loss, flooding, storm and cyclones, air pollution, water security and food security. The figure shows that each of these factors are themselves linked to a number of other factors. These linkages may be the result of different risk relationships which are not silo based or fully characterised and require further investigation.

2.3.3 Risk assessment

Risk assessment is an essential part of any risk management process positioned after problem definition and before the appraisal of options (ISO 31000, 2009; Defra, 2011).

There is significant inconsistency as to where and when hazard identification takes place (Aven, 2011). For example the ISO 31000 risk management process incorporates risk assessment which is comprised of three components; risk identification, analysis and evaluation (ISO31000, 2009). It does not explicitly state where or if hazard identification takes place and the guidance for ISO 31000 Clause 5.4.2 states that if a risk is not identified it cannot be managed. Within the ISO31000 framework it would seem that hazard identification should take place prior to a risk being identified and therefore it must take place as part of the risk identification process. However Aven (2011) has questioned whether risks are identified suggesting that hazards are identified as risk sources and that risks are analysed and characterised in the risk analysis module of risk assessment.

The lack of clarity as to where hazard identification takes place is further confused by the view of Redmill (2002), who suggests that the process of risk analysis consists of three processes: hazard identification, hazard analysis, and risk assessment. Greater emphasis is placed on ensuring that hazard identification is rigorous and robust. Inconsistency results from the fact that the terms ‘risk assessment’ and ‘risk analysis’ are not clearly and consistently applied (Redmill, 2002; Aven, 2011). Further uncertainty results from the US National Research Council report (2009) which suggests that risk assessment includes: problem formulation and scoping; risk assessment planning and conduct; and risk management. Whereas conventional risk assessment comprises hazard identification, dose response assessment, exposure assessment and risk characterisation (Defra, 2011). Beck and Kropp (2011) state that it is not uncommon for incidents to result from risk relationships excluded in previous risk assessments. Fundamentally the risk assessment process is only as robust as the identification of hazards.

2.4 Generic risk identification

Generic risk identification is concerned with the identification of risks within a specific generic framework, such as health and safety. These generic frameworks have specific approaches and frameworks for the characterisation of risks and the identification of hazards which are unique to their discipline. This section critically reviews the risk identification for environmental, health and safety, financial, legal and technical generic risks.

2.4.1 Environmental

The identification of environmental hazards is the initial step after problem formulation in the process of environmental risk management and takes place as part of the risk assessment process at a number of different levels. Recent guidelines for environmental risk assessment and management define hazards as:

a situation or biological, chemical or physical agent that may lead to harm or cause adverse effects (Defra, 2011).

The guidance does not stipulate the media to which harm is caused although it is assumed to be land, water, flora, fauna and humans as defined in the EU Environmental Liability Directive for Environmental Damage (200/35/CE). Air is not explicitly included in the Directive but implicitly included by way of the term “emissions”. The pollution linkage model or S-P-R paradigm includes three parts; a source, pathway and receptor and is a means of visualising the relationship between environmental hazard and risk. Linkage between the three parts of the model has to occur for a risk to exist (Pollard, 2008).

The initial purpose of environmental risk assessment is to evaluate harm (Pollard et al., 2006) and this underpins the need to identify and characterise hazards. The evaluation of harm is determined by severity and the potential to exceed regulatory or accepted standards when set in context of problem definition and potential for detrimental impact. The breaching of a standard alone is not necessarily sufficient to indicate an environmental hazard (Pollard et al., 2004)

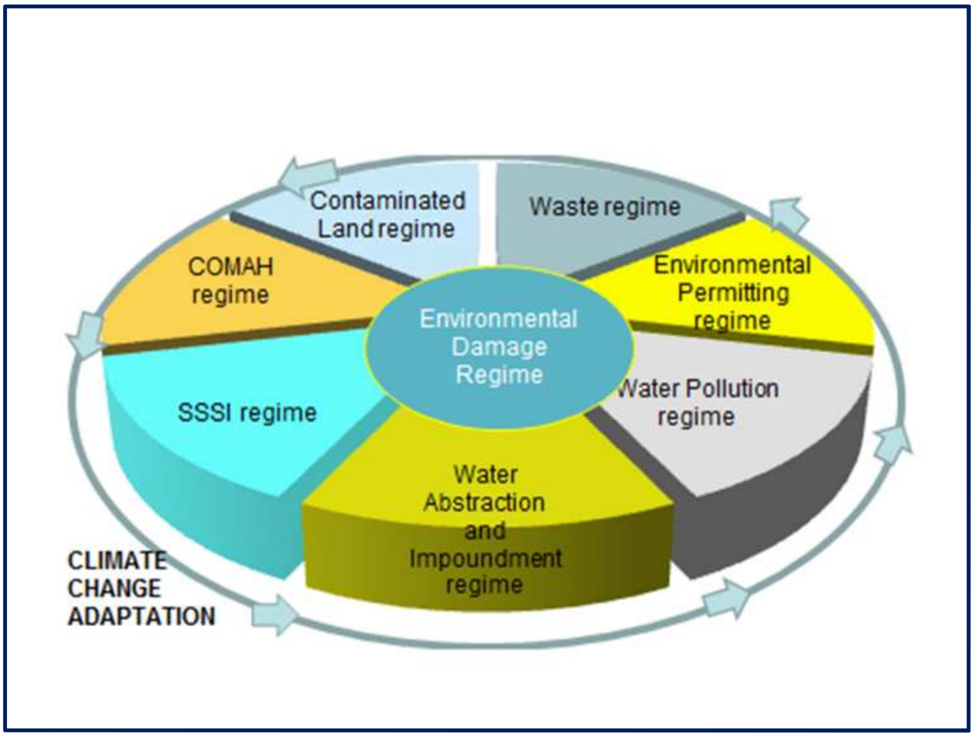

Figure 2-3 Environmental regimes (adapted from BLG, 2008)

Each of the environmental liability regimes in Figure 2-3 has parameters that provide guidance as to whether there is the potential for an environmental hazard. The management of the environment within the European Union is determined by the 'precautionary principle', the 'polluter pays', and 'preventative action' which are enshrined in National and European environmental law. These principles provide boundaries for the identification of known hazards. For example, the pollution linkage model is used for the identification of hazards and assessment of contaminated land (Luo et al. 2009). The assessment of risk in respect of contaminated land requires there to be significant harm being caused, or significant possibility of significant harm being caused, for the land to be designated “contaminated land” (Part IIA Environmental Protection Act 1990). The fact that harm needs to occur means that the source of the harm, has to be identified. The UK Contaminated Land Regime encapsulates the principles of ‘the polluter pays’ and ‘proportionality’ and puts forward a statutory risk based definition of contaminated land (Nathanail. and Bardos, 2004 Luo, et al., 2009)

The initial UK Government guidance stated that hazards are associated with substances, operations, processes, organisms and location (DOE, 1995). This definition has been replaced with “a situation or biological, chemical or physical agent that may lead to harm or cause adverse effects” (Defra, 2011). It also suggests that questions, such as those highlighted in Figure 2-4, should be used as a checklist to facilitate the identification of hazards.

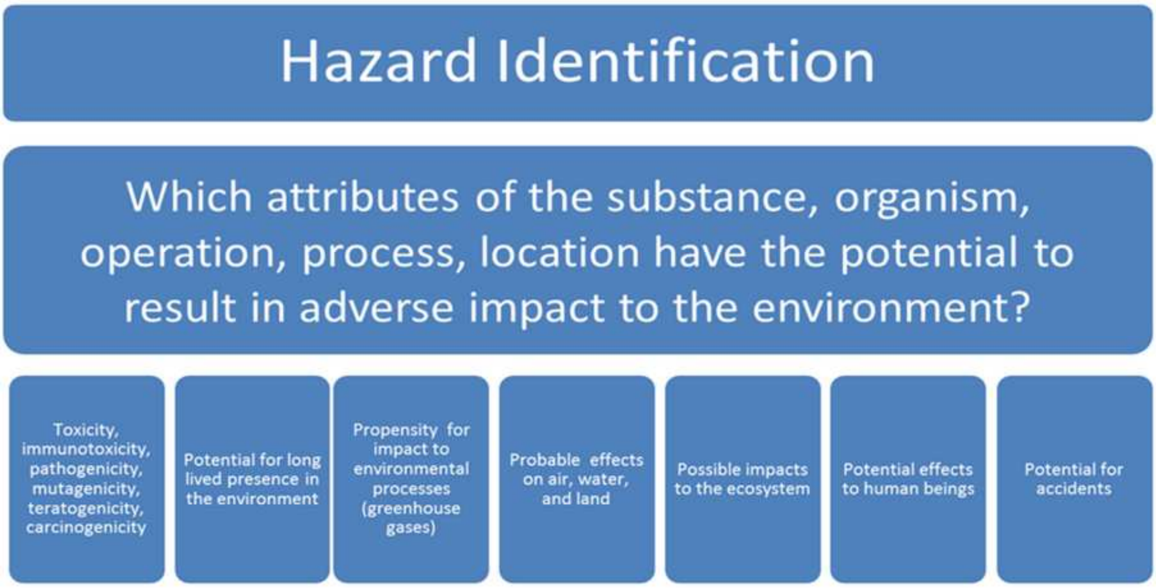

Figure 2-4 Questions and considerations for hazard identification (adapted from DOE, 1995; Defra, 2011)

Where there is insufficient information and or uncertainty, the precautionary principle will prevail (Defra, 2011). The next stage of hazard identification will require responding to the questions “how”, “when” and “where” might an environmental event, operation, process or phase of operation (either through normal operations or failure) result in harm to the environment. Techniques to identify failure have been adapted for use in the identification of environmental hazards and include event tree analysis, fault tree analysis, hazard and operation studies (HAZOP) and reliability and failure analysis (DOE, 1995; Defra, 2011). These techniques are similar to those used for hazard identification in health and safety (see Section 2.4.2).

Although there are many different risk assessment methodologies for environmental exposure there does not seem to be an agreed set of tools for hazard identification across the environmental disciplines. There are methods for identifying hazards for the different media which seem to focus on breaching generally accepted statutory limits and concepts such as contaminated land, air and water quality. Additionally it would seem that the focus is on determining the dose exposure response relationship of pollutants and contaminants to humans and the impact on the quality of land, water, air and biodiversity (EU Liability Directive, 2004). This shows a focus on risk based management and regulation rather than on hazard identification.

The impacts of pollutants are not the only hazards. There are hazards with respect to numerous impacts from climate change, stability of land, changes in river direction, these are clearly environmental and should all be accommodated in environmental hazard identification. Additionally the environment does not function in isolation; it interfaces and has interconnecting and dependency relationships with legal exposures, health and safety, technology, finance and economic factors. These relationships should be explored to identify currently unidentified hazards.

2.4.2 Health and safety

The management of health and safety risk requires an understanding of three concepts, hazard, harm and risk. Hazard is defined by the United Kingdom Health and Safety Executive (HSE) as anything that might cause harm (HSE, 2006). Risk is defined as the likelihood that harm may be caused (HSE, 2005). Harm is the physical or emotional disease or injury that may be caused as a result of an accident, operations or the environment. There is no single all-encompassing definition of harm within the health and safety framework (HSE, 2003). There is an accepted interrelationship between hazards, harm and risks illustrated in Figure 2-5.

HAZARD → HARM →RISK

Figure 2-5 The health and safety hazard, harm risk relationship

The HSE (2006) propose a five step framework for health and safety risk assessments which include the following:-

Step 1 Hazard identification by characterisation.

Step 2 Establish the circumstances in which the target is likely to be harmed.

Step 3 Evaluation of the risk - (severity and frequency) identifying options for mitigation, assess adequacy and prioritise.

Step 4 Record and mitigate.

Step 5 Audit, review and update risk assessment protocol.

Hazards are identified by establishing that harm results from them. Regulations are in place to highlight liability and additional hazard by application of concepts such as “So Far as Is Reasonably Practicable” (SFAIRP) and “As Low as Reasonably Practicable” (ALARP) (HSE, 2001). Site owners and operators need to ensure that mitigation is as far as “reasonably practicable” which is incorporated in the Health and Safety at Work Act 1974.

Risks are evaluated by physical observation of the site, accurate reporting and collecting of data, actual and expected cost of injury, disease and damage, areas for improvement, methods of mitigation identified, and the production of a risk register (HSE, 2005).

The Health and Safety Laboratory (HSL) have conducted an extensive study into hazard identification for control of major accident hazards (COMAH) regulated installations commenting on 40 techniques and classifying techniques into four groups: (1) process hazards; (2) hardware hazards; (3) control hazards; and (4) human hazards (HSL, 2005). The techniques were evaluated based on their effectiveness to identify hazards at different times in a process lifecycle.

Process hazard identification techniques evaluate the failure of an operation and attempt to detect latent hazards. These techniques concentrate on the identification of hazards highlighted by deviations from expected performance and exposure to harmful elements. Hardware hazard identification methods focus on the failure of hardware and the resulting impact of that failure. Control hazard identification tools are concerned with the hazards that result from mal-operation of safety systems including computer systems. The fourth category of hazard identification, human hazard identification, identifies hazards that result from the interface between humans and the process, the focus being hazards that result from exposure to human error. Table 2.1 provides details of the different tools that apply to the four categories of hazard identification.

Table 2.1 Health and safety hazard identification tools (adapted from HSL, 2005)

Process Hazard identification techniques	**Hardware hazard identification techniques**	**Control hazards identification technique**	**Human hazard identification technique**
Hazard and operability study (HAZOP)	Safety audit	Computer HAZOP	Task analysis
What if? Analysis	Failure mode and effect analysis (FMEA)	Structure methods	Hierarchical task analysis
Concept hazard analysis	Functional FMEA	Structured English	Human reliability analysis
Concept safety review	Failure mode and criticality analysis (FMECA)	Specification language	Pattern search method
Preliminary hazard analysis (PHA)	Maintenance and operability study	Structure analysis and design techniques	Predictive human error analysis
Fault tree analysis(FTA)	Maintenance analysis	State transition diagrams	
Cause and consequence analysis	Sneak analysis	Petri-nets	

Process Hazard identification techniques	Hardware hazard identification techniques	Control hazards identification technique	Human hazard identification technique
Pre- HAZOP	Reliability and block diagram	GRAphe De Commande Etat-Transition (GRAFCET)	
Standards codes of practice	Structural reliability analysis		
Functional Integrated hazard Identification	Vulnerability assessment		
Checklists	DEFI Method		
Methods organised systematic analysis of risk			
Goal orientated failure analysis			
Matrices			
Inherent Hazard analysis			

The majority of the hazard identification techniques produce qualitative results which are applicable across a broad range of industry sectors and sizes of organisation. The different hazard identification techniques are not applicable to all stages of the infrastructure or process lifecycle (HSL, 2005). The hazard analysis stage is the first and most important part of the risk management process as mitigation cannot be used to manage unidentified hazards (HSL, 2005). Additionally, with the exception of HAZOP, there was little formal guidance as to the application of these methods of hazard identification.

2.4.3 Financial

Crockford (1986), states that financial risk management is the activity of generating economic value by the application of tools and methods to control identified hazards (Verbano and Venturini, 2011). The hazard identification of financial risk is based on the source of financial harm which can result from financial and non-financial sources. This includes the inability to obtain credit, liquidity, interest rate volatility, overtrading, unidentified liabilities, fraud, misuse of resources, misstatement of financial information, accounting system breakdown and unreliable management information (Dunne and Morris, 2008). In corporate finance, financial risk is the difference between the equity and business risk (Brealey et al., 2006). The greater an organisations level of debt, the greater its exposure to financial harm (Brealey et al., 2006). Financial risk results from third party transactions, fluctuations in markets and the calibration of debt, equity and negative variability in revenue and asset values (Verbano and Venturini, 2011). Financial risk is managed by a number of different financial specialists who are reliant on other parts of the organisation to provide data to help identify financial exposures (Verbano and Venturini, 2011). There are many facets to financial risk, a few of these are presented in Figure 2-6.

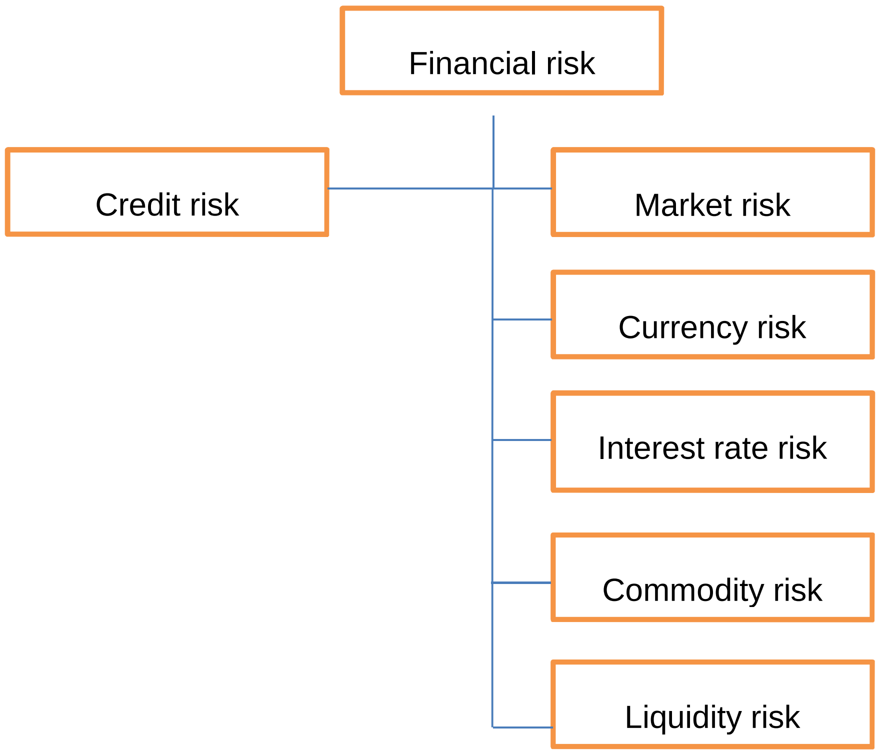

Figure 2-6 Composition of financial risk (adapted from Verbano and Venturini, 2011)

Financial risk management has a framework which is not dissimilar to the other generic frameworks as it includes the stages risk identification, risk assessment, risk response and risk finance. Risk identification involves analysing financial data using generally accepted metrics such as ratio analysis, comparative analysis, value at risk (VaR), gearing, benchmarking for identifying deviations from expected performance and strategic objectives (Asaf, 2004).

An organisation is said to have risks which can be categorised as strategic, financial, operational, commercial and technical (Asaf, 2004). These risks all have the potential to interact in different combinations and create hazards which are not identified. It is not unusual for the threatening risk to be the hazard that has not been identified (Culp, 2001). This has proven to be the case in respect of the systemic risk of large financial institutions such as AIG, Lehman Brothers and Bear Stearns (Rosenberg, 2009). The focus on quantifiable risk, rather than the identification of hazards, facilitated the blindness to moral hazards as they were not part of the audit procedure. Dowd, (2009) states that financial hazards can result from:

1. erroneously applied assumptions (not everything follows a normal distribution);
2. the exclusion of interconnectivity from many financial risk models,
3. valuation models that are inappropriate for economic climate;
4. inexperienced practitioners of the downside risk of complex financial instrument; and
5. traders speculating not just with the instrument or commodity but with the risk management system.

These sources of financial hazards illustrate that, although periodic evaluation of financial performance takes place in the form of reports and accounts, these will not take into account the strategic, operational and regulatory hazards and risks that may hamper an organisations ability to remain as a going concern and achieve its strategic financial objectives. Financial hazards are the hazards that jeopardise an organisation’s ability to remaining as a going concern. The tools for financial hazard identification need to identify those factors that impact the ability to remain a going concern and include elements such, as supply chain management, choice of technology marketing, employee talent pool and reputation (Asaf, 2004). As a result most hazards have a financial impact.

2.4.4 Legal

Definitions for legal risk fall into two groups: legal uncertainty and uncertainty about factual elements (Mahler, 2007). Legal risks differ from other risks as they are usually identified from an *ex post* perspective after the event by a judge (Burnett, 2005). Whereas the majority of generic risks would be identified and risk managed from an *ex ante* position, for example values at risk (VaR) in financial risk, the source-pathway-receptor in environmental risk, or the 5 steps used by the UK HSE in health and safety.

The main factor differentiating legal risk from other risks is the impact of time on the identification and crystallisation of a legal risk. Lawyers do not look at the probability of a risk. Lawyers focus on the allocation of risk/ liability or the chance of winning a case. This is especially true with respect to the identification of risk in a contract and the resulting negative impact of loss to the parties of the contract. The definition of legal risk is not consistent (Mahler, 2007). Legal risk management deals with two aspects of legal risk which lawyers purport to manage: firstly legal risks and secondly the management of risk with the use of legal instruments (Mahler, 2007).

Legal risks result from a hazard emanating from a legal source. If there is no legal source, a legal risk is absent (Mahler, 2007). The source for legal risks can derive from two types of norm. Firstly, hazards which result from prescriptive norms requiring adherence to legislation, regulations and societal obligations and secondly hazards which originate from deterministic norms requiring qualifying a set of facts based on competence and validity (McCormick, 2011). Maher (2007) states that a solid basis for a general theory for legal risk does not exist and suggests the following methodology for the identification of risk which has three stages:

> Stage 1.The identification of legal risk resulting from the consequences of an event and the subsequent application of legal norms to a set of facts, the *ex-post* position.

Stage 2. An *ex-ante* position should be adopted to examine the potential for future liability, damage or loss to property or objective from expected future events.

Stage 3. The identification of uncertainty in respect of the unknown outcome of future events, and uncertainty resulting from how the law would regulate a set of facts. Mahler makes no reference to legal hazard in his methodology for the identification of legal risk (Maher, 2007).

The evaluation of legal risk is based on the type of legislative system being applied. In the UK, legislation, judicial precedent, local custom, legal books as well as European custom and community law will be used to evaluate the legal risk. Legal risk is a term widely used in the public and private sectors and it is identified as a risk to be managed in the majority of transactions that take place. The lack of definition may be due to the fact that it is multifaceted. Law has a number of specialisms including health and safety, environmental and employment, property, company, international, and marine.

Prior to the recent financial crisis the focus has been on governance and compliance with existing regulations rather than the identification of hazards such as moral hazards in the financial sector (Dowd, 2009). The legal risks associated with the protection of assets and mitigation of liability requires formal inclusion in the risk management process. The focus in the last 10 years has been on the implementation of compliance and regulatory risk frameworks. These result from the development of integrated frameworks such as the implementation of enterprise wide risk management, corporate governance codes of conduct, e.g. the UK Corporate Governance Code 2012 and the 2002 US Federal Regulation for public companies, the Sarbanes-Oxley Act 2002 (SOX), the Model Business Corporation Act 2005 (MBCA),and Basel Capital Accord II (Ai et al., 2012).

In Europe, the Transparency Directive 2004/109/EG obliges companies to install a risk and uncertainty detection system. It is assumed that this Directive applies to all risks including legal risks and as such there should be a mechanism for legal hazard identification at all stages of the lifecycle for a process, project or organisation. As legal risks cross the boundaries of all disciplines and operations, hazard identification should be multidimensional and not silo focused. It is not clear if legal hazards or risks get the attention they should within the individual generic silos or if cross-disciplinary hazards are identified. There is a need for comprehensive legal risk assessment, in addition to compliance, in order to provide auditable and tangible evidence that hazard identification supports the resulting risks and evaluation of legal liabilities associated with a project, private or public sector entity not just at the point of sale or *ex-post*.

There are three components of risk; the hazard, the consequence of the hazard, and the probability of occurrence. Table 2.2 provides a summary of the legal response to the components of risk. With respect to legal risk, the hazards are not identified *ex-ante* so the incident may have already occurred.

Table 2.2 Summary of legal response to components of risk

	Component of risk	Legal response
Source	The hazard	Hazards are not identified *ex-ante* and if ex-post they relate to the outcome of legal action.
Effect	The consequence	Legal analysis looks at the effect and the potential for harm resulting from the situation or the legal implication (Maher, 2007).
Risk	The probability of occurrence	The probability occurrence is concerned with the probability of liability based on the facts of the case and past case law. (Burnett, 2005).

Burnett, (2005) has stated that the legal risk management of information technology takes a proactive position due to the continuous operation of e-commerce (commercial transaction which takes place on the internet). Therefore proactive identification of legal hazards which reflects complexity should be applied to projects and organisations.

2.4.5 Technical

For the purpose of this research a technical hazard is defined as originating from manmade technological or industrial conditions such as design, engineering, manufacturing and processes. It includes the technical hazards and associated uncertainties of systems engineering required to meet key performance targets (Verbano and Venturini, 2011). Technical risks are the focus of engineering risk management and concentrate on the malfunction of a system (Verbano and Venturini, 2011). The impact of these technical hazards result in harm, that is evidenced by loss of life, injury, illness, property damage, loss of livelihoods and services, social and economic disruption and / or environmental damage (UNISDR, 2009). Technological hazards can result in disasters such as industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires, and chemical spills (UNISDR, 2009).

Hazards may arise directly as a result of the impacts on technology of a natural hazard event (Natech) accident (Ozunu et al., 2011). Technical hazard identification methods have to consider the hazards that result from the physical process, infrastructure and chemicals being used, and adhere to applicable codes and regulations. Hazard identification of technology involves a plethora of different methodologies and tools which are either qualitative, quantitative or both. The selection of hazard identification methods is dependent on the particular process and the stage in the process lifecycle (HSL, 2005). At the initial stage of the lifecycle, methods such as checklists, indices, and preliminary hazard analysis will be used as there may be minimal information. Where there is more information (such as technical drawings of the site, the pipe, utility networks and technical infrastructure) comprehensive methods such as 'what-if' analysis, hazard and operability studies, fault tree analysis, failure modes and effect analysis can be integrated within scenario analysis to establish the outcome of failure on different parts of the process (Greenberg et, al., 1991 ; Sutton, 1992).

The engineering element of a technical risk is defined using quantitative parameters such as probability and severity, and the application of methods such as probabilistic risk analysis (Verbano and Venturini, 2011). Although the integration of different methods of identification in technical hazard identification takes place, for example the inclusion of environmental impacts and safety within engineering risk management, the focus is on the different ways malfunction evolves from known failures, not on the interaction of cross-disciplinary hazards within the system or process. One of the main challenges of an engineering risk management system is the identification and characterisation of the risks of malfunction and the acquisition of data for dynamic decision making (Verbano and Venturini, 2011).

2.4.6 Comparison of generic risk identification

The previous section illustrated that generic risk frameworks have very different metrics specific to the idiosyncrasies of their risks. They all require the presence of harm for the characterisation of a hazard. With the exception of legal risks, they are unified in the use of similar qualitative hazard identification techniques such as checklists, brainstorming, what if techniques and scenario analysis. Technical, environmental, health and safety risk management frameworks all use similar hazard identification techniques, for example fault trees, preliminary hazard analysis, cause and effect analysis, hazard and operability studies and variations such as hazard analysis and critical control point, failure mode and effect analysis, bow tie and the 'Swiss cheese model' (Greenberg, et al., 1991;Sutton, 1992; HSL, 2005; Defra, 2011) .

2.4.6.1 Silo risk identification

The traditional method of risk identification is the result of identification within generic risk management frameworks such as health and safety, environmental, financial, legal and technical. Each of these generic frameworks commences with the problem definition for their own generic risk and the generic risk experts identify risks according to the metric and philosophy of their respective discipline. Silo hazard and risk identification does not facilitate the identification of hazards and risk in a multi-dimensional world which requires a multidisciplinary approach and recognises interconnectivity and dependence (Hatfield and Hipel, 2002). Fundamentally these individual generic methods of risk identification do not fully embrace cross-disciplinary hazard identification. They have attempted to include other generic disciplines, but this has been at the fringe of the specific silo, for example environmental law within the environment or the impact to human health in respect of a pollution impact.

2.5 Tools and techniques of hazard identification

Hazard identification tools and studies have predominately been developed for identification of hazards in systems and processes at various stages of the lifecycle but are not necessarily applicable to all phase of a process or every stage of a system or process lifecycle (HSL, 2005). There are a plethora of techniques for hazard identification. These tools focus on the identification of harm, loss, damage, failure or injury and depend on human interpretation of observations (Redmill, 2002).

Generic tools have developed from disciplines such as health and safety, engineering, reliability analysis and the social sciences. Hazard identification techniques are categorised according to their application to the identification process into look-up methods, scenario analysis, support techniques and functional analysis (BS EN 31010, 2010). These categories and the resulting methods are presented in Figure 2-7.

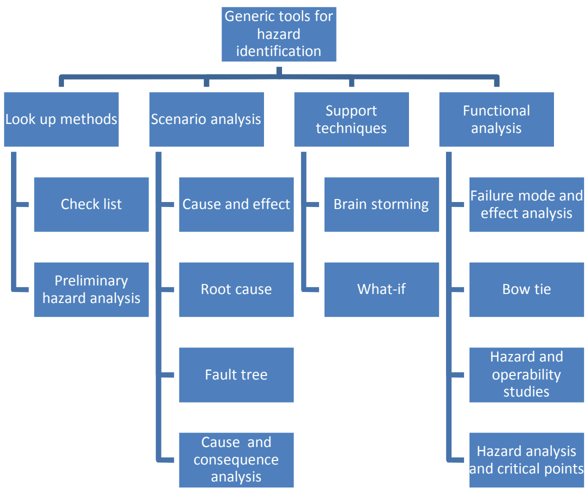

Figure 2-7 Tools and techniques of hazard identification (BS EN 31010; 2010)

2.5.1 Look-up methods

Look-up methods are straightforward methods that have a broad application and are not process, system, activity or event specific. They include checklists and preliminary hazard analysis.

2.5.1.1 Checklists

Checklists are a qualitative hazard identification methods which are widely used but are only effective if there is a solid understanding of the process, system or circumstances in which a hazard may occur (Redmill, 2002). The breadth of knowledge required applies not only to compilation of the checklist but also the person administering the checklist (HSL, 2005).

Checklists are classified as a look-up method in BS EN 31010 (2010) and a process hazard identification method (HSL, 2005). They do not encourage independent thought or creativity as they are predominately structured to be observational and focused on addressing the absence or existence of known hazards. As a result they are unlikely to identify new or emerging risks (HSL, 2005). Redmill (2002) suggests that use of checklists should take into account historical hazard, fault and failure experiences. However the past is not necessarily a good indicator of the future (Harris et al., 2006) as has been illustrated with the 2008 /2009 financial recession and the resulting contagion (Dowd, 2009).

2.5.1.2 Preliminary hazard analysis

Preliminary hazard analysis requires a checklist of hazard groups and identification of potential areas of failure. It is easy to perform, requires a low level of detail and is flexible enough to accommodate risks at the concept stage (Greenberg et, al., 1991). It is often used as means of obtaining initial data for more complex hazard identification tools, such as fault and event trees. As it tends to focus on identification of high level hazards it is unlikely to provide the most comprehensive identification of all hazards or causes.

2.5.2 Supporting techniques

The main objective of support techniques is to facilitate the application of expert opinion on pre-existing and collected data. Techniques such as 'Brainstorming' and 'what if' are included in this category.

2.5.2.1 Brainstorming

Brainstorming is defined as a creative group technique used to elicit the spontaneous information from group participants as they try to find a solution to a specific problem (BS EN 31010I, 2010). Brainstorming may be formal or informal (Scarvarda et al., 2006). When used for hazard identification it needs to be structured and it is crucial to the quality of the output that the members of the group are knowledgeable about the process, system, organisation or application being brainstormed (BS EN 31010I, 2010). The success of the brainstorm is a function of the quality of the facilitator's cues. The value of this method may be undermined by group dynamics (Stroebe et al., 1992). The more unstructured the process, the more unlikely there will be a comprehensive outcome. This method has been used in conjunction with other methods of hazard identification such as Hazard Analysis and Critical Control Points (HACCP) in the food sector (Sperber, 2001). It has most recently been used to support the identification of hazards in Carbon Capture and Storage (CCS) with hazard identification studies (Wilday, et al., 2011).

2.5.2.2 What if Technique

This method is a structured form of brainstorming which relies on the knowledge and experience of the facilitator. The facilitator develops prompt words for a preselected group of experts to discuss by responding to 'what if' scenarios with respect to a process, procedure or theme which is being investigated.

A variation of this technique is the 'Structured What If Technique' (SWIFT) which was originally developed as a systematic and efficient substitute to HAZOP and incorporates supporting tools such as checklists (Aarnes et al., 2009). This method has broad application but is limited by the quality of the facilitator's preparation and knowledge of the subject matter. Fundamentally application of the right prompt words / phrases and management are critical. The workshop team needs to have a broad and deep pool of experience. Lack of experience could result in risks and hazards not being identified (HSL, 2005). The methodology has a top-down approach to hazard identification which focuses on checklist systems and operations rather than features and events. It also facilitates mapping uncertainties, risk and the positioning of barriers (Aarnes et al., 2009).

2.5.3 Scenario analysis

Techniques are used to prompt the identification of hazards by consideration of different scenarios (HSL, 2005). The different techniques include 'cause and effect analysis', 'cause and consequence analysis', 'fault tree analysis' and 'root cause analysis'.

2.5.3.1 Cause and effect analysis

This method was developed initially in the 1960s and is a structured method for deriving the initial causes for a specific effect by harnessing the response of a brainstorming exercise diagrammatically in a fishbone or Ishikawa diagram (Scarvarda et al., 2006). The resulting diagrams, known as causal maps, can take numerous forms and include: cause and effect diagrams, risk-assessment mapping, impact wheels, and issue trees (Scarvarda et al., 2006).

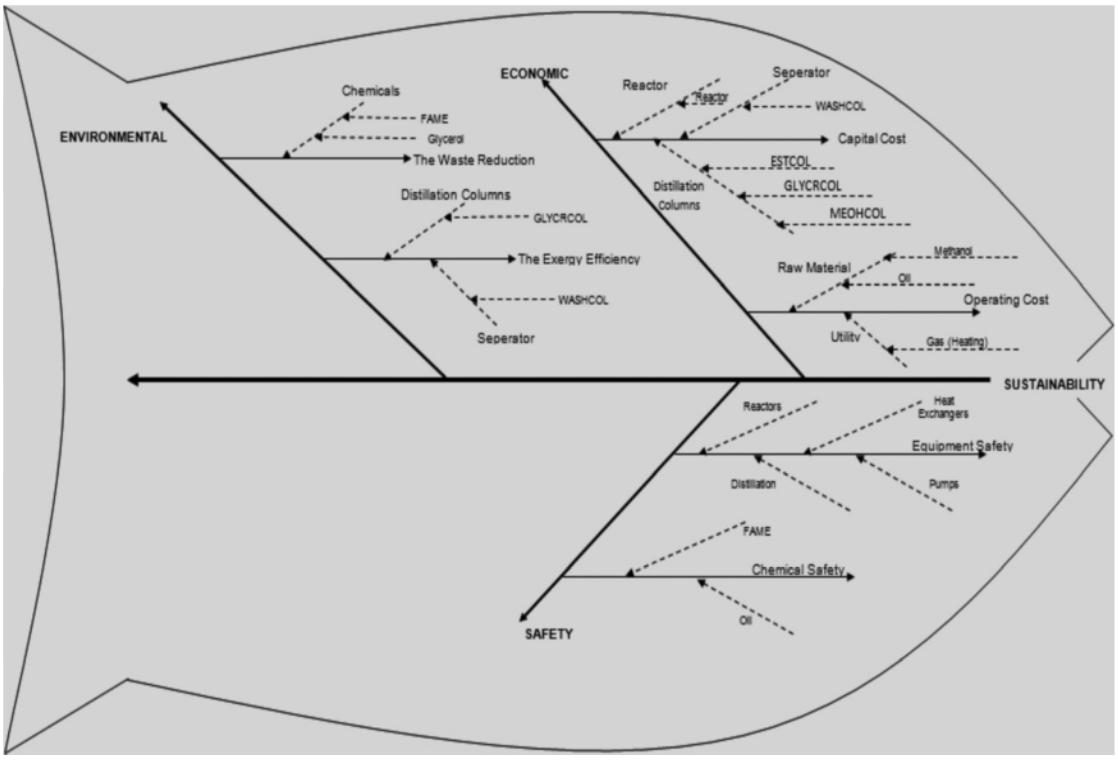

Figure 2-8 Example of a fishbone diagram (Jayswal et al., 2006)

The diagram in Figure 2-8 shows the generic risks which impact sustainability, defined as the end effect. The diagram confirms the inclusion of silos which have a uniting intention but does not facilitate the identification of the interrelationship of sub-branches of each generic classification. This technique of 'cause and effect' is hierarchical with causes resulting in one effect. It is not a complete process and needs to be used with other methods, such as root cause, if recommendations are required (BS EN 31010, 2010). This method segregates causal elements into significant categories. It is a method for visual representation of brainstorming output rather than an analytical technique where recommendations are required at the hazard identification stage (BS EN 31010, 2010)**.**

2.5.3.2 Cause and consequence analysis

This method combines the identification of hazards with quantification in fault tree and event tree analysis. The method incorporates the following steps: identification of the initial event, the subsequent events that result from the initial event, the accident path, using fault tree analysis determine the originating event and the cause of the potential failures of the initiating event; and establish shortest sequence events for the originating event to occur. A diagram is produced which facilitates the quantification of the risk, and the results are documented. The advantages of this method are its ability to combine quantitative results with both cause and consequence. Its disadvantage is that it is highly dependent on the experience of the team involved and can be costly in terms of time and resource (HSL, 2005).

2.5.3.3 Fault tree analysis

Fault tree analysis (FTA) is an analytical method that provides a graphical illustration of events or contributing factors that result in a defined outcome, for example success or failure. The defined outcome is the “top event" (EN61025, 2007) such as an explosion or fire. FTA can be qualitative and/or quantitative. It can be used independently or in conjunction with other hazard identification techniques, such as ‘failure mode and effect analysis (FMEA) or event tree analysis (ETA). When combined with ETA it is sometimes known as ‘cause and consequence’ analysis (BS EN31010, 2010).

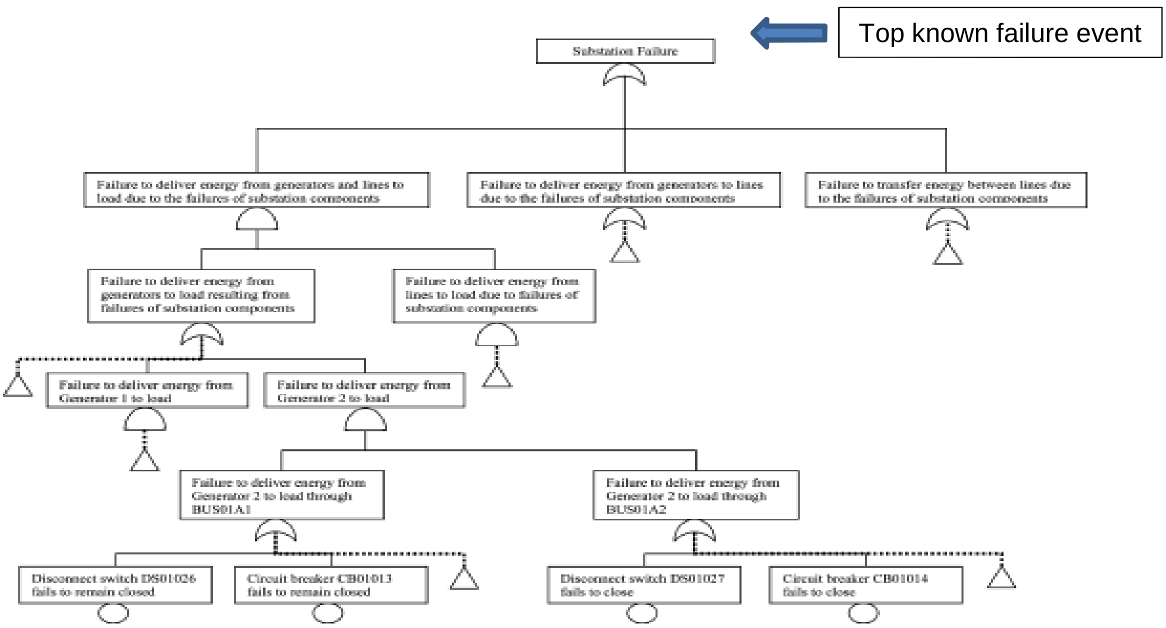

Figure 2-9 Example of a fault tree for substation failure (Volkanovski et al., 2009),

A fundamental issue of FTA is that the outcome needs to be known before the analysis occurs and the logic is focused on how this outcome can occur. This linear approach does not look at how the causes interact with each other and the potential for hazards from these relationships and encounters. Accuracy of the end probability is questionable where the probabilities of base events are not known or may not be accurate. Care needs to be taken when causal events are not highlighted as there is no control in the method to ensure that all pathways are identified. FTA is a static model that does not accommodate time dependencies and human error is not easily accommodated (ISO 31010, 2009; HSL, 2005).

2.5.4 Functional analysis

These methods focus on the identification of hazards resulting from the functional aspects of a system or process. They include techniques such as FMEA of which there are a number of variations such as: HAZOP and HACCP.

2.5.4.1 Failure mode and effect analysis (FMEA)

FMEA is an engineering technique initially developed by the US military in 1949. It is widely applied in the manufacturing, automotive and aerospace sectors to characterise failures. It is a tool that is used to evaluate produce and process reliability at the pre-commissioning stage (Bowles, 1998, Braaksma et al., 2013). FMEA has three phases which include;

1. Identifying failures, their cause and effect;
2. Establishing how likely the failures are to occur and the likely consequences which results in risk characterisation and prioritisation; and
3. The actions that need to be taken to mitigate the impact.

With these three phases the most critical task is the identification of failures (Steven et. al., 1999). From an applied prospective a list of components failure modes is compiled and analysts strive to establish the effects on the system or process.

TFMEA-SALES AND SERVICE

COMPONENT NAME : Submersible pump — Date :
Part Name : Impeller — Last updated on:
TFMEA No. : 1. — Updated by :
Members present :

Failure Mode	Cause of Failure	Effects of Failure	Present Control	Rating	Departments	Remarks	Approved by
1. Rubbing and noise	Customers resent the noise	Competitor overtakes	-	9	P, D	Insist design and production engineers for taking action	-

Figure 2-10 Example of an entry of a component using failure mode effects analysis (Devadasan et al., 2003).

A criticism of FMEA is its inability to deal with complexity as it is time consuming and takes more time to complete than the design and development phases (Steven et al., 1999; Papadopoulos et al., 2004). Classic FMEA can only be used for a single event/or failure mode as it does not facilitate combinations of failure modes and can be complicated and difficult to check for multilayer systems. FMEA is also unlikely to detect failure that results from the interaction of components (Redmill, 2002).

FMEA has evolved with different variations such as the Advanced Failure Mode and Effect Analysis (AFMEA) which introduces a structured behavioural approach to failure identification (Steven et al., 1999). This variation uses FMEA approach which focuses on the function of the process or system. The analysis then focuses on the failure of the functions. Failure mode effects and criticality analysis (FMEAC) includes quantitative attributes by establishing frequency and severity. These variations do not reduce the liability of resources in data requirements or time and they do not necessarily identify failures in respect of new technologies or unknown risks. This is due to the need for the process of this method to commence with a known malfunction. This technique has no checks or prompts that force analysts to identify unknown failures. The failure is known from the start and as a result this method helps to characterise what is already known (HSL, 2005). A recent study by Braaksma et al. (2013) found that FMEA was selectively applied to specific assets which were perceived to be critical; there was insufficient evidence to confirm that failure modes and effects were accurately or consistently identified. Braaksma et al. (2013) also found FMEA was applied as a one off exercise and not a method for the application of continuous improvement; there was an over reliance on expert judgement which was not available for the different stages of the lifecycle and inadequate quality information and knowledge management which led to a questionable robustness of the results.

2.5.4.2 Hazard and operability studies (HAZOP)

Hazard and operability studies are the most extensively used hazard identification techniques and have broad industry application having initially being developed for the chemical sector. HAZOP can be used at any time during the lifecycle of a process (BS IEC 61882, 2001). This method requires a multidisciplinary team approach to ensure the comprehensive hazard identification. Guidewords are used to ensure systematic application to each parameter and process. The steps of the process are illustrated in Figure 2-11.

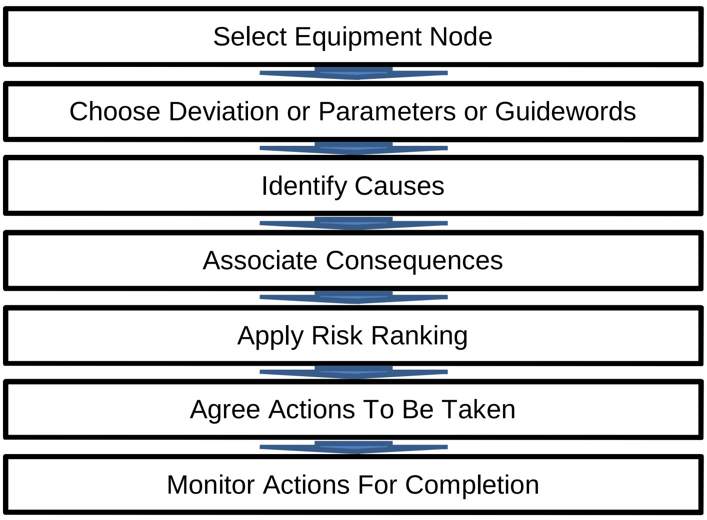

Figure 2-11 The stages of the HAZOP process(HSL, 2010)

The effectiveness of this technique is dependent on team dynamics, quality of participant knowledge, experience, planning, leadership and clarity of the process (BS IEC61882, 2001). This method requires detailed analysis which can be resource and data hungry. Its focus on finding detailed solutions can detract from the identification process, and a preoccupation with design issues can result in externalities being ignored. A narrow focus on the scope at the early stage of the identification process may impede the identification of new or emerging risks that may not be identified or noted for further investigation. HAZOP is an expensive identification technique and its ability to provide comprehensive identification may be curtailed by cost cutting which would result in a compromised identification study (Redmill, 2002).

The most concerning fact is that HAZOPs tend to focus on one event as a cause for deviation. This method of identification does not facilitate the identification of hazards from more than one deviation (HSL, 2005). Additional concern results from the heavy reliance on designers who have a vested interest and therefore create bias in the identification process (BS EN 31010, 2010).

There is a requirement for the development of existing methods and new approaches that respond to hazard relationships which are multidimensional, cross-disciplinary and facilitate a broad identification of hazards (Redmill, 2002).

2.5.4.3 Hazard analysis and critical control points (HACCP)

HACCP is a systematic method that attempts to identify hazards. It is designed to facilitate proactive control by focusing on prevention by assuring safety, quality and reliability. It is widely used in the food industry. Its main limitations, are that it only identifies known hazards and not unknown or unidentified hazards (Sperber, 2001). In order to mitigate these limitations open ended brainstorming has been integrated into the HACCP process to facilitate identification of new and unknown hazards (Sperber, 2001).

2.5.4.4 Bow tie analysis

Bow tie analysis is a diagrammatic representation of the pathways of a top event (hazard) from cause to consequence. Figure 2-12 shows that causes can be identified using fault tree analysis and the consequence event tree.

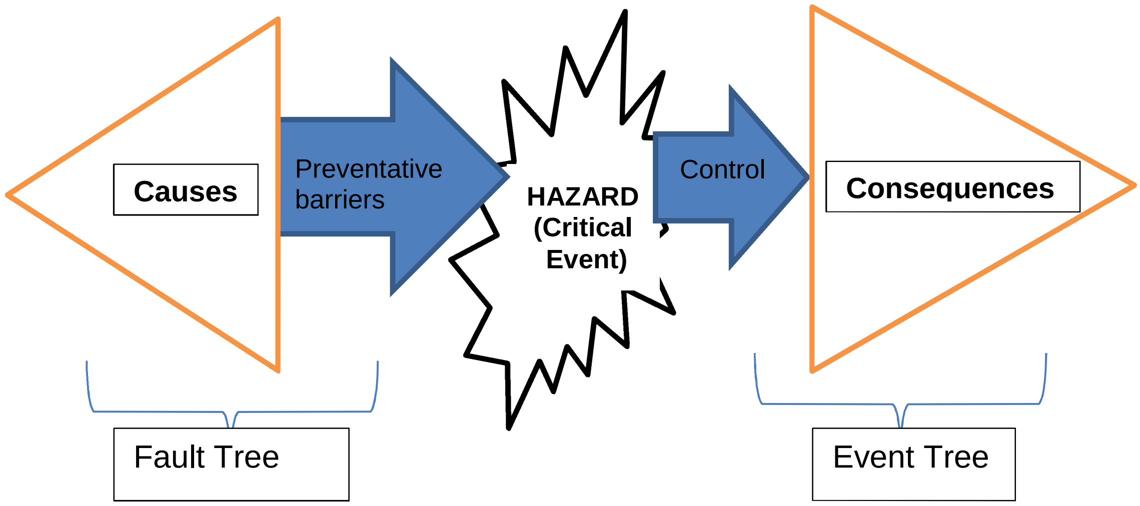

Figure 2-12 Example of Bow tie method (after Diaous and Fieves 2006; Suardin et al. 2008).

This tool can incorporate barriers and controls. Its advantage is that it is simple to use and does not require a high level of expertise to view. The 'bow tie' method is not able to depict multiple causes which occur simultaneously (Wilday et al., 2011) and can over simplify complex events.

2.6 Whole system risk management frameworks

The term 'whole system risk management' for the purposes of this research, includes integrated systems whose aim is the management of risk for an entire entity, project, product or event. The reason for critically reviewing whole system risk management frameworks are that they aim to manage the risk of a whole system and therefore should have methods for the identification of hazards in the entire system. These methods may be different to those used in the generic risk silos (identified in Section 2.5). Examples of whole system generic risk management frameworks include: ISO 31000:2009; enterprise risks management (ERM); project management and lifecycle assessment (LCA).

ISO 31000:(2009) was chosen for further investigation as it is an internationally accepted standard for risk management and therefore the reference point for comprehensive risk management incorporating identification. ERM is a new framework which aims to integrate the management of risks in an enterprise; therefore the identification of hazards in an integrated framework may provide an insight into cross-disciplinary identification. Project management is a framework whose objective is the successful management of a project. LCA is a framework which identifies environmental impacts from the sourcing of resources, the beginning of the lifecycle; to the end of life. These different frameworks incorporate the identification of risks and hazards and an evaluation may provide insight to the inclusion of cross-disciplinary hazard identification.

2.6.1 ISO31000

ISO 31000 (2009) is a whole system risk management framework which superseded the Australian and New Zealand standard AZ/NZS 4360 of 2004 (Purdy, 2010).

2.6.1.1 ISO31000 framework overview

The new framework is illustrated in Figure 2-13 and is comprised of three components; (1) the principles, (2) framework and (3) process for managing risk.

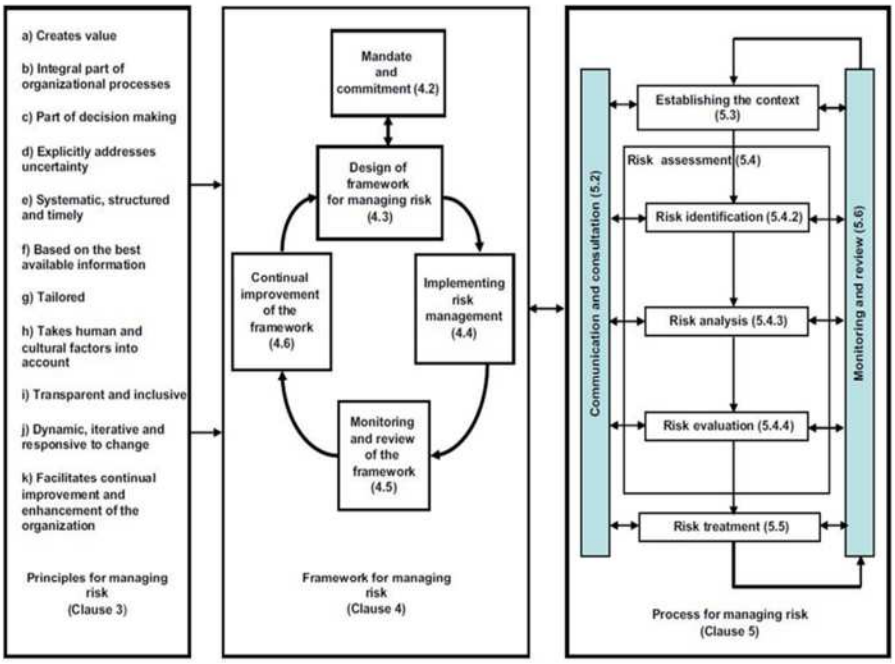

Figure 2-13 ISO 31000 Main principles, framework and process for managing risk (ISO 31000, 2009)

The ISO31000 framework involves the identification of risk in Clause 5.4.2. However the identification process begins in Clause 5.3 “establish the context”, which is concerned with setting the context and defining the risk criteria by looking at the types of causes and consequences that occur. At this stage there is no mention of hazard or harm. Clause 5.4.2 states that identification of the source of risk should take place and include knock on effects, cascade and cumulative effects (ISO 31000, 2009). The standard also states that the identification tools should be suitable for accommodating the objectives of the organisation, but does not suggest which tools could be used. It would seem that the focus of ISO31000 is on safeguarding the objectives of the organisation and not on minimising harm unless that harm is to the organisation.

As risk identification is the first stage of the risk management process, and risks need to be quantified, this may result in only those hazards which are capable of quantification being taken through the risk management process. This could result in excluding uncharacterised hazards and unidentified risks. Although the ISO 31000 risk management framework is iterative unlike the environmental risk management framework it does not explicitly request the inclusion of hazard identification. As a result it may not be capable of identifying known and uncharacterised hazards or unknown hazards.

2.6.2 Project management

2.6.2.1 Definition of project management

Project management is defined as the process by which the completion of a set of tasks for a given specification within the constraints of time, cost and resources are achieved (Turner, 1992).

2.6.2.2 The project lifecycle

There are a number of different project management methodologies. The two most widely used are Project Management Body of Knowledge developed by the Project Management Institute and the Project in Controlled Environments (Prince2) which was developed by the Office of Government Commerce (OGC) (Mcmanus and Wood-Harper, 2002; McHugh and Hogan, 2011). The Project lifecycle can be broken down into 5 stages as highlighted in Figure 2-14.

The aim of the process is to ensure that the project is completed on time, within budget and delivers the benefits agreed at project commencement (OGC, 2007). However these aims which are rarely met (White and Fortune, 2002).

2.6.2.3 Overview of framework and integration with risk management

Risk management is an integral part of the project management lifecycle. Figure 2 14 shows that each stage of the entire risk management framework should be included in each stage of the project lifecycle. For example during the “conceive” stage all the stages of risk management and the associated activities will take place.

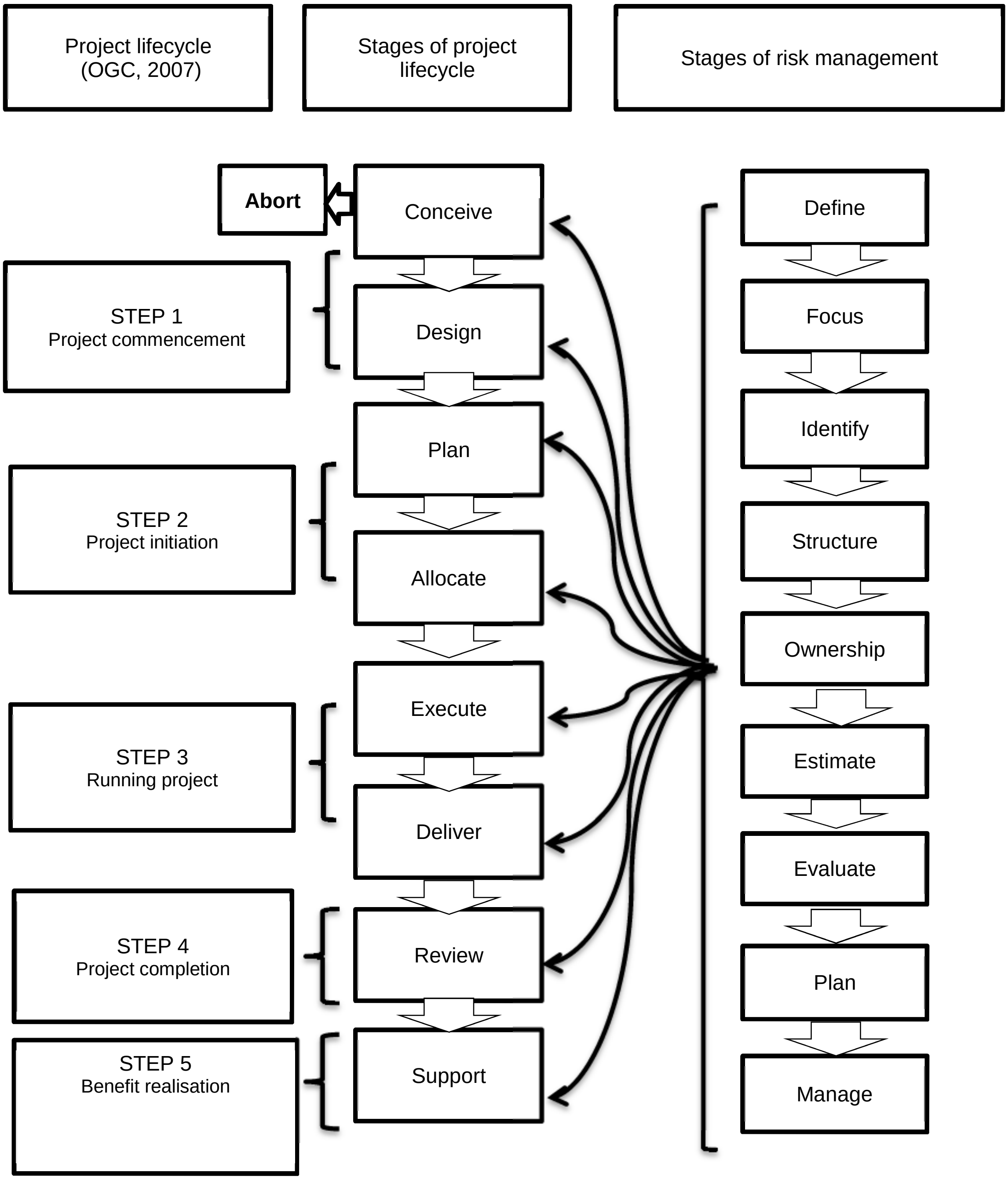

Figure 2-14 Alignment of the stages of the project lifecycle with the stages of risk management (adapted from Chapman and Ward 1998 and OGC, 2007)

The management of risk is critical to the "systematic identification, appraisal and management of project related risk" (Chapman and Ward, 1998). Chapman and Ward, (1998) showed that the nine stages of risk management were applied to each of the eight stages of the project lifecycle; a more detailed lifecycle than the OGC project lifecycle. This shows that the application of risk management within project management is cyclical and iterative as it follows the lifecycle of the project Figure 2-14.

The identification of risk is central to the decision to proceed or terminate a project, as well as sustaining the on-going viability of a project (Chapman and Ward, 1998). The identification of risks in the project management process is evidenced in a number of different documents including the project brief, project initiation, progress report, risk register change control, lessons learnt and post project review.

Risk identification commences at project commencement in project governance where monitoring and control regimes are set up to help manage uncertainties, problems and changes. At this stage risks are identified and reported in the project brief. In the scoping stage (conceive and design) the concern is the risk of not achieving the project objectives and defined benefits and this is the focus of risk identification. This is evidenced in the production of a Gantt chart and an updated risk assessment that may include quantification of risks in the form of probabilities. Workshops may take place which will highlight the risks that need to be considered. A business case is developed which should state the risks to the project an how these should be addressed.

If the planning stage produces a successful business plan, planning of the project commences in stage 2 project initiation (allocation) and this is where for the first time in the process there is a distinct task to identify risks and design controls. The focus is to identify risks that may prevent the execution of the project plan and jeopardise the delivery of the project on time, within budget and with the required benefits. The guidelines clearly state that the focus should be project related and not constant risk issues (OGC, 2007).

The guidelines go onto state that the risk register is positioned during stage 3 “the running of the project” (execution and delivery) and risks should be managed as they occur. This would seem to use the risk register as a log of risks as they arise, this is reactive rather than proactive. At each of the following stages of the project lifecycle the project decision makers will review risk to ensure they are managed and acceptable. The risk assessment tools used in the project management process include; checklists and templates.

In a recent study to establish empirical evidence on project management using Prince2[R] the researchers identified;

"no formal risk planning – risks not properly managed or quantified thus unforeseen issues during the project execution(UST,2010)"

This finding was one of the highest framework issues in Prince2[R] project management (UST, 2010). Additional comments relating to risk included the identification of a need for adequate contingency for unknown unknowns, a formalised risk management process and the adoption of a one size fits all to project management was identified (Shenhar, 2001; UST, 2010). This research, and the review of literature, found little if any reference to the identification of hazards in project management.

The focus on integrating risk management into the project management lifecycle is concerned with risks which are known to impact projects according to set guidelines. These guidelines may constrain the identification of unidentified hazards and unknown risks and there is an assumption that the generic risks have been identified earlier prior to project management. As a result, the project management framework is solely focused on the identification of risks which may jeopardise the delivery of the project on time, within budget and with the benefits set out at commencement (OGC, 2007).

Project management incorporates risk management and risk identification. It does not look at the hazards that result from the combination of numerous generic risks and the hazards that result from a dynamic project portfolio. It is a reactive framework as evidenced by the position of the risk register in stage 3 and its work in progress compilation.

However there would seem to be a miss-match as industry specific project management, such as construction projects, include hazards (Carter and Smith, 2006). What is unclear is whether this focus is at contractor level or project management as a whole system framework. A study of 45 method statements for three United Kingdom construction projects (railway, nuclear and general construction) found that only 6.7% identified all known hazards (Carter and Smith, 2006). This shows that an improvement is required in the methods and tools currently used to identify hazards. Additionally project management requires a methodology which facilitates proactive integrated hazard identification.

2.6.3 Enterprise risk management

Enterprise risk management (ERM) is an inclusive risk management framework with organisation-wide application and a portfolio approach to risk. It is designed to improve corporate governance and risk management (Beasley et al., 2005). The objective of ERM is to increase value to all stakeholders (Liebenberg and Hoyt, 2003; Beasley et al., 2010) by providing an integrated approach to risk management that contrasts with traditional silo based risk management. ERM is described as a discipline that applies to all industries exploiting risk where all sources of risk are accommodated (Ai et al., 2012).

ERM is a strategic decision support framework (CAS, 2003) comprised of seven steps which are comparable to those found in AS/NZS 4360:2004 and include the following stages: (1) establish the context; (2) identify the risks; (3) analyse and quantify; (4) integrate; (5) assess and prioritise; (6) treat and exploit and (7) monitor and review. The risks are then categorised as hazard, financial, operational and strategic. In the ERM framework hazards are defined as relating to natural perils, injury, harm or damage within the organisation for example to employees and third parties via public liability and product liability (CAS, 2003).

The framework for ERM is illustrated in Figure 2-15 and shows the collection of silos on which the framework is based includes: facets of objectives, components and level of the enterprise which are comprised of silos.

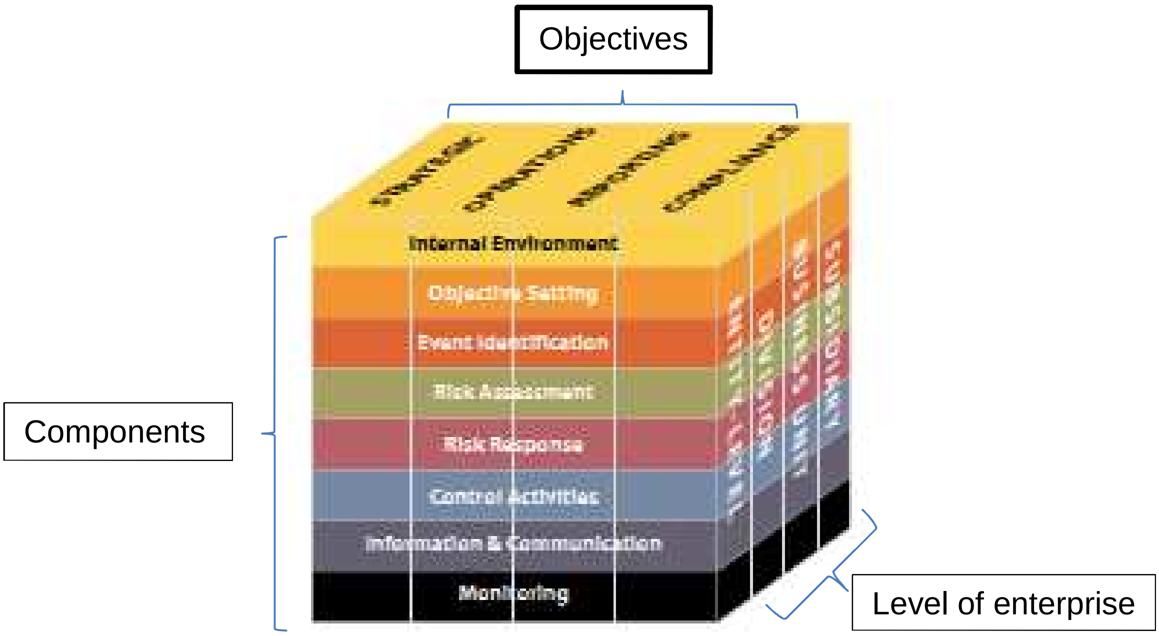

Figure 2-15 Enterprise risk management framework of silos (COSO, 2004).

The identification of hazards within ERM lacks clarity as there are no guidelines for hazard identification. The term hazard is used and interpreted by risk professionals such as actuaries and accountants with a bias towards quantification. This is evidenced by the application of ERM as a whole system risk management framework which was initially embraced by the financial sector (Verbano and Venturini, 2011). The largest industry sector to embed ERM has been the financial sector (Protiviti, 2010).

ERM supports a statement of intent to enterprise-wide risk management as it can be applied to different enterprises across a broad range of industry sectors as well as to public sector organisation (Protiviti, 2010). However there is little consistency in how it is implemented. This may be due to the fact that it is a whole system framework which is embedded in a myriad of different organisations and therefore has to be flexible. However guidance states that after the identification of risk, a shortlist of the most significant risks should be compiled (Frigo and Anderson, 2011). The tools used for identification include methods for assessing the impact of risks on capital, registers of risks, risk mapping and risk matrices (Verbano and Venturini, 2011).

The ERM guidance suggests that a top down approach is adopted by obtaining the most important risk exposures from the leading executives (Frigo and Anderson, 2011). This identification process results from a discussion of risks which could impact the organisation's ability to achieve its strategic goals. The guidance suggests that experts are included as the process matures (Frigo and Anderson, 2011). A more structured approach to risk identification includes documenting conditions and events that represent a significant threat to the organisation achieving its objectives (CAS, 2003).

The tools to aid risk identification include surveys, internal workshops, brainstorming sessions and internal audit. No mention is made of hazard identification or the identification of unknown risks (CAS, 2003; COSO, 2004). Within the specific broad categories of hazard, financial, operational and strategic risk there is no agreed approach to identify risks other than within the pre-existing generic silos.

Within the "analyse and quantification stage", the existing risks are analysed and quantified which involves allocating probability distributions to individual risks even though the guidance states that not all risks lend themselves to quantification. Further focus on quantification is evidenced with the addition of a new quantitative metric, velocity (Frigo and Anderson, 2011). It is unclear how qualitative risks are dealt with in the ERM framework.

The section" integrates risk" does not observe or analyse the interconnection, dependency or identifying new or latent risk; it is concerned with the aggregation of existing risk distributions and their cumulative impact on the key performance indicators of the organisation (CAS, 2003). ERM is focused on the aggregation and integration of existing identified significant high level risks from existing generic risk silos, therefore it is not structured to facilitate the identification of risks outside the existing silos. Its current form does not have the ability to identify the interconnectivity or dependency of new or latent hazards.

2.6.4 Lifecycle assessment

Lifecycle assessment (LCA) is a whole system environmental assessment tool which aims to assess environmental impacts throughout the product lifecycle (Finnveden et al., 2009). International standardisation of LCA has taken place in the last 10 years with the ISO standards (ISO 14040 and 14044 in 2006).

LCA is a methodical process involving four stages as shown in Table 2.3. LCA is unique in assessing environmental impacts along the process and supply chain and it has been applied to many different industry sectors and value chains including CCS (Idrissova, 2004; Hendel, 2006).

Table 2.3 Description of the stages of lifecycle assessment

LCA Phase	Activity
Stage 1 **Goal definition and scope**	Goal setting boundaries by precise definition of the project taking account of functional units, system parameters, and time frame the assessment takes place (Pehnt and Henkel, 2007).
Stage 2 **Inventory analysis**	Identification and qualification of inputs, processes and outputs involves the development of a Lifecycle Inventory (LCI) where environmental inflows and outflows of the investigated systems are collected, calculated and analysed. New technology requires clear assumptions which are interrogated by the application of sensitivity analysis (ISO,14040:2006; SAIC,2006)
Stage 3 **Impact assessment**	Assess the ecological and human impacts of resource usage, water, air, energy and raw materials through inflows and outflows. Assessment involves selection, classification, characterisation, normalisation, grouping weight, evaluation and reporting (Pehnt and Henkel, 2007; ISO,14040:2006; SAIC,2006; Finnveden et al.,2009).
Stage 4 **Interpretation**	The objective of interpretation of the results is to facilitate making recommendations and conclusions and should incorporate a critical review of the result (SAIC, 2006; ISO14040:2006).

LCA is an integrated framework of concepts and techniques to address, environmental, economic, technological and social aspects of products, services and organisations (SAIC, 2006). LCA models are based on accepted risk assessment frameworks for the various inputs, processes, outputs and use the assumptions and values from the underlying risk assessments as defaults (Finnveden et al., 2009).

This framework is time and resource intensive (Finnveden et al., 2009). The quality of the output is a function of the access to quality data. LCA does not result in a solution, instead it provides data to support the decision making process. The diversity of stressors being evaluated makes control of rigor difficult when compared to traditional risk assessment (SAIC, 2006; Finnveden et al., 2009). As a framework for hazard identification it is suitable for relative comparisons but not sufficient for absolute predictions of risk (Finnveden et al. 2009). It is unlikely to facilitate hazard identification and is used in conjunction with other methods and tools. LCA is not a solution but it is an important tool when looking to identify emerging hazards and risks which have environmental impacts it is limited by the lack of data that exists on emerging risks (Wilday et al., 2011).

2.6.5 Critical evaluation of hazard and risk identification in whole system risk management frameworks

The whole system risk management frameworks (ISO 31000 and ERM), with respect to hazard identification, are focused on hazards that result in harm to the organisation which is defined as the inability to meet corporate 'Key Performance Indicators'. Project management is focused on the attainment of the project objectives which relate to cost, time and pre-agreed benefits. In contrast generic frameworks focus on harm caused to humans, tangible and intangible property, and the wider environment; this is likely to result in an insular approach to risk management in an increasingly interconnected world.

Although the frameworks (ERM, ISO 31000, project management and LCA) are very different the base data and process of hazard identification are arrived at via the generic silo risk frameworks. Using the same methods of hazard identification, they are subject to the same limitation of the generic risks and tools used to identify hazard and risk (White and Fortune, 2002; ISO 31000, 2009; Ai et a l, 2012). ERM takes a top down approach to risk identification only focusing on significant risk (see Section 2.6.3). Although all frameworks wish to include qualitative and quantitative data the emphasis is on quantitative data of existing identified hazards and risks. The structures do not currently facilitate interconnectivity or identification of new risks, as their focus is the aggregation of existing risks not integration. LCA is concerned only with the impact of its value chain and not of the impact of externalities. It is not a framework that includes risk identification but the product of LCA can provide information to support hazard identification in the supply chain and its inputs and output could be used to identify latent hazard.

Further work is required to introduce an inclusive approach to cross-disciplinary multifunctional hazard identification. This methodology for hazard identification needs to prompt identification of yet-to-be identified hazards and risks which are not included in generic or whole system risk management frameworks. Both ISO 31000 and ERM state that their objective is to provide more comprehensive risk identification and integrated risk management but neither state how this should take place. Project management attempts to integrate risk management throughout its lifecycle but does not identify hazards. Therefore an integrated method of hazard identification is required to provide a more comprehensive portfolio of known hazards and risks for whole systems risk management frameworks.

2.6.6 Limitations of current hazard identification techniques

The majority of the generic risks are identified using the same hazard identification tools as a result they have the same advantages and limitations. The majority of these tools start with known outcomes and then proceed to identify cause and effect. Their approach is linear and they are unable to accommodate consecutive or simultaneous events or failures. This is especially true of fault trees, preliminary hazard analysis, cause and effect analysis, hazard and operability studies and variations such as hazard analysis and critical control point, failure mode and effect analysis, bow tie and the Swiss cheese model (Greenberg et al., 1991; Sutton, 1992; HSL, 2005). The issue is highlighted in the methodology used for evaluating the hazards of carbon dioxide by Wilday et al. (2011) where the approach was a “structured top down hazard identification study" (HAZID) followed by a "top down knot in a bow tie diagram".

The Health and Safety Laboratories review of hazard identification tools and ISO 31010 (HSE 2005; BS EN 31010, 2010) found that the methods used in Table 2.4 had top-down approaches to hazard identification. The different hazard identification techniques are not appropriate for all stages of the process, product or infrastructure lifecycle (HSL, 2005); and there does not seem to be a prescribed method for a specific stage of the lifecycle or for a specific process. Additional limitations specific to these methods and tools are stated in Table 2.4.

Table 2.4 Limitations of tools which take a top-down approach to hazard identification (after BS EN 31010, 2010)

Hazard identification method	Limitations
HAZOP	Focuses on deviation from one event (HSL, 2005).
HACCP	Requires characterisation of hazards and resulting risks. Does not work well with incomplete knowledge (BS EN31010, 2010).
FMEA	Does not facilitate interdependency and interconnections (Greenberg et, al., 1991).
FTA	Requires the known top event to be identified in order to commence the process of establishing how the subsequent event can occur (Greenberg et, al., 1991; HSL, 2005).
ETA	The initiating event has to be identified. It is concerned only with success or failure options. It accommodates events which are conditional on previous event but is not structured to ensure comprehensive identification of dependencies (BS EN 31010, 2010)
Cause and effect analysis	A method for visual representation of brainstorming output rather than an analytical technique. This method segregates causal elements into significant categories at the commencement of the analysis and subsequently may not adequately include interaction between the categories.
Bow tie	Not able to depict multiple causes which occur simultaneously (BS EN31010, 2010).

With the limitations highlighted in Table 2.4, it is not uncommon for combinations of methods and tools to be used in the identification process (Arvanitoyannis and Varzakas, 2007; Jayswal et al., 2011; Scavarda et al., 2006). For example preliminary hazard analysis has been used for the initial identification of failure modes, cause and effect analysis was used with HACCP to identify the critical control point for a process and, for the same process, FMEA was used with Pareto diagrams to optimise the application of FMEA. All of these methods build on the initial identification of a known failure of a process.

In summary, the tools used to identify hazards do not specifically facilitate the identification of the unknown hazards. They are focused on the outcomes of a known failure, whether that failure is of a part or whole system, process or event.

2.7 Current issues with hazard and risk identification

2.7.1 Risk identification versus risk analysis

One of the fundamental problems with risk management is the absence of the explicit inclusion of hazard identification within the standard risk management process (ISO31000, 2009; Aven, 2011). A study of fatal accidents in the Finnish manufacturing sector during 1999-2008 found that insufficient hazard identification was among the most frequently quoted factors that result in accidents (Nenonen, 2011).

Whole system and generic risk frameworks show that a significant amount of time is spent analysing existing known risks rather than improving the identification of hazards and pushing the boundaries to identify new, emerging and unknown hazards. Tixier et al. (2002) in a study of industrial companies found that risk analysis tools concentrated on the main sources of hazards and the risk analysis methodologies had three phases: identification; evaluation, and prioritisation. Risk identification is critical to risk analysis as the result of the identification phase contributes to the evaluation and prioritisation phases

(Tixier et al., 2002). Risk identification is dependent on robust hazard identification.

2.7.2 Consistency of application

There is no consistency as to how the identification of hazards takes place and no consensus as to whether hazard identification is incorporated in the risk identification process or risk analysis. If hazard identification is part of risk analysis the process has already excluded potential risks which are not quantifiable and these are excluded from the risk management process (Aven, 2011).

Once silo risk analysis has taken place these risks are presented to management boards as proof of risk identification and subsequently become the basis of strategic decision making in whole system frameworks such as ERM (Frigo and Anderson, 2011; Allan and Yin, 2010). No further cross-disciplinary hazard or risk identification takes place, and as a result cross-disciplinary hazards are unlikely to be identified. The inconsistency of application does not provide a robust and consistent basis for concluding that there is evidence of comprehensive hazard identification.

2.7.3 Interconnectivity of risk

The environment, systems and infrastructure in which hazards and risk exist is complex, multidisciplinary and requires identification tools which are able to provide comprehensive identification mirroring that world (Sage and White, 1980; Hoffmann, 2011). There is a need to acknowledge the interconnectivity of risk and seek the means to understand the profile of these interconnections (WEF, 2011). Methodologies that profile the relationship between existing risks are being developed but do not facilitate the identification of new or emerging hazards as they are based on silo identification (Allan and Yin, 2010). Current methods of hazard and risk identification are driven by the components of a process where there are two outcomes, success or failure. The focus of methods for the identification of hazards is the failure of a component and the numerous impacts that result from that failure. The focus is on linear relationships with a known failure, not on cross-disciplinary or multidimensional relationships. Tools and methods used have not evolved to tackle identification in complexity.

Risk connectivity (Allan and Yin, 2010) advances the identification of risk by recognising the connectivity of existing identified risks and provides a framework for systematic visualisation of the relationships using graph theory which is a mathematical method for expressing the interconnectivity. The resulting additional dimension to risk is then documented in an adapted risk register. The result is a third stage in the development of risk, that of connectivity and the introduction of the concept of a risk system. Allan and Yin (2010) have not looked to identify hazards, new or emerging, neither has the objective been to establish whether the risks in the system resulted in more comprehensive identification of risk. The initial data is still based on hazards identified in generic risk management silos arrived at by linear hazard and risk identification.

2.7.4 Adequacy of risk and hazard identification tools

The current qualitative tools for hazard and risk identification are similar and open to subjectivity (see Section 2.6). This is especially true of FMEA, FTA and HAZOP which are not able to deal with the outcome of multiple simultaneous events and connectivity which may not result in the initial failure or event. However, these tools do not embrace a multidisciplinary hazard identification process (Hatfield and Hipel, 2002; Hoffmann, 2011). Beck and Kropp, (2001) suggest that the focus on new product development to lead to a better understanding of risk is fundamentally floored, what is required is an examination of the complex web of connections of existing risks and hazards which are currently unknown and yet to be identified.

2.7.5 Cross-disciplinary hazard identification

There is a gap in knowledge as existing methods of hazard identification do not accommodate cross-disciplinary hazard identification (see Section 2.5.5). Rasmussen (1997) acknowledged the inadequacy of models of risk in the

1990s and suggested that cross-disciplinary models were required using a systems approach. Allan and Yin (2010) provide a contribution to reducing this gap in knowledge as they suggest that interconnectivity and dependency relationships should be incorporated in risk identification but their proposition is the quantification of existing risks and identification based on the sum of the resulting probabilities. It does not necessarily follow that the sum of the parts are either realistic or correct. 1+1 may not with respect to risk, result in 2. It could result in 0 or 10 and the context of the risk could change the way that it behaves.

2.7.6 Documentation of risk

The current risk register approach (see Section 3.5) accommodates the linear identification of risk and does not prompt the identification of new hazards, risk or facilitate interconnectivity (Allan and Yin, 2010). A review of risk analysis by Tixier et al. (2002) examined the inputs and outputs of 62 risk analysis methods for industrial operations and not one included the output contributing to a risk register. Many different lists were produced as outputs but none included a risk register. Tixier et al. (2002) concluded that no individual model would provide a solution, what was required was a combination of methods, such as 'what if' and 'safety analysis'. The evidence from the risk analysis should also be combined and evidenced in a central repository, such as a risk register.

Allan and Yin (2010) suggested a methodology to accommodate the interconnectivity of risk which helped facilitate the identification of existing risks at the risk analysis stage where probabilities have been assigned but additional hazards which result from interconnectivity were not characterised. Prior to assigning probabilities the identification, characterisation of cross-disciplinary hazard relationships is required. Although contributing to the presentation of interconnectivity in a register, Allan and Yin's proposed methodology does not accommodate a truly multidimensional documentation of hazards and risks. A risk register which is dynamic and accommodates multidisciplinary and multidimensional hazard and risk identification is required to meet the needs of complexity.

2.7.7 Quantification versus characterisation

One of the greatest errors in risk management is the failure to identify and characterise hazards (Redmill, 2002). This results from the focus on the quantification of known hazards, and is borne out by the methodology of risk identification in ERM (Frigo and Anderson, 2011). The rush to quantify risk, resulting from Kaplan and Garrick's introduction of risk triplets into the quantitative definition of risk (Kaplan and Garrick, 1981), has meant that there has been significant research to fine tune the quantitative attributes of known risks and less development has taken place on characterising and prioritising hazards and risks (Haimes et al., 2002). Many of the methods used in risk analysis are deterministic because; "*historically organisations have initially tried to quantify damages and consequences of potential accidents, before understanding why and how they could occur" (Tixier, et al., 2002)*.

The quantifiable attributes of a hazard in the form of frequency and severity can only be established if the hazard has been identified. Characterisation has to occur prior to quantification. As a result the identification of currently unidentified cross-disciplinary hazards needs to be evidenced by characterisation prior to quantification. The quantitative attribute of a hazard are not within the scope of this research project instead the focus is on the identification and characterisation of cross-disciplinary hazards.

The prioritisation of hazards requires comprehensive characterisation and the identification of systematic scenarios to highlight what can go wrong (Haimes et al., 2002). This does not currently take place with respect to hazard identification.

2.7.8 Proportionality of hazard identification

Proportionality, within risk management, is one of the five principles of better regulation (Hampton, 2005) and refers to the idea that effort should be appropriate to the risk posed. The concept of proportionality was initially applied in Article 5 European treaty of Rome 1957 which stated "Any action by the Community shall not go beyond what is necessary to achieve the objectives of this Treaty". Proportionality was employed in the pursuit of better regulation in the Hampton Report 2005 and has been applied across disciplines. It is demonstrated in the application of the Contaminated Land Regime Environment Protection Act 1990 Part IIA where the UK took a pragmatic position on the management of contaminated land where land is remediated to a standard with respect to its proposed use as set out in planning regulations. The principle of proportionality should be applied to the application of the proposed method development.

Hazard identification is the foundation of risk identification and, although the objective is to be through and robust, this approach has to be tempered by proportionality which requires taking account of size, scale of impact, type of activities, complexity and resources of the entity for which hazard identification is taking place.

2.7.9 Temporal attributes of hazard identification

Hazard attributes may change over time and as such the identification of a hazard and its development to a risk requires examination over its lifecycle. For example, toxic effects can decrease or increase over time and impacts will vary between receptors at different points in time. It is important for the decomposition and aftercare requirements of waste over numerous years and should be considered as part of hazard identification accommodated in the form of phases of the lifecycle. This is the case for nuclear waste and the geological storage of CO_2 (Wilday et al., 2011).

2.8 Summary

Although there has been significant research into risk assessment this has not improved the identification of cross-disciplinary hazards and risks. The preoccupation with the quantification and management of existing risks results in new risks going undetected leading to complexity in risk portfolios and the inability to identify systemic risks because we have not identified the potential hazards that result from the interconnection of systems. This is characterised by the complexity of our world and requires a multidimensional approach to hazard and risk identification (Allan and Yin, 2010; Hoffmann, 2011; World Economic Forum, 2011; Campbell and Currie, 2006).

Current methods of hazard identification are not necessarily applicable to all stages of a process, system or infrastructure lifecycle (HSL, 2005). Hazards are predominantly identified in generic silos whereas the world is increasingly becoming interconnected and multidimensional in nature. A hazard identification method which replicates these attributes of the real world is absent.

The qualitative tools and techniques for hazard identification focus on a top down approach where the failure or event must be known, and it is the cause of the failure which is identified. The existing hazard and risk identification tools are linear in their approach and do not accommodate simultaneous events or interconnectivity. There is a need to understand the interrelationship of hazards and risks.

Although whole system risk management frameworks have stated that their intention is to provide a broader approach to risk identification to include ‘knock on’ effects, cascade and cumulative effects, little guidance as to how this is to be accomplished is provided. One of the benefits stated by ERM is its integrated approach to risk which is based on existing silo risk management and the aggregation of risks already identified in the existing generic silos. This highlights a need for a methodology which identifies cross-disciplinary hazards from a multidimensional prospective.

3 EXPLORING THE KNOWLEDGE GAP

3.1 Introduction

This chapter explores the existing position with respect to the status of applied knowledge on hazard identification. It builds on the gaps identified in Chapter 2 which include the following;

1. Identifying the different dimensions of hazard used in the applied world.
2. Ascertaining the different modes of documenting multiple dimensions of risk.
3. Evaluating the research methods that should be considered in the development of the research methodology for this project.

The identification of appropriate dimensions, modes of documentation and methodologies available to formulate the research will facilitate greater precision in the research aim, questions and objectives and the further development of a method for hazard identification.

3.2 Multidimensional approach to hazard identification

Previously it was established that current methods of hazard identification did not facilitate cross-disciplinary identification as the methods were linear in their approach (see Section 2.7.5). The majority displayed a top-down approach to hazard identification ignoring the potential hazards that exists as a result of interrelationship across the disciplines. The identification of these hazards requires an approach which incorporates different types of cross-disciplinary interrelationships. These different interrelationships could include:

- silo hazards from a generic family of risks (generic);
- hazards which interface with each other (interface);
- hazards that are dependent on a prior hazard and relationships which are not necessarily from the same generic silo (causation); and
- Inter-portfolio hazards which have the possibility of interconnectivity (accumulation).

If all were incorporated in a method, the result would be the identification of multiple dimensions of a pre-existing group of identified hazards. These dimensions may not be conclusive but would provide a starting point for basic types of interrelationship.

3.3 Dimensions of identification

The most recent literature on hazard and risk identification recognises that the world is not linear and tools need to be developed to reflect the multidimensional attributes of an interconnected world which is exposed to contagion (Hatfield and Hipel, 2002; Beck and Kropp, 2011). In response this section introduces four dimensions of hazards which are used in the applied world; generic, interface, causation and accumulation

3.3.1 Generic

In Section 2.2.2 the timeline for the identification and development of generic risks was explored. It commenced with qualitative characterisation (hazard identification) and was further characterised by quantification and most recently the realisation of inter-risk relationships, such as dependency and interconnectivity.

Spatial approach to hazard and risk identification are not explored in this research project as this aspect is implicitly included in each generic discipline. For example the dispersion of pollution would be considered in environmental, health and safety and technical generic classifications. The temporal aspect was commented on in Section 2.7.8 as a stage of the lifecycle and is highlighted as an area requiring further investigation. This is based on responding to the requirement to know the cross-disciplinary relationships over the lifecycle of a project which is in line with the requirement to identify hazards throughout the project lifecycle.

3.3.2 Interface

An interface is defined as: *"a point where two systems, subjects, organizations, etc. meet and interact" (Oxford, 2010).*

It is a term which is widely used across the disciplines. In geology it refers to the layer between two geological structures; in physics it is the area or gap between two types of matter and in chemistry the layer between two phases in a varied mixture; for example the layer between oil and water. Interface is also used in technology to explain the interaction that takes place between different actors, sections of a process or structure. It has a wide application in computer technology where the interfaces of user, hardware and software facilitate the operating of computer technology.

Interface management was highlighted as an exposure to safety management systems when operations in the oil and gas sector required a number of parties to operate safely within different interfaces (Thom, 2000). The interfaces in operation were on two levels: (1) the client, contractor interface; and (2) the operator-contractor interface (Thom, 2000). However, there were more than two interfaces in this scenario which included; contractual, environmental, geological, technical, regulatory and operational interfaces; this is not an exhaustive list.

Industry guidance for the management of interfacing health and safety management systems was produced for the HSE (Spencer and Davies, 2001). The guiding principles included:

- Individual actors should be in control and accountable for the risks of their own activities;
- When a third party may be exposed to another's risks a mutual interface agreement through consultation should be agreed;
- This agreement should be communicated to all involved;
- The interface arrangements should be audited for effectiveness; and
- The interface agreement should be a working reference and guidance document.

The outline format of an interface agreement includes the process and structure of the interfaces. The risks are assessed, organised and documented but there is no explicit identification of the interfaces. The identification of interfaces was one of eight factors where Identification of interfaces was one of eight factors which should be covered in an interface document (HSE, 2001). This is an obvious gap in methodology for the identification of interface hazards. The guidance was published in 2003 by Step Change but there has been no further update to the guidance.

With respect to the communication of interface management in process safety Kelly and Berger, (2006) propose a method which asks for the identification and evaluation of interfaces. These interfaces are the process and organisational interfaces that need to be involved in the communication of interface exposures. These exposures are assessed according to the criticality of the designated interfaces; environment, reputation, quality and process safety. The identified interfaces are focused on system failure; not on the identification of interfaces of the portfolio of risks and hazards that result from the operations of an organisation, project or process. The focus is on safety which is only one of many generic risks in the portfolio.

Human machine interface (HMI) is a risk which has most recently had a higher profile and subject to greater investigation, as a result of the consequence of increased strain on workers from evolving work practices interfacing with complex and new technology (Flaspoleret et al., 2006). This illustrates the evolution of a change in the identification of risks from two distinct and separate actors; the machinery and the human bringing an additional dimension to the interaction of the human and the machinery.

There are many interfaces which should be investigated as part of hazard identification (Pasquale et al 2003). The following were suggested for a railway system: (1) interfaces between subsystems of the network; (2) system interface with the environment; and (3) equipment operability interfaces (Pasquale et al., 2003). The process of interface identification for the railway network involved the use of HAZOP techniques and expert elicitation where both internal and external interfaces were identified. The resulting interface hazards were presented in a hazard log (Pasquale et al., 2003).

Hazard identification for patient safety is a complex web of internal and external interfaces (Wiig and Lindoe, 2009). This complexity is not translated into the current understanding of patient safety which takes a silo approach with two actors; the hospital and the doctors (Wiig and Lindoe, 2009). This is similar to the silo identification within the individual generic risks (see Section 2.4) and shows the immature stage of interface hazard identification in patient safety. Although there are many interfaces these can be categorised into two types of interface; generic interfaces hazards and system interface hazards. Generic interface hazards are generic hazards that act in combination to result in an additional hazard.

In medicine causality was developed as a concept to understand the evolution of disease. Multi-causality occurs when more than one cause could contribute to an event (Dekkers and Rikkert, 2006). The same term is used in law when there are multiple causes but it is not possible to point to one cause (Knutsen, 2010). Following this logic it is not inconceivable that two or more risks could interface and result in a previously unidentified hazard as expressed in Figure 3-1 .

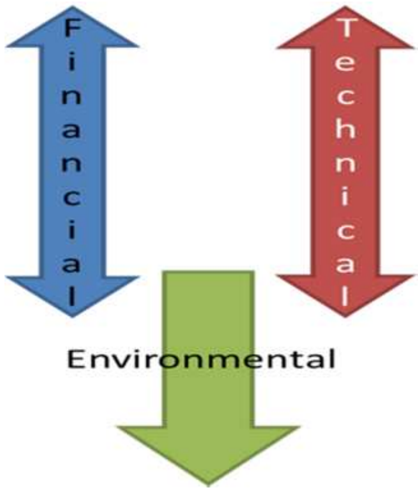

Figure 3-1 Diagram to illustrate the evolution of an environmental interface hazard which results from financial and technical impacts.

In this research this will be known as **Interface Level I,** hazards that occur concurrently with two or more generic risks and result in an additional hazard (multi-causality).

System interfaces include organisational, process and value chains. Interface identification is evolving at different levels of maturity dependent on the industry sector. Organisational hazard identification seems to rely on the assumption that hazard identification of generic interfaces has taken place. The absence of this in the literature shows that this is not the case. In fact the interfaces that are identified are those that relate to safety, the process, organisation and regulation and this is confirmed across the industry sectors of medicine, transport, oil and gas (Thom, 2000; EOR, 2006; Pasquale et al., 2003; Dekkers and Rikkert, 2006; Wigg and Lindoe, 2009).

In this research **Interface II** are hazards which result from the need to integrate consecutive modules in order for the entire process, value chain or system to function (systems interface).

An essential part of managing risk is the identification of hazards at the interface of a complex web of interactions (Beck and Kropp, 2011). Too often it is the hazards that result in the failure of a component that is identified not the unidentified and unmanaged hazards at the interface.

3.3.3 Causation

Causation has been defined by the Scottish philosopher Hume in the 18th Century as the situation where if the initial object did not exist the second object could never have come into existence (Hume, 1739 cited in Lorkowski, 2010).

The concept of causation is used in law and is a critical factor required to establish criminal and civil liability. In both cases a causal link between the claimant's loss and negligent behaviour has to exist (Honore, 2010). There are two tests which are applied in respect of legal causation. The first is referred to as "causation in fact" where the question is asked "but for what the defendant did would the consequence have occurred." The second is called imputable causation or causation in law and this requires that the defendant's actions were an operative and substantial cause of the consequence and that there was no other intervening event (Honore, 2010).

Causation is also used as a means of apportioning liability in European Directives (e.g. the Environmental Liability Directive (2004/35/CE). LCA also uses physical and chemical causation for the apportionment of environmental impacts (Finnveden et al., 2009). The concept of causation is also used in the provision of insurance and determines the breath of coverage provided by insurance and the application of exclusions and warrantees as well as the trigger for the insurance of a potential loss (Knutsen, 2010). In the provision of insurance the concept of causation is used to establish the link between events and impact, damage, loss or injury so that the insured can be placed in no better or worst position than they were prior to the loss or damage.

The concept of causation was applied in the medical profession when disease was believed to be the result of a single cause (Broadbent, 2009). Most recently this view has changed to consider that disease is not the result of mono-causality but multi-causality and probability (Dekkers and Rikkert, 2006). Risks at the preliminary level can be managed by breaking causation linkages for their specific generic risk application (Figure 3-2).

Cause---------------→ Risk-------------------→ Effect

Dose--------------------→ Exposure-----------------→Response

Source---------------→ Pathway--------------------→ Target

Figure 3-2 Example of causation linkages

It is also possible that the resulting effect, response, and target could be the tipping point for another hazard. If the linkage is not broken it has simply changed. Reason (2000) uses the Swiss cheese model to show that an event can break through defences, barrier’s and safeguards. As a result accurate and comprehensive hazard identification across the generic risks is critical to ensure the correct calibration of mitigation and tolerance.

The concept of causation is used in a number of risk and hazard identification tools, where the objective is usually to establish what has caused; a failure or the impact of a specific failure. Tools and methods include those highlighted in Section 2.5 such as FMEA, cause and effect, fishbone diagrams and HAZOP. Causation can also be accommodated in checklists, structured brainstorming, horizon planning and scenario setting. These methods and tools do not currently accommodate cross-disciplinary application and this is required to establish if there is chain reaction.

Many major accidents are the result of a chain of events known as the domino effect (Khan and Abbasi, 2001).These events are some of the most serious and significant accidents for example Buncefield in 2005 (Buncefield Major Incident Investigation Board, 2008), and the Vishakhpatnam disaster (Khan and Abbasi, 2001). Cozzani et al., (2007) state that an accident displays the domino effect if it possesses the following characteristics:

1. a primary incident that acts as the tipping point for the domino phenomenon;
2. the dissemination outcome that results from the primary incident on the subsequent targets;
3. subsequent targets involving a different part of the same structure or other plant in the same vicinity; and
4. escalation phenomena which result in exponential severity of the initial primary incident.

Industrial sites that fall within the regulations of Seveso-II Directive (2012/18/EU; Seveso II Directive) are obliged to identify and assess domino effects both on and off-site (Antonioni et al., 2009). Recent literature shows that the focus of the domino effect has been on determining the physical impact to plant of specific escalation vectors (heat, load, radiation, overpressure, loss of containment), and known outcomes such as damage to equipment, fire and explosion. Additionally methods have been developed to establish the likely impact to units using probabilistic analysis to assess the possibility of domino effect scenarios and their impact (Khan and Abbasi, 2001; Cozzani et al., 2006;

Abdolhamidzadeh et al., 2009; Antonioni et al 2009). The hazard identification that results from the domino effect should not be limited to industrial sites that are required to adhere to the Seveso II Directive it should be applied to generic risks and not just technical and safety risks. Application of causation to a portfolio of existing hazards establishing whether interconnectivity within the portfolio results in currently unknown hazards and risks materialising should be explored. Causation is an accepted concept which may be applied differently across the generic disciplines of law, safety, the environment, technology and health: it can be documented within its generic risk with existing risk and hazard identification tools.

The identification of causal relationships from the starting point of a failure is already possible. Identified risks maybe part of an existing portfolio of risks, but could result in a chain of causal hazards previously unidentified. This unidentified chain of causation could have a significant impact on human health, the environment or the ability of a corporation to operate as a going concern (Figure 3-3).

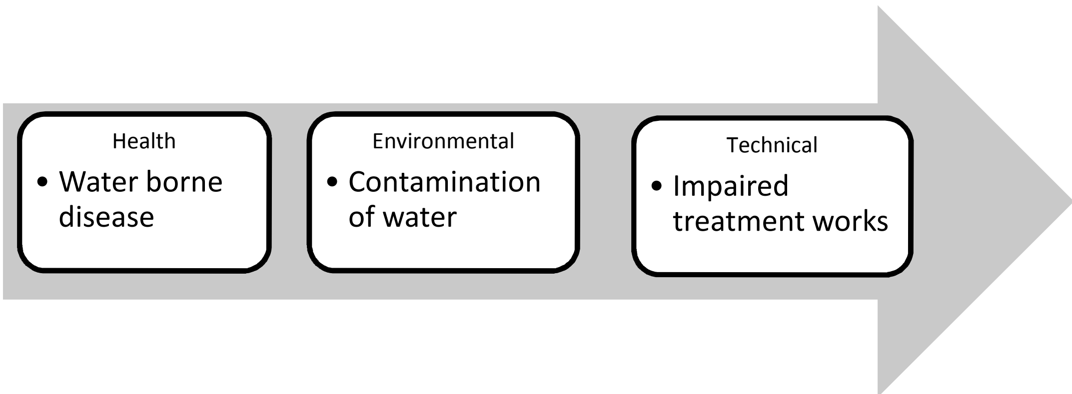

Figure 3-3 Development of a chain of causation

Causation exposures are currently not consistently identified and therefore not reported and remain unmanaged as the final hazard is not initially connected with the primary failure of a process. Time is a critical component of the development of a hazard in a chain of causation.

3.3.4 Accumulation

The insurance sector in the United Kingdom has since the 17th Century identified, assessed and managed risk through various insurance and reinsurance entities and products. It is an efficient market whose purpose is the carrying and distribution of risk. One of the dimensions of risk that insurers and reinsurers both observe and manage is accumulation risk (IAIS, 2012). Accumulation risk refers to a combination of hazards from property and casualty risks which occur from one or more perils (IRMI, 2012). Accumulation results from a concentration of risk in a portfolio of business resulting in a severely impaired financial position for the insurer (IAIS, 2012). The Swedish financial services authority states that accumulation risk; *"…involving risk concentration, e.g. via multiple insurance objects being so closely correlated that the insurance provider risks incurring a loss on all or more than one of these objects as the result of a single event"* (Finansinspektionens, 2012).

Niehaus (1986) suggests that insurers should know the individual risks that comprise their portfolio, as well as the accumulations. The reinsurer needs to make sure that he does not unknowingly assume uncontrolled accumulation risk (Niehaus, 1986) and there is no reason why this approach should not be incorporated in the identification of hazards across descriptor outside the insurance sector.

Catastrophe Risk Evaluating and Standardizing Target Accumulation (CRESTA) was founded by the insurance and reinsurance sector in 1977 to provide technical management of natural hazard coverage. Its main goal is to provide a consistent system to transfer aggregated exposure data for accumulation risk. The accumulation risks relate to natural hazards, terrorism and comprise a number of property and casualty exposures (CRESTA, 2009). CRESTA provides a framework for reporting accumulation risk which comprise a portfolio of risks across geographical zones, perils covered and lines of insurance, to design insurance solutions for accumulation risks a register is formulated (CRESTA, 2009). This portfolio approach to hazards is driven by the protection of the insurer's capital. This should be the approach taken by private and public institutions to protect physical, social and financial equity.

There are a number of different scenarios in which the insurance sector encounters accumulation risk. Most recently these have included:

- Natural catastrophes which commence with a natural peril for example the Great Eastern Japanese's Earthquake of 2011 and may result in the inclusion of other secondary risks such as flooding, and damage to major infrastructures such as nuclear plant (Munich Re, 2012);
- Interconnectivity (WEF, 2011);
- Latent disease such as asbestosis which impacts subsequent generations as well as the original recipient (HSE, 2010);
- Longevity of life which has an exponential impact on life related policies such as pensions (Munich Re, 2012); and
- Terrorism: a large single event which includes a number of secondary events (Bugmann, 1997) such as 9/11 (Liedtke and Schaz, 2011).

The events of 11th September 2001 (9/11) illustrate not only the complexity and interdependency of risks worldwide but the resulting accumulation exposure as shown in Figure 3-4.

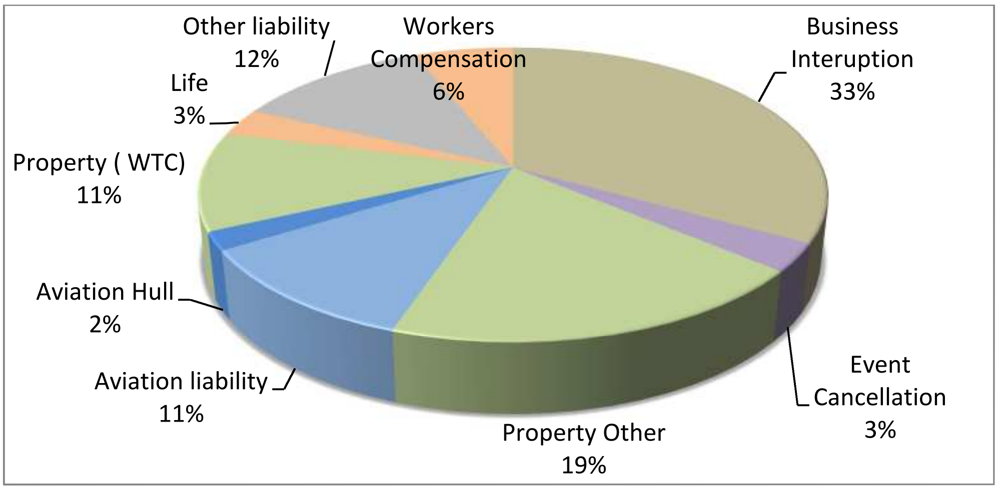

Figure 3-4 Percentage of insured losses from the different lines of property and casualty insurance for the September 11 2001 World Trade Centre accumulation risk (adapted from Insurance Information Institute, 2010)

The World Trade Centre 9/11 event was the result of an accumulation of hazards and risks that resulted in losses across every class of insurance. The total claims cost US$ 23.1bn included 33% of business interruption losses which caused economic impacts when the stock markets undermined the financial stability of insurers, and major companies worldwide (Ortolani et al., 2011). A post event evaluation of 9/11 hazards and risks shows that accumulation includes a plethora of risks and hazards Figure 3-4 (III, 2010). Accumulation risk is not something that only insurers should be concerned with identifying but it should be embedded in hazard identification. If a proactive stance is taken to identify the generic risks that comprise accumulation hazards (such as those in Figure 3-5) there is a greater opportunity to manage currently unidentified accumulation exposures.

Figure 3-5 Diagrammatic representation of the composition of an accumulation hazard

The accumulation portfolios should reflect the phases of a lifecycle, the concentration of risk in specific parts of a process or the scenario where a number of generic risks occur within a short time frame similar to a 9/11 event. Accumulation exposures may be categorised as ‘black swan’ events (Taleb, 2007) but with increased concentrations and interdependency globally it would seem appropriate to include accumulation exposure as a dimension of hazard identification.

A summary of feedback from the Turner Review (a regulatory review of the global financial crisis) suggested that enhanced data capture should also be introduced to increase transparency and supervisory monitoring of risk accumulation in specific areas (FSA, 2010). If insurers, as expert risk managers, identify accumulation exposure to protect their capital and provide insurance capacity then this dimension of hazard identification should be included in the identification of risk for the protection of capital and social equity for both public and private entities.

3.4 Characterisation of the dimensions

Having established the use of the generic, interface, causation and accumulation dimensions in the previous section, this section confirms the definitions which will be used in this research project.

3.4.1 Generic

A predefined classification of risks which are associated with a specific widely accepted discipline, such as environmental, legal, financial, health and safety.

3.4.2 Interface

This type of hazard arises when two or more generic risks interface and result in an additional hazard. This dimension can manifest in two ways:

Interface Level I: Generic interface hazards; and

Interface Level II: System interface hazards.

3.4.3 Causation

A causation hazard is dependent on a prior hazard occurring. If the prior hazard does not occur then causation will not take place. This is monocausality (Dekkers and Rikkert, 2006).

3.4.4 Accumulation

Accumulation hazards occur when the cumulative impact of a portfolio of hazards result in a negative outcome.

The four dimensions result from different inter-hazard relationships. The resulting unique dimensions require a repository that characterises the hazard within a risk register format. The inclusion of these four dimensions will provide an improved repository of hazard data which can be used by risk managers as part of the risk management processes. It will address the requirement for comprehensive identification and provide auditable evidence.

3.5 Repository for evidencing the identification of hazards and risk

3.5.1 Risk report

Risks are reported in organisations on two levels internal reporting and external reporting.

External reports include the risk report which is audited as part of the annual accounts in accordance with UK Corporate Governance Code September 2012 (UKCGC). This code requires that the board of a corporation should be "….. *Responsible for determining the nature and extent of the significant risks it is willing to take in achieving its strategic objectives. The board should maintain sound risk management and internal control systems*" (UKCGC, 2012).

There is no formally agreed format for a risk report. The reports are specific to the organisations or regulators requesting the report. The attributes for reporting have been stated but not what should be reported. The focus is on the aggregation of data, governance and integrity, transparency and completeness (BIS, 2012).

A recent risk report (ThyssenKrupp AG 2010/11) was structured such that it included information on the risk management philosophy for the organisation, methods used to mitigate risks followed by sections providing details on risks which impact the business. The generic risk practitioner will provide reports specific to the generic risk for example environmental risk assessments, health and safety audits, compliance reviews and insurance schedules. The departmental manager and project manager will provide bespoke status reports.

Reports have a tendency to have a short shelf life and provide a snapshot of a risk profile. They are not interactive dynamic methods of providing, analysing or receiving data.

3.5.2 Hazard log (Issue log)

A hazard log is used in project management frameworks such as Prince2[R] and is the precursor to the development of a risk register for the documentation of hazards Table 3.1 provides an outline of the descriptors for a hazard log.

Table 3.1 Outline of the descriptors used in a hazard log (adapted from Pasquale, et al., 2003.)

Fields	Purpose
Identification number	To facilitate an audit trail
Description	Description of the hazard
Cause	Details of the cause of the hazard
Consequences	The consequences that result from the hazard.
Mitigation	Methods used to reduce the hazard
Action	Further action required to better understand or mitigate the hazard
Responsibility	The responsibility of the hazard is assigned to a responsible person
Status	The current status of the hazard for example open, cancelled, resolved, transferred, closed
Note	The rationale for the designated status
Date	Dates which the hazard status has been modified.

The hazard log is simple and easy to use for generic risks but does not, in its current form easily identify the characteristics of an interface hazard as it does not have a field to identify the interfaces. This is also true of causation and accumulation hazards.

3.5.3 Risk register

The current methodology for the compilation of a risk register in the context of a project is to produce a summary risk register in a tabular form from which data is presented for management of the risks. Although this method is simple and can be expedited quickly it is not without issues.

The majority of risk registers follow a structure which includes the following sections; risk identification, risk assessment, risk response and risk management (Ward, 1999). Table 3.2 compares seven structures for the tabulation of a risk register. Although the seven risk register structures follow the four sections, the level of detail and focus differs. The structure tends to be one dimensional and is presented on two levels; a detailed tabulation and a summary table of risks which are used for decision making.

Of the seven different risk register structures in Table 3.2 only one stipulates the explicit requirement for hazard identification data requesting the hazard reference and description (Whipple, 2010). Interdependencies are discussed and included in the risk register format suggested by Ward (1999) but they are not explicitly included in any of the other risk register structures. Secondary risks, although not included in the risk identification section of the risk register, are included in the risk mitigation section of the Williams (1994) register.
As a result none of these risk register structures are complete**.**

Table 3.2 Comparison of seven different risk registers.

References	Ward ,1999	Willams, 1994	Whipple and Pitblado, 2010	Zhao, 2005	Carter et al 1995	Paterson 2002	Mulambya, 2007
Disclosed corporate application			BP Exploration Alaska			BMW	SASOL
Risk Identification Includes the category "events" as stated in Willams, 1994	• Risk identifier, title and description. • Description of causes and trigger events. • Description of impacts on cost, time and quality and quantitative assessment of range of impacts where appropriate. • Nature of any inter-dependencies with other sources of risk	• Risk description • Likelihood of occurrence • Owner • Ameliorator of risk	• Source Risk Tool • Source Reference (date, revision) • Event Identifier from Source Tool (Hazard reference) • Business Unit • Facility Name • Hazard description • Event Type (safety, environment, business interruption)	• Risk category • Risk description(symptoms and root causes) • Risk initiator • Date of origin • Risk recipient	• Risk description • Risk identify number • Activity at risk/work breakdown reference • Risk owner reference/work package manager • Risk cause ownership reference	• The area of the project in which the risk may materialise (based on the generic risk areas [6]). • Risk Identification Number. • Brief description of the risk. • Risk owner.	• Risk Number • Risk category • Risk description • Root cause/ source of risk • Risk consequence

References	Ward ,1999	Willams, 1994	Whipple and Pitblado, 2010	Zhao, 2005	Carter et al 1995	Paterson 2002	Mulambya, 2007
Risk Assessment/ (Includes "impacts" Willams, 1994: Qualitative assessment –initial risk ranking Zhoa , 2005)	• Timing of likely impacts • Probability of occurrence	• Objective being impacted • Severity of impact • Receptors of impact	• Frequency (per year) • Frequency Ranking (Risk matrix scale: 1–8) • Consequence Ranking (Risk matrix scale: A–H) • Risk Ranking (Risk matrix level: 1–15)	• Probability • Impact • Priority • Stability • Initial score • Risk level • Cost impact	• Risk impact estimate • Risk probability estimate • Risk exposure as calculated • Risk exposed as adjuster (where applicable) • Risk trigger indicator	• Probability value (probability or likelihood of the risk occurring, determined within the risk assessment stage of the RMM). • Impact value (impact of the risk, often in separate terms of time and cost, determined at the risk assessment stage of the RMM). • Total impact value (combination of the impact values in terms of time and cost). • Severity value (combination of the probability and total impact values). • Ranking of the risk within the project (ranked risks are those with a high severity and are active within the project). • Track of the risk (i.e. has the risk increased, remained the same or decreased in severity since the previous month). • Phase/time by which the risk must be evaluated.	• Initial inherent Risk assessment • Impact rating • Probability rating • Risk level • Owner

References	Ward ,1999	Willams, 1994	Whipple and Pitblado, 2010	Zhao, 2005	Carter et al 1995	Paterson 2002	Mulambya, 2007
Risk response (Includes "Actions" Willams, 1994 and Risk response plan, Zhoa, 2005)	Description of feasible responses, including • Timing required resource implications of response. • Likely effect of responses on this risk. • Nature of any significant inter-dependencies with other risks and responses.	• Risk mitigation • Contingency plans • Secondary risks		• Risk trigger • Response (TEAM) • Risk response action plan • Action owner • Action Due date • Response cost $	• Risk mitigation strategy	• Brief description of the reduction/mitigation plans which have been developed. • Whether the risk is active on the register. • Whether the risk has been solved	• Risk Treatment plan • Due date
Risk management (Includes "Contractual" Willams,1999 and residual risk Zhoa, 2005)	• Residual risk after effective response. • Party bearing the consequences of the risk. • Party responsible for managing the risk and implementing responses.	• Degree of risk transfer		• Residual probability • Residual consequence • Residual score • Risk Level • Action Sign-off • Residual risk cost $ impact • Reserve funds			• Residual Risk assessment • Impact rating • Probability rating • Risk level

Table 3.2 shows that risk identification is clearly one of the modules in the risk management process and that there are some common elements to the structure of the risk identification section of a risk register. The common elements of risk register structure from Table 3.2 are presented and compared in Table 3.3.

Table 3.3 Comparison of common elements in the structure of the risk identification section of a risk register (YES= included, Blank =not included)

Element of risk register	Ward, 1999	Willams, 1994	Whipple and Pitblado, 2010	Zhao, 2005	Carter et al., 1995	Paterson, 2002	Mulambya, 2007
Risk identifier	YES		YES		YES	YES	YES
Risk category			YES[i]	YES			YES
Risk description	YES	YES		YES	YES	YES	YES
Root cause/ source of risk	YES			YES	YES		YES
Hazard description			YES				
Description of impacts and consequences	YES						YES
Risk owner		YES		YES	YES	YES	
Risk location			YES[1]		YES	YES	
Nature of interdependencies	YES						

[1] includes business unit, faculty name

Table 3.3 shows common elements include: the risk identification number, risk location and risk description. If the root cause and hazard description are amalgamated there are references to hazards in the risk register but not explicit hazard characterisation. Although there is an implicit consensus on the minimum level of detail and this is reflected in the review of the seven articles in

Table 3.2 and Table 3.3, overall the information in the risk register template with respect to the identification of hazards and risk does not result in a comprehensive register. This is due to a lack of information evidencing the identification of the source of risk.

3.6 Issues with the risk register

There is no agreed standard from the British Standards Institute, International Standard Organisation or the Institute of Risk Management for compiling a risk register. There is guidance within the generic disciplines for specific organisations such as the Association of British Insurers, the construction sector (Risk management of Tunnelling), and UK Government guidance (BTS, 2003). Within the risk register, hazards are not characterised sufficiently and this leads to increased uncertainty (Ward, 1999) Table 3.3 shows that this was still the case (Allan and Yin, 2010).

Although interdependencies were highlighted as an important factor that should be included in risk registers in the 1990s, practical identification has only recently being highlighted (Ward, 1999; Allan and Yin, 2010; WEF, 2011). Issues with the current method of identification and documentation include the fact that a list of hazards and risk drivers are produced and prioritised without confirming that this pool is complete. The resulting list is subject to linear interrogation and management. Little if any analysis of the interrelationship within the existing pool of hazards and the resulting risks takes place.

It is common practice to simply rank risks, but this ignores contextual data about dispersion, exposure and therefore impact (Ward, 1999). Qualitative contextual data exists within the existing pool of explicit risks and implicit hazards embedded in the risk register and these should be interrogated further providing a more comprehensive pool of hazards. This comprehensive pool of hazards may identify known unknowns and unknown hazards.

Risk registers are widely used but, can provide a false sense of security, a ritualistic approach to identification and risk management (Drummond, 2011). This illustrates the need for a register to be an interactive repository which documents and prompts action. In Section 2.7.5 and 3.1 the gaps in knowledge with respect to the identification of hazards across disciplines have been identified. The next step will be to develop a research strategy based on a review of the different methods of research that are available.

3.7 Methods of research to be considered

3.7.1 Research methods

There are three generally accepted types of research design: qualitative, quantitative and mixed method research (Johnson et al., 2007; Creswell, 2008).These will be reviewed in turn taking account of the three components of research design: the philosophical world view; strategies for inquiry; and research methods (Creswell, 2008).

3.7.2 Qualitative research

Qualitative research facilitates the use of research techniques where there is an emerging phenomenon. It provides a framework where there is insufficient quality data, obtaining experimental conditions are not possible and it is difficult to obtain an acceptable sample population and response rate (Yin, 2011). These attributes would meet the requirement for researching the identification of hazards and risk resulting from complexity, interconnectivity and dependency. Although identified as requiring investigation, little data is available in this area and much of the data that may be available is proprietary. This is the case for new and evolving technologies such as CCS and climate change. It is also the case for environmentally sensitive installations such as landfills.

Five features set qualitative research aside from other approaches to research: including: the study of participants; in real time, in their natural environment; capturing the viewpoints of participants; providing insight into evolving phenomena; and endeavouring to utilise multiple sources of evidence (Yin, 2011). The use of multiple sources of evidence is a feature that is critical to ensuring validation and accuracy of the research method and data quality. It creates insight into evolving phenomena and attributes that are to be incorporated into this research methodology.

3.7.3 Quantitative research

Quantitative research uses numerical techniques as a method of inquiry, data collection and analysis. This approach to research is based on theory building through deductive reasoning which is progressed by focusing on the significance of statistical hypothesis testing (Kaplan and Duchon, 1988). This is both an advantage and disadvantage as it only allows science to develop incrementally as a result of hypothesis testing. Additionally quantitative research relies on experimental and statistical control such that part of the process is the isolation of variables to ensure reproduction of the results and experiment (Creswell, 2008). The cost of removing context is the attainment of objectivity and testability but this undermines the purpose of the research that of understanding the phenomena in its natural setting (Kaplan and Duchon, 1988; Echambadi et al., 2006). The development and testing of a hazard and risk identification has to be carried out in the context of the real world.

Reliance on quantitative data alone can result in incomplete data collection and analysis (Kaplan and Duchon, 1988). This could result in the exclusion of non-numerical data which may have a fundamental impact on the quality of data collection and analysis (Echambadi et al., 2006).

3.7.4 Selection of inquiry strategy

The strategies of inquiry are determined by the three different research strategies outlined in Table 3.4. The choice as to the type of inquiry is determined by the requirements of the research questions and objectives.

Table 3.4 Characteristics of qualitative, quantitative and mixed methods research strategies (adapted from Creswell, 2008).

Characteristics	Qualitative	Quantitative	Mixed Method
Philosophical assumptions	Constructivist	Post- positivist	***Pragmatic***
Strategies of inquiry	• Ethnography • Grounded theory • Narrative research • Phenomenological • ***Case studies***	• ***Survey research*** • Experimental research	• ***Sequential*** • Concurrent • Transformative
Question structure	• ***Open questions***	• ***Closed questions***	• ***Mixture of closed and open questions***
Approach to data gathering	• ***Emerging***	• ***Predetermined***	• ***Emerging and predetermined approaches***
Data characteristics	Data is scripted or in the form of images for example: • ***Documents*** • Audio visual • ***Interviews*** • Observational • Collecting • Feeling	Numerical data which includes: • Performance • Observational • ***Census/ Survey*** • Attitude	• Inclusive data pool facilitating many data types
Research practices	• Researcher is positioned as an observer • Research is focused on a specific phenomena • The research arenas in which participants are observed are also studied. • ***Accuracy and validation of research results is essential.*** • ***Researcher draws conclusions from interpretation of data.***	• ***Researchers external to the research variables Research variables are identified*** • Standards of reliability and validity are applied • ***Numerical data capture*** • Unbiased scientific approach • ***Utilises statistical methods***	• Quantitative and qualitative data collection • Requires a rational for the integration of numerical and qualitative methods. • ***Facilitates integration of data at various stages of inquiry.*** • Can include visual, text and numerical representation of the methods in the research. • ***Both quantitative and qualitative methods are applied.***

The attributes applicable to this research project are highlighted in bold italics. It is clear that this research project has attributes from both qualitative and quantitative research. The following section provides a critical review of tools from both quantitative and qualitative strategies of inquiry and their appropriateness for this specific research project.

3.7.5 Qualitative strategies

Ethnography and narrative research are focused on human events. This research is not focused on human events as they happen and as such phenomenological research is not applicable as a strategy of inquiry. It will not be possible to observe the process of hazard and risk identification and the objective of the research is not to explore the human experience, feelings behaviour or emotions of hazard identification.

Grounded theory involves the development of a process theory or phenomena from the opinions of participants (Strauss, 1997). The main characteristic of this type of inquiry is the numerous stages of data collection, the iterative process and comparative evaluation of different population samples to identify common themes and differences (Creswell, 2008; Yin, 2011). A case study strategy of inquiry involves researching phenomena in its real world context. This method of inquiry may not be appropriate for the initial exploratory stage of research but is suited to the testing and validation of the developed method. This aspect will be accommodated in this research methodology.

3.7.6 Quantitative strategies

Quantitative strategies of inquiry include experimental designs and survey research (Creswell, 2008). Experimental designs involve comparing the impact of one variable to a control where that variable is absent (Creswell, 2008). Due to the complexity and dynamic relationship of hazard and risk identification it would not be possible to carry out this line of inquiry. This research is at the formative stage of identification and thus once the identification method has been verified experimentation could be considered.

Survey research is an appropriate method of inquiry for this research project as it will provide numeric data on trends and views of the sample population. This method of inquiry uses questionnaires and interviews to collect data (Creswell, 2008) and will be applied to this research project by the use of interviews and a web survey.

3.8 Aims and research questions

3.8.1 Aims

The aim of this research project is to identify and investigate (using case studies) why robust and encompassing hazard identification does not occur, particularly in areas where multiple fields overlap and to design a framework that will address these deficiencies.

The accomplishment of this aim and the review of both the prior art and applied literature has resulted in research questions which focus on responding to the gaps in knowledge and formulating a method for systematic and comprehensive hazard identification and documentation.

3.8.2 Research questions

The research questions to be answered by this project include;

Are the current risk management frameworks able to identify cross-disciplinary hazards?

Can the categories of generic, interface causation and accumulation be used to identify cross-disciplinary hazards?

Is it possible to develop and evaluate a model for the identification and documentation of cross-disciplinary hazards and risks?

These research questions support the formulation of objectives which facilitate answers to these questions.

The research hypothesis to be addressed by this project is;

Can a method be developed to identify and document cross-disciplinary hazards by applying the dimensions of generic, interface, causation and accumulation?

3.9 Conclusion

There is a need for proactive hazard identification which builds on the existing risk management frameworks providing a solution to the difficulties of applying a multidisciplinary approach to the identification of risks and hazards.

The method should introduce three additional dimensions to the identification process, interface, causation and accumulation. The application of these dimensions to the identification process requires the development of a risk register which is dynamic and accommodates the multidimensional attributes of hazard and risk which does not currently exist.

This method should be inclusive and proactive in its identification. not ignoring hazards that are not capable of quantification and prompting identification beyond the currently identified silos of generic risk by looking to identify interrelationships between generic risks and hazards (Rasmussen, 1997; Beck and Kropp, 2011; Ai et al., 2012). This will allow the identification of new, emerging or previously unknown hazards and risks.

4 METHODOLOGY

4.1 Background

4.1.1 Introduction to method development

This chapter sets out the methodology for the attainment of the following objectives:

- Review current approaches to hazard identification and risk management to identify their suitability for the identification of cross discipline hazards in an interconnected world;
- Define the dimensions of generic, interface, causation and accumulation risk and critically evaluate their application to the identification of hazards; and
- Develop and evaluate a model for the identification and documentation of multidimensional attributes of cross discipline hazards.

The achievement of these objectives will require a range of methods. This chapter provides details of the selection and sequencing of these methods.

4.2 Selection of research method

4.2.1 Research strategy

There are three generally accepted types of research design: qualitative, quantitative and mixed method research (Johnson et al., 2007; Creswell, 2009). The chosen research strategy for this research project is mixed methods (see Section 3.2.4).

Mixed methods research is a structured combination of quantitative and qualitative research which allows the researcher to take advantage of the attributes of both modes of research. It facilitates interdisciplinary research and provides the researcher with a wider palette of techniques which makes maximum use of limited information (Creswell, 2008).

This research project requires a pragmatic approach because the objective is to develop a methodology to identify new or currently unidentified risks and hazards. As a result it is necessary to ensure that the research is inclusive with respect to data collection but also systematic in its analysis. The strategy of inquiry will be sequential including: literature review, interviews, surveys and case studies. Whilst the main modes of research will be sequential, all of the modes will, at different times, require input from literature, for example to set the context of the generic risks and case studies.

Both open and closed questions have been used in the interviews and survey. The approach to data gathering will incorporate both emerging and predetermined data. Achieving the aim of this research project will require the identification of unknown and known attributes. Therefore the data pool will comprise of observed, scripted and numerical data which will include, documents, images, observation, interviews, and surveys.

The research variables are identified as hazards and risks. This novel area will require conclusions to be drawn from the interpretation of the data using both qualitative and statistical methods. The attributes of the different research strategies were expressed in Section 3.7.4 and the attributes that relate to this research are highlighted.

4.3 Mixed method inquiry strategy

The choice of type of inquiry is determined by the requirements of the research questions and objectives. Mixed methods strategies take many forms, and can involve the sequential or concurrent application of quantitative and qualitative techniques (Morse, 1991). For this research study a sequential mixed method of inquiry is proposed where qualitative research is used for the exploratory stage of the research as it can provide a rich contribution to the development of new processes and theories (Kaplan and Duchon, 1988). This attribute is to be used in the proposed methodology. The resulting research design will follow a mixed method structure.

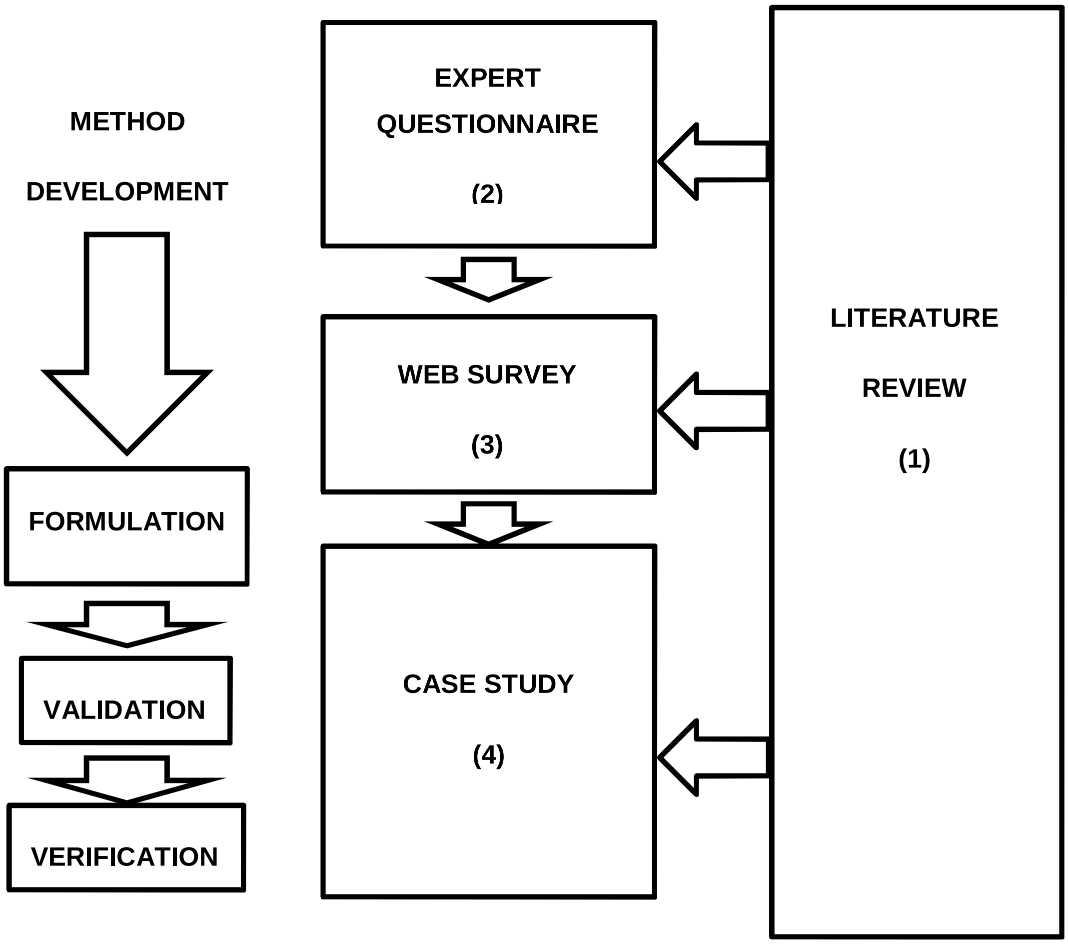

Figure 4-1 Structure of research methodology for the development of a novel approach to hazard identification

The mixed method data collection for this research project as set out in Figure 4-1 is based on four pillars:

Literature review. This is a central pillar where an iterative literature review provides the context of the research project and helps develop the focus and structure of modes of data collection.

Expert elicitations. Using structured questionnaires to obtain empirical data from generic experts on applied identification of risk.

Web surveys. Accessing a wider population of risk professional to obtain applied data on risk identification.

Case studies. To develop, formulate and test a method for the identification of hazards.

The method development will commence with the (1) literature review which will provide the prior art on which to base the questions for the (2) expert questionnaires. The results from the expert questionnaires and literature review will facilitate the structure of the (3) web survey and help to formulate the method. The method will be tested by application to (4) case studies which will assist with validation and verification.

4.4 Selection of data collection and valuation strategies

4.4.1 Ethical considerations

The methodology and its execution were agreed by the Universities Ethics Committee (see Appendix A). The ethical policy of Cranfield University was adhered to. All participants were provided with details of the context of the research and were able to withdraw at any point (see Appendix B).

It was decided that personal and corporate names would not be published in the output of this research as the identification of hazards for individuals and organisations are a highly sensitive issue and could affect the use of valuable information required for this research project.

4.4.2 Parameters of research its impact on the definition of data and sources

Data collection takes place on two levels in this research project; firstly in respect of identifying the parameters of the methodology, and secondly in the development of the method of hazard and risk identification. This chapter establishes the requirements of the methodology for ascertaining the current status of hazard identification in Chapter 5.

Qualitative data collection of human behaviour includes: interviewing; observing; collecting; examining, and feelings (Creswell 2008; Yin, 2011). Although experts may apply emotional and psychological feelings in the formation of their opinions, this research topic is not concerned with the emotional or psychological aspects of hazard or risk identification but with the process and robustness of the identification process. The collection of data from experts who have experience of risk and hazard identification and their current practices and opinions on different aspects of identification is a fundamental building block of this research project.

This evolving area of research requires tangible evidence from literature, risk professional and expert details of the context of the identification processes to be extracted from documents and other media. The process for the analysis of data collected from expert interviews and a web survey included the following stages: 1. obtain the raw data; 2. organise and prepare the data for analysis and synthesis; 3. review the data; 4. code and collate the data; 5. identify interrelating themes; and 6. interpret the identified themes and descriptions (Creswell, 2009). These stages are explored in greater detail in the following section for each type of data collection.

4.5 Published evidence

Peer reviewed data from academic journals are the most robust as they are subject to peer review prior to publication. Data on how hazard and risk identification takes place and the actual methods used by experts to document these variables is empirical and not widely available in academic journals at present, hence the need to use grey literature.

Selective reviews of data from peer reviewed articles as well as professional institutions, government and corporate documents were used to help focus the structure of the expert interviews, formulate the content of the web survey and choose and develop the methodology for the case studies. Data was accessed using the academic search engines: ABI Inform Complete (ProQuest), Business Source Complete, British Standards online, Scopus, Google Scholar and ISI Web of Knowledge. Non-academic published data was accessed from UK Government sources such as the Department of Energy and Climate Change, Department of Environment, Food and Rural Affairs, Department of Business Innovation and Skills, Office of Government Commerce and professional institutions such as the Institute of Risk Management, Chartered Insurers Institute, Association of British Insurers, additionally, corporate information was obtained from seminars, conferences, and via corporate web sites. All data were assessed for quality before inclusion into the assessment (see Section 4.5.4).

4.5.1 Design

The compilation of suitable literature was obtained by specifying keyword searches. The key words for the initial search were: hazard, risk, and uncertainty, risk identification, hazard identification, risk analysis, risk assessment, risk management, risk reporting and risk documentation. Searches were structured using Boolean terms for each of the following areas: parameters of research; generic risks and hazards; whole system risk; management frameworks; methods and tools for identification; dimensions; and multidimensional identification. For example for parameters of research, the Boolean search terms are presented in Figure 4-2. The subject of the research is on the left hand side and the variations of the subject are on the right-hand side.

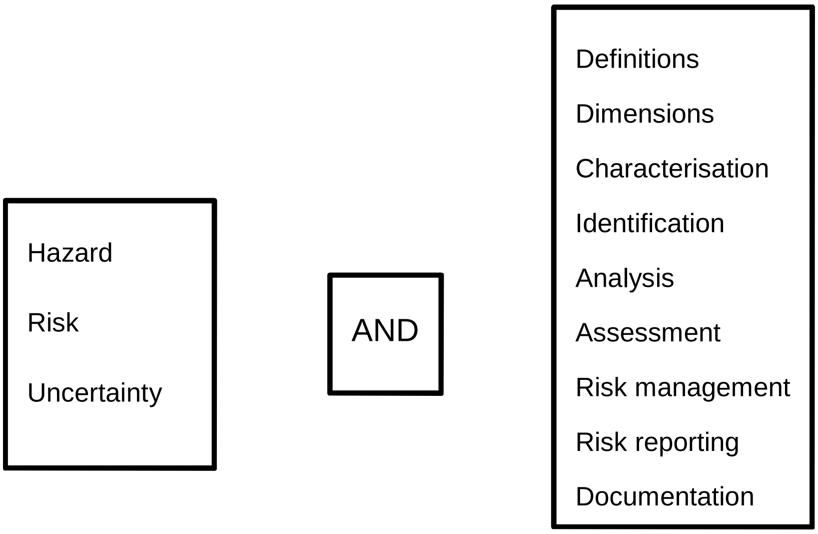

Figure 4-2 Structure of Boolean search for parameters of research

As the focus was to look at the identification of hazards and risk in new, emerging and currently unknown areas of risk, searches were also carried out looking at risk and hazard identification in carbon capture and storage. Additional searches were carried out to provide context for hazard and risk identification in the management of landfills and climate change adaptation.

4.5.2 Selection

. The following criteria were used to select data:

- Article must include the keywords in its title as this indicated the focus of the article.
- Preference was given to quality journal articles which were rated as cited in the search engine.
- Journal articles published between the time periods 1990 to 2012.
- Grey literature published between the time periods 1990 to 2012.

A quality journal was defined as an academic journal in which an identified article was cited. Academic journals have an impact factor, derived from the average citation number for recently published articles. Although the impact factor of the journal is an accepted indicator it does not mean that the specific article is acceptable and that is why cited articles were predominantly used. The search focused on keywords which were highlighted in the previous section and present in the title of the article, as this was the focus of the article. The result of the search was refined by reviewing the abstracts and then excluding unrelated data by subject or date of publication. If there were no results from keywords in the title the search was widened to references in existing articles and authors in the specific area.

The use of journal articles was acceptable for the areas of risk and hazard as there was a long history of research in this area. This was not the position for case studies such as CCS. As the CCS data was evolving and tended to be published up to a year after a development at which time there would be further developments. Journal articles were not up to date and, as a result, data for CCS was obtained predominately from grey literature supplemented with data from journals, conferences and seminars. The grey literature was usually government data or data requested by the government and compiled by consultants.

4.5.3 Analysis

The published sources of data (grey and peer reviewed) were reviewed for relevance to the development of the method and information surrounding the case studies. The data sources that were considered for the development of the method were mainly books and information on the development of the questionnaire structure and appropriate question structure was identified for use with the web survey as well as the semi-structured expert interviews. Additional information was identified on the methods for the analysis of the qualitative and quantitative data from the survey and interviews. For the case studies, grey and peer reviewed sources were interrogated for information on the specific case study as well as the regulations and government literature surrounding the topics. Current topical peer reviewed articles were also interrogated to supply additional information in the case study. Where data were identified as relevant to the risk register, these were included in the discussion of the case study.

4.5.4 Validation

The value of using published data is its validity and quality. Bowden (2004) states that indicators of source quality include the scientific, method, theoretical basis, auditability, validation and objectivity which are similar to the requirements for peer reviewed data. As a result if published data was peer reviewed, cited and from high impact journals this was the preferred source of data. Where the development of new methods for emerging areas, these criteria cannot always be met as knowledge is evolving and not yet published. As a result the vast majority of literature was peer reviewed either as a consequence of being published articles in a peer reviewed journal or from experts and government bodies who have their own bespoke internal peer review process.

4.6 Expert elicitation using structured questionnaires

This method of qualitative data collection was chosen as it provided a structured framework with focused questions. It facilitates the collection of data without compromising confidentiality when participation is not possible and provides control over the direction of questions (Creswell, 2008). Data collected from interviews via questionnaires can provide the flexibility to produce quantitative data, where available.

4.6.1 Design of interview and questions

Face to face interviews with insurance, environmental, health and safety, and legal experts were carried out using a structured questionnaire following Yin, (2011) requirements for structured interviews. The questionnaire included a mixture of open and closed questions. Each questionnaire was divided into two sections; questions specific to CCS and questions specific to the expert's area of generic risk specialism. The questions across all the questionnaires were similar but accommodated specific anomalies of the generic risk and gaps in knowledge (see Appendix C). The use of a structured questionnaire where the interviewee is provided with the questionnaire prior to the interview was used to minimise interviewer bias and maximise response rates.

Where it was possible and consent was obtained interviews were recorded both electronically and in written format. Where an interview was not logistically possible the relevant questionnaire was forwarded to the expert by email for completion electronically. Prior to receiving the questionnaire the expert was provided with ethical guidelines for this research project (see Section 4.4.1) and was made aware that if they did not wish to complete the questionnaire that was an acceptable response via informed consent. Additionally experts were informed that personal and corporate data would not be retained. Data was retained electronically with restricted access to the researcher and supervision staff.

The sample includes four expert interviews which were conducted for the following generic risks; insurance, environmental, legal and health and safety. These specific generic risks were chosen as they are distinctly different but are inherent in most projects and organisation (see Table 4.1). Technical risks were excluded from expert interviews as they are specific to the operations of the project or organisation.

Table 4.1 Rationale for expert elicitations from generic risk

Generic risk	**Rationale**
Environmental	Highly regulated, risk evolving to accommodate emerging environmental exposures with wide impact.
Health and safety	High profile regulated risks with significant accessible research
Insurance	Applied risk, that transcends a number of generic risks, managed by a proactive mixture of physical, legal, and financial means
Legal	A generic risk which touches all aspects of life and is predominately reactive identified and managed *ex post.*

The rationale for questions on generic risks has to establish how risk experts accommodate the identification and the documentation of existing and new risks. The structured questionnaires used in the interviews contained questions which asked for clarification as to the attributes of risk identification within generic risk frameworks. The focus on risk identification was used as an indication of the evidence of hazard identification.

The construction of questionnaires was based on identified gaps in the literature review to the applied identification of hazards and risk (see Section 3.1). The questionnaires were designed to facilitate the acquisition of data to respond to the following gaps:

1. Ascertain the different approaches to generic risk identification;
2. Determine whether the same methods are used by different generic risk for the purpose of identification;
3. Establish if the dimensions of interface, causation, and accumulation risk are identified;

4. Verify the repositories used to document identified risk; and
5. The attributes that should be taken into account when developing a method for the identification of hazards.

How these gaps relate to the research questions and the relevant sections of the questionnaires are expressed in Table 4.2 Interviews were carried out after the initial risk register was developed using CCS data and prior to the web survey.

Table 4.2 Relationship between the research question, focus of inquiry and interview subject

Research question	Focus of inquiry
Are the current risk management frameworks able to identify cross discipline hazards?	Who identifies risk?
	What is identified?
	How does identification take place?
	How are risks documented?
Can the categories of generic, interface causation and accumulation be used to identify hazards?	Can the current method for identification of generic risk identify new and emerging hazards?
	Are interface I risks identified?
	Are interface II risks identified?
	Are causation risks identified?
	Are accumulation risks identified?
Is it possible to develop and evaluate a model for the identification and documentation of cross discipline hazards?	What are the attributes of identification? Is compliance with ISO31000? required, Does the method need to be corporate governance compliant? What are the preferred methods of documenting risks?

4.6.2 Selection of expert interviewees

The requirements for participation in the expert interviews were that individuals recognised as experts in a specific generic risk areas well as CCS. A summary of the credentials of the specific generic risks which included: legal, insurance, environmental, and health and safety are presented in Table 4.3.

Table 4.3 Credentials of generic expert who participated in data collection

Generic risk	Generic expert credential	CCS credentials	Number of years' experience
Environmental	Environmental special projects	Environmental regulator for CCS	20
Health and safety	UK COMAH[1] and MAH[2] inspector	Health and safety adviser to the European Union	15+
Legal	UK and USA legal expert, Professor of Law	Legal advisor to International Energy Authority	20+
Insurance	Underwriter for major composite insurers	Head of European underwriting for environmental risks in the London market	15+

[1] COMAH= Control of major accidents hazards http://www.hse.gov.uk/comah/index.htm

[2] MAH= Major accident hazards

4.6.3 Data collection

Interview results were documented by recording the expert interviews and writing the responses to the structured interviews in the questionnaire which was sent to the expert prior to the interview. Recording as well as documenting of the questionnaire was carried out to ensure that if the technology did not work the data was captured in a written format. Where it was not possible to conduct an interview, the questionnaire was supplied to the expert electronically with the same guidelines; and requirements of the ethics committee which were applied to the interviews. Responses to the interview questions were transposed on to a matrix which captured themes, quotes and frequency of occurrence. The matrix was compiled in Microsoft^{TM} Excel (Version 7, 2010), and stored there (full details are in Appendix C2).

The interviews and questionnaires were structured and analysed initially by separating the CCS questions and the non CCS questions. The non CCS part of the questionnaire was structured with questions clustered in the following sections: A. identification of risk; B. assessment of risk; C. documenting of risk, and D. risk management.

The completion of matrices for all generic interviews resulted in common themes being identified relating to the sections of the interview as well as expert specific data which corresponds to the sections: identification, assessment, documentation and management of risk.

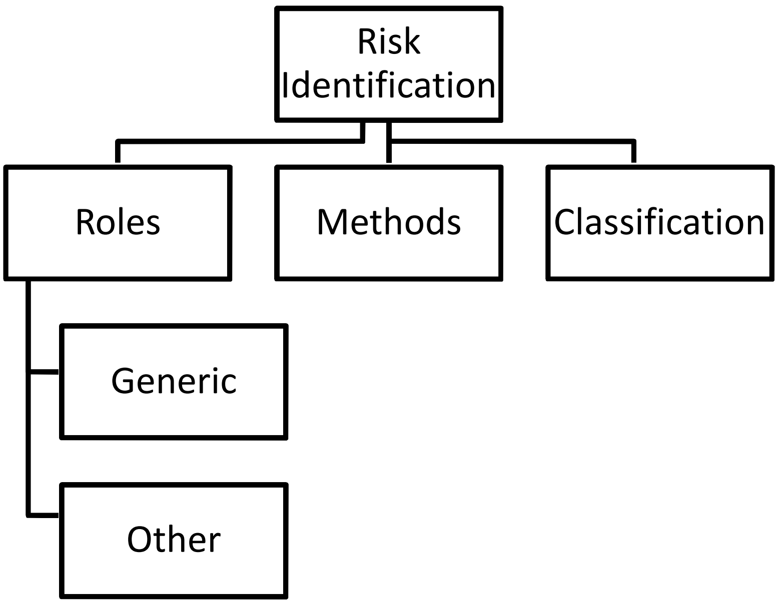

Figure 4-3 Section A - Risk identification with themes role and sub themes; generic and other which relate to the expert questions

The themes and sub themes for risk identification are shown in Figure 4-3. The resulting output was summarised in tables for each sub theme and comparisons made across the generic risks to identify trends and anomalies (see Appendix

C3). A summary of the research methodology for the expert elicitation is provided in Figure 4-4.

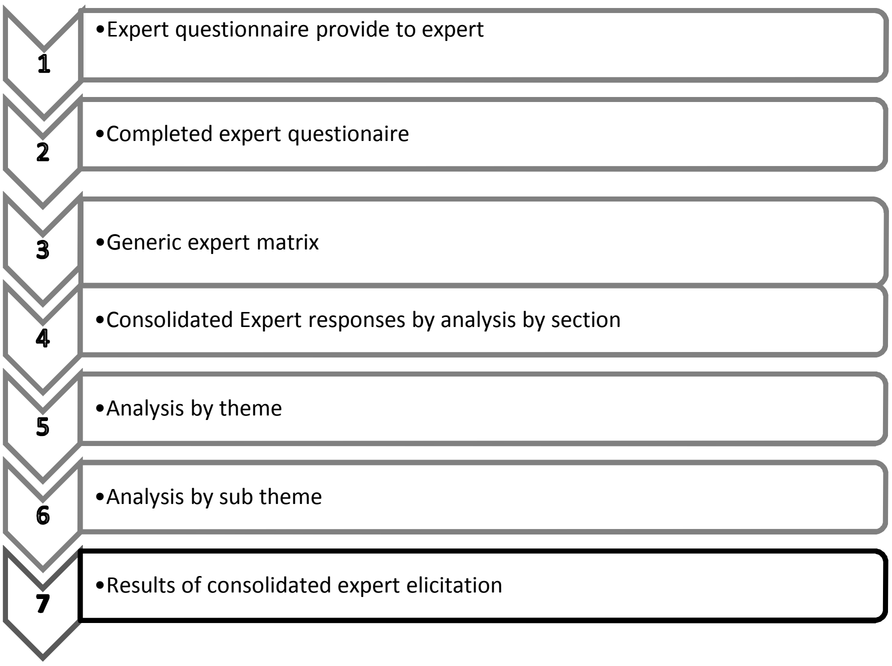

Figure 4-4 Stages of data analysis for expert elicitations

The individual expert interview results were synthesised across the generic risks and the resulting data used to structure the web survey for a wider population.

4.7 Web survey

A survey was used as a tool to collect data from the wider risk community, as it is a tool that can be carried out using many different media such as: telephone, email, mail and web. The objective of this survey was to respond to the lack of data on the methods used to identify hazards and risks by risk professionals. A web survey was the preferred mode of data collection due to speed of administration and the ability to access a wider population.

The software used to produce the survey was a Cranfield University web form application developed to be accessed via a web browser. https://webapps2.cranfield.ac.uk/webforms/admin/. The results were transferred automatically and stored on Microsoft TM Excel spread sheets.

The survey was delivered by inclusion of a URL within a covering letter which included the code of ethics, details of data protection, and informed consent instructions for completion, purpose of the survey and contact details. This method of data collection enabled instantaneous collection of results and presentation in a Microsoft Excel spread sheet allowing for the efficient application of quantitative analysis with minimal potential for error which could result from manual data input and transposition of data.

The survey was collected during the period May 2011 to August 2011. To improve the responses, email reminders were sent out after 3 weeks. A copy of the web survey is included in Appendix D1.

4.7.1 Design of questionnaire

The survey consisted of 22 questions structured in five sections:

A. Carbon Capture and Storage specific identification of risk

B. Identification of risk

C. Assessment of risk

D. Documentation of risk

E. Risk management frameworks

The survey questions are a mixture of open and closed questions. Section A (carbon capture and storage) included the use of continuous scales and the remainder of sections B to E included a mixture of continuous and categorical scales, e.g. Yes or No and ranking responses in respect of significance and importance. A pilot study was sent out to 3 respondents to test the efficiency of the questionnaire construction. Feedback from the pilot study was used to improve the format and structure of the questions. Table 4.4 shows the alignment of research questions to the area of focus and web survey item.

Table 4.4 Relationship of research questions to focus of inquiry in the web survey

Research question	Focus of inquiry
Are the current risk management frameworks able to identify new and emerging hazards?	Who identifies risk?
	What is identified?
	How does identification take place?
	How are risks documented?
Can the categories of generic, interface causation and accumulation be used to identify hazards?	Generic
	Interface I
	Interface II
	Causation
	Accumulation
Is it possible to develop and evaluate a model for the identification and documentation of previously unidentified hazards and risks?	What are the attributes of identification? Compliance with ISO31000, Corporate governance, Preferred methods of documenting risks

The web survey provided access to risk professionals who may not have time to participate in an interview or workshop. It also provides anonymity and a vehicle to collect information which participants may not wish to disclose publicly, due to contractual reasons, the sensitivity of risk to corporate operations or for reputational impact.

Limitations of the web survey include the fact that reliance on a third party to send out the surveys meant that surveys were delayed in their inclusion on third party websites and newsletters. Once sent out there was no way of knowing who completed the survey. When placing a survey on a web page there is a presumption that the footfall for the website will encourage completion, but this may not be the case.

4.7.2 Selection of participants

The selection of participants to the web survey were risk professionals whose expertise was either in a specific generic risk or CCS risk professional obtained from the UK Carbon Capture and Storage Community (UKCCSc) network, Enterprise Risk Management Association Linkedin network (ERMA) and the Institute of Risk Management (IRM) (see Table 4.5). The sample was structured to maximise the responses from managers in a highly sensitive area.

Table 4.5 Potential populations provided with access to the web survey

Potential respondent population	Number invited to participate in web survey
Institute of Risk Managers (IRM)	Placed on the IRM electronic newsletter potential audience according to IRM knowledge manager in the region of 1,300
LinkedIn Enterprise Risk Management Association (ERMA)	Placed on LinkedIn group which has an approximate 31,000 members at the time of the survey.
Risk management professionals	32
CCS risk professionals	United Kingdom Carbon Capture and Storage Community network (1,000 members at the time of the survey)
Number of people contacted Percentage expected to complete	33,332 1%

4.7.3 Data analysis

The analysis and synthesis of web survey results followed the same logic as the flow diagram in Figure 4-3.

Data were analysed using quantitative and qualitative methods to establish trends, gaps in knowledge, highlight benefits and value as well as anomalies. The web survey data was collected electronically via a web form and transferred to a spread sheet. The spread sheet was reviewed and checked to ensure data was transferred without error. Hard copies of the individual sheets were printed off as a precaution against damage or loss. The structure of the web survey had four sections and analysis took place by analysing these clusters of questions.

Two statistical tests, Chi-squared test and analysis of variance (ANOVA) were applied to specific types of data collected from the web survey. Questions where categorical data were collected were subject to analysis by a mix of qualitative analysis and Chi-squared test. Results were analysed in the cluster of the four sectors and conclusions from identified themes used to develop the method for hazard identification. Figure 4-5 provides a summary of the steps taken in the data capture and analysis of the web survey results.

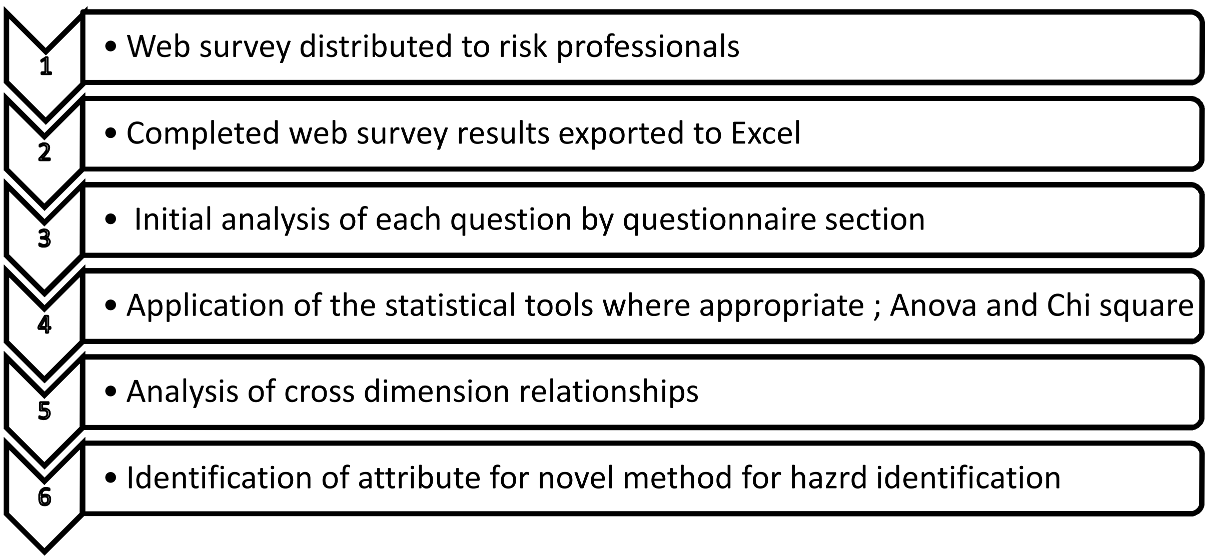

Figure 4-5 Summary of the production of web survey results

The results of the web survey and expert elicitation provided empirical evidence to formulate the development of a method using case study research methodology.

4.8 Case studies

The case study method of research was chosen as a tool best suited to respond to the question: is it possible to develop and evaluate a model for the identification and documentation of previously unidentified hazards and risks? In response to this question the third objective was to develop and evaluate a model for the identification and documentation of multidimensional attributes of hazards was set. Academic justification for using case study research methodology for this part of the research is to respond to the question: how will the proposed method for hazard identification be applied to the real life context?

Table 4.6 Research options available to respond to the research question: how will the proposed method apply to the real life context?

Research methods	Type of research question	Conditional on controlling behavioural events	Focus on current real world events
Experiment	**How,** why	YES	YES
Case study	**How**, why	NO	YES
History	**How**, why	NO	NO
Archival Analysis	Who, what, where, how many, how much	NO	YES/NO
Survey	Who, what, where, how many, how much	NO	YES

(Adapted from Creswell, 2008; Yin, 2009; Yin, 2011)

Three factors influence the decisions to use case study research methods as opposed to other methods such as survey, interviews and observation (Yin, 2009). These are; firstly responding to how and or why questions; secondly, the lack of researcher influence on the case study subject and environment; and lastly a requirement to obtain data in a real life situation (see Table 4.6). These three requirements are fulfilled by the data requirements to meet the third research objective by establishing how the proposed method for hazard identification will apply to the real life context.

The proposed use of the case study method will take a number of different forms in this methodology. Firstly, it will be used to develop the novel method by exploring its application in a pilot case study (exploratory). Secondly, it will be used to test the methods ability to be applied to different situations which will accommodate descriptive and explanatory attributes. This approach was chosen as it facilitates the demonstration of the risk register methodology within the risk management framework of different industries.

4.8.1 Requirement for a pilot case study

A pilot case study was carried out to test the methodology for the multidimensional identification and documentation of hazards. The pilot was designed to aid the development of the method for each of the dimensions and establish the feasibility of inclusion in a single document. It is also able to highlight additional information requirements or redundancy in the methodology.

The attributes required for the pilot case study included the need to be an evolving technology which comprised a chain of components. The data needed to include a risk register for the entire lifecycle verifiable by a third party and publically available. Additionally the results of the application of the novel method need to be capable of verification by an informant involved in the development of the initial risk register for the project. CCS fulfils these criteria as it is an evolving value chain comprised of existing technology which will be used to capture, and transport CO_2 offshore. The UK Government, via DECC, held a competition where details of the risk register for the entire value chain and for all phases of the lifecycle were publically available and verified by the corporate entities which were in charge of the different modules.

Background information to provide context to the pilot case study was obtained from the output of a review of literature, interviews, web survey, and attendance to knowledge transfer meetings and the provision of data in the Front End Engineering and Design (FEED) report which was the result of the First UK CCS demonstration competition.

4.8.2 Case study selection

This research project will follow multi-case design. The use of multiple case studies with the application of the logic of method replication is to be used in this research (Yin, 2008). A sampling logic was not appropriate as the objective is to establish a method which is repeatable.

With respect to the number of case studies required to validate the research methodology three to four would seem appropriate (Flyvbjerg, 2006). The proposed case study selections are highlighted in Table 4.7.

Table 4.7 Rationale for the three case studies

Case study	Rationale
Case study 1 Carbon capture and storage	Publically available data is available with respect to a consortium to the UK competition. This is an example of a project approach to a demonstration project for an evolving technology.
Case study 2 Waste management	Closed landfills are an example of existing operations with known and characterised risks. The proposed landfill does not have a risk register so this will need to be developed and verified. This will test whether the methodology can be applied to raw data.
Case study 3 Climate change adaptation	The United Kingdom government has requested via the UK Climate Change Act 2008 that Climate Change adaptation reporting should be carried out every five years. This requires business to identify the risks that result from climate change adaptation. These are currently unidentified and evolving hazards and there is no agreed protocol for hazard identification.

4.8.3 Evidence collection

A case study method of research does not preclude other methods of research; indeed it should embrace other methods (Creswell, 2008). As a result multiple sources of evidence are used to encourage triangulation. The sources of evidence widely used in case studies include: documentation; archival records; interviews; direct observations; participant observation and physical artefacts (Yin, 2009). In this study physical artefacts and participant observation will not be used as they are not applicable to the development of an applied methodology.

Direct observation will take the form of a site visit where appropriate. Archival records and documentation will be used and weaknesses with respect to accessibility, retrievability and bias addressed by using publically available information which is verified by an expert. Interviews will be used to verify the different dimensions and supplement gaps in documents and archival records.

This research method embeds an iterative process which is applied to each case study. This iterative process needs to be flexible enough to facilitate unexpected disclosures, which can then be tested, and, if appropriate, result in amendments to the design of the novel method. The intertwining of method and analysis are a distinct quality of a case study approach. These amendments may also result in changes to the research design. To ensure that the rigour of the research is maintained an audit trail of amendments is documented.

4.8.4 Data analysis and validation

The initial analysis of the case study involves reviewing and agreeing the generic risk register. This base data will be used to identify the hazards for the different dimensions. Once the generic risk register is agreed, this base data is used to identify hazards resulting from the application of specific systematic reviews for each of the dimensions. The identified hazards are documented in their respective specific register format and the result is a compilation of registers which document identified hazards for different dimensions for each of the selected case studies.

The registers of identified hazards can be compared to the initial generic risk register to ascertain if there are any additional viable hazards that were not previously identified. Expert review and validation of the resulting register of hazards were carried out to establish whether additional hazards, classified by dimension, were identified and to confirm that the new identified hazards are feasible.

On completion of the three case studies cross-case synthesis will be carried out (Yin, 2008) The objective of this type of synthesis being applied to the development of a novel method for hazard identification will be to establish any common problems that occur across all the case studies and identify enhancements that need to be made to improve the method.

4.8.5 Building robustness in case studies

The case study element of this methodology is significant and it underpins the development of the methodology for the identification and documentation of hazards. It is essential that conclusions drawn from them are valid and reliable. Fyvbjerg (2006) states that there is great value in the use of case studies; however case study research has constraints and the resulting limitations described in Table 4.8 need to be mitigated.

Table 4.8 Five misconceptions of case studies and proposed solutions to these constraints (adapted from Flyvbjerg, 2006 and Yin, 2008)

Misconception	Proposed solutions (Flyvbjerg, 2006)	Solution to be applied in this study
Context dependent knowledge is not seen as valuable as context independent knowledge.	Context is more important than predictive theories	Context will be taken into account as part of this study
One case study cannot be used to generalise and thus add to scientific knowledge	Generalisations based on a single case study are acceptable if that case study is seen as" an example". This results from the fact that value in the specific case study may be central to scientific development.	In addition to the pilot case study two case studies will be used
Case studies should be used as the initial stage of hypothesis development not hypothesis testing or theory formulation	With respect to this limitation the proposed case selection strategy to minimise this is to adopt information orientated selection where selection is based on the data content.	This limitation can be addressed by an iterative systematic review of data and replication logic in multiple case studies.
Case studies have an inherent bias towards researcher verification (Diamond, 1996).	It was not verification that was the problem but falsification of preconceived ideas.	Accommodate review from key experts for each case study.
It is difficult to extrapolate theories from limited case studies.	The fifth limitation can be addressed by improving the narrative of the case study which should read as a story.	Use multiple cases studies and replication of logic

The most important factors to be taken into account in case study development are the reliability and validity of the findings of a case study. This is achieved through triangulation of the data, analysis and results. This is accommodated by multiple applications of the case study protocol to a number of the case studies.

In addition to mitigating the misconceptions and limitations of case studies it is necessary to ensure that the results are valid and reliable.

4.9 Validity of evidence

4.9.1 Validity and triangulation

This section is concerned with the validity of the entire research project. The research incorporates four of Maxwell's (2009) seven strategies for reducing threats to validity in qualitative research which include: triangulation; comparison; statistics; and respondent validation. There are four tests for validity which apply to all social science research and these include: construct validity; internal validity; external validity, and reliability (Yin, 2008).

4.9.2 Internal and external threats to validity

Internal threats to validity can be allayed during the data analysis stage by using: pattern matching, explanation building, addressing rival explanations, and the use of logic models (Yin, 2008). The application of replication logic in multiple case studies at the research design stage is an accepted approach to the achievement of external validity (Flyvbjerg, 2006; Yin, 2008).

Construct validity is concerned with ensuring the appropriate measures are taken in data collection. This is achieved by using several sources of evidence and establishing a chain of evidence. This includes using additional experts to validate data collection at different stages, for example structured questionnaires, confirmation of consent and copy of completed interview either in hard copy or electronically. A summary of the steps taken to achieve validity in this research are outlined in Table 4.9.

Table 4.9. Application of the four tests of case study reliability and validity to this research (adapted from Yin, 2008)

Test for validity and reliability	Tactic for achieving validity	Application to this study
Construct validity	• Numerous sources of evidence	The original base data is the result of compilation of data from a number of sources.
	• Auditable chain of evidence	Data used was subject to audit prior to use and well as during the compilation.
	• Key participants review case study results	The data collection results will be subject to audit by key participants of the specific case study. Where this is not possible review will be carried out with an academic expert.
Internal validity	• Patten matching	In this research this applies to the identification of the different dimensions using the same methodology.
	• Explanation building	Not applicable to this research project.
	• Resolve rival explanations	These will be addressed during the application of the method to the different case study data.
	• Apply logic model	Cross case study analysis will be applied.
External validity	• Theory utilisation in single case studies	Not applicable to the case studies in this research project.
	• Logic replication in multiple case studies	Multiple case studies with different levels of data and for different objectives will be used to test the replicability of the method. By cross case study synthesis.
Reliability	• Application of case study protocol	The case study protocol will be applied within the application of the method development and presented with the results of the individual case studies.
	• Development of case study database	Not applicable in this research project.

With respect to the case studies, expert validation takes place by experts at each stage of the case study development and this formalised in the case study protocol. The validation of the initial data, interpretation of the data and the method was sought by experts. Reliability is sought by developing a case study repository and audit trail to ensure reproducibility.

4.9.3 Triangulation

Triangulation is a research technique used to support validation of information by verification from more than two origins of data (Yin, 1999; Johnson et al., 2007). Triangulation of information can act as an early warning system to analytical errors and omissions (Kaplan and Duchon, 1988; Johnson et al., 2007). There are four variations of triangulation: data, investigator, theory and methodological (Denzin, 1978; Barbour, 2001; Johnson et al., 2007). This research incorporates triangulation as a means of validation of data collection and verification of analysis. The use of four modes of data collection, the integration of qualitative and quantitative data in the initial data collection and the use of multiple sources in the compilation of the case studies attempt to increase the validity and reliability of the data quality and the resulting research.

Limitations of triangulation highlighted by Barbour (2001) include that efficient triangulation is not easy to expedite as the different methods of inquiry do not always facilitate direct comparison, collaboration of consensus may be the result of research bias rather than objective research.

4.10 Summary of strategies selected for research

The methodology to identify and investigate (using case studies) why robust and encompassing hazard identification does not occur, particularly in areas where multiple fields overlap and to design a framework that will address these deficiencies is based on a mixed research design. The research strategy is composed of four components: literature reviews, expert interviews, survey and case study as presented in Figure 4-6.

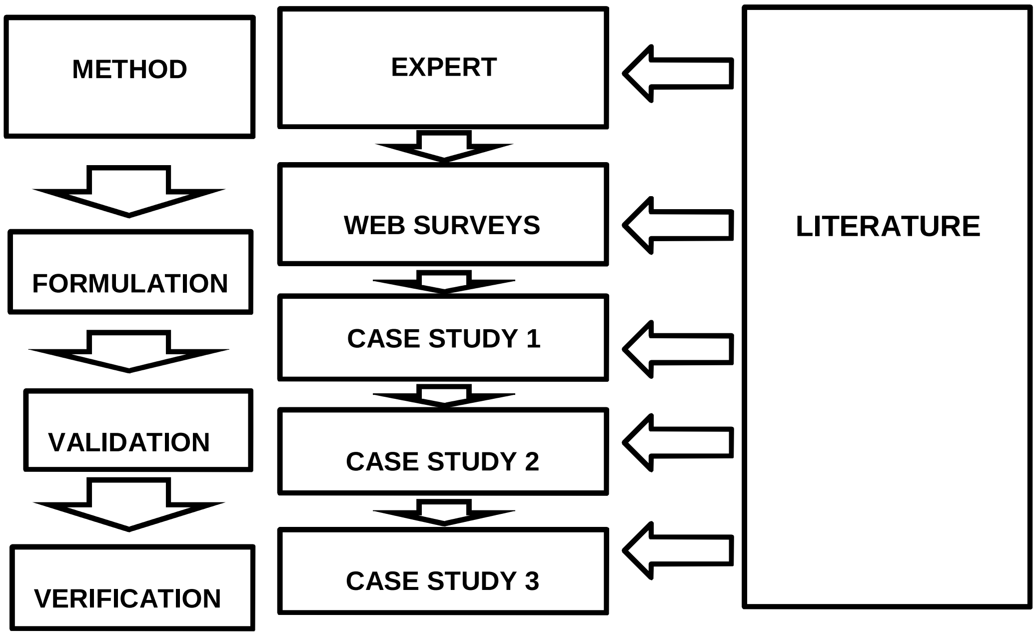

Figure 4-6 Summary of the research methodology for the development of a method for the multidimensional identification of hazards

The questionnaires and web survey were structured to provide empirical data for each dimension and for the sections of risk identification, documentation, risk assessment and risk management. This is expressed in Figure 4-7.

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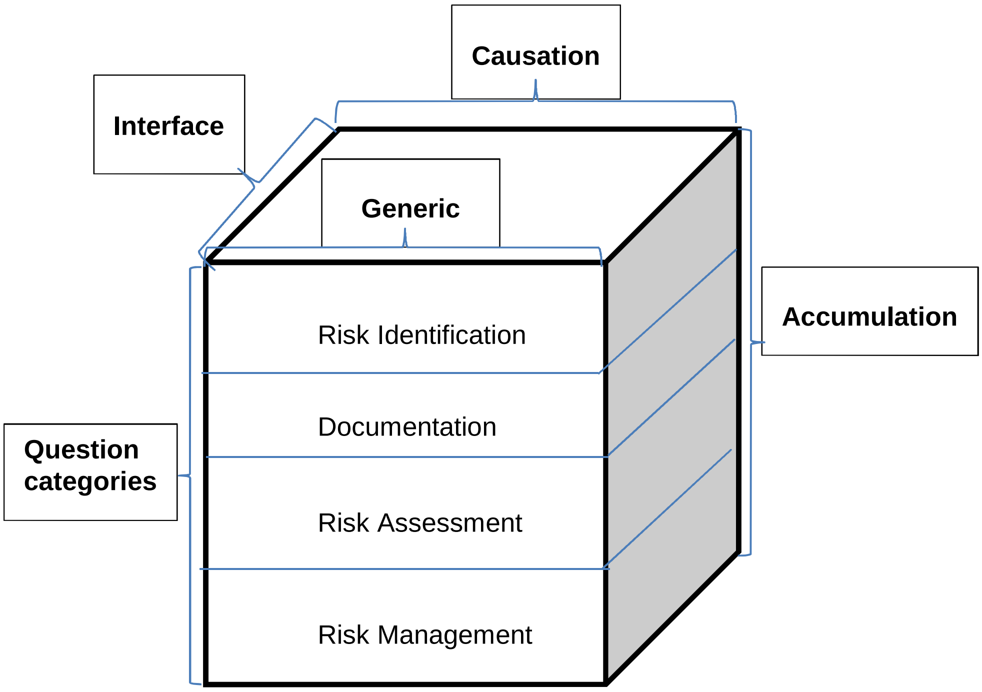

Figure 4-7 Diagrammatic representation of the headline themes for data collection from expert questionnaires and the web survey

The themes developed from the consolidated results of the expert questionnaires and web survey will provide an outline for the development of a method of multi-discipline hazard identification. The integration of these themes into the research strategy facilitates an iterative process of data collection and result in the formulation of a method of hazard identification which is tested for reliability and validation using three case study scenarios.

5 INITIAL RESULTS: EXPERT ELICITATION AND WEB SURVEY

5.1 Background

5.1.1 Introduction

This chapter presents the initial results from expert elicitations captured via risk specific questionnaires and a web survey distributed to the wider professional risk population. Both methods of data collection were structured to obtain data on CCS risks and generic risk (non-CCS risks). CCS was used as an example of a new technology with a number of unknown hazards. The results of the CCS data collected will be presented in Chapter 6 where information on CCS is used to develop the novel method for hazard identification. This will take into account the results of the data captured on generic risks from expert elicitations and the web survey.

This chapter provides responses from four experts from the genetic disciplines of the environment, insurance, legal, health and safety. The web survey was structured by building on the findings of the expert elicitations and the themes of risk identification, risk assessment, documentation and risk management frameworks.

5.1.2 The mix of qualitative and quantitative results

The mixed methods research included expert data collated into sections themes, sub themes and quotes used. The data from the web survey was subject to both qualitative and quantitative analysis of the different responses to the various types of questions within the themes from the expert interviews (see Section 5.2). Quantitative analysis included examining frequency, and where applicable, statistical tests such as Chi-squared and ANOVA were used to establish the significance and validity of the data collected (see Section 4.7.3).

5.1.3 Main Themes

The main themes for both the expert interviews and web survey were: risk identification; risk assessment; the documentation of risk; and risk management frameworks (see Section 4.6 and Figure 4-7).These themes were identified from the literature review (see Sections 2.3 and 2.4) as factors affected by the identification of hazards. The introduction of the dimensions of interface, causation and accumulation (defined in Section 3.3) are tested in the expert questionnaires and the web survey to establish whether and how these dimensions are identified.

5.2 Results from expert elicitations

5.2.1 Initial data collection

A copy of the consolidated response of the individual matrices for each expert is provided in Appendix C3. The consolidated responses of the four experts were tabulated as a result of an iterative process into themes and sub themes. The resulting themes and sub themes are presented in Table 5.1. The sections, themes and sub themes were developed from the initial analysis of data capture from the interviews and questionnaires.

Table 5.1 The sections, themes and sub themes developed from the initial analysis of data capture from the interviews and questionnaires

Sections	Themes	Sub themes
Risk identification	Roles	• Generic • Other
	Methods	• New technologies • Bespoke • Specific process • Issues • Embedded • Interface • Causation • Accumulation • General • Type
	Classification	• Interface • Causation • Accumulation
Risk assessment	Methods	• General • Existing

Sections	Themes	Sub themes
		• New risks • Generic • Interface • Causation • Accumulation • Environmental damage • Third party damage • Regulatory • Contractual
Documentation	Data capture	• Advice • Risk register • Project risk • Permitting • Compliance • Environmental risk register • Insurers own portfolio • Other
Risk management framework	ISO31000	• Compliance
	Methods	• Embedded • Procedures • Legal instruments for liability reduction • Other considerations for risk mitigation when using legal instruments
	Embedded in organisations risk management	• Reputational risk • No sub theme
	Current frameworks	• Adequacy • Improvements
	Risk evaluation	• Corporate • Operational concerns • No sub theme applicable
	Risk mitigation	• No sub theme applicable
	Importance	• Legal liabilities • Corporate • Internal corporate • No sub theme applicable
	Improvement	• Development of Risk Management Framework

The analysis of consolidated data found themes evidenced by the frequency of their occurrence. Table 5.2 provides an illustration of the matrix used to populate the data from the interviews and questionnaires. It also provides comments and frequency of themes and sub themes. The responses in Table 5.2 relate to the question “Who in your experience identifies your generic risk?” This question requires respondents to choose from a selection of roles; the responses can be found in the comments and examples section of the table.

Table 5.2 Tabulation of responses from experts across the generic disciplines for the roles that they perceive as identifying generic risk

Generic expert	Section	Theme	Sub theme	Frequency	Comments and examples
Health and safety	Risk identification	Roles	Generic	1	Generic risk specialist- health and safety officer
Environmental	Risk identification	Roles	Generic	1	Generic risk specialist
Legal	Risk identification	Roles	Generic	1	Lawyer
Insurer	Risk identification	Roles	Generic	1	Generic risk specialist

Analysis of expert responses presented in the grids was possible across the generic disciplines as well for the sections, themes and sub themes. Conclusions were drawn from the comments and frequency and are presented in the following section.

5.2.2 Identification of generic risks

The expert elicitation results found that, for all respondents, generic risks were identified by the generic risk specialist. Table 5.3 shows the additional roles where risk was identified.

Table 5.3 Roles acknowledged by generic experts as identifying risk

Role	Frequency
Project manager	2
Risk manager	2
Department manager	1
Environmental Manager	1
Consultant	1
Insurance professional	1
Major hazard regulator	1
Joint competent authority	1

Methods and tools used to identify risk

When asked how generic risks were identified, the approaches were very different. The legal expert identified risks by way of:

“application of law to facts”

and stated that identification was an iterative process in line with the definitions of legal risk given by Maher (2007) and McCormick (2011); (see Section 2.4.4).The environmental expert identified risk from two perspectives: firstly, a project management approach was taken towards the identification of new risks and secondly, existing risks were identified through permitting procedures, inspections and compliance. The environmental expert stated that risk was also identified through research and changes in legislation being integrated in project management and compliance.

Identification of risks in new technology

The results with respect to the identification of hazards and risks in new technologies show that there were very different approaches from each of the experts. The health and safety expert stated:

> *“For new technologies hazard identification and risk assessment would be farmed out to consultants. Consultants may lack expertise”.*

Whereas the environmental expert stated that although there was no specific process for identifying new and emerging environmental risks:

> *”There is a project management approach which focuses on the identification of risk”*

The insurance expert commented that insurers have a bespoke method of identification but did not provide details. The legal expert confirmed that;

> *“Legal advisors look at those risks which they are directed to look at by the client”.*

The difference between new risks and existing risks for the legal expert being that with new risks, professionals:

"…… don't have facts but potential facts"

The health and safety expert stated that where bespoke risk identification was applied to new technologies the approach was:

> *"1. systematically identifying the key stages … and 2. Identifying the major hazard analogues from existing industries"*

Table 5.4 Specific processes for the identification of new and emerging risk

Generic expert	Example comments
Health and safety	Aware of specific process for new and emerging health and safety risks
Environmental	No specific process for identifying new and emerging environmental risks.
Insurer	Yes

The responses from the four experts (Table 5.4) shows that there is no consensus in the methods used to identify hazards for new technology and no specific process for the identification of new and emerging risks.

5.2.3 Identification of dimensions

The health and safety, environmental and insurer experts all stated that they identify the dimensions of interface, causation and accumulation (Table 5.5).

Table 5.5 Experts response to the question do they identify the dimensions of interface causation and accumulation

<table>
<tr><th>Expert</th><th>Interface</th><th>Causation</th><th>Accumulation</th></tr>
<tr><td>Health and safety</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td rowspan="2">Environmental</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td colspan="3">Identified at a high level as part of the environmental risk identification process</td></tr>
<tr><td>Legal</td><td>Not identified by the legal profession</td><td>Yes</td><td>Business provide facts and lawyers respond with legal risk assessment.</td></tr>
<tr><td>Insurer</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
</table>

The legal expert could only confirm explicitly that causation risks were identified because *"Causation is a legal concept"* (see Section.3.4.3). The legal expert also confirmed:

There was…no specific framework. It is identified by application of law and facts" and stated that interface risks are not identified by the legal profession because:

> *"A business or technical issue has to be highlighted first prior to legal risk identification*."

The reactive stance of legal risk identification is evidenced by the comment made by the legal expert with respect to the identification of accumulation risk:

> *"Business provide facts and lawyers respond with legal risk assessment"*

The legal profession would as a result of responses from the legal expert take a reactive approach to the identification of the dimensions of interface, causation and accumulation.

5.2.4 Methods used to identify the dimensions of interface, causation and accumulation risk

Interface risk

The analysis of comments made by experts did not identify a common method or approach to the identification of interface risk. The health and safety expert provided details of the approach taken for major hazards stating:

"….. Identification of all foreseeable scenarios then evaluation of likelihood and consequence at the interface (domino effect – well understood) to produce risk.

This comment is a little confusing, as although commenting on impacts at the interface of a process, the expert seems to be describing causation as the expert uses the "domino effect" to characterise the risk behaviour of interface risk.

The environmental expert simply stated environmental risk assessment would be used and;

“The regulator would assess whether the tools to deal with the risk was available at the stage of permitting”.

This clearly intimates that experts use a number of existing methods to identify this dimension.

Table 5.6 Analysis of results from experts when asked to confirm the identification of interface risk and the resulting methods used for identification

Generic expert	Confirmation of identification	Disclosure of method used to identify Interface dimension	Specific Method for identification of Interface
Environmental	✓	✓	X
Health and safety	✓	✓	X
Insurer	✓	X	X
Legal	X	X	X

Whilst three out of four experts stated that they identified interface risk, only two (the environmental and health and safety experts) provided details of the method which they used. The health and safety expert focused on the physical interfaces of the process and the environmental expert focused on fulfilling the assessment of risk for permitting. The four experts were not able to provide details of a specific method for the identification of interface risk as presented in Table 5.6. This suggests that there may not be a specific or generally accepted method for the identification of interface risk within these disciplines. It may be that as these are generic experts their respective disciplines are focused on the identification of generic risks and not interface risks or cross-disciplinary hazards.

Causation dimension

The causation dimension (defined in Section 3.4.3) was the only dimension which was identified by all experts. There was however no consensus in respect of the methods used to identify causation. Each discipline had their own distinct approach and most did not have a specific framework. The environmental expert stated that the methods used would be applied on a:

“Site by site basis”.

Insurers stated that they used a selection of tools which can be categorised as quantitative or qualitative and outlined in Table 5.7.

Table 5.7 The selection of tools used by the environmental insurer to identify risk

Quantitative	Qualitative
• Mathematical modelling • Frequency • Severity	• Age of infrastructure • Integrity of infrastructure • Proximity and sensitivity to receptors • Experience of technological usage

The quantitative tools listed in Table 5.7 do not identify a risk. They quantify an already identified risk either by the number of times a risk occurs (frequency) or magnitude of a risk (severity). A risk must be identified prior to quantification. The qualitative tools which were identified by the insurer in Table 5.7 are all factors which contribute to the characterisation of a hazard or risk. What is lacking is a specific method which brings the identified attributes together to establish the trigger for a causation hazard and thus the resulting characterisation of a causation risk.

Although all of the experts stated that they identified causation and stated methods which they used to identify these risks they did not provide a specific method of identification for causation risks.

Accumulation dimension

The accumulation dimension was not identified by the legal expert, but was identified by the environmental, health and safety and insurance experts (Table 5.8).

The health and safety expert stated that in respect of the methods used for the identification of the accumulation dimension there were a:

"number of systems available, now all digitalised which integrate and iterate risks of complex hazard interactions causing escalation of an initiating event into a major (off-site) incident".

The environmental expert did not state the method used to identify accumulation risks but stated the approach taken which was to identify accumulation risk by looking at the accident potential at the permitting stage on a site by site basis.

The insurance expert stated that there were two approaches to the identification of accumulation risk: firstly, identification on;

"*a risk by risk basis*"

and secondly, within the internal corporate group. The insurer stated that the methods applied tended to focus on*:*

"modelling and financial analysis".

The common theme is that both the insurers and environmental experts were explicit in disclosing that accumulation risk was identified on a risk by risk/ site by site basis. All the factors provided by all the experts are considerations or one of a number of tools, none of the experts provided a specific method for the identification of accumulation risk.

Table 5.8 Summary table showing those generic experts who classified the dimension of accumulation, stated that they had a method for identification and whether that method was a specific method for the identification of accumulation

Generic expert	Dimension identified	Method	Specific method
Environmental	✓	✓	X
Health and safety	✓	✓	X
Insurer	✓	X	X
Legal	X	X	X

The dimensions of interface, causation and accumulation risk are not universally identified by all generic experts but different generic risks had comprehensive methods of identification for their specific risk (Table 5.8) The data collected from the four experts did not result in a uniform level of risk identification across the generic risks for all the dimensions (Table 5.9).

From the results of the expert elicitation it can be seen that there were no specific methods for the identification of the dimensions of interface, causation and accumulation. There was no auditable approach to establishing that the results of the existing identification process were the most comprehensive across the generic risks. None of the experts stated that a multidisciplinary approach was taken for any dimension by any generic expert. The current approach to identification of risk would seem to be focused within the generic risk silos. Further clarification is required to establish if the conclusions drawn from the experts also apply to the wider risk community.

Table 5.9 Summary of comments regarding the identification of the interface, causation and accumulation dimensions of risk

Dimension	Legal	Environmental	Health and safety	Insurance
Interface	Level I interface risks are not identified. A business or technical issue has to be highlighted first prior to legal risk identification. Are not identified by the legal profession. They are identified by business and legal risk analysis results from this. Legal analysis involves legal compliance, facts and due diligence.	Site by site basis	In respect of major hazards, identification of all foreseeable scenarios then evaluation of likelihood and consequence at the interface (domino effect – well understood) to produce risk. From risk or dangerous dose develop control measures – eliminate, reduce, or protect from.	None given
Causation	Causation is a legal concept. Causation risk is identified by the legal profession. There is no specific framework it is identified by application of laws and facts.	Accident potential at permitting stage	In major accident hazard systems – nuclear, onshore major hazards near populations, and offshore, consequences of loss of containment are systematically evaluated as part of risk assessment. Problem for new/emerging technologies is lack of source terms whereas dispersion models are well known. Key weakness is incorporating new knowledge and invention into frequency and consequence models – expensive and time consuming. Usually only done in response to a major accident.	Yes 1. Mathematical modelling 2.Ffrequency and severity 3. Age of infrastructure 4. Risk management 5. Integrity of infrastructure 6. Proximity and sensitivity to receptors 7. Experience of technological usage Q10

Dimension	Legal	Environmental	Health and safety	Insurance
Accumulation	Business provide facts and lawyers respond with legal risk assessment. Timing is a consideration for accumulation risks	Site by site	Number of systems available, now all digitalised which integrate and iterate risks of complex hazard interactions causing escalation of an initiating event into a major (off-site) incident. However it is necessary to identify all hazard components for likelihood and consequence before this process can begin. Well known in risk assessment professions, and has practical utility in determining necessary reliability of safety integrity systems – railways, aircraft, chemical plants etc.	Yes 1. Per risk basis, modelling and financial analysis. 2. Group point of view(modelling)

5.2.5 Documentation of risk

The documentation of identified risk is an important means of evidencing the identification of risks. Documentation provides details of the characteristics of the risk and facilitates its assessment and mitigation. It is vital for auditing the management of a risk. The identification of a hazard and its characterisation is essential to the documentation of risk.

When asked if a risk register was used to document risks all experts with the exception of the legal expert stated" Yes" (see Table 5.10).

Table 5.10 The use of risk registers in the generic occupations of the experts

Generic expert	Example comments
Health and safety	Yes Required for any major accident regime
Environmental	Yes Environmental risks are included in a risk register
Legal	Legal risks are not included in a risk register. They may only be included if asked by the client.
Insurer	Yes Circulated by transfer to underwriters through the issuance of new underwriting guidelines

Additional comments from the legal expert provided evidence of the legal approach to the documentation of risk:

"Identified legal risks are reported by giving advice on the facts, law and application of the facts and recommendations based on the facts".

Additionally legal risks were not documented in a register but in reports such as due diligence reports. The legal expert confirmed that:

"Due diligence reports involve going through a significant list of facts and assessing the advice accordingly."

This seems to indicate a reactive approach to risk identification which is guided by legal facts which may or may not include a cross-disciplinary approach.

The environmental expert stated that risks were documented in three ways:

> "…*Project risk register in the project management structure,...during the permitting stage by a system of decision documents for justification of decisions* and*,"…for compliance by the use of inspection and monitoring reports*".

The environmental expert confirmed that projects examining new and emerging risks would use a:

"formalised risk register system"

The insurer identifies risk on two levels the clients risk portfolio and the insurance company basis. At the client level:

> *…"risks were identified by the broker and presented to the insurer on a silo basis"* [for a specific project]*.*

In respect of the insurer's corporate operations, the method of identification was disclosed but not the means of documentation. This industry sector is regulated and so the modelling and financial analysis would have to be provided by the finance and compliance department in the form of returns to the Financial Conduct Authority (FCA) usually by class of insurance. The class of insurance tends to follow the generic risk classifications, for example environmental risk - environmental impairment liability, property risks – property insurance, marine risks- marine insurance.

In summary, data captured was specific to the generic risk and the purpose of capturing the data. There are a number of media used to document risks. Three of the four experts (environmental, health and safety and insurance) used a risk register for documenting risk.

5.2.6 Risk assessment frameworks

Experts were asked to state their approach to generic risk assessment. The legal expert stated that the legal risk assessment followed:

"the business process.. and...the application of existing generic risk assessment frameworks".

This underpins the importance of accurate and comprehensive risk identification within and across the generic risk assessment frameworks. If the risk is not identified by the generic risk assessment framework it is unlikely to be identified by the legal expert; as they are only concerned with the facts presented to them. As a result the implications of the risk and any potential hazard will remain unknown.

The health and safety expert stated that a number of different tools and methods are used to assess risk. These tools which are presented in Table 5.11 can be divided into modelling and other tools and are evaluated in Section 2.5.

Table 5.11 Risk assessment tools used to assess health and safety risks

Modelling	Other tools
• Consequence modelling • Frequency modelling • Hazard stream modelling • Interface modelling • Dispersion modelling • Reliability modelling	• Failure mode and effect analysis • Fault tree analysis • Dangerous dose estimation • Major accident scenario

The insurance expert also used a number of tools and methods in their risk assessment process. The integrated approach used by the environmental insurer to assess risks is summarised in Table 5.12.

Table 5.12 The risk assessment models used by insurance expert for environmental risk

Risk Type	**Underwriting models and guidelines**	**Engineering assessment**	**Legal assessment**
Environmental damage	✓	✓	-
Third party damage	✓	✓	-
Regulatory	✓	✓	-
Contractual issues	-	-	✓

This approach comprises environmental data incorporated in underwriting models and guidelines, engineering and legal risk data which are used to assess a risk for insurability and its potential to have a negative impact on the insurer's capital. This method takes data from three different assessments in respect of the four risk types. It does not look at the risks of the engineering assessment and legal assessment as potentially triggering a line of causation beyond the identified generic environmental risks.

Table 5.13 shows that the methods used were general methods which were specific to the generic risk but not tailored to the identification of interface, causation and accumulation. Experts were given the opportunity to suggest other methods and tools, however only the health and safety expert suggested an alternative method "frequency analysis". The legal expert stated that they did not use any methods or tools for the identification of the dimensions, and the insurer did not use any tools for the interface dimension.

Table 5.13 The different methods and tools used to identify the dimensions of interface, causation and accumulation by the generic risk experts

	Generic risk assessment framework	Project management	Fault tree	Best guess	Expert elicitation	Other	None
Interface							
Environmental		✓					
Health and safety	✓	✓	✓				
Insurer							✓
Legal							✓
Causation							
Environmental	✓						
Health and safety	✓	✓	✓	✓		✓	
Insurer	✓						
Legal							✓
Accumulation							
Environmental	✓						
Health and safety			✓	✓	✓		
Insurer	✓						
Legal							✓
Total	6	3	3	2	1	1	4

The environmental expert did not provide a method for accumulation risk and the insurer provided no details for the interface dimension. The insurer used best guess in addition to the application of existing generic risk assessment frameworks and the health and safety expert used a selection of different methods for each of the dimensions.

When asked to specify the methods used for the identification of the dimensions of interface, causation and accumulation risk, there was some consensus between experts. The environmental, insurance, health and safety experts all used their existing generic risk assessment frameworks. This is illustrated in Figure 5-1 where the application of existing generic risk assessment was the most frequently quoted method for all dimensions.

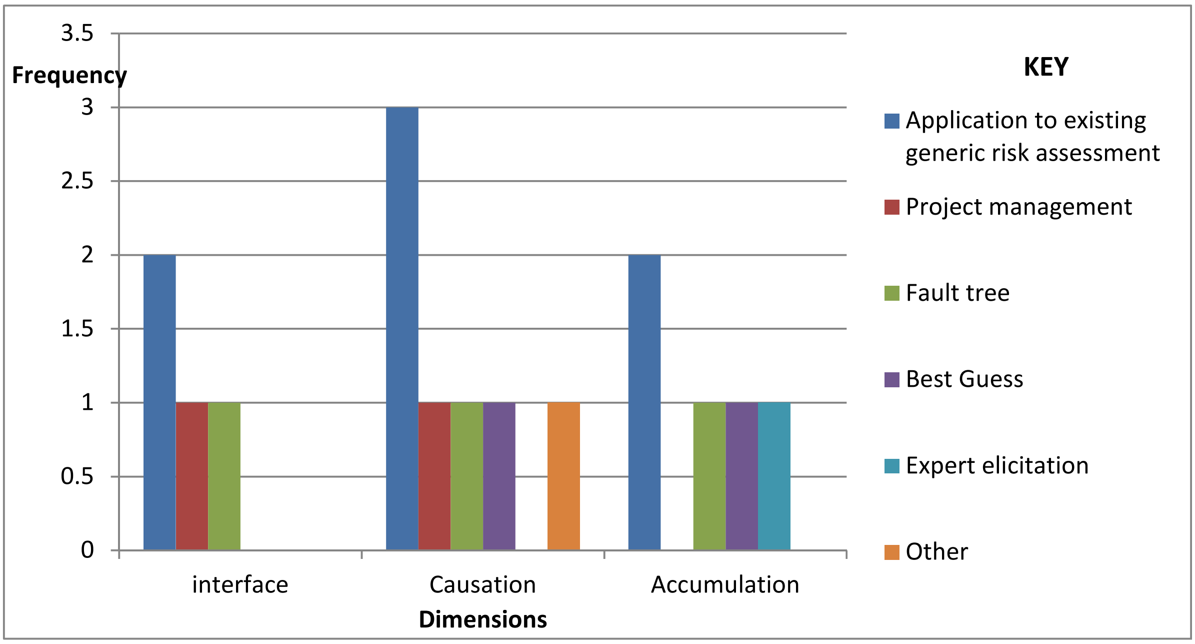

Figure 5-1 The frequency of methods and tools to identify risks in the dimensions of interface, causation and accumulation

In summary, there was no consensus on the methods used to identify the dimensions of interface, causation and accumulation. As a result the following methods should be included in the web survey to establish if there is any consensus from the wider population of risk professionals:-

- Application of existing generic risk assessment frameworks
- Project management risk assessment framework
- Best guess
- Fault tree
- Expert elicitation

5.2.7 Requirements for risk management

5.2.7.1 Attributes of risk management

Experts were asked to comment on the attributes of generic risk management frameworks. The insurance expert was unable to provide details of the risk management framework and the legal expert stated that the development of a risk management framework:

“is an evolving situation. Risk management is important for the management of legal liabilities especially if these can be transferred”.

The environmental expert provided a list of tools and procedures that were used to aid environmental risk management which included:

“Geographic information systems (GIS), computer modelling, process and environmental monitoring, quality of rivers and stack emissions”.

The health and safety expert gave an overview of the quality of risk management in organisations:

“In best major hazard industries there are integrated safety and environment management programmes supported by quality management systems (HSG65) and independent verification schemes… In worst companies, statutory minimum is practised and systems are degraded and not up to date.

Many major hazard companies in the UK will be subject to COMAH [Control of Major accident hazards] *or nuclear safety regulation, so safety frameworks are statutory and systematic. “*

5.2.7.2 Compliance with ISO31000

With respect to ISO31000 compliance, only the health and safety expert provided any comment stating, that health and safety risk management was not structured to be compliant with ISO31000 guidelines. Both the environmental and insurance expert thought that risk management was important, in the case of the environmental expert the level of importance is illustrated by the fact that:

“*the first condition of a permit is that the operator understands the risk*”

The insurance expert took a similar position stating that it is important that the strategy for risk management should be evidenced throughout the organisation requesting insurance.

5.2.7.3 Embedding risk management in an organisation

The insurer confirmed that risk management is embedded in their organisation. The health and safety expert gave an interesting insight into the acceptance of risk management and the corporate culture of different organisations when it came to embedded risk management stating:

"Most major hazards industries – chemicals, oil and gas, nuclear, public transport identify health and safety risks as a key reputational and financial risk, particularly large and global businesses whose success depends on licensing by public authorities and even governments, and whose operations are scrutinised by NGO's, or where public aversion to major accidents is a risk (e.g. nuclear, and offshore oil)".

The legal expert indicates that legal experts do not actively promote proactive risk management beyond the confines of the generic legal silo. The health and safety expert suggested that experts in this area take the most proactive approach to risk management. The health and safety expert talked about the incorporation of aspects of technical and environmental risk; and would be the most advanced in respect of operating across the disciplines and looking to facilitate the dimensions of interface, causation and accumulation. Further investigation was required from a larger population of risk professionals to identify key attributes that a method for hazard identification should possess to benefit risk identification, risk assessment, documentation and risk management.

5.3 Web survey

5.3.1 Structure of analysis

The web survey had a similar structure to the expert elicitation with the following sections:

Section A CCS - the results from this section is provided in Chapter 6.

Section B Identification of risk

Section C Assessment of risk

Section D Documentation of risk

Section E Risk management frameworks

5.3.2 Analysis of data

The objective of collecting data from risk professionals via a web survey was to establish how the identification of risk was performed and evidenced. The focus on risk was that these professionals would identify hazards which would be characterised both qualitatively and quantitatively facilitating risk analysis, assessment and management. The data was analysed using similar themes as the expert interviews. The analytical techniques applied were those stated in Section 4.7.3. The survey was sent out to three formal professional groups who had a cumulative membership of approximately 33,332 and the number of responses received was 27.

5.3.3 Risk identification

In Section 5.1 experts had identified a number of occupational roles where risk was identified (Table 5.1). This section of the web survey builds on the responses given by the experts and asks a wider population of risk professionals to state who identifies the risk dimensions of generic, Interface I , Interface II , causation and accumulation risk. The results of their responses are captured in Table 5.14.

Table 5.14 Roles which are perceived to identify the dimensions of generic, interface, causation and accumulation risk

Roles where risk is perceived to be identified	Generic risks	Interface I risks	Interface II risks	Causation risks	Accumulation risks
Generic risk specialists	8	5	4	3	0
Risk manager	15	12	11	13	9
Departmental manager	12	8	8	12	5
Finance department	8	5	4	5	5
Project manager	10	7	7	7	7
Risk committee	11	7	9	9	8
Business continuity professional	4	3	7	2	4
Board of directors	6	3	2	3	0
Insurance professional	7	3	2	2	3
Not part of the identification process	1	4	3	1	4
other	0	3	3	3	0

The results confirm that a risk manager has the highest frequency of respondents for each dimension of risk, followed by a departmental manager and risk committee. There was little difference between the roles which were considered to identify causation, interface I and II. Although interface and causation risks are identified by the generic risk specialists, the accumulation dimension was not identified by the generic risk specialist. The most widely identified dimension was generic risk and the least identified by the portfolio of occupational roles was accumulation risk this is in line with the findings of the expert questionnaires (see Section 5.2.4 and Table 5.8.)

Roles which are perceived by respondents as identifying risk across the dimensions of generic, interface, causation and accumulation are the risk manager, department manager, risk committee and project manager. The board of directors were perceived as focusing on generic risk and less on the other dimensions. A Chi-squared test confirmed that there was not a statistically significant relationship between the occupational roles and the identification of the dimensions generic, interface, causation and accumulation risk ($p<0.05$).

However it is not clear whether it is the methods, tools, procedures or dimensions used to identify hazards that need adopting or the fact that there is no means of identifying all the dimensions.

5.3.4 The identification of new risks

When asked whether new and emerging risks were identified by respondents 18 out of 24 stated that they identified new and emerging risks. Five stated that did not, and 1 respondent used a bespoke method of identification.

When asked to state their level of confidence 77% of respondents had a positive level of confidence in the methods used by their organisation to identify new or unknown risks, the impact of this is illustrated in Figure 5-2.

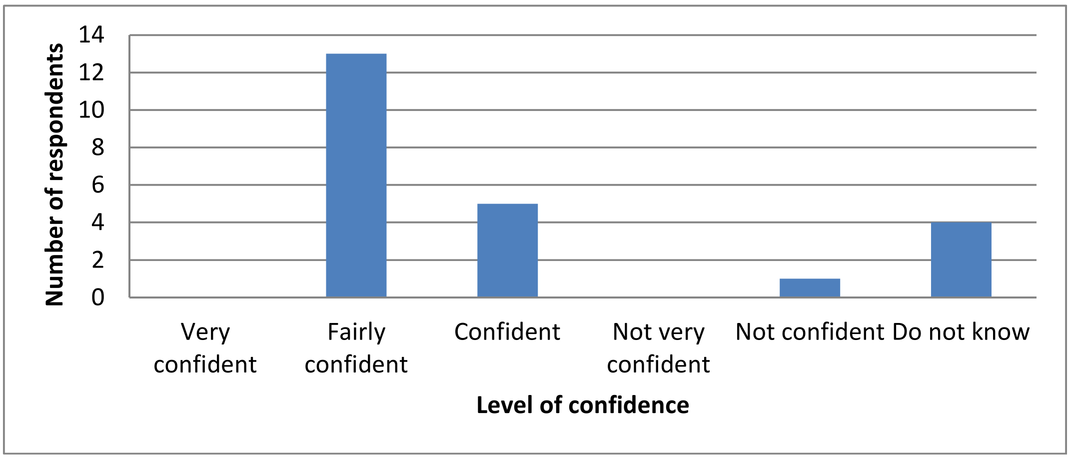

Figure 5-2 The number of respondents and level of confidence in the identification of new or unknown risks

No respondents had 100% confidence in the current methods which illustrated that there was room for an improved method of identification. Respondents were asked to provide details of the methods they used to identify new and unknown risks. Of the 24 respondents, 6 did not respond to this question. Their responses are provided in Table 5.15 and show that there is a wide selection of different methods, tools and procedures.

Table 5.15 methods used by respondents to identify new and unknown risks

No	**Response**
1	Systematic questionnaire to some 50 people
2	Business Model Risk Framework (BRMF)
3	Board regular review of risk list
4	Did not comment
5	ERM Champions review their lists and global suggestions
6	Did not comment
7	Quarterly review of risk map within the business
8	Lawyers attend Continuing Legal Development training
9	Emerging risk are continuously assessed either via the departmental risk committees or business imperatives that would have a transversal impact on the business e.g. global warming; disaster response etc.
10	We run scenarios using reverse stress testing based on its broken - what broke it?
11	Scenario planning, Game theory and environmental scanning and brain storming
12	Quarterly Risk Certification
13	EU, DNV and company guidelines
14	Standing agenda item at all four of our meetings dealing with risk.
15	Facilitated structured workshops involving different teams
16	Part of the ESIA process
17	Iterative Risk Assessment and Risk Management exercises
18	Did not Comment
19	Aspects register - review of emerging science
20	Did not comment
21	Dedicated emerging risk identification sessions at different levels within the organisation using generic risk categories and often external data as a prompt to identify risks which could prevent us delivering against or influence future business strategy
22	Did not comment
23	Did not comment
24	Risk Register & full risk review process

There was no consensus with respect to the methods that are used to identify new and unknown risk by respondents. Respondents used a wide selection of methods which included lists generated from ERM champions, who are managers within the organisation who are tasked with the implementation of ERM (Section 2.6.3). Other methods included questionnaires, inclusion as an agenda item at board meetings, facilitated workshops, and inclusion in aspects

register by review of emerging science. Two respondents provided details of how their organisation identified emerging risks. The first stated:
“Dedicated emerging risk identification sessions at different levels within the organisation using generic risk categories and often external data as a prompt to identify risks which could prevent us delivering against or influence future business strategy”

The second respondent stated:

“Emerging risk are continuously assessed either via the departmental risk committees or business imperatives that would have a transversal impact on the business e.g. global warming; disaster response etc.”

Out of the 24 respondents, 18 stated that it is part of a process or covered in other operations and 6 did not comment. The large number of different methods shows a willingness to identify risk and the use of a number of different tools.

5.3.5 The identification of the dimensions interface, causation and accumulation

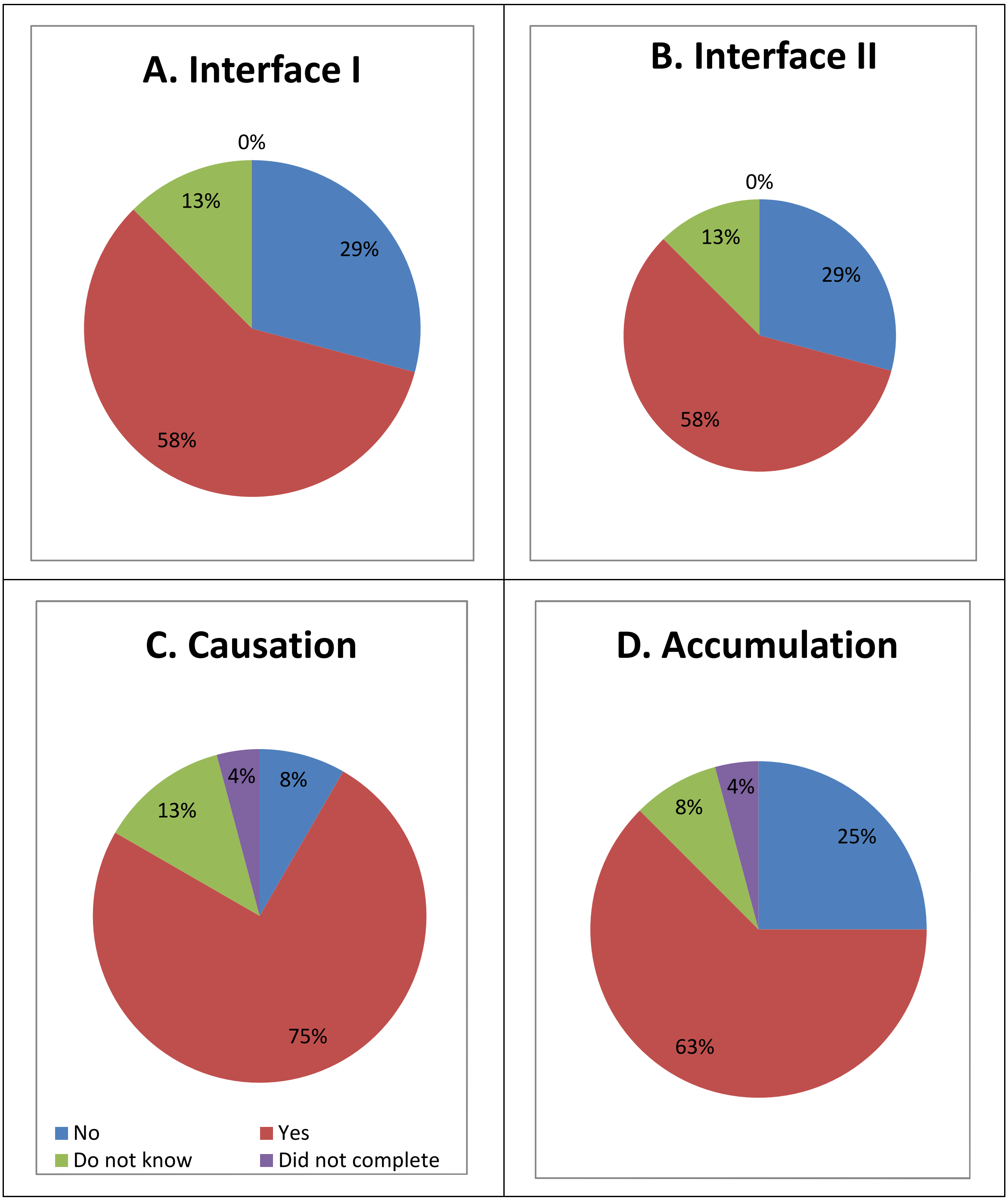

Figure 5-3 Frequency of respondents who stated that they identified (A) interface I, (B) II, (C) causation, (D) accumulation risks (n=24)

The respondent population for all dimensions was the same and so standardisation adjustments were not required. When asked whether interface, causation and accumulation risks were identified, over 58% stated that interface risks were identified, 72 % stated that causation risk were identified and 63% stated that accumulation risks were identified.

The number of negative responses ("No" or "Don't know") shows that 42% of respondents were unable to confirm that they identified interface (I and II) risks compared to 21% for causation and 33% for accumulation risks. This shows that interface and accumulation risks are two dimensions of risk which are less likely to be identified by the population who responded**.**

The majority of respondents (over 50%) shown in Figure 5-3 reported that the dimensions of interface, causation and accumulation were identified. This would mean that efforts were being made by the respondents to identify these dimensions. The results also show that interface and accumulation are the two dimensions of risk which are less likely to be identified by the respondents to this web survey, and this was also the case with respect to the outcome of the expert interviews (see Section 5.2.4). This could indicate that 1. the respondents were not the individuals who would identify these dimensions of risk as part of their remit; 2. it was difficult to identify these risks with the available tools and methods; and /or 3. It was not felt necessary to identify theses dimensions. Options 1 and 3 are unlikely to be the case and as a result show that over 50% reported that these dimensions were identified. This seems to indicate that it is the method of identification which is the issue.

5.3.6 Preferred methods for identification of the dimensions

The 24 respondents provided 22 different methods of identification for four different dimensions. The results were categorised into four categories, formal, qualitative, quantitative and bespoke methods. Some respondents gave more than one answer for one dimension, indicating that a number of methods may be used to identify a dimension.

Formal methods

Formal methods are well characterised and have an agreed structure. These methods are also outlined in Section 2.5.

Table 5.16 Formal methods of identifying dimension

Formal methods	Interface I	Interface II	Causation	Accumulation	Total
HAZOPs	**0**	**0**	**1**	**0**	1
HAZID	**0**	**0**	**1**	**0**	1
BRMF	**1**	**1**	**1**	**0**	3
COMA	**0**	**0**	**1**	**0**	1
Swiss Cheese	**0**	**0**	**0**	**1**	1
Bowtie	**0**	**1**	**2**	**0**	3
Features events and processes	**1**	**1**	**2**	**1**	5
Failure mode and effect analysis	**0**	**0**	**1**	**0**	1
Supply chain risk assessment	**0**	**1**	**0**	**0**	1
Source pathway receptor	**0**	**0**	**1**	**0**	1
Sub total	**2**	**4**	**10**	**2**	**18**

Qualitative methods

Qualitative methods are the result of a collaboration and capture of expert elicitation, and scenario testing in workshops.

Table 5.17 Qualitative methods for identification of dimensions

Summary of results	Interface I	Interface II	Causation	Accumulation	Total
Risk register	**1**	**1**	**0**	**0**	**2**
Scenario	**2**	**4**	**2**	**3**	**11**
Brain storming	**1**	**1**	**0**	**0**	**2**
Risk workshops	**2**	**2**	**3**	**1**	**8**
Reviews (not scenarios)	**2**	**1**	**3**	**2**	**8**
Expert judgement	**1**	**1**	**0**	**1**	**3**
Business process mapping	**1**	**1**	**2**	**0**	**4**
Cross business risk meeting	**0**	**0**	**1**	**0**	**1**
Sub total	**10**	**11**	**11**	**7**	**39**

Quantitative techniques

Quantitative techniques are quantitative in approach and output.

Table 5.18 Quantitative techniques for the identification of dimensions

Quantitative techniques	Interface I	Interface II	Causation	Accumulation	Total
Multivariate analysis	0	0	0	1	1
Risk correlation	0	1	1	1	3
Quantitative analysis	0	1	0	2	3
Total	0	2	1	4	7

The table shows that very few respondents used quantitative techniques for the identification of dimensions with only two techniques being identified multivariate analysis and risk correlation. No quantitative methods were identified as being used for the identification of Interface I hazards.

Bespoke methods

Bespoke methods are those methods created and developed by the respondent's organisation.

Table 5.19 Bespoke methods for the identification of dimensions

Bespoke	Interface I	Interface II	Causation	Accumulation
Specific CCS risk identification	0	1	0	1

The only bespoke methods were those developed for CCS risk identification. This may be due to the fact that this was an emerging technology and an untested new value chain which was subject to drivers such as: intense regulatory scrutiny and a need for financial underwriting by numerous stakeholders.

Analysis of non-responses

Table 5.20 Analysis of non-responses

Type of non-response	Interface I	Interface II	Causation	Accumulation
Did not comment (DNC)	**9**	**8**	**8**	**12**
None	**1**	**2**	**1**	**0**
Subtotal of non responses	**10**	**11**	**9**	**13**
Total responses	**24**	**26**	**31**	**26**

A large number of respondents to the survey did not respond to this specific question. The highest number of non-respondents was 13 (50%) for accumulation risk followed by 42% each for interface and causation. This would seem to indicate that more than 40% of respondents did not state the method used to identify the dimensions of interface, causation an accumulation. The results show that there is no clear method used across all the dimensions and the variable totals show that more than one method is used to identify a dimension; this is especially true of the causation dimension. Alternatively the results could be showing that the percentage of non-respondents could indicate a lack of methods available to identify these dimensions or that these dimensions are not identified.

5.3.7 Risk assessment

The survey also asked risk professionals about risk assessment frameworks to capture data on the identification of hazards and risks where identification takes place as part of the initial risk assessment (Aven, 2011).

Respondents were asked to state the risk assessment methods used to assess generic risks. The results of the 24 respondents were collated in their generic risks and a list of all the methods, concepts and frameworks used to assess generic risks produced. Table 5.21 shows the thirty-nine different methods for seven generic risks which included: economic, environmental, finance, geological, legal and technical.

Table 5.21 Risk assessment methods used to assess generic risks

Quantitative	Method	Economic	Environmental	Finance	Geological	Health and safety	Legal	Technical	Total responses per method
	Aspects register and legal register						1		1
Q	Aspects register risk scoring		1						1
Q	Audit and financial review	1							1
	Bow tie analysis		1						1
	BRMF	1		1	1		1	1	5
	Common risk management	1				1	1	1	4
	Common risk management process		1	1	1				3
	Contract risk register						1		1
	Committee of Sponsoring Organizations of the Treadway Commission (COSO) related own framework	1							1
Q	Defined risk assessment + Hazard					1			1
	Discursive review							1	1
Q	Econometric expert evaluation	1							1
Q	Engineering and technical standards							1	1
	Enterprise Risk Management	1	1	1		1	1	1	6
	Expert evaluation				1			1	2
Q	Fault tree	1				1	1	1	4
Q	Feature Events and Processes(FEP)	1	1	1	1	1	1	1	7
Q	Financial modelling			1					1
	General review					1			1
	Hazard and effect management process (HEMP[1])		1			1			2
	HSE, BRMF, COMAH		1			1			2
Q	Impact description 1-5 scale		1	1		1	1		4
	individual review		1	1	1				3
Q	Insurance	1							1
	ISO 31000	2	2	2	1	3	1	2	13
	Legal						2		2
	Legal analysis		1						1
	Periodic review					1			1
	Process and procedure review						1		1
	Process reviews							1	1
Q	Project risk register			1					1

[1] Hazard and effects process management

Quantitative	Method	Economic	Environmental	Finance	Geological	Health and safety	Legal	Technical	Total responses per method
	Projects -implementation of new legislation review and prosecution cases						1		1
Q	Quantitative evaluation of data			1					1
	Regulatory requirement			1			1		2
Q	Risk assessment semi quantitative					1			1
Q	Severity / probability assessment group	1	1						2
Q	Severity/probability			1		1	1	1	4
	Source pathway receptor		1		1				2
Q	TESLA				1				1
	Total Number	12	14	13	8	15	15	12	89
	Not applicable	4	0	3	9	2	2	3	23
	No response	7	9	7	6	6	6	8	49
	Overall total	23	23	23	23	23	23	23	161

[3] Hazard and effects process management

The broad list of methods in Table 5.21 shows that generic risk practitioners did not provide a consensus on the methods of risk assessment for generic risks. The table shows that 11 out of the 39 methods were specific to a generic risk such as “engineering and technical standard” for a technical risk or contract risk review” for a legal risk. Apart from the method features, events and processes (FEPs) which were applied across all generic risks, there was no convergence of methods even in respect of regulated generic risks such as health and safety.

Those methods which were applied across most of the generic risks tended to be frameworks such as ERM and general descriptors such as business risk management framework (BRMF) and common risk management. These methods were not specific in providing an agreed methodology. Respondents who gave these responses applied them to all generic risks. Common concepts and broad frameworks predominated as responses for example frameworks such as ERM and ISO31000. Concepts included process reviews and qualitative methods; general reviews and individual reviews. Of the 39 methods 16 were quantitative methods as highlighted in Table 5.21 by the letter Q in the first column.

Some respondents gave the same reply to each generic risk type this was the case for the ERM, BRMF, common risk management and common risk management processes. In some cases this may be appropriate; such as ISO31000 which may be applicable to all risk types and is accepted as a whole system risk management framework. However, there were no specific guidelines or methods for the identification or assessment of the generic risks. This shows that there is no consistent framework used for the assessment of generic risk, either perceived or actual. It may not be appropriate to use the same method of risk assessment for all disciplines; however the objective of this question was to establish if there were common methods or tools used to assess risks. If this was the case, this information would help to formulate the proposed method for cross-disciplinary hazard identification. As there was not a common method for risk assessment for the different disciplines it would seem appropriate to develop a method which could identify hazards across the disciplines this would require a new method rather than the use of an existing method.

Table 5.22 Analysis of non-responses to the question; what generic risk assessment frameworks are used to assess generic risk in your project or organisation?

Non-response	**Economics**	**Environment**	**Finance**	**Geological**	**Health and safety**	**Legal**	**Technical**
N/A = Not applicable	1	3	3	9	2	2	3
DNC = Did not comment	5	6	7	6	6	6	8
Total	6	9	10	15	8	8	11
%	26.09%	39.13%	43.48%	65.22%	34.78%	34.78%	47.83%

Table 5.22 shows that respondents failed to respond either because they did not feel the question applicable or did not comment. The highest non-response was for geological risk and this is likely to be due to the lack of geological risk

expertise from the majority of the respondents to the survey. The non-responses are an indicator of the lack of expertise in risk assessment in areas outside the specific generic risks. This shows that lack of cross-disciplinary knowledge may contribute to silo focused identification and assessment of risk. This may be a reason for the reliance on broad frameworks to act as umbrella frameworks to consolidate the identification, assessment and management of risks.

The results of this question show that although there are generally accepted frameworks and concepts which are a mixture of quantitative and qualitative method; no single method apart from FEP is used across the disciplines to assess risk if identification occurs in the risk assessment process.

5.3.8 Risk assessment frameworks used to assess interface, causation and accumulation risks

The methods used to assess the dimensions of interface, causation and accumulation risk are collated and presented in Table 5.23.

Table 5.23 Comparison of risk assessment methods for the dimension of interface, causation and accumulation

Observed	Dimensions of risk			
Method of assessment	Interface	Causation	Accumulation	Total
Project management risk assessment framework	3	1	1	5
Best guess	5	4	2	11
Expert elicitation	6	5	7	18
Fault tree	1	2	1	4
Application of existing generic risk assessment frameworks	4	8	7	19
operational process review	1	0	0	1
Other	1	0	1	2

The results are biased by the fact that the same number of respondents did not respond to each dimension; even though they were given the same opportunity to respond. The results were ranked according to the total frequency for the individual dimensions. The results in Table 5.24 show that the preferred methods of risk assessment are predominantly based on expert knowledge in the form of best guess or expert elicitation. Frameworks were also used; the application of existing risk assessment frameworks was most widely used for interface and causation risks, with project management risk assessment framework being ranked equal with best guess for accumulation risk**.**

Table 5.24 Results of the ranking of methods of risk assessment for the dimensions of interface, causation and accumulation risk

Ranking of interface risks

Method of assessment	Frequency
Expert elicitation	6
Best guess	5
Application of existing generic risk assessment frameworks	4
Project management risk assessment framework	3
Fault tree	1
operational process review	1
Other	1

Ranking of risk assessment methods for causation risk

Application of existing generic risk assessment frameworks	8
Expert elicitation	5
Best guess	4
Fault tree	2
Project management risk assessment framework	1
operational process review	0
Other	0

Ranking for accumulation risk

Best guess	7
Project management risk assessment framework	7
Expert elicitation	2
Application of existing generic risk assessment frameworks	1
Fault tree	1
Other	1
operational process review	0

The top three ranked methods for risk assessment

The preferred methods for the risk assessment across for all dimensions of risk were best guess and expert elicitation. There is a heavy reliance on experts and their opinions and this confirms the fact that there is no clearly agreed method for the assessment of risk across disciplines. Given that identification of hazards is part of the assessment of risk then there is no clear method identified**.**

5.3.9 Documentation of interface, causation and accumulation risks

To establish if there was a preferred method of documenting risks respondents were asked to state their preferred method of documentation for each of the dimensions. The results are presented in Table 5.25.

Table 5.25 Showing the frequency of different methods used to report the dimensions of Interface, causation and accumulation risk

Method of documentation	Interface I	Interface II	Causation	Accumulation	Total
Specific inclusion in the risk register	13	12	13	0	38
Meeting of the risk committee	8	8	7	7	30
Meeting of generic risk committee	7	6	4	4	21
Risk report	8	9	9	12	38
Other	4	2	2	1	9

All the media provided in the survey as options for documentation were used for the four dimensions of risks. Table 5.25 shows that if ranking the methods of identification based on the total frequency, the risk register and risk report would be equal followed by the meeting of the risk committee, the generic risk committee and other. However a risk register was not the vehicle of choice for the documentation of accumulation risk by the respondents to the survey. A risk report was the most popular method used to document accumulation risks.

A Chi-squared test was applied to establish if there was an association between the identification of the dimensions and the different method of documenting risks. The test found there was no statistically significant association between the method of documentation and the dimension, of interface, causation and accumulation ($P>0.05$).The fact that all media are used shows that there is no consensus with respect to a central repository for the documentation of identified risk.

When respondents were asked if they produce a risk register, 71% of the 23 respondents stated that they produced a risk register. Where a risk register is used, 74% of respondents stated that it is embedded in the management system of the organisation. When asked if the dimensions were included in their risk register more than half of the 20 respondents (n= 17) included three or more dimensions in their risk register. However, only eight out of twenty respondents stated that they included all the dimensions in their risk register. Four of the 24 respondents did not provide a response.

In summary, a number of methods are used to document risk. A risk register is widely used but it is not able to accommodate all the dimensions and this is evidenced in the results for accumulation risk where 12 of the 38 responses (31%) from the 23 respondents used a risk report to document risk and this was the most frequently used method of documenting accumulation risk. If it were possible to document accumulation risk in a risk register this would provide a central repository for evidencing identified hazards and risks. This would seem to be a gap in knowledge.

5.3.10 Risk management frameworks

Table 5.26 showing the frequency of factors used to prioritise risks for management by ranking. (The highlighted areas are the most frequent reason given for prioritisation of risk.)

	Most widely used 1	2	3	4	5	6	7	8	9	10	11	Least used 12
Frequency	1	6	1	2	1	3	0	1	0	0	1	1
Significance/severity	11	3	3	0	2	0	0	0	0	0	0	0
Risk tolerance	1	3	5	1	1	3	0	0	1	1	0	0
Financial impact	4	1	5	5	1	3	0	0	0	0	0	0
Compliance	0	1	2	4	3	1	3	3	0	0	1	0
Reputational risk exposure	0	4	1	3	4	1	3	1	0	1	0	0
Cost benefit analysis	1	1	1	0	0	0	2	1	5	0	1	0
Public perception	0	0	0	3	1	4	2	0	0	0	0	0
Potential for legacy liability	0	0	1	1	3	0	1	3	3	2	1	0
Access to cost effective capital	0	0	0	0	1	0	2	1	2	6	0	1
Access to insurance markets	0	0	0	0	0	1	0	1	2	2	7	0
Other	2	0	0	0	0	0	0	0	0	0	0	9
DNC	4	5	5	5	7	8	10	11	11	11	13	13

Important drivers for the identification of risk are the factors which motivate risk professionals to identify risk. Respondents were asked to rank those factors which they thought were most widely used to prioritise risk for management from 1 to 12, where 1 was the most widely used and 12 the least used. The resulting data from Table 5.26 were analysed using ANOVA. The result of the univariate test of significance show that there is a statistically significant relationship at the 95% confidence interval ($p < 0.005$) between the 12 different drivers for motivating professionals to identify risk. The implication is that the independence of the residuals and assumptions of normality are being met.

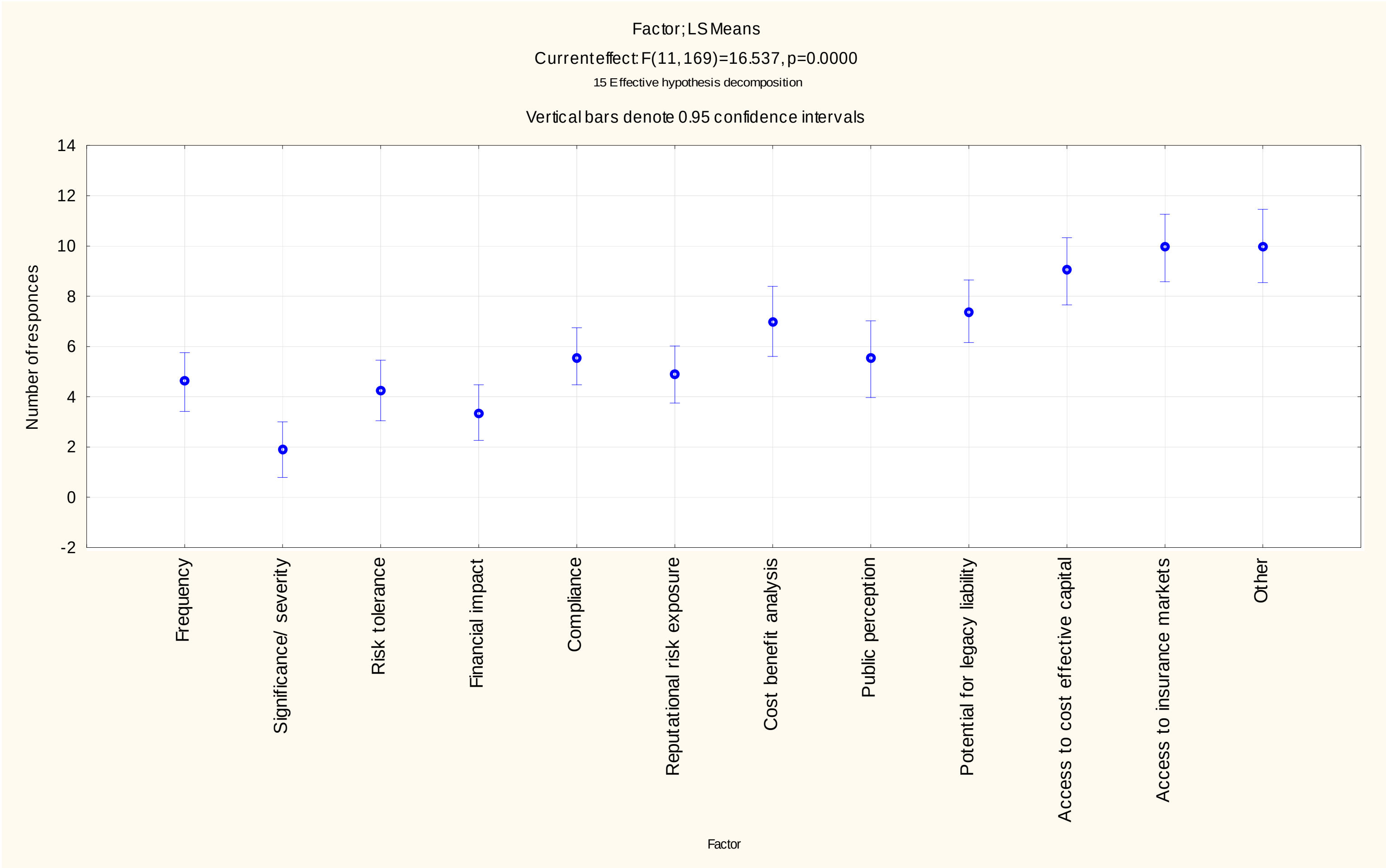

Figure 5-4 Confirmation of the factors used to prioritise risk for management

The graph in Figure 5-4 confirms the ranking of factors which respondents considered a priority for the management of risk. The greatest priority was given to factors where there would be an immediate impact to an organisations' ability to continue as a going concern and included, severity, financial impact, frequency and risk tolerance. The second group of factors were important, requiring swift resolution and involved third parties. They included; reputation, compliance and public perception. The third group of factors were operational aspirations which required management and included, cost benefit analysis, potential legacy liability, access to cost effective capital and access to insurance markets Figure 5-5.

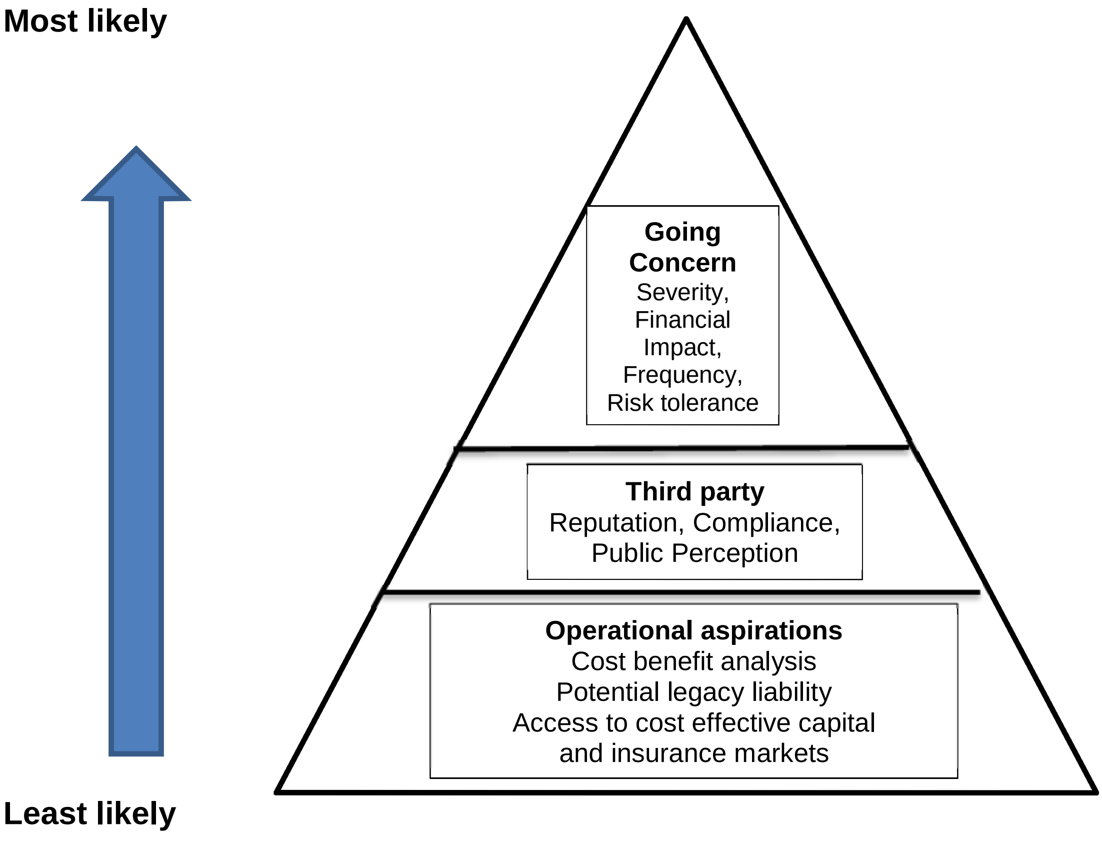

Figure 5-5 Analysis of the results of ranking the factors used to prioritise risk for management based on grouping of the ANOVA results in Figure 5-4

The most widely used parameter for prioritising risk for management is significance / severity, followed by financial impact and risk tolerance.

Criteria used as the basis for managing risk

When asked to state the basis for managing risk, the 24 responses from respondents were allocated to the categories of risk tolerance, severity, cost, benefits, compliance, other and did not comment. The result of this categorisation are presented in Table 5.27 and shows the key considerations for managing risk are risk tolerance, severity and cost.

Table 5.27 Summary of criteria used as a basis for managing risk

Risk Tolerance	5
Severity	5
Cost	5
Benefits	1
Compliance	2
Other	2
Did not comment	4
Total	24

One of the considerations in developing a methodology for cross-disciplinary hazard identification is the need to integrate the different risk management frameworks Figure 5-6.

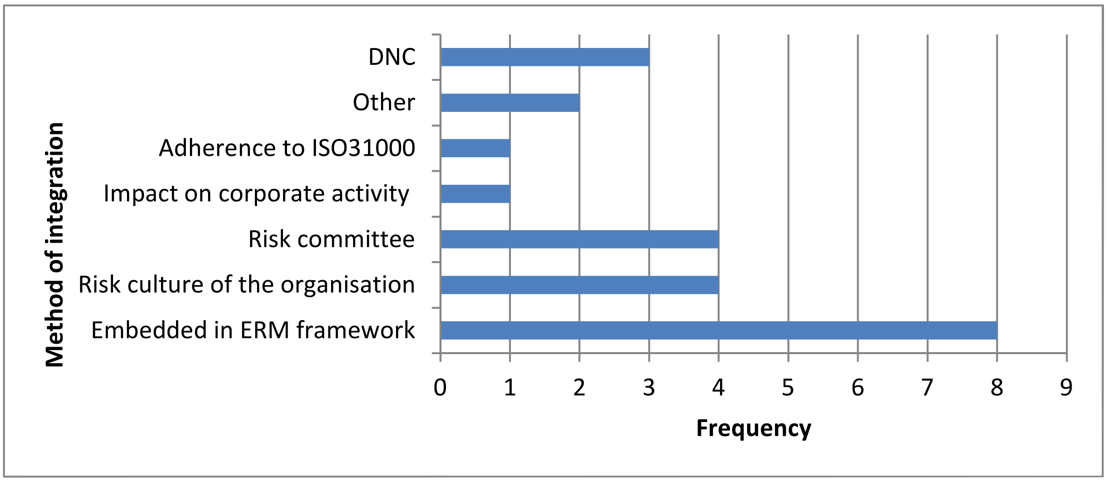

Figure 5-6 Options used to integrate the different methods risk management frameworks

The integration of numerous risk management frameworks is accommodated in a number of different options which include, embedding in an ERM framework, the risk culture of an organisation, risk committee, potential impact on corporate activity and adherence to ISO31000. The most frequently cited option by respondents is embedding in an enterprise risk management framework. ERM was identified by respondents as an important framework integrating numerous risk management frameworks.

Adequacy of current methods to manage new and emerging risks

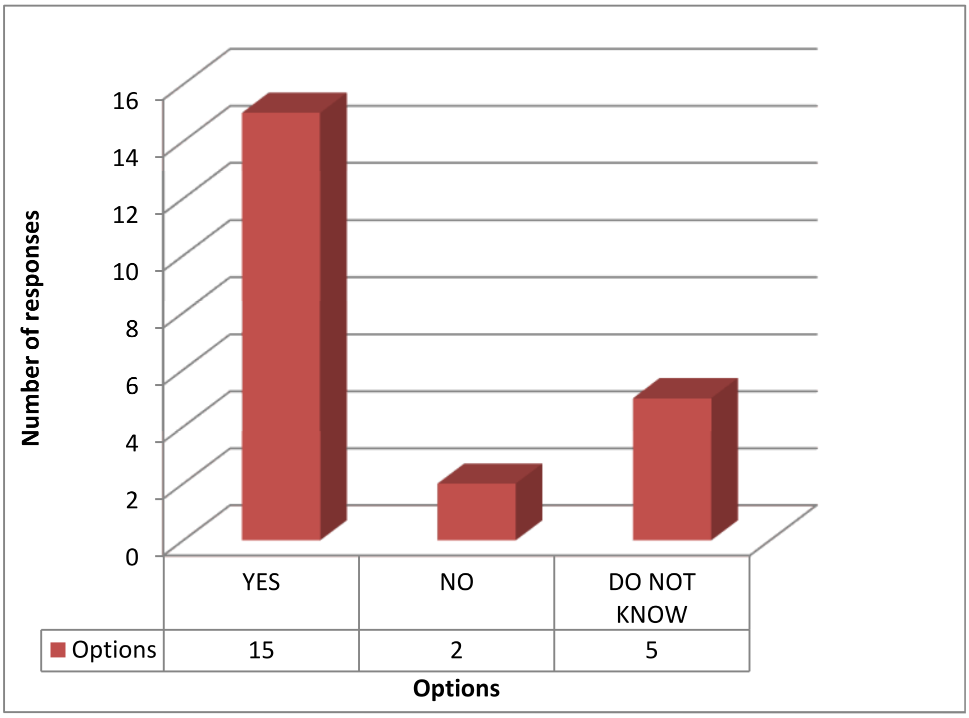

Figure 5-7 The number of respondents who stated that current methods of risk management are adequate for the management of new and emerging risks

The majority of respondents (15 out of 22) stated that the current method of risk management was adequate for the management of new and emerging risks (Figure 5-7).

5.3.11 Attributes

Respondents were asked to comment on the compliance of risk management frameworks to corporate governance, ISO31000 and ERM. The results show that the majority of respondents (17 out of 23) stated that it was important for a new framework to accommodate corporate governance requirements. Respondents were unsure as to whether the current ISO31000 risk management standard was adequate for the identification and management of risk. This is evidenced by 15 of the 23 stating “no” it would not be adequate or that they “do not know” whether it was adequate. Although eight respondents stated” yes” it would be adequate, there was clearly a view that there is a need for a better framework for the identification and management of risk. When respondents were asked whether they used ERM 13 of the 23 respondents confirmed that they used ERM. In summary the attributes of a new method of hazard identification should accommodate corporate governance, and ERM. However respondents were not convinced that compliance with ISO 31000 would result in adequate identification and management of risk.

5.4 Key findings from the experts and web survey respondents

The result of the expert interviews and web survey confirms that risk is identified by a number of different roles in an organisation and not just generic risk specialists. The risk manager, project manager, departmental manager, risk committee are the most commonly quoted roles where risks are identified. Additionally there is no consensus in the methods used to identify hazards and risk for new and emerging risks and no specific process for new and emerging risk identification.

The survey and elicitation results suggest that efforts were being made to identify all the dimensions as all the experts stated that they identified the dimensions and over 58% of web survey respondents stated that they identified the dimensions, interface, causation and accumulation. The results also show that interface and accumulation are the two dimensions of risk which are less likely to be identified by the respondents to this web survey. This was also the case with respect to the outcome of the expert elicitation.

There was no specific method for identifying the interface dimension. The results did not identify methods for the identification of interface risk despite three of the four experts stating that they identified interface risk. Two experts provided details of the method which they used but these were not specific methods for the identification of interface risk.

Both experts and web survey respondents did not have a specific method for identifying the causation dimension. There was a definite need to identify this dimension which was met by using a collection of different methods. With respect to the accumulation dimension there was no specific method for the identification of this dimension. The most frequently cited methods were qualitative scenario planning and reviews.

A number of methods were used to document risks with three of the four experts using a risk register for documenting environmental, health and safety and insurance risk. A risk register was the most widely used but it was not able to accommodate all the dimensions and this is evidenced in the results for accumulation risk where 12 of the 38 respondents (31%) used a risk report, which was the most frequently used method of documenting accumulation risk. If it were possible to document accumulation risk in a risk register this would provide a central repository for evidencing identified hazards and risks. This would seem to be a gap in knowledge.

Both the experts and respondents to the web survey found a heavy reliance on experts and their opinions during risk assessments and this confirms the fact that there is no clearly agreed method for the assessment of risk across disciplines. If identification is part of the assessment of risk then there is no clear method for the identification of risks or hazards as the source of risk.

Risk management is important but there was no consensus on the approach taken by experts. Risks are prioritised for management based on significance and severity, cost and tolerance (Section 5.3.10). ERM is seen by risk professionals as important in facilitating the integration of a number of risk frameworks. The ISO31000 risk standard does not seem to have a positive profile as it is not seen as an adequate framework for the identification and management of risk this is evidenced by the fact that the health and safety expert did not think that it was adequate for the management of health and safety risk. There was a clear need for a method which was seen as more comprehensive in the applied identification and management of risk.

5.5 Summary

Although it is clear that both experts and risk professionals wish to identify the dimensions of interface, causation and accumulation, a method which identifies all these dimensions does not currently exist.

The research shows that:

- The dimensions of interface, causation and accumulation should be identified.
- Experts believe that the dimensions are useful in assessing new and unidentified risks.
- Evidence suggests that this does not currently occur.

The requirements of the proposed method based on the results of the initial research are:

- A method that facilitates the identification of hazards across the generic risks.
- The method should identify the dimensions of interface, causation and accumulation.
- These identified dimensions should be evidenced in the same repository and as the most frequently used media is a risk register method this is the chosen method of documenting hazards.

The results of the initial research from expert elicitation and the web survey identified a gap in knowledge for a robust and applied method of hazard identification which provides the foundation and framework for consistent and comprehensive risk identification. The gap between belief and actual evidenced identification is illustrated in Figure 5-7 which showed that respondents stated that they believed the current method of risk management was adequate for the management of new and emerging risks. Further evidence is required to investigate this gap. The carbon capture and storage value chain could provide a useful analogue to develop a method of identification of cross-discipline hazard identification using the dimensions of interface, causation and accumulation..

6 METHOD FOR HAZARD IDENTIFICATION AND DEVELOPMENT OF REGISTER

6.1 Introduction

A risk register was one of two preferred tools for the documentation of risk and the most widely used as expressed by responses from the web survey (Section 5.3.9). Currently risk registers accommodate linear documentation of hazards, so a format that facilitates multiple dimensions needs to be developed to fill this gap in knowledge (Section 5.3.9) and accommodate cross-disciplinary hazard identification. This chapter shows the process for the development of a method for cross-disciplinary hazard identification and how this is incorporated into a register method.

6.1.1 Requirements for a solution

The solution should accommodate the identification of the different dimensions of hazards and accommodate the fact that frequently a hazard may by itself be negligible but coupled with others may result in a significant impact (Ward and Chapman, 2003). These dimensions should consider the inclusion of chains of causation (Section 3.4.3), hazards that may result from the interface of two or more risk sources (Section 3.4.2) and portfolios of hazards that can result in an accumulation hazard (Section 3.4.4) (Ward, 1999; Ward and Chapman, 2003). The current method of compiling a risk register by documenting the identified hazards is linear, documenting only those hazards that can be quantified. Although conceptual thinking does not require quantification, the applied nature of compiling a risk register as evidenced in Section 3.5.3 and Table 3.2 has historically included some combination of quantitative metric in the form of probability, severity, frequency, impact or exposure. The requirement to include quantitative data may create a tendency towards identifying those hazards and risks which can be quantified. As a result it does not take account of all the available information on hazards and risks within the register (Allan and Yin, 2010). Additionally it does not facilitate the inclusion and synthesis of qualitative data which could be included in a register. The proposed method will focus on identification not quantification (Aven, 2012). The development of a multidimensional approach to hazard identification requires a risk register framework that is familiar to risk professionals (Patterson, 2002) and constructed to provide a systematic, auditable process capable of documenting different dimensions of hazard. This chapter concentrates on the development of a risk register method for the identification and documentation of the four dimensions of hazards.

6.2 Initial methodology for the register of hazards

The proposed method needs to identify cross-disciplinary hazards and present the results in a register. The dimensions of interface, causation and accumulation will be used to identify the systematic identification of cross discipline hazards. Prior to the identification of the new dimensions a register of generic hazards had to be developed which is required to formulate the generic register. This is the basic data for the identification of cross-disciplinary hazards. The stages involved in the development of the register of hazards are outlined in

Figure 6-1.

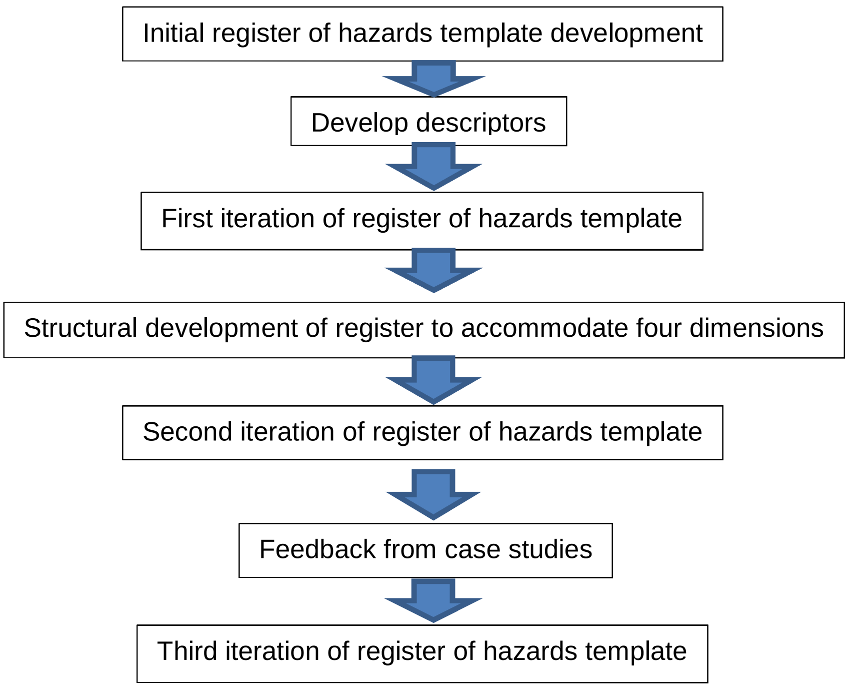

Figure 6-1 Stages of development for the register of hazards

The first iteration of the risk register involved obtaining a basic structure that could be applied to all dimensions. This required the identification of descriptors to ensure the correct information was collected. The pilot method was developed using the information from the CCS case study which is discussed in more detail in Chapter 7.

6.2.1 Development of descriptors

The initial risk register template had a linear structure which was developed using an Excel spread sheet with 21 column descriptors. The descriptors were formulated as a result of a review of seven risk registers and the identification of common descriptors highlighted in Section 3.4.3. The descriptors were categorised to obtain the following data: reference; component; lifecycle; classification; characterisation; mitigation; quantification; and dimensions. Details of the origin of the descriptors are provided in Table 6.1.

Table 6.1 Details of descriptors used in the initial register template

Aim of the descriptor	Descriptor	Details
Reference	Risk Identification number	Specific number which identifies a risk (Carter et al, 1995; Paterson, 2002)
	Risk classification	Risk classification from original data
	Reference	Reference from the literature
Component	Module option	Business unit/ facility name (Whipple and Pitblado, 2010).
Lifecycle	Phase of lifecycle	Requires identification of the different stages of the lifecycle and subsequent assignment of a risk/ hazard to the stage of the lifecycle that it relates to.
Classification	Generic risk classification	Event type , safety, environment (Whipple and Pitblado, 2010)
	Risk category	Sub category of risk classification
	Risk type	Sub category of risk category
	Risk sub category	Sub category of risk type
Characterisation	Source	Source of the risk which cause and trigger an event (Whipple and Pitblado, 2010 Ward, 1999; Cox, 2007).
	Description	Description of the risk and its context (Allan and Yin, 2010, Ward,1999)
	Hazard identification	Identification of the hazard that makes it a risk (Whipple and Pitblado, 2010). The data includes a hazard description.
Mitigation	Method of risk mitigation	Method of risk management used to mitigate this risk (Carter et al 1995; Willams, 1994; Paterson, 2002). avoid, modify, transfer or accept ISO31100, 2007
Quantification	Residual risk	The risk that remains after mitigation and management (BS ISO31000, 2009 ; Ward, 1999; ISO31100, 2007)
	Risk threshold	Level of risk above which and organization is not prepared to accept, tolerate or be exposed. Data not available and not required for hazard identification
	Probability	Likelihood of occurrence (Kaplan and Garrick 1981; Willams, 1996)
	Impact	Cost of risk, damage, harm etc. (Jaafari, 2001; Willams 1994) result or effect of an event (ISO31100, 2007)
	Expected value	Probability x impact or consequence (Zhao, 2005; Aven, 2012).
Dimensions	Interface	Hazard at the interface arise when two or more generic risks occur and result in an additional risk not captured by either of the generic risk management frameworks (see Section 3.4.2).
	Causation	This hazard derives from one hazard causing another generic risk, (See Section 3.4.3).
	Accumulation	This type of hazard occurs from the culmination of a number of risks crystallizing at the same time (See Section 3.4.4).

The practical application of some of the descriptors requires further explanation as to why they are required and this is provided in the following sections.

6.2.1.1 Reference

- Risk identification number (Risk ID)

It was important that the individual risks were allocated a unique number as this was used throughout the application of the method to identify the hazard dimensions and maintain an audit trail. Where the data relates to a hazard it will be a known by its hazard Identification number (Hazard ID).

- References

These are the references for the origin of the characterisation data in the literature for the risk. This data will commence the audit trail. For the initial register the data was obtained from a mixture of published data from journals, books, and grey documents.

6.2.1.2 Components

This referred to the specific module in the process for which the data related. In the initial register this was the transportation module of CCS by pipeline.

6.2.1.3 Phase of lifecycle

This method proposes to have risks which are lifecycle specific. This requires identification of the phases of the lifecycle that are appropriate for the; event, project, process or entity. The stages may be defined time periods such as short, medium and long term; they could also be actual time periods if this information is available. The rationale for including the phases of the lifecycle is that a hazard may change during the lifecycle and anticipating this change will facilitate the identification of hazards in the transition of the lifecycle. The lifecycle phases which were used in the initial CCS transportation register were, concept development, pre-commissioning, construction, pre operational, operational, mothballing and decommissioning and “all”.

6.2.1.4 Classification

The characterisation of hazards needs to be comprehensive, correct and precise. As a result hierarchical classification has been incorporated into the model and includes the generic risk classification, risk category, and risk type. A diagrammatic representation of this hierarchical characterisation is illustrated in

Figure 6-2.

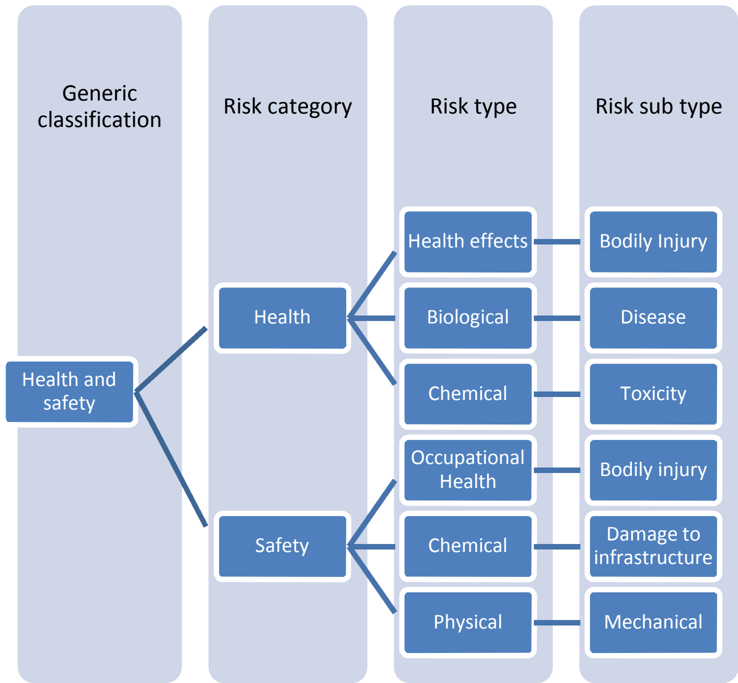

Figure 6-2 Diagrammatic representation of hierarchical characterisation for the generic health and safety risk

The generic risk in the example in Figure 6-2 is health and safety. Health and safety is the result of two risk categories, health and secondly safety. Health is concerned with the wellbeing of an employee and safety with the protection of the employee. As a result health risk types include health effects which include a number of different effects one of which is bodily injury. The purpose of the hierarchical risk classification is to be as precise as possible with the hazard that is being identified. The classification applies to all generic risks and requires sufficient knowledge of the generic to be completed accurately.

- **Generic risk classification**

The initial classification of risks commenced with a sample portfolio of generic risks which would be included at all stages of the value chain and lifecycle. The proposed sample portfolio included the following generic risk classifications: health and safety; environmental; financial; economic and technical.

- **Risk category**

The individual generic risk classification is broken down into risk categories identified from analysis of the processes, respective risk frameworks and corresponding literature search.

- **Risk type**

Each of the risk classes had their own specific group of risk categories, and each risk category has a number of risk types as outlined in Figure 6-2. For some risks it may be necessary to have an additional sub risk type.

6.2.1.5 Characterisation

Hazard descriptors are the section of the register that provides details of the attributes of the hazard and included the source of the risk, description and hazard identification.

- **Source**

This descriptor requires details of the source of the risk.

- **Description**

This description refers to the risk. It requires qualitative details as to the construction of the risk, the damage caused, the harm or loss.

- **Hazard identification**

This descriptor was used to obtain a response to the question; what is the potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation?

6.2.1.6 Mitigation

The reason for including risk mitigation was that, if this data was available, it would highlight new hazards by identifying hazards that could not be mitigated with the current resources.

6.2.1.7 Quantification

As well as the descriptors outlined in the previous section the original register template included sections which required quantitative data on the residual risk, impact, risk threshold, probability and expected value of the risk. This information is usually specific to a project or organisation and is difficult to obtain for emerging technologies as it is proprietary information which is not publically available.

6.2.1.8 Dimensions

Following the traditional linear approach to risk registers the additional dimensions were accommodated by adding separate columns for each of the dimensions. The register collected information for the individual generic risks on separate spread sheets. The initial template of the generic register was tested by populating with data from the transportation module of CCS using references from literature on the transportation of CO_2 by pipeline. Main issues with the initial template

The main issues with the initial template (Appendix E) were (1) the quality of the data, (2) the structure of the register and (3) the relevance of the descriptors.

6.2.1.9 Data quality

At the time of collecting data from published literature to populate the register there was a lack of credible quantitative data and when revisited this data was not publically available until December 2011. Additionally methods of mitigation for CCS pipelines were in the process of development and this data was held by National Grid Plc and not publically so this descriptor was excluded from the proposed register. The fact that CCS technology was emerging meant that there was a lack of robust published literature and it was not possible to complete all the descriptors from one source for one hazard. This meant verification and validation of the individual hazards was not possible and a number of column descriptors were excluded (Table 6.2).

Table 6.2 Rationale for inclusion and exclusion of the 21 column descriptors in the initial register template

NO	Column descriptor	Reason for inclusion	Reason for exclusion
1	Risk ID No	Identification and audit trail	
2	Risk classification		
3	Reference		
4	Module option	Component part	
5	Phase of lifecycle	Allocation to stage of lifecycle	
6	Generic risk classification	Classification	
7	Risk category		
8	Risk type		
9	Risk sub category		
10	Source		Confusion over the difference with hazard identification resulting in errors.
11	Description	Characterisation	
12	Hazard identification		
13	Method of risk mitigation		Risk mitigation requires hazard identification therefore it is not part of the identification
14	Residual risk		Quantification not identification
15	Risk threshold		
16	Probability		
17	Impact		
18	Expected value		
19	Interface		Does not allow characterisation or accommodation of attributes
20	Causation		
21	Accumulation		

6.2.1.10 Descriptors

The quantitative data did not support the identification of hazards as the identification of the hazards came prior to quantification and so was not relevant to this research project. The method of mitigation was also not relevant to the identification of hazards as the hazard needed to be identified prior to the application of appropriate mitigation. The source identification in the context of safety is called hazard identification (PD ISO IEC, 2002); having a descriptor for source and hazard identification caused confusion and duplication in cross discipline application and as a result the source descriptor was removed.

The characterisation of the component risks and the resulting relationship were not adequately accommodated in the initial format. It became clear that this was an essential part of the context of the hazard and so this descriptor was added by making the module option specific to the project or process. The descriptors that were taken forward to the next stage of register development are highlighted in Table 6.2.

6.2.1.11 Generic classification

The initial generic risk classifications of health and safety, environmental, financial, economic and technical were amended to include regulatory and societal. Regulatory risk was added as legal risk did not include compliance and the implication of changing regulations in an evolving regulatory landscape. The previous list of risk classifications did not accommodate risks such as reputation and societal impacts and so societal classification was included. Financial risk was removed and included in the economic risk. The generic classifications used in this research are defined below.

Regulatory

Regulatory risks are the result of harm caused by non-compliance with existing regulations, or potential changes in regulations. A regulatory risk can result from the way that regulations are implemented by the regulator (process of regulation) or uncertainty as to which regulator or regulations will be applied to a specific situation.

Legal

A legal hazard includes; the non-performance of a contract or warranty, legal liability resulting from a duty of care, negligence, misrepresentation, strict liability or fraud. Legal risk results from a hazard emanating from a legal source. If there is no legal source a legal risk is absent (Mahler, 2007). Legal risk is the exposure to legal action, liability, fines or other legal remedies that result from the uncertainty of application, changes in laws, directives and the unknown outcome of legal proceedings (Section 2. 4.4).

Environmental

Environmental hazards include: land degradation, deforestation, desertification, wild land fires, and loss of biodiversity, land, water and air pollution, climate change, sea level rise and ozone depletion. Environmental risks are a source of harm to media such as: air, land, water, flora, fauna and humans (Section 2.4.1).

Health and safety

Health and safety hazards include the following: biological, ergonomic, chemical, physical, psychosocial, slipping/tripping hazards, inappropriate machine guarding, equipment malfunctions or breakdowns, adverse health effects. Health risks are concerned with impact on the health and wellbeing of an individual and would result in disease and adverse health effects. Safety risks are those risks which arise from lack of precautions and can result in injury. The Health and Safety at Work Act 1974 states the aim is to secure the health and safety of employees by protecting at work.

Economic

Economic hazards impact the economic process and include the distribution of factors of production, and consumption (goods and services). The economic process includes members of the population and firms who carryout economic activities producing productive resources in return for wages, interest, profits and rent used to consume goods and services. Economic risks also arise from the calibration of markets and fiscal policy via supply, demand, inflation, exchange rates, taxation and pricing. Business and financial risks are taken as a subset of economic risks.

Societal

Societal hazards occur as a result of negative exposure to trends in norms, mores, culture, behaviour, perception, attitudes and demographics. Social factors may influence demand for a company's products and the structure of its business model. For example, negative impacts to a brands reputation may result from a pollution incident such as Union Carbide in Bhopal 1984 (Power et al., 2009).

Technical

Technical hazards originate from processes and components of manmade infrastructure, or products which include mechanical, chemical, technological and engineering impacts which cause harm (Section 2.4.5).

6.2.1.12 Structure of the register

The register included individual columns on the same spread sheet for each dimension with the intention of documenting the different dimensions. This linear approach did not accommodate the classification or characteristics of the dimensions. The requirement to be able to document the dimensions was physically impossible in the registers linear format, as:

- It was not possible to show the risks that were interconnected on the same spread sheet and thus the requirement for an audit trail was not possible.
- It was impossible to include the characteristics for the interface, causation or accumulation dimensions within their individual columns. It became clear that the dimensions had to have register structures that captured their specific attributes as well as the original base data.

The development of the initial register structure provided confirmation of why respondent to the web survey have stated that they identify these dimensions and are included in repositories other than a register (see Section 5.3.9).

The production of the initial register confirmed that identification of hazards did not require the descriptors for mitigation and quantification as you needed to know what you were quantifying before you were able to quantify it and the same is true of mitigation. The initial register did not meet the criteria of a comprehensive, clear, precise and auditable characterisation of hazards which supported identification. The result of this exercise proved that the focus of this research should be on dimension led registers with descriptors that facilitated identification.

The resulting generic register structure remained with ten risk descriptors focused on characterising hazards using hazard related risk register data. This included: the risk ID number, reference, phases of lifecycle, component, risk classification, risk category, risk type, risk description and hazard identification as defined in Section 6.2.1. This register structure was the basis for the development of the additional dimensions of hazard not just for the documentation of hazards in a register but for the development of the method of identification. As a result the development of the register and the method of dimension identification were developed jointly.

6.3 Multidimensional hazard identification method development

6.3.1 Stages of developing the hazard identification method

The development of the method is the result of an intertwining and iterative process between the hazard identification method development and the evolution of the register documentation from

Figure 6-1 to Figure 6-2.

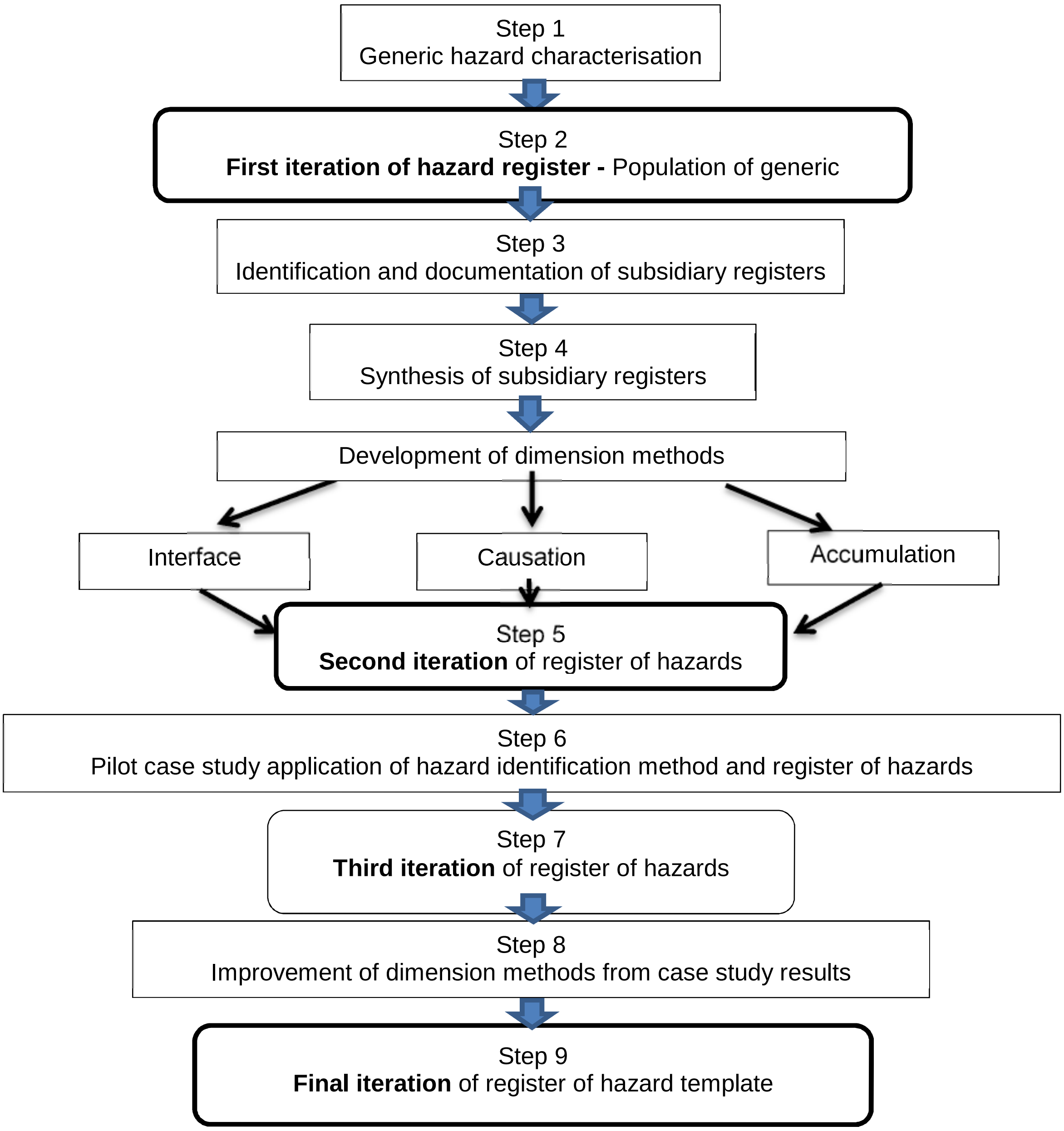

Figure 6-3 Hazard Identification method developments and the integration of the register of hazard development

6.3.2 Generic hazard classification and register of hazards

The Generic register of hazards sets the standard for the minimum level of information required for the characterisation of hazards within the dimensions of interface, causation and accumulation. To obtain the generic register of hazards an existing risk register was reviewed and the individual risks were classified according to the generic risk classifications in Section 6.2.1.4. The register template was then populated with the data which corresponds to the ten descriptors: hazard ID, risk reference chain component, phase of lifecycle, classification and characterisation. Table 6.2 shows a section of a generic register of hazard for a CCS project using the risk register template. For each risk there is a unique number, reference, and chain component, applicable phase of lifecycle, classification and characterisation.

Table 6.3 Template for the generic register of hazards

			PHASE OF LIFECYCLE									
RISK ID Number	Reference	Chain Component	FEED	Construction	Commissioning and proving	Operations	Decommissioning	Post closure	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK DESCRIPTION	HAZARD IDENTIFICATION

6.3.3 Engineering of register of hazards template

The development of the hazard identification method and the documentation of identification results were intertwined. This section is structured to provide details of the tasks required to identify the hazards and to document them in the register. Each dimension has its own specific idiosyncrasies and these are accommodated in their respective sections.

The draft registers were developed firs,t but it became clear that it would be the method of identification that would drive the structure of the register for each dimension. The dimensions were developed in the following order; interface, causation and accumulation because it was assumed that the interface dimension would be the most challenging to produce an auditable method. This was due to the need to document two separate hazards and their attributes.

6.3.4 Production of the subsidiary register

The original register of hazards categorised the phase of lifecycle and the module, location, business unit or process (Appendix E). Each phase of the lifecycle was used to create a separate subsidiary register. This was achieved by filtering the respective column in the Excel spreadsheet by the respective phase of the lifecycle. The rationale for producing subsidiary registers was that it was necessary to identify hazards that were in the same stage of the lifecycle. The result was a complete set of hazards for each stage of the lifecycle. A matrix (illustrated in Table 6.4) is completed so that each subsidiary register is easily identifiable. This provides context for the hazards and facilitates visualising potential realistic dependency and interconnection not possible to ascertain from an arbitrary list of hazards. The result is a matrix of hazards compiled by lifecycle.

Table 6.4 Template for matrix of subsidiary registers filtered by lifecycle

Subsidiary register reference	Phase of lifecycle	Module of process
A.		
B.		
C.		
D.		
E.		

Once the subsidiary registers are produced the number of hazards per generic classification for each subsidiary register was calculated. The inclusion of the total number of hazards allowed cross checking of the number of hazards in the register and further analysis of the dimensions. Where there are no details on the phases of the lifecycle then the register provided details for one phase. Each hazard from the initial subsidiary register was matched with another in the same subsidiary register.

6.4 Development of dimension identification methods

6.4.1 Interface hazard identification

The initial interface dimension was tested using couplings of risks. A coupling is defined as the method of creating a cross-disciplinary pairing of two risks from different generic classifications but from the same stage of the lifecycle. The initial method for the production of the interface dimension involved listing all the individual risks by generic risk and risk classification and then numbering them consecutively. A random number generator was then applied to pick the two risks which would result in a coupling. Although the risks were chosen objectively the result was not a portfolio of all the couplings. In fact the random number generators had a tendency to pick the same risk IDs. This undermined the fact that the register was a complete list of real identified risks for which all the risks should result in a coupling. This approach did not create an improved position as it did not use all the identified risks in the generic register or produce all coupling combinations.

Interface hazard identification method

As using a random number generator did not provide couplings for all the identified hazards in the original register it was decided that a method would be developed which produced couplings of all the hazards in the original risk register. The objective of interface hazard identification was to produce a register of hazards where two risks occur simultaneously and together result in an additional hazard. The interface portfolio of hazards was the result of all possible coupling combinations from the generic register subject to conditions:

1. Risks from the same generic group were not included in the register of interface hazards as it was assumed that the chance of more than

one generic risk occurring would have been explored within the generic risk identification framework. This may not be the case but the objective of this research project is to look at cross-disciplinary hazards not the relationship of hazards within a generic risk classification.

2. Each risk was categorised using a uniform approach to classification and characterisation. The approach to classification was generic hazard and project specific. For example the technical hazards for a landfill would be different to the technical hazards for an offshore oilfield.
3. A hierarchy for classification of the relevant generic hazards was developed by reviewing the individual risks in the register and from an understanding of the context of each project gained from experts, literature such as project specific reports and risk assessments. With respect to characterisation the risk reports and registers provide hazard specific characterisation.
4. The resulting risks were then grouped into subsidiary risk registers which related to the specific phase of lifecycle. The individual risks within each subsidiary register were grouped into their generic risk families. Within each subsidiary risk register a risk from one generic family was coupled with a risk from a different generic family. An example of this is shown in Figure 6-4.

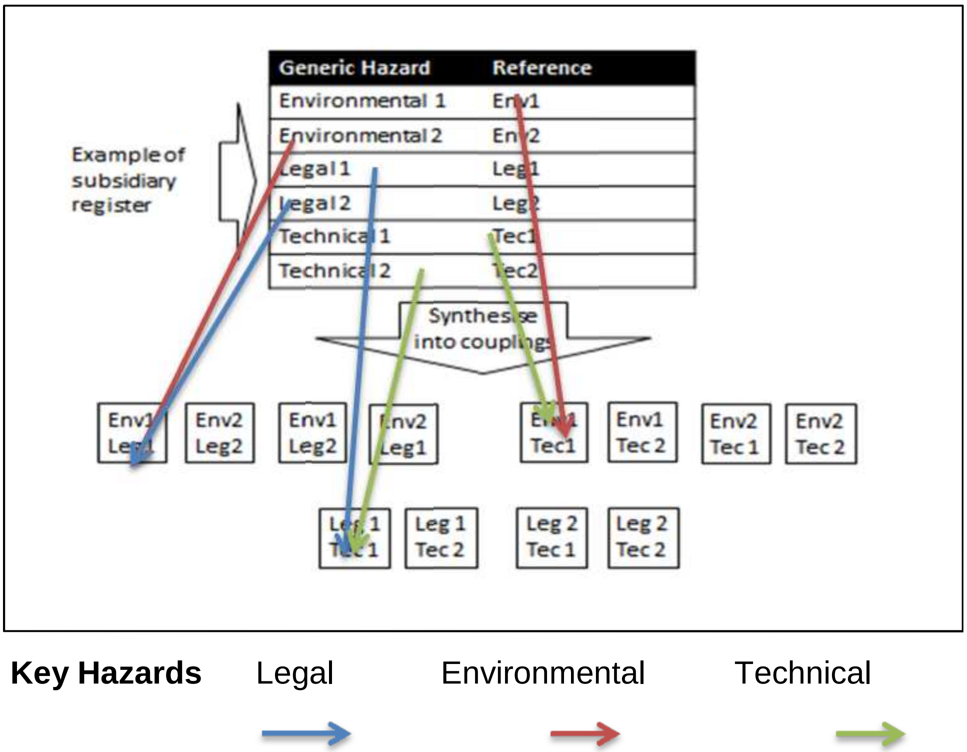

Figure 6-4 Example of the couplings that result from a subsidiary register comprised of two generic hazards from each of three generic risk classification environmental, legal and technical

5. The couplings were assigned a unique interface identification number (interface ID No) which made it possible to identify the phase of the lifecycle /subsidiary register that the hazard was derived as illustrated in Figure 6-5.

Figure 6-5 An example of a matrix showing the total number of interface hazards for each subsidiary register and the allocation of unique hazard identification numbers

Subsidiary register	Number assigned		Number of Hazards
	Start	**End**	
Design A	10	19	10
Construction B	20	49	30
Operational C	50	59	10
Closure D	60	100	41
Total number of risks			**91**

The resulting interface hazards were characterised, identified and documented in the respective dimension of the register. The resulting hazard couplings for each subsidiary register were amalgamated into a master register of interface hazards. The list of couplings was verified by an expert who has knowledge of the initial risk register.

Development of a register template for interface hazards

The unique requirement of the interface hazard identification methodology is that it requires the register to show the hazards that are coupled together. It also needs to be flexible enough to accommodate groups of more than two hazards.

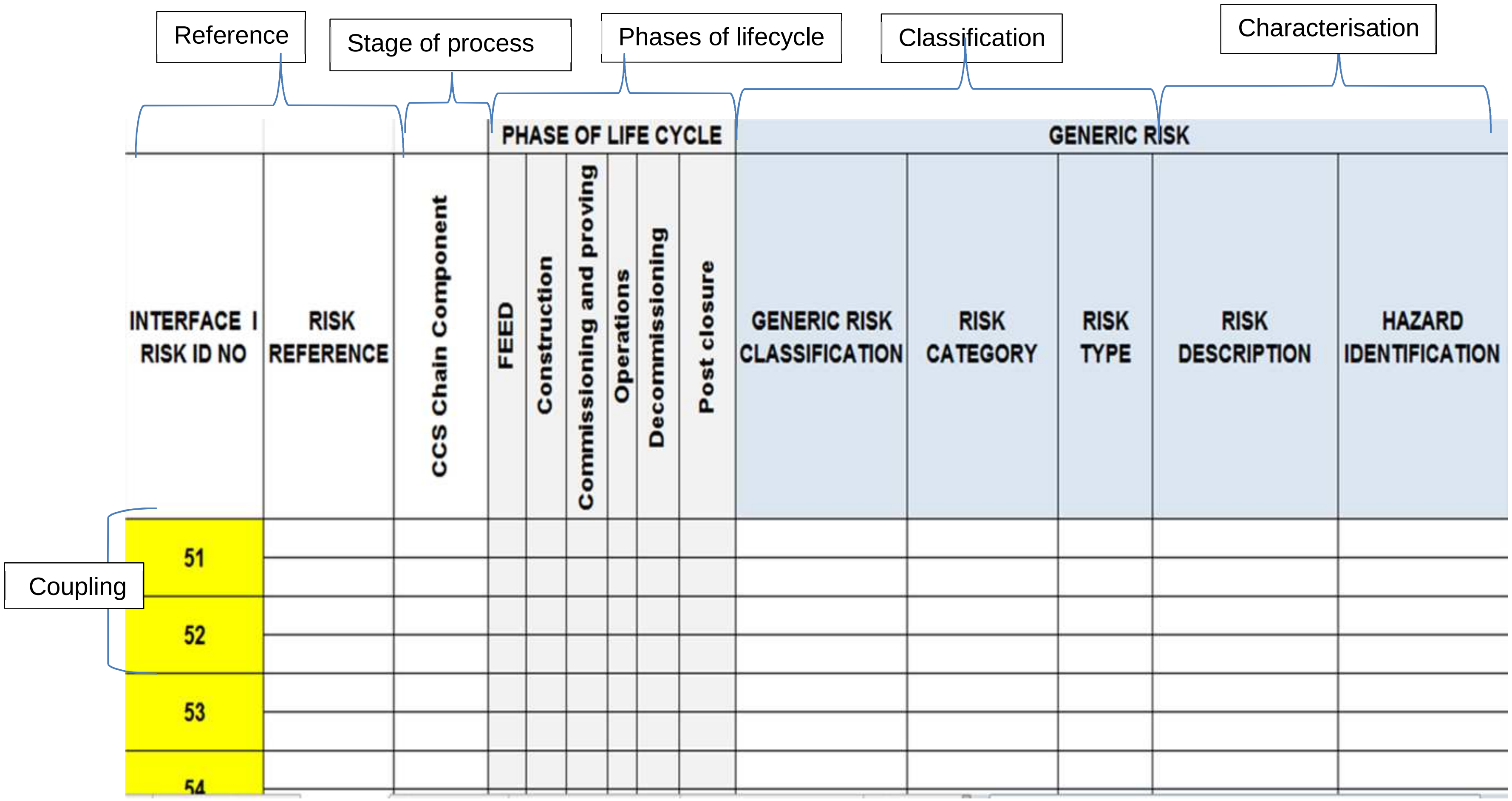

Figure 6-6 Example of register structure for interface hazards

The allocation of the interface ID No provides a specific reference for the interface hazard that result from the grouping of the original generic risks.

Figure 6-6 shows a template for the presentation of interface hazards in a register. The resulting couplings are characterised from the initial risks. The output needs to be verified as possible and applicable by an expert of the system for which the register has been provided.

6.4.2 Causation hazard identification

The line of causation was developed by establishing if one hazard triggers a subsequent hazard. This is an iterative process and can continue until the project is terminated, the entity is no longer a going concern or no further potential hazard could be triggered. There are two types of causation hazards which need to be tested by application to the case study data they include:

6.4.2.1 Option 1 Causation within a stage of the lifecycle

This option takes each of the subsidiary registers as described in Section 6.3.4 and establishes whether there is a line of causation for each hazard in the respective stage of the lifecycle. For each subsidiary register the results were reviewed taking into account the stage of the lifecycle, placing the hazards in context and stating the next progression of hazard if applicable. Taking the prior hazard I tried to establish if this initial hazard could trigger or result in a subsequent hazard. This iterative process was continued until the outcome was termination or an acceptable outcome for the continuance of the project under normal conditions.

6.4.2.2 Option 2 Cross lifecycle causation

Additional lines of causation are hazards that occur across all phases of the lifecycle. These hazards were compiled by applying the same criteria as in Option 1 (Section 6.4.2). The resulting chain of causation was compared with the outcome of the generic list of hazards to establish if these hazards were identified. If not they should be included in the register of causation hazards.

When reviewing the hazards for all options any hazards that would immediately result in the termination of the project should be removed but highlighted as having a negative impact on the viability of the project. For all the options the results were compared with the generic table to establish if the context makes a difference to the line of causation and the resulting feasible portfolio of causation hazards. The final stage of the methodology required the provision of a comprehensive list of causation hazards that included the output of the three different means of obtaining lines of causation and removal of any duplication that was highlighted in the comparison.

6.4.2.3 Development of a register template for causation hazards

The causation register required the user to review the originating hazard and establish the subsequent hazard it triggers. As a result the register needed to have a number of columns to accommodate the subsequent hazards. Table 6.5 shows the addition of column descriptors for each subsequent hazard. This structure shows the base data from the original register and the resulting chain of causation.

Table 6.5 Example of a register for causation hazards

Generic register										Initial hazard	Chain of causation					
			PHASE OF LIFE CYCLE			GENERIC RISK (RISK 1)					CAUSATION					
RISK ID NO	SCOTTISH POWER DECC REFERENCES	CCS Chain Component	1	2	3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION	HAZARD 2	HAZARD 3	HAZARD 4	HAZARD 5	HAZARD 6	COMMENTS

6.4.3 Accumulation hazard Identification

Accumulation hazards result from a number of hazards occurring in a short period of time and whose cumulative impact is significant. The differentiating attribute is that the hazard is a portfolio, not an individual hazard. The result is the identification of a variety of feasible accumulation hazard portfolios. This method introduces three types of accumulation hazard portfolios:

6.4.3.1 Type 1 lifecycle portfolio

The subsidiary registers are a portfolio of identified hazards for an entire stage of a lifecycle and thus provide a list of the worst case scenario, should all these hazards occur simultaneously.

6.4.3.2 Type 2 transversal portfolio

The transversal portfolio includes hazards which occur across all the phases of the lifecycle. They are identified by filtering the generic register by lifecycle to establish those risks that occur across all phases of the lifecycle. This results in a transversal portfolio.

6.4.3.3 Type 3 component portfolio

This portfolio includes hazards which occur within one component process or business unit. This third option is concerned with the concentration of hazards in a specific operation. Filtering by the component, process or business unit provides the potential portfolio for the specific component.

These options require a review to establish if the individual compilations are feasible and provide reasons why individual hazards or compilations should be excluded. This will be investigated when the method is applied to the case study data.

6.4.3.4 Development of register template for accumulation hazards

The accumulation hazard register needs to accommodate options that examine the data in a number of ways and cannot be easily presented in one worksheet as one accumulation hazard is comprised of a set of multiple hazards. It is important to present all the data so that context can be taken into account. As a result data for accumulation hazards include subsidiary registers as each individual register is an accumulation hazard. The format for this option is the same as the generic characterisation but a portfolio of hazards. Option two is displayed in a separate worksheet showing all the hazards that traverse all phases of the lifecycle. Option three is displayed in a separate worksheet showing the potential concentration of hazards in one part of a process. As a result the inclusion of accumulation hazard identification includes a number of accumulation portfolios all presented in individual spread sheets. The number of accumulation hazards is a function of the number of phases of the lifecycle plus the transversal portfolio and the number of components.

6.5 Second iteration of register of hazards

The development of the generic register to accommodate the four dimensions alongside the development of the hazard identification methodology for each dimension resulted in a second iteration of the register of hazards. The register evolved from a single master register of hazards to a family of subsidiary registers which facilitate the respective methods of identification to provide a working document for the synthesis and further analysis of hazard identification. The second iteration of the register and the methodology for the identification of multidimensional hazards was tested by application of the method to real data.

6.5.1 Testing the development of the risk register methodology

The method for the identification and documentation of the hazard dimensions of generic, interface, causation and accumulation was tested by application to a Pilot case study (Step 6) using the data from “First United Kingdom’s CCS Demonstration Competition FEED Close out report” (see Chapter 7). The method was subsequently applied to a closed landfill without a risk register (Chapter 8) and to the data in climate change adaptation risk assessment for a utility company (Chapter 9).

6.6 Chapter summary

This chapter provided an outline of a method for the identification and documentation of cross discipline hazards by application of the multiple dimensions of interface, causation and accumulation. The next stage of development is outlined in Figure 6-7.

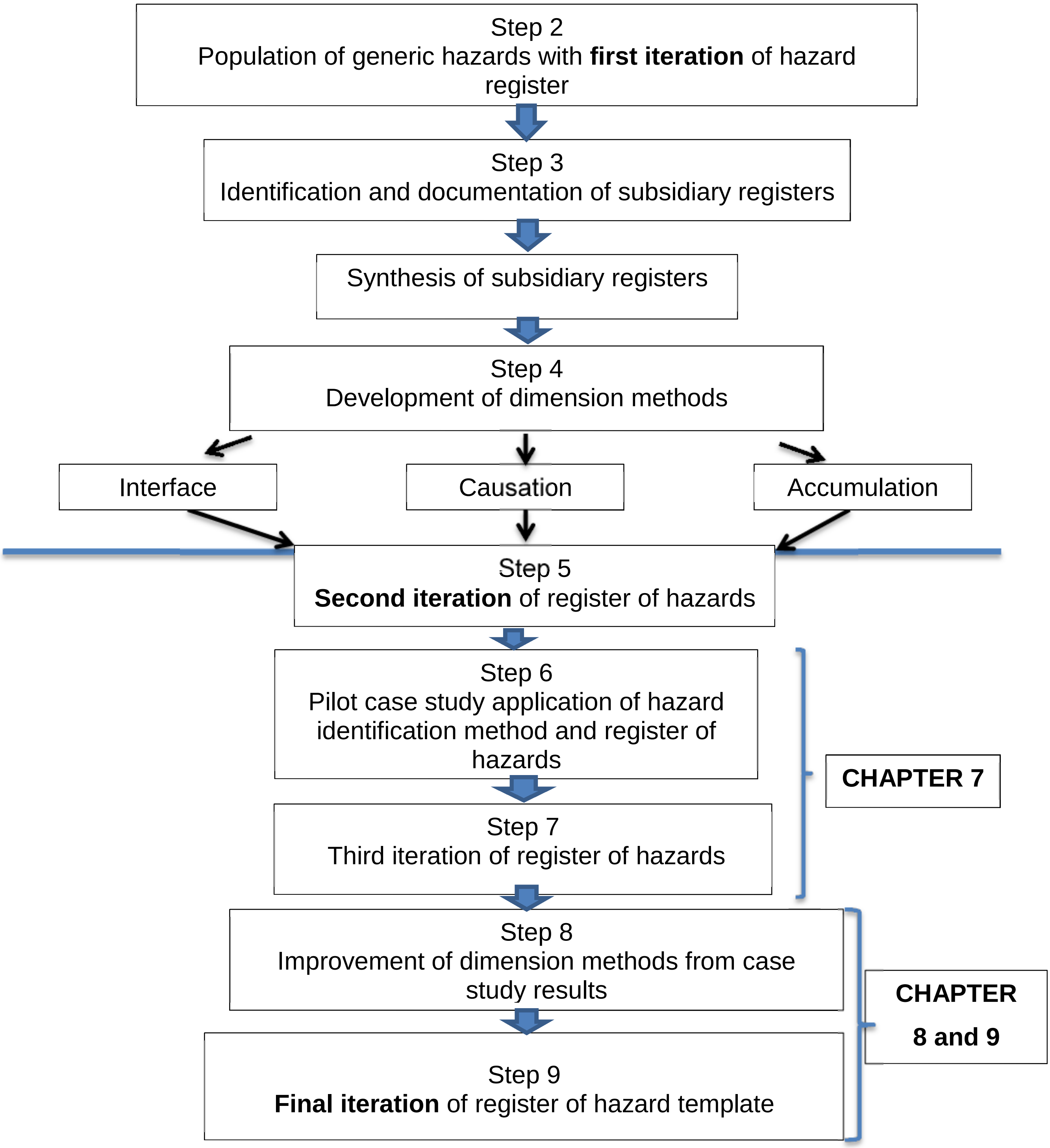

Figure 6-7 Progression of results from validation of hazard identification and register from step 6 to step 9

7 PILOT CASE STUDY - CARBON CAPTURE AND STORAGE

7.1 Introduction

This chapter presents the results of applying the cross-disciplinary multidimensional hazard identification model outlined in Chapter 6 to one of the two front end engineering design studies (FEED) for CCS.

Carbon capture and storage (CCS) is regarded as the most practical option to reduce greenhouse gases (GHG) (Yu et al., 2008: Davison and Thambimuthu, 2009). CCS is a bridging technology which for the purpose of this research includes the capture of carbon dioxide (CO_2) from industrial installations and transportation to a suitable geological formation for permanent storage (EU Directive 2009/31/EC). This method of CCS is known as geologically engineered CCS. The main technologies used for the engineered capture of CO_2 are: post-combustion, pre-combustion and oxy-fuel combustion (Haszeldine et al., 2009).

The FEED studies are the result of a competition launched in 2007 by the UK Government to demonstrate full-scale CCS power generation in the UK using post combustion technology. A major power generation company responded to the competition by forming a consortium which will be known as XP which included; an oil company (Oil Co), an energy distribution company (Distribution Co) and a power generation company (Power Co). The project included both onshore (land) and offshore (marine) activities and each consortium member had expertise aligned to specific modules of the CCS value chain, this is illustrated diagrammatically in Figure 7-1

Module	Capture	Transportation	Storage
Location	Onshore	Onshore / Offshore	Offshore
Consortium Risk ownership	Power generation (Power Co)	Energy distribution (Distribution Co)	Oil company (Oil Co)

Figure 7-1 The location and allocation of risk for each module of the CCS value chain by member of the consortium

The XP consortium included the generation of electricity from an existing coal-fired power station off the coast of Scotland which will be upgraded and retro fitted with abatement technologies. The Distribution Co were responsible for the transportation of CO_2 from the power station which requires construction of two new sections of pipeline, (1) modification of existing pipeline (known as Feeder 10) so it is compatible with the transportation of CO_2 and (2) the construction of a new compressor station at Blackhill near to the St Fergus Terminal. Oil Co.'s responsibility is to transfer CO_2 from the Distribution Co pipeline to permanent containment in the subsurface environment. This involves confirming that the available storage capacity is a minimum 20 million tonnes of CO_2 and that this capacity is capable of safe storage (DECC, 2011).

7.2 The issue

Stenhouse et al., (2009) highlighted the need for factors other than safety to be considered in risk assessments and Gerstenberger et al., (2009) identified that risk assessment for CCS should extend beyond the primary containment and address a wide range of economic, social, political and engineering issues. Both Stenhouse and Gerstenberger refer to risks and their assessment but neither comment on the identification of hazards. Gerstenberger et al. (2009) proposed a novel method of risk assessment using modularised logic trees. The method relies on expert elicitation at each stage of the risk assessment process and its intentions are: identification of risk variables; identification of additional research to reduce risk variables; uncertainty; and assignment of probabilities to risk variables (Gerstenberger et al., 2009). The focus was on already identified and known exposures not on the identification of unidentified hazards or cross discipline exposures. Gerstenberger et al. (2009) introduced five dimensions which were then applied to the modules of the CCS value chain. The conclusion of the modularised approach does not reduce uncertainty but may highlight unacceptable risk issues which need to be addressed. Aarnes et al. (2009) suggests the use of experts to identify and rank hazards using the DNV Structured What-if Technique (SWIFT). Wilday et al. (2011) have developed a new tool for the identification of hazards using CCS as an emerging technology.

The tool includes the time dimension, a lifecycle approach to risk management and communication which is stated as having application to generic emerging risks. The proposed inclusion of time introduces three dimensions; severity, frequency and probability (Farret et al., 2010).

Wilday et al, (2011) also suggest the use of Dynamic Procedure for Atypical Scenarios Identification (DyPASI). DyPASI hazard identification involves five steps which focus on the collection of data for the individual parts of the process and equipment. For each part of the equipment the critical event is identified and fault trees and event trees are built. The analysis of these fault and event trees result in bow-ties. In each case the approach is to look at the critical event and thus follow a top down approach to hazard identification. This approach is part of the solution to hazard identification as it only works for known or pre-identified critical events. It is not proactive in identifying unidentified critical events which may arise from non-technical hazards or cross discipline hazards.

7.3 Method

The main objective of applying the method for the identification of multidimensional hazards to the risk register for a CCS project is to establish if applying the method outlined in Section 6.3 to the initial XP risk register results in the identification of the dimensions: interface, causation and accumulation. The second objective is to establish whether the identified dimensions can be evidenced in a register. Any variations to the method are documented in this chapter at the appropriate stage.

7.3.1 Generic register

The data was provided by the Department of Energy and Climate Change (DECC) United Kingdom's CCS Demonstration Competition Front End Engineering Design (FEED) Close out report for XP. The XP report contained a risk register, reports on risk and the context of the proposed CCS demonstration project. The full register compiled by XP for DECC in the post feed report was cross checked with information in the report. Although both contained the same risks, they differed in the priority allocated to the individual risks within the following ranges 23-25, 33-38 and 40-42. This research is not concerned with the prioritisation of the risks but with the identification of risk. This research project used the list in the report as this was the most up-to-date list. A list of the top 50 risks is presented in Table 7.1 (DECC, 2011).

It has been assumed that because the information was supplied as part of a request from the UK Government and the risks reviewed and evaluated by the three parties to the consortium as well as various regulatory bodies it is the results to a robust risk pool.

Table 7.1 XP consortium post FEED top 50 risks for the first UKCCS competition showing the ranking and location of components (DECC, 2011)[2]

Register ranking	Report Ranking No	Risk description	Onshore/ Offshore/ Whole system
	1	Key project onshore construction consents not obtained to programme - to be managed by third parties outside the Consortium	**Onshore**
	2	Key project onshore operational consents not obtained to programme- to be managed by third parties outside the Consortium	**Onshore**
	3	Key project onshore construction consents not obtained to programme- to be managed by the Consortium	**Onshore**
	4	Offshore decommissioning and post-closure consent uncertainties.	**Offshore**
	5	Offshore construction and operation consent uncertainties.	**Offshore**
	6	Project team disbanded due to significant gap between FEED and contract award.	**Whole system**
	7	Key project onshore operational consents not obtained to programme - to be managed by the Consortium	**Onshore**
	8	Complications due to scaling-up CCS technology.	**Whole system**
	9	Adverse public reaction to CCS.	**Whole system**
	10	Operations staff unfamiliar with CO_2.	**Whole system**
	11	Offshore system sensitive to variable flow rates.	**Offshore**
	12	Offshore construction and operation risks.	**Offshore**

[2] Adapted from the XP Outline solution top 50 risks

Register ranking	Report Ranking No	Risk description	Onshore/ Offshore/ Whole system
	13	Macroeconomic volatilities impacting project economics.	**Whole system**
	14	CCS levy fails to be adopted.	**Whole system**
	15	Uncertainties with mine workings along the new onshore pipeline route.	**Onshore**
	16	Integrity of existing offshore equipment found to be poor.	**Offshore**
	17	Migration of CO_2 from the storage site	**Offshore**
	18	Other construction works at power station impact on CCS programme.	**Onshore**
	19	Items of novel plant have shorter life than predicted.	**Onshore**
	20	Failure to agree offshore asset transfer terms.	**Offshore**
	21	Archaeological finds along new onshore pipeline route.	**Onshore**
	22	Unit supplying flue gases to Carbon capture plant (CCP) not operating at required load factor.	**Onshore**
24	23	Low CCP operating efficiency due to flexible power plant operation.	**Whole system**
25	24	Inability to agree flue gas composition specification.	**Whole system**
23	25	Problems encountered during River Forth pipeline crossing.	**Onshore**
	26	Disruption on online assets during disconnection of onshore pipeline.	**Onshore**
	27	Changes to proposed new pipeline crossing methodologies.	**Onshore**
	28	Damage to onshore pipeline system due to transportation of CO_2.	**Onshore**
	29	Industrial disputes and relationship issues.	**Onshore**
	30	Further ground contamination at proposed CCP site.	**Onshore**
	31	Uncertainty in the level of change instigated by stakeholders.	**Whole system**
	32	Depressurisation of CO_2 cause low temperature embrittlement of onshore plant.	**Onshore**
34	33	Third Party Access to CCS infrastructure is required.	**Whole system**
35	34	Insufficient suitably qualified and experienced resources to deliver CCS project.	**Whole system**
38	35	Two-shift operation introduced at the power station.	**Onshore**
33	36	Construction risks with unidentified adverse ground conditions along pipeline route.	**Onshore**
36	37	Further intrusive civil works required along onshore pipeline route.	**Onshore**

Register ranking	Report Ranking No	Risk description	Onshore/ Offshore/ Whole system
	38	Further ground contamination along CO_2 pipeline route (power station boundaries).	**Onshore**
	39	Further ground contamination along CO_2 pipeline route.	**Onshore**
42	40	Onshore pipeline commissioning delays due to switch from natural gas to CO_2.	**Onshore**
40	41	CCP is below required performance acceptance criteria.	**Onshore**
41	42	CCP degrades more readily due to amine degradation.	**Onshore**
	43	Failure to address applicable safety legislation.	**Onshore**
	44	Low availability of flue gas to CCP due to aged power plant assets.	**Onshore**
	45	Political changes result in withdrawal of CCS funding / interest.	**Whole system**
	46	Legal challenge is made against state aid / funding.	**Whole system**
	47	Inadequate control of project due to scale of project.	**Whole system**
	48	Intellectual property infringement.	**Whole system**
	49	Regulator unwilling to license aquifer.	**Offshore**
	50	Additional compressor requirements for onshore pipeline due to friction in pipe.	**Onshore**

7.4 Risk descriptors

The risk descriptors to this CCS case study are discussed in this section.

7.4.1 Reference

The risk Identification number used in this case study were the numbers allocated to each risk in the column risk ranking in Table 7.1. These numbers are referred to in the development of the different risk dimensions. The XP reference provides detail of where the risk details originated in the XP data set.

7.4.2 Carbon capture and storage chain component

This column provides details of the infrastructure modules for the CCS value chain. Although different descriptors were used in the initial development of the risk register template the XP descriptors were used for the structure of the generic risk register as they related to the risk owner in the consortium. The categories were broadly divided into 3 groups:

A. those that relate to the whole system;
B. onshore (land based); and
C. Offshore (marine based) components.

The component categories have been allocated to the respective risks in Table 7.1 and a summary of components and subcomponents are provided in Table 7.2.

Table 7.2 The components and sub components of CCS

Component	Sub component
Whole system	• Not applicable
Onshore	• Power station and carbon capture plant • Feeder 10 • Onshore elements • On shore pipelines • Surface facilities and wells
Offshore	• Offshore Elements • Offshore platform • Wells and reservoir • Offshore storage

7.4.3 Phases of the lifecycle

The following phases of the lifecycle included; FEED, construction, commissioning and proofing, operations, decommissioning and post closure. These phases were the phases designated for the project in the report (DECC, 2011).

7.4.4 Risk classifications

The generic risk portfolio for the XP top 50 post feed risks include; regulatory, legal, environmental, health and safety, economic, societal and technical. The definitions of these generic risks which were applied to classification of the 50 risks in XP risk register can be found in Section 6.2.2.3.

7.4.5 Risk categories

Analysis of 50 risks disclosed in the Post FEED risk register found that XP used 18 risk categories. These were used along with the risk descriptions and consequences in the XP risk register to apply a risk classification. The XP risk register did not breakdown the risks into risk categories but included variations in the basic risk category, for example there are seven different types of technical risks and three types of construction risk as illustrated in Table 7.3.The data has been developed further by providing risk specific clarification for each risk classification and this is summarised in Table 7.3

Table 7.3 The development of risk classification of the XP risk for CCS

<table>
<tr><th>XP risk categories for component chain</th><th>Generic risk classification</th><th>Risk category</th><th>Risk type</th></tr>
<tr><td>Technical process</td><td rowspan="10">Technical risk</td><td rowspan="10">• Logistical complications
• Network engineering
• Power plant depreciation
• Project management
• Quality assurance
• Scale-up technology</td><td>Project delay</td></tr>
<tr><td>Technical transportation</td><td>Increased cost of works</td></tr>
<tr><td>Technical mechanical</td><td>Amine degradation</td></tr>
<tr><td>Technical storage and transportation</td><td>Scale-up</td></tr>
<tr><td>Technical offshore and market</td><td>Plant longevity
Inefficient operations
Operating inefficiency
Capture plant
Reliability</td></tr>
<tr><td>Technical storage</td><td rowspan="5">Uncertainty</td></tr>
<tr><td>Technical power plant</td></tr>
<tr><td>Construction mechanical</td></tr>
<tr><td>Construction civil</td></tr>
<tr><td>Construction</td></tr>
<tr><td>Commercial contractual</td><td rowspan="4">Economic risks</td><td rowspan="4">• Micro Economic
• Macro-Economic
• Human Resources
• Socio political</td><td>Funding</td></tr>
<tr><td>Commercial financial funding</td><td>Volatility in tax treatment</td></tr>
<tr><td rowspan="2">Structures, governance and supply chain</td><td>Employee skills
Industrial relations</td></tr>
<tr><td>Funding</td></tr>
<tr><td>Consents</td><td>Regulatory risks</td><td>• Consents
• Quality assurance
• Process</td><td>Compliance
Onshore / operational
CO_2 quality assurance specification</td></tr>
</table>

XP risk categories for component chain	Generic risk classification	Risk category	Risk type
Political/ societal, contractual,	Legal risk	• Contractual • Intellectual property	Funding
Legal			Infringement of 3rd party rights
Political societal	Societal risk	• Stakeholders • uncertainty	Reputational Commercial uncertainty
Health and safety	Health and safety risk	• Human resources • Non compliance	Employee skills Liability
	Environmental risk	• Land contamination	Contaminated land Increased cost of works

7.4.6 Risk descriptions

The risk descriptions presented in the initial generic risk register were taken from the original FEED study (see Table 7.1) based on the rational they are concise and would allow easier critical analysis of the data in the risk register as additional dimensions were developed. The more detailed XP risk register data was used as a reference repository to confirm the intent of the disclosure.

7.4.7 Hazard identification

The detailed descriptions of the XP risk register were used to support the attributes of hazard identification. Hazard identification was achieved by asking the question;" what was the hazard that is the source of the risk?" When answering this question the definition of hazard applied was a source or cause of; adverse effects, danger, harm, loss, injury, damage, disruption, and degradation (Smith, 1981; Sutton, 1992; IPCS, 2004; Kaplan and Garrick, 1981; IPCS, 2008; HSE, 2011). The resulting complete generic risk register is provided in Appendix F and an example of part of the register is provided in Table 7.4.

Table 7.4 An example of a section of the resulting risk register

RISK ID NO	CCS Chain Component	FEED	Construction	Commissioning and proving	Operations	Decommissioning	Post closure	GENERIC RISK CLASSIFICATION	RISK CATEGORY	SP RC	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
1	Onshore Elements	Yes	Yes		Yes	Yes		Regulatory	Consent	**Consents**	Compliance	Key project onshore construction consents not obtained to programme- to be managed by third parties outside the Consortium	Consents not acquired in required timeframe threatening viability of project
2	Onshore Elements	Yes			Yes			Regulatory	Consent	**Consents**	Compliance	Key project onshore operational consents not obtained to programme- to be managed by third parties outside the Consortium	Consents not acquired in required timeframe threatening viability of project
3	Onshore Elements	Yes	Yes		Yes	Yes		Regulatory	Consent	**Consents**	Compliance	Key project onshore construction consents not obtained to programme- to be managed by the Consortium	Consents not acquired in required timeframe threatening viability of project
4	Offshore Elements	Yes				Yes	Yes	Regulatory	Consent	**Political, Societal, Contractual, Legal**	Compliance	Offshore decommissioning and post-closure consent uncertainties.	Consents not acquired in required timeframe threatening viability of project
5	Offshore Elements	Yes	Yes	Yes	Yes			Regulatory	Consent	**Political/ Societal/ Legal**	Compliance	Offshore construction and operation consent uncertainties.	Consents not acquired in required timeframe threatening viability of project
6	Whole System	Yes						Economic	Human resources	**Commercial - Financial/ Funding**	Employee Skills	project team disbanded due to significant gap between FEED and contract award.	Loss of intellectual, technical and financial capital
7	Onshore Elements	Yes			Yes			Regulatory	Consent	**Consents**	onshore/ operational	Key project onshore operational consents not obtained to programme - to be managed by the Consortium	Consents not acquired in required timeframe threatening viability of project

7.5 Subsidiary risk register

7.5.1 Method for the production of subsidiary registers

The next stage was the preparation of the subsidiary risk registers which involved dividing the registers into onshore and offshore registers for the respective stage of the lifecycle. Table 7.5 and Table 7.6 provides a matrix of the subsidiary registers produced from the initial top 50 post FEED list for onshore operations from XP. The subsidiary registers help to establish the clustering of risks which occur at the same phase of the lifecycle and in respect of the CCS components.

Table 7.5 Subsidiary register for onshore operations of CCS

Sub register reference	Onshore	Phase of lifecycle	CCS components					
A	Onshore	FEED	Onshore elements			Power station and carbon capture plant	Feeder 10	Whole system
B	Onshore	Construction	Onshore elements	Onshore pipeline	Surface facilities	Power station and carbon capture plant	Feeder 10	Whole system
C	Onshore	Commissioning	Onshore elements	Onshore pipeline	Surface facilities	Power station and carbon capture plant	Feeder 10	Whole system
D	Onshore	Operations	Onshore elements	Onshore pipeline		Power station and carbon capture plant		Whole system
E	Onshore	Decommissioning	Onshore elements					Whole system
F	Onshore	Post closure				Power station and carbon capture plant		Whole system

	Component is not applicable to this phase of the lifecycle

Table 7.6 Subsidiary register for the offshore operations of CCS

Sub register reference	Offshore	Phase of lifecycle	CCS components				
G	Offshore	FEED	Offshore elements	Offshore platform	Offshore storage	Wells and reservoirs	Whole system
H	Offshore	Construction	Offshore elements	Offshore platform	Offshore storage	Wells and reservoirs	Whole system
I	Offshore	Commissioning	Offshore elements	Offshore platform	Offshore storage	Wells and reservoirs	Whole system
J	Offshore	Operations	Offshore elements	Offshore platform	Offshore storage	Wells and reservoirs	Whole system
K	Offshore	Decommissioning	Offshore elements		Offshore storage		Whole system
L	Offshore	Post closure	Offshore elements		Offshore storage	Wells and reservoirs	Whole system

The number of risks per generic risk for each stage of the CCS lifecycle using the subsidiary registers listed above for onshore and offshore risks was collated in Table 7.7 for onshore hazards and Table 7.8 for offshore hazards. This information would be needed to identify the interface hazards and compile the interface register.

Table 7.7 Number of generic risks per offshore subsidiary register

Onshore Generic risk	FEED	Construction	Commissioning	Operations	Decommissioning	Post closure
Economic	5	2	3	2	1	1
Environmental	1	4	1	2	0	1
Health and safety	2	0	1	1	0	0
Legal	2	1	1	1	0	1
Regulatory	5	2	0	4	2	0
Societal	2	2	2	2	0	2
Technical	4	11	10	7	0	2
Total	**21**	**22**	**18**	**19**	**3**	**7**

Table 7.8 Number of generic risks per onshore subsidiary register

Offshore Generic Risk	FEED	Construction	Commissioning	Operations	Decommissioning	Post closure
Economic	5	2	2	2	1	1
Environmental	0	0	0	0	0	0
Health and safety	1	0	1	1	0	0
Legal	4	2	2	2	0	2
Regulatory	4	1	1	1	1	1
Societal	2	2	2	2	0	2
Technical	6	4	6	7	1	3
Total	**22**	**11**	**14**	**15**	**3**	**9**

7.5.2 Results of the subsidiary registers

Subsidiary registers were successfully produced for all stages of the lifecycle. A review of the subsidiary registers highlighted some inconsistencies with the original data in the risk register. The onshore and offshore decommissioning subsidiary registers did not contain any hazards which were specific to the decommissioning. Some of the hazards which comprise this register in some cases should not exist at the decommissioning stage of the project. One would suggest that by the time decommissioning was about to occur construction consents (ID 1) would have been obtained and the macro economic viability (ID

13) would have been addressed during the earlier stages of the project. The onshore post closure stage of the project also has inconsistencies such (ID 23) Low CCP operating efficiency due to flexible power plant operation; this issue is not applicable to this stage of the lifecycle as decommissioning has already taken place.

7.6 Interface hazard identification

7.6.1 Method of interface hazard identification

A register of concurrent hazards was produced by matching each of the 50 generic risks with another risk in the initial risk register. The intention being that these two risks occur simultaneously and result in an additional hazard. The conditions set out in Section 6.4.1 were applied and the following CCS specific variations made;

1. No variation was made to the first condition.
2. Condition 2 was varied as each risk was categorised by the specific generic classification (Table 7.7 and Table 7.8) the stage of the CCS lifecycle, designating whether they were onshore or offshore and the module of the CCS component (Table 7.5 and Table 7.6). The resulting variation required amendments to the structure of the register which included the addition of 6 columns, one for each phase of the lifecycle. Two columns were also added for the components, one to distinguish between onshore and offshore and another to state the applicable components. Figure 7-2 shows a section of a subsidiary register for the presentation of the interface hazards.

Reference | Stage of process | Phase of lifecycle | Classification | Characterisation

INTERFACE I RISK ID NO	XP RISK REFERENCE	CCS Chain Component	FEED	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
100	6	Whole System	**Y**	Economic	Human resources	Employee Skills	project team disbanded due to significant gap between FEED and contract award.	Loss of intellectual, technical and financial capital
	30	LPS & CCP	**Y**	Environmental	Land contamination	Contaminated land	Further ground contamination at proposed CCP site.	Time and financial implications of delay
101	13	Whole System	**Y**	Economic	Macro economic	Volatility in tax treatment, exchange rates	Macroeconomic volatilities impacting project economics.	financial implications of uncertainty
	30	LPS & CCP	**Y**	Environmental	Land contamination	Contaminated land	Further ground contamination at proposed CCP site.	Time and financial implications of delay
102	14	Whole System	**Y**	Economic	Micro economic	Funding	CCS levy fails to be adopted.	financial viability of the project proposition
	30	LPS & CCP	**Y**	Environmental	Land contamination	Contaminated land	Further ground contamination at proposed CCP site.	Time and financial implications of delay

Coupling

Figure 7-2 Diagram showing an example of the structure of a register of interface hazards incorporating an audit trail to the initial base data after the first iteration of interface hazards.

3. The hierarchy for classification was developed (Table 7.3).
4. The resulting generic risks were then grouped into subsidiary registers/ phases of the lifecycle.
5. Taking each subsidiary register option the risks were allocated a unique number. The numbering system used started at 100 and increased by 200.

Table 7.9 The allocated unique hazard identification number for the respective sub register and the total number of interface hazards for each sub register

	Sub register	Number assigned		Number of hazardss
		Start	End	
ONSHORE	A. FEED	100	267	167
	B. Construction	300	420	120
	C. Commissioning	500	597	97
	D. Operations	700	841	141
	E. Decommissioning	900	901	1
	F. Post closure	1100	1117	17
OFFSHORE	G. FEED	1300	1379	79
	H. Construction	1500	1545	45
	I. Commissioning	1700	1772	72
	J. Operations	1900	1980	80
	K. Decommissioning	2100	2102	2
	L. Post closure	2300	2328	28
	Total number of hazards			**849**

The allocation of a unique number for the resulting coupling/ concurrent hazard facilitated an audit trail from the initial generic risk register (base data) through to the subsidiary registers, iterations of the data and the final register of concurrent hazards. Additionally this facilitated each subsidiary register and the combinations of generic risks to be identified from the base data. The resulting 849 interface hazards were characterised identified and documented in their respective register.

6. The interface register was synthesised by application of the following:

The hazard couplings which occurred ‘most frequently’ in the master register were identified. Most frequently occurring was defined as frequently occurring across all stages of the lifecycle. The twelve frequently occurring hazards have been identified in Table 7.10.

Table 7.10 The twelve most frequently occurring hazards

Generic Hazard	Risk ID	Risk description
Economic	13	Macroeconomic volatilities impacting project economics.
	34	Insufficient suitably qualified and experienced resources to deliver CCS project.
Environmental	30	Further ground contamination at proposed CCP site.
Legal	33	Third Party Access to CCS infrastructure is required.
	48	Intellectual property infringement.
Regulatory	3	Key project onshore construction consents not obtained to programme – to be managed by consortium.
	5	Offshore construction and operation consent uncertainties.
Societal	9	Adverse public reaction to CCS.
	31	Uncertainty in the level of change instigated by stakeholders.
Technical	12	Offshore construction and operation risks.
	17	Migration of CO2 from the storage site
	23	Low CCP operating efficiency due to flexible power plant operation.

The twelve frequently occurring hazards were used to create a matrix of couplings (Figure 7-3). Hazards from the same generic family were not coupled and this is illustrated in Figure 7-4 by using the letter N (not coupled). The shaded area is a mirror image of the result of couplings in the un-shaded area, as this is duplication it has been excluded from further analysis.

GENERIC CLASSIFICATION	ECONOMICS		ENVIRONMENT	LEGAL		REGULATORY		SOCIETAL		TECHINCAL			
Risk ID	13	34	30	33	48	3	5	9	31	12	17	23	
13	N	N											
34	N	N											
30	4	5	N										
33	4	5	0	N	N								
48	8	8	5	N	N								
3	3	3	3	0	4	N	N						
5	4	4	0	3	4	N	N						
9	8	9	2	5	7	2	4	N	N				
31	8	10	4	4	8	2	4	N	N				
12	4	4	0	3	4	0	4	4	4	N	N	N	
17	4	4	0	4	4	0	0	3	4	N	N	N	
23	8	10	3	5	10	2	4	10	10	N	N	N	
TOTAL NUMBER OF COUPLINGS	55	62	17	24	41	6	16	17	18	0	0	0	**256**
NIL COUPLING FREQUENCY	0	0	4	1	0	2	1	0	0	0	0	0	**8**

Figure 7-3 Matrix of frequently occurring hazards from the XP risk register

A register was created using the matrix of frequently occurring couplings (Figure 7-3). The result was 256 coupling hazards (see Appendix H 1).

Using the 256 resulting concurrent hazards those couplings that were identified as similar because they took place at the same stage of lifecycle and CCS chain component were identified and the result was a register of 41 concurrent hazards (see Appendix H 2) of which an example is presented in Figure 7-4.

RISK IDENTIFICATION REFERENCE				PHASE OF LIFE CYCLE						GENERIC RISK				
FINAL RISK ID	XP DECC RISK REFERENCE	ONSHORE OR OFFSHORE	CCS Chain Component	FEED	Construction	Commissioning and proving	Operations	Decommissioning	Post closure	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
1	34, 31	Onshore	Whole System	214	317	517	837		1103	Economic	Human resources	Employee Skills	Insufficient suitably qualified and experienced resources to deliver CCS project.	Technical and safety exposure.
	34,31	Offshore	Whole System	1353	1511	1716	1918		2304	Societal	Uncertainty	Commercial uncertainty	Uncertainty in the level of change instigated by stakeholders.	Uncertainty results in lack of confidence from potential investors
2	9,23	Onshore	Whole System	261	390	522	777		1114	Societal	Stakeholders	Reputational	Adverse public reaction to CCS.	Negative reputational impact
	9,23	Offshore	Whole System	1471	1540	1765	1971		2321	Technical	Quality assurance	Operating inefficiency	Low CCP operating efficiency due to flexible power plant operation.	Increased energy penalty negates objective of CCS
3	34,23	Onshore	Whole System	230	379	561	826		1110	Economic	Human resources	Employee Skills	Insufficient suitably qualified and experienced resources to deliver CCS project.	Technical and safety exposure.
	34,23	Offshore	Whole System	1373	1524	1735	1936		2306	Technical	Quality assurance	Operating inefficiency	Low CCP operating efficiency due to flexible power plant operation.	Increased energy penalty negates objective of CCS

Figure 7-4 Example of the final iteration of the interface register of hazards produced

A sample of the structure of the register used for the final iteration and documentation of interface hazards is presented in Figure 7-4 and a full copy is provided in Appendix H 2.

7.6.2 Results of interface hazard identification

The identification of cross-disciplinary hazards was achieved by the couplings produced from the register of 50 risks. Couplings were produced from the 12 most frequently occurring hazards. Although two health and safety risks were identified in the original risk register they were not identified as being one of the most frequently occurring hazards. This was due to the fact that one of the hazards (ID 43) only occurred at the FEED stage of the lifecycle and the other hazard (ID10) was present at the FEED, commissioning and operations stages. The most frequently occurring hazards include all the other generic classifications.

The most frequently occurring interface hazards should provide a reason for focusing the active management of these hazards. Frequency in the context of interface identification is the most coupled risks. This should however be tempered with the potential for bias that could be introduced by the large number of whole system risk (14) in the portfolio of 50 risks. Also the designation of the classification whole system itself does mean that the hazards will affect the whole system. This highlights the requirement to make sure that whole system risks actually apply to the whole system and across the stages of the lifecycle where this is appropriate. If this is not the case errors in the identification of cross discipline hazards may occur.

7.7 Causation hazard identification

7.7.1 Method of causation hazard identification

A causation hazard is dependent on a prior hazard occurring. If the prior hazard does not occur then causation will not take place. The method set out in Chapter 6 was applied to the XP data and involved taking the individual subsidiary risk registers derived from the generic risk register and for each individual risk establish if this risk triggers a hazard. This line of thinking was repeated until there were no additional hazards or the project was terminated. For each of the 50 hazards if the initial risk did not take place the subsequent hazard would not arise. An example of the structure of the causation register is provided in Table 7.11.

Table 7.11 Structure of the causation register for XP

CAUSATION RISK REGISTER		PHASE OF LIFECYCLE						GENERIC RISK			Causation		
RISK ID NO	CCS Chain Component	FEED	Construction	Commissioning and proving	Operations	Decommissioning	Post closure	GENERIC RISK CLASSIFICATION	RISK DESCRIPTION	HAZARD 1	HAZARD 2	HAZARD 3	HAZARD 4
10	Whole System	Yes	NO	Yes	Yes	NO	NO	Health and Safety	Operations staff unfamiliar with CO_2.	Unqualified employees	Non compliance	Safety event	Loss of life, injury or disease

Figure 7-5 Structure of the causation register for XP

The rationale for using the subsidiary register is that these registers provide details of risks which would occur within one stage of the CCS lifecycle. By using these registers there is a complete and verified pool of risks for the specific stage of the lifecycle. The second step was to identify any hazards which would result in the termination of the project.

Option 1 causation within a stage of the lifecycle

The identification of causation hazards was achieved by taking each sub register and using knowledge about the stage of the lifecycle, placing the hazards in context, and stating the next progression of the hazard. At each stage the question; ”does the prior hazard result or triggers the subsequent hazard?” was asked and was continued with each subsequent hazard until the outcome was termination or an acceptable outcome for the continuance of the project under normal conditions. A summary of the results are provided in Table 7.12 and the full results are in Appendix I-2.

Table 7.12 Generic risks and resulting causation hazards by stage of lifecycle

Onshore / Off shore	Sub Registers/ stage of lifecycle	Number of initial risks with a defined hazard per sub register	Number of hazards comprising the causation linkages
Onshore	A. FEED	21	60
	B. Construction	22	46
	C. Commissioning	18	64
	D. Operations	19	62
	E. Decommissioning	3	6
	F. Post closure	7	8
Offshore	G. FEED	22	57
	H. Construction	11	42
	I. Commissioning	14	60
	J. Operations	15	64
	K. Decommissioning	3	10
	L. Post closure	9	19
	Total	**164**	**498**

Option 2 non-lifecycle specific causation The same approach as option 1 was taken to the generic risk register (option 2) and resulted in a summary register of causation hazards (see Appendix I.1).

Option 3 transversal causation. This involved highlighting all the hazards that transverse five or more of the stages of the lifecycle. This was applied to the consolidated lifecycle register. There were 10 transversal hazards which are detailed in Table 7.13 and the resulting causation hazards are highlighted in orange in the consolidated causation register (Appendix I.3).

Table 7.13 List of transversal hazards

Risk ID	Hazard description
9	Adverse public reaction to CCS.
13	Macroeconomic volatilities impacting project economics.
17	Migration of CO_2 from the storage site
23	Low CCP operating efficiency due to flexible power plant operation.
30	Further ground contamination at proposed CCP site.
31	Uncertainty in the level of change instigated by stakeholders.
33	Third Party Access to CCS infrastructure is required.
34	Insufficient suitably qualified and experienced resources to deliver CCS project.
47	Inadequate control of project due to scale of project.
48	Intellectual property infringement.

7.7.2 Results of identification of causation hazards

The identification of causation hazards facilitated cross discipline hazard identification as many of the initial hazards did not result in a hazard from the same generic classification. This is illustrated in Appendix J an example is ID 42 (amine degradation of CCP) a technical risk which results in increased CAPEX to replace the CCP. This is also the case for ID 29 which is an economic risk concerned with the use of unskilled labour which results in a health and safety exposure. It is clear that each hazard may have a number of outcomes of which one is shown in the register for each hazard and subsequent hazard produced for this research.

An observation from all the chains of causation is that in many cases the project is only terminated when the financial feasibility of the project is in question resulting in stranded assets and project termination. The chains of causation provide knowledge of potential outcome so as to allow corrective action to be taken if this is an option. The objective of the pilot was to establish whether the method set out in Chapter 6 could be applied to real data and with respect to the identification of causation hazards and compile a register of causation hazards, this has been achieved and evidenced in Appendix J.

7.8 Accumulation hazard identification

7.8.1 Method of accumulation hazard identification

Section 6 proposed three different types of accumulation hazards which were applied to the XP risk register data set. They are;

Type 1 portfolio - hazards that are stage of lifecycle specific.

Type 2 portfolio - hazards that occur across the stages of the lifecycle.

Type 3 portfolio - hazards that occur within a component or module of the process or project.

Type 1 portfolio - stage of lifecycle specific accumulation hazards. The subsidiary registers as shown in Table 7.14 are portfolios which comprise all the hazards that occur within a specific stage of the CCS lifecycle.

Table 7.14 List of subsidiary registers and the corresponding number of hazards which comprise the respective accumulation hazard portfolio

Location	Subsidiary Registers	Number of hazards comprising an accumulation hazard
Onshore	A. FEED	21
	B. Construction	22
	C. Commissioning	18
	D. Operations	19
	E. Decommissioning	3
	F. Post closure	7
Offshore	G. FEED	22
	H. Construction	11
	I. Commissioning	14
	J. Operations	15
	K. Decommissioning	3
	L. Post closure	9
	Total	**164**

Type 2 portfolio There were six stages of the lifecycle and the maximum number of hazards across all the stages of the lifecycle was five. Those hazards which occur across the maximum stages (5) of the lifecycle are listed in Table 7.15.

Table 7.15 The Risk ID for those hazards that occur across the maximum number of stages (5) accross the lifecycle with their respective generic risk classifications

RISK ID NO	CCS Chain Component	FEED	Construction	Commissioning and proving	Operations	Decommissioning	Post closure	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
9	Whole System	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Societal	Stakeholders	Reputational	Adverse public reaction to CCS.	Negative reputational impact
13	Whole System	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**		Economic	Macro-economic	Volatility in tax treatment, exchange rates	Macroeconomic volatilities impacting project economics.	Financial implications of uncertainty
17	Offshore Storage	**Yes**		**Yes**	**Yes**	**Yes**	**Yes**	Technical	Loss of containment	Storage site compromised	Migration of CO_2 from the storage site	Financial implications of loss of captured CO_2
23	Whole System	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Technical	Quality assurance	operating inefficiency	Low CCP operating efficiency due to flexible power plant operation.	increased energy penalty negates objective of CCS

RISK ID NO	CCS Chain Component	FEED	Construction	Commissioning and proving	Operations	Decommissioning	Post closure	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
30	LPS & CCP	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Environmental	Land contamination	Contaminated land	Further ground contamination at proposed CCP site.	Time and financial implications of delay
31	Whole System	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Societal	Uncertainty	Commercial uncertainty	Uncertainty in the level of change instigated by stakeholders.	Uncertainty results in lack of confidence from potential investors
33	Well & Reservoir	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Legal	Contractual	Commercial	Third Party Access to CCS infrastructure is required.	Loss of potential commercial capacity.
34	Whole System	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Economic	Human resources	Employee Skills	Insufficient suitably qualified and experienced resources to deliver CCS project.	Technical and safety exposure.
47	Whole System	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Technical	Project management	Scale -up	Inadequate control of project due to scale of project.	Inexperienced project management

RISK ID NO	CCS Chain Component	FEED	Construction	Commissioning and proving	Operations	Decommissioning	Post closure	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
48	Whole System	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**	Legal	Intellectual property	Infringement of 3rd party rights	Intellectual property infringement.	Lack of knowledge on 3rd party Intellectual Property

Type 3 portfolio

A third type of accumulation hazard is the portfolio of hazards within one component or module. These hazards are identified in the XP risk register by applying the filter to the respective CCS chain component and obtaining registers of hazards from each of the nine components/ modules identified in Table 7.2.

Table 7.16 Accumulation hazards for each component of the CCS module

CCS Component	Hazard ID	Number of hazards in an accumulation portfolio	Accumulation potential
Feeder 10	26,38	2	The hazards are unlikely to occur at the same time additionally risks are manageable. As a result little chance of accumulation.
Power Station and Carbon capture plant	18,19,22,27,29,30,41,42,43,44	10	19, 22,41,42,44 are performance related and go to the heart of the rationale for the process and could result in an accumulation hazard.
Onshore elements	1,2,3,7	4	It is feasible that all risks materialise at the same time
Offshore platform	12	1	Not applicable
Offshore storage	17,49	2	Accumulation potential
Offshore elements	4,5,11,20	4	Not applicable
Onshore pipeline	15,21,25,28,32,36,37,39,40,50	10	Accumulation potential
Surface facilities and wells	16	1	Not applicable
Well reservoirs	33,35	2	Accumulation potential
Whole system	6,8,9,10,13,14,23,24,31,34,45,46,47,48	14	Accumulation potential
	Total number of hazards	50	

On reviewing the hazards that comprise the portfolio of component hazards in Table 7.16 it was clear that some of these portfolios were not portfolios due to the small number of hazards (offshore platform) and the possibility of the hazards to resulting in a significant event (offshore elements). The remaining six accumulation hazards are presented in Appendix K.

Unlike the other pools of risk these risks are not additive they have to remain in their components. However the “whole system risks” can be allocated to each portfolio and the result is a potential compilation of accumulation hazards.

As the whole system risks traverse all components they have the potential to trigger and create accumulation hazards that could result in a catastrophic loss impact or event as a result they are included as a separate transversal accumulation hazard.

The resulting three methods of identifying accumulation hazards result in a register which is comprised of:

1. Sub registers from each phase of the lifecycle and additionally for on shore and offshore operations.

2.Hazard relationships which cross all the stages of the lifecycle and which include identified hazards as well as those designated whole system hazards, and

3. Individual registers for the individual CCS chain components.

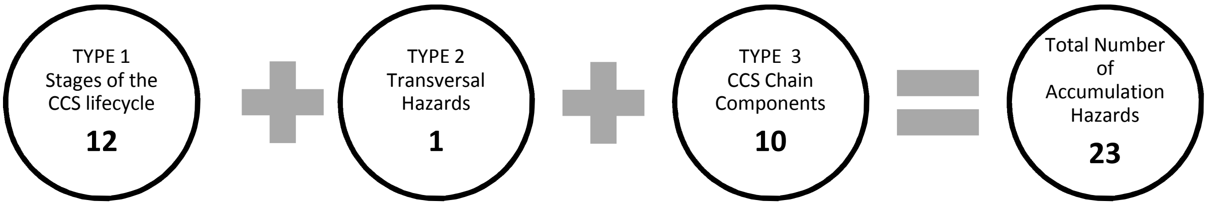

Figure 7-6 The number and composition of the different accumulation hazard portfolios for the CCS Pilot case study

As a result of applying the XP CCS data the steps for the method for identifying the accumulation hazards will be;-

1. Produce subsidiary registers for each stage of the lifecycle of a new project or technologies taking into account the context such as onshore or off shore operations.

2. Identify those risk relationship which occur across all stages of the lifecycle.

3. Produce the individual registers for each of the modules of the process and value chain.

With the outcome of each of these steps establish if the compilation is feasible and give reasons why the hazard should be excluded.

7.8.2 Results of identification of accumulation hazards

The compilation of accumulation hazards provides examples of portfolio hazards within which there is the potential for interaction of a number of hazards within a short period of time. This means that there is the potential for hazards to interact with each other and cross discipline hazards are implicit in the identification process. This occurs with transversal hazards in an accumulation portfolio and the concentration of component hazards. It is illustrated in the power station, onshore pipeline and whole system components (Appendix K, L and Table 7.16) where there is a concentration of different generic risks.

Table 7.17 The influence of whole system components on lifecycle accumulation hazards

Location	Subsidiary Registers	Number of whole system hazards comprising an accumulation hazard	Percentage of whole system component hazards
Onshore	A. FEED	2	62%
	B. Construction	22	36%
	C. Commissioning	18	50%
	D. Operations	19	47%
	E. Decommissioning	3	33%
	F. Post closure	7	86%
Offshore	G. FEED	22	36%
	H. Construction	11	82%
	I. Commissioning	14	64%
	J. Operations	15	60%
	K. Decommissioning	3	33%
	L. Post closure	9	67%
Total		**145**	62%

The results show that whole system hazards have a significant influence on the accumulation hazards. Of the 14 whole system risks 6 traverse all stages of the lifecycle with the exception of decommissioning. Table 7.17 shows the number of whole system hazards as a percentage of the total number of hazards in subsidiary registers. All the risks are over 33% and eight out of the 12 are over 50%. This highlights the important influence that the whole system component has over the results of the entire project. Further investigation should be carried out to ensure that the allocation of a generic component is correct.

7.9 Register developments

7.9.1 Generic register

The generic register was successfully adapted to include the six stages of the lifecycle, the onshore and offshore locations and ten components. The original risk register data was used to derive the classification and characterisation of the 50 risks from the original risk register. This parameter proved to be able to accommodate the information required for characterising this specific project.

7.9.2 Subsidiary register

Compiling the subsidiary registers is a function of the quality of the original data. Hazards which are stated as occurring throughout the entire system and across all stages of the lifecycle may not be applicable or appropriate to all stages of the lifecycle and this is highlighted when analysing the subsidiary registers. For example in the subsidiary register for the onshore decommissioning phase (Table 7.18) there are three hazards of which two regulatory hazards would not be hazards as they are concerned with the onshore construction consents and as such at the decommissioning stage would not threaten the viability of the project post operation. However if the objective of this register is that it is highlighting risks from later stages in the lifecycle that need to be addressed early in the lifecycle then this would be correct. The third hazard is economic and is a potential exposure. Based on the decommissioning of power stations and pipelines there should be other hazards identified in the onshore decommissioning stage. The absence of these hazards is highlighted at the stage of reviewing the subsidiary registers.

Table 7.18Subsidiary register for decommissioning stage of the lifecycle

RISK ID NO	CCS Chain Component	Decommissioning	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
1	Onshore Elements	Yes	Regulatory	Consent	Compliance	Key project onshore construction consents not obtained to programme- to be managed by third parties outside the Consortium	Consents not acquired in required timeframe threatening viability of project
3	Onshore Elements	Yes	Regulatory	Consent	Compliance	Key project onshore construction consents not obtained to programme- to be managed by the Consortium	Consents not acquired in required timeframe threatening viability of project
13	Whole System	Yes	Economic	Macro economic	Volatility in tax treatment, exchange rates	Macroeconomic volatilities impacting project economics.	financial implications of uncertainty

The post closure stage of the lifecycle for XP (Table 7.19) highlights additional issues as it is unlikely that an infrastructure project of such substantial investment and which spans a significant time frame would be in a position where the risks highlighted in red would still be outstanding.

Table 7.19 Post closure subsidiary register for carbon capture and storage.

RISK ID NO	CCS Chain Component	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
4	Offshore Elements	Regulatory	Consent	Compliance	Offshore decommissioning and post-closure consent uncertainties	Consents not acquired in required timeframe threatening viability of project
9	Whole System	Societal	Stakeholders	Reputational	Adverse public reaction to CCS.	Negative reputational impact
17	Offshore Storage	Technical	Loss of containment	Storage site compromised	Migration of CO_2 from the storage site	Financial implications of loss of captured CO_2
23	Whole System	Technical	Quality assurance	Operating inefficiency	Low CCP operating efficiency due to flexible power plant operation.	Increased energy penalty negates objective of CCS
31	Whole System	Societal	Uncertainty	Commercial uncertainty	Uncertainty in the level of change instigated by stakeholders.	Uncertainty results in lack of confidence from potential investors
33	Well & Reservoir	Legal	Contractual	Commercial	Third Party Access to CCS infrastructure is required.	Loss of potential commercial capacity.

RISK ID NO	CCS Chain Component	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
34	Whole System	Economic	Human resources	Employee Skills	Insufficient suitably qualified and experienced resources to deliver CCS project.	Technical and safety exposure.
47	Whole System	Technical	Project management	Scale -up	Inadequate control of project due to scale of project.	Inexperienced project management
48	Whole System	Legal	Intellectual property	Infringement of 3rd party rights	Intellectual property infringement.	Lack of knowledge on 3rd party Intellectual Property

Analysis of the highlighted hazards in Table 7.19 shows an incomplete position for the onshore post closure stage of the lifecycle as a result of the following;

- Risk ID No 4, 23, would be dealt with prior to the operational stage and are unlikely to have an impact on the post closure stage after decommissioning.
- Risk ID No 34, is concerned with the delivery of the project. It could be said that at the post closure stage the project has been delivered what is required is maintenance and security of containment CO_2 at the post closure stage.
- Risk ID No 33, is according to the XP risk register positioned after closure and decommissioning so it is unclear what the threatened commercial capacity would be at the post closure stage.
- Risk ID No 47 It is difficult to see what the scale up exposure would be at the post closure stage as the project is completed. The lack of experience of post closure containment and remediation would be the specific hazard for this stage of the lifecycle, but this was not included.

Even if the assumption is made that these are hazards highlighted now, for resolution early in the project lifecycle, there are additional hazards which have not been identified. One reason for this could be that these additional hazards were not in the top 50 risks.

7.9.3 Interface hazard identification

The method for the identification of interface hazards produced 849 potential interface hazards in the first iteration (Table 7.20). The objective of the pilot study was to establish if interface hazards were identified from the original data set and this objective was met as hazards were identified for each subsidiary register. To produce a more manageable number of hazards the second iteration focused on those hazards which occurred most frequently across the lifecycle (256) couplings. Analysis of these couplings found that a number were repeated and the result was a register of 49 interface hazards.

Table 7.20 Summary of the number of interface hazards identified from 50 generic hazards

	Dimension of hazard	**Hazards within dimension**	**Number of hazards**
Original register of generic hazards		**50**	
Interface hazards			
Onshore	A. FEED	21	167
	B. Construction	22	120
	C. Commissioning	18	97
	D. Operations	19	141
	E. Decommissioning	3	1
	F. Post closure	7	17
Offshore	G. FEED	22	79
	H. Construction	14	45
	I. Commissioning	14	72
	J. Operations	15	80
	K. Decommissioning	3	2
	L. Post closure	9	28
	Total first iteration	**167**	**849**
	Total second iteration		**256**
	Consolidated total		**49**

7.9.4 Causation hazard identification

The three methods of causation were successfully applied to the XP data set. Application of the causation method to the generic register did not allow consideration of the risks within the context of their lifecycle. Examination of the resulting data highlighted the issue of assuming that hazards result in the same causation irrespective of where they are in the lifecycle. This is illustrated by the inclusion of operational hazards which would not apply in the decommissioning and post closure phases. As a result applying the methodology by stage of lifecycle is the most acceptable approach. The importance of the application by lifecycle is illustrated by the fact that with the identification of transversal hazards it is possible to identify where mitigation should occur to minimise the potential of a creeping hazard. From the 50 risks taken from the generic register 498 additional hazards were identified. The number of causation hazards for each stage of the lifecycle is presented in Table 7.21.

Table 7.21 The results of the causation register using the consolidation of the subsidiary registers

Stage of the lifecycle	Hazards within dimension
A. FEED	60
B. Construction	46
C. Commissioning	64
D. Operations	62
E. Decommissioning	6
F. Post closure	8
G. FEED	57
H. Construction	42
I. Commissioning	60
J. Operations	64
K. Decommissioning	10
L. Post closure	19
Total	**498**

7.9.5 Accumulation hazard identification

The three methods of identifying accumulation hazards were successfully applied to the XP data. When analysing the results there are four portfolios with less than 10 hazards which should be investigated further as they may not meet the conditions of an accumulation risk. These have been excluded from the calculation of the number of type 1 accumulation hazards.

Table 7.22 Type 1 accumulation portfolio - stage of lifecycle

Stage of the lifecycle	Hazards within dimension	Number of hazards
A. FEED	21	1
B. Construction	22	1
C. Commissioning	18	1
D. Operations	19	1
E. Decommissioning	3	0
F. Post closure	7	0
G. FEED	22	1
H. Construction	14	1
I. Commissioning	14	1
J. Operations	15	1
K. Decommissioning	3	0
L. Post closure	9	0
Total	**167**	**8**

Type 2 – transversal accumulation hazards were identified and the summarised results show that there are very few component hazards that are transversal. With the exception of the whole system component the majority of components have less than three transversal hazards in their portfolio. As the whole system component has more than three hazards it is the only portfolio that has been included.

Table 7.23 Type 2 accumulation portfolio - transversal

Component	Number of hazards which traverse 3 or more phases of lifecycle	Number of transversal accumulation hazards
Feeder 10	0	0
Power Station and Carbon capture plant	1	0
Off shore elements	2	0
Offshore platform	1	0
Offshore storage	1	0
Onshore elements	2	0
Onshore pipeline	0	0
Surface facilities and wells	1	0
Well reservoirs	1	0
Whole system	9	1
Total	-	1

The application of the method for identification of type 3 component accumulation hazards was successfully applied and a summary of the results are provided in Table 7.24. This table highlights that there are components where there is only one hazard (offshore platform, storage and, surface facilities and wells) and these were excluded as not fulfilling the definition of an accumulation hazard. When some of the components were analysed it was not possible for the hazards to result in an accumulation hazard, for example Feeder 10. With respect to the well reservoir component this is only an exposure during the operational stage of the lifecycle. If these five components are excluded there are five potential accumulation portfolios from the component parameter.

Table 7.24 Summary of the type 3 portfolio - component results

Component	Hazards within dimension	Number of hazards
Feeder 10	2	0
Power Station and Carbon capture plant	10	1
Off shore elements	4	1
Offshore platform	1	0
Offshore storage	2	0
Onshore elements	4	1
Onshore pipeline	10	1
Surface facilities and wells	1	0
Well reservoirs	2	0
Whole system	14	1
Total	**50**	**5**

7.10 Validation

Steps of validation of XP data, application and results are summarised in Table 7.25 and involved checking the base data as presented was correct, the application of the method was possible and resulted in registers of cross-disciplinary hazards.

Table 7.25 Table to show the method of validation applied to data integrity, method application, register production and cross-discipline hazard identification

<table>
<tr><th>Parameter</th><th>Validation of process</th><th>Validation of results</th></tr>
<tr><td>Data integrity</td><td>Data was cross checked with risk register and table within the report.</td><td>Discrepancies were identified and the most recent data used.</td></tr>
<tr><td>Application of the method in Section 6</td><td>Method applied to the identification of cross-disciplinary hazards in accordance to the method laid out in chapter 6.</td><td>Production of the registers of cross discipline hazards.</td></tr>
<tr><td>Generic register</td><td>Initial data was validated by the three companies who compiled the risk register and report and by DECC.</td><td>CCS expert reviewed the application of the descriptors and the resulting generic register of hazards</td></tr>
<tr><td>Subsidiary register</td><td rowspan="4">Audit trail back to original data.</td><td rowspan="4">Method reviewed by CCS expert.</td></tr>
<tr><td>Interface</td></tr>
<tr><td>Causation</td></tr>
<tr><td>Accumulation</td></tr>
</table>

7.11 Summary

This chapter applied the method outlined in Chapter 6 to the XP data set and found that the method identified cross discipline hazards through the additional dimensions of interface, causation and accumulation hazards. The subsidiary register presented the generic register in subsidiary lifecycle registers and was essential to the identification of the novel dimensions.

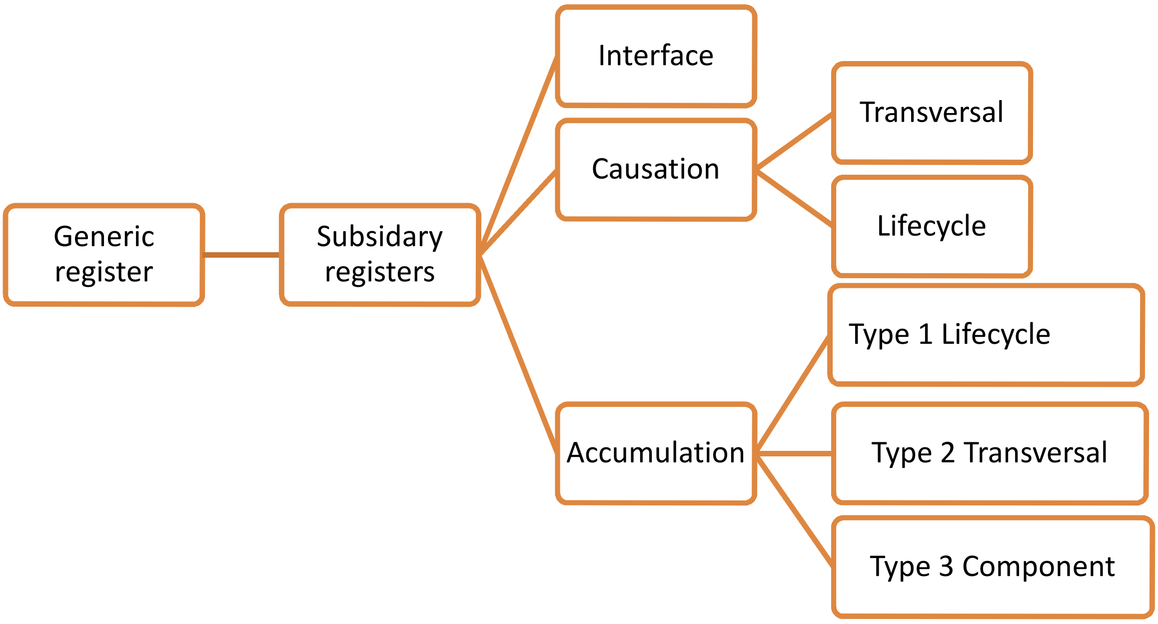

Figure 7-7 Method resulting from the outcome of the pilot case study

The new method for the identification of hazards has provided three additional dimensions to the original register which have identified previously unidentified cross-disciplinary hazards. The enhanced method which resulted from the pilot study will be tested to establish whether it is possible to identify the generic, interface, causation and accumulation dimensions for a process which does not have a risk register.

8 CASE STUDY 2 - CLOSED LANDFILL HAZARD REGISTER

8.1 Introduction

This chapter presents the application of the method for identifying novel hazards (see Chapter 6) to a risk register from a closed landfill site. The aim of this case study was to test whether it was possible to produce a register of generic hazards from original data, and identify the dimensions and evidence in a register.

A closed landfill was chosen because landfills at this stage of the lifecycle are well characterised and have been in existence for many years. As a result verification of the generic register by experts would be possible and infringement of intellectual property would not be an issue. The rationale for choosing this site was based on the fact that a site specific risk register did not exist. As a result a register of identified hazards would need to be compiled in accordance with the method (Chapter 6) which requires a risk register as the base data to commence the identification of the dimensions. Divulging the details of the actual site was an issue as landfills are sensitive structures which can result in reputational damage to the company and the area that it is located. As a result these details have been excluded from the case study in line with the requirements of the Cranfield Ethics Committee (Section 4.4.1).

A landfill is defined as a waste disposal site for the deposit of waste onto or into land (Article 2(g) of the Landfill Directive 1999/31/EC). The studied site is defined as a historic closed landfill as it fulfils the requirements of the Environment Agency Closed Landfill High Priority Review Process which are that the landfill is closed, no longer has a permit, and was closed prior to the EU Landfill directive (1999/31/EC; EA NTS, 2010). The footprint of the site is presented in Figure 8-1.

The site is a disused quarry located on the outskirts of a small town in the Midlands. To the north-east perimeter of the site there is residential housing which is within the 250 metre boundary (Town and Country Planning – General

Development Procedure- Order 1995) and a lagoon to the west edge of the site. The site is adjacent to an ex-local authority landfill which has no gas or leachate management. This landfill ceased operating in the early 1990s and planning permission was given to allow restoration for use as pasture and grazing. Subsequently, in 1993, the waste disposal license was handed back to the local authority.

The entity identified as the polluter under the Contaminated Land Regime (Part II A) is not the original owner but now has been tasked with addressing the residual contamination. An indemnity for a fixed amount to fund the aftercare costs for this site was given to the current owner of the site when the site was sold by the original owner. The contamination results from the migration of landfill gas towards potential receptors and the migration of leachate from the site. A remediation statement was agreed in 2005 requiring;

- The installation of a gas management system, monitoring, collection of landfill gas; and
- The monitor of leachate on the basis of management by long term monitored natural attenuation (Site Specific Quarterly Report, 2011).

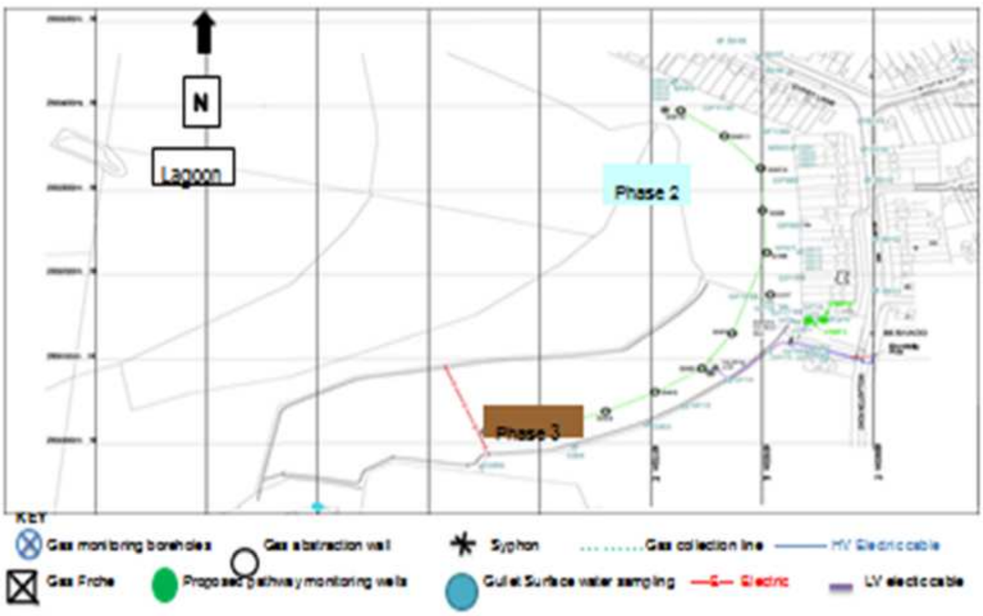

Figure 8-1 Map of the closed landfill (September 2011 Quarterly review)

The local Borough Council agreed to carryout off-site environmental monitoring to support the gas management remediation strategy. On-site monitoring has been carried out on a monthly basis by a third party, who is also responsible for the maintenance of the gas management system. The monitoring data collected on-site and offsite is used to calibrate the gas management equipment to ensure maximum collection of landfill gas. The determinations (2000 and 2002) and the remediation statement required that the landfill gas and leachate were managed until they no longer posed a further threat to the environment or human health.

8.2 Method specific to this case study

The method of multidimensional hazard identification requires a register of verified hazards prior to the identification of interface, causation and accumulation hazards (Section 6.3.2). The register of hazards for this site was compiled from the perspective of the site and not as an owner, tenant or stakeholder. The quantification of the identified hazards could not take place as monitoring data was not available. There were three sources of data; the unpublished September 2011 quarterly review completed by the consultant to the site, information on the website from local authority, and researcher site visits in December 2011 and March 2012 (see Appendix M). Additional data was obtained from academic journal articles and UK regulatory guidance which provided details on the impacts of generic closed landfills and the knowledge of the researcher having placed environmental impairment insurance for over 1000 landfills in the UK.

In the previous case study (Chapter 7) the risk register was already complied and used as the base data prior to the application of the method. In this case study the initial register did not exist. As a result the compilation of the register was achieved by identifying hazards using all the sources of data highlighted above.

Figure 8-2 outlines the stages followed to compile the register of hazards prior to the application of the method outlined in Chapter 6.

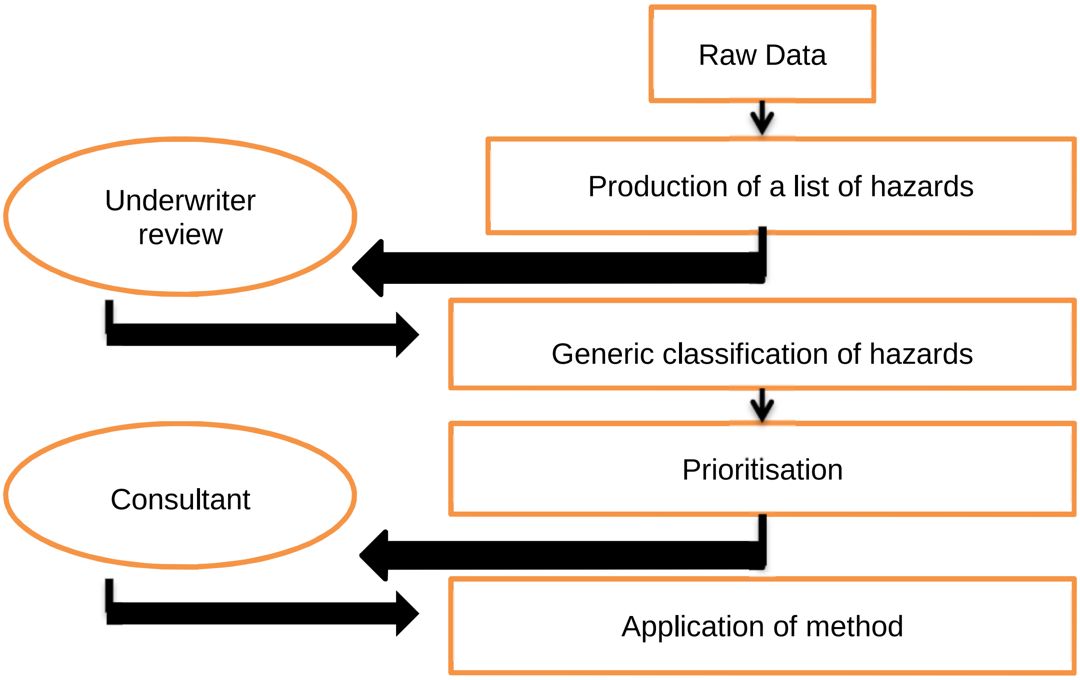

Figure 8-2 Steps involved in producing the register of hazards prior to the application of the method

The figure shows that the lists of 71 hazards were reviewed twice prior to the application of the method. Firstly by an environmental underwriter who is an expert at underwriting landfills and confirmed that the hazards were a fair reflection of those expected on a closed landfill; and secondly after prioritisation by the consultant in charge of the aftercare for the site. The resulting prioritised risks were then reviewed and used to apply the method for the identification of cross-disciplinary hazards as stated in Chapter 6.

8.3 Risk descriptors

8.3.1 Risk identification number

In the absence of a risk register a register of hazards was compiled and as a result each hazard was given a unique hazard Identification number (hazard ID). The hazard ID was used in the same way as the Risk ID in the XP pilot study (Chapter 7), providing an audit trail throughout the synthesis of data used to produce the different dimensions of hazards.

8.3.2 Chain component

Although operational landfill activities have not taken place on-site for over 18 years, the following processes are occurring responding to the remediation statement and general aftercare:

- Gas management which includes the management of landfill gas;
- Leachate management;
- Stability; and
- Aftercare which includes restoration as well as the physical and financial maintenance of the site.

These landfill specific processes will be used instead of the CCS chain components in Chapter 6. These are specific processes which need to be managed to ensure the improvement of the site to a position of negligible impact to health, safety and the environment.

8.3.3 Stages of the lifecycle

Based on discussions with the consultant (Appendix M notes from November 2011 and March 2012) it is assumed that the site ceased operating as a landfill and closed in the early 1990s. The waste disposal licence was given back to the local authority in 1993. The consultant stated that the site is believed to have been closed for at least 18 years. There has been no agreed timeframe within which the landfill would be deemed safe. As a result of the potential open ended length of the post-closure stage, the lifecycle has been divided into three phases:

- Short term (1- 4 years inclusive);
- Medium term (5 -14 years); and
- Long term (15 + years).

Data on hazards was collected for all the phases of post closure lifecycle by the researcher.

8.3.4 Risk classification

The same generic classification of hazards used in the pilot study was used in this case study and included; health and safety, environmental, economic, societal, technical, regulatory and legal (Section 6.2.2.3).

8.3.5 Prioritisation of closed landfill hazards

After the initial review by an underwriting risk expert, the register of 71 hazards were prioritised to ensure that the hazards in the resulting register; used to derive the interface, causation and accumulation hazards, posed a threat. The method of prioritisation involved using a scale of high, medium and low. These categories were used to assign quantitative and qualitative scoring of hazards and risk (Ward, 1999: HSE, 2006). The scale used by the Environment Agency for closed landfills used the parameters high, medium and low and divides each parameter into knowns and unknowns, resulting in 6 strata (EA, 2010). As there was no access to monitoring or quantitative data, a decision was made to use the three parameters of high, medium and low with qualitative descriptors (Table 8.1). The rationale for using a scale was to highlight the hazards that are likely to have the greatest negative impact on a site and thus pose a threat in respect of cost to the owner, liability, regulatory impact and damage to human health and safety.

Table 8.1 Criteria used to rank the individual hazards in the initial generic register

Parameter	High	Medium	Low
Health and safety	• High likelihood of loss of life, disease and /or injury • Potential for corporate manslaughter	• Possibility of disease and /or injury	• Low likelihood of injury
Regulations	• Noncompliance	• If left unmanaged would result in noncompliance, a fine or penalty	• Within required parameters for compliance with UK regulations
Cost	• Capital expenditure required • Legal expenses • Third party liability costs • Loss of use of property • Potential for a class action	• Operational expenditure which is unplanned and may not be covered in the indemnity • Planned expenditure • Third party property damage	• Planned expenditure within the indemnity

Each individual hazard was assessed based on its likelihood to have the impacts identified in the descriptors listed in Table 8.1. The result of prioritisation was captured in the register as part of the characterisation of the hazard.

8.3.6 Generic hazard classification

The initial portfolio of 71 hazards (Appendix N) were produced and presented in a register according to the structure in Section 6.2.2. The portfolio was prioritised in accordance with Section 8.3.5 and this resulted in a register of 49 medium and high rated hazards (Appendix O). The 22 hazards categorised as low risk were excluded from the register as they are not considered sufficient risk to require special consideration outside of the normal operations of the site. The resulting register of hazards was used to identify the dimensions of interface, causation and accumulation Table 8.4. The review of the initial register of hazards resulted in the classification of hazards using the following classifications, categories and hazard types which were specific to closed landfills (Table 8.2).

Table 8.2 The generic hazard classification with the respective hazard category and hazard type for the closed landfill site

Generic hazard classification	Hazard category	Hazard type
Economic	Macro	Greenhouse gas tax
	Financial	Economic use of land Financial provision Adequacy of indemnity Capital expenditure Maintenance costs
	Labour	Key person
Environmental	Air	Landfill gas Greenhouse gas Odour Noise Vibration
	Water	Ground water contamination Surface water contamination Leachate
	Land	Quality of land
	Ecosystem	Biodiversity Hares Livestock
Health and safety	Health	Chemical Disease Bodily injury
	Safety	Chemical Bodily injury Mechanical Labour skills
	Non compliance	Liability
	Human resource	Operator skills
Legal	Contractual	Indemnity Ownership Duty of care Access Agreement
	Third party liability	Loss of income Nuisance Damage to third party
Regulatory	Contaminated land regime	Compliance
	Regulator	Conflict of interest

Generic hazard classification	Hazard category	Hazard type
		Acceptance of phase 1 liability
	Regulatory regime	Compliance Changing regulations
Societal	Stakeholder	Conflict
	Reputational	Adverse stakeholder reaction Competence
Technical	Gas plant infrastructure	Maintenance Damaged infrastructure Performance Depreciation
	Engineering	Cap integrity Stability Drainage Noise Odour Vibration Performance
	Monitoring	Calibration Exit strategy
	Passive leachate management	Change in conditions Stability

8.4 Result of prioritisation

In preparation of the identification of the dimensions and production of registers for these dimensions it was necessary to prioritise the base register of hazards to obtain a comparable number of hazards to the pilot case study (Chapter 7). Table 8.3 provides a summary of the outcome of prioritising the base data, full details are in Appendix O.

Table 8.3 The number of high and medium generic hazards that result from the prioritisation of hazards using the parameters in Section 8.3.5

Generic hazard classification	Ranking		Total
	High	Medium	
Economic	5	3	8
Environmental	0	12	12
Health and Safety	3	9	12
Legal	0	3	3
Regulatory	0	3	3
Societal	0	2	2
Technical	2	7	9
Total	**10**	**39**	**49**

The rankings in Table 8.3 show there to be a higher number of economic risks compared to health and safety. This is due to a non-operational site with no public access; and the fact that the funding for the aftercare of the site is threatened by a fixed indemnity, which needs to be sufficient for an unknown period of time. The actual generic hazard IDs for the 49 hazards are presented in Table 8.4.

Table 8.4 Matrix of generic hazards with their respective Hazard IDs for the closed landfill site

Generic Hazard	Hazard ID												Total Number
	1	2	3	4	5	6	7	8	9	10	11	12	
Economic	30	31	32	33	34	35	36	37					8
Environmental	17	19	20	21	22	23	24	25	26	27	28	71	12
Health and safety	1	2	3	4	6	7	8	9	10	11	12	16	12
Legal	64	65	66										3
Regulatory	41	42	44										3
Societal	38	39											2
Technical	47	48	49	54	56	57	58	62	63				9
											Total		49

The hazard IDs in Table 8.4 will be used to process the interface hazards.

8.5 Identification and documentation of subsidiary registers

The subsidiary registers of hazards were compiled from the generic register of 49 hazards by filtering the data by stage of the lifecycle. This resulted in three registers, one for each phase of the lifecycle. Table 8.5 shows the components that comprise the different subsidiary registers.

Table 8.5 Matrix of subsidiary registers for each stage of the closed landfill lifecycle

Sub risk register reference	Phase of lifecycle	Chain component				
F.	Short term	Stability	Gas Management	Leachate management	Leachate and gas management	Aftercare
G.	Medium term	Stability	Gas Management	Leachate management	Leachate and gas management	Aftercare
H.	Long Term		Gas management		Leachate and gas management	Aftercare

The identification of the chain components highlight the concentration of hazards identified within the specific components. This is particularly useful in the identification of the chain component accumulation hazards. Highlighting the components at this stage of analysis illustrated gaps in the components, such as the fact there were no stability or leachate management hazards in the last phase of the lifecycle. The subsidiary registers facilitate the identification of hazards which occur at the same stage of the lifecycle and can be found in Appendix P.

8.5.1 Synthesis of subsidiary registers

The number of hazards for each generic hazard and phase of the closed landfill lifecycle using the subsidiary registers listed above are presented in Table 8.5. The results show a decline in the number of hazards over the lifecycle phases; short, medium and long term, which is to be expected as a result of reduced gas and leachate production. The declining production of landfill gas results in a negligible exposure to the residential housing on the periphery of the site. This results in a reduced exposure to health and safety, legal, societal and technical hazards. In preparation for the identification of interface hazards it was necessary to identify by Hazard ID the specific generic hazards, these are tabulated in Table 8.6. This would facilitate an orderly coupling of hazards.

Table 8.6 The number of hazards per generic classification for each stage of the lifecycle. Showing the Hazard ID for each subsidiary register

Generic classification	Hazard ID for short term (A)subsidiary register												Total number of hazards
Economic	30	31	32	33	34	35	36	37					8
Environmental	17	19	20	21	22	23	24	25	26	27	28	71	12
Health and safety	1	2	3	4	6	7	8	9	10	11	12	16	12
Legal	64	65	66										3
Regulatory	41	42	44										3
Societal	38	39											2
Technical	47	48	49	57	58	62	63						7
	Total												**47**
Generic hazards	**Hazard ID for medium term (B)subsidiary register**												
Economic	30	31	32	33	34	35							6
Environmental	17	19	20	21	22	23	24	25	26	27	28	71	12
Health and safety	1	2	3	4	6	7	9	10	11	12	16		11
Legal	64	65	66										3
Regulatory	41	42	44										3
Societal	38	39											2
Technical	47	48	49	57	58	62	63						9
	Total												**46**
Generic hazards	**Hazard ID for long term (C)subsidiary register**												
Economic	30	31	32	33									4
Environmental	17	26	28	71									4
Health and safety													0
Legal	64												1
Regulatory	41												1
Societal	38	39											2
Technical	47	58											2
	Total												**14**

8.6 Interface hazard identification

8.6.1 Method of interface hazard identification

The initial stage of deriving the interface hazard register is the compilation of subsidiary registers for each phase of the lifecycle as listed in Table 8.5. The assumptions set out in Chapter 6 with respect to interface hazards were adhered to. The resulting matrix of generic hazards are found in Appendix Q1 and summarised in Table 8.7.

Table 8.7 The number of interface hazards for each subsidiary register and their unique identification number

Subsidiary register	Number assigned		Number of hazards
	Start	Finished	
A Short Term	100	1073	973
B Medium Term	2000	2864	864
C Long Term	3000	3064	64
		Total number of hazards	**1901**

The process for compiling the interface register (see Section 6.4.1) was followed and a matrix of couplings from these frequently occurring hazards was produced see Table 8.8. The result was 195 couplings made up of the most frequently occurring hazards (Appendix Q1). The next step involved using the 195 resulting concurrent hazards and identifying those couplings that are the same by stage of lifecycle and chain component. This resulted in a register of 43 concurrent hazards (Appendix Q2).

Table 8.8 Matrix of frequently occurring couplings produced from the register of generic hazards for a closed landfill for the identification of interface hazards. (N= Not applicable as these couplings are a mirror image of remainder of the table.)

	GENERIC RISK FAMILY													
	ECONOMICS				ENVIRONMENT				LEGAL	REGULATORY	SOCIETAL		TECHNICAL	
	30	31	32	33	17	26	28	71	64	42	38	39	47	
30	N	N	N	N	N	N	N	N	N	N	N	N	N	
31	N	N	N	N	N	N	N	N	N	N	N	N	N	
32	N	N	N	N	N	N	N	N	N	N	N	N	N	
33	N	N	N	N	N	N	N	N	N	N	N	N	N	
17	3	3	3	3	N	N	N	N	N	N	N	N	N	
26	3	3	3	3	N	N	N	N	N	N	N	N	N	
28	3	3	3	3	N	N	N	N	N	N	N	N	N	
71	3	3	3	3	N	N	N	N	N	N	N	N	N	
64	3	3	3	3	3	3	3	3	N	N	N	N	N	
42	3	3	3	3	3	3	3	3	3	N	N	N	N	
38	3	3	3	3	3	3	3	3	3	3	N	N	N	
39	3	3	3	3	3	3	3	3	3	3	N	N	N	
47	3	3	3	3	3	3	3	3	3	3	3	3	N	
TOTAL NUMBER OF COUPLINGS	27	27	27	27	15	15	15	15	12	9	3	3	0	**195**

The results of the top 49 hazards from the initial register are 43 interface hazards (Appendix Q2). The compilation of the register of hazards and verification both on initial compilation and post prioritisation by both risk and landfill experts increased the validity and integrity of the base data. The method successfully identified interface hazards which were evidenced in a register adapted for a closed landfill.

The application of the method for the identification of interface hazards produced 1901 hazards. The first iteration of the interface hazards resulted in 195 hazards which when consolidated by looking at the most frequently occurring couplings produced 43 interface hazards. A summary of the additional cross-disciplinary hazards identified by the application of the interface method of identification for two concurrent hazards are presented in Table 8.9.

Table 8.9 Summary of the number of interface hazards identified from 49 generic hazards for a closed landfill

Dimension of Hazard	**Number of Hazards within Dimension**	**Total Number of Interface hazards**
Original register of hazards	71	-
Post prioritisation	**49**	-
Interface		
Portfolio A – short term	47	973
Portfolio B - medium term	46	864
Portfolio C – long term	14	64
Total first iteration		1901
Total second iteration		**195**
Consolidated		**43**

The total number of interface hazards is a function of the number of generic risk classifications and the number of hazards in each classification. The second column in the table shows that the reduction in initial hazards results in a reduction in interface hazards for each stage of the lifecycle. The first iteration includes all the interface hazards that result from the prioritisation of the hazards in the generic register of hazards (1901) and the second iteration shows the application of including only the frequently occurring hazards (195). The consolidation includes those interface hazards that occur across all the stages of the lifecycle (43). Table 8.8 shows that from an initial register of 71 hazards 49 hazards where ranked as high or medium 43 interface hazards of cross-disciplinary hazards were identified.

8.6.2 Results of interface hazard identification

A review of the interface hazards found that the method was applied as stated in Section 6. 4.1. However the method in Section 6.4.1 did not accommodate the prioritisation of risk based on whether the impact was high, medium or low as a result it was based on the frequency of the hazards across the lifecycle. This resulted in only 3 out of the 10 hazards which were ranked high being included in the hazards used to derive the interface dimension (Table 8.10). Additionally, 3 out of the 13 most frequently occurring hazards across all the stages of the lifecycle were used for the identification of interface hazards. With respect to the identification of interface hazards it suggests that further analysis of the residual interface hazards should take place and the inclusion of all high risk hazards should be added to the portfolio of hazards, which would be used to identify cross- disciplinary hazards.

Table 8.10 The hazards ranked as high risk in prioritisation of hazards for the closed landfill. The hazards included in the application of the interface method are highlighted in white.

		Stages of post closure life cycle			Classification			Characterisation	
ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
1	Gas Management	YES	YES		Health and safety	Safety	Chemical	Migration of landfill gas containing methane a combustible gas beyond the boundary which collects in the cellars of houses situated within 250 meters of the landfill.	Migration of landfill gas towards residential housing where there might be a source of ignition out of the control of the Class A polluters of the site. Hazard exists if the quality of methane is equal to or above 5% in the air the percentage of methane in landfill gas is likely to be much higher than this.
4	leachate management	YES	YES		Health and safety	Health	Chemical	Contamination of ground water from leachate.	Leachate becomes more concentrated as reduced rainfall reduces the efficiency of natural attenuation. It is possible that natural attenuation is no longer an acceptable method of management.
9	Gas Management	YES	YES		Health and safety	Safety	Chemical	The boundary of the site is less than 250 meters from residential housing.	Potential migration and collection of methane in residential housing.
31	Aftercare	YES	YES	YES	Economic	Financial	Financial provision	There is no financial provision for the aftercare of historic landfills. There is only an indemnity for this site.	The basis of the indemnity may not be adequate for the remediation and aftercare required for this site. This may result in additional and an unexpected annuity of costs.

		Stages of post closure life cycle			Classification			Characterisation	
ID NO	**Chain Component**	**Short Term**	**Medium Term**	**Long Term**	**GENERIC RISK CLASSIFICATION**	**RISK CATEGORY**	**RISK TYPE**	**RISK DESCRIPTION**	**HAZARD IDENTIFICATION**
32	Aftercare	YES	YES	YES	Economic	Financial	Economic use of land	The land does not provide any economic value for the Class A polluter. Economic value is only extracted by the owner and tenants at the expense of the Class A polluter.	Potential long tail liability which is not capable of financing within the existing indemnity and draws on the resources of Part II A polluter.
33	Gas and Leachate management	YES	YES	YES	Economic	Financial	Adequacy of indemnity	The current indemnity was put in place in 2006 to manage the gas and leachate on site. The requirements for aftercare have changed and the current indemnity may not be adequate for the length of time that remediation may be required.	Inadequate funding for aftercare requirements.
34	Gas management	YES	YES		Economic	Financial	Capital expenditure	Longer remediation period requires replacement of gas management infrastructure e.g. pump.	Increased cost
35	Aftercare	YES	YES		Economic	Financial	Maintenance costs	Increased maintenance costs with changing ownership and higher remediation standards over the period of remediation.	Increased cost
56	Gas management	YES	YES		Technical	Monitoring	Calibration	Offsite monitoring regime is not adhered to by the local authority and the corrective calibration of the gas management infrastructure is not possible due to lack of offsite information. This results in unmanaged gas migration.	Incomplete monitoring data

		Stages of post closure life cycle			Classification			Characterisation	
ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
57	Gas management	YES	YES		Technical	Monitoring	Exit strategy	Erratic monitoring regime does not provide consistency for the management and reporting of gas and leachate required to illustrate that there is a reducing risk to the environment and human health.	Site is unable to demonstrate a declining risk and so move towards satisfying the exit requirements for the Class A polluter.

An additional improvement to the interface method of cross-disciplinary hazard identification would be to apply the method for interface hazard identification to the pool of 10 hazards which were ranked as high risk in Table 8.10.

8.7 Causation hazard identification

8.7.1 Method

The lifecycle method of causation hazard identification successfully identified causation hazards and resulted in 452 additional hazards from the initial 49 hazards as summarised in Table 8.11. The full register for causation hazards is provided in Appendix R.

Table 8.11 Generic risks and resulting causation hazards by stage of the lifecycle

Subsidiary register	Number of initial risks with a defined hazard per sub risk register	Total number of hazards comprising causation linkages excluding initial hazard
Portfolio A = Short-term	47	208
Portfolio B= Medium Term	46	195
Portfolio C=Long-term	13	49
Consolidated total		<u>452</u>

8.7.2 Results

Analysis of the chains of causation for the landfill case study highlighted the importance of the indemnity to the continued aftercare of the site. Out of the 49 hazards, 10 hazards immediately required funding for management and the remainder require funding at some point in the chain of causation. It is clear that if the indemnity is insufficient to fund the aftercare requirements of this site there is the potential for it to become an abandoned site. The chains of causation illustrate the different points at which action could be taken to stop a hazard resulting in additional cost, reputational issues or non-compliance.

The difference in lifecycle is facilitated initially by the variation in the number of hazards that comprise the different stages of the lifecycle (Table 8.12). The chains of causation for the different stages of the lifecycle were presented as having the same chains of causation, with respect to the hazards in the respective lifecycle. However, this is unlikely to be the case as those hazards identified at the start of the short-term stage of the lifecycle would be at a different stage of development at the medium or long-term and so the initial hazard would be different. This would require the register to be updated to accommodate these changes.

Without a register of hazards it is difficult to see how decisions about effective allocation of funds can be made for the long-term management of the site and the prudent use of the indemnity. The consequence of inadequate funding for the aftercare is the greatest issue for this site and one which transcends all stages of the lifecycle. Most hazards result in a financial implication to the owner, past owner, tenant, residents, regulator or other stakeholder, as financing is required to take corrective action.

8.8 Accumulation hazard register

8.8.1 Method of accumulation hazard identification

As stated in Section 6.4.3 there are three different methods for synthesising the identification of accumulation hazards and all three were applied to post prioritisation register of hazards in the closed landfill.

Type 1 portfolio phases of the lifecycle accumulation hazards

The subsidiary risk registers shown in Table 8.5 are risk portfolios which comprise all the risks that occur at a specific stage of the closed landfill lifecycle. The accumulation registers for the three stages of the lifecycle are presented in Appendix S.

Table 8.12 List of subsidiary hazard registers and the applicable number of hazards which comprise the respective accumulation hazard pool.

Sub Registers	Number of hazards comprising the accumulation hazard
A Short term	49
B Medium term	45
C Long term	13

The table shows there are three accumulation hazards, one for each stage of the lifecycle. It also shows the number of hazards that comprise an accumulation hazard over the lifecycle declines. In this case study the potential impact of this accumulation hazard reduces as the number of high and medium hazards are reduced. The process of ranking hazards took place at one point in time it is possible that the hazards in the long-term stage of the lifecycle could change to medium or low. This would change the profile of the accumulation hazard for this case study.

Type 2 portfolio - transversal accumulation

A second accumulation portfolio results from hazards which occur at all the stages of the lifecycle. For the closed landfill there are three stages of the lifecycle and the maximum number of hazards across all the stages of the lifecycle is three. There are 13 hazards that occur across all stage of the lifecycle (Table 8.13).

Table 8.13 the Type 2 generic accumulation hazards

Generic classification	Generic hazard identification number
Economic	30, 31, 32, 33
Environmental	17, 26, 28, 71
Health and safety	None
Legal	64
Regulatory	42
Societal	38, 39
Technical	47
Total number of hazards	13

The following schedule of hazards was compiled from the generic register by applying the condition that all type 2 accumulation hazards occur in their respective stage and filtering the generic register of hazards to establish those hazards that are common to all stages of the lifecycle. The result was a list of 13 generic hazards which occur in all three stages of the post closure lifecycle and are presented in Table 8.14.

Table 8.14 composition of the Type 2 accumulation hazard

Risk ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
17	Aftercare	Y	Y	Y	Environmental	Land	Quality of Land	Land impaired by unidentified hotspots of pollutants.	Time and financial implications of additional remediation costs.

Risk ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
26	Aftercare	Y	Y	Y	Environmental	Waste	Hazardous waste	The site is supposed to have taken mainly building waste and wood rather than municipal waste as the permit was given back in 1993 no details are available. If the waste was building waste from the 1970s it is not inconceivable that asbestos was included in waste deposited at the site.	Hares and rabbits could disturb buried asbestos which could have a detrimental impact to human health.
28	Gas management	Y	Y	Y	Environmental	Air	Air quality	The management of landfill gas is the subject of a determination and its reduced impact on the environment is required for the Class A polluter to exit the gas management liability for this site.	Long term gas management costs and exposure
30	Aftercare	Y	Y	Y	Economic	Macro-economic	Tax	There is the potential that closed landfills will be subject to a greenhouse gas tax.	Unexpected additional costs with no revenue on which to offset it.
31	Aftercare	Y	Y	Y	Economic	Financial	Financial provision	There is no financial provision for the aftercare of historic landfills. There is only an indemnity for this site.	The basis of the indemnity may not be adequate for the remediation and aftercare required for this site. This may result in additional and an unexpected annuity of costs.
32	Aftercare	Y	Y	Y	Economic	Financial	Economic use of land	The land does not provide any economic value for the Class A polluter. Economic value is only extracted by the owner and tenants at the expense of the Class A polluter.	Potential long tail liability which is not capable of financing within the existing indemnity and draws on the resources of Part II A polluter.

Risk ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
33	Gas and Leachate management	Y	Y	Y	Economic	Financial	Adequacy of indemnity	The current indemnity was put in place in 2006 to manage the gas and leachate on site. The requirements for aftercare have changed and the current indemnity may not be adequate for the length of time that remediation may be required.	Inadequate funding for aftercare requirements.
38	Gas management	Y	Y	Y	Societal	Reputational	Adverse public reaction	Migration of gas to residential housing results in property blight and claims for compensation.	Property blight resulting from migration of gas.
39	Aftercare	Y	Y	Y	Societal	Stakeholder Relationship	Conflict	A breakdown in the relationship between the Part II A polluter, owners, tenants, and regulators could impact the safe management of the sites portfolio of risks at the heart of this is facilitating access to the site, active management and monitoring when required.	Breakdown in communication between all parties leads to inadequate management and monitoring.
42	Aftercare	Y	Y	Y	Regulatory	Regulatory regime	Compliance	The waste disposal licence was handed back in 1993 and as a result it is not subject to the landfill directive as it is not retrospective. There is uncertainty as to the potential impact of changing regulations on the compliance required for a site without a permit (historic landfill site) and uncertainty as to the regulations that apply. Much of the regulations are subjectively implemented.	Unknown compliance requirements and potentially escalating cost.

Risk ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
47	Aftercare	Y	Y	Y	Technical	Engineering	Cap integrity	There are no details as to the capping strategy so there is uncertainty as to the integrity of the cap and the exposure to disturbance of waste on site.	Questionable cap integrity
64	Aftercare	Y	Y	Y	Legal	Contractual	Ownership	Currently the Class A polluter has access to the site until 2016. The September 2011 quarterly review states that it will take many years before the site does not present further risk to the environment and human health. If access is not facilitated beyond 2016 the Class A polluter losses control of the remediation, cost of remediation and liabilities that result from migration of gas towards sensitive receptors.	Uncertainty results from loss of access after 2016 with respect to the quality of remediation and monitoring.
71	Aftercare	Y	Y	Y	Environmental	Land	Land Quality	Land quality impaired by mobilised and reactivated pollution due to increased flooding resulting from changing climatic conditions which were not accommodated in the remediation plans or aftercare.	Increased flooding mobilises previously ring-fenced pollution hotspot.

The contents of Table 8.14 shows that the majority of hazards are aftercare components (10). These are the hazards that continue through to the long-term phase of the lifecycle. This is confirmed in Table 8.15 where the number of hazards are 13, made up of 10 aftercare hazards and 3 gas related hazards. With respect to a closed landfill there are unlikely to be any additional hazards at the end of its lifecycle as the objective is to remediate the site back to a level of providing public amenity.

Type 3 portfolio component accumulation hazards

The component accumulation hazards are identified in the closed landfill register by applying the filter in the relevant lifecycle spread sheet to the chain component and obtaining registers from each of the five components/ modules. Table 8.15 shows the concentration of component hazards over the lifecycle.

Table 8.15 Type 3 portfolio accumulation hazards for each stage of the lifecycle

Chain component	**Number of hazards in chain component accumulation portfolio**		
	Short term	**Medium term**	**Long term**
Gas management	**18**	**18**	**3**
Leachate management	**7**	**7**	**0**
Aftercare	**21**	**18**	**10**
Total number of risks	**46**	**43**	**13**

The table above shows the decline in the number of hazards over the lifecycle of the closed landfill. It shows that the majority of hazards are aftercare hazards and it also shows that the leachate management component is not an exposure in the long-term which would be expected as natural attenuation should be complete. Gas management exposures show a significant reduction over the lifecycle which significantly reduces the exposure to residential housing. The result of these two reductions leaves the on-going aftercare exposure which is mainly concerned with the ability of the indemnity to have sufficient funds to maintain the aftercare which is the greatest exposure of this site. Three aftercare hazards were excluded from the medium term portfolio as they were ranked as low risk by the consultant during the review and are presented in Table 8.16.

Table 8.16 The three aftercare hazards reclassified as low risk and excluded from the generic register of hazard

		Phases of post closure lifecycle			Classification			Characterisation		Prioritisation of risks
Risk ID	**Chain Component**	**Short Term**	**Medium Term**	**Long Term**	**GENERIC RISK CLASSIFICATION**	**RISK CATEGORY**	**RISK TYPE**	**RISK DESCRIPTION**	**HAZARD IDENTIFICATION**	**High Medium and Low**
8	Aftercare	YES			Health and safety	Health	Disease	Respiratory disease is a potential latent exposure to past employees and occupants in residential housing on the periphery of the site from the landfill. The exposure results from the operational phase of landfill and the range of microbes and microbial activity in the landfill waste.	Exposure to microbes capable of triggering respiratory disease	**M**
36	Aftercare	YES			Economic	Financial	Funding	Inability to raise cheap finance on a site which has pre-existing conditions.	Increased cost of finance	**M**
37	Aftercare	YES			Economic	Labour	Key person	Knowledge of site is with key person. Replacement personnel may have insufficient knowledge of site specific issues.	Technology and safety exposure.	**M**

One leachate and gas hazard (33) was identified in the initial register of hazards, and this was included in the gas management portfolio. One stability hazard was identified (48), which could result in a catastrophic incident but does not result in an accumulation exposure as it is not in a group of other identified hazards. It could trigger other events and therefore would need further investigation. This should be addressed in the chain of causation. Unlike the other pools of hazards the components are not additive they have to remain in their components as the objective of this accumulation hazard is to look at where hazards are concentrated within the specific components and identify components at risk. Those hazards that traverse all components have the potential to trigger and create accumulation hazards that could result in a catastrophic loss, impact or event. The gas management and aftercare components also contain hazards which traverse all stages of the lifecycle; this resulted in two subsidiary component registers as presented in Table 8.17.

Table 8.17 Register of gas management component that traverse all stages of the lifecycle

Gas Management		Phases of Post closure lifecycle			Classification			Characterisation		Prioritisation of risks
RISK ID NO	**Chain Component**	**Short Term**	**Medium Term**	**Long Term**	**GENERIC RISK CLASSIFICATION**	**RISK CATEGORY**	**RISK TYPE**	**RISK DESCRIPTION**	**HAZARD IDENTIFICATION**	**High=H Medium =M**
28	Gas management	YES	YES	YES	Environmental	Air	Air quality	The management of landfill gas is the subject of a determination and its reduced impact on the environment is required for the Class A polluter to exit the gas management liability for this site.	Long term gas management costs and exposure	**M**
33	Gas and Leachate management	YES	YES	YES	Economic	Financial	Adequacy of indemnity	The current indemnity was put in place in 2006 to manage the gas and leachate on site. The requirements for aftercare have changed and the current indemnity may not be adequate for the length of time that remediation may be required.	Inadequate funding for aftercare requirements.	**H**
38	Gas management	YES	YES	YES	Societal	Reputational	Adverse public reaction	Migration of gas to residential housing results in property blight and claims for compensation.	Property blight resulting from migration of gas.	**M**

This table shows that the three hazards all have financial implications. The central hazard is the adequacy of funding for aftercare as without this it would be difficult to manage long-term gas management and property blight. Both of these hazards require financial management. With respect to the aftercare accumulation register in Table 8.18, a significant amount of calibration is required to ensure that access is maintained to facilitate economic and effective aftercare so that best value is obtained from the existing indemnity. This is highlighted by the characterisation of hazards in Table 8.18.

Table 8.18 Aftercare accumulation register for a closed landfill

After care		Phases of post closure lifecycle			Classification			Characterisation		Prioritisation of risks
RISK ID NO	**Chain Component**	**Short Term**	**Medium Term**	**Long Term**	**GENERIC RISK CLASSIFICATION**	**RISK CATEGORY**	**RISK TYPE**	**RISK DESCRIPTION**	**HAZARD IDENTIFICATION**	**High=H Medium =M**
17	Aftercare	YES	YES	YES	Environmental	Land	Quality of Land	Land impaired by unidentified hotspots of pollutants.	Time and financial implications of additional remediation costs.	**M**
26	Aftercare	YES	YES	YES	Environmental	Waste	Hazardous waste	The site is supposed to have taken mainly building waste and wood rather than municipal waste as the permit was given back in 1993 no details are available. If the waste was building waste from the 1970s it is not inconceivable that asbestos was included in waste deposited at the site.	Hares and rabbits could disturb buried asbestos which could have a detrimental impact to human health.	**M**
30	Aftercare	YES	YES	YES	Economic	Macro-economic	Tax	There is the potential that closed landfills will be subject to a greenhouse gas tax.	Unexpected additional costs with no revenue on which to offset it.	**M**

After care		Phases of post closure lifecycle			Classification			Characterisation		Prioritisation of risks
RISK ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION	High=H Medium =M
31	Aftercare	YES	YES	YES	Economic	Financial	Financial provision	There is no financial provision for the aftercare of historic landfills. There is only an indemnity for this site.	The basis of the indemnity may not be adequate for the remediation and aftercare required for this site. This may result in additional and an unexpected annuity of costs.	H
32	Aftercare	YES	YES	YES	Economic	Financial	Economic use of land	The land does not provide any economic value for the Class A polluter. Economic value is only extracted by the owner and tenants at the expense of the Class A polluter.	Potential long tail liability which is not capable of financing within the existing indemnity and draws on the resources of Part II A polluter.	H
39	Aftercare	YES	YES	YES	Societal	Stakeholder Relationship	Conflict	A breakdown in the relationship between the Part II A polluter, owners, tenants, and regulators could impact the safe management of the sites portfolio of risks at the heart of this is facilitating access to the site, active management and monitoring when required.	Breakdown in communication between all parties leads to inadequate management and monitoring.	M
42	Aftercare	YES	YES	YES	Regulatory	Regulatory regime	Compliance	The waste disposal licence was handed back in 1993 and as a result it is not subject to the landfill directive as it is not retrospective. There is uncertainty as to the potential impact of changing regulations on the compliance required for a site without a permit (historic landfill site) and uncertainty as to the regulations that apply. Much of the regulations are subjectively implemented.	Unknown compliance requirements and potentially escalating cost.	M

After care		Phases of post closure lifecycle			Classification			Characterisation		Prioritisation of risks
RISK ID NO	Chain Component	Short Term	Medium Term	Long Term	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION	High=H Medium =M
47	Aftercare	YES	YES	YES	Technical	Engineering	Cap integrity	There are no details as to the capping strategy so there is uncertainty as to the integrity of the cap and the exposure to disturbance of waste on site.	Questionable cap integrity	M
4	Aftercare	YES	YES	YES	Legal	Contractual	Ownership	Currently the Class A polluter has access to the site until 2016. The September 2011 quarterly review states that it will take many years before the site does not present further risk to the environment and human health. If access is not facilitated beyond 2016 the Class A polluter losses control of the remediation, cost of remediation and liabilities that result from migration of gas towards sensitive receptors.	Uncertainty results from loss of access after 2016 with respect to the quality of remediation and monitoring.	M
71	Aftercare	YES	YES	YES	Environmental	Land	Land Quality	Land quality impaired by mobilised and reactivated pollution due to increased flooding resulting from changing climatic conditions which were not accommodated in the remediation plans or aftercare.	Increased flooding mobilises previously ring-fenced pollution hotspot.	M

8.8.2 Results of accumulation hazard identification

The resulting three methods of identifying accumulation hazards produced eight hazards (Figure 8-3).

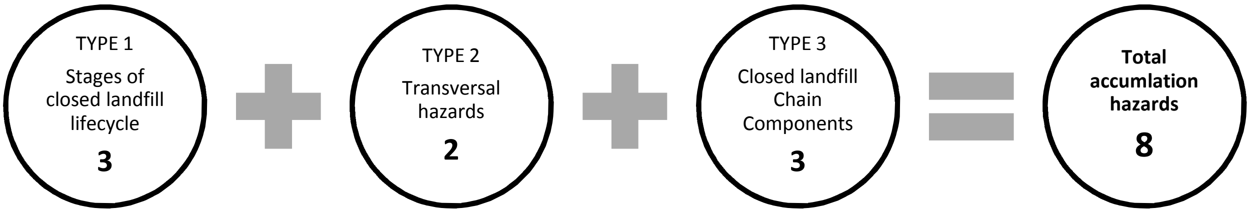

Figure 8-3 The number and composition of the different accumulation hazard portfolios for closed landfill

The three methods for identifying the accumulation hazards were successfully applied to the 49 hazards identified as generic hazards. The method identified seven accumulation hazards Figure 8-3. Table 8.19 provides a summary of the identified accumulation hazards. The table shows that where a component has one hazard this is not accepted as an accumulation hazard, as previously stated an accumulation hazard is a portfolio of hazards. That is not to say that a significant event would not happen as a result of one hazard for example the stability hazard. The purpose of this research is to identify cross-disciplinary hazards and this cannot occur with one hazard.

Table 8.19 Summary of identified accumulation hazards

Subsidiary register	**Number of hazards within dimension**	**Number of accumulation hazards**
Portfolio A Short term	49	1
Portfolio B Medium term	45	1
Portfolio C Long term	13	1
Components		
Gas Management	18	1
Leachate	7	1
Stability	1	0
Aftercare	21	1
Transversal consolidated		
Aftercare	10	1
Gas management	3	1
Total number of hazards		8

The synthesis of the 49 generic risks resulted in the following additional hazards; 43 interface hazards, 452 causation hazards and 8 accumulation hazards.

The accumulation hazards for the closed landfill are comprised of portfolios of hazards from a wide range of generic hazards. These portfolios provide an environment for cross-disciplinary hazard identification whether this is via the subsidiary / lifecycle registers, transversal or the components. These cross-disciplinary hazards are presented in registers in Appendix S, T and U.

8.9 Problems issues and developments of applying the method to the closed landfill

The main issues that arose from the application of this method were with the preparation of the generic register. It was clear that a significant amount of expert knowledge was required to identify the hazards and to verify the results of the identification. The expert knowledge was required to assess the stages of the lifecycle and chain components. This problem was overcome in this case study by engaging the expert who has managed this site from the end of the 1990s and is experienced in managing the operational and aftercare requirements as a consultant for a large portfolio of landfills in the UK.

Prioritisation of the hazards was the greatest challenge because of the impact of the changing profile on the dimensions as a result of inclusion in the post prioritisation register of hazards. This was illustrated by the downgrading of the three aftercare hazards from medium to low (Table 8.16). The process of prioritisation also highlighted the subjectivity of the prioritisation process based on the person who compiled the register and the person reviewing the register. The prioritisation was reviewed by the consultant to the site who would have different considerations compared to an underwriter who would prioritise based on different criteria and have a different appetite for risk. The different experiences of the experts are likely to provide different results. The underwriter is likely to be more risk averse than the consultant as he has more detailed knowledge of the site.

The stability hazard (ID48 in Appendix S) highlighted the issue of a single hazard that can trigger multiple hazards and have catastrophic implications. This is in conflict with the accumulation requirement (Section 6.4.3) for a number of risks to occur within a short space of time. This hazard was excluded as an accumulation hazard but is highlighted in the causation. However with respect to interface hazard identification the stability hazard did not occur as a hazard across the three phases of the lifecycle but if the method included the hazards that had a high ranking it would be included. This method highlights the need for a level of expert knowledge to identify hazards which should be traced throughout the application of the dimensions to obtain its multidimensional impact. As a result of the dimensions it is possible to illustrate the potential impact of this individual hazard through interdependency and the chain of causation.

When a component descriptor covers two components such as leachate and gas management hazard (ID33 in Appendix N), there needs to be an appropriate means of incorporating it into a suitable existing component group. As there was only a component group for gas management it was included within that grouping, however, it would also have been included in a group for leachate if present. Further investigation into the proportional composition of the hazard would need to take place if that was the case. Alternatively it highlights the need to have component groupings which are singular in the component description.

The accumulation dimensions in respect of transversal gas management highlighted the issue of the minimum number of hazards that should be included in an accumulation portfolio. This has to depend on the individual hazards, their potential impact and would require further investigation of the hazards and context. In this case three hazards were initially not considered sufficient for an accumulation hazard but on closer inspection the three hazards are linked and it is feasible for them to all occur within a short period of time.

This case study facilitated the development of the method to produce the register of hazards prior to the application of the method highlighted in Chapter

6. These developments included gaining access and preparation of the original data, site visits, prioritisation, validation and presentation of the data in the generic register template outlined in Chapter 6.

8.10 Validation of case study results

To validate the closed landfill case study results, a meeting was held with the consultant who has managed the long-term aftercare of the site. The purpose of the meeting was to confirm that the application of the hazard identification method provided value to the expert. Value was defined as:

- The identification of hazards which have not previously been identified,
- A practical method providing a mechanism for management of hazards throughout the lifecycle,
- Presentation of the identified dimensions of hazards in a register format that is easy to use and provides tangible information on the qualitative characterisation of the hazards.

The meeting was structured in four sections which related to the identification of the four dimensions (Appendix BB2).

8.10.1 Generic hazard identification and prioritisation

After compiling the initial register of 71 hazards, a scale for categorising the hazards was applied as stated in Section 8.3.5. The consultant was asked to comment on the method used to prioritise the hazards. The consultant stated that the rationale for prioritisation of the generic hazards (using the descriptors high, medium and low) was plausible and the criterion applied to the descriptors was acceptable. As a result no changes were suggested to the existing scale descriptors or parameters.

The consultant suggested that the attributes of frequency and severity could be added as parameters. This would be acceptable if data was available to provide an indication of these parameters. Additionally this research is focused on characterisation of hazards using qualitative data and not on the quantitative attributes of the hazard.The focus is on identification of hazards not on the severity or frequency of a hazard as a means of identification. The consultant reviewed the 71 hazards in the initial register and confirmed that 3 hazards which were designated as medium should be rated as low. This change was made and resulted in a register of 49 hazards. The consultant confirmed the 49 hazards used for the identification of interface, causation and accumulation as a fair reflection of the hazards that would result from the close landfill.

8.10.2 Interface dimension

The methodology for deriving the interface dimension was explained to the consultant and the resulting consolidated register shown (Appendix Q). The consultant stated that he did not foresee any issues with the method and the resulting interface risks were feasible as they were derived from the original 49 risks in the generic register. When the consultant was asked if he would use this methodology he stated that he would “as it would be of value to operators in planning for the future”. The merits of using this methodology in respect of the current requirements of the regulator (Environment Agency) according to the consultant are:

1. the regulator wants operators to be proactive in their hazard identification;
2. the regulators would also like to see evidence of planning and assessment of risk ahead of the risk occurring;
3. the consultant felt that once set up cost savings could result by allocating resources where they may have the greatest mitigation and facilitating planning; and
4. the identification of the interface dimension may enable improved comprehensive corporate social reporting.

The consultant suggested that there may be issues with the practical application of this method. The regulator would need to audit the method to ensure that it was acceptable and did not have unidentified downside risks. Additionally, small companies will not be able to afford the time or expertise to synthesis the data.

8.10.3 Causation hazard

The consultant found no issues with the methodology used to identify the causation dimension. With respect to the feasibility of the resulting causation risks, these were seen as feasible and valuable as "it forces the individual to think what could subsequently happen once the initial hazard has occurred". The consultant saw the method for this dimension as one which he would use. The suggested advantages of using this causation identification method are that it adds value by prompting forward thinking as an individual and a group. The consultant suggested that the information and method were required for permitting/ risk management of new waste sites. Problems that need to be addressed are the timing of the components of a chain of causation, as in some cases, the subsequent hazard will be a function of time. Additionally the likelihood of whether these hazards are likely to occur as well as severity will need to be taken into account.

8.10.4 Accumulation hazards

There were no issues with the method applied to derive the accumulation hazards. The consultant felt the resulting hazards were feasible in so far as they were derived from the generic register of 49 hazards. The consultant stated that he would use this method of identification for accumulation hazards. The merits of using this methodology were that the components for the accumulation hazard have already been identified and are feasible as a result it may be more realistic than brainstorming scenarios. The consultant stated he felt that the main difficulty was that this approach to risk was so different that initially it may be difficult for the logic to be followed by the layman. As a result simplification of the method may be required if it is to be used.

9 CASE STUDY 3 - CLIMATE CHANGE ADAPTATION

9.1 Background

The Climate Change Act 2008 (CCA) provided the impetus for the Statutory Climate Change Adaptation Program implemented by Defra to aid adaptation reporting powers. Reporting authorities (RA) of key national infrastructure were requested to provide an assessment of the current and future impacts of climate change in relation to the reporting authority's functions. The definition of a reporting authority includes; statutory undertakers, utility companies and organisations carrying out functions of a public nature (CCA, 2008). Authorities were specifically asked to report on:

- The assessment of current and predicted climate change impacts on the authorities functions;
- Provide details in the form of a statement of proposals and policies to be used to employ adaptation in expediting the authority's function; and
- A time-frame for advancing the adaptation policies and procedures (CCA, 2008).

Guidance and tools to aid the production of the climate change risk assessment (CCRA) report were provided by various sources (see Table 9.1) for use by the reporting authorities.

Table 9.1 List of guidance and tools made available to reporting authorities to aid the production of CCRA (CCRA, 2012)

Guidance	Tools
Statutory Guidance to reporting Authorities 2009 (Defra, 2009)	Adaptation wizard for climate change adaptation (UKCIP, 2010)
Environment Agency's supplementary guidance (EA, 2006)	Adaptation plan
Frequently asked questions (Defra, 2010) Cranfield Evaluation Framework	UKCP09 (UKCIP, 2009)

The resulting assessment had to include: a summary of statutory and other identified functions; an outline of the methodology used to assess impacts in relation to these functions and results of the climate change impact assessment on the identified functions.

This case study is based on documents provided by an RA in a highly regulated industry sector of strategic importance in terms of the infrastructure and service it provides. The RA is one of the major providers of water and waste water services in the UK, covering an area of 21,000 km^2 and serving 7.8 million customers (CCRA, 2011). The identified functions of this organisation are firstly to provide a continuous supply of quality water and secondly, treat waste water effectively. The key strategic intentions, planning requirements, operational priorities and investment drivers are set out in Figure 9-1 and the challenges associated with climate change are embedded in each of these. Additionally the organisation has identified three main constraints to its activities: climate change impacts; the ability to accommodate an expanding and changing population; and protection of the environment and natural resources.

The RA stated that climate change is incorporated in the RA Enterprise Risk Management Framework, used to implement corporate risk management (CCRA, 2011). The key activities for the RA are: water, waste water and support services as identified in the RA CCRA report.

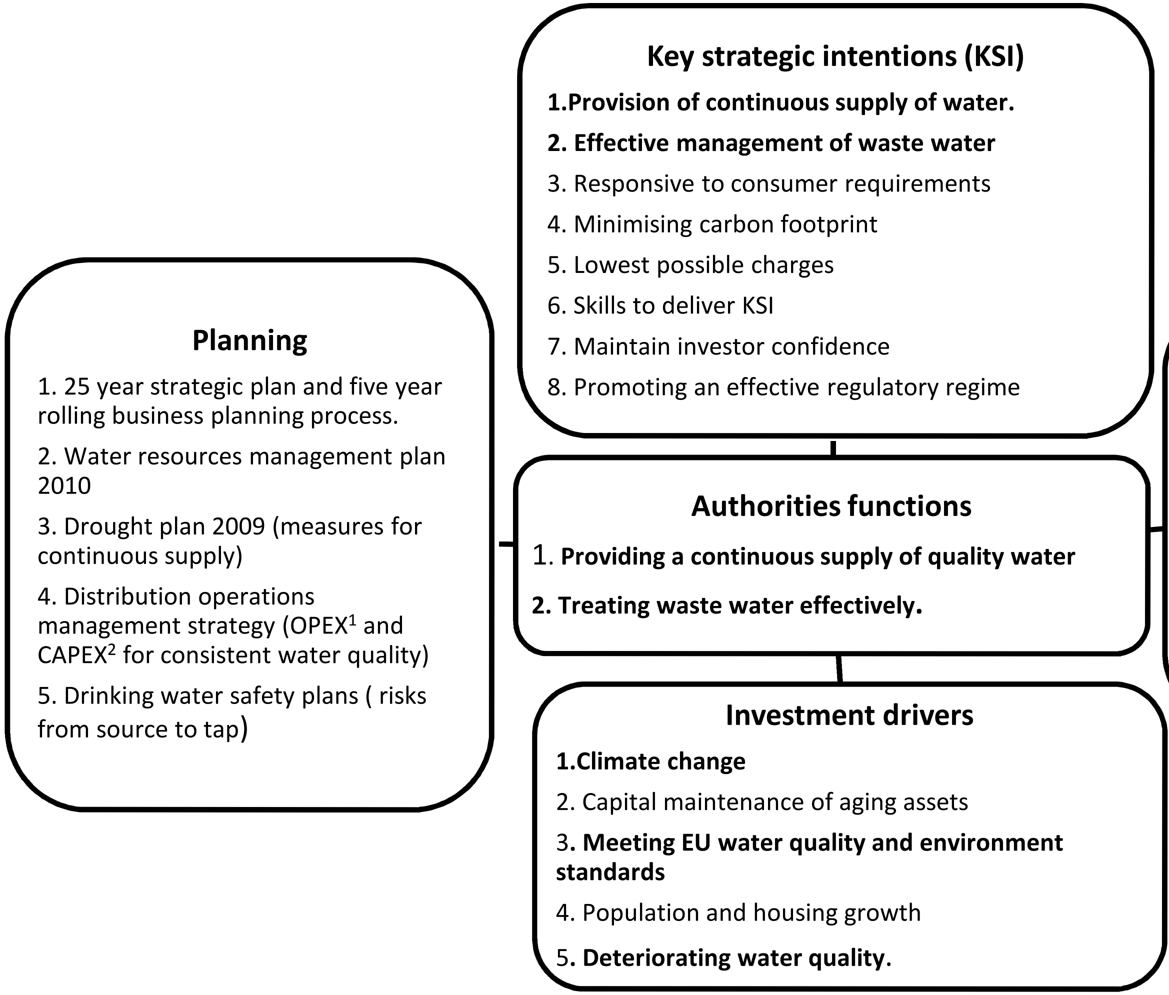

Figure 9-1 The key functions, investment drivers, operational priorities plans and strategic initiatives within which climate change adaptation has to be managed (Where [1]= operational expenditure [2] = capital expenditure; factors highlighted in bold are impacted by climate change)

Climate change adaptation is an essential requirement for the short term and long term commercial viability of RA. Water is the primary resource which is being provided without the primary resource there is no service and therefore no revenue for the RA. The rationale for using the RA climate change risk assessment was to establish if the method for the identification of hazards (Chapter 6) and developed in the case studies (Chapter 7 and 8) could be applied to a climate change risk assessment as required under Climate Change Act 2008 (CCA). The rationale for using the RA publically available report was that the data had been verified and validated by the company, and used by Cranfield University as part of its bench-marking exercise (Drew et al., 2010). Additionally the report provided a detailed register of climate adaptation risks for each of its business units in the appendix to the CCRA.

9.2 Method specific to this case study

9.2.1 Data for derivation of a register of hazards for climate change hazard assessment

The data for the register of climate change hazards was provided by the RA in a Climate Change Adaptation Report in response to a government request under the Climate Change Act (2008). The report by the RA provided details of the method used to produce the register of climate change risks for the climate change risk assessment and an overview of the risks and operations of the business units: water services, wastewater services and support services. Details of the uncertainties and assumptions made in the data, strategy for managing climate change and consideration of stakeholder engagement were also included. As requested by Defra, dependencies and interdependencies were addressed along with barriers to implementing the adaptation programme although not included in the register.

The data required to derive a register of hazards for climate change was contained in the report, which included registers for each of the business units; water, waste and support services.

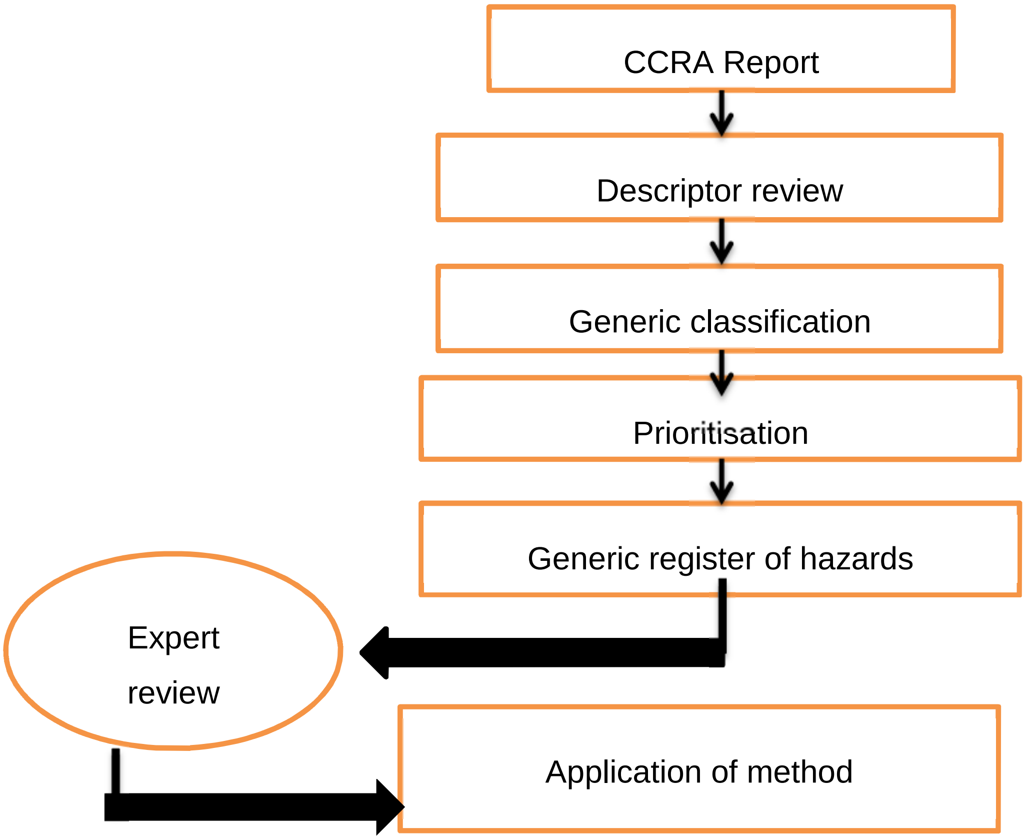

Figure 9-2 Steps involved in preparing the generic register of hazards from the CCRA report

9.2.2 Review of base data

The review of the base data commenced with a comparison of the parameters for the risk assessment registers for each of the business units highlighted in Figure 9-2. The water and waste water units followed a similar structure but the support services business unit did not provide data on asset levels 2 and 3 or the pedigree of data (Table 9.2). Asset Levels 2 and 3 refer to the infrastructure components of the water business unit. These are explained and compared in Section 9.2.5.

Table 9.2 The data descriptors applied to the water, wastewater and support services business for the RA

Descriptor	Business units of the RA		
	Water	**Wastewater**	**Support services**
Reference	**YES**	**YES**	**YES**
Climate effect	**YES**	**YES**	**YES**
Climate impact	**YES**	**YES**	**YES**
Consequence	**YES**	**YES**	**YES**
Asset level 2	**YES**	**YES**	**NO**
Asset level 3	**YES**	**YES**	**NO**
Threat/ Opportunity/ Neutral	**YES**	**YES**	**YES**
Proximity	**YES**	**YES**	**YES**
Likelihood	**YES**	**YES**	**YES**
Total	**YES**	**YES**	**YES**
Population	**YES**	**YES**	**YES**
Severity	**YES**	**YES**	**YES**
Total	**YES**	**YES**	**YES**
Overall risk rating	**YES**	**YES**	**YES**
Pedigree of data	**YES**	**YES**	**NO**
Confidence	**YES**	**YES**	**YES**
Comments	**YES**	**YES**	**YES**
Data/ Evidence source	**YES**	**YES**	**YES**
Climate drivers	**YES**	**YES**	**YES**

The focus of this report was the provision of information on climate adaptation. The three descriptors that relate to climate change are: 1. climate effect; 2. climate impact; and 3.climate drivers. It is critical to the subsequent synthesis of data for hazard identification that these parameters have been applied consistently.

9.2.3 Climate change specific descriptors

The climate effect

The water business unit used the descriptors in UKCP09 (summarised in Table 9.3) and took into account the two different time periods (i.e. to 2050s and 2080s) over which climate change affects have been modelled for climate effect. Figure 9-3 shows the seven 30 year time periods for which projections have been provided.

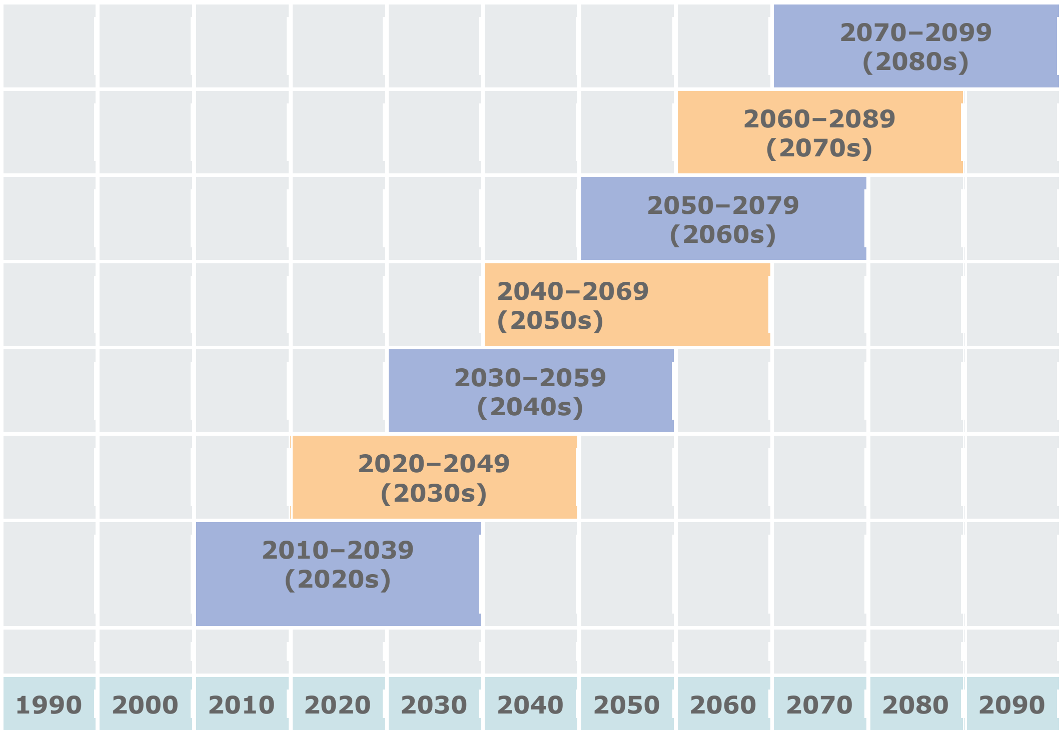

Figure 9-3 The seven time periods used to provide scenarios for the projection of climate change impact (adapted from UKCP09; http://ukclimateprojections.defra.gov.uk/22915)

Each time period has projected scenarios for temperature, precipitation, and emissions for a specific geographic location. The CCRA has taken the 2050s and the last decade the 2080s.

Table 9.3 UKCP09 descriptors used by the water business unit for climatic effects

Descriptor	**Year**		**Emissions**	
	2050	**2080**	**Medium**	**High**
Drier summers	√	√	√	√
Extreme higher temperatures	√	√	√	√
Warmer summers	√	√	√	√
Warmer winters	√	√	√	√
Wetter winters	√	√	√	√

The three descriptors used for climate effect for the waste unit did not include a time period or level of emissions. They were; lower precipitation infiltration and inflow plus water conservation, higher winter precipitation intensities, and high temperature.

The support services business unit used the following 21 different climatic effects;

- Hotter drier summers
- Higher average summer temperatures
- Higher average temperatures
- Higher temperatures and longer growing seasons
- Higher average temperatures and increase hours of sunshine plus lower cloud cover.
- Higher average winter temperatures
- Wetter, warmer atmosphere
- Warmer winters/ decreased snowfall.
- Higher average hours of sunshine
- Increased localised flooding
- Reduced raw water available coupled with increased localised flooding
- Variations in water quality
- Increased precipitation and intensity
- Increased precipitation leading to increase flooding
- Increased incidence of extreme precipitation events
- Increased storm conditions, extremes of weather
- Increased windstorm/ gales
- Increased magnitude of extreme winter events
- More extreme weather events, increase in wind.
- Increase in tropical air borne disease
- Windstorm/ gales

The lack of uniform application of the climate effect descriptors, illustrates a lack of consistency in the descriptors used for climatic effect across the three business units. This made it impossible to provide a consolidated register for the three business units that comprise the RA for the specific objective of climate adaptation. Each parameter for every business unit was not the same, therefore there was not a uniform climate on which to base a consolidated position for the RA. The water subsidiary, wastewater and support services provided results based on different climate descriptions.

Climate drivers

A climate driver is defined as including precipitation, temperature, and evaporative demand (determined by net radiation at ground level, atmospheric humidity, wind speed, and temperature) for water availability (IPCC, 2007). When the climatic drivers for each of the business units were compared there was no consistent application across the business units. Table 9.4 shows that although it may be possible to align the water and waste units, the support services descriptors did not fit either water or waste drivers. The support services also introduced the descriptors of wind and weather variability which was not explicitly included in either the water or waste units.

Table 9.4 Comparison of the climatic drivers used in the CCRA registers for the three different business units Source adapted from CCRA, 12)

Water	Waste water	Support services
Increased winter precipitation	High winter precipitation	Change in summer temperature and precipitation
Increased winter mean temperature	High temperature	Winter temperature and precipitation
Increased summer mean temperature		Changes in annual, seasonal or daily precipitation
Increase winter minimum daily temperature		None provided
Summer maximum daily temperature		None provided
Decreasing summer precipitation	Low summer precipitation	None provided
None provided	None provided	Increasing variability of weather
None provided	None provided	Changing wind patterns

The approaches taken may suit the individual business units but the climate descriptions should be consistent for all business units, as there will only be one climate impact being experienced in the same region which impacts all three business units. Whilst this research project is not focused on the CCRA process, this inconsistency is noted and descriptions which are similar will be paired across the business units. However, as a result of the inconsistencies this parameter cannot be used to consolidate the business units of the RA.

Water and wastewater activities focus only on temperature and precipitation as mutually exclusive drivers for two seasons, winter and summer. Support services have focused on variability of temperature, precipitation across the seasons. Wind is not included in either of the operational units of the RA and no comment has been identified on wind or the efficient working of infrastructure for either wastewater or water business units, however it is included in support services.

Climate impact

The climate impact parameter in the RA data is a function of the climate effect and the operations carried out by the business unit. Therefore it is unlikely that there are consistencies across the three business units due to inconsistencies in the climate effect descriptors. In order to apply the method of hazard identification to the data provided in the climate change assessment the business unit which adhered to the UKCP09 descriptors was chosen as the unit to apply the model. As a result all reference to the CCRA report will relate to the data and register for the water services business unit.

9.2.4 Risk identification number

The original risk IDs were retained when the generic register of hazards was compiled. Throughout this case study only the RA ID numbers will be used.

9.2.5 Chain component

The CCRA report was not consistent in the identification of the components that comprise the water service activities Table 9.5 shows the activities highlighted in the CCRA report.

Table 9.5 The activities highlighted in CCRA Report for the water services business unit

Activity as expressed CCRA	Commercial function of activity
Power supplies	Externalities required for water services to operate
Supply chain	
Distribution meter areas	Demand
River	Supply
Distribution storage	
Raw storage reservoir	
Distribution pumping	Distribution
Strategic aqueducts	
Abstraction - Ground water - As a result the Potable - Agricultural	
Sewage works discharge	Treatment and quality management
Agricultural pollution	
Treatment works	

The activities expressed in the register as Asset Levels 2 and 3 in Table 9.6 were not compatible with those in Table 9.5.

Table 9.6 The composition and relationship between Asset level 2 and Asset level 3 activities

Asset Level 2	Asset Level 3 = chain component
Water resources	All
	Borehole Abstractions
	Borehole pumping stations
	Borehole / Reservoirs
	Boreholes
	Distribution Pipes
	Raw water reservoirs, service reservoirs, water treatment works
	Reservoirs
	River abstraction /Reservoirs /Boreholes
	Water treatment works
Water network	Chlorine boosters, service reservoirs, distribution mains
	Pressure boosters, service reservoirs, distribution mains
Water treatment	River abstraction

The components that were applied in the generic hazard register were those designated as Asset Level 3. These were the lowest level attributable to an asset and thus should result in less ambiguity in the actual component within the activity of water services (Table 9.6). The component described as "All" refers to the fact that the hazards relate to all the parts of the water services i.e. water resources, water network and water treatment.

9.2.6 Stages of the lifecycle

The climate effects are identified as the 20 scenarios stated in UKCP09. These were used as the stages of the lifecycle for the register of climate change hazards (Table 9.7).

Table 9.7 The 20 scenarios used as the stages of the lifecycle for the register of climate change adaptation hazards (CCRA, 2012)

Season description	Time frame	Emissions
Drier summers	2050	Medium
Drier summers	2050	High
Drier summers	2080	Medium
Drier summers	2080	High
Extreme higher temperatures	2050	Medium
Extreme higher temperatures	2050	High
Extreme higher temperatures	2080	Medium
Extreme higher temperatures	2080	High
Warmer summers	2050	Medium
Warmer summers	2050	High
Warmer summers	2080	Medium
Warmer summers	2080	High
Warmer winters	2050	Medium
Warmer winters	2050	High
Warmer winters	2080	Medium
Warmer winters	2080	High
Wetter winters	2050	Medium
Wetter winters	2050	High
Wetter winters	2080	Medium
Wetter winters	2080	High

The definition for emissions used in the CCRA report refers to the projected levels of greenhouse gases and other aerosols. The IPCC special report on emission scenarios (IPCC, 2000) is the basis of the UKCP09 projections which puts forward three emissions scenarios for greenhouse gases; (1). high, (2).medium and (3).low. The RA used only the medium and high levels of emissions in the CCRA.

9.2.7 Generic Classification

The hazards designated as threats were classified using the generic classifications of economic, environmental, health and safety, legal, regulatory societal and technical as set out in Section 6.2.2.3.

9.2.8 Prioritisation of risks

The initial number of risks in the water services register was 52. These risks were categorised by the RA as threats, opportunities or neutral where neutral was neither a threat nor an opportunity. The objective of this research is the identification of hazards, therefore only those risks categorised as threats were included in the generic register of hazards. As a result the post prioritisation of the generic register of hazards comprised of 45 hazards.

9.2.9 Structure of the register of hazards

The review of the base data in the CCRA required the structure of the template for the register of generic hazards (Section 6.3.2) to be adapted to include the 20 stages of the lifecycle listed in Section 9.2.6. An example of the structure is presented in Figure 9-4.

RISK ID NO	RA Original reference	Chain Component = asset level 3	Drier Summers (2050's medium emissions)	Drier Summers (2050's high emissions)	Drier Summers (2080's medium emissions)	Drier Summers (2080's high emissions)	Extreme higher temperatures (2050's, medium emissions)	Extreme higher temperatures (2050's, high emissions)	Extreme higher temperatures (2080's,	Extreme higher temperatures (2080's, high emissions)2	Warmer summers (2050's Medium emissions)	Warmer summers (2050's High emissions)	Warmer summers (2080's Medium emissions)	Warmer summers (2080's High emissions)	Warmer winters (2050's Medium emissions)	Warmer winters (2050's High emissions)	Warmer winters (2080's Medium emissions)	Warmer winters (2080's High emissions)	Wetter Winters (2050's Medium emissions)	Wetter Winters (2050's High emissions)	Wetter Winters (2080's Medium emissions)	Wetter Winters (2080's High emissions)
	Climate Driver : Increased Winter precipitation																					
1	2	Borehole pumping stations																	Yes	Yes	Yes	Yes
2	5	River abstraction																	Yes	Yes	Yes	Yes
3	6	River abstraction																	Yes	Yes	Yes	Yes
	Climate Driver : Increased Winter Mean Temperature																					
4	9	River abstraction													Yes	Yes	Yes	Yes				
5	10	Reservoirs													Yes	Yes	Yes	Yes				
6	12	All													Yes	Yes	Yes	Yes				
7	13	Pressure boosters, service reservoirs,													Yes	Yes	Yes	Yes				

Figure 9-4 Showing hazard Identification number, location of component, and stage of lifecycle sections of the generic register of hazards for climate change adaptation.

This amended structure allowed each of the climate scenarios to be represented and the hazard to be characterised taking account of the scenario, component, generic risk classification and hazard identification. The collation of the twenty options on the same spread sheet allowed patterns and trends to be identified.

9.2.10 Risk description

The risk description for the climate change register was taken from the climate change impact descriptions in the RA CCRA. No amendments were made as these have been verified by experts from the Reporting Authority.

9.2.11 Hazard identification

The hazard identification descriptors were the result of a synthesis of the consequences and comments made by the RA experts and presented in the CCRA report. Figure 9-5 shows the structure of the generic hazard register excluding the 20 stages of the lifecycle.

RISK ID NO	RA Original reference	Chain Component = asset level 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
	Climate Driver : Increased Winter precipitation						
1	**2**	**Borehole pumping stations**	**Environmental**	Hydrology	**Pollution**	Increased pollution of aquifer due to leaching which impairs raw water quality	Increased leaching of nitrates from bare fields in winter.
2	**5**	**River abstraction**	**Environmental**	Hydrology	**Flooding**	Increased risk of flooding due to silt movement caused by high river base flows	Silt blockages at river inlets / abstractions.
3	**6**	**River abstraction**	**Environmental**	Hydrology	**Flooding**	Increased risk of flooding of river intakes and water treatment works due to high river levels	Flooding of river inlets and water treatment works.
	Climate Driver : Increased Winter Mean Temperature						
4	**9**	**River abstraction**	**Environmental**	Hydrogeological	**Increased evapotranspiration**	Lower summer base flows	Lower winter river flows
5	**10**	**Reservoirs**	**Environmental**	Hydrogeological	**Increased evapotranspiration**	Reduced water reserves available to meet demand	Lower reservoir levels
6	**12**	**All**	**Economic**	Resource	**Demand**	Insufficient water available to meet household demand	Increase in household demand

Figure 9-5 Section of the hazard register showing the component, classification risk description and hazard identification

The resulting generic register was reviewed by water scientists to confirm that the application of the descriptors was correct and the resulting methodology for the identified hazards was acceptable. After the register of generic hazards was agreed the method, as stated in Section 6.4 was applied to produce the cross-disciplinary hazards of interface, causation and accumulation.

9.2.12 Generic hazard classification

The generic classification of each of the 45 individual risks designated as threats was classified according to the method in Section 6.2. The assignment of hazard categories and hazard types involved applying the respective climate impacts, consequences and comments provided by RA in the CCRA register to each risk. The resulting classification is provided in Table 9.8.

Table 9.8 The generic hazard classification with respective hazard categories and hazard types for and RA of a water subsidiary

Generic hazard classification	Hazard category	Hazard type
Economic	Resource	Demand
		Supply
		Labour availability
	Marginal value of water	Scarcity
	Soil moisture deficit	Domestic demand
Environmental	Hydrology	Pollution
	Hydrogeological	Flooding
		Increased evapotranspiration
	River quality	Ecological
	Soil moisture deficit	Ground stability
Health and safety	Health	Disease Bacteriological
Regulatory	Compliance	Licence constraints
		Abstraction restrictions, greater regulation
		Abstraction constraints
		River abstractions constraints
		Borehole abstraction constraints
		Breaking river abstraction daily licence
		Breaking groundwater daily licence

Generic hazard classification	Hazard category	Hazard type
Technical	Capacity	Demand
		Increased compensation releases
		Over pumping
		Maintenance of pressure levels
	Treatment process	Efficiency of treatment process and works
	Treatment capacity	Water quality and quantity
	Distribution network	Network integrity
	Pipeline integrity	Over pumping
	Soil moisture deficit	Ground stability
	Supply	Increased compensation releases
	Infrastructure integrity	Over pumping

The classification of the risks in the CCRA highlighted the fact that there were no identified legal or societal generic risks reported or identified for the water business unit. The resulting generic register of hazards was compiled and a summary of the register excluding the stages of the lifecycle provided in Table 9.9. The complete register can be found in Appendix V.

Table 9.9 Summary of the register of hazards as compiled from the CCRA excluding the stages of the lifecycle and separated by climate driver

RISK ID NO	CHAIN COMPONENT = ASSET LEVEL 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
	Climate Driver : Increased Winter precipitation					
1	Borehole pumping stations	**Environmental**	Hydrology	**Pollution**	Increased pollution of aquifer due to leaching which impairs raw water quality	Increased leaching of nitrates from bare fields in winter.
2	River abstraction	**Environmental**	Hydrology	**Flooding**	Increased risk of flooding due to silt movement caused by high river base flows	Silt blockages at river inlets / abstractions.

RISK ID NO	CHAIN COMPONENT = ASSET LEVEL 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
3	River abstraction	**Environmental**	Hydrology	**Flooding**	Increased risk of flooding of river intakes and water treatment works due to high river levels	Flooding of river inlets and water treatment works.
	Climate Driver : Increased Winter Mean Temperature					
4	River abstraction	**Environmental**	Hydrogeology	**Increased evapotranspiration**	Lower summer base flows	Lower winter river flows
5	Reservoirs	**Environmental**	Hydrogeology	**Increased evapotranspiration**	Reduced water reserves available to meet demand	Lower reservoir levels
6	All	**Economic**	Resource	**Demand**	Insufficient water available to meet household demand	Increase in household demand
7	Pressure boosters, service reservoirs, dist mains	**Technical**	Capacity	**Demand**	Potentially higher average demand places stress on maintaining pressure levels currently. All scenarios will exacerbate this.	inability to maintain pressure reference level
8	Chlorine boosters, service reservoirs, dist mains	**Health and safety**	Health	**Disease**	Risk of bacteriological failure affecting small sections of the distribution system	Increased bacteriological growth in the distribution system (including reduced winter die off)

RISK ID NO	CHAIN COMPONENT = ASSET LEVEL 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
	Climate Driver : Increased Summer Mean Temperature					
9	Borehole pumping stations	**Regulatory**	Compliance	**Licence constraints**	Drying of wetland areas and small watercourses, leading to possible licence restrictions	Increased evaporation
10	River abstraction	**Regulatory**	Compliance	**Abstractions constraints**	Abstraction restrictions resulting in greater regulation pressures and practices	Lower river flows and less water to abstract from rivers.
11	Borehole/ Reservoirs	**Technical**	Capacity	**Increased compensation releases**	Increased compensation releases required due to lower river flows, this will also reduce deployable output and the company will be subject to greater regulation.	Lower river flows
12	Reservoirs	**Economic**	Resource	**Supply**	Company is unable to meet its service requirements and KSIs	Low raw reservoir levels.
13	Reservoirs	**Regulatory**	Compliance	**Licence constraints**	Increased compensation releases required from raw water reservoirs impacted by site specific licence conditions which requiring releases (or increased releases) to be made once the river reaches a particular level rather than with demand.	Increased compensation releases required from raw water reservoirs which need to be managed alongside site specific regulatory constraints.
14	River abstraction	**Regulatory**	Compliance	**River abstractions constraints**	Further reductions in river abstraction licences and pressure increased as a result of Water Framework Directive.	Pressure on ecological flow indicators
15	Boreholes	**Regulatory**	Compliance	**Borehole abstractions constraints**	Further reductions in boreholes abstraction licences	Groundwater affects river flows creating increasing pressure on ecological flow indicators.
16	Boreholes	**Regulatory**	Compliance	**Licence constraints**	Breaking annual and 5 year licence requiring identification and access to alternative sources.	Increase demand is not capable of being meeting with existing abstraction licence criteria.

RISK ID NO	CHAIN COMPONENT = ASSET LEVEL 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
17	River abstraction	**Technical**	Treatment process	**Efficacy of treatment process and works**	Increased impact on costs incurred as a result of changing treatment processes and developing new treatment works.	Higher evaporation and lower river levels leads to less dilution of pollutants. River quality will deteriorate
18	Distribution Pipes	**Technical**	Distribution network	**Network integrity**	Increased leakage breakout	Increased soil moisture deficiency
19	Pressure boosters, service reservoirs, dist mains	**Technical**	Capacity	**Maintenance of pressure levels**	Higher than anticipated demand results in more areas at risk of failing pressure reference level	The stress of higher demand reduces ability of infrastructure to maintain pressure levels.
20	Raw water reservoirs, service reservoirs, water treatment works	**Technical**	Treatment capacity	**Water quality and quantity**	Impaired water quality, reduction in the volume that can be abstracted and treated at any one time and reducing the volumes that can be output into supply.	Increase in algal blooms in reservoirs
21	Water treatment works	**Technical**	Treatment capacity	**Water quality and quantity**	Creates additional operational stress on the treatment works and process required to reach the required quality and quantity of water.	Stressed treatment works
22	Distribution Pipes	**Technical**	Pipeline integrity	**Over pumping**	Localised problems in the distribution system due to increased pressures from extra pumping in the network.	Pipelines integrity compromised due to over pumping
23	Distribution Pipes	**Technical**	Soil moisture deficit	**Ground stability**	Localised problems in the distribution system due to bursts causing DG2 (pressure) and DG3 (loss of supply) issues. SMD driven failures are generally dramatic - complete failure of the main.	Instability of ground movement resulting from lack of moisture lead to stress on pipeline and increased burst events
24	All	**Economic**	Soil moisture deficit	**Domestic demand**	Correlation between SMD and domestic demand. When SDM is equal or greater than 60mm there is an increase in domestic demand and this creates localised supply issues such as pressure in the system.	Increased demand compromises the supply system.

RISK ID NO	CHAIN COMPONENT = ASSET LEVEL 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
25	Chlorine boosters, service reservoirs, dist mains	**Health and safety**	Health	**Bacteriological**	Risk of bacteriological failure compounded by reduced winter die off.	Increased bacterial growth in the distribution system
	Climate Driver : Decreased Summer Precipitation					
26	Borehole pumping stations	**Regulatory**	Compliance	**Licence constraints**	Abstraction may need to be reduced to protect sensitive rivers and streams due to regulatory pressure.	Lower river flows due to groundwater depletion
27	River abstraction	**Regulatory**	Compliance	**Abstraction restrictions, greater regulation**	Less water to abstract from rivers, further reductions possible through regulatory pressures and practices.	Lower river flows
28	Boreholes	**Technical**	Capacity	**Increased compensation releases**	Increased compensation releases required due to lower river flows, this will also reduce deployable output and the company will be subject to greater regulation.	Lower river flows
29	Reservoirs	**Technical**	Supply	**Raw reservoir levels**	Low reservoir levels, crossing trigger levels earlier and more frequently compromising water availability and service.	Raw reservoir levels, crossing trigger levels earlier and more frequently.
30	Reservoirs	**Regulatory**	Compliance	**Licence constraints**	Increased compensation releases required from raw water reservoirs impacted by site specific licence conditions which requiring releases (or increased releases) to be made once the river reaches a particular level rather than with demand.	Increased compensation releases required from raw water reservoirs which need to be managed alongside site specific regulatory constraints.
31	River abstraction	**Regulatory**	Compliance	**River abstractions constraints**	Further reductions in river abstraction licences and pressure increased as a result of Water Framework Directive.	Pressure on ecological flow indicator
32	Boreholes	**Regulatory**	Compliance	**Borehole abstractions constraints**	Further reductions in boreholes abstraction licences	Groundwater affects river flows creating increasing pressure on ecological flow indicators.

RISK ID NO	CHAIN COMPONENT = ASSET LEVEL 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
33	River abstraction	**Environmental**	River quality	**Ecological**	Lower river levels leads to less dilution of pollutants and river quality deterioration.	Lower river levels
34	River abstraction	**Economic**	Marginal value of water	**Scarcity**	Impact on company strategy due to change in SELL. Impact on Water Resources Planning requires investigation.	Economic level of leakage
35	Distributio n Pipes	**Technical**	Capacity	**Over pumping**	Pipelines integrity compromised due to over pumping as a result of increased demand.	Infrastructure cannot cope with the demand.
36	Distribution Pipes	**Environmental**	Soil moisture deficit	**Ground stability**	Instability of ground movement resulting from lack of moisture lead to stress on pipeline and increased burst events	Increased soil moisture deficiency leads to instability
37	All	**Economic**	Soil moisture deficit	**Domestic demand**	Correlation between SMD and domestic demand. When SDM is equal or greater than 60mm there is an increase in domestic demand and this creates localised supply issues such as pressure in the system.	Increased demand compromises the supply system.
	Climate Driver : Summer Maximum Daily Temperature					
38	River abstraction	**Regulatory**	Compliance	**Breaking river abstraction daily licence**	Risk to individual licences, cost to company is fines for licence and bad publicity. This will largely be a localised issue.	Demand which exceeds licence requirements
39	Borehole Abstractions	**Regulatory**	Compliance	**Breaking groundwater daily licence**	Risk to individual licences, cost to company is fines for licence and bad publicity. This will largely be a localised issue.	Demand which exceeds licence requirements
40	River abstraction /Reservoirs /Boreholes	**Economic**	Resources	**labour availability**	Impact on company strategy. Requires improved dry weather event response planning and re-deployment of staff resources to water stressed areas.	Labour shortage and not deployed where needed.

RISK ID NO	CHAIN COMPONENT = ASSET LEVEL 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
41	Pressure boosters, service reservoirs, dist mains	**Technical**	Capacity	**Maintenance of pressure levels**	Peak demand places stress on maintaining pressure levels currently. All scenarios will exacerbate this.	Higher demand increases stress on infrastructure and reduces ability to maintain pressure levels.
42	Distribution Pipes	**Technical**	Infrastructure integrity	**Over pumping**	Localised problems in the distribution system due to increased pressures from extra pumping in the network.	Pipelines integrity compromised due to over pumping as a result of increased demand.
43	Chlorine boosters, service reservoirs, dist mains	**Health and safety**	Health	**Bacteriological**	Risk of isolated bacteriological failure in small sections of the distribution system	Increased bacterial growth in the distribution system
	Climate Driver : Increased Winter Minimum Daily Temperature					
44	Pressure boosters, service reservoirs, dist mains	**Technical**	Capacity	**Maintenance of pressure levels**	Potential higher average demand places stress on maintaining pressure levels currently. All scenarios will exacerbate this.	Higher demand stress reduces ability to maintain pressure levels.
45	Chlorine boosters, service reservoirs, dist mains	**Health and safety**	Health	**Bacteriological**	Risk of isolated bacteriological failure in small sections of the distribution system.	Increased bacterial growth in the distribution system

9.3 Identification and documentation of subsidiary register

The 45 hazards designated as threats were filtered by stage of the lifecycle. This resulted in 20 subsidiary registers. Analysis of the subsidiary registers found no difference between the climate effects for the emission levels of high and medium, or between the years 2050 and 2080. As a result only five subsidiary registers were produced, one for each descriptor of the lifecycle. The description of these parameters as stages of the lifecycle would not seem appropriate as they do not provide details which actually relate to a stage in the lifecycle; instead they relate to a specific climate effect and within the climate effect there is the same impact, description and hazard identification. The following are the climate effects that were used to apply the novel method to produce the dimensions of interface, causation and accumulation:

1. Drier summers;
2. Extreme higher temperatures;
3. Warmer summers;
4. Warmer winters; and
5. Wetter winters.

Table 9.10 shows that there may be a direct relationship between the UKCP09 and the climate drivers.

Table 9.10 Comparison of climate drivers and climate effect descriptors for water subsidiary

Subsidiary register	UKCP09 derived descriptor	Climate drivers
A	Drier summers	Decreased summer precipitation
B	Extreme higher temperatures	Summer maximum daily temperature
C	Warmer summers	Increased summer mean temperature
D	Warmer winters	Increased winter mean temperature
E	Wetter winters	Increased winter precipitation

When filtering the stages of the climate effects, all the hazards for the specific climate driver were found to be the same, confirming that irrespective of the year or level of emission the corresponding impact was the same. Additional synthesis of the subsidiary registers resulted in identifying the components where hazards have been identified as occurring with respect to the specific climate effect/ stage of lifecycle (Table 9.11).

By identifying the components that comprise each stage of the lifecycle where hazards have been identified, it was possible to ascertain hazards which were common to components. It was also possible to recognise hazards that transverse the water business unit for the different climate scenarios.

Table 9.11 Matrix of chain components that comprise the subsidiary registers Components which are excluded from the specific subsidiary registers are shaded and Y= components which are included in the specific register

Sub Risk register	Chain component										
	Borehole pumping stations	Borehole Abstractions	Borehole/ Reservoirs	Boreholes	Distribution Pipes	Raw water reservoirs, service reservoirs, water treatment works	Reservoirs	River abstraction /Reservoirs /Boreholes	River abstraction	Pressure boosters, service reservoirs, dist mains	Chlorine boosters, service reservoirs, dist mains
A. Drier summers	Y			Y	Y		Y		Y		
B extreme higher temperatures		Y			Y				Y	Y	
C Warmer summers	Y		Y	Y	Y	Y	Y	Y	Y	Y	
D Warmer winters							Y		Y	Y	Y
E. Wetter winters	Y								Y		

9.3.1 Synthesis of subsidiary register

For each subsidiary register of climate effects, the individual hazards were identified and the resulting risk ID numbers for the original generic register were used in Table 9.12. The full register for each of the five subsidiary registers can be found in Appendix W.

Table 9.12 The generic hazard ID that comprise the five subsidiary registers and climate scenarios for a water subsidiary used for the identification of dimensions

Generic hazards	**Subsidiary register A (Drier summers)**							
Economic	40	43						
Environmental	39	42						
Health and safety								
Regulatory	32	33	36	37	38			
Technical	34	35	41					
Generic hazards	**Subsidiary register B (Extreme higher temperatures)**							
Economic	46							
Environmental								
Health and safety								
Regulatory	44	45						
Technical	47	48						
Generic hazards	**Subsidiary register C (Warmer summers)**							
Economic	18	30						
Environmental								
Health and safety								
Regulatory	15	16	19	20	21	22		
Technical	17	23	24	25	26	27	28	29
Generic hazards	**Subsidiary register D (Warmer winters)**							
Economic	12							
Environmental	9	10						
Health and safety	14	31	52	49				
Regulatory								
Technical	13	51						
Generic hazards	**Subsidiary register E (Wetter winters)**							
Economic								
Environmental	2	5	6					
Health and safety								
Regulatory								
Technical								

The shaded areas on the table highlight the absence of generic hazards identified in the CCRA register. There are no identified health and safety hazards for the warmer summers, extreme higher temperatures, wetter winters and drier summers subsidiary registers. The CCRA register suggests that warmer winters would not result in a regulatory hazard, and a wetter winter would not have any technical, economic, health and safety or regulatory hazards. The area that the RA covers has had flooding events during the summer season but the CCRA has only identified environmental hazards from wetter winters, which suggests that the CCRA was not complete or only subject to environmental hazards resulting from wetter winters as no environmental hazards are identified for any other scenarios (drier summers and extreme higher temperature). However, later in 2012, a newspaper report for this RA stated:

"*This year's extremes in weather and the immediate distress caused by widespread flooding in many areas covered by RA will be the main concerns for many of its customers"* (Kavanagh, 2012)

This quote shows that after the CCRA report, the impact of flooding from wetter summers and wetter winters were an issue for customers even if it was not captured in the CCRA report. The register did not identify any societal hazards and additionally there is no scenario for a wetter summer. The risks associated with flooding may be seen as manageable as at present these impacts are partially managed by insurance. This may not be the position in the long-term. A more precautionary approach to hazard identification in the future stages of the lifecycle should be taken as the same resources may not be available to mitigate hazards in the future. The subsidiary registers identified gaps in the identification of hazards for the five scenarios and the need for additional mitigation and further investigation. Once the generic hazards for the subsidiary registers were compiled and reviewed the method for the identification of the dimensions of interface, causation and accumulation could be derived.

9.4 Interface hazard register

9.4.1 Method of interface hazard identification

The first stage of compiling the interface hazards required the identification of those hazards that comprise the subsidiary registers (Table 9.12). The requirements for the identification of interface hazards (Section 6.4.1) were applied to each subsidiary register. The resulting synthesis of hazards in the climate scenarios produced 163 hazards. A summarised breakdown of the additional interface hazards are presented in Table 9.13. The complete register of interface hazards can be found in Appendix X.

Table 9.13 The number of interface hazards for each climate scenario for a water subsidiary

Climate scenario/Subsidiary register	Number of hazards
A. Drier summers	51
B. Extreme higher temperatures	8
C. Warmer summers	76
D. Warmer winters	28
E. Wetter winters	0
TOTAL	**163**

Applying the method (Section 6.4.1) to subsidiary registers highlighted that interface hazards cannot be obtained from the three environmental hazards in subsidiary register E which relates to wetter winters (Table 9.14) as they are from the same generic classification.

Table 9.14 The three hazard that comprise the subsidiary register E (wetter winters) for a water subsidiary

RISK ID NO	Chain Component = asset level 3	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE	RISK DESCRIPTION	HAZARD IDENTIFICATION
1	Borehole pumping stations	**Environmental**	Hydrology	**Pollution**	Increased pollution of aquifer due to leaching which impairs raw water quality	Increased leaching of nitrates from bare fields in winter.
2	River abstraction	**Environmental**	Hydrology	**Flooding**	Increased risk of flooding due to silt movement caused by high river base flows	Silt blockages at river inlets / abstractions.
3	River abstraction	**Environmental**	Hydrology	**Flooding**	Increased risk of flooding of river intakes and water treatment works due to high river levels	Flooding of river inlets and water treatment works.

The initial interface hazards which result from the subsidiary registers cannot be synthesised further as the hazards are specific to the stage of the lifecycle. The hazards do not cross over to other subsidiary registers, and these are not related to stages of the lifecycle but are related to different climate scenarios The subsidiary registers for this case study can be found in Appendix X.

It would not be prudent at this stage to enforce the maximum number of hazards for the interface register to 50 as each scenario is unique. It cannot be assumed that there is sufficient knowledge of the scenarios to enforce the exclusion of hazards from the synthesised interface register at present.

9.4.2 Results of Interface identification

The application of the method identified cross-disciplinary hazards which are evidenced in the individual climate scenario register.

The drier summer scenario interface hazards were comprised of a combination of economic, environmental, technical and regulatory hazards where 25 out of the 51 interface hazards have a regulatory interface. Interface hazards in this scenario are a combination of reduced river flow, insufficient infrastructure capacity, and pressure on ecological flow indicators, increased compensation releases and increased soil moisture deficiency (SMD) leading to instability, breaching economic level of leakage, increased demand on infrastructure. These hazard combinations may have a causal relationship, for example lower river flows, and ground water depletion (ID100) with groundwater depletion and lack of infrastructure capacity (ID102).

Extreme higher temperatures show that the respective interface hazards are the result of the calibration of demands to meet the licence requirements, labour shortages, and stress on the infrastructure and pipeline integrity as evidenced in the register (Appendix X “extreme).

9.5 Causation hazard register

9.5.1 Method of hazard identification

A causation hazard for climate change adaptation considers whether the individual hazards in the subsidiary registers relating to the five climate effects, can result in a subsequent and different hazard. The full result of the causation hazards can be found in Appendix Y and a summary is provided in Table 9.15.

Table 9.15 The number of causation hazards resulting from the initial hazards in the subsidiary registers for a water subsidiary

Climate scenario/Subsidiary register	**Number of initial risks with a defined hazard per subsidiary risk register**	**Number of hazards within causation linkages excluding initial hazard**
A. Drier summers	12	67
B. Extreme higher temperatures	5	20
C. Warmer summers	16	52
D. Warmer winters	9	52
E. Wetter winters	3	15
Total	45	206

9.5.2 Results of causation identification

The causation registers identified cross-disciplinary hazards through the 206 hazards that comprise the chains of causation. The causation results in Table 9.15 highlight the fact that the RA is either familiar with or more able to manage wetter weather than drier weather as more hazards result from drier weather and increasing temperature compared to wetter winters. Apart from flooding, wetter weather provides additional water the resource which the RA requires recharging aquifers and reservoirs so that it can sell water as a product. This only becomes a significant issue when there is flooding or extreme cold.

The causation register (Appendix Y) for the water business unit shows that, with respect to climate change, none of the hazards identified would result, in the immediate failure of the business unit. Only ten hazards out of 45 would result in the organisation failing to be a going concern across all the climate drivers. These ten hazards are highlighted in bold. Additionally these failures occurred at the fifth or sixth chain of causation giving ample time for corrective action (Appendix Y).

9.6 Accumulation register

9.6.1 Method of accumulation identification

Type 1 portfolio - phase of the lifecycle accumulation hazard

The accumulation type 1 portfolio refers to hazards which occur during the same stage of the lifecycle. There are no type 1 portfolios for this particular climate change risk assessment. This is because the risks were not compiled with any difference between the stages of the lifecycle for 2050 and 2080. Instead the subsidiary registers were a portfolio of hazards that relate to a specific climatic effect (Table 9.1) and these are presented as Type1 portfolios for climate change in the absence of accurate characterisation of risks or hazards for the periods of 2050 and 2080 (Appendix.Z.1)

Table 9.16 The type 1 accumulation hazards for climate effects for a water subsidiary

Portfolio- Type 1 subsidiary registers		Number of hazards in the scenarios	Accumulation portfolio
A	Drier summers	12	1
B	Extreme higher temperatures	5	1
C	Warmer summers	16	1
D	Warmer winters	9	1
E	Wetter winters	3	n/a
	Total	45	4

Type 2 portfolio - transversal accumulation hazards

The method used to compile the hazards did not accommodate hazards that would traverse all stages of the lifecycle. The identified hazards occurred within the specific climate effect scenarios. As a result the hazards in the register were specific to the climatic conditions. The method used to identify climate change hazards did not identify any hazards which may arise during the transition from drier summers and wetter winters or drier summers and extreme higher temperatures. There was one identified parameter "All" which comprised of 3 hazards which could be said to be transversal (Table 9.17).

Table 9.17 The three chain components classified as 'All' in the risk assessment register of the water business unit

RISK ID NO	GENERIC RISK CLASSIFICATION	RISK CATEGORY	RISK TYPE		RISK DESCRIPTION	HAZARD IDENTIFICATION
6	**Economic**	Resource	**Demand**	Warmer Winters	Insufficient water available to meet household demand	Increase in household demand
24	**Economic**	Soil moisture deficit	**Domestic demand**	Warmer summers	Correlation between SMD and domestic demand. When SDM is equal or greater than 60mm there is an increase in domestic demand and this creates localised supply issues such as pressure in the system.	Increased demand compromises the supply system.
37	**Economic**	Soil moisture deficit	**Domestic demand**	Drier summers	Correlation between SMD and domestic demand. When SDM is equal or greater than 60mm there is an increase in domestic demand and this creates localised supply issues such as pressure in the system.	Increased demand compromises the supply system.

The issue is that the hazards are specific to climate scenarios. However for two of the hazards the risk description is the same and across the three hazards they are similar.

Type 3 portfolio - component accumulation hazards

There were 13 components within Asset Level 3 (Table 9.6). The descriptions for the components were not consistent and in some cases incorporated other components. The first column in Table 9.18 gives the descriptor used in the base data whilst the second column provides a descriptor for the grouping of components. A filter was applied to each of the component groups and results in a potential accumulation portfolio for each component (Table 9.18).

Table 9.18 The number of hazards which make up each accumulation portfolio per component for a water business unit.

Components		**Number of hazards that comprise the accumulation portfolio**
RA classification of component	Component group	
Borehole pumping stations Boreholes Borehole/ Reservoirs	Boreholes	9
River abstraction	Abstraction	12
Chlorine boosters, Pressure boosters, Service reservoirs, Distribution mains	Boosters and distribution	14
Reservoirs River abstraction /Reservoirs /Boreholes Raw water reservoirs, service reservoirs, water treatment works	Reservoirs	6
All	All	3
Water treatment plant	Water treatment plant	1
	Total	45

The objective of applying this method was to establish whether the method can be applied to a climate change adaptation risk assessment. Simply grouping the hazards by component is not appropriate as this does not provide details of the relationship between the components and the concentration of risk in respect of the climate scenario. Further analysis taking into account: 1. the climate scenario; 2. the components, 3. generic hazard, and 4. the number of generic hazards within a. component and climate scenario was carried out and the consolidated results are presented in Table 9.19 (Appendix Z.2).

The results show that none of the grouped components (Table 9.18) had hazards for every generic hazard classification for the climate effect scenarios. The table does not include climate scenarios where there are no generic hazards identified for the component. The largest number of identified hazards was identified as the booster and distribution components and these were concentrated in two generic hazards; health and safety, and technical hazards. The components and scenarios with more than one generic hazard were the reservoirs in the warmer summers scenario and abstractions for the drier summer climate scenario.

The data provided in the RA CCRA does not suggest that the treatment plant component with one generic technical hazard fulfils the requirements of a type 3 accumulation hazard. The component "All" only included the economic hazards and did not apply to extreme higher temperatures or wetter winters. Although there are three economic hazards within the component "All", they related to three different climate effects. One hazard might have a catastrophic impact but it does not fulfil the requirements of an accumulation hazard, which are that there are a number of generic hazards.

The component groupings in Table 9.19 are made up of shaded areas which represent accumulation components, The un-shaded areas are not applicable as they comprise hazards from the same generic classification or insufficient in number. The final column which is headed Accumulation has a Y where there is an accumulation hazard and N when there is not an accumulation hazard.

Table 9.19 Results of the component groupings, generic hazards and climate scenarios for a water subsidiary.

Generic hazards	Economic	Environmental	Health and safety	Regulatory	Technical	Accumulation
Component	**Boreholes**					
Drier summers				32, 38	34	Y
Extreme higher temperatures				45		N
Warmer summers				22, 15, 21	17	Y
Wetter winters	2					N
Component	**Abstractions**					
Drier summers	39	40		33, 37		Y
Extreme higher temperatures		46		44		Y
Warmer summers				16, 20	23	Y
Warmer winters	9					N
Wetter winters	5, 6					Y
Component	**Boosters and distribution**					
Drier summers		42			41	Y
Extreme higher temperatures			49		47, 48	Y
Warmer summers			31		25, 24, 28, 29	Y
Warmer winters			14		13	Y
Wetter winters			52		51	Y
Component	**Reservoirs**					
Drier summers				36	35	Y
Warmer summers	18			19	26	Y
Warmer winters		10				N
Component	**All**					
Drier summers	43					N
Warmer summers	30					N
Warmer winters	12					N
Component	**Treatment plant**					
Warmer summers					27	N

There were no identified hazards for the following components, and climate scenarios: boreholes in warmer winters, reservoir in extreme higher temperatures, all in extreme higher temperatures, treatment plant in extreme higher temperatures, drier summers, warmer winters and wetter winters (Table 9.19).

From the identified and reported risks in the water services CCRA report and Table 9.19 there are three accumulation type 3 hazards for three different components. The components include;

- booster and distribution component hazard based on the number of hazards;
- the reservoir component for warmer summers; and
- the abstractions component for the drier summer climate scenario.

9.6.2 Results of the identification of accumulation hazards

The three methods of identifying accumulation hazard produced seven accumulation hazards (Figure 9-6).

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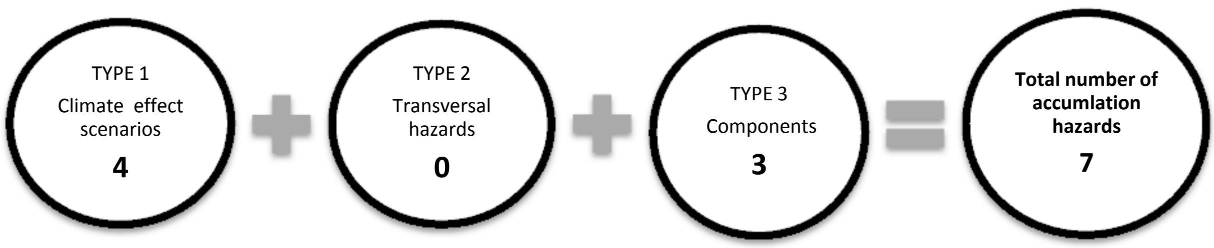

Figure 9-6 The number and composition of the different accumulation hazard portfolios for case study 3 for a water business unit

The identification of the seven accumulation hazards provided portfolios of hazards where cross-disciplinary interaction of hazards can occur. The different climate drivers do not facilitate further consolidation.

9.7 Problems issues and developments of hazard identification using a climate change risk assessment

The tabulation of parameters in Table 9.19 shows that there is a lack of identified and reported health and safety hazards resulting from climate impacts. The CCRA shows that, with respect to the abstraction component, drier summers and warmer winters have an economic impact; however no economic impact was identified for the extreme higher temperatures scenario across all components. This does not seem correct as extreme higher temperatures would result in a greater reduction of water and therefore greater costs and reduced revenue. Additionally there were no economic or regulatory hazards reported in the risk assessment for the, boosters and distribution, component.

The generic risks (Section 9.2.7) identified in the CCRA did not include societal or legal hazards such as product liability, bodily injury, disease or reputational exposures. The report discussed dependencies such as, the regulators energy suppliers, information technology, telecommunications and other suppliers. Interdependencies such as local authorities and land managers were also referred to in the report. There was no evidence of either dependencies or interdependencies in the CCRA register. This may be evidence of the difficulties faced when including aspects which have dimensional attributes in the current register structure. It may also be a symptom of the focus of the CCRA report on impact to infrastructure. However the impact to the infrastructure has additional impacts such as societal hazards when water quality is poor or there is no water.

The rationale for the inclusion of the lifecycle parameters in the model was to provide a means of relating the hazard to a stage in the lifecycle of a project. The inclusion of the lifecycle is critical to the production of the subsidiary registers as each subsidiary register refers to a stage of the lifecycle. The importance of the lifecycle is highlighted when applying the method to the climate change risk assessment (see Section 9.2.3) when, although the descriptors had different time periods, there were no differences in the characteristics of the hazards for the time periods, 2050 and 2080. As a result, although the objective was to identify the impact of climate for the specific years of 2050 and 2080, this was not achieved. Instead the result was the identification of the general impact of particular climate scenarios. It would have been possible to use the lifecycle parameter if the base data was complete and time specific results were available.

The identification of risks resulting from specific climate effects was the essential objective for the risk assessment. It is difficult to see how this was achieved when the lifecycle parameters were the same and the climatic scenarios were focused on two seasons; winter and summer. Additionally, there were no comments or identified hazards included in the register during the transition of these weather exposures. This is evidenced by the lack of transversal hazards in the accumulation dimension. One hazard not identified was the issue of calibrating the infrastructure across the extremes of weather.

The application of the model highlighted the need for a review of the base data to ensure that it was accurate and the descriptors used here appropriate and correctly applied for the purpose for which the register was created. For this case study the objective was to identify and communicate the risks/ hazards that would result from the application of climate scenarios set out by UKCP09. The process of applying the model highlighted shortcomings, such as the absence of non-technical hazards resulting from climate change in the register. This is illustrated by inconsistent impacts with respect to the economic impacts for extreme high temperatures and a lack of societal impacts, when clearly there are societal and reputational risks with dealing with extremes of weather highlighted in Section 9.3.1. There were no legal hazards identified such as product liability bodily injury or disease. Additionally there were no transversal hazards and no scenarios showing continuous extremes of weather, with respect to temperature and precipitation from winter to summer. In fact a silo approach to the seasons, emission and weather was taken, which fails to take into account the impact of one season on another. Interdependency and dependency were not included in the register but were included in the report.

These were concerned with the supply chain and not with cross-disciplinary hazard identification and relationships.

A major shortcoming was the lack of consensus in the method applied to data capture and presentation of the initial data in the CCRA. It is crucial that climate scenarios for infrastructure in one geographic region are uniformly applied so that stakeholders, regulators and government can acquire the data they need to plan for the future climate change adaptation requirements.

The resulting application of this method highlights the possibility that the RA may not have the data required in a form that can easily be communicated or that the data may not currently exist. With respect to the time periods of 2050 and 2080, the reasons that there is not perceived to be any difference in the 30 year timeframe maybe due to this time period not being consider a long enough time period for a difference to occur. Secondly, the scenarios with respect to temperature and emissions and precipitation do not result in a different impact or the data does not exist to extrapolate into the future.

The application of the method highlighted the need for the auditing of risk registers to ensure that they are fit for purpose. The result of the method showed that there were additional hazards which were not identified in the CCRA register but were contained in the cross discipline hazards of interface, causation and accumulation.

9.8 Validation of climate change adaptation case study results

The validation of the climate change adaptation case study took the following steps. Firstly, the validation of the methods used to derive the generic register of hazards was achieved by internal validation by an academic expert from the water sector and by maintaining an audit trail during the synthesis of the data. Secondly, the validation of the synthesis of data to identify and document the dimensions of interface, causation and accumulation hazards incorporated a review of the generic register of hazards and dimensions during a meeting with the RA.

A second level of validation was achieved from this meeting with two experts with knowledge of the production of the climate change risk assessment report and the operations of the RA. The meeting took the same structure as that of the closed landfill, focusing on the identification of hazards for the four dimensions (Appendix BB1).

9.8.1 Generic hazard identification and prioritisation

The experts were asked if the rationale for prioritising the hazards using the descriptor of threat was plausible and they confirmed this to be acceptable. When asked to confirm the generic descriptors, the experts stated that the generic descriptors used were one way of using the data. Although the societal data was not included in the register, the experts thought that this should be included. The experts were shown the component descriptors and agreed with the component descriptors. They also agreed with the lifecycle parameters which were applied by using the climate change scenarios in UKCP09. The experts stated that the resulting generic register of climate change hazards (Appendix V) was a fair translation of the hazards presented in RA CCRA report.

9.8.2 Interface dimension

The methodology for the identification of interface hazards was explained to the experts and they were shown the results of the application of the method in the form of a register of interface hazards. The experts stated that they may consider these types of hazards but they were not captured in the register. The interface hazards were feasible and the experts said that they would use this methodology, but would take a corporate approach to verification.

The experts also stated that the merit of using this method of hazard identification was taking existing risks and examining their relationship rather than investigating increasing severity to establish impact. It facilitates the identification of synergies and conflict, and helps to manage the downside risk. The main practical constraints with using this method is the resource required to synthesis the data and the need for brevity of reporting.

9.8.3 Causation hazard

The explanation of the identification of causation hazards and the resulting production of subsidiary registers using the climate effects were presented to the RA experts who stated that they saw the methodology as feasible and aiding mitigation, although the process was time consuming. The experts stated that they would use this method in the assessment and management of risk. They stated that the merits of this method were that it prompted a full understanding of chains of causation. The experts stated that a potential problem was the fact that different people would have a different view of the next steps and there would need to be a means of normalising these chains of causation.

9.8.4 Accumulation hazard

The different method of identifying accumulation portfolios was explained and the results of the different registers presented to the experts. The experts did not foresee any issues with the methodology and confirmed that accumulation hazards were feasible. The experts said that they would use the method but might amend the grouping of the components. They suggested a split between infrastructure and non-infrastructure as the current focus was on infrastructure. They suggested that a problem might be the concept of an overall risk/ hazard which is a novel approach to hazards type.

When shown the resulting number of hazards per dimension (Appendix AA) for the climate change assessment register they confirmed that the figures made them reconsider how they identify hazards and how a register of hazards might be produced.

9.9 Summary

The application of the enhanced method applied to the closed landfill as presented in Figure 9-7 was successfully applied to the climate change risk assessment report for RA.

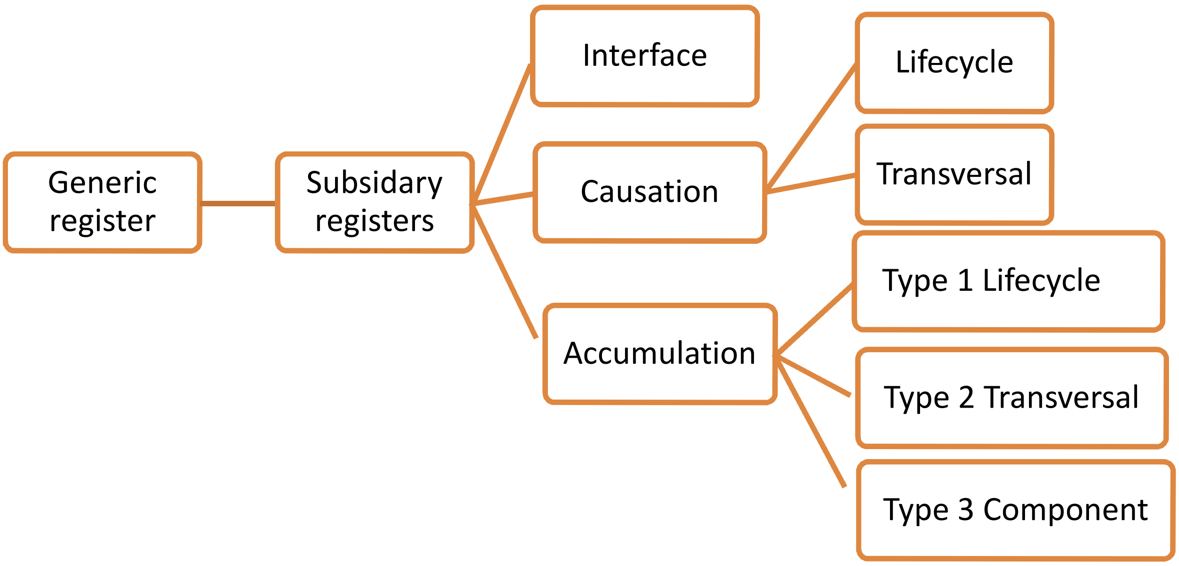

Figure 9-7 Method for the cross-disciplinary identification of hazards

The application highlighted shortcomings in the base data and the absence of consistency in the production of a comprehensive register for all the business units of this utility company. The use of the subsidiary register and lifecycle parameters set context to the identification of hazards in a multidimensional world and quickly identified inconsistencies in the base data. The application also successfully presented the resulting identified hazards for each dimension in a register of hazards.

The next stage of this research is to establish if the method developed was novel, adds to existing knowledge and meets the objectives set out in Section 1.3. These questions are discussed in the following chapter.

10 DISCUSSION

10.1 Prior art

During the last twenty years there has been a greater emphasis on risk quantification and risk-based management rather than hazard based management (Fairman et al., 1998). The world has evolved from the identification of hazards within generic silos to a world where hazards are intertwined and manifest themselves through interconnectivity and dependency which proliferates in complex systems. Hazards have no respect for the generic silos used to historically identify and manage hazards and risks. A move towards hazard identification is required to identify currently unidentified hazards which result from the increased complexity of hazard and risk relationships. Allan and Yin (2010) introduce the connectivity of risks as a third dimension and simply translate qualitative characteristics into quantitative terms which are then used to rate the connectivity of the risk. Fundamentally this view does not recognise the metamorphosis of risks and the creation of new hazards from connectivity. It is adding to the quantitative characterisation of the existing risks in the risk register.

The focus of this research project was on the qualitative cross-disciplinary identification of hazards and development of a method which incorporates a proactive and multidimensional approach, by the introduction of the dimensions of interface, causation and accumulation. The method evidences the identified cross-disciplinary hazards in a compendium of registers which allows the classification and characterisation of hazards according to stage of the lifecycle.

Many methods focus on the quantification of risk to support risk-based management. As a result it is unlikely that the current top down methods of identification identify all the emerging hazards that result from interconnectivity, dependency and new technologies. As the initiating hazard has to have been identified, and characterised prior to the start of the risk identification process, uncharacterised hazards remain unidentified. Aven (2012c) states that there is a need to focus on the foundation issues within risk assessment, including robust hazard identification.

10.1.1 Cross- disciplinary identification

The generic disciplines (e.g. health and safety, legal, environmental and economic) have different methods for identifying and assessing risks and hazards which are a function of their needs (Aven, 2012a) and this is illustrated by their different approaches to hazard and risk. For example Maher (2007) states that the legal profession identifies risk *ex post* as opposed to the majority of disciplines that identify risk *ex ante* (Section 2.4.4). This was supported by the responses from the generic experts (Chapter 5).

The methods for the identification of new and emerging risks that result from cross-disciplinary relationships, such as connectivity and dependency, have not developed as these risks and hazard have evolved. There is no formal structure for the inclusion of cross-discipline hazard identification in whole system risk management frameworks such as; ISO31000, ERM or project management (Section 2.6.5). Although technological risks can result in health and environmental exposures, there is a lack of prescribed communication across the disciplines in both commerce and academia on risks and hazards (Löfstedt and Perri, 2008). Cross-disciplinary hazard identification is exceptional.

10.1.2 Tools and methods

The tools and method used for risk and hazard identification commence with a focus on existing known and identified failure (Section 2). Evidence of this is the fact that the following methods: FTA, ETA, FMEA, HAZOP, HAZID were used in the DyPASI methodology when applied to CCS, which clearly states that the approach to hazard identification was a top-down approach (Wilday et al., 2012a). In many cases the results of these methods are used as a basis for expert elicitations, which are focused on a generic expert identification meeting where existing frameworks are based on, prioritisation using top down identified risks and existing known failure focused scenarios. Examples of this include the decommissioning of the first nuclear reactor in Korea (Jeong et al., 2008).

There are a plethora of tools and methods used to identify hazards (Section 2.5) which would seem to indicate that no one tool or method is able to satisfy identification of all the numerous types of hazards. The underlying philosophy for hazard identification is failure focused, based on pre-existing and known failures. If we always start with a known event or failure it is unlikely that new failures would be identified, or new hazards highlighted, as only known hazards identified in the existing generic silos using existing tools are likely to be identified (Section 2.5.5).

10.1.3 Risk identification or risk analysis

The fact that hazard identification is not consistently given an agreed position in risk management frameworks across the disciplines leads to different levels of identification, and different hazards and risks being identified (Aven, 2011). For example if hazard identification was the initial stage it would include all characterised hazards, irrespective of whether they can be quantified. Alternatively if hazard identification is part of quantitative risk analysis it is likely that only those hazards which have a tendency towards quantification will be identified.

Conceptual thinking could be considered for the identification of cross-disciplinary hazards as it does not require quantification (Section 6.1.1). However the objective of this research is not the development of a conceptual model but an applied model. The focus on qualitative attributes was taken so as not to exclude those hazards that cannot be quantified from inclusion in the initial identification and documentation of the dimensions.

When the focus is on the quantitative analysis of hazards it is possible that the object of analysis, the identified register of hazards may not be correct or complete as hazards are excluded from identification This will impact the quality and robustness of the resulting portfolio of identified risks which is evidenced in the water company case study (Section 9.2.2) where different climate effects were used to produce the risk registers for the different business units and in the CCS decommissioning portfolio which did not include any decommissioning specific risks (Section 7.2).

10.1.4 Whole system risk management

Whole system risk management frameworks and methods have been developed in an attempt to bring together multiple disciplines and processes and have contributed to the development and application of frameworks such as ERM (Section 2.6.3). However the ERM methodology does not provide an integrated approach to risk identification (Beasley et al, 2010a).

The immaturity of ERM may be due to silo identification and aggregation of the original risks by generic experts as opposed to the inclusion of cross-disciplinary hazard identification. Integrated identification or assessment is not embedded in the ERM process. Although the ERM process is presented as including multiple dimensions in a cube, the component parts are presented in silos and aggregated. Transversal identification is not evidenced in the ERM process as the focus is on root cause events and intermediate events that result in a known risk event (Beasley et al, 2010b).

Figure 10-1 The ERM root cause approach to risk events (Beasley et al., 2010b)

This is similar to the failure focus of the tools and methods used to identify hazards and risks (Section 10.1.4) where the interactions of identified hazards are not taken into account. The focus is on a known failure and the causes and impacts of that known failure as illustrated in Figure 10-1. The approach taken to establish a root cause does take into account timing but this is in terms of the staging of the risk event/ failure and not the lifecycle of the hazards or their interactions. Although the COSO survey stated that ERM is immature in its development it is recognised as the preferred frameworks for risk professionals (Verbano and Venturini, 2011) and is the framework that respondents suggest should be accommodated in the development of any method for hazard identification (Section 5.3.11).

Another whole system generic framework for hazard identification is found in project management (Section 2.6.2) which incorporates risk identification but is reactive and does not accommodate integrated hazard identification (Carter and Smith, 2006). Frameworks such as LCA (Section 2.6.4) are important supporting tools for hazard and risk identification but do not provide a solution for hazard identification (Wilday et al., 2011).

10.1.5 Documentation

The main methods of documenting hazards and risks are in a register, log or report (Section 3.5). Risk registers accommodate one characteristic at a time and there is no facility to link the characterisation of risks/ hazards to illustrate interconnectivity or dependency. Whilst Allen and Yin (2010) have introduced the strategic risk register system (SSRS), this does not facilitate identification of all the potential relationships between risks. The SSSR's reliance on quantification of risk means that, as a result, assumptions on aggregation of the probability of risk are made rather than the identification of emerging hazards or cross-disciplinary hazards. This indicates that robust hazard characterisation followed by quantification of risks would be preferable.

The gap in the identification of hazards is highlighted by reactive identification in silos that are perpetuated in new whole system frameworks and apply identification in generic silos using "top down" failure-focused methods and tools that identify already known hazards. A method for the identification of hazards across generic disciplines which focuses on characterisation in preference to quantification is required to accommodate the different dimensions of hazards that result from cross discipline relationships. Although Lambert et al. (2001) introduced Hierarchical Holographic Modelling (HHM) to identify hazards as a source of risk by decomposition of the functions of a system there has not been any significant development in the methods for characterisation of the source of risks.

The initial review of the prior art (in Chapters 2 and 3) considered the suitability of the current methods for the identification of hazards across multiple disciplines, and concluded that neither a method nor tools exist to identify hazards or risks across multiple disciplines. What was required was a method whose objective was the identification of cross discipline hazards where identified hazards are defined as risk sources and failure scenarios (Lambert et al., 2001).

10.2 Risk register structure for generic identification

A risk register structure was chosen as the preferred repository for the characterisation and evidencing of identified hazards (Section 5.3). Obtained results confirmed that risk registers are widely used and are the preferred structure used by risk practitioners for documenting identified risks (Drummond, 2011; Section 3.1).

When asked what methods were used to identify the dimensions of hazards, the risk register was only used with respect to interface risks and was not used for accumulation and causation (Section 5.3.6). This contradicted the response respondents gave when asked to state which methods of documentation were used (Section 5.3.9). Table 5.25 shows that a risk register was predominantly used to document interface and causation hazards, however no respondents stated that it was the mode used for accumulation hazards. The results of the survey show that the risk register was supplemented equally by meetings of the risk committee, the generic risk committee and risk reports. None of these are publically accessible and this creates an issue with respect to verifying these outputs using the case studies. Accumulation was predominately evidenced in a risk report and supplemented meetings of both the risk committee and generic risk committee (Section 5.3.9).

The lack of inclusion of the dimensions may be due to the fact that these hazards are difficult to characterise in the traditional linear structure of a risk register. This is evidenced in the initial register template for the transportation module of CCS (Section 6.2.2) and the lack of identifiable documented evidence of these dimensions in the risk register for the CCS case study

(Section 7.3.1) and the water utility company (Section 9.3.1). This highlights a gap in knowledge not only with identification but also with evidence in a register of hazards or risks. Risk registers are widely seen as repositories which evidence that risks have been identified and therefore the normal assumption is made that they are being managed (Drummond, 2011; Section 5.2.5).

The initial results (Section 5.4) showed a need for the identification of hazards across the generic disciplines and that the dimensions of interface, causation and accumulation hazards should be identified as a potential solution to this gap. This is based on the fact that these dimensions are recognised as requiring identification and in some cases experts and survey respondents state that they are identified. However they cannot state the method used to identify the dimensions and the dimensions are not evidenced in a register (Section 5.4).

10.3 Characterisation of dimensions

Previous attempts at the inclusion of dimensions have included adding an additional quantitative characterisation to the identified risk in the risk register (Farret, 2010) and not the development of interrelationships between the individual risks that comprise the portfolio of risks, for example the aggregation of probabilities in ERM and the allocation of probabilities to interconnectivity in SSRS. The dimensions of interface, causation and accumulation were developed from analogues in a variety of sectors as explained in (Section 3.3) and propose to identify some of the different interrelationships between hazards.

10.3.1 The characterisation of generic hazards

A review of the identification of risk within generic frameworks in Section 2.4.6 identified that silo hazard and risk identification does not facilitate the multi-disciplinary approach required to identify hazards in a multidimensional world. The initial identification of risks commences with the characterisation of hazards; the source of risk (Aven, 2012b). As risks are identified in generic silos the generic risk classification was established as the initial step in the characterisation of a hazard and is defined in Section 3.3.1 as a predefined classification of risks which are associated with a specific widely accepted generic disciplines, such as environmental, legal, financial, health and safety.

10.3.2 Interface dimension

In this research there are two types of interface hazards: generic interface hazards (Level I) and system interface hazards (Level II) (Section 3.3.2). Although there has been much discussion in the literature of risk and hazards at the interface of systems, processes and human interaction, interface hazard identification has not been formally included as an accepted dimension of hazard identification (Section 3.2.2). The inclusion of the interaction of two hazards from a portfolio of hazards has not been properly recognised as a potential hazard by the risk community and therefore not identified or included in a register of hazards. A contributing factor may be that the interface dimension was not seen as capable of inclusion in the standard risk register structure, alternatively it may be documented in reports which are not publically available and so remain unknown.

When generic experts were asked if they identified interface risks three out of four experts stated that they identified this dimension but were not able to state a specific method for identification (Section 5.2.4). The results from the survey show that the methods used to identify interface hazards were predominately qualitative and included scenario, reviews and workshops (Section 5.3.6). No quantitative techniques were suggested by either experts or respondents to the web survey.

Many of the results from the web survey (Section 5.3) for the two different types of interface hazards were the same and it was decided that it would be preferable to focus on one category. An additional consideration was lack of public access to the data required for the systems interface hazards. The risk registers do not provide the additional information needed to produce the register of interface II risks, as a result this dimension was excluded from the research and instead focused on the interaction of the interface hazard that result from two generic risks.

The development of the method for interface hazards commenced with a robust portfolio of generic risks and this was achieved by generic classification and characterisation, as discussed in Sections 6.3 and10.3. The second stage of development required the objective matching of generic hazards into couplings. This was achieved by filtering the hazards by generic classification and phase of lifecycle. The result was a portfolio of hazards which can occur at the same phase of the lifecycle known as subsidiary registers (Section 6.3.4). By filtering within the phases of the lifecycle by generic classification assumptions were applied to the method used to produce generic couplings (Section 6.4.1).

The analysis of the generic register of hazards resulted in a register of cross-disciplinary hazards which included all the risks or hazard in the original register in its formulation. This initial iteration of the interface hazards responded to the gap identified in Section 2.7.5 highlighting a need for a method to identify cross-disciplinary hazards. However the application to the CCS case study (Section 7.6.2) found a number of couplings were duplicated across the different stages of the lifecycle and the method was enhanced to include the most frequently occurring couplings across all phases of the lifecycle. The result was a register of 41 interface hazards which were previously unidentified.

10.3.3 Causation dimension

Causation is widely used in the medical, legal profession and by insurers as discussed in Section 3.3.3. It is defined as a hazard which is dependent on a prior hazard occurring (Section 3.4.3). If the prior hazard does not occur then causation will not take place (Dekkers and Rikkert, 2006). There was recognition that this dimension of hazard identification should be carried out and a number of methods used to identify this dimension of risk were identified (Section 5.3.5). The preferred methods were mainly formal methods or qualitative methods (Section 5.3.6). It is interesting to note that neither the ‘root cause’ nor the ‘domino effect’ was suggested by any respondents as a method. With respect to risk assessment methods, the preferred methods from the web survey were the application of existing generic risk assessment frameworks, expert elicitation and best guess (Section 5.3.8). There was no specific method used for causation identification.

The documentation of causation was accommodated across a number of methods and tools; the preferred method was for the specific inclusion in the risk register (Section 5.3.9) although it was not used as a qualitative method for the identification of causation hazards (Section 5.3.6). It was not possible from the case studies to identify causation hazards or hazards which had been identified as having causation relationships in the risk registers as these were not structured to show this relationship (Appendices I and Y). As a result it is difficult to see how causation relationships could be communicated to investors, regulators or the steward of a company from the risk register. The number of different media used to communicate causation risks and hazards suggest that, although widely applied, the risk register is used in combination with other methods to document and communicate the identification of causation hazards (Section 5.3.9).It is likely that many different methods and tools will have to be used as neither a specific tool nor method currently meets the requirements of the risk community to identify causation hazards.

10.3.4 Accumulation dimension

An accumulation hazard is defined as a number of hazards which occur within a short period of time and the resulting cumulative impact is significant (Section.3.3.4). Accumulation risk is proactively used in the insurance industry by insurers who are pursuing a balanced and diversified risk portfolio (Section 3.4.4). The reason for including this dimension in the method for cross-disciplinary hazard identification is to recognise that accumulation does not just occur for insurers but for every entity, whether private, public or corporate. Recent literature recognises the interconnectivity of hazards and the fact that the precise order of interconnectivity is unknown so it is prudent to identify all hazards in the accumulation portfolio (Allan and Yin, 2010). Complexity science attempts to quantify connectivity in systems, but this focus is on pre-existing individually identified hazards whereas an accumulation hazard recognises a portfolio of hazards as a single hazard. The identification of the accumulation hazard is precautionary as it provides details of all the hazards for a specific parameter whether a component or a stage of the lifecycle.

The accumulation dimension was identified by some experts and respondents to the web survey (Section 5.3.5), but there was no consensus on a specific method. Only the formal processes of ‘Swiss cheese’ and ‘features events and processes were reported as being used for the identification of accumulation risks. The main methods used were qualitative methods such as scenario, reviews workshops and expert judgement. Quantitative techniques were also used (Section 5.3.6). With respect to risk assessment, the most popular methods used to assess accumulation risks were best guess, project management risk framework, and expert elicitation. The accumulation hazard was the only dimension which zero respondents used a risk register to document the risk (Section 5.3.9). This risk was presented in reports and discussed at risk meetings. It is likely that accumulation risks were excluded from a register because they did not fit the traditional one line for a hazard in the tabular structure of a register.

10.4 New and emerging risks

Experts and respondents surveyed in this research had confidence in the methods currently used (Section 5.3.4) and believed that the methods that they use are adequate for the identification of new and emerging risks (Figure 5-7). This may be due to the fact that respondents are not aware that it is possible for the current methods to be improved. Additionally there was no consensus with respect to the methods of identification and many people chose not to respond. The non-responses could be evidence that;

- Respondents were not aware of methods of identification for the respective dimensions or recognise that they used them for this;
- They did not identify the dimension or recognise its description;
- Risk managers and experts felt that they could not state that the risks are not identified so assume that they are but do not know how;

- Respondents may not be involved in the identification of risks just in the consolidation of risk data and therefore not qualified to answer the questions;
- Respondents may also assume these dimensions were identified within the generic silos; and
- With respect to the level 1 interface and level II interface hazards, respondents may not recognise these hazards.

Due to the anonymity of the respondents it was not possible to establish what the reason was for non-response. This could be addressed by repeating the survey conducting a face to face survey or changing the question to a closed response.

Whilst, respondents did not formally identify these dimensions in their risk registers, they believe that they are included. The survey was sent out to professional risk management associations (Section 4.7.2). A reason for this response may be that risk and hazards are emotive subjects, and risk managers may be perceived as not doing their job if they do not say that they have identified the dimensions of interface, causation and accumulation and are confident that the current methods enable the identification of new and emerging risks.

10.5 Main findings from the expert elicitations and web survey results

The results of the web survey and the expert interviews found that the dimensions were viable, feasible and required (Section 5.4). When respondents were asked what method was used to integrate different risk management frameworks the largest response (40%) stated that this was achieved by the risk management being embedded into the ERM framework (Section 5.3.11).

The result of these findings found there was a need for a method to facilitate the identification of hazards across the generic disciplines as there is no consensus as to the method used or the mode of documentation. A method for the identification of hazards across multiple disciplines was developed as outlined in Chapter 6 and developed by application to the three case studies in Chapters 7, 8 and 9, (Figure 10-2).

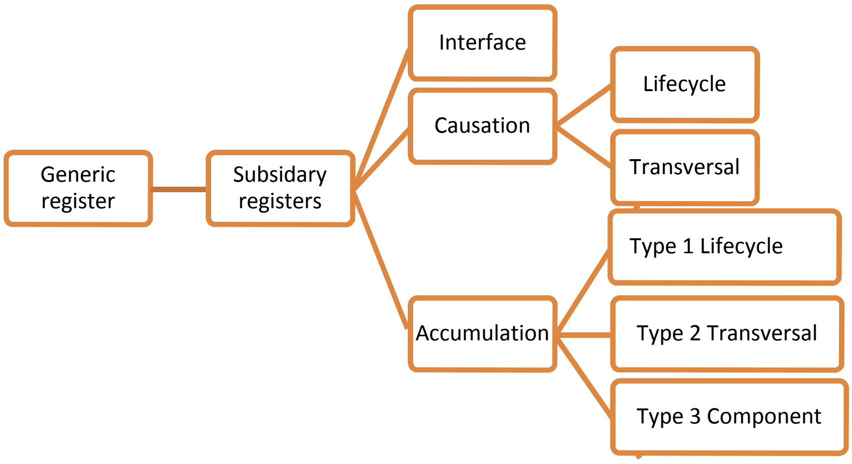

Figure 10-2 Outline of method for cross-disciplinary hazard identification

10.6 Cross case study analysis

The three case studies were chosen as the mode of research to test the method for the identification of the dimensions, interface, causation and accumulation. **Case study (1)** the initial pilot case study, was a study of a consortium for a CCS project (Chapter 7). CCS was chosen as an example of a new technology and value chain with emerging risks (Wilday et al., 2011a). This case study demonstrated that the method could transform the data in the existing risk register and produce a generic register of hazards for use as base data prior to synthesis of the dimensions. From this base data it was possible to identify the dimensions of interface, causation, and accumulation and to document these in a register

Case study (2), a closed landfill, was chosen to test the ability of the method to be applied when a risk register was not available (Chapter 8). In this case the initial register of hazards needed to be completed and the results of the initial identification of hazards, method and register were validated.

Case study (3) applied the method to climate change adaptation risk assessment. This was chosen to test the flexibility of the method to apply to a subject where a register of hazards was not previously compiled and for which there was no previous structure for documentation (Chapter 9). It was possible to use the method to produce a register of generic hazards using the data in the report. Additionally the dimensions were identified and documented in a register.

Success of the method was evidenced by the application of the method, identification of cross-disciplinary hazards within the dimensions and the evidencing of the dimensions in a register. Challenges that arose in the case studies resulted in amendments and enhancements to the method.

10.6.1 Integrity of the base data

All three case studies required the application of the method to an existing risk register and the importance of the integrity of this base data was found to be critical to the robustness of the resulting identification of dimensions. A common issue with the integrity of the base data occurred when the risk registers were the result of a combination of three units (Chapter 9) or three separate companies (Chapter 7); the consolidated result had fundamental inconsistencies identified in the application of the method. As a result it cannot be assumed that the registers produced for tenders or government requests are correct. The registers should be audited to ensure that they are fit for purpose. The translation of the risk registers into the generic register template facilitated an audit of the base data in all case studies.

10.6.2 Generic classification

The initial generic classifications used in the CCS transportation register resulted in financial risk being removed and included within economic risk; regulatory risk was added to distinguish between legal risks and regulatory risks and societal risks, were added as a generic classification as there were a number of reputational risks in the CCS case study. The result was a portfolio of generic classifications which included economic, environmental, health and safety, legal, regulatory, societal and technical risks / hazards. The generic classifications used in the CCS case study were applied to the other case studies.

10.6.3 Prioritisation

Prioritisation took place after the classification and characterisation of hazards took place in case study (2). Prioritisation was applied using different metrics in the three case studies. Firstly the objective was the identification of hazards which have a negative impact. In case study (1) the risks were already prioritised and the portfolio used in this research was the top 50 risks. In case study (2), the hazards identified were prioritised as high medium and low based on impact criteria (Section 8.3.5.). The register prior to prioritisation was verified by a landfill risk expert and the method of prioritisation and resulting register post prioritisation was verified by the aftercare landfill expert. With respect to case study (3,) the original register characterised risks as threats, neutral and opportunities. Applying the objective that the focus was on hazards which had a negative impact, only those risks designated as threat were used in the application of the model on case study (3). Prioritisation of the initial data is required as part of the preparation of the data to be used to produce the generic register and synthesis of the dimensions.

10.6.4 Chain component

The chain component as defined (Section 6.2) were different for each of the case studies as this descriptor was found to be context and process specific. This is evidenced in case study (1) where the geographical location required a division divided between onshore and offshore components (Table 7.6 and 7.7). Registers produced on a component basis highlighted components which had few identified risks for example the stability component in case study (2) and the water treatment plant in case study (3). The inclusion of the chain component was possible, applicable and of value to the characterisation of hazards in the three case studies. The chain component descriptor when filtered is able to establish concentrations of hazard by components. It also facilitates the identification hazards which follow the sequence of a process. The addition of the chain component is a good addition to this method because it provides details of the concentration of hazards in different parts of the process, system or project. It facilitates the identification of components that may be vulnerable to generic hazards. Coupled with the lifecycle descriptor it is possible to establish the time of greatest exposure in the lifecycle.

10.6.5 Lifecycle

The lifecycle parameter was important in providing context to the timing of hazard occurrence and highlighted errors where hazards were unlikely or absent. This phase of the lifecycle was critical to the identification of the subsidiary register and the accumulation hazards. The three cases studies were able to incorporate the application of the lifecycle descriptor. In each case the descriptor was unique to the context of the case study.

In all case studies the lifecycle parameter proved to be an important factor in producing an accurate register of hazards. For the landfill case study time was important due to the financial constraints of the indemnity and the unknown period of time that aftercare would be require. In the case of the climate change case study, Defra wish to obtain an indication of how reporting authorities would be able to deal with the hazards that result from climate change over periods of 30 years. The RA in case study (3) provided the same information for the two scenarios and this was realised by the application of the lifecycle parameter. The application of time as a critical factor is highlighted in case study (1) where CO_2 storage is required for 1000 years. This establishes that the parameter of time in a register is critical when evaluating CCS projects (Farret et al., 2010; Wilday et al., 2011a). The CCS case study and the climate change case study both seem to have difficulty in providing robust data on the hazards that occur into the future. It would seem that these inconsistencies may be lost in the linear registers of risk but highlighted in the cross-disciplinary hazard identification.

10.6.6 Characterisation

The characterisation of the hazards included the risk descriptors and hazard identification. The three case studies provided evidence that the risk description details were able to be completed with or without an existing risk register. The risk descriptions for case study (2) which did not have an existing risk register were obtained from a mixture of the site visits and quarterly review. As stated earlier for all the case studies the details for the hazard identification descriptor were obtained by responding to the question ”what is the source of the risk?”

10.6.7 Subsidiary register

The subsidiary registers formulated from the decomposition of the consolidated register and creation of portfolios of hazards for each stage of the lifecycle. The method and the resulting register proved to be flexible enough to accommodate the data provided and the intent of the register.

The value of the subsidiary register is realised by the fact that they provide a pool of real hazards that occur at the same stage of the lifecycle. These hazards are not fictional or based on probability, they have been independently identified and not the result of brainstorming. Knowing the hazards are at the same stage of the lifecycle allows analysis of possible interactions between hazards at the same phase of the lifecycle and across the stages of the lifecycle. It also highlights basic errors, with respect to time and the applicability of hazards, that are said to apply across the lifecycle in the original risk registers. For both case studies (1) and (3), basic errors were identified in the base data as a result of the introduction of time in the form of the lifecycle parameter and the creation of the subsidiary registers. In both cases this is a concern as it goes to the heart of the purpose of producing the register.

The subsidiary registers provide a pool of individual hazards which have been verified by experts and considered relevant and valid for the initial registers. Additionally these hazards are presented in the relevant lifecycle register. Knowing which hazards are at the same phase of the lifecycle allows analysis of possible interactions between hazards in the same phase of the lifecycle and across the phases of the lifecycle.

10.7 Application of the dimensions

The methods used to identify the dimensions were outlined initially in Section 6 and developed during the application of case study (1), which was the pilot case study, and subsequent case studies.

10.7.1 Interface

The identification of the interface dimension required the systematic coupling of generic risks. As the aim of this research was to look at the identification of hazards across multiple disciplines, couplings were only combined with hazards from different generic classifications (Section 6.4.1). This process was reliant on the robustness of the base data. The interface results were based on the frequency of occurrence across the maximum phases of the lifecycle and excluded less frequently occurring couplings. This highlighted those hazards that occurred across the phases of the lifecycle and did not focus on the frequency of a hazard actually happening. As a result it is an objective method of coupling and prioritising interface hazards. The resulting method from case study (1) was successfully applied to the closed landfill data in case study (2) and resulted in an interface register of 43 hazards (Section 8.6).The method was also applied to case study (3) and there were no issues with the application. The method resulted in the identification of four registers of interface hazard; as the four climate scenario could not be combined into one register. The total number of interface hazards across the climate scenarios was 163 couplings (Section 9.4). The method has to accommodate the objective of the hazard identification process which was to establish what the risk and hazards were for specific climatic scenarios. The results would not be credible if the different climatic scenarios were consolidated, the weather related to different seasons and a decision would need to be made to choose the mixture of seasons to comprise a year. This could be done but that was not the objective of the initial CCRA report.

The initial method for interface hazard identification (set out in section 6.4.1) stated that the focus should be on those hazards that occur most frequently across the phases of the lifecycle; however consideration should be given to the inclusion of the residuals. The rationale being that the prioritisation of hazards means that it is possible to examine those hazards which are ranked as high, and include those in the interface register. As a result a further development for this dimension would be to examine the impact of the residuals ranked as high on the resulting interface register.

10.7.2 Causation

The identification of causation hazards initially commenced with three modes of identification: generic register; lifecycle register and transversal register (which includes all of the hazards that occur across the phases of the lifecycle). The generic register was quicker to process but it was not able to place the hazards in context of the phase of lifecycle. As a result this option was not pursued and the lifecycle in the form of the subsidiary registers were used as the base data for the identification of causation hazards. The lifecycle was critical to causation identification as it placed the individual hazards in a portfolio of hazards which relate to the same stage of the lifecycle. Without this context it is not possible to see errors or to accurately identify potential hazards and chains of causation. Transversal hazards were identified and highlighted on the subsidiary /lifecycle registers. This action highlighted hazards which would reoccur during multiple phases of the lifecycle and therefore hazard relationships that should be addressed for management to minimise impact during the lifecycle.

The process of identifying subsequent hazards highlighted the need to establish the point at which the subsequent hazard may be realised i.e. “the tipping point” (Gladstone, 2008). This is an area for further research and should be linked to the risk tolerance of the entity for which the hazards are being identified and register compiled. The identification of the subsequent hazards is open to bias as they are dependent on the experience and judgement of the person assessing the hazards. These should be validated by an individual who was not involved in the synthesis of the data but has sufficient knowledge of the process and context. This was achieved in this research project by expert review for case studies 2 and 3.

The rationale for stopping the chain of causation was that the hazard would be resolved either because the action was part of normal operations or that the result was that the project or entity was no longer a going concern (section 6.4.2). The method developed by application to case study (1) resulted in no further amendments when applied to case study 2 and 3 as the method was successfully applied. A comparison of the number of causation hazards identified by case study in Table 10.1 illustrates that there was variation between the case studies. The rationale for the difference may be the result of the uncertainty inherent in the organisations, process and the time period of the activities at risk. There is uncertainty in the technology of the CCS value chain, its operations and the regulatory, economic and societal impacts. Additionally the time period over which this proposition has to contain CO_2 safely and economically is vast and fraught with uncertainty and the cost implications of the value chain do not provide a commercially viable business model. As a result there are more potential financial impacts which have to be resolved with a negative revenue stream. This is the same position for the closed landfill which has a fixed indemnity with an infinite period of aftercare. On the other hand the water company is operating an activity which is producing revenue on a number of sites and has options to manage its exposures. Because it is revenue generating it is able to resolve issues before they threaten the business, employees or the environment as a result the chains of causation can be reduced from “a threat to going concern” to “business as usual”.

Table 10.1Comparison of identified causation hazards by case study

	Case study 1	Case study 2	Case study 3
Number of generic hazards	50	49	45
Number of causation hazards	463	452	206

10.7.3 Accumulation

Although the concept of accumulation is applied in the reinsurance and insurance sectors, it is a novel approach to hazard identification outside this sector. This approach does not consider an individual hazard but a portfolio of hazards which could occur at the same time or within a short period of time. Three different types of accumulation hazards were defined: stage of lifecycle, transversal and components (Section 6.4.3 and Section 7.3.5). The method was applied to the three case studies with no changes required to the initial method. Case study (1) highlighted a problem with the use of the component “whole system issues”. This designation resulted in errors highlighted in the decommissioning register/ phase of lifecycle where all the hazards that comprise the subsidiary register were whole system and was not applicable to this phase of the lifecycle.

10.8 Value of results

This method highlights cross-disciplinary hazards within an existing risk register by the introduction of the dimensions of interface, causation and accumulation. The method is able, through the use of descriptors such as the lifecycle and the subsidiary registers, to identify inconsistencies. As a result it provides a tool for the auditing of risk registers. It is of value to the risk community as it is a proactive structured method for the identification of hazards across disciplines. The landfill experts suggested that this method could be included within the requirement for a risk assessment for new waste management facilities (Section 8.10.2). In addition it could be used as an early warning system for projects as illustrated in the decommissioning subsidiary register of hazards (Section 7.9.2).

Company directors and officers have an obligation to ensure that they are aware of the risks of the entity for which they are acting as steward and to mitigate those risks as appropriate. The method allows directors and officers to have more comprehensive information on the hazards which they are managing. The method also tests the robustness of the existing risk register and supports the requirement of corporate governance.

This method provides an alternative to linear top-down identification which is the main approach to the identification of hazards (Section 2.5) as it introduces multiple dimensions to hazard identification. It complements the existing generic frameworks by encouraging proactive and robust hazard identification through the implementation of the identification of the dimensions. This should ensure a more comprehensive characterisation thereby facilitating improved risk identification and quantification. Integration of this method into existing risk management frameworks should enhance the existing frameworks.

The method facilitates asset protection with the inclusion of the component descriptors and facilitates multidimensional hazard identification within components and across the process. Inclusion of transversal hazards in the interface, causation and accumulation registers facilitates the identification of hotspots as identified in Chapters 7, 8 and 9.

The prior art found that risk registers did not accommodate the different dimensions of risks or hazards (Section 3.9) and depended on expert knowledge albeit with formal checklists and similar processes. This method included the development of a register template (Section 6.5.) which provides comprehensive hazard characterisation and accommodates the generic, interface, causation and accumulation dimensions in a single file. This responds to the lack of a central repository for the documentation of all the dimensions of hazards and risks which was identified as absent in the web survey (Section 5.3.9).

10.9 Issues with the method

10.9.1 Base data integrity

The method is dependent on complete and correct risk registers. The need for robust quality data is highlighted by the errors and omissions identified in the base data for case study (1) (Chapter 7) and case study (3) (Chapter 9). These errors and omissions were identified by the translation of the base data into the generic template and the subsidiary registers which were lifecycle focused. Case study (2) illustrated that it was possible to produce a generic register for an entity where a risk register did not exist. In order to produce the generic register access to risk data was required as well as knowledge of the operations, process, industry sector and regulations.

10.9.2 Accommodating multidimensional results

The identification of the dimensions could not be easily synthesised without the mutual development of the register (Section 6.2.2). It was difficult to explain the hazard relationships and the dimensions beyond one or two generic hazards as the approach required a completely new way of identifying hazards, for example as: couplings, a portfolio, and chains of causation. The approach of multiple relationships was at odds with the linear approach of singular hazards identified from one generic family of hazards (Section 3.4). It also required spatially translating the different types of hazard combinations into a document which was recognisable but accommodated dimensions of hazards which had not previously been accommodated in a risk register (Section 3.1). The landfill expert stated that this method was so different that initially it may be difficult for the logic to be followed by the layman (Section 8.10). Although the method has been progressively simplified in the process of its application to the three case studies further simplification is required.

10.9.3 Complexity

The method was produced by hand and documented which was time consuming. The decision to apply the method by hand, made it possible to see what was happening to the data and to exclude possible errors which were software specific. The amount of time taken to synthesise the data would need to be reduced if it were to be considered for commercial application. This is especially true of the identification of interface hazards in the CCS case study where few of the first iteration remained in the final register. Development in the method reduced this time further, but further improvement would be required for commercial application. Additionally the hazards that were discarded based on lack of frequency should be reviewed as there may be hazards which are not frequently occurring but could result in a significant impact (Section 8.6.2).

10.9.4 The use of general components

The use of general component terms such as ‘all’ or ‘whole system’ which cover the entire system, process or entity should be used sparingly as they can create inconsistencies and errors. This was illustrated in the decommissioning subsidiary register and in the transversal component registers for case study (1), where the ‘whole system’ component was used to provide a response but not always a correct response.

10.9.5 Integration into existing risk management

The method was structured so that it could be included in the whole system frameworks and the generic frameworks, outlined in (Section 2.6). This was difficult to accommodate as hazard identification and risk identification took place in different parts of the framework, additionally some frameworks were prescriptive and others open to wide interpretation. Attempting to amend the risk management frameworks was outside the scope of this research project which was focused on making sure the identification of hazards could be integrated into any framework.

10.9.6 Proportionality

It is important that in line with the pursuit of better regulation and risk management proportionality is taken into account when applying this method (Hampton, 2005). The case studies used to test and develop the method were all concerned with the identification of hazards in infrastructure at different stages of development; CCS at the project design stage, the water business was at the operational stage and the landfill at the aftercare stage. These three case studies involve entities managing strategic infrastructure and so the time and resources required to identify the cross-disciplinary hazards by the application of the dimensions would be acceptable as there is the potential for significant negative impact. Additionally the activities carried out by the respective case studies are regulated by a number of different entities and so a comprehensive register of hazards would have additional benefits, which would include providing a comprehensive register of hazards for each component or phase of lifecycle. However, the allocation of resource and time to this level of hazard identification may not be acceptable to a small and medium enterprise which has commercial and social value but is not complex, of strategic importance, or likely to have a significant negative environmental or health and safety impact. As a result the application of this method should be proportionate and relevant to the size, potential impact of the activities and strategic impact of the project, infrastructure or entity.

Furthermore this method may be of greater value when a better understanding of the associated hazards of emerging technologies is required and where there are limited analogues for example in the case of CCS (Chapter 7). The benefits arise as it is proactive in its approach to hazard identification, reproducible and provides an audit trail.

10.9.7 Validity of all options

There were issues with validating the case studies for example the personnel who were involved in the identification of risks and compiling the risk register for the CCS case study (1) were disbanded in 2012 when it was decided that the first competition would not result in a project and that a new competition would commence. As the objective of the case study (1) was to establish whether the dimensions could be identified from the initial risk register this was acceptable as it was possible to obtain validation of the results for the application of the method to case study (2) and case study (3).

10.10 Summary

The methods and tools used to identify hazards and risks have a top-down approach to hazard identification and this method provides an alternative and complementary approach. The dimensions, generic, interface, causation and accumulation were defined and a critical evaluation of their application to the identification of hazards undertaken. A robust and auditable risk register method for the identification and documentation of hazards across multiple disciplines has been developed to identify cross-disciplinary hazards. The method has been applied to three case studies and it has shown that the method identifies additional hazards from the dimensions of interface, causation and accumulation not previously identified or documented in a register of hazards. The method has a unique approach to hazard identification which utilises the lifecycle by introduction of subsidiary register. This makes a significant contribution to the identification, characterisation and documentation of interconnecting and cross-disciplinary hazard

11 SUMMARY AND CONCLUSIONS

11.1 Project context and drivers

The rapid increase in population, globalisation and the speed of technological development from concept to operation has resulted in the development of complex interconnected multidisciplinary systems with risk and hazards which are identified in generic silos. Historically hazards were identified within their generic disciplines with methods and tools which took a linear approach to identification. These tools and methods for generic silo hazard and risk identification are not capable of identifying hazards and risks in a multidimensional world where the attributes of interconnectivity, dependency and complexity result in cross-disciplinary relationships and unidentified hazards. This research presents the development of a new method for the identification of cross-disciplinary hazards.

Hazard identification is in transition with new approaches trying to capture the complexity with the inclusion of time, and dependency. There are gaps in current knowledge for example: data for integrated frameworks relies on the identification of hazards in generic silos for risk management. The tools for hazard identification predominately commence with a known failure followed by the identification of known outcomes and impacts. There is also a top down approach to risk management based on a list of prioritised hazards which result from generic silo identification. Additionally, when scenario analysis is carried out it is not documented in a register. Risk registers are predominately a list of risks focusing on quantification rather than the identification and characterisation of potential hazards.

The aim of this research project was to identify and investigate (using case studies) why robust and encompassing hazard identification does not occur, particularly in areas where multiple fields overlap and to design a framework that will address these deficiencies, within the following specific objectives:

- Critically evaluate current approaches to hazard identification and risk management to identify their suitability for the identification of hazards in an interconnected world;
- Define the dimensions of generic, interface, causation and accumulation risk and critically evaluate their application to the identification of hazards; and
- Develop and evaluate a method for the identification and documentation of multidimensional attributes of hazards.

11.1.1 Implication of findings

Review of the prior art established that the methods and tools used to identify hazards as well as the current risk management frameworks were not able to accommodate the identification of hazards across disciplines. This was due to the silo focus of generic risk management, the fact that whole systems risk management frameworks were still fundamentally based on silo based identification, and there was a move away from the characterisation of hazards to quantification of risks when the world had changed from simple silo linearity to complexity (Johnson, 2006). The critical evaluation of the methods for hazard identification found the methods and tool for identification did not accommodate complexity and have not developed to include interconnectivity; multiple risk relationships across a number of disciplines which result in hazards with multiple dimensions.

The introduction of the dimensions of generic, interface, causation and accumulation were found to add value to the identification of hazards as they were able to facilitate additional multidimensional relationships between risks and the resulting hazards. It was possible to develop a method for multidimensional hazard identification incorporating the dimensions. The application of the method to complex infrastructure projects at different stages of the lifecycle and from a wide range of operations shows that the method is feasible, practical and flexible.

11.1.2 Scientific achievements

The identification of hazards through the lens of the dimensions of generic, interface, causation and accumulation brings structure to the identification of hazards across disciplines. The method accommodates interconnectivity through the different hazard relationships; couplings in interface hazards, chains of causation and portfolio relationships in accumulation. The method returns to the fundamentals of risk by focusing on qualitative characterisation of hazards prior to quantification of hazards in risk identification. This facilitates complexity by recognising the multidimensional attributes of hazards rather than focusing on the results of quantifying existing identified risks.

The new method challenges the top-down approach to hazard identification from a plethora of tools and methods. It also provides an alternative solution which enhances current approaches to hazard identification across the disciplines.

11.2 Addition to knowledge

11.2.1 Identification

The move away from hazard identification to risk quantification needs to be redressed in light of the changing complexity of our world as quantification in preference to characterisation does not lead to robust hazard identification. Aven (2012c) states there is a need to return to the fundamentals of risk. This research project shows that unidentified hazards are present within an existing portfolio of risks evidenced in a risk register. As a result of cross-disciplinary hazard identification these hazards have been identified. The tools for identification need to accommodate the changing complexity of our world. Silo generic hazard identification is not adequate for cross discipline identification as evidenced in this research by the results of case studies1, 2 and 3 as hazards are not linear but have multidimensional attributes.

11.2.2 Dimensions

Confirmation that the dimensions of interface, causation and accumulation can be identified provides additional knowledge about the interrelationships between hazards and risks. The method contributes to the discussion on the evolution of a hazard to a risk and the development from a linear to multidimensional construct. The method identifies hazards that were previously not identified and adds to the knowledge of interconnectivity and complexity science. Interconnectivity is accommodated by recognition of the three different hazard relationships interface, causation and accumulation.

11.2.3 Complexity and connectivity

The acceptance that the dimensions of hazards exist and are evidenced in a register provides additional knowledge to our understanding of the identification of hazards and risk within complex systems. Addition to complexity science is provided by the application of a structured method identifying different hazard relationship as a result of the application of dimensions and evidencing in a register.

11.2.4 Emerging risk identification

The application of the method to the CCS case study and climate change adaptation are evidence of a method which is proactive in its identification of hazards across time, lifecycle, components, and generic disciplines. As it is not a top-down method the initial identification does not exclude hazards based on known failures but provides a pool of hazards for prioritisation and risk management. As a result it provides a pool of real hazards from which emerging hazards and risks are identified.

11.3 Practical application

The method adds additional steps to the current identification of hazards prior to quantification and provides an alternative to top down hazard identification. The method enhances hazard identification within existing risk management frameworks, providing realistic scenarios for cross-disciplinary hazard identification. This method supports the requirement for directors and officers to identify and manage the risks of their organisation so as to comply with corporate governance requirements. It contributes to providing a comprehensive register of identified hazards and an audit trail for the decision making that results in the prioritisation of hazards for mitigation.

The method, by the application of the dimensions and inclusion of the descriptors, lifecycle and chain component, is able to highlight the concentration of hazards at the different phases of the lifecycle and within the various components of a process, value chain, project and commercial or public entity.

The resulting method provides funders and regulators with an indication of hazards over the lifecycle of a project, infrastructure, value chain or service. This offers a proactive and realistic view of the potential legacy liabilities which they may actually knowing or unknowingly retain.

The application of the method to the three case studies included the analysis of existing risk registers as part of the process of identifying the cross-disciplinary hazards. This resulted in testing the robustness of risk registers and the highlighting of inconsistencies. As a result the method could be applied to risk registers submitted for funding, permitting and in response to government requests to establish if they are a fair reflection of the hazards and risks which should be identified. This practical application was also suggested by the expert who validated the results of case study 2 for the permitting of new infrastructure as the inclusion of the lifecycle allows proactive management of hazards and risks.

11.4 Future work

This research has contributed to knowledge surrounding the identification of hazards and risks in a multidimensional world and has also highlighted gaps in knowledge that may benefit from further research in the future.

This study introduced the interface dimension to cross-disciplinary hazard identification. There were two aspects to the interface dimension; interface level I and interface level II. Interface level I requires additional research into those residual hazards with a high ranking and which do not traverse all the phases of the lifecycle. Additionally the investigation should establish what impact the inclusion of these hazards make on the existing portfolio.

The development of a method to identify cross-discipline hazards at the interface of modules of a value chain (Interface II) should be investigated. This will add another dimension to the existing suite it will require access to sensitive information but it will have practical application to new value chains and will enhance the identification of risk in complexity. This method will require an understanding of the supply chains, types of interface relationships and hazards that occur at interfaces. A workshop could be used to understand the formal and informal systems that may result from interactions at the interface of value chains. The objective would be to understand the context, issues and risks of interface management, The CCS value chain could be used as the subject for this research. Key individuals who were involved in the first CCS FEED study should be approached via a structured questionnaire focusing initially on the separate interfaces in the CCS value chain such as the interface between capture and transportation.

Another area of further research is the examination of chains of causation. There is a need to test using historical claims data the actual behaviour of these chains and the different options that may exist from one generic hazard tipping point to establish whether there are any common sequences of chains. This research will require actuarial input and the use of quantitative models. It should be possible to test to see if there are any trends. Claims experts should be approached to verify the chains of causation

The method produces a significant number of additional hazards specifically for the interface I and causation dimensions. It is necessary to reduce the number of interface hazards without diluting the importance of identifying the interface I cross disciplinary hazards. Additionally it is imperative that the relationship identified from the results of the case studies between the context of the case study, the identification of hazards and the resulting register of hazards is incorporated in any proposed method for the reduction in the number of hazards. The frequency of occurrence should not be the sole basis for inclusion in the register. Hazards that occur less frequently could have catastrophic consequences and these should not be excluded. As a result further research should consider the application of the method to additional case studies focused on the systematic reduction of the number of hazards. This could include the increased use of expert elicitation based on an acceptable logic for the specific case study, resulting in the development of a protocol for the staged reduction in number of interface I hazards to a manageable size that will allow risk professionals to focus on those cross-disciplinary hazards that require urgent mitigation.

Additionally, for interface I hazards, research should be carried out to establish the significant hazard relationships for the specific context of the subject of the register. These should be carried out by incorporating the use of expert knowledge and an agreed table of criteria for prioritisation which is specific to the context of the subject for which the register is being compiled. Separately, for causation hazards, research should look to establish common trends in the sequence of chains of causation which will help to reduce the number of causation hazards when represented as single chains rather than single hazards. This research would also benefit from the outcome of the proposed research on claims behaviour and chains of causation suggested earlier in this section.

The method should be tested on a live project which facilitates access to real data so that a better understand of the practical implications of application can be obtained. Additionally there is a need to measure the costs and benefits of traditional hazard identification compared to the implementation of cross-disciplinary identification.

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APPENDICES

Please read prior to opening the CD.

Appendix A to F Chapter 1 to 6. Appendix G to L Chapter 7, Appendix M to V Chapter 8 and Appendix U to BB Chapter 9.

Appendix A Ethic committee proposal

Appendix B Informed consent

Appendix C Expert questionnaires

C1 Interview questions

- Legal, environmental,
- Health and safety
- Environmental
- Insurer

C2 Matrix of interview results

C3 Analysis of interview results

Appendix D Web survey

D1 Web Form questions

D2 Web survey results

Appendix E Initial CCS transportation template

Appendix F Risk register template

Chapter 7

Appendix G CCS generic register

Appendix H CCS interface register

H1 First iteration and

H2 Second iteration

Appendix I CCS causation risk register

I1 Non-lifecycle

I2 Lifecycle

I3 Transversal

Appendix J CCS Consolidation causation register

Appendix K CCS Offshore component accumulation hazards

- Offshore platform
- Offshore storage
- Offshore elements

Appendix L CCS onshore component accumulation hazards

- Feeder 10
- Power Station and Carbon capture plant
- Onshore elements
- Onshore pipeline
- Surface facilities and wells
- Well reservoirs
- Whole system

Chapter 8

Appendix M Closed landfill site visit notes and quarterly report

Appendix N Closed landfill Initial generic register

Appendix O Closed landfill post prioritisation register

Appendix P Closed landfill subsidiary registers

- Short-term
- Medium term
- Long term

Appendix Q Closed landfill interface register

Q1 First iteration

Q2 Second iteration

Appendix R Closed landfill causation register

Appendix S Closed landfill accumulation lifecycle registers see subsidiary registers

Appendix T Closed landfill accumulation transversal registers

Appendix U Closed landfill accumulation component register

Chapter 9

Appendix V CCRA register of generic hazards

Appendix W CCRA Subsidiary register = the accumulation lifecycle in appendix Z

- Drier summers
- Extreme higher temperatures
- Warmer summers
- Warmer winters
- Wetter winters

Appendix X CCRA Interface register

Appendix Y CCRA Causation register

Appendix Z Accumulation registers

Z1 RA Accumulation lifecycle register

Z2 RA Accumulation Component registers

Appendix AA Frequency tables for the CCRA

Appendix BB Validation questions

BB1 Questions for CCRA validation meeting

BB2 Questions for Landfill validation meeting