

Modeling a GIS-Based Physical Asset Management Plan: A Case of Gondar City Administration



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Modeling a GIS-Based Physical Asset Management Plan: A Case of Gondar City Administration

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I the under signed, declare that the thesis entitled “**Modeling a GIS-Based Physical Asset Management Plan: A Case of Gondar City Administration**”, Has been carried out by me under the supervision of Daniel Alemayehu (Ph.D.) and A.S. Mohammed Abdul Athick (M.Sc.) in the Department of Geomatics Engineering at Adama Science and Technology University during 2018-2019 academic year.

I further declare that this work has not been submitted to any other University or Academic Institution for the award of any degree or diploma and that all sources of material used for the thesis have been duly acknowledged.

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CERTIFICATE

This is certified that the thesis entitled “**Modeling a GIS-Based Physical Asset Management Plan: A Case of Gondar City Administration**”, is a work carried out by under our guidance and supervision. This is the actual work done by Alexander Girma for the partial fulfillment of the award of the Degree of Master of Science in Geoinformatics Engineering, Adama Science and Technology University, Adama, Ethiopia.

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LIST OF ACRONYMS

AMP	Asset Management Plan
ANRS	Amhara National Regional State
APA	Annual Performance Assessment
CSA	Central Statistical Agency
DBMS	Database Management System
EA	Enterprise Architect
EFY	Ethiopian Fiscal Year
EMR	Environmental Maintenance Rate
ES	Environmental Service
ER	Entity Relationship
ERR	Environmental Replacement Rate
ESRI	Environmental System Research Institute
ETB	Ethiopian Birr
FCs	Feature Classes
GB	Gigabyte
GCA	Gondar City Administration
GIS	Geographical Information System
GML	Geography Markup Language
ha	Hectare
IT	Information Technology
kms	Kilometers
MB	Megabyte
MDG	Model Driven Generation
MMR	Movement Network Maintenance Rates
MN	Movement Network
MRR	Movement Network Replacement Rates
MSE	Micro Scale Enterprise
msl	Mean Sea Level
MUDHCo	Ministry of Urban Development and Housing Construction
RGs	Regional Governments
SAA	Strategic Activity Area
SES	Social and Economic Service
SMR	Social Maintenance Rate
SRR	Social Replacement Rate
TB	Terabyte
ULGDP	Urban Local Government Development Program
ULGs	Urban Local Governments
UML	Unified Modelling Language
WMR	Water Supply Maintenance Rate
WRR	Water Supply Replacement Rates
WSN	Water Supply Network
XML	Extensible Markup Language

ABSTRACT

GIS-Based Asset Management Plan (AMP) has been a key component of the Ministry of Urban Development and Housing Construction (MUDHCo). The main intention is to upgrade the 44 Urban Local Governments (ULGs) storing, processing, and retrieving of all the collected physical asset inventory data, which leads the ULGs to accomplish effective AMP decisions. However, the current AMP GIS is susceptible to problematic challenges such as redundant data models, inconsistent attribute coding scheme, inaccurate data processing, any of which may result in the inadequate use of advanced GIS functionality. The objective of this study is to evaluate the existing AMP geodatabase model of Gondar City Administration (GCA, one of the ULGs), and to design a comprehensive geodatabase model based on the MUDHCo requirements. The GCA AMP geodatabase were evaluated by descriptive approach using the imported existing AMP geodatabase XML schema into UML diagrams. To resolve the outlined problems as the results of the existing evaluation, a set of spatial and non-spatial geodatabase requirements of the AMP were specified and a comprehensive AMP geodatabase was designed. The study geodatabase design incorporates ESRI's conceptual, logical, and physical geodatabase design phases and applies them to GCA's AMP geospatial data needs. The evaluation results revealed that the GCA AMP geodatabase contains about 62 % redundant feature classes, 81 % of undefined attribute validations and 14 % of missing required AMP attributes. Within the designed geodatabase, twenty-three feature classes, eight object classes, ten relationship classes, forty-eight domains and nine subtypes were created to establish this geodatabase design. As per the four AMP strategic activity areas (i.e. movement network, water supply network, environmental service and social-economic services), the geodatabase was built and tested on the pilot sub-cities of GCA. The designed geodatabase model will aid the GCA adequately to document, process, retrieve, and analyze their AMP geospatial requirements as per the MUDHCo AMP manual. As the obtained validation test result indicated, the designed geodatabase model is efficient and appropriate for AMP geospatial management, and it can be used as a template geodatabase for other ULGs in Ethiopia.

Key Words: AMP, GIS, Geodatabase Design

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Asset management Plan (AMP) is an integrated approach to monitoring, operating, maintaining, upgrading, and disposing of assets cost-effectively, while maintaining a desired level of service (NALAS, 2014). AMP has universally received much attention in recent years by federal departments, regional governments, municipalities, and universities have responsibility for a diversified set of constructed facilities. These assets range from interrelated underground water supply networks to buildings, as well as roadway and drainage systems, parks, and any other equipment necessary to maintain this infrastructure. (D. J. Dana, 2001).

In Ethiopia, AMP is introduced by Ministry of Urban Development and Housing Construction (MUDHCo) and has been a key component of the federal governments urban growth and development strategy since its inception in 2008 (MUDHCo, 2016). Its primary focus is on the 44¹ Urban Local Governments (ULGs), which are a member of the Urban Local Governments Development Plan (ULGDP²) program.

The first AMP operational manual introduces in December 2008 by MUDHCo; it focused primarily on the management of the network infrastructure assets of the city (MWUD, 2008). The second edition of the AMP manual released in June 2016 by superseding the first edition, this second edition has been expanded to cover all the city's physical assets (MUDHCo, 2016).

A large amount of geospatial data is required in order to meet the ULGs AMP requirements and formulate effective AMP decisions. Geographic data is essential to organize processes, manage, and evaluate the many geographic asset components present on the ULGs. These components include road network, administrative buildings, drainage networks, water supply pipes, streetlights, schools, playgrounds, recreations, bridge, culverts, MSE shades, etc. Most of the AMP data is geographically located, and its availability is necessary to support accurate analytical AMP assessments.

To facilitate this expansion of the asset base, ESRI's ArcGIS for desktop introduced as the primary database management platform for physical asset management by the revised AMP

¹ list of the ULGs members is attached in the Appendix A

² This program is supported by the World Bank

Manual, which is proposed to store and process all the collected physical asset inventory data in to the geodatabase (MUDHCo, 2016). The geodatabase contains; citywide physical asset inventory of the four asset categories labeled as Strategic Activity Area (SAA), (1) the Movement Network, (2) the Water Supply Network, (3) Environmental Service, and (4) Social and Economic Service (MUDHCo, 2016).

In many cases, technology is acquired by organizations without the appropriate research, design, and implementation plans required for a successful system. An organization may observe the benefits of a GIS by other sources, assuming the GIS will demonstrate success once acquired. This is a common mistake, and the end result creates many data management problems. For maximum performance, the organization needs to understand the functional capabilities of its GIS and their organizational goals. GIS data design is a critical element necessary for foundation of any GIS system. Once created, several geospatial processes may be used for further analytical capability.

Currently, most ULGs AMP GIS users faced many challenges (Gondar, 2017; Burayu, 2017). The primary sources of this challenges includes disorganized GIS such as data model selection, containing a surplus of redundant data, lack of consistent attribute coding scheme, and inappropriate data processing. Due these issues, a variety of problems has been occurring and lead the users to deal a lot of time be spent in data retrieving, updating, and interpreting. These lacks of data organization also lead the ULGs to a lower processing speed and decreased efficiency in the AMP.

The evolution of GIS technology has brought with it a variety of GIS functionalities. Selecting the appropriate GIS functionalities depends on organizational requirements and availability functionalities during the time period it was created. Within the last couple of decades, GIS functionalities and data formats have changed from coverages, to shapefiles, to feature classes.

Unfortunately, many ULGs use unorganized GIS, which are inefficient GIS data models (Adama, 2016; Bahirdar, 2017; Debre Markos, 2016) . These data models are lack many of the GIS capabilities associated with more advanced technologies currently available. Nowadays, the GIS technologies contain multiple advantages, including a variety of database and mapping functionalizes that will be discussed in detail in the following chapter.

Data design is vital in creating a proficient and successful GIS (Arctur D., et al., 2004). If not designed properly, data may be incomplete and incapable of performing relevant organizational and functional tasks. Incomplete data may only contain spatial coordinates of the geographic

feature and lack any significant attribute data. For example, there may be five similar polyline comprising a single area of interest, yet they may be contained in five separate GIS files. These polyline files may even lack the specific data needed for documentation or analysis.

The fundamental idea behind GIS is to associate tabular data with spatial representations. If geospatial data is lacking tabular attribute data, this will likely generate difficulty in documenting relevant data for labeling, classifying and conducting analysis and queries. Data must be designed with extreme consideration based on the desired needs of the user. These problems and concerns can be addressed, corrected, and improved by employing an updated GIS, while concentrating mainly on the data needs and design elements to ensure its potential success. This effort would allow the AMP to organize all of their data in a more proficient manner, and use their spatial data in the most efficient way.

Due to the large amount of AMP GIS data models, a complete GIS model assessment of many ULGs is too large of a project for a master's thesis. Instead, a case study that examines the most critical needs of one ULGs would represent a more acceptable scope for this thesis. It is the intention that this case study will produce a model for designing and managing spatial data, which ultimately can be adopted by other ULGs throughout the country.

Thus, this study evaluates the existing Gondar City Administration (GCA³) AMP geodatabase, based on the assessment results requirement analysis are defined for designing a comprehensive AMP geodatabase model. Ultimately, the study designs a comprehensive AMP geodatabase, which is assured AMP manual requirements as well as ERSI's conceptual, logical, and physical geodatabase design phases. The designed geodatabase model built and tested by populating the existing physical asset inventory data of selected sub cities of the GCA.

³ GCA is one of the ULGs Member

1.2 Statements of the Problem and Research Questions

A comprehensive and updated AMP geodatabase is crucial for all ULGs to support the AMP decision-making process. However, how this geodatabase designed received little attention. Currently, The AMP is not protected from the problematic challenges faced by most ULGs GIS users. Many problems can subject from an unorganized GIS such as data models, unnecessary duplication, inconsistent attribute coding scheme, and inaccurate data processing, any of which may result in the inadequate use of the GIS advanced functionality. In addition, the users' misconception of the AMP GIS requirements and nonexistence of a well-structured AMP GIS model are creating these problems. At present GIS is not always utilized to its full potential by the ULGs, and in many cases, they utilized only for its cartographic capabilities.

A variety of problems has occurred due to the AMP data is not organized properly in the GCA AMP. For example, in the GCA AMP, GIS data models are fragmented into a number of feature classes, this creates a great deal of time spent in retrieving and interpreting the characteristics of AMP GIS data's. This lack of data organization leads users to adopt their own organizational structure for data processing, update, and retrieving by individual interest. This problem also causes the process of data storing, updating, and retrieving to be highly dependent on manual editing.

Even if the geodatabase is selected as primary AMP database management platform by the AMP manual, in most ULGs about 85 % of the AMP data processing/computation operations execute outside the geodatabase environment (Adama, 2016; Bahirdar, 2017; Gondar, 2017; Woldia, 2017; Debre Tabor, 2017; Burayu, 2017). Commonly the computations executed by Excel sheets and then transfer it into the geodatabase, this creates data inconsistency and updating problems throughout the AMP and unable to retrieve a correct information that will underpin the effective AMP decision-making processes of the ULGs. This practice also leads the ULGs to perform a lower processing speed, as well as decreased their efficiency in the AMP decisions.

Moreover, Many ULGs, over six from eight, failed to maintain the AMP geodatabase effectively (Gondar, 2017; Burayu, 2017; Bahirdar, 2017; Debre Tabor, 2017; Debre Markos, 2016; Woldia, 2017). The major reasons are poor data model structure, excessive data redundancy, and inappropriate data processing. Furthermore, The ULGs do not have similar AMP GIS schemes, which includes spatial and attribute data models selection, data validations, and AMP computations techniques are a few to mention of inconsistency between the ULGs.

When data is organized properly, maximum processing speed is achieved and the ULGs efficiency is enhanced. Establishing the structure and developing the data's organization and relationships are an important step in planning an efficient GIS. Therefore, in order enable GCA to store the AMP data properly and to process the data independently in the geodatabase environment, this study will design a comprehensive AMP geodatabase model. The designed geodatabase model can save the GCA a great amount of time and resources. Additionally, within the design geodatabase model, the GCA may perform; instant AMP computations, generate versatile AMP reports, easily updating of attributes, eliminating data redundancies, and clearing the path for more informed decisions lead to increased AMP performance of the GCA. Thus, in order to resolve the current AMP GIS management drawbacks, and to design a comprehensive AMP geodatabase model, the study formulates the following research questions:

- What are the major drawbacks of the existing GCA AMP geodatabase?
- Which possible design is effective to develop a comprehensive AMP geodatabase model?

1.3 Objectives

1.3.1 General Objective

To develop a GIS-based Physical Asset Management Plan Model for Gondar City Administration.

1.3.2 Specific Objectives

- To evaluate the existing AMP geodatabase of Gondar City Administration.
- To conduct requirement analysis for designing AMP geodatabase model.
- To design the physical AMP geodatabase model.
- To populate and test the designed AMP geodatabase model.

1.4 Significance of the study

The significance of this study may provide direction for evaluate, design, and maintain the AMP Geodatabase, which is intended for all ULGs throughout the country. The followings are the major beneficiaries of the study:

- Ministry of Urban Development & Housing Construction: The Ministry office may use the proposed geodatabase Model as a template for all ULGs throughout in Ethiopia. Furthermore, it may understand the current AMP geodatabase management status of the study area.
- Urban Local Governments: ULGs perform data storing, processing, and analyzing of AMP data independently in the ArcGIS environment. This will have an advantage of data consistency and retrieval. In addition, by using simple visual interface ArcGIS tools, they will automate all AMP computation and generating versatile AMP reports.
- Gondar City Administration: Create an awareness for the GCA, whether the existing GCA AMP geodatabase model is effective or not in the actual of the AMP manual requirements.
- Organizations: Nowadays, GIS enabled physical asset management is widely used by different organization such as; federal and regional road authorities, telecommunications, electric and water supply, real states etc. Therefore, this study may shows a direction how these organizations optimize their current asset management practice by using the GIS.

- Researchers: this study will be able to provide an opportunity for future researches, carrying out similar or related research.

1.5 Scope of the study

1.5.1 Spatial Scope

The spatial scopes of the research for evaluate the existing GCA AMP geodatabase cover the entire geodatabase elements/asset inventories of the city. However, for populating and testing the designed AMP geodatabase model the study use pilot three sub-cities (Abajale, Abiyezgi, and Medhanialem) asset data.

1.5.2 Thematic Scope

The thematic scope of the study is focused on the existing asset inventory data of the GCA based upon the AMP Manual (2016) asset categories (i.e. Strategic Activity Area) shown in the Table 1.1 below.

Table 1.1: Thematic Scope of the Study

S/N	Strategic Activity Area (SAA)	Category
1.	The Movement Network	• Road Network • Pedestrian Walkway • Road Structures (Bridge & Culvert) • Streetlights
2.	The Water Supply Network	• Water supply pipes • Boreholes • Reservoir
3.	Environmental Service	• Drainage Network • Sanitations • Recreation and Greenery
4.	Social & Economical Service	• Administrative and Community Service Buildings • Fences

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Asset Management

According to the report on international asset management practice, “*Asset management is an integrated approach to monitoring, operating, maintaining, upgrading, and disposing of assets cost-effectively while maintaining a desired level of service*”. It may apply to both physical assets, such as utility grids, transportation network and buildings, and non-physical assets such as intellectual property (NALAS, 2014). Although, Publicly Available Specification (PAS 55) defined as, Asset management is “*systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan*”.

The asset management specification PAS55 identifies the following types of the asset within organizations, Financial Assets, Physical Assets, Human Assets, Information Assets and Intangible Assets (PAS, 2008). According to a study, the utility asset management market is expected to grow from an estimated USD 2.75 Billion in 2017 to USD 4.09 Billion by 2022, registering a CAGR⁴ of 8.25%, from 2017 to 2022 (MarketsandMarkets, 2018).

Effective Asset management plan practices require the application of asset management concepts and principles in order to maximize the benefit of the limited funding available annually for asset maintenance and new project plan, sustaining the availability and level of service of the assets and improving the overall condition of all assets (MUDHCo, 2016).

2.1.2 Asset Management in Ethiopia

In Ethiopia, Asset Management has been a key component of the Federal Governments Urban Growth and Development Strategy since its inception in 2008. The first Standard AMP introduced by developing operational manual in December 2008; it focused primarily on the management of the network infrastructure assets of the City (MWUD, 2008). The second edition of the AMP manual released in June 2016 by superseding the first edition, this second

⁴ Compound Annual Growth Rate

edition has been expanded to cover all the city's physical assets. To facilitate this expansion of the asset base, the Asset Management Plan has been integrated into a GIS-based management system (MUDHCo, 2016). The Ethiopian approach to AMP took the concept behind the Canadian approach, which was based upon the use of a step-based process, and adapted it to the needs of Ethiopian Cities.

As stipulated in AMP manual, asset management is expensive to construct and maintain the strategic solutions of a city at one time (MUDHCo, 2016). The merit of a GIS-based database is the provision of ample, seamless integration, dynamically updateable tabular and spatial data, easy query/analysis facilities and versatile for generating the report for project planning, budgeting, and maintenance schedule. Besides, based on the information generated, one can produce effective capital investment planning and strategies for long-term operation and maintenance of infrastructure asset. With regard to the existing infrastructure, the AMP answers the following questions (MUDHCo, 2016):

1. What infrastructure does the City have?
2. Where is it?
3. What is its condition?
4. What is it worth?
5. How much money needs to be spent on maintaining it?
6. How does the City keep this information available for easy access in the future?

Regarding new infrastructure, the AMP Manual questions the following points:

7. What is the planned investment, in terms of both new and existing assets, as defined by the Capital Investment Plan and where will the new investment in assets be located?
8. What is the most effective investment in maintenance that will ensure the City keeps its assets in good condition?
9. What will the total investment budget be, and when will that investment take place?
10. How will the new assets and the maintenance and improvement to existing assets be integrated with the existing asset base?

The first level is that of managing the information associated with the assets. In this context, these ten questions provide the underpinning structure for the Ethiopian 10-step approach to building an Asset Management Plan. By working through this approach in a systematic way,

and providing the outputs specified by each step, the Cities will be able to produce a clearly defined and well-constructed Asset Management Plan that provides a comprehensive analysis of their assets and a system for managing future investment.

On the second level, the outcomes from the ten steps enable the information outflow from each step to provide the basis for a more strategic analysis, both of the existing asset base, and of the capital requirements and capital flows for new assets. Used in this way, the Asset Management Plan becomes the basis for more sustainable capital investment planning; for more effective maintenance budgeting, efficient staffing needs planning and allocation; and improved urban planning. The 10 steps of the AMP described in the AMP manual shown in the table below, together with their primary outcomes.

Table 2.1 : The description of the 10 AMP steps and their outcomes

Step	Description	Outcome
1	Build the GIS project and the data management structure	A GIS-based data and information management system for Asset Management
2	Build the institutional framework and the asset management structure.	An institutional framework for Asset Management and a comprehensive, integrated, structure for managing the City's Assets
3	Compile an inventory of assets	A complete inventory of existing infrastructure assets
4	Assess the condition of all assets	A condition indicator table for all infrastructure assets
5	Calculate the maintenance budget and deficit	A comprehensive maintenance budget, and a detailed maintenance deficit
6	Cost and value the existing asset base	The replacement cost and, as far as is possible, the current value of all assets
7	Cost, and prioritise, new works projects within the CIP process	A fully costed list of proposed New Works set out in order of priority
8	Develop the Maintenance Plan	A detailed plan for ongoing maintenance, together with a plan to address the maintenance deficit
9	Convert the CIP agreed budget for all new works and maintenance projects to a 3-year rolling program	A set of summary tables that show both the approved new works, and the maintenance projects, set out as a 3-year rolling program
10	Manage the transition of all completed new works and maintenance projects across to the existing assets database	A system of tracking the progress of all new works, through construction, to become part of the existing asset base in the step 3 of the AMP. Modification of step 4 of the AMP to reflect the updated status of completed maintenance projects

2.1.3 Geodatabase Design Steps

The methods and techniques used to design geodatabases were developed by ESRI, and adopted in this study. The methodology for this study incorporates ESRI's design techniques and applies them to GCA geospatial data needs.

The ESRI geodatabase design contains three phases: conceptual, logical, and physical. The conceptual phase examines the research component, the logical phase illustrates the design elements, and the physical phase discusses the implementation of the geodatabase design. This study adopts ESRI's conceptual, logical and physical geodatabase steps, and concentrates solely on identifying the GCA AMP needs and requirements, and designing the geodatabase components necessary for a successful AMP management.

The conceptual, logical and physical design phases include (Zeiler, 2007):

Conceptual Design

- 1) Model the User's View of Data
- 2) Define Geographic Data Entities
- 3) Identify Representation of Entities

Logical Design

- 1) Match to the Geodatabase Model
- 2) Organize into Geographic Datasets
- 3) Diagram Geodatabase Model

Physical Design

- 1) Implement the design
- 2) Design workflows for building and maintaining of layer
- 3) Design Documentation

2.1.3.1 Conceptual Design

Conceptual design is the research phase of designing a geodatabase model. This phase helps identify and characterize all data requirements. Each AMP Strategic Activity Areas (SAA) is analyzed and their data needs assessed based on AMP requirements.

1. Model the User's View of Data:

This step in the conceptual phase studies the needs and responsibilities of each AMP SAA. This is basically a needs assessment, the foundation of any effective geodatabase model. A needs assessment is the process required to evaluate the needs and requirements of the GIS system. The AMP SAA were studied and evaluated by using their job descriptions, and AMP manual specifications (Zeiler, 2007).

2. Define Geographic Data Entities

The purpose of this stage of the conceptual phase is to identify and group the key geographic entities required to accomplish job tasks and responsibilities. This step defining the geographic data entities requires a transformation from the ideas and needs into the creation of concrete feature classes or object classes (Zeiler, 2007).

3. Identify Representation of Entities

The geographic entities are broken down further in this stage to represent points, lines, polygons, or tables (object classes). The objective of this phase is to determine how data is grouped and represented in the geodatabase model by classifying entities according to their type of representation (Zeiler, 2007).

2.1.3.2 Logical Design phase

The logical phase illustrates the complexity of the geodatabase including all design elements required to establish a productive system. All design elements are based on the previously determined data needs described in the conceptual phase of design. The logical phase illustrates data specifications, structure, and relational properties. This phase requires the development of representation specifications, relationships, and ultimately, geodatabase elements and their properties. It identifies the tabular data, gives data definitions, and identifies relationships. The logical phase basically takes the data researched in the conceptual design and plugs it in to a geodatabase model. Data types, record length, field descriptions, subtypes, domains, and relationships are examined in further detail, requiring additional evaluation of the data. This

phase takes the data researched in the conceptual design and plugs it in to a geodatabase model (Arctur D., et al., 2004).

1. Match to the Geodatabase Model

The focus now turns from understanding the user requirements to developing an efficient and effective database schema. Schema refers to the structure or design of a geodatabase. The expertise of the GIS specialist in geodatabase modeling, GIS functionality, and analytical capabilities is critical in this phase. Understanding these GIS components is essential in designing the data in the most proficient and effective manner. This stage assesses all previously determined categories of data one at a time, examining all required data, and their descriptions. This step identifies attribute fields, data types, field descriptions, character size, associated domains, and sub-types. Results of this stage are descriptive tables for each layer or table organized by AMP SAA. The data elements are dissected in detail, and the fields and records for each database will be created and described (Zeiler, 2007).

2. Organize Geodatabase Structure

The feature classes are divided into feature datasets within this step. Feature datasets are organized according to data similarities and assigned integrity rules based on relationships. Relationships are also defined within this section, illustrating the relationship type, cardinality, and key fields in origin and destination tables. Results of this stage outline the feature datasets, relationship classes and their descriptions (Zeiler, 2007).

3. Create Geodatabase Model Diagram

This stage develops a model in the form of a flow diagram to help users visualize the data properties and relationships between data sets. Such a diagram will allow the reader to better interpret vast amounts of information created by displaying the data and associated relationships. Due to the intricacy of this work, a visual representation is necessary to illustrate the datasets, relationships, and organizational structure and flow (Zeiler, 2007).

2.1.3.3 Physical Design Phase

1. Implement the design

Construct data schema to reside in a database management system. Test the computability of the data schema

2. Design workflow building and maintaining layers

Define updating workflow processes for layers

3. Design documentation

A series of diagram is documented the specification of Geodatabase elements, metadata, and map layers in each of data model templates.

2.1.4 Unified Modeling Language

Object modeling methodologies such as the Unified Modeling Language (UML) are becoming increasingly popular in both database and software design. These methodologies go beyond database design to specify the detailed design of software modules and their interactions using various types of diagram. UML combines commonly accepted concepts from many object-oriented (O-O) methods and methodologies. It is generic, and is language-independent and platform-independent. Software architects can model any type of application, running on any operating system, programming language, or network, in UML. That has made the approach very widely applicable (Ramez , et al., 2011).

Tools like Enterprise Architect (EA) are currently popular for drawing UML diagrams; they enable software developers to develop clear and easy-to-understand models for specifying, visualizing, constructing, and documenting components of software systems. Since the scope of UML extends to software and application development at large, this study will not cover all aspects of UML here. Our goal is to show some relevant UML notations that are commonly used in the ArcGIS Geodatabase design.

EA, using Model Driven Generation (MDG) Technologies, supports the Geography Markup Language (GML) application schemas and the modeling of ArcGIS geodatabases. MDG Technology for GML is the implementation of the Open Geospatial Consortium's GML 3.3 for Enterprise Architect, which provides an Extensible Markup Language (XML) grammar for geographical feature modeling capabilities within EA. The information precursors to these models, such as community conceptual models, can also be modeled and traceability can be used to connect the models together. EA supports the design of geodatabases for the ArcGIS 10.x suite of tools developed by ESRI (SparxSystems, 2016).

Using UML profile for ArcGIS, EA provides (SparxSystems, 2016):

- Create a visual UML model of your ArcGIS geodatabase.
- Validate an ArcGIS Workspace.

- Export your modeled ArcGIS schema as an XML Workspace document that is readable by ArcGIS 10.x.
- Import existing ArcGIS database schemas to an EA model

A key feature component of UML Profiles for ArcGIS (SparxSystems, 2016):

- Domains - for coded value and range domains.
- Features and Tables – Point, Polyline, Polygon, and tables
- Network Features - for geometric network and topology Packages.
- Raster - for raster datasets and
- Workspace - for ArcGIS workspace and spatial reference information.

2.1.5 Customized ArcGIS Geoprocessing Tools Development

In ArcGIS, Geoprocessing tools perform small, yet essential operations on spatial and non-spatial data, such as extracting and overlaying data; changing map projection; adding a field to a table; and calculating attribute values, to name a few. Tools are stored in toolboxes and toolset. ArcGIS ships with numerous tools organized into a dozen of toolboxes and toolsets, providing a rich set of functionality across a wide range of disciplines (ESRI, 2018).

There are hundreds of tools installed with ArcGIS, which are built using ArcObjects and a compiled programming language like .NET, ModelBuilder and scripts. A user can create its own customized tools using scripts, ModelBuilder, and .NET or a combination of any of these tools (ESRI, 2018). The goal of creating customized tools is to become empowered to save time and resources by using customized tools and to more efficient in users' workflow processes.

By adding variables and parameters to a customized tool that are created by ModelBuilder/scripts, a user can expose input and output parameters of layers, and tool variables. The main reason of specifying parameters and variables are to run the ModelBuilder/script with different input layers without having to open ModelBuilder/Scripts every time.

2.2 Empirical Reviews

Relational Database Management System such as the ESRI Geodatabase has been used extensively in the last decade for the compilation of data as well as ArcGIS for visualizing the spatial data (Chesnaux R., et al., 2011). There are various research projects regarding establishing Geodatabase models for different types of spatial data. Some of those researches will be mentioned in this section to demonstrate the usage of Geodatabase.

For Road network environmental quality: The research placed in the city of Chania and the goal was to develop a Geodatabase model in order to evaluate the environmental quality of the urban roads (Tsouchlaraki A., 2010). Geodatabase design consisted of four stages as defining the Geodatabase, conceptual design, logical design, and physical design of the geodatabase. Eight main categories defined to address the tabular behavior of the road features as urban planning and architectural, construction materials, road equipment's, road traffic, land uses, pollution, climatic, and economic indices. This geodatabase gave the opportunity to examine the study area, to analyze the indices separately and in combination and to provide useful results concerning the road environment quality of the study area.

For mapping hydrogeological features: In this research project, a spatial database implemented utilizing ESRI personal Geodatabase as a repository of hydrological spatial data (Chesnaux R., et al., 2011). The geographical information organized into datasets created from Microsoft Access, which is a relational database. Various spatial data such as, topography, wetlands, land use, administrative, transportation, and hydrogeological content were added and organized as feature classes in the Geodatabase. The geodatabase created in this study allows the user to request the relevant data required for a specific hydrological study. In addition, the data stored within the geodatabase may be utilized for constructing 3D subsurface hydro structure model.

For Storm-water management: A campus GIS developed in this project to provide a spatial and tabular framework for storm-water system management in North Carolina State University (NCSU) (Charlynn T., et al., 2006). Moreover, the GIS system is an evaluation tool to measure the performance in the storm-water management plan. The data layers stored in the Geodatabase datasets as polygons, polylines, and points to generate the NCSU campus basemap. Storm-water data developed utilizing editing session in ArcGIS and then stored in the Geodatabase.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location Description

Gondar is one of the eldest and largest cities not only in Amhara National Regional State (ANRS) but also in Ethiopia. Many past studies have revealed that Ethiopia had no permanent capital, until the 17th Century that was until the designation of Gondar as a capital by Emperor Fasilides Decree in 1635/36 E.C that remained until 1855. This marked historical foundation of Gondar, which then grew as agricultural, market, commercial, transport, administrative and tourist centers in the country. In fact, even prior to this, Gondar used to serve as a market center for the surrounding areas. In addition, since then it grew tremendously in every aspect of urban sanctity to become an imperial capital in the 17th and 18th centuries, a capital of the Amhara Region during the Italian Occupation of 1936-1941, and the capital of one of fourteen provinces in Haile Selassie's reign (Gondar, 2017).

At present, Gondar is one of the 44 ULGs in the country and capital of North Gondar Zone. According to the ZIKRE-HIG of ANRS the Revised Cities' Organizational Category Determination and Establishment, Council of the Regional Government Regulation (Regulation No: 65/2009) Gondar labeled as Metropolitan City in ANRS. Gondar, including the surrounding small towns within a radius of 20km is reorganized as one of the three Metropolitan areas in the region, consisting 21 urban kebeles that recently have been merged into 12 sub-city Administrations and 11 Rural Kebele Administrations and that of Tseda Sub-municipal Town. As it has been stated in the 2017 AMP of Gondar the current total physical area of the city is about 313.24 km² (Gondar, 2017).

Astronomically, Gondar's center lays on the geographical coordinates of 12.61°North Latitude and 37.47°East Longitude and sits at an average elevation of 2,100 meters, and surrounded by three sides ring of 3,000-meter high mountains. To the south, the landscape opens to a valley and distant views of Lake Tana, the source of the Blue Nile. The city stretches along a ridge centered on a complex of castles built during the seventeenth and eighteenth centuries when Gondar was the imperial capital of Ethiopia. It expanded significantly around 1635 under the rule of Fasiladas, the son of the city's founder, Susenios.

With regard to its relative location, it is found north of Lake Tana on the Lesser Angereb River and southwest of the Semien Mountain in ANRS at about 737km north of Addis Ababa, 175 km north of Bahir Dar, 180 km from Metema and Humera, and 200 km from Axum and Lalibela. It is bounded in the north by the eastern slopes of mountains. such as, Mushira Dengay, Tigrie Machohiya, Hog and Amba Soni; in the west by the cressets of Mt. Amba Terara, Mt. Bilajig and Mt. Anchi Duba; in the east by River Angereb, and in the south by the plain areas that run along and towards the Tewodros II AirPort (Gondar, 2017).

3.1.2 Population

Based on the 2007 national census conducted by the CSA of Ethiopia, Gondar had a total population of 207,044 (98,120 Male and 108,924 Female, the first populated city in ANRS, which has estimated to 218,464 populations in 2013. The majority of the inhabitants practiced Ethiopian Orthodox Christianity, with 84.2% reporting that, as their religion, while 11.8% of the population said, they were Muslim and 1.1% was Protestant (CSA, 2007).

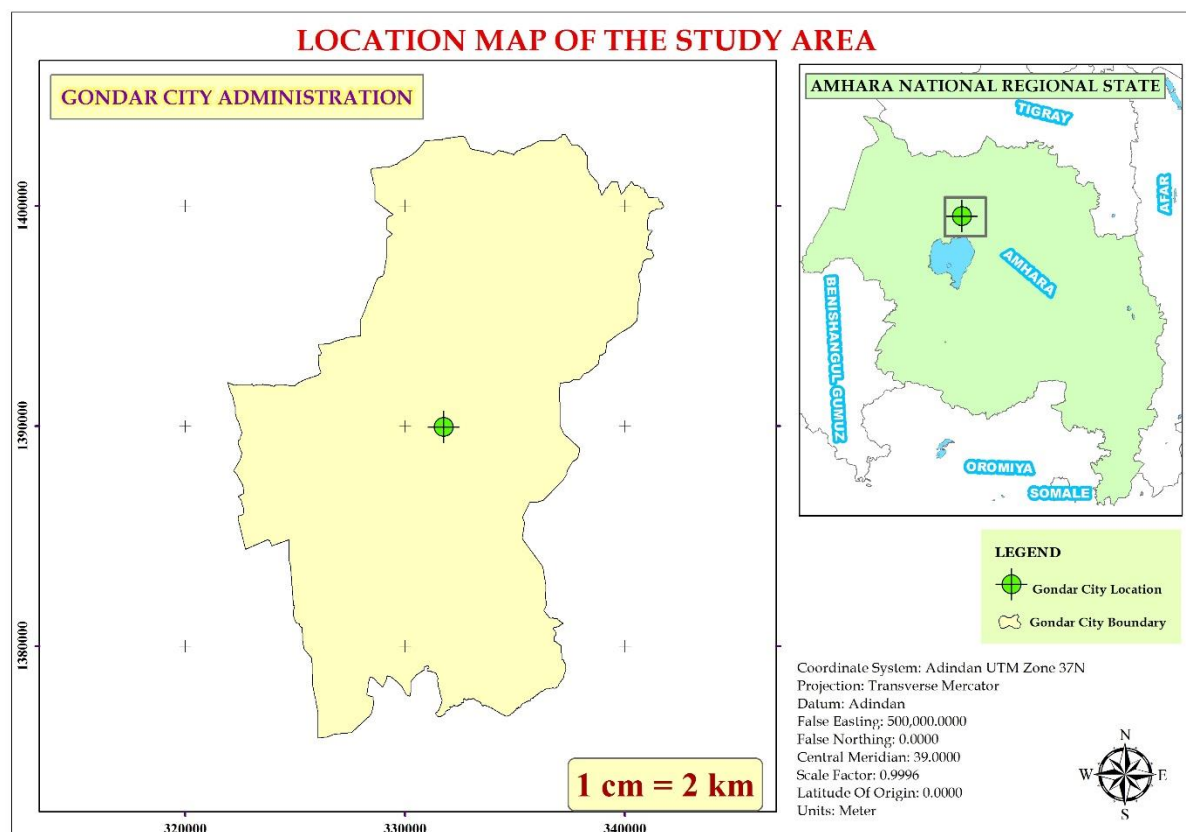


FIGURE 3.1: LOCATION MAP OF THE STUDY AREA

3.1.3 Climate Condition

3.1.3.1 Temperatures

Gondar located at an average of 2,100 metres above msl, though the altitude in different districts of the City varies from 2000 to 2200 meters, and has mild climate, with cool nights, when lows drop below 10°C. Moreover, pleasantly warm days, around 23/25°C, except in July and August, at the height of the rainy season, when highs drop to about 20°C. The period from March to May, as often happens in Gondar, is the warmest of the year (Climatestotravel, 2018). Table 3.1 shows the average annual temperatures.

Table 3.1: Average annual temperature of Gondar City (2016)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min (°C)	9	10	11	12	12	11	11	11	11	10	9	9
Max (°C)	24	24	25	24	25	23	21	21	22	22	23	24

Source: Climate to Travel

3.1.3.2 Precipitation

Throughout the year, 1,200 mm of rain fall, with a maximum from June to September, which is the only remarkable rainy period. From November to February, there is little rain, and rare showers occur; from March to May, afternoon showers become a bit more frequent, occurring for 6/7 days per month, while in July and August they occur on average every other day. Table 3.2 shows the average annual precipitation.

Table 3.2: Average annual precipitation of Gondar City (2016)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec. (mm)	16	45	70	85	95	135	280	295	190	80	50	30
Days/ Month	4	4	5	7	7	11	14	16	13	7	5	4

Source: Climate to Travel

3.1.3.3 Sunshine

The amount of sunshine in Gondar is good from October to May, while in the rainy season, from June to September, the sunshine hours decrease, and especially in July and August the sky is often cloudy. Table 3.3 shows the annual average sunshine hours.

Table 3.3: Average annual Sunshine of Gondar City (2016)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours	9	9	8	7	6	3	3	5	8	8	9	9

Source: Climate to Travel

3.1.4 Asset Descriptions

3.1.4.1 Movement Network: The Road Network Extent of GCA

According to the 2017 asset inventory result, there was a total length of about 336.71 kms of road in the GCA urban boundary, which the total area reserved of 257.77 ha (Gondar, 2017). The Inventory further revealed that compacted earth road has the maximum coverage, which accounted 172.9 kms (50.28%), followed by cobblestone road, which has a total length of 77.81kms (22.63%). The other road surface types are depicted in Figure 3.4 below.

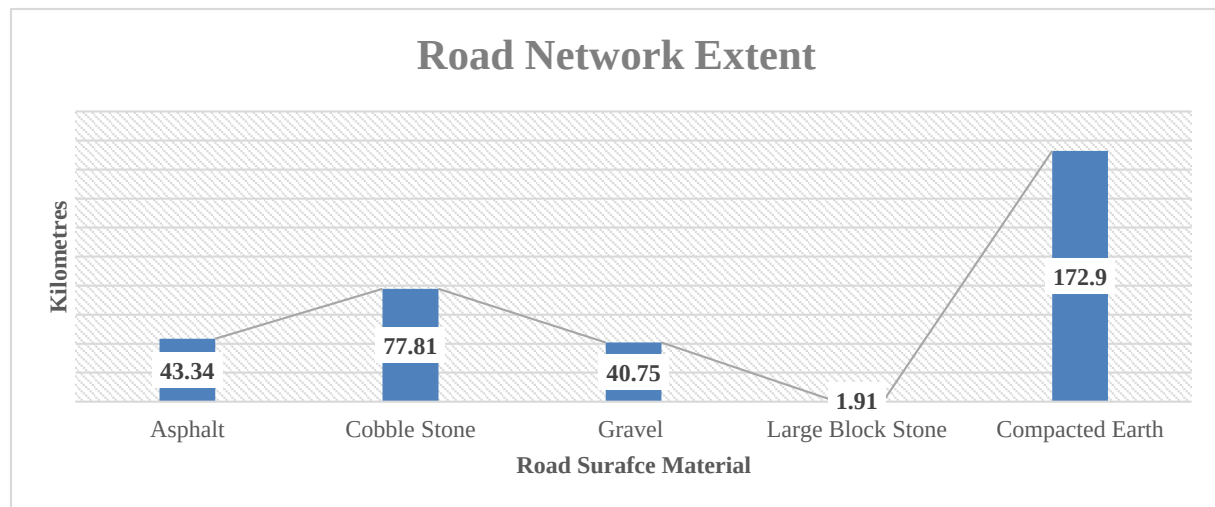


FIGURE 3.2 : ROAD NETWORK EXTENT OF GONDAR CITY

3.1.4.2 Water Supply Network: The Water Supply Pipes Extent of GCA

The water supply system of GCA mainly comprises production of water at the source, transmission of water to reservoirs and distribution to customers. Accordingly the water supply network asset revealed that the city has 69.00 kms length of distribution network while 360 kms transmission network (Gondar, 2017).

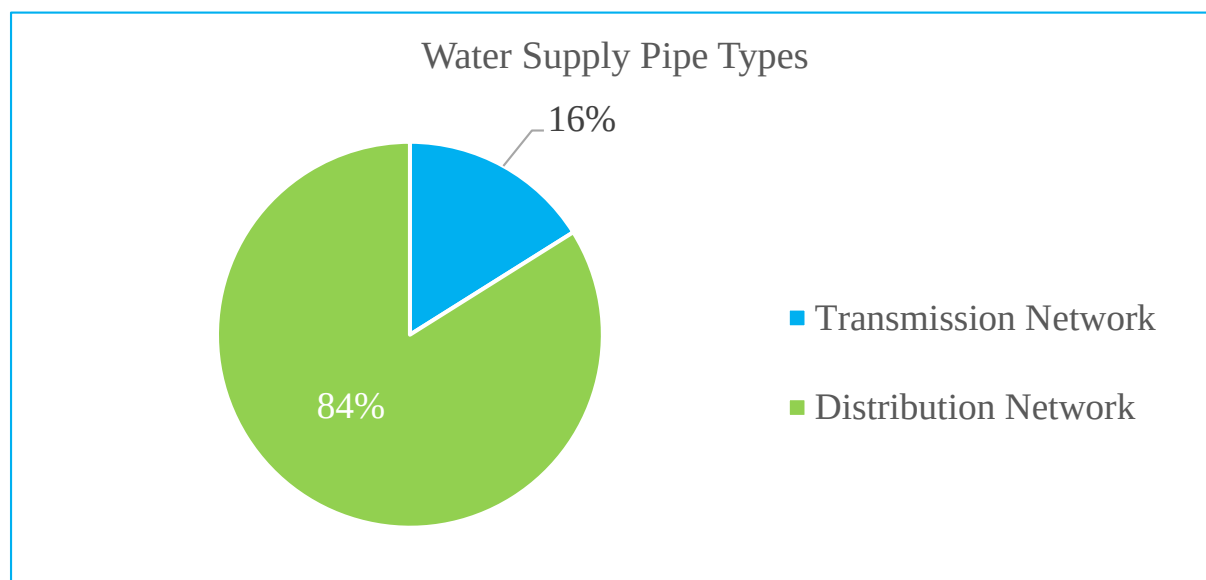


FIGURE 3.3: WATER SUPPLY PIPE TYPES OF GONDAR CITY

3.1.4.3 Social and Economic Service: The Health Facilities of GCA

The total area covered with the health center buildings is about 6762.32 m². Table 3.5 below shows, the inventory result further revealed that about 65 buildings of health centers are registered from seven health centers, which are found under the city administration.

Table 3.4 : Health facilities of GCA

SN	Name of Health Center (HC)	Establishment Year	Unit Measures	
			No	Area (m2)
1	Bilajig HC	2003	5	82.53
2	Gabriel HC	2003	9	763.41
3	Ginbot 20 HC	2003	9	922.72
4	Maraki HC	1999	11	1399.97
5	Poly HC	2000	12	2014.71
6	Tseda HC	1978	13	904.77
7	Weleka HC	2000	6	674.21
Total			65	6762.32

3.1.4.4 Environmental Service: The Drainage Extent and Condition Assessments of GCA

The GCA AMP results revealed that there is a total 86.15 kms of drainage channel in City; of which about 42.87 kms (50 %) of the drainage line is masonry drainage followed by concrete drain and cobblestone drain with a total length of 29.68 kms (34 %) and 13.60 kms (16 %) respectively. Moreover, according to the five level condition assessment result that from the total of 42.87 kms Masonry drainage; about 67 % were in very good condition followed by good condition which accounted 22 % and the details of each drainage type versus condition assessment are depicted in the Figure 3.4 below (Gondar, 2017).

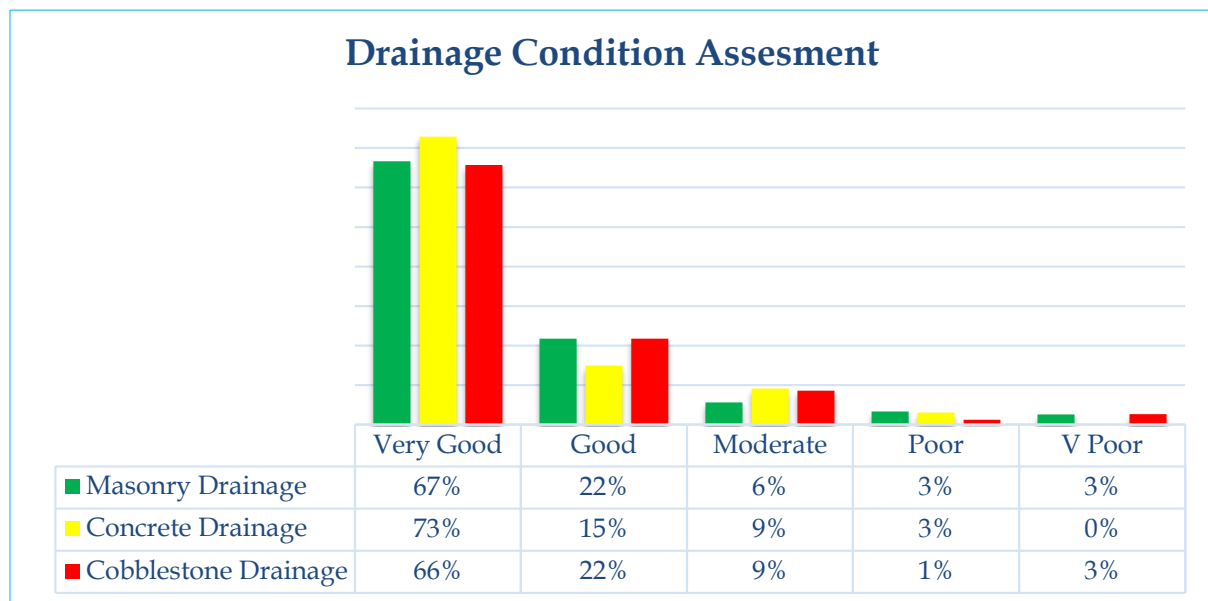


FIGURE 3.4: DRAINAGE CONDITION ASSESSMENTS OF GONDAR CITY

3.1.5 Pilot Study Area Descriptions

As specified in the thematic scope of the study for populating and testing the designed AMP geodatabase model the study uses three sub-city assets, named as Abajale, Abiyezgi, and Medhanialelem sub-cities. The major reason is; geographically they are located adjacently in the inner part of city, as a result, most of the city administration assets are located in these sub-cities. From the total pilot area of 344.57 ha, Medhanialelem shares 191.26 ha (56 %) followed by Abiyezgi and Abajale which shares 124.39 ha (36 %) and 28.93 ha (8 %), respectively.

Geographically the pilot study area located in northeast of the city and it is extent lays on the projected coordinates of 332202.62, 1395135.01m Top-Left and 335764.11, 1393156.85m Right-Bottom. With regard to its relative location, it is found on north of Adebabay Eyesus and Mehal Arada sub-cities, on south of Gebriel and Arbegnoch Adebabay sub-cities and east of the Lideta sub-city.

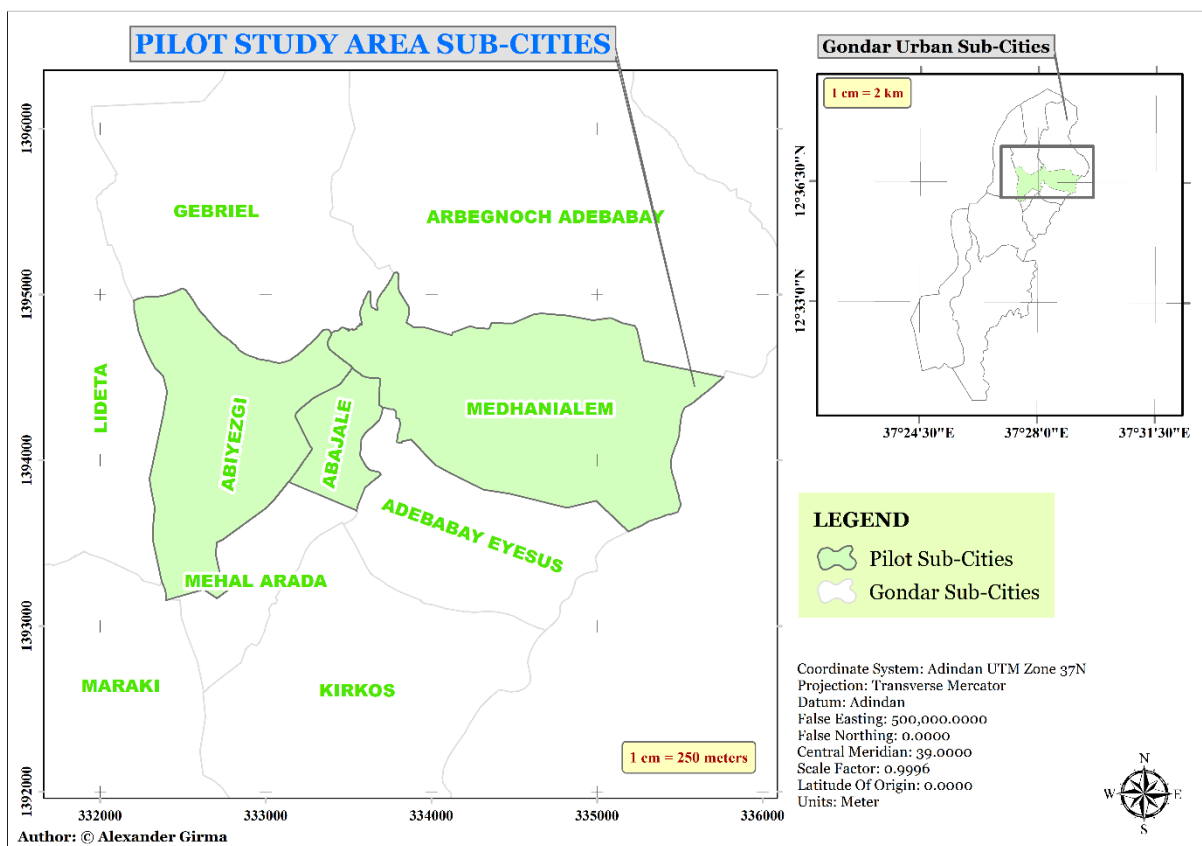


FIGURE 3.5 : LOCATION MAP OF THE PILOT STUDY AREA

3.1.5.1 The Movement Network of Pilot Study Area

As despite in the Table 3.6, the sum of three sub-cities assets in the movement network SAA categorized in to three categories, and further sub-categories. Accordingly, road network category has a total of 35.82 km of road coverage within the selected sub-cities. A pedestrian walkway also covers 6.17 kms. While road structures category inventory revealed that the pilot sub-cities has culvert and bridge with a total number of 14 and 3 respectively. Likewise, in the Tables 3.6 to 3.9, asset sub-categories as per there SAA that used for the pilot study area are presented.

Table 3.5: Pilot Study Area - Movement Network Assets

Strategic Activity Area (SAA)	Category	Sub-Category	Unit of Measurements	
			No	kms
Movement Network	Road Network	Asphalt Road		8.99
		Cobble Road		18.20
		Earth Road		8.32
		Gravel Roads		0.31
		Streetlight	323	
		Total	418	35.82
	Pedestrian walkway	Pedestrian Precast		0.43
		Asphalt Walkway		0.11
		Tiles walkway		5.57
		Total		6.11
	Road Structures	Culvert	14	
		Bridge	3	
		Total	17	

3.1.5.2 The Water Supply Network

The water supply system of the selected sub-cities accounted about 13.62km length of water distribution network (Table 3.7).

Table 3.6 Pilot Study Area - Water Supply Network Assets

SAA	Category	Sub-Category	Unit of Measurements
			Kms
Water Supply Network	Water Supply	Distribution Network	13.62
		Total	13.62

3.1.5.3 Social and Economic Service of the Pilot Study Area

Pilot study area has three educational institutes, nine health centers, and two playgrounds in public service asset category, with a total of 19,674.27 m² area coverage of land. Accordingly, market shades accounted 11 in number with a total 1,884.15 m² area coverage (Table 3.8).

Table 3.7 : Pilot Study Area - Social & Economic Service Assets

SAA	Category	Sub-Category	Unit of Measurements	
			No.	Area (m ²)
Social & Economical Activities	Public Services	Health Center	9	922.72
		Educational Institute	3	7190.77
		Play Ground	2	11560.79
		Total	14	19674.27
	Market Shade	Market Shade	6	1334.56
		Total	11	1884.15

3.1.5.4 Environmental Service of the Pilot Study Area

The asset inventory result revealed that there is a total 17.95 kilometers of drainage line in the selected sub-cities. On the other hand, Drainage manholes found in three sub-cities collectively about 67 in number. The greenery and recreational category inventory results revealed that the selected sub-cities have a total of 37,456.60 m² area coverage. Accordingly, the pilot area also has 19 communal toilets, 1 public bath, and 1 public toilet, as shown in the Table 3.9 below.

Table 3.8 : Pilot Study Area - Environmental Service Assets

SAA	Category	Sub-Category	Unit of Measurements		
			No.	Kms	Area (m ²)
Environmental Service	Drainage Channel	Drainage Channel		17.95	
		Drainage Manholes	67		
		Total	67	17.95	
	Greenery & Recreation	Median Green Area			1132.27
		Green Area			30132.57
		Park			6191.76
		Round About	3		
		Total			37456.60
	Sanitation	Communal Toilet	19		
		Public Bath	1		
		Public Toilet	1		
		Total	21		

3.2 Major Data Type and Sources

In this study, various data was collected and produced in order to accomplish objective of the study. The collected relevant data, which were in the geodatabase obtained from the GCA, processed using ArcGIS 10.6.1 software. Then, individual entities are processed in order to make them suitable for this study. The data, software and general method used for this study are shown in Table 3.10.

Table 3.9 : Data used for the study

Dataset	Format	Content	Source
Road Network	Vector	- Asphalt Road Feature Class (FC) - Cobblestone Road FC - Gravel Road FC - Large Block Stone Road FC - Compacted Earth Road FC	<i>Gondar City Administration (GCA)</i>
Drainage Network	Vector	- Open Concrete Drain FC - Cobblestone Drain FC - Closed Concrete Drain FC - Open Masonry Drain FC - Closed Masonry Drain FC - Manhole FC - Culvert FC - Bridge FC	GCA
Pedestrian Walkways	Vector	- Asphalt Walkway FC - Cobblestone Walkway FC - Clay tile Walkway FC - Precast Walkway FC	GCA

Greenery & Recreation	Vector	• Park FC • Playground FC • Road median FC • Green area FC • Roundabout FC	GCA
Buildings	Vector	• Administrative Buildings FC • Educational Buildings FC • Housing facility Buildings FC • Health Center Buildings FC • Pubic/Communal Toilet Buildings FC • Public bath Buildings FC • Terminal Buildings FC • Youth Center Buildings FC • Shade Buildings FC	GCA
Water supply	Vector	• Transmission Network FC • Distribution Network FC • Borehole FC • Reservoir FC	GCA
Fence	Vector	• Fence FC	GCA
Excel Spread sheets	.xlsx	• Maintenance & Replacement cost rates	GCA
Orto rectified Arial Photograph	Raster	• Base map, the spatial resolution of 0.15m, 3 bands (R, G, B) True color.	GCA

3.4 Software Application Purpose and Sources

Software applications used in this study are selected based on the availability and capability to work on the existing problems in achieving the predetermined objectives. The summary of all software applications used in this study are depicted in the Table 3.11 below.

Table 3.10: Software Applications used for the Study

Software application with specifications	Purpose	Source
ArcGIS 10.6.1 (2017)	- To manage AMP geodatabase - To import/export XML schema - To build GIS models - To load existing AMP data - To create customized toolboxes	<i>ESRI® Inc.</i>
Enterprise Architect 13.5 (2017)	- To import and analyze existing geodatabase schema - To develop and Validate UML diagrams - To Export XML schema	<i>SparxSystems®</i>
PyCharm community edition 2017.3.1	To develop and debug python scripts	<i>JetBrains®</i>
Flowchart Maker 8.7.5 software (2017)	To draw flowchart and diagrams	<i>Edraw®</i>
Microsoft office 2016 (MS Word, MS Excel)	- To report writing - To generate statistical information - To Make graphs	<i>Microsoft® Inc.</i>
Adobe illustrator CC 2015	To illustrate images, graphs and charts	<i>Adobe® Inc.</i>

3.5 Method

The current study concentrates on the assessment, requirement analysis, design and test of the AMP GIS model in the most recent geodatabase format, using all of its pertaining technical functionality. The main priority is to design a proficient GIS model based on the needs of the four AMP Strategic Activity Area (SAA) of the AMP manual. This AMP SAA includes: The Movement Network, The Water Supply Network, Environmental Service, and Social and Economic Service.

Prior to developing the AMP GIS model, existing GCA AMP GIS will evaluate by importing the existing AMP geodatabase XML schema into UML diagrams. Evaluation of the existing GCA AMP geodatabase is conducted via standard geodatabase design requirements (ESRI, 2018) and AMP manual geodatabase design requirements (MUDHCo, 2016). For each issue, which is presented as drawback of the current AMP geodatabase design a set of requirement analysis are specified in order to design an effective and comprehensive AMP geodatabase, as well as to solve the current problems outlined as the results of the existing AMP geodatabase assessment.

Based on the requirement analysis results, a comprehensive AMP geodatabase design will be conduct as per each SAA. The methods and techniques used to design the geodatabases were developed by ESRI. The methodology for this study incorporates ESRI's design techniques and applies them to GCA's geospatial data needs. The ESRI geodatabase design contains three phases: conceptual, logical, and physical. The conceptual phase examines the research component, the logical phase illustrates the design elements, and the physical phase discusses the implementation of the geodatabase design.

In the physical AMP geodatabase design phase, the study will build the designed geodatabase for the pilot sub-cities, and test the geodatabase functionality by AMP computations and information retrieval. Finally, the study provides build AMP geodatabase model. The general method of the study is depicted in following Figure 3.6, followed by the overall work flow of the study (Figure 3.7)

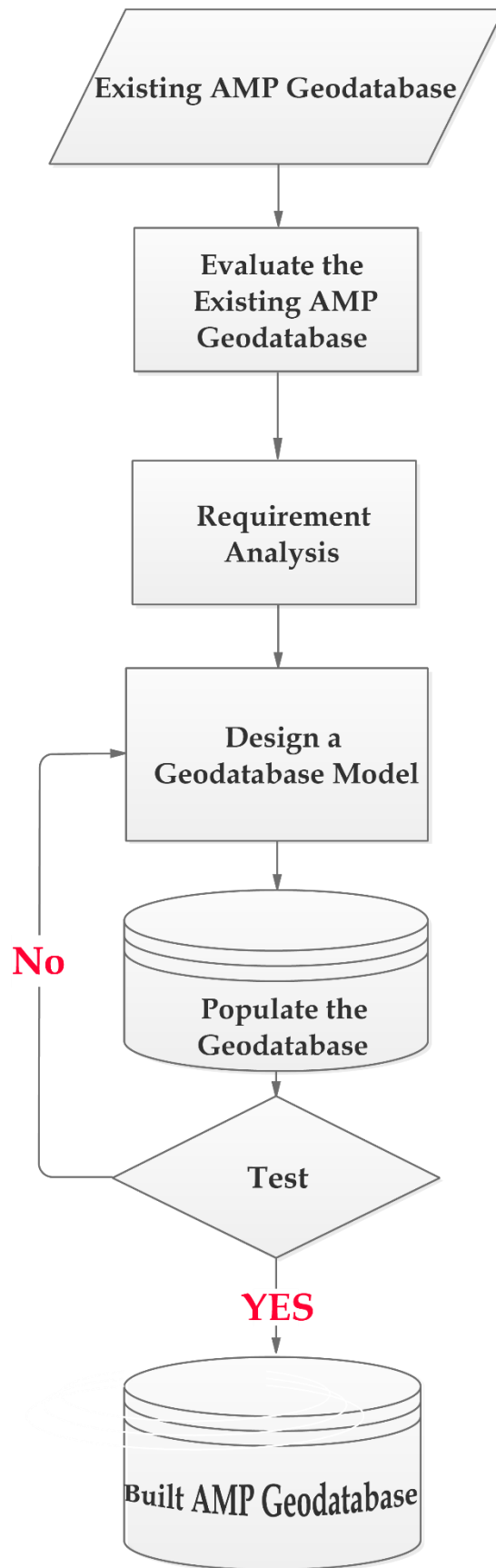


FIGURE 3.6 : GENERAL METHOD OF THE STUDY

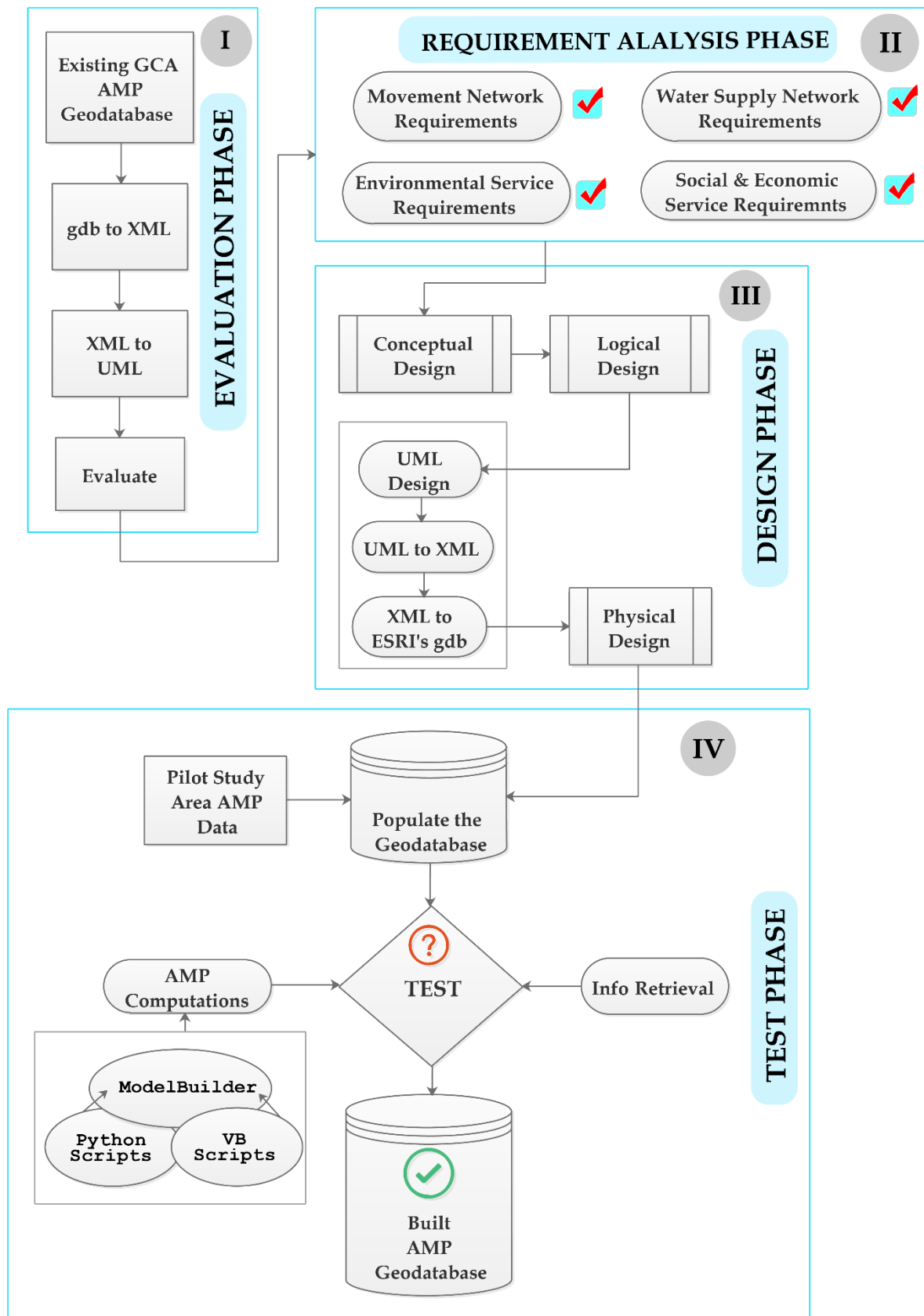


FIGURE 3.7: WORKFLOW OF THE STUDY

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter focuses on describing the overall results and discussions of the evaluation, requirement analysis, and designing of the AMP geodatabase. In the first section, the results from the evaluation of the GCA geodatabase are presented. For issues, which are presented as drawback of the current geodatabase design, the study analyzes the AMP geodatabase requirements so as to how a particular issue can be resolved. Based on the requirement analysis the conceptual, logical and physical design of the AMP geodatabase presented. Next, the study built the designed geodatabase for the selected three sub cities and tests its functionality by AMP computations and information retrieval. Finally, the study results will discuss by examining the initial problems faced by the GCA AMP geodatabase, followed by the designed geodatabase is discussed to identify how results of the model were formed, and how the goals were reached.

4.2 Results

4.2.1 Evaluation of the GCA AMP Geodatabase

Selections of data models, validation rules and attribute formations have direct correlation with the performance of data storing, integrity and retrieval in the geodatabase (ESRI, 2012). Therefore, prior to developing the model AMP geodatabase, the existing GCA AMP geodatabase were assessed by descriptive approach using the imported existing AMP geodatabase XML schema into UML diagrams. Evaluation of the existing GCA AMP geodatabase is conducted via standard geodatabase design requirements (ESRI, 2018) and AMP manual geodatabase design requirements (MUDHCo, 2016). This assessment of the geodatabase could help to identify the existing issues regarding to (1) data modeling - the structure of existing AMP geodatabase data models, (2) attribute validation scheme - validation rules in the existing attributes, and (3) attribute formation – the structure of existing attributes. In the following sub sections, each assessment results are presented as per the four strategic activity area of the AMP.

4.2.1.1 Evaluation of Data Modeling

One of the major factor to increase the performance of the geodatabase is representing a variety of real-world objects as a subset of features in a given feature class instead of creating new for each object (ESRI, 2018). Based on this (ESRI's) standard data modeling technique the GCA AMP geodatabase data models were evaluated. To evaluate the GCA data models the study first counted the GCA geodatabase Feature Classes (FCs) UML diagrams, then the counted feature classes were compared with the number of possible required feature classes of the standard data modeling techniques. The assessment result is presented as per each AMP SAA in the following Table 4.1, the detail data model evaluation result is attached in the Appendix B.

Table 4.1: Data Model Evaluation Result of the GCA AMP Geodatabase

SAA	Existing FCs	Possible Required FCs	Redundant FCs	Redundant FCs Percentage	Redundant FCs Distributions
Movement Network	12	4	8	67%	35%
Water Supply Network	4	3	1	25%	5%
Environmental Service	11	4	7	64%	30%
Social & Economical Service	10	3	7	70%	30%
Total	37	14	23	62%	100%

As the Table 4.1 shows, it was found that from thirty-seven feature classes of GCA geodatabases, about twenty-three (62%) of them found as redundant feature classes. From the total redundant feature class, about 35% belongs to Movement Network followed by Social & Economical Service that accounted 30 % of redundant feature class. The evaluation further revealed that Water Supply Network has the minimum share, which accounted 5% of redundant layer. On the other hand, from the ten feature classes of Social & Economical Service, about seven feature classes (70%) are found as redundant. The evaluation result implies there is a surplus of inappropriate feature class creation in the existing geodatabase. This leads the users to deal a great amount of time spend in retrieving and interpreting AMP data characteristics, accordingly the GCA AMP decisions efficiency is decreased.

4.2.1.2 Evaluation of Attribute Validation Scheme

Attribute information is the basis of geographic features as well as critical factors in developing an efficient AMP geodatabase (ESRI, 2018). They allow faster and easier object identification,

queries and retrieving. In relational database like ArcGIS, by defining validation rules the user could easily control the integrity of the new attribute data entered in the geodatabase. Attribute domains are one of the rules that describe the legal values of a field type, providing a method for enforcing data integrity (ESRI, 2018). Once the domain is created only coded domains are considered legal attribute values and to ensuring data consistency. In this study, the GCA geodatabase attribute validation scheme was examined by comparing the existing feature classes UML diagram of attribute validations against the required AMP attribute validations. The assessment results are presented as per each AMP SAA in the following Table 4.2, the detail attribute validation evaluation result is attached in the Appendix C.

Table 4.2 : Attribute Validation Evaluation Result of the GCA AMP Geodatabase

S/N	SAA	No of Required Attribute Validation	Existing Attribute Validation	Percentage
1	Movement Network	58	26	45%
2	Water Supply Network	14	0	0%
3	Environmental Service	56	7	13%
4	Social & Economical Service	87	7	8%
Total		215	40	19%

As the Table 4.2 shows, the evaluation results of the existing GCA AMP geodatabase revealed that from the total 215 required coded value attributes, only 40 attributes (19%) are properly assigned the coded value attributes, while from the total 87 Social & Economical Service required coded value attributes only 7 (8%) attributes have coded value attributes. The evaluation further revealed that the Water Supply Network SAA requires about 14 coded value attributes, unfortunately the no any coded value attributes in this SAA. The evaluation result implies that in existing GCA AMP geodatabase attributes are subjected to inconsistent attribute coding scheme. For example, as shown in Figure 4.1 B, a user code culvert condition field, as “VeryGood” whereas another uses “verygood” and the other also use “VEryGood” in the geodatabase all three-attribute codes are different, additional similar sample issues are shown in Figure 4.1 A (Culverts Road_Hierarchy field) & Figure 4.1 C (Primary_Schools Wall attribute). This problem causes the process of data queries or analysis to be highly dependent on manual editing.

A

Culverts	
Road_Hierarchy	
▶	Collector&local
	Collector&Local
	Collector&local
	Collector & Local Roads
	Collector & Local Roads
	Collector&local
	collector&Local
	Collector&local
	Collector&local
	Collector&local
	Collector&local

B

Culverts	
Condition	
	VeryGood
	VeryGood
	verygood
	verygood
	VEryGood
	VErYgood
	VeryGood
	Verygood
	Verygood
	Verygood
	VeryGood

C

Primary_Schools	
Wall	
	Masonry
	Masonry
	Masonry
	Masonry
	Masonry
	Maasonry

FIGURE 4.1: EXAMPLE OF INCONSISTENT ATTRIBUTE CODING SCHEME OF THE EXISTING (A & B) CULVERT AND (C) PRIMARY SCHOOL LAYERS

4.2.1.3 Evaluation of Attribute Formations

Defining the appropriate attributes is one of the major factor to increase the effectiveness of the geodatabase (Arctur D., et al., 2004). It should be precise and well defined, especially for large databases as AMP, because every information generated by the database will affect the decision making process of the GCA AMP. List of required attributes for each asset categories are described in different section of the AMP manual; unit of measurements (MUDHCo, 2016 p. 65), condition assessments (MUDHCo, 2016 pp. 83-86), maintenance rates (MUDHCo, 2016 p. 113) and list of fields for current replacement cost (MUDHCo, 2016 p. 121) are a few attributes of an asset to mention. The study examined each geodatabase feature class attributes against the AMP manual attribute specifications. Table 4.3 shows the evaluation of attribute formation results in terms of number of existing attributes against the number of redundant and missed attributes⁵, followed by example of redundant fields in asphalt road layer (FIGURE 4.2).

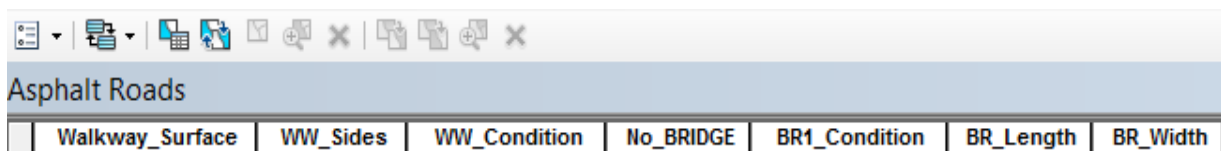
⁵ the detail redundant and missed attributes evaluation result is attached in the Appendix D

Table 4.3 : Attribute Assessment Result of the GCA AMP Geodatabase

SAA	No. of Existing Attributes	Redundant Attributes		Missed Attributes	
		No.	Percentage	No.	Percentage
Movement Network	460	180	39%	28	30%
Water Supply Network	66	0	0%	8	9%
Environmental Service	155	0	0%	16	17%
Social & Economical Service	159	0	0%	40	43%
Total	840			92	100%

As the Table 4.3 shows, the evaluation result revealed that about 92 attributes required by the AMP manual were missed in the GCA AMP geodatabase. Social & Economical Service has the maximum share which accounted 40 (43%) missed attributes followed by Movement Network which has a total missed attributes of 28 (30%) and while Environmental Service and Water Supply Network has a total missed attributes of 16 (17%) and 8 (9%) respectively. The evaluation further revealed that from 460 Movement Network attributes about 180 (39%) found as redundant. Fortunately, the remaining SAA does not have redundant attributes.

As shown in Table 4.3, about 92 required AMP attributes were missed in the existing GCA geodatabase this implies that the geodatabase is not meet the actual attribute requirements of the AMP manual, and this creates data variation problems throughout the AMP and unable to retrieve a correct information that will underpin the effective AMP decision-making processes of the GCA. The study also examined in this geodatabase, Movement Network features have about 39 % redundant fields⁶ as shown an example of asphalt road layer in Figure 4.2, this attribute redundancy also leads the GCA geodatabase to perform a lower processing speed and decreased there efficiency in the AMP decisions.



Asphalt Roads						
Walkway_Surface	WW_Sides	WW_Condition	No_BRIDGE	BR1_Condition	BR_Length	BR_Width

FIGURE 4.2 : EXAMPLE OF REDUNDANT ATTRIBUTE OF ASPHALT ROAD LAYER

⁶ this attribute fields are not defined by the AMP manual

4.2.1.4 Summary of the GCA AMP Geodatabase Evaluation

The study evaluations were focuses on the two major categories of a GIS data (i.e. spatial and tabular data). In the spatial data evaluation, the study evaluated the GCA AMP geodatabase spatial data modeling techniques. Unfortunately, the GCA AMP geodatabase spatial models tend to be too extensive; containing a surplus of redundant data. This lacks GIS data modeling has made it increasingly difficult to query and find data, update, or run AMP computations or reporting the city AMP using GIS as the primary geospatial tool. On the other hand, in the tabular data evaluation, the study were evaluated the GCA AMP geodatabase attribute formations and attribute validation scheme. The finding revealed that in the GCA geodatabase required AMP attributes were missed, and this implies that the geodatabase is not meet the actual attribute requirements of the AMP manual and creates data variation problems throughout the AMP and unable to retrieve a correct information that will underpin the effective AMP decision-making processes of the GCA. Moreover, the existing attributes are subjected to inconsistent attribute coding scheme. This attributes lack the organization and processing capabilities of the newer geodatabase functionality, and this problem causes the process of data storing and retrieving to be highly dependent on manual editing.

All of the above concerns ultimately tend to create more problems and deter GCA from the best use of the AMP geodatabase, regarding to create, update and query of the AMP data, leads the user to deal a great of time to spend in retrieving the required AMP information, and decreased the AMP decisions efficiency. In the next sections, the study outlined a set of requirement analysis, which is intended to design an effective AMP geodatabase based on the standard geodatabase specifications and AMP manual requirements, as well as to resolve the current problems outlined as the results of the existing AMP geodatabase assessment.

4.2.2 Requirement Analysis of AMP Geodatabase

In order to design an effective AMP geodatabase, as well as to solve the current problems outlined as the results of the existing AMP geodatabase evaluation, a set of requirements are outlined in this section. This requirement analysis of AMP geodatabase could help to identify the AMP manual required parameters of spatial and non-spatial geodatabase objects. This includes (1) define the spatial reference system, (2) linkage of assets to the GIS, (3) define the spatial data models, (4) allocating of features to feature dataset, (5) define the required AMP attributes, and finally (6) validation of attributes. Applying the requirement analysis will significantly avoid the data redundancy and attribute coding inconsistencies issues that presented in the existing geodatabase evaluation results; thus, a faster and easier data storage, validation, processing, retrieval and usage will be experienced in the geodatabase.

4.2.2.1 Define the Spatial Reference System

Before a geodatabase can be designed for the GCA AMP, the basic spatial geometry of the geodatabase must be reviewed. The spatial reference is the geographic information including the projection or coordinate system, and datum that the agency uses for mapping display. These geographic mapping elements will be addressed in this section.

The Asset Management Plan manual adopted Universal Transverse Mercator (UTM) grid throughout the ULGs (MUDHCo, 2016 p. 27). In this grid, the world is divided into 60 north-south zones, each covering a strip 6° wide in longitude. These zones are numbered consecutively beginning with Zone 1, between 180° and 174° west longitude, and progressing eastward to Zone 60, between 174° and 180° east longitude (USGS, 2001). Thus, Ethiopia covered by three UTM zones, from zone 36 on the west through zone 38 in east, specifically GCA located in zone 37 (Figure 4.3). In addition, the datum chosen for best results is the Clarke 1880 modified spheroid. This datum is necessary to account for the irregular shape of the earth's surface, or geode. Therefore, this study geodatabase design uses UTM grid specifically zone 37 projected coordinate system spatial reference for horizontal measurements with Clarke 1880 ellipsoid.

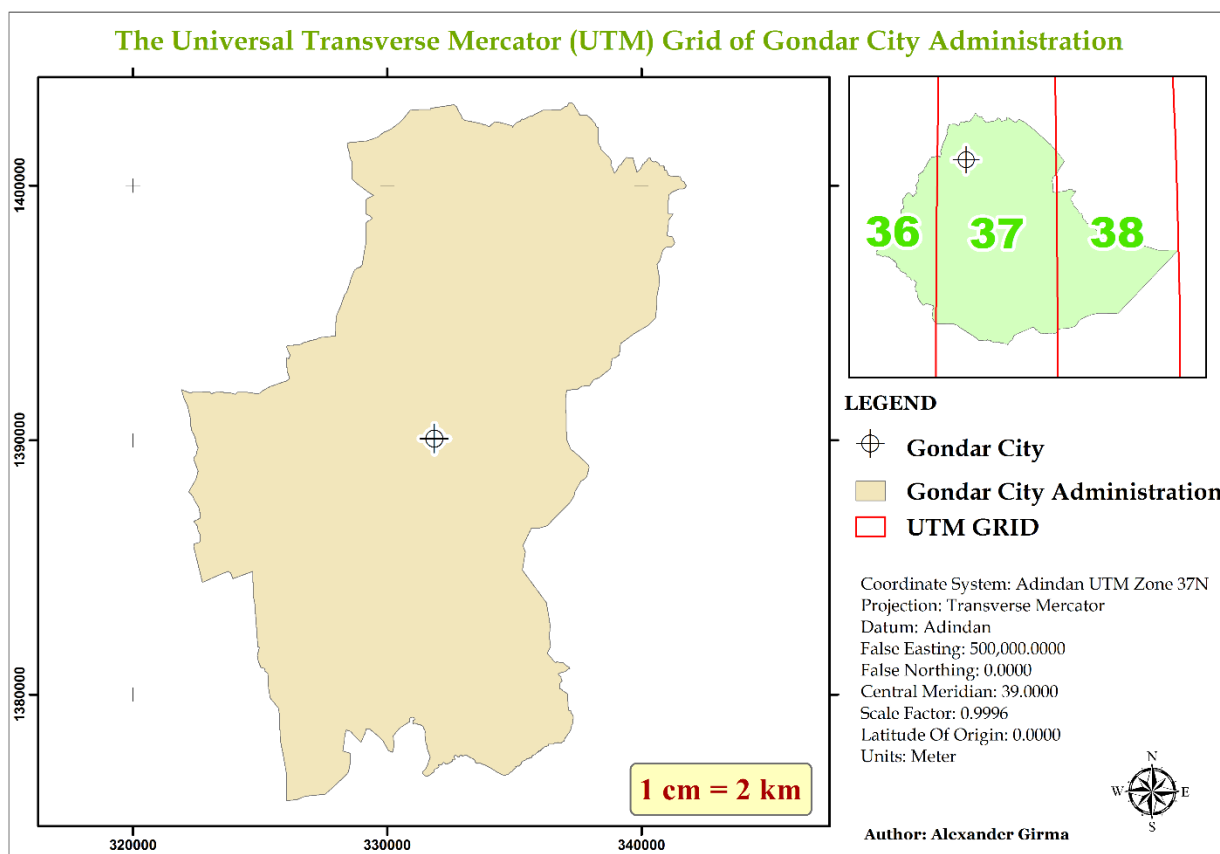


FIGURE 4.3: UTM GRID OF GONDAR CITY ADMINISTRATION

4.2.2.2 Linkage of Assets to the GIS Environment

As stated in the AMP manual, building the complete list of asset categories is different from one ULGs to another. The manual provides an example of a list of asset categories that could be associated with each of feature class in the AMP geodatabase (MUDHCo, 2016 p. 49). Although, if a ULGs has additional asset types that it has identified, then these should be added to its AMP geodatabase. Equally, it need not include asset types from this list that are not part of its own asset base (MUDHCo, 2016). Therefore, in this study, the selection of feature class/assets types depends on the existing asset inventory result data that are already exist in the GCA AMP geodatabase of 2010 EFY. As a result, the lists of asset categories/feature class included in this study are listed in Table 4.4 (Gondar, 2017).

Table 4.4 : List of feature classes in the existing GCA AMP geodatabase

S/N	Feature Class	S/N	Feature Class
1	Asphalt Road	20	Fence
2	Cobblestone Road	21	Administrative boundary
3	Gravel Road	22	Sub city boundary
4	Compacted Earth Road	23	Green Area
5	Large Block Stone	24	Park
6	Pedestrian Walkway Asphalt	25	Play Ground
7	Pedestrian Walkway Cobblestone	26	Terminals
8	Pedestrian Walkway Tiles	27	Communal Toilet
9	Pedestrian Walkway Precast	28	Public Bath
10	Round About	29	Schools
11	MSE Shade	30	Locations/Landmarks
12	Municipal Buildings	31	Public Toilet
13	Bridge	32	Health centre
14	Culvert	33	Transmission line
15	Road Median	34	Distribution lines
16	Drainage channel	35	Building and Facility
17	Manhole	36	Youth Centre Facility
18	Reservoir	37	Boreholes
19	Streetlights		

As the Table 4.4 shows, the study defined list asset categories of the existing GCA AMP geodatabase. The results revealed that there are a total of required 37 feature classes. Asphalt road, cobblestone road, drainage channel, bridge, culvert, streetlights, health center, schools water transmission line, boreholes etc. are a few to mention. In the next section, the study allocates the listed feature classes based on the standard vector spatial data models.

4.2.2.3 Define the Spatial Data Models

Once the list of asset linked to feature classes (Table 4.4), each feature class should be tested against the GIS vector data models to ensure that it comprises one of the three defined GIS data models. As the outcomes of the AMP are the vector data models; thus, these data must be represented with points, lines, and polygons considering the feature types indicating by the data. Table 4.5 shows the preferred spatial representation with percentage from the total layers.

Table 4.5 : The list of feature classes associated with their respective vector spatial data model

Point Feature	Line Feature	Polygon Feature
Manhole	Asphalt Road	Roundabout
Boreholes	Cobblestone Road	Administrative boundary
Bridge	Gravel Road	Sub city Boundary
Culvert	Compacted Earth Road	Building and facility
Locations/Landmarks	Large block Stone Road	MSE Shade
Public Toilet	Drainage Network	Municipal Buildings
Streetlights	Water Transmission line	Health Centre
Public Bath	Water Distribution lines	Youth Centre Facility
Reservoir	Fence	Green Area
Communal Toilet	Pedestrian Walkway Asphalt	Park
24%	Pedestrian Walkway Cobblestone	Play Ground
	Pedestrian Walkway Tiles	Terminals
	Pedestrian Walkway Precast	Schools
	34%	Road Median
		42%

As the Table 4.5 shows, the study spatial requirement analysis results revealed that from the required 37 spatial data models, polygon feature class has the maximum number, which accounted 14 (38%) followed by polyline feature class which has a total 13 (35%) feature class and while point feature class has a total 10 (27%) feature class. Point data models are used to represent singular, discrete features such as manholes, boreholes and toilets. Line data models are used to represent linear features such as roads, pedestrian walkway, water supply lines, and drainage channels. While polygon data models are used to represent such as buildings. This factor will highly support the advanced visualizing, identification, and cartographic results.

4.2.2.4 Allocating of Feature Dataset

In the AMP manual, all physical assets of a ULG are linked into four SAA, which includes; (1) The Movement Network (MN), (2) The Water Supply Network (WSN), (3) Environment Services (ES) and (4) Social and Economic Services (SES) (MUDHCo, 2016 p. 44). The allocation of the of defined spatial data models results in Table 4.5 are shown in Table 4.6 as per the four SAA feature dataset.

Table 4.6: Allocation of existing feature classes asper each SAA dataset

MN Dataset	WSN Dataset	ES Dataset	SES Dataset
Asphalt Road	Transmission line	Drainage Network	Building and facility
Cobblestone Road	Distribution lines	Manhole	MSE Shade
Gravel Road	Bore Holes	Public toilet	Municipal Buildings
Compacted Earth Road	Reservoir	Communal toilet	Health Centre
Large Block Stone Road	11%	Road Median	Admin Building
Bridge		Green Area	Fence
Culvert		Park	Youth Centre Facility
Asphalt Walkway		Play Ground	Terminals
Cobblestone Walkway		Public Bath	Schools
Precast Walkway		Roundabout	26%
Tiles Walkway		29%	
Streetlights			
34%			

As the Table 4.6 shows, the feature dataset requirement analysis results revealed that from the existing total feature classes, movement network dataset has the maximum number feature class, which accounted 34% followed by environmental service dataset, which has 29% feature classes. While social and economic service and water supply dataset has, 26% and 11% feature classes respectively. Linking physical asset categories to these SAA enables the GCA to make more informed about how to allocate their future capital investment, as well as to understand where their previous investment has been allocated (MUDHCo, 2016 p. 44)

4.2.2.5 Identify the Required AMP Attributes

In the AMP manual, feature class/asset attributes are defined in five Tabular Data Sets (TDS 1-5). The first dataset TDS 1 is all about physical characteristics of an asset. For example, in a road segment, this dataset requires surface material, width and construction period of the road. Whereas, TDS 2 is core component of the financial data set that contains a list of unit rates (costs) for each feature class of assets. TDS 3 is about for new asset works included in a ULGs plan for the future, which is not defined in the existing assets and beyond of this study scopes. The completion of the condition indicator of an asset is defined in TDS 4. The final dataset i.e. TDS 5 is describes about maintenance activities of an asset (MUDHCo, 2016 pp. 34-35). The attribute dataset example for the three data model types (point, line, and polygon) used for this study depicted in the Table 4.6 to 4.8 below.

Table 4.6: Example of attribute types for Point feature – Streetlight feature class

S/N	Attribute Name	S/N	Attribute Name
1	Auto ID (ObjectID) ^{TDS 1}	15	Total Replacement Cost ^{TDS 2}
2	Element Unique ID ^{TDS 1}	16	EUL (Expected Useful Life) ^{TDS 2}
3	X-Coordinate ^{TDS 1}	17	RUL (Remaining Useful Life) ^{TDS 2}
4	Y-Coordinate ^{TDS 1}	18	Percent RUL ^{TDS 2}
5	Construction Year ^{TDS 1}	19	Maintenance Deficit ^{TDS 2}
6	Streetlight Type ^{TDS 1}	20	Depreciated Replacement Cost ^{TDS 2}
7	Pole Material ^{TDS 1}	21	Asset Deficit ^{TDS 2}
8	Operation function ^{TDS 4}	22	Strategic Activity Area ^{TDS 1}
9	Condition ^{TDS 4}		
10	Maintenance rate ^{TDS 2}		
11	Maintenance Cost ^{TDS 5}		
12	Current Year ^{TDS 1}		
13	Age of Asset ^{TDS 1}		
14	Unit Replacement Cost ^{TDS 2}		

As the Table 4.6 shows, example of point feature attribute requirement analysis results revealed that from the required 22 attributes/fields, TDS 1 attributes has the maximum number, which accounted 10 (45%) followed by TDS 2 which has a total 9 (41%) attributes. While TDS 4 and TDS 5 attributes has a total 2 (9%) and 1 (5%) attributes respectively.

Table 4.7: Example of field types for Polygon - Building feature class

S/N	Attribute Name	S/N	Attribute Name
1	Auto ID (ObjectID) ^{TDS 1}	18	Maintenance rate ^{TDS 2}
2	Element Unique ID ^{TDS 1}	19	Maintenance Cost ^{TDS 5}
3	X-Coordinate of Centroid ^{TDS 1}	10	Current Year ^{TDS 1}
4	Y-Coordinate of Centroid ^{TDS 1}	21	Age of Asset ^{TDS 1}
5	Auto-generated Area ^{TDS 1}	22	Unit Replacement Cost ^{TDS 2}
6	Construction Year ^{TDS 1}	23	Total Replacement Cost ^{TDS 2}
7	Building Function ^{TDS 1}	24	EUL (Expected Useful Life) ^{TDS 2}
8	Foundation Material ^{TDS 1}	25	RUL (Remaining Useful Life) ^{TDS 2}
9	Foundation Condition ^{TDS 4}	26	Percent RUL ^{TDS 2}
10	Floor Material ^{TDS 1}	27	Maintenance Deficit ^{TDS 2}
11	Floor Condition ^{TDS 4}	28	Depreciated Replacement Cost ^{TDS 2}
12	Wall Material ^{TDS 1}	29	Asset Deficit ^{TDS 2}
13	Wall Condition ^{TDS 4}	30	Strategic Activity ^{TDS 1}
14	Roof Material ^{TDS 1}		
15	Roof Condition ^{TDS 4}		
16	Area ^{TDS 1}		
17	Structure Concatenation ^{TDS 1}		

As the Table 4.7 shows, example of polyline feature attribute requirement analysis results revealed that from the required 30 attributes/fields, TDS 1 attributes has the maximum number, which accounted 16 (53%) followed by TDS 2 which has a total 9 (30%) attributes. While TDS 4 and TDS 5 attributes has a total 4 (13%) and 1 (3%) attributes respectively.

Table 4.8 : Example of field types for Polyline – Road Network feature class

S/N	Attribute Name	S/N	Attribute Name
1	Auto ID (ObjectID) ^{TDS 1}	16	Condition ^{TDS 4}
2	Element Unique ID ^{TDS 1}	17	Maintenance rate ^{TDS 2}
3	X-Coordinate – start node ^{TDS 1}	18	Maintenance Cost ^{TDS 5}
4	Y-Coordinate – start node ^{TDS 1}	19	Current Year ^{TDS 1}
5	X-Coordinate – end node ^{TDS 1}	20	Age of Asset ^{TDS 1}
6	Y-Coordinate – end node ^{TDS 1}	21	Unit Replacement Cost ^{TDS 2}
7	Auto-generated Length ^{TDS 1}	22	Total Replacement Cost ^{TDS 2}
8	Start node reference ^{TDS 1}	23	EUL (Expected Useful Life) ^{TDS 2}
9	End node reference ^{TDS 1}	24	RUL (Remaining Useful Life) ^{TDS 2}
10	Construction Year ^{TDS 1}	25	Percent RUL ^{TDS 2}
11	Surface Type ^{TDS 1}	26	Maintenance Deficit ^{TDS 2}
12	Width ^{TDS 1}	27	Depreciated Replacement Cost ^{TDS 2}
13	Area ^{TDS 1}	28	Asset Deficit ^{TDS 2}
14	Deterioration type ^{TDS 4}	22	Strategic Activity Area ^{TDS 1}
15	Deterioration Area ^{TDS 4}		

4.2.2.6 Validation of Attributes

As this study previously presented in the evaluating section of attribute validation schemes the existing attribute coding schemes are inconsistent (Table 4.2). To overcome this problem this study proposed one of the attribute validating rules called as coded value attribute domains. Attribute domains are one of the validation rules that describe the legal values of a field type that provides a method for enforcing data integrity and prevent mistakes when the user apply a value to an attribute.

The study validates the required attribute fields for the entire feature class's as per there SAA. Domain codes used for attribute validation are adapted from the AMP manual coding scheme (MUDHCo, 2016 p. 60), which is attached in the Appendix E. However, due to similarity of some domain codes the two alphabetical coding scheme is changed into three alphabetical scheme. In the Table 4.9 below example of the coded value domains for Road Surface Material, Streetlight Type, and General Condition are shown.

Table 4.9: Example of Coded Value Domain of Road Surface, Streetlight Type and General Condition

Attribute/Field Name	Domain Code	Description
Road Surface Material	ASR	Asphalt Road
	CBR	Cobblestone Road
	GRR	Gravel Road
	CER	Compacted Earth Road
	LBR	Large Block Stone
Streetlight Type	HPS	High-Pressure Sodium
	FLO	Florescent
	INC	Incandescent
General Condition	VRG	Very Good
	GUD	Good
	MOD	Moderate
	POR	Poor
	VPO	Very Poor

As shown in Table 4.9, to increase the accuracy of data entry of the AMP geodatabase, coded value attribute domains are assigned for necessary feature attributes. Suppose a road network has surface material field has one of the five material types domain code i.e. ASR (Asphalt Road), CBR (Cobblestone Road), GRR (Gravel Road) CER (Compacted Earth Road), and LBR (Large Block Stone). The same concept works for Streetlight Type and General Condition attribute fields. Within this study geodatabase design, about forty-eight coded value attribute domains are created to establish this geodatabase design, the remaining coded value domains are attached in the Appendix F.

4.2.2.7 Summary of the GCA AMP Geodatabase Requirement Analysis

Prior to develop the AMP geodatabase model, the GCA existing AMP geodatabase were analyzed to identify the spatial model redundancy, attribute coding inconsistency, and attribute creation problems. After identifying the existing problems in the GCA geodatabase, the requirements analyses were specified to resolve the current problems then to optimize the AMP geospatial processes in the geodatabase. The requirement analysis began by specifying the parameters of the spatial reference system used for mapping; The UTM grid projection was reviewed based on its requirements by the GCA AMP, the datum also discussed. List of asset categories/feature class included in the study also specified, and allocated based on the three point, line, and polygon data models. Following, the feature classes are assigned into the four AMP SAA datasets. Moreover, the requirement analysis also investigated the required five tabular datasets (TDS1 – TDS5) of the AMP manual. Finally, the study validated the required attribute fields based on the AMP manual attribute-coding scheme. Based on the specified requirement analysis the next section of the study will demonstrate the conceptual, logical and physical design phase of the AMP geodatabase model.

4.2.3 Design Phases of the AMP Geodatabase Model

The fundamental principles behind planning a successful GIS are based on an attempt to discover its real purpose, and decide what output and information is needed (Tomlinson, 2007). The research and design of a geodatabase is a critical stage in ensuring its effectiveness and proficiency. If the design is incorrectly implemented, as the current experience of GCA the organization's GIS will not function to its full potential, essentially creating problems for the users. Intuitive

The main theoretical approaches within this study is to develop a proficient geodatabase model design to accommodate the AMP data needs of the GCA, while using all necessary geodatabase functionality. Therefore, this section outlines the conceptual design phase addresses the research conducted, and the logical and physical design phase illustrates the resulting to create a comprehensive AMP geodatabase model.

The AMP geodatabase conceptual, logical and physical design phase results are presented based on the four Strategic Activity Area (SAA) of the AMP including Movement Network, Water Supply Network, Environmental Service, and Social and Economical Service. In the next section, SAA the study presented the conceptual entirety design of the AMP geodatabase, followed by the logical and physical design of the AMP geodatabase.

4.2.3.1 Conceptual Design Phase of the AMP Geodatabase

The conceptual phase examines the research component of the AMP geodatabase, which includes (1) Data requirements of the AMP and (2) Define AMP geographic data entities & representation. In the following sub sections, the two conceptual design elements will be discussed for the four AMP SAA datasets (i.e. The Movement Network, The Water Supply Network, Environmental Service, and Social and Economic Service).

4.2.3.1.1 Data Requirements of the AMP

This step in the conceptual phase studies the needs of AMP. This is basically a needs assessment, the foundation of any effective geodatabase model. A needs assessment is the process required to evaluate the needs and requirements of the GIS system. The four AMP SAA will be examine by using their asset descriptions of the AMP manual requirements, as well as the available asset categories data of the GCA AMP geodatabase. The ultimate objective of the AMP is to analyze the extent of ULGs physical assets, to assess the current

physical condition, to allocate maintenance budgets for deteriorated assets, and to estimate the current economic value of the existing physical assets under the control of the ULGs.

The Movement Network (MN) SAA dataset first group comprises those assets directly associated with movement network. This includes all type road network, footpaths, and cycle path. The second group includes structures that are associated with the movement network, comprising bridge, culverts, retaining walls, tunnel, road furniture and streetlights on the ULGs AMP (MUDHCo, 2016 p. 86). On the other hand, the GCA AMP report (2017) revealed that the city inventory was conducted only road network, footpaths, streetlights, and road structures (bridge and culverts) (Gondar, 2017). Therefore, in this study the data category selection of the MN SAA dataset is depend on the GCA MN asset inventory of 2017, and two additional geodatabase tables (object classes). That includes all types of road network, footpaths, streetlights, road structures, maintenance rate table, and replacement table. The conceptual diagram of the Movement Network SAA dataset is illustrated in the following Figure 4.4.

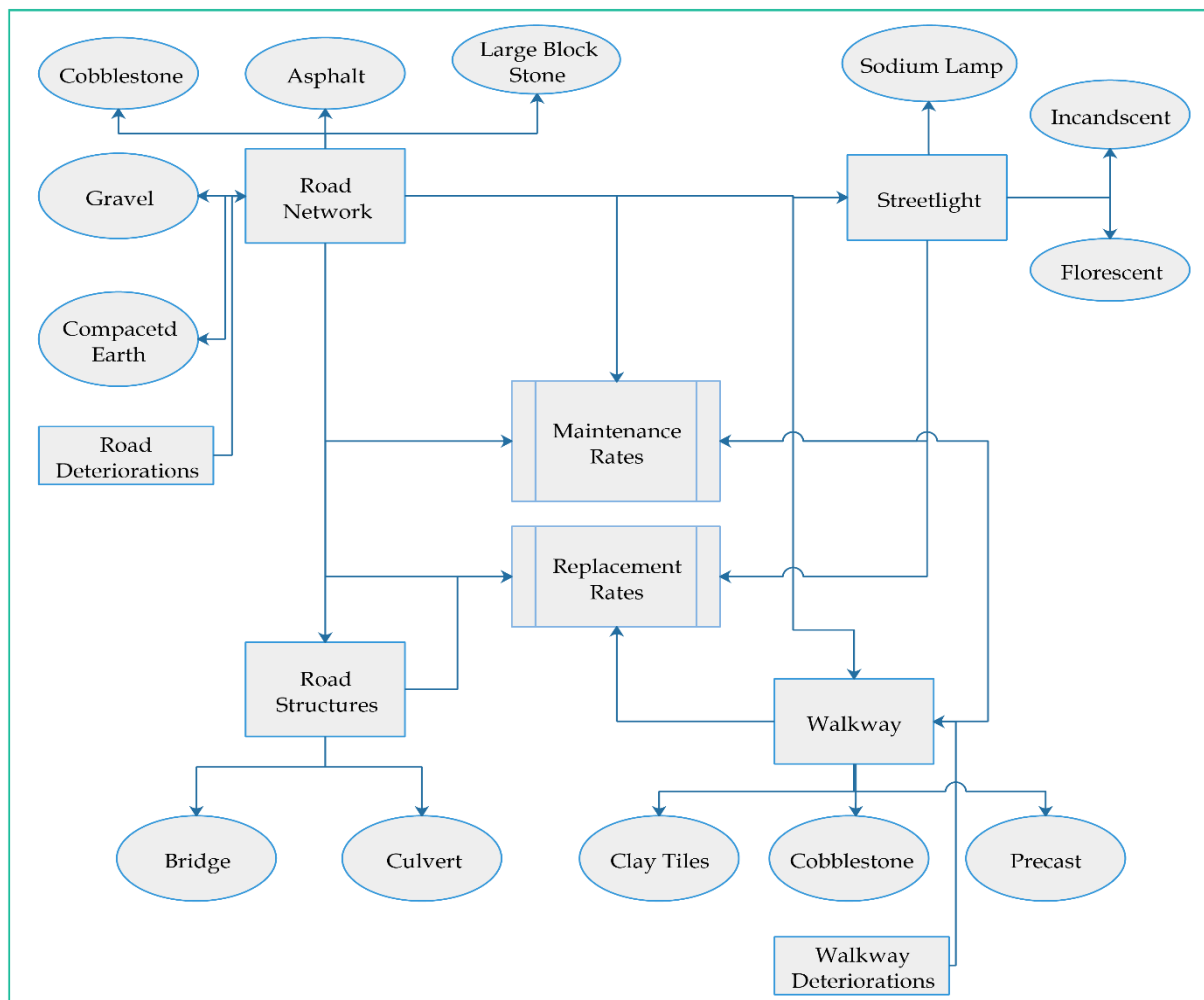


FIGURE 4.4: CONCEPTUAL DIAGRAM OF THE MOVEMENT NETWORK SAA DATASET

The Water Supply Network (WSN) SAA dataset is mainly comprises production of water at the source, transmission of water to reservoirs and distribution to customers. The major assets being used for provision of the water supply service includes water pipe line, reservoir, pumps, valves, boreholes/wells, water taps, collection chambers, and springs (MUDHCo, 2016). However, according to the GCA AMP (2017), the city inventory was conducts only for water distribution and transmission pipelines, reservoir and boreholes (Gondar, 2017). In this study the data category selection of the WSN SAA dataset is depend on the GCA WSN asset inventory of 2017, and two additional geodatabase tables (object classes). That comprises water distribution and transmission pipelines, reservoir, boreholes, maintenance rate table, and replacement table. The conceptual diagram of the Water Supply Network SAA dataset is illustrated in the following Figure 4.5.

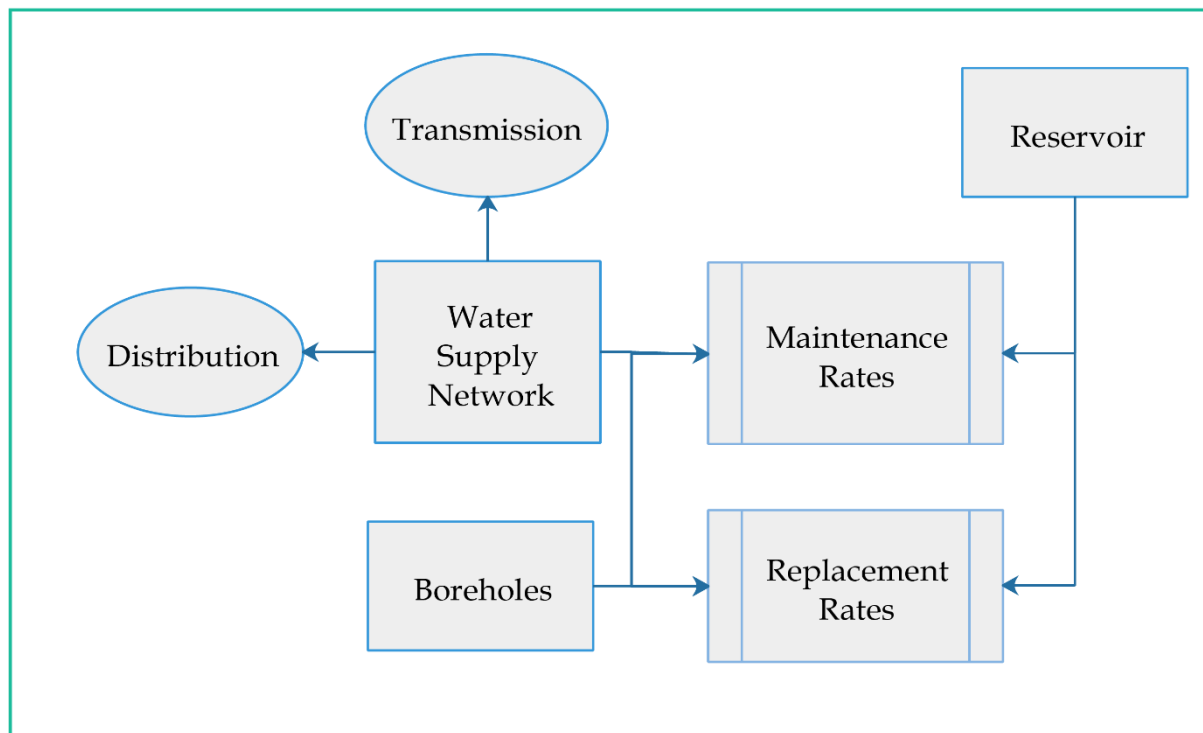


FIGURE 4.5: CONCEPTUAL DIAGRAM OF THE WATER SUPPLY NETWORK SAA DATASET

Environmental Service (ES) SAA dataset is primarily comprises environmental infrastructure asset components. According to the AMP manual, the major assets being used for provision of the environmental service includes urban drainage, public toilets, communal toilet, public bath, liquid waste, solid waste, urban greenery, parks, play grounds, road median, roundabouts, rivers, wetlands and natural areas (MUDHCo, 2016). However, the GCA AMP (2017) report revealed that the city inventory was conducts only for urban drainage, public toilets, communal toilet, public bath, greenery, parks, road median, roundabouts and playgrounds (Gondar, 2017). Accordingly, in this study the data category selection of the ES SAA dataset is depend on the GCA ES asset inventory of 2017, and two additional geodatabase tables (object classes). That comprises urban drainage, public toilets, communal toilet, public bath, greenery, parks, road median, roundabouts, playgrounds, maintenance rate table, and replacement table. The conceptual diagram of the Environmental Service SAA dataset is illustrated in the following Figure 4.6.

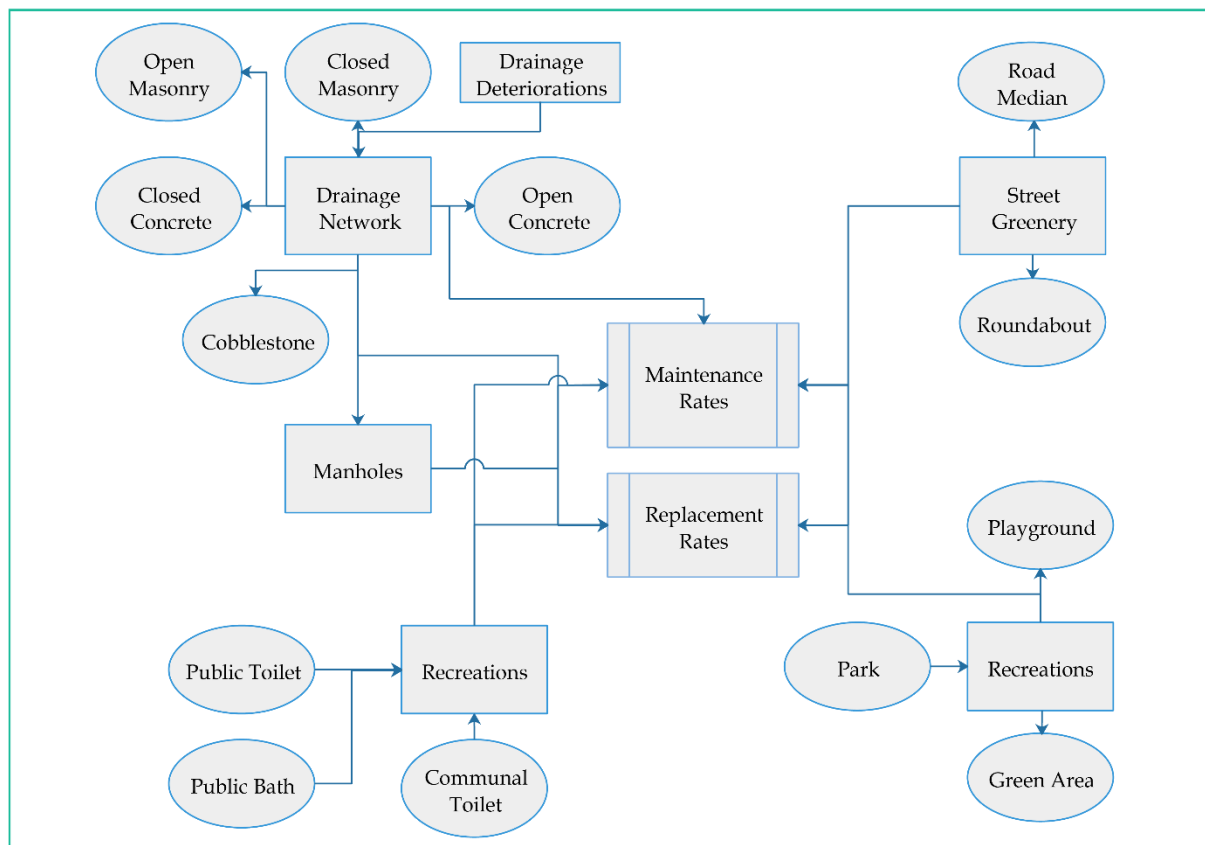


FIGURE 4.6: CONCEPTUAL DIAGRAM OF THE ENVIRONMENTAL SERVICE SAA DATASET

Social and Economic Service (SES) SAA dataset is typically comprises building asset infrastructures. According to the AMP manual, the major assets being used for provision of SES includes Abattoirs, Municipal markets, MSE facilities, Fire Station, Schools, Health Clinics, and Youth Centers. On the other hand, the GCA AMP (2017) report revealed that the city inventory was conducts for health services, educational institute, housing facility, administrative buildings, youth center, and MSE shades (Gondar, 2017). In this study, the asset category selection of the SES SAA dataset depends on the GCA SES asset inventory of 2017, and two additional geodatabase tables (object classes). That includes health services, educational institute, housing facility, administrative buildings, youth center, MSE shades, maintenance rate table, and replacement table. The conceptual diagram of the Social and Economic Service SAA dataset is illustrated in the following Figure 4.7.

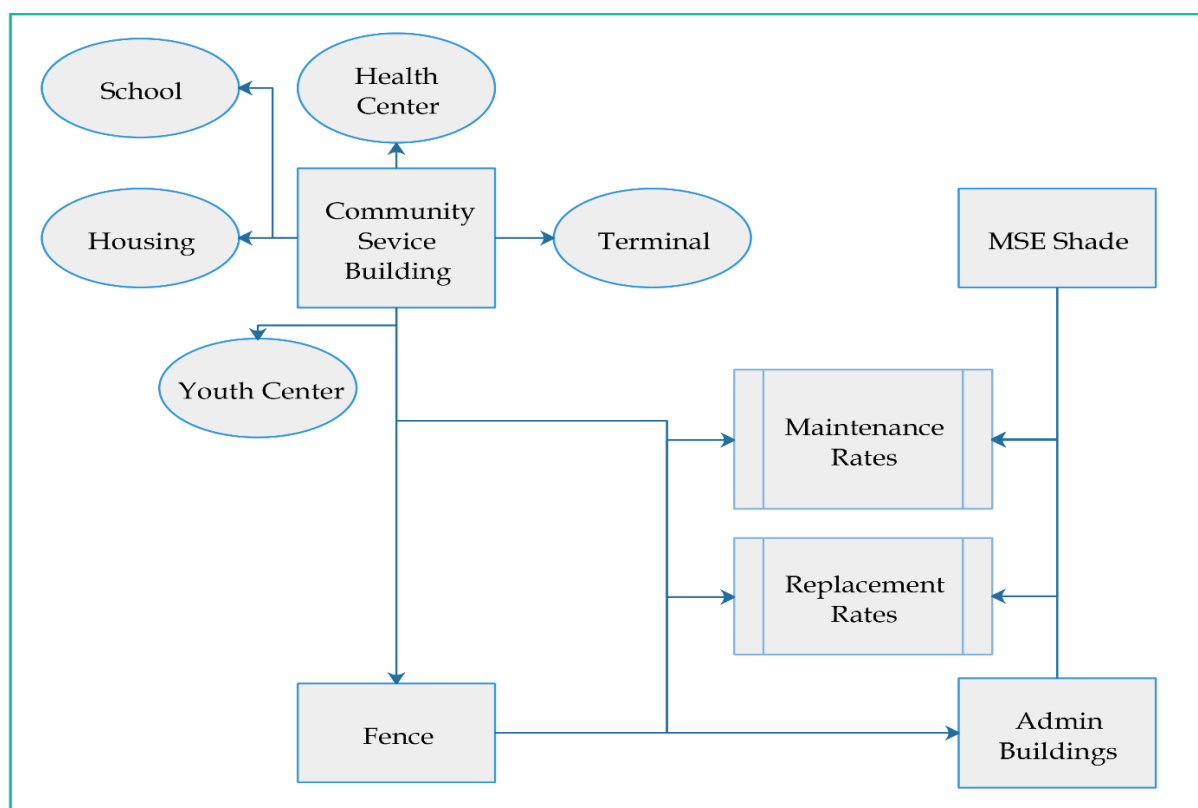


FIGURE 4.7: CONCEPTUAL DIAGRAM OF THE SOCIAL AND ECONOMIC SERVICE SAA DATASET

The data requirement of the conceptual design section begins by data requirement and conceptual diagram of the movement network dataset, and completed with the conceptual diagram of social and economic service. Next, AMP geographic data entities and representation illustrated.

4.2.3.1.2 Define AMP Geographic Data Entities & Representation

The purpose of this stage of the conceptual phase is to identify and group the key geographic entities required to accomplish the GCA AMP. This step defining the geographic data entities requires a transformation from the ideas and needs into the creation of concrete feature classes or object classes. The geographic entities are broken down further in this stage to represent points, lines, polygons, or tables (object classes). The objective of this phase is to determine how data is grouped and represented in the geodatabase model by classifying entities according to their type of representation.

As this study presents in the previous section, the Movement Network SAA dataset includes road network, streetlights, bridge, and culverts categories. In the GCA AMP, based on the AMP manual (MUDHCo, 2016 p. 126), the road network asset category divided into a set of operational function sub-categories, which includes Asphalt, Cobblestone, Gravel, Large block stone, and Compacted earth roads. While footpaths asset category divided into Asphalt, Cobblestone, Precast, Tiles walkways. Streetlights, Bridge, and Culverts asset categories are not divided into further operational functions.

The list of Movement Network SAA dataset geographic data entities & there representation, which is developed from the study requirement analysis result (Table 4.6) shown in the Table 4.10 below.

Table 4.10: Geographic data entities & representation of the Movement Network dataset

Layer	Data Model		
	Point	Polyline	Object Class (Table)
Streetlights	✓		
Culverts	✓		
Bridge	✓		
Road Node	✓		
Walkway Node	✓		
Road Deterioration	✓		
Walkway Deterioration	✓		
Asphalt road		✓	
Cobblestone road		✓	
Gravel road		✓	
Compacted earth road		✓	
Large Block Stone Road		✓	
Asphalt Walkway		✓	
Cobblestone Walkway		✓	
Precast Walkway		✓	
Tiles Walkway		✓	
Movement Maintenance Rates			✓
Movement Replacement Rates			✓

As shown in the above Table 4.10, the study presents the Movement Network SAA dataset geographic data entities & there representation. Next, the study presents the Water Supply Network dataset geographic data entities & there representation, which is developed from the study requirement analysis result (Table 4.6) that includes transmission network, distribution network, reservoir, and borehole are shown in the Table 4.11 below.

Table 4.11: Geographic data entities & representation of the Water Supply Network dataset

Layer	Data Model		
	Point	Polyline	Object Class
Transmission Network		✓	
Distribution Network		✓	
Pipe Node		✓	
Reservoir	✓		
Borehole	✓		
Water Supply Maintenance Rates			✓
Water Supply Replacement Rates			✓

As shown in the above Table 4.11, the study presents the Water Supply Network dataset geographic data entities & there representation. Following, the study presents the Environmental Service SAA dataset geographic data entities & there representation. It includes urban drainage, public toilets, communal toilet, public bath, greenery, parks, road median, roundabouts and playgrounds categories. In the GCA AMP, based on the AMP manual (MUDHCo, 2016 p. 126), the urban drainage asset category divided into a set of operational function sub-categories, which includes Cobblestone drain, Open Concrete and Closed Concrete Lined Drain, Open Masonry Drain, and Closed Masonry Drain.

The list of Environmental Service SAA dataset geographic data entities & there representation, which is developed from the study requirement analysis result (Table 4.6) are shown in the Table 4.12 below.

Table 4.12 : Geographic data entities & representation of Environmental Service dataset

Layer	Data Model			Layer	Data Model			
	Point	Polyline	Polygon		Point	Polyline	Polygon	Object Class
Cobblestone Lined Drain		✓		Public Toilet	✓			
Open Concrete Lined Drain		✓		Public Bath	✓			
Closed Concrete Lined Drain		✓		Play Ground			✓	
Open Masonry Drain		✓		Park			✓	
Closed Masonry Drain		✓		Green Area			✓	
Road Median			✓	Manhole	✓			
Roundabout			✓	Drainage Deterioration	✓			
Drainage Node	✓			Environmental Maintenance Rates				✓
Communal Toilet	✓			Environmental Replacement Rates				✓

As shown in the above Table 4.12, the study presents the Environmental Service SAA dataset geographic data entities & there representation. Next, the study presents the remaining AMP SAA i.e. Social and Economic Service dataset geographic data entities & there representation, which is developed from this study requirement analysis result (Table 4.6) that includes building and facility, Health Centre, Admin Building, Youth Centre, Terminals, Schools, Fence are shown in the Table 4.13 below.

Table 4.13: Geographic data entities & representation of Social and Economic Service dataset

Layer	Data Model			
	Point	Polyline	Polygon	Object Class
School			✓	
Youth Center			✓	
Health Center			✓	
Terminal			✓	
Housing facility			✓	
MSE shade			✓	
Fence			✓	
Administration Buildings			✓	
SocialReplacementRates				✓
SocialMaintenanceRates				✓

As shown in the above Table 4.13, the study presents the Social and Economic Service SAA dataset geographic data entities & there representation. These two stages (model the AMP data and define AMP geographic data entities & representation) are developed simultaneously for each AMP SAA datasets, and included in the conceptual section under each AMP SAA datasets. The conceptual research section begins by researching the AMP SAA dataset requirements, and completed with a list of the basic GIS datasets necessary to reach their goals. In the following section, the study will present the logical design phase of the AMP geodatabase.

4.2.3.2 Logical Design Phase of the AMP Geodatabase

The logical phase illustrates the complexity of the geodatabase including all design elements required to establish a proficient geodatabase. All design elements are based on the previously determined data needs described in the conceptual phase of design. In this phase, the study defines the spatial and non-spatial behaviors of the feature classes and object classes in terms of data types, record length, field descriptions, subtypes, domains, and relationships are examined in further detailed.

In this study, the requirements for each AMP SAA are further discussed and broken down in to their individual logical phase database components are illustrates in terms of (1) Data structure, (2) Data specifications, and (3) Relationship properties.

4.2.3.2.1 Data Structure of the AMP Geodatabase

The geographic data entities & representation of the AMP SAA are defined in the conceptual phase. The next step is to add a special attribute called a subtype for the attributes of feature classes. Subtypes can be applied for feature classes and used for major geometrically groupings of objects to increase the performance of the geodatabase by representing a variety of real-world objects as a subset of features in a given feature class instead of creating new feature classes for each object (ESRI, 2018).

In this study, by using subtypes the GCA road network varieties (asphalt, cobblestone, gravel, large block stone and compacted earth roads) geometrically modeled in a single feature class that will enforce data integrity specifically for each subtype and it avoids of creating new future classes for each road types. The same concept will work for pedestrian walkway, road structures and streetlights. The detail of feature and object classes with their subtype in the Movement Network SAA dataset is depicted in Table 4.14 below.

Table 4.14 : Feature classes and Subtypes of the Movement Network SAA dataset

S/N	Feature class/Object class	Subtype
1	RoadNetwork	1. Asphalt Road 2. Cobblestone Road 3. Gravel Road 4. Large Block Stone Road 5. Compacted Earth
2	PedestrianWalkway	1. Asphalt walkway 2. Cobblestone walkway 3. Clay Tile walkway 4. Precast walkway
3	Streetlight	1. High-Pressure Sodium 2. Florescent 3. Incandescent
4	RoadStructures	1. Culvert 2. Bridge
5	RoadNode	No subtype
6	WalkwayNode	No subtype
7	RoadDeteriorations	No subtype
8	WalkwayDeteriorations	No subtype
9	MovementMaintenanceRates	No subtype
10	MovementReplacementRates	No subtype

As shown in the above Table 4.14, the Movement Network SAA dataset feature classes with corresponding subtypes presented. RoadNetwork feature class has five selection types of subtypes. The subtype permits the selection of five separate coded value domain behaviors of RoadNetwork types. The subtype selections are: 1. Asphalt Road, 2. Cobblestone Road, 3. Gravel Road, 4. Large Block Stone Road, and 5. Compacted Earth. While PedestrianWalkway subtype selections are: 1. Asphalt walkway, 2. Cobblestone walkway 3. Clay Tile walkway, and 4. Precast walkway. In Movement Network SAA dataset, it is unnecessary to define subtypes for RoadNode, WalkwayNode, RoadDeteriorations, and WalkwayDeteriorations feature classes.

In the Water Supply Network (WSN) SAA dataset by using subtypes the GCA water supply network pipe varieties (transmission and distribution) geometrically modeled in a single feature class. The following Table 4.15 shows the WSN SAA dataset feature/object classes and subtypes.

Table 4.15 : Feature classes and Subtypes of the Water Supply Network SAA dataset

S/N	Feature class/Object class	Subtypes
1	WaterSupplyNetwork	1. Transmission Network 2. Distribution Network
2	PipeNode	No subtype
3	Reservoir	No subtype
4	Borehole	No subtype
5	WaterSupplyMaintenanceRates	No subtype
6	WaterSupplyReplacementRates	No subtype

As shown in the Table 4.15, in the Water Supply Network SAA dataset, WaterSupplyNetwork feature class has two subtypes (Transmission Network and Distribution Network). The subtype selections are: 1. Transmission Network and 2. Distribution Network. In Water Supply Network SAA dataset, it is unnecessary to define subtypes for PipeNode, Reservoir, and Borehole feature classes.

In the above two Tables (4.14 & 4.15) the study presented the Movement Network and the Water Supply Network SAA dataset feature classes and subtypes. The following Table 4.16 shows the Environmental Service SAA dataset feature classes and subtypes, followed by the Social and Economic Service SAA dataset feature classes and subtypes (Table 4.17).

Table 4.16 : Feature classes and Subtypes of Environmental Service SAA dataset

S/N	Feature Class/Object class	Subtypes
1	DrainageNetwork	1. Cobblestone Lined Drain 2. Open Concrete Lined Drain 3. Closed Concrete Lined Drain 4. Open Masonry Drain 5. Closed Masonry Drain
2	Sanitation	1. Communal Toilet 2. Public Toilet 3. Public Bath
3	StreetGreenery	1. Road Median 2. Roundabout
4	Recreations	1. Play Ground 2. Park 3. Green Area
5	Manhole	No subtype
6	DrainageNode	No subtype
7	DrainageDeteriorations	No subtype
8	EnvironmentalMaintenanceRates	No subtype
9	EnvironmentalReplacementRates	No subtype

As shown in the above Table 4.16, Environmental Service SAA dataset feature classes with corresponding subtypes are presented. DrainageNetwork feature class has five selection types of subtypes. The subtype permits the selection of five separate coded value domain behaviors of DrainageNetwork types. The subtype selections are: 1. Cobblestone Lined Drain, 2. Open Concrete Lined Drain, 3. Closed Concrete Lined Drain, 4. Open Masonry Drain, and 5. Closed Masonry Drain. In Environmental Service SAA dataset, it is unnecessary to define subtypes for Manhole, DrainageNode, and DrainageDeteriorations feature classes.

Table 4.17 : Feature classes and Subtypes of Social and Economic Service SAA dataset

S/N	Feature Class/Object classes	Subtypes
1	CommunityServiceBuildings	1. School 2. Terminal 3. Youth Center 4. Health Center 5. Housing Facility
2	MSEShade	No subtype
3	Fence	No subtype
4	AdministrationBuildings	No subtype
5	SocialReplacementRates	No subtype
6	SocialMaintenanceRates	No subtype

As shown in the Table 4.17, Social and Economic Service SAA dataset feature classes with corresponding subtypes are presented. CommunityServiceBuildings feature class has five selection types of subtypes. The subtype permits the selection of five separate coded value domain behaviors of CommunityServiceBuildings types. The subtype selections are: 1. School, 2. Terminal, 3. Youth Center, 4. Health Center, and 5. Housing Facility. In Social and Economic Service SAA dataset, it is unnecessary to define subtypes for MSEShade, AdministrationBuildings, and AdministrationBuildings feature classes.

The data structure of the AMP geodatabase section begins by defining the Movement Network SAA dataset data structures requirements, and concludes with Social and Economic Service SAA dataset data structures requirements necessary to reach their goals. In the next section, the study will illustrate data specification of each AMP geodatabase elements.

4.2.3.2.2 Data Specifications of AMP Geodatabase

In this section, the study examines the spatial and non-spatial data specifications of the feature classes and object classes in terms of field name, data types, record length, domains, and field descriptions of each AMP SAA datasets.

The Movement Network (MN) SAA dataset contains eight feature classes (RoadNetwork, RoadNode, RoadDeteriorations, PedestrianWalkway, WalkwayNode, WalkwayDeteriorations, Streetlight, and RoadStructures) and two object classes (MovementMaintenanceRates and MovementReplacementRates) (Table 4.14). Each feature class and object class data specification in terms of field name, data types, record length, domains, and field descriptions of the Movement Network SAA dataset presented below, followed by the Water Supply Network, Environmental Service, and Social and Economic Service SAA datasets.

MN-RoadNetwork Feature Class

The RoadNetwork feature class is a polyline layer with five subtypes to represent all types road in the GCA, its tabular database choices develop from the study requirement analysis results (Table 4.8), which is based on the AMP manual specifications. The detail data specification of RoadNetwork feature class is defined in the Table 4.18 below.

Table 4.18: RoadNetwork feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polyline (Default)
Age	Integer	3	---	Age of Road
AssetDeficit	Double	---	---	Asset Deficit
Carriage Width	Double	---	---	Carriage Width
<u>RoadType</u> ⁷	Integer	---	---	Road Type
Condition	String	15	GeneralCondition	Road Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
DP	Double	---	---	Deterioration Percentage
EQL7mkm	Double	---	---	Equivalent Length in 7m width (km)
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
NodeStart	String	7	---	Start Node
NodeEnd	String	7	---	End Node
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
RH	String	20	RoadHierarchy	Road Hierarchy
RouteID	String	7	---	Route ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
SurfaceArea	Double	---	---	road surface area
TDA	Double	---	---	Total Deterioration Area
TMC	Double	---	---	Total Maintenance Cost

⁷ underline represent Key attributes

MN-RoadNode Feature Class

The RoadNode feature class is a point layer to represent starting and ending junction of road segment, its tabular database includes local location name, X and Y Coordinate of Node. The detail data specification of RoadNode feature class is defined in the Table 4.19 below.

Table 4.19: RoadNode feature class data specifications

Field Name	Data Type	Length	Domain	Description
SHAPE	Geometry	---	---	Point (default)
LocalName	String	50	---	Local Name
NodeX	String	7	---	Node X Coordinate
NodeY	String	7	---	Node Y Coordinate
RoadID	String	7	---	Road ID

MN-RoadDeteriorations Feature Class

The RoadDeteriorations feature class is a point layer to represent deterioration along the road segment, its tabular database includes deterioration type, deterioration area, and maintenance cost for the deteriorated area. The detail data specification of RoadDeteriorations feature class is defined in the Table 4.20 below.

Table 4.20 : RoadDeteriorations feature class data specifications

Field Name	Data Type	Length	Domain	Description
SHAPE	Geometry	---	---	Point (default)
DeteriorationArea	Double	---	---	Road Deterioration Area
<u>DeteriorationType</u>	String	20	DeteriorationTypeForRoad	Road Deterioration Type
MaintenanceCost	Double	---	---	Road Maintenance Cost
<u>RoadID</u>	String	7	---	Road ID

MN-RoadStructures Feature Class

The RoadStructures feature class is a point layer with two subtypes to represent Bridge and Culverts, its tabular data includes Age, Asset Deficit, Condition, Structure Type, etc. The detail data specification of RoadStructures feature class is defined in the Table 4.21 below.

Table 4.21 : RoadStructures feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Shape (Default)
Age	Integer	3	---	Age of Road Structure
AssetDeficit	Double	---	---	Asset Deficit
Width	Double	---	---	Carriage Width
<u>StructureType</u>	Integer	---	---	Bridge or Culvert
Condition	String	15	GeneralCondition	Road Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
DP	Double	---	---	Deterioration Percentage
EQA	Double	---	---	Equivalent area
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
<u>RouteID</u>	String	7	---	Route ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
Area	Double	---	---	Structure surface area
DA	Double	---	---	Deterioration Area
<u>Material</u>	String	20	RoadStructureMaterialType	Structure Material Type
MC	Double	---	---	Maintenance Cost
Length	Double	---	---	Length

MN-PedestrianWalkway Feature Class

The PedestrianWalkway feature class is a polyline layer with four subtypes to represent all types of walkways, its tabular data includes Carriage Width, Condition, Estimated Current Value, Construction Year, are a few to mention. The detail data specification of PedestrianWalkway feature class is defined in the Table 4.22 below.

Table 4.22 : PedestrianWalkway feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polyline (Default)
Age	Integer	3	---	Age of Walkway
AssetDeficit	Double	---	---	Asset Deficit
CarriageWidth	Double	---	---	Carriage Width
WalkwayType	Integer	---	PedestrianWalkwayMaterialType	Bridge or Culvert
Condition	String	15	GeneralCondition	Walkway Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
DP	Double	---	---	Deterioration Percentage
EQL	Double	---	---	Equivalent length
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
NodeStart	String	7	---	Start Node
NodeEnd	String	7	---	End Node
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
RouteID	String	7	---	Route ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
Area	Double	---	---	Surface area
TDA	Double	---	---	Total Deterioration Area
WalkwayID*	String	7	---	Walkway ID
TMC	Double	---	---	Total Maintenance Cost

MN-WalkwayNode Feature Class

The WalkwayNode feature class is a point layer to represent starting and ending junction of Walkway segment, its tabular data includes local location name, X and Y Coordinate of Node. The detail data specification of WalkwayNode feature class is defined in the Table 4.23 below.

Table 4.23 : WalkwayNode feature class data specifications

Field Name	Data Type	Length	Domain	Description
SHAPE	Geometry	---	---	Point (default)
LocalName	String	50	---	Local Name
NodeX	String	7	---	Node X Coordinate
NodeY	String	7	---	Node Y Coordinate
WalkwayID	String	7	---	Road ID

MN-WalkwayDeteriorations Feature Class

The WalkwayDeteriorations feature class is a point layer to represent deterioration along the Walkway segment, its tabular data includes deterioration type, deterioration area and maintenance cost for the deteriorated area. The detail data specification of WalkwayDeteriorations feature class is defined in the Table 4.24 below.

Table 4.24 : WalkwayDeteriorations feature class data specifications

Field Name	Data Type	Length	Domain	Description
SHAPE	Geometry	---	---	Point (default)
DeteriorationArea	Double	---	---	Walkway Deterioration Area
<u>DeteriorationType</u>	String	20	DeteriorationTypeForWalkway	Walkway Deterioration Type
MaintenanceCost	Double	---	---	Walkway Maintenance Cost
<u>WalkwayID</u>	String	7	---	Walkway ID

MN-Streetlight Feature Class

The Streetlight feature class is a point layer with three subtypes to represent all types of Streetlight, its tabular data includes Streetlight Type, Installation Year, Remaining Useful Life, Pole Material, are a few to mention. The detail data specification of Streetlight feature class is defined in the Table 4.25 below.

Table 4.25 : Streetlight feature class data specifications

Field Name	Data Type	Length	Domain Name	Description
Shape	Geometry	---	---	Point (Default)
Age	Integer	3	---	Age of Streetlight
AssetDeficit	Double	---	---	Asset Deficit
<u>StreetlightType</u>	Integer	30	StreetLightType	Streetlight Type
<u>Condition</u>	String	15	GeneralCondition	Road Condition
InstallationYear	Integer	4	---	Year of Installation
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
DP	Double	---	---	Deterioration Percentage
EQA	Double	---	---	Equivalent area
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
<u>RouteID</u>	String	7	---	Route ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
StreetlightID	String	7	---	Streetlight ID
MC	Double	---	---	Maintenance Cost
PoleMaterial	String	20	StreetlightPoleMaterial	Streetlight Pole Material Type
OperationFunction	String	20	StreetlightOperation	Streetlight Operational Function
Xcoordinate	Double	---	---	X Coordinate of Streetlight
Ycoordinate	Double	---	---	Y Coordinate of Streetlight

MN-MovementMaintenanceRates Object Class

The MovementMaintenanceRates (MMR) object class is a table layer is used to store maintenance rates for all Movement Network feature classes; it contains maintenance rates for all types of maintenance functions. The detail data specification of MMR table is defined in the Table 4.26 below.

Table 4.26 : MMR object class data specifications

Field Name	Data Type	Length	Domain	Description
<u>MaintenanceFunction</u>	String	30	MoveMaintenanceRatesFunctions	Movement Maintenance Function
MaintenanceRates	Double	---	---	Movement Maintenance Rates

MN-MovementReplacementRates Object Class

The MovementReplacementRates (MRR) object class is used to store replacement rates for all Movement Network feature classes; it contains replacement rates for all types of replacement functions. The detail data specification of MRR table is defined in the Table 4.27 below.

Table 4.27 : MRR object class data specifications

Field Name	Data Type	Length	Domain	Description
<u>ReplacementFunction</u>	String	30	MoveReplacementRatesFunctions	Movement Replacement Function
ReplacementRates	Double	---	---	Movement Replacement Rates
EstimatedUsefulLife	integer	3	---	Design life of the asset

The data specification of the Movement Network SAA dataset begins by defining the RoadNetwork feature class, and completed with MovementReplacementRates object class data specification. Next, the study will present the Water Supply Network SAA dataset data specifications.

The Water Supply Network (WSN) SAA dataset contains four feature classes (WaterSupplyNetwork, PipeNode, Reservoir, and Borehole) and two object classes (WaterSupplyMaintenanceRates and WaterSupplyReplacementRates) (Table 4.15). Each feature class and object class data specification in terms of field name, data types, record length, domains, and field descriptions of the Movement Network SAA dataset presented below.

WSN-WaterSupplyNetwork Feature Class

The WaterSupplyNetwork feature class is a polyline layer with two subtypes to represent transmission and distribution water supply pipes in the GCA, its tabular data includes Pipe Type, Pipe Diameter, Construction Year, are a few to mention. The detail data specification of WaterSupplyNetwork feature class is defined in the Table 4.28 below.

Table 4.28 : WaterSupplyNetwork feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polyline (Default)
Age	Integer	3	---	Age of the pipe
AssetDeficit	Double	---	---	Asset Deficit
Pipe Type	String	30	WaterSupplyPipeType	Transmission or Distribution Network
<u>PipeMaterial</u>	String	---	WaterSupplyMaterialType	Pipe material Type
Pipe Diameter	Double	---	---	Pipe Diameter
<u>Condition</u>	String	15	GeneralCondition	Pipe Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
Length km	Double	---	---	Length (km)
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
NodeStart	String	7	---	Start Node
NodeEnd	String	7	---	End Node
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
PipeID	String	7	---	Pipe ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
MC	Double	---	---	Maintenance Cost

WSN-Reservoir Feature Class

The Reservoir feature class is a point layer to represent reservoir in the GCA, its tabular database structure is somehow similar with other asset types its additional attribute includes capacity of the reservoir and operational function. The detail data specification of Reservoir feature class is defined in the Table 4.29 below.

Table 4.29: Reservoir feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Point (Default)
Age	Integer	3	---	Age of the reservoir
AssetDeficit	Double	---	---	Asset Deficit
Capacity	Double	---	---	Capacity of the reservoir
<u>Material Type</u>	Integer	---	ReservoirMaterialType	Reservoir material type
<u>Condition</u>	String	15	GeneralCondition	Reservoir condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
DP	Double	---	---	Deterioration Percentage
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
OperationalFunction	String	---	GeneralOperation	Operation of the Reservoir
RUL	Integer	3	---	Remaining Useful Life
ReservoirID	String	7	---	Reservoir ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
MC	Double	---	---	Maintenance Cost

WSN-Borehole Feature Class

The Borehole feature class is a point layer to represent reservoir in the GCA, about 85 % of its tabular database structure is similar with other asset types its additional attribute includes well depth and operational function. The detail data specification of Borehole feature class is defined in the Table 4.30 below.

Table 4.30: Borehole feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Point (Default)
Age	Integer	3	---	Age of the borehole
AssetDeficit	Double	---	---	Asset Deficit
Depth	Double	---	---	Depth of well
<u>Material Type</u>	Integer	---	BoreholeMaterialType	Borehole material type
<u>Condition</u>	String	15	GeneralCondition	Borehole condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
DP	Double	---	---	Deterioration Percentage
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
WellOperationalFunction	String	---	GeneralOperation	Operation of the Well
RUL	Integer	3	---	Remaining Useful Life
BoreholeID	String	7	---	Borehole ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
MC	Double	---	---	Maintenance Cost

WSN-PipeNode Feature Class

The PipeNode feature class is a point layer to represent starting and ending junction of pipe segment, its tabular database includes local location name, X and Y Coordinate of Node. The detail data specification of PipeNode feature class is defined in the Table 4.31 below.

Table 4.31: PipeNode feature class data specifications

Field Name	Data Type	Length	Domain	Description
SHAPE	Geometry	---	---	Point (default)
LocalName	String	50	---	Local Name
NodeX	String	7	---	Node X Coordinate
NodeY	String	7	---	Node Y Coordinate
PipeID	String	7	---	Pipe ID

WaterSupplyMaintenanceRates Object Class

The WaterSupplyMaintenanceRates (WMR) object class is a table layer is used to store maintenance rates for all Water Supply Network SAA feature classes; it contains maintenance rates for all types of maintenance functions. The detail data specification of WMR table is defined in the Table 4.32 below.

Table 4.32: WMR object class data specifications

Field Name	Data Type	Length	Domain	Description
<u>MaintenanceFunctions</u>	String	30	WaterSupply MaintenanceFunctions	Water Supply Maintenance Functions
MaintenanceRates	Double	---	---	Water Supply Maintenance Rates

WSN-WaterSupplyReplacementRates Object Class

The WaterSupplyReplacementRates (WRR) object class is used to store replacement rates for all Water Supply Network SAA feature classes; it contains replacement rates for all types of replacement functions. The detail data specification of WRR table is defined in the Table 4.33 below.

Table 4.33: WRR object class data specifications

Field Name	Data Type	Length	Domain	Description
ReplacementFunction	String	30	WaterSupplyReplacementFunctions	Water Supply Replacement Function
ReplacementRates	Double	---	---	Water Supply Replacement Rates
EstimatedUsefulLife	integer	3	---	Design life of the asset

The data specification of the Water Supply Network SAA dataset begins by defining the WaterSupplyNetwork feature class, and completed with WaterSupplyReplacementRates object class data specification. Next, the study will present the Environmental Service SAA dataset data specifications.

The Environmental Service (ES) SAA dataset contains seven feature classes (DrainageNetwork, DrainageNode, DrainageDeteriorations, Sanitation, StreetGreenery, Recreations, and Manhole) and two object classes (EnvironmentalMaintenanceRates and EnvironmentalReplacementRates) (Table 4.15). Each feature class and object class data specification in terms of field name, data types, record length, domains, and field descriptions of the Environmental Service SAA dataset presented below.

ES-DrainageNetwork Feature Class

The DrainageNetwork feature class is a polyline layer with five subtypes to represent a drainage network in the GCA, its tabular data includes Drainage Type, Depth, Area, Volume, are a few to mention. The detail data specification of DrainageNetwork feature class is defined in the Table 4.34 below.

Table 4.34 : DrainageNetwork feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polyline (Default)
Age	Integer	3	---	Age of the drainage
AssetDeficit	Double	---	---	Asset Deficit
<u>Drainage Type</u>	String	30	DrainageType	Choices between five subtypes
Width	Double	---	---	Drainage Width
Depth	Double	---	---	Drainage Depth
Area	Double	---	---	Drainage Area
Volume	Double	---	---	Volume of the drain
Condition	String	15	GeneralCondition	Drainage Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
DP	Double	---	---	Deterioration Percentage
Length km	Double	---	---	Length (km)
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
NodeStart	String	7	---	Start Node
NodeEnd	String	7	---	End Node
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
<u>DrainageID</u>	String	7	---	Drainage ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
TMC	Double	---	---	Total Maintenance Cost

ES-Sanitation Feature Class

Sanitation feature class is a point layer with three subtypes to represent public toilet, communal toilet and public baths, its tabular data includes Sanitation Type, Foundation Material and Foundation Condition, Wall Material and Wall Condition, Floor Material and Floor Condition, are a few to mention. The detail data specification of Sanitation feature class is defined in the Table 4.35 below.

Table 4.35: Sanitation feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polygon (Default)
Age	Integer	3	---	Age of building
AssetDeficit	Double	---	---	Asset Deficit
SanitationType	String	30	DrainageType	Choices between three subtypes
FoundationMaterial	String		BuildingFounation Material	Building foundation material
FoundationCondition	String	15	GeneralCondition	Building foundation condition
FloorMaterial	String		BuildingFloorMat erial	Building floor material
FloorCondition	String	15	GeneralCondition	Building floor condition
WallMaterial	String		BuildingWallMate rial	Building wall material
WallCondition	String	15	GeneralCondition	Building wall condition
RoofMaterial	String		BuildingRoofMate rial	Building roof material
RoofCondition	String	15	GeneralCondition	Building roof condition
<u>Structure Concatenation</u>	String	50	---	Building structure concatenation
NoOfRooms	Integer	3		No of building rooms
<u>Average Condition</u>	String	15	GeneralCondition	Average building condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
BuildingID	String	7	---	Building ID
MC	Double	---	---	Maintenance Cost

ES-StreetGreenery Feature Class

StreetGreenery feature class is a polygon layer with two subtypes to represent median, and roundabout, its tabular data includes Greenery Type, Kerbing Material, Paved Material, Fence Material, are a few to mention. The detail data specification of StreetGreenery feature class is defined in the Table 4.36 below.

Table 4.36 : StreetGreenery feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polygon (Default)
Age	Integer	3	---	Age of the greenery
AssetDeficit	Double	---	---	Asset Deficit
<u>GreeneryType</u>	String	30	GreeneryType	Choices between two subtypes
KerbingMaterial	String	20	KerbingMaterial	Kerbing material
PavedMaterial	String	20	GreeneryMaterials	Paved material of the greenery
FenceMaterial	String	20	FenceMaterial	Fence material of the greenery
Area	Double	---	---	Shape area (default)
<u>Condition</u>	String	15	GeneralCondition	Greenery Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
GreeneryID	String	7	---	Greenery ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
MC	Double	---	---	Maintenance Cost

ES-Recreations Feature Class

Recreations feature class is a polygon layer with three subtypes to represent Park, Green Area, and recreations, its tabular data includes Recreation Type, Paved Material, Construction Year, are a few to mention. The detail data specification of Recreations feature class is defined in the Table 4.37 below.

Table 4.37: Recreations feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polygon (Default)
Age	Integer	3	---	Age of the recreations
AssetDeficit	Double	---	---	Asset Deficit
<u>RecreationType</u>	String	30	RecreationType	Choices between three subtypes
PavedMaterial	String	20	GreeneryMaterials	Paved material of the greenery
Status	String	20	GeneralOperation	Operational function of the recreations
Area	Double	---	---	Shape area (default)
<u>Condition</u>	String	15	GeneralCondition	Recreation Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
RecreationID	String	7	---	Recreation ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
MC	Double	---	---	Maintenance Cost

ES-Manhole Feature Class

Manhole feature class is a point layer to represent a manhole along the Drainage Network, its tabular data includes Material Type, Length, Width, Depth, Volume, are a few to mention. The detail data specification of Manhole feature class is defined in the Table 4.38 below.

Table 4.38: Manhole feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Point (Default)
Age	Integer	3	---	Age of the manhole
AssetDeficit	Double	---	---	Asset Deficit
<u>MaterialType</u>	String	30	MaterialType	Material type of manhole
Status	String	20	GeneralOperation	Operational function of the manhole
Length	Double	---	---	Length of manhole
Width	Double	---	---	Width of manhole
Depth	Double	---	---	Depth of the manhole
Volume	Double	---	---	Volume of manhole
Area	Double	---	---	Shape area (default)
<u>Condition</u>	String	15	GeneralCondition	Recreation Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
RecreationID	String	7	---	Recreation ID
<u>DrainageID</u>	String	7	---	Drainage ID
SAA	String	30	StrategicActivityArea	Strategic Activity Area
MC	Double	---	---	Maintenance Cost

ES-DrainageDeteriorations Feature Class

The DrainageDeteriorations feature class is a point layer to represent deterioration along the Drainage Network segment, its tabular data includes deterioration type, deterioration area and maintenance cost for the deteriorated area. The detail data specification of DrainageDeteriorations feature class is defined in the Table 4.39 below.

Table 4.39: DrainageDeteriorations feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Point (default)
DeteriorationArea	Double	---	---	Drainage Deterioration Area
DeteriorationType	String	20	DeteriorationTypeForDariange	Drainage Deterioration Type
MaintenanceCost	Double	---	---	Drainage Maintenance Cost
DrainageID	String	7	---	Drainage ID

DrainageNode Feature Class

The DrainageNode feature class is a point layer to represent starting and ending junction of Drainage segment, its tabular data includes local location name, X and Y Coordinate of Node. The detail data specification of DrainageNode feature class is defined in the Table 4.40 below.

Table 4.40 : DrainageNode feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Point (default)
LocalName	String	50	---	Local Name
NodeX	String	7	---	Node X Coordinate
NodeY	String	7	---	Node Y Coordinate
DrainageID	String	7	---	Drainage ID

ES-EnvironmentalMaintenanceRates Object Class

The EnvironmentalMaintenanceRates (EMR) object class is a table layer is used to store maintenance rates for all Environmental Service SAA feature classes. It contains maintenance rates for all types of maintenance functions. The detail data specification of EMR is defined in the Table 4.41 below.

Table 4.41: EMR object class data specifications

Field Name	Data Type	Length	Domain	Description
<u>MaintenanceFunctions</u>	String	30	Environmental MaintenanceFunctions	Environmental Maintenance Functions
MaintenanceRates	Double	---	---	Environmental Maintenance Rates

ES-EnvironmentalReplacementRates Object Class

The EnvironmentalReplacementRates (ERR) object class is used to store replacement rates for all Movement Network feature classes, it contains replacement rates for all types of replacement functions. The detail data specification of ERR table is defined in the Table 4.42 below.

Table 4.42 : ERR object class data specifications

Field Name	Data Type	Length	Domain	Description
<u>ReplacementFunction</u>	String	30	EnvironmentalReplacementFunctions	Environmental Replacement Function
ReplacementRates	Double	---	---	Environmental Replacement Rates
EstimatedUsefulLife	integer	3	---	Design life of the asset

The data specification of the Environmental Service SAA dataset begins by defining the DrainageNetwork feature class, and completed with EnvironmentalReplacementRates object class data specification. Following, the study will present the Social and Economic Service SAA dataset data specifications.

The Social and Economic Service (SES) SAA dataset contains four feature classes (CommunityServiceBuildings, AdministrationBuildings, Fence, and MSEShade) and two object classes (SocialReplacementRates and SocialMaintenanceRates) (Table 4.15). Each feature class and object class data specification in terms of field name, data types, record length, domains, and field descriptions of the Environmental Service SAA dataset presented below.

SES-CommunityServiceBuildings Feature Class

The CommunityServiceBuildings feature class is a polygon layer with eight subtypes to represent a school, bus terminal, youth center, health center and other community service buildings in the GCA as shown in Table 4.43, its tabular database choices develop based on the study requirement analysis results (Table 4.7). The detail data specification of CommunityServiceBuildings feature class is defined in the Table 4.43 below.

Table 4.43: CommunityServiceBuildings feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polygon (Default)
Age	Integer	3	---	Age of building
AssetDeficit	Double	---	---	Asset Deficit
<u>BuildingType</u>	String	30	CommunityServiceBuildingTypes	Choices between eight subtypes
BuildingFunction	String	50	Variable	Depend on the subtypes type
FoundationMaterial	String	30	BuildingFoundationMaterial	Building foundation material
FoundationCondition	String	15	GeneralCondition	Building foundation condition
FloorMaterial	String	30	BuildingFloorMaterial	Building floor material
FloorCondition	String	15	GeneralCondition	Building floor condition
WallMaterial	String	30	BuildingWallMaterial	Building wall material
WallCondition	String	15	GeneralCondition	Building wall condition
RoofMaterial	String	30	BuildingRoofMaterial	Building roof material
RoofCondition	String	15	GeneralCondition	Building roof condition
<u>Structure Concatenation</u>	String	50	---	Building structure concatenation
NoOfRooms	Integer	3	---	No of building rooms
NoOfRooms	Integer	2	---	No of building floors
<u>Average Condition</u>	String	15	GeneralCondition	Average building condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
BuildingID	String	7	---	Building ID
MC	Double	---	---	Maintenance Cost

SES-AdministrationBuildings and MSE Shade Feature Classes

The AdministrationBuildings and MSE Shade feature classes are a polygon layers to represent administrative buildings and MSE shades in the GCA, both feature classes attributes structure is similar except the building function attribute. The detail of AdministrationBuildings and MSE Shade feature class data specification is defined in the Table 4.44 below.

Table 4.44: AdministrationBuildings and MSE Shade feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polygon (Default)
Age	Integer	3	---	Age of building
AssetDeficit	Double	---	---	Asset Deficit
BuildingFunction	String	50	Variable	Depend on the feature class type
FoundationMaterial	String	15	Building Foundation Material	Building foundation material
FoundationCondition	String	15	GeneralCondition	Building foundation condition
FloorMaterial	String	30	BuildingFloorMaterial	Building floor material
FloorCondition	String	15	GeneralCondition	Building floor condition
WallMaterial	String	30	BuildingWallMaterial	Building wall material
WallCondition	String	15	GeneralCondition	Building wall condition
RoofMaterial	String	30	BuildingRoofMaterial	Building roof material
RoofCondition	String	15	GeneralCondition	Building roof condition
<u>Structure Concatenation</u>	String	50	---	The sum of building structure materials Codes
NoOfRooms	Integer	3	---	No of building rooms
NoOfRooms	Integer	2	---	No of building floors
<u>Average Condition</u>	String	15	GeneralCondition	Average building condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
BuildingID	String	7	---	Building ID
MC	Double	---	---	Maintenance Cost

SES-Fence Feature Class

The Fence feature class is a polyline layer to represent fence or boundary walls in the GCA, the attribute types includes fence wall material, name of institution and fence condition, a few to mention. Its detail data specification is defined in the Table 4.45 below.

Table 4.45: Fence feature class data specifications

Field Name	Data Type	Length	Domain	Description
Shape	Geometry	---	---	Polyline (Default)
Age	Integer	3	---	Age of building
AssetDeficit	Double	---	---	Asset Deficit
NameOfInstitute	String	50	Variable	Name of the Institute
<u>FenceWallMaterial</u>	String	30	FenceWallMaterial	Fence Wall Material
<u>FenceWallCondition</u>	String	15	GeneralCondition	Fence Wall Condition
Construction Year	Integer	4	---	Construction Year
CurrentYear	Integer	4	---	Current year
DRC	Double	---	---	Depreciated Replacement Cost
ECV	Double	---	---	Estimated Current Value
ERC	Double	---	---	Estimated Replacement Cost
PercentRUL	Double	---	---	Percent Remaining Useful life
RUL	Integer	3	---	Remaining Useful Life
FenceID	String	7	---	Building ID
MC	Double	---	---	Maintenance Cost

SES-SocialMaintenanceRates Object Class

The SocialMaintenanceRates (SMR) object class is used to store maintenance rates for five condition types, it contains fractional figure as a product factor of replacement cost of an asset. The detail data specification of SMR table is defined in the Table 4.46 below.

Table 4.46: SMR object class data specifications

Field Name	Data Type	Length	Domain	Description
<u>MaintenanceFunction</u>	String	30	GeneralCondition	Condition based maintenance rates
MaintenanceRate	Double	---	---	Maintenance Rate (MR)

SES-SocialReplacementRates Object Class

The SocialReplacementRates (SRR) object class is used to store replacement rates for all building types, it contains replacement rates for each building material types. The detail data specification of SRR table is defined in the Table 4.47 below.

Table 4.47: SRR object class data specifications

Field Name	Data Type	Length	Domain	Description
FloorMaterial	String	30	BuildingFloorMaterial	Environmental Replacement Function
FloorUnitRate	Double	---	---	Environmental Replacement Rates
FoundationMaterial	String	30	BuildingFoundationMaterial	Building Foundation Material
FoundationUnitRate	Double	---	---	Unit rate of foundation materials
RoofMaterial	String	30	BuildingRoofMaterial	Building Roof Material
RoofMaterialUnitRate	Double	---	---	Unit rate of roof materials
WallMaterial	String	30	---	Building Wall Material
WallMaterialUnitRate	Double	---	BuildingWallMaterial	Unit rate of wall materials
StructureConcatenation	String	50	---	Sun of building material codes
TotalReplacementUnitRate	Double	---	---	The sum of maintenance rate of all building structures from Foundation to Roof
EstimatedUsefulLife	integer	3	---	Design life of the asset

The data specifications of the AMP geodatabase section begin by defining the Movement Network SAA dataset data specification requirements, and concludes with Social and Economic Service SAA dataset data specification requirements necessary to reach their goals. In the next section, the study will present relationship properties of each AMP SAA dataset elements.

4.2.3.2.3 Relationship Properties of the AMP Geodatabase

Building relationship classes, between tables, is another way to organize data in a more proficient and effective manner. In this study, relationships were created between feature classes, feature classes and object classes. The purpose this relationship class is to link datasets between interrelated data using unique identifiers. The unique identifier is used to link two data types, using an identical field found in both database tables. The benefit of relationships in this study includes easy access to related data, effective data storage, and quicker data edits and performance. Beyond the relationship classes, there are additional key attributes; these key attributes help to link the datasets and automate the AMP computations by joining datasets. This study only requires simple one-to-many relationship classes. The structure of relationship classes in the Movement Network SAA dataset is depicted in the Figure 4.8 below.

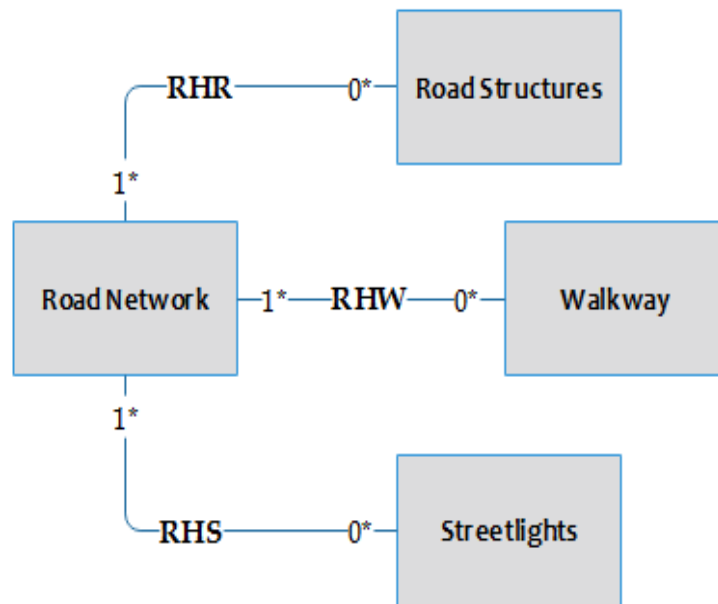


FIGURE 4.8 : RELATIONSHIP CLASSES DIAGRAM OF THE MOVEMENT NETWORK SAA DATASET

As shown in the Figure 4.8, RouteHasRoadStructure (RHR), RouteHasStreetlights (RHS), and RouteHasWalkway (RHW) relationship classes are designed in Movement Network SAA dataset. The RHR relationship class is associated with the RoadNetwork and RoadStructures feature class in a one-to-many relationship. Within this study, relationship classes are named origin table with destination table. For example, the RoadNetwork feature class is the origin table, while RoadStructures is the destination table. This naming convention was used to name all relationship classes, giving them a consistent naming scheme.

Beyond the relationship class, there are ten additional key attributes in this SAA. The structure of key attributes in the Movement Network SAA dataset is depicted in the Figure 4.9 below, abbreviated texts represent key attributes between datasets.

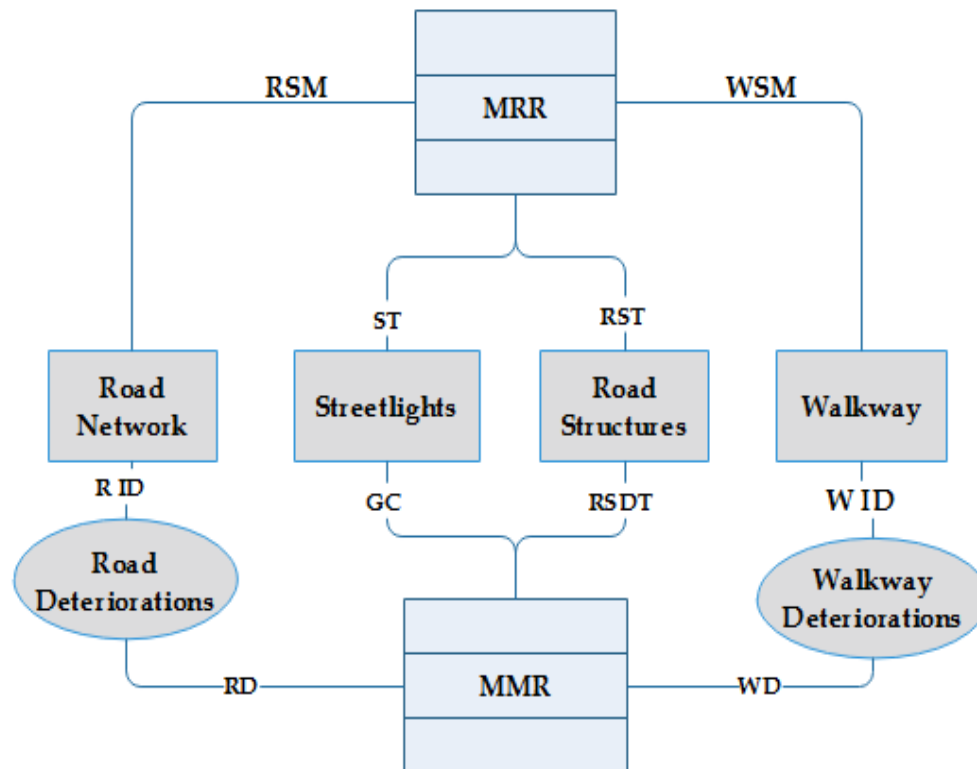


FIGURE 4.9 : KEY ATTRIBUTES DIAGRAM OF THE MOVEMENT NETWORK SAA DATASET

As shown in the Figure 4.9, the Movement Network SAA dataset has ten key attributes that helps the user to automate the AMP computations by joining datasets. The overall logical relationships of the Movement Network dataset UML diagram is shown in the Figure 4.10 below, followed by the Water Supply Network SAA dataset relationships and key attributes.

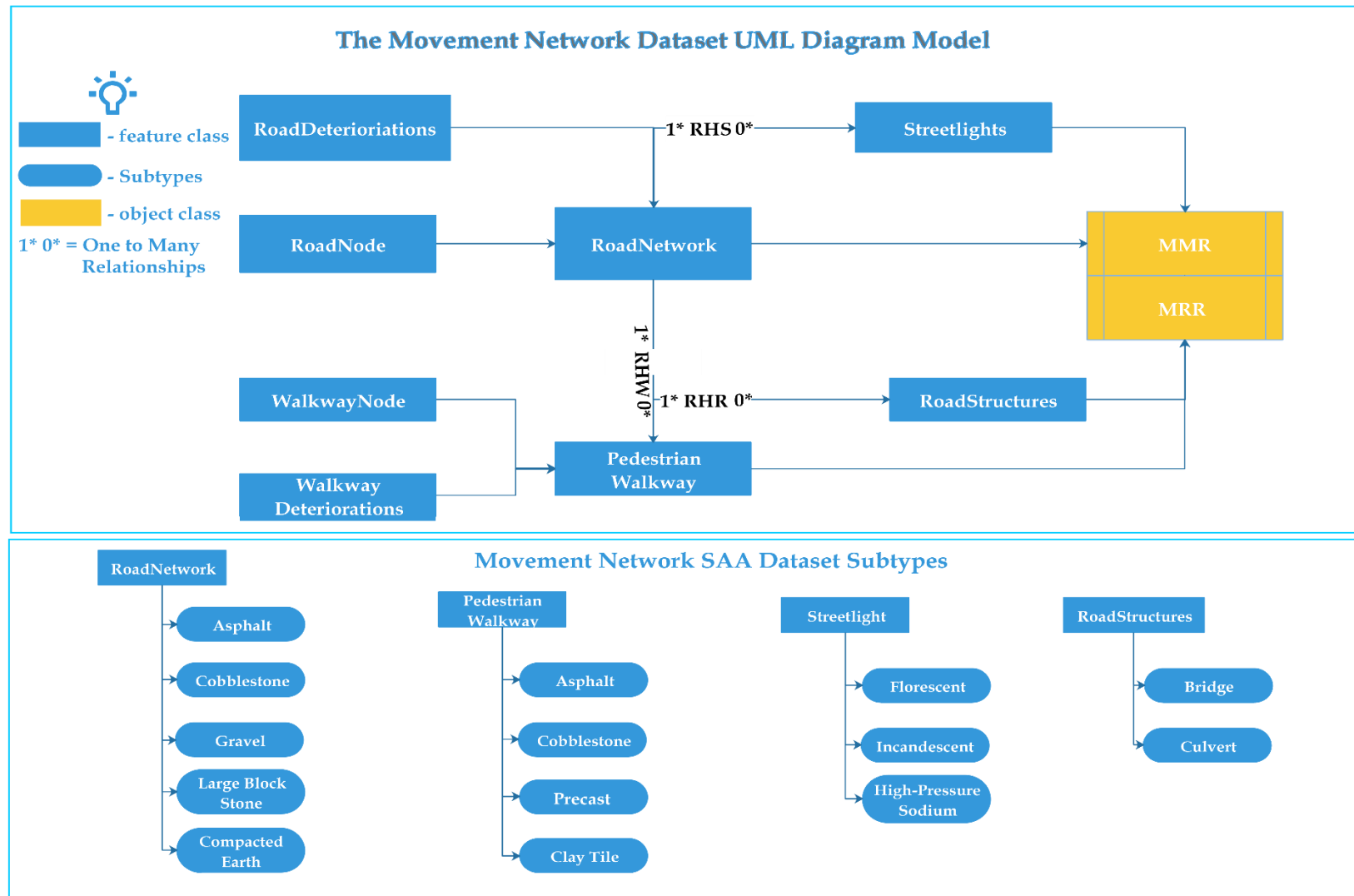


FIGURE 4.10: LOGICAL RELATIONSHIPS OF THE MOVEMENT NETWORK DATASET UML DIAGRAM

The Water Supply Network SAA has six key attributes; these key attributes help the user to automate the AMP computations by joining object attributes. The diagram of key attributes in the Water Supply Network SAA is depicted in the Figure 4.11 below.

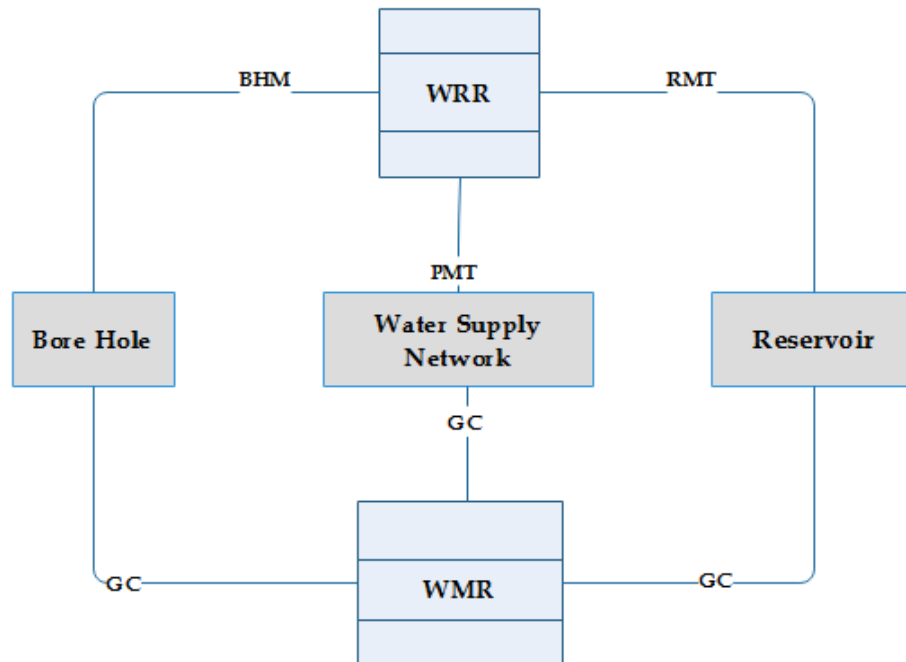


FIGURE 4.11 : KEY ATTRIBUTES DIAGRAM OF THE WATER SUPPLY NETWORK SAA DATASET

The overall logical relationship of the Water Supply Network SAA dataset UML diagram is shown in the Figure 4.12 below.

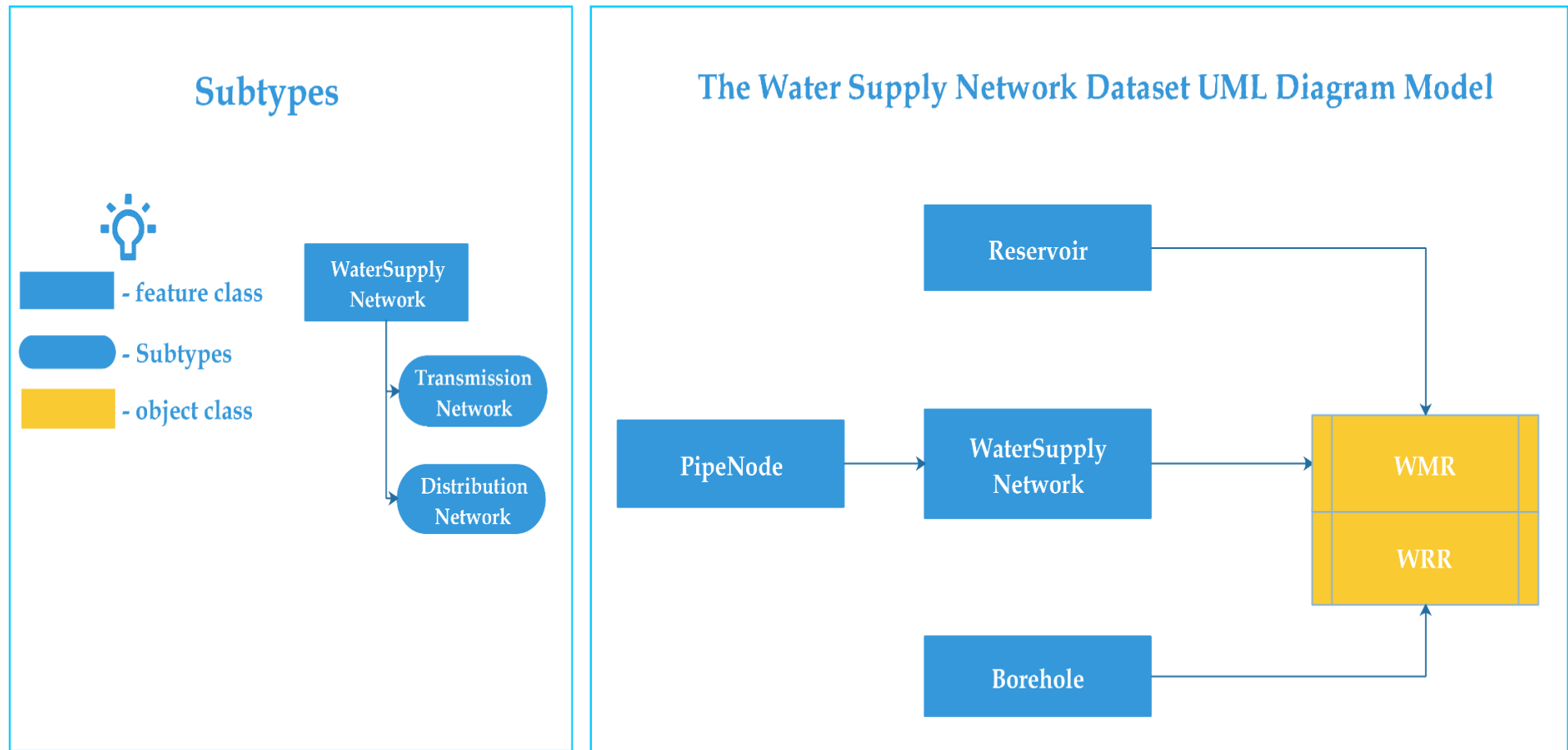


FIGURE 4.12: LOGICAL RELATIONSHIPS OF THE WATER SUPPLY NETWORK SAA DATASET UML DIAGRAM

A DrainageHasManhole (DHM) relationship class is the only designed in Environmental Service dataset. The DHM relationship class is associated with the DrainageNetwork and Manhole feature class in a one-to-many relationship. Additionally, Environmental Service SAA had six key attributes; these key attributes help the user to automate the AMP computations by joining datasets. The relationship class diagram shown in Figure 4.13, followed by the diagram of key attributes depicted in the Figure 4.14 below.

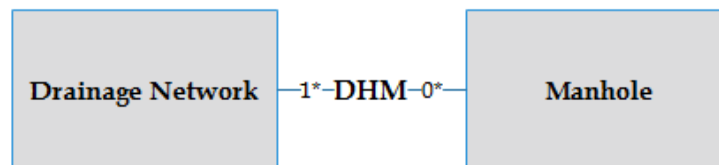


FIGURE 4.13: RELATIONSHIP CLASS DIAGRAM OF THE ENVIRONMENTAL SERVICE SAA DATASET

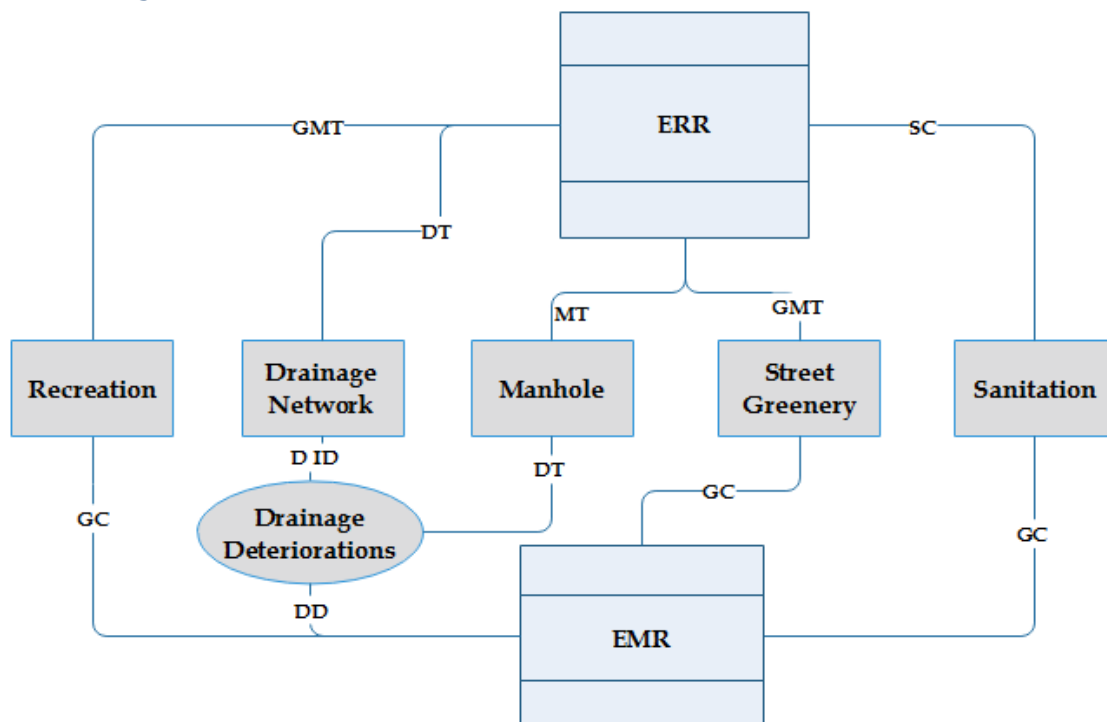


FIGURE 4.14: KEY ATTRIBUTES DIAGRAM OF THE ENVIRONMENTAL SERVICE SAA DATASET

As shown in the Figure 4.14, the Environmental Service SAA dataset has eleven key attributes that helps the user to automate the AMP computations by joining datasets. The overall logical relationship of the Environmental Service SAA dataset UML diagram is shown in the Figure 4.15 below.

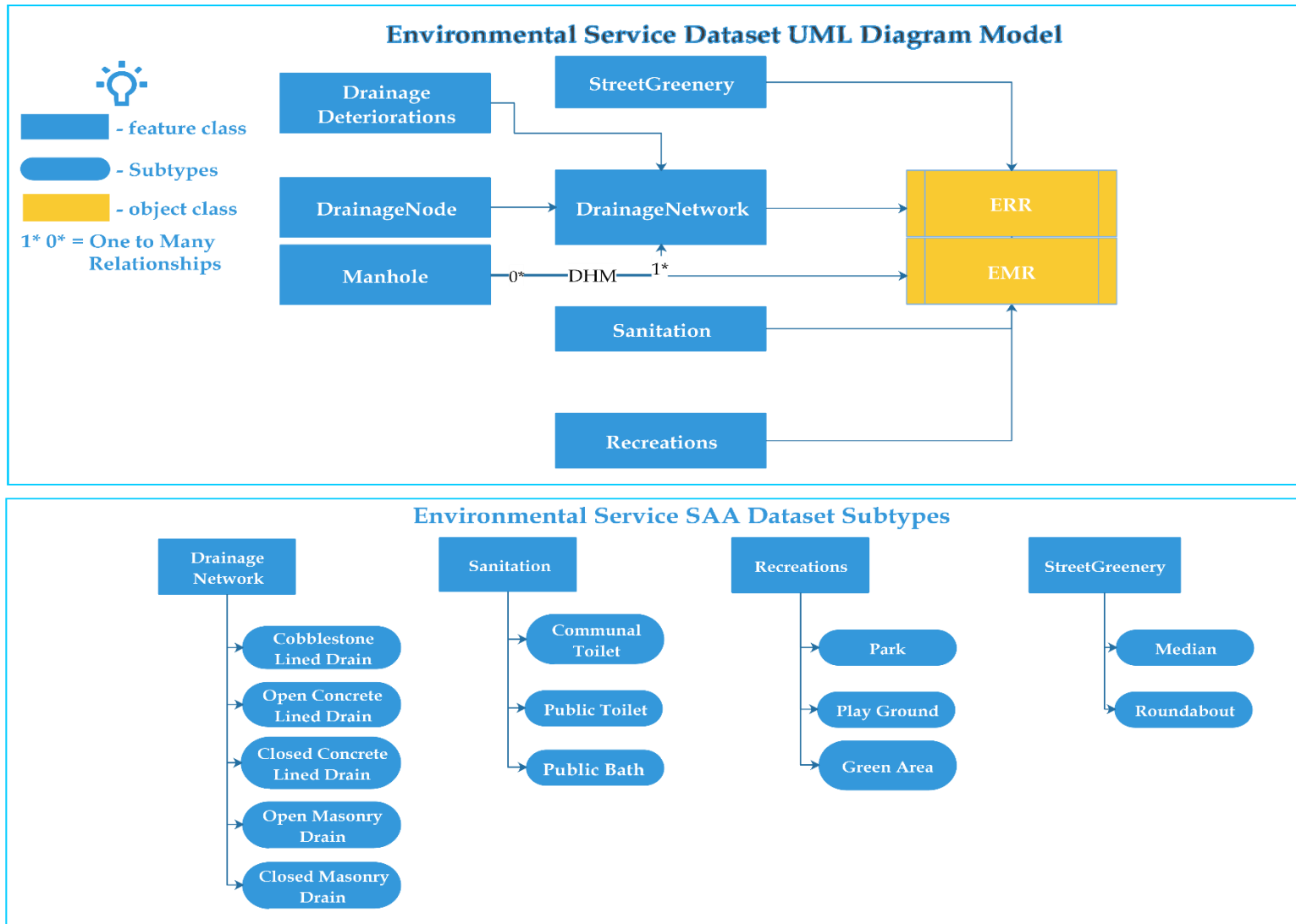


FIGURE 4.15: LOGICAL RELATIONSHIPS OF THE ENVIRONMENTAL SERVICE SAA DATASET UML DIAGRAM

The Social and Economic Service SAA had six key attributes; these key attributes help the user to automate the AMP computations by joining object attributes. Its key attributes diagram depicted in the Figure 4.16 below.

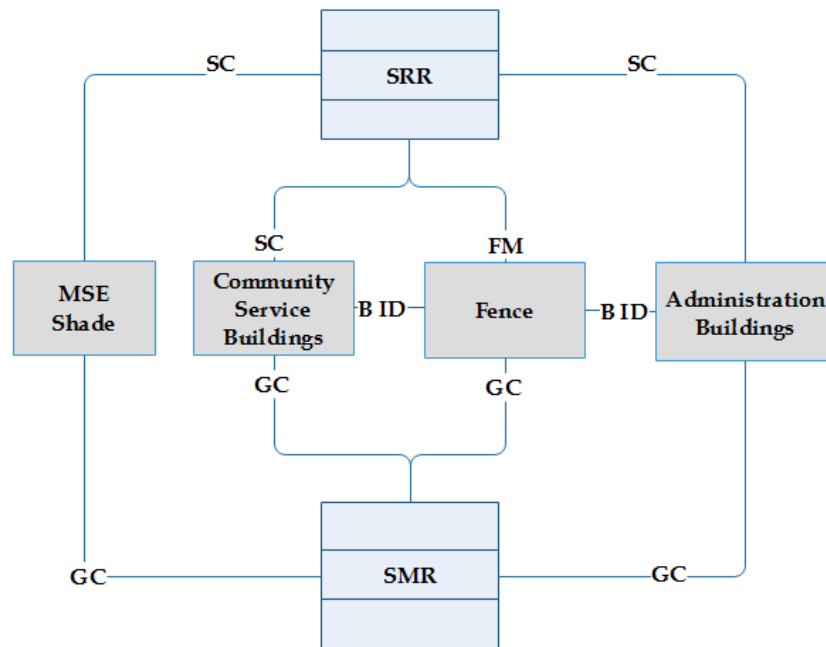


FIGURE 4.16: KEY ATTRIBUTES DIAGRAM OF THE SOCIAL AND ECONOMIC SERVICE SAA DATASET

The overall logical relationship of the Social and Economic Service SAA dataset UML diagram is shown in the Figure 4.17 below.

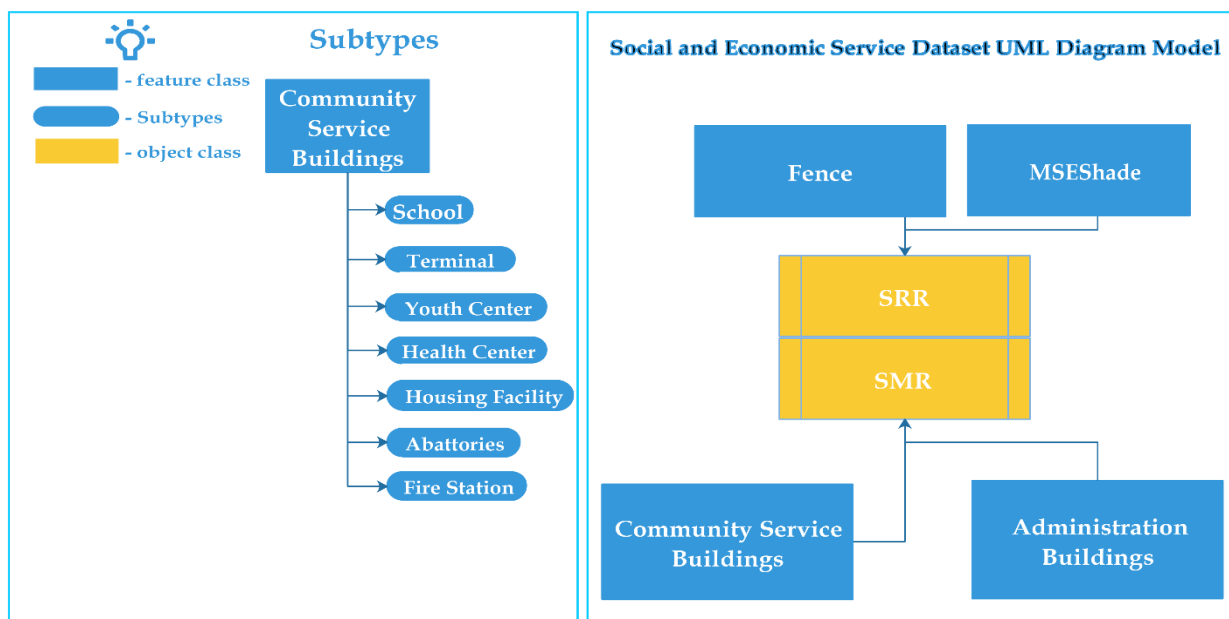


FIGURE 4.17: LOGICAL RELATIONSHIPS OF THE SOCIAL AND ECONOMIC SERVICE SAA DATASET UML DIAGRAM

The logical phase described the four AMP SAA datasets needed for the created geodatabase in this study. Within each feature dataset, feature classes, associated tables, and relationship classes were defined in detail. Two object classes (tables) were created for each dataset, and descriptions were employed to explain the associated data. Geodatabase elements were the primary focus of this section. The ArcGIS 10.6 geodatabase format was utilized to organize GIS data for easy storage, editing, manageability, and ultimately maximizing the performance of geospatial data. Within the four AMP SAA datasets examined, twenty-three feature classes, eight object classes, six relationship classes, thirty-four key attributes, forty-eight domains and nine subtypes were created to establish this geodatabase design. In the next section, the physical AMP geodatabase model diagram will be created to assist in the visual representation of this geodatabase design.

4.2.3.3 Physical Design Phase of the AMP Geodatabase

In the physical design phase, the procedure of building the geodatabase will be described in terms of applying the specifications identified in conceptual and logical design phases. ArcGIS workspace were created in EA UML diagrams, the datasets and feature classes were established and added to the corresponding datasets according to the structure mentioned in the conceptual and logical design phases. In addition, the valid subtypes and domains are associated to the features' attributes and relationship rules were applied to the feature classes as well. Ultimately, the UML diagram of ArcGIS workspace is validated⁸, exported as XML schema, and imported into ArcCatalog. The model is diagrammed using standardized database and geodatabase symbolization to assist the reader in observing basic components and relationships within the geodatabase.

The following sections illustrate the geodatabase model, beginning with the complete geodatabase, which is then separated into individual AMP SAA for further discussion. The feature datasets are labeled at the top of large green boxes and further identified with feature dataset symbols. Feature classes and object classes displayed under each feature dataset. Feature classes contain the standard point, line, or polygon symbols within their title boxes, and object classes display a table symbol within theirs. The following diagrams illustrate the organization, data models, relationships, and discussed more broadly, by explaining the data's purpose and function. Figure 4.18 illustrates the geodatabase model in its entirety.

⁸ The validation report is attached in the Appendix H

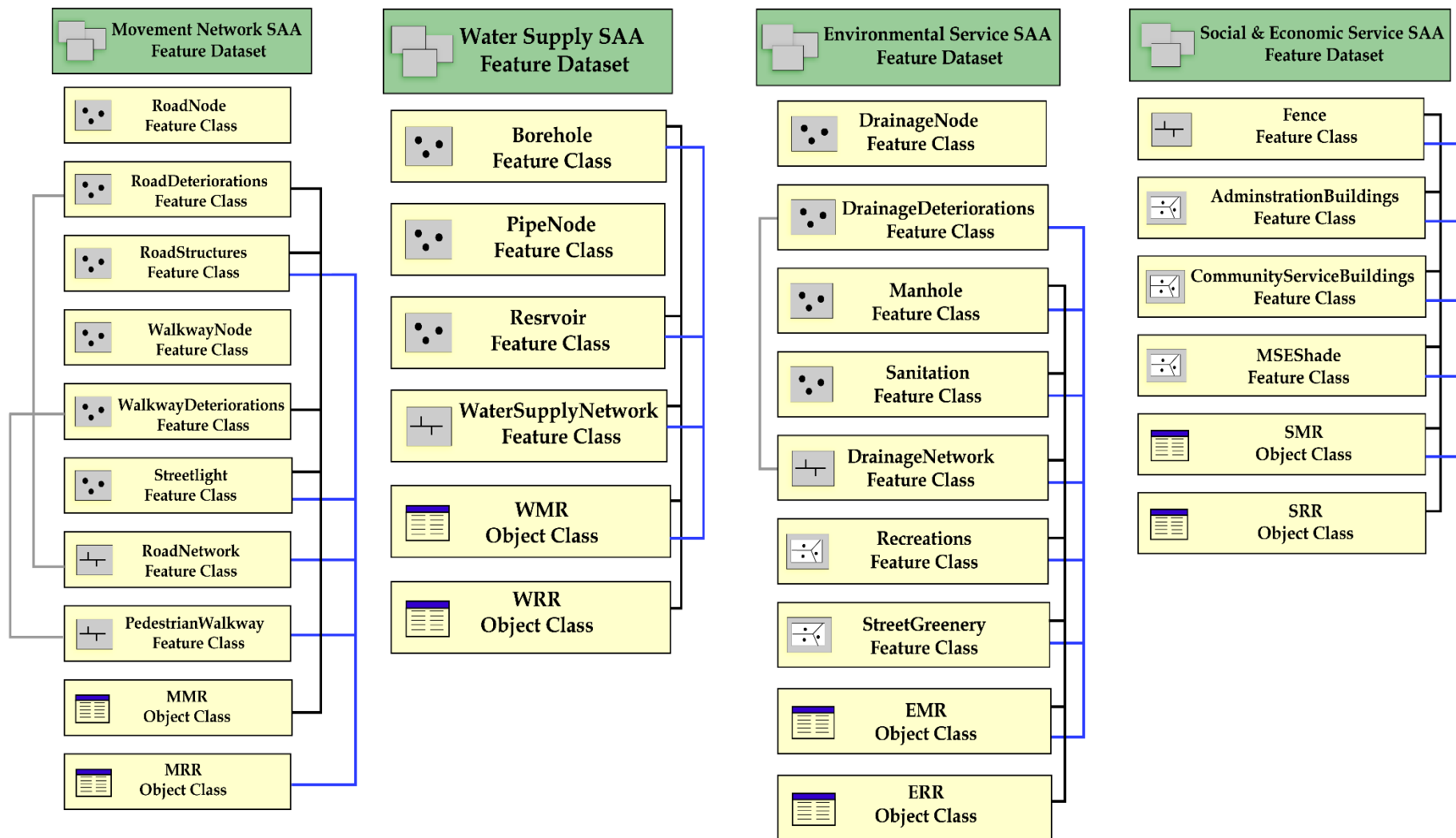


FIGURE 4.18: THE DESIGNED AMP GEODATABASE MODEL

4.2.3.3.1 The Movement Network Dataset Model

The movement network dataset captures the data requirements of the movement network SAA. The road network, road structures, pedestrian walkway, and various features and objects are represented in the movement network model. Figure 4.19 illustrates the movement network dataset model

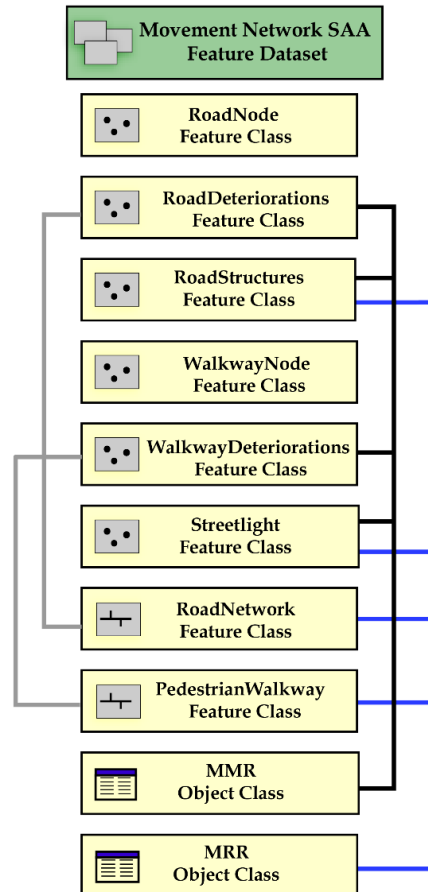


FIGURE 4.19 : THE MOVEMENT NETWORK SAA DATASET MODEL

The RoadNode, RoadDeteriorations, RoadStructures, WalkwayNode, WalkwayDeteriorations, Streetlight, RoadNetwork, and PedestrianWalkway feature classes, MovementMaintenanceRates (MMR), and MovementReplacementRates (MRR) object classes are the ten datasets contained in the movement network feature dataset.

Notice the symbols next to the feature or object classes. These symbols represent the geographic representation of the data such as point, line, polygon, or table. The relationship class is located on the right side (feature-to-object class) and left side (feature-to-feature class) of the model.

The RoadNode and WalkwayNode feature classes primary functions are to represent starting and ending junction of a segment. Both feature classes store all discreet information concerning road node locations, such as x and y coordinate of a road junction, and its locality name.

The RoadDeteriorations feature class contains deterioration extents and maintenance cost requirements of the deteriorated area within road networks. The MMR object class documents all of the important maintenance cost information. In order to estimate the maintenance cost of road deteriorations, a key attribute was created between RoadDeteriorations feature class and MMR object class by using the DeteriorationType field as a key field to link the two datasets. Additionally, one key attribute was created to link RoadDeteriorations and RoadNetwork feature classes, the RoadID is the key field linking the two datasets. This operation is also works for WalkwayDeteriorations and PedestrianWalkway feature classes.

The Streetlight feature class locates streetlights on GCA. Its attribute structure built to store all discreet information concerning streetlights, such as streetlight pole material, condition, installation year, and streetlight operational function. To estimate the maintenance cost of streetlights a key attribute was created with MMR object class by using the GeneralCondition field as a key field. The MRR object class documents all of the important replacement cost information. In order to estimate the current economic value of streetlights, a key attribute was created to link Streetlights feature class to MRR object class. The StreetlightType is the key field linking the two datasets. The RoadStructures feature class is also has virtually similar characteristics.

The RoadNetwork feature class contains all necessary subtypes to represent various types of road features found in GCA. Its attribute structure built to store all discreet information concerning road network, such as surface material, carriage width, construction year, and road hierarchy. In order to estimate current value of roads, a key attribute was created to link RoadNetwork feature class to MRR object class. The RoadType is the key field linking the two datasets. The PedestrianWalkway feature class is also has virtually similar characteristics.

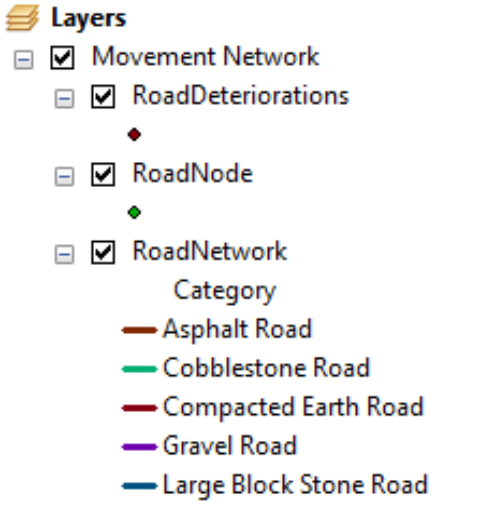
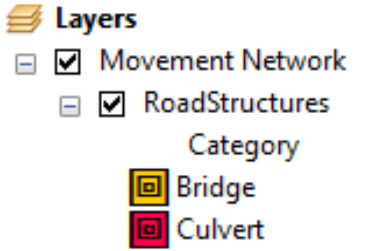
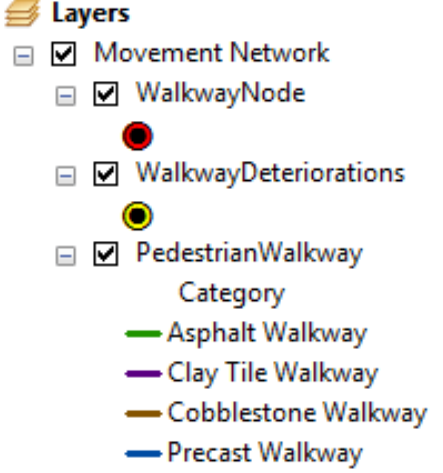
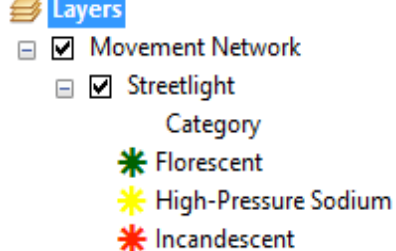
The MMR object class houses all of the prudent data including each maintenance rates of Streetlights, RoadStructures, RoadNetwork, and PedestrianWalkway feature classes. Its attribute structure built to store all discreet information concerning maintenance rates, such as maintenance type and maintenance rate.

The MRR object class houses all of the necessary data including each replacement rates of Streetlights, RoadStructures, RoadNetwork, and PedestrianWalkway feature classes. Its

attribute structure built to store all discreet information concerning replacement rates, such as material type and replacement rate.

The Movement Network SAA feature dataset contains all of the necessary geospatial data in a powerful geodatabase structure to capture streetlights, road networks, road structures, and pedestrian walkway assets on GCA. The defined key attributes will allow the capability of to store necessary required information for easy management, documentation, and analysis. Table 4.48 shows, the physical design of the Movement Network SAA dataset in the ArcGIS environment with layer descriptions.

Table 4.48: Physical design of the Movement Network SAA dataset in ArcGIS Environment

Layer Name	Movement Network	Road Structures	Pedestrian Walkway	Streetlights
Physical Design				
Description	The physical design of RoadNetwork (with five subtypes), RoadNode and RoadDeteriorations layers are pictured as shown in the ArcGIS window.	The physical design of RoadStructures layer with Bridge and Culvert subtypes is pictured as shown in the ArcGIS window.	The physical design of PedestrianWalkway (with four subtypes), WalkwayNode and WalkwayDeteriorations layers are pictured as shown in the ArcGIS window.	The physical design of Streetlights layer with High-Pressure, Incandescent and Florescent subtypes is pictured as shown in the ArcGIS window.

4.2.3.3.2 The Water Supply Network Dataset Model

The water supply feature dataset includes all of the geospatial data desired by the water supply SAA. Borehole, water supply networks, and reservoir data are contained in the water supply network feature dataset (Figure 4.20).

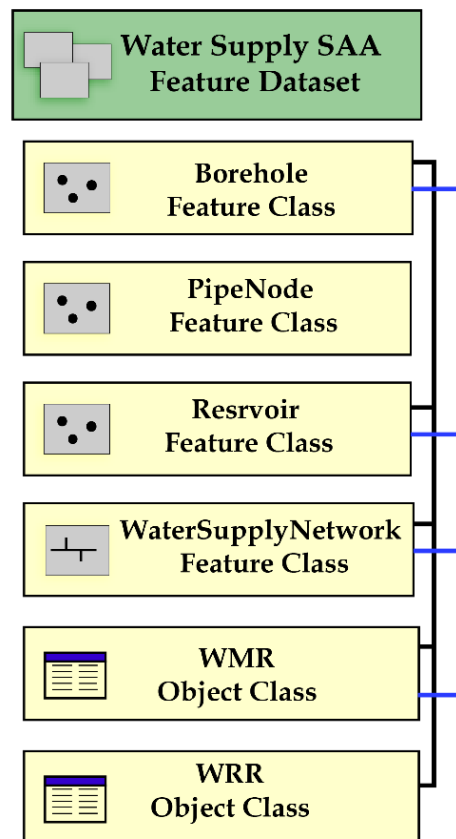


FIGURE 4.20: THE WATER SUPPLY NETWORK SAA DATASET MODEL

The Borehole, PipeNode, Reservoir, and WaterSupplyNetwork feature classes, WaterSupply MaintenanceRates (WMR), and WaterSupplyReplacementRates (WRR) object classes are the six datasets contained in the water supply network feature dataset.

The Borehole feature class documents boreholes on GCA. Its attribute structure built to store all discreet information concerning boreholes, such as well depth, construction year, and construction materials. The WMR object class documents all of the important maintenance cost information. In order to estimate the maintenance cost of boreholes, a key attribute was created between Borehole feature class and WMR object class by using the GeneralCondition field as a key field to link the two datasets.

The PipeNode feature class primary function is to represent starting and ending junction of a pipe segment. It store all discreet information concerning pipe node locations, such as x and y coordinate of a water pipe junction, and its locality name.

The Reservoir feature class contains reservoir locations and, associated reservoir management data. The WRR object class documents all of the important replacement cost information. In order to estimate the current economic value of reservoir, a key attribute was created to link Reservoir feature class to WRR object class. The MaterialType is the key field linking the two datasets. To estimate the maintenance cost of reservoirs another key attribute was created with WMR object class by using the GeneralCondition field as a key field.

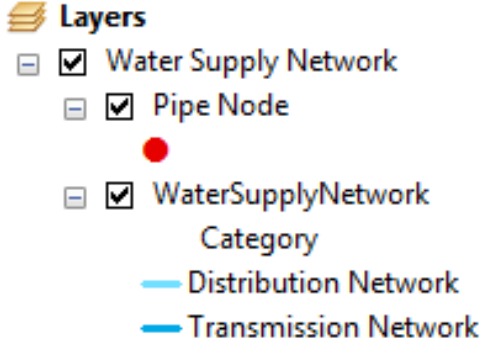
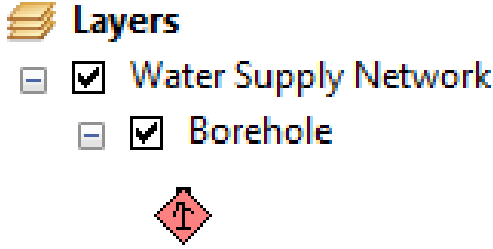
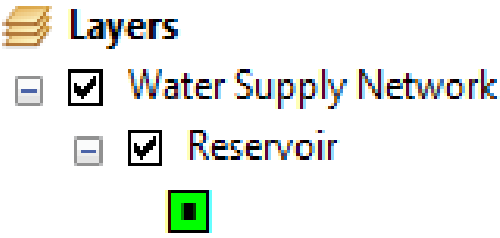
The WaterSupplyNetwork feature class contains all necessary subtypes to represent transmission and distribution networks found in GCA. Its attribute structure built to store all discreet information concerning water supply network, such as pipe material, diameter, and installation year. In order to calculate current economic value of pipes, a key attribute was created to link RoadNetwork feature class to MRR object class. The PipeMaterial is the key field linking the two datasets.

The WMR object class houses all of the necessary data including each maintenance rates of Boreholes, Reservoir, and WaterSupplyNetwork feature classes. Its attribute structure built to store all discreet information concerning maintenance rates, such as maintenance type and maintenance rate.

The WRR object class contains each replacement rates of Boreholes, Reservoir, and WaterSupplyNetwork feature classes. Its attribute structure built to store all discreet information concerning replacement rates, such as material type and replacement rate.

The Water Supply Network SAA feature dataset contains all of the necessary geospatial data in a well-organized geodatabase structure to capture water supply network, boreholes, and reservoirs assets on GCA. The defined key attributes will allow the capability of to store necessary required information for easy management, documentation, and analysis. Table 4.49 shows, the physical design of the water supply network SAA dataset in the ArcGIS environment with layer descriptions.

Table 4.49: Physical Design layers of the Water Supply Network

Layer Name	Physical Design	Description
WaterSupplyNetwork	 Layers ☒ Water Supply Network ☒ Pipe Node  ☒ WaterSupplyNetwork Category  Distribution Network  Transmission Network	The physical design of Pipe Node and WaterSupplyNetwork layer with Transmission and Distribution Network subtypes shown in the ArcGIS window.
Borehole	 Layers ☒ Water Supply Network ☒ Borehole 	The physical design of Borehole layer shown in the ArcGIS window.
Reservoir	 Layers ☒ Water Supply Network ☒ Reservoir 	The physical design of Reservoir layer is shown in the ArcGIS window.

4.2.3.3.3 Environmental Service Dataset Model

The environmental service feature dataset contains all of the desired geospatial data for the environmental SAA at GCA. Datasets needed include drainage network, recreations, and street greenery information. Refer to Figure 4.21.

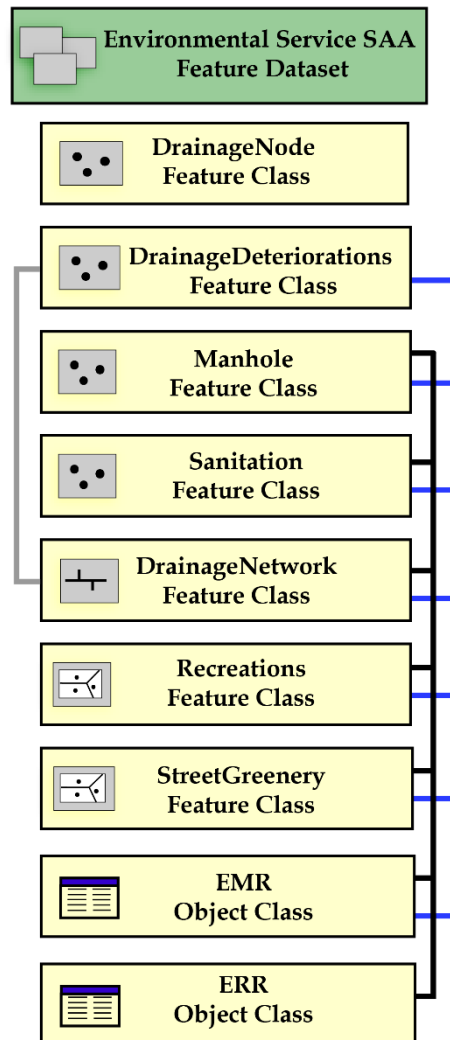


FIGURE 4.21 : THE ENVIRONMENTAL SERVICE SAA DATASET MODEL

The environmental service feature dataset contains DrainageNode, DrainageDeteriorations, Manhole, Sanitation, DrainageNetwork, Recreations, and StreetGreenery feature classes, EnvironmentalMaintenanceRates (EMR), and EnvironmentalReplacementRates (ERR) object classes are the nine datasets contained in the water supply network feature dataset.

The DrainageNode feature class primary function is to represent starting and ending junction of a drainage segment. It store all discreet information concerning drainage node locations, such as x and y coordinate of a drainage junction, and its locality name.

The DrainageDeteriorations feature class contains deterioration location, deterioration extent, and maintenance cost requirements of the deteriorated area within drainage networks. The EMR object class documents all of the important maintenance cost information. In order to estimate the maintenance cost of drainage deteriorations, a key attribute was created between DrainageDeteriorations feature class and EMR object class by using the DeteriorationType field as a key field to link the two datasets. Additionally, one key attribute was created to link DrainageDeteriorations and DrainageNetwork feature classes, the DrainageID is the key field linking the two datasets.

The Manhole feature class documents manholes on GCA. Its attribute structure built to store all discreet information concerning manholes, such as manhole depth, construction year, and construction materials. The ERR object class documents all of the important replacement cost information. In order to estimate the current economic value of manholes, a key attribute was created between Manhole feature class and ERR object class by using the MaterialType field as a key field to link the two datasets.

The Sanitation feature class contains the spatial location information of public bath, communal toilets and public toilets. In order to estimate the maintenance cost of sanitation, a key attribute was created between Sanitation feature class and EMR object class by using the GeneralCondition field as a key field to link the two datasets. Additionally, to calculate the current economic value of sanitations, a key attribute was created between Sanitation feature class and ERR object class by using the MaterialType field as a key field to link the two datasets.

The DrainageNetwork feature class contains all necessary subtypes to represent various types of drainage networks found in GCA. Its attribute structure built to store all discreet information concerning drainage network, such as drainage width, deterioration type, and construction year. In order to calculate current economic value of drainages, a key attribute was created to link DrainageNetwork feature class to ERR object class. The DrainageType is the key field linking the two datasets.

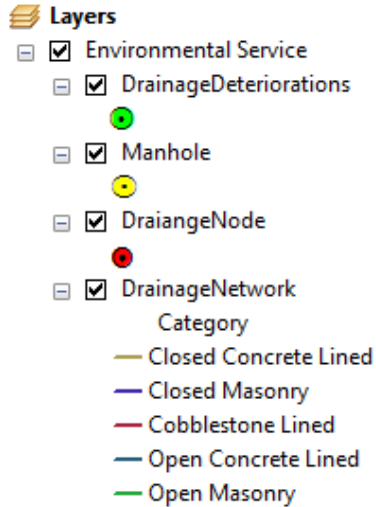
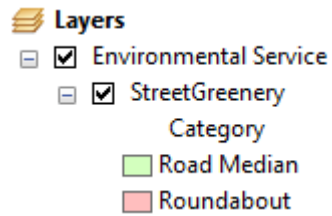
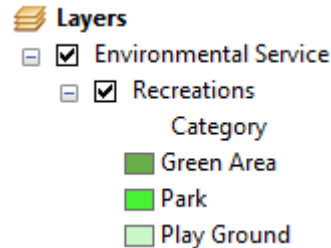
The Recreations feature class documents recreations including park, playgrounds, and green areas on GCA. Its attribute structure built to store all discreet information concerning manholes, such as paved material, fence material type, and condition of recreations. In order to estimate the current economic value of recreations, a key attribute was created between Recreation feature class and ERR object class by using the MaterialType field as a key field to link the two datasets.

The StreetGreenery feature class contains road median greenery, and roundabouts found in GCA. In order to estimate the maintenance cost of street greenery, a key attribute was created between StreetGreenery feature class and EMR object class by using the GeneralCondition field as a key field to link the two datasets. Additionally, to calculate the current economic value of street greenery, a key attribute was created between StreetGreenery feature class and ERR object class by using the MaterialType field as a key field to link the two datasets.

The EMR object class houses all of the necessary data including each maintenance rates of DrainageNetwork, Sanitation, Manhole, Recreation and StreetGreenery feature classes. Its attribute structure built to store all discreet information concerning maintenance rates, such as maintenance type and maintenance rate.

The ERR object class contains each replacement rates of DrainageNetwork, Sanitation, Manhole, Recreation and StreetGreenery feature classes. Its attribute structure built to store all discreet information concerning replacement rates, such as material type and replacement rate. The environmental service feature dataset captures all of the prudent information necessary for the GCA users to accomplish their duties and responsibilities. Table 4.50 shows, the physical design of the environmental service SAA dataset in the ArcGIS environment with layer descriptions.

Table 4.50 : Physical Design layers of the Environmental Service

Layer Name	DrainageNetwork	Sanitation	StreetGreenery	Recreations
Physical Design				
Description	The physical design of DrainageDeteriorations, Manhole, DrainageNode, and DrainageNetwork (with five subtypes) layers are pictured as shown in the ArcGIS window.	The physical design of Sanitation layer is pictured as shown in the ArcGIS window.	The physical design of StreetGreenery layer with Road Median and Roundabout subtypes is pictured as shown in the ArcGIS window.	The physical design of Recreations layer with Green Area, Park and Play Ground subtypes is pictured as shown in the ArcGIS window.

4.2.3.3.4 Social and Economic Service Dataset Model

The social and economic service dataset captures all of the geospatial data requirements by social and economic service SAA. Community service and administrative buildings, MSE shades, and fence data are contained in this feature dataset model (Figure 4.22).

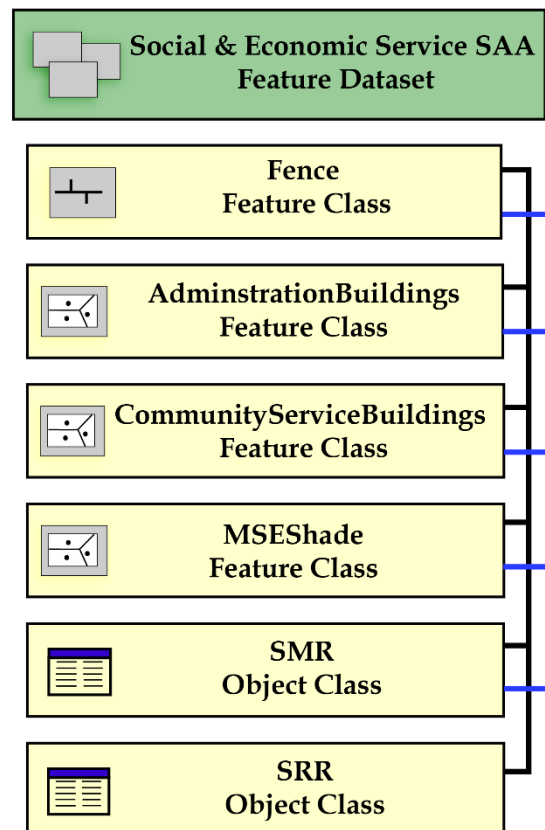


FIGURE 4.22: THE SOCIAL AND ECONOMIC SERVICE SAA DATASET MODEL

The social and economic service feature dataset contains the Fence, AdministrativeBuildings, CommunityServiceBuildings, and MSEShade feature classes, SocialMaintenanceRates (SMR), and SocialReplacementRates (SRR) object classes.

The Fence feature class documents boundary fences of different institutions owned by the GCA. Its attribute structure built to store all discreet information concerning fences, such as fence material, condition, and construction year. The SMR object class documents all of the important maintenance cost information. In order to estimate the maintenance cost of Fence, a key attribute was created between Fence feature class and SMR object class by using the GeneralCondition field as a key field to link the two datasets.

The AdministrativeBuildings feature class contains all necessary data to represent administrative buildings found in GCA. Its attribute structure built to store all discreet information concerning buildings, building function, building structure materials, and condition. The SRR object class documents all of the important replacement cost information. In order to calculate current economic value of buildings, a key attribute was created to link AdministrativeBuildings feature class to SRR object class. The StructureConcatenation is the key field linking the two datasets.

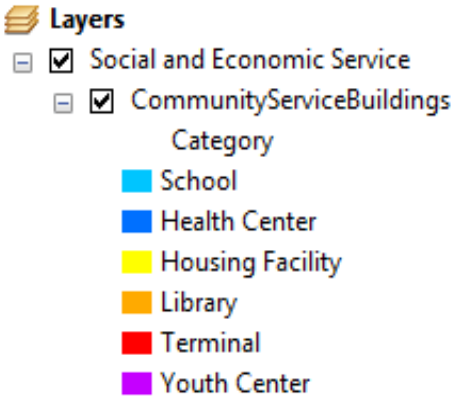
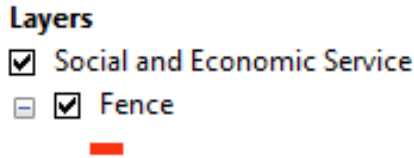
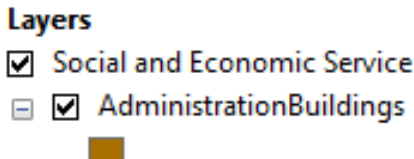
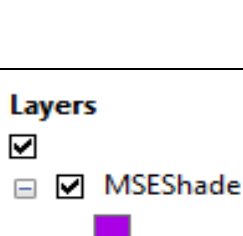
The CommunityServiceBuildings feature class documents all necessary subtypes to represent various types of administrative buildings such as schools, health center, terminals, youth center, and housing facilities found in GCA. Its attribute structure built to store all necessary information concerning buildings, such as building function, building structure materials, and construction year. In order to estimate the maintenance cost of buildings, a key attribute was created between CommunityServiceBuildings feature class and SMR object class by using the GeneralCondition field as a key field to link the two datasets.

The MSEShade feature class documents MSE shades on GCA. Its attribute structure built to store all discreet information about manholes, such as shade structure materials, construction year, and condition. In order to estimate the maintenance cost of buildings, a key attribute was created between MSEShade feature class and SMR object class by using the GeneralCondition field as a key field to link the two datasets. Additionally, to calculate the current economic value of MSE shades, a key attribute was created between MSEShade feature class and SRR object class by using the StructureConcatenation field as a key field to link the two datasets.

The SMR object class houses all of the necessary data including each maintenance rates of AdministrativeBuildings, CommunityServiceBuildings, and MSEShade feature classes. Its attribute structure built to store all discreet information concerning maintenance rates, such as maintenance type and maintenance rate.

The SRR object class contains each replacement rates of AdministrativeBuildings, CommunityServiceBuildings, and MSEShade feature classes. Its attribute structure built to store all discreet information concerning replacement rates, such as material type and replacement rate. The social and economic service feature dataset fulfills all of the data requirements of the social and economic service SAA of the AMP manual. Table 4.51 shows, the physical design of the social and economic service SAA dataset in the ArcGIS environment with layer descriptions.

Table 4.51 : Physical Design layers of the Social and Economic Service dataset

Layer Name	Physical Design	Description
CommunityService Buildings		The physical design of CommunityServiceBuildings layer with Six subtypes shown in the ArcGIS window.
Fence		The physical design of Fence layer shown in the ArcGIS window.
Administration Buildings		The physical design of AdministrationBuildings layer is shown in the ArcGIS window.
MSE Shade		The physical design of MSE Shade layer is shown in the ArcGIS window.

The physical phase were illustrates the geodatabase model in its entirety, beginning with the complete geodatabase, which is then separated into individual AMP SAA for further discussion. The diagrams were illustrate the organization, data models, relationships, and discussed more broadly, by explaining the data's purpose and function. The ArGIS 10.6 geodatabase format was utilized to organize and display AMP GIS layers. In the next section, the study will populate and test the designed AMP geodatabase model functionality by AMP computations and information retrieval.

4.2.4 Populate the Designed AMP Geodatabase Model

Build the geodatabase is the last component in geodatabase design. In order to build the designed geodatabase, it was necessary to populate and test a prototype implementation for the selected sub cities. This section discusses two related topics: (1) populate the prototype AMP geodatabase, and (2) testing of the functionality of AMP geodatabase performance. The result of the populated geodatabase layers will present as per the four SAA of the AMP.

4.2.4.1 Populate the Movement Network

The summary of spatial and tabular data used to populate the designed MovementNetwork dataset layers is depicted in tables below; the populated spatial data (Table 4.52) is generated based on the pilot sub cities asset, whereas the tabular data (Table 4.53 and 4.54) is collected from GCA urban development and housing constriction office.

Table 4.52 : The Populated Movement Network Dataset Spatial Layers

Dataset	Feature Class	Sub Subtype	Populated Data Extent		Percent Populated
			<i>no</i>	<i>kms</i>	
MovementNetwork	RoadNetwork	Asphalt Road		8.99	21%
		Cobblestone Road		18.20	23%
		Compacted Earth Road		8.32	5%
		Gravel Road		0.31	1%
		Total		35.82	11%
	Streetlight	High-Pressure Sodium	275		24%
		Incandescent	29		
		Florescent	19		
		Total	323		
	PedestrialWalkway	Precast Walkway		0.43	15%
		Asphalt Walkway		0.11	29%
		Tiles walkway		5.57	28%
		Total		6.11	21%
	RoadStructures	Culvert	14		10%
		Bridge	3		10%
		Total	17		10%

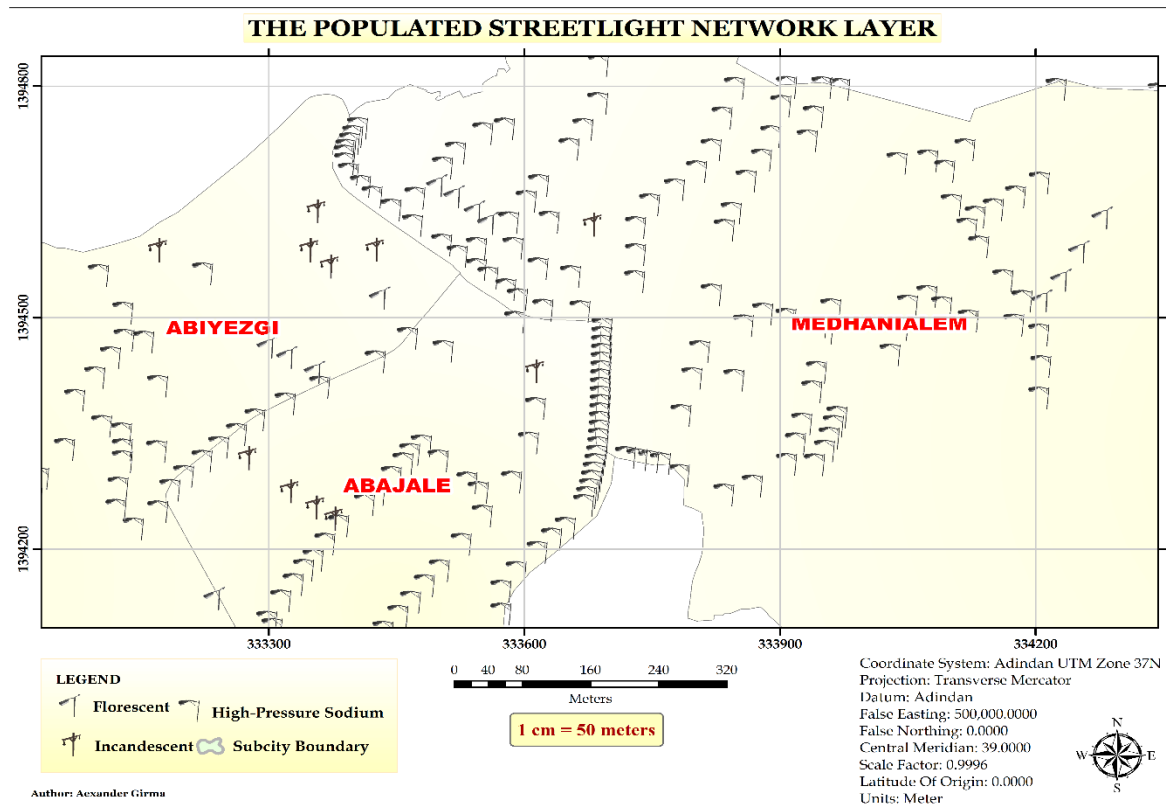


FIGURE 4.23 : PARTIAL VIEW OF THE POPULATED STREETLIGHT LAYER

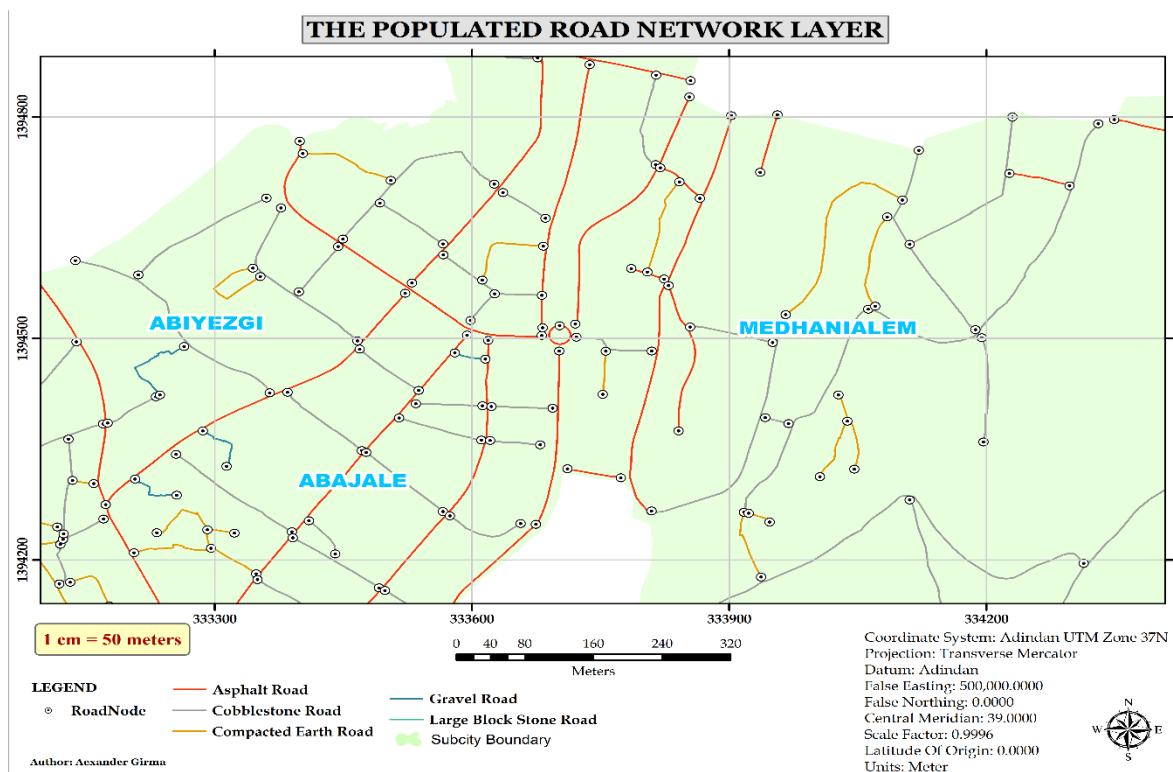


FIGURE 4.24 : PARTIAL VIEW OF THE POPULATED ROADNETWORK LAYER

Table 4.53 : The populated Movement Network replacement rate tabular data

ReplacementFunctions	Replacement Unit Rates ETB	EstimatedDesignLife
Asphalt Road	10,000,000.00	20
Asphalt Walkway	3,500,000.00	20
Bridge	83,336.00	20
Clay Tile Walkway	3,100,000.00	20
Cobblestone Road	11,046,554.00	20
Cobblestone Walkway	2,500,000.00	20
Compacted Earth Road	1,500,000.00	20
Culvert	5,952.00	20
Gravel Road	2,870,000.00	20
Large Block Stone	2,500,000.00	20
Precast Walkway	3,000,000.00	20
Florescent	8,500.00	30
High-Pressure Sodium	26,477.00	30
Incandescent	4,200.00	30

Table 4.54 : The populated MovementNetwork maintenance rate tabular data

MaintenanceFunctions	MaintenanceUnitRates ETB
RN Channeling	105.00
RN Cobble Edge Failure	650.00
RN Crack	470.00
RN Depression	415.00
RN Lifting of Cobblestone	690.00
RN Peeling Major	395.00
RN Peeling Minor	395.00
RN Pothole	713.00
RN Wash Away	105.00
RS Abutment Failure	2,500.00
RS Siltation	470.00
RS Slab Failure	2,000.00
WN Crack	300.00
WN Depression	600.00
WN Lifting of Cobble Stone	690.00
WN Surface Peeling	295.00

4.2.4.2 Populate the Water Supply Network

Table 4.55: The Populated WaterSupplyNetwork Dataset Spatial Layers

Strategic Activity Area	Category	Sub-Category	Populated Data Extent
			Kms
The Water Supply Network	Water Supply	Distribution Network	13.62
		Total	13.62

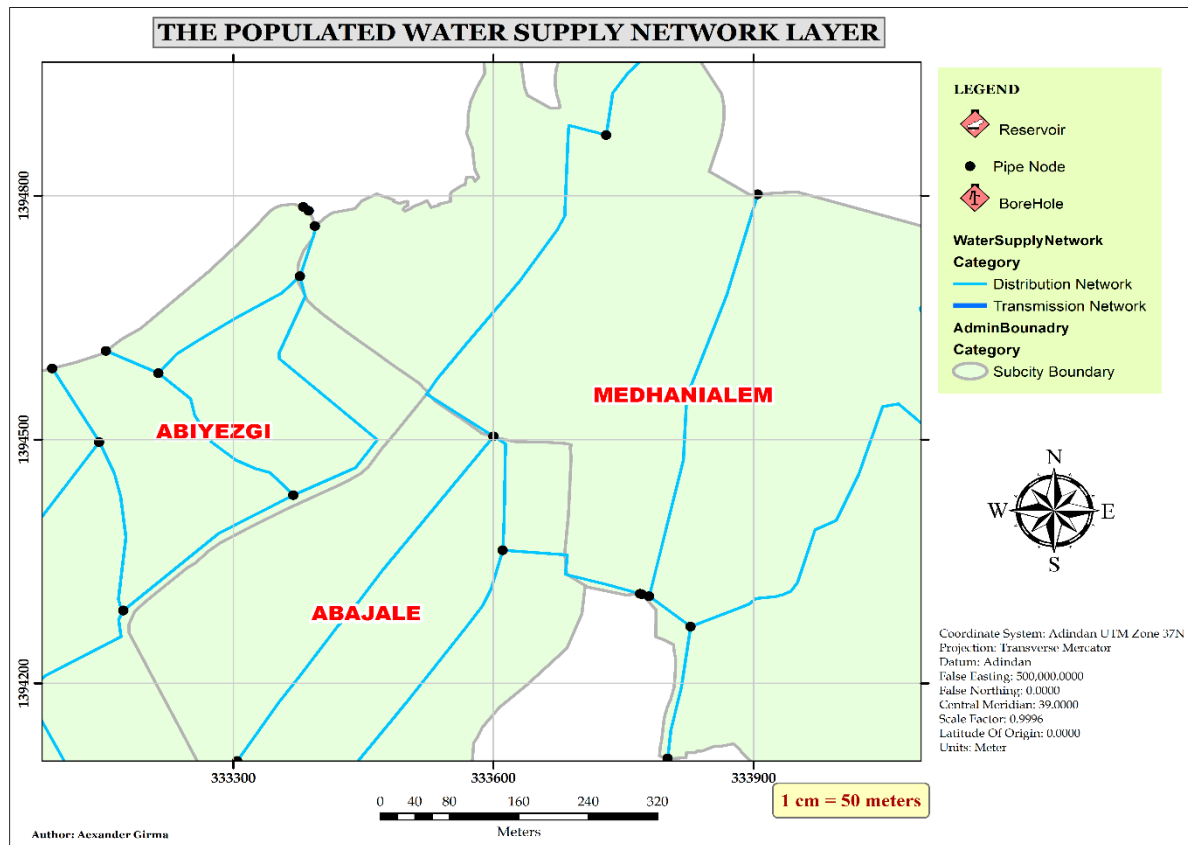


FIGURE 4.25 : PARTIAL VIEW OF THE POPULATED WATER SUPPLY NETWORK LAYER

4.2.4.3 Populate Environmental Service

Table 4.56 : The Populated Environmental Service Dataset Spatial Data

Dataset	Feature Class	Subtypes	Populated Data Extent		
			No.	Kms	Area (m2)
Environmental Service	Drainage Channel	Closed Concrete Drain		2.70	
		Cobble Lined Drain		2.87	
		Closed Masonry Drain		3.67	
		Open Masonry Drain		4.81	
		Open Concrete Drain		3.90	
		Drainage Manholes	67		
		Total	67	17.95	
	Greenery & Recreation	Pay Ground			622.25
		Green Area			1582.20
		Park			455.45
		Road Median			1132.27
		Round about			265.43
		Total		17.95	4057.61
	Sanitation	Communal Toilet	19		
		Public Bath	1		
		Total	20		
		Grand Total	87	17.95	4057.61

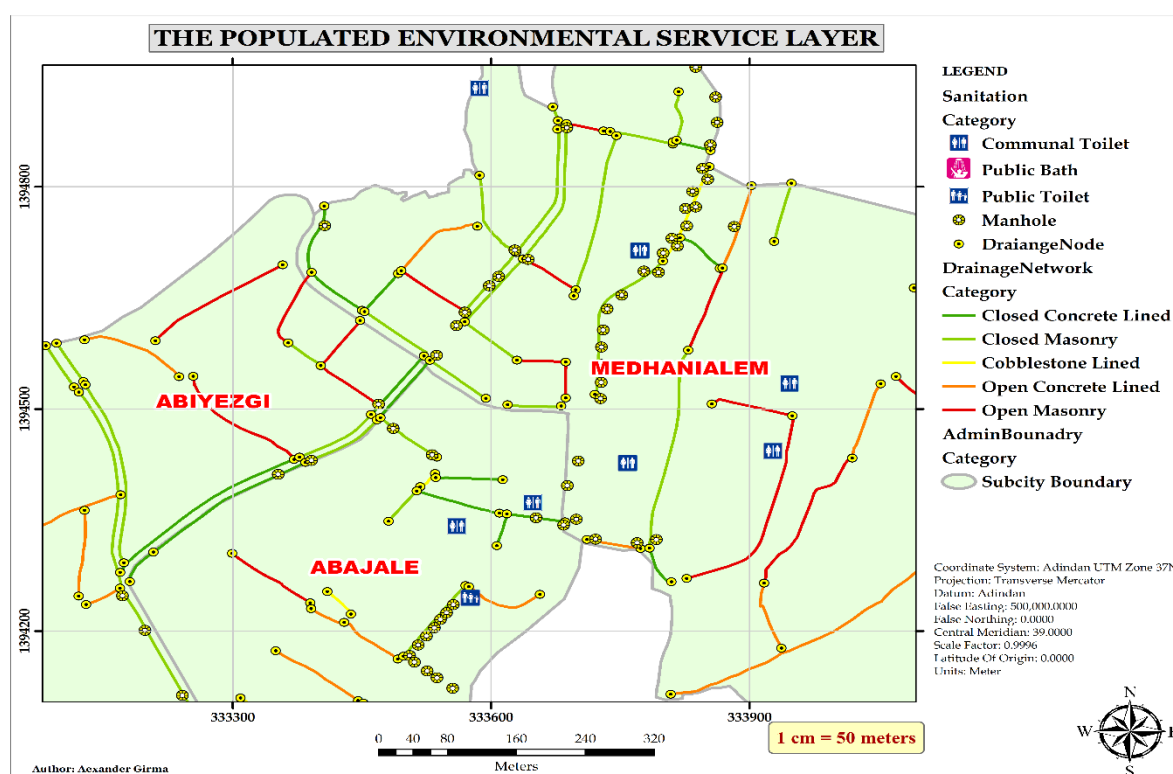


FIGURE 4.26 : PARTIAL VIEW OF THE POPULATED ENVIRONMENTAL SERVICE LAYERS

Table 4.57 : The populated building structure replacement rate tabular data

Foundation		Floor		Wall		Roof	
Material	Unit Rate ETB	Material	Unit Rate ETB	Material	Unit Rate ETB	Material	Unit Rate ETB
Concrete	3,200.00	Concrete	1,900.00	CIS	750.00	CIS	500.00
Timber	1,150.00	Earthen	1,000.00	Concrete	3,000.00	EGA Sheet	750.00
Stone	2,300.00	Wooden	1,500.00	Timber	1,500.00	Concrete	2,200.00
				Hollow Blocks	2,200.00		
				Lamera	1,250.00		
				Stone Masonry	2,100.00		

Table 4.58 : The populated DrainageNetwork replacement rate tabular data

Drainage Network Maintenance Rates	
Deterioration Type	Unit Rate ETB
Minor Joint Damage	120.00
Major Joint Damage	140.00
Wall Collapse	1,005.00
Floor Damage	170.00
Cover Material Damage	1,045.00
Siltation and Deposition	520.00

4.2.4.4 Populate Social and Economical Service

Table 4.59 : The Populated Social and Economic Service Dataset Spatial Layers

Dataset	Feature Class	Sub Subtype	Populated Data Extent	
			No.	Area (m2)
Social & Economical Activities	CommunityServiceBuildings	Health Center	9	922.72
		Educational Institute	3	7190.77
	AdministrationBuildings	---	26	6713.76
		Total	38	14827.24
	MSEShade	---	6	1334.56
		Total	6	1334.56
		Grand Total	44	16161.80

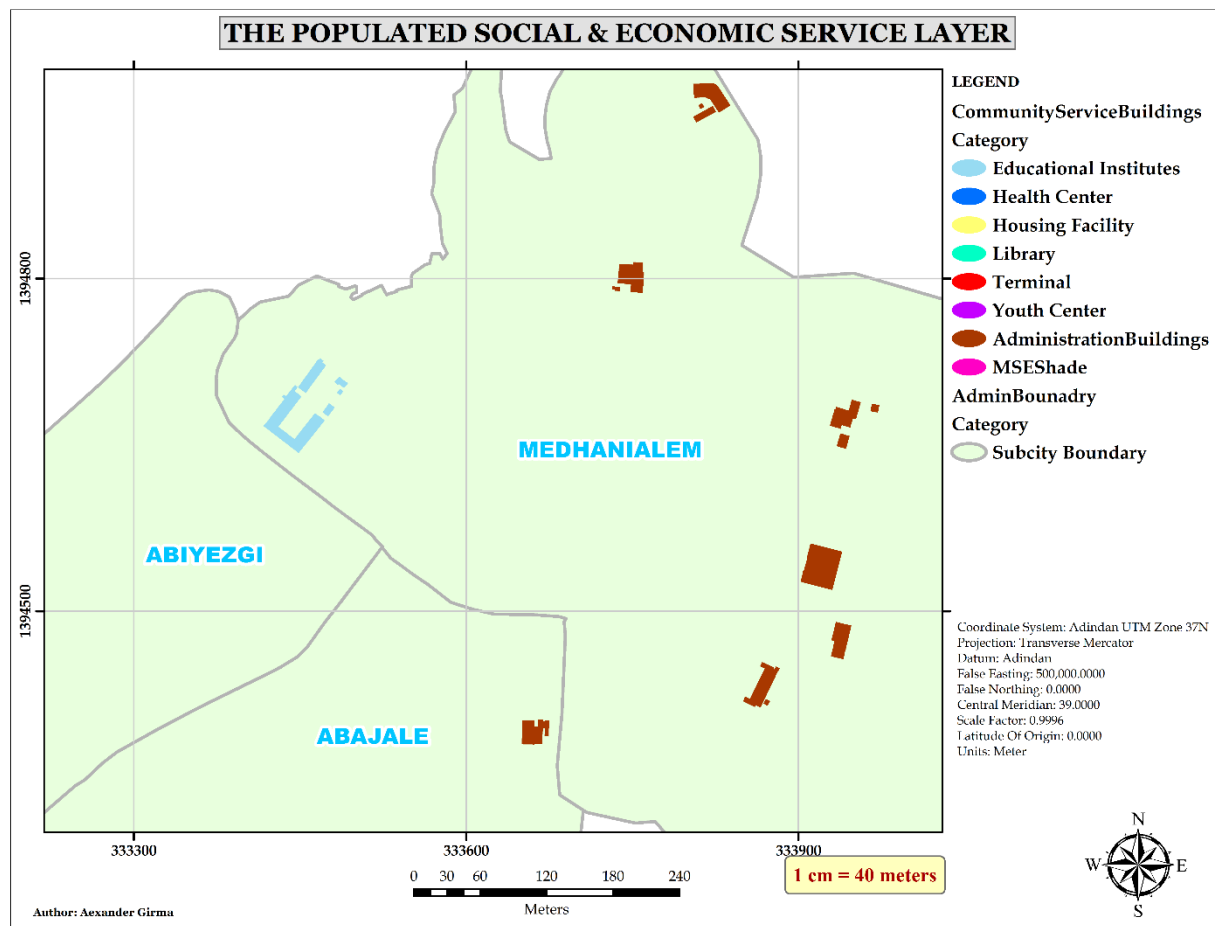


FIGURE 4.27 : PARTIAL VIEW OF THE POPULATED SOCIALECONOMINC SERVICE DATASET LAYERS

4.2.5 Development of Customized AMP Geoprocessing Tools

Geoprocessing functionality has come a long way since it was first introduced in released of ArcGIS 9, geoprocessing functionality can be accessed by running tools in ArcToolbox (ESRI, 2013). There are hundreds of tools installed with ArcGIS, which are built using ArcObjects and a compiled programming language like .NET, ModelBuilder and Python Scripts. A user can create its own customized tools based its interest (ESRI, 2018).

As the study examines, from the total attributes of an AMP layer, on the average usually only 30 % of attribute values are encoded by the user. The remaining 70 % attributes are estimated by computations (MUDHCo, 2016 pp. 121-124). This computations output primarily determines maintenance and replacement costs of an asset. The AMP computation comprises several formulas, which are contains from simple arithmetic operations to advanced logical relationships between attributes. List of AMP formulas that are used to compute the RoadNetwork layer attributes is described in the following Table 4.60.

Accordingly, the study develops customized AMP geoprocessing tools that are intended to automate the AMP computations of the RoadNetwork layer. The main objective of developing these geoprocessing tools is to perform the AMP computation independently inside the ArcGIS environment, aimed to solve the current computation inconsistency issues.

In this study, AMP computation operation is executes by using customized AMP tools, which are developed by integrating ModelBuilder with Python and VB scripts. These toolboxes are aided by simple user visual interfaces, and they are instantly execute multiple AMP geoprocessing operations. Additionally, the customized AMP tools will used to test the designed geodatabase model.

List of attribute fields used to compute the road network AMP computations with respect to corresponding formulas⁹ are depicted in the Table 4.60 below.

Table 4.60 : List formulas used to develop customized geoprocessing tool for RoadNetwork layer

Field Name	Field Name Code	Formula	Description
Age	Ag	$Cu - Cy + 1$	Age of the road
AssetDeficit	As	$EC - Mc$	
Carriage Width	Ca	(User Input)	Encoded by the user
Condition	Co	(Conditional Statements) ¹⁰	
CurrentYear	Cu	(VB Script)	Determined by using VB scripts
Construction Year	Cy	(User Input)	Construction Year of the road, encoded by the user
Deterioration Percentage	Dp	Da/Su	The percent of deteriorated area against the total surface area
Deterioration Area	Da	(User Input)	Deterioration area measured from field observation
DRC	DR	(Conditional Statements)	Depreciated replacement cost
EstimatedCurrentValue	EC	(Conditional Statements)	
EQL7mkm	EQ	$Su/7000$	Equivalent length of the road in km with standard seven meter width
ERC	ER	$EQ * Re$	Estimated replacement cost
EUL	EU	(User Input)	Expected useful life
Length	Le	(default)	Auto generated by the geodatabase
Maintenance Rate	Ma	(User Input)	Maintenance rate encoded by the user
Maintenance Cost	Mc	$Da * Ma$	Maintenance cost
PercentRUL	Pe	Ag/EU	Percent remaining useful life
Replacement Rate	Re	(User Input)	Replacement rate
RUL	RU	$EU - Ag$	Remaining useful life
SurfaceArea	Su	$Le * Ca$	Surface area

⁹ The formulas are used from the AMP Manual (2016) pp 121 - 124

¹⁰ Determine by python script expression, the detail syntaxes are attached in the Appendix E

The above Table 4.60 formulas and scripts are transformed into syntaxes and imported in the ArcGIS ModelBuilder models, to interact the users easily with the models two customized ArcGIS tools were created for RoadNetwork as pictured in Figure 4.28 and 4.29.

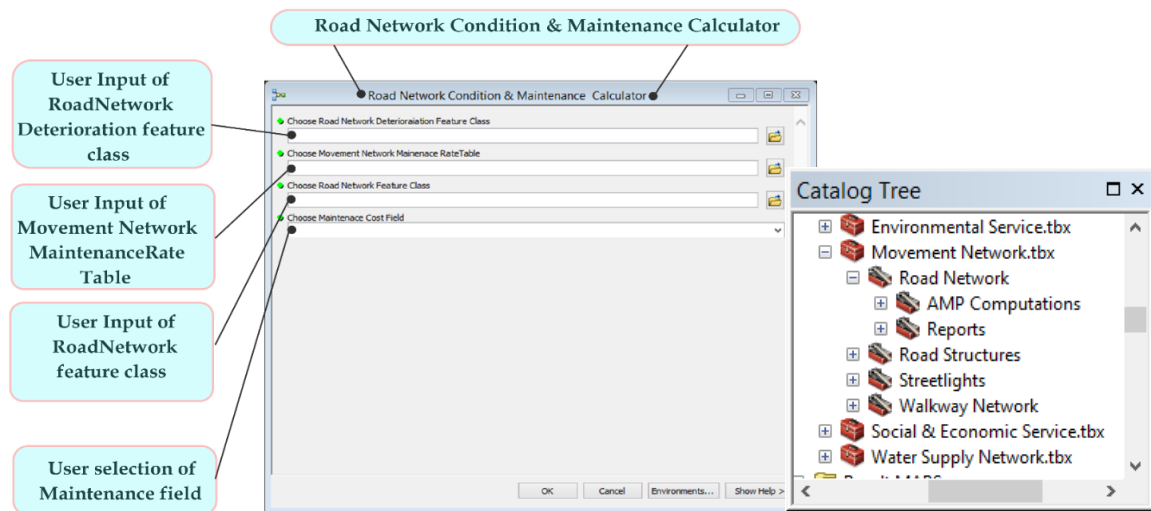


FIGURE 4.28: ROAD NETWORK CONDITION & MAINTENANCE CALCULATOR TOOL

The first customized tool¹¹ (Figure 4.28) calculates the RoadNetwork condition and maintenance cost, it has four input parameters; (1) RoadDeteriorations feature class, (2) MovementMaintenanceRates table, (3) RoadNetwork feature class and (4) MaintenanceCost field.

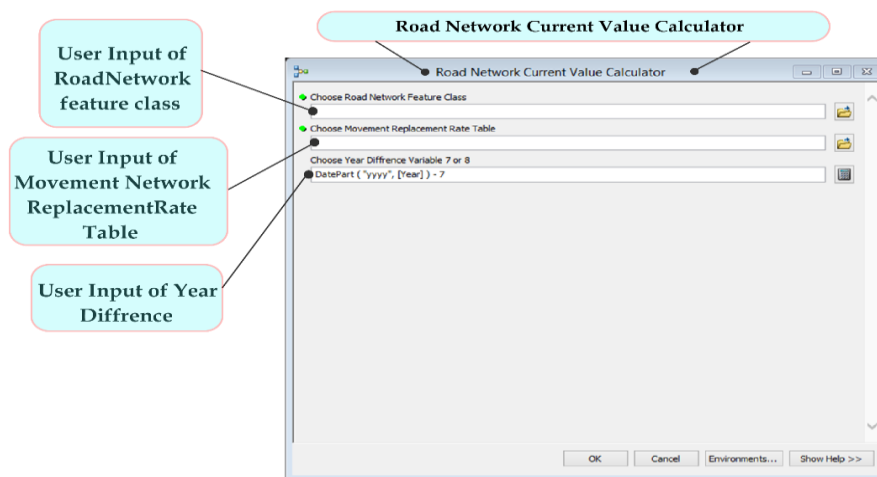


FIGURE 4.29: ROAD NETWORK CURRENT VALUE CALCULATOR TOOL

The second tool (Figure 4.29) calculates the RoadNetwork current value; it has three input parameters, (1) RoadNetwork feature class, (2) MovementReplacementRates table, and (3) the year difference between Ethiopian and Gregorian calendar (7/8). The last parameter is

¹¹ The source code of both tools is attached in the Appendix G

particularly used to calculate the current Ethiopian year based on the computer Gregorian calendar.

4.2.6 Test the Designed Geodatabase Model

Testing of the designed geodatabase performance is conducted by AMP computation and data retrieval operations, for this task the developed AMP geoprocessing tools are used here to test the RoadNetwork layer. Parameter

4.2.6.1 Test the Geodatabase Model via AMP Computations

The first AMP computation test output primarily determines condition and maintenance cost of the road network assets. Figure 4.30 shows the events of (A) before and (B) after the customized road network condition & maintenance calculator tool (Figure 4.28) execution.

A

Table			
RoadNetwork			
	Condition	TotalDeteriorationArea	TotalMaintenanceCost
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0

B

Table			
RoadNetwork			
	Condition	TotalDeteriorationArea	TotalMaintenanceCost
	Moderate	88.058125	ብር 34,782.96
	Good	59.826979	ብር 34,393.92
	Poor	323.447867	ብር 33,962.03
	Very Poor	314.175559	ብር 32,988.43
	Poor	310.419878	ብር 32,594.09
	Very Poor	292.925989	ብር 30,757.23
	Poor	289.731305	ብር 30,421.79

FIGURE 4.30 : EVENTS (A) BEFORE AND (B) AFTER THE ROAD NETWORK CONDITION & MAINTENANCE CALCULATOR EXECUTION

As shown in the Figure 4.30 B, the geodatabase correctly retrieve the necessary condition and maintenance cost computations of road network asset.

The second AMP computation test output primarily determines current economic value of the road network assets. Figure 4.31 shows the events (A) before and (B) after the customized road network current value calculator tool (Figure 4.29) execution.

A

Table				
RoadNetwork				
	AssetDeficit	CurrentYear	DepreciatedReplacementCost	EstimatedCurrentValue
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

B

Table				
RoadNetwork				
	AssetDeficit	CurrentYear	DepreciatedReplacementCost	EstimatedCurrentValue
	ብር 160,888.79	2011	ብር 83,463.99	ብር 47,771.19
	ብር 926,020.29	2011	ብር 479,897.02	ብር 445,114.06
	ብር 4,388,834.95	2011	ብር 1,866,189.01	ብር 1,831,795.10
	ብር 151,106.12	2011	ብር 78,096.06	ብር 44,134.04
	ብር 86,847.10	2011	ብር 35,905.78	ብር 2,917.34
	ብር 144,178.62	2011	ብር 74,389.69	ብር 41,795.60
	ብር 80,973.11	2011	ብር 33,477.26	ብር 2,720.03
	ብር 135,354.65	2011	ብር 69,955.24	ብር 39,533.46

FIGURE 4.31 : EVENTS BEFORE (A) AND AFTER (B) THE ROAD NETWORK CURRENT VALUE CALCULATOR EXECUTION

As shown in the Figure 4.31 B, the geodatabase correctly retrieve the necessary current economic value computations of road network asset.

4.2.6.2 Test the Geodatabase Model via Information Retrieving

In order to test the designed geodatabase model via information retrieving, two AMP manual requirement cases are chosen (1) report on maintenance activities and required budgets for deteriorated assets (MUDHCo, 2016 p. 106) and (2) current economic value of asset (MUDHCo, 2016 p. 126). In this section, the study present how these computations successfully summarized and reported from the designed geodatabase. The following Figure 4.32 shows, the summarized deteriorated area with the required maintenance budget of the road network subtypes. Additionally, Figure 4.33 shows, the summarized replacement costs and current economic value of the road network subtypes.

Table				
Road Network Maintenance				
OBJECTID *	Surface Material	TotalDeterioration Area	Total Maintenance Cost	
1	Asphalt Road	1844.96	ብር 1,132,569.24	
2	Cobblestone Road	1552.49	ብር 458,861.69	
3	Compacted Earth Road	22361	ብር 2,380,296.29	
4	Gravel Road	99.1009	ብር 16,886.97	

FIGURE 4.32 : SUMMARIZED INFORMATION OF THE ROAD NETWORK DETERIORATION AREA VS MAINTENANCE COST

As shown in the Figure 4.32, the geodatabase correctly retrieve the necessary maintenance budget information of road network asset. Accordingly, based on the results, the GCA require approximately 4 million ETB budget for all road network surface material types (for only pilot sub-cities) maintenance. The result further revealed that compacted earth road has the maximum deteriorated area of 22,361.00m² (2.2 ha), which requires an estimated of 2.3 million ETB maintenance budget.

Table				
Road Network Current Value				
OBJECTID *	Subtypes	Estimated Current Value	Estimated Replacement Cost	Maintenance Cost
1	Asphalt Road	ብር 19,164,460.71	ብር 89,858,832.50	ብር 1,132,569.24
2	Cobblestone Road	ብር 134,119,886.07	ብር 201,039,427.37	ብር 458,861.69
3	Compacted Earth Road	ብር 2,045,102.81	ብር 12,485,349.28	ብር 2,380,296.29
4	Gravel Road	ብር 424,056.16	ብር 891,396.75	ብር 16,886.97

FIGURE 4.33 : SUMMARIZED INFORMATION OF THE ROAD NETWORK CURRENT ECONOMIC VALUE

As shown in the Figure 4.33, the designed geodatabase correctly retrieve the road network current value information. The result revealed that the estimated current value (ECV) of road network is about 155.75 million ETB (for the pilot sub-cities). The result further revealed that cobblestone road has the maximum ECV, which is accounted about 134.11 million ETB.

4.3 Discussions

This section reviews the work accomplished in this thesis, by examining the initial problems faced by the GCA AMP geodatabase. The study research questions are restated below in section 4.3.1 and 4.3.2, in order to verify their realization and state the discussion drawn from the associated research questions.

The theoretic approach is discussed to demonstrate the need for effective AMP geodatabase schema design. The GIS approach is discussed to identify how results of the model were formed, and how the goals were reached.

4.3.1 The Existing GCA AMP Geodatabase

The stated first research question was “what are the major drawbacks of the existing GCA AMP geodatabase?”

A number of discussion can be drawn from the results presented in result section and which belong to the first research question. Although the GCA AMP geodatabase was assessed based on the standard geodatabase requirements and AMP specifications, the study results still provide meaningful finding and insights that could be generalized the overall geodatabase current status.

Results during the in-depth geodatabase assessment revealed that GIS data model selection mostly carried out without consideration of the ultimate objective of the AMP geodatabase. As presented in Table 4.1, revealed that from the total thirty-seven feature classes of the existing geodatabase about 62% were found as redundant. For example, the GCA annually must report its Movement Network (MN) SAA assets extent based on the AMP manual requirements (MUDHCo, 2016 pp. 70-72). As shown in the Table 4.1, the MN SAA has a total of twelve feature classes. Therefore, to report the MN SAA asset extents, the user must access all the twelve feature classes. However, as the evaluation result revealed from the existing MN SAA feature classes, about eight (67 %) of feature classes unnecessarily created. That means data models in the MN SAA are modeled redundantly fragmented into a number of feature classes, this create the users to deal triple of times spent in data retrieving than the expected, as the required data model for MN SAA is only four feature classes (Table 4.1). The overall feature class redundancy of the GCA AMP geodatabase is about 62 % from the total thirty-seven feature classes; this implies that to report the whole GCA assets as per the AMP manual, the

user takes again triple of times more from the expected, as the required feature classes are only fourteen.

The results, as presented in Table 4.2, also showed that from the required 215 coded value domain attribute validation, about 81 % of the validations are not assigned in the existing attributes. The attribute assessment revealed that the GCA geodatabase is highly subject to attribute coding error. A misspelled word, using the wrong characters, spaces before or after characters are all common mistakes in the existing geodatabases (FIGURE 4.1). This incorrect attribute coding errors will affect the AMP queries or analyses focusing on those attribute values. For example, the GCA annually must report its road structures (culvert) assets maintenance deficit based on the five level of condition¹² of the AMP manual (MUDHCo, 2016 p. 45), as pictured the example of culvert feature class condition attribute in FIGURE 4.1 B, the culvert feature class condition attribute had several misspelled words of very good condition. This problem leads to the process of data retrieving to be highly dependent on manual editing. The overall attribute validation assessments is carried out by importing the GCA AMP geodatabase into UML profiles and summarized as presented in Table 4.2. The study therefore argues that those 81 % unassigned attribute are likely ready to accept any wrong or incorrect attributes.

The geodatabase assessment results further revealed that the existing layers attributes structure development is somehow carried out without examining of the tabular data sets of the MUDHCo AMP manual requirements. As presented in Table 4.3, revealed that from the required AMP attributes, about 14 % of them are forgotten. As shown in the Appendix D (the detail of attribute formation evaluation) one of the common forgotten attribute of all layers is % URL (Percent Remaining Useful Life) attribute of an asset. As specified in the AMP manual (MUDHCo, 2016 p. 123), in order to estimate CV (Current Value) of an asset, % URL parameter is critically important. However, as the result revealed almost all GCA assets CV estimation is conducted without the % URL parameter. This implies that the existing attribute is not complete or meet the actual attribute requirements of the AMP manual, and this incorrect asset CV estimation creates data variation problems throughout the AMP and unable to retrieve a correct information that will underpin the effective AMP decision-making processes of the GCA.

¹² V. Good, Good, Moderate, Poor or V. Poor

4.3.2 The AMP Geodatabase Design

The other research question was “which possible design is effective to develop a comprehensive AMP geodatabase model?”

A number of discussion can also be drawn from the results presented in result section and which belong to the second research question. The AMP geodatabase was designed based on the ESRI’s conceptual, logical and physical geodatabase design phases and applies them to GCA’s AMP geospatial data needs.

The study approach was to keep the AMP geodatabase design as proficient as possible, only including the AMP manual necessary data to meet the GCA AMP geospatial needs. AMP manual geospatial requirement analysis was needed for each SAA; this was essential to the success of designing of the AMP geodatabase. The main theoretical approaches within this study were to develop a proficient AMP geodatabase model schema to accommodate the data needs of the GCA AMP, while using all necessary geodatabase functionality. The design will based on the AMP manual requirements, which in turn will provide a sense of ownership to the GCA users. The design elements presented here are original designs created solely for this thesis, the primary and ultimate goal is to design an efficient GIS for the GCA to assist in their AMP geospatial needs. A main component in this design was to identify the requirements of the AMP, and capture the data needs from the observation during the past projects undertakings.

The GIS approach utilized the advanced functionality of the geodatabase model, customized the design for each of the AMP SAA, and captured all data needs of the GCA, while keeping the schema proficient and intuitive. Object classes were utilized to their full potential in housing the financial AMP data, and separating it out into similar categories. Key attributes were devised to connect appropriate data elements, making it easier to manipulate and manage the data. Design considerations included mapping functionality, update and data retrieval requirements, AMP manual requirements, and being user friendliness.

4.3.2.1 The AMP Geodatabase Model

One goal of relational database schema design is avoiding redundancy (Ramez, et al., 2011) (Hugh, 2010), recording the same information more than once. Storing redundant values leads to an additional problem referred to as update anomalies. These can be classified into modification anomalies, deletion anomalies and insertion anomalies (Ramez , et al., 2011), only modification anomalies is discussed solely for this study.

For example, consider the existing Road_Network GIS data model sample attributes of the following seven ULGs (Adama, 2016; Ambo, 2017; Burayu, 2017; Bahirdar, 2017; Debre Tabor, 2017; Gondar, 2017; Woldia, 2017) in the Table 4.61.

Table 4.61 : Example of the existing seven ULGs road network data model

Road_Network

RoadID	RSM	DT	MR (ETB)	RC (ETB)	EUL
1	Asphalt Road	Peeing Minor	395.00	10,000,000.00	20
2	Gravel Road	Depression	415.00	2,870,000.00	20
3	Cobblestone Road	Lifting	690.00	8,000,000.00	50
4	Asphalt Road	Peeing Minor	395.00	10,000,000.00	20
5	Cobblestone	Lifting	690.00	8,000,000.00	50
6	Gravel Road	Depression	415.00	2,870,000.00	20
7	Asphalt Road	Crack	470.00	10,000,000.00	20

As shown in the Table 4.61, Road_Network data model has; road number (RoadID), road surface material (RSM), deterioration type (DT), maintenance rate (MR), replacement cost (RC), and expected useful life (EUL) attributes.

Consider DT and MR attributes, for each Depression DT there is a corresponding MR value of 415.00 ETB. The same is true for RSM and RC attributes, for each Asphalt road in RSM there is RC value of 10,000,000.00 ETB. Therefore, the existing ULGs Road_Network GIS model is subjected to store redundant values, which leads update anomalies.

In this data model (the existing), if the user wants to change the value of one of the attributes of a particular MR say, Depression DT from 415.00 ETB to 500.00 ETB. The user must update the records of all MR, which corresponding in that DT; otherwise, the database will become inconsistent. If the user fails to update some records, the same DT will be shown to have two different values for MR in different records, which would be lead for a wrong maintenance cost estimation. These update anomalies presented here by the example of the road network

asset, but this type data model design is occur in all types of assets the existing ULGs AMP data.

Normalization is a theoretical approach of reducing such types of redundancies data in a relational database (Ramez , et al., 2011; Darwen, 2010); it applies by dividing a big table into smaller ones. Therefore, the designed geodatabase of study uses the normalization concept for each AMP SAA data models. Consider the Road_Network data model of the designed geodatabase model in the following Table 4.62.

Table 4.62 : The road network data model of the designed geodatabase

Road_Network		
RoadID	<u>RSM*</u>	<u>DT*</u>
1	Asphalt Road	Peeing Minor
2	Gravel Road	Depression
3	Cobblestone	Lifting
4	Asphalt Road	Peeing Minor
5	Cobblestone Road	Lifting
6	Gravel Road	Depression
7	Asphalt Road	Crack

MMR		
<u>DT*</u>	MR	
Peeing Minor	395.00	
Depression	415.00	
Lifting	690.00	
Crack	470.00	

MRR		
RSM*	RC	EUL
Asphalt Road	10,000,000.00	20
Gravel Road	2,870,000.00	20
Cobblestone Road	8,000,000.00	50

As Table 4.62 shows, the designed road network has three separate data model components, (1) Road_Network feature class with (RoadID, RSM, DT) attributes, (2) MMR object class with (DT, MR) attributes and (3) MRR object class with (RSM, RC, EUL). In this data model, if the user wants to change the value of MR of Depression DT from 415.00 ETB to 500.00 ETB, the operation will takes place just in one cell.

Hence one of the major advantage of the designed AMP Geodatabase Model is kept all-financial information i.e. unit rates are in a separate attribute table. As shown in FIGURE 4.18, each AMP SAA dataset has two object classes (tables) (1) for maintenance rates and (2) replacement rates for respective asset categories. This helps the users to easily access and modify financial rates for required asset types, and it reduce redundant data in the geodatabase, which leads to avoid update anomalies of the geodatabase.

As initially described in the statement problems, currently most ULGs, over seven executes about 85 % of the AMP data processing/computation operations outside the geodatabase environment (Adama, 2016), (Bahirdar, 2017), (Gondar, 2017), (Woldia, 2017), (Debre Tabor, 2017), (Burayu, 2017), (Ambo, 2017), (Debre Markos, 2016). Commonly the computations executed by Excel sheets and then transfer it into the geodatabase; this creates data inconsistency problems throughout the AMP. One of the major achievement of the designed geodatabase is performing 100 % of AMP computations independently inside the ArcGIS environment. In order to able the designed geodatabase completely perform the AMP computation operations instantly, the study integrates ModelBuilder with python and VB scripts, as presented in testing phase. Within the designed geodatabase, by using the customized toolboxes any user, even without being a GIS expert can perform the AMP computation at any time. This leads data processing consistency throughout the AMP and easy to generate versatile AMP reports.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter, the study general objective is first restated and reference is made to the specific objectives in section 5.2 and then deal with the achievement of each of the four specific objectives. In section 5.3, recommendations are drawn for future research in this field.

5.2 Conclusions

In this section, the study general objective is restated below, and reference is made to the four specific objectives that are dealt with individually in the bulleted that follow, in order to verify their realization and state the conclusions drawn from the associated specific objectives.

The stated general objective of the study was “To develop a GIS-based Physical Asset Management Plan Model for Gondar City Administration”.

In order to achieve the above general objective, the research has followed and achieved four specific objectives, which are bulleted below.

- Objective One was “To evaluate the existing AMP geodatabase of Gondar City Administration”.

The existing geodatabase created by the GCA does not adapt the AMP manual requirements, as well as ESRI’s design methodology. Based on the evaluation results, it is clear that the existing attributes create data variation problems throughout the AMP and retrieve incorrect information that will underpin the AMP decision-making processes of the GCA. Additionally, the GCA geodatabase data models has made it increasingly difficult to query and find data, update, run AMP computations or reporting the city AMP using GIS as the primary geospatial tool.

- Objective Two was “To conduct requirement analysis for designing AMP geodatabase model”.

The requirement analysis of the existing GCA geodatabase requires more AMP attributes and attributes validations. All required AMP attributes were identified by the study, based on the literature review these requirements are specified (MUDHCo, 2016). Additionally, the entire GCA geodatabase spatial data elements and their representation were specified. The obtained

requirements were aided to resolve the existing GCA geodatabase drawbacks, as well used as input for the designing of AMP geodatabase model.

- Objective Three was “To design the physical AMP geodatabase model”.

The geodatabase model created in this thesis consists all the required features by the methods of data management practices of the AMP manual. Based on the requirement analysis results, the physical AMP geodatabase model had been created for the four AMP manual strategic activity areas. Accordingly, the proposed geodatabase model was contains the required feature classes, subtypes, attributes, relationship classes and coded value domains.

- Objective Four was “To populate and test the designed AMP geodatabase model”.

The obtained results indicated that the model is efficient and appropriate for AMP geospatial management. The testing mechanism of the model is explained and the outputs were demonstrated. The designed geodatabase model is unmatched in the existing GCA geodatabase model, and has the ability to improve the GCA AMP productivity, efficiency and analytical ability. Moreover, using the developed customized tools, AMP computations were instantly computed independently in the designed geodatabase model, as well as retrieves versatile AMP reports correctly. This model has been validated and can be applicable in the future.

5.3 Recommendations

The research and development stages presented here, and methods and techniques applied are recommended to use ultimately to continue the design and establish the geodatabase for the remaining ULGs. The study concentrated on the particular data needs necessary to facilitate an effective GIS system for the GCA AMP. According to the tasks of the AMP GIS, this geodatabase design will prove successful in assisting the GCA in capturing and processing their AMP geospatial data needs.

It is recommended that the designed geodatabase model developed in this study can be used as a template geodatabase for other ULGs in Ethiopia. This geodatabase model provides structural integrity, manageability, data integrity, advanced AMP computation operations capabilities, and improved user-friendly abilities. The study suggestion in regards to designing a regional or countrywide geodatabase is to start at one particular ULGs, and adequately design all necessary data. Next, move from one ULGs to another, modifying the data design, while standardizing similar needs. All ULGs share a common four SAA dataset and close to one another will most likely share many feature class similarities, with only minor revisions.

Revisions may include adding and subtracting subtypes, fields, or coded value domains. It is anticipated that all ULGs data will only change slightly, while further ULGs may require minor transformations.

A development of countrywide scale AMP geodatabase is recommended to conduct by other scholars. Accordingly, the scholars possibly will refer the current study method and the unique or results as a base for their future attempts in the area of the current application. The designed geodatabase model described in this study the way geospatial data created considered for the GCA AMP. Methods, techniques, objectives, and responsibilities for the AMP will ultimately change over time, but in the hope that many of the design considerations.

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APPENDIX A - List of the 44 ULGs

S/N	City	Prior ULGDP II /Project Exposure	City Population (1995)	City Population (2007)	% Annual Growth 1995-2007	Population (Est. 2013)	Annual Growth Rate (Est.)
1	Dire Dawa CA	ULGDP PG	173,188	233,224	2.51%	269,134	2.07%
2	Gonder	ULGDP PG	112,249	207,044	5.23%	264,964	3.59%
3	Bahir Dar	ULGDP PG	96,140	155,428	4.08%	198,909	3.59%
4	Dessie	ULGDP PG	97,314	120,095	1.77%	153,691	3.59%
5	Kombolcha	ULGDP PG	39,466	58,667	3.36%	75,078	3.59%
6	Debre Markos	UGDP/KfW	49,297	62,497	2.00%	79,980	3.59%
7	Debre Brehan	ULGDP CB	38,717	65,231	4.44%	83,479	3.59%
8	Debre Tabor	ULGDP CB	22,455	55,596	7.85%	71,149	3.59%
9	Woldiya	ULGDP CB	24,533	46,139	5.40%	59,046	3.59%
10	Mota	ULGDP CB	18,160	26,177	3.09%	33,500	3.59%
11	Finote Selam	ULGDP CB	13,834	25,913	5.37%	33,162	3.59%
	Subtotals		512,165	822,787	4.03%	1,052,958	3.59%
12	Adama	ULGDP PG	127,842	220,212	4.64%	282,974	3.65%
13	Jimma	ULGDP PG	88,867	120,960	2.60%	155,434	3.65%
14	Shashemene	ULGDP PG	52,080	100,454	5.63%	129,084	3.65%
15	Bishoftu	ULGDP PG	73,372	99,928	2.61%	128,408	3.65%
16	Nekemte	UGDP/KfW	47,258	75,219	3.95%	96,657	3.65%
17	Assela	ULGDP CB	47,391	67,269	2.96%	86,441	3.65%
18	Sebeta	ULGDP CB	14,100	49,331	11.00%	63,391	3.65%
19	Burayu	ULGDP CB		48,876		62,806	3.65%
20	Ambo	ULGDP CB	27,636	48,171	4.74%	61,900	3.65%
21	Robe	ULGDP CB	21,516	44,382	6.22%	57,031	3.65%
22	Zeway / Batu	ULGDP CB		43,660		56,104	3.65%
	Subtotals		500,062	918,462	5.20%	1,180,230	3.65%
23	Hawassa	ULGDP PG	69,169	157,139	7.08%	225,686	5.31%
24	Sodo	ULGDP PG	36,287	76,050	6.36%	109,225	5.31%
25	Arba Minch	ULGDP PG	40,020	74,879	5.36%	107,542	5.31%
26	Dilla	ULGDP PG	33,734	59,150	4.79%	84,952	5.31%
27	Hosaena	ULGDP CB	31,701	69,995	6.82%	100,528	5.31%
28	Butajira	ULGDP CB	20,509	33,406	4.15%	47,978	5.31%
29	Areka	ULGDP CB	12,294	31,408	8.13%	45,109	5.31%
30	Yirga Alem	UGDP/KfW	24,183	30,348	1.91%	43,586	5.31%
31	Mizan	ULGDP CB	10,652	23,144	6.68%	48,946	5.31%
	Subtotals		278,549	555,519	5.92%	813,552	5.31%
32	Mekele (Debub/Semen)	ULGDP PG	96,938	215,914	6.90%	286,624	4.13%
33	Adigrat	ULGDP PG	37,417	57,588	3.66%	76,447	4.13%
34	Shire Endaselasi	ULGDP PG	25,269	47,284	5.36%	62,769	4.13%
35	Axum	ULGDP PG	27,148	44,647	4.23%	59,269	4.13%
36	Adwa	UGDP/KfW	24,519	40,500	4.27%	53,763	4.13%
37	Alamata	ULGDP CB	26,179	33,214	2.00%	44,092	4.13%
38	Wukro	ULGDP CB	16,421	30,210	5.21%	40,103	4.13%
39	Humera	ULGDP CB	14,451	21,653	3.43%	28,744	4.13%
	Subtotals		268,342	491,010	5.16%	651,811	4.13%
40	Harar	ULGDP PG	76,378	99,368	2.22%	112,781	1.83%
41	Jijiga	UGDP/KfW	65,795	125,876	5.56%	152,674	2.80%
42	Gambella	UGDP/KfW		39,022		64,499	7.44%
43	Asosa	UGDP/KfW	11,749	24,214	6.21%	40,686	7.70%
44	Samera/Logiya	UGDP/KfW		16,663		25,209	38.94%

APPENDIX B – Details of Data Modeling Evaluation

S/N	SAA	Asset Category	No of existing Layers	Feature Class Name
1	Movement Network	Road Network	5	Asphalt, Cobblestone, Gravel, LBS, and Compacted Earth Roads
2		Road Structures	2	Bridge and Culvert
3		Streetlight	1	Streetlight
4		Walkway	4	Asphalt, Cobblestone, Precast and Clay Tile Walkways
Total			12	
5	Environmental Service	Drainage	1	Drainage Network
6		Sanitation	4	Public Bath, Communal Toilet, Public Toilet, and Manhole
7		Greenery	6	Green Area, Park, Road Median, Roundabout, Playground
Total			11	
8	Social & Economic	Buildings	10	MSE Shade, MSE Cluster, Garage, Primary & Compound School, Health Center, Water Supply Building, Youth Center Facility, Daily Market, Buildings
Total			10	
9	Water Supply Network	Water supply network	4	Transmission and Distribution Network, Borehole, Reservoir
Total			4	
Grand Total			37	

APPENDIX C – Details of Attribute Validation Scheme Evaluation

SAA	Layer Name	No of Required Attribute Validation	Existing Attribute Validation	Required Validation Attribute Names
The Movement Network	Bridges	4	3	Condition, MaterialType, DetoType, SAA
	Culverts	4	2	Condition, MaterialType, DetoType, SAA
	Streetlights	5	4	PoleCondition, LampType, OperationalFun, SAA, Road Hierarchy
	AsphaltRoad	5	9	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	GravelRoad	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	Asphalt Walkway	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	Checkered Walkway	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	Cobble Walkway	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	Precast Walkway	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	Cobblestone Roads	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	Compacted Earth Road	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
	Large Block stone	5	1	SurfaceType, Condition, DetoType, Road Hierarchy, SAA
Total		58	26	
Water Supply Network	Bore Hole	5	0	Condition, MaterialType, OperationalFun, SAA
	Distribution Line	3	0	PipeMaterial, Condition, SAA
	Reservoir	3	0	MaterialType, Condition, SAA
	Transmission Line	3	0	PipeMaterial, Condition, SAA
Total		14	0	
Environmental Service	Play Ground	4	4	MaterialType, Condition, OperationalFun, SAA
	Park	8	1	MaterialType, Condition, OperationalFun, SAA
	Drainage Network	4	0	Condition, MaterialType, DetoType, SAA

	Median Green Area	3	1	MaterialType, Condition, SAA
	Public Bath	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Public Toilet	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Communal Toilet	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Manhole	4	0	Condition, MaterialType, OperationalFun, SAA
	Roundabout	3	1	Condition, MaterialType, SAA
Total		56	7	
Social & Economic Activity	Fence	3	0	FenceMat, Condition, SAA
	HealthCenter	10	2	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Terminals	4	0	MaterialType, Condition, OperationalFun, SAA
	MarketShade	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	MSEClusters	10	2	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Buildings	10	3	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Municipal Garage	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	School	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Youth center	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
	Water supply Buildings	10	0	Condition,FounMat,FounCon,FloorMat,FloorCon,WallMat,WallCon,RoofMat,RoofCon,SAA
Total		87	7	
Grand Total		215	40	

APPENDIX D – Details of Attribute Formation Evaluation

SAA	Layer Name	No. Fields	No. of Unnecessary fields	No. of Missed fields	Missed Field Name
Movement Network	Bridge	17	0	4	DetoArea, DetoType, % URL, AD
	Culvert	19	0	4	DetoArea, DetoType, % URL, AD
	Streetlight	22	1	2	% URL, AD
	Asphalt Roads	62	35	2	% URL, AD
	Gravel Road	63	36	2	% URL, AD
	walkway (Asphalt)	22	0	2	% URL, AD
	Walkway (Tiles)	22	0	2	% URL, AD
	Walkway (Cobble)	22	0	2	% URL, AD
	Walkway (precast)	22	0	2	% URL, AD
	Cobblestone Road	62	35	2	% URL, AD
	Compacted Earth	64	37	2	% URL, AD
	Large block stone	63	36	2	% URL, AD
Total		460	180	28	
WSN	BH	24	0	4	% URL, AD, CV, MR
	Pipe Line	24	0	2	% URL, AD
	Reservoir	18	0	2	% URL, AD
Total		66	0	8	
Environmental Service	Paly Ground	20	0	2	% URL, AD
	Green Area	19	0	2	% URL, AD
	Park	18	0	2	% URL, AD
	Drainage Network	22	0	2	% URL, AD
	Public Bath	20	0	2	% URL, AD
	Public Toilet	21	0	2	% URL, AD
	Communal Toilets	22	0	2	% URL, AD
	Drainage Manholes	13	0	2	% URL, AD
Total		155	0	16	
Social & Economic Activity	Health Center	20	0	2	% URL, AD
	Terminals	24	0	2	% URL, AD
	MarketShade	18	0	6	% URL, AD, FouMat, FloorMat, WallMat, RoofMat
	Cluster	19	0	6	% URL, AD, FouMat, FloorMat, WallMat, RoofMat

	Building	20	0	6	% URL, AD, FouMat, FloorMat ,WallMat, RoofMat
	School	22	0	6	% URL, AD, FouMat, FloorMat ,WallMat, RoofMat
	Youth Center	14	0	10	% URL, AD, FouMat & Condition, FloorMat & Condition, WallMat & Condition, RoofMat & Condition,
Total		159	0	40	
Grand Total		840	180	92	

APPENDIX E - AMP Manual Attribute Coding Scheme

Category	Code	Layers	Code	Layers	Code
The Road Network	RN	Asphalt road	AS	Water meter	WM
The Urban Drainage Network	UD	Cobblestone road	CB	Hydrant	HY
The Street Lighting Network	SL	Gravel/ red ash road	GR	Customer connection	CC
The Water Supply Network	WS	Compacted earth road	CE	Communal standpipe	CS
Water Resources	WR	Footpath	FP	Public and communal toilet	PT
The Liquid Waste Network	LW	Paved area	PA	Bucket collection point	BP
Solid Waste Management	SW	Roundabout	RO	Landfill site	LS
Sanitation	SA	bridge	BR	Weigh bridge	WB
Urban Greenery	UG	culvert	CU	Solid waste container	SC
Parks and Play Areas	PA	Retaining wall	RW	River channel centre line	RC
River Systems	RS	Road furniture	RF	Tunnel	TU
Wetlands	WE	Drainage channel	DC	Lighting pole and mast	LP
Nature Reserves	NR	Pipe drainage	PD	Construction plant	CP
Abattoirs	AR	Retention and detention ponds	RP	Machinery	MA
Fire Service Assets	FF	Manhole	MH	Vehicle	VE
Municipal Markets	MM	Reservoir	RE	Building and facility	BU
MSE Facilities	MS	Water pipeline network	WN	Fence	FE
Schools	SC	Pump	PU	Administrative boundary	AB
Health Centres	HC	Valve	VA	External site boundary	EB
Youth Centres	YC	Access box	AC	Internal boundary	IB
Municipal Buildings	MB				

APPENDIX F – Designed Domains

Domain Name	Domain Code	Description	SAA			
			Movement Network	Water Supply Network	Environment services	Social and economic services
RoadSurfaceMaterial	ASR	Asphalt Road	✓			
	CBR	Cobblestone Road				
	GRR	Gravel Road				
	CER	Compacted Earth Road				
	LBR	Large Block Stone				
DrainageType	CLD	Cobblestone Lined Drain			✓	
	OCD	Open Concrete Lined Drain				
	CCD	Closed Concrete Lined Drain				
	OMD	Open Masonry Drain				
	CMD	Closed Masonry Drain				
	ERD	Earthen Drain				
WaterSupplyPipeMaterialType	DCI	DCI		✓		
	GI	GI				
	GS	GS				
	HDC	HDC				
	PVC	PVC				
	uPVC	uPVC				
BuildingRoofMaterial	CSI	Corrugated Iron Sheet			✓	✓
	EGA	EGA sheet				
	COC	Concrete				
BuildingFloorMaterial	COC	Concrete			✓	✓
	EAR	Earthen				
	STO	Stone paved				
	WOD	Wooden				
BuildingWallMaterial	CIS	Corrugated Iron Sheet			✓	✓
	HCB	Hollow Blocks				
	LAM	Lamara				
	TIM	Timber				
	MAS	Stone masonry				
	BRI	Brick				
FoundationMaterial	STM	Stone Masonry			✓	✓

	TIM	Timber				
	COC	Concrete				
StreetlightType	HPS	High-Pressure Sodium	✓			
	FLO	Florescent				
	INC	Incandescent				
StreetlightOperation	FUN	Functional	✓			
	NFU	Non-functional				
StreetlightPoleMaterial	STE	Steel	✓			
	WOD	Wooden				
PedestrianWalkwayMaterialType	ASW	Asphalt Walkway	✓			
	CBW	Cobblestone walkway				
	CTW	Clay Tile Walkway				
	PCW	Precast Walkway				
DeteriorationTypeForRoad	PEM	Peeling Minor	✓			
	DEP	RN Depression				
	WAA	RN Wash Away				
	PEMG	RN Peeling Major				
	SIL	RN Siltation				
	POT	RN Pothole				
	CHA	RN Channeling				
	LIF	RN Lifting of Cobble Stone				
	CRA	RN Crack				
	COB	RN Cobble Edge Failure				
	NOD	RN No Deterioration				
DeteriorationTypeForWalkway	PEM	Surface Peeling	✓			
	DEP	Depression				
	POT	Pothole				
	LIF	Lifting of Cobble Stone				
	CRA	Crack				
	NOD	No Deterioration				
DeteriorationTypeForDariange	MID	Minor Joint Damage			✓	
	SID	Siltation and Deposition				
	FLD	Floor Damage				
	MAD	Major Joint Damage				
	WAC	Wall Collapse				
	COD	Cover Material Damage				
	NOD	No Deterioration				
AdminBuildingFunctions	OFF	Office				✓
	TOI	Toilet				
	STT	Store				
	WAA	Waiting Area				

	CAA	Cafeteria				
	GUH	Guard House				
	WAS	Waiting Shade				
	BAA	Bath Room				
	WAR	Waiting Room				
	WOO	Workshop				
	OFC	Office Complex				
	IND	Information Desk				
	GAR	Garage				
	UNC	Under Construction				
	OTA	Other Activity				
MedianFenceMaterial	STE	Steel			✓	
	COS	Concrete & Steel				
	COC	Concrete				
	WOW	Wood & Wire				
	STW	Steel & Wire				
	NON	None				
ShadeBuildingFunction	SAD	Shade				✓
	CLU	Cluster				
	UCO	Under construction				
SchoolBuildingFunctions	CLR	Class Room				✓
	CRC	Class Room Complex				
	STS	Store				
	HAH	Hall				
	CAC	Cafeteria				
	OFF	Office				
	GUH	Guard House				
	LIL	Library				
	TOT	Toilet				
	ICR	ICT Room				
	LAL	Laboratory				
	UNO	Under construction				
	OTF	Other Function				
HealthBuildingFunctions	OFC	Office				✓
	TOT	Toilet				
	STO	Store				
	WAA	Waiting Area				
	CAC	Cafeteria				
	GUH	Guard House				
	WAS	Waiting Shade				
	BAS	Bath Room				
	WAR	Waiting Room				

	OFC	Office Complex				
	IND	Information Desk				
	EXR	Exam Room				
	UNO	Under Construction				
	OTF	Other Activity				
RoadHierarchy	PAS	Principal Arterial Street	✓			
	SAS	Sub Arterial Street				
	CLS	Collector & Local Street				
GeneralCondition	VRG	Very Good	✓			
	GOD	Good				
	MOD	Moderate				
	POR	Poor				
	VPO	Very Poor				
RoadStructureShape	BOX	Box	✓			
	PIP	Piped				
	WOD	Wooden				
RoadStructureType	BR	Bridge	✓			
	CU	Culvert				
RoadStructureMaterialType	CO	Concrete	✓			
	WO	Wooden				
RoadStructuresDeteriorations	SIL	Siltation	✓			
	SLF	Slab Failure				
	ABF	Abutment Failure				
	CRK	Crack				
	NOD	No Deterioration				
SubCities	ARA	Arbegnoch Adebabay	✓			
	KIK	Kirkos				
	MEA	Mehal Arada				
	ABI	Abiyezgi				
	ABA	Abajale				
	GEB	Gebriel				
	LIL	Lideta				
	AZD	Azezo Demaza				
	AZA	Azezo Ayermarefia				
	ADE	Adebabay Eyesus				
	MED	Medhanialem				
Ownership	GCA	Gondar City Administration	✓			
	FDRE	Federal Government				
ManholeMaterials	COC	Concrete			✓	
	STE	Steel				
ReservoirMaterials	COC	Concrete Reservoir		✓		
	MAS	Masonry Reservoir				

WaterSupplyReplacementFunctions	DCI	DCI	✓			
	GI	GI				
	GS	GS				
	HDC	HDC				
	MAS	Masonry Reservoir				
	PVC	PVC				
	STE	Steel Borehole				
	uPVC	uPVC				
WaterSupplyPipeType	DNT	Distribution Network	✓			
	TNT	Transmission Network				
WaterSupplyMaterialType	DCI	DCI	✓			
	GI	GI				
	GS	GS				
	HDC	HDC				
	PVC	PVC				
	uPVC	uPVC				
SanitationType	COT	Communal Toilet			✓	
	PUB	Public Bath				
	PUT	Public Toilet				
StreetGreeneryType	RME	Road Median			✓	
	ROU	Roundabout				
CommunityServiceBuildingTypes	EDU	Educational Institutes				✓
	HEC	Health Center				
	HOU	Housing Facility				
	LIB	Library				
	TIM	Terminal				
	YOU	Youth Center				
RecreationTypes	GRE	Green Area			✓	
	PAR	Park				
	PLY	Play Ground				
WaterSupply MaintenanceFunctions	VRG	Very Good	✓			
	GOD	Good				
	MOD	Moderate				
	POR	Poor				
	VPO	Very Poor				

The physical design example of UML diagram of RoadNetwork Coded Value Domain for RoadSurfaceMaterial and RoadHierarchy is pictured in FIGURE A. In addition, the equivalent physical design result of the road network table is shown as a valid dropdown list of surface material and hierarchy a road segment in ArcGIS window (FIGURE B).

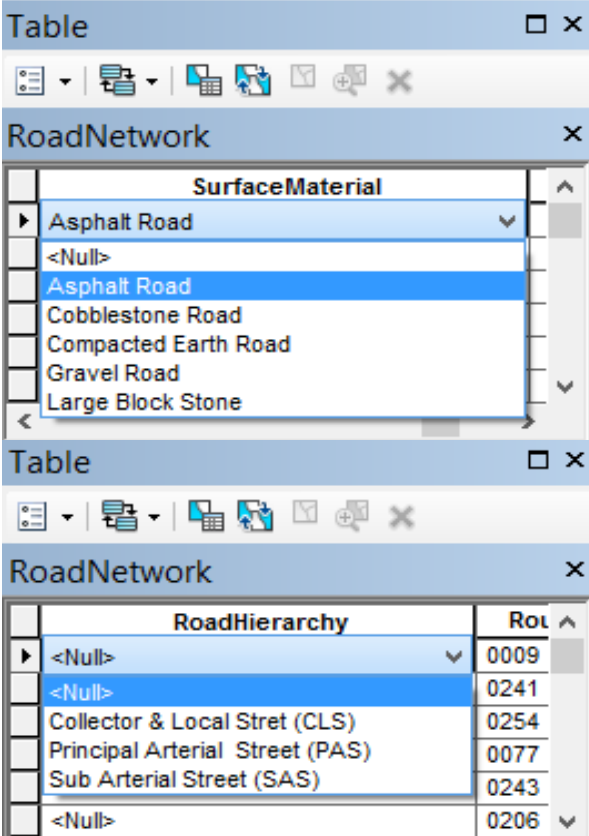
A
B

RoadSurfaceMaterial

- + FieldType: esriFieldType = esriFieldTypeString
- + MergePolicy: esriMergePolicyType = esriMPTDefaultValue
- + SplitPolicy: esriSplitPolicyType = esriSPTDuplicate
- «DomainCodedValue»
- + Asphalt Road: esriFieldTypeString = ASR
- + Cobblestone Road: esriFieldTypeString = CBR
- + Compacted Earth Road: esriFieldTypeString = CER
- + Gravel Road: esriFieldTypeString = GRR
- + Large Block Stone: esriFieldTypeString = LBR

RoadHierarchy

- + FieldType: esriFieldType = esriFieldTypeString
- + MergePolicy: esriMergePolicyType = esriMPTDefaultValue
- + SplitPolicy: esriSplitPolicyType = esriSPTDuplicate
- «DomainCodedValue»
- + Collector & Local Stret (CLS): esriFieldTypeString = CLS
- + Principal Arterial Street (PAS): esriFieldTypeString = PAS
- + Sub Arterial Street (SAS): esriFieldTypeString = SAS



The screenshot shows two 'Table' windows in ArcGIS. The top window displays the 'SurfaceMaterial' dropdown list with options: <Null>, Asphalt Road, Cobblestone Road, Compacted Earth Road, Gravel Road, and Large Block Stone. The bottom window displays the 'RoadHierarchy' dropdown list with options: <Null>, Collector & Local Stret (CLS), Principal Arterial Street (PAS), Sub Arterial Street (SAS), and <Null>. A second column labeled 'Route' is visible in the bottom window with values: 0009, 0241, 0254, 0077, 0243, and 0206.

APPENDIX G - Syntax and Scripts

A. RoadNetwork Condition and Maintenance Calculator Syntax & Scripts

```
# Syntax for Calc: Maintenance Cost [Mc]

arcpy.CalculateField_management

(RoadDeteriorations, MaintenanceCost, "[MaintenanceUnitRates] *
[DeteriorationArea]", "VB", "")

# Syntax for Calc: Deterioration percentage [Dp]

arcpy.CalculateField_management

(RoadNetwork, "DeteriorationPercentage", "[DeteriorationArea] /
[SurfaceArea]", "VB", "")

# Syntax for Calc: Condition [Co]

arcpy.CalculateField_management

(RoadNetwork, "Condition", "cond", "VB", "Dim cond\\nIf
[DeteriorationPercentage] > 0.5 Then\\n cond = \"VPO\"\\nelseif
[DeteriorationPercentage] > 0.2 Then\\n cond = \"POR\"\\nelseif
[DeteriorationPercentage] > 0.05 Then\\n cond = \"MOD\"\\nelseif
[DeteriorationPercentage] > 0 Then\\n cond = \"GOD\"\\nElse \\n
cond = \"VRG\"\\nEnd if\\n\\n\\n\\n\\n\\n\\n")
```

B. RoadNetwork Replacement Cost and Current Value Calculator Syntax & Scripts

```
# Syntax for Calc: EQL7mkm [EQ]

arcpy.CalculateField_management

(RoadNetwork, "EQL7mkm", "[SurfaceArea] /7000", "VB", "")

# Syntax for Calc: EstimatedReplacementCost[ER]

arcpy.CalculateField_management

(RoadNetwork, "EstimatedReplacementCost", "[EQL7mkm] *
[ReplacmentUnitRates]", "VB", "")

# Syntax for Calc: CurrentYear [Cu]

arcpy.CalculateField_management
```

```

(RoadNetwork, "CurrentYear", "Now ( )", "VB", "")

# Syntax for Calc: Age [Ag]
arcpy.CalculateField_management

(RoadNetwork, "Age", "[CurrentYear] - [ConstructionYear] + 1",
"VB", "")

# Syntax for Calc: RemainingUsefulLife [RU]
arcpy.CalculateField_management

(RoadNetwork, "RemainingUsefulLife", "[EstimatedUsefulLife] -
[Age]", "VB", "")

# Python Scripts for Calc: Final RemainingUsefulLife [fRU]
arcpy.CalculateField_management

(RoadNetwork, "RemainingUsefulLife", "TextValue (!ReULTEMP!,!
RemainingUsefulLife! )", "PYTHON_9.3", "def TextValue

(FromCode, RemainingUsefulLife):\\n        if FromCode < 0:\\n
return 0\\n        else: \\n            return RemainingUsefulLife\\n")

# Syntax for Calc: PercentRUL [Pe]
arcpy.CalculateField_management

(RoadNetwork, "PercentRUL", "[RemainingUsefulLife] /
[EstimatedUsefulLife]", "VB", "")

# Syntax for Calc: DepreciatedReplacementCost [DR]
arcpy.CalculateField_management

(RoadNetwork, "DepreciatedReplacementCost",
"[EstimatedReplacementCost] * [PercentRUL]", "VB", "")

# Python Scripts for Calc: Final DepreciatedReplacementCost
[fDR]
arcpy.CalculateField_management

(RoadNetwork, "DepreciatedReplacementCost", "TextValue(
!DRCTEMP! , !DepreciatedReplacementCost! )", "PYTHON_9.3", "def

```

```

TextValue(FromCode,DepreciatedReplacementCost):\\n            if
FromCode <= 0:\\n            return 10\\n            else:\\n            return
DepreciatedReplacementCost\\n\\n")

# Syntax for Calc: EstimatedCurrentValue [EC]

arcpy.CalculateField_management

(RoadNetwork,"EstimatedCurrentValue",
"[DepreciatedReplacementCost] - [TotalMaintenanceCost]", "VB",
"")

# Python Scripts for Calc: Final EstimatedCurrentValue [fEC]

arcpy.CalculateField_management

(RoadNetwork, "EstimatedCurrentValue", "TextValue (!CVTEMP!,!
EstimatedCurrentValue! )", "PYTHON_9.3", "def TextValue

(Value,EstimatedCurrentValue):\\n            if Value <= 0:\\n
return 10\\n            else:\\n            return
EstimatedCurrentValue\\n\\n\\n\\n")

# Syntax for Calc: AssetDeficit [AD]

arcpy.CalculateField_management

(RoadNetwork, "AssetDeficit", "[EstimatedReplacementCost] -
[EstimatedCurrentValue]", "VB", "")

```

APPENDIX H - UML ArcGIS Workspace Model Validation Report

ArcGIS Model Validation

```
=====
Start Time: 12:59:57 PM
Loading Feature Dataset packages...
...done
Loading Spatial Reference elements...
...done
Loading other workspace elements...
...done
Validating Workspace Properties...
Validating Spatial References...
Validating Domains...
Validating Workspace Packages...
Validating Default Subtype Codes for Feature Classes...
Validation Complete! Found 0 errors, 0 warnings.
End Time: 1:00:01 PM
=====
```
