Chapter 5: The requirements for the establishment of a conceptual model of an effective spatial information system

5.1 Introduction

In this chapter the aim of the study, namely to identify and conceptualize the requirements for an effective conceptual model of a geo-spatial information system namely, a GIS for Disaster Risk Management by the Tlokwe Local Municipality is provided. This section focuses on the requirements for a conceptual model. Therefore, the concepts modelling, conceptual model, physical model and the relationship between conceptual modelling, the Systems Development Life Cycle (**SDLC**), the Framework for the Application of Systems Thinking (**FAST**), and the Problem Solving Methodology are discussed in the first section. The aim is to provide a comparison between the SDLC, FAST and Problem Solving Methodology. This is followed by the identification of a few of the requirements for the conceptual model of the GIS system, arising from the study of the first three research objectives. An example of the conceptual model data requirements is then provided. The aim of this section is to identify the conceptual model requirements. The next section provides a systems model of a GIS that could assist in the effective risk management and disaster management. This is followed by a concise overview of the chapter.

5.2 Systems development

In this section the conceptual model in relationship to the SDLC, FAST and, Problem Solving approach is discussed.

A model can be described as an abstraction or an approximation of reality, including the real-world or event (Rob & Coronel, 2004:771; Stair & Reynolds, 1999:672; Burch & Grundnitski, 1989:232). During the development of an information system using either SDLC or FAST, there are two models developed, firstly, the conceptual (logical, essential or business) model, which is then followed by the physical (implementation or technical) model.

The conceptual model is a non-technical pictorial (graphic) representation that can be presented to high-level non-technical users or system developers, that depicts what the system is or does, provides the functional requirements and excludes all the technical aspects of the system (Rob & Coronel, 2004:767; Whitten, *et al*., 2004:766; Stair & Reynolds, 1999:570). In this study the aim is to determine the requirements for the development of a conceptual model.

The physical model is a technical pictorial (graphic) representation of the physical components (including hardware and software), indicating what the components do, that depicts what a system does and how the system will be implemented (Rob & Coronel, 2004:723; Whitten, *et al.,* 2004:770; Stair & Reynolds, 1999:540).

Information system development uses a system approach, involving system thinking, that is, the ability to see both the "trees and forest". In this process the interrelationship, rather than the cause effect relationship and the process, rather than discrete snapshot of change between the systems are recognized, in identifying an information system solution for a problem or opportunity that exists (O' Brien & Marakas, 2006:402; Daellenbach, 1995:18).

This multi-step process used to develop a system is called the SDLC. For the purpose of this study, an adaption of the traditional SDLC namely FAST is also considered. Figure 23 conceptualizes the SDLC and the relationship between the SDLC and FAST, and their relationship to the problem solving, and the phases covered in this study. Although the number of steps in the SDLC varies between authors, the process itself is similar. For the purpose of this study, the cycle is divided into five sequential steps. The sequential steps are system investigation and initiation, system analyses, system design, system implementation and system maintenance (O'Brien & Marakas 2006:402-403; Whitten, *et al*., 2004:36-37; Stair & Reynolds, 1999:532). In FAST, the sequential steps are scope definition, problem analyses, requirement analyses, conceptual design, decision analyses, physical design and integration, and constructing and testing (Whitten, *et al*., 2004:89). Figure 23, provides a summary of the phases and their relationship to the study.

In the next section, the requirements for a conceptual model based on the previous chapters of this study are provided.

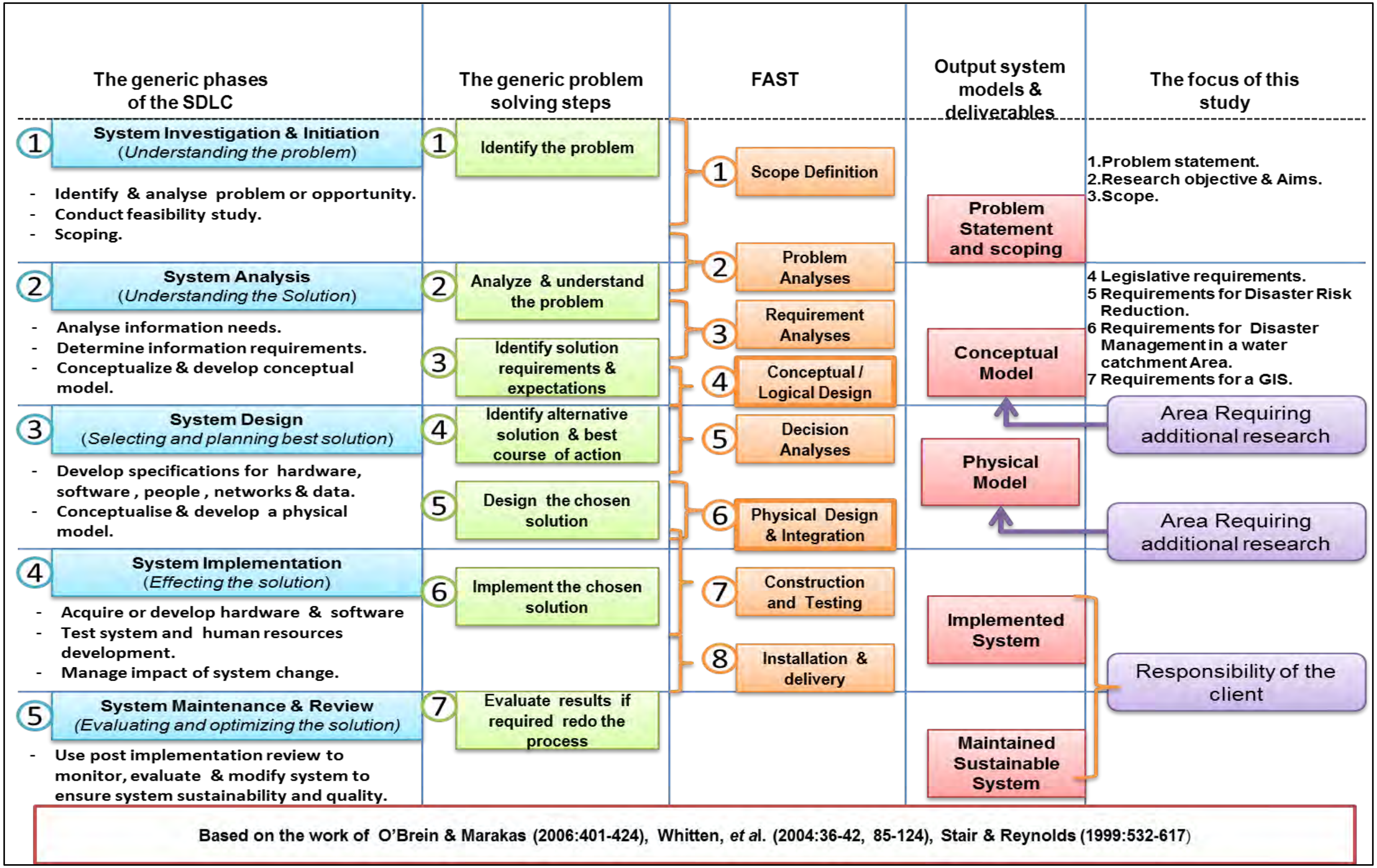

Figure 23: Comparison of the SDLC, Generic Problem Solving, FAST and focus of this study

5.3 Requirements for a conceptual model

5.3.1 The process of determining the requirements for a conceptual model

In determining the requirements for a conceptual model, the following steps are used in the study (O'Brein & Marakas, 2006:401-424: Whitten, *et al*., 2004:36-42, 85-124; Stair & Reynolds, 1999:532-617).

1. The problem or/and solution is identified and analysed.
2. The scope of the project is determined.
3. The information needs are then analysed.
4. Based on the information needs analyses the information requirements are then determined.

Each of these steps are briefly discussed below

5.3.2 The identifying and analyses of the problem and a possible solution that must be addressed by the model

The Tlokwe Local Municipality is constitutionally (Constitution, Act 108 of 1996) and legislatively (Local Municipal Structures Act 117 of 1996; National Water Act 36 of 1998; National Environment Act 107 of 1998; Local Government Municipal Systems Act 32 of 2000; Disaster Management Act 57 of 2002 & Local Government Municipal Finance Act 56 of 2003) obliged to avoid or reduce the risk of a disaster that could manifest itself within its municipal boundaries (Demarcation Board, 2014c:Online). The two problems that the Tlokwe Local Municipality encounters is that its surface water and ground water that are potential sources of disasters, upper catchment areas extend beyond the boundaries of the Tlokwe Local Municipality, and can be effected by natural and anthropogenic events in these catchment areas beyond the boundaries (Demarcation Board, 2014d:Online) of the Tlokwe Local Municipality. Secondly, the Tlokwe Local Municipality, does have an effective system or tools to manage the risk of disasters or/and disaster that can originate in complex ground- and surface water catchments portions of which are beyond its barriers. This implies that the Local Municipality must consider and manage the potential hazards that can arise beyond its boundaries when undertaking the process of disaster risk reduction, disaster management and rehabilitation, development and reconstruction. Disaster risks and disaster events can be linked to geographic location, therefore a system that can capture, process, manipulate spatially or geo-referenced data within and beyond the borders of the Local Municipality could assist in addressing the problem. A spatial information system, namely a GIS that processes geographical data is a possible solution that could assist the Tlokwe Local Municipality, in the disaster prevention phase, disaster preparedness phase, disaster relief phase and the disaster rehabilitation phase of disaster risk reduction and disaster management (Bahuguna, *et al*., 2013:5632).

5.3.3 Determining the scope of the model

The scope of the model is limited to the surface-water catchment of the Mooi River and the related groundwater dolomitic compartments as it is events related to the water catchment area of the Mooi River that are the potential sources of hazards that can have disastrous affects downstream within the boundaries of the Tlokwe Local Municipalities. The quaternary surface-water catchments that are considered in the model are C23D, C23E, C23F, C23G, C23H, C23J and C23L (Department: Water Affairs, 2012a:Online; Department: Water Affairs, 2012b:Online). The dolomitic water compartment with their mining voids that are considered include the dolomitic compartments in the north, namely the Mooi River-, Holfontein- and Steenkoppies Compartment, The dolomitic compartments in the south include Boskop-Turfontein-, Oberholzer-, Bank-, Venterspost-, Gemsbok-, Zuurebekom- and Natal Spruit Compartments (Winde & Erasmus, 2011:294).

5.3.4 Determining and analysing the information needs for the model

The Tlokwe Local Municipality is obliged to manage the risk of potential disasters, prepare for potential disasters, effectively responds to potential disaster and implement an effective reconstruction strategy after a disaster, to eliminate or reduce the impact of a potential disaster. Ensuring at the same time the realisation of the Rights enshrined in the Bill of Rights (Constitution, Act 106 of 1996) within its boundaries. Therefore, the information required will be that which will assist the Tlokwe Local Municipality in realising the above.

Determining the information needs requires outlining the activities involved, in avoiding or reducing the effects of a potential disaster. These processes include, firstly, the constitutional and legislative framework that obliges and assists the Tlokwe Local Municipality in ensuring that disaster are avoided or the effect thereof is reduced. Secondly, the processes of disaster risk reduction, the prevention or mitigating of disasters, the preparing for a disaster, early warning systems, the response to a disaster and the rehabilitation and re-development after a disaster (Bahuguna, *et al.,* 2013:5632; Van Westen, *et al., 2011*:1-17). Each of the aspects are summarised below.

5.3.4.1 Constitutional and legislative obligations

The Tlokwe Local Municipalities obligations and responsibilities in respect of disaster risk reduction and the management of disasters are based on constitutional and legislative prescripts. At the same time, the Constitution and Legislation provides the Tlokwe Local Municipality with the necessary instruments to manage and enforce compliance in respect of avoiding or reducing the impact of disaster. It is therefore that these constitutional and legislative obligations and recourses available to the Tlokwe Local Municipality be considered in the development of the conceptual models.

5.3.4.2 Managing the risk of disaster

During this phase, a hazard and vulnerability risk analyses and assessment must be conducted and a risk management plan must be developed to assist in avoiding, mitigating or reducing the impact and probability of the risk. The hazard risk assessment includes identifying the anthropogenic and/or natural hazard (ECB, 2012:9; Van Westen, 2011:1-17), its nature, location, intensity and the likelihood of the potential risk that may be prevailing. Thus identifying the location or source of the potential hazard, this involves a geographical location of the potential hazard or source of the hazard. The vulnerability risk assessment involves firstly an exposure assessment, to identify populations, assets and environments risk and delineating the disaster prone areas. Secondly identifying the potential social, economic or environment capacity that is, resilience, or the lack thereof that is, vulnerability (ECB, 2012:13; UNDP, 2010:1). Vulnerability therefore occurs within a geographic location. A hazard on its own will not manifest in a disaster, unless its impact on a social-, economic- or environment vulnerabilities, to such an extent that there is injury, or loss of life, and damage is to the extent that the community will not be able to recover on its own (Van Westen, *et al.,* 2011:1-3). For the development of the model, potential hazards of natural or anthropogenic nature that may be related to the catchment area and/or the water resource must be considered.

5.3.4.3 Mitigation and prevention of disasters

Disasters mitigation and prevention are all those activities undertaken to avoid or reduce the impact of a disaster. It could include effective utilisation of land, through avoiding potential risk areas such as dolomitic ground, flood plains, geological faults, area prone to landslides and mudslides, building near explosive and hazardous chemical production plan. Mitigation and prevention can be attained through improved spatial planning, improved building standards, other engineering initiatives, land use regulations, effective agriculture methods for example contour ploughing and the use of crops and livestock most suited to the land and environment, etc.(Bahuguna, *et al.,* 2013: 5632; Van Westen , *et al.,* 2011:1-17)

The information required is that which will assist in identifying potential vulnerability, hazards, its location and the knowledge base of previous events, and research, and initiatives undertaken in similar situations to avoid or mitigate the impact of potential disasters. In the latter, the interventions occur in specific locations, which can be geographical plotted.

5.3.4.5. Disaster preparedness

Disaster preparedness involves:

The development of disaster plans and procedures to ensure sufficient resources including food, medicine and water are available in a case of a disaster.

The educating and training to make community aware of potential disasters, the early warning signs and the action that should be taken to avoid or reduce the impact of a disaster.

Logistic planning; training and preparing emergency teams, including first aid, firefighting and water recovery teams, these teams must be equipped and participate in regular drills.

The identification of safe assembly points and alternative assembly points; the identifying of evacuation routes; the establishment and maintaining of communication procedures technology; emergency and evacuations drills, etc. (Bahuguna, et al., 2013:5632; ECB, 2012:36; Van Westen, *et al*., 2011:1-17).

Therefore, the information required for a conceptual model of a GIS will include, location of assembly points, escape routes, location of response team members, the location of firefighting resources, the contact details of Joint Operation Centre team members, the location of clinics, hospitals etc., communication net-works, location of vulnerable population, routes that can be used by emergency services, distribution locations, etc.

5.3.4.6 Early warning systems

This phase includes the use of technology (technology can be modern or as primitive as poles planted in a river bed to indicate the water level in a river), this can include in time remote meteorological, seismic, water flow, heat and smoke sensors. Historical information together with information received from early warning systems can assist in making proactive informed decision, enabling appropriate response and the provision of early warning to the vulnerable communities through effective communication systems (Van Westen, *et al*., 2011:1-17). The early warning systems are either spatially located for example water levels indicators, or/and provides information on a spatial location for example a metrological forecast, implying the importance GIS in early warning systems.

5.3.4.7 Disaster recovery and response

This phase includes, search rescue, recovery, resource requirement analyses, the establishment of Joint Operation Centres, assembly points for victims, first aid, temporary morgue, distribution of food and other resources, crowd control and protection of property (Van Westen, *et al*., 2011:1-17). All takes place within geographical locations, and the model must accommodate these activities.

5.3.4.8 Rehabilitation and reconstruction

Rehabilitation includes, the establishing sustainable infrastructure, agriculture, water supply, sanitation, housing, etc., solutions that assist in social, economic and environment recovery from the impact of the disaster (Van Westen, et al., 2011:1-17).

5.3.5 The information requirements

5.3.5.1 Introduction

Bases on the analyses in section 5.3.4 the information that will be required for the establishing of a conceptual model is outlined below.

5.3.5.2 International, constitutional and legislative requirements

To assist the local municipality in complying and meeting with its International, Constitutional and Legislative obligations in respect of disaster risk management and disaster management, the following must be taken into consideration:

The information requirements in respect of generic disaster risk management and disaster management functions the municipality will be obliged to effect in accordance with the disaster risks reduction (53(2), Act 57 of 2002), and information required to assist in disaster response and recovery (54(2), Act 57 of 2002).

Information that will enable the municipality to sustainably realize its obligation in respect of the Bill of Rights. This includes, promoting a safe and healthy environment in it is area of jurisdiction (A4(1)(i) Act 32 of 2000). As well as the realization of the right to property (section 25 Act 108 of 1996), housing (section 26, Act 108 of 1996), health care, food, water and social security (section 27, Act 108 of 1996). Therefore the information requirements considered for the model should include the following:

- Information, in respect of, vulnerable environments, persons, and infrastructures within the local municipality that can be affected by potential short-, medium- and long-term hazards related to the water resource and arising in the catchment area of the Mooi River.
- Information required to assist in identifying potential hazards related to the water resource and the potential origin of hazards that could arise in the catchment area of the Mooi River.
- Information required that will assist in avoiding and/or mitigating and/or preparing for potential disasters in the boundaries of the Tlokwe Local Municipality.

- The establishing of early warning systems, the implementation and the maintenance thereof.
- Information that will be required to ensure that the municipality meets its constitutional and legislative obligations in respect of water resources, including the provision of basic water supply, basic sanitation supply to all person in its jurisdiction area.

The conceptual model must make provision for the type of information that the municipality will be obliged to report on, including information:

- That is required in respect of the water services development plan (section, 12, 13, Act 108 of 1996).
- That will be required in the disaster management plan (20(1), R1689 of 2005; 53(1) (d), Act 57 of 2002).
- That will be required by the National Disaster Management Information System (17(1) & 46(1) (b), Act 57 of 2002).
- That will be required for the development of spatial plans and the IDP.

5.3.5.3 Water resource, catchment system and hazards

To assist the local municipality in disaster risk reduction within the water catchment area the following requirements for the conceptual model must be considered:

- Information to enable the identification and monitoring of the route of water-flow from precipitation to the river streams, sources of possible pollution including point sources and approximate location of diffuse pollution (Davis, 2008:129). Including, water extraction points, the factors influencing the speed and quantity of water-flow, town planning and development and other structures that could impact or be impacted upon potential hazards related to the water catchment area and water resource.
- Information on hydrological and geo-hydrological dynamics, including:
    - Historical and current records on base, peak and maximum flows of the river and its tributaries.
    - The historical and current records on the natural and anthropogenic reservoirs and aquifers levels and capacities; flow rates of natural

ingresses (springs, etc.) in rivers from aquifers; historical and current records of rain fall in the catchment area and elevation profiles, that will assist in the establishment of an effective disaster risk and disaster management system.

The conceptual model requires information to assist in identifying and monitoring the possible flood hazards and high-risk geographic land types related to flooding. These include river flood plains, low-lying land and flanking riverbanks.

Information, including spatial information is required of all activities within the catchment area that are potentially hazardous or are potential hazard sources. This includes portions of the catchment area beyond the boundaries of the local municipality.

5.3.5.4 Generic requirements in respect of a GIS

A spatial information system can provide a spatial representation of an object or event that occurs on the planet earth in a two-dimensional format. It is important to note that to link data, images, etc. to spatial objects or events will require that all data sets have fields (for example coordinates) that will enable them to be linked to the spatial object or event.

As an information system, the components of the system must be considered at all times to ensure its effectiveness and sustainability. These are the data, hardware, software, telecommunication, process and arguably the most important, the people (human) component.

As a system, it has a specific outcome to achieve, namely a spatial system that will assist in avoiding or reducing the impact of potential disasters.

The information therefore required for the system will be determined firstly, accordingly to the outputs and outcome that the system must provide for (this includes disaster management and risk reduction, effective sustainability projects, Integrated Development Planning (**IDP**) and service delivery planning).

Secondly, the data required must enable the Tlokwe Local Municipality to monitor its progress towards complying with its constitutional and legislative obligations.

Thirdly, operational data that will enable the Tlokwe Local Municipality to effectively respond to any hazardous event or disaster must be considered and included, for example, data arising from the risk and vulnerability analysis.

Fourthly, historical data and records of events (knowledge base) that will be required to enhance future operations and planning must be processed so that it can be used to enhance effective decision making.

Fifthly, existing data sources, systems, processes, practices, etc. must be considered to ensure optimal integration and minimum data redundancy.

Figure 24, provides an example of a few of the data requirements that should be considered in designing the conceptual model. It demonstrates how each class of information required can be compiled for presentation in the Conceptual Model

In the next section a concise systems model of a GIS that could assist with disaster risk and disaster management is provided.

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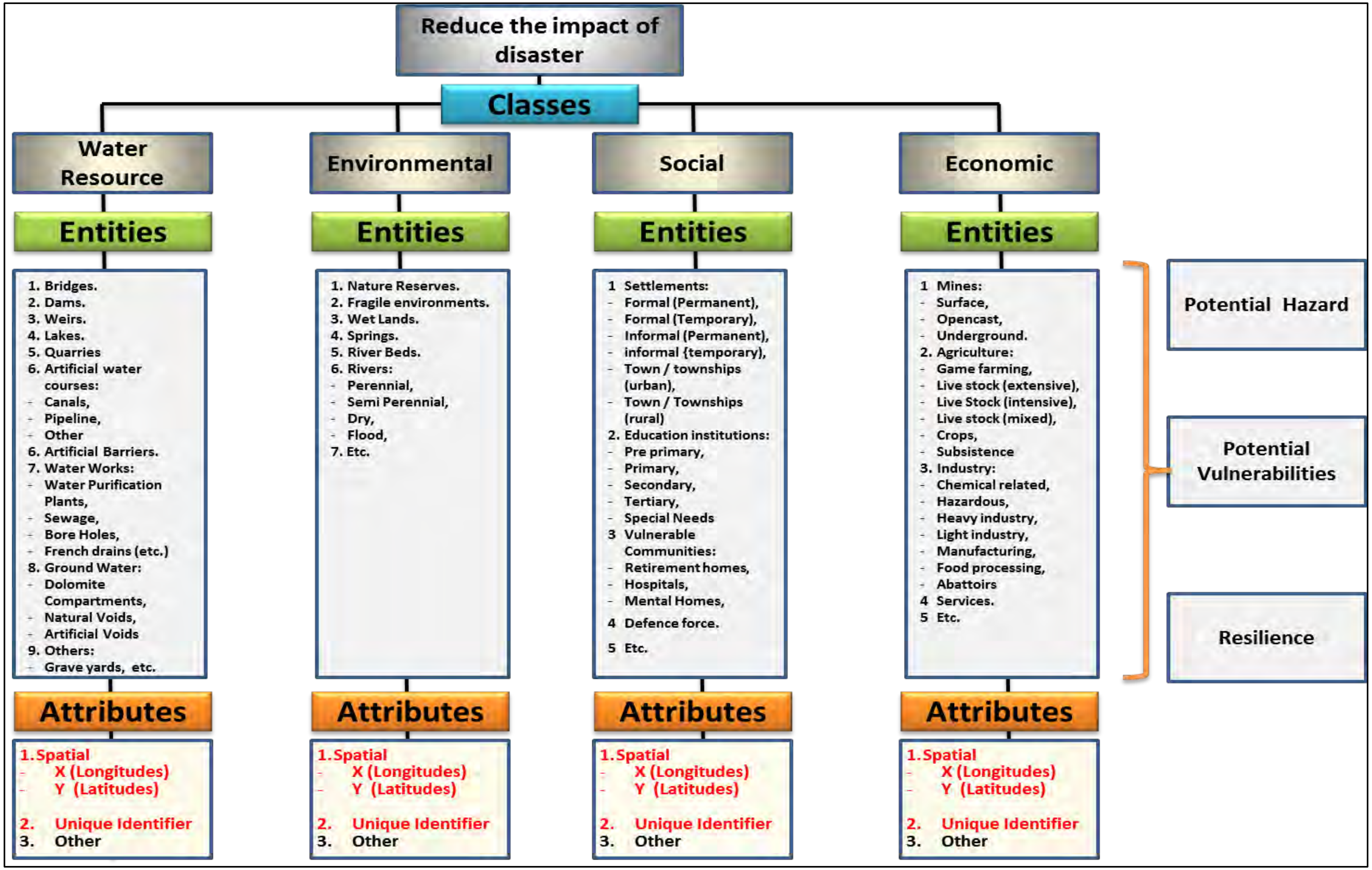

Figure 24: Example of a few of the data requirements for a conceptual model

5.4 Systems conceptualisation of a Geographic information System

The spatial information system is a system of procedure and people, data, software, hardware, and network resources, aligned through a common goal that receives inputs and transforms them to outputs that assist the system in achieving its goal.

In this study, it is assumed that if the outputs listed in Figure 25 are achieved, the goal of the system, namely “avoiding and reducing the impact of disaster” will be achieved. It is therefore important that although the assumption is based on existing theories, the dynamics’ of the system itself and the system it is developed for complexity must be considered. To ensure that the system goal is achieved will require continuous monitoring, feedback, control, research and development.

The focus area for which the spatial information system will be developed is itself a complex and dynamic system with a number of sub systems. The focus system in the catchment area of the Mooi River, within the boundaries of this system, namely the surface watershed, there are a number of sub systems, including quaternary catchment areas with their boundaries, water resource ecological sub systems each with their boundaries, transport systems with transport infrastructure, means and goods conveyed as components, spatial development system with the boundaries for which it is developed, etc. This will require extensive evaluation of the focus system, its components, its processes and sub systems and the sub systems of the sub system, components and processes that can impact on the focus system.

Figure 25 is the conceptualization of the production process expected from the information system to be developed and is based on the assumption that the achievements of the output outlined in Figure 25 will enable the achievement of the system goal.

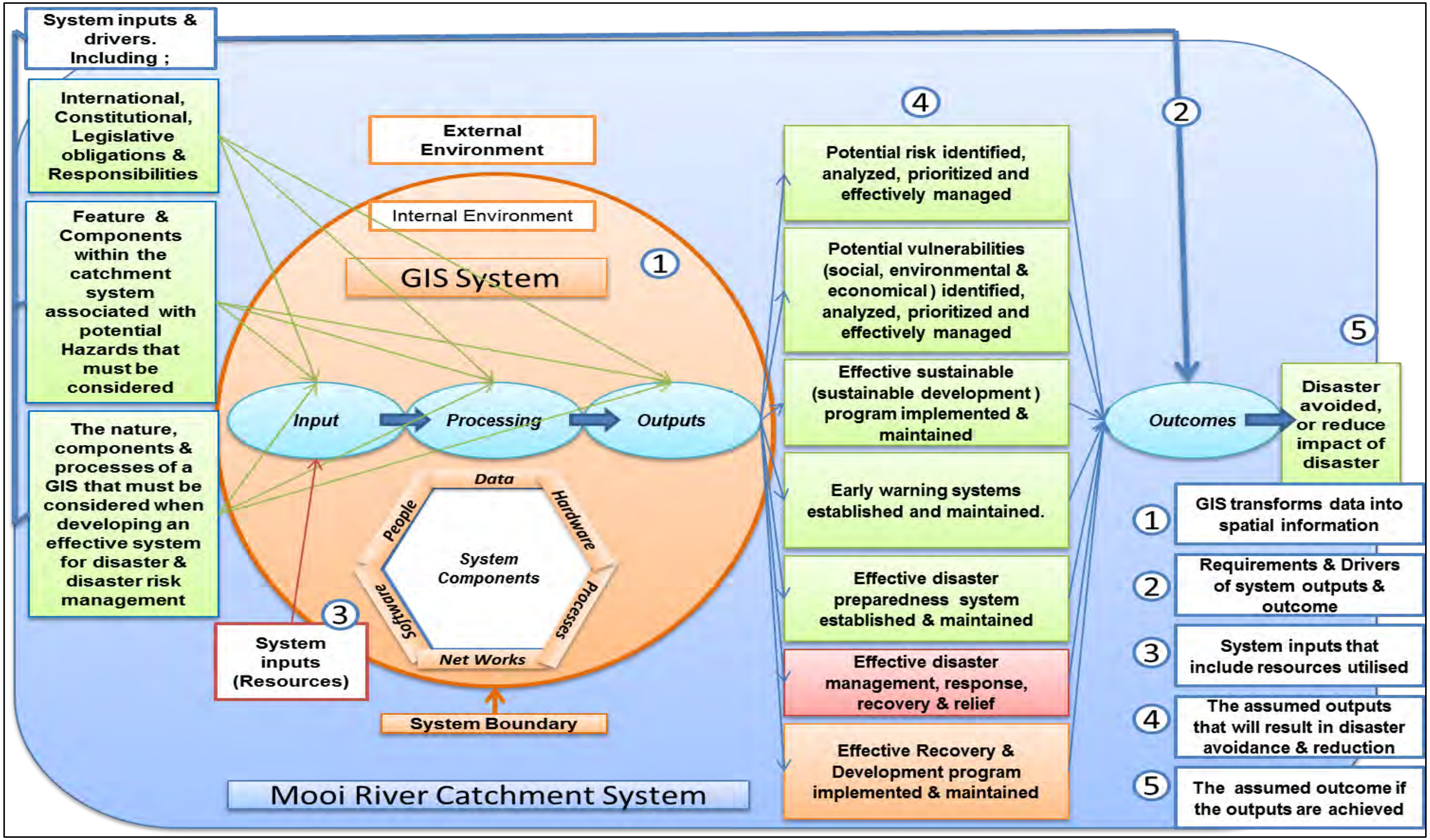

Figure 25: Example of a few of the data requirements for a conceptual model

In the next section, a concise summary of the chapter is provided.

5.5 Summary

In this chapter, a concise description of the concept modelling, conceptual model and physical model was provided. The phases of the SDLC, FAST and problem solving methodologies are listed. SDLC, FAST, and problem solving were compared and the phases addressed in this study are provided.

This was followed by a concise listing of the requirements of a conceptual model based on the requirements identified in the previous chapters of the mini-dissertation.

A system conceptualisation of a GIS that will enable effective disaster risk and disaster was then provided.

The next chapter provides a concise summary of the study and recommendations.

Chapter 6 Summary and recommendations

This chapter provides a short summary of the study and recommendations arising from the study. A concise summary of the three research questions and the aim of the study are provided in the first section. The additional requirements for an effective GIS not addressed in this study are identified and formulated as recommendations in the section that follows. A concise summary of the study is provided in the next paragraph.

6.1 Concise summary of study

In Chapter 1 the problem statement and a possible ICT solution to address the problem were identified and formulated as the aim of the study, name*l*y, to identify and conceptualize the requirements for an effective conceptual model of a geospatial information system namely, a GIS for Disaster Risk and Disaster Management by the Tlokwe Local Municipality. Three research questions to support the aim were identified, stated and formulated as research objectives. The three research objectives and the aim of the study were then addressed in separate chapters in the study.

Chapter 2 addresses the first research objective, namely, to identify and conceptualise the Constitutional and legislative obligations in respect of Disaster Risk Management in general, and specifically those governing the Disaster Risk Management in the water catchment of the Mooi River that could impact directly or indirectly on the Tlokwe Local Municipality section of the surface catchment area. A concise discussion of the international, constitutional, legislative, regulatory and procedural framework, for disaster management, water resources and the associated environment to which the Local Municipality is obliged and required to comply and implement is provided. These obligations contribute to part of the inputs and drivers of the proposed system, and provide the Conceptual Model requirements from a legislative perspective.

Chapter 3 addresses the second research objective, namely, to identify and conceptualize the generic hazards that are related to water catchment areas including the related dolomitic groundwater compartments and those specific in the Mooi River catchment area that can effect directly or indirectly on the Tlokwe Local

Municipality's section of the catchment. As the study is focused on a catchment area, a concise discussion on catchment cycle and system is provided. This is followed by a concise discussion of disaster risk and its component and a model for risk and vulnerability assessment and management. A concise classification of generic risks is then provided. The surface area, groundwater and potential hazards of quaternary catchment C23D is identified and discussed. These discussions cumulate in the identification of the Conceptual Model requirements from a disaster risk, water resource and catchment area perspective.

Chapter 4 addresses the third research objective, namely, to identify and conceptualize the requirements for an effective conceptual model of a geospatial information system GIS for Disaster Risk Management by the Tlokwe Local Municipality. In this chapter the GIS, Coordinate system, Raster and Vector layers and data are discussed. The GIS as an information system with the generic components, namely, data, people, hardware, software, procedures and telecommunication is discussed. These discussions cumulate in the identification of the Conceptual Model Requirements from a Geographic Information Systems perspective.

Chapter 5 addresses the aim of the study which is to identify, and conceptualize the requirements for an effective conceptual model of a geospatial information system GIS for Disaster Risk Management by the Tlokwe Local Municipality. The concepts modelling, conceptual model, logical models, their relationship with the SDLC, FAST, problem solving methodology and phases and section covered in the study are provided. A system conceptualisation of a GIS is provided. The requirements cumulating from the previous chapters in the study are briefly outlined as the requirements of the conceptual model.

It should be noted that the format and the requirements of this study do not provide for a more detail discussion of the topics in the study.

The next section provides a few recommendations arising from the study.

6.2 Recommendations

Outstanding issues identified and that should be addressed are formulated as recommendations.

Firstly, a comprehensive study of all the quaternary catchment areas of the Mooi River is required, so that features, events and activities that are potentially related to disaster risks and disasters can be identified.

Secondly, the design of a conceptual model is required; this includes a logical data model, logical process model, a logical interface model and a logical telecommunications model (Whitten, et al., 2004:185).

Thirdly, the design of a physical model is required; this includes physical database design specification, business process design (including physical software design specifications), the physical user and system interface design specifications and the telecommunications specifications (Whitten, et al. 2004:185).

Fourthly, there is need to develop a generic model that will effectively reduce disaster risks, avoid disasters or reduce the effect of disasters based on this study and that can be applied to other river catchments.

The above recommendations provide opportunities for future research projects.