

Vulnerability as a multi-faceted phenomenon: A GIS-based data model for integrated development planning, environmental management and disaster risk reduction

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ABSTRACT

People and the surrounding environment are affected by development. In striving to improve their livelihoods, people have through their development activities and exploitation of natural resources contributed to the degradation of the environment. The environment is seen as the totality of the biosphere within which anthropological and ecological activities take place. These activities are influenced by forces of nature, and in some events referred to as hazards, which can cause disruption, injury and loss of life. This premise forms the basic concept of disaster, to which people and the environment react from a position of vulnerability.

Vulnerability is multi-faceted construct that is primarily associated with social conditions. It relates to concepts of development planning and environmental management from a causal as well as a preventative perspective. Since disaster risk reduction has become the key focus of mankind's reaction to disasters, the concept of vulnerability has also become a key focus for research, and has linked various research communities, particularly those involved in disaster risk management, climate change adaption and development research in a multi-disciplinary research environment.

Socio-economic developments inspired mainly by the Second World War have since the 1940s focused research attention on development planning and disaster risk management. Hazards-based research made way for a focus on vulnerability research so as to reduce disaster risk. At the same time, an increased focus on development planning triggered a shift in philosophy away from a procedural rational planning approach to strategic, communicative planning. Disaster risk reduction along the lines of development planning has seen the emergence of a multi-disciplinary approach to vulnerability research. An apparent increase in disaster-related losses and environmental degradation has nonetheless changed people's thoughts and alerted them to the unsustainability of the course of development. With the introduction of the Bruntland Report in 1987, the concept of sustainable development was introduced as a long-term environmental strategy.

Sustainable development objectives have created a focus on the human–environment system and an understanding of relationships between anthropological and ecological entities. A special interest in spatial patterning and the geographic distribution of organisms has led to the development of landscape ecology as a study of spatial patterns

and ecological processes. A need to capture environmental criteria in a computerised spatial database emerged in the 1960s, and gave rise to the development of geographic information systems (GIS) technology. GIS-based thinking about how the real world can be presented in various conceptualisations of data structures, led to the development of GIS science (GIScience). The latter was based on research by Michael Goodchild who seeks to redefine geographic concepts and their use in the context of geographic information systems. Hence GIS should be defined as a data-processing tool, as opposed to the popular view of a map-making tool. By approaching GIS from an information system perspective that includes the development of conceptual, logical and physical data models, a platform is provided for the integration of spatial-based disciplines such as development planning, environmental management and disaster risk management.

A synthesis of the theoretical foundation of these three disciplines shows commonalities in terms of a multi-disciplinary approach, as well as a concern for the environment and for social upliftment based on sustainable development principles. They also share a strong spatial orientation, which provides for GIS technology to serve as an entry point for the integration of these disciplines. The aim of the current research was therefore to develop a GIS-based data model that would address the landscape-based relationships between spatial entities from a database design point of view. The model is founded on the principles of database design, specifically the concept of entity-relationship modelling. It also incorporates basic Boolean logic to identify the functioning of an entity in its landscape setting as either acceptable or unacceptable. This concept supports the analysis of environmental sensitivity and disaster risk from the level of small geographic units, thereby enabling vulnerability reduction efforts at a local scale.

The research in hand was useful to define and investigate the theoretical grounding of development management, environmental management, disaster risk reduction and geographic information systems, as well as to identify their common focus areas. An analysis of GIS technology and the development of a data model provided a focus on database development as the key for providing an information-based entry point and integration of development management, environmental management, disaster risk management. A case study for an area near Richards Bay, where development affected a wetland by increased vulnerability to flooding, has proven the GIS-based data model to be valuable as a tool that can be implemented to reduce vulnerability through informed and improved planning practices.

SAMEVATTING

In sy strewe na ontwikkeling beïnvloed die mens sy omgewing. Die omgewing word beskryf as die omvattende biosfeer waarbinne menslike en natuurlike sisteme funksioneer. Deur die onttrekking van natuurlike hulpbronne, en die voortdurende strewe om sy lewenstandaard te verbeter, het daar reeds grootskaalse agteruitgang in die omgewing begin plaasvind. Menslike aktiwiteite is onderhewig aan kragte in die natuur, sommige waarvan as bedreigings beskou word, wat ontworteling, besering en verlies van lewe kan meebring. Hierdie beskouing vorm die basiese konsep van 'n ramp. Die mens en die omgewing se reaksie op rampe vind plaas vanuit 'n posisie van kwesbaarheid.

Kwesbaarheid is 'n veelvlakkige konsep wat hoofsaaklik met sosiale omstandighede verband hou. Dit hou verband met ontwikkelingsbeplanning en omgewingsbestuur vanuit 'n reaktiewe, sowel as 'n voorkomende perspektief. Ramprisikobestuur is gefokus op die vermindering van risiko, teenoor bloot voorkomende aksie om rampe af te weer. In die lig hiervan is navorsing op die vermindering van mense se kwesbaarheid gefokus. Hierdie benadering bring verskillende navorsingsgemeenskappe bymekaar, veral die in die veld van klimaatsverandering en ontwikkelingsbestuur. 'n Hoofkenmerk is die multi-dissiplinêre aard van die navorsing.

Sedert die Tweede Wêreldoorlog word sosio-ekonomiese ontwikkeling met 'n fokus op ontwikkelingsbeplanning en ramprisikobestuur vereenselwig. Waar navorsing eers op bedreigings gefokus was, het die fokus na risikobestuur en die verlaging van die mens se kwesbaarheid teenoor rampe verskuif. Terselfdertyd het daar in die beplanningsgemeenskap 'n fokusverskuiwing plaasgevind, weg van rasionele, prosesgedrewe beplanning, na deelnemende strategiese beplanning. Dit het die multi-dissiplinêre benadering tot navorsing oor kwesbaarheid verder versterk. Met die toenemende bewustelikheid van die kwesbaarheid van die omgewing, en die agteruitgang wat met ontwikkeling gepaard gaan, het die besef van die onvolhoubaarheid van ontwikkelingspraktyke al hoe sterker geword. Met die bekendstelling van die Bruntlandverslag in 1987, het die konsep van volhoubare ontwikkeling as 'n langtermyn doelwit al hoe sterker geword.

Kennis van die onderliggende verwantskappe tussen menslike en natuurlike sisteme het al hoe belangriker begin word, namate die doelwitte van volhoubare ontwikkeling tot die voorgrond begin getree het. 'n Spesifieke belangstelling in ruimtelike verwantskappe en

patrone, en die verspreiding van organismes, het die ontwikkeling van landskap-ekologie aanleiding gegee. Dit fokus op die studie van ruimtelike patrone en ekologiese prosesse. Die behoefte om hierdie prosesse en omgewingsaspekte in gerekenariseerde ruimtelike databasisse vas te lê, het saam met die ontwikkeling van rekenaartegnologie ontwikkel. Dit het tot die ontwikkeling van tegnologie rondom geografiese inligtingstelsels (GIS) aanleiding gegee. 'n GIS-gebaseerde benadering tot die voorstelling van verskynsels op aarde, en verwante datastrukture, het tot die ontwikkeling van 'n GIS wetenskap aanleiding gegee. Die fondasie vir die ontwikkeling van die wetenskap is deur die werk van Michael Goodchild gelê, wat daarop ingestel is om geografiese konsepte en die toepassing daarvan in die konteks van GIS te herdefinieer. Gevolglik behoort GIS eerder in terme van dataprozessering gedefinieer te word, as wat dit as 'n werksmiddel beskou word om bloot kaarte te maak. GIS behoort vanuit die perspektief van inligtingstelsels benader te word. Hierdie perspektief sluit die ontwikkeling van konsepsuele, logiese en fisiese datamodelle in, wat 'n platform vir die integrasie van ontwikkelingsbeplanning, omgewingsbestuur en ramprisikobestuur bied.

'n Sintese van die teoretiese onderbou van die drie dissiplines dui op sekere gemeenskaplikhede wat afgelei kan word uit die multi-dissiplinêre aard daarvan, sowel as 'n gemeenskaplike benadering tot omgewingsbewaring en sosiale opheffing, wat in die beginsels van volhoubare ontwikkeling saamgevat is. Daar is ook 'n sterk verband ten opsigte van 'n ruimtelike oriëntering. Dit bepaal dat GIS tegnologie as 'n vertrekpunt beskou kan word, ter wille van die integrasie van die dissiplines. Die doel van hierdie studie is om 'n GIS gebaseerde data model te ontwikkel wat op die verwantskap tussen menslike en natuurlike entiteite, soos dit in 'n landskap funksioneer, ingestel is. Die model dra 'n sterk fokus op databasisteorie, spesifiek die konsep van entiteitsverwantskap modellering. Dit steun ook op beginsels van Booleaanse logika, wat die funksionering van entiteite in 'n landskap as aanvaarbaar of onaanvaarbaar kan aandui. Die koppeling word gemaak aan geografiese entiteite wat op die kleinste moontlike skaal as ruimtelike eenhede vasgelê word. Op hierdie wyse kan die kwesbaarheid van sosiale en ekologiese komponente as eenhede in die landskap aangespreek word.

Die waarde van hierdie studie kan gesien word in die ondersoek van die teoretiese fundering van ontwikkelingsbeplanning, omgewingsbestuur en ramprisikobestuur, sowel as geografiese inligtingstelsels. Die belangrikheid om onderliggende gemeenskaplikhede te bepaal, word uitgelig. 'n Beskrywing van GIS tegnologie, en die ontwikkeling van 'n datamodel, dui op databasisontwerp as die sleutel om 'n

gemeenskaplike vertrekpunt tussen die drie dissiplines te bepaal. Die waarde van die datamodel word deur 'n gevallestudie in Richardsbaai geïllustreer. Die gebied word deur 'n sensitiewe ekologie en blootstelling aan oorstromings gekenmerk, gepaardgaande met die druk op ontwikkeling en uitbreiding van menslike aktiwiteite. In die opsig bewys die datamodel as 'n waardevolle hulpmiddel om die kwesbaarheid van menslike en ekologiese sisteme uit te wys.

KEYWORDS

Data model
Development
Development planning
Disaster risk
Disaster risk reduction
Ecology
Environmental management
Framework
Geographic Information systems (GIS)
Hazard
Landscape
Planning
Resilience
Sustainable development
Vulnerability

ACRONYMS

ACDS	African Centre for Disaster Studies
BSU	Basic Spatial Units
CSD	United Nations Commission on Sustainable Development
CSIR	Council for Scientific and Industrial Research
DAEARD	Department of Agriculture, Environmental Affairs and Rural Development.
DFID	UK Department for International Development
DRR	Disaster Risk Reduction
EAP	Environmental Assessment Practitioner
EIA	Environmental Impact Assessment
EMF	Environmental Management Framework
EMP	Environmental Management Plan
EU	European Union
GIS	Geographic Information Systems
GIScience	Geographic Information Science
GAP	Geospatial Analysis Platform
GDARD	Gauteng Department of Agriculture and Rural Development
GVA	Gross Geographic Value Added
IEM	Integrated Environmental Management
IDP	Integrated Development Planning
IDZ	Industrial Development Zone
MAUP	Modifiable Area Unit Problem
MCDA	Multi-Criteria Decision Analysis
MDGs	Millennium Development Goals
NEMA	National Environmental Management Act (Act 107 of 1998)
NEPA	(United States) National Environmental Policy Act
NFSD	National Framework for Sustainable Development
NRC	(United States) National Research Council
NSSD	National Strategy for Sustainable Development and Action Plan
OED	Oxford English Dictionary
RIA	Rapid Impact Assessment
SANBI	South African National Biodiversity Institute
SDF	Spatial Development Framework
SEA	Strategic Environmental Assessment
SoER	State of the Environment Reports

TFL	Tobler's First Law
UN	United Nations
UNEP	United Nations Environment Programme
UN/DESA	United Nations Department of Economic and Social Affairs
UN/ISDR	United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction
US	United States of America

TABLE OF CONTENTS

CHAPTER 1: ORIENTATION AND PROBLEM STATEMENT	1
1.1 INTRODUCTION	1
1.2 ORIENTATION AND PROBLEM STATEMENT	3
1.2.1 Problem statement	10
1.2.2 Key research questions	11
1.3 RESEARCH OBJECTIVES	12
1.4 CENTRAL THEORETICAL STATEMENT	13
1.5 RESEARCH METHOD	14
1.6 CONTRIBUTION MADE BY THE STUDY	17
1.7 CHAPTERS IN THE STUDY	18
1.8 CONCLUSION	20
 CHAPTER 2: THEORY OF DEVELOPMENT PLANNING	 21
2.1 INTRODUCTION	21
2.2 CONCEPTUALISATION OF DEVELOPMENT	23
2.2.1 Development theory	23
2.2.1.1 <i>The 1940s</i>	23
2.2.1.2 <i>The 1950s</i>	24
2.2.1.3 <i>The 1960s</i>	24
2.2.1.4 <i>The 1970s</i>	24
2.2.1.5 <i>The 1980s</i>	24
2.2.1.6 <i>The 1990s</i>	25
2.2.1.7 <i>2000 and onward</i>	25
2.2.2 Hegemony as a spatial construct	26
2.2.3 Economic approaches to development	29
2.2.3.1 <i>Modernisation theory</i>	30
2.2.3.2 <i>Dependency theory</i>	31

2.2.3.3 <i>Neo-liberalism</i>	33
2.2.3.4 <i>Post-development</i>	33
2.3 CONCEPTUALISATION OF PLANNING	35
2.3.1 Planning – a definition	37
2.3.2 The development of planning theory	40
2.3.3 Blueprint planning	42
2.3.4 Rational planning	43
2.3.4 Strategic planning	44
2.3.5 Advocacy and a communicative planning in perspective	45
2.3.6 Crisis planning	46
2.3.7 Planning: an integrated process	47
2.3.8 The planning theory dilemma	51
2.3.8 Planning theory: Future perspectives	52
2.4 DEVELOPMENT PLANNING – AN INTEGRATED ENDEAVOUR	54
2.4.1 Development planning and sustainable development.....	56
2.4 INFORMATION AND DEVELOPMENT PLANNING	58
2.5 CONCLUSION	58
 CHAPTER 3: THEORY OF ENVIRONMENTAL MANAGEMENT	 60
3.1 INTRODUCTION	60
3.2 ENVIRONMENTAL MANAGEMENT	62
3.3 INTEGRATED ENVIRONMENTAL MANAGEMENT	65
3.3.2.1 <i>Environmental Impact Assessment (EIA)</i>	68
3.3.2.2 <i>Environmental Management Plans (EMPs)</i>	71
3.3.2.3 <i>Strategic Environmental Assessment (SEA)</i>	72
3.3.2.4 <i>Environmental Management Framework (EMF)</i>	75
3.4 ENVIRONMENTAL MANAGEMENT AND DEVELOPMENT	76
3.4.1 Sustainable development	77
3.5 LANDSCAPE ECOLOGY	81

3.6	CONCLUSION	84
CHAPTER 4:	THEORY OF DISASTER RISK MANAGEMENT	86
4.1	INTRODUCTION	86
4.2	HISTORY OF DISASTER RISK MANAGEMENT	87
4.3	THEORETICAL GROUNDING OF DISASTER RISK MANAGEMENT	89
4.3.1	Defining disaster	90
4.3.1.1	<i>Paradigm 1: The Patterns of War Approach</i>	92
4.3.1.2	<i>Paradigm 2: Disaster as Social Vulnerability</i>	92
4.3.1.3	<i>Paradigm 3: Disaster as Uncertainty</i>	92
4.3.2	Research frameworks – Approaches to disaster study	93
4.3.2.1	<i>Human Ecology School</i>	93
4.3.2.2	<i>Disaster Research School</i>	94
4.3.3	The Disaster Phase Model	95
4.3.4	Critique of the Disaster Phase Model	97
4.3.5	Propositions and principles of the Disaster Phase Model	100
4.3.6	Concepts of vulnerability and hazard.....	102
4.3.6.1	<i>Understanding hazards</i>	104
4.3.6.2	<i>Understanding vulnerability</i>	106
4.3.6.3	<i>Understanding Resilience</i>	110
4.3.6.4	<i>Understanding risk</i>	113
4.4	MULTI-DISCIPLINARY NATURE OF DISASTER.....	113
4.4.1	Disaster risk in developmental context	115
4.4.2	Disaster management in a social and sustainability context.....	118
4.5	CONCLUSION	120
CHAPTER 5:	THEORY OF GEOGRAPHIC INFORMATION SYSTEMS (GIS)	123
5.1	INTRODUCTION	123
5.2	AN OVERVIEW OF GIS HISTORY	124

5.3	THE CONTEXT OF GIS AS AN INFORMATION SYSTEM	126
5.4	GEOGRAPHIC INFORMATION SCIENCE.....	133
5.4.1	The “GIS as a science” debate	133
5.4.2	What is geographic information science?	134
5.5	FUNDAMENTAL GEOGRAPHIC CONCEPTS OF GISCIENCE.....	137
5.5.1	The nature of geographic data and its modelling.....	138
5.5.1.1	<i>Fields</i>	139
5.5.1.2	<i>Discrete objects</i>	140
5.5.1.3	<i>Geo-atoms</i>	141
5.5.1	Representation of conceptual views: rasters and vectors.....	143
5.5.2	Human cognition of the spatial world	146
5.5.3	Abstraction and issues of accuracy, quality and uncertainty.....	147
5.5.4	Spatial relationships.....	150
5.5.5	GIS and relational database concepts.....	151
5.5.6	The Relational Database Model	152
5.5.6.1	<i>The Entity Relationship Model</i>	154
5.5.7	Information and knowledge as a product of data.....	156
5.6	GIS FUNCTIONS	161
5.7	CONCLUSION	163
CHAPTER 6: INDICATORS, FRAMEWORKS AND MODELS OF VULNERABILITY, SUSTAINABLE DEVELOPMENT AND THE ENVIRONMENT		165
6.1	INTRODUCTION.....	165
6.1	INDICATORS AND FRAMEWORKS	166
6.2.1	Indicators	166
6.2.2	Frameworks	169
6.2	AN OVERVIEW OF INTEGRATED VULNERABILITY FRAMEWORKS AND INDICATORS.....	170
6.3.1	The Dual Structure of Vulnerability: Bohle (2001).....	171

6.3.2 The Coupled Human–Environment Framework: Turner <i>et al.</i> (2003b) and Birkmann (2005)	172
6.3.3 Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) Framework: Birkmann <i>et al.</i> (2013)	174
6.3.4 BBC conceptual framework: (Birkmann, 2006)	176
6.3.5 Land Use Intensity: Spangenberg (2002)	178
6.3.6 Social Vulnerability Index (SoVI): Cutter <i>et al.</i> (2003)	179
6.3 AN OVERVIEW OF INTEGRATED DEVELOPMENT AND ENVIRONMENTAL FRAMEWORKS.....	181
6.3.1 The PSR and DPSIR Frameworks	182
6.3.2 The DPSIR Framework	183
6.4 THE USE OF INDICATORS IN GIS IN RESPECT OF DEVELOPMENT, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT	185
6.4.1 Multi-Criteria Decision Analysis: Georgetown Case Study (Cutter <i>et al.</i> , 2000)	186
6.4.2 Geospatial Analysis Platform (Naudé <i>et al.</i> , 2007)	188
6.4.3 Environmental Sensitivity Analysis	189
6.5 CONCLUSION	192

CHAPTER 7: INTEGRATING DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT, DISASTER RISK MANAGEMENT AND GIS	193
7.1 INTRODUCTION.....	193
7.2 MAIN FINDINGS AND CHARACTERISTICS.....	193
7.2.1 Development planning	193
7.2.2 Environmental Management	194
7.2.3 Disaster Risk Management	194
7.2.4 Geographic information systems (GIS)	195
7.3 INFERENCE: COMMONALITIES BETWEEN DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT	196
7.4. CONCLUSION	200

CHAPTER 8: A GIS-BASED MODEL FOR INTEGRATING DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT

8.1	INTRODUCTION.....	201
8.2	DATA MODELS.....	202
8.2	PROPOSED FRAMEWORK AND DATA MODEL	204
8.3	VALUE OF THE GIS-BASED MODEL FOR INTEGRATING DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT	208
8.4	APPLICATION OF THE GIS-BASED MODEL: CASE STUDY	210
8.5	EXPANSION OF THE GIS-BASED MODEL.....	216
8.6	CONCLUSION	216

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1	INTRODUCTION.....	218
9.2	KEY FINDINGS.....	219
9.2.1	Key findings of development planning	219
9.2.2	Key findings of environmental management.....	221
9.2.3	Key findings of disaster risk management	223
9.2.4	Key findings of geographic information systems.....	224
9.2.5	A summary of key findings	225
9.3	A GIS-BASED FRAMEWORK FOR THE INTEGRATION OF DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT	226
9.4	RELEVANCE AND VALUE OF THE STUDY.....	227
9.5	CONCLUSION AND RECOMMENDATIONS	228

ANNEXURES

ANNEXURE 1 TO CHAPTER 3	229
Rostow's Stages of Economic Growth (Sources: Potter <i>et al.</i> , 2008:33; Hopper, 2012:31).	229

ANNEXURE 2 TO CHAPTER 3	230
A comprehensive framework for strategic planning (Dale, 2004:27).....	230
ANNEXURE 3 TO CHAPTER 3	233
Sustainable development process: methodological framework of analysis and evaluation (Vreeker & Nijkamp, 2006:169).....	233
BIBLIOGRAPHY	234

LIST OF FIGURES

Figure 1.1: Interaction of vulnerability factors	4
Figure 1.2: The integration of related disciplines conceptualised as different focus areas and a single entry point.....	8
Figure 1.3: The research focus shown as a triangle connecting the fields of interest	10
Figure 1.4: A structural layout of the study method	17
Figure 1.5 A structural layout of the study illustrating the development of chapters.....	19
Figure 2.1: Map showing the extent of the British Empire by the late 19 th century in red .	28
Figure 2.2: Map showing the spatial conceptualisation of the Third World.....	28
Figure 2.3: Map showing the spatial conceptualisation of a developed North in blue, and a developing South in red	29
Figure 2.4: Gunder Frank's model of underdevelopment.....	32
Figure 2.5: The decision-centred view of planning	39
Figure 2.6: The continuum of reality and abstraction	45
Figure 2.7: Finding the fit between goal, resources and context.....	48
Figure 2.8: Different schemes of organisations' collaboration in strategic planning	50
Figure 2.9: Planning as a network of interrelated actions	54
Figure 2.10: The four main disciplines in the interdisciplinary field of development studies	56
Figure 3.1: A typical step-wise EIA process	70
Figure 3.2: The relationship between SEA, EIA and processes.....	72
Figure 3.3: The range of SEA models	73
Figure 3.4: A comparison of SEA and EIA processes indicating similarity, albeit on different levels.....	74
Figure 3.5: Hierarchy of IEM tools in relation to a typical development cycle.....	76
Figure 3.6: Integrated objectives of sustainable development	78
Figure 3.7: Holistic nature of sustainability – equilibrium by advancing on several fronts	79
Figure 3.8: Map indicating conflicting development and conservation priorities.....	80
Figure 3.9: Framework for ecosystem and human system linkages	84
Figure 4.1: Core topics for research in disaster risk reduction	91
Figure 4.2: Disaster Phase Model	96
Figure 4.3: Continuum of disaster risk management activities within a time framework...	99
Figure 4.4: Model of disaster impacts.....	103
Figure 4.5: The Pressure and Release Model	109
Figure 4.6: Schematic representation of varying coping ranges	112
Figure 4.7: 'Vicious spirals' of disaster risk and development failure	118

Figure 4.8: The sustainable livelihoods framework.....	119
Figure 5.1: Value adding: progression from data to wisdom.....	129
Figure 5.2: GIS and related information systems.....	131
Figure 5.3: Forming knowledge from conceptualisations of the real world.....	138
Figure 5.4: Representation of geographical entities in a topological database	144
Figure 5.5: Example of pixel values stored in a matrix of rows and columns	145
Figure 5.6: Visualisation representation of pixel values by colour (refer to Figure 5.5) ..	145
Figure 5.7: Visualisation of raster data (elevation) and vector data (roads) on a topographical map	146
Figure 5.8: The concept of extended entity as human cognition of spatial objects.....	147
Figure 5.9: The anatomy of a relation.....	153
Figure 5.10: Basic notation used in ER diagrams.....	154
Figure 5.11: Illustration of ER diagram development.....	156
Figure 5.12: The Information Process	158
Figure 5.13: The cyclical process of information management.....	159
Figure 5.14: Schema of organisational tasks and related GIS functions.....	162
Figure 6.1: The data / information pyramid.....	168
Figure 6.2: Conceptual Model for Vulnerability Analysis.....	172
Figure 6.3: Vulnerability framework	174
Figure 6.4: The MOVE framework.....	176
Figure 6.5: The BBC conceptual framework for vulnerability	178
Figure 6.6: The overlapping natural and anthropogenic regulation systems	179
Figure 6.7: The Hazards-of-Place Model of Vulnerability.....	180
Figure 6.8: Dimensions of social vulnerability.....	181
Figure 6.9: The PSR framework.....	183
Figure 6.10: The DPSIR framework	184
Figure 6.11: Spatial distribution of overall hazard vulnerability in Georgetown County ..	187
Figure 6.12: Gross Geographic Value-Added (GVA) map for Ekurhuleni, extracted from mesozone data	189
Figure 6.13: Sensitivity map for the EMF study area, created from facets data	191
Figure 6.14: Ecological status retrieved from the sensitivity facets dataset	191
Figure 7.1: The integration of development planning, environmental management and disaster risk management through GIS as a data management platform	198
Figure 7.2: Integration of Geographical Information Systems with the RIA process.....	199
Figure 7.3: Framework for GIS operation in a multi-disciplinary development planning project.....	199
Figure 8.1: Levels of abstraction for database development.....	204

Figure 8.2: The integration of anthropological and ecological activities in the functioning of the landscape	205
Figure 8.3: An ecosystem – human system framework expressed in the form of an ER diagram.....	206
Figure 8.4: Entity relationships between anthropological and ecological units in the landscape	207
Figure 8.5: Example of a compound table that can be joined with a spatial database ...	208
Figure 8.6: An example of the iterative process of data processing to create spatial data at geo-atom level.	212
Figure 8.7: Two iterations of the join table.....	212
Figure 8.8: Extract of the attribute table of the land cover GIS feature, showing the join table.....	213
Figure 8.9: Map according to the values in table (a) of Figure 8.7.	214
Figure 8.10: Map according to the values in table (b) of Figure 8.7.	214
Figure 8.11: Map showing the results of a compound query with the land cover value included.	215
Figure 9.1: Increased need for information sharing in planning models.....	221
Figure 9.2: A framework for GIS science.....	225
Figure 9.3: A framework for the integration of development planning, environmental management and disaster risk management.....	227

LIST OF TABLES

Table 5.1: The principle of set theory explained in terms of GIS datasets	151
Table 5.2: Conclusive list of universal analytical GIS operations	163
Table 6.1: Input data layers with illustrative weighting values.....	190
Table 7.1: Integration matrix showing commonalities between development planning, environmental management and disaster risk management.....	197
Table 9.1: Summary of research objectives and related chapters	219
Table 9.2 Summary of key findings	225

CHAPTER 1: ORIENTATION AND PROBLEM STATEMENT

1.1 INTRODUCTION

Development of the living space by humans is an everyday activity that has been taking place since the beginning of time. As the human population increased, and so the extent of its economic activities, the living space has expanded, with an inevitable impact on and shrinkage of the natural environment (Singh, 2006). The living space of people, and so the people themselves, are exposed to the energy of natural events that are associated with atmospheric or geological cycles, and hence result in a disaster situation when the magnitude of the event surpasses their ability to absorb the impact (Cannon, 1990).

The research community's wide interest in disasters and disaster-related topics is confirmed by the plethora of studies on vulnerability, hazards, mitigation, preparedness and recovery, as is evident in the collected work of Rodriguez, Quarantelli and Dynes (2006). Vulnerability is a primary interest of this study as it relates to concepts of development planning and environmental management. It is a multi-faceted construct and difficult to assess because of its dynamic nature (Birkmann *et al.*, 2013).

The above premises are explored in this study as the background to development planning, environmental management and disaster risk management. James Lewis states that development is the necessary inevitable (Lewis, 1999:xi). However, continued land use and land-cover change (Turner, 1997), which have caused large-scale environmental degradation (UNISRD, 1994; Renaud, 2006) and global climate change (IPCC, 2014), have forced mankind to take note of the unsustainability of its development practices. In reaction, the World Commission on Environment and Development (WCED) published a report titled *Our Common Future* in 1987, which called for *sustainable* development as a long-term environmental strategy (Ling, 2012). This was followed by a number of international summits. In 1992 the United Nations Framework Convention on Climate Change, the so-called Earth Summit, took place in Rio de Janeiro, associated with a declaration of principles and desired actions (Agenda 21) as an implementation action plan for sustainable development. The World Summit on Sustainable Development subsequently took place in Johannesburg in 2002 and focused on the effects of climate change. In 2005, the World Conference on Disaster Reduction was held in Hyogo, Japan,

where the present *Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters* report was drafted (UN, 1992; UN-ISDR, 2005).

The Hyogo Framework for Action adopts a strategic and systematic approach to reducing vulnerabilities and risks to hazards. It also calls for the development and implementation of information systems, particularly Geographic Information Systems (GIS). GIS, as an information technology, has gained much attention for its application in disaster risk management (Miletti, 1999), but also in development planning and environmental management (Barrow, 2006; Green, 2010). It is increasingly being utilised as a tool to support decision making. However, it is often regarded as mainly a map-making tool, and its use in decision making is therefore limited to the production of maps (Jansen van Vuuren, 2013).

This study aims to develop a GIS-based data model that can be applied in development planning, environmental management and disaster risk management as a spatial analysis and decision support tool. An earlier publication by the author that also resulted from the current research presents a GIS-based framework for rapid disaster impact assessment. This framework proved to be valuable in the decision to declare a disaster after a series of wild fires in the Tlokwe Municipality in 2012 (Jansen van Vuuren, 2013).

The proposed data model will demonstrate its value in an improved methodology to capture the spatial relationships between geographical entities on the grounds of their integral functions and interrelationships. The model should be useful in the furthering of vulnerability reduction. It will also (for example) be possible to model the relationship between a house and a floodplain in terms of the intricate function of the house and of the floodplain, based on the compatibility of their respective functions in the landscape.

This chapter serves as an introduction to the study and provides the reader with an orientation to past and current approaches, followed by a problem statement. This will be followed by stating the research objectives and central theories, while a description of the research method will outline the approach taken in this study. The chapter is concluded with an overview of the contribution of the study, followed by explanation of the structuring of the thesis into nine chapters and a conclusion that will guide the reader into the next chapter.

1.2 ORIENTATION AND PROBLEM STATEMENT

Vulnerability is an indicator of disaster risk (Blaikie *et al.*, 1994; Lewis, 1999; Turner *et al.*, 2003a;2003b; Bankoff, Frerks & Hilhorst, 2004; ISDR, 2004; Kienberger, Lang & Zeil, 2009). It reflects the reality of what makes people and environmental assets susceptible to hazards (ISDR, 2004). The concept of vulnerability has emerged from continuing research on risks and hazards and has been brought to the fore by climate change studies (Turner *et al.*, 2003a; Kienberger *et al.*, 2009; Prabhakar, Srinivasan & Shaw, 2009). It has emerged as a multi-faceted concept, realising the complexity of physical, social, economic and environmental conditions at hand (Blaikie *et al.*, 1994:21; Coppola, 2007:148; ISDR, 2002:46).

Vulnerability can be defined in many ways, but it mostly underpins aspects of susceptibility of a receiving environment to the impacts of hazards (Blaikie *et al.*, 1994:9; Lewis, 1999:4; ISDR, 2002:46; Turner *et al.*, 2003a; Wisner, Blaikie, Cannon & Davis, 2004:97). Oliver-Smith (2004:10) describes vulnerability as a political-ecological concept that focuses on the relationship between people and the environment in which they live. From a disaster risk perspective, he describes vulnerability as “the conceptual nexus that links the relationship that people have with their environment to social forces and institutions and the cultural values that sustain or contest them”. The concept of vulnerability is therefore seen as providing a theoretical framework that encompasses the multi-dimensionality of disasters.

Underlying vulnerability is the combination of relationships within a given situation, where a combination of social conditions and environmental forces may or may not result in a disaster (Oliver-Smith, 2004:10). Exploring the totality of relationships ultimately involves related concepts between socio-economic (developmental) sciences on the one hand and environmental sciences on the other hand, thereby promoting a strong interdisciplinary approach. Research is therefore focused on the status of and relation between human settlement and environmental (biophysical) systems, particularly referred to as a “coupled human-environment system” (Turner *et al.*, 2003a). This interaction is illustrated in Figure 1.1.

The concept of physical vulnerability is rooted in material goods and considers aspects of location and the built environment (ISDR, 2004: 68). Linked to this is the aspect of social and economic environments, where the social component is linked to the level of wellbeing of individuals, communities and society. Such wellbeing, in turn, is influenced by

economic status – under certain conditions poor communities may be more vulnerable than affluent communities. The environmental component refers to natural resources and the way in which these are threatened by developmental expansion. In this context, the pressure on ecological systems in terms of pollution and physical destruction represents elements that shape environmental vulnerability. The natural environment can be considered as the receiving environment of development, while developmental factors are inclusive of physical, social and economic conditions.

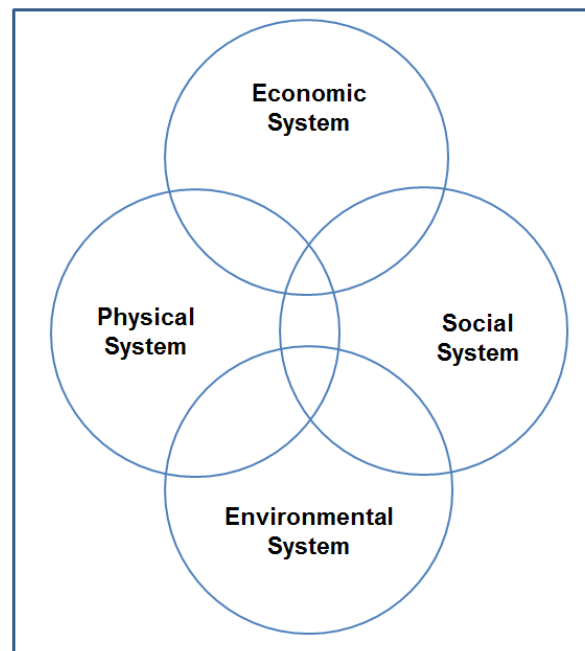


Figure 1.1: Interaction of vulnerability factors
Source: ISDR (2004)

Lewis (1999:40) states that development objectives should “take an integral account of hazards and of disaster probability”. The apparent failure to implement this norm is echoed by Van Niekerk (2010:65) who states that “there has been a widespread failure to recognise and address the ways in which changes in land use, settlement policies, population distribution and the attendant degrading of habitats dramatically increase hazard exposure and vulnerability, and ultimately increase the risk of disasters”. The commonalities between development planning and environmental management are further highlighted by a number of other authors such as Renaut (2006), Kelly (2010), Haigh and Amaratunga (2010), Kaplan, Renaud and Lüchters (2009), ISDR (2004), and McEntire (2007). Stakeholders in the development-planning and environmental management arena are becoming more involved in the management of risk and vulnerability reduction (UN-ISDR, 2002:4). The urgency of research in this field is

highlighted by the UN-ISDR (2004:4), stating that "the relationships between human actions, environmental stewardship, climate change, and disaster risks are becoming ever more crucial".

Analysis of vulnerability considers a number of questions such as: who is vulnerable to what and what is the spatial pattern thereof? To answer these questions, Turner *et al.* (2003b) propose a conceptual framework that accounts for the vulnerability of coupled human–environment systems. The emergence of vulnerability assessment within such a framework is further described by Renaut (2006) and Kienberger *et al.* (2009) where the use of geographical information systems as a spatial analysis tool in particular comes to the fore.

Mora and Keipi (2006:157), Kaplan *et al.* (2009) and ISDR (2004) describe the link between development planning, environmental management and disaster risk management as functions where the one should take the other into consideration. This holistic approach is imperative if healthy and safe environments are to be provided for people wherever they live – in cities, towns or rural villages. In this regard, Hardoy, Mitlin and Satterthwaite (2001:2) identify certain goals that settlements have to meet to be successful in providing safe environments. These goals include the provision of water supply, sanitation, waste management and health services as essential service delivery. They also include the wider context of natural resources and exploitation thereof and the demand for sustainable relationships between the demands of consumers to draw from ecosystems and the way in which they draw their resources.

The goal of achieving an ecologically sustainable relationship between the built environment and the natural environment puts development and conservation into the equation of disaster risk reduction, meaning that disaster risk reduction becomes a function of development planning and environmental management (Randolph, 2004:203). This is echoed by Hardoy *et al.* (2001:3) who state that understanding the links between the built environment and the physical environment is essential if environmental hazards are to be minimised. Lewis (1999:xi) describes development as “the necessary inevitable”, but also as an “appropriate vehicle for vulnerability and disaster reduction”.

Whereas disaster risk reduction is a function of government as well as communities (Randolph, 2010; Haigh & Amaratunga, 2010), some institutional capacity is required to act as a vehicle for communication and implementation. Hardoy *et al.* (2001:3) describe the need for political and administrative systems that will take up the views and priorities

of communities, through which policies can be put into place and that will ensure that actions are carried out in response to community needs. Such administrative arrangements should also be imbedded in legal systems that safeguard citizens' rights to basic services and a healthy living environment. Lewis (1999:5) echoes this viewpoint by referring to a social, institutional and political responsibility to protect communities from the causes of disasters. Efforts to remove or alleviate those causes, give rise to the concept of institutional capacity.

Otim (2006) links vulnerability to institutional capacity. According to him, the realities of natural disasters such as hurricanes that occur regularly, and the way in which they are managed, still reveal "institutional vulnerability and inadequacy of decision models to confront large-scale disasters". A key aspect of institutional capacity is the use of information systems to inform decision makers and policy makers. Margetts (1999) describes how information systems have brought government to the 'ante-postmodernist' era, becoming a vital part of the state. The power of information systems is demonstrated in the fact that they can take over and reshape the organisational role of government. Whereas this viewpoint is described from a Western perspective, referring to Britain and America, Cavric (2002) describes the apparent failure of information systems and in particular Geographical Information Systems (GIS) in developing countries. According to him there is a dire need for research to address "the problem of human familiarisation and organisational frameworks in which newly established GIS units [are] supposed to function".

The use of Geographic Information Systems (GIS) as a tool to analyse and visually represent a range of variables, attributes and phenomena is described by Bankoff *et al.* (2004:45). Van Deursen, Wesseling and Karssenbergh (2000) sketch a picture of GIS and Information Technology (IT) specialists who are regarded as technologists on the one hand and end-users who are domain experts on the other hand. GIS specialists have knowledge of and control over the technology to develop applications for users in various fields. The end-users (domain experts) are allowed access to these applications to fulfil various tasks, such as entering new data and retrieving information. This kind of access is limited to the degree in which the application has been designed to allow for such functions. Understanding the technical aspects of the technology, the GIS expert will know how to exploit its powers to the full extent and will often try to allow for the maximum functionality without knowledge of the application field (Van Deursen *et al.*, 2000). Further problems with regard to GIS applications relate to operational aspects such as data

capturing, visualisation and data management (Van Oosterom, Zlatanova & Fendel, 2005) which often result in the technology not being implemented (Cavric, 2002).

On the other hand, domain experts study their particular problem areas and are not directly involved in the development of GIS applications (Van Deursen et al., 2000). Due to the described situation, GIS tools tend to become intimidating to the extent that users will often revert back to their traditional methods. Instead of gaining access to these technologies, domain experts will then continuously have to rely on the GIS experts to make changes to or develop new tools (Van Deursen et al., 2000). In this regard, McEntire (2004:17) warns against an over-reliance on computer technology since it “may make us vulnerable to complicated and cascading disasters”.

These apparent problems with the use of GIS and the domain of information technology at large require that further attention be given to the drivers of disaster risk reduction. The Global Assessment Report on Disaster Risk Reduction (2009) describes three underlying drivers of disaster risk, i.e. vulnerable rural communities, poor urban governance and declining ecosystems. Recognising the inherent link between the environment and disasters, the Disaster Environment Working Group for Asia (DEWGA) undertook a study to identify available resources that link environmental management with disasters and risk reduction efforts (Asian Disaster Management News, 2009). One of the objectives of the study is to “[r]aise awareness of the intersections of environment, disasters and development and thereby provide a practical and common basis for practitioners from various sectors to discuss and agree on concrete plans and activities to advance mainstreaming”. This implies a functional connection between the three disciplines of environmental management, disaster management and development planning. DEWGA identifies the following three strategic entry areas for integration:

- i. Environment-development convergence
- ii. Disaster-development convergence
- iii. Environment-disaster convergence

These strategic entry areas should ideally be integrated to such an extent that all three of them converge at a single entry point, as is illustrated in Figure 1.2.



Figure 1.2: The integration of related disciplines conceptualised as different focus areas and a single entry point

Source: Asian Disaster Management News (July-December 2009)

The significance of a central entry point is that it provides a holistic point of departure and gives an overall background from where a particular focus area could be further explored. Given the potential of information technology in disaster risk reduction (Hiltz, Van de Walle & Turoff, 2010: 16), it can be argued that geographic information system technology may provide that holistic point of departure that would ultimately strengthen the integration of the related disciplines. The need for research in this regard is implied by the International Union of Geodesy and Geophysics' Commission on Geophysical Risk and Sustainability (2010), which inter alia recommends that

“[m]ultidisciplinary and multinational research programs and research networks on geophysical hazards and risks be developed in all countries prone to natural hazards including those of the Caribbean region and Latin America in order to integrate diverse data streams, to improve understanding of the natural phenomena associated with the disasters, to develop predictive modelling capability, and to generate and to disseminate timely and accurate information needed by decision makers and the public.”

The researcher has an interest in this study because of his involvement in Geographical Information Systems (GIS) over the past 25 years, during which he has applied this technology in various projects relating to development planning, environmental

management and disaster risk management. The type of projects include development plans on a local and regional level, environmental management frameworks, environmental impact studies and disaster risk assessments. The GIS component of these projects includes two perspectives, i.e. design and application. It involves GIS database design and a wide array of applications such data capture, data processing, spatial analysis, and mapping. A further interest in education and research has also inspired this study. The researcher is associated with the African Centre for Disaster Studies at the North-West University and has published research work in the accredited *Jamba Journal of Disaster Risk Studies* in 2006 and 2013. The research undertaken for the latter publication forms part of the current research and informs components thereof.

Development planning, environmental management and disaster risk management have in common the need for information and the spatial representation thereof by using geographical information systems technology. This interest frames the research focus shown in Figure 1.3 as a triangle connecting the three application fields, with GIS in the centre as an integrating factor.

The present research is aimed at the development of a data model based on geographical information technology, which will serve as an entry point for vulnerability assessment. The research will be focused on the aspect of vulnerability as it is fundamentally embedded in functions relating to disaster risk management, environmental management and development planning. The research will be carried out with a view to integrating these disciplines in as far as the use and the processing of spatial data is concerned.

The research will be carried out by studying the interrelationships between the disciplines mentioned above and indicating their dependence on common data sources and data features. The validity of this data model will be tested within the Southern African context, as well as in selected overseas countries, including developed and developing countries.

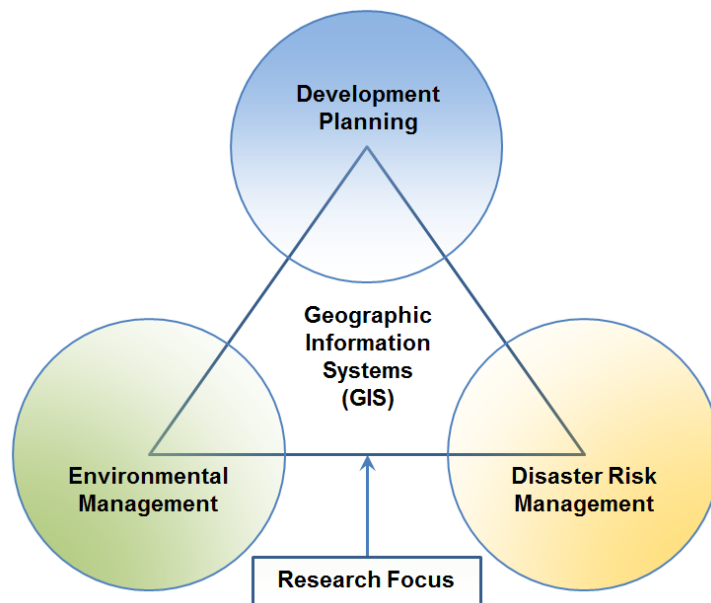


Figure 1.3: The research focus shown as a triangle connecting the fields of interest

1.2.1 Problem statement

According to the National Education, Training and Research Needs and Resources Analysis Report (NDMC, 2010), the reduction of vulnerability has become the focal point in disaster risk management practice and research. This report describes a number of issues that constitute the agenda for further research. These issues take account of aspects relating to development planning and information technology, and include the following (NDMC, 2010:16-18):

- i. There is a need for more trans-disciplinary and interdisciplinary research to reduce the fragmented and reductionist approach to disaster risk management.
- ii. Disaster risk reduction principles and policy have a limited influence on integrated development planning. (This aspect is also highlighted by Hoogstad and Kruger (2008).)
- iii. There is an urgent need for DRM officials to develop an understanding of development planning to ensure that the disaster management function has its intended statutory impact.
- iv. There is a need for an IT research and development programme specifically focused on disaster risk reduction and management.
- v. Standardised systems for Disaster Management are lacking.
- vi. Communities should participate actively and meaningfully in risk reduction.
- vii. There is a need for the sharing of baseline information on the SA risk profile.

These issues remind of the commonalities between development planning, environmental management and disaster risk management, which have been described above. These disciplines are characterised by a plethora of tools assisting in various activities relating to planning, checking and acting (Nel & Kotze, 2009; Koua *et al.*, (2010). For example, development planning is assisted by Spatial Development Frameworks (SDFs), Integrated Development Plans (IDPs), environmental management by Environmental Impact Assessments (EIAs), strategic environmental assessments (SEAs), disaster risk management by Disaster Management Plans (DMPs) and disaster risk assessments (DRAs). The apparent failure to integrate these tools in disaster risk management – as described by Hoogstad and Kruger (2008), the National Disaster Management Centre (2010) and Van Niekerk (2010) – highlights the need for an alternative approach to interdisciplinary research. Such an approach draws on the universal premises between these disciplines and goes beyond close collaboration between domain specialists (Barrow, 2006:4). One such universal premise or common theme is the use of information. Given the challenges with regard to the use of information technology and in particular GIS in disaster risk management, as described above, it is postulated that the systematic integration of information technology in the processes relating to development planning, environmental management and disaster risk reduction will assist in understanding vulnerability as a multi-faceted phenomenon. Therefore, and in the light of the above discussion, the problem under investigation is the *integration of development planning, environmental management and disaster risk management into a GIS-based data model that captures the relationships between anthropological and ecological entities in an interrelated database, which will be useful to analyse vulnerability in various facets.*

1.2.2 Key research questions

With reference to the problem statement above, the research will aim to answer the following key research questions:

- What is the theoretical grounding of development management, environmental management, disaster risk reduction and GIS?
- What common focus areas in development management, environmental management and disaster risk reduction can be identified?
- What is model development and data modelling in GIS?
- What is the entry point for development management, environmental management and disaster risk reduction to be integrated in a data model for vulnerability reduction?

- What would a GIS-based data model for vulnerability reduction entail?
- What recommendations can be made for the implementation of a GIS-based data model for vulnerability reduction?

1.3 RESEARCH OBJECTIVES

The primary objective of the study is to develop a GIS-based data model that will be useful in development planning, environmental management and disaster risk management. A specific focus is vulnerability, as it is influenced by policy and patterns in each of these fields. The application of the model must be useful particularly in respect of vulnerability reduction.

To reach this objective, a sequence of secondary objectives is identified which expands the research topic into its underlying ontologies:

- i. Define and investigate the theoretical grounding of development management, environmental management, disaster risk reduction and geographical information systems.
- ii. Identify the common focus areas in development management, environmental management and disaster risk reduction.
- iii. Describe model development and data modelling in GIS.
- iv. Determine the entry point for development management, environmental management and disaster risk reduction to be integrated in a data model for vulnerability reduction.
- v. Provide recommendations for the implementation of a GIS-based data model for vulnerability reduction.

1.4 CENTRAL THEORETICAL STATEMENT

This study looks at GIS as an overarching technology that supports development planning, environmental management and disaster risk management. The following theoretical statements that reflect views in these disciplines guide this study:

- i. Disaster risk management is a multi-disciplinary field that is influenced by disciplines such as environmental management and development planning (McEntire, 2004; Randolph, 2004; Haigh & Anaratunga, 2010; Van Niekerk, 2010).
- ii. Vulnerability is a complex aspect. In trying to understand this complex system, a need for analysis arises which should bring together different interactions between man, nature and society (Trim, 2004).
- iii. Information is one of the elements that bring together the various disciplines that are implied in disaster risk management by explaining the interactions between man and the environment from within these disciplines (Haigh & Anaratunga, 2010; Charlton & Andras, 2003).
- iv. A clear understanding of the perspectives and problems of these disciplines is imperative for successful implementation of GIS technology. A GIS paradigm built around these concepts and perspectives would enable systems that deliver the power of GIS technology to the end user (Van Deursen et al., 2000).
- v. The implementation of risk reduction policies requires interdisciplinary strategies, tools and approaches to ensure proper management and resourcing of pre-disaster, disaster and post-disaster efforts. There are strong calls for interdisciplinary solutions to address the many and varied challenges that disasters create (Haigh & Amaratunga, 2010).
- vi. Information is fundamental to any system, irrespective of the discipline (Shastri, Diwekar & Cabezas, 2008).
- vii. The integration of environmental and social considerations is a challenge that requires the development of methods, processes and data streams to create capacity for sustainable development, with the aim of reducing vulnerability.
- viii. Apart from vulnerability, there are a variety of other topics that have a bearing on or a relation to disasters, such as attitudes about development and record keeping (McEntire, 2008). Record keeping can include any aspect of development or disaster events.
- ix. Research that goes beyond disciplinary boundaries is core to understanding linked phenomena, and to informing policy and management settings (Dovers, 2005).

1.5 RESEARCH METHOD

A qualitative research design is used to conduct the present research as it is useful in exploring processes and links. This approach helps to interpret and better understand the complex reality of how development planning, environmental management reduction and disaster risk management are interlinked with one another. The design includes a literature study and an empirical study, and is briefly highlighted as follows (the reader is also referred to Figure 1.4 which gives a diagrammatic overview of the research method):

1.5.1 Literature study

A variety of literature is studied as the primary data source for this research. It includes books, academic articles, reports, conference proceedings and research reports or document that are focused on the theory of development planning, environmental management and disaster risk management. The purpose of the literature study is to discover commonalities between these disciplines and to identify interrelationships, as these are central to the research topic.

1.5.2 Empirical study

A synthesis of the literature study highlights commonalities and interrelationships between development planning, environmental management and disaster risk management (Chapters 6 and 7). By applying principles of database theory (described in Chapter 5), a GIS-based data model is developed and tested in a case study. The method for constructing the data model is based on grounded theory and described in the following paragraphs.

1.5.2.1 Content analysis

Content analysis is the main empirical method employed in this study. It is a research technique that can be applied to data derived from texts for making replicable and valid inferences in the context of the text (Krippendorff, 2004). Content analysis helps to analyse data within a specific context, in view of the meanings that are attributed to it by a person or a group. Theories for development planning, environmental management and disaster risk management have developed over a relatively short period of time, and are marked by changes and differences (Chapters 2, 3 and 4). Content analysis will not only

help to identify the commonalities in these fields and explore their interrelationships, but will also be used together with grounded theory to develop a data model (Chapter 8).

1.5.2.2 Grounded theory

Grounded theory is a pre-eminent qualitative research method that comprises a systematic yet flexible approach for collecting and analysing data with the aim of constructing theories grounded in the data itself. This method allows for constant interaction between data collection and analysis, with each process informing the other, thereby making the collected data more focused and the analysis more theoretical (Bryant & Charmaz, 2007:1).

Grounded Theory approaches are evident in research literature regarding information systems, because the method is useful in developing context-based, process-oriented descriptions and explanations (Myers, 1997). The core of Grounded Theory is in the analysis and search for patterns in the data. By identifying unique properties in each of the interest fields (development planning, environmental management and disaster risk management), an inductive strategy is applied to arrive at a synthesis of relating patterns in the data, which are ultimately presented in a model. This study entails an analysis of processes, procedures, legislation and information requirements across three disciplines, and is aimed at the identification of similar patterns and trends in each, specifically with regard to the use of information and the implementation of GIS.

1.5.2.3 Development of a GIS-based data model

Based on the need for resolving spatial relationships among geographic entities, this study presents a GIS-based data model that is grounded in database theory that will be able to identify such relationships. By using this model, areas characterised by development pressure, environmental sensitivity and disaster risk can be identified and mapped based on the intricate relationships between geographical objects that constitute anthropological and environmental entities.

1.5.2.4 Case study

A case study is presented to test the data model. It involves the development and implementation of a GIS project by identifying an appropriate study area and creating a spatial database that incorporates the model. The selected study area represents an

area in Richards Bay that is characterised by development pressure, environmental sensitivity and communities' vulnerability to flooding. The GIS database consists of existing data, as well as a land cover-based dataset of spatial objects created for the purpose of the study. By manipulating variables in the model, the researcher demonstrates how different scenarios of vulnerability can be simulated without changing the spatial data. Maps generated from spatial queries are included to illustrate the functioning of the model.

1.5.3 In-depth interviews

As a professional GIS Science Practitioner, the researcher is involved in multi-disciplinary projects on a daily basis. His specialisation is in development planning, environmental management and disaster risk management. During the course of this study he took the opportunity to conduct in-depth interviews with professionals working in these fields and to extract from their knowledge and experience. The information gained could be applied to

- i. triangulate findings from the literature study,
- ii. determine the professionals' perceptions on the use of GIS in their respective fields, and
- iii. test the applicability of the data model in the field.

Following a deductive approach, the research method is applied to develop a GIS-based model based on the commonalities extracted from development planning, environmental management and disaster risk management theories. These were applied according to database principles that were extracted from the information systems theory. The reader is next referred to Figure 1.4 which gives a visual presentation of the development of chapters in this report.

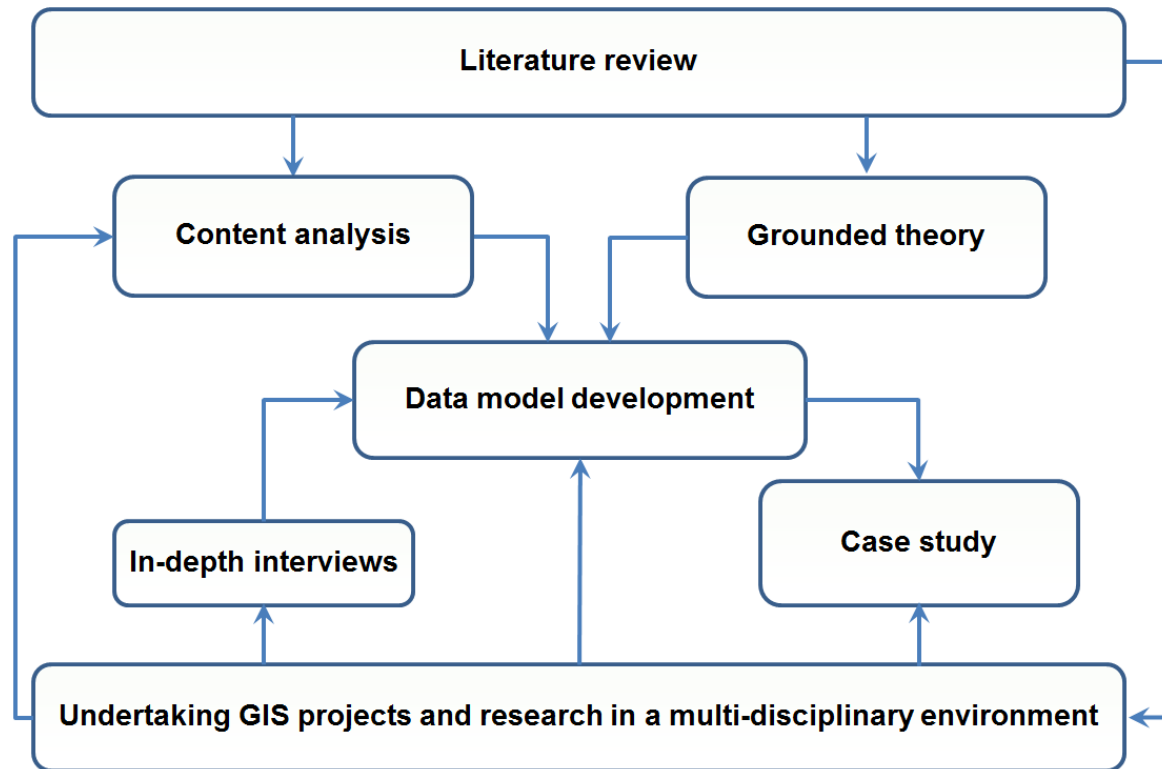


Figure 1.4: A structural layout of the study method

1.6 CONTRIBUTION MADE BY THE STUDY

The orientation sketch above indicates that there is a strong link between the disciplines of development planning, environmental management and disaster risk management. The study provides a GIS-based data model for integrated database development, taking into account the vulnerability of communities, the sensitivity of the environment and the pressures of development in a sustainable planning context. The model is practical in nature and can be used by practitioners in development planning, environmental management and disaster risk management alike. It can also be incorporated in the day-to-day functioning of government departments, municipal offices and other institutions where information systems for disaster risk management are being used – specifically where work is focused on the reduction of vulnerability. The study will therefore add value to the body of knowledge within the disaster risk management fraternity and also inform international best practices in so far as supranational disaster risk reduction measures are concerned. This study will therefore contribute significantly to the integration of disaster risk management, environmental management and development planning by developing a GIS-based data model that provides a platform for the integration of these disciplines in a practical manner.

In the end, the study may provide impetus towards further research, as it presents a framework for integration whereby inter- and intradisciplinary approaches can be facilitated.

1.7 CHAPTERS IN THE STUDY

The study is structured into nine chapters that render a thematic exposition of the topic. The diagram in Figure 1.5 provides a graphical overview of the structure of the study. The theme and purpose of each chapter is briefly indicated and discussed below:

Chapter 1 introduces the reader to the problem statement, key research questions, as well as aim and objectives of this study. The idea and motivation for the study is explained by placing development planning, environmental management and disaster risk management into context. The research methodology is outlined and the contribution of this study to the body of knowledge in the field of development management is described.

A theoretical grounding of the study is developed through examining three interrelated disciplines: development planning, environmental management and disaster risk management. Underlying these, is geographic information systems which, as a fourth discipline, provides further grounding to this study. To effectively explore the theoretical aspects that contributed to each field, their historical development and theoretical models are described in three separate and consecutive chapters. Development planning is explored in Chapter 2, environmental management in Chapter 3, disaster risk management in Chapter 4, and geographic information systems in Chapter 5.

Chapters 6 and 7 are aimed at finding commonalities among development planning, environmental management and disaster risk management. Chapter 6 focuses on frameworks and models that have been developed in these three disciplines and provides a bridge to the development of a data model that can integrate them. Chapter 7 serves to identify the commonalities between the three disciplines and provides a framework for the model to be developed in the next chapter.

Chapter 8 provides a background to the concept of data models and describes the development of a GIS-based data model that integrates development planning, environmental management and disaster risk reduction on the grounds of spatial relationships.

The study is concluded with Chapter 9 which presents conclusions and recommendations for further studies.

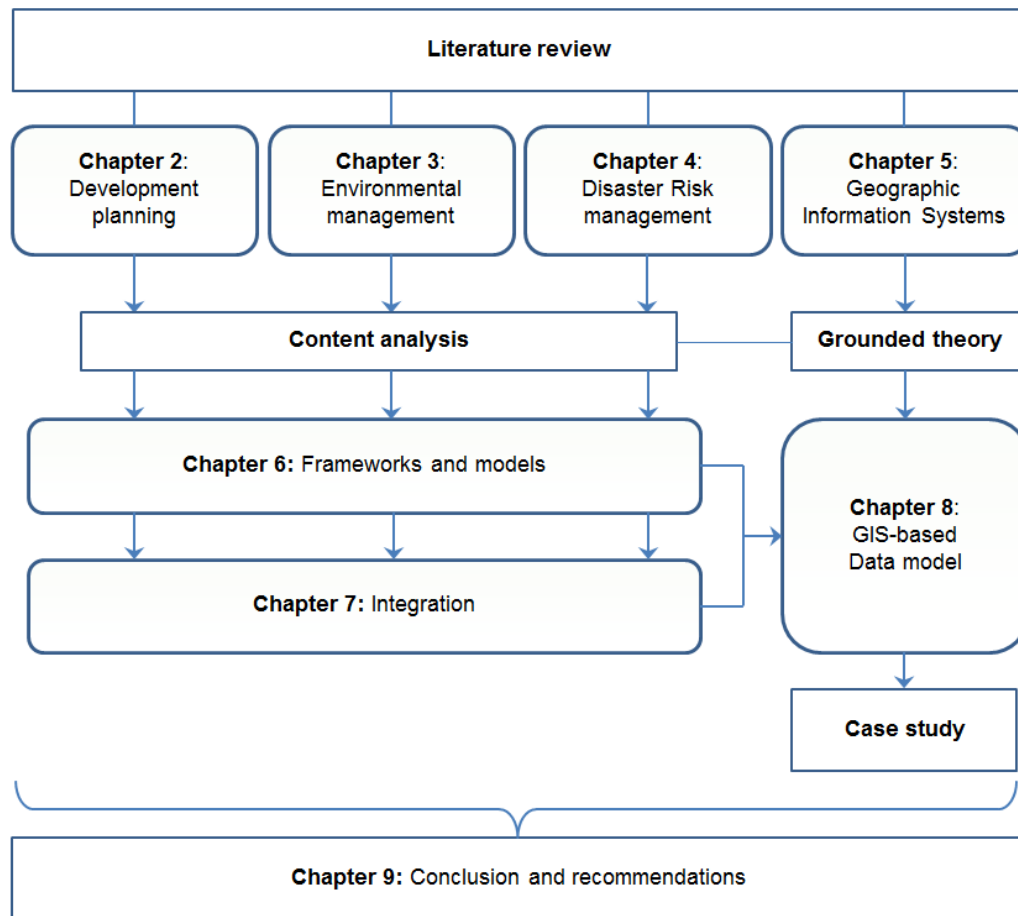


Figure 1.5 A structural layout of the study illustrating the development of chapters

1.8 CONCLUSION

Chapter 1 provided an overview of the background to the study and explained the reason for the author's interest in the research. An orientation towards and the key concepts of the four disciplines included in the study were followed by a statement of the research problem. The central theoretical statements that will guide this study were listed and the research method described in detail. A number of diagrams were used to give a visual representation of the research focus, the study method and the development of chapters.

A clear understanding of the relationship between development planning, environmental management and disaster risk management is important to deduce common aspects between these fields. The spatial context of these commonalities provides further insight into the requirements for a GIS-based data model, which in turn is informed by GIS science theory. An in-depth study of the underlying theories is undertaken and described in the four chapters that follow, starting with development planning in Chapter 2.

CHAPTER 2: THEORY OF DEVELOPMENT PLANNING

2.1 INTRODUCTION

Development planning is an activity undertaken by the state (Friedmann, 1998; Van Niekerk, 2005; Marcellus, 2009; Oranje, 2010) to set in place visions, goals and means of realising development through effective direction and control (Marcellus, 2009). Different types of legislation in South Africa, such as the Municipal Systems Act (Act 32 of 2000), and the Spatial Planning and Land Use Management Act (Act 16 of 2013) require organs of state such as municipalities to have certain plans in place, for example Integrated Development Plans (IDPs) and Spatial Development Plans (SDFs) (South Africa, 2000; South Africa, 2013). One of the purposes of an IDP is to provide a vision for the long-term development of a municipality with special emphasis on the municipality's most critical development and internal transformation needs. SDFs are required to guide planning and development decisions across all sectors of government, and they represent the spatial development vision of the responsible sphere of government. Other planning instruments include special initiatives and government policy such as Spatial Development Initiatives (SDIs), which are aimed at regional growth and development (Oranje, 2010). Based on lessons learnt with regard to regional development in the European Community, SDIs are focused on expenditure on social and economic infrastructure in areas with the potential for economic growth. Lastly, the National Development Plan is mentioned, which provides a developmental vision to eliminate poverty and reduce inequality by 2030 (South Africa, 2011).

The integration of development plans with other government sectors such as disaster management and environmental management is evident (van Wyk, 2003). Not only must an IDP provide the vision for long-term development of a municipality, it must also include an appropriate disaster management plan. This is reinforced by the Disaster Management Act 57 of 2002, which prescribes that a disaster management plan must form an integral part of a municipality's IDP. Furthermore, the Environmental Management Framework (EMF) Regulations of 2010 provide for the inclusion of SDFs and IDPs in the preparation of an EMF (South Africa, 2012).

An integrative development planning process prescribed by legislation and policy is emphasised above. In practice, commonalities between development planning, environmental management and disaster risk management are also evident (ISDR, 2004; Renaud, 2006; McEntire, 2007; Kaplan *et al.*, 2009; Leidel *et al.*, 2009; Haigh & Amaratunga, 2010; Kelly, 2010).

Environmental, social and economic conditions can have positive and negative influences on human health and wellbeing (Duhl & Sanchez, 1999), which in turn affect the vulnerability of communities to hazards – whether natural or anthropogenic. Awareness of human-induced conditions that increase vulnerability to natural disasters is frequently raised on international platforms such as the UN. In the foreword to *Living with Risk: A Global Review of Disaster Reduction Initiatives* (UN-ISDR, 2003), the then Secretary-General of the UN, Kofi Annan, is quoted to have said:

“Destitution and demographic pressure have led more people than ever before to live in flood plains or in areas prone to landslides. Poor land-use planning; environmental management; and a lack of regulatory mechanisms both increase the risk and exacerbate the effects of disasters.”

The interaction between development, vulnerability and disaster risk management is evident. Lewis (1999:40) states that development objectives should “take an integral account of hazards and of disaster probability”. The apparent failure to implement this is echoed by Van Niekerk (2010:65) who believes that “there has been a widespread failure to recognise and address the ways in which changes in land use, settlement policies, population distribution and the attendant degrading of habitats dramatically increase hazard exposure and vulnerability, and ultimately increase the risk of disasters”.

In order to understand the intersection between development planning, disaster risk management, as well as environmental management, it is important to gain insight into the development planning paradigm and its theoretical underpinnings. The objective of this chapter is therefore to define and investigate the theoretical grounding of development planning. The chapter is structured along two main lines: conceptualisation of development, and conceptualisation of planning. It further looks at development planning as an integrated endeavour, and lastly examines the link between development planning and information.

2.2 CONCEPTUALISATION OF DEVELOPMENT

According to Pieterse (2010:8), development theory is influenced by its historical context and political circumstances. Understanding development theory in its historical context therefore means understanding it as a response to problems and arguments raised at the time. Next, an overview of the history of development studies is given, followed by an exposition of different theories.

2.2.1 Development theory

The formative period of 'modern' development economic theory was the first two decades after the Second World War (Pieterse, 2010:41). The period was characterised by two focus areas for development policy; firstly, economic development and reconstruction after the war, and secondly, decolonisation and the development of new independent countries. A decade-by-decade overview of advances in development theory is given in the next paragraphs and demonstrates the change in views on development in recent history by drawing on the work of Potter (2014).

2.2.1.1 *The 1940s*

The inaugural speech of the United States' newly elected President Truman on 20 January 1949 is generally regarded as the origin of development thoughts and practice, as described by Esteva (1992), Sidaway (2012), and Potter (2014). Standing firm against communism and with a focus on peace and recovery after World War II, Truman announced four major courses of action as a post-war vision. The first involved support to the United Nations; the second, programmes for world economic recovery; the third, strengthening security against aggression, and the fourth, a programme of upliftment of underdeveloped areas by making use of US-based scientific advances and industrial progress. As mentioned above, the latter is cited most when defining development studies. A shift away from imperialism further marked the speech in which Truman stated that "[w]hat we envisage is a program of development based on the concepts of democratic fair-dealing. All countries, including our own, will greatly benefit from a constructive program for the better use of the world's human and natural resources". The impact of this speech is summarised by Esteva (1992:7) as a "political and philosophical proposition of Marx, packaged American-style as a struggle against communism ... succeeding in permeating both the popular and intellectual mind for the rest of the century".

2.2.1.2 The 1950s

This decade saw continued post-war reconstruction and economic development. Underdevelopment was regarded as an initial state beyond which Western industrialised countries have managed to progress (Potter, 2014:51). In terms of scientific advances, the concept of a “new geography” was formed, which searched for explanations of the real world by means of development models and quantitatively derived generalisations and laws. At the time, there was still not a separate field of development studies.

2.2.1.3 The 1960s

This period saw the emergence of new political thoughts that started to reflect in mainstream sociological sciences to a lesser or greater extent (Potter, 2014:51). The so-called ‘dependency theory’ emerged, rooted in Latin American and Caribbean development. It was argued that the Western model for development had served to keep the poor world poor, rather than accelerating development in those countries. Dependency theory further argued that it would be better for ‘undeveloped’ countries to de-link from the Western-led development model and follow an alternative path. The 1960s also saw the emergence of interdisciplinary development studies, with the lead taken by British institutions, as mentioned above. It was also during this time that the quantitative revolution in Geography appeared as a new research methodology. The emergence of GIS technology was also noted, as will be discussed in Chapter 5.

2.2.1.4 The 1970s

The 1970s were marked by the emergence of a humanistic approach and a critique of top-down neo-classical-inspired development policies that see economic growth as contingent upon the accumulation of human capital and technological progress (Stone, 2004; Potter, 2014:51). The acceptance of political-economic approaches encouraged the emergence of development geography as a distinct sub-discipline. Alternative and humanistic-oriented approaches influenced thinking about development practice, and led to the emergence of ‘another development’ thinking.

2.2.1.5 The 1980s

Yet a new thinking on development practice and policy developed in the 1980s, characterised by neo-conservatism. This gave rise to a neo-liberal agenda and the view that liberal free trade and unregulated markets should be left to make their own economic decisions, as reflected by policies introduced by Prime Minister Margaret Thatcher in the

UK and President Ronald Reagan in the US (Potter, 2014:52). Development studies were by then firmly established as a distinct field, with a focus on Europe and North America.

2.2.1.6 The 1990s

At the start of this decade, postmodernism emerged as an alternative paradigm to the social sciences. This paradigm suggested that emphasis should be placed on a wide range of views and discourses, of which 'development' would be one of various meta-narratives (big explanations) associated with modernising as the inevitable path to development (Potter, 2014:52). The success of Western and Eurocentric approaches of development as rooted in the advances of the 1940s and 1950s was questioned, and new views such as 'anti', 'post' and 'beyond' development started to emerge.

2.2.1.7 2000 and onward

The new millennium saw an increased focus on climate change and the impact of development on the environment (Potter, 2014:53). Realities of the global financial crisis, unregulated and unruly globalisation, and global conflict reflected novel issues that gave a new face to development.

Since it was studied from various perspectives such as geographical division or economic powers (Potter *et al.*, 2008; Hopper, 2012; Sidaway, 2012), economic growth (Robbins, 1968; Woolcock & Narayan, 2000) and structural societal change (Sumner & Tribe, 2008), thinking about development was characterised by debate and controversy, especially in relation to development theory. Sumner and Tribe (2008:10) rightfully state that the definition of 'development' has been controversial and unstable over time. The subject has over time accrued many different approaches, areas of interest and theories and has thus developed as a multi-faceted phenomenon (Hopper, 2012:11). This character is reflected in two major theoretical approaches that define development, i.e. a geographical and a historical-political perspective of development and economic growth. The first examines development in terms of a geographical division of different regions or power blocks that indicate different stages and types of economic growth in parts of the world. The second examines major strands of thought such as modernisation theory, dependency theory, structuralism, neo-liberalism, and post-development theory (Potter *et al.*, 2008; Hopper, 2012).

An overall, encapsulating view of development is that of 'change'. Various authors agree that change is a common theme within most definitions of what development encompasses (Sumner & Tribe, 2008; Potter *et al.*, 2008; Pieterse, 2010; Hopper, 2012). Sumner and Tribe (2008:10) and Hopper (2012) refer to the concept of 'good change' and 'bad change', but admit that it is subject to the view of what constitutes 'good' and 'bad'. What all can agree on, is that mankind has developed from a primitive state of subsistence living to a highly industrialised and modernised state, as is recorded in history and archaeological research. In the process, however, inequalities emerged between rich and poor, and distinct differences arose in development status between countries. Three levels of inequality can be described (Hopper, 2012:18):

- i. National inequality, referring to the distribution of income among people within a country
- ii. International inequality, referring to the economic disparity that exists between countries
- iii. Global inequality, referring to all individuals in the world, including national and international inequality

A historical overview of 'changes' is given by Pieterse (2010) and summarised in Table 2.1. It is important to note that the concept of 'development', as it has been examined in development studies, is a post-World War II concept, and that the term has not been used before, as we see it today. In his attempt to make sense of the shift in meanings of development over time, Pieterse (2010:8) refers to a "kind of archaeology of development discourse as a deconstruction of development and as part of a development critique" as one of three views. A second view is the examining of historical context, where the meaning of development changes in relation to changing circumstances. A third view is to combine the aforementioned views as dimensions of development, as a mosaic and synthesis of components that offer "a Gestalt of development", i.e. a total picture from where development can be viewed from different angles. Pieterse concludes that development theories offer a kaleidoscopic view into a collective mirror of changing economic and social capacities, priorities and choices, and that the different meanings of development relate to changing relations of power and hegemony. A theoretical overview of development is further presented by looking at geographical and historic-economical approaches.

2.2.2 Hegemony as a spatial construct

A well-known attempt at spatial division of the world in respect of development status has been to describe the planet as consisting of three worlds (Hopper, 2012:25). This view reflects a post-1940 perspective, which revealed international economic and political turmoil after World War II and consists of a Western block (capitalist Europe and North-America), an Eastern Block (Soviet-based communism), and the so-called Third World, or 'developing countries' (Hopper, 2012). The latter is a construct of post-colonial focus on the development of countries where European colonial rule in Africa, Asia and the Caribbean came to an end after 1945. The term 'Third World' was first used in 1952 by a French journalist, Alfred Sauvy, to describe countries that were not part of the industrial world (the First World) or the Communist block (the Second World) (Hay, 2008). At that stage the British Empire was the largest formal empire that the world had known, with colonies on each continent, including islands in all hemispheres (Roy Rosenzweig Center for History and New Media, 2014). British influence on development in the post-colonial era is, for example, reflected in the South African planning paradigm of the pre-1994 period (Jansen van Vuuren, 1992).

The use of economic classifications to demarcate world regions on the basis of their levels of development is increasingly being disputed (Sidaway, 2012). In history, various alternative groupings such as the Non-Aligned Movement (NAM) were formed in reaction to the international influences of the Western-Soviet Cold War and owing to the desire of member countries to remain outside of this grouping. The NAM was influential in the establishment of the Group of 77 (G-77) in the UN that led to the practice of Southern states as a block against issues like trade. A distinct North-South divide emerged following the collapse of the Soviet bloc (post-Second World) in the early 1990s, and together with that the use of the term 'Third World' became defunct (Hopper, 2012:26). Recent economic groupings include the BRIC countries (Brazil, Russia, India, China) on a global scale, SADEC (Southern African Development Community) and the EU (European Union) on a regional scale. Despite dichotomies in the composition of 'North' and 'South', such as problems with northern hemisphere countries in Africa and Asia labelled as 'Southern' countries, and southern hemisphere countries such as Australia and New Zealand grouped with 'Northern' countries, the conceptualisation of a developed 'North' and a developing 'South' is common in development studies (Hopper, 2012:29).

The categorisation of countries according to colonial rule or economic development blocks can be expressed in a spatial context, as is illustrated by the maps in Figures 2.2, 2.3 and 2.4. These maps are useful as a visualisation tool to illustrate the change from political to economical hegemony. However, as such they remain static images of history,

and to compare them, each map has to be examined visually. From a geoscience point of view, the underlying relationships between these maps can be captured using GIS technology, as will be explored in Chapter 5 and demonstrated by a data model in Chapter 8.

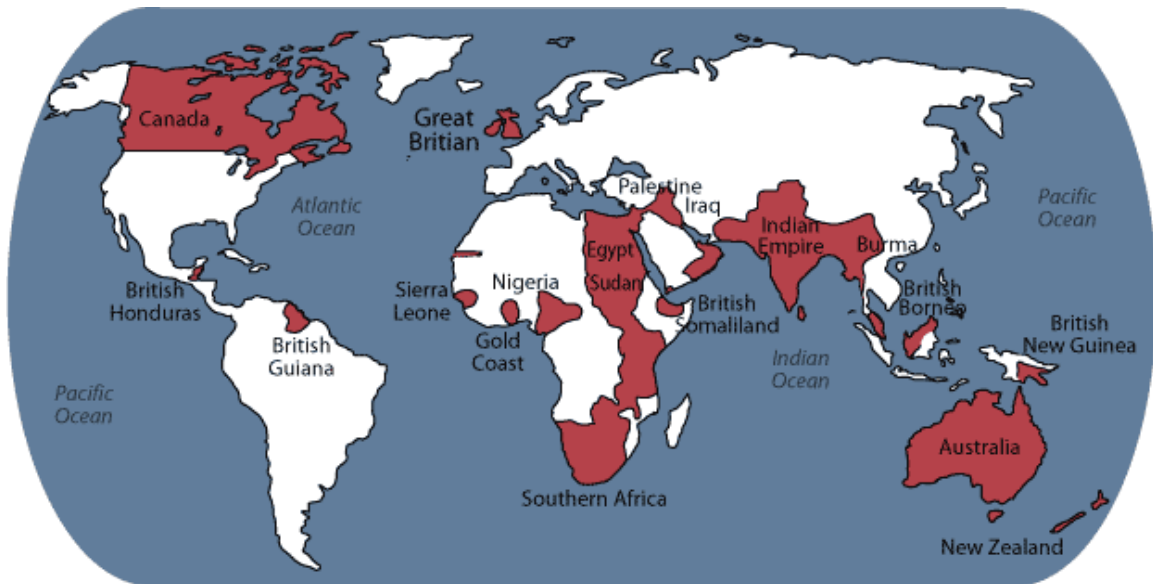


Figure 2.6: Map showing the extent of the British Empire by the late 19th century in red
 Source: Roy Rosenzweig Center for History and New Media (2014)

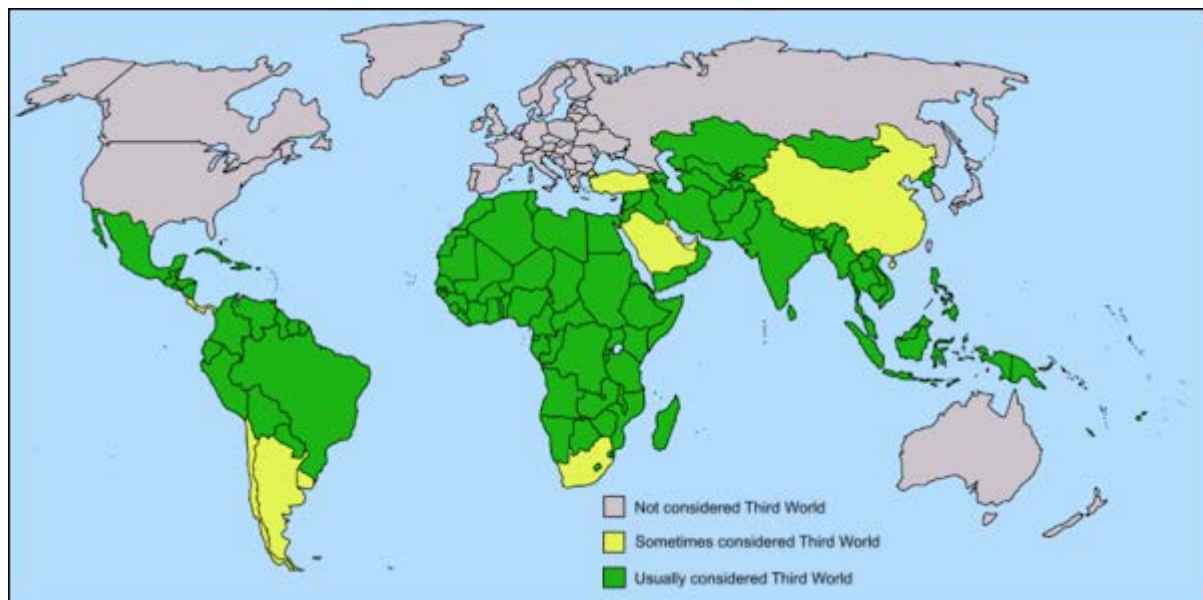


Figure 2.7: Map showing the spatial conceptualisation of the Third World
 Source: Hay (2008)

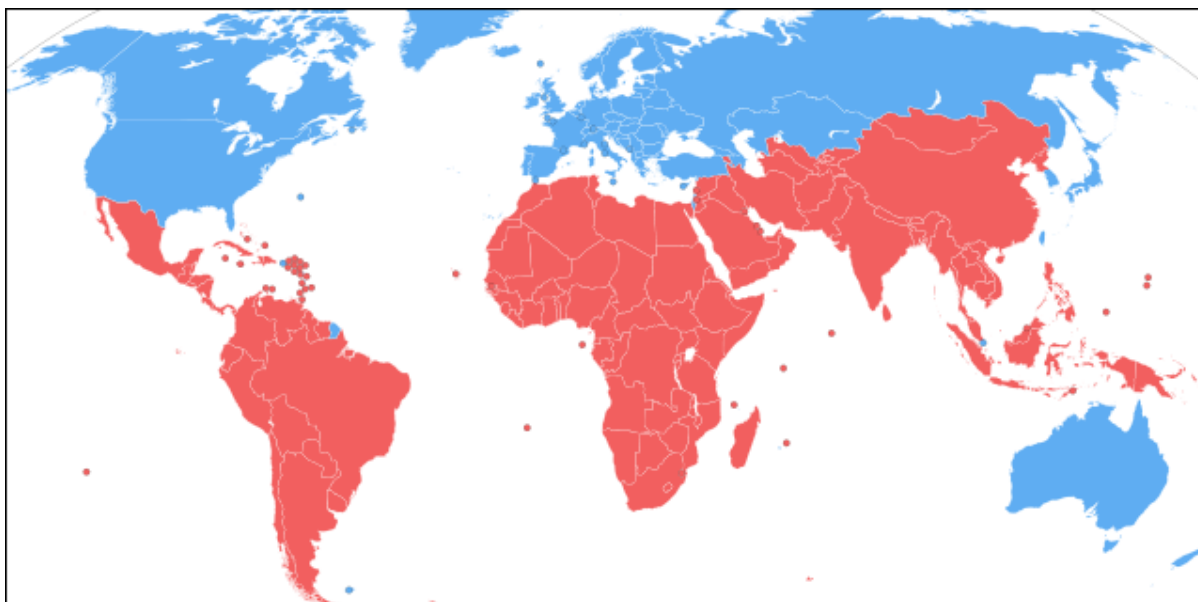


Figure 2.8: Map showing the spatial conceptualisation of a developed North in blue, and a developing South in red

Source: Hay (2008)

2.2.3 Economic approaches to development

According to Potter *et al.* (2008:31), development theory was established following recognition that the problems of the South were different to those that the North (particularly Europe and the USA) had experienced historically. Linked to the changing material conditions of the world after 1945, a vast body of theory on development emerged. However, views on development changed rather rapidly from the 1940s to the new millennium. In his book, *The General Theory of Employment, Interest and Money* (1936), John M. Keynes laid the foundation for economic growth theory (Hopper, 2012:30). Written at the time of the economic hardships of the Great Depression, the book was primarily a study of the forces that determine changes in the scale of output and employment. Keynes emphasised the positive role that governments could play in stimulating economic growth through investment in infrastructure projects, even if money had to be borrowed to do so, based on the multiplier effect of such action. His influence, known as Keynesian economics or development economics (Potter *et al.*, 2008:40), helped shape theories such as *modernisation* and *structuralism*. Although his focus was the economy, his influence is reflected in many works on development and planning, notably Sachs (1992), Friedmann (1998), Stiffler (2000), Almendinger (2002), Archibugi (2004), Potter *et al.* (2008), and Pieterse (2010), all of who are quoted in this Chapter. The four major theories of development are briefly described next.

2.2.3.1 Modernisation theory

Modernisation theory has been formed as a single theory from many disciplines such as economics, sociology, geography and politics (Hopper, 2012:30). Although it is generally described as a single theory, it can also be regarded as a school of thought or an approach that comprises a range of perspectives following the same basic argument, namely that development is a positive and irreversible process through which all societies eventually pass (Potter *et al.*, 2008:31). Modernisation is rooted in 19th century evolutionary theory and leans heavily on the European experience of development. The theory takes the position of underdevelopment in countries that can be remedied by following the blueprint of Western countries who have followed a growth path to industrialisation. The Western input is seen as an alternative to that of communist- and ideology-based Soviet influences. Based on Rostow's stages of economic growth, these countries should be guided in a transition from traditional to modern societies (see Annexure 2.1 for Rostow's five-stage model). Prerequisites for modernisation include a change of attitude among the members of a society to promote innovation, rationalisation of economic activity and the accumulation of capital. Tradition and culture were seen as barriers to development, which should be eradicated through the assimilation of Western ideas.

The process of modernisation involves the following processes (Potter *et al.*, 2008:34):

- i. Urbanisation
- ii. Industrialisation and commercialisation of the agricultural sector, changing from subsistence farming to cash-cropping
- iii. Educational growth
- iv. Development of mass media to disseminate Western information and values
- v. Replacement of patterns of authority, based on traditional loyalties by formal law and democracy

Criticism of modernisation theory followed the failure of its implementation due to limited economic growth in developing countries, a persistence of widespread poverty, and the increasing polarisation between rich and poor (which at the international scale paralleled a widening of the gap between most and least developed countries) (Potter *et al.*, 2008:34). Further criticism included critiques of Rostow's model and the Eurocentric approach. The latter was associated with ethnocentric Western values and denigration of traditional societies, whereby the diversity and sophistication of many ancient and

contemporary non-Western societies was overlooked. Lastly, the aspiration of 'Southern' countries to foster their own development goals and strategies was largely disregarded.

2.2.3.2 Dependency theory

Following the apparent failure of modernisation, views for an alternative approach were open for more radical and neo-Marxist influences (Hopper, 2012:35). Critiques of the modernisation theory emerged mostly from a Southern, Latin American perspective, and were often written in Spanish. From a new school of thought referred to as the *dependencia* school and scholars known as *dependistas* (Potter *et al.*, 2008:35), the dependency theory emerged as a reaction to widespread poverty in the Global South, and in Latin America in particular. Scholars argued that the growth in the Northern countries was only possible because of the active exploitation and sustained underdevelopment of Southern countries. This theory also found its origins in colonialism, by virtue of the fact that colonial economies developed around European markets. As a consequence, many former colonial entities remained one-product economies, for example based on the production of cocoa, bananas, sugar cane, etc. (Hopper, 2012:35). This would make them extremely susceptible to price fluctuations on international markets, and thereby increase their vulnerability to external shocks.

Thoughts on dependency were fed by structuralism, a strand of thought arguing that development involves changes in underlying social and economic structures, and a movement that was strong in Latin America (Potter *et al.*, 2008:36; Hopper, 2012:33). Rooted in the economic hardships of the Great Depression of the 1930s when Latin American countries found it difficult to buy manufactured goods from raw material exports, structuralists followed a Keynesian approach, which regarded governmental intervention as a means of stimulating economic growth. Similarities with modernisation and trust in industrialisation are apparent, although Western industries had the advantage of earlier development and the opportunity to grow and mature without the degree of international competition and constraints that emerging non-Western countries had to overcome (Hopper, 2012:33).

The characteristics of dependency theory are best summarised by Gunder Frank (cited in Benn (2004), Potter *et al.* (2008), Pienaar (2010) and Hopper (2012)), who argues that development of the West depends on the exploitation and active underdevelopment of the periphery (Latin America). This argument makes a direct link between development and underdevelopment, which is perpetuated over time through the '*development of*

underdevelopment'. This implies a distinct geographical chain of metropolitan–periphery (satellite) relations that ensures development and domination for metropolitan (First World) countries, and underdevelopment and dependency for those countries on the periphery (Third World). Regions that are the most underdeveloped are those with the closest ties historically to the metropolis (refer to Figure 2.4). According to Gunder Frank, satellite economies experience their greatest economic development when their ties with their metropolis are cut, thereby suggesting that genuine change for the developing world could only come about through de-linking from the West and socialist revolution (Potter *et al.*, 2008:37)

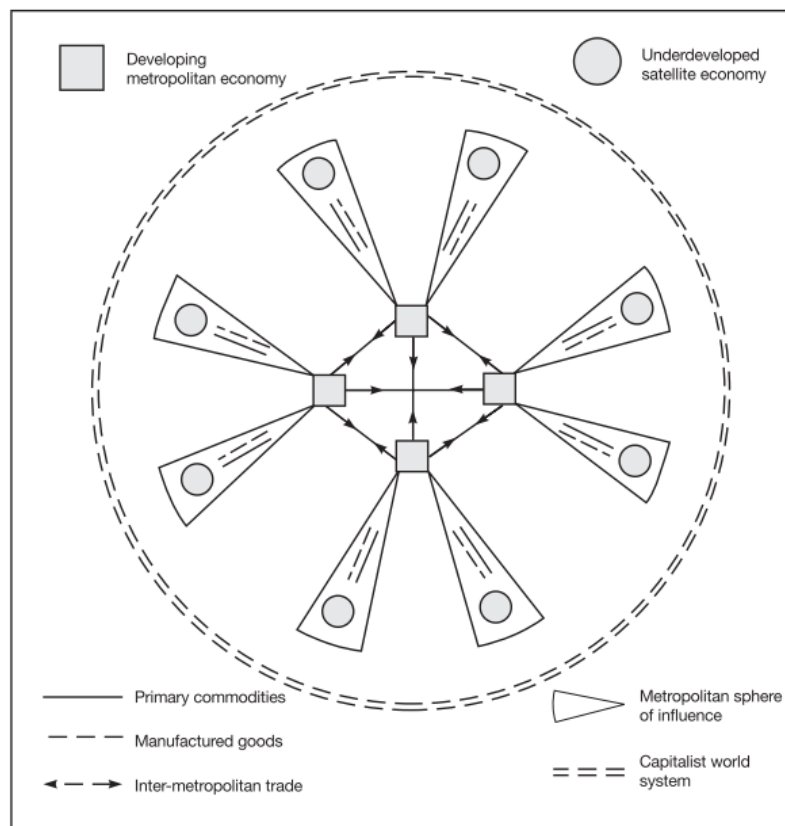


Figure 2.9: Gunder Frank's model of underdevelopment
Source: Corbridge (1987) quoted in Elliot (2006)

According to Potter *et al.* (2008:37) and Hopper (2012:37), criticisms against dependency are indicative of overstatement and over-simplification, and they are not in touch with reality. To blame the West for underdevelopment elsewhere is an overstatement that overlooks the internal causes linked to domestic factors such as political, social, cultural and environmental issues that have a negative effect on development. According to Hopper (2012:37) it is now recognised that local authoritarian elites have a major influence on and largely determine the nature and extent of development. In this regard,

underdevelopment is often linked to corruption and inappropriate strategies for achieving economic growth. Lastly, it is argued that dependency theory does not offer an alternative to development other than escaping from the cycle of exploitation when dependency has ended, or else, when developing countries are disconnected from the global economy.

2.2.3.3 Neo-liberalism

Neo-liberalism is seen as an economic and political approach that in essence seeks to reduce the role of the state and deregulate markets as much as possible in order to promote free trade (Benn, 2004:6; Potter *et al.*, 2008:40; Pieterse, 2010:7). The central objective – economic growth – is to be achieved through deregulation, liberalisation and privatisation, where the focus shifts from government intervention to market forces. During the 1980s this approach received strong support from the US and the UK governments, as well as from institutions such as the World Bank.

One of the effects of neo-liberalism is the cost to the environment. According to Hopper (2012:41), the shrinking of environmental resources of developing countries is notable, as they have little to offer in terms of manufactured goods and have to rely on exports of natural resources as they seek to compete in the global marketplace. This opens up further debates around sustainable development and environmental impact, as will be discussed in Chapter 4.

2.2.3.4 Post-development

Delusion and disappointment with the failures of development are highlighted by authors such as Sachs (1992), Pieterse (1996, 1998), Sidaway (2007, 2014) and Potter *et al.* (2008). Development has been associated with “loss of indigenous culture”, “destruction of the environment”, a “set of worldviews and powers to intervene, to transform and to rule”, and its origins are believed to be “bound up with Western power and strategy for the Third world, enacted and implemented through local elites” (Sidaway, 2014:147). In 1992, Wolfgang Sachs wrote that the age of development is coming to an end. In 2008 Potter *et al.* declared the concept of development dead, and hence introduced an era of ‘post-development’ – summarised by Potter *et al.* (2008:48) as follows:

“Ideologically, post-development is rooted in the postmodern tradition. This involves a rejection of notions of modernisation and modernity in favour of

highlighting diversity, context and alternative voices. There is a strong emphasis on bottom-up, non-hierarchical growth strategies which consider each situation on its own context-specific merits... In an attempt to move away from the 'grand narratives' or 'meta-theories' (over-arching theories characterised by high levels of generalisation and abstraction) of modernisation or dependency, some advocates of post-development argue for abandoning the term 'development' altogether."

Pieterse (1996) offers a strong argument against development theory as a homogenised, coherent and consistent entity, "as if it were cut from a single cloth". He exposes development theory as "a plethora of competing and successive currents, schools, paradigms, models, several of which claim to exclude one another". In his summary of development theory, Pieterse (1996:547) offers three arguments:

- i. Development thinking has not been the single paradigm for which it is often taken. It is "a heterogeneous set of approaches that has been not only variable over time but highly diverse at any given time".
- ii. Development thinking is characterised by a "disparity and tension between endogenous and exogenous dynamics in development".
- iii. All societies are developing as part of a global process. Development is a process that is occurring in both developed and developing countries, which juxtaposes development discourse and globalisation.

Within the framework of 'development as change', to criticise development does not necessarily mean to reject the notion of change, but rather a criticism of the view that 'all change is development' (Sidaway, 2014:150). Pieterse (1996:547) suggests that one should take a step back and consider the underlying ideas of change, and not development theory as such. According to Potter *et al.* (2008:47), post-development lends itself to alternative visions of improvement (change) through considering various views such as democracy, culture, resourcefulness and environmental impact. They conclude that "there is no question that there is a need for development in the sense of change for the better, the theoretical question remains of how this may best be achieved."

In the context of the geography of development, post-development approaches demand the use of spatial information technology to scrutinise relationships.

2.3 CONCEPTUALISATION OF PLANNING

The places where people live have always been planned in some way or another, being it the management and organisation of space in the broad sense, or the controlling of land use and property rights, or the provision of services (Healey, 1997:8). Planning is mostly associated with the development of cities, which emphasises planning activity as the management of an outcome, the morphology and spatial organisation of the urban region. However, such initiatives are rooted in specific traditions that have evolved over centuries and have been influenced by philosophical and social transformation – referred to by Healey as an “intellectual sea which we now label in the history of Western thought as the ‘Enlightenment’”. Planning has been shaped by technological, political and economic advances and events in history, and the reaction of society on these (Friedmann, 1987; Healey, 1997; Stiftel, 2000; Allmendinger, 2002; Oranje 2002). From this perspective, planning can be seen as deeply embedded in social theory (Allmendinger, 2002:3).

There are a multitude of perspectives on planning (Dale, 2004:4). Planning theory addresses a whole range of issues that can be grouped as follows (Alexander, 1992:7):

- i. *Definitional* – What is planning?
- ii. *Substantive* – What do we know about what and whom we are planning for?
- iii. *Process* – How does planning take place, and how are plans implemented?
- iv. *Normative* – How do we plan, and why should we plan?

From a broad perspective, planning can be regarded as inclusive of all of the above. Some theorists may, however, prefer to limit their view of planning to a particular aspect, and three scholars are mentioned in this regard. Ernest R. Alexander asserts that the core of planning is the planning process, as it applies to individuals, groups, firms and governments. According to him, planning theory explores the planning process by looking at its components and the way they relate and interact. It involves the context of planning efforts and how they determine planning outcomes (Alexander, 1992:8). Patsy Healey approaches planning from the view of planning traditions and takes a normative approach. She argues that the culture of planning stands in relation to a particular inheritance that emerged from three planning traditions, i.e. economic planning, physical development and public administration (Healey, 1997:10). The first tradition aims to manage productive forces of regions and nations, and is linked to social politics and the framework of a “welfare state”. The second involves the management of cities from a health and aesthetical point of view. The third aims to achieve effectiveness and efficiency in meeting specific goals that are set for public agencies. John Friedmann

approaches planning from a socio-historical perspective and identifies the four traditions of planning thought. He documents a typology of planning that spans two centuries, and traces the origins of planning theory to as far back as 1789. Friedmann maps out the intellectual influences that have shaped contemporary planning theory up to 1980, and describes various intellectual influences such as neo-classical economics, public administration, systems engineering, sociology and pragmatism, among others (Alexander, 1992). He places key figures in the history of planning in the context of four planning traditions, each of which meets three requirements, i.e. the same technical language, philosophical outlook, and central questions that define each tradition. These four groupings are *Policy Analysis*, *Social Reform*, *Social Learning* and *Social Mobilisation*. According to Allmendinger (2002:81), this approach broke new ground in that the four 'traditions' pointed to a much more disparate basis to planning knowledge than had thus far been acknowledged. Departures from previous conceptions and the degree of detail and understanding are briefly described as follows:

Policy Analysis is influenced by the work of Herbert Simon (Friedmann, 1987:78) whose contribution to planning theory is rooted on the traditions of Public Administration. Based on rational thinking, policy analysis is engaged in the concept of "what is best" and seeks to identify the best possible decisions and courses of action within an organisation.

Bound by rational constraints such as resources, information and time, planners strive to reach the ideal decision by means of the following distinct stages of action:

- i. Formulation of goals and objectives
- ii. Identification of alternatives for reaching these goals and objectives
- iii. Evaluation of the consequences that would be expected from each alternative
- iv. Decision making based on the information provided by the above preceding steps
- v. Implementation of the decision
- vi. Feedback by monitoring the results after implementation

Lacking a distinctive philosophical position (Friedmann, 1996:23), practitioners in the tradition of Policy Analysis regard themselves as technicians by virtue of their application of scientific theories and mathematical techniques in order to calculate the ultimate solution.

Social Reform seeks to institutionalise planning practice and focuses on the role of the state in planning. Planning is regarded as a scientific endeavour with non-planners (citizens and politicians) regarded as "not sufficiently informed to be seriously engaged in

planning". In this tradition, planning is seen as the application of scientific knowledge to public affairs, and it seeks for the state's intervention in three areas: economic growth, employment and redistribution of income (Friedmann, 1996:20).

Social Learning: The tradition of Social Learning focuses on overcoming the contradictions between theory and practice (Friedmann, 1996: 24). This concept developed from two streams of thought, namely pragmatism as postulated by John Dewey and his epistemology of learning by doing, and the revolutionary thoughts of Marxism and its proposition concerning the unity of revolutionary theory and practice (Friedmann, 1996:25). This tradition is a major departure from earlier planning theory based on scientific knowledge. Social learning asserts that knowledge is derived from experience that is validated in practice. New understanding that is obtained in this way is applied in the continuing process of action and change. The tradition of Social Learning further claims that social behaviour can be changed through social experimentation and the observation of results. This presupposes the willingness to admit error and learn from it.

Social Mobilisation: Social mobilisation developed as counter-movement of social reform (Friedmann, 1987:225). It differs from the other traditions in having a radical orientation toward existing social institutions, and in particular the state. Instead of social guidance, this tradition is inclined towards social transformation, blending Marxism with utopian and anarchist ideas (Alexander, 1992:7). When it emerged as a movement in France and England around 1820, it was a response to the social upheaval and human suffering that accompanied the Industrial Revolution, and is as such rooted in the ideology of the dispossessed who are strengthened by social solidarity, an emphasis on political rhetoric and determination to change existing relations of power. The tradition of Social Mobilisation stands in stark contrast with the other traditions where planning tends to be more of a political conduct, with no inclusion of scientific reasoning and analysis (Friedmann, 1996:26).

Within this framework, the concept of 'what is planning?' is discussed by looking at a few definitions of planning and giving a broad overview of planning theory development.

2.3.1 Planning – a definition

The above section describes theoretical underpinnings of planning by highlighting a multitude of perspectives. This section looks at the meaning of the term from a more

practical point of view, and given the various approaches and traditions of planning, it serves a purpose which in the context of this chapter relates to development. Dale (2004:15) broadly defines development planning as “the planning of any organised endeavour that aims at promoting development”.

According to Healey (2003:118), providing an objectively complete definition or a ‘full’-range definition of planning is an impossibility. Banfield (1959:361) states that “[t]he word “planning” is given a bewildering variety of meanings. To some it means socialism. To others the layout and design of cities. To still others regional development schemes like TVA (Tennessee Valley Authority), measures to control the business cycle, or “scientific management” in industry”. Friedmann (1998:246) notes that theorists do not want to be “fenced in” by any definition of planning discourse. However, a few definitions from literature can be presented. Banfield puts planning in an action frame of reference, where an actor (who can be a person or an organisation) is oriented towards the attainment of ends. He thus defines planning as the process by which the actor selects a course of action for the attainment of his ends (Banfield, 1959:361). Kroon (1990:125) describes planning as a management task concerned with the goals and objectives of an organisation, the activities involved and the implementation of a plan that aims at achieving such goals and objectives. The same understanding of planning is maintained by Conyers and Hills (1984:3), who see planning as a continuous process that involves decision or choices about alternative ways of using available resources, with the aim of achieving particular goals at some time in the future. Polydorides (1989:363) sees planning as a task that deals with the management of spatial information for the purpose of supporting the formulation and evaluation of policy on spatial problems, as well as the implementation of plans for the change of spatial structure. According to Faludi (2000:299), planning is about the coordination of what is going to happen – “it must make the various agents that are normally shaping development according to priorities of their own, fall into line”. From these definitions the following characteristics of planning are evident:

- i. *Planning is a management activity.* Planning is basically a management activity that, together with other activities such as organisation and control of urban and regional environments, forms part of a management process (Kroon, 1990; Allmendinger & Tewdwr-Jones, 2002).
- ii. *Planning is concerned with achieving objectives and aimed at action.* The outcome of planned action must conform to what the plan says. Faludi (2000) distinguishes between ‘project’ plans and ‘strategic’ plans. The former are “blueprints” of the intended end-state of a proposed plan and the measures

- (objectives) needed to achieve that state. The latter concerns the coordination of projects and other measures taken by a multitude of actors. This relates to decisions (see *iv* below). The coordination of decisions is a continuous process.
- iii. *Planning addresses uncertainties of the future.* Uncertainty is inherent to any future-inclined activity. Planning aims at reducing the uncertainty of what may happen in future by managing and controlling change in such a way that desired objectives are met (Coyers & Hills, 1984:70).
 - iv. *Planning is aimed at decision making.* Various authors emphasise the link between planning and decision making. There has been an important move away from planning as the preparation of documents, towards the concept of planning as a process of decision making (Conyers & Hills, 1984:14). Allin and Walsh (2010) assert that the status of the planning strategies may be viewed as less important than the capacity of the planning process to provide a framework for institutional capacity building, coordination and collaboration among actors in spatial development. According to Faludi (2000:306), a plan is fulfilling its purpose (being used for its intended purpose, in other words, performing), “if and only if it plays a tangible role in the choices of the actors to whom it is addressed”. ‘Choices’ refer to the planning object, which is the set of decisions and actions that are being coordinated by means of a plan. The planning object is directed at the material object, which is the problems in the outside world that the plan relates to (refer to Figure 2.5).

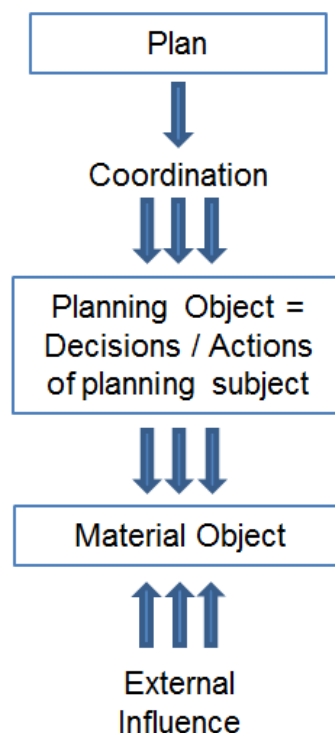


Figure 2.10: The decision-centred view of planning

2.3.2 The development of planning theory

The development of a planning theory within which planners operate can be traced back to the 1930s and the days of US president Roosevelt's *New Deal*, when institutions like the National Resources Board, the Resettlement Administration, and the Tennessee Valley Authority attempted basic planning exercises, guided by emerging Keynesian economic principles (Stiftel 2000:4). This included programmes that followed a basic methodology involving the examination of data, the evaluation of alternative courses of action and the creation of systems for implementation. A landmark publication by Karl Mannheim in 1935, *Man and Society in an Age of Reconstruction*, triggered a series of debates on scholarly and political level on the question of "who would plan". Mannheim envisioned the state's participation in economic and social planning, and argued that if the planning bureaucracy was subject to parliamentary control, it could apply its technical expertise to the solution of social problems (Fainstein, 2005:122). This vision laid the foundations for later theorising by describing a democratic planning process that would enable experts to plan under the guidance of the public through their elected representatives.

From these beginnings, various planning models developed, such as the Blueprint model or Master Plan model, the Rational Planning model, the Strategic Planning model (seen as an alternative to the Rational Planning model), the Pragmatic Planning model, and the Communicative Planning model, which has dominated thinking by theorists since the beginning of the new millennium (Jansen van Vuuren, 1994; Stiftel, 2000; Zhang, 2006). Before these models are discussed, two significant developments in the way town planning has been conceived, as detailed by Taylor (1999), are briefly discussed and highlighted as background. Town planning, as a branch of the planning profession, has significant linkages with development, and advances in this field are important to include and understand further linkages with planning in its broader context.

Taylor (1999) identifies three distinct periods since World War II that are marked by specific developments in planning theory. The changes in planning thoughts are seen as theoretically significant, although not fundamentally enough to witness any paradigm shifts (Taylor, 1999:341). From its conception in the 1940s, and for almost twenty years onwards, town planning was essentially seen as an exercise in physical design. At the time the function of town planning was assumed to be most appropriately carried out by

architects (refer to Glasston and Marshall, 2007:4), with a close connection between architecture and town planning. The only distinction would be that planning was architecture on the larger scale of a whole town or at least part of a town, as distinct from individual buildings. This *status quo* remained until the 1960s, as is evident from the fact that most planners in the post-war years were architects by training, and that aesthetic considerations were regarded as central to town planning (Taylor, 1999:330).

A major shift from this view occurred in the 1963 with the introduction of the systems and rational process views of planning, which represented a break with the old tradition. The systems view introduced a new approach, seeing the town or a region as an object that planning had to deal with. The rational process view of planning was concerned with the method or process of planning itself. This new approach advanced an 'ideal-type' conception of planning as a procedure for making rational decisions (Taylor, 1999:332). The most significant progression of this shift was the fact that, for the first time, theorists of the systems and rational process described town planning as a science. This stood in stark contrast with the design-based tradition which saw town planning primarily as an art. It must be noted, however, that the shift in planning thought did not replace the physical design view of planning, but rather added to that another facet, thereby advancing planning theory to a new level. A most relevant development of the shift was that a distinction was made between strategic and longer-term planning on the one hand, and short-term planning on the other.

In relatively short succession, through the 1970s and 1980s, a new tradition of planning theory emerged, which viewed the town planner's role as one of identifying and mediating between different interest groups involved in or affected by land development (Taylor, 1999:330). Referred to initially as advocacy planning, this tradition developed into communicative planning theory, which was inspired by Habermas's theory of communicative action, as is detailed in Allmendinger and Tewdwr-Jones (2003) and in Bolton (2005). Although not a primary function, the 'facilitator' role of the town planner soon required the skills of interpersonal communication and negotiation.

The change in planning theory is consistent with the change from modernistic to post-modernistic views after World War II, and is highlighted in the works of Allmendinger (1998), Pieterse (2010), Healey (2003), Coetzee (2012) whose discussions of planning theory are referenced in this chapter. Principles of planning theory as discussed above are reflected in the development of planning models, which will be focused on next.

2.3.3 Blueprint planning

Based on the concept of urban design (Taylor, 1999; Fainstein, 2005), blueprint planning (also known as master planning) was popular in the 1950s and 1960s and aimed at setting a comprehensive framework for future development (Jansen van Vuuren, 1994:8). It was, for example, particularly appropriate for the British New Town Programme in the 1950s (Healy, 2003). There are, however, two perspectives on blueprint planning. The first sees it as a technocratic design that decides the future living conditions of people, and the second as a course of action for the implementation of a plan. These perspectives are briefly described as follows.

Design: As a technocratic 'macro' approach, blueprint planning is a predefined idea of what should be done and how (Sachs, 1992:189). It provides a long-term vision of development as an idealistic view of the future. In the late 20th century, the year 2000 was seen as a popular target date for achieving the objectives of a 'development plan' (Polydorides & Petropoulos, 1989:342). The disadvantage of this approach was the rigidity of plans that made no provision for change or deviation, a situation which Polydorides and Petropoulos refer to as "a static glimpse into a distant future". Sachs (1992) describes it as an "ideologically biased knowledge system" that requires the transforming of everything to meet that blueprint, ignores the "living 'nose'" of the people who are directly concerned for what is appropriate and sensible to do, and has a disregard for life designing its own course.

Coordination: From another perspective, blueprint planning is associated with coordination during the implementation of plans (Faludi, 2000; Healey, 2003; Archibugi, 2008). It is a short-term vision that would steadily be translated into built form on the ground (Healey, 2003). During the implementation of a plan, any action undertaken independently by an institution without regard for actions simultaneously undertaken by other institutions in the same environment is in danger of neutralising or annulling the plan (Archibugi, 2008:70). As mentioned earlier, Faludi (2000) distinguishes between two types of plans, *project* and *strategic* plans, which he regards as the two ideal types of plans. A project plan, according to him, is a blueprint of the intended end-state of a material object and the measures needed to achieve that state. It is a document "giving a set of prescriptions for action, a blueprint for how to bring the desired state of affairs about". A strategic plan can also include various projects and is open ended in nature (this aspect is further discussed below). Built into the project plan is a time element that

guides the implementation process in a phased approach, keeping it in line with the requirements of producing the final outcome.

In terms of spatial expression, blueprint plans are associated with drawings produced by architects and engineers, and have as such become the prototype project plan (Faludi, 2000:303). This would ultimately attenuate a plan to the status of a “static glimpse”, as described above. Archibugi (2008:100) asserts that in carrying on the operations of blueprint plans, the prospects of other ways to carry out plans are diminished. He states that the “possibility is impugned, for instance, of deriving plans from intense analysis and debating among the multiple policy-makers, a possibility that holds real promise, especially if we start from the remark that in modern political societies, decision-making is a fact so evident and “real” that it cannot be neglected without some elements of foolish irrationality”. This shortfall highlights the need for rationalist and communicative thinking.

2.3.4 Rational planning

In reaction to the shortcomings of the master plan model, the rational planning model was formulated by Edward Banfield in his work *Note on a Conceptual Scheme* (Banfield, 1955). This work gives a detailed account of a public housing project in Chicago, during which Elizabeth Wood, the Executive Secretary of the Chicago Housing Authority (CHA) played a substantial role in giving direction to the purpose and functioning of the CHA Planning Division. Banfield describes a plan as “a course of action which can be carried into effect, which can be expected to lead to the attainment of the ends sought, and which someone (an effectuating organization) intends to carry into effect” (Banfield, 1955:312). A *course of action* is seen as a sequence of prospective acts that are viewed as a unit of action, that Banfield describes as a *selected rationality*, and that are aimed at the attainment of ends. In this context Banfield views *rational planning* and *efficient planning* to be the same. Based on the achievement of goals and objectives, this model indicates a shift away from control to decision making (Landre, 1988(b):36). A rational decision is made by firstly considering all of the alternatives (courses of action) open to the decision maker. Second, he identifies and evaluates all of the consequences that would follow for each alternative. He also predicts how a situation would be changed by each course of action. Third, he selects the preferable alternative in terms of its most valued ends. This framework reminds of the WHAT-IF analysis process, as discussed in Chapters 5 and 8. From a spatial planning alternative, different courses of action and their possible outcomes can be modelled using geographic information systems technology.

According to Archibugi (2004), rational planning deserves respect as a scientific approach, as embracing it would render plans more consistent (i.e. more rational), and therefore, more feasible and implementable. In this context Archibugi identifies *rationality* with *reality*. However, realistically speaking, plans cannot exactly coincide with reality. Reality is too complex; there are too many possible alternatives, too many consequences to be traced through an uncertain future (Lindblom, 1979:518). Archibugi states that rational plans must be *ex post* or historical. "Plans try to have an impact on this reality; they intend to govern and possibly modify it. Otherwise what kind of plans would they be?" (Archibugi (2004:427). In this sense, plans must be "irrealistic" (*ex ante*).

Further criticism of rational planning includes the view of Charles Lindblom (1979) who suggested that comprehensive or synoptic planning (as he called it) was unachievable and out of step with political realities. As an alternative he introduced the concept of *incrementalism*, which calls for change by small steps. Although Lindblom's views reflect his political background, his critique was powerful and influenced many planners (Stiftel, 2000:7). This effected a shift from rationalism to strategic analysis.

2.3.4 Strategic planning

According to Stiftel (2000) the strategic planning movement drew heavily on Lindblom's ideas, which are rooted in Herbert Simon's concept of *bounded reality*. Referring to mathematical modelling and decision making in economics, Simon (1972) asserts that the actor must have perfect knowledge of the constraints in his equation when processing data to obtain conclusive information. Risk and uncertainty can be built into the model, in which case the assumption of the actor's perfect knowledge of constraints is replaced with perfect knowledge of the variation thereof. Drawing on this theory, Lindblom (1979) presents the concept of a continuum on which analysis is organised according to a continuum or spectrum of differentiation between completeness and synoptic quality. Within this continuum one can indicate both hypothetical and real alternatives, as illustrated in Figure 2.6. The one end of the continuum represents reality (rationality), which would meet all theoretical requirements, and the other end a grossly incomplete analysis of reality, which sets a case for strategic analysis. As Lindblom asserts, reality is too complex, and our knowledge too limited – hence, even with all the resources of modern electronic computation, we cannot complete the analysis of a complex problem (this assertion also reflects in the spatial representation of things on Earth, as described in Chapter 5).



Figure 2.11: The continuum of reality and abstraction

Source: Lindblom (1979:518)

Thus, strategic planning occurs where there is uncertainty (Faludi, 2006), it concerns the co-ordination of a multitude actors, and it is a continuous process. According to Faludi (2000:303) the strategic plan itself is no more than a momentary record of agreements reached. In line with Lindblom's concept of incrementalism, strategic documents are no more than fleeting records of agreements between actors. They constitute a frame of reference for negotiations and are merely indicative of intentions. The future remains open. As an example, Faludi refers to the European Spatial Development Perspective (ESDP), stating that although it is not a formal plan – the ESDP may count as a strategic document – its makers clearly wished for it to be followed through (Faludi, 2006:121). A strategic plan is a complex document and directed at many actors. It is often necessary for the content to be broken down into parts that convey certain planning concepts. The ESDP, for example, contains sixty policy options. A strategic plan continues to fulfil its goal and function as long as it continues to inform the actors involved in spatial development about the reasoning behind the plan and of its objectives. This continuous reference and feedback reassures learning.

Plan implementation reflects a technical notion of planning. When the implementation stage of planning is reached, all issues are assumed to have been resolved in the plan and all that needs to be done, is to follow it. Any failure puts the goals of the plan in jeopardy. The implementation of a plan assumes a very close relationship between the plan makers and those applying it, all of whom are regarded as equals in the process. The strategic plan is seen as an action of learning. This is contrary to the master plan or blueprint approach. With reference to the ESDP, Faludi refers to the Commissioner who emphasised that there is no room at European level for any master plan or blueprint (Faludi, 2006:123).

2.3.5 Advocacy and a communicative planning in perspective

In his article *Advocacy and Pluralism in Planning*, Paul Davidoff (1965) criticised the lack of integration of social and economic issues in planning, specifically with regard to the

poverty and discrimination that characterised American cities in the 1960s. At the time he criticised the practice of what he called the “unitary plan”, which was the idea that one agency, the city planning department, should be the only party in the community that prepares a comprehensive plan. He rightfully asked the question “[w]hy is only one agency concerned with establishing both general and specific goals for community development, and with proposing the strategies and costs required to effect the goals?” (Davidoff, 1965:332). He highlighted the compelling need for intelligent planning, for specification of new social goals and for the means to achieve them. Davidoff advocated the inclusion of communities in the planning process. Under his influence, planning services were introduced in low-income neighbourhoods by means of *advocate planners* who would be physically located in those neighbourhoods to represent the interests of those residents in planning issues. He encouraged communities to appoint their own advocates, and should that not be possible, it would be the duty of the local government to appoint advocates on their behalf. This proved to be a popular move. Many advocate planners would take this seriously and compete for dominant positions by openly acting “in the best interest of the public” (Stiftel, 2000:8).

Communicative planning, also referred to as collaborative planning, interactive planning, and participatory planning (Brömmelstroet, Hoetjes & Straatemeier, 2002), draws on discontent among influential fractions of the population. Such disgruntlement becomes a social force when mobilised by a set of ideas that seems to define a reason for feelings of dissatisfaction (Fainstein, 2000). It includes mainly two aspects, namely social conditions (as highlighted by Davidoff (1965)), and increased environmental awareness (Healy, 2003; Wenban-Smith, 2013). Built on the concept of community involvement and realising the need for a more pragmatic approach towards planning (Fainstein, 2000:4; Allmendinger, 2002:93), the concept of communicative planning developed from post-modern ideas in planning. Communicative planning seeks to facilitate the active interchange of ideas and issues between interested parties and is not necessarily restricted to developmental issues such as land use (Huxley & Yiftachel, 2000:101). An increasing awareness of planners not having all the answers and solutions to developmental problems has shifted the focus to planning as a more democratic endeavour that involves citizen participation (Huxley & Yiftachel, 2000:101; Brömmelstroet *et al.*, 2002:1).

2.3.6 Crisis planning

The increased complexity of modern-day life, with increased pressures of urbanisation and environmental degradation, is a reality that leans toward crisis management. The reality of rapid (and in places uncontrolled) development seems to be ahead of many conceptions and models of a perceived reality (Brömmelstroet *et al.*, 2002:1). As a result, planners do not always have the luxury of time to adhere to a rational planning process, but are forced to follow their planning instincts to solve a crisis situation (Jansen van Vuuren, 1994:10). This is echoed by Leary (1989:286) who states that “[t]he present trends in planning theory and practice are also away from rational towards pragmatic planning or, in areas of greatest development pressure, towards crisis management”.

Planning has become selective in that specific issues can be addressed (Jansen van Vuuren, 1994:11). In this tradition of project plans (Faludi, 2000), the concept of precinct planning developed as a streamlined and strategic process aimed at improving efficiency, reducing complexity and saving time and money. Precinct planning is effective in defining desirable directions and indicating a localised system of actions, which in some cases involve partnerships between the private and the public sector.

2.3.7 Planning: an integrated process

Planning has been described above as an activity. Aspects of management, control, plan making and decision making are mentioned. Two distinct directions have developed in planning practice: *procedural planning* (focusing on the planning process), and *substantive planning* (focusing on the growth and development of cities) (Stiftel, 2000). Faludi (2000) distinguishes many forms of “process”, to which he refers as *soft* processes. This definition is inclusive of activities such as learning and negotiation, in which planners are often involved. In this context, he sees the outcome of planning not always as the production of material things (plans), but rather as a process of interaction between a multitude of actors.

Drawing from various perspectives ranging from Banfield’s focus on the attainment of ends to Faludi’s continuous planning process or Healey’s collaborative planning, planning theory is conceptualised as extremely wide, as if no boundaries of a unified theory can be drawn. Archibugi (2008) calls it an *uneasiness*, and a *derangement* of planning itself. Such sentiments are discussed in the next section. However, the issue is addressed in this section by looking at a framework for integrated planning.

Dale (2004) gathers various conceptions of development planning under the heading of strategic planning. He sees the purpose of strategic planning in the development sphere as obtaining the best possible fit, or as finding congruence between an intended action (the goal), the resources and abilities for undertaking it, and its societal context. This framework is conceptualised as a triangle of main concerns, which balances as a perfect fit between all three concerns, as illustrated in Figure 2.7

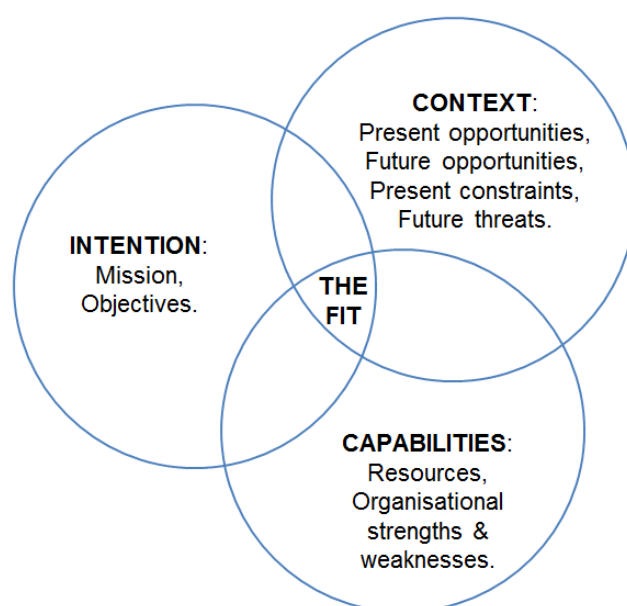


Figure 2.12: Finding the fit between goal, resources and context
Source: Dale (2004:18)

The above framework assumes one organisation undertaking planning and development work. In reality, and in line with post-modernistic approaches, such work is undertaken in greater organisational complexity. The dynamics of a multi-disciplinary development project in which more than one organisation is involved is too vast to analyse in this section.¹ Dale (2004:18-19) highlights the above components as major entities in a generic framework, which can be adjusted as discussed and be described later in this section. The nature of an organisation, its working environment and capabilities are defined as follows:

Organisation: Any purposefully established body designed to undertake some kind of work – in this context, development work. The work is regulated by a set of rules, and supported by administrative systems, technology and incentives. The body may be anything from a small community-based group, government and

¹ The author's experience in multi-disciplinary projects and research over many years is informing this statement. This includes development plans, environmental management frameworks and disaster risk assessments, as well as working together with specialists in various fields. In many of these projects more than one government institution or corporation was also involved.

non-government institution, or a donor agency, focused on development planning tasks, responsibilities and initiatives (refer to Pieterse, 2010 and his concept of innovation-driven economic growth).

Environment: The context within which the organisation functions, which can be characterised in terms of opportunities (present and future), constraints and threats, or problems relating to quality of life. These are translated into objectives for development work with input and output linkages to the organisation.

Capabilities: Financial and physical resources that enable the functioning of an organisation. Internal strengths and weaknesses.

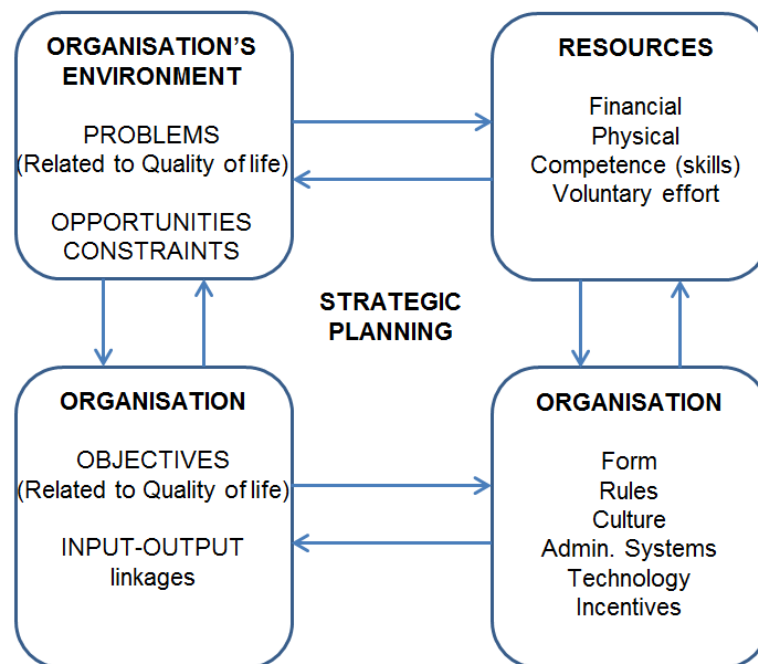
Development thinking is problem-driven (Pieterse, 2010). It is worldly, grounded, and “street-smart”, driven by field knowledge. This perspective of Pieterse is indicative of an information-based process. The generation and flow of information (communication) in a strategic planning framework is therefore essential. The starting point for development work is the identification and analysis of problems (Dale, 2004:19). The need to address these problems is translated into objectives that will guide the planning process, as well as the types and magnitudes of outputs necessary for attaining these objectives. The organisation is responsible for acquiring the resources (capital, technology and skills) that constitute the inputs required for carrying out the work. The abilities of the organisation determine whether it will be able to carry out the work itself, or whether other organisations need to be contracted to assist. A generic framework is presented in Figure 2.8a, while a comprehensive framework is presented in Annexure 2.2.

As mentioned above, the reality is that direct collaboration in the same development project implies that the organisations may share and contribute towards the same general objective. They may also have a set of more specific objectives relating to the core function of each from which they draw distinct outputs as value-added benefits. They may also be exposed to similar environmental conditions (opportunities, constraints and threats), and relate to separate niches, posing their own challenges (refer to Figure 2.8a).

A different scheme of collaboration relates to general overall strategic planning for an area of diverse character, which involves many government agencies and other organisations specialising in different fields (refer to Figure 2.8b). These organisations share the same overall objective, but may have unique internal objectives relating to the work they do. They contribute their internal resources (including information) to a shared

pool, operate independently and their input is coordinated according specific requirements² (Dale, 2004:23).

(a)



(b)

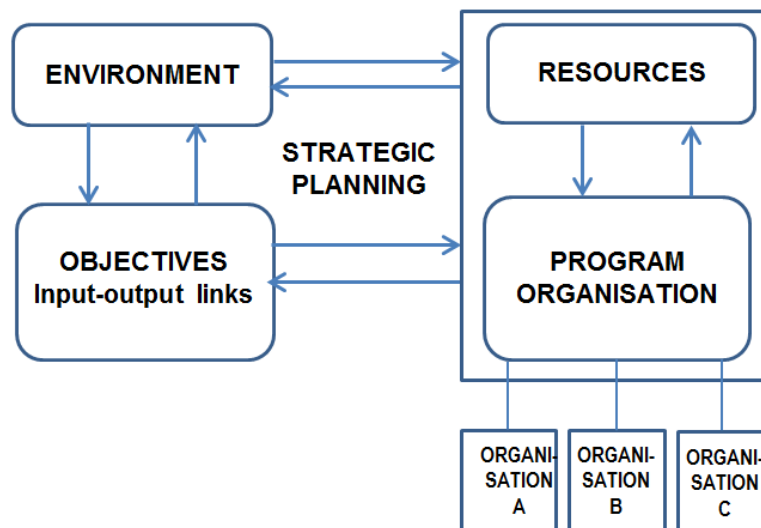


Figure 2.13: Different schemes of organisations' collaboration in strategic planning
Source: Dale (2004)

² Here the author draws from Dale (2004) as well as his own experience, as mentioned in the previous footnote. The framework in Figure 2.8b bears a striking resemblance to his own framework as proposed in Jansen van Vuuren (2013), which he developed without knowledge of Dale at the time.

2.3.8 The planning theory dilemma

The contributions of theorists such as Banfield, Faludi and Friedmann have received wide recognition (Archibugi, 2008). However, following decades of debate on theories and methodologies, theorists agree that consensus has still not been reached about a planning paradigm. The nature of planning has always been contested and disagreement on the meaning of planning is evident in many discourses (Glasson & Marshall, 2007:3). According to Fainstein (2000: 51), planning theorists “have reframed their debates over methods and programs to encompass issues of discourse and inclusiveness”. Brömmelstroet *et al.* (2002:1) argue that there is not much left of modernist, rational, goal-oriented planning in current planning practice and that planners have lost much of their powers to “unilaterally realise their ideas”.

Alexander (1996:45) asserts that planning theory is “in a state of turmoil”, based on the observation that “nothing is accepted; everything is questioned”. In his research briefing *Planning Theory: Reconstruction or Requiem for Planning*, Franco Archibugi undertakes an in-depth investigation into the causes of what he refers to as the “‘derangement’ of planning itself, both as practice and profession” (Archibugi, 2004:425). He postulates that there is a certain uneasiness about planning theory and that, in spite of the progression in the quantity of scholars who have devoted themselves to theoretical reflections about planning, this wide reflection and debate about planning theory has been made worse instead of better. He uses a metaphor that he describes as follows: planning is a dark pond “in which objects at the bottom can only be seen in an obscure, deformed way, people would throw stones (planning theory) into the pond, in the hope of being able to clarify and better define the objects. Instead, all they would accomplish would be to muddy the situation further and make comprehension impossible. After continuing in this manner for some time, these people would become discouraged and arrive at the conclusion that either: (a) (for some people) it will never be possible to discern the objects clearly; (b) (for others) the act of clarifying the pond creates new situations of darkness, subject to analogous uncertainties; (c) (for some at last) there is no need to make the pond any clearer” (Archibugi, 2004:425.)

Glasson and Marshall (2007) confirm that the nature and objectives of planning are being contested, confirming a state of affairs noticeable from the previous century and that is expected to remain the case in the coming decades. This is contributed to two major tendencies: firstly, perhaps more specific to the European context, a limiting of the ambition of planning by governments, attributed to widespread political ascendancy of business interests in Europe and their influence in policy in most European countries.

Secondly, changes in the understanding of spatial planning as a physical land-use-oriented concept, to consider social, economic and environmental objectives and impacts. They conclude that “there is no such thing as an abstract ‘correct’ definition of planning valid for any place or time” and see planning as an activity that focuses on control and management of land use change within a comprehensive grasp of spatial changes in society, economy and the environment. This integrated view is further explored below, as well as in Chapter 6, Section 6, where the concept of landscape ecology is described.

2.3.8 Planning theory: Future perspectives

Planning activities are diverse by nature, covering a wide spectrum of land use control, the design of change, and directing future development (Glasson & Marshall, 2007:3). Attempting to define the turmoil in planning theory, Glasson and Marshall argue that the different conceptualisations of planning are connected with the clashing of ideas in the wider intellectual arena where different professional traditions are associated with planning. This includes professionals such as engineers, architects and even public health officials who have been performing planning functions in times before the establishment of planning as a profession (Parnell, 1993:476; Duhl & Sanchez, 1999:1; Glasson & Marshall, 2007:4).

In setting a new agenda for research in planning, theorists have realised the need for a multidisciplinary approach involving disciplines concerned with environmental, economic and social goals (Huxley & Yiftachel, 2000:104; Stiftel, 2000:8; Archibugi, 2003:436; Bertolini *et al.*, 2005:207). Understanding the multidisciplinary nature of planning, is seen as “... the foundation of a unitary and integrated corpus of methods, knowledge, and know-how”, constituting the agenda for research on a new and integrated theory of planning (Archibugi, 2004:436).

In joining together different disciplines that lie at the basis of planning as a science, it must first be realised that these disciplines represent a large quantity of theoretical studies from which an integrated theme must be developed. Archibugi (2004:437, 438) foresees the integration of socio-economic planning with specific study areas, i.e. technological forecasting, environmental planning, institutional organisation, political coordination and information systems. This theme forms the focus of this research, as explained in Chapter 1.

Abiding by this principle, Bertolini *et al.* (2005: 208) describe planning as a network of interconnected actions involving distinct stakeholders. These actions are not necessarily sequential, but they are connected in such a way that they support a specific goal. In the context of this framework, planning professionals, officials in the public sector and politicians are all involved in planning, but all have different tasks and responsibilities (planning behaviour), as highlighted by Hopkins (2001). Considering the role of politicians, civil servants and professionals as stakeholders, Bertolini *et al.* (2005) propose a network that links the core actions of each in such a way that feasible projects (designed by professionals) can be implemented (by public servants) with sufficient financial support (endorsed by politicians). The concept of this network is summarised in Table 2.1 and illustrated in Figure 2.9.

Table 2.1 A classification of planning tasks in a multi-stakeholder environment

Planning Environment	Planning Tasks
Professional Practice	Define a vision
	Analyse spatial concepts
	Develop a plan
	Identify feasible projects
Public Service	Identify trends
	Define goals
	Define development strategies
	Set up a development programme
	Identify projects to be implemented
Political Arena	Identify issues
	Identify acceptable interventions
	Identify projects
	Provide budgets for the execution of projects

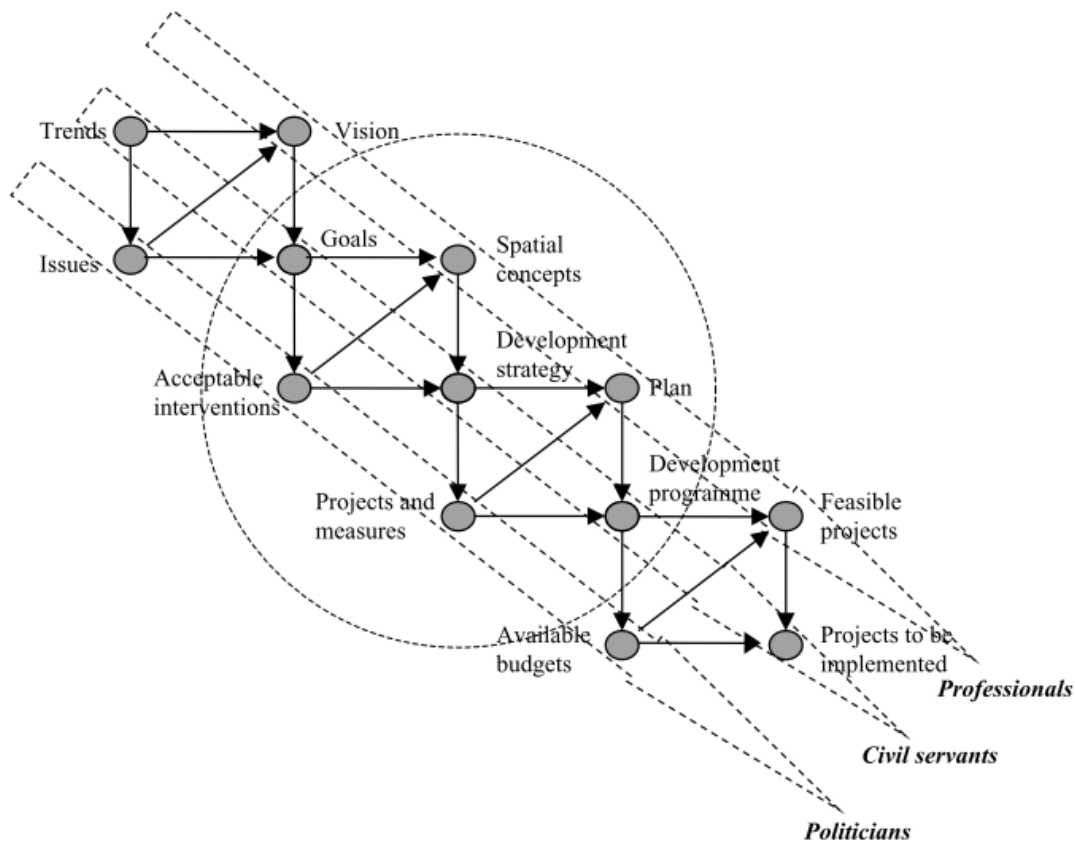


Figure 2.14: Planning as a network of interrelated actions

Source: Bertolini *et al.* (2005:209)

A planning society where different sectors of planning are integrated through logical and methodological connections, as well as its operative functioning, is seen by Archibugi (2004:435) as the appropriate field of planning theory. He argues that planning theory would be far more successful in the integration of different approaches, as it would try to bring into the discussion scholars involved in many different types of planning (e.g. agricultural, industrial, commercial, services, governmental). Included in this vision are also different scales of planning – from urban, metropolitan and regional planning to national, international and global. Interdisciplinary and intradisciplinary research is strongly encouraged by Van Niekerk (2012) and Van der Waladt (2013), specifically with regard to integration between development planning and disaster risk assessment. This topic will be further highlighted in Chapters 3 and 4.

2.4 DEVELOPMENT PLANNING – AN INTEGRATED ENDEAVOUR

Sectoral theories, such as macro-economic governance that initially dominated development studies, were marked by a gap between economic development on the one hand and social and political development on the other (Archibugi, 2004). Failures in

development policies, emerging problems that require combined approaches, and development crises and emergencies contributed to a gradual shift towards an interdisciplinary approach (Pieterse, 2010:14). Discontent with the approach of the 1940s and 1950s among a number of British economists and social scientists saw the emergence of the so-called “new universities” in Britain and the establishment of the Institute of Development Studies at the University of Sussex in 1966. They were displeased with the traditional insights and quantitative approaches of social and economic science at the time (Potter, 2014:48). Being largely influenced by Marxist thoughts, new development studies brought together a number of disciplines in the study of poverty and inequality as the central concern. This particular focus, which Esteva (1992:6) refers to as “The Invention of Underdevelopment”, is rooted in the 1949 declaration of US president Harry Truman in his inauguration speech. This development heralded the introduction of interdisciplinary approaches in development planning. According to Potter (2014:49), development studies can make a strong claim to be cross-disciplinary in nature, which implies that development theory cannot be tied to a single discipline.

Main stream disciplines that have contributed to the rise of development studies include politics, sociology, economics and geography, which led to the emergence of the sub-disciplines ‘development economics’ and ‘development geography’ (Potter, 2014). These fields are linked through commonalities in related disciplines such as demography, international relations, anthropology, history, and urban and regional planning, adding to the cross-disciplinary character of development studies (refer to Figure 2.10).

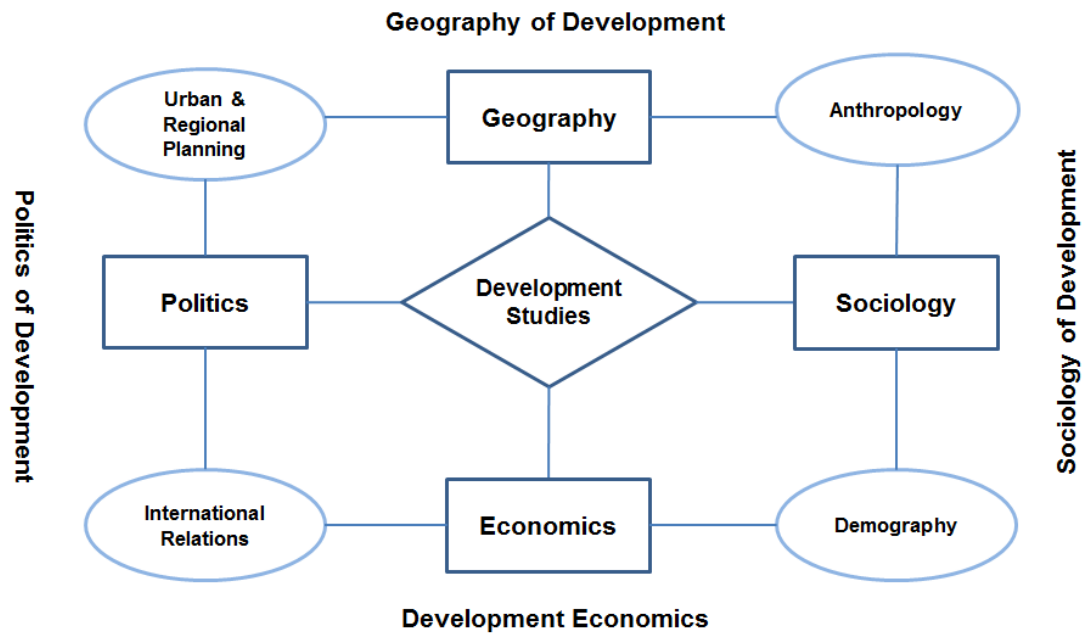


Figure 2.15: The four main disciplines in the interdisciplinary field of development studies
Source: Adapted from Potter (2014:49)

From a planning perspective, Archibugi (2008:95) defines strategic planning as the confluence of a series of interdisciplinary and transdisciplinary fields of study. He goes as far as describing strategic planning as the *main pillar* of planning science, believing that this notion “directs us towards the constitution of a new discipline”.

The interdisciplinary nature of development planning is fundamentally rooted in human–nature relations, and is thus concerned with social-ecological learning (Wilkinson, 2011). According to Wilkinson, a social-ecological approach towards planning is conducive to improving a society’s resilience to a wide range of surprises, which puts planning into the context of sustainable development.

2.4.1 Development planning and sustainable development

The notion of sustainable development has become fashionable in modern planning (Vreeker & Nijkamp, 2006:175), and has developed into a focused research field that brings together perspectives from disciplines across the spectrum of the natural and social sciences, including engineering and medicine (Clark & Dickson, 2003). Sustainable development is discussed in detail in Chapter 4, but as a concept within planning, it is briefly discussed here to highlight its developmental context and integration imperatives.

Vreeker and Nijkamp (2006) define sustainable development as the development of an economy that has to take place within a set of pre-specified normative constraints or pathways. They identify four attributes of sustainability constraints: (a) they are expressed in measurable parameters that are linked to (b) sustainability targets. These parameters have (c) a proper geographical scale and (d) a relevant time dimension. Sustainable development, therefore, contains a strong element of information and related data streams. In an earlier work, Nijkamp and Vreeker (2000) present a framework to assess the sustainability of development strategies. This framework is based on a systematic multi-criteria flag model under the heading *Sustainability Assessment of Development Scenarios*. Moreover, the framework is developed with a view to dealing with information, in particular uncertain information, but based on expert opinion and scientific foundation. Development constraints are defined in various ways and may include safe minimum standards, carrying capacity, maximum sustainable yield, eco-capacity, critical loads, and vulnerability, all of which are encapsulated under the general heading of *critical threshold values* (CTVs). The framework provides for a band of CTV values from a minimum to a maximum value for a range of criteria. Exceeding a CTV would impose an unacceptably high cost on the environment. The criteria cover a number of sectors that are grouped into three main categories, i.e. economic, social and environmental.

The imperative for integration stems from recognition of the interdependence of human and natural systems (Dovers, 2005), which are discussed in Chapter 4. At this juncture the need for integrated planning and decision making is highlighted. The integration of environmental, social and economic considerations is a challenge that requires the development of methods, processes and data streams to create integrative capacity. Integration is challenged at two levels: first, integration in research, which combines disciplinary perspectives that point to intra-disciplinary efforts, and second, integration in policy making, which cuts across different agencies, issues and sectors. Integration is thus approached from an *informative* and a *decisive* perspective, both of which appeal to the development and use of information systems. (In this context, Chapter 6 deals with the concept of indicators.) The next section takes a brief look at the general use of geographic information systems (GIS) in development planning.

2.4 INFORMATION AND DEVELOPMENT PLANNING

The use of information systems, particularly GIS, is central to this research. An observation from the above study of development and planning is the general lack of reference to information and information systems, notably GIS. Yiftachel (2001) asserts that most of the influential literature on planning treats planning as a generic, procedural activity that focuses on issues of decision making and collaborative planning, while ignoring the relationship between development and space. Calling it “spaceless planning”, he makes a strong statement by comparing the lack of spatial processes in planning theory with medical theory ignoring the human body, or legal theory overlooking the impact of laws on human affairs. Brömmelstroet et al. (2002) make it clear that there is a need for relevant, useful and understandable information in planning. The need for processes of information gathering in the context of monitoring is highlighted by Wenban-Smith (2010), while the aspect of information and its importance in communicative planning is highlighted by Yiftachel (2001) and Healy (2003).

Friedmann (1998) refers to development processes that manifest in phenomena such as urbanisation, regional economic growth and change, and the transformation of nature as *socio-spatial* processes. In the context of a productivist view of the city, he refers to these spaces as *human habitat*. Talking about the unique competence of planners, Friedmann (1998:251) also states that planners should “have a grounding in knowledge about the socio-spatial processes that, in interaction with each other, produce the urban habitat”.

The need for integrating information and planning theory is best summarised in the words of Yiftachel (2001:8):

“It may be high time for a ‘spatial turn’ among other leading theorists, in order to create a shared theoretical discourse directly relevant to the actual practice and material consequences of planning.”

2.5 CONCLUSION

In order to understand the intersection between disaster risk management and development planning, this chapter describes the origins of development planning in order to understand its theory, claims and proclamations.

The history of planning shows that it is a reaction to socio-economic realities where it was realised that intervention is required to improve the living conditions and prospects of

communities. In the aftermath of industrialisation and urbanisation, planning has emerged as a profession supported by schools for research and for the training of planners, specifically in Europe and the United States.

During decades of planning practice, theorists and scholars have been writing about the roots of the planning profession and the paradigms within which it was practised. The first observation is that the origins of planning are rooted in disciplines such as economics, public administration and sociology. In the period after 1955, theorists have established a distinct planning paradigm, which evolved from a blueprint-planning approach to rationalism and a communicative approach where planning is seen as an inclusive process that involves various stakeholders and disciplines.

In the next chapter the theoretical background of environmental management is described as a discipline related to development planning.

CHAPTER 3: THEORY OF ENVIRONMENTAL MANAGEMENT

3.1 INTRODUCTION

Burton, Kates and White (1993) devote the first chapter of their book *The environment as hazard* to answering the question: “Is the environment becoming more hazardous?” According to their assessment, the natural environment is indeed becoming more hazardous, but in a number of complex ways. They also conclude that the process is not easy to reverse. The link between industrial-based development and global warming is receiving increased international attention (Hopper, 2012) against the background of unequivocal evidence of warming of the climate system (IPCC, 2014). In this context, the commonalities between development, environmental change and disaster risk become even more significant to explore.

The link between environmental degradation and disasters from a causation perspective is well documented (Bankoff, 2001; Renaud, 2006; Labadie, 2007; Bacon 2012). The growing impact of hazards and disaster on human society is seen as a consequence of environmental degradation caused by overpopulation, unsustainable development practices and economic development policies (Bankoff, 2001; Bacon 2012). Environmental degradation is a broad concept that translates into the conscious destruction of the three spheres of our planet that support life, i.e. land, air and water (Thornhill, 2014). It manifests in seven major environmental problems (UNRISD, 1994): water pollution and water scarcity; air pollution; solid and hazardous wastes; soil degradation; deforestation; loss of biodiversity. The effects of environmental degradation are divergent for various social groups, and for different contexts (UNRISD, 1994). They include reduced production opportunities due to erosion and contamination, health problems related to pollution, and decline in the nutritional value of soils. Furthermore, environmental damage caused by humans increases the vulnerability of communities and the risk of disasters such as flooding and drought (Renaud, 2006).

On the other hand, the impact of disasters on the environment is also evident (Labadie, 2007). The Exxon Valdez oil spill in 1989 near Prince William Sound in Alaska, and the Deepwater Horizon oil spill in the Gulf of Mexico in 2010 are mentioned as an example of human-induced disasters that had large-scale effects, particularly on marine life and local economies linked to the fishing industry and tourism (Picou & Martin, 2007; Norse &

Amos, 2010; Trannum & Bakke, 2012). Although the full impact on ecosystems in the Gulf of Mexico could not be established due to a lack of field data (Trannum & Bakke, 2012), these two events are regarded as the most destructive technological disasters in the history of North America. It is known that in Prince William Sound, only eight out of 22 affected species recovered from the effects of the Exxon Valdez oil spill (Picou & Martin, 2007).

Simon (2012:209) argues that creeping environmental changes have a cumulative effect on environmental degradation, and causes the eroding of the quality of soils, water and the atmosphere. These Creeping Environmental Problems and Changes (CEPs) caused by human activity are seemingly accumulating and moving towards a threshold beyond which major crises may evolve. The effects in terms of the Earth's population are described by Barrow (2006:68) as "... gradual or sudden, limited or catastrophic collapse in numbers, a vacillation, or a cyclic boom-and-bust growth pattern". Simon (2012) further highlights the effect of global climate change (GCC), which is expected to increase both the number of vulnerable people and the extent of their vulnerability. The *Climate Change 2014 Synthesis Report* confirms that human influence on the climate system is clear, and that recent anthropogenic emissions of greenhouse gases are the highest in history (IPCC, 2014). The reduction of vulnerability and disaster risk needs a focus away from natural hazards, and a shift towards environmental conservation. Bankoff (2001:20) states that "[h]ow to mitigate the effects of hazards and relieve the consequences of disasters seem destined to be major issues of academic enquiry in the new century if for no other reason than that they are inseparably linked to questions of environmental conservation, resource depletion and migration patterns in an increasingly globalised world". This remark places issues about environmental management in the domain of disaster risk reduction research.

The theoretical grounding of environmental management is one of the key research questions that would link this discipline with development management and disaster risk reduction. Chapter 3 focuses on the theoretical underpinnings of environmental management by looking at the development of the field, the methods of environmental assessment and a brief analysis of sustainable development as a notion that stands central to environmental management, disaster risk management and development planning.

3.2 ENVIRONMENTAL MANAGEMENT

The concept of environmental management is broadly defined as the application of skills and techniques to care for the Earth (Fuggle, 1992:3). As a practice it appeared in the 1970s as a problem-solving field, providing practical assistance mainly to state officials (Barrow, 2006:20). The growth path, as described by Barrow (2006), shows similar developments as was described in Chapter 2 in respect of development planning. Environmental management developed in the 1970s as a reactive, policy-based endeavour that was carried out largely by experts trained in the natural sciences in a top-down manner, and that was implemented and enforced by coercion. This approach soon shifted to a multi-disciplinary undertaking, addressing social and economic issues and incorporating public consultation. From a management perspective, it relates to the execution of planned controls so as to achieve a desired outcome. These controls are linked to goals associated with the principles of sustainable development. Barrow (2006) and Labadie (2007) see environmental management as a mixture of objective and subjective scientific approaches that encapsulates environmental science, environmental engineering, ecology, and related disciplines. It involves policy making, planning and management. However, it lacks a widely adopted framework to shape its application. This leads to ad hoc and problem-solving approaches in reaction to specific situations (Barrow, 2006:25). From these two broad definitions, the concepts of '*environment*' and '*management*' are taken as constituting the foundation for an understanding of environmental management.

The scope and nature of the environment is vast (Glasson & Marshall, 2007). The literary meaning of '*environment*' is the surrounding external conditions that influence development or growth of people, animal or plants. In short, it is the living and/or working conditions of living things (Singh, 2006). The term is widely used and means various things to different people. It is normally used in the context of a particular premise, for example a town planner may see environment as the spatial structure of a city, whereas an architect will relate to the fabric of buildings, and an ecologist will see it in the context of faunal and floral habitat (Fuggle, 1992). Hence it has become common to speak of the '*built environment*', the '*natural environment*', and also the '*social*' or '*cultural*' environment to distinguish different settings. The National Environmental Management Act (Act 107 of 1998) defines environment as

“the surroundings within which humans exist and that are made up of -

- (i) the land, water and atmosphere of the earth;
- (ii) micro-organisms, plant and animal life;

- (iii) any part or combination of (i) and (ii) and the interrelationships among and between them; and
- (iv) the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and wellbeing” (South Africa, 1998).

Barrow (2006:378) defines environment as

“the sum total of conditions within which organisms live; the result of the interaction between non-living (abiotic) physical and chemical, and, where present, living (biotic) components”.

From the above definitions it is clear that the environment is constituted by interacting systems of physical, biological and cultural elements that are interrelated in various ways. These elements constitute the landscape within which interaction between these elements takes place. The concept of landscape ecology defines the interaction between humans and the environment, and is described in more detail in Chapter 7. At this juncture, the environment is described as consisting of three main elements: physical, biological and cultural (anthropogenic) (Singh, 2006:3; Nhamo & Inyang, 2011):

- i. *Physical elements*: atmosphere, landforms, water, climate, rocks and minerals, soils, etc. These elements determine the variable character of the human habitat, its opportunities and constraints.
- ii. *Biological elements*: plants, animals, micro-organisms and man, constituting the biosphere.
- iii. *Cultural (anthropogenic) elements*: economic, social and political constructs that are essentially anthropogenic features.

Environmental science, therefore, is a multi-disciplinary field comprising various branches of study such as ecology, zoology, agriculture, archaeology, and public health (Fuggle, 1992:4; Singh, 2006:1). From an anthropological and physical perspective, it also relates to sociology and geography.

The ‘*management*’ component is briefly described to establish the context of environmental management. Dale (1960:4), after considering various definitions from literature, defines management as

“the process by which a manager of an organisation efficiently utilizes resources to achieve its overall goals at minimum cost and maximum profit. When used

collectively, the term management refers to the group of people who are responsible and accountable for directing the work force and seeing to it that the organization meets its goals or objectives”.

Weihrich (1993) defines management as

“the process of designing and maintaining an environment in which individuals, working together in groups, accomplish efficiently selected aims”.

The definition of management, and its functions, highlights important features of the concept. First, management is a process, a systematic way of doing things, involving skilled people. Second, it utilises resources efficiently, including materials, time, effort and money. Third, management actions work toward a stated goal. Dale (1960) and Weihrich (1993) identify five functions of management, namely planning, organisation, staffing, leading (motivating) and controlling. In all of these functions, two essential processes occur: decision making and communicating, which imply the creation, administration and dissemination of information. Data acquisition and processing is seen as the starting point and a key aspect of environmental management (Barrow, 2006). This includes qualitative and quantitative data and implies the involvement of specialists such as statisticians and GIS practitioners.

Applying these principles means that environmental management is a concerted effort to plan, organise, implement and control actions that are aimed at caring for the Earth. The question “who is responsible for environmental management?” brings the issue of environmental governance to the fore. Environmental governance refers to an inclusive process of decision making regarding the control and management of the environment (Fakier, Stephens & Tholin, 2005). *Governance* is a function of public administration and refers to the system of values, policies and institutions by which a society manages its economic, political and social affairs through interactions within and among the state, civil society and the private sector (Fakier *et al.*, 2005; Feris, 2010). In view of global issues such as climate change, the concept of global environmental governance builds on international environmental cooperation that dates from even before the 1972 Stockholm Conference on the Human Environment (Biermann, 2004) (refer to Section 3.3.1 with regard to the significance of this conference). Global environmental governance is described as the sum of organisations, policy instruments, financing mechanisms, rules, procedures and norms that regulate the processes of global environmental protection (Najam, Papa & Taiyab, 2006:3), and focuses on transboundary issues relating to human

activity and natural processes. Transboundary human activities include issues such as food production, loss of biodiversity, water resource problems, nuclear energy, HIV/AIDS, and malaria. Natural processes that involve international cooperation include climate change, stratospheric ozone damage, major volcano eruptions, tsunamis, epidemic diseases, and ocean/atmospheric circulation shifts (Barrow, 2006).

Frameworks for environmental governance are further discussed in the context of integrated environmental management, which provides an outline for environmental management practices.

3.3 INTEGRATED ENVIRONMENTAL MANAGEMENT

As a theory, environmental management can be structured under the paradigm of integrated environmental management (IEM). IEM has developed to be “an underlying philosophy and set of principles supported by a range of environmental assessment and management tools that are aimed at promoting sustainability” (DEAT, 2004:8). As such, IEM cannot be defined in terms of processes. It provides a *way of thinking* that can be used to underpin a stand-alone process such as environmental impact assessment, or it can be integrated into complementary processes such as comprehensive regional planning (Barrow, 2006) or integrated development planning (IDP), as described in Chapter 2.

IEM developed from a growing awareness of the adverse impacts of development on the environment, which gave rise to the need to understand and deal with those impacts (Preston, Robins & Fuggle, 1992:748). Developments in the international arena, followed by the institutionalisation of environmental law in many countries, saw the emergence of increased concern about the environment, and frameworks within which issues could be addressed (Elliot, 2006:126). These frameworks are briefly assessed in the setting of international initiatives and environmental management tools that were developed in response.

3.3.1 International initiatives

Certain global initiatives mark the emergence of environmental governance (Rabie & Fuggle, 1992; Nhamo & Inyang, 2011). These include the promulgation of legislation in various countries, as well as international summits.

The United States was the first country to enact the requirement of environmental impact assessment of proposed developments with its promulgation of the National Environmental Policy Act in 1969 (Aucamp, 2009:4). Furthermore, international concern about the environment, particularly acid rain and critical air pollution in Western Europe (Nhamo & Inyang, 2011:9), led to the United Nations' Conference on the Human Environment in Stockholm in June 1972. This was regarded as the most successful international conference at the time (Sohn, 1973:423). The success was in the so-called Stockholm Declaration, which contained a set of principles to inspire and guide the preservation and enhancement of the human environment. The resolution also included institutional and financial agreements and recommendations that would make it an ambitious action plan. The Action Plan inter alia recommended that the UN General Assembly formulate an inter-agency Environmental Co-ordinating Board that would ensure cooperation and coordination among major bodies involved in the implementation of environmental programmes within the UN systems. This gave rise to the formation of the United Nations Environment Programme (UNEP). The success of these initiatives is also reflected in the fact that the environment was placed firmly as a matter of concern on most government agendas (Nhamo & Inyang, 2011:11).

Increased environmental degradation, as well as divisions between developed countries of the North and emerging and developing countries of the South, contributed to the United Nations General Assembly initiating an independent body, the World Commission on Environment and Development (WCED) (Ling, 2012:2). The aim of the commission was to find practical ways of addressing the environmental and developmental problems of the world (WCED, 1987). From this initiative emerged a report "Our Common Future", also referred to as the Brundtland Report (named after the Norwegian Prime Minister and chairman of the commission), which inter alia called for '*sustainable development*' as a long-term environmental strategy. Key issues that would require urgent action included population and human resources, food security, the urban challenge, energy, industry, species and ecosystems, managing the commons, and conflict and environmental degradation (Nhamo & Inyang, 2011:12).

A Heads-of-State conference followed in June 1992, with a large contingent of NGOs, community, government and citizens' groups gathering in Rio de Janeiro. During this conference, the North-South conflict surfaced again. Whereas governments from the North had an agenda to solve environmental issues, the South was focused on industrialisation, development and poverty alleviation (Nhamo & Inyang, 2011; Ling 2012). The concept of sustainable development was debated in depth and after long and difficult deliberations, the Rio Declaration on Environment and Development, containing 27 principles on the general rights and obligations of states, was adopted. This set a new course in development thinking and became a central theme in the mission of organisations and institutions (NRC, 1999:22).

Environmental management gained increased importance on socio-political agendas all over the world (Hart, 1992:53). Concerted international efforts following the Rio de Janeiro summit include the Millennium Summit (UN General Assembly, 2000), which saw the formulation of the Millennium Development Goals, and the World Summit on Sustainable Development in Johannesburg, 2002 (Nhamo & Inyang, 2011:23; UN, 2014) – all of which furthered the objectives of sustainable development. As a unifying concept, the latter is further explored in Section 3.4.1.

3.3.2 Environmental management tools

Emerging environmental awareness in the 1960s resulted in the adoption of two major approaches and tools for environmental management, i.e. environmental impact assessment (EIA) and strategic environmental assessment (SEA). The concept of EIA was institutionalised in the US under the National Environmental Policy Act (NEPA) in 1969 (Smith, Richardson & McNab, 2010:10), and for the first time environmental evaluations were introduced into the realm of public policy (Preston, Robins & Fuggle, 1992:748; Barrow, 2006:20). Following the US lead, EIAs became widely institutionalised, with at least 100 countries having adopted some kind of EIA legislation, system or guideline (Aucamp, 2009:8). Shortcomings of an EIA identified in the 1970s led scholars and practitioners to seek alternative approaches and tools, eventually resulting in the establishment of SEA as a policy-based tool. In addition, the concept of environmental management frameworks emerged as an activity-based tool in support of an EIA (South Africa, 2010). A description of these tools provides an understanding of decision making with regard to environmental issues.

3.3.2.1 Environmental Impact Assessment (EIA)

An EIA forms part of an array of tools and techniques for environmental assessment. Porter and Fittipaldi (eds.) (1998) compiled a comprehensive volume on tools and techniques for environmental assessment and impact assessment, which includes domain-orientated assessments such as social, economic, public health, risk, ecological, and climate impact and adaptation assessments. This points to the interdisciplinary nature of environmental assessment.

Aucamp (2009:5) states that environmental quality is preserved and improved through proactive and reactive measures. The first strives to prevent degradation and promote conservation. The main tools in this respect are environmental impact assessment (EIA) and strategic environmental assessment (SEA). Reactive measures are focused on existing impacts and strive to mitigate their effects through measures such as rehabilitation of degraded areas, reducing of emissions, and a general clean-up of the environment. The tools used in this regard are specific legislation with compliance and enforcement powers, using international standards such as ISO 14001 (Labadie, 2007).

There is no universal definition of what an EIA is, and it is best treated as a generic term for a process that seeks to integrate administration, planning, analysis and public involvement in an assessment that precedes decision making (Barlow, 2006:205). In South Africa EIAs are enforced by law through the National Environmental Management Act (Act 107 of 1998), generally referred to as the NEMA, and the Environmental Impact Assessment Amendment Regulations, 2010 (South Africa, 1998; South Africa, 2010). EIAs are undertaken on a project level, and are specific to a particular project design and development application. Aucamp (2009:5) defines an EIA as a systematic process of examining the potential impacts of a proposed development on the environment (biophysical, socio-economic and cultural). As an integrated process, an EIA involves public consultation and review in a range of steps that are prescribed in the regulations. A generic framework for EIA is presented in Figure 3.1.

An EIA is conducted through a number of steps or phases, which starts with an initial proposal for development of a specific activity. In South Africa the NEMA provides for the listing of activities that require an EIA and the identification of competent authorities responsible for granting environmental authorisations in respect of those activities. A screening process of the proposed activity and the appropriate legislation ensures that there is no uncertainty as to whether an EIA should be carried out or not. If not, a

decision to approve the activity can be taken, else an EIA must be carried out. This is normally undertaken in two main phases, namely a scoping and an EIA phase. Scoping may overlap with the screening or the EIA process, and may be repeated following public review. The main purpose of a scoping report is to identify issues relating to environmental impact and preparing a scope of work for an EIA, which follows approval of the scoping report by the competent authority. The EIA is carried out by a duly qualified environmental assessment practitioner (EAP). During the EIA phase, environmental impacts are assessed, normally by a team of experts in various fields such as botany, zoology, hydrology, archaeology, and other specialist fields, as required by the competent authority. Within the EIA, a series of steps are undertaken that build up to the identification of specific impacts. This normally follows a process of data collection, processing and analysis, which informs the EAP of all the possible environmental impacts. An EIA report compiled by the EAP is submitted to the competent authority who will consider it for approval. The flow diagram in Figure 3.1 gives a synopsis of the EIA process.

The aim of an EIA is to prevent the substantial detrimental effects of a development to the environment. As a process regulated by law, it has a record of decision (authorisation) as outcome, and is only relevant to a proposed development. An assessment of existing projects is undertaken as an '*environmental risk assessment*', which takes known effects on the environment into consideration (Bina, 2008; Aucamp, 2009:7).

Problems relating to an EIA include lack of enforcement (Aucamp, 2009:8), the project-specific nature of the EIA, cumulative impacts on a regional scale (Barrow, 2006:228), and an awareness that environmental issues must be integrated into the process of policy making and planning, as well as administration (Wiseman, 1996; Barrow, 2006:228). To cope with the challenges of EIA and integrated environmental management, the concept of SEA has been developed as an activity to be undertaken early in the development process (Barrow, 2006:230; Bina, 2008) (discussed in Section 3.3.2.3). The diagram in Figure 3.4 gives a synoptic comparison of the EIA and the SEA processes, indicating similarities, but on different levels, i.e. project level and policy level.

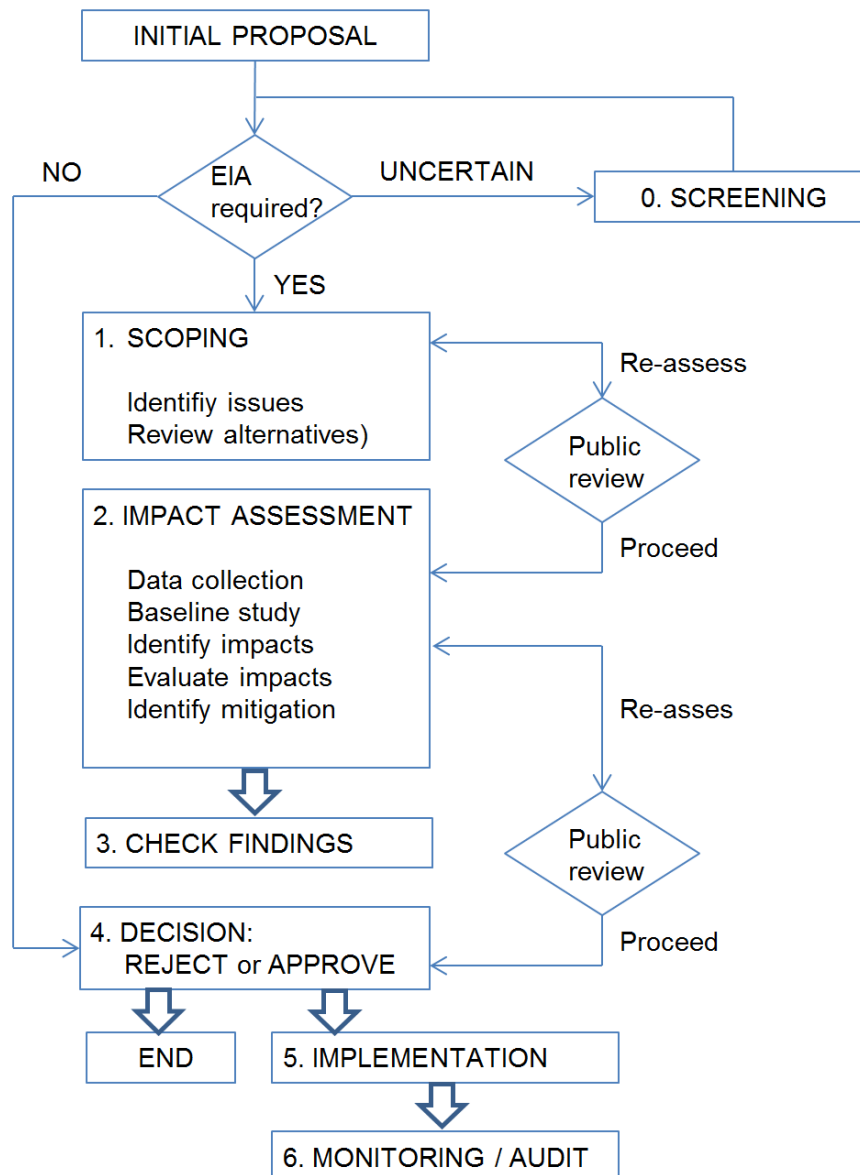


Figure 3.16: A typical step-wise EIA process

Source: Barrow (2006:207)

The EIA process, as described above, is indicative of a large information component. The use of geographic information systems technology is implied in the NEMA, Section 24(3), which stipulates as follows (South Africa, 1998):

“The Minister, or an MEC with the concurrence of the Minister, may compile information and maps that specify the attributes of the environment in particular geographical areas, including the sensitivity, extent, interrelationship and significance of such attributes which must be taken into account by every competent authority.”

A *geographical area* is a spatial unit determined by the unique combination of environmental attributes in which specified activities may not commence without environmental authorisation from the competent authority (NEMA, Section 24(2)). The expansion of this concept into a data model is proposed in Chapter 8.

The approval of an EIA means the proposed activity can be implemented. This is the last phase in the EIA process and requires monitoring of the development activity in terms of an environmental management plan (EMP), which is briefly described below.

3.3.2.2 Environmental Management Plans (EMPs)

Mitigation measures to avoid or minimise damage to the environment that may be caused by a development project are prescribed within an EIA (Aucamp, 2009). Environmental management plans (EMPs) outline the mitigation, monitoring and institutional measures to be taken during project implementation and operation to avoid or control adverse environmental impacts, and the actions needed to implement these measures (World Bank, 1999; DEAT 2004b). There is no standard format for EMPs. The format needs to fit the circumstances in which the EMP is being developed and the requirements which it is designed to meet, and it should be formulated in such a way that it is easy to use. The South African Department of Environmental Affairs and Tourism provides for three broad categories of EMPs in the lifecycle of a development project and distinguishes between construction, operation and decommissioning. Each of these phases presents different types of activity that require specific mitigation and monitoring measures (DEAT, 2004b). According to the World Bank (1999), an EMPs should contain the following components:

- i. A summary of the predicted negative environmental impacts for which mitigation is required.
- ii. Detailed description of feasible and cost effective mitigation measures to reduce significant negative environmental impacts to acceptable and legal levels. Mitigation measures should be accompanied by designs, equipment descriptions and operating procedures.
- iii. Description of a monitoring programme to ensure that mitigation measures are implemented. The monitoring programme should clearly indicate the linkages between impacts, indicators to be measured, measurement methods and definition of thresholds that will signal the need for corrective actions.
- iv. A clear definition of responsibilities and institutional arrangements for mitigation and monitoring actions.

- v. A legal framework to support the enforceability of an EMP.
- vi. Implementation schedule and reporting procedures indicating the timing, frequency, and duration of mitigation. These measures should be specified in an implementation schedule and show links with the overall project.

3.3.2.3 Strategic Environmental Assessment (SEA)

An SEA refers to a process that integrates sustainability considerations with the formulation and implementation of policies, plans and programmes. It is a systematic process that evaluates the environmental consequences of a policy, plan or programme (Aucamp, 2009:8; Glasson & Marshall, 2007:227). An SEA therefore functions on a strategic level and informs the EIA as a project on ground level (refer to Figure 3.2).

Policies ↓ Plans ↓ Programmes	SEA	National/Provincial Strategies & Policies
		Land Use Planning
		Catchment Management
Strategic Management Plans		Environmental Management Frameworks
		Land Use Management
Projects	EIA	Project Design
		Environmental Management Plans

Figure 3.17: The relationship between SEA, EIA and processes

Source: Adopted from Aucamp (2009:9)

According to Aucamp (2009:8) several approaches to SEA have been developed in different parts of the world, indicating different understandings of and approaches to SEA. Buckley (1998:81) identifies seven major types of SEA based on different approaches worldwide:

- i. Policy: Environmental assessment of existing policies or proposed changes
- ii. Issue-based: Assessment of factors relating to a specified environmental issue
- iii. Geographical: Regional and national environmental planning and assessment
- iv. Temporal: Environmental planning and assessment for social and economic change
- v. Technological: Environmental assessment for technological innovation
- vi. Sectoral: EA for alternative development options for entire industry sectors
- vii. Generic-project: Framework EIA documents for similar projects

Bina (2008) identifies different conceptualisations of SEA, as it developed through history. Early views of SEA see it as an information tool, providing a prediction and evaluation of the impacts of a proposed development, and delivered as a report. In practice, however,

this exercise was rarely performed sufficiently early on in the process to influence the framing of the problem, the development objectives or the subsequent ideas and strategic alternatives. As a result, SEA fell short of its purpose. As the concept gained momentum during the 1990s, definitions of SEA gave rise to two normative claims that are still current: first, SEA should contribute to sustainable development, and second, it should help improve policy making. A third conceptualisation of SEA sees a move towards process integration in reaction to the earlier problems of integration with the development process.

According to Bina (2008:139), SEA practices can be categorised according to four models (see Figure 3.3 for illustration). The first (Model A) resembles the early approach of SEA's focus on impact assessment and reporting. Models B and C represent a move towards closer integration with the planning and assessment processes, which is also highlighted by Glasson and Marshall (2007) from the perspective of regional planning. Model D sees SEA as an overarching process where planning in itself is weak and SEA has to compensate for the lack of strategic thinking and planning.

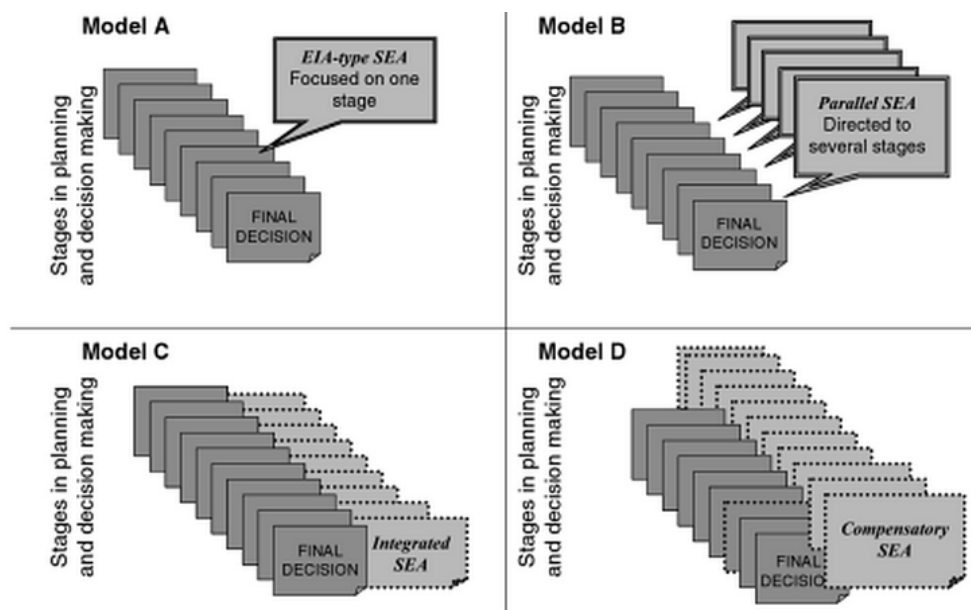


Figure 3.18: The range of SEA models
Source: Bina (2008:141)

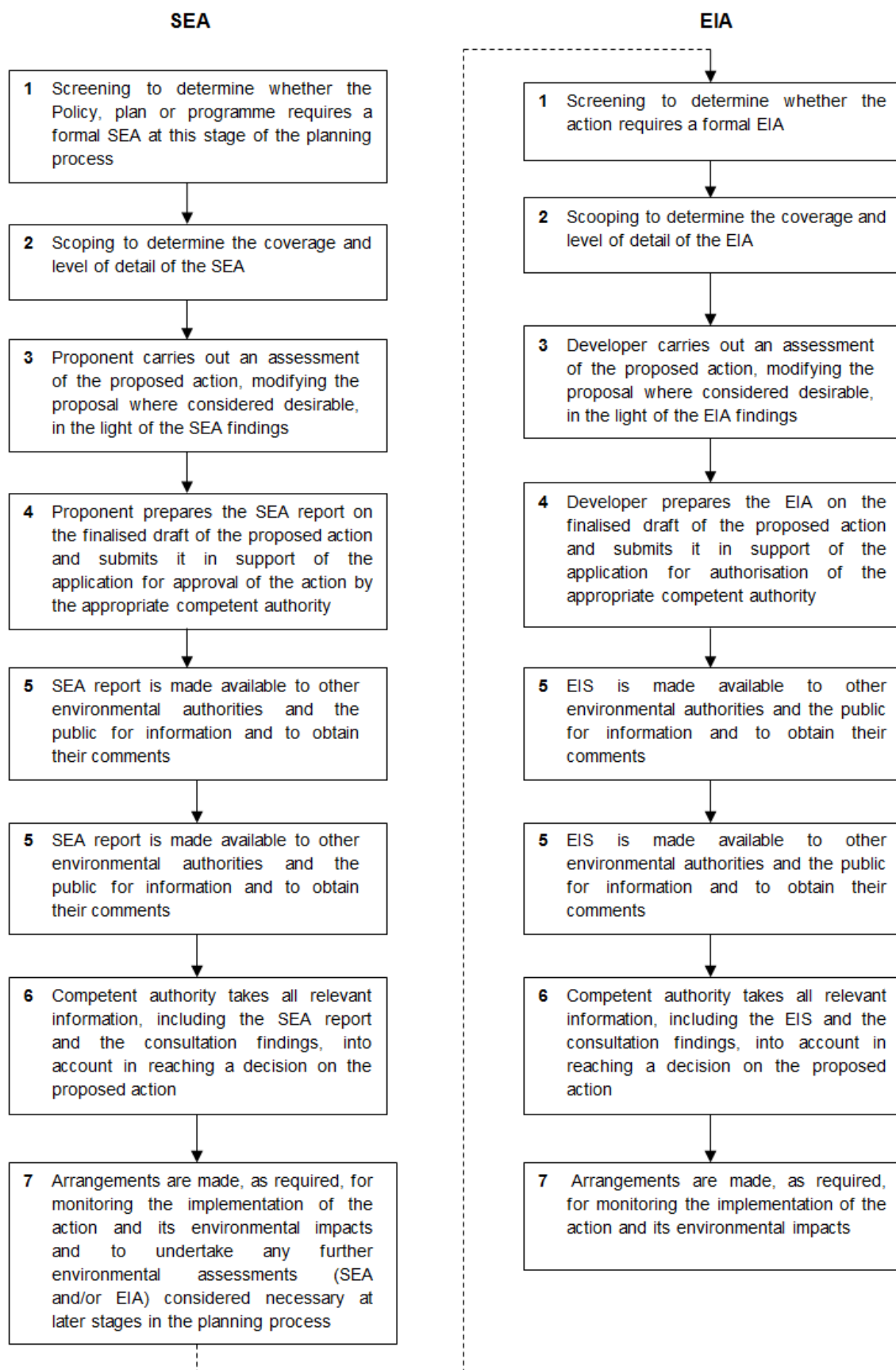


Figure 3.19: A comparison of SEA and EIA processes indicating similarity, albeit on different levels

Source: Barrow (2006:231)

From a planning perspective, Glasson and Marshall (2007:210) acknowledge that the environment is under increasing threat of development actions. They see SEA as an important component of regional planning, as it provides the framework for planning and development activity. It is seen as an important activity that should be carried out concurrently with the plan-making process, and not as an add-on at the end of the process, thereby highlighting the integration of processes as suggested by Bina's Models B and C.

One of the disadvantages SEA is the lack of legal status (Bina, 2008:146). As legal structures on strategic level, environmental management frameworks (EMF) seem to fill the gap between SEA and EIA.

3.3.2.4 Environmental Management Framework (EMF)

Apart from the US and EU, where SEA enjoys strong legal requirements (Bina, 2008:146), it is mostly undertaken as a principle of best practice in other parts of the world (Buckley, 1998:80). In South Africa environmental management frameworks (EMF) have been established as an environmental management tool, promulgated under the Environmental Management Framework Regulations, Regulation 547 of the National Environmental Management Act, 1998 (Act 107 of 1998). EMF is defined as

“a study of the biophysical and socio-cultural systems of a geographically defined area to reveal where specific land uses may best be practiced and to offer performance standards for maintaining appropriate use of such land” (South Africa, 2010:190).

EMFs assist authorities responsible for the environment and other government decision makers to make informed decisions on environmental matters (EMM, 2007). The development of an EMF is a geo-spatially oriented process aimed at the identification of environmental sensitivity, development constraints and the spatial demarcation of environmental management zones. These are linked to management guidelines and a list of development activities, indicating preferred use of land in specific management zones (South Africa, 2012:213).

Integration with planning practice is emerging slowly, with EMFs providing input into the development of spatial development frameworks (Thornhill, 2014). This development is

mostly contributed to the high level of spatial data integration, which provides analytical and baseline input from an information point of view.

3.4 ENVIRONMENTAL MANAGEMENT AND DEVELOPMENT

Chapter 2 described concepts of development and planning. From a broad perspective, development is seen as change, with planning the instrument that is used to direct such change. It is difficult to separate environmental management from the process of development (Barrow, 2006). As a rapidly increasing human population places more stress on the environment, environmental management must identify threats and, if assessed as significant and likely, it must seek avoidance, mitigation or adaption. Thus, environmental management plays an important role in strategic planning, as described by Dale (2004). In this regard, the reader is referred to Chapter 2, Section 2.3.7 where planning as an integrated process was discussed. Environmental management therefore seeks to steer development and take advantage of opportunities, while taking into account threats. This includes aspects of hazard identification and vulnerability assessment, as will be highlighted in Chapter 3. Barrow (2006:8) presents a typical scheme of environmental management practice (see Figure 3.5), which reminds strongly of the framework for strategic planning presented in Chapter 2, Annexure 2.2.

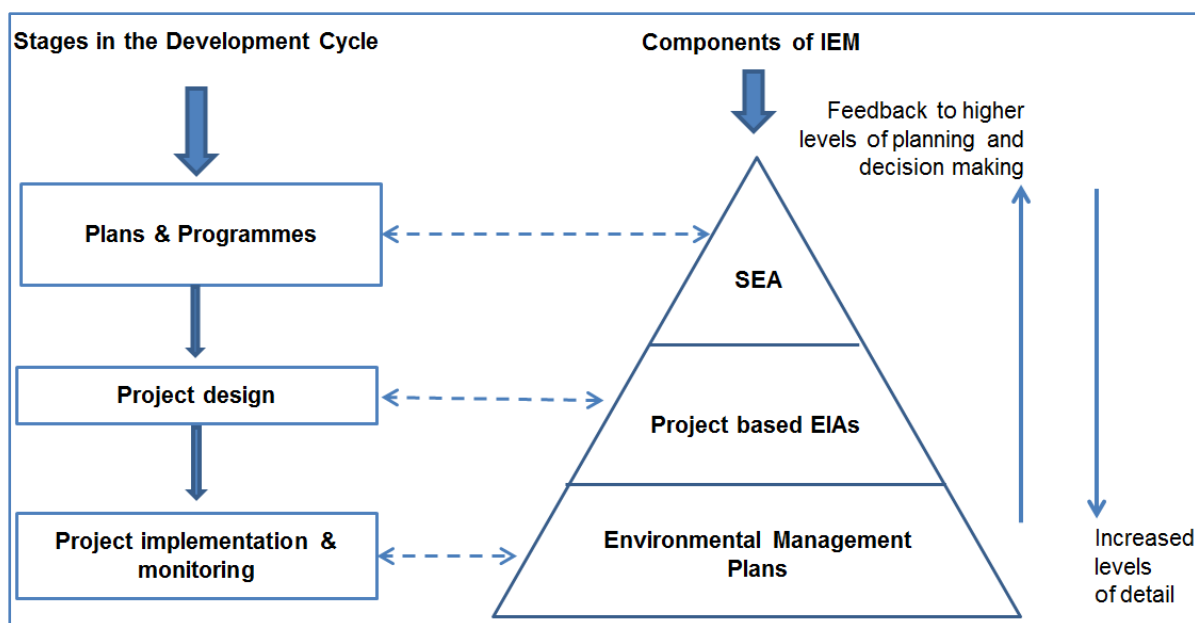


Figure 3.20: Hierarchy of IEM tools in relation to a typical development cycle
Source: DEAT (2004:15)

Environmental management is concerned with human-environment interactions and seeks what is environmentally desirable, bearing in mind physical, economic, social and technological constraints (Turner, 1997; Turner *et al.*, 2003a; Barrow, 2006:5; Renaud, 2006; Strange & Bayley, 2008). This integration points to the concept of sustainable development which aims at achieving benefits for the widest range of sectors through development (Strange & Bayley, 2008:24).

3.4.1 Sustainable development

Sustainable development has become an imperative for environmental management, disaster reduction and development planning. *Living with Risk* (UNISDR, 2004:20) states that disaster risk reduction has emerged as “an essential requisite for sustainable development”. A publication by the World Commission on Environment and Development, *Our common world* (WCED, 1987) calls for humanity to make development sustainable “to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs”. Planners recognise the fact that economic development and environmental degradation can be a causal downward spiral that can be hard to reverse (Glasson & Marshall, 2007:80).

It is generally accepted that there is no easy solution to ensure a balanced approach to sustainable development, as suggested by WCED (1987), and that action will have to proceed simultaneously on several fronts (Fuggle, 1992:2). Despite the global acceptance of the concept, however, its nature and scope is confused territory (Glasson & Marshall, 2007:82). Furthermore, the meaning of the term has evolved and changed in public debate and scholarly literature (NRC, 1999; Faber, Jorna & Van Engelen, 2005). From the static perspective that development should meet the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987), the definition of sustainability changed to a relative and dynamic perspective: “Sustainability no longer targets an ultimate sustainable state, but instead becomes a process of constant improvement of the sustainability of artefacts” (Faber *et al.*, 2005:27).

Building on the advances of the Brundtland report, and one year before the Rio de Janeiro summit, *Caring for the Earth, a strategy for sustainable* was published in 1991 as a partnership between The World Conservation Union (IUCN), the United Nations Environmental Programme (UNEP) and the World Wide Fund For Nature (WWF). Regarded as a significant contribution to fostering human responsibility for the earth (Fuggle, 1992:2), nine principles for building a sustainable society are proposed:

- i. Respect and care for the community of life
- ii. Improve the quality of human life
- iii. Conserve the earth's vitality and diversity
- iv. Minimise the depletion of non-renewable resources
- v. Keep within the earth's carrying capacity
- vi. Change personal attitudes and practices
- vii. Enable communities to care for their own environments
- viii. Provide a national framework for integrating development and conservation
- ix. Create a global alliance

Various conceptualisations of sustainability emerged from the 1990s onward, illustrating its dynamic nature. This is reflected in various definitions, as analysed by Faber *et al.* (2005) and Elliot (2006). In essence it refers to maintaining development over time, and finding an equilibrium between an artefact and its supporting environment. The objectives of sustainable development reflect the importance of environmental, social and economic factors in decision making, which can be modelled with the following union statement:

$$\{Economic Prosperity\} \cup \{Environmental Protection\} \cup \{Social Advancement\}$$

(after Glasston & Marshall, 2007:83).

The integrated and holistic dimensions of sustainability, as described by Elliot (2006:13) and Glasston and Marshall (2007:82) are illustrated in Figures 3.6 and 3.7.

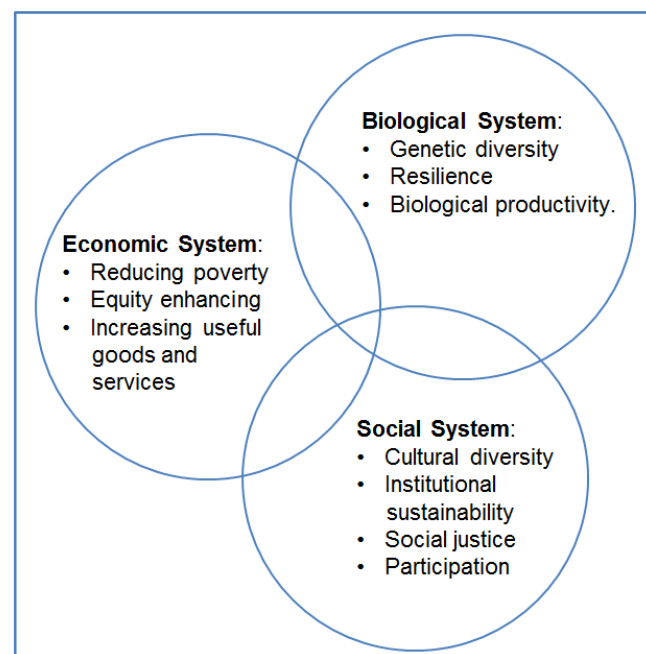


Figure 3.21: Integrated objectives of sustainable development
Source: Elliot (2006:13)

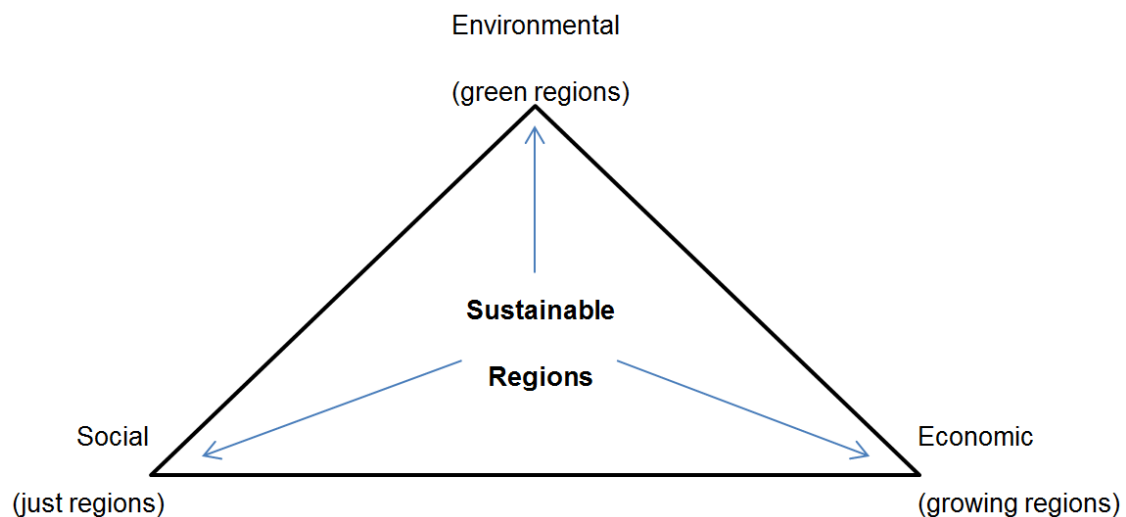


Figure 3.22: Holistic nature of sustainability – equilibrium by advancing on several fronts
Source: Glasson & Marshall (2007:83)

Both perspectives see the environment as a continuum within which the ideal is a balance between the ecological, social and economic spheres, which would ultimately represent a sustainable community. The perspective of integrated domains stands central to this thesis, seeking spatial expression of indicators. Various iterations of integration can be represented, as demonstrated in the following examples, making use of set theory expressions³:

- i. $\{\text{Economic Prosperity}\} \cup \{\text{Environmental Protection}\} = \{\text{Ecological Economics}\}$
- ii. $\{\text{Economic Prosperity}\} \cup \{\text{Social Advancement}\} = \{\text{Community Health}\}$
- iii. $\{\text{Environmental Protection}\} \cup \{\text{Social Advancement}\} = \{\text{Sense of place}\}$

The above statements may also return negative realities. The spatial expression of the first example above is illustrated on a map in Figure 3.8. It shows the overlay of *development priority areas* with *conservation priority areas* that are integrated into a single, unioned dataset. The red colours on the map show regions where priority areas in terms of development planning and conservation overlap, which is indicative of conflicting policies. This analysis becomes useful in the preparation of environmental management guidelines.

³ Refer to Chapter 5 describing the concept of set theory, and how it is used in GIS.

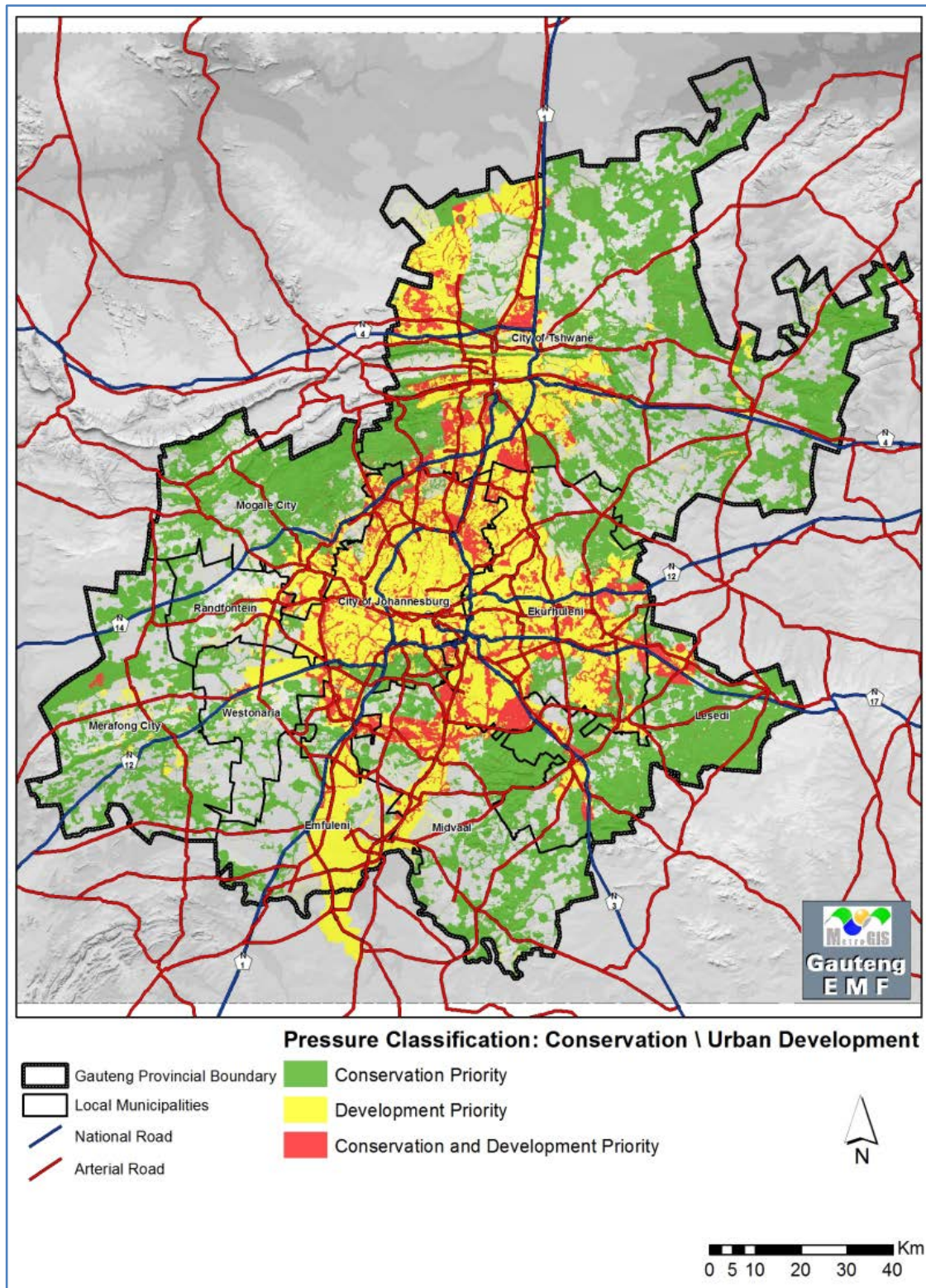


Figure 3.23: Map indicating conflicting development and conservation priorities
Source: GDARD (forthcoming)⁴

⁴ The map was prepared by the researcher and forms part of the Gauteng EMF, which will be launched in January 2015.

With sustainable development as an objective, little is still known of mechanisms that link development patterns to ecological and human functions in developed landscapes. As Alberti *et al.* (2003:1174) put it: “Ecologists and social scientists have studied emergent ecological and social phenomena, but they have not explored the landscape-level implications of interactions between social and ecological agents.” The dynamics of interaction between ecological and anthropological processes is best understood in the context of landscape ecology (Turner, 1989; Forman, 1995; Opdam, Foppen & Vos, 2002; Thornhill, 2014), and is further explored in the next section.

3.5 LANDSCAPE ECOLOGY

Landscape ecology is a branch in the natural sciences that developed from an interest in the spatial patterning and geographic distribution of organisms (Turner, 1989:171). The sub-science is rooted in a long tradition of interest in the spatial patterning and geographic distribution of organisms (*Pflanzen Geographie*), as inspired by the work of German scientist Alexander von Humboldt (Von Humboldt, 1807). Botanists and zoologists described the spatial distributions of various taxa, particularly as they related to factors such as temperature, precipitation, altitude and geological conditions throughout the 19th century (Von Humboldt, 1807; Turner, 1989). This landscape-oriented thinking led to the development of landscape ecology as a study of spatial patterns and ecological processes.

Landscape can be defined as “[a] bounded area containing heterogeneity in patterns and/or processes of interest” (Cumming *et al.*, 2013:1142). Landscape and regional ecology is particularly aimed at providing spatial solutions that are useful in addressing society’s land use objectives (Forman, 1995:133), thus described as a problem-oriented science (Opdam *et al.*, 2002:767).

The understanding of landscape functioning is important for planning. It provides spatial solutions that are useful in addressing all of society’s land use objectives. A landscape perspective provides a framework for understanding spatial patterns and ecological processes, spatial and temporal scales, the heterogeneity effect on fluxes and disturbance, changing patterns, and a framework for natural resource management (Forman, 1995:133). This concept is expanded to include the human component, as suggested by Alberti *et al.* (2003).

The landscape approach provides perspectives on interactions and associations on different scales. Forman (1995) identifies three key aspects that define landscape characteristics, i.e. landscapes and regions; patches and corridors; and mosaics.

Landscape and region consist of a “mix of local ecosystem or land use types ... repeated over the land forming a landscape, which is the basic element in a region at the next broader scale composed of a non-repetitive, high-contrast, coarse-grained pattern of landscapes” (Forman, 1995:135). These represent two scales, and include human activity. Understanding a landscape requires information on broader and finer scales. As heterogeneous units, the boundaries between landscapes are easy to define, and spatially demarcated in different scales. Patches and corridors within the landscape are a major determinant of functional flows and movements through the landscape, and of changes in its pattern and process over time. The forms and structures we see in a landscape are the result of historical processes, whether historical geological processes that produce mountains or recent social processes that lead to the development of cities (Thornhill, 2014). Mosaics are spatial elements that exist from microscopic level to the whole World (Forman, 1995:134). The arrangement of these elements determines the resistance to flow or movement of species, energy, material and disturbance over a landscape. Typically, deforestation will impact on the flow of species and energy. For example, where a corridor is impacted, the cleared area acts as a barrier and limits the movement through destroyed corridors. Where it occurs on steep slopes, the energy of increased water flow is the cause for erosion and mudflows.

A major property of landscapes is that all ecosystems are interrelated, characterised by movement or flow of objects (Forman, 1995:136). Tobler's first law of geography, which states that all things are interrelated but that near objects are more related than distant objects, also applies to the interaction between ecosystems and is useful to describe species behaviour (refer to Chapter 5 Section 5.5.4 for a discussion of Tobler's law). Flows are spatial and temporal in character, and understanding these is useful for planning and management.

Landscape change results from the transformation of land through various spatial processes. Change effects are defined in terms of fragmentation, perforation, dissection, shrinkage and attrition. These effects cause habitat loss and isolation, and they have an impact on ecological processes and spatial patterns (Forman, 1995:138). Perforation is the process where holes are made in a habitat or land type, caused by dispersed development or wild fires in a forest. Dissection is the subdividing of an area by means of

linear development, e.g. by roads and power lines. Fragmentation is caused by the breaking up of a homogeneous region into pieces. Shrinkage refers to the decrease in size of objects, and attrition is their disappearance. These spatial processes can overlap in time, or follow upon each other in sequence, with attrition being the final disappearance of an affected landscape object.

The impact of human activity on the landscape is strongly suggested in the above analysis, and human habitation of the landscape is characterised by flows of energy and materials (Lawrence, 2001). Inevitably, these flows change the environment upon which humans depend for subsistence. This gives rise to a human-ecology perspective that is characterised by a wide range of physiological and cultural processes, and a strong interdependent relationship between people and the environment. This premise includes humans as part of the landscape ecology concept. Alberti *et al.* (2003:1172) state that the greatest challenge for ecology is to fully and productively integrate the complexity and global scale of human activity into ecological research. They challenge the assumption that a '*human-free*' ecosystem paradigm can be productively applied to human-dominated ecosystems, and argue that humans cannot be left out of the ecological equation, as that would lead to inadequate explanations of ecosystem processes on an "increasingly human-dominated Earth".

Cleveland *et al.* (1996) propose a framework for ecosystem and human system linkages that is structured in parallel to facilitate an analysis of interactions (see Figure 3.9). Both systems consist of stocks, flows, controls and attributes. Stocks result from the flow of external inputs and outputs that are influenced by controls. Attributes of stocks and flows describe their character. The integration of human systems and ecological systems creates new facets showing modified attributes of both systems. Each is subject to unique flows and processes, which are, when integrated, modified at the unioned level. For example, the erection of residential and other structures as well as infrastructure to facilitate movement of people, goods and services will transform the composition of faunal and floral species and the way in which there is movement among them. At the unioned level, urban ecosystems evolve that are unique in their own way, with different dynamics to that of natural ecosystems. They have rich spatial and temporal heterogeneity – a complex mosaic of biological and physical patches in a matrix of infrastructure, human organisation and social institution.

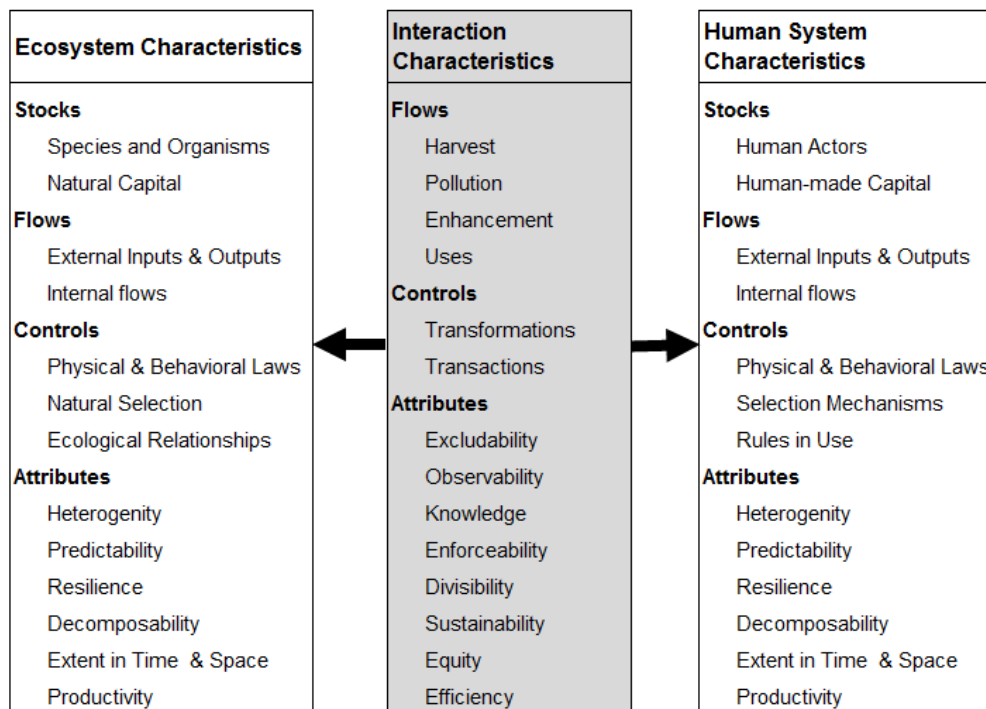


Figure 3.24: Framework for ecosystem and human system linkages

Source: Cleveland *et al.* (1996)

The GIS-based data model discussed in Chapter 8 draws on the interrelationship between landscape objects. Landscape ecology and, integrated into that, human ecology, therefore provides a theoretical grounding for the development of the model which is aimed at finding a solution for the representation of spatial relationships in a database structure.

3.6 CONCLUSION

This chapter examines the concept of environment as the sphere within which the coupled human-environment system functions. Different environmental management tools are described, highlighting commonalities with planning and disaster risk management.

Environmental management, through the tools of EIA, SEA and also EMF, opens up opportunities for integration, specifically with disaster risk reduction. The golden thread of sustainable development provides a link with developmental issues, which in turn relate to concepts of vulnerability and resilience. *Living with Risk* (UNISDR, 2004:303) states that “[t]he characteristics of disaster reduction and environmental policies are similar. Both

must meet local needs and sustainable development requirements and produce multiple benefits. Both rely on extensive participation of the public, relevant sectors and stakeholders.” These commonalities are highlighted in terms of the following eight features of integrated environmental and disaster reduction policies:

- i. Assessment of environmental causes of hazards' occurrence and vulnerability
- ii. Assessment of environmental actions that can reduce vulnerability
- iii. Assessment of the environmental consequences of disaster reduction actions
- iv. Consideration of environmental services in decision-making processes
- v. Interdisciplinary approaches that will ensure the use of natural and social sciences in disaster reduction planning and decision making
- vi. Partnerships and regional approaches to land use and nature conservation
- vii. Reasonable alternatives to conflicts concerning alternative uses of resources
- viii. Advice and information to involve actors in enhancing the quality of the environment

With regard to point (v) above, Chapter 8 will demonstrate how GIS science is used to develop a data model that connects spatial objects of the coupled human-environment on the basis of sustainable relationships. This model can be used to support the decision-making process mentioned in point (iv) with regard to land use planning, with the goal of reducing the vulnerability of communities, as well as enhancing the quality of the environment, as mentioned under point (viii).

CHAPTER 4: THEORY OF DISASTER RISK MANAGEMENT

4.1 INTRODUCTION

All throughout time, mankind has been challenged to deal with disasters (Quarantelli, 2000; Wilson & Oyola-Yemaiel, 2001). Examples of extreme disaster events in history are numerous and include events such as the destruction of Pompeii by volcanic activity from Mount Vesuvius in AD79, the great fire of London in 1666, and the eruption of Krakatoa that caused great tsunamis claiming some 36 000 lives in 1883 (Wilson & Oyola-Yemaiel, 2001). Events in modern times include devastating tropical cyclones such as the Bhola cyclone that struck East Pakistan (now Bangladesh) and India's West Bengal in November 1970 (Burton *et al.*, 1993); the South Asian tsunamis of December 2004 (Birkmann, 2005); Hurricane Katrina that struck the Gulf Coast and the city of New Orleans in August 2005 (Alexander, 2001; Lewis & Kelman, 2012); and the devastating earthquake in Haiti in 2010 (Alexander & Davis, 2012).

Adding to the above are disasters that result from technological development. Examples include the September 11, 2001 attacks on the World Trade Center in New York (McEntire, 2004:1) and the Chernobyl nuclear disaster (Boin, 2005) that caused radiation fallout that affected many countries in Europe, including pollution of the Rhine River.

Extreme events occur as part of the natural cycles of Earth, or as the result of technological failure. Some of these events result in physical and social impacts at a scale and intensity that overwhelm response capacity, and are thus referred to as disasters (Copolla, 2007:25). As these events continue to occur, the above list of disasters will expand accordingly.

According to observations, climatic and environmental changes will increase the intensity and frequency of events such as storms and cyclones, and human and material losses resulting from disasters are increasing (Bankoff, 2004:26; Wisner *et al.*, 2004:83). Furthermore, the increase in the world's population is likely to further increase the frequency of major events as described above (Trim, 2004:218). The reduction of disaster risk calls for disaster management and planning to be approached holistically and to address the ways in which changes in land use, settlement policies, population distribution and the resultant degrading of habitats increase the risk of disasters (Van Niekerk, 2010:65). This premise is a key focus of this study. Chapter 4 builds further on

the exposition of development planning in Chapter 2 and focuses on the concept of disaster risk reduction within the wider context of disaster risk management.

Disaster risk reduction is defined as follows:

“The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events” (UN-ISDR, 2009).

The above definition focuses disaster risk reduction (DRR) efforts on two terrains: socio-related management of causal factors, and technical design to mitigate impact. The Hyogo Framework for Action promotes a development agenda aimed at the management of risks and knowledge, and the promotion of preparedness and education (UN-ISDR, 2005). Technical design as a DRR function can be traced back in history, studying cases such as ancient Chinese measures to protect cities from flooding (Alexander & Davis, 2012) and the design of earthquake resistant buildings in ancient Greece and Armenia (Quarantelli, 2009).

The development of disaster risk reduction as a concept, therefore, is rooted in a long history of mankind reacting to the challenges of natural and social forces. The meaning of disaster risk reduction is further explored in this chapter in terms of its history, looking at the development of concepts such as ‘*disaster*’ and ‘*risk*’.

Chapter 4 begins with an overview of the history of disaster risk management, followed by a description of the theoretical grounding of disaster studies. A specific focus on hazard and vulnerability highlights the theme of this research. To link this chapter with Chapter 2, the multi-disciplinary nature of disaster studies is highlighted by specific reference to disaster risk management in a developmental and social context.

4.2 HISTORY OF DISASTER RISK MANAGEMENT

Before the institutionalisation of disaster management as a profession and the establishment of a field of research, disasters have mostly been dealt with on an ad-hoc basis (Wilson, 2001:39; Dilling, 2009:18). The delineation of a separate body of knowledge that is commonly referred to as Disaster Management or Emergency Management is a recent undertaking. The literature on the history of Disaster

Management reflects a rather short time period in which the discipline has been institutionalised and professionalised, and the concepts of Disaster Management have been established (Quarantelli & Dynes, 1977:23). Whereas in the past Disaster Management was associated with emergency operations such as firefighting, it now functions as a discipline with its own research agenda and as a profession with coordinated programmes, employing a variety of resources, techniques and skills (Wilson, 2001:46). In support of these fields stands a well-established contingent of academics and professionals who have contributed to the development of Disaster Management theories and practice (McEntire, 2004:1).

The development history of this field shows a singular path of growth in incremental stages where large-scale events or shocks such as the First and Second World War (Wilson, 2001:50; McEntire, 2003:120; Van Niekerk, 2006:99; Alexander, 2007:50) and the September 11, 2001 attacks on the World Trade Center (McEntire, 2004:1) have resulted in a significant reformulation of the purpose and the role of Emergency / Disaster Management. The impetus of large-scale devastating disasters is also evident in this development, particularly in as far as it has drawn attention to issues of vulnerability, for example the events that unfolded in New Orleans after Hurricane Katrina.

The air raids and bombings of civilian targets in Europe during the Second World War heralded a new era in warfare, bringing war from the battlefield closer to home. This prompted the establishment of civil protection measurements and institutions. The bombings of Hiroshima and Nagasaki with nuclear weapons further opened up a new kind of threat that continued throughout the Cold War. When a series of research projects on human behaviour during natural disasters was undertaken in the USA in the 1950s, those studies were more inclined towards the civilian population's reaction to extreme stresses in war-time than towards the disasters themselves (Wilson, 2001).

It was not until the late 1960s and early 1970s that the focus returned to natural disasters. Inadequacies of protection programmes against disasters and nuclear threats prompted social scientists to give more attention to the effects of devastating disasters. During this time the nomenclature of disaster management began to appear as a field of study (Wilson, 2001:63). A body of knowledge began to appear and a new field for skilled practitioners in disaster management emerged. Since inadequacies were recognised in responding to disasters, new efforts were made to enact legislation and employ new mechanisms. An increasing number of planning experts became involved in a proliferation of programmes. With each disaster new lessons were learnt, leading to

incremental advances in the improvement of disaster management. Wilson and Oyola-Yemaiel (2001:118) offer the following definition of Disaster Management:

“Emergency management is the discipline and profession of applying science, technology, planning, and management to deal with extreme events that can injure or kill large numbers of people, do extensive damage to property, and disrupt community life.”

Disaster research historically focused on response and recovery, but the focus has gradually shifted to societal aspects of vulnerability, mitigation and preparedness. The United States National Research Council (NRC) views these five topics as central to disaster research, but combined in an integrated framework, with vulnerability and mitigation related to hazard, and response and recovery related to disaster as phenomena. The above concepts of disaster are further explored within a framework of theoretical grounding.

4.3 THEORETICAL GROUNDING OF DISASTER RISK MANAGEMENT

The fundamental motive for our concern with disasters is that they cause human suffering and social disruption (Bates, Dynes & Quarantelli, 1991:288). Understanding the factors that underlie disasters is central to the efforts to reduce disaster risk. However, the research agenda in this field is characterised by different viewpoints on the disaster construct. Cutter (2001:16) asserts that terms such as disaster, hazard and risk are used interchangeably to indicate harm. Looking beyond the lexicon of disaster at a phenomenon described as “losses stemming from unexpected events” (Mileti, 1999b), or as “a moment of materialization” (Birkmann *et al.*, 2014:4), concepts of hazard, vulnerability and resilience emerge as key determinants of disaster risk (Alexander, 2012; Lewis & Kelman, 2012; Birkmann *et al.*, 2014). Knowledge of these concepts would be essential to explain and understand disaster, and to apply it to successful disaster risk reduction (Bates *et al.*, 1991:288).

There is currently not an overarching theory that is adhered to in disaster management (McEntire, 2004; Van der Waladt, 2013). Different conceptualisations of ‘disaster’ indicate a historical development from an association with bad luck (Khan *et al.*, 2008:43) to Acts of God (Quarantelli, 1987:9) and the development of disaster sociology as a “sub-science” of sociology (Dombrowsky, 2005:80). The conceptualisations of disaster are influenced by the individual ontologies and epistemologies that academics contribute to the academic literature (Dilling, 2009:8). Dombrowsky (1995:242) quotes Quarantelli (1981) who states

that “[w]e all have a habitual way of looking at disaster phenomena”. This statement underpins the different approaches to disaster and the diversity of meanings – as Dombrowsky puts it: “Those who declare, defines what they intend to do with ... disaster.” Different conceptualisations of disaster are also highlighted by Hewitt (2013), ranging from an environmental perspective with the focus on environmental degradation, to a developmental perspective with the focus on urbanisation and related concepts of poverty, disease and malnutrition, and the perspective of conflict and insecurity with related aspects of refugees. These are all too wide to be discussed in depth, hence disaster is further defined in the context of three main paradigms that have developed in history.

4.3.1 Defining disaster

A central issue related to theoretical development of disaster pertains to what the field of study defines and understands as disaster (Neal, 1997:239). In their attempt to define disasters, Jennifer Wilson and Arthur Oyola-Yemaiel ask questions such as “Is disaster the disruption of natural ecosystems? Is it the destruction of property? Is it the loss of human life? Is it the loss of vital human resources? Or is it a combination of these things?” (Wilson & Oyola-Yemaiel, 2001:40). Whereas it is argued that if people and people’s assets are not affected, it is not a disaster (Alexander, 2005:27), the inclusion of the natural environment as an affected party in the definition of disaster (South Africa, 2003:6) may contradict this. When contemplating the meaning of disaster, the student is indeed entwined in an epistemological conundrum (McEntire & Marshall, 2003:119).

The causes of disaster do not simply lie in the processes by which energy of natural phenomena such as hurricanes, landslides and earthquakes is released in the atmosphere, on the earth's surface or below. The fact that people reside and establish their social environments within natural environments that have been formed by natural processes (Wilson, 2001:39), and that these processes may cause harm, highlights the premise that disaster is primarily a social phenomenon and thus identifiable in social terms (Quarantelli & Dynes, 1977:24).

Since the mid-1970s, scientists from various disciplines such as geography, sociology, political science, psychology, economics, decision science, regional science and planning, public health, and anthropology have continuously contributed to the development of knowledge about societal response to hazards and disasters (NRC, 2006:1). The forming of a unified theory was, however, hampered by a rapid and

pluralistic development within two schools of thought (Alexander, 2012:1). Whereas research initially focused on response and recovery, societal aspects of vulnerability, mitigation and preparedness gradually gained greater prominence. Referring to a “tyranny of disciplines”, Alexander (2012:1) concludes that a situation resulted within which “researchers with different perspectives have often failed to reconcile their differences in a common view of the phenomena they are studying”.

As stated earlier (see Section 4.2), the NRC (2006) proposed an integrated framework of five core topics that stand central to disaster research, thereby defining the concept as a multi-faceted construct. A dualistic approach distinguishes between hazard research and disaster research, with vulnerability and mitigation as concepts associated with hazard, and response and recovery related to disaster. Preparedness is seen as a common denominator that integrates the two approaches as a unity. This approach is graphically illustrated in Figure 4.1.

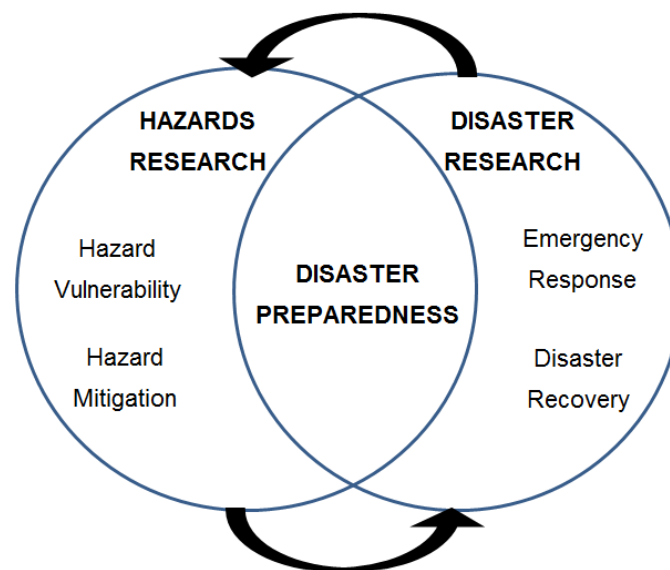


Figure 4.25: Core topics for research in disaster risk reduction

Source: Adapted from NRC (2006:2)

According to Gilbert (1998:3), the numerous theoretical approaches to disaster can be classified into three main paradigms. The first sees disaster as a duplication of war, the second sees disaster as an expression of social vulnerabilities and the third describes disaster as an entrance into a state of uncertainty.

4.3.1.1 Paradigm 1: The Patterns of War Approach

According to Wilson (2001:40) the first serious effort to conceptualise the term '*disaster*' comes from Fritz (1961:655) whose definition has been the standard for many years in the field of disaster research (quoted in Wilson, 2001:40 and Dilling, 2009:17):

“A disaster is an event, concentrated in time and space, in which a society, or a relative self-sufficient subdivision of a society, undergoes severe danger and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfillment of all or some of the essential functions of the society is prevented.”

Fritz's definition was grounded in the bombing events of World War II, the event in history that marks the establishment of civil defence organisations, which is widely recognised as the roots of Disaster Management (McEntire, 2003:120; Van Niekerk, 2006:99; Alexander, 2007:50; Grist 2007:3). The idea of harmful attacks brought against people in acts of war is described by Gilbert (1998:3) as particularly relevant to the field of disaster studies. The resemblance between disaster and war is the cause of the emergency being sought outwardly, leaving the community harmless to the mercy of fate. The enemy, loaded with arms, becomes the agent, resembling the hazard as an external factor. In this view, people organise themselves to react in terms of defence (planning) and response (emergency aid).

4.3.1.2 Paradigm 2: Disaster as Social Vulnerability

The second paradigm follows a critical review of the patterns of war, which were seen as related to external destructive agents. This paradigm considers the causes of disaster on structural and contextual grounds. Disaster is therefore closely associated with social vulnerability (Gilbert, 1995:234).

This paradigm is developed on the tendency that disasters are considered crises that develop in a community as a result of an event. It takes away the focus from physical reaction following an event to the underlying factors within the community that caused its susceptibility to physical impact (Gilbert, 1995:234).

4.3.1.3 Paradigm 3: Disaster as Uncertainty

The third paradigm breaks away from tendencies to consider disasters as crises that develop in a community as a result of an event. It represents a turning point that defines disaster as chaos built on uncertainty, following upon a break in communication.

Uncertainty is caused by the absence of communication, which is a sudden change in the situation where information was flowing freely. According to Gilbert (1988:8), uncertainty is at the core of disaster theory, highlighting three aspects: (1) uncertainty arises when a community is threatened by danger; (2) uncertainty results from complex modern societies; and (3) uncertainty results from the loss of capacity in modern societies to identify and define a situation that they see as serious. Weichselgartner (2001:86) confirms the role of uncertainty, and states: "The only certain thing is uncertainty".

4.3.2 Research frameworks – Approaches to disaster study

The field of disaster research has grown in close association with the applied natural and social sciences, and is characterised by fragmentation through specialisation that threatens the development of a separate identity (Alexander, 1993:12). Two distinct schools of thought have emerged since the beginning of the 1900s – the Human Ecology School, and the Disaster Research School (Mileti, 1999).

4.3.2.1 Human Ecology School

The association of disaster research with the natural sciences gave rise to the birth of human ecology as a concept that marks out a distinctive field for geography (Barrows, 1923:3) and sociology (Hawley, 1969:68). The ecologist viewpoint is developed as a distinctive approach in the study of society (Duncan & Schnore, 1969:70). It defines social structure in terms of behaviour relations and seeks to explain it by referring to phenomena that are imposed on the social structure by non-human environments (Hawley, 1969).

With its roots in geography⁵ (Mileti, 1999:39), in studies of contemporary urban life (Duncan & Schnore, 1969:71) and in ecological conceivements of life as a subject for investigation (Hawley, 1969:64), human ecology has emerged as an approach of studying the form and the development of the community of human populations (Hawley, 1969:64). Tenets of human ecology have subsequently been used to study disaster, as they represent an environmental imperative to society (Alexander, 1993:12). From this

⁵ There seems to be some controversy as to the foundation of human ecology in geography vs. sociology. Hawley (1969:68) maintains that human ecology emerged as a sociological concern, since it deals with the development and organisation of the community. On the other hand, Barrows (1923:3) who describes geography as the mother of sciences, states that geography is the science of human ecology, as it focuses on the relationships between natural environments and the activities of man.

perspective, human ecology denotes “the prevailing techniques of adjustment by which a population maintains itself in its habitat” (Hawley, 1969:66).

The ecological perspective of the environment originated in the natural sciences. The term 'ecology' was first used in 1866 by Ernst Haeckel (Lawrence, 2001:676; Williams, Roberts & McIntosh, 2007:2). The term is derived from the ancient Greek *oikos* and *logos* which means the science of home or habitat. As the founder of a new science “oekologie”, Haeckel was influenced by the work of Charles Darwin and Alexander von Humboldt (Egerton, 2013:222). In today's terms, ecology refers to the study of the interrelationships between organisms and their surroundings (Bodini & Klotz, 2002).

The human ecology perspective was philosophically explored by John Dewey who stated that people live in a natural world that is intrinsically hazardous – hence resulting in insecurity (Mileti, 1999:38). According to Browne (2007), Dewey considered all human endeavours to be one with the natural world. His conception of environment includes both the natural and the anthropogenic. This thought provides a key to help us understand the role of human cultures in the environment, and lays the foundation for the emergence of human ecology, which developed as a sub-discipline in sociology and geography (Mileti, 1999:38). Dewey's contribution to the development of thoughts on the relationship between disasters and social forces is supported by a generation of social scientists who have been shaped by his influence – in particular, the geographer Gilbert F. White who is recognised as the father of natural hazards research and management (Peek & Mileti, 2002:512).

Following White, the concept of human ecology was further explored in sociology by MacIver (1931) who focused on adaptation and described it as a physical, biological and social adjustment of society to the natural environment (cited in Mileti, 1999:39-40). Although his ideas were subsequently expanded by other sociologists, the human ecology school became nearly dormant by the 1960s.

4.3.2.2 Disaster Research School

Grounded in the work of the NRC during the 1950s, the Disaster Research School developed as an alternative in sociology independently from the human ecology heritage (Mileti, 1999:20) by focusing on the social impact of disaster. Thoughts of this school are rooted in the anxiety over the Cold War and directed by aspects of calamity and “social disorganization” (Mileti, 1999:40). Since it would be heavily funded by government,

disaster research was initiated “to be current with the post World War II phenomena of social science research” (Quarantelli, 1988:27) and to improve disaster preparedness. Research investigates scenarios of nuclear war from a civil defence perspective and focuses on people’s behaviour during a disaster by analysing their response to emergencies, disasters and catastrophes (Metzger & Robert, 2014:29).

Being modelled on the Cold War scenario and focused on aspects of early warning, recovery and reconstruction (Mileti, 1999:41), this way of thinking lacks consideration of essential social problems such as poverty and disparities, which limits the effectiveness of disaster risk reduction (Metzger & Robert, 2014:29). Metzger and Robert highlight the Hurricane Katrina disaster as an example of where emergency management was perfectly planned from a technical point of view, but failed to anticipate the social impact of the disaster.

4.3.3 The Disaster Phase Model

Codification and taxonomies are part of the scientific process. The use of phases, and organising these in sequence of ‘*life cycles*’, is common in social science and research (Neal, 1997:240). The temporal character of disaster, which in many instances occurs as an unexpected event, and the human reaction to respond by means of aid, relief, re-development and planning to reduce the magnitude of impact of the next event, represent a series of subsequent activities that can be recorded in terms of a time scale. It therefore becomes understandable to categorise the type of activities that relate to a specific situation in unique phases. It further provides coherence to an analysis that is otherwise not possible (Drabek, 2006:224).

The disaster phase model is a popular framework used in literature to describe concepts of disaster (Kendra & Wachtendorf, 2006). It is, however, complex to understand and difficult to apply in practice (Coetzee & Van Niekerk, 2012). The origins of the model are traced back to the work of Samuel Henry Prince who was the first to categorise various responses to disaster. Based on the historic event of a massive explosion following the collision of two ships in Halifax harbour, Prince (1920) identifies three stages of societal response. The first stage is referred to as an emergency period, characterised by general panic and confusion. The second stage is a transition period during which emergency relief is provided. The third phase is a rehabilitation period. However, Prince’s thesis is only concerned with the post-disaster situation, as he limits his investigation to “those

social changes which follow upon catastrophes, rather than precede them” (Prince, 1920:1).

The phase approach to the study of disasters has been adapted and built upon by various scholars (Neal, 1997). A landmark development was the conceptualisation of the four-phase model by the National Governor’s Association report (*Emergency Preparedness Project: Final Report*) in 1979, which depicts *Preparedness*, *Response*, *Recovery*, and *Mitigation* as the “defining events” of disaster (Jensen, 2010:14) (refer to Figure 4.2). Neal (1997) observes a distinction between temporal and functional categories of the model. The first category relates to a temporal classification of situations before, during and after disaster events. Functional categories refer to activities such as preparation, search and rescue, and recovery. Important, however, is the social orientation of these codification efforts that draw upon the social nature of disaster and not the physical.

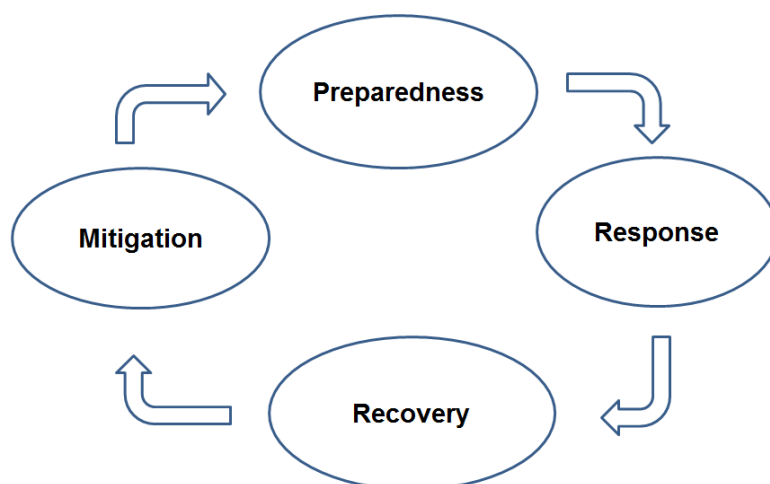


Figure 4.26: Disaster Phase Model
Source: Adapted from Jensen (2010:14)

The social approach separates the phased model of disaster management activities from similar models in other fields such as cyclogenesis. Cyclogenesis embodies the study of the physical development of a tropical cyclone and describes the initiation, development, maturation and decay of a tropical storm in terms of different stages (Terry, 2007:16-19). Tropical cyclones are formed over the ocean and may weaken or decay before they reach land. There is no recognition of cyclogenesis in any of the disaster management phases apparent from the literature study. However, monitoring the movement of a hurricane and predicting its expected landfall are crucial to early warning, planning and preparation activities aimed at absorbing the impact of the storm. This introduces concepts such as communication, which is not built into the phased model.

4.3.4 Critique of the Disaster Phase Model

Whereas the four-phase model has been adopted widely as a standard disaster management framework (Jensen, 2010:13; De Smet *et al.*, 2011:2) and is considered a cornerstone in disaster management practice throughout the United States by the National Governor's Association (Carr, 1997:245; Jensen, 2010:13; Drabek & Evans, 2004:3), researchers and practitioners experience problems with the use of disaster phases, especially those in other fields such as geography, civil defence and development planning (Carr, 1997:246; Coetzee & Van Niekerk, 2012:7). Problems are mostly experienced when the concept is applied in practice, since the phases are not discrete events. Phases overlap with one another and activities within the one may have an impact on those of a subsequent phase (Neal, 1997:247). Phases are also characterised by sub-phases that are not strictly discerned either (De Smet *et al.*, 2011:5).

Weichselgartner and Obersteiner (2002:74) state that the disaster cycle model creates false assumptions about the appropriate response to disaster. The division of phases does not match the perceptions of individuals in communities who tend to regard their own responses as part of a personal coping strategy. According to McEntire (2004:4), the organising of disaster management functions into phases is useful, but overly simplified. It is also important to realise that "a single perspective can limit understanding and explanation". This is illustrated by the inability of the model to capture "the wider political, economic and cultural explanations of disasters". Bankoff (2004:28) describes the disaster management cycle as a schematic of an open-ended process that "barely distinguishes between a pre-disaster risk-reducing phase and a post-disaster recovery one".

Rather than being seen as individual phases, the conceptions of the Disaster Phase Model are captured as a collection of ideas that become managerial functions and are commonly referred to as "Comprehensive Emergency Management" (Drabek & Evans, 2004:3). Haddow *et al.* (2011) describe these as "disciplines of disaster management". This framework allows for disaster management activities to be undertaken across the boundaries of phases, and in places simultaneously (Bankoff, 2004:28; Gurtner *et al.*, 2011:13).

According to Gurtner *et al.* (2011:15), reality depicts a pre-disaster and post-disaster situation, with activities that are associated with different modes of action, as illustrated by Figure 4.3. This can be interpreted as a continuum of periods within which primary

activities are focused on achieving specific goals, being it the preparation of contingency plans, the education of communities or response to a disaster event. This continuum incorporates phases as proposed by the Disaster Phase Model, but with the distinct characteristic that the one period may flow into the next. This may happen abruptly (as in the case of initiating response) or gradually, as in the event of the withdrawal of relief agencies. James Lewis not only expands the concept of a continuum to include development, but also recognises the significance of development in the sequence of disaster response, specifically with regard to the negative impact that disasters have on development (Lewis, 1999:134). This idea is further explored in Section 4.5.1, where the interrelationship between development and disaster risk management is examined.

The pre-crisis period is associated with normal day-to-day social and economic activities. Disaster risk management programmes are focused on the collection and dissemination of information and the assessment of hazards and risks. During this period individuals and organisations can prepare for any event by building management and emergency response capability to facilitate an effective response when it is needed (Mileti, 1999:22). It includes programmes and services that enable individuals and organisations to make physical preparations with the aim of reducing loss of life, injury and destruction of property when a disaster event occurs (Borgia *et al.*, 2008:5).

Early warning systems allow for to the detection of potential hazards (e.g. the detection of a tropical cyclone from satellite images). During this period, information with regard to the magnitude of the approaching event is communicated by issuing alerts and public warnings. Contingency plans are put into place and, if needed, people are evacuated from high-risk areas.

Following the onset of a disaster event, immediate response action is undertaken by mandated authorities and organisations in order to preserve lives, limit damage and end the emergency. This includes the provision of short-term assistance in the form of food, clothing, blankets, and temporary shelter, and the search and rescue of the wounded and dead. Recovery and relief programmes that provide longer-term assistance for people who have suffered injuries or incurred losses are also introduced. Amongst it all, an initial rapid impact assessment is undertaken and information is exchanged as an ongoing activity (Borgia *et al.*, 2008:5).

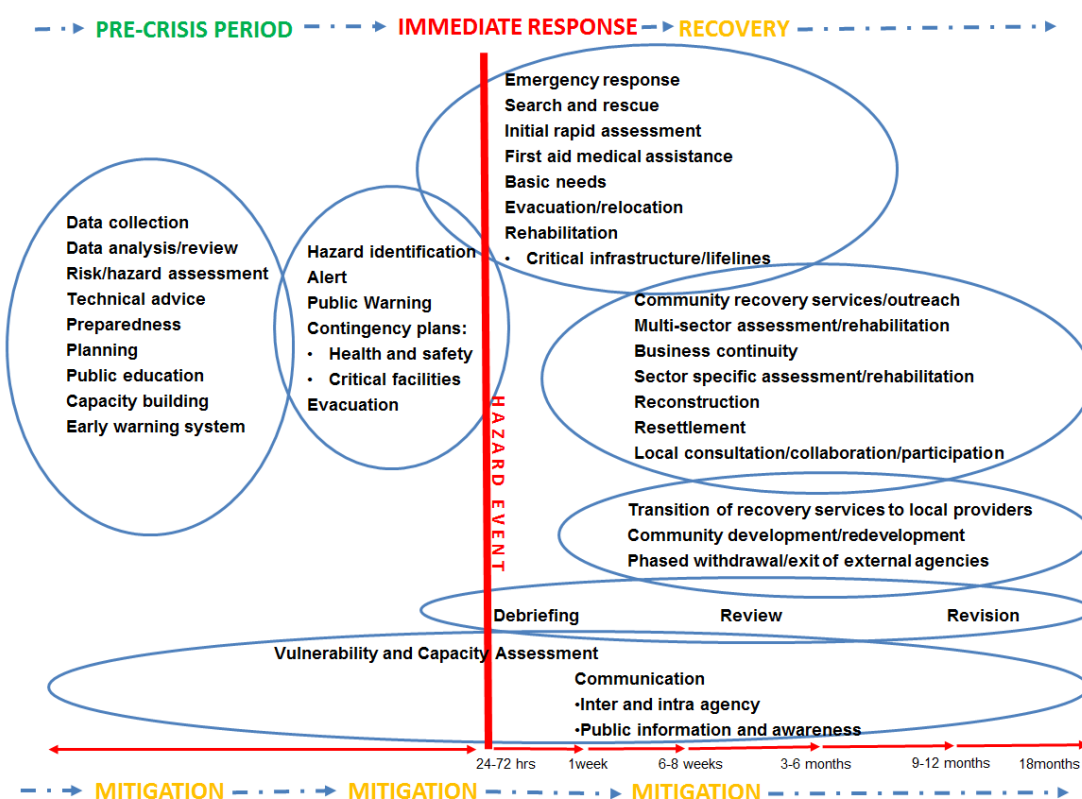


Figure 4.27: Continuum of disaster risk management activities within a time framework
Source: Gurtner *et al.* (2011:15)

Recovery follows initial response in an attempt to restore critical infrastructures and lifelines. During this period the focus is on business continuity, reconstruction and resettlement of displaced people. The initial rapid impact assessment (RIA) is followed up by a multi-sector assessment, with the quantification of losses being the main aim. External agencies that have been involved in relief activities start with the transition of recovery services to local providers and will eventually withdraw from the disaster area. Community development and redevelopment now become the primary objective of institutions and organisations.

Following recovery there is a period of reviewing what has happened. Debriefing sessions highlight information on the magnitude, extent and impacts of the disaster. This is followed by the revision of policy and programmes. Information once again plays an important role, reflecting back on the work of the impact assessments.

The task of vulnerability and capacity assessment spans over all the phases or periods of activity. Not only is it functional in disaster risk assessment during pre-disaster periods, it also focuses relief efforts during response operations.

The theoretical context of disaster risk management has mostly been described in terms of strict phases and conceptualisations of hazards and vulnerability. Traditionally, impact assessments have been associated with response and recovery, with little to no guidance on and integration with risk reduction activities (Treadgold, 2006). By shifting the focus to a continuum of disaster risk management activity, a holistic approach can be embraced, allowing for expanding the knowledge base of disaster risk management, promoting inter- and intra-agency communication, improving public awareness, and enhancing response planning and the level of overall preparedness within communities.

4.3.5 Propositions and principles of the Disaster Phase Model

Propositions are components of theory that are already used explicitly and implicitly in research, teaching and practice (Jensen, 2010:15). Several propositions of the Disaster Phase Model have been tested by empirical research. Jensen (2010:14) lists these as follows:

- “There are periods before, during and after a disaster when human beings can engage in various types of activity related to disaster events.
- Certain types of activities are suited to specific phases.
- Actions taken in one phase have an impact on the outcomes of other phases.
- Meeting the needs generated by disasters requires activity in all the phases.
- Use of the phase approach will improve the ability of humans to adapt to disasters.”

When propositions derived from repeated research efforts are generally accepted as the truth, they may be formalised as principles promoted by academics (Drabek, 2007:19; Jensen, 2010:16). One such principle is that preparedness is a continuous process (Drabek, 2007:20). This implies that planning and other activities related to risk assessment and mitigation are not once-off achievements and should therefore not be constrained to a specific phase.

The disaster phase model provides a framework to categorise multi-disciplinary activities related to different components within the continuum of disaster risk management activities (Lewis, 1999; Drabek, 2006). This includes ecological modelling (Beaton *et al.*,

2008), adaptation strategies for communities (Kendra & Wachtendorf, 2006), and government performance analysis (Drabek, 2006). In the case of geographic information systems (GIS), this framework is used to provide an overview of GIS applications in disaster risk management (Thomas *et al.*, 2006:87), and it is illustrated in Table 4.1. Mapping constitutes a core component of GIS, such as the mapping of hazard zones to assess which populations are at risk for a variety of hazards. However, the functionality of GIS reaches beyond mapping functions and includes value-adding functions such as analysis (e.g. in risk assessments and early warning), decision support (e.g. prioritising actions), and data sourcing and processing throughout the continuum of disaster management activities.

The need for a framework that integrates GIS activities with disaster risk management tasks is demonstrated by Jansen van Vuuren (2013). He highlights the fact that GIS is not fully integrated in activities such as rapid disaster impact assessment and provides a framework for GIS integration across process phases. Kendra and Wachtendorf (2006) demonstrate how the disaster phase model can be modified innovatively to develop adaptation strategies by proposing a pre-disaster, trans-disaster, and a post-disaster framework.

Table 4.1. Examples of GIS Supporting in Disaster Risk ManagementSource: Adapted from Thomas *et al.* (2006:87)

Disaster Phase	GIS Activity
Mitigation	Evaluation of mitigation alternatives
	Prioritisation of efforts
Preparedness	Environmental monitoring
	Event mapping (detecting, monitoring, and modelling virtually all different types of individual hazards)
	Risk assessment
	Risk communication (public and emergency workers)
	Evacuation planning
	Identification of vulnerable populations
Response	Damage assessment Response and relief coordination
	Coordination of relief efforts
	Aid allocation
	Monitoring of lifeline status
	Early warning
Recovery	Resource allocation
	Coordination and monitoring of clean-up

The impetus for innovative approaches to adaptation is the susceptibility of communities to hazards, and the focus on vulnerability reduction (Kendra & Wachtendorf, 2006:321). As known concepts in the lexicon of disaster risk management, the terms ‘vulnerability’ and ‘hazard’ have become so commonly used and general that their intertwined meanings are not always understood (Timmerman, 1981). The next section takes an in-depth look at these terms. Understanding their true meaning becomes important in GIS science thoughts and will provide a foundation for the development of a data model in Chapter 8.

4.3.6 Concepts of vulnerability and hazard

Wisner *et al.* (2004:49) state that “... the risk faced by people must be seen as a cross-cutting combination of vulnerability and hazard”. Vulnerability and hazard are seen as interdependent. Any change in vulnerability will alter the level of hazard, and vice versa (Glade *et al.*, 2006:185). Disasters are a result of interaction between these two phenomena. Therefore, the impacts of a disaster event can be linked to the status of the

balance between hazard and vulnerability in different places. For risk to exist, elements of hazard and risk need to be present. As Cardona (2004:38) remarks, “[i]f there is no hazard it is not feasible to be vulnerable, when seen from the perspective of the potential damage or loss due to the occurrence of an event”.

The physical impacts of a disaster event are related to the affected community’s vulnerability and resilience in terms of hazard mitigation, preparedness practices and response capabilities. Physical impacts are caused by a combination of the intrinsic characteristics of a hazard and the level of vulnerability. The impact of a disaster on communities manifests in the impact on community structures, such as their social and economic fabric. Social impacts, for example, can be reduced by a community’s own recovery resources to deal with a specific hazard, aided by extra-community assistance (Lindell & Prater, 2003:176). The model of disaster impacts is illustrated in Figure 4.4.

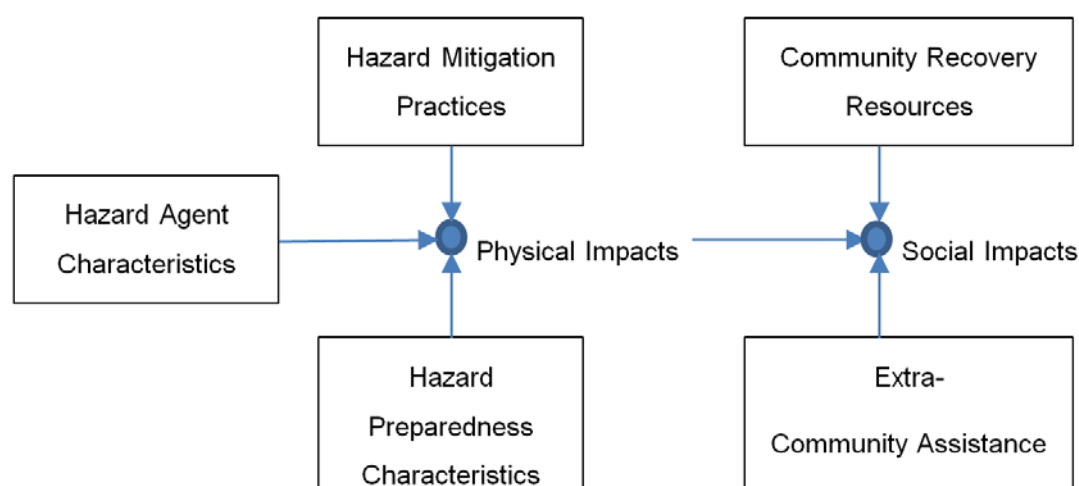


Figure 4.28: Model of disaster impacts
Source: Lindel & Prater (2003:177)

Ambiguities with regard to the concepts of ‘risk’, ‘vulnerability’, and ‘hazard’, and the interchanging use of these words (for example seeing ‘risk’ as synonymous with ‘hazard’, or using ‘hazard’ to describe an event (Timmerman, 1981)) require an understanding of the underlying principles that distinguish these concepts. This is particularly relevant in view of theoretical approaches, for example relating hazards to natural phenomena and vulnerability to social characteristics. It further clarifies aspects of spatial representation and defines spatial relationships that will give an answer to questions such as *who is vulnerable to what?* This links this topic to the data model described in Chapter 8.

4.3.6.1 Understanding hazards

Hazards can be described as events that have potentially harmful outcomes (Birkmann, 2005:1) and are regarded as a causal factor or a trigger for disaster (Wisner *et al.*, 2004:7). Although hazards have been known to mankind since the beginning of time, broad-based research into natural hazards did not begin until almost the middle of the 20th century. Before then, hazards had been viewed as isolated events that were being dealt with reactively, mostly by means of engineering intervention, for example the building of dams or levees to mitigate flood risk (Smith, 2013:4).

Traditionally, natural hazards are listed as hurricanes, earthquakes, volcanoes, floods, tsunamis, etc. Referring to these as trigger events or hazard agents, Lindell and Prater (2003:176) characterise hazards in terms of particular threats that are the actual causes of damage. For example, tropical cyclones may cause casualties and damage through wind, rain, storm surge, and inland flooding. The characteristics of a hazard are therefore determined by the nature of these events, the probability of occurrence, the speed of onset and the ability to mobilise early warning. Together with knowledge of community resilience and the capacity to deal with events, authorities can pro-actively model the extent of casualties among the population and the degree of damage to structures in the affected area (Lindell & Prater, 2003:176). A hazard is thus best viewed “as a naturally occurring or human-induced process, or event, with the potential to create loss, that is, a general source of future danger” (Smith, 2013:6).

Based on the notion that hazard is not the natural event itself, but the risk encountered in occupying a place that is subject to an event, such as a floodplain (Burton *et al.*, 1993:31), hazard presents a strong spatial connotation. As Smith (2013:22) puts it, “hazard exposure is created by people and property being in the wrong place at the wrong time”. This allows for the mapping of hazard zones in terms of the natural concentration of geo-physical phenomena such as volcanoes, earthquakes, tsunamis and severe storms (Smith, 2013:23).

Being physical phenomena, hazards present with distinct physical attributes. Scales of measurement have been developed for certain events such as earthquakes (Richter and Mercalli scale) and hurricanes (Category classes, USA). The following broad index of measurement for the different characteristics is proposed by Burton *et al.* (1993:41):

Magnitude is the maximum force of an event that can be measured by instruments and in terms of calibrated scales. For example, floods are measured by the maximum height (elevation) reached by the flood waters. Earthquakes are measured in terms of the Richter or the Mercalli scale. Hurricanes are measured in terms of wind speed and classified in Categories 1 - 5.

Frequency asserts how often an event is expected to occur, e.g. once every year or once in ten years.

Duration describes the length of time over which the effects of an event persist. This is different from the *speed of onset*. Duration can be days (flood), weeks (earthquakes) or years (drought).

Areal extent is an indication of the space (footprint) occupied by an event. A tornado has a narrow swath and short distance, whereas a drought may cover thousands of square kilometres. Remote sensing and GPS technology is often used to delineate the extent that can be presented in spatial context on maps.

Speed of onset refers to the length of time between the first noticeable or recorded appearance of an event and its peak. Examples of slow onset are drought and soil erosion. Examples of fast onset events are earthquakes and snow or mud slides.

Spatial dispersion depicts the pattern of spatial distribution. Droughts are widespread, whereas floods can be dispersed, in accordance with the topography of an area. As with areal extent, spatial dispersion can also be mapped.

Temporal spacing refers to the sequence of events. Volcanoes, for example, approximate a random time distribution, whereas as tropical storms are seasonal.

The significance of measuring the seven dimensions of hazardous events is linked to the type of response each requires in terms of mitigation and readiness. The more powerful an event (magnitude), the less adequate the technology to control it. The more frequent,

the more steps are needed to respond effectively, and the larger the area being affected, the broader the segment of society that is likely to be subjected to loss or disruption. Preparedness and early warning is influenced by the speed of onset, and duration determines the range of possible responses (Burton *et al.*, 1993:35).

4.3.6.2 Understanding vulnerability

The concept of vulnerability is central to this research. It stands in relation to constructs of hazard and resilience, which holistically determine disaster risk (Wisner *et al.*, 2004). According to Birkmann *et al.* (2014), vulnerability is a core concept that links various research communities, particularly those involved in disaster risk management, climate change adaption and development research. Vulnerability assessment is also seen as a key endeavour within disaster risk reduction. The approaches to vulnerability research are rooted in political economy, social ecology, and climate change science. In as far as there is general consensus that vulnerability translates into disaster, this concept is further explored as a construct.

The focus on vulnerability demonstrates the evolution of disaster paradigms from the *Patterns of War* approach, where the emphasis was centred on the technocratic knowledge of hazards, to *Disaster as Vulnerability*, where social theory became a central viewpoint for disaster research. Whereas the former was useful as a first theoretical framework to understand and deal with disasters, the vulnerability approach looks for answers in a socio-political environment (McEntire, 2005:207). This supports Weichselgartner's alternative definition that states disaster as "a product of a cumulative set of decisions taken by humans over long periods", and changes the focus from physical-natural drivers to aspects of policy and governance. Anthony-Smith (2004:10) states that vulnerability is fundamentally a political-ecological concept focusing on the relationship between people and their environment. Political and economic forces shape the environment that people live in, which present a particular characteristic of the condition of that relationship. According to Anthony-Smith, vulnerability provides a theoretical framework that encompasses the multidimensionality of disasters by combining elements of environment, society and culture in various proportions.

It is generally accepted that vulnerability is a property of human society, coupled with the natural environment. It is regarded as the key to understanding the cause and impact of disaster (Turner, 2003a; Hilhorst & Bankoff, 2004; Birkmann *et al.*, 2014). It is a multi-faceted construct that is difficult to define (Birkmann, 2005:3). It also means different

things to different people (Timmerman, 1981; Cutter, 1996). Researchers such as Greg Bankoff, Jörn Birkmann, Piers Blaikie, Terry Cannon, Susan Cutter, Ian Davis, Anthony Oliver-Smith, Ben Wisner, and others have published widely on this topic and introduced various conceptualisations of vulnerability. Four publications are highlighted for their contribution to conceptualise vulnerability and develop thoughts on the modelling and representation thereof:

Vulnerability, Resilience and the Collapse of Society: A Review of Models and Possible Climatic Applications. Environmental Monograph No. 1 by Timmerman (1981). This work is noted for its conceptualisation of vulnerability, shifting the focus from hazard and disaster impact to the relationship between climatic fluctuations and social systems (refer to Weichselgartner, 2001).

At Risk: Natural Hazards, people's vulnerability and disasters by Wisner, Blaikie, Cannon and Davis (two editions, in 1994 and 2004). This work is widely referenced, and particularly noted for the Pressure and Release Model of Disaster.

Measuring Vulnerability to Natural Hazards: towards disaster resilient societies, edited by Björn Brinkmann (2006). This work is noted for its evaluation of and contribution to vulnerability frameworks. (Refer to Chapter 7 for an overview of various frameworks.)

Vulnerability to environmental hazards by Susan Cutter (1996). In this work the Hazard of Place Model of Vulnerability is introduced, which expands the geographical context of vulnerability. This work forms the basis for further work by the author, such as the development of the GIS-based Social Vulnerability Index (SoVI), which is discussed in Chapter 7.

Vulnerability describes concepts of susceptibility, weakness and exposure in the context of being prone to damage or injury (Wisner *et al.*, 2004:11). It implies an inherent or innate susceptibility to harm and is the antithesis of the ability to resist or withstand and cope with the impact of disaster. It represents the inability of societal processes to cope, neutralise or overcome harm when it threatens people and helps to clarify the concepts of risk and disaster (Wisner *et al.*, 2004; Cordona, 2003; Birkmann *et al.*, 2014).

The work of Wisner *et al.* (2004) is acknowledged as the foundation of vulnerability theory (Zakour & Gillespie, 2013:37). Grounded in systems theory (Zakour & Gillespie, 2013:10;

Birkmann *et al.*, 2014:25) the vulnerability framework is embedded in processes beginning with *root causes* that set up *dynamic pressures* and further translate effects from the root causes into *unsafe conditions*. Within this framework, vulnerability functions in combination with hazard to produce risk (Wisner *et al.*, 2004:49). Disasters are seen as the result of the interaction of both; the one presupposes the other. Theoretically there can be no disaster if a hazard exists, but there is no vulnerability. Likewise, if there is a vulnerable community, but no hazard event, there will also be no disaster. From this assertion, Wisner *et al.* (2004) develop two models; first a pseudo-equation that disaster risk is a compound function of hazard and the number of people, characterised by a specific level of vulnerability, and second a model of the progression of vulnerability. The equation is expressed as:

$$R = H \times V,$$

where R = risk, H = hazard, and V = Vulnerability

The above equation is developed as the Access Model which explains the state of normal life of a community and explains how livelihoods differ in terms of access to material, social and political resources (Wisner *et al.*, 2004:89).

The second model is the Pressure and Release Model (PAR) (Wisner *et al.*, 2004:50), which describes the progression of vulnerability and the existence of a hazard as two forces that meet at the moment of impact – i.e. the occurrence of a disaster. In other words, a disaster occurs when the energy of a hazard is released at a time and place when unsafe conditions of a vulnerable community are at such a low level that they can neither resist the force, nor cope with the consequences of the event. In this model, vulnerability is defined as a process characterised by the progression of root causes, coupled with dynamic pressures that result in unsafe conditions. The root causes of vulnerability exist as exogenous and endogenous factors, the first being socio-political systems, and the second limited access to resources, which is a unique characteristic of a community. This viewpoint highlights the fact that not all communities facing the same hazard at the same location and time will suffer the same level of damage and loss. The PAR model is illustrated in Figure 4.5.

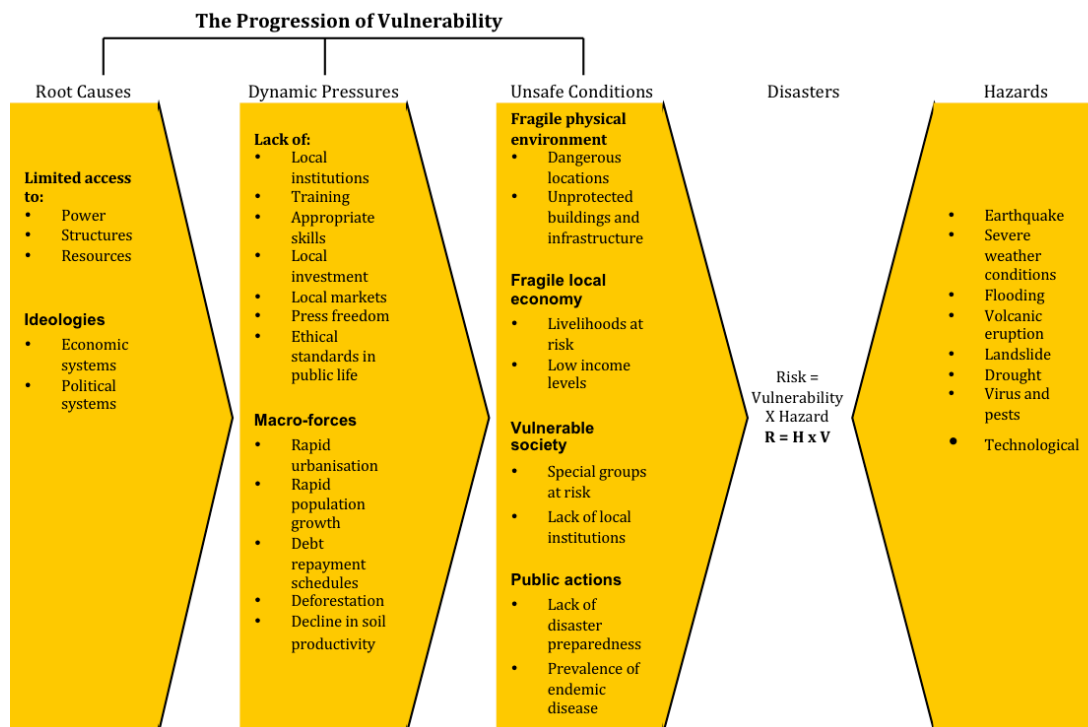


Figure 4.29: The Pressure and Release Model

Source: Wisner *et al.* (2004:51)

Vulnerability is defined as an internal risk factor of a system that is exposed to hazard and represents the physical, economic, political and social predisposition of a community to damage in the case of a destabilising phenomenon (Cardona, 2004:37). This concept is echoed by Wisner *et al.* (2004) who explore the concept of cause and effect within the framework of complex and varied sets of social and environmental processes and events that fuse under unique circumstances into disaster. Vulnerability remains, however, a hypothetical concept.

The analysis and measurement of vulnerability is an essential prerequisite for reducing disaster risk and a key function of disaster risk assessment (Birkmann, 2006:55; Queste & Lauwe, 2006:103). However, vulnerability is a complex construct with multiple uses of the term (Anthony-Smith, 2004:10; Cardona, 2004:37; Birkmann *et al.*, 2014:18). With a plethora of definitions found in literature, scientists are confronted with several paradoxes that are associated with the vulnerability concept (Alexander, 2009:1). First, it is an intangible, hypothetical concept, but it does not lack reality; it manifests itself as impact. In this context, scientists attempt to measure vulnerability and develop indicators, but still they cannot define it precisely (Birkmann, 2006:11; Birkmann *et al.*, 2013:195). Second, vulnerability can be disaggregated into sectors or components such as physical, social,

economic or psychological, but it is essentially a holistic concept – harm is linked to the whole construct (Alexander, 2009:1). Perhaps one should simplify the concept and consider vulnerability as a useful rhetoric; in other words, use the idea and not the term, as stated by Timmerman (1981:17).

4.3.6.3 Understanding Resilience

The concept of resilience originated within the engineering field where the Scottish engineer William Rankine employed the term to describe the strength and ductility of steel beams (Alexander, 2013:2710). The resilience property of a steel beam indicates its ability to withstand a force applied to it by virtue of its strength (rigidity) and its flexibility or ductility (ability to deform under stress). Subsequently the term entered the fields of natural ecology and human ecology, as an analogy of the concept of dynamic equilibrium, the persistence of systems and their ability to absorb change and disturbance under stress (Alexander, 2013:2710). In the context of social systems, resilience refers to the 'state space' where a system would tend to remain in the absence of strong perturbations (Gallopín, 2006:297). The state of a system can change in time, which can be followed by the trajectory from its initial state to its current state. The successive changes of state through time can be measured as a trajectory. If the variables of a system are known, and the trajectory of change can be interpreted, the future state of a system can also be projected.

At origin, resilience had different meanings. Alexander (2013) provides a detailed overview of the etymology of the term, tracing it from the middle ages through various disciplines to the social context of disaster studies. Gallopín (2006) analyses resilience in the context of socio-ecological systems and explores the concept of dynamic changes in the state of systems. The core definition of resilience indicates the ability of communities to cope with external stress, showing strength to absorb an impact or recover from it (Holling, 1973:17; Timmerman, 1981:21; Gallopín, 2006:297; UN-ISDR, 2009:24; Weichselgartner & Kelman, 2014:2).

Resilience is often used in association with vulnerability. Timmerman (1981) and Twigg (2007), for example, see resilience and vulnerability as the opposite sides of the same coin. However, this distinction is not so clear. In terms of the 'capacity to cope', as described by the MOVE framework of Birkmann *et al.* (2013), resilience is by definition included in the framework. Weichselgartner and Kelman (2014:1), on the other hand, state that "'resilience' has been replacing 'vulnerability' and 'sustainability' as a currency

in academic and policy discourses". Resilience is not the opposite of vulnerability. The opposite of vulnerability is invulnerability (Timmerman, 1981:17), which reflects a notion of equilibrium and safety. Gallopín (2006:300) prefers the term "robustness" to indicate the flip side of vulnerability. This places resilience outside the vulnerability framework as a separate concept with its own historical base and theoretical foundation, which is echoed by Miller *et al.* (2010) who highlight the different emphases, interpretations and approaches taken by researchers in respect of resilience and vulnerability.

In the wider context of disaster risk, the relationship between vulnerability and resilience is defined by the concept of 'coping', suggesting a 'coping range' within which impacts can be tolerated (Lim *et al.*, 2004:95). Beyond the coping range, effects will be experienced as harmful. At that point, damages and losses are no longer tolerable, thereby indicating a resilience threshold beyond which the probability of extinction (total collapse) exists (with reference to Holling's definition (1973:17)). Figure 4.6 refers to the work of Lim *et al.* (2004), indicating vulnerability as the state of "not being able to cope". This assertion may contradict the earlier statement that vulnerability is not the flipside of resilience. In this context the relationship between resilience, vulnerability and adaptation (widening the coping range) needs attention further attention.

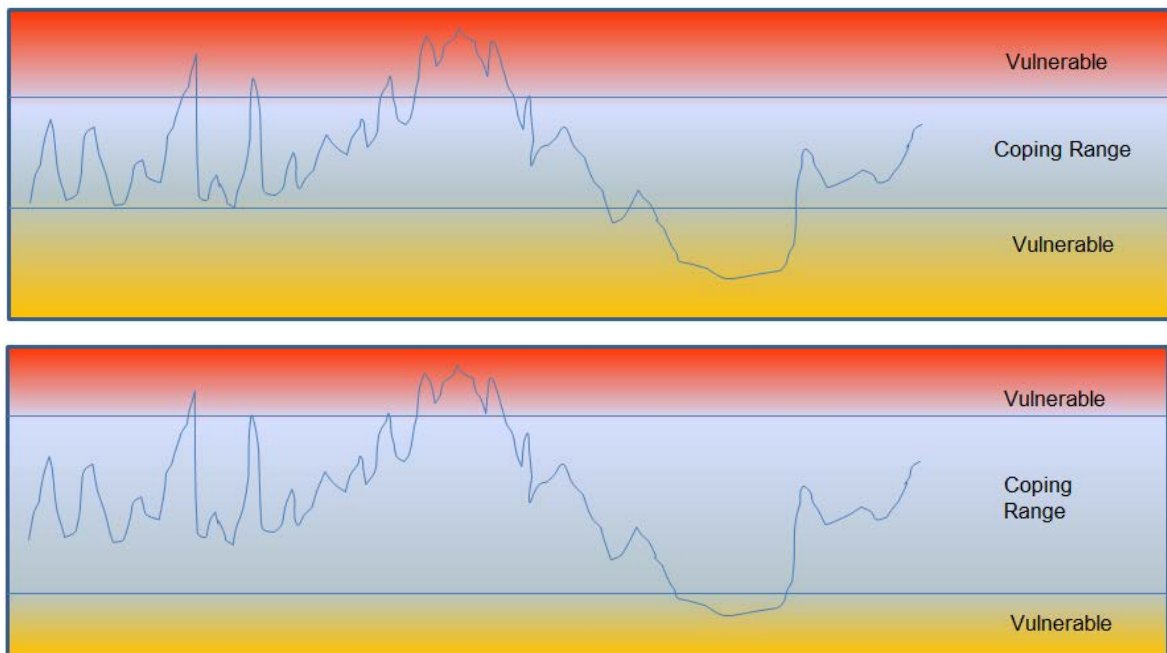


Figure 4.30: Schematic representation of varying coping ranges

Source: Adapted from Lim *et al.* (2004:95)

The relations between the concepts of vulnerability, resilience and adaptive capacity are analysed by researchers such as Gallopín (2006), Vogel, Moser and Kasperson (2007), Miller *et al.* (2010), and Hinkel (2011), which is indicative of a new focus in disaster research. This focus points to concepts of sustainability. According to Perrings (2006:417), the connection between resilience and sustainability stems from the fact that the ecological concept of resilience has been exercising an increased influence on the economics of development. He states that “understanding system dynamics is important to sustainability because it enables decision-makers to choose between actions that involve adaptation to future changes, and actions that mitigate those change” (Perrings, 2006:423). Vogel, Moser and Kasperson (2007:350) connect vulnerability, adaptation and resilience science to sustainability via climate change impacts, whereas Kates, Parriss and Leiserowitz (2005:14) take a more pragmatic position by simply linking the development of environmental sustainability to ‘becoming less vulnerable’. Hinkel (2011:204), however, highlights the lack of scientific rigor in the application of vulnerability indicators in the sustainability domain. A more in-depth analysis of sustainable development appeared in Chapter 3.

4.3.6.4 Understanding risk

To arrive at an understanding of disaster risk reduction, the concept of risk is examined. The Oxford English Dictionary (OED) defines risk as a "hazard, danger; exposure to mischance or peril". People can be put 'at risk' by means of voluntary or involuntary participation in an activity or event that could lead to injury, damage or loss. Some people will choose knowingly to live and work in such places in spite of risks, threats or hazards. The factors that influence these decisions are embedded in the way our societies are organised and in the beliefs that sustain and perpetuate the system (Oliver-Smith, 2013:1).

To imply that risk is the same as hazard, as quoted from the OED above, can be confusing. As described earlier, hazard is a source of potential harm or damage, and has properties such as intensity. Hazard exists in the potential of an event occurring, and needs a trigger mechanism to occur. Risk, on the other hand, is the chance or probability that a person or a community will suffer harm as a result of the hazard.

As indicated above, risk develops from the way societies are organised. Risk is, according to Oliver-Smith (2013:2), a social construct associated with socio-cultural processes. It is seen as a symptom of a deeper problem that is rooted in culture and political economy, particularly in respect of nature–society relations and interactions. Alexander and Davis (2012:1) identify five underlying factors that together constitute the problem of risk:

- i. The human right to hazard information
- ii. Explosive population growth
- iii. Corruption
- iv. People being placed at risk by the actions of governments
- v. Discrimination

In terms of the Hyogo Framework for Action 2005-2015 (UN-ISDR, 2005), risk is being addressed in conjunction with sustainable development, which highlights the multi-disciplinary approach to disaster risk reduction.

4.4 MULTI-DISCIPLINARY NATURE OF DISASTER

There is a growing consensus that multi- and interdisciplinary approaches are needed to analyse and understand complex problems of our day (McEntire, 2007). McEntire

(2004:12) lists not less than eleven disciplines that have a close relationship with and contribute to disaster risk management in some way or another. Apart from having a long history of studying hazards, Geography looks at vulnerability in terms of land use and hazard-prone areas. Engineering is concerned with structures that cannot withstand the forces of hazards, environmental sciences with sensitivity of the environment, and sociology with the behaviour of people reacting to a disaster.

The multi- and interdisciplinary approaches to the study of disaster and disaster management practice are reflected in pre- and post-disaster activities (McEntire, 2007:3). Researchers from various disciplines study hazards, vulnerability and resilience, as is reflected in the large number of publications on these topics (Alexander, 2012:1). In post-disaster situations, numerous actors from various disciplines converge on the disaster scene to contribute to the protection of life and alleviation of human suffering (McEntire, 2007:3). Jensen (2010:15) argues for a multi-disciplinary approach to higher education in disaster studies, stating that “a growing complexity of the body of knowledge that one has to know to be competent in emergency management is vast, specialized, and separate from any one other discipline”.

The value of multi- and interdisciplinary approaches, according to McEntire (2007), is found in various applications, such as the following:

- i. Understanding and effectively dealing with complex problems
- ii. Synthesising knowledge and bridging gaps across functional areas
- iii. Widening the knowledge base of practitioners
- iv. Establishing collective research methodologies internationally

McEntire's edited publication, *Disciplines, Disasters and Emergency Management: The Convergence and Divergence of Concepts, Issues and Trends in the Research Literature* (2007), with contributions from various fields, points to the need for multi- and interdisciplinary research. He concludes in his introductory chapter that they “are exploring uncharted waters, and that there are undoubtedly stormy seas, misty views, and jagged rocks posing a threat to the multi- or interdisciplinary vessel” (McEntire, 2007:13). The ensuing challenge is hopefully addressed to some extent by the current research. The multi-disciplinary nature of disaster risk studies was further explored in Chapter 3, with special reference to the relationship between development planning and environmental management.

4.4.1 Disaster risk in developmental context

Development was described in Chapter 2 as 'change'. Lewis (1999:xi) describes development as "the necessary inevitable", referring to the imperative of producing goods and services and maintaining livelihoods. From a more holistic perspective, disaster risk is seen in the context of changes of the human-environment system (Turner *et al.*, 2003a). Oliver-Smith (1994) highlights the perspective that disasters do not simply happen; they are caused, and the causal factors lie primarily in the domain of development. Thus, events such as earthquakes, volcanoes and tsunamis are all part of natural processes that bring about change in some form or other. When such changes affect and disrupt people's lives, they manifest as disasters. This premise was addressed in detail earlier (see Section 4.3.1).

An analysis of disaster risk and development based on the available literature shows five conceptualisations of their interrelationships, namely:

- i. Development is the root cause of disasters.
- ii. Disasters have a negative impact on development.
- iii. Development plays an important role in disaster risk reduction.
- iv. Disasters can provide development opportunities.
- v. Disaster risk is exacerbated by improper disaster management policies combined with development failure.

The origins of vulnerability are firstly linked to developmental factors, as illustrated by Anthony Oliver-Smith in his chapter *Peru's Five Hundred Year Earthquake: Vulnerability in Historical Context* (Oliver-Smith, 1994). He traces the vulnerability of the Peruvian people back to a multitude of 'natural' hazards during the Spanish conquest and colonisation of the region some 500 years ago. People were forced to transform their traditional way of living and indigenous systems to conform to the economic and social systems of a developing world, the conditions and context of which were far beyond their control. With no knowledge or regard of indigenous systems, the Spanish conquerors developed towns in potentially hazardous areas that were previously avoided by the local people. The forced migration and concentration of people in larger settlements resulted in the change of spatial development patterns from dispersed, small rural communities to an urbanised setting with a grid-like spatial pattern of narrow streets. Houses were built according to the Spanish style of tall double-storey structures with tiled roofs, making them more dangerous in a collapse (Fordham, 2006). When an earthquake struck Peru on 31 May 1970, registering 7.7 on the Richter scale, the north-central coastal and

Andean regions of Peru were devastated, making this the worst historic 'natural' disaster in the Western hemisphere at the time (Oliver-Smith, 1994).

A more recent and modern example of the link between development and vulnerability is demonstrated by the effect of globalisation, and the world-wide effect of a disaster event in a single location. The earthquake in Kyoto, Japan, in 2011 and the ensuing tsunami led to the closure of two Japanese plants accounting for 25% of the world's supply of silicon wafers used in computer manufacturing. This led to a world-wide shortage of supply from this location for some time (Barrow, 2006; Nanto, Cooper & Donnelly, 2011). This elevates disaster risk and vulnerability assessment from a local and national perspective to a global scale.

In the context of the PAR model, as described in Section 4.3.3.2, development is a root cause for disaster. This is, however, a one-sided perspective as disasters in turn also have a negative impact on development. This dualistic view is highlighted by the Department for International Development (DFID) (2005) and Fordham (2006). According to the DFID (2005), major disasters not only have negative long-term consequences for economic growth, development and poverty reduction, but also undermine efforts to achieve the Millennium Development Goals (MDGs). The DFID (2005:20) identifies a number of direct and indirect impacts against each of the eight MDGs, as shown in Annexure 4.1.

A third view is the role development plays in disaster risk reduction. Describing development as “the necessary inevitable”, Lewis (1999) sees it as an appropriate vehicle for vulnerability and disaster reduction, stating that development objectives should take account of hazards and of disaster probability. By informing the development process of the nature of hazards, avoidance and mitigation strategies can be incorporated in strategic planning and in the design of infrastructure, for example by avoiding hazard zones and constructing earthquake-resistant housing (Oliver-Smith, 1994; Lewis, 1999; Fordham, 2006).

A fourth view on the link between disaster and development is the fact that disasters can also provide development opportunities (Fordham, 2006:339). The extension of relief operations into post-disaster livelihood development programmes increases the ability of households and communities not only to rebuild what was lost in the disaster, but also to enhance their everyday coping capacities and household incomes.

The lack of integration between disaster risk management and development planning is rooted in what Lewis (1999) refers to as the *self-centric disaster cycle* (see the discussion of the disaster cycle in Section 4.4.1). He criticises the exclusion of the development process in the traditionally viewed 'disaster cycle' and the multi-sectoral approach to disaster risk management which is rarely co-ordinated or objectively interrelated. Lewis uses the analogy of a bicycle with disaster risk management and development planning seen as the two wheels, and which is (ideally) steered by one person. This view points to inter- and intra-disciplinary concepts, as described by Van Niekerk (2012).

The DFID (2005) adds another conceptualisation to the analysis, with what they call the '*Vicious spirals*' of disaster risk and development failure. The failure of development and government policy to reduce disaster risk, combined with increased vulnerabilities, stalled economic development, reduced capacity to cope with or adapt to risk, and increased exposure to hazard and susceptibility to harm, constitutes a vicious spiral of disaster risk and development failure. The anticlockwise spiral in Figure 4.7 shows how development failures undermine the capacity to cope and increase exposure to hazard. In the clockwise spiral, failed development is seen to undermine national capacity to respond strategically to disaster impacts, which means development resources are redirected towards humanitarian assistance or emergency coping (DFID, 2005:31). The developmental context of disaster risk management is best summarised by Lewis (1999:134) who states that "[d]evelopment continues to be regarded as the goal when everything else has been accomplished; relief, and rehabilitation are expected to modify so as to integrate with and not to impede or counter development".

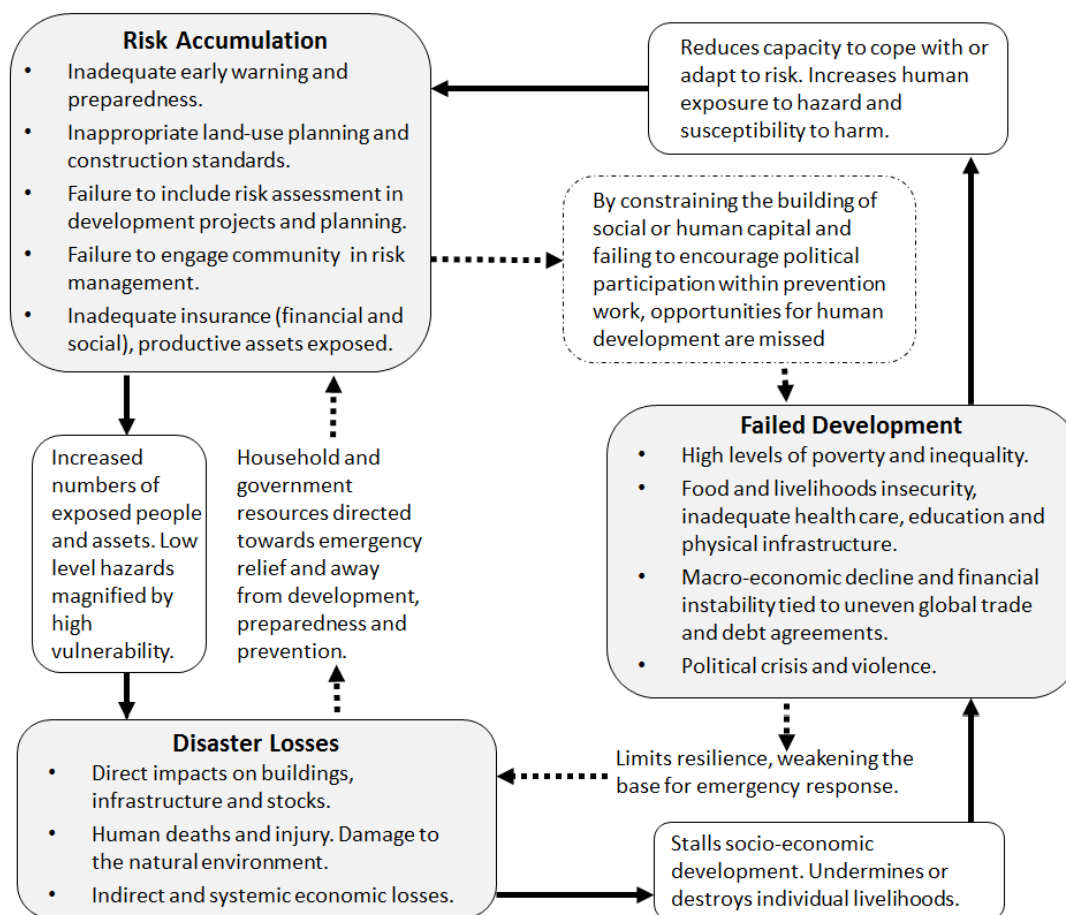


Figure 4.31: 'Vicious spirals' of disaster risk and development failure

Source: DFID (2005:31)

4.4.2 Disaster management in a social and sustainability context

Within the multi-disciplinary context of disaster risk management, geographers usually (UNBurton, 2001:84). Contributions on the sociological context of disasters have been made by scholars such as Mileti and Quarantelli who witnessed the development of theory from its infancy. Quarantelli and Dynes (1977:23) state that until the middle 1960s, only a number of pages might have sufficed to summarise the totality of research work on response to social crises and disasters. In the mid-1990s there was no epistemology of the sociology of disaster (Dombrowsky, 1995:241). The growth in this area has since been exponential. Research efforts and theoretical advances have reached a state of maturity where substantive statements can be made, such as the assumption that “disaster is primarily a social phenomenon and is thus identifiable in social terms” (Quarantelli & Dynes, 1977:24). This premise underpins theoretical perspectives on attributes such as vulnerability, as discussed in Section 4.3.

Given the inter-relationship between disaster risk management and development planning, the social context of the latter is highlighted. In this regard, reference is made to Chapter 2, where post-modernistic views of development and of planning were discussed. The development discourse points to the concept of sustainable development, which is also highlighted in vulnerability analysis. Although sustainable development is primarily linked to environmental concerns, as described in Chapter 3, concepts of sustainability are also relevant to vulnerability analysis. Chambers and Conway (1992) introduce the idea of *sustainable livelihoods* as an integrated concept, exploring the terms 'sustainability' and 'livelihoods' as a focus for policy and research in the 21st century. This concept is expanded by the DFID (1999) into a *sustainable livelihoods framework* as a tool to improve our understanding of livelihoods, with a focus on the alleviation of poverty (refer to Figure 4.8). The framework views vulnerability as a broad concept, encompassing livelihood assets, livelihood strategies, and institutional structures and processes. The social context of vulnerability is highlighted, which frames the external environment in which people exist, and over which they have limited or no control. People's livelihoods are fundamentally affected by three factors, i.e. critical trends caused by national and international activities (e.g. economic, political and technological trends); shocks experienced as unexpected events (e.g. natural shocks, economic shocks and conflict); and seasonality (e.g. fluctuation of prices, production, health and employment opportunities). This framework expands on disaster ontologies by associating shocks (disasters) with exogenous factors of trends and seasonality.

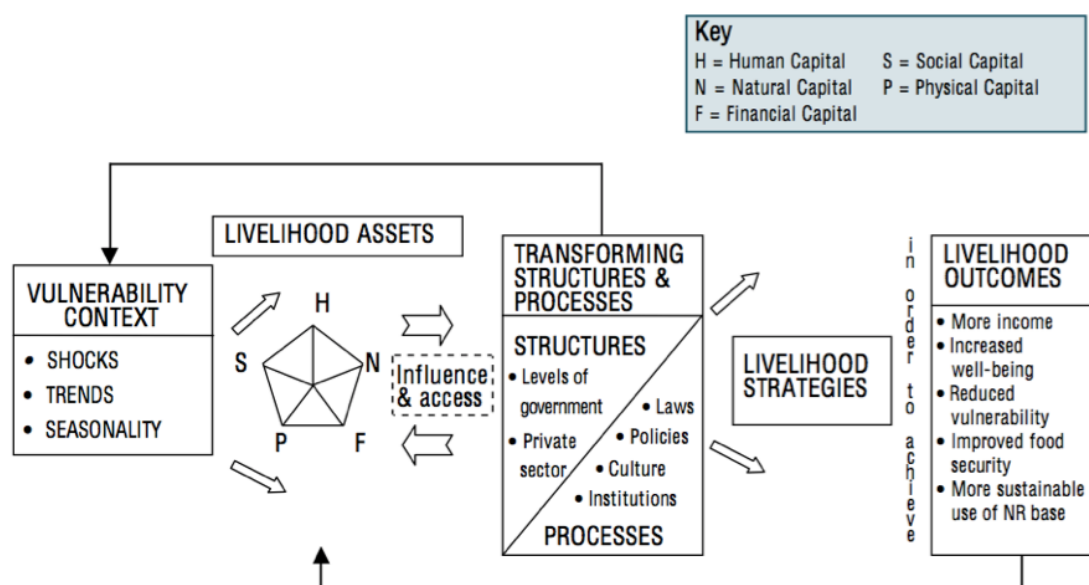


Figure 4.32: The sustainable livelihoods framework
Source: DFID (1999)

4.5 CONCLUSION

Chapter 4 follows on two previous chapters that described development planning and environmental management. It defines and investigates the theoretical grounding of disaster risk reduction, with a strong supposition that disasters are primarily the result of development and environmental degradation. Although efforts of disaster risk reduction are evident in ancient history, disaster risk management as a science is a recent development that (as in the case of development planning), follows a post-modern development pattern.

The multi-disciplinary nature of disaster risk management is highlighted in this chapter. It provides a background for various frameworks that aim to explain disaster risk management in terms of content analysis. A number of selected frameworks that are presented in Chapter 6 highlight the use of information – specifically geographic information systems (GIS) technology. An exposition of GIS will be presented in Chapter 5.

ANNEXURE 1 TO CHAPTER 4

MDG	Direct impacts	Indirect impacts
1. Eradicate extreme poverty and hunger	• Damage to housing, service infrastructure, savings, productive assets, and human losses reduce livelihood sustainability.	• Negative macroeconomic impacts including severe short-term fiscal impacts and wider, longer-term impacts on growth, development and poverty reduction. • Forced sale of productive assets by vulnerable households pushes many into long-term poverty and increases inequality.
2. Achieve universal primary education	• Damage to education infrastructure. • Population displacement interrupts schooling.	• Increased need for child labour for household work, especially for girls. • Reduced household assets make schooling less affordable, girls probably affected most.
3. Promote gender equality and empower women	• As men migrate to seek alternative work, women/girls bear an increased burden of care. • Women often bear the brunt of distress 'coping' strategies, e.g. by reducing food intake.	• Emergency programmes may reinforce power structures that marginalise women. • Domestic and sexual violence may increase in the wake of a disaster.
4. Reduce child mortality	• Children are often most at risk, e.g. of drowning in floods. • Damage to health and water & sanitation infrastructure. • Injury and illness from disaster weaken children's immune systems.	• Increased responsibilities and workloads create stress for surviving mothers. • Household asset depletion makes clean water, food and medicine less affordable.
5. Improve maternal health	• Pregnant women are often at risk of death/injury in disasters. • Damage to health infrastructure. • Injury and illness from disaster can weaken women's health.	• Increased responsibilities and workloads create stress for surviving mothers. • Household asset depletion makes clean water, food and medicine less affordable.
6. Combat HIV/AIDS, malaria and other diseases	• Poor health and nutrition following disasters weaken the population's immunity. • Damage to health infrastructure. • Increased respiratory diseases associated with damp, dust and air.	• Increased risk from communicative and vector-borne diseases, e.g. malaria and diarrhoeal diseases following floods. • Impoverishment and displacement following disaster can increase exposure to disease, including HIV/AIDS, and disrupt health care.
7. Ensure environmental sustainability	• Damage to key environmental resources and exacerbation of soil erosion or deforestation. • Damage to water management and other urban infrastructure. • Slum dwellers/people in temporary settlements often heavily affected.	• Disaster-induced migration to urban areas and damage to urban infrastructure increase the number of slum dwellers without access to basic services and exacerbate poverty.

8. Develop a global partnership for development	• Impacts of tropical storms, tsunamis, etc., on programmes for small-island-developing states.	• Impacts on commitment to good governance, development and poverty reduction – nationally and internationally.
ALL MDGS		• Reallocation of resources.

CHAPTER 5: THEORY OF GEOGRAPHIC INFORMATION SYSTEMS (GIS)

5.1 INTRODUCTION

From the available literature it is evident that a substantial amount of attention is given to the use of geographic information systems (GIS) in disaster management (Thomas *et al.*, 2003; Reitsma, 2004; Longley *et al.*, 2005; MacFarlane, 2005; Van Vuuren, 2006; NRC, 2007; Goodchild, 2009; Jansen van Vuuren, 2013; Metzger & Robert, 2014). Extreme events become topics for research and documentation of the use of geo-information technology, specifically in respect of response. One such example is Thomas *et al.* (2003) who described the use of spatial data and geographic technologies in response to the September 11 attack on the World Trade Center in New York. Driven by the magnitude of Hurricane Katrina's impact in 2005, the US National Research Commission evaluated the use of geospatial data and tools in emergency management and made recommendations to improve the use thereof (NRC, 2007). Baldwin (2010) documented the use of GIS in city, state and federal agencies during the response and recovery efforts of the same event, and made special reference to the role of participatory GIS (PPGIS) and partnerships from the disaster response community. Guidelines are developed for the application of GIS that can be used by managers and end-users in the civil protection environment (MacFarlane, 2005). Research on the development of models and frameworks is reflected in dissertations and journals, for example those of Reitsma (2004) and Jansen van Vuuren (2013). Seeing that the application field of GIS is growing and society is becoming more spatially enabled (Schmitz, 2008) as a result of technological advances such as the worldwide streaming of remotely sensed images of Earth by Google Earth™ (NRC, 2007), an understanding of the theoretical underpinnings of GIS is important – especially as this will guide the development of a GIS data model as proposed in this thesis.

The relevance of a focus on information – and on GIS in particular – is rooted in the fact that those involved in development planning, environmental management and disaster risk management activities have a need for information, most of which has spatial connotations (Longley *et al.*, 2005; MacFarlane, 2005; Goodchild & Glennon, 2010). The need for information is the key driver behind the development and implementation of GIS (MacFarlane, 2005:7). However, the demand for information is often met only partially when it is most needed, with negative effects in respect of outcomes and decision

making. This problem is illustrated by a comment made by a local authority Chief Executive in speaking about the Lockerbie disaster in 1988: “The quality of the response is only as effective as the reliability of the information which is available” (quoted by MacFarlane, 2005:7).

Although the processing of data – from its initial collection to the production of maps – receives much attention, there is far more to GIS than just the production of maps (Jansen van Vuuren, 2013). This premise requires the examining of the deeper context of GIS to establish a deeper understanding of what GIS is, and why it has experienced “explosive growth” and “pervasive spread throughout the sciences”, as stated by Blaschke, Strobl and Donert (2011:140).

Michael F. Goodchild is one of the great exponents of GIS science and has played a key role in establishing the foundations of this new research field (Raper, 2000; Mark, 2003; Kavouras & Kokla, 2008; Blaschke & Merschdorf, 2014). Following his work, a variety of scholars have since published in books and journals, and delivered conference papers, as will be shown through references in this chapter. The growth and interest in GIS science is acknowledged on an academic level by Blaschke *et al.* (2011), who argue for the establishment of more structured education and training in GIS science at a doctoral level.

The dependency on GIS in the social sciences is evident (Anselin, 1999; Janelle & Goodchild, 2011). Since the need for a deeper scientific understanding was briefly described above, this chapter begins with an overview of GIS history, and further explains the context of GIS within the domain of information systems. The theoretical background of GIS, with specific focus on the development of a GIS science, provides a background for the description of fundamental GIS concepts and GIS functions. In its totality, Chapter 5 provides an important background to the development of a GIS data model, as will be described in Chapter 8.

5.2 AN OVERVIEW OF GIS HISTORY

GIS started off as a computer-based technology and a modern extension of traditional (analogue) cartography (Longley *et al.*, 2005; Morais, 2012). In November 1962, Roger F. Tomlinson submitted a report entitled *An introduction to the use of electronic computers in the storage, compilation and assessment of natural and economic data for the evaluation of marginal lands* (Tomlinson, 1962) to the National Land Capability Inventory Seminar held under the direction of the Agricultural Rehabilitation and

Development Administration of the Canadian Department of Agriculture. Considering the capability of computers to store, compile and assess soil survey data to assess and evaluate marginal agricultural lands, he concluded that “computers have a definite capability that may be applied to the immediate tasks of the Agricultural Rehabilitation and Development Administration.” He further proposed “that this capability should be thoroughly investigated in relation to the specific data available for the study concerned and with direct application to the assessments that have to be made” (Tomlinson, 1962).

In 1963 Tomlinson produced a follow-up report entitled *Feasibility Report of Computer Mapping System* which specifies a series of maps that can be captured in a digital form for the Canadian Land Inventory project. The report suggested four types of transcription devices for data capturing, i.e. tracing (by hand), optical tracing, line following and scanning devices. It also specified data file organisation as a critical factor in the system, and a coordinate system to reference all common data in the system. Lastly, it identified tabular and graphic outputs (Tomlinson, 1963). Conforming to the components of an information system, Tomlinson prepared the specifications for a ‘geographic information system’, although this term would only be used for the first time a few years later.

Implementation of the system, named the Canada Geographic Information System (CGIS), began in 1965 and was completed in 1967. In his publication, *An Introduction to the Geo-Information System of the Canada Land Inventory*, Tomlinson (1967) gave an overview of the development and implementation of the system and for the first time used the term ‘geographic information system’. In his conclusion he prophetically stated that “[t]he system can be of inestimable value to a country such as Canada in providing a sound basis on which decisions on planning and development of resources can be made, particularly in the context of regional rehabilitation and project planning. The system is basic to a geographical understanding of the country and has application in any nation where the developing economy is concerned with the natural resources” (Tomlinson, 1967:21).

Parallel developments in this direction occurred in North America, Europe and Australia (Longley *et al.*, 2005:16). In the late 1960s the US Bureau of the Census developed the Dual Independent Map Encoding System, and created a digital record of all streets in the US as a tool for the purposes of the 1970 population census. Further development by the Harvard University’s Laboratory for Computer Graphics and Spatial Analysis led to the development of a general-purpose GIS – the ODYSSEY GIS of the late 1970s. During the same time, the UK Experimental Cartography Unit (ECU) developed high-quality

computer mapping and published the world's first computer-made regular map series, in cooperation with the British Geological Survey. The ECU also pioneered GIS work in education. Government departments in the US, the UK and France, including the military, began to investigate the use of computers to support the production and editing of maps, in order to avoid the expensive and slow process of hand correction and redrafting. Nevertheless, the Canada Geographic Information System (CGIS), as described above, is lauded as the first real GIS (Longley *et al.*, 2005:16-18).

Notwithstanding a massive effort by federal and provincial governments in Canada, CGIS's main success was the measurement of area, and the production of tabular information. From the 1980s onwards, however, GIS technology has shown rapid growth, with strong development as a spatial analysis and modelling tool (Gatrell, 1991:119). GIS also expanded into various modern technologies, notably the internet (Goodchild, 2009). Coppock and Rhind (1991) provide a detailed overview of the history of GIS and classify developments in four overlapping phases. The first is the period between the 1950s to about 1975, earmarked by research and pioneering work in North America and Europe. From 1973 to the early 1980s, formal experiment and government-funded research was the norm, with less innovation by individuals. With the release of ArcInfo as the first major commercial GIS software in 1981 (Longley *et al.*, 2005:19), a rapidly growing commercial phase took off, marked by strong competition among vendors. The fourth phase saw the emergence of a strong GIS user base that required systems with more efficient and speedy handling capabilities of large quantities of geographical data (Coppock & Rhind, 1991:39). GIS developed into a technology that is distinguished from other spatial data-handling activity by virtue of its spatial analysis capability (Goodchild, 1987:327).

Tomlinson (1967) introduced his report by referring to the concept of *information systems*, and was clear about his intention to associate with the emerging computer-based information systems technology. Half a century later GIS has developed into an industry with more than a million core users, five million casual users (Longley *et al.*, 2005:21), and a multi-disciplinary research field (Blaschke & Merschdorf, 2014:196). The association of GIS with information systems theory is further described in the next section.

5.3 THE CONTEXT OF GIS AS AN INFORMATION SYSTEM

An information system is “an arrangement of people, data, processes, and information technology that interact to collect, process, store and provide as output the information

needed to support an organisation" (Bentley & Whitten, 2007:6). Palmius (2005) sees an information system as all within an organisation that contributes to the distribution of information. This includes 'nodes' of information storage, 'channels' of distributing information, and 'users' (actors) that act and re-act upon that information. By including the human component, Palmius' definition of an information system is characterised as "a human activity system ... engaged in the function of the organisation, its people and its technological artifacts". The terms *information* and *system* define the context within which the target area *information systems* is further clarified.

To define the meaning of information, the difference between 'information' and 'data' must first be clarified, as these terms are sometimes used interchangeably. Classically, 'data' is stated as having the meaning 'raw facts', which indicates that the facts are unorganised and have not been processed to reveal real meaning (Rob & Coronel, 2009:5). 'Information' is the result of processing raw data to reveal its meaning (Rob & Coronel, 2009:6). The activity of processing data into information relates to the meaning of 'system', which Bentley and Whitten (2007:6) describe as "a group of interrelated components that function together to achieve a desired result". Alexander (2002) and Palmius (2005) next provide a more in-depth analysis of 'data' and 'information'.

5.3.1 Data

Alexander (2002:61) identifies three aspects of data that correspond with the ontologies of realism, nominalism and social reality, and that emphasise different roles of data, i.e.

- i. Record "objective facts which will be understood in exactly the same way by everyone"
- ii. Record "absolutely any type of concept, with no guarantees as to its accuracy or validity, which will be interpreted in all sorts of different ways by individuals"
- iii. "Use agreed structures and conventions for representing information, recording it and transmitting it, all in order to communicate it"

The objective view of data assumes that data is explicit, recorded from measurable events or objects, and is factual as a result. In this view, data can be true to reality if measured and recorded accurately (Alexander, 2002:61). An example would be the demographics of a region.

The subjective view of data assumes that data is not necessarily true or accurate since not all errors can be detected, or it consists of subjective opinion that cannot be measured

and does not constitute facts (Alexander, 2002:62). An example would be the results from interviews conducted with individuals after a disaster event.

The third view of data, the intersubjective point of view, focuses on communication and assumes the following (Alexander, 2002:63):

- i. Data is extracted from information, in other words, the information exists before the data is created.
- ii. Data must be recorded in a formalised structure. Knowledge of this structure must be shared as prior shared meaning.
- iii. Data is represented using agreed characters, codes, syntax and structure. Knowledge of these properties by all actors is a prerequisite for all to be able to use and decode the data.
- iv. The data stands in relation to context and a history. The capture of data supposes a pre-defined purpose.

An example of this view would be data collected during a rapid impact assessment after a disaster event, which is based on the event (historical context) and focused on immediate assessments and communication of data for further relief and reconstruction purposes (refer to Jansen van Vuuren, 2014).

5.3.2 Information

In order to define 'information', Palmius (2005) identifies a number of concepts that are related to (but not the same thing as) information in order to obtain a deeper understanding of the term:

- i. Data: As per the previous definition, data is a key concept, without which information cannot exist. Whereas data is tangible (measurable), information is not. Information is generated from data, and carries meaning. This notion is further related to the next concept of human understanding.
- ii. Human understanding: Information contains some form of meaning that is humanly attributed. This characteristic is the main attribute that differentiates information from data. Human understanding implies concepts of interpretation and pre-understanding, which are expanded into knowledge and experience (wisdom) (refer to Figure 5.1). The latter further relate to the concept of cognition, as described in Section 4.3.3.

- iii. Communication: As mentioned earlier, information is communicated through 'channels' of distribution. Communication is seen as the path that information travels between two actors, and is described as the transmission of information in a structured way through a medium by a carrier.
- iv. Decision making: This concept introduces the aspect of human behaviour. Without humans, information would not exist. Through processing and output, information is made operational and can serve a purpose such as supporting decision making.

To define information, Worboys and Duckham (2004:5) add the contextual perspective within which data is collected. Useful information is produced within the context of careful modelling and analysis of raw data with a particular goal in mind, for example the production of weather forecast maps. Data is obtained from various sources, e.g. meteorological stations and satellite imagery and processed through mathematical models to provide information that will support weather-related decisions. Thus, information is defined as "data plus context".

Decision-making support infrastructure	GIS example
Wisdom	Policies developed and accepted by stakeholders
↑	
Knowledge	Personal knowledge about places and issues
↑	
Evidence	Results of GIS analysis of many datasets or scenarios
↑	
Information	Contents of a database assembled from raw facts
↑	
Data	Raw geographic facts

Figure 5.33: Value adding: progression from data to wisdom

Source: Adapted from Longley *et al.* (2005:13)

Conceptions of data and information, as described above, become relevant when GIS and GIS science are discussed further.

5.3.3 Geographic Information Systems (GIS)

As discussed in Section 2, the term 'geographic information systems' was first coined by Roger Tomlinson in 1967. According to his description, GIS is defined as follows:

“A system whereby the map and related data could be stored in a form suitable for processing by a computer, which is also a computer- oriented system capable of rapid measurement and comparison of the data, is clearly desirable” (Tomlinson, 1967:2).

By examining Tomlinson’s previous reports in motivation for the Canada Land Inventory System, it becomes clear that the initial focus was on the capturing of existing hard copy maps into a digital format by using different hardware devices. As technology grew, various definitions developed, to the effect that a precise definition of a GIS does not exist (Grimshaw, 1996:547; Harvey, 2008:262).

In discussing a taxonomy of GIS, Grimshaw (1996) highlights different perspectives on the definition of GIS in literature and cites the definition from the UK-based Chorley Report of 1987 as the most widely used definition at that time:

“A system for capturing, storing, checking, manipulating, analysing, and displaying data which are spatially referenced to the Earth” (Grimshaw, 1996:547)

This definition is criticised for placing undue emphasis on geographic data, stating that “GIS is simply an information system where the data have a geographical dimension.” Grimshaw examines GIS in relationship to other information systems such as computer-aided design (CAD); cadastral or land information systems; automated mapping and facilities management (AM/FM); global positioning systems (GPS); spatial information systems; geo-data systems; and remote sensing, which all have a geo-spatial connotation. He also includes database management systems (DBMS) and transaction-processing systems that are non-spatial.

The diagram in Figure 5.2 depicts a matrix with two variables; a spatial data component, and a non-spatial (attribute data) component. These are placed on two axes indicating increasing intensity from the origin. GIS is placed in the segment where both components indicate a high ranking, whereas other systems are high in either the spatial or the attribute category. An interpretation of the matrix returns two observations: first, GIS is a subset of the Information Systems domain. Second, a system with the ability to handle intense amounts of both spatial and attribute data, would qualify as a GIS. In this sense GIS is strongly associated with software capabilities. In his paper, Grimshaw (1996:548) quotes his own definition as follows:

“[A] Geographical Information System is a group of procedures that provide data input, storage and retrieval, mapping and spatial analysis for both spatial and attribute data to support the decision making activities of the organisation.”

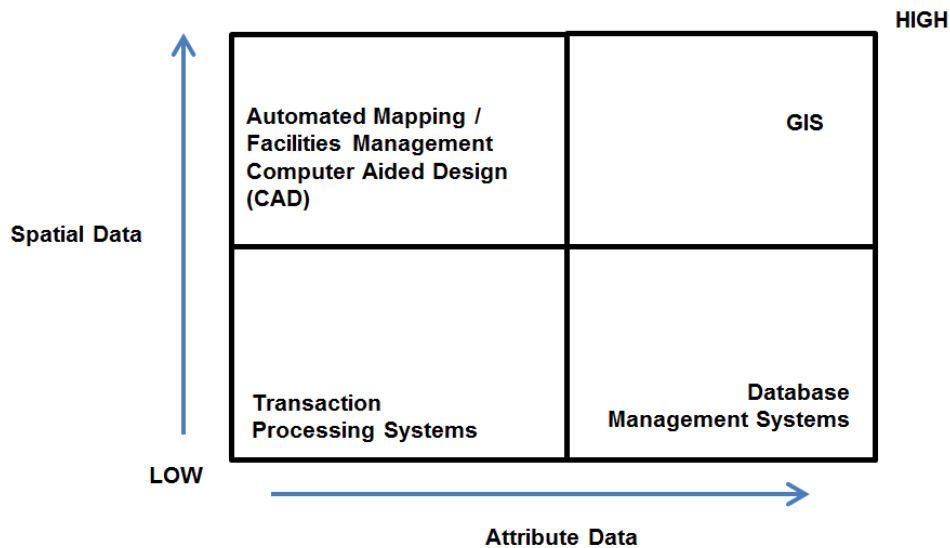


Figure 5.34: GIS and related information systems

Source: Grimshaw (1996:548).

Grimshaw's definition indicates a more balanced approach, highlighting process, content and purpose of the system.

Harvey (2008) deliberates on three definitions from literature to describe the relationship of GIS to geographic information analysis operations and the role of GIS in representation and communication. The first is the definition quoted from Duecker and Kjerne (1989) (quoted in Harvey, 2008:262), which states that GIS is

“[a] system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth”.

Harvey criticises this definition for its lack of geographic and cartographic representation and its focus on *what* GIS can be used for, but excluding the *how*, *by whom*, and *for whom*.

The second definition states that GIS is:

“Organized activity by which people measure and represent geographic phenomena then transform these representations into other forms while

interacting with social structures” (Chrisman, 1999, quoted in Harvey, 2008:263).

This definition is formulated in reaction to the previous one by Duecker and Kjerne, and focuses on the activities of measuring and representing in the context of social structures. Chrisman’s definition addresses the “for whom” and how GIS is used. The aspect of data processing (transformations) points to GIS operations that are commonly used, taking into account the goals of GIS.

The third definition is quoted from an internet source by Harvey (<http://www.extension.umn.edu/distribution/naturalresources/components/DD6097ag.html>), which states that GIS is a

“[s]ystem of computer hardware, software, and procedures designed to support the compiling, storing, retrieving, analyzing, and display of spatially referenced data for addressing planning and management problems. In addition to these technical components, a complete GIS must also include a focus on people, organizations, and standards” (in Harvey, 2008:264).

This definition combines the previous two into one, and includes the general purpose of GIS. It takes the emphasis away from technology and includes a focus on people. An interesting characteristic is the inclusion of standards, which points to interoperability between different systems.

A synthesis of GIS definitions highlights the geographical component, which points to the special characteristics of spatial data (Grimshaw, 1996:548; Longley *et al.*, 2005:8). It further highlights the value added to data, progressing from conceptualisations of reality (data) to information, knowledge and even wisdom, as illustrated by Longley *et al.* (2005:13) (refer to Figure 5.2 above). Lastly, it highlights a particular goal of GIS, as it functions in a particular domain. Since its inception in the environmental field (Tomlinson, 1962), GIS has been adopted slowly in many other fields, specifically the social sciences (Anselin, 1992; 1999).

One of the major advances in GIS is the emergence of a geographic information science, which was basically non-existent until the end of the 1980s. In 1987, Michael Goodchild wrote that at that time academic focus was on technical issues, with no supporting theory: "To some, this may be interpreted as indicative of the lack of significance of the field as a whole; to others, it is more a matter of the field's novelty, as theory and philosophy

traditionally lag behind basic research activity" (Goodchild, 1987:327). How this situation came to be changed, is discussed further in the next section.

5.4 GEOGRAPHIC INFORMATION SCIENCE

Geographic information science (GISc, or GIScience) is a new field of study that has emerged from an awareness and observation that there is more to GIS than the mere application of software (Goodchild, 1999; Raper, 2000). This section gives an overview of the emergence of a GIScience by starting with earlier debates on the issue and looking at the questions: What is GIScience? What are the fundamental geographical concepts?

5.4.1 The "GIS as a science" debate

During the 1990s, lively debates around GIS as a 'tool' or a 'science' arose from uncertainties around what was meant by 'doing GIS' (Wright, Goodchild & Proctor, 1997). In their article, *Demystifying the Persistent Ambiguity of GIS as 'Tool' versus 'Science'*, Wright *et al.* take the position that the science of GIS provides a sufficient condition for science. At the time 'doing GIS' seemed to be simply nothing more than interacting with a particular class of software. The 'GIS community' was seen as no more than a group of individuals with an interest in GIS software, and 'GIS research' seemed an oxymoron (Wright *et al.*, 1997:346).

The question, 'does it matter if GIS is a science or not?', first received attention from Wright *et al.* (1997) and more than a decade later from Reitsma (2013). Wright and colleagues concluded that the two positions of GIS as a tool or a science constituted an oversimplification of the problem and suggested that it be viewed as a continuum from tool to science. They focused on the meaning of 'doing GIS' rather than 'GIS' alone and identified three positions: (1) GIS as a tool; (2) GIS as tool making; and (3) the science of GIS.

'GIS as a tool' is seen as the use of a particular software platform and associated hardware tools such as digitisers, scanners and GPS devices that are used to create digital data. The tool itself is inherently neutral. Being technology driven, its development is largely independent of its use. As such, the tool does not drive the research (Wright *et al.*, 1997:353). 'Tool making' refers to an academic setting that is concerned with advancing the tool's capabilities and ease of use through education, thus ensuring its

responsible use. The 'science-of-GIS' approach involves research on a set of basic problems that exist independently from GIS as technology and that become relevant because of the technology (i.e. the modelling of geographical space).

According to Wright *et al.* (1997:354), GIS is widely viewed as a subset of geographical science. Just as development of the digital computer has led to the discipline of computer science, it may also have lead to the development of the discipline of geographic information science (GISc).

Femke Reitsma approaches the question about GIS as a science by reflecting on certain criteria to be met by a science such as simplicity, predictive accuracy, the ability to give rise to successor theories as new experimental evidence (fertility), coherence, unified theory, and testability. Taking a cautious approach as to how science is defined, she concludes that GIScience can indeed be considered a science. What makes it different from other sciences is the fact that the GISc practitioner does not study the world, but rather the representations of that world (Reitsma, 2013:219).

5.4.2 What is geographic⁶ information science?

Geographic information science emerged as the study of applied research issues involving geospatial information (Montello, 2005:61). It is a multi-disciplinary field with its foundations in geography, cartography, surveying, mathematics and computer science (Raper, 2000:4). It emerged as a science concerned with the handling of data, and the analysis and modelling thereof (Mark, 2000; Timf, 2003; Blaschke, 2011, 2012). The impetus for the development of GIS theory was the landmark paper by Michael Goodchild (1992) in which the term 'geographical information science' was first introduced. It developed as a research field that investigates scientific questions about geographic information and GIS (Montello, 2009:1825). Reflecting on all the developments in the GIS field over three decades, including research and training, Goodchild (1992) concludes that there ought to be more to it than just enthusiasm and excitement. With the focus on the unique characteristics and modelling of spatial data, he claims that the underlying technical problems of GIS were largely solved at that time, and that attention has moved "from primitive algorithms and data structures to the much more complex problems of

⁶ The terms 'geographic' and 'geographical' are used interchangeably to denote the 'g' in 'GIS'; for example, Goodchild refers to 'geographical' and Montello to 'geographic' when writing about GIScience. Since it has the same meaning in each case, a decision was made to use the term 'geographic' in this thesis.

database design, and the issues surrounding the use of GIS technology in real applications” (Goodchild, 1992:33). The key issues representing substantial scientific questions relate to the following aspects of geo-spatial data management:

- i. *Data collection and measurement:* An understanding of complex structures of spatial dependence and the nature of spatial variation, which relate to aspects of generalisation, abstraction and approximation associated with data collection, compilation and interpretation.
- ii. *Data modelling and theories of spatial data:* Frameworks that are used to represent geographical variation in digital databases.
- iii. *Data structures, algorithms and processes:* Various breakthroughs with regard to internal representations of data and the algorithms that operate on them were achieved. Whereas generic problems have been solved, for example the modelling of terrain by means of Triangular Irregular Network (TIN), more advanced methods to distinguish landforms (mountains, plains, valleys, etc.) may add intelligence to data structures.
- iv. *Display:* The relationship between geo-spatial objects stored in a database and their display on a map requires more attention. This includes advances such as animated displays, three-dimensional display, and multimedia.
- v. *Spatial analysis:* A host of geometrical operations have been developed and are included as standard algorithms in GIS software. However, some loosely coupled analysis modules (functioning outside of the standard software interface) lack integration structures such as topology, object identity and metadata.

Goodchild (1992) provides a framework for the expanding of GIScience into a wider research agenda, particularly in the field of data modelling. With regard to technological advances, it must be appreciated that, at that time, most GIS software was functioning on mainframe computers, Unix workstations and in a Disk Operating System (DOS) environment on IBM compatible personal computers.

Goodchild (1992) did not provide a definition for GIScience, but rather outlined the scope of the field as indicated above. In December 1994, a group of academics met to establish an organisation – the University Consortium for Geographic Information Science (UCGIS) – to represent the GIS research community. A full definition of GIScience was subsequently formulated at a workshop in January 1999 (Mark, 2003:3). In an article, *Geographic Information Science: Critical Issues in an Emerging Cross-Disciplinary*

Research Domain, David Mark highlighted the research agenda for GIScience and provided the following definition:

"Geographic Information Science (GIScience) is the basic research field that seeks to redefine geographic concepts and their use in the context of geographic information systems. GIScience also examines the impacts of GIS on individuals and society, and the influences of society on GIS. GIScience re-examines some of the most fundamental themes in traditional spatially oriented fields such as geography, cartography, and geodesy, while incorporating more recent developments in cognitive and information science. It also overlaps with and draws from more specialized research fields such as computer science, statistics, mathematics, and psychology, and contributes to progress in those fields. It supports research in political science and anthropology, and draws on those fields in studies of geographic information and society" (Mark, 2000:51).

Mark (2000) distinguishes two distinct, but deeply interconnected research areas: *Geographic Information Science research*, and *research using Geographic Information Systems*. The latter sees GIS as a tool to conduct scientific research, supporting both inductive and deductive approaches. Like statistical packages, GIS software is used both within and outside the research community. GIScience research, on the other hand, is the basic research field that seeks to redefine geographic concepts and their use in the context of geographic information systems, and that seeks to provide a theoretical foundation for GIS. It addresses complex problems that require multidisciplinary solutions, a topic that was explored extensively by Thomas Blaschke and his fellow researchers in Salzburg, Austria (Blaschke *et al.*, 2011; Blaschke & Merschdorf, 2014). Reflecting many of the key issues identified by Goodchild (1992), the challenges that motivate research are summarised by Mark (2000) as follows:

- i. Representation: Finding ways to express the spatio-temporal continuum of the geographical world in the discrete code of a digital computer.
- ii. Uncertainty: Geospatial data include uncertainty that stems from measurement error; errors due to imperfect interpolation between measurements gaps in the data (incomplete data); artifacts of graphic or digital processing, and human error. This affects the way in which the real world is represented. Research can find ways in which the differences between GIS-based representation and real world phenomena can be modelled.
- iii. Cognition: Cognitive representation of real-world phenomena through processes of symbolisation, abstraction, and generalisation on maps are fused

with the judgement of human operators. The challenge is to achieve better transitions between cognitive and computational representations and the manipulations of geographic information.

- iv. Simulation: The simulation of geographic phenomena provides a way to understand geographic processes. Through research, improved simulations of geographic phenomena that are indistinguishable from their real counterparts can be created on a GIS platform.

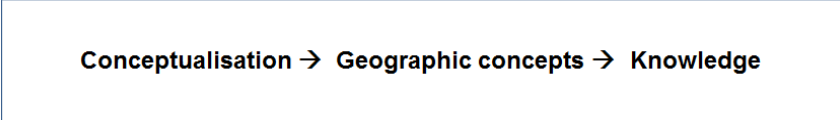
Having established the foundation for GIScience in 1992, Michael Goodchild continued to reflect on its growth and highlighted various conceptualisations of GIScience in various publications. He emphasised process (Goodchild, 2004), stating that GIS remains poorly equipped to handle dynamic data, and warned that the persistent use of the 'map' metaphor to conceptualise GIS resulted in a focus on static data (also an observation by Jansen van Vuuren, 2013). This caused problems with regard to modelling changes over time, and simulated the actions of physical and social processes. He subsequently reflected on significant discoveries in GIScience – discoveries being a characteristic of science (Goodchild, 2009) – which included theories of representation that postulate the ways in which humans conceive of the geographic world around them. The conceptualisations of discrete objects, continuous fields and the geo-atom as geographic abstraction are some of the discoveries that will receive more attention in this thesis. In 2010, reflecting on two decades of development, Goodchild acknowledges the contributions of other researchers, introducing concepts such as fuzzy data (Burrough & Frank, 1995).

Raper (2000:4) highlights the developing nature of the field and proposes a more holistic understanding that is based on the view of GIScience as both the process and product of representation. This approach goes beyond the traditional cartographic perspective of GIS and is concerned with human cognition of geo-spatial objects and the flow of information.

5.5 FUNDAMENTAL GEOGRAPHIC CONCEPTS OF GISCIENCE

One of the most fundamental questions about GIScience is how we conceptualise geographic reality and how the formed conceptions represent the world as well as our knowledge of that world (Kavouras & Kokla, 2007:3). The schema in Figure 5.3 below reminds of the fact that knowledge comes from information, which in turn is created from

data, as discussed in Section 3. The similarity here is the fact that geographic data provides conceptualisations of the real world from which geographic concepts are defined. The analysis and interpretation of these concepts eventually constitute knowledge. The representation of that knowledge is organised into collections, nomenclatures, taxonomies or ontologies (Kavouras & Kokla, 2007:3).



Conceptualisation → Geographic concepts → Knowledge

Figure 5.35: Forming knowledge from conceptualisations of the real world

Conceptualisations may differ for various reasons, for example how different disciplines understand the concept of 'land use'. Kavouras and Kokla (2007:6) list a multitude of different conceptualisations by planners, environmentalists and land surveyors. These range from different taxonomies, disciplinary approaches and methodologies, to socio-cultural views and cognitive diversity. Thus it is important to understand the identity and characteristics of geographic concepts.

5.5.1 The nature of geographic data and its modelling

In GIS, the analogue of a map is the electronic database (Longley *et al.*, 2005:76). Objects such as roads and rivers, which we as humans cognitively interpret as lines on a map, are represented in different symbols and/or colours. In GIS they need to be stored in a database as features or objects, with an associated geometry (Morris, 2008:82). The representation of geographic phenomena in digital databases is a central and fundamental issue in Geographic Information Science (Mennis, Peuquet, & Qian, 2000:501). Just as a map is a simplified model of reality, some level of abstraction is required to design the database. Data abstraction refers to the suppression of details of data organisation and storage, and the emphasising of the essential features of the represented object (Elmasri & Navathe, 2001:30). A data model provides the necessary means to achieve this abstraction. The latter can be seen as a collection of concepts that describe the structure of a database (Elmasri & Navathe, 2011:30), and serve as the bridge between real-world objects and the database that resides in the computer (Rob & Coronel, 2009:30). The data model can be regarded as the 'blueprint' that contains the instructions to build a database that will meet the requirements of the end user (Rob & Coronel, 2009:31).

Geographic data requires a scientific understanding of the key geographic characteristics of real-world systems. This includes the state of objects, their behaviour, and the relationships between them (Longley *et al.*, 2003:196), which is an imperative for endowing spatial analysis capabilities in GIS (Gatrell, 1991:119). With reference to the geographic information model as described by Jansen van Vuuren (2013:4), a further understanding of how this relates to the goals and tasks of the GIS application is required, since the choice of the type of data model determines how that data can be represented and which operations can be performed. In this regard, the relationship between data, GIS operations, tasks and goals is important. The choice of data model is determined by factors such as the format in which existing data is presented, the time and effort required to convert data if necessary, and the nature of the geographic features involved. Longley *et al.* (2003:196) distinguish between rich and simple feature models. An example of a rich type is a water distribution network that consists of a collection of pipes, valves, meters and pumps, which are related to each other in a unique configuration to establish a network. The implementation and operation of the network (object class) is dependent on the functioning of each component (object).

The role of data modelling is to represent the key aspects of the real world in a structured spatial database for management, analysis and display purposes. Due to the complexity of the real world, geographical units must be abstracted, generalised or approximated in the process of creating the database (Goodchild, 1992b:401). Data models are based on two main conceptualisations of geographical reality (Goodchild, 1992a:405): as infinite sets of tuples approximated by regions and segments and referred to as *fields*, and as planes scattered with independent objects, referred to as *discrete objects*. These are outlined below.

5.5.1.1 Fields

According to Goodchild (1992b:402), the fundamental element of geographical reality can be defined as a tuple

$$T = \langle x, y, z_1, z_2, \dots, z_n \rangle,$$

where (x,y) represents location, and (z) a set of variables with descriptive values of that location. By adding a vertical dimension (*h*), and a time component (*t*), the tuple can be extended to

$$T = \langle x, y, h, t, z_1, z_2, \dots, z_n \rangle.$$

The number of (x,y) locations in space is infinite, therefore the number of tuples that represents geographical reality is infinite. A set of infinite tuples is referred to as a *field*, representing a continuous field of an infinite number of (x,y) locations. Similarities in the z-values determine the partitioning of a field into homogeneous, simply connected regions, with variations within each region described by function (Goodchild, 1992b:402). Due to the constraints of digital storage, the number of tuples required to represent reality must be reduced in order to be accommodated in the spatial database. This is referred to as abstraction, as was discussed above.

5.5.1.2 Discrete objects

Reality can also be conceptualised by discrete objects located in a plane (Goodchild, 1992a:402). The location of objects is described by a set of tuples

$$T = \langle x, y, o_1, \dots, o_i \dots \rangle,$$

where o_i is a binary variable indicating the presence or absence of object i at location (x,y). Spatial variation is represented by the set of tuples

$$T = \langle i, a_1, a_2, \dots, a_m \rangle,$$

where i is an object and a_1 through a_m are attributes of the object.

In many situations, objects pose problems with regard to variation by virtue of the degree of approximation and generalisation (Goodchild, 1992a:402). For example, a soil map would show variation in soil type on a plane with each soil type uniquely demarcated according to an approximated criterion, whereas in reality the boundary between distinct soil types is not exact and easily identifiable. This leads to issues of uncertainty, which were discussed in Section 4.3.4.

Within the above two views of reality, five classes of geographical units or objects can be identified (Goodchild, 1992a:405). *Regions* and *segments* are associated with field views. Regions refer to the partitioning of the plane into homogenous, simply connected areas. Segments are associated with linear objects, where *segment* refers to a discrete element of the object, for example a road network. Variation in the gradient (slope) across the network can be indicated by segments of constant gradient. *Points*, *lines* and *area* are associated with object views that exist as distinct objects on the plane, with areas of 'no data' in between.

The above distinction reminds of the raster and vector data concept. *Raster* and *vector* refer to data types that are handled differently by different GIS software packages and that are often stored in proprietary formats. Goodchild (1992a:406) highlights issues of ambiguity from a data-modelling perspective, concluding that “neither ‘vector’ nor ‘raster’ provide unambiguous information on how the data represents reality”, and, therefore, “do not provide an adequate and sound basis for a discussion of data modelling”. In general, a line feature such as a road network can be captured in both vector and raster data formats. Likewise, an area feature such as soil type can also be captured in both data formats. As Couclelis (1992:71) puts it: “Lakes may be polygons, and coastlines may be lines, but the contour lines of topography only work in concert, as in a field: they are not independent objects, slices to be sorted, stacked and manipulated, and checked for illegal overlaps.” The choice of data format will depend on the level of abstraction, considering processing requirements such as data integration and spatial analysis.

According to Couclelis (1992), the ‘raster’ vs ‘vector’ debate relates to technical considerations, whereas ontologies of ‘object’ and ‘field’ views are useful from a philosophical point of view to conceptualise geographic space. She argues that

“[h]uman cognition had sorted out the basic properties of [the] world long before digital spatial databases came about, and (unlike what is the case with the next law in quantum electro-dynamics), it probably has little to learn from the next spatial data model that is built. Thus, in applied geography – the geography that GIS is supposed to serve – the question of whether an object or field view is more correct, is neither a philosophical nor a theoretical issue, but largely an empirical one: how is the geographic world understood, categorized, and acted in by humans?” (Couclelis, 1992:70).

The choice of raster or vector is determined by the application and the scale of representation. This aspect is further explored in Chapter 7.

5.5.1.3 *Geo-atoms*

The primitives of geographic representation are further explored by Goodchild, Yuan and Cova (2007), who introduce the concept of a geo-atom as the most primitive form of geographic information. The geographic domain not only includes space; it also includes the dimension of time. The concept of change detection, for example, suggests variation in space over time. Yuan, Nara and Bothwel (2014:2) define the geo-atom as follows:

“A geo-atom is a space–time point with semantic properties and associated values for the properties. When geo-atoms are bounded by the same identity over space and time, these geo-atoms represent a geo-object. When geo-atoms are bounded by the same property over space and time, these geo-atoms represent a geo-field. Various means of aggregation and agglomeration of geo-atoms in space and time form representations of complex geographic phenomena.”

Referring to this concept as ‘bottom-up thinking’, it forms the basis for exploring the problem of time-representation in GIS. Goodchild *et al.* (2007:243) define the geo-atom as an association between a point location in space–time and a property, denoting it as a tuple

$$\langle x, Z, z(x) \rangle$$

where x defines a point in space–time, Z identifies a property, and $z(x)$ defines the particular value of the property at that point. They give the following example to illustrate:

“For example, a geo-atom might indicate that at 120uW, 34uN, at 0m above mean sea level, and at local noon on 11 July 2005 (a four-dimensional definition of x), the Celsius temperature (the property Z) was 20u (the value $z(x)$).”

Geo-atoms are aggregated into geo-fields and geo-objects. A geo-field aggregates geo-atoms over space by the property Z , irrespective of its value. An example is a coverage (field) of elevation data, where all points represent the property ‘elevation’ in two-dimensional space, with the value (x) denoting elevation as the third dimension of space. Geo-objects are defined as an aggregation of points in space–time whose geo-atoms meet certain requirements, such as having specified values for certain properties. An example is ‘Johannesburg City’, where all geo-atoms have the value (*Johannesburg City*) for the property [City]. In terms of GIS practice, a geo-object would constitute a feature represented as a point, line or area/polygon.

Goodchild *et al.* (2007) extend the geo-atom concept into a three-dimensional framework that has three key characteristics: (1) a geo-object may be static or may move; (2) it may change shape through time; and (3) it contains internal structure, indicating whether an object is internally uniform, or whether it has heterogeneous and evolving internal characteristics. In combination, it produces eight possible iterations, as described below:

- i. Uniform + Stationary + Rigid: buildings and streets in a city.

- ii. Uniform + Stationary + Elastic: the seasonal expansion or contraction of a lake when only the extent of the lake is considered.
- iii. Uniform + Moving + Rigid: moving vehicles, and the lifelines through space created by human life histories.
- iv. Uniform + Moving + Elastic: a spreading wildfire when only the burn scar is considered.
- v. Evolving + Stationary + Rigid: soils in a watershed and digital elevation models.
- vi. Evolving + Stationary + Elastic: heat-island effects in an urban area, and vegetation cover during desertification.
- vii. Evolving + Moving + Rigid: changing landscapes on moving, rigid tectonic plates.
- viii. Evolving + Moving + Elastic: oil spills and hurricanes.

The above conceptualisations of continuous fields and discrete objects represent theory of world abstraction (the way in which we think about geographic phenomena), but do not solve the problem of digital representation and storage of data. In a digital database, geographical data is stored in either raster or vector data format. These two formats are exchangeable by using algorithms to convert from the one to the other, bearing in mind the effect it will have on storage capacity and processing speed (as will be discussed in the next section).

5.5.1 Representation of conceptual views: rasters and vectors

Geographic phenomena can be stored in two types of database structures, namely rasters and vectors. These are extensively described in Burrough (1986), Melnick (2002) and Longley *et al.* (2005). GIS is distinguished from other spatially orientated systems, such as graphic design or computer-aided design (CAD) by virtue of its topological data structure and database orientation. Topology is the ability of GIS to define spatial relationships between adjacent or neighbouring features (Theobald, 2001:689). This is achieved through a set of rules and behaviours that interpret the coordinates in a database in such a way that it models how points, lines and polygons share geometry. It represents the way in which the human eye would interpret lines and points on a map as specific features according to a legend on the map, and simultaneously construe the spatial relationships between entities. This concept is illustrated in Figure 5.4, showing the definition of a road and a village as a series of connected points, and the spatial relationship between these two features where they share the same line segment.

Topology is fundamentally used to guarantee the quality of geographical data and to aid in data compilation. Further advantages of GIS topology include the following:

- i. Data integrity rules are enforced (e.g. no gaps should exist between adjacent polygons, there should be no overlapping features, the junction of lines must be solid (not overshooting or undershooting), and so on).
- ii. Relationship dependent queries are supported (e.g. shortest route analysis).
- iii. Features are constructed from unstructured geometry (e.g. to construct polygons from lines).

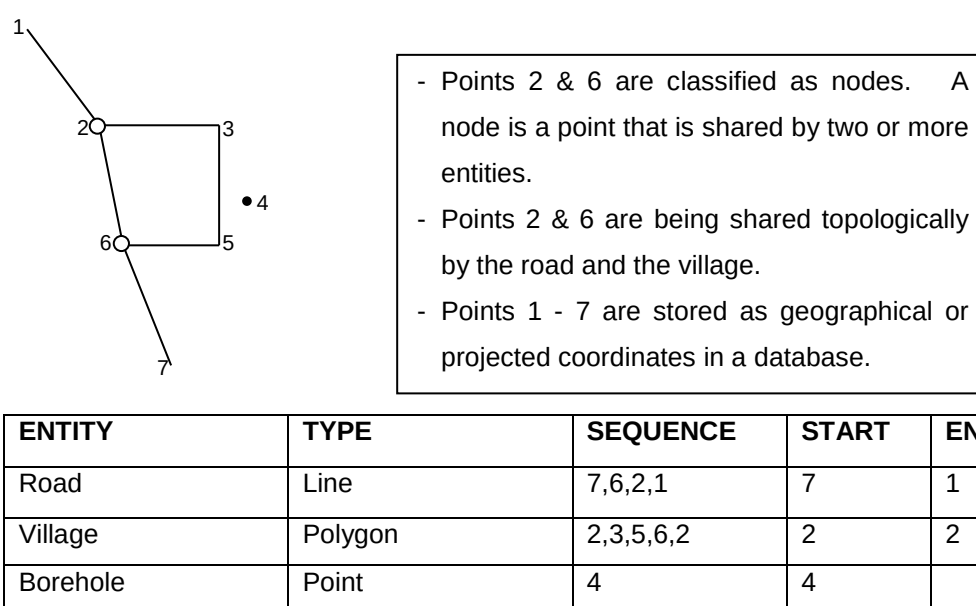


Figure 5.36: Representation of geographical entities in a topological database
Source: Adapted from Aronoff (1989:175)

The basic structure of a raster dataset consists of a matrix of rows and columns, the combination of which presents an array of cells (see Figure 5.5). Also referred to as pixels, these cells represent a field of values representing a geographic phenomenon. Each pixel carries a specific value in terms of the feature that it represents and the distinct combination of pixels in terms of individual or grouped values will return strings of connected cells as lines, or aggregated cells as a surface or an area. The illustration in Figure 5.6 shows the visualisation of values in the raster by means of a distinct colour for each value.

15	15	15	15	100	100
100	100	100	100	100	100
100	100	100	100	25	25
175	175	25	25	25	25
175	175	25	25	25	25

Figure 5.37: Example of pixel values stored in a matrix of rows and columns



Figure 5.38: Visualisation representation of pixel values by colour (refer to Figure 5.5)

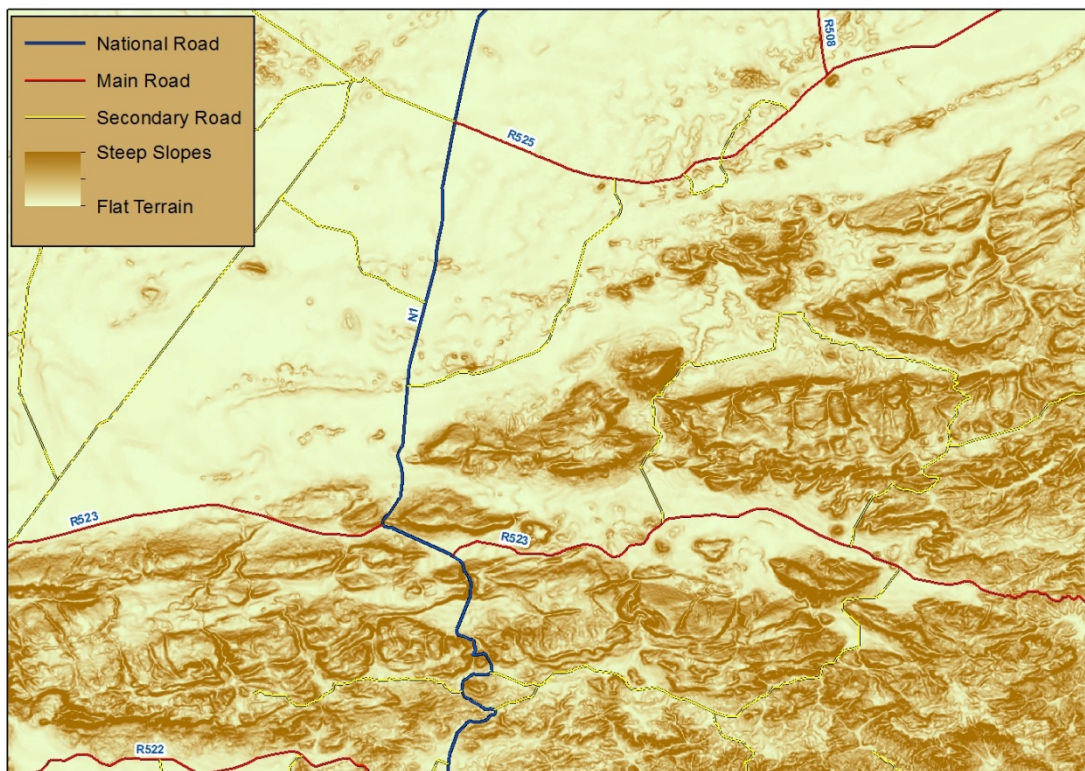


Figure 5.39: Visualisation of raster data (elevation) and vector data (roads) on a topographical map

The power of GIS lies in the capability of spatial analysis. Looking at the roads and the topography on the map in Figure 5.7, the map itself can be visually interpreted to identify sections of road that are influenced by steep slopes. Visual interpretation of a map product is however limited, especially if large geographical areas with a large number of features are to be studied. Being an information system with data structured in a database, the GIS database can be interrogated to determine, calculate and isolate those sections of road for further analysis, for example: *extract the sections of road that are exposed to slopes steeper than 6 degrees and put those in a new data file*. The new data can furthermore be overlaid on soils data where the stratification of soils is analysed in terms of the risk of land slides.

5.5.2 Human cognition of the spatial world

Problems exist with regard to the conceptualisation of the geographic world in a technical domain, such as in geographic databases. The key to a better understanding is in human cognition, i.e. the way in which people experience and deal with the geographic world (Couclelis, 1992:65). Cognitive science seeks to understand the processes of cognition,

the functioning of the mind and the nature of intelligence. According to Montello (2005:62), cognitive research in GISc “will lead to improved systems that take advantage of an understanding of human geographic perception and conception, including that of spatial and geographic ‘experts’.”

The representation of data within a cognitive context combines elements of Psychology with the way in which humans cognitively represent geographic-scale environments (Mennis *et al.*, 2000:502). However, cognitive subjects, in an approximated state, are liable to error and uncertainty and are best resolved when the objects towards which human cognition is directed, are seen as parts of reality (Smith, 1994:1). Smith argues that objects can be divided, in reality or in thought, into spatial parts. He introduces the concept of ‘extended entity’ and distinguishes between objects extended in space and processes, with process extended in time. Both consist of ‘inner’ and ‘outer’ boundaries, as is illustrated in Figure 5.8.

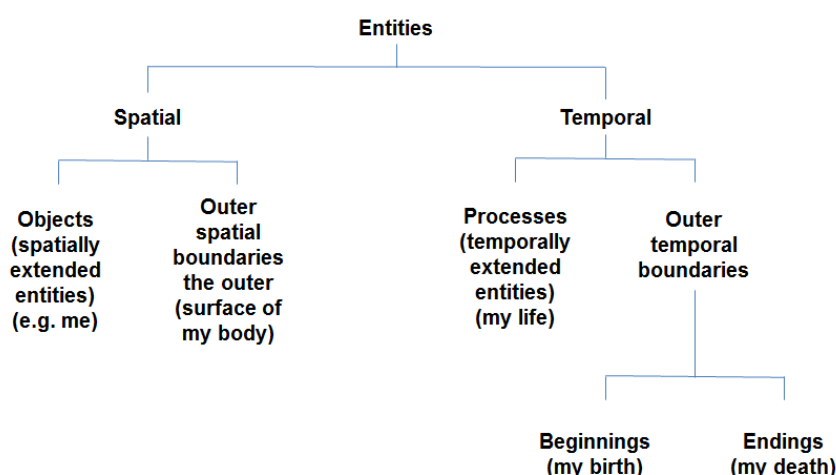


Figure 5.40: The concept of extended entity as human cognition of spatial objects
Source: Smith (1994:2)

5.5.3 Abstraction and issues of accuracy, quality and uncertainty

The world, as it is comprised of natural and man-made objects, is infinitely complex. Viewed from outer space, Earth would appear as a sphere, and as one draws closer, more detail would appear; first colour, then shape, then texture and form. Based on human cognition, texture and form are interpreted as discrete objects in the world. In GIS, these objects are represented in a spatial database. The real world is therefore viewed through the medium of the database. To be useful in a specific application, the database must be relevant in terms of the level of cognition. For example, on a small

scale, a city would be expected to be modelled by its outline, and not by a point symbol. This highlights the fact that Euclidean points, lines and polygons do not exist in the natural, full-scale geographic world (Coucleis, 1992:66).

GIS ontologies are concerned with the boundaries of geographic objects, as these are subject to vagueness, which complicates their representation (Galton, 2003: 156; Kavouras & Kokla, 2008). Features such as mountains and rivers are intuitively reckoned as geographic features, but how are their boundaries defined? (Duckham, Goodchild & Worboys, 2003; Smith & Mark, 2003). Cognitive conceptions such as mountains exist because of human partition, based on the recognition of some form and dimension. Smith (1994) introduces the concept of 'fiat' and 'bona fide' objects, based on the conception of boundaries. Earth, as an object, has the qualitative of heterogeneity, of material constitution (Smith, 1994), and is demarcated from its surroundings independently of human partitioning activity (Bittner & Smith, 2003). On this basis, it exists as a bona fide object. The partitioning of Earth into a northern and southern hemisphere, or the demarcation of land into political borders or districts, presupposes imaginary lines that are regarded as fiat boundaries (Smith, 1996:104; Bittner & Smith, 2003:119). Fiat objects, therefore, only exist because of human partitioning activity.

On this distinction, Galton (2003) creates a classification of 'physical' and 'institutional' boundaries (albeit different in some respect from Smith). According to Galton (2003:152) "[a]ll boundaries exist by virtue of the distribution of matter and energy in space and time, but boundaries may differ as to just how their existence depends on such distribution". Arbitrary boundaries created intentionally by individual or collective human activity, are institutional boundaries. All other boundaries are physical boundaries.

Galton (2003) further classifies physical boundaries into material and epiphenomenal boundaries. The first is composed of matter. The second exists by virtue of the distribution of matter in space and time, but is in itself not made of matter. An example is a woodland and an adjacent grassland. The boundary between the two exists solely by virtue of the distribution of woodland and grassland, and how it is cognitively observed – hence it is an epiphenomenal boundary. If a stone wall is built on the division between the woodland and grassland, the wall is a material boundary, cognitively associated with the division between the two types of land (Galton, 2003:153).

Material boundaries are further classified into 'separation zones' and 'transition zones'. Separation zones are characterised by distinct differentiations between two adjacent

zones, which would easily define the location of the wall, as mentioned in the above example. A transition zone is characterised by gradation between the regions on each side and the separation zone itself, where elements of both sides occur in the separation zone (Galton, 2003:154). An example is the separation of climate zones.

Couclelis (1992:65) states that “the technical question of the most appropriate data structure for the representation of geographic phenomena begs the philosophical question of the most appropriate conceptualization of the geographic world.” The above analysis illustrates the complexity of modelling the real world. In terms of data management, it raises issues of accuracy, error, quality and uncertainty, which are defined by Messina *et al.* (2008:14) as follows:

“accuracy: a general term for the degree to which a spatial data set conforms to the idealized phenomenon, as specified by the conceptual model. The means by which this may be quantified depends on various factors, including the conceptual model itself, the application domain, associated data quality specifications, and the type of available reference information, if any.

Error: the difference between the actual condition of the measured spatial phenomenon and its representation in the data set. ‘Actual condition’ implies an independently collected reference measure to compare against a portion of the data set. The comparison may be complicated by mismatches between the ontological bases for the spatial data set and the reference data set (Bishr 1998; Fonseca, Davis, and Camara 2003), inaccuracies in the reference, and the relatively restricted set of sampled locations over which reference information are typically available.

Quality: synonymous with accuracy, but more applied in data production and distribution. Generally describes a variety of specified factors with possibly quite different quality measures. Much government produced or funded spatial data must meet particular quality specifications in order to be approved for distribution (FGDC 1998). For US federal government data, documented data quality components are positional and attribute accuracy, logical consistency (such as topological characteristics), completeness, and the source materials, or lineage (Veregin 1999). Increasingly data quality is couched in fitness for use terminology; however, it remains unclear how this mandate is to be met.

Uncertainty: for spatial data, this is the degree to which the fidelity of the data to the phenomenon at a location is open to question. In the words of Unwin (1995), it is a measure of doubt. Employing a stochastic conceptual model of the phenomenon of interest, uncertainty is the degree of variability we attach

to data values. Spatial data may also be subject to uncertainty due to vagueness in category definitions such as land cover classes (Fisher 1999)."

5.5.4 Spatial relationships

Longley *et al.* (2005:8) ask the question 'why is spatial special?' In the context of GIS, space relates to location on the Earth's surface, i.e. geographic space. Hence, the term 'geospatial' is often used. But why is it special? Human activity and decisions involve space, hence providing a geographical component. Furthermore, geographic entities have spatial associations or relationships. Waldo Tobler is quoted extensively in geography (Miller, 2004:284) for what he calls "the first law of geography: everything is related to everything else, but near things are more related than distant things" (Tobler, 1970:236). Tobler used this principle in the development of urban growth simulation models, a principle which has become known as Tobler's First Law (TFL). It is used to indicate that the attributes of places that are near to each other tend to be more similar than attributes of places that are far apart (Janelle & Goodchild, 2011:34). This concept is a core aspect of neighbourhood analysis.

Miller (2004) undertakes an in-depth analysis of TFL and highlights three core applications with regard to spatial analysis. First, it reveals the spatial associations among geographic entities – a concept called spatial autocorrelation. This is a quantitative technique for analysing correlation relative to distance or connectivity relationships. Second, TFL is used as an analytic technique to undertake spatial interpolation, which is a technique for generating unknown values between two known locations. An example is the interpolation of elevation values between two contour lines, to create a Digital Elevation Model (DEM) (refer to the field view, as discussed above). Lastly, TFL is useful for guiding research specifically with regard to future development, as is noted from its use in temporal GIS (space–time) analysis.

The aspects of spatial relationships and database structures have been a key research area since the establishment of the University Consortium for Geographic Information Science (UCGIS) in 1994 (Goodchild, 2004), and is a key aspect of the development of a data model in Chapter 8.

Connectivity relationships are mathematically related to set theory (Kainz, 2010). Spatial features represented as points, lines or polygons can be regarded as sets. Overlay

operations in GIS correspond to the different ways of set interaction, i.e. intersection, union, difference and complement. The application of set theory in GIS is illustrated below.

Given two datasets, A and B, these can be analysed in different ways, as is illustrated in Table 5.1.

Table 5.1: The principle of set theory explained in terms of GIS datasets

Operation	Notation		Result
A intersect with B	$A \cap B$	Returns the overlap of A with B	A value must be in both sets
A union with B	$A \cup B$	Returns all of A plus all of B	A value is in either set
The difference of A and B	$A - B$	Returns only A	A value is in one set (A) but not the other (B)

Overlay operations in GIS are among the most common functions in GIS, and provide for powerful spatial analyses (Kainz, 2010:29). The power lies in identifying spatial relationships between entities that are denoted in terms of four main geometries:

- i. Equals – the geometries of overlying entities are the same.
- ii. Disjoint - entity geometries share no topology and are related in terms of distance.
- iii. Intersects – entities overlay partially with intersected geometries.
- iv. Touches - entity geometries intersect at their boundaries.

The relationships between spatial entities constitute a key aspect of the model that is presented in Chapter 8. The concept of entity relationships and its modelling in a database environment are discussed in more detail in Section 5.5.6.

5.5.5 GIS and relational database concepts

Geographic information consists of spatial and thematic (non-spatial) components. The spatial component represents data as independent layers of different themes, or as a single space-composite layer that integrates all thematic information into the largest areas so that all attribute values are spatially homogeneous within each area. The non-spatial component describes individual geographic entities with linked spatial and non-spatial properties (Yuan *et al.*, 2005). GIScience largely explores the spatial component, as discussed in the sections above, while it largely ignores the non-spatial component.

Kuhn (2012:2268) distinguishes between *spatial thinking* and *spatial information*, with the latter including non-spatial information concepts such as meaning and value. Without

location, data would be regarded as non-spatial or aspatial (Longley *et al.*, 2005:110) and is only of value outside of GIS. However, once such data is geo-coded, or geo-referenced, it becomes part of the spatial domain. In other words, all data that relates to defined geographical places or features (points, lines or areas in vector format data or grid-cells or pixels in raster format data) can be integrated within GIS, irrespective of their origin (MacFarlane, 2005:32). The spatial-aspatial link of data relates the concept of relationships and relational databases, as defined in database theory.

Within the context of information systems, all data is stored in one or more files and managed by a database management system (DBMS) (Shekhar & Vatsavai, 2008:111; Rob & Coronel, 2009:6). Shekhar and Vatsavai rightfully comment that “[d]atabases and the software which manages them are the silent success story of the information age”. A database is a shared, integrated computer structure that stores a collection of data (Rob & Coronel, 2009:6). A database management system (DBMS) is a collection of programs that manages the database structure and controls access to the data stored in the database (Rob & Coronel, 2009:7). Throughout history, a number of database file systems were developed, notably the network, hierarchical and relational DBMSs. Of these, relational database management systems (RDBMS) have gained widespread popularity (Shekhar & Vatsavai, 2008:111). The database management systems approach enforces certain rules that protect the integrity of the data (Yuan *et al.*, 2005:129) and provide structure, which is necessary to query and process the data. In this regard, database design becomes important, as it focuses on the design of the database structure that will be used to store and manage the data for the use, as intended by the information system (Rob & Coronel, 2009:10). In view of relationships, which are key to understanding GIS, two related concepts deserve attention: the relational database model and the entity relationship model.

5.5.6 The Relational Database Model

The relational database model is an important concept in database theory, as it appeals to the notion of relationships between things (Darwen, 2009:18). The model was introduced in 1970 by E.F. Codd, and represented a breakthrough for both users and designers at the time (Rob & Coronel, 2009:38). The model is founded in the mathematical concept known as a relation (refer to Figure 5.9). In its simplest form, it can be described as a matrix or a table (*relation*) composed of intersecting rows (*tuples*) and columns (*attributes*). The *cardinality* is the number of tuples in a relation, and the *degree*,

the number of attributes. The contents (data) represent the *attribute values*. The *heading* is the set of attributes. The *body* is the set of tuples. An important rule is that no attributes or tuples may be duplicated in the relation (Darwen, 2009:21). A key characteristic of a relation is that each tuple can be uniquely identified by virtue of a *key attribute*. This becomes important when two or more relations are linked, either with each other or with spatial objects.

The relational data model is implemented through a relational database management system (RDBMS), which deals with all of the physical details during construction, while the user observes the database as a collection of tables consisting of rows and columns (Rob & Coronel, 2009:38). The RDMS provides an interface between the end-user and the data, which is used to create or change database files, capture or edit data, and extract or process data for use as information. The design of a database incorporates three phases: conceptual, logical and physical. The next sub-section will focus on the aspect of conceptual design and the use of entity relation diagrams as a visual tool for the representation of different data entities, using conventions that describe how these entities are related to each other. This framework will be used later in Chapter 8 as an analogue to develop a data model.

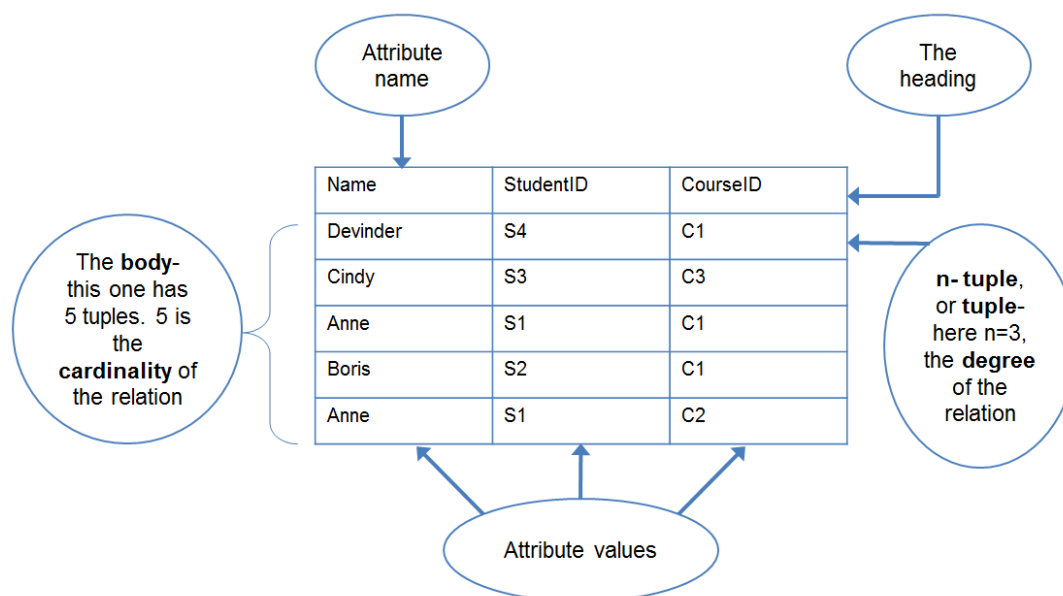


Figure 5.41: The anatomy of a relation
Source: Darwen (2009:21)

5.5.6.1 The Entity Relationship Model

To examine database structures and assist in the design, Peter Chen introduced the *Entity Relationship Model* (ERM) in 1976. It is a graphical representation of entities and their relationships in a database structure, and functions on the conceptual level of data abstraction. A relationship is an association between two or more entities. Attributes describe characteristic values of entities and relationships (Kainz, 2004:32; Rob & Coronel, 2009:38, 48). Three main types of relationships exist: one-to-one (1:1), one-to-many (1:M), and many-to-many (M:N). In terms of database design, the M:N relationship is not supported as this may lead to duplicate tuples, which is not allowed. This should be dissolved through a dual 1:M structure. On the conceptual level, connectivity labels are used in an entity relationship diagram (ER diagram) to visualise relationships (Rob & Coronel, 2009). (Refer to Figure 5.10.)

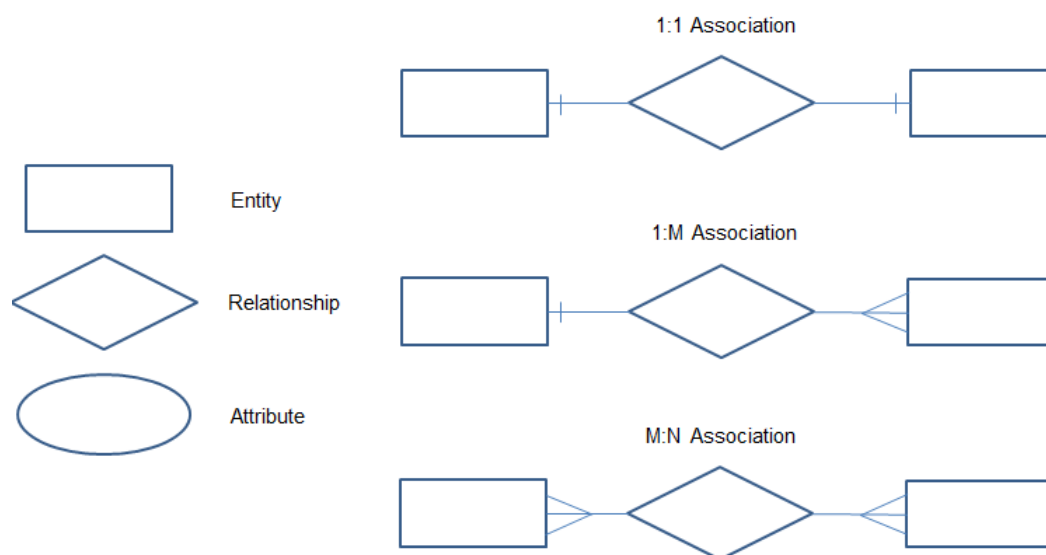


Figure 5.42: Basic notation used in ER diagrams

Standard notations in the ER diagram are used to conceptualise entities, their attributes and relationships in such a manner that it defines the database as a schema (Kainz, 2004:32). The ER diagrams in Figure 5.11 demonstrate the progression of an ER diagram from its first conception to the final relational database model. The schemas represent the following hypothetical scenario:

One community, identified by its name and the number of households, utilises certain forests, identified by their size, to extract medicinal plants from certain vegetation types, identified by the vegetation types that grow in the forests. A database must be

designed that will capture the attributes for each entity. The addition of an attribute may not change the integrity of the database.

The schema in (a) identifies the three entities and their relationships. Basic attributes describe the entities. The schema in (b) identifies the type of relationships as follows:

- Community and Forests = 1:M
- Vegetation and Forests = M:N, which results in the duplication of tuples in the relation

The schema in (c) resolves the M:N relationship by adding an additional entity, which incorporates the ID Fields of both entities. This results in a compound key attribute that accommodates more than one vegetation type for each of the forests. The combination of IDs is unique with no duplicates. The final design represents the following relationships:

- Community and Forests = 1:M
- Vegetation and Forest Vegetation = 1:M
- Forest Vegetation and Forests = 1:M

A main characteristic of ERM notation is the use of a noun to describe an entity, and a verb to describe the relationship that is indicative of activity. This characteristic is expanded in Chapter 7 to develop a data model that integrates the disciplines being studied in this research.

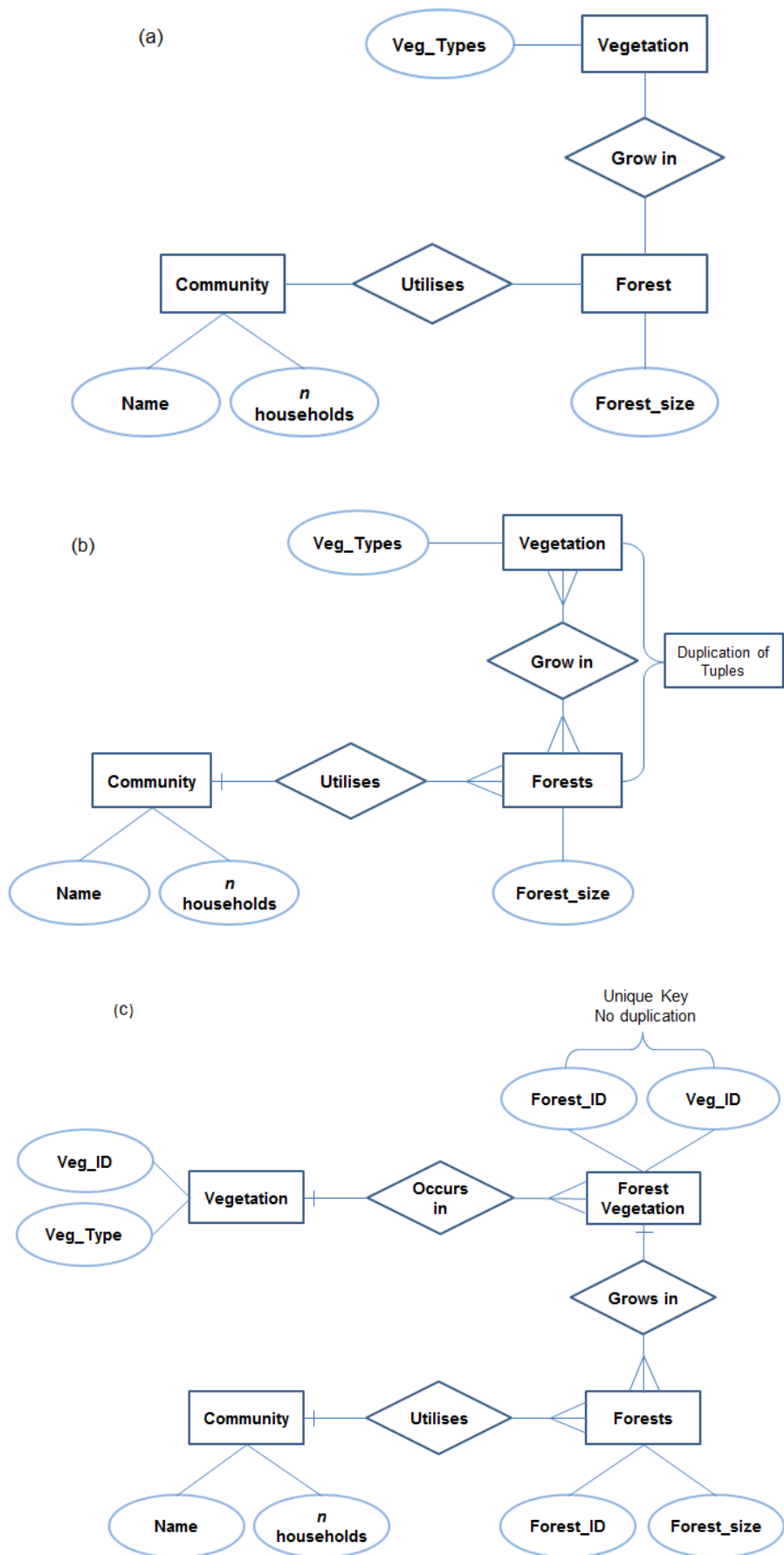


Figure 5.43: Illustration of ER diagram development

5.5.7 Information and knowledge as a product of data

The meaning of data, information and information systems was explored in Section 3. The fundamentals of these concepts are further applied in respect of GIS. Data does not exist by itself, and needs to be created as an abstraction of reality (Comber, Fisher & Wadsworth, 2005; Longley *et al.*, 2005; Harvey, 2008). Comber *et al.* (2005) define data as “the result of measurement of some agreed phenomenon”. Data needs to be contained as text or numeric values in a database, designed for the specific purpose to host the data in a particular structure. For it to become useful, it needs to be processed.

The fundamentals of information systems are anchored in the concept of data processing. As was mentioned in Section 5.3, data may be described as raw facts, which, when arranged in a meaningful manner, become information. Information is therefore a collection of specifically organised facts that have additional meaning beyond the value of the facts themselves (Stair & Reynolds, 2009:5).

An information system is the link between the providers of data on the one hand, and the users of data on the other hand (Willis, 1974). The question is, how can data become useful to the user and what should be the role of an information system? According to Stair and Reynolds (2009:6), information is the result of a process where data is transformed into information. This requires a set of logically related tasks that are performed (with the aid of computer technology) to achieve a defined outcome. Understanding these tasks, and the relation between data items, requires knowledge. This knowledge is domain specific and in terms of disaster risk management it implies knowledge about an array of related fields such as development planning, community health, infrastructure design, etc. Stair and Reynolds (2008:6) define knowledge as “the awareness and understanding of a set of information that can be made useful to support a specific task or reach a decision”. The relationship between data, knowledge and information is illustrated in Figure 5.12.

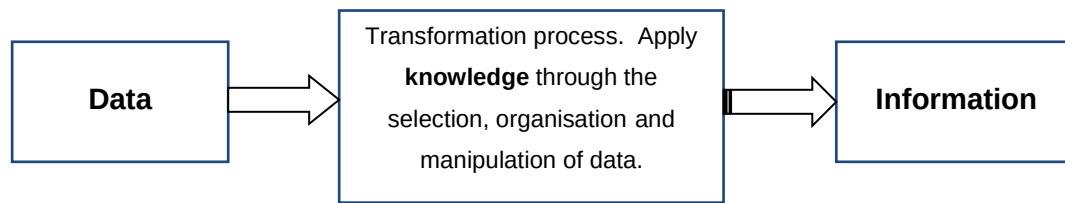


Figure 5.44: The Information Process

Source: After Stair and Reynolds (2009:6)

Information needs to conform to certain characteristics to be valuable to a user. These characteristics are common to all types of information and, according to Stair and Reynolds (2009: 7), include the following:

- i. Accessibility
- ii. Accuracy
- iii. Completeness
- iv. Economic viability
- v. Flexibility
- vi. Relevancy
- vii. Reliability
- viii. Security
- ix. Simplicity
- x. Timeliness
- xi. Verifiability

For understanding the relationship between data, knowledge and information, an information system can be defined as a set of interrelated components that manage and carry out the process of data collection, data processing and dissemination of the resultant information. Bentley and Whitten (2007:6) define an information system as

“an arrangement of people, data, processes, and information technology that interact to collect, process, store and provide as output the information needed to support the organisation”.

Realising that this is an ongoing process, especially where updating of information is important, it becomes a cyclical process of continuous information management, as is illustrated in Figure 5.13. The validation of information is a required step to evaluate its usefulness in terms of organisational goals. This knowledge is fed back into the system

as approval or flagging for improvement. Information that has been validated and accepted is disseminated to its users, in the format as required by them.

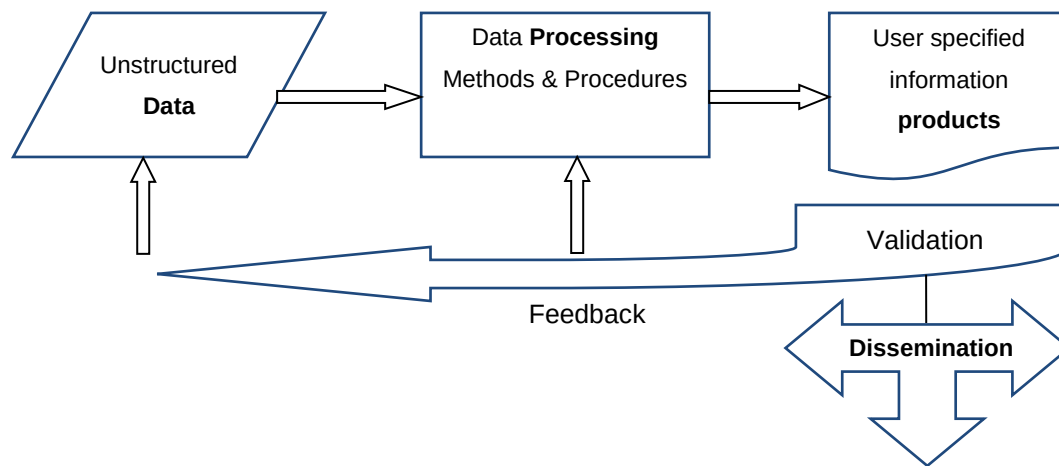


Figure 5.45: The cyclical process of information management

Burch and Grudnitski (1986:37) define six building blocks of an information system, i.e. *input, models, output, technology, database* and *controls*. These building blocks should relate to the management goals they serve, and should not be purely a display of technological innovation. The building blocks are briefly described as follows:

- i. **Input** represents data in raw format, including text, voice and images. Each is captured and entered into the information system by means of specific methods, making use of the technology of the day.
- ii. **Models** consist of a combination of procedural, logical or mathematical models that manipulate input and stored data. In general, this is referred to as data processing.
- iii. **Output** is the product of the information system, and guides and influences the design of an information system to a large extent. Importantly, output cannot be better than input and the models that were used to produce it. It is therefore essential to take into account the user requirements in terms of the outputs that are expected when designing the models and input.
- iv. **Technology** is the 'toolbox' that is used to perform actions within an information system. It provides the platform for capturing input, driving models and producing output. Technology also comes into play in the transmitting or dissemination of output. This building block is extremely dynamic and exposed to technological innovation and improvement that change constantly. Care

must be taken not to regard technological products as 'information systems' in themselves. Such an approach is fatal, especially where budgets provide only for the acquisition of hardware and software (failing to recognise the cost of data), and the training or appointment of staff to manage and operate the system.

- v. **The database** is the structural element where all the data is stored. Database design is crucial and incorporates two basic elements: physical and logical design. The physical component involves the storage media such as disks, magnetic cards and chips. How to access the data, search for and retrieve selected entities is a matter of logical design. If designed and structured correctly, the timely, relevant and accurate retrieval of information is achieved.
- vi. An often neglected part is the safeguarding of an information system. Information systems are vulnerable to a variety of hazards and threats, from natural events such as fire, to malicious or careless actions of people. The threat of viruses, hacking, inadequate operational procedures and incompetent personnel requires the implementation of **controls** to ensure the protection, integrity and smooth operation of an information system.

Within an organisation, information systems provide output on two levels, i.e. the management and operational level. On an operational level, individuals send and receive data in accordance with their organisational tasks. On a managerial level, decision makers converge to interpret data in response to a problem (Daft & Lengel, 1986). Likewise, on a top organisational level, managers/directors will interpret data in response to strategic planning challenges. On the basis of this division, a typology of information systems is described by McLeod (1990:302, 340, 411) and Van der Vlugt (1989:462). The following types of information systems are mentioned:

- i. Transaction Processing Systems
- ii. Decision Support Systems
- iii. Management Information Systems
- iv. Expert Systems

A **transaction processing system** is used in day-to-day operational tasks of an organisation and is focused on data processing. This would entail the capturing of new data or the retrieval of standard information, e.g. a list of names. The information is used in the preparation of reports for management purposes.

The purpose of a **decision support system** is to assist with decision making and it is focused on finding solutions for particular problems. Essentially, these types of systems are used on a management level and are designed for particular aspects within an organisation.

Management information systems refer to a wider continuum of coordinated subsystems that are integrated to transform data in a variety of ways. The focus is on specific outcomes requiring specific criteria for data processing and analysis. A typical example in the disaster management domain would be the integrated use of GIS and an Incident Command System.

Marksjo (1986:266) describes an **expert system** as “a piece of computer software giving the illusion of being a human expert within a restricted field of competence”. This type of information system includes artificial intelligence and is pre-programmed with expert knowledge and experience in a particular field. By applying a set of rules, it is able to fulfil the tasks of human operators. A typical example of expert systems is weather forecasting systems.

The above typology of information systems is indicative of their association with specific tasks on different levels within an organisation, informing a wide range of users. Given the multi-disciplinary nature of disaster risk management, where functions and responsibilities lie across a spectrum of agencies, units and departments, it can be concluded that different types of information systems are needed, where these have specific functionalities for specific objectives in mind. It is also concluded that the development of these systems should be firmly based on the fundamentals of information systems as described above.

5.6 GIS FUNCTIONS

The interface between the user of GIS and the GIS technology functions as the user's expression of a task within the context of an activity and the sequence of operations within a GIS (Timpf, 2003:241). In this context, GIS is briefly defined as having in place computer hardware components with sufficient storage and processing power, software with the ability to undertake spatial operations, a database of spatially referenced and linked attribute data contained in the computer storage medium, skilled personnel, and a proper organisational context (Fischer, 1994:2). The organisational context defines the tasks and activities that need to be undertaken by the user. The interface with the GIS

lies in the abilities of the user to interpret the information needs of the user environment in terms of anticipated GIS operations. GIS operations, also referred to as spatial operations, refer to the computer-based manipulation of geographical data through which information is generated (Jansen van Vuuren, 2013). Spatial operations encompass all GIS functions that are carried out to perform specific tasks.

Albrecht (1995) proposes a taxonomy of fundamental GIS operations that can be applied, regardless of the structure of the data and the GIS software applied. He differentiates between goals, tasks and functions, which are organised in a hierarchical order, with geographical data being the enabler allowing for the performance of functions and tasks with a specific goal in mind. Albrecht (1995) places these in a hierarchy of organisational goals, such as land management, which involves tasks such as flow analysis. To perform these tasks, GIS functions such as nearest-neighbour analysis are undertaken, making use of specific data (see Figure 5.14). Berry (2005:10–6) summarises these in three elements: data, operations and applications.

ORGANISATIONAL GOALS ← TASKS ← GIS FUNCTIONS ← DATA

Figure 5.46: Schema of organisational tasks and related GIS functions

Albrecht identifies a list of 144 universal GIS functions, many of which are related. For example, the function 'Data Editing' is related to a number of functions, i.e. 'Distortion Elimination', 'Sliver Polygon Removal' and 'Line Thinning / Smoothing' (Albrecht, 1995:242). These functions can be classified in analytical and non-analytical functions. The previous examples are non-analytical functions related to data manipulation. An example of an analytical function is 'Neighbourhood Analysis', which is related to 'Nearest Neighbour Search'. Albrecht (1998) further summarises analytical GIS operations in six categories of functions (Table 7.2) and describes each in detail.

Table 5.2: Conclusive list of universal analytical GIS operations

Category	GIS Operation
Search	Interpolation; Spatial Search; Thematic Search; Reclassification
Locational Analysis	Buffer; Corridor; Overlay; Thiessen/Voronoi
Terrain Analysis	Slope/Aspect; Watershed; Drainage/Network; Viewshed
Distribution/ Neighbourhood	Cost/Diffusion/Spread; Proximity; Nearest Neighbour
Spatial Analysis	Multivariate Analysis; Pattern/Dispersion; Centrality/Connectedness; Shape
Measurements	Measurement

Source: Albrecht (1998)

Despite some polymorphisms where certain operations carry different names in various domains, these operations represent the conclusive list of user-oriented, analytical, universal GIS operations (Albrecht, 1998). Built on this premise, Timpf (2003) proposes the geographic activity model. The intention of the model is to store information about user activities, task chains and corresponding operations. These operations represent the building blocks of all geographic tasks within a certain application area (Timpf, 2003:243).

Jansen van Vuuren (2013) proposes a framework for rapid impact assessment, within which various GIS functions are demonstrated in a case study of wildfires. He illustrates how these functions relate to specific tasks, with the goal of determining the extent of burned areas and the identification of impacted property and vegetation types. The use of satellite imagery to extract raster data and the integration of these with vector data are demonstrated. A model indicating various functions and iterations of data processing demonstrates aspects of abstraction, representation, processing and visualisation of discrete objects and field data. This framework will form a basis for further development, as presented in Chapter 7.

5.7 CONCLUSION

Geographic information systems (GIS) technology was described in Chapter 5 as a spatial-orientated information system that is grounded in the principles of information systems theory. The chapter gave an overview of the origins of GIS, highlighting it as a

relatively new computer-based technology. The context of GIS as an information system and the focus on the representation of geo-spatial objects in a spatial database (using various models of conceptualisation) are emphasised. This chapter also explored the development of the concept of GIS science and defined its theoretical grounding.

The functioning of GIS relates to specific goals in the field of application, which is an imperative for database design and incorporates identified relationships. The notion of spatial relationships is a key aspect of this study and its understanding is necessary for the development of the GIS-based data model in Chapter 8.

GIS technology supports development planning, environmental management and disaster risk reduction. It can be regarded as an entry point where these disciplines meet in an intra-relationship. To further examine this premise, the next chapter examines various frameworks that describe the functioning of these disciplines, with examples of GIS implementation.

CHAPTER 6: INDICATORS, FRAMEWORKS AND MODELS OF VULNERABILITY, SUSTAINABLE DEVELOPMENT AND THE ENVIRONMENT

6.1 INTRODUCTION

Development increases vulnerability to disaster through unintentional consequences that have an impact on and weaken the social, ecological or economic fabric of a society that allows systems to absorb and rebound from disaster events (Brett & Oviatt, 2013:60). The 2011 Global Assessment Report on Disaster Risk Reduction (GAP, 2011:6) states that “[e]xtensive risk exists wherever development occurs, and it is directly constructed by risk drivers such as badly planned and managed urbanization, environmental degradation and poverty”. The connection between disaster risk, poor development planning and environmental degradation has been described in previous chapters (Chapters 2, 3 and 4). The recognition that disaster is predominantly an indicator of unsustainable development, points to a shift in focus from reduction efforts to addressing the drivers of development that lead to the intensification of disaster risk in the first place (Lavell & Maskrey, 2014). The concept of *risk drivers* deserves more attention, specifically the way in which these can be measured from different perspectives. Mitchell (1996) states that, in the field of sustainable development, the debate has moved from the issue of definition to one of measurement. The same is true in respect of vulnerability, where the development of frameworks and indicators indicate a paradigm shift from quantification and analysis of hazards to the identification, assessment and ranking of vulnerabilities (Birkmann, 2006b:9). This highlights the need to assess and measure the various dimensions and dynamic nature of vulnerabilities, as suggested by Birkmann, Kienberger and Alexander (2014:19). The use of frameworks and indicators allows for valuable comparative analysis to take place and provides insight into the many ways a country, state or region could be vulnerable (Malone, 2009:9).

Various frameworks and indexes have been developed to model vulnerability and sustainable development as elements of a *conceptual cluster* for integrative human–environment research (Newell *et al.*, 2005; Füssel, 2007). This includes the Pressure-State-Response (PSR) model of environmental impact (OECD, 1993), which reminds of the PAR model; the Expanded-Vulnerability Framework (Turner *et al.*, 2003b); the Social Vulnerability Index (SoVI) developed by Cutter *et al.* (2003); the CSD indicators and DSR framework for sustainable development by UN-DESA (2007); the disaster resilience of

place (DROP) model by Cutter *et al.* (2008); the SeVI model by Holland (2011), and the MOVE framework by Birkmann *et al.* (2013). Vulnerability frameworks are also developed for specific hazards, such as the Extreme Heat vulnerability framework developed by Wilhelmi and Hayden (2010) and vulnerability indicators for flood disasters by Kuhlicke *et al.* (2011). These models and frameworks are contextualised by authors such as Birkmann (2006b), Lundgren and Jonsson (2012), and Arma  and Gavri  (2013).

An overview of a selected few is useful to draw from current approaches and provide a bridge to the development of a data model in Chapter 8. This chapter gives an overview of indicators and frameworks described in literature for the purpose of identifying commonalities between disaster risk management, environmental management and development planning. It provides a structuralist view of the elements that define vulnerability and environmental sensitivity, and helps to identify the underlying relationships with the larger, overarching socio-environmental system.

Chapter 6 first defines the meaning of 'indicators' and 'frameworks', to highlight their importance in science and practice. Thereafter, three groups of frameworks are explored: vulnerability, sustainable development, and environmental frameworks. This will be followed by a description of GIS-based frameworks to provide a focus on different spatial-orientated approaches, and a conclusion.

6.1 INDICATORS AND FRAMEWORKS

The theoretical grounding of indicators and frameworks are discussed in the next sub-sections.

6.2.1 Indicators

The interest in measurement and indicators in social science developed in the early 1970s is described in depth by the editors and co-authors of the volume *Toward a metric of science: The Advent of Science Indicators* (Elkana *et al.*, 1973). They advocate the use of quantitative measurements in the science of sociology. This development introduces an inter-disciplinary approach, as reflected by the representation of different disciplines in this volume, including mathematics, economics and statistics.

An indicator can be defined as “a parameter or a value derived from parameters, which provides information about a phenomenon” (OECD, 1993:5). According to Jörn Birkmann (2006a), indicators are defined differently by different authors. Within the discourse of measuring sustainable development, for example, it is defined as “a sign that summarises information relevant to a particular phenomenon”. Vulnerability or hazard indicators, on the other hand, are defined as “a variable which is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event linked with a hazard of natural origin” Birkmann (2006a:57). Indicators, and in general scientific indicators, are a necessary part of the stream of information we use to understand the world (Meadows, 1998:1). They serve as modes that shape knowledge and order values (Yehuda *et al.*, 1973:5) and can be used to make a particular statement with regard to a particular issue (Birkmann, 1999:121).

In science there is a large body of literature on indicators and their use in decision making (Turnhout, Hisschemöller & Eijsackers, 2007:216). Indicators are used widely to monitor complex systems (Elkana *et al.*, 1978:1; Meadows, 1998:1). For example, in an aircraft, the air speed indicator monitors the speed of airflow over the wings, which is required to maintain flight. Medical personnel use a thermometer to monitor the body temperature of a patient. In both examples the particular indicator values are not just an indicator of speed or body temperature, but an indicator of state, i.e. safety or health (refer to Niemeijer and De Groot, 2008:15 in respect of health indicator). Furthermore, they are also indicative of thresholds below or above which life-threatening situations can evolve. Indicators have significance that extends beyond the properties directly associated with the parameter value. Indicators therefore possess a synthetic meaning and are developed for a specific purpose (OECD, 1993; Stevens, 2005; Boulanger, 2008). Indicators are not only used to describe, but also to undertake comparative analysis and assessments (Birkmann, 1999:122).

The primary function of indicators is to communicate. As such it demands simplicity to reduce the complexity of reality and provide critical information about the condition of something. Indicators also have the defining character of quantifying information so that its significance is more readily apparent (Hammond & Woodward, 1995; Smeets & Weterings, 1999:5). Hammond & Woodward (1995:1) state that indicators “communicate information about progress toward social goals such as sustainable development”. They present a means of communication by reducing the number of measurements and parameters that normally would be required to give an exact presentation of a situation,

and simplify the communication process by which the information of results of measurement is provided to the user (Hammond & Woodward, 1995:1; OECD, 1993:5). Whereas indicators represent an empirical model of reality, they are not reality itself. Nonetheless, they must be analytically sound and have a fixed methodology of measurement (Hammond & Woodward, 1995:1). The progression from primary data level to indicator level is illustrated in Figure 6.1.

Indicators are produced and used by scientists and groups having varied priorities, programmes and preoccupations, and dealing with a plurality of sciences (Yehuda *et al.*, 1973:3). Indicators are developed with a particular goal and purpose in mind (Birkmann, 2006a:59). Birkmann distinguishes two main types of indicator–goal relations. The first relates to a focus on the direction a development is taking. The assessment of development trends allows one to evaluate their vulnerability. An increasing or decreasing development trend would indicate a higher or lower vulnerability. Second, a set of indicators would focus on a specific target that shows whether the development has reached the defined goal. In terms of vulnerability, for example, such a goal would be to confirm vulnerability according to a pre-defined standard (refer to Figure 6.1).

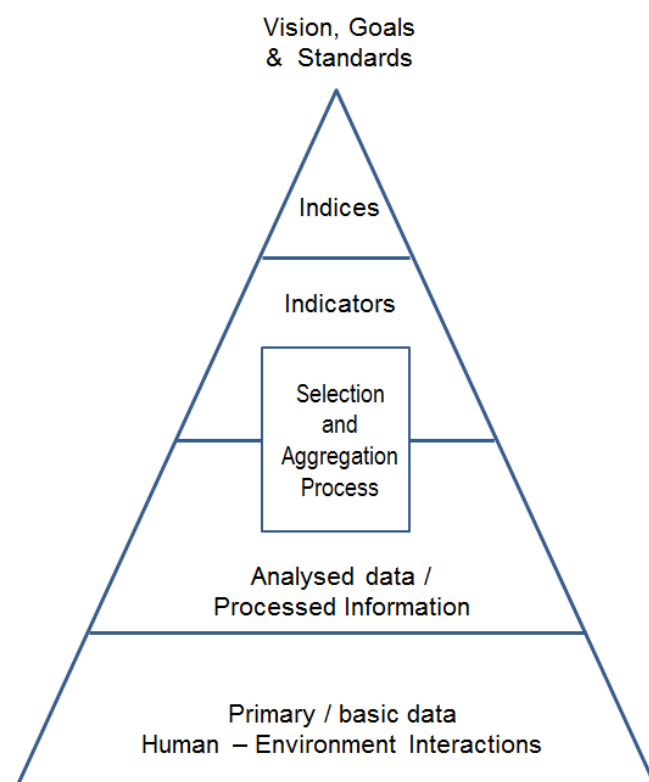


Figure 6.47: The data / information pyramid

Source: Adapted from Hammond & Woodward (1995:1) and Birkmann (2006a:59, 60)

In the context of this research, the development and use of indicators in disaster risk management and environmental management is explored to highlight its value for assessment, and particularly how it is used to represent reality by using GIS technology.

6.2.2 Frameworks

The goal of a conceptual framework is to categorise and describe the concepts relevant to the topic of a specific study (Miles & Huberman, 1944; Rocco & Plakhotnik 2009:122). It explains the main things to be studied: the key factors, constructs or variables, and the relationships among them. Relevant theory and empirical research that help to organise the conceptual framework are incorporated by qualitative researchers to view overlaps, contradictions, refinements or qualifications. Rocco and Plakhotnik (2009) highlight the relevance of frameworks in scientific study by stating that all empirical studies, both qualitative and quantitative, are connected to a framework of literature that binds its 'big ideas'. The main ideas and the network of relationships between them are demonstrated in conceptual frameworks.

Frameworks are useful in content analysis, and are used to reduce and summarise text (the main source of data in qualitative research) (Krippendorff, 2004). According to Miles and Huberman (1944:22), conceptual frameworks are best done graphically, rather than in text. This way discrete phenomena can be visualised in 'bins', the relationships among them can be mapped, and variables that are functionally distinct can be divided. As a graphic illustration, the researcher works with all the information at once at the inference level. This functionality of frameworks is illustrated by its use throughout this thesis.

Frameworks are used extensively to illustrate the underpinnings of concepts such as vulnerability and sustainable development. The next section gives an overview of frameworks and indicators described in literature that have been developed to analyse and describe vulnerability, sustainable development and environmental status. Lastly, the use of indicators in GIS illustrates the integration abilities of structured data models.

6.2 AN OVERVIEW OF INTEGRATED VULNERABILITY FRAMEWORKS AND INDICATORS

It is widely accepted that vulnerability is multidimensional, and often difficult to define and be observed (Cutter *et al.*, 2003; Clichevsky, 2003; Cardona, 2004; Birkmann, 2006:56; Tate, 2012:325). Cutter (1996) identifies three distinct themes in vulnerability studies:

- i. Vulnerability is a pre-existing condition.
- ii. It is a social construct.
- iii. It is conceived as a biophysical risk and social response within a specific geographic space.

As a pre-existing condition, vulnerability is perceived as an internal risk factor of the subject or system that is exposed to a hazard (Cardona, 2004). Furthermore, vulnerability implies a specific disciplinary focus, as in *social vulnerability*, or *economic vulnerability*, or *structural engineering vulnerability*, etc. (Wisner, 2004:183). Therefore, the analysis of vulnerability relates to multiple aspects arising from physical, social, economic and environmental factors that are interacting in space and time (Ciurean *et al.*, 2013:3). As an ontology, this premise constitutes the foundation for the development of vulnerability frameworks that range from simplistic (e.g. Bohle, 2001) to multi-faceted conceptualisations (e.g. Birkmann *et al.*, 2013).

As vulnerability is a major aspect of this study, a selection of vulnerability frameworks has been chosen to describe its components as viewed from different perspectives. To choose from the abundance of models in literature is difficult. Birkmann (2005:4) states that it is impossible to include every approach towards the measurement of vulnerability, and concludes that by examining selected representative approaches, their differences and similarities can be analysed and their differences and similarities be understood. The frameworks chosen for analysis in this chapter are representative of different approaches, and are also indicative of advances in theory and technological development. They are first summarised as follows, and then described in further detail.

- i. The dual structure of vulnerability (Bohle, 2001).
- ii. The coupled human–environment nature of vulnerability (Turner *et al.*, 2003a; Birkmann, 2005).
- iii. The multi-faceted nature of vulnerability (Birkmann *et al.*, 2013).

- iv. The link between vulnerability, human security and sustainable development – a holistic perspective (Birkmann, 2006).
- v. The overlapping nature of environmental and anthropogenic systems – a regulatory perspective (Spangenberg, 2002).
- vi. The social vulnerability index (SoVI) – a spatial perspective (Cutter *et al.*, 2003).

6.3.1 The Dual Structure of Vulnerability: Bohle (2001)

Based on his empirical research, Bohle (2001:3) concludes that the general distinction between an *external* and an *internal* side of vulnerability proves to be useful. The external perspective refers mainly to the structural dimensions of vulnerability and risk. It relates to the exposure to risks and shocks and is influenced by political-economic approaches (e.g. social inequities, disproportionate division of assets); human ecology perspectives (population dynamics and environmental management capacities); and entitlement theory (relating vulnerability to the incapacity of people to obtain or manage assets via legitimate economic means) (Ciurean *et al.*, 2013:8). The internal dimension of vulnerability relates to the capacity to anticipate, cope with, resist and recover from the impact of a hazard. It is influenced by crisis and conflict theory (control of assets and resources, capacities to manage crisis situations and resolve conflicts); action theory approaches (how people act and react freely as a result of social, economic or governmental constraints); and model of access to assets (mitigation of vulnerability through access to assets). The framework that is graphically presented in Figure 6.2 integrates these concepts into a simplistic model on the causal structure of vulnerability.

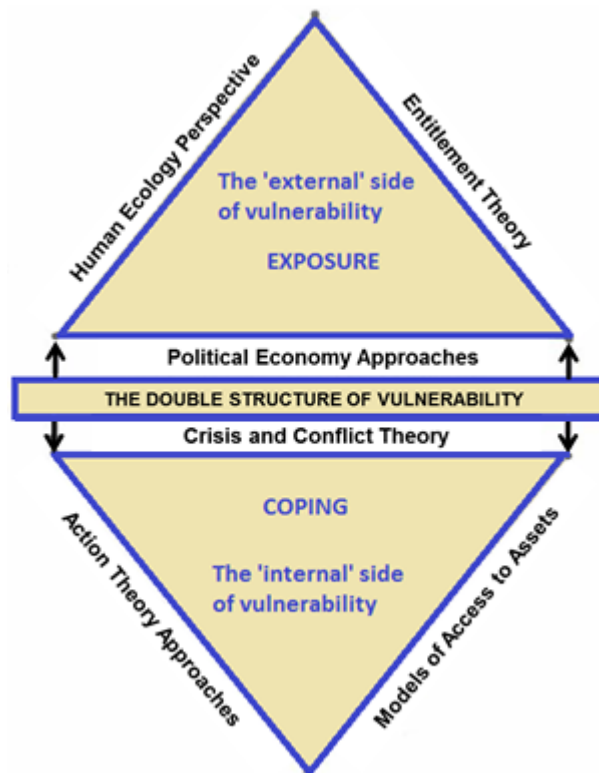


Figure 6.48: Conceptual Model for Vulnerability Analysis
Source: Bohle (2001:4)

The above model serves as a framework for vulnerability analysis, provides insights into the causal structures of vulnerability, and is included as two of the three facets of place-based vulnerability in the coupled human–environment framework, which is discussed next.

6.3.2 The Coupled Human–Environment Framework: Turner *et al.* (2003b) and Birkmann (2005)

According to Turner *et al.* (2003), the sustainability theme directs the focus of vulnerability to coupled human–environment systems. The vulnerability and sustainability of these anthropological and ecological systems are predicated on the synergy between these systems as they are affected by processes operating at different spatiotemporal and functional scales. The analysis of vulnerability must be approached from the conditions and dynamics of the coupled human– environment system and its exposure to hazards, as it varies on a spatial and temporal basis. Given the reality that real-world data cannot capture the totality of coupled human–environment systems, and that it would be impossible to include every approach to the measurement of vulnerability (Birkmann, 2005:4), a reduced vulnerability assessment approach is necessitated. Guided by this

principle, Turner *et al.* (2003b) propose a framework that describes the broad classes of components and linkages that comprise a coupled system's vulnerability to hazards.

The framework puts vulnerability in the context of space, coping capacities of social units, resilience of the environment, and exogenous and endogenous stressors (hazards). Each of these components is characterised by variability, and is illustrated in Figure 6.3. The spatial context of vulnerability includes local, regional and world-wide influences, which are indicated in different colours in the diagram. The grey area is the immediate place, where human-environment interaction occurs in a local state. This is surrounded by a wider region, the yellow area, from where human and environmental influences act as exogenous impacts (from outside the place). Beyond this lies a world-wide area that operates at multiple spatial, functional and temporal scales. Coping mechanisms include both social and biophysical capital and function primarily at the local level. They relate to impact response capabilities that exist at the local, regional, as well as world-wide level. Environmental influences also function at all three spatial levels and concern the state of the biosphere and dynamics such as global environmental changes.

The human–environment system is exposed to interactions with hazards, which act as perturbations, stresses and stressors on the coupled system and are located both within and beyond the place where vulnerability is assessed. The external variability and change of human and environmental conditions influence these interactions of hazards.

Turner *et al.* (2003b) present the framework as a template that is useful for reduced form analysis. It recognises the limitations of modelling the totality of the real-world system, which necessitates a reduced vulnerability assessment. This view is concurrent with the approach of GIS science to model the real world in a 'reduced' format by discrete objects or continuous fields (refer to Chapter 5 for a discussion of these concepts). This view also forms the basis for the data model presented in Chapter 8.

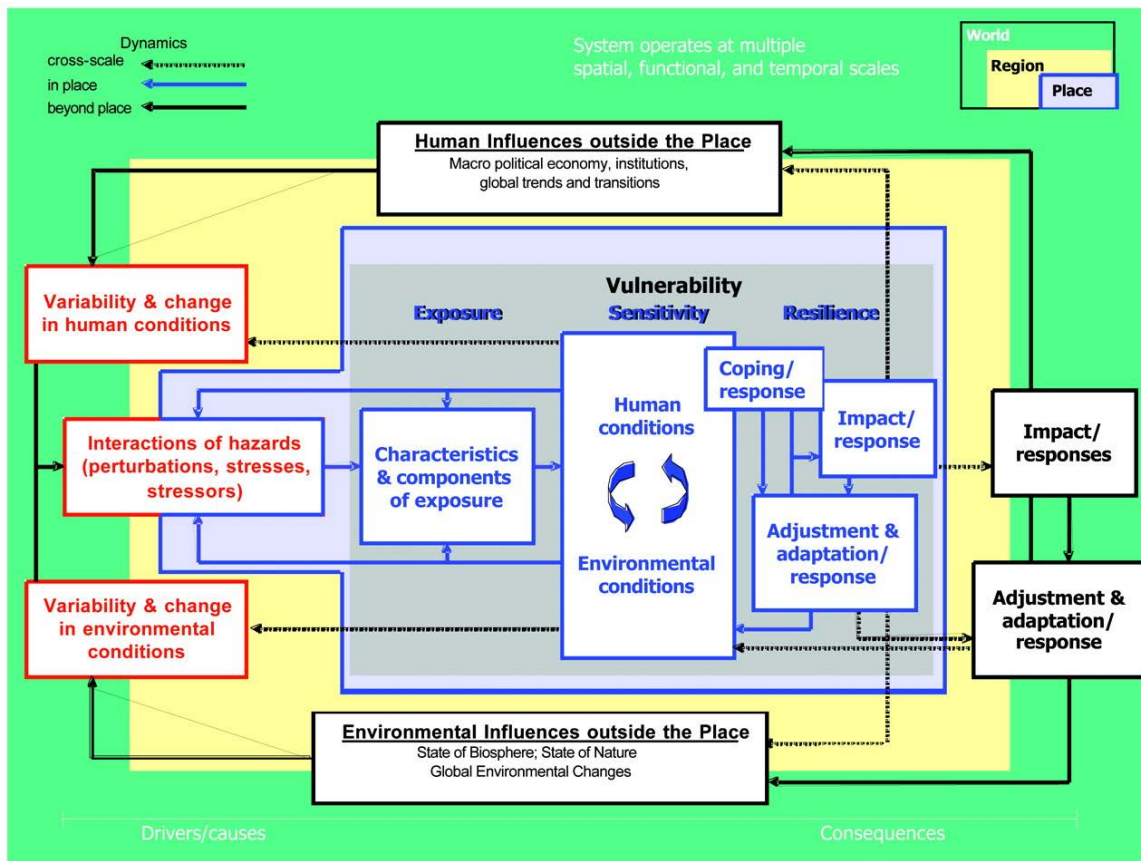


Figure 6.49: Vulnerability framework

Source: Turner *et al.* (2003b:8076)

6.3.3 Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) Framework: Birkmann *et al.* (2013)

In recognition of the lack of a common shared language and the fact that there is no universal definition for vulnerability, Birkmann *et al.* (2013) propose the *Methods for the Improvement of Vulnerability Assessment in Europe* (MOVE) framework as a multi-dimensional, holistic vulnerability assessment framework. This follows research sponsored by the European Commission within the framework of the FP-7 programme, and includes contributions from leading scientists in the field, i.e. Birkmann, Cardona, Pelling, Schneiderbauer, Kienberger, Zeil, Keiler and Alexander.

The key objective of the MOVE framework is to gain consensus between different approaches to vulnerability assessment. The framework differentiates key factors of vulnerability and shows its different thematic dimensions. It further integrates with risk governance as an intervention agent. The following key factors of vulnerability are defined (Birkmann *et al.*, 2013:200):

- i. **Exposure**, describing the extent to which a unit of assessment falls within the geographical range of a hazard event.
- ii. **Susceptibility (or fragility)**, describing the predisposition of elements at risk (social and ecological) to suffer harm.
- iii. **Lack of resilience or societal response capacity**, determined by limitations in terms of access to and mobilisation of the resources of a community or a social-ecological system in responding to an identified hazard.
- iv. **Hazard**, describing the potential occurrence of natural, socio-natural or anthropogenic events that may have physical, social, economic and environmental impact in a given area and over a period of time.

In addition to the above key factors, thematic dimensions of vulnerability have to be addressed as part of a holistic assessment process. These include dimensions and characteristics of the social, economic, physical, environmental, institutional and cultural sectors within a community. Integrated risk governance and adaptation techniques imply institutional intervention.

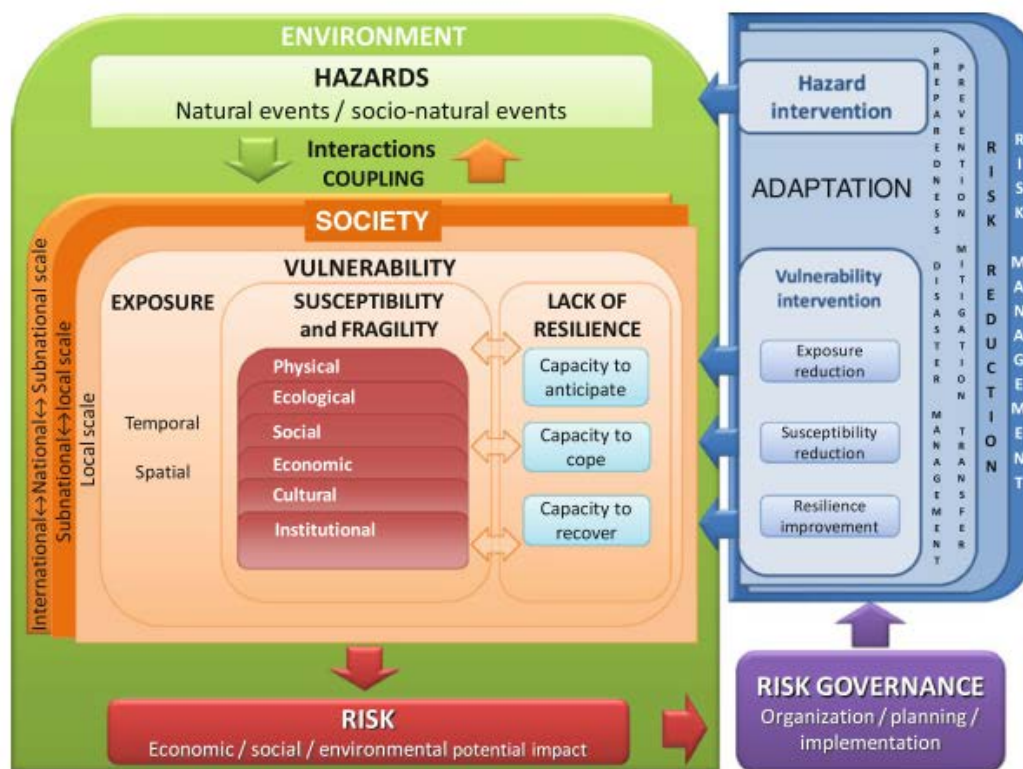


Figure 6.50: The MOVE framework
Source: Birkmann *et al.* (2013:199)

The MOVE framework (Figure 6.4) is proposed as a heuristic and a thinking tool to guide systemic assessment processes and the development of indicators (Birkmann *et al.*, 2013:207). It is not intended as a specific assessment method or a pre-defined list of indicators. As a framework it can be adopted to set analysis criteria in accordance with target groups and scale, as suggested by Queste and Lauwe (2006). The multi-disciplinary nature of the framework suggests cross-cutting interventions between sectors, represented as separate research fields. Linkages between the social and physical sciences are also implied.

6.3.4 BBC conceptual framework: (Birkmann, 2006)

The BBC conceptual framework is proposed by Birkmann as a combination of different elements of frameworks. The term 'BBC' refers to the work of Bogardi and Birkmann (2004) as well as Cardona (1999, 2001), which focuses on the link between vulnerability, human security and sustainable development, the impact of environmental degradation as a causal factor, and the notion of a holistic approach to disaster risk assessment (Birkmann, 2006:34).

The BBC framework accounts for the three main thematic spheres of sustainable development according to which vulnerability should be measured, namely economic, social and the environment. Through the linkages between sustainable development and vulnerability reduction, the BBC conceptual framework considers environmental conditions on which human well-being depend, as described by Turner *et al.* (2003b). Importantly, the framework promotes a problem-solving perspective by analysing the probable losses and deficiencies of the environmental, social and economic elements at risk. Coping capacities and intervention measures are also considered within the three thematic spheres, which Birkmann describes as “the inner thematic composition in which vulnerability should be measured”. Institutional objectives such as vulnerability reduction would address interventions within each theme, for example pollution control (environment), early warning (social) and insurance (economic). Aspects of hazard and risk are regarded as external factors, reflecting exposure to external threats.

The diagram in Figure 6.5 shows the relationships between the three elements of an internal sphere, exposure to external threats, coping capacity and institutional intervention. Specific indicators and the flow of information are not specified, although the effect of intervention measures on planning and land use changes, and its effect on either mitigating or exacerbating external threats (hazards), is implied.

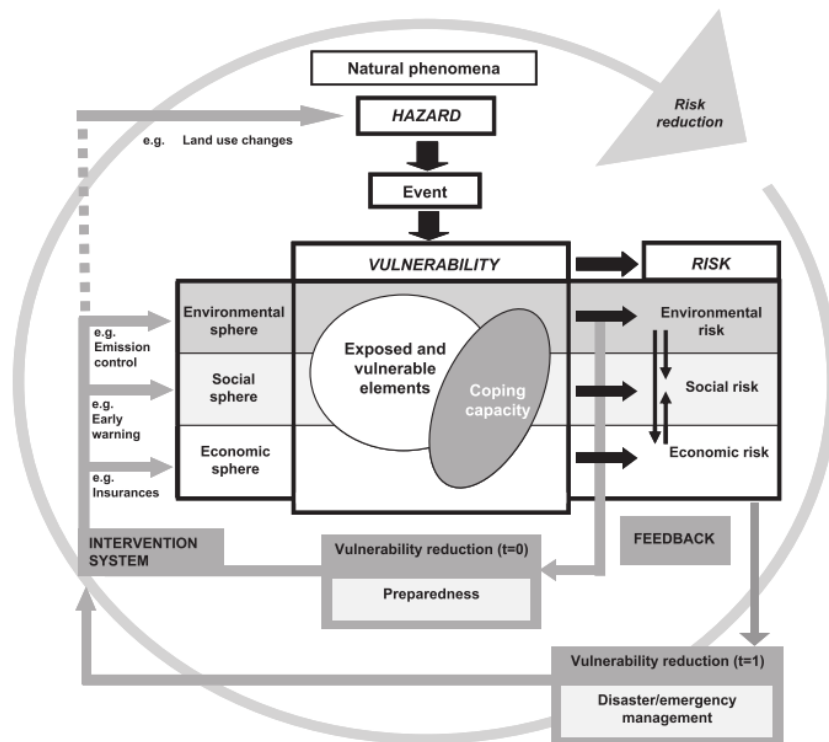


Figure 6.51: The BBC conceptual framework for vulnerability
Source: Birkmann (2006b:35)

6.3.5 Land Use Intensity: Spangenberg (2002)

Anthropogenic systems such as the built environment cause the transformation of the natural environment, often with the loss of species and biodiversity. According to Spangenberg (2002:201), different institutions have proposed land use as an indicator in this regard, but quantitative measures are difficult to develop. In reaction, he proposes a semi-quantitative hierarchy of land use intensities that result in decreasing environmental quality. He suggests four classes of decreasing levels of transformation and four classes of environmental conditions that are arranged in two overlapping domains, i.e. a sphere of human domination and a sphere of natural regulation. The representation of this model in Figure 6.6 indicates a continuum of total human domination (total transformation of the natural environment), and undisturbed, protected nature on the other. The four classes are categorised as follows:

- i. Class 1: Anthropogenic systems, i.e. built environment, characterised by total transformation and removal of vegetation, with soil surfaces sealed off by settlement, transport and production infrastructure. Anthropogenic systems replace natural regulation processes.

- ii. Class 2: Anthropogenically controlled eco-systems with high input levels, for example intensive agriculture. Humans dominate natural regulation processes.
- iii. Class 3: Anthropogenically cultivated eco-systems with low external inputs, like sustainable forestry or fishing. Cultivation sets some framework conditions and uses the natural regulation mechanisms to produce the harvest.
- iv. Class 4: Anthropogenically protected eco-systems, for example nature reserves and other protected or unused areas. Humans harvest a share of the yield from natural regulation, like small-scale forest dwellers or hunters and gatherers, or tourism.

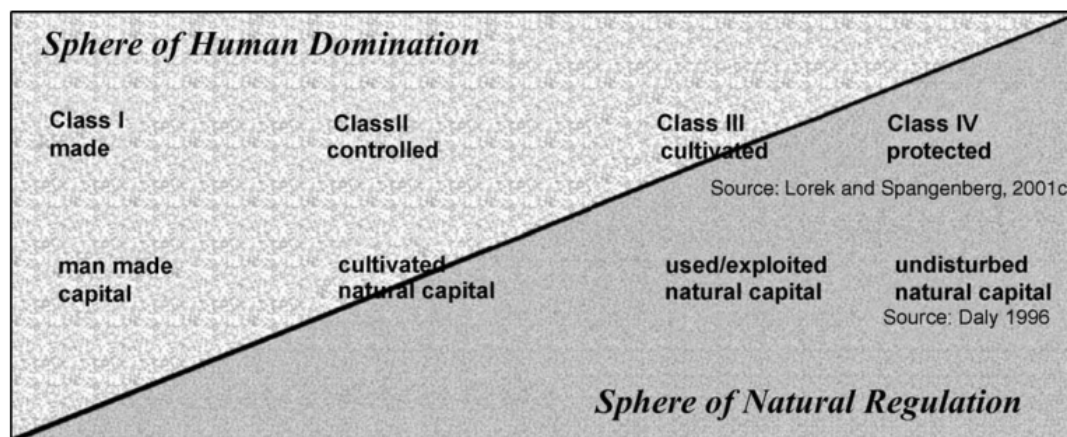


Figure 6.52: The overlapping natural and anthropogenic regulation systems
Source: Spangenberg (2002:302)

The significance of the above model is increased vulnerability where anthropogenic systems destroy natural systems of resilience. The model can further be expanded by applying GIS technology to conceptualise and calculate the different levels of transformation, linking it to indicators of vulnerability, as will be explored in Chapter 7.

6.3.6 Social Vulnerability Index (SoVI): Cutter *et al.* (2003)

Cutter *et al.* (2003) utilise the Hazards-of-Place Model (Cutter, 1996) to examine the components of social vulnerability. In this model, social and biophysical vulnerabilities interact to produce the overall place vulnerability (see Figure 6.7). Using only the social vulnerability component of the model, Cutter *et al.* (2003) develop a county-level Social Vulnerability Index (SoVI) for the USA by using a factor analysis approach.

The SoVI is a composite index that measures differences in social vulnerability between counties. It is used to quantify social vulnerability and differentiate between places based

on their relative levels of vulnerability (Cutter *et al.*, 2003). The SoVI is highlighted as a benchmark for indicators-based research (Malone, 2009) and it is adapted or used in conjunction with other models to develop localised indicators. For example, Arma and Gavri (2013) analyse the SoVI combination with the Hazard Potential Model) to determine the vulnerability of the city of Bucharest in an earthquake. Holland and Lujala (2013) construct a replicated and an adapted index to measure the effect of contextualisation of the SoVI in Norway.

To construct the index, Cutter *et al.* (2003) collected socioeconomic data from the 1990 census for all of the 3 141 counties in the USA that formed the spatial unit of analysis. More than 250 variables were collected and reduced through a process of normalisation to 42 demographic and social variables used for statistical analysis (factor analysis). A total of 11 factors were identified that differentiated US counties according to their relative level of social vulnerability in 1990 (see Figure 6.8). The factor scores were added to the original county database file as 11 additional variables. These were then placed in an additive model to produce the composite social vulnerability index score (SoVI) for each county. Linked to the spatial component of the county database, the SoVI scores could be classified and spatially represented as the dimensions of social vulnerability in the USA.

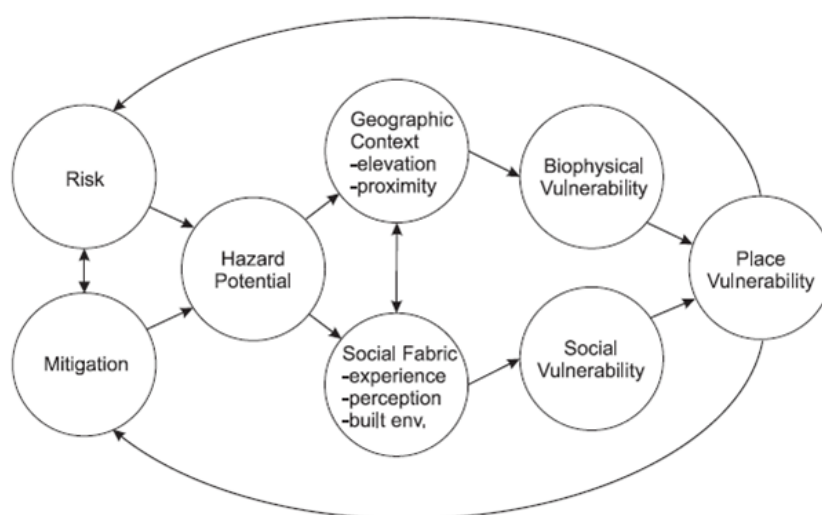


Figure 6.53: The Hazards-of-Place Model of Vulnerability
Source: Cutter *et al.* (2003:244)

Factor	Name	Percent Variation Explained	Dominant Variable	Correlation
1	Personal wealth	12.4	Per capita income	+0.87
2	Age	11.9	Median age	– 0.90
3	Density of the built environment	11.2	No. commercial establishments/mi ²	+0.98
4	Single-sector economic dependence	8.6	% employed in extractive industries	+0.80
5	Housing stock and tenancy	7.0	% housing units that are mobile homes	– 0.75
6	Race—African American	6.9	% African American	+0.80
7	Ethnicity—Hispanic	4.2	% Hispanic	+0.89
8	Ethnicity—Native American	4.1	% Native American	+0.75
9	Race—Asian	3.9	% Asian	+0.71
10	Occupation	3.2	% employed in service occupations	+0.76
11	Infrastructure dependence	2.9	% employed in transportation, communication, and public utilities	+0.77

Figure 6.54: Dimensions of social vulnerability

Source: Cutter *et al.* (2003:252)

The progression of statistical analysis to include GIS technology is illustrated in this model. The emphasis is on the processing of statistical data, and little processing of spatial data is involved. The GIS component functions as a loosely coupled system linking the textual (alpha-numerical) data with a fixed spatial component (i.e. county boundaries).

The frameworks discussed above illustrate the multi-faceted nature of vulnerability and the need to approach its assessment from different perspectives. The spatial context of vulnerability is highlighted by both Cutter *et al.* (2003) and Turner *et al.* (2003b), and it provides the foundation for the data model developed in Chapter 8.

6.3 AN OVERVIEW OF INTEGRATED DEVELOPMENT AND ENVIRONMENTAL FRAMEWORKS

A variety of environmental indicators and frameworks are in use in environmental management (Smeets & Weterings, 1999). As indicated in Chapter 2, the assessment of environmental impact is part of the development process, and it is undertaken on a strategic and project level by means of SEA and EIA. Two of the most widely used

frameworks to assess the interaction between environment and development are the Pressure-State-Response (PSR) and the Drivers-Pressure-State-Impact-Response (DPSIR) frameworks (Tapio & Willamo, 2008; Thornhill, 2014). The PSR model is used in state of the environment reports (SoER) and environmental education, while the DPSIR framework is used by the European Environment Agency (EEA) and its member states in reporting activities. A brief overview of these two frameworks provides further context to vulnerability assessment as discussed in the previous section, notably the coupled human–environment framework.

6.3.1 The PSR and DPSIR Frameworks

The Pressure-State-Response (PSR) framework was initially developed by the Organisation for Economic Co-operation and Development (OECD) in the 1980s to provide an overview of the pressures of human activities on the environment, the state of the environment, and natural resources, and to structure its work on environmental policies and reporting (OECD, 2003:21; Tapio & Willamo, 2008:125). The model highlights these cause-effect relationships and provides a means of selecting and organising indicators. The most frequently used version of the framework is presented in Figure 6.9.

Environmental pressures describe the pressures that human activities exert on the environment and on natural resources. This includes direct pressures (e.g. the use of resources and the discharge of pollutants and waste materials) and indirect pressures (related to human activities and trends of environmental significance). Indicators of environmental pressures are closely related to production and consumption patterns; they often reflect emission or resource use intensities, along with related trends and changes over a given period (OECD, 2003:21).

Environmental conditions relate to the quality of the environment and the quality and quantity of natural resources, and they reflect the impact of environmental policies. Indicators of environmental conditions are designed to give an overview of the situation (the state) concerning the environment. Examples of indicators include the concentration of pollutants in the air, soil or water, the exceedance of critical loads, and the status of wildlife and ecosystems (OECD, 2003:21).

Societal responses show the extent to which society responds to environmental concerns. They refer to individual and collective actions and reactions intended to mitigate, adapt to

or prevent negative impacts on the environment caused by human activity, to halt or reverse environmental damage that has already been inflicted, and to preserve and conserve nature and natural resources. Examples of indicators include environment-related legislation, pollution abatement rates, waste recycling, enforcement and compliance activities. In practice, indicators mostly relate to control measures (OECD, 2003:21).

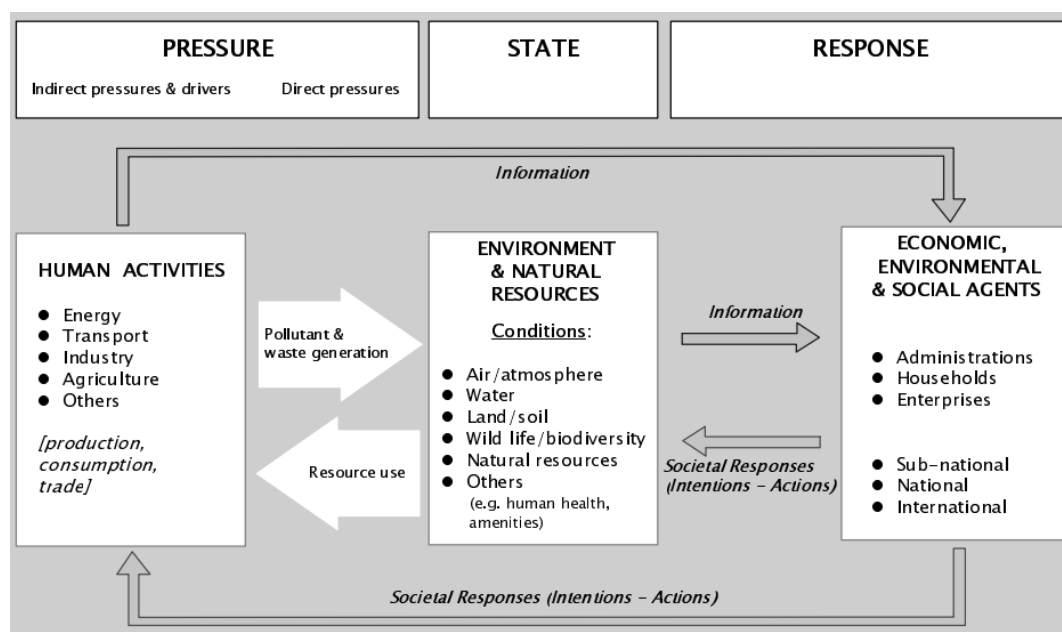


Figure 6.55: The PSR framework
Source: OECD (2003:21)

The PSR framework highlights the relationships between the environment and economic dimensions of development. One of the key functions is the flow of information from sectoral (developmental) activities and resulting impacts to policy makers (environmental agents) who respond by designing policies and taking decisions that would address problems at the appropriate level. This implies the use of information technology in all its facets, as was described in Chapter 5.

6.3.2 The DPSIR Framework

According to Carr *et al.* (2007:544), the PSR's focus on anthropocentric pressures and responses proved to be problematic in that it tended to push aside natural variability. It also failed to address underlying reasons for the pressures. In reaction, the model was further developed by the European Environment Agency (EEA) to separate human action (for example industry) from driving forces that cause the pressures (for example emissions), and further separating the resulting state of the environment from its impact

(for example acidification). Referred to as the *drivers-pressures-state-impact-response* (DPSIR) framework, it improved analysis of the drivers and responses to environmental change (Tapio & Willamo, 2008:126).

The DPSIR framework describes the relationships between the origins and consequences of environmental problems (Smeets & Weterings, 1999:7). It analyses changes in the state of the environment that result from developments that exert pressure on the environment. Changes in and impacts on health, resources and ecosystems can be measured, which elicit a societal response that feeds back on the driving forces of development. In order to understand their dynamics, the links between DPSIR elements must be understood. For example, the relationship between the *drivers* and *pressures* by economic activities is a function of the eco-efficiency of the technology and related systems in use, with less *pressure* coming from more *drivers* if eco-efficiency is improving. Similarly, the relationship between the *impacts* on humans or eco-systems and the *state* depends on the carrying capacities of and thresholds for these systems. *Response* by society to *impacts* depends on how these impacts are perceived and evaluated. The results of *response* on the *drivers* depends on the effectiveness of the *response* (refer to Figure 6.10).

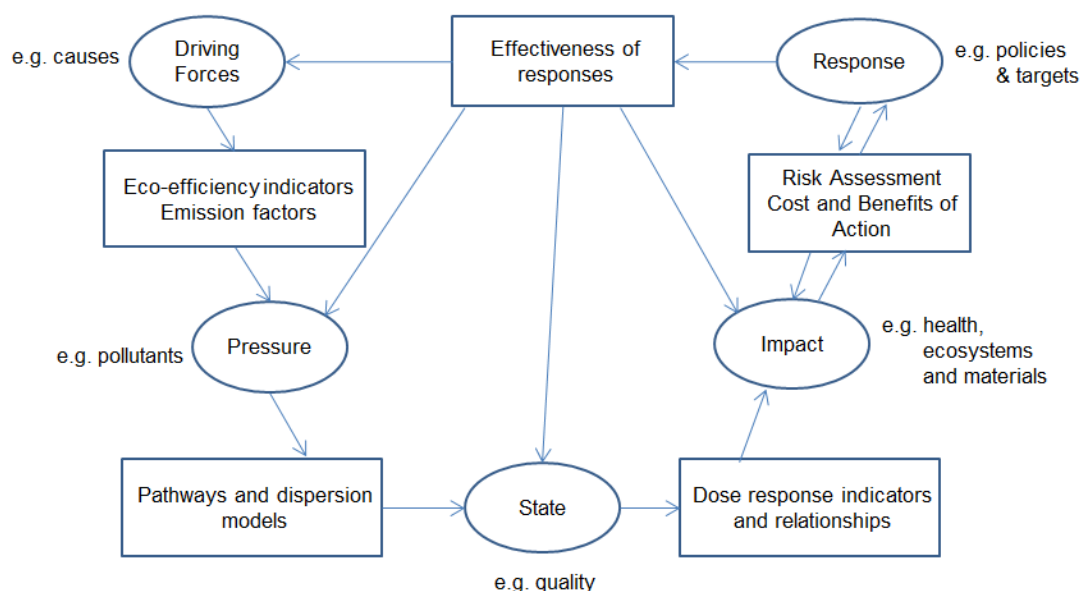


Figure 6.56: The DPSIR framework

Source: Adapted from EEA (2003:13), and Smeets and Weterings (1999:7)

Further developments of the PSR and DPSIR were undertaken, but these frameworks became the most widely used by institutions to assess the interaction between environment and development (Smeets & Weterings, 1999; Carr *et al.*, 2007; Thornhill, 2014).

6.4 THE USE OF INDICATORS IN GIS IN RESPECT OF DEVELOPMENT, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT

Many demands to GIScience arise from the need to collect and analyse large amounts of data on nature-society systems, and to present results in a meaningful way (Davis, Fonseca & Camara, 2011). This premise indicates that the use and application of GIS lies deeper than the need to present information on maps. In describing the role of Geographic Information Science in the integration of people and nature, Davis, Fonseca & Camara (2011) state that there is a need to improve our modelling skills in order to analyse more complex systems and the interaction between human actions and natural systems. They identify four main topics for a GIScience research agenda: modelling, data collection, knowledge discovery, and support for policy making. Models are used to simplify and approximate aspects of reality by reflecting on particular views thereof. In terms of GIS, the intention of a model is therefore not to create a “mini Earth”, but to give a spatial representation of some aspect. Data is collected for a particular use, linked to spatial operations and the need to achieve a specific goal, as highlighted in Chapter 5.

Cutter *et al.* (2000:731) state that “hazard exposure and social susceptibility to hazards must be understood within a geographic framework, that is, the hazardousness of a specific place. This uniquely geographical concept considers the threat from all hazards in a given place and provides the opportunity to mitigate several hazards concurrently”. The concept of a place-based metric and measurement of environmental sensitivity, economic growth and disaster risk has been extensively explored in literature, and forms a central theme of this thesis. As an analogue of the above statement, it can be argued that hazard exposure and social susceptibility to hazards, as well as environmental susceptibility to development, are all interrelated concepts and that these interrelationships must be understood within a geographic framework. The question is how to meet the needs for spatial analysis in the context of GIS. Openshaw (1996:65) asserts that much of the information that requires spatial analysis is zonal in nature. Different types of zonal data are used to represent statistically processed data, for example census blocks (Cutter *et al.*, 2000), district boundaries (Cutter *et al.*, 2003),

hexagonal tessellations (Game & Grantham, 2010; Nhancale & Smith, 2011), land facets (Totte & Henquin, 1993; Beier & Brost, 2010), and Thiessen polygons (Longley *et al.*, 2005). These represent administrative boundaries, regular geometrical shapes, and irregular geometrical shapes. The key characteristics of zonal data are that, being polygon data, they do not overlap and there are no gaps in between. This is indicative of a field data approach. Three case studies next describe the use of indicators in GIS to spatially represent vulnerability, environmental sensitivity and economic status.

6.4.1 Multi-Criteria Decision Analysis: Georgetown Case Study (Cutter *et al.*, 2000)

Cutter *et al.* (2000) describe the use of GIS to establish areas of vulnerability based on twelve environmental threats and eight social characteristics for Georgetown County, South Carolina, in the USA. They use a non-compensatory conjunctive method (Greene *et al.*, 2011:417) to combine various layers of spatial data representing different hazard zones and vulnerability zones. Based on the hazards-of-place model of vulnerability (Cutter, 1996) and primary tasks for hazard and vulnerability assessment as described in Cutter *et al.* (1997), they produced an integrated dataset consisting of land facets and census block boundaries, with indexed attribute values.

The process entailed an iterative process of data capture and integration. More than 25 different data layers of different hazard zone were created. All the layers were combined into a single composite of intersecting polygons. Rating scores (based on the rate of occurrence) were stored for each polygon. These were subsequently classed into deciles and mapped to produce an integrated geospatial database and a visual display of biophysical hazards.

The SoVI approach was used to calculate social vulnerability index values. Once the index values were computed, they were assigned to each census block and entered into a spatial data layer. The same procedure used to develop the composite biophysical hazard dataset was used to create a social vulnerability dataset. The index values for each variable were summed to arrive at a composite index score for each census block, which represents an aggregate measure of social vulnerability. These values were also placed into deciles.

By further combining the hazard and social vulnerability components, an overall assessment of the vulnerability of Georgetown County was produced. The work of Cutter

and colleagues demonstrates the value of GIS to create and integrate datasets, using statistically calculated indicators to create a spatial vulnerability index, which becomes an indicator of vulnerable places (refer to the map in Figure 6.11).

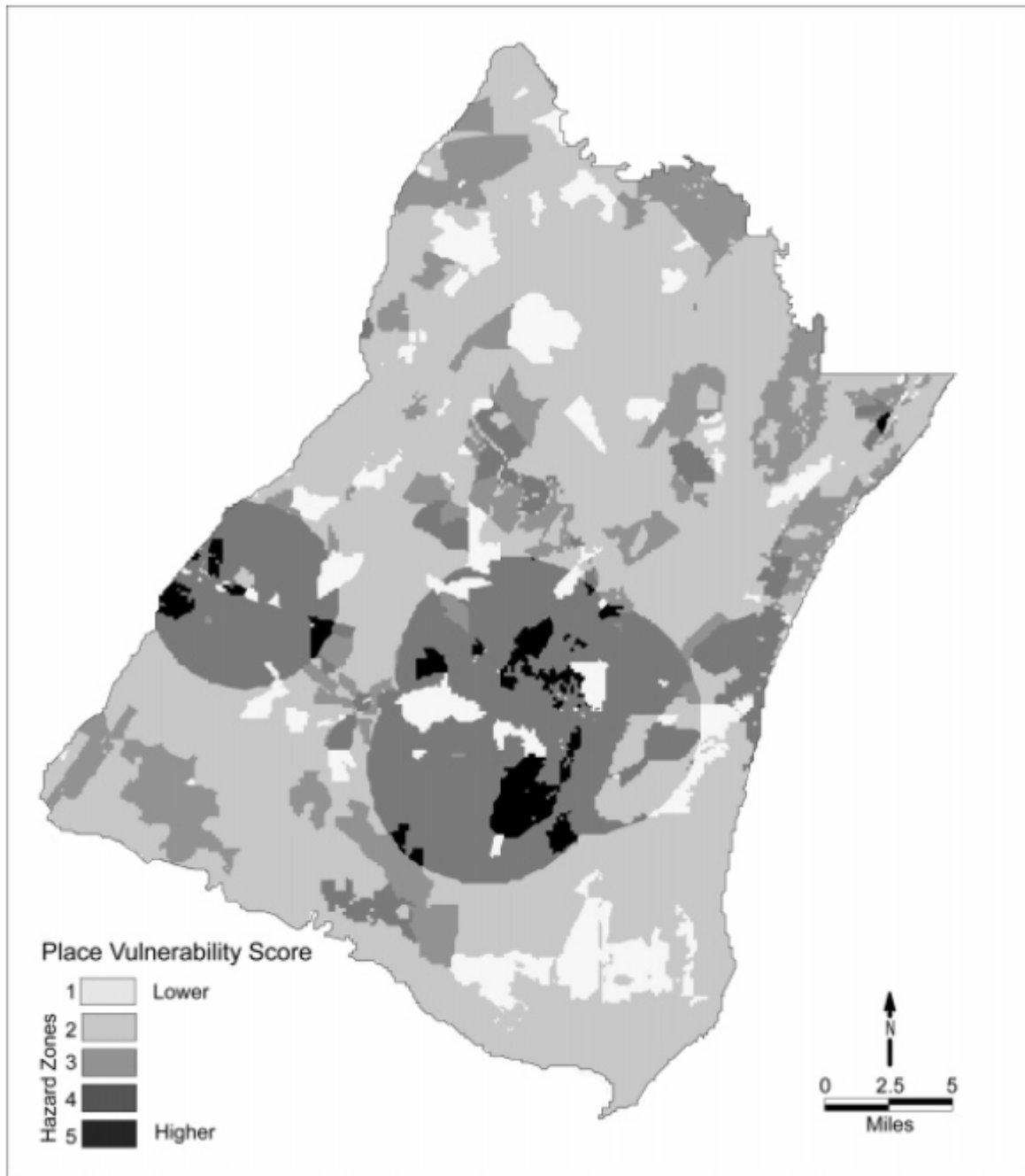


Figure 6.57: Spatial distribution of overall hazard vulnerability in Georgetown County
Source: Cutter *et al.* (2000:729)

6.4.2 Geospatial Analysis Platform (Naudé *et al.*, 2007)

Using integrated datasets on a detailed level for spatial analysis is sometimes hindered by problems related to the aggregation of data, scale of representation and overgeneralisation (Maritz & Badenhorst, 2008; Naudé *et al.*, 2007; Naudé *et al.*, 2008). Administrative area units such as municipal boundaries are seldom spatially compatible with environmental area units, such as vegetation types or hydrological features. When data is aggregated from its smallest or basic spatial unit (BSU) (Openshaw, 1977:462) to an aggregated level of several BSUs, such as a district, the resulting summary values (e.g. totals and proportions) are influenced by the spatial extent of the district boundaries. These boundaries are modifiable and may change from time to time, as is the case with municipal and district boundaries in South Africa (South Africa, 1998). This gives rise to the modifiable area unit problem (MAUP). The problem relates to the effect of scale on statistical and mathematical models of spatial patterns, as defined by Openshaw (1977), and discussed by Dark and Bram (2007). In response to these challenges, the requirements for the modelling of a spatially complex human-ecosystem and rural-urban interactions, the Council for Scientific and Industrial Research (CSIR) developed the Geospatial Analysis Platform (GAP) that serves as “a common, mesoscale geo-spatial platform for the assembly, analysis and sharing of economic, development and demand information” (Naudé *et al.*, 2007).

Based on the concept of hexagonal tessellation, a field of mesozones was created for South Africa by means of an iterative process of data capture and adjustment (Naudé *et al.*, 2007). Thiessen polygons were created from a field of random points within a pre-defined macro frame with internal subdivisions such as functional urban areas, low human activity areas, and protected areas. These polygons were adjusted and refined using baseline polygon data such as village polygons and land cover to avoid the unnatural bisection of units such as towns and villages, to reduce the size variation of mesozones, and to improve the homogeneity of the mesozones. One of the important characteristics of the mesozones is the standardisation of polygon sizes to be almost equal – not more than 20% larger or smaller than the chosen size norm (Maritz, 2008).

The mesozones were populated with various disaggregated multi-scale datasets to produce a socio-economic framework consisting of levels of economic activity, numbers of households in different income brackets, land cover composition, etc. From these, a variety of GIS datasets was produced on a national scale and made publically available on the Internet. The map in Figure 6.12 shows an extract for the Ekurhuleni Metropolitan

Municipality in South Africa, with a core of economic activity around the O.R. Tambo International Airport.

The mesozones framework is valuable as a standardised BSU, and its support of the aggregation of data on different themes. This concept is also illustrated in the next section, albeit a different approach to creating the BSU for an environmental sensitivity analysis.

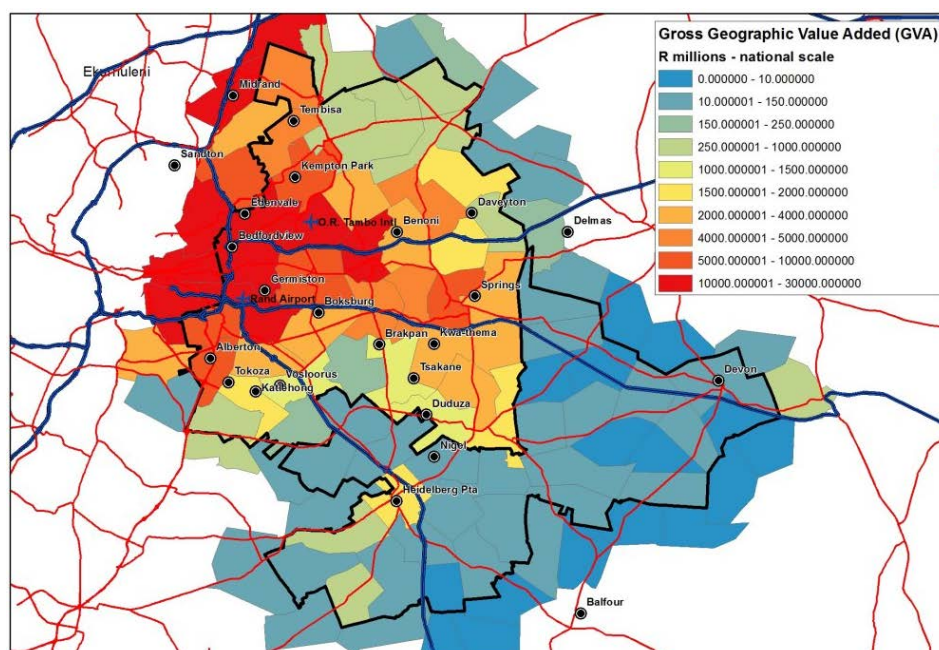


Figure 6.58: Gross Geographic Value-Added (GVA) map for Ekurhuleni, extracted from mesozone data
Source: Mesozone data supplied by CSIR

6.4.3 Environmental Sensitivity Analysis

The Department of Agriculture, Environmental Affairs and Rural Development (DAEARD, 2010) describes the development of an environmental sensitivity map that was produced as part of the Environmental Management Framework (EMF) for the Richards Bay Port Expansion Area and Industrial Development Zone. A *Fuzzy Additive Weighting* technique (Greene *et al.*, 2011:420), also known as simple additive weighting, was used in the processing of data. It adds normalised criteria scores for each geographical feature in a combined spatial dataset to produce an environmental sensitivity index for the EMF study area. Four data categories, comprising of ten geospatial features (layers) were integrated through an iterative unioning process (refer to Table 6.1) to create a single dataset containing an integrated spatial topology and the non-spatial attributes of all the layers

(the reader is also referred to Chapter 5 where the use of set theory to integrate spatial datasets was described).

As a spatial construct, this layer has no relevance to any real-world phenomena and does not represent any discrete objects or fields. These are generated as an aggregation of attributes based on a theme, being it the calculated sensitivity or the attribute values of a specific feature, for example ecological status, displaying the aggregated values of 'vulnerable', 'least threatened' and 'critically endangered'. It is important to note that the aggregation takes place through a spatial query, and not through the processing of data. The maps in Figures 6.13 and 6.14 represent these two examples. As a visualisation, the maps are totally different, but each was created from the same underlying dataset. This approach to spatial database design informs the development of a data model in Chapter 8.

Table 6.3: Input data layers with illustrative weighting values

Hydrology	Estuary	0	12.7
	Aquifer	0	
	River	3	
	Stream	3	
	Wetlands	0	
	Lakes	0	
	Topography	3	
	Red Data Species	0.7	
Ecology	Ecosystem Status	2	
	Ecosystem Protection	1	

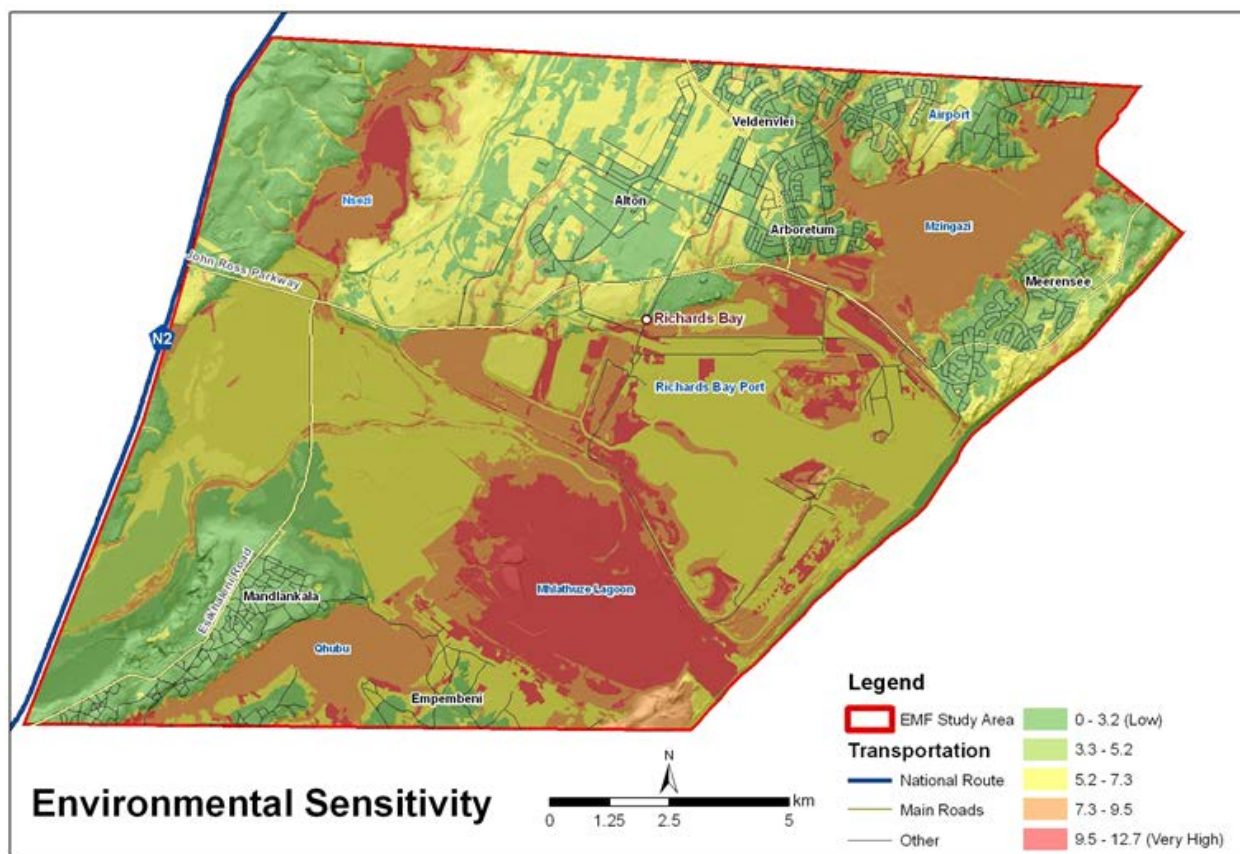


Figure 6.59: Sensitivity map for the EMF study area, created from facets data

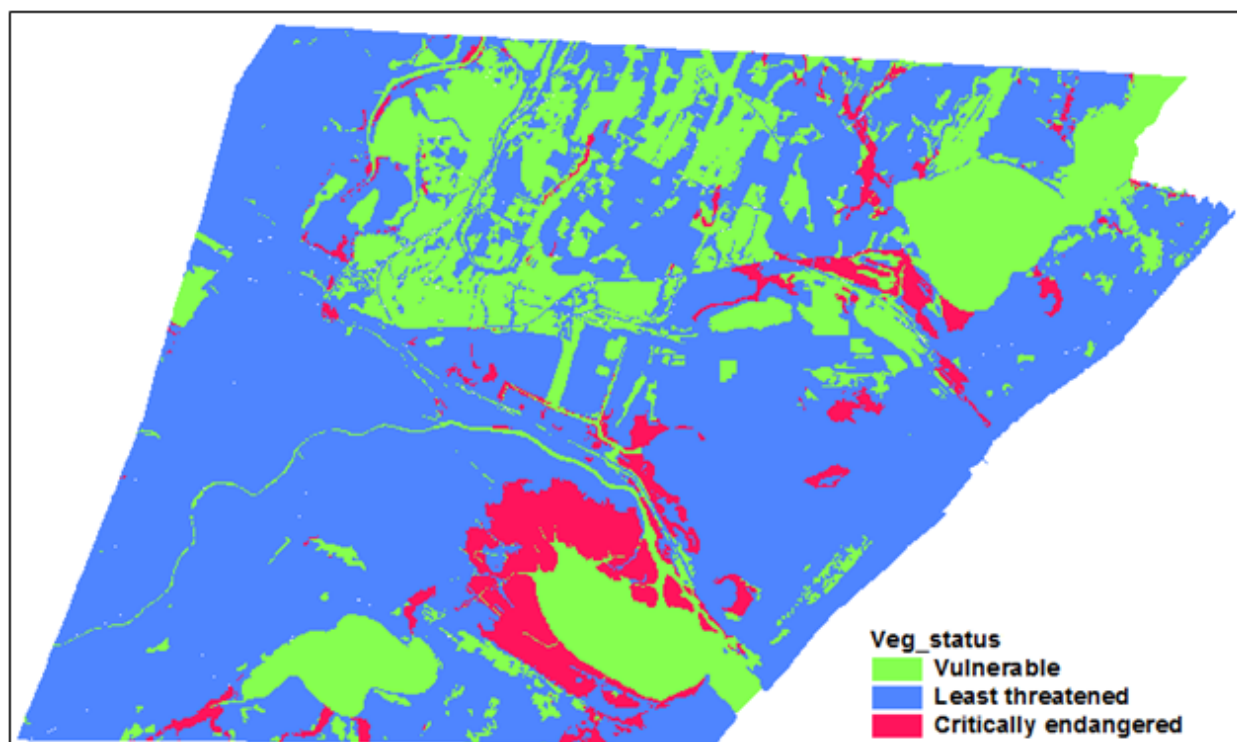


Figure 6.60: Ecological status retrieved from the sensitivity facets dataset

6.5 CONCLUSION

Chapter 6 provided an overview of the theoretical grounding of indicators and frameworks, and how these have been applied in various ways to conceptualise vulnerability, sustainable development and environmental sensitivity. Frameworks such as the coupled human–environment system, the PSR and the DPSIR framework demonstrate the multidimensional, and interrelated character of concepts such as vulnerability and sustainable development. This gives answers to key research questions by identifying the common focus areas in development management, environmental management and disaster risk reduction, and by highlighting information as the common entry point that will integrate development management, environmental management and disaster risk management in a data model for vulnerability reduction.

At this juncture, the theoretical grounding of development planning, environmental management, disaster risk management and geographic information systems has been described. A synthesis of theories, and attempts to find commonalities between these disciplines, are discussed next in Chapter 7.

CHAPTER 7: INTEGRATING DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT, DISASTER RISK MANAGEMENT AND GIS

7.1 INTRODUCTION

The first part of this thesis focused on the exploration of theories that describe development planning, environmental management, disaster risk management and geographic information systems (Chapters 2, 3, 4 and 5). These disciplines are regarded as relatively young, with a strong post-modernistic development tradition. Their integration is explored along commonalities that are rooted in their ontological premises, as the existence and development of their theories have been greatly debated, especially in the development planning and disaster risk management fields.

This chapter serves to identify the commonalities between development planning, environmental management and disaster risk management with the view to developing a data model that provides the structure for integrating these fields from a spatial information perspective. The findings are then drawn together in a matrix to get a visual perspective of the degree of similarities, along the lines of which integration should be explored. Finally, a GIS-based integration platform is presented, showing how development planning, environmental management and disaster risk management can be integrated through the flow of data and information.

7.2 MAIN FINDINGS AND CHARACTERISTICS

The main findings and characteristics of development planning, environmental management, disaster risk management and geographic information science are summarised in the sections below.

7.2.1 Development planning

Development planning is conceptualised in terms of *development* and *planning*. Development thoughts are centred around economic growth, land use change and social change, and they are rooted in mainly Western (First World) thoughts. Planning reflects

activities that aim to manage and control the development process. It is focused on decision making in a post-modern tradition, with an emphasis on cooperative planning.

Development planning displays the following characteristics:

- i. It is a multi-disciplinary field.
- ii. It is spatially orientated.
- iii. It concerns environmental degradation.
- iv. It concerns social upliftment.
- v. It is focused on sustainable development principles.

From a governance perspective, the principles of sustainable development are entrenched in integrated development planning (IDP). Spatial development frameworks provide a strategic and spatial context, whereas project plans direct development on a project basis.

7.2.2 Environmental Management

In short, environmental management is concerned with caring for the Earth, and it focuses on the mitigation or avoidance of environmental degradation. It is influenced by a strong international agenda that is spearheaded by sustainable development objectives. Strategic environmental assessment (SEA), environmental impact assessments (EIA) and environmental management frameworks (EMF) have been developed as tools to support environmental management.

Environmental management displays the following characteristics, which are identical to those of development planning:

- i. It is a multi-disciplinary field.
- ii. It is spatially orientated.
- iii. It addresses environmental degradation.
- iv. It concerns social upliftment.
- v. It is strongly focused on sustainable development principles.

7.2.3 Disaster Risk Management

The field of disaster risk management is relatively young and follows a history of strong theoretical and practical development, from a hazard- and response-oriented discipline to

a pro-active field where the focus is on disaster risk reduction. Research is focused on vulnerability reduction and the building of resilience. Information and communication play an important role in disaster risk management, with GIS being a primary tool in modelling vulnerability, monitoring the onset of possible hazardous events and assisting in post-disaster assessments.

Disaster risk management displays the following characteristics, which show a close resemblance to those of both development planning and environmental management:

- i. It is a multi-disciplinary field.
- ii. It is spatially orientated.
- iii. It is directly influenced by environmental degradation.
- iv. It largely concerns social upliftment.
- v. Is directly influenced by development planning policy and systems.

7.2.4 Geographic information systems (GIS)

GIS developed as a relatively young science from early computer-based technology to transform analogue maps into geo-spatial data. As a science, it is concerned with the representation of spatial features as fields or discrete objects in a spatial database. As a technology, it is concerned with providing decision support in a vast array of disciplines, notably development planning, environmental management and disaster risk management.

The main characteristics of GIS are the following:

- i. It draws from information and database theory.
- ii. It integrates spatial and non-spatial data.
- iii. It deals with spatial relationships.
- iv. It provides strong mapping capabilities.
- v. It provides strong spatial analysis capabilities.
- vi. It supports decision making.

7.3 INFERENCE: COMMONALITIES BETWEEN DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT

Development planning, environmental management and disaster risk management mainly have to deal with problem solving, and the same problem is often presented in each of these disciplines, albeit in different ways. Phenomena such as urbanisation, environmental pollution, depletion of resources, disasters, and social problems such as poverty, are just symptoms of problems. Underneath these issues that are being sensed, perceived and observed, lie complexities that define the development context and the real challenges of an area. The causes of vulnerability in certain communities in South Africa, for example, may be rooted in past apartheid-planning policies that segregated communities and exposed them to environmental hazards. However, current-day policy measures that have been introduced to address past injustices may very well facilitate choices with inefficient attention to the environmental constraints of particular locations, thereby increasing community vulnerability.

GIS has the capability to integrate information on vulnerable communities with areas of hazard, and to create a better context for decision makers. The principle that information is generated from data is a key aspect of information systems, and understanding the concepts thereof provides insight into the integration of various fields along common relationships. The outputs of GIS can therefore improve the development decision capacity that causes vulnerability through planning and development projects by making information available in a practical and usable format.

Integration possibilities between development planning, environmental planning and disaster risk management are found in commonalities with regard to theoretical approaches, theoretical grounding, interrelated planning mechanisms, integrative governance, a shared developmental perspective (sustainable development) and, importantly, the spatial contextualisation of problems and opportunities. The matrix in Table 7.1 provides a synopsis of how these integration possibilities are structured.

Table 7.4: Integration matrix showing commonalities between development planning, environmental management and disaster risk management

	Development Planning	Disaster Risk Management	Environmental Management
Theoretical approaches	Post-modernism		
Theoretical grounding	Social- and natural sciences		
Strategic planning mechanisms	Integrated development planning (IDP) Spatial development frameworks (SDF)	Disaster risk assessment (DRA)	Strategic environmental assessment (SEA) Environmental management frameworks (EMF)
Integrative governance	IDP		
Implementation	Project Plan	Disaster management plan	Environmental impact assessment (EIA) Environmental management plan (EMP)
Spatial contextualisation	Geographic information science (GIScience)		
Spatial analysis	Multi-criteria decision analysis (MCDA)		
Visualisation	Mapping		
Framework	Sustainable development		

Spatial contextualisation is taken as the main approach for integration. Within GIS science, database theory provides for the design of a framework that identifies entities and their relationships. This concept is used as an analogy to structure development planning, environmental management and disaster risk management as entities in a framework where the relationship is defined through the flow of data and information. GIS technology is inclusive of database structures in spatial and non-spatial formats and can be used as a platform to integrate all data and information flows among the different domains. Given commonalities and overlaps in terms of geographical space within which the human–environment system functions, GIS-based database design principles can be applied to develop fully integrated applications from which practitioners in each of the three domains can draw data and process information.

Information systems theory further explains the creation of information from data through a transformation process. The integration of information from different disciplines may further contribute to the acquisition of knowledge. Thus, an integrated database environment is imperative for dealing with domain-related responsibilities such as strategic planning, environmental impact assessment and disaster risk reduction. A framework for a GIS-based platform to integrate these disciplines is presented in Figure 7.1. It is based on the principles of entity-relationship modelling, as described in Chapter

5, and illustrates how the relationships are established through the flow of information from a centralised GIS data management function.

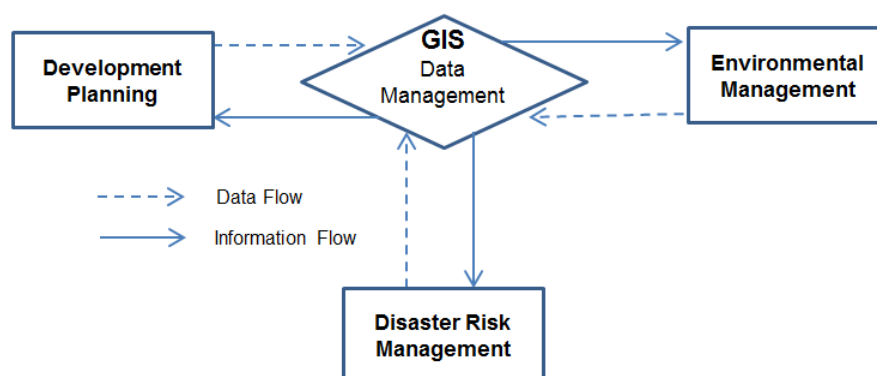


Figure 7.61: The integration of development planning, environmental management and disaster risk management through GIS as a data management platform

The application of this framework is demonstrated by referring to works of the author that followed from this research. The first is a framework for rapid disaster impact assessment (RIA) published as a research article (Jansen van Vuuren, 2013), and the second is a planning project in Richards Bay that forms part of the case study that is presented in Chapter 8 (refer to Figures 7.2 and 7.3).

These two examples show the application of GIS in a multi-disciplinary environment. The RIA framework is the result of a research intervention initiated by the African Centre for Disaster Studies (ACDS) at the North-West University in Potchefstroom, South Africa, following a series of devastating wildfires in August 2012 in the North-West Province. The research involved specialists from various fields, including disaster risk management, governance, environmental management, agricultural economics, communication studies, psychology, and GIS. The framework highlights the use of different spatial databases that are integrated into a dedicated RIA application. The GIS process is linked to all the RIA phases, from planning through to reporting. As is highlighted by Jansen van Vuuren (2013), it is imperative that GIS design must form part of the RIA planning process wherein the data needs for all the RIA participants can be identified and the survey and data collection process can be coordinated from a GIS perspective. Map production for reporting purposes then follows easily by querying the integrated spatial database.

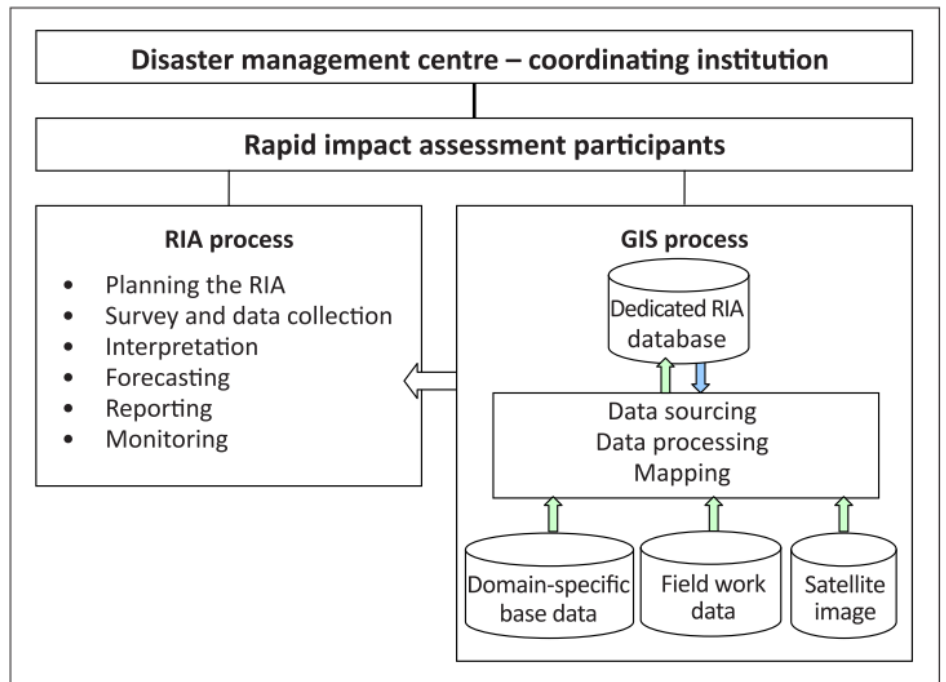


Figure 7.62: Integration of Geographical Information Systems with the RIA process
Source: Jansen van Vuuren (2013:6)

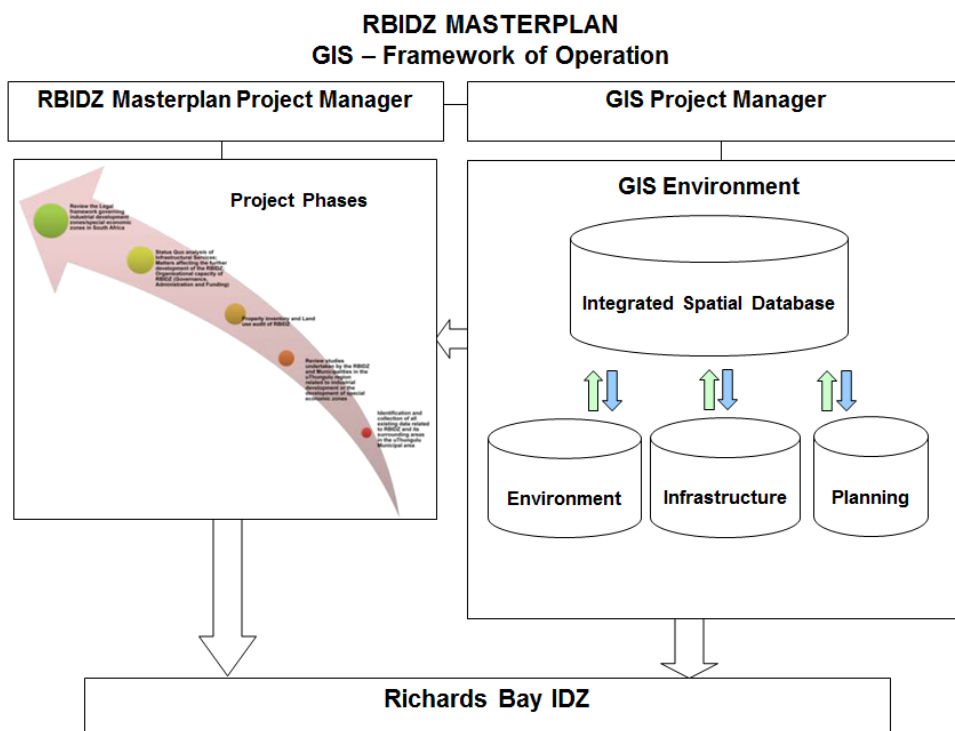


Figure 7.63: Framework for GIS operation in a multi-disciplinary development planning project
Source: Created by the author for reporting purposes

The development of the Richards Bay Industrial Development Zone (IDZ) is a multi-disciplinary project involving planners, environmental specialists, engineers and

economists. GIS functionality exists within each of these fields at different levels of expertise. The author was appointed to coordinate the GIS operations and conduct a multi-criteria decision analysis (MCDA) to identify the location for developing a new industrial area in Richards Bay. His knowledge based on this research was applied to establish a framework for operations on a project management level. He assisted specialists in the different fields and drew from various spatial databases to establish an integrated spatial database for the project. This approach facilitated GIS support in all the phases of the project and a location for industrial development was identified in an area with the least environmental impact.

7.4. CONCLUSION

The commonalities between development planning, environmental management and disaster risk management are found in their nature as multi-disciplinary fields, their spatial orientation, concerns with environmental degradation and social upliftment, a focus on sustainable development principles, and post-modern approaches. The use of GIS as the entry point for development management, environmental management and disaster risk reduction to be integrated in a data model for vulnerability reduction has been demonstrated from the inference of theory and the implementation of the approach in practice.

Although the development of inter- and intra-disciplinary theory is not the objective of this thesis, the voices of scholars such as Van Niekerk (2012), Van der Waldt (2013), and Lavell and Maskrey (2014) are noted from within the disaster risk management field to change views towards theory integration. Chapter 7 clearly demonstrated that a platform for integration exists in GIS science. The next chapter aims to establish a GIS-based data model that is focused on resolving inter-relationships along database theory principles, and that could possibly serve as a point of departure for theory integration.

CHAPTER 8: A GIS-BASED MODEL FOR INTEGRATING DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT

8.1 INTRODUCTION

Vulnerability mapping models such as proposed by Cutter *et al.* (2000), and GIS-based reports such as the South African Vulnerability Atlas (Archer *et al.*, 2010), present indicator values at the aggregated level, which restrict its use for local planning to the level of strategic thinking. The concept of disaster has been linked to different human–environment interactions. Simplified representations, however, do not discriminate among such interactions. Decision making with regard to development frameworks and the spatial location of different economic activities requires analyses of the coupled human–environment system on a local level, taking into account environmental sensitivity and disaster risk.

Various spatial operations in GIS are used to create datasets from different inputs. Aerial photography or satellite images, for example, are typically used to create land cover data. Contour lines are used to extrapolate and create a field of elevation values. From these, various processing techniques can be used to create other value-added datasets. A visualisation perspective (making maps) of GIS restricts its power of cognition of what is presented on the map. From a database perspective, however, the processing power of GIS can be used to create data on a scaleless and seamless manner – in other words the creation of basic spatial units close to the geo-atom level that reference features in the real world upon which further spatial operations can be performed to generate datasets and visualisations at any aggregated level. The question is, how can this be applied to model the coupled human–environment system?

The entity-relationship (ER) model was described in Chapter 5 as a conceptual data model that uses primitives like *entity type* to describe independently existing entities, *relationship type* to define relationships between entities, and *attributes* to describe characteristic values of entities and relationships. This model lends itself to resolving the relationship between entities in space. Chapter 3 described the landscape-ecology

framework that provides for the integration of human and ecological activities and the analysis of interactions between socioeconomic and biophysical processes. Based on these concepts, Chapter 8 now proposes a framework and conceptual model that identifies and solves the many-to-many relationship problem that exists in the coupled human–environment system. It uses Boolean logic and database theory, as described in Chapter 5, to model relationships between anthropological and ecological entities within the ecological landscape. The model is then applied and tested in a case study, and the possibilities for expanding the model are highlighted.

8.2 DATA MODELS

The process of abstraction of real-world phenomena into a spatial database is called spatial modelling, and is one of the most useful tools for database design (Kainz, 2004). Worboys and Duckham (2004:19) assert that the choice of an appropriate data model is a critical factor for the success or failure of an information system, and that it is fundamental to the database idea. The understanding of a data model is, however, expressed differently by GIS scholars, and confusion exists in this regard (Maguire & Dangermond, 1991:320). For example, the raster / vector representation of space is a recurring view of data modelling in literature. Another view is the field–object data model (Goodchild, 1992), which provides a particular perspective on data models from a geographic reality. Peuquet (1984) and Harvey (2008) distinguish between data modelling from a geographic or cartographic perspective, and a database perspective. These perspectives view data models from the viewpoint of a physical schema, i.e. the data structures (rasters, points, lines and polygons) as described in Chapter 5. Another perspective of data modelling is design (Longley *et al.*, 2005), the process that begins with a view of the real world, followed by a sequence of steps from a conceptual schema to the physical design of the database. It is this view of data modelling that informs the development of a data model for the integration of development planning, environmental management and disaster risk management.

Built on the premise that a map (and by implication a spatial database) is a model of reality, the process of developing an information system can essentially be seen as a process of model building (Worboys & Duckham, 2004:19). Given the complexity of reality, it is impossible to design a general-purpose data model that is useful in all situations (Peuquet, 1984:71). Therefore, a design and abstraction that serve the purpose of the intended use of the system are important. According to Peuquet (1984), there are two main approaches to designing spatial data models, i.e. the *phenomenon-*

based design, and the *intended use design*. The first attempts to include all identifiable entities and their relationships in a data model, hence attempting a close representation of reality. This results in a complex model that would be far beyond that which is efficient in a computer context, and would contain many entities and relationships that are not essential to the application at hand. The second approach adopts the philosophy that the data model design should be driven by its intended use. Such a model would exclude many entities and would be far from a complete representation of reality, but it would at least contain the essential elements that are necessary for a particular task. This *intended use* approach is adopted by Albrecht (1995), who asserts that all GIS tasks, irrespective of any data structures, relate to a small number of functional groups that are subservient to specific goals (refer to Jansen van Vuuren, 2013).

Peuquet (1984:67) defines a data model as “a general description of specific sets of entities and the relationships between these sets of entities”. Entities are things that exist and are distinguishable, such as a person, a house or a lake. Entities that possess certain common characteristics can be grouped into a class of entities and form an entity set. For example, a set of wetlands in a landscape constitutes the class *wetlands*. Entities and classes are associated with each other through specific relationships. The need for a model to conceptualise entities and their underlying relationships was identified by E.F. Codd, who developed the Entity-Relationship (ER) model for this purpose (see Chapter 5, Section 5.5.6). As such, the ER diagram is a tool for developing a data model at the conceptual level.

Peuquet (1984:69) introduces a theoretical framework for data modelling that describes four levels of abstraction that are required to determine how a collection of data will be represented in digital form. These levels, which progress from reality to the storage of data in digital files through a process of abstraction focused on the specific needs of the user, are summarised below (refer to Figure 8.1):

- i. *Reality* – Phenomena on Earth as they exist in space.
- ii. *Data model* – This is a conceptual model and an abstraction of the real world represented by only those entities that are relevant to a specific application. The ER model functions on this level.
- iii. *Data structure* – A representation of the data model in terms of diagrams that reflect how data will be recorded in digital files – referred to as a logical model. The ER model is extended to describe the structure of database files in terms of field names, field types and key fields.

- iv. *File structure* – The physical model consisting of the group of digital files that are stored on computer hardware.

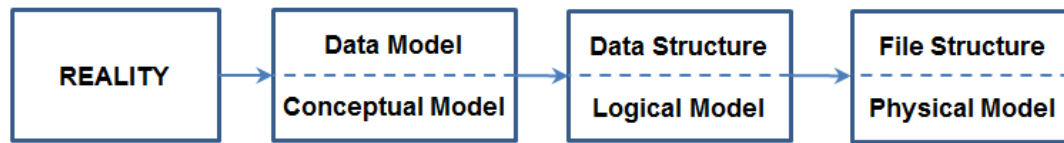


Figure 8.64: Levels of abstraction for database development

Source: Peuquet (1984); Maguire and Dangermond (1991); Longley *et al.* (2005)

The above analysis provides a background for the development of a GIS-based data model from a modelling point of view. Further background was provided in previous chapters that highlighted the coupled human–environment system, particularly Chapter 3, where the concept of landscape ecology was highlighted as the framework for describing the relationships between environmental and anthropological entities. Chapter 5 described the ER model as the structure for accommodating various relationships in the design of a database. Understanding this background is important for the next section, which describes the development of a GIS-based model to integrate development planning, environmental management and disaster risk reduction.

8.2 PROPOSED FRAMEWORK AND DATA MODEL

It has been stated that the relationship between anthropological activities and ecological activities exists in the functioning of the landscape, where the activities of the one impact on the activities of the other (refer to Figure 8.2a). For example, land use activities such as industries impact on ecological activities such as hydrological systems through its functioning in the landscape; by allowing effluent to pollute water systems. On the other hand, water systems support land use activities through their functioning in the landscape by natural recharging through precipitation, and the availability of the water to be extracted and used in manufacturing processes. The relationship between these activities in the landscape manifests in a many-to-many configuration, which is dissolved through an infinite number of one-to-one or one-to-many relationships.

All landscape functions occur in space (see Figure 8.2b). Although many activities occur on many places in space, two activities cannot occur in the same place. Where two or more activities compete for the same space, the dominant activity will eventually override the other, which leads to the transformation of the other activity, either partly or in total.

External stressors have an impact on the status of activities. These stressors exert energy on places, which may lead to the transformation of the affected activities. Based on the nature of their resilience, such activities may either recover from temporary transformations, cease to exist, or change their behaviour in adaptation.

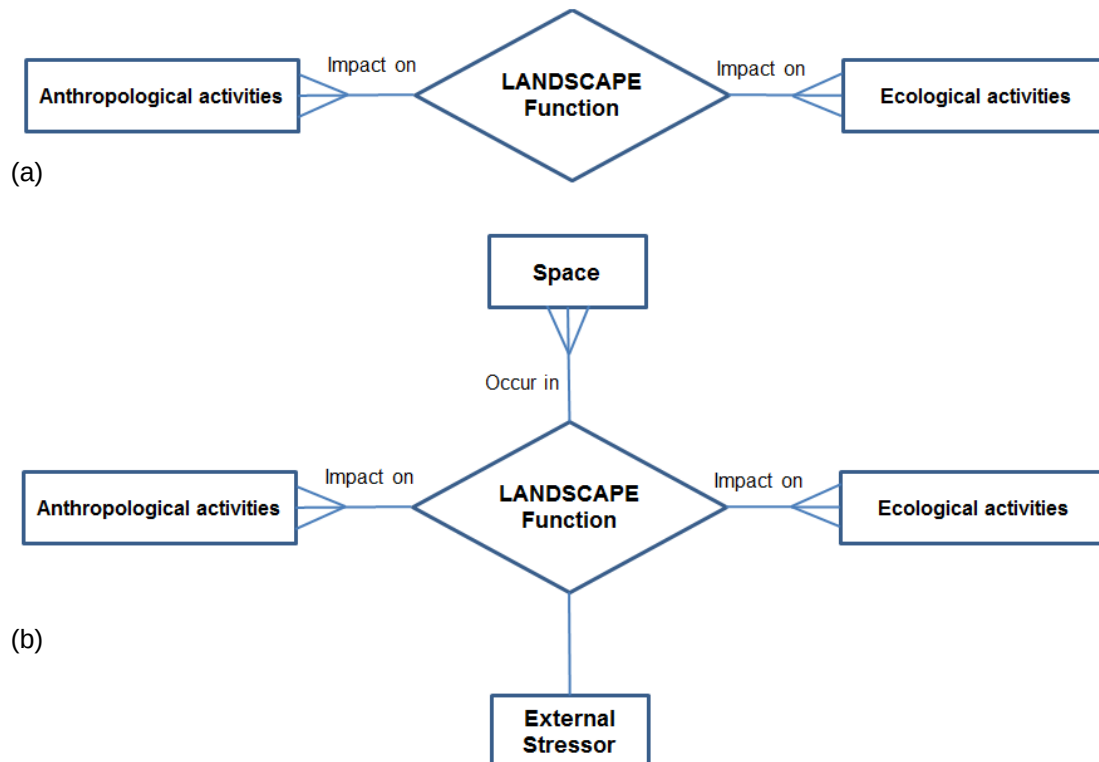


Figure 8.65: The integration of anthropological and ecological activities in the functioning of the landscape

The above concept is useful to model existing schemas, such as the framework for ecosystem and human system linkages of Cleveland *et al.* (1996). The reader is referred to Section 3.5 for a discussion of this framework. Controls, flows and stocks in the framework can be modelled in an ER diagram as entities with intrinsic attributes. The particular value of the model is the ability to define the relationships between these entities, as illustrated in Figure 8.3.

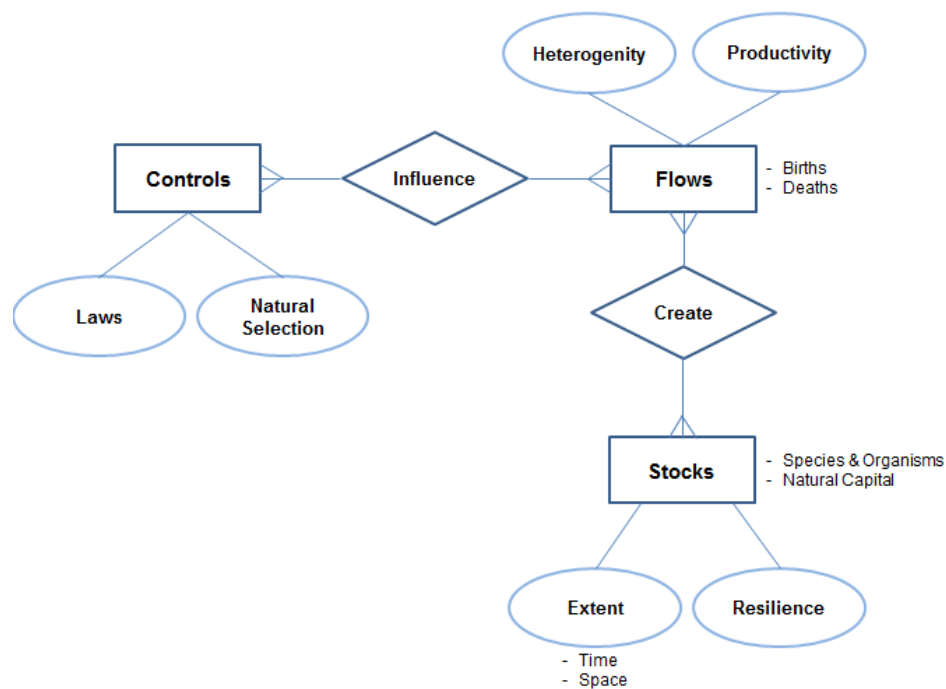


Figure 8.66: An ecosystem – human system framework expressed in the form of an ER diagram

The landscape-ecology framework as described in Chapter 3 provides a foundation for expanding the conceptual ER model into a logic framework. The basic construct of the framework is that, for any activity occurring in an anthropological or ecological unit, the association between human and environmental activities is either acceptable or unacceptable. Boolean logic, which is based on the concept of a set of {0,1} values to denote properties of *True* (1) or *False* (0) (Epp, 2004), can be used as an analogy to set property values in a database table to indicate acceptability, as illustrated in Figure 8.4.

The framework models the integration of anthropological and ecological units as spatial objects in a field-based landscape, where anthropological and ecological activities function in an interactive manner. Data is captured on the geo-atom level, providing for the smallest basic spatial units possible. Anthropological units are made up of spatial units at the functional level, such as *houses*, *schools*, *commercial buildings*, *roads*, etc. These can be aggregated to the community level, or higher, and then classified as *village*. Likewise, ecological units are captured on the functional level, such as *wetlands*, *floodplains*, *grasslands*, etc., which can be aggregated to *biomes*. The basic units can be identified in a spatial database as objects with attributes that specify activity and status. This concept is illustrated in Figure 8.4. (In this example each table represents one geo-atom, or basic special unit. Status is derived from Boolean logic, where True (T) = 1, and False (F) = 0. The status is determined by the product of the two fields, for example

1x0=0. A product of 1 is indicative of an acceptable relationship, and 0 of an unacceptable relationship.)

		Spatial Objects	
		Anthropological Unit	Ecological Unit
(a)	Region	Village	Wetland
	Object	Buildings	Buildings
	Acceptable: (T/F)	1	0
	Status	0 : Vulnerable / Sensitive	
(b)	Region	Village	Wetland
	Object	Buildings	Phragmites
	Acceptable: (T/F)	1	1
	Status	1 : Normal / Resilient	
(c)	Region	Village	Wetland
	Object	Agricultural Fields	Water
	Acceptable: (T/F)	1	1
	Status	1 : Normal / Resilient	
(d)	Region	Village	Wetland
	Object	Agricultural Fields	Agricultural Fields
	Acceptable: (T/F)	1	0
	Status	0 : Vulnerable / Sensitive	

Figure 8.67: Entity relationships between anthropological and ecological units in the landscape

At the aggregated level, anthropological and ecological units occur in a region. For example, the object *houses* occur in the region *village*. *Houses* can also occur in the region *wetland* (refer to Figure 8.5). By virtue of association, object activities can be identified as related to or not related to the functional region. Houses, for example are not related to the function of a wetland, and will therefore carry a negative value. This property is represented by the values 1 being a positive association, and 0 being a negative association. As integrated units within the landscape, the product of these values will be either positive or negative. Positive associations indicate a healthy, acceptable status, whereas negative associations are indicative of an unacceptable or problematic status. Such disassociations are further indicative of a vulnerable or sensitive status.

The compound structure of the two unit types (anthropological and ecological) is the key to resolving the many-to-many relationships, as mentioned above. This structure can be expanded into a database design where entity functions are captured in lookup tables that are joined with the attribute tables of spatial features (refer to Figure 8.5). These contain

the relationship values that are associated with the landscape features. For example, for the entity *Village* the relationship value for the function *Houses* is [1], which specifies a 'True' value, meaning a positive or acceptable relationship. For the function *Water Flow* the value is [0], implying a negative or unacceptable relationship. The entity *Wetland* shows the opposite values for these two functions. According to this schema vulnerability is identified from two perspectives – from a land use perspective, looking at *Village*-related functions, and from an ecological perspective, looking at *Wetland*-related functions. The vulnerability schema could be interpreted as follows:

- i. If the *Village-Wetland* relation for *Houses* is [1,0], then acceptability is *False* ($1 \times 0 = 0$), thereby indicating a vulnerable status for *Houses*.
- ii. If the *Village-Wetland* relation for *Houses* is [1,1], then acceptability is *True* ($1 \times 1 = 1$), meaning that *Houses* would not be regarded as vulnerable.

Entity: Village U Wetland			
Id	Function	Relation Value (Village)	Relation Value (Wetland)
1	Houses	1	0
2	Phragmites	1	1
3	Water Flow	0	1
4	Agricultural Fields	1	0
n	n^{th} activity	{0,1}	{0,1}

Figure 8.68: Example of a compound table that can be joined with a spatial database

8.3 VALUE OF THE GIS-BASED MODEL FOR INTEGRATING DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT

The value of the model is grounded in two principles: first, the integration of spatial objects at a small scale (geo-atom level), and second, the relationship between anthropological and ecological activities, which exists within the union of spatial entities. At this level, spatial objects define the type of activity, for example *Houses* define residence where people live, and *Phragmites* define natural vegetation that is associated with wetlands. From this basis, data can be aggregated to calculate and represent the variation within a region, from which aspects of vulnerability, sensitivity or resilience can be extrapolated. For example, the level of transformation within a wetland can be quantified and analysed against indicators of thresholds or carrying capacity that have

been determined scientifically to maintain resilience. From the disaggregated level, impacts can be extrapolated to determine the level of fragmentation, perforation, dissection, shrinkage or attrition of a region (refer to Section 3.5 for a discussion of these terms). This approach shifts the focus away from the demography-related profiling of communities at census level to infer and differentiate levels of vulnerability in a community. To illustrate, the following hypothetical example is offered:

In a landscape where a river (classified as a wetland to include the riparian zone and floodplain as part of the wetland) intersects a village, the village and the river represent two regions within the landscape. Various objects in each region indicate specific activity. With each activity captured as a spatial object (including attributes that define properties such as the object type, its status, and its extent), the association of the activity in relation to the region where it is located is captured in terms of the proposed model. The database is designed to join external lookup tables (as described above) with the attribute tables of the GIS feature classes. A scientific evaluation of the wetland would provide a classification of resilience thresholds in terms of the extent (area) of transformation. Hypothetically, the thresholds could be determined as follows:

If $R_v > 0.5$, Resilience = Low

If $R_v \geq 0.25$ and $R \leq 0.5$, Resilience = Moderate

If $R_v < 0.25$, Resilience = High

The following formula can be applied to calculate R_v :

$$R_v = (\sum_{i=1}^n H + \sum_{i=1}^n F) / \sum_{i=1}^1 W$$

Where R_v = Resilience value; H = Area of Houses, F = Area of Agricultural fields; and W = Area of Wetland (in which houses and agricultural fields occur).

The vulnerability of the community in terms of flooding is determined in two ways. First, the houses located within the wetland are exposed to a higher risk of flooding than those outside the wetland. Second, the community uses certain parts of the wetland to plant crops. As a sustainable farming practice, these fields are also at risk of flooding. The destruction of these fields in case of extensive rains and flooding of the wetland may increase the vulnerability of the community in terms of food security.

The value of the model can also be demonstrated by research interventions, where field work is undertaken among community members. By approaching the research design from a spatial data management perspective, the survey can be structured to capture the

required data that would be relevant to the application of the model, for example the dependency of the community on subsistence farming. With reference to the example that is used above and in the case study below, the applicable data items from the survey can be related to the object *Agricultural Fields*. The relationship between this object and *Wetlands* allows for further statistical analysis to determine the ratio of possible loss of the agricultural resource in case of flooding.

8.4 APPLICATION OF THE GIS-BASED MODEL: CASE STUDY

To test the model, a GIS application was developed for a case study in Richards Bay. The case study involves the identification of wetlands that are exposed to impact by human development. Wetlands are associated with the rivers and lake systems in the Richards Bay area, many of which are located within the 1:50 year and 1:100 year flood lines. The impact of development on wetlands, such as the continual degradation of the wetlands and the riparian vegetation, poses an ever-increasing danger of flooding and damage to low-lying infrastructure (CSIR, 2014).

The case study sets out to identify a goal, establish a GIS project, create a join table that reflects the anthropological and ecological relationships of entities, and link that with the relevant GIS dataset.

The goal is the identification of anthropological activities within a wetland by means of a relational database, where the relation between anthropological activities and a wetland is determined by an externally linked table designed in terms of Boolean logic, as explained in Section 8.3. This table functions as a 'join' table, meaning that it can be joined externally with the attribute table of a GIS data feature. The values in this table can be changed independently from the GIS. When the GIS is active, the values of the joined table can be used to simulate different vulnerability scenarios without changing values in the GIS – a process that is aimed at creating maps, but is independent of static maps. The development of a case study GIS project is described below.

The GIS project is established through an iterative process of data creation and processing, as indicated in Figure 8.6. Two primary input sources are used, to which data-processing algorithms are applied to extract new data sets. An orthogonal-rectified aerial photograph is used to create broad land cover (LC) classes through an unsupervised classification process. A digital elevation model (DEM) is created from the contour data. From the LC classes, buildings and agricultural fields can be extracted,

which become input in further processing. A potential floodplain (wetland) that coincides with the 1:50 year flood line is identified and extracted from the DEM. An intersect of the LC classes and the wetland is used to populate the [IN-Flood] field of the LC feature class with binary TRUE and FALSE values (1 = TRUE; 0 = FALSE). On its own, the value '1' would identify an entity as located within the wetland; however, the relation between the entity function and the wetland function and the compatibility of these two functions are not known from a database perspective. This requires a join table that identifies the relationship and can be linked to the LC feature class in a GIS.

The join table contains the ID values of the LC feature (consisting of six classes), and two columns that contain a TRUE/FALSE value for the anthropological and the ecological component for each of the LC classes (see Figure 8.7). The join table is linked to the LC feature class database by means of a primary–foreign key join, expressed as follows:

Target Table: LC_extract = LC feature
Target Field: GRIDCODE = LC feature primary key field
Join Table: Lookup1\$ ('Lookup1\$') = MS Excel Spreadsheet
Join Field: Link_Code = Join table foreign key field

A spatial query is created, based on the combination of the [IN_Flood] attribute of the LC feature and the [Eco_Unit] attribute of the join table. This query identifies the TRUE / FALSE combinations whereby the following combinations are possible:

1,0: Entity located in the wetland = True, and associated with wetland functions = False;
1,1: Entity located in the wetland = True, and associated with wetland functions = True;
0,0: Entity located in the wetland = False, and associated with wetland functions = False;
0,1: Entity located in the wetland = False, and associated with wetland functions = True.

By manipulating the values in the join table, different spatial expressions will result. This is illustrated by the maps in Figures 8.9 and 8.10. This analysis shows that the explicit associations and relationships between anthropological and ecological functions can be represented in a GIS database structure where an external join table becomes a key component of the database design. The significance of this finding is demonstrated by the fact that the spatial database for the LC feature contains more than 800 000 records in the database that needs no manipulation or update to effect any changes to the data. Changes in the join table are quick and easy to do. The resulting changes in spatial context are instant, with the map view in the GIS being automatically updated as the

project is re-opened. A more detailed description of the data tables and associated maps is given below.

Input	Process	Output
Satellite image	Classification	Land cover (LC) classes
DEM	Extract < 10m	Potential Floodplain (Wetland)
	Re-classify	
	Raster to polygon conversion	
Land cover classes	Extract	Buildings, Agricultural Fields
Buildings	Wetland - LC Intersect;	Attribute: {Inside = 1; Outside = 0}
Potential Floodplain	Identify LC components	

Figure 8.69: An example of the iterative process of data processing to create spatial data at geo-atom level.

(a)	Link_Code	Anth_Unit	Ecol_Unit
	1	0	1
	2	0	1
	3	1	1
	4	0	1
	5	0	1
	6	1	1

(b)	Link_Code	Anth_Unit	Ecol_Unit
	1	0	1
	2	0	1
	3	1	1
	4	1	1
	5	1	0
	6	1	0

Figure 8.70: Two iterations of the join table.

Figure 8.7 illustrates two iterations of the join table (a, and b), each with different values for the anthropological ('Anth_Unit') and ecological (Ecol_Unit) entities. Different relationships between the anthropological and ecological units are illustrated for the LC classes, represented by the 'Link_Code' field. This field provides the link with the land cover GIS feature. From within the GIS, the values of the join table are visible (refer to Figure 8.8), and can be used in a spatial query which will reflect the changes of values in the join table. This is illustrated by the maps below (Figures 8.9 - 8.11).

Land_Cover_Code	IN_Flood	Link_Code	Anth_Unit	Ecol_Unit
4	0	4	0	1
4	0	4	0	1
2	0	2	0	1
4	0	4	0	1
2	0	2	0	1
4	0	4	0	1
4	0	4	0	1
2	1	2	0	1
3	1	3	1	1
4	1	4	0	1
2	1	2	0	1
4	1	4	0	1
3	1	3	1	1
3	1	3	1	1
3	1	3	1	1
3	1	3	1	1
3	1	3	1	1
3	0	3	1	1
3	0	3	1	1
3	0	3	1	1
2	0	2	0	1
3	0	3	1	1
3	0	3	1	1
1	0	1	0	1
2	0	2	0	1
3	0	3	1	1
4	0	4	0	1
5	0	5	0	0
5	0	5	0	0
4	0	4	0	1
4	0	4	0	1
2	0	2	0	1

Figure 8.71: Extract of the attribute table of the land cover GIS feature, showing the join table.

The legend of the maps in Figures 8.9 and 8.10 shows the compound values for the two fields [IN-flood] and [Ecol_Unit], representing a field from the GIS attribute table and a field from the join table respectively. The [IN-Flood] values indicate the location status of features in relation to the floodplain, where 1=True and 0=False. The [Ecol_Unit] values indicate the acceptability status in terms of the ecological function, where 1=True (acceptable) and 0=False (unacceptable).

The blue colour in the maps represent a wetland associated with a floodplain, which is susceptible to flooding. This reflect the compound value [1,1], indicating a 'True' or 'Acceptable' status. The red colours in the blue region represent the compound value [1,0], indicating a 'False' or 'Unacceptable' status.

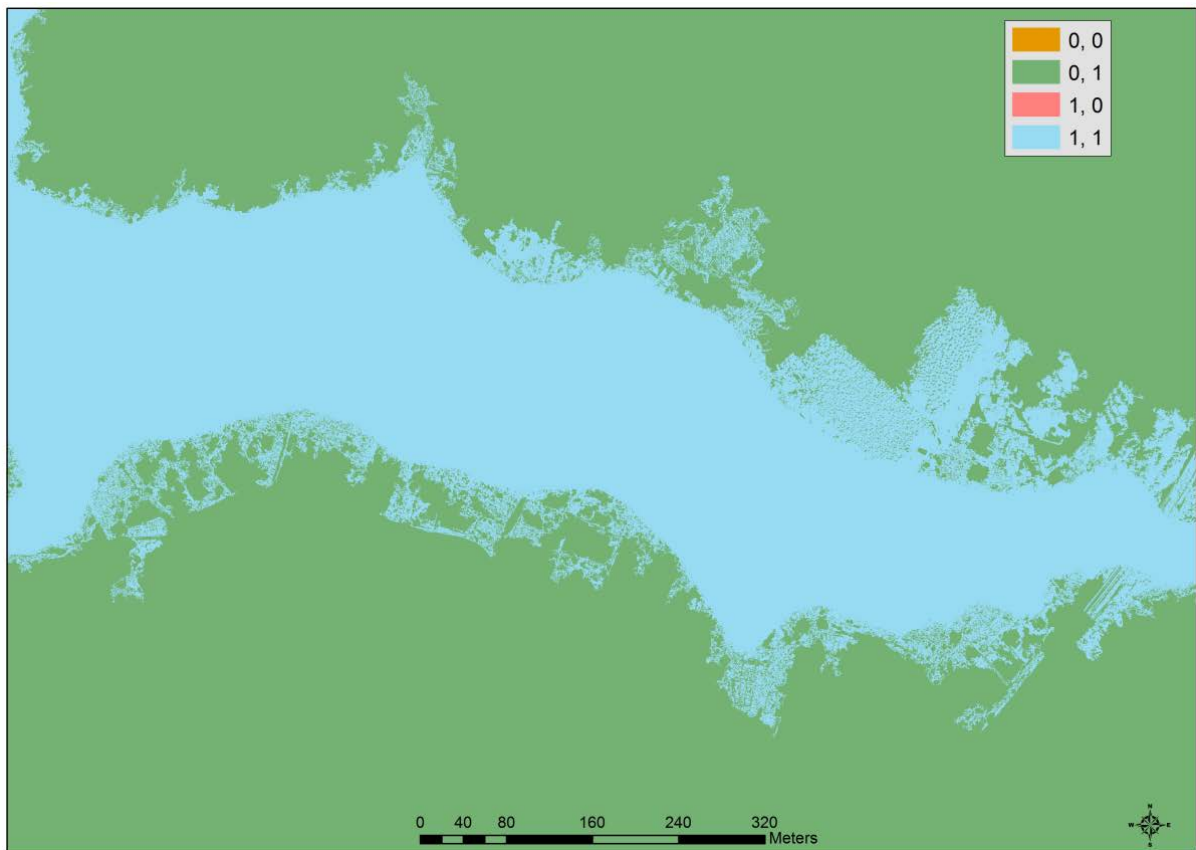


Figure 8.72: Map according to the values in table (a) of Figure 8.7.

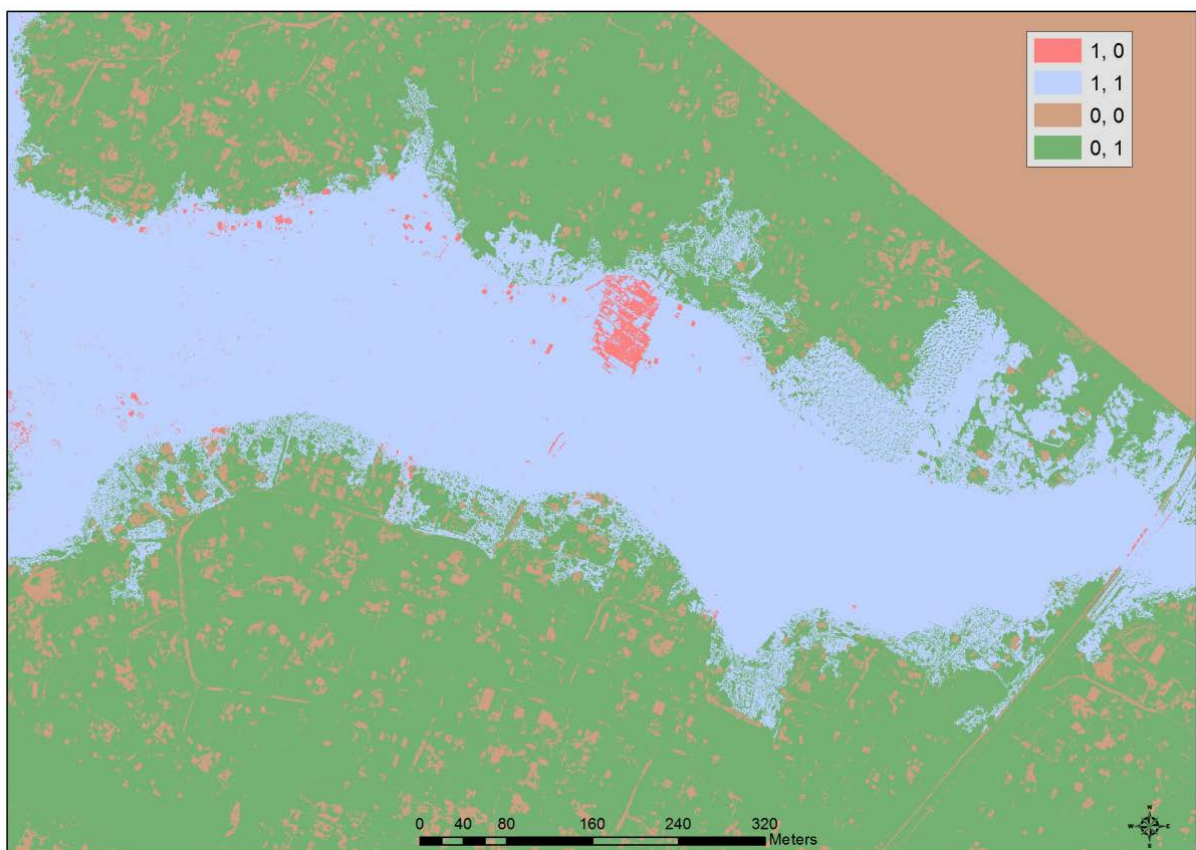


Figure 8.73: Map according to the values in table (b) of Figure 8.7.

Changes in the join table were made for land cover values representing anthropological land uses, such as houses and agricultural fields. By adding the land cover field to the compound query, a finer resolution of results can be obtained, as is illustrated by the map in Figure 8.11. The total number of unique combinations of values on this map is 11, as opposed to 4 in the previous maps.

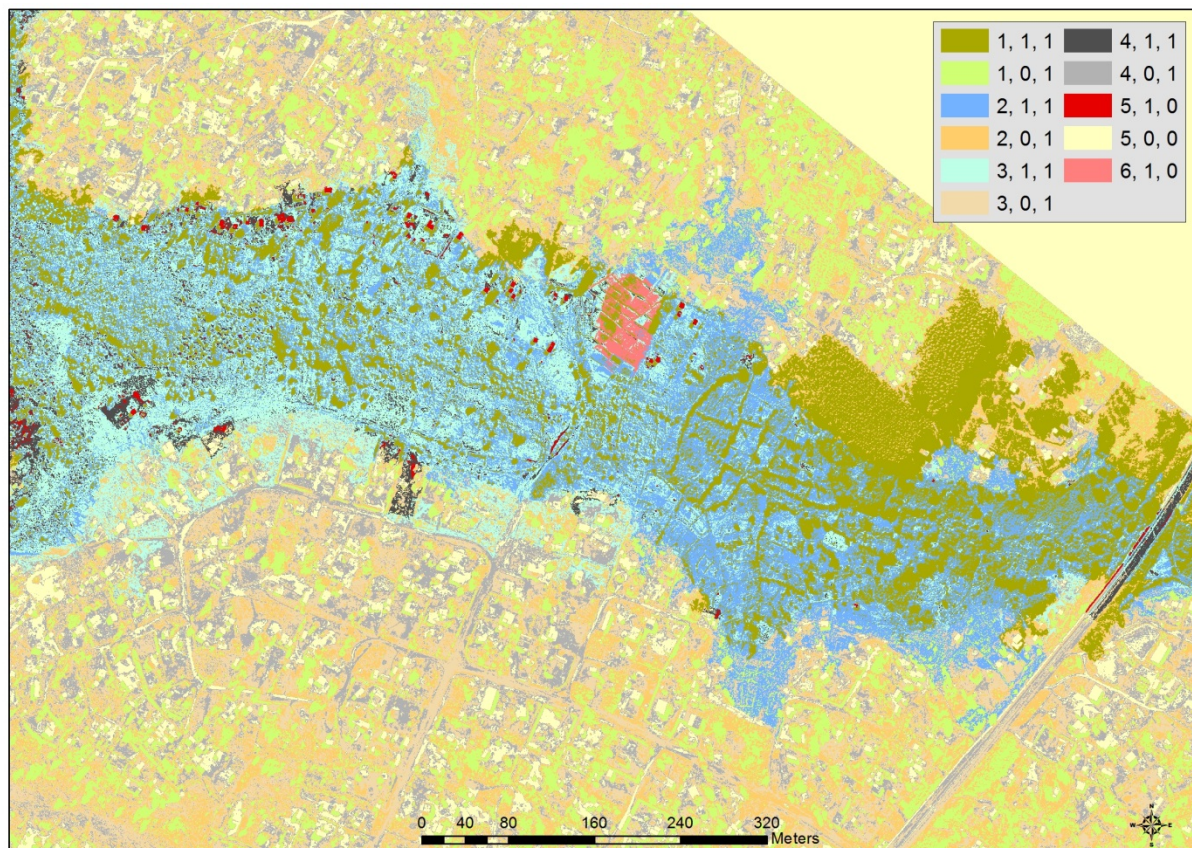


Figure 8.74: Map showing the results of a compound query with the land cover value included.

GIS query capabilities allow for the inclusion of a third attribute in a compound query. The map in Figure 8.11 above shows the results of a query where the first value represents a land use code (refer to the legend in the map). The code is not a Boolean value and is part of the set {1,2,3,4,5,6}, which includes all land use categories for the case study. The second and third values represent the [in wetland] and [ecological function] Boolean values, similar to the maps in Figures 8.8 and 8.9. This example shows 11 unique combinations of compound values, and a higher level of differentiation.

The Richards Bay case study demonstrates the value of the proposed integrated GIS data model. As a physical data model based on the conceptual design described in Section 8.2, the spatial database built for the case study shows how spatial relationships

can be established in terms of entity attribute modelling, providing an alternative perspective to the topological-based spatial data model.

8.5 EXPANSION OF THE GIS-BASED MODEL

This model can be expanded in various ways. First, it should be expanded to include other entities that define a landscape, such as landform and habitats from an ecological perspective, and elements of economic activity and infrastructure from an anthropological perspective. Second, the model can be expanded to develop rule-based “IF...THEN” statements and knowledge systems (Smith & Jian, 1991). Sustainability development objectives command that development in potentially hazardous zones should be avoided. Spatial analyses based on this model should thus prove useful, not only to identify risk zones, but to quantify risk in terms of possible losses and relative vulnerability on a landscape level.

Third, the model can be expanded to include the concept of process and flows, as described in Chapter 7. Worboys and Hornsby (2004) distinguish between two types of entities that define our world, i.e. *continuants* and *occurents*. Continuant entities describe features that remain in the landscape over an extended time period, such as buildings, roads and cities. Occurrent entities happen over a short period of time, and include processes such as the construction of buildings, roads and cities. Occurents can also happen repetitively, such as the ongoing development of new cities, or the expansion thereof. In terms of the disaster framework, an event can also be seen as an occurrent. In terms of landscape ecology, continuants and occurents exist in both the anthropological and the ecological domain. The relationship between continuants in these domains has been described above. The proposed model should also be able to describe the relationship between occurents.

Lastly, the model can be expanded to include a third dimension, such as time. Both continuants and occurents are influenced by time, in terms of beginning, end and duration, within which their status may change.

8.6 CONCLUSION

This chapter described the concept of data modelling in GIS, making a clear distinction between data structures as models, and modelling in terms of database design. A

conceptual data model was presented based on the principles of ER modelling and Boolean logic, demonstrating the possibility to model the relationships between anthropological and ecological entities through their functioning in a landscape.

The value of the model was demonstrated by a case study that implemented the proposed conceptual model in the physical design of a GIS application. It showed how the relationship between entities of the coupled human–environment system can be spatially represented, and how the model can be used to undertake different ‘WHAT-IF’ analyses. It was further demonstrated how, through this model, GIS can function as the entry point for the integration of development management, environmental management, and disaster risk management in a data model for vulnerability reduction.

Chapter 8 concluded with suggestions on how the model can be expanded in different ways. The next chapter concludes this thesis with a framework for the implementation of the data model in the wider context of integrated development management, environmental management and disaster risk management.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 INTRODUCTION

A key concept of disaster risk is vulnerability. It is a phenomenon that is not restricted to social patterns, and is also reflected in environmental sensitivity. It is a multi-faceted concept that has inspired wide research in sociology and development studies. Vulnerability is also a concept that relies on geo-spatial information for its assessment. From this perspective, the title for this study was chosen to read: *Vulnerability as a multi-faceted phenomenon: A GIS-based data model for integrated development planning, environmental management and disaster risk reduction.*

This study has been structured according to three main objectives: the exploring of grounding theories, the identification of commonalities in theories and approaches, and the development of a GIS-based data model. To guide the study, five research objectives were formulated, which were addressed in the chapters of this thesis. Table 9.1 contains a summary of the objectives and the relevant chapters addressing these.

Chapter 9 serves as a conclusion and presents the key findings gleaned from the literature study, as well as a framework for the implementation of the data model that was developed. A summarising statement and recommendations for further research are presented in the concluding section.

Table 9.5: Summary of research objectives and related chapters

Research Objectives		Chapters
i.	Define and investigate the theoretical grounding of development management, environmental management, disaster risk reduction and geographic information systems	2, 3, 4, 5
ii.	Identify the common focus areas in development management, environmental management, disaster risk reduction	6
iii.	Describe model development and data modelling in GIS	5, 8
iv.	Determine the entry point for development management, environmental management and disaster risk reduction to be integrated in a data model for vulnerability reduction	7, 8, 9
v.	Provide recommendations for the implementation of a GIS-based data model for vulnerability reduction	9

9.2 KEY FINDINGS

Chapters 2, 3, 4, and 5 provide the theoretical grounding of development management, environmental management, disaster risk reduction and geographic information systems. The subsections below describe the key findings in each discipline.

9.2.1 Key findings of development planning

Development planning is an activity to set in place visions, goals and means of realising development through effective direction and control. Development is defined broadly as 'change' and is largely influenced by the new world order that developed after the Second World War. A main characteristic of this order was the spatial categorisation of three worlds according to economic development criteria, i.e. a First World (Western, including mainly capitalist countries), a Second World (an East block, including mainly communist countries), and a Third World (comprising developing countries).

Development theory emerged in the succeeding decades along post-modern lines, yet differing perspectives. What stands out, though, is a strong emphasis on social and environmental conditions. Processes of modernisation led to increased urbanisation, industrialisation and commercialisation of the agricultural sector, which changed practices from subsistence to cash-cropping. These processes, together with increased

exploitation of natural resources, have a causal effect on the increased vulnerability of communities and the degradation of the environment, and they bring aspects of planning to the fore.

Planning is seen as a diverse activity that has largely been influenced by changes in political and scientific thoughts, and that may mean different things to different people. As a vision and objective-driven activity, planning is broadly defined as the coordination of development activities. Planning is driven from within four main perspectives:

- (i) Planning is a management activity.
- (ii) Planning is concerned with achieving objectives and aimed at action.
- (iii) Planning addresses uncertainties of the future.
- (iv) Planning is aimed at decision making.

Different models for planning have been identified through history. Blueprint planning was aimed at setting a comprehensive framework for future development and was the main approach during the 1950s and 1960s. As an autocratic measure, the disregard for social needs created a need for more rationalist and communicative thinking. Rational planning introduced the concept of decision making in planning, and saw it as a process where goals and objectives are achieved by considering various alternatives and courses of action open to the decision maker. This model created a shift away from control to decision making, and is indicative of the need to collect data and process information.

Criticism levelled at the concept of rational planning involved the difficulty to model reality in all its diversity and the need to consider various planning options in a lengthy decision-making process. A shift to strategic planning was initiated by drawing from Simon's concept of *bounded reality* and further developments by Lindblom who introduced the concept of a *continuum of reality and abstraction*. Within the context of an abstraction of reality, it is possible to prepare strategic plans and set courses of action that follow the vision and objectives of such plans, but with an openness to allow changes and re-alignments of plans based on mutual agreement between the actors in the planning process, which is dictated by the changing circumstances of reality. This approach further advanced towards the development of communicative and participatory approaches in planning, with an associated increase in the need for sharing information.

Development planning thinking is problem-driven and is concerned with what is happening in the world. It is worldly, grounded, and driven by field knowledge. This perspective is indicative of an information-based process. The focus on information has

increased along with the development of information and communication technology, and has become essential in the planning process. The increased need for sharing information is demonstrated by the diagram in Figure 9.1.

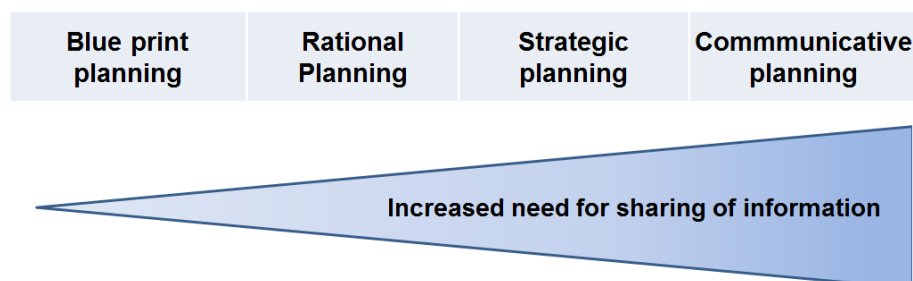


Figure 9.75: Increased need for information sharing in planning models

Development planning has also increasingly become a multi-disciplinary undertaking. The integration of modern planning with other fields such as sociology and environmental studies has been largely facilitated through sustainable development, as it developed into a focused research field that brings together perspectives from disciplines across the natural and social sciences. The imperative for integration stems from recognition of the interdependence of human and natural systems. In this context, an exploration of environmental management theory is important.

9.2.2 Key findings of environmental management

The concept of environmental management is broadly defined as the application of skills and techniques to care for the Earth. Similar to development planning, it is a problem-solving field that reacts to the impact of development on the environment. Environmental management follows two streams of scientific approaches. First, by dealing with the environment from a physical perspective, it draws on natural sciences and is concerned with learning about processes on land, in water and in the atmosphere. The defining of interactions and interrelationships in ecosystems constitutes an important aspect of such learning. Second, the anthropological domain is part of the environment, which gives environmental management a social perspective as it includes aspects of economic, social and political primitives.

The 'management' context of environmental management highlights three perspectives. First, it is a process, a systematic way of doing things, involving skilled people. Second, it

utilises resources, including materials, time, effort and money. Third, it is a goal-orientated objective that sets targets for the protection of species and biodiversity.

Environmental management takes place within the framework of integrated environmental management (IEM). The latter provides an underlying philosophy and a set of principles that are aimed at promoting the sustainability of development projects. As a management function, it is seen as a public administration function that is directed nationally and internationally by legislation, agreements and policy, and through which various tools have been developed to steer decision making. Two important environmental management tools are environmental Impact assessment (EIA) and strategic environmental assessment (SEA). The aim of EIA is to prevent substantial detrimental effects of a development on the environment. It is normally carried out in phases (a scoping and an EIA phase) by a team of experts in various fields, such as botany, zoology, hydrology, archaeology and other specialist fields. Each of these experts is involved in a process of data acquisition and processing, most of it in a GIS environment. The integration of data is a primary function, which is required to undertake a sensitivity analysis (as was demonstrated in Chapter 6).

SEA is a systematic process that evaluates the environmental consequences of a policy, plan or programme. It forms part of strategic planning and provides an environmental framework for development. In terms of spatial planning, SEA functions on a regional to national level. As in the case of EIA, information is a crucial component of SEA, specifically GIS, albeit at a coarser scale.

Sustainable development is a key objective of environmental management and is aimed at achieving equilibrium between social, biological and economic systems. Despite challenges to maintain the principles of sustainable development, it remains an important goal to achieve economic prosperity, environmental protection and social advancement. This is reflected in the wide body of research on sustainable development, and the development of indicators that are published regularly to monitor progress on achieving sustainability targets.

The spatial context of sustainable development is reflected in landscape ecology, which is aimed at defining the functioning of anthropological and ecological systems in a landscape. A landscape perspective provides a framework for understanding spatial patterns and ecological processes, and provides inputs for development planning and

environmental management. This finding is key to the development of the data model in this study, as it is grounded in spatial relationships that exist in patterns and processes.

9.2.3 Key findings of disaster risk management

Disaster risk management provides the wider context within which disaster risk reduction is undertaken. The theoretical development of this field is characterised by changes in approaches and, similar to development planning, follows a post-modern development pattern that is rooted in the post-World War II developments. Approaches to disaster risk management seek to define concepts of disaster, hazard, vulnerability and resilience.

Disaster is clearly defined as a multi-faceted construct, with a strong social component that conceptualises response to disaster. Disaster risk management includes a continuum of activities that relate to two main lines of activity, i.e. risk reduction and disaster response. This study has focused on the first line and is mainly concerned with aspects of vulnerability. Vulnerability is a property of human society, and is coupled with two conditions: the status of development and the natural environment, referred to as the coupled human-environment system, which is further linked to planning and management. From this perspective, vulnerability studies contribute to the understanding of the cause and impact of disaster.

Disaster risk management is a multi-disciplinary undertaking and is strongly connected to development planning. An analysis of disaster risk and development shows five conceptualisations of their interrelationships:

- (i) Development is the root cause of disasters.
- (ii) Disasters have a negative impact on development.
- (iii) Development plays an important role in disaster risk reduction.
- (iv) Disasters can provide development opportunities.
- (v) Disaster risk is exacerbated by improper disaster management policies combined with development failure.

The interrelationships of vulnerability and the coupled human–environment system provide a foundation for the spatial representation of disaster risk. Just as vulnerability is a multi-faceted concept, so is its spatial representation. Just as disaster risk management calls for an integrated approach, so should the associated information management systems also function in an integrated environment. The framework that is presented in Figure 9.3 illustrates how data collection activities in the domains of disaster risk

management and development planning should be approached with a view to integration, and not to different isolated GIS applications.

9.2.4 Key findings of geographic information systems

Geographic information systems (GIS) developed from a computer-based technology to capture analogue maps into a science that is concerned with the representation of geo-spatial phenomena in an electronic database format, and the processing, analysis and visualisation of the data. Its use has expanded to include a wide variety of applications, notably development planning, environmental management and disaster risk management.

As an information system, GIS is grounded in information systems theory. The development of a GIS application is primarily concerned with database issues. The design of the system is informed by different levels of abstraction, starting with a conceptual model of reality in which geo-spatial objects and their interrelationships are identified. These relationships are determined by their functioning in the landscape, as was highlighted in Section 6.2.2. The design is further informed by the goals of the application field, which direct activities along tasks and related functions. These goals will determine the scale of representation, which in turn informs the level of data abstraction. In this context, the concepts of geo-atoms and basic spatial units are important to understand, as these present the smallest spatial units from where the aggregation of data can take place.

GIS science is concerned with the collection and processing of spatial data. The analysis of data occurs within a decision-making framework, where the outputs of the system are visualised in various formats ranging from statistics presented in tables to spatial features on maps. At this juncture, it must be emphasised that the analytical power of GIS lies in its data-processing abilities, and not in the visual interpretation of maps. The cognitive analysis of the information that is presented on maps generated from GIS is the same as any other kind of map, which could have been generated by hand or any other type of image-based computer software. The major difference is that any changes in reality that affect the modelled objects, or changes in the analysis requirements of the application field, are best handled in a GIS, as is demonstrated by the data model in Chapter 8. A framework for GIS science is next presented in Figure 9.2.

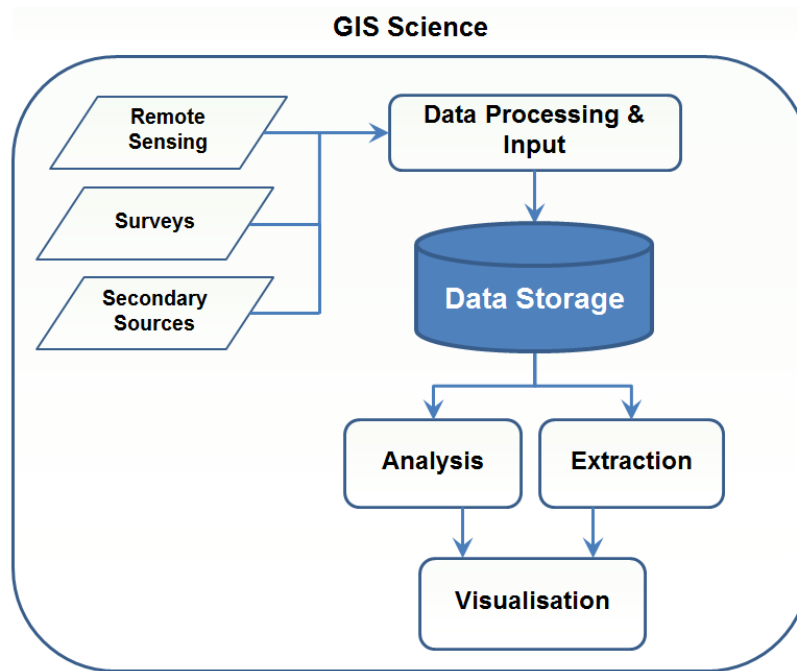


Figure 9.76: A framework for GIS science

9.2.5 A summary of key findings

A summary of key findings is presented in Table 9.2. It indicates the high level of commonalities that exist between development planning, environmental management, and disaster risk management, as was highlighted in Chapter 7. The dependence on GIS technology can be emphasised, as it supports the concept of GIS as a central and integrating factor. This is demonstrated by the GIS-based model presented in Chapter 8, which provides grounding for a framework for the integration of development planning, environmental management and disaster risk management.

Table 9.6 Summary of key findings

		Development planning	Environmental management	Disaster risk management
i	Multi-disciplinary field	●	●	●
ii	Spatial orientation	●	●	●
iii	Concerned with environmental degradation	●	●	●
iv	Concerned with social upliftment	●	●	●
v	Focus on sustainable development	●	●	●
vi	Influenced by development planning		●	●
vii	Influenced by environmental management	●		●
viii	Dependent on GIS technology	●	●	●

9.3 A GIS-BASED FRAMEWORK FOR THE INTEGRATION OF DEVELOPMENT PLANNING, ENVIRONMENTAL MANAGEMENT AND DISASTER RISK MANAGEMENT

The GIS-based data model presented in Chapter 8 demonstrates the ability of GIS to capture the relationships that exist between anthropological and environmental objects in geographical space in a database environment. The principles of database theory that define entity relationships are used as an analogy to define the relationship between development planning, environmental management and disaster risk management, using Entity Relationship (ER) modelling. The model offers a response to the research objective *to determine the entry point for development management, environmental management, disaster risk reduction to be integrated in a data model for vulnerability reduction*, and demonstrates the database approach of GIS science as the entry point for integration. Vulnerability reduction is effected by placing the whole concept of GIS science central in an integrated framework. Such a framework is presented in Figure 9.3.

With GIS as the entry point, important activities such as data collection and processing take place in a coordinated and integrated environment. The integrated environment exists where the objectives of development planning, environmental management and disaster risk management are coordinated in an encapsulating development framework. Within this environment, GIS operations can be coordinated to fulfil tasks that are required in all three of the domains. For example, data that is required for undertaking an EIA or SEA could be the same as is required for developing a strategic plan, or a disaster management plan. Also, data that is captured during a disaster impact assessment could be useful for analysis in strategic planning. This framework, therefore, provides for effective integrative approaches. In such an integrated and coordinated environment, objectives of sustainable development are jointly achieved, thereby contributing to the reduction of vulnerability.

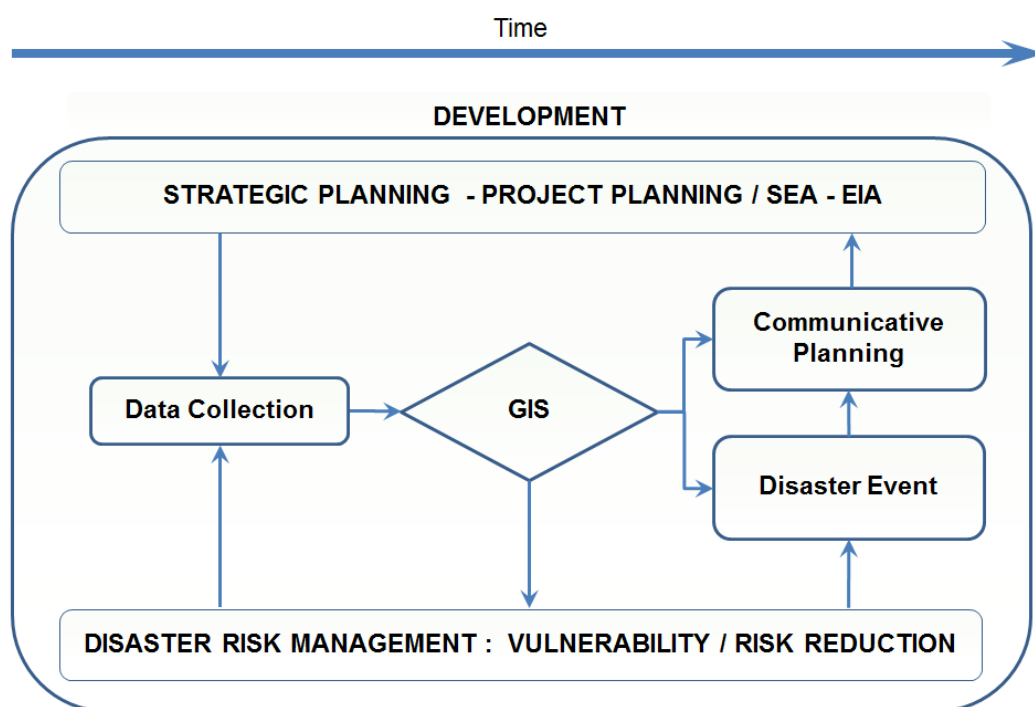


Figure 9.77: A framework for the integration of development planning, environmental management and disaster risk management

9.4 RELEVANCE AND VALUE OF THE STUDY

This study is relevant to development planning, environmental management and disaster risk management as established disciplines. It provides a GIS-based model that can be applied in practice in any of these disciplines. The integrative approach of this study is also relevant to the ideas of developing a unified theory that incorporates disaster risk reduction, development planning and environmental management. In this regard, the framework presented in Section 6.3 above provides an outline for further research.

The implementation of the integration framework provides an opportunity to inform thoughts on inter-disciplinary approaches in disaster risk management practice. It also offers an opportunity for innovative thinking, for example a view that disaster events are part of reality. Hence, they could be approached as special projects, where response activities can inform the planning process through the interface of spatial information and communicative planning. Within this framework, sector-based activities such as strategic planning, disaster risk assessments, SEA, EIA, EMFs, IDPs, SDFs and RIAs form part of the goals and objectives of holistic development planning approaches.

9.5 CONCLUSION AND RECOMMENDATIONS

This chapter presented the key findings of a literature study that described the theoretical grounding of development planning, environmental management, disaster risk management and geographic information systems. It then presented a framework for the integration of these disciplines through a GIS-based data model, indicating the latter's value for developing new approaches towards disaster risk reduction.

In conclusion, it is recommended that the data model be further explored with a view to expansion and testing in a research environment.

ANNEXURE 1 TO CHAPTER 3

Rostow's Stages of Economic Growth (Sources: Potter *et al.*, 2008:33; Hopper, 2012:31).

Stage 1: Traditional societies

The initial stage in which society and economy are relatively static. Characterised by the primitive nature of science or technology, people's values being fatalistic, and production and trade based on custom and barter.

Stage 2: Conditions for take-off

Industrialisation becomes possible through the development of entrepreneurship, capital investment, educational expansion and centralisation of nation states.

Stage 3: Take-off

Take-off occurs when the manufacturing sector lifts away from its economic base. Characterised by removal of traditional barriers to economic growth, increased investment, growth of economic elites, rapid economic growth and commercialisation of agriculture. This is the most important stage when net investment and savings as a ratio to national income grow from 5 to 10 per cent, which nominally facilitates industrialisation.

Stage 4: Drive to maturity

This stage follows take-off and enters a lengthy phase of up to six decades or more. Characterised by the economy taking its place in the international order, a move away from heavy industry, diversification of industrial and agricultural sectors, investment increases to between 10 and 20 per cent of national income.

Stage 5: Age of high mass consumption

Characterised by increasing importance of consumer goods and services, and development of a welfare state.

ANNEXURE 2 TO CHAPTER 3

A comprehensive framework for strategic planning (Dale, 2004:27)

1 Problem analysis

- Identify the general problem that is intended to be addressed or general problems that may be addressed.
- If more than one general problem is considered, prioritise between them and decide on the one that will be in focus in the present planning exercise.
- Try to agree on and specify a component of the general problem that most clearly expresses the difficulty for the people who are affected.
- Identify cause-effect links to/from this sub-problem (core problem) that result in a structure of sub-problems in cause-effect terms (sometimes called a problem tree).

2 Analysis of external stakeholders

- Identify the stakeholders by their stakes – they may include:
 - Those who are affected by the problem
 - Those who cause the problem
 - Those who may be affected by measures against the problem
 - Those who may contribute in dealing with the problem
 - Those who may work against envisaged measures
 - Any other organisation, programme or project that does or may do the same or similar work as envisaged, partly or fully.
- Categorise the stakeholders by main relevant criteria (individuals, interest groups, private organisations, government agencies, etc.).
- Get an overview of the needs and interests of each category of stakeholders.
- Discuss and decide on whose needs, interests and views should be given priority.
- Analyse further the needs and interests of the prioritised individuals, groups and/or organisations and, if needed, clarify further who should be beneficiaries of the planned scheme.
- Analyse the strengths and weaknesses of potential external contributors – individuals, groups and/or organisations that may be involved in or otherwise contribute to the envisaged work.

- Analyse the constraints or threats posed by any hostile individuals, groups or organisations.
- **Feedback to the problem analysis**

3 Formulation of objectives with linkages

- Reformulate components of the cause-effect structure into positive statements, i.e. into intended benefits (objectives) for the intended beneficiaries and underlying perceived requirements for attaining these benefits (means-ends structure).
- Discuss and decide on any deletion, addition or revision of objectives and underlying requirements, in the light of
 - the legitimacy and importance of any objections by any stakeholders to intended measures:
 - whether or to what extent any objectives may be attained through development work that is being or may be undertaken by others.
- **Feedback to the stakeholder analysis (particularly, decision on beneficiaries)**

4 Assessment of resources

- Estimate generally the requirement for money, expertise (personnel with the needed competence), equipment, and any other resources for attaining the intended objectives.
- Clarify the feasibility of acquiring these resources.
- **Feedback to the stakeholder (actor/beneficiary) analysis**
- **Feedback to objectives / means-ends formulation**

5 Analysis of external influencing factors

- Explore external factors (in addition to supportive stakeholders) that may facilitate the realisation of the programme or project (opportunities).
- Explore external factors (in addition to hindering stakeholders) that may constrain or prevent the realisation of the programme or project (present constraints).
- Explore external factors (in addition to hindering stakeholders) that may pose problems for the continuation of the programme or project, for maintenance of facilities created, or for the upkeep or augmentation of benefits generated (threats).
- Examine and determine whether, to what extent and how the programme or project organisation or organisations may exploit identified opportunities and counteract identified constraints and threats.
- **Feedback to the problem analysis**

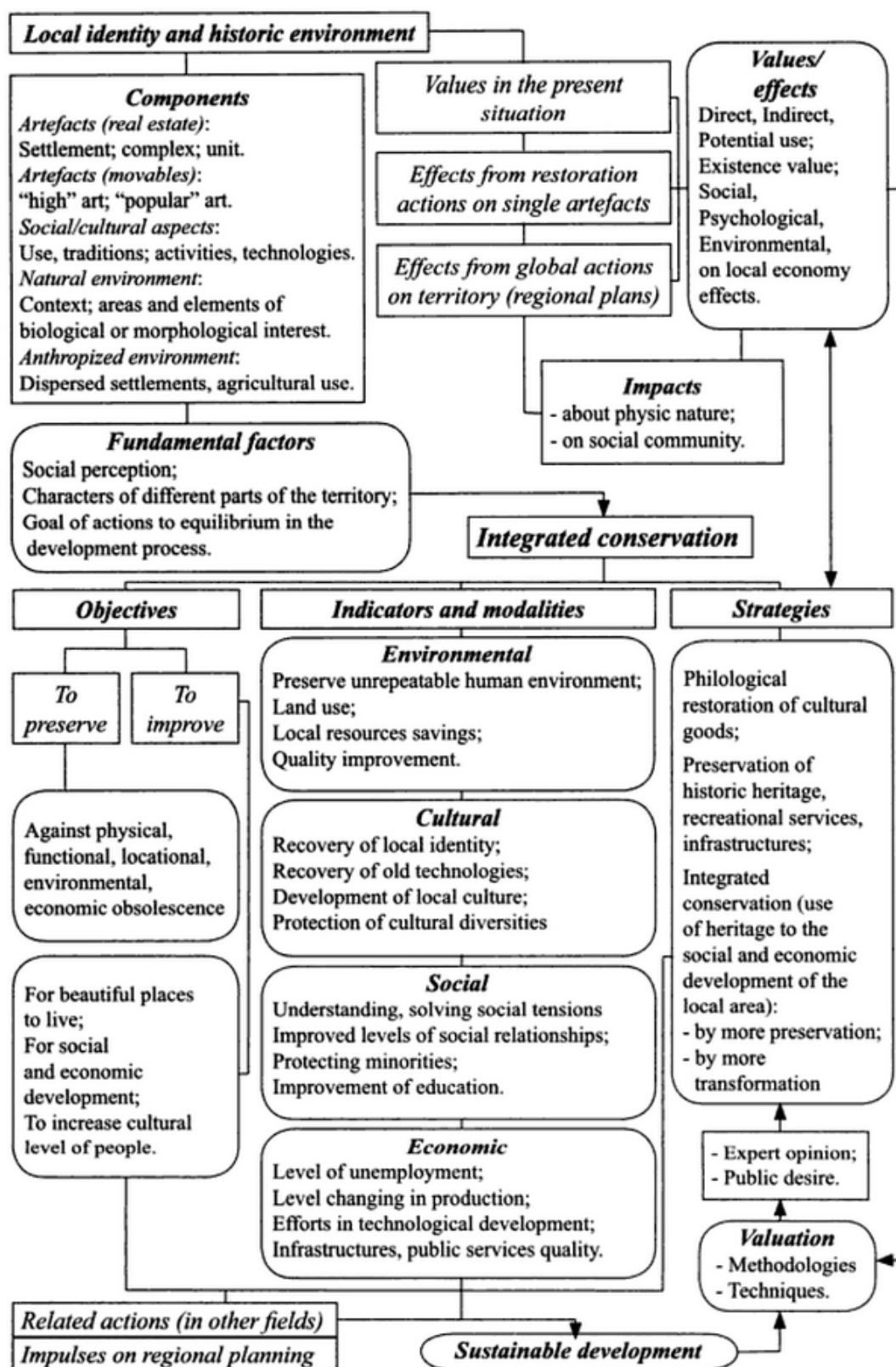
- ***Feedback to the stakeholder (beneficiary/actor) analysis***
- ***Feedback to objectives / means-ends formulation***
- ***Feedback to the resources assessment***

6 Assessment of organisational ability

- Undertake an internal stakeholder analysis: i.e. examine the interests, views and capabilities of units and individuals in the responsible organisation(s).
- Clarify, in general terms, necessary or desirable structures, rules, work systems and incentives of the responsible organisation(s) for undertaking the intended work.
- Explore necessary or desirable measures (such as formal training, workshops and on-the-job training) for creating the necessary or desirable organisational capabilities and, if needed, for harmonising the interests and views of units and individuals in the organisation(s).
- Determine the eventual organisational ability for implementing intended measures, and undertake any corresponding prioritisation.
- ***Feedback to the external stakeholder analysis***
- ***Feedback to objectives / means-ends formulation***
- ***Feedback to the resources assessment***

ANNEXURE 3 TO CHAPTER 3

Sustainable development process: methodological framework of analysis and evaluation (Vreeker & Nijkamp, 2006:169)



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I declare that: "***Vulnerability as a multi-faceted phenomenon: A GIS-based data model for integrated development planning, environmental management and disaster risk reduction***" is my own work, that all sources used or quoted have been indicated and acknowledged by means of complete references, and that this thesis was not previously submitted by me or any other person for degree purposes at this or any another university.

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