DEVELOPMENT OF INFORMATION SYSTEM TO SUPPORT HYDRO-ENVIROMENTAL-ECONOMIC MODELLING OF LAKE NAIVASHA AREA

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DEVELOPMENT OF INFORMATION SYSTEM TO SUPPORT HYDRO-ENVIROMENTAL-ECONOMIC MODELLING OF LAKE NAIVASHA AREA

By

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Abstract

Growing population has increased pressure on land and water resources. Water is limiting resource throughout most of Africa. In Kenya problem is critical as 75% of the country is either arid or semi-arid and remaining 25% is agricultural and heavily populated, leading to excessive use of land. Lake Naivasha which is the second largest fresh water lake in Kenya has gained much economic important recently due to horticulture farming. The excessive use of Lake Naivasha water for irrigated agriculture is leading to a drop in the level of water in the lake. The net economic return of farms around the lake per use of unit cubic metre of water has been used as a primary management tool to regulate and manage the use of water in the lake among the competition sectors and to provide a safe environment.

The number of studies related to use of water in the Naivasha catchment, have been carried out by ITC students and staff members. Over the last decade, an enormous amount of information has been collected. Not all data are in easily accessible form; formats and most of databases are not linked to georeference land units.

The study aims at the development of a GIS-based information system that integrates Hydro-Environmental-Economic models. This study used a structured methodology, which is one of the system development methodologies to build an information system. The system was designed through three main phases such information system analysis, system design and system implementation. Context data flow diagram (DFD) and its decomposition into low-level diagrams used in the system analysis. Top-level diagrams in the DFD emphasis sub systems of data collection and irrigated area mapping, economic modelling, crop-hydrological processing and analysis. Data modelling techniques such conceptual and logical modelling, were used in the system design. These data modelling steps were consisted of Entity-Relationship diagrams. The hydro-environmental-economic modelling database was designed in Microsoft Access 2000. The proposed GIS was implemented by ArcView package and Microsoft Access. The out come of the system is in the form of maps and reports.

Finally, a user friend interface for the system process was designed to the system user to visualize different scenarios based on input parameters.

Table of Content

List of Tables

List of figures

List of Equations

List of Plates

List of Appendices

CHAPTER 1 : INTRODUCTION

1.1 General Introduction

Growing human population has increased pressure on land and water resources. On the other hand, land and water are limited resources and water scarcity is rapidly increasing in many regions of the world. A better use of the limited land and water resources is essential to achieve sustainable production of food and other agricultural products in the future (FAO, 1997).

Irrigation can make a significant contribution to reducing poverty and hunger, as reported by the UN Food and Agriculture Organization (FAO) to mark the occasion of world water day 22 March 1999. Irrigated agriculture provides 40 percent of the world food production and around 60 percent of extra food required to sustain a world population of about 8 billion by 2025 must come from irrigated agriculture (FAO, 1997).

In Africa there exists considerable potential for the future expansion of irrigation, but also water is growing scarcer in those regions where the need for irrigation is greatest. Availability of land and water is one of the major factors for food security as reiterated during the World Food Summit in November 1996. Competition among agriculture, industry and cities for limited water supplies is already constraining development effort in many countries. As populations expand and economies grow, the competition for limited supplies will intensify and so will conflicts among water users.

Despite water storages, misuse of water is widespread. Small communities and large cities, farmers and industries, developing countries and industrialized economics are all mismanaging water resources. Surface water quality is deteriorating in key basins from urban and industrial wastes (FAO, 1993).

In drier regions competition for water may arise among the different sectors. In general the quantity of water available for agriculture is the difference between the total quantity of water available and the water demand of the sectors (FAO, 1997). The governing forces that could precipitate water conflict and competition in any region can be categorized as follows: flow variation in time and space, increase population, inefficient agricultural practices, variation in rainfall and declining groundwater (Salah, 1993).

The use of fertilizers, pesticides as well as application of irrigation have increased global agricultural production and thus helped feed the expanding human population. For this reason, modern farmers are using fertilizers, pesticides and irrigation water in ever increasing amounts. If too much is applied it cannot be contained in the soil, large quantities of the chemicals can change the ph and electrical conductivity properties of soil and water. Therefore excessive application of agricultural chemicals and irrigation may contribute to soil variability while leaching contributes to water pollution.

As discussed above water is a limiting resource throughout most of Africa. In Kenya problem is critical as 75% of the country is either arid or semi-arid and remaining 25% is agricultural and heavily populated, leading to excessive use of land. The population in this area depends on reservoirs and boreholes as a result of low rainfall of less than 600 mm/year, which is unevenly distributed. The recharge of these water reservoirs is highly variable in time and space. Water consumption for domestic, agriculture and livestock is influenced by natural, economic and social conditions such as poverty, topography, water availability, quality and distance from water source.

1.2 Problem Definition

Lake Naivasha is the second largest freshwater lake in Kenya. It has gained much economic importance recently due to the horticulture farming. Also the lake and its environment are important because of their biological diversity and the lake functions as a fresh water resources. In the vicinity of the lake, over 100 large, medium and small commercial farms are running irrigated floriculture, vegetables and dairy production. Flowers and vegetables are produced mainly for export to international markets. The expansion of irrigated agriculture took place after mid 1980. The excessive use of Lake Naivasha water for irrigated agriculture is leading to a drop in the level of water in the Lake.

Naivasha catchment is subject to driving forces of surface water depletion such as rapidly increasing population, expanding commercial agriculture, agro industrial, less rainfall and high evapotranspiration. Rainfall and evapotranspiration can be identified as climatic elements. These driving forces have led to surface water resource depletion, land degradation and socio-economic and environmental problems.

Various studies show the relationship between the drop of the lake level and the irrigation expansion (Salah, 1993). The long-term water balance of lake shows that the difference between predicted water level and actual lake level has changed sharply after mid 1980 (Gitonga, 1994). It can be observed that at end of the year of long-term water balance (1932-1997) the storage is a loss of 6.88 million m^3 /year and the drop in Lake level is 47 mm/year (Ahamad, 2001). Excessive use of fertilizer and pesticide can affect the quality of water in Lake Naivasha. The impact of a growing agricultural economy and agricultural inputs on the environment has been found to be significant. The net economic return of farms around lake, per use of unit cubic metre of water has been used as a primary management tool to regulate the use of water in the lake among the competition sectors and to provide safe environment (Ahamad, 2001).

A number of studies related to use of water in the Naivasha catchment have been carried out by ITC students and staff members. The studies have cut across a number of divisions and disciplines. These include biodiversity assessment, land cover change detection, water pollution and geology and soil classifications. Over the last decade, an enormous amount of information has been collected. Not all data are in easily accessible form; formats and most of databases are not linked to georeference land units. The geo-data sets have different scales and contain both raster (remotely sensed) and vector datasets.

This study aims at the development of a GIS-based information system that integrates Hydro-Environmental-Economic models. This will include information gathered over the years by various research groups of water, soil, geo-information and geophysics division from ITC. The purpose of this information system will be to assist the various stakeholders, ITC research groups and water managers around Lake Naivasha in assessing farm input, history and production information, water productivity and agrochemical use in an effective manner.

1.3 Research Objectives

The main objective of this research is to develop an information system that integrates Hydro-Environmental – Economic parameters that can be used by various decision makers including farm managers, government institutions, hydrologists and environmental researchers for better management of water and environment in the Lake Naivasha Catchment.

1.4 Specific Objectives

Specific objective of the research are: -

1. Design the hydro-environmental-economic information system that integrates the three components based on land parcel information.
2. Identifying stakeholders of the system, information requirement, data flows and data stores.
3. Design a prototype system.
4. Implement the Information System in a GIS software.
5. Design a user interface for the geographical information system.
6. Evaluation by the users based on system products.

1.5 Research Questions

1. What are the Hydro-Environmental-Economic information assessment needs and data flows?
2. Who are the stakeholders?
3. How should the data model be structured and implemented?
4. What are the information requirements in order to calculate parameters such as water consumption (theoretical and applied), water productivity, fertilizer and pesticide loads, and farm and crop economies?
5. How can the Hydro-Environmental- Economic modelling be done in Access database and organized in Geographic Information system using Arc view?
6. How should processes, the data inputs and outputs be structured to build an information system?

1.6 Materials and Equipments

The following materials and equipments were used while carrying out this research:

(i) Thesis and reports concerning the subject area.
(ii) Topographic map of Kenya 1975 Scale 1:50,000 by Survey Department of Kenya.
(iii) Landsat Satellite images of March 2000, January 1995 and January 1986
(iv) Cadastral Map (1:50,000) of Naivasha area by Physical Planning Department, Ministry of Lands and Settlement, Kenya and digitized cadastral map

(v) Garmin 12XL receiver
(vi) Digitizer

1.7 The Research Approach

The research methodology comprised the following three phases

1.7.1 Pre fieldwork

This includes
(i) Identifying user groups of Department of Water Resources at ITC.
(ii) Exploring and collecting existing spatial and non-spatial data from previous work and ITC database about Lake Naivasha Catchment.
(iii) Study the previous work related to the subject.
(iv) Study of Landsat TM images of May 21, 2000 and January 21, 1995 and the Landsat MSS image of January 28, 1986.
(v) Preparation of different formats (Questionnaires and data sheets) that are useful to register data or information for capturing spatial data during the fieldwork (Appendix 3 and 4) (Standard interview questionnaires and Spatial data recording format).
(vi) Set up of Hydro-environmental-Economic information system design approach.

1.7.2 Fieldwork

(i) Interviewing the local stakeholders (Farmers and Lake Naivasha Reparian Association) in relation to data necessary, such as landuse history, irrigated area, crop information, production cost of crops and diary, and economy.
(ii) Interviewing user groups of Hydro-Environmental-Economic modelling information system.
(iii) Field observations making use of GPS readings, images and the Cadastral map.
(iv) GPS readings to get irrigated area, crop information, borehole points and farm boundaries together with the help of Cadastral map and images in order to update the irrigated area demarcated by the previous studies.
(v) Cross-checking the farm boundaries together with Cadastral boundary.

1.7.3 Post field works

(i) Updating the irrigated area map of Lake Naivasha area and the area were shown using GIS.
(ii) Updating newly abstraction points of individual farms and they were shown using GIS.
(iii) Information system modelling.
(iv). Spatial and non-spatial data modelling.
(v) Spatial and non-spatial data integration.
(vi). Hydro-Environmental-Economic modelling using Microsoft Access package.
(vii) Add the time series (1986 and 2000) to the hydro-environmental-economic model.
(viii) The Hydro-Environmental-Economic database was organized with Geographic Information system using Arc view.
(ix) Outcome of the hydro-environmental-economic model such as water productivity, agrochemical use, water consumption and returns produced in the form of reports and maps.
(x) Designing user-friendly interface to improve user accessibility.

(xi) Thesis writing

1.8 Information System Development Method

Systems development is not a trivial task: it costs time and money because of the complex nature of modern information systems and therefore needs a clear step-by-step approach in the process of development. This is the concept behind methodologies (Paresi, 2000).

Benefits from Methodologies include

1.High quality products, which are easy to maintain and upgrade.

2.Better control during design process.

3.Reduction time to completion and lower costs of developments.

Five system development methodologies have been developed to build an information system (Hawryszkiewycz, 1997). These are Formal, Structured, Soft, Socio-technical and Object Oriented.

This research uses a Structured methodology. Structured methodologies take the Top-Down approach with clear and separate the logical from the physical design (Paresi, 2001). Much effort is put into developing the conceptual system during which the analyst gets overall grasp of the system, and then breaks the picture down into manageable modules.

Associated tools and techniques include, among others, decision trees, decision tables, DFDs and data dictionaries. Documentation includes documents describing the logical (real world), not just their physical (implementation) level designs. Most parts of the analysis and design can be developed, maintained and held on computer systems. User participation is highly recognized in information requirements determination and verification that is an important stage in the methodology.

Structured methodologies are based on the life-cycle approach with clear and well-defined phases and activities. Review and changes take place as the system goes through the phases, going back to previous phases if needed.

The iterative cyclic nature of the phases is shown in Fig1.1

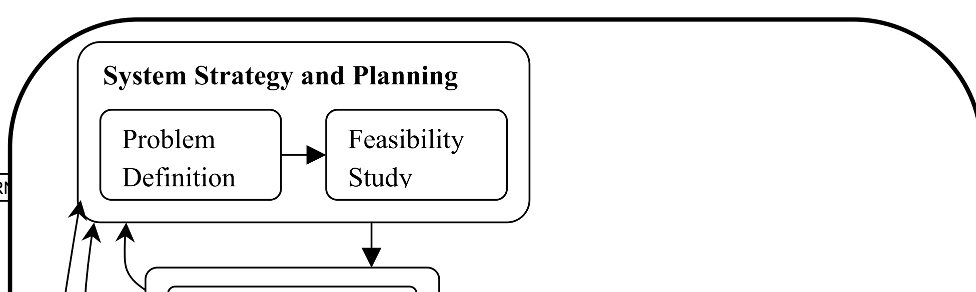


Figure 1-1: Major phases and life cycle (Adapted from Paresi, 2000)

1.9 Thesis Outline

The thesis will be presented in six chapters.

Chapter 1 is the introduction chapter. It starts by describing general problem of water, constraints and problems in Kenya and then focuses on the subject to formulate the problem definition and to identify research objectives and questions that are to be answered in this research. Then material and equipments that are used for this study and research approach are described in this chapter. Finally it describes briefly the information system method that is going to be used in this thesis.

Chapter 2 describes the study area and mentions unique properties, opportunities and foreseeable problems. It follows this by describing the historical content of the area including economic importance, agricultural potential and sustainable resource use. All the above include the sub titles of geographical location, climate, natural resources, geology, topography, soils, hydrology, economy & environmental and landuse /vegetation.

Chapter 3 describes the methods of design a hydro-environmental-economic information system. It mainly includes design of data and process modelling. Firstly, it describes generally about data flow diagrams and describes process modelling, context diagram and finally information requirement, information analysis, user requirement analysis and data processing in MS Access.

Chapter 4 describes the overall design of Hydro-environmental-Economic modelling, which includes design of database model. Firstly, it describes generally about modelling techniques and then conceptual, logical and physical data modelling. Finally, it describes modelling of Hydro-Environmental-Economic database.

Chapter 5 explains the implementation of an information system for Hydro-Environmental-Economic modelling.

Chapter 6 presents and describes the user interface for hydro-environmental-economic modelling information system.

Chapter 7 presents the conclusion of the study and recommendation for future studies.

CHAPTER 2 : DESCRIPTION OF STUDY AREA

2.1 Geographic location

2.1.1 Kenya

Kenya, a republic in East Africa, is bounded on the north by Sudan and Ethiopia, on the east by Somalia and the Indian Ocean, on the south by Tanzania, and the west by Lake Victoria and Uganda. Nairobi is the country’s capital city. Kenya has a total area of 582,646 sq km (224,961 sq miles). The equator passes through the middle of the country. Approximate location of Lake Naivasha is shown in fig. 2-1.

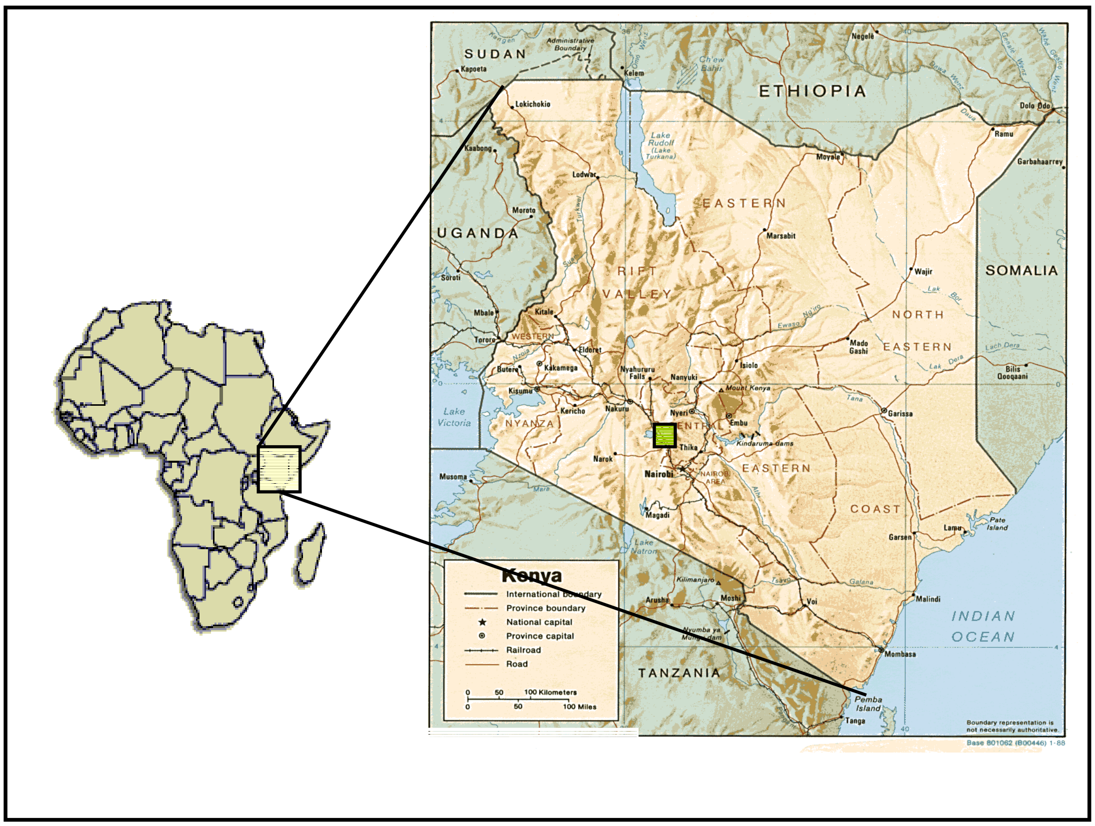


Figure 2-1: Approximate location of the study area.

2.1.2 Lake Naivasha

Lake Naivasha is located 100 km Northwest of Nairobi. Administratively it is situated in the Naivasha Division of Nakuru District, Rift Valley Province, Kenya. The geographic location of the study area

lies between 00^0 40$^{'}$ to 00^0 53’S latitude and 36^0 15’ to 36^0 30’E longitude. It is within the UTM zone 37. Altitude is around 1890m.

The study area for this research is the agriculture area surrounding the lake, where irrigation takes place. The location of the study area is shown with a background of a satellite image of March 2000 in fig. 2-2.

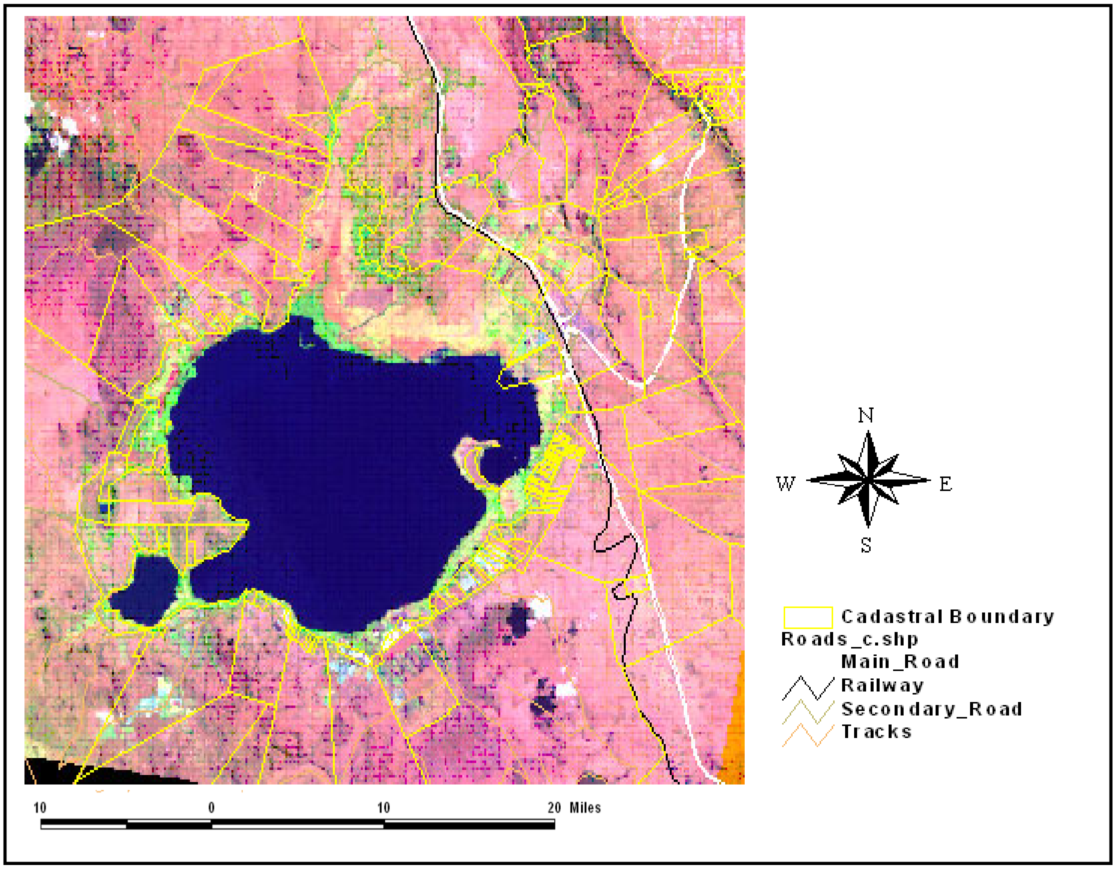


Figure 2-2: Location of the study area

The water surface of the lake covers an area of about 130 km^2 with the average depth of 4m. The lake receives 90% of its discharge from Malewa, Gilgil Rivers. It is a fresh water lake surrounded by the alkaline lakes of Elmenteita, Nakuru, Magadi, and Bogoria. It is in a closed drainage basin and has no visible outlet.

Plate 1: North view of the Lake

2.1 Climate

The climate is humid to sub-humid in the highland and Semi-arid in the Rift Valley. The average monthly temperature ranges between 15.9 ^{0}C and 17.8 ^{0}C while minimum temperature is 6.8 – 8.0 ^{0}C and maximum temperature is between 24.6 –28.3 ^{0}C (fig 2-3).

Lake Naivasha is situated in the highest part of Rift valley at an altitude of 1890 masl. In spite of this, the lake and its drainage basin are in the rain shadow of winds coming from both the west and, more importantly, from the east. The average annual figure for rainfall at Naivasha D.C for the period 1931-1960 was 608 mm (East African Meteorological Department 1966). It exhibits smooth to very high relief in April/May and again in November. The area has two rainy seasons short rainy season (mid October to mid December) and long rainy season (March to June) (fig 2-4). Dry season occurs from December to February.

There are generally calm conditions or slight winds in the morning over the lake. In the afternoon winds of 11-15 km/h are typical. Winds are strongest in August to October when they reach speeds of 21 km/hr. There are often violent storms over the lake leading to serious water movement.

The evapotranspiration around the lake is about 1360 mm a year, (Ref) which clearly exceeds the rainfall. Ase et.al, (1986), studied the evaporation during the period of 1965-1982 and reported the evaporation amounts to 1492 mm, which is more than twice the annual average rainfall in Lake Naivasha area.

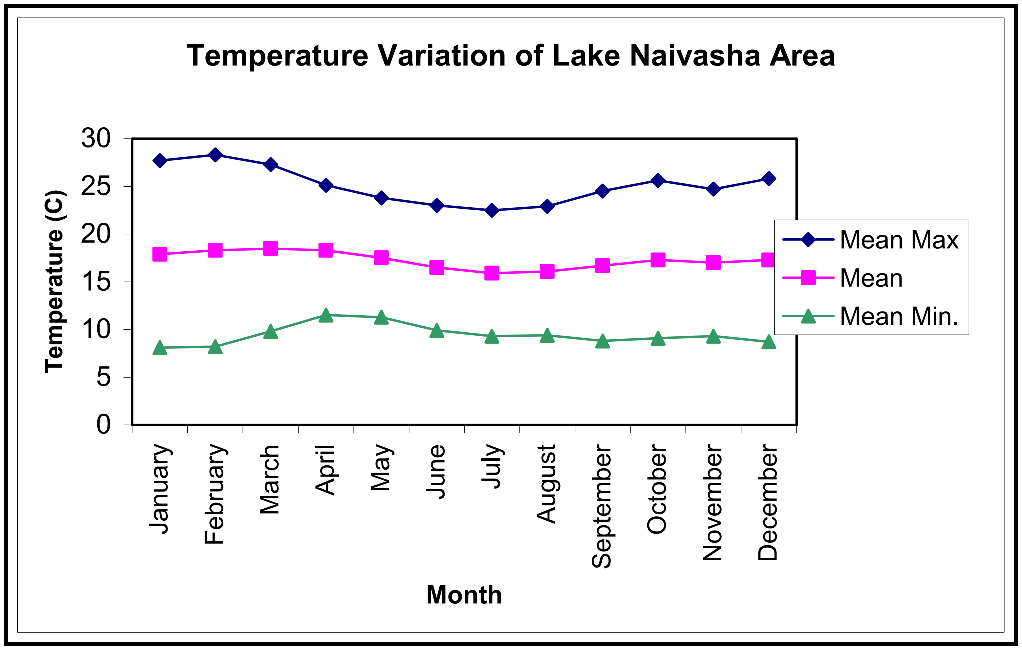


Figure 2-3: Min, Max and Mean Temperature variation of Lake Naivasha Area

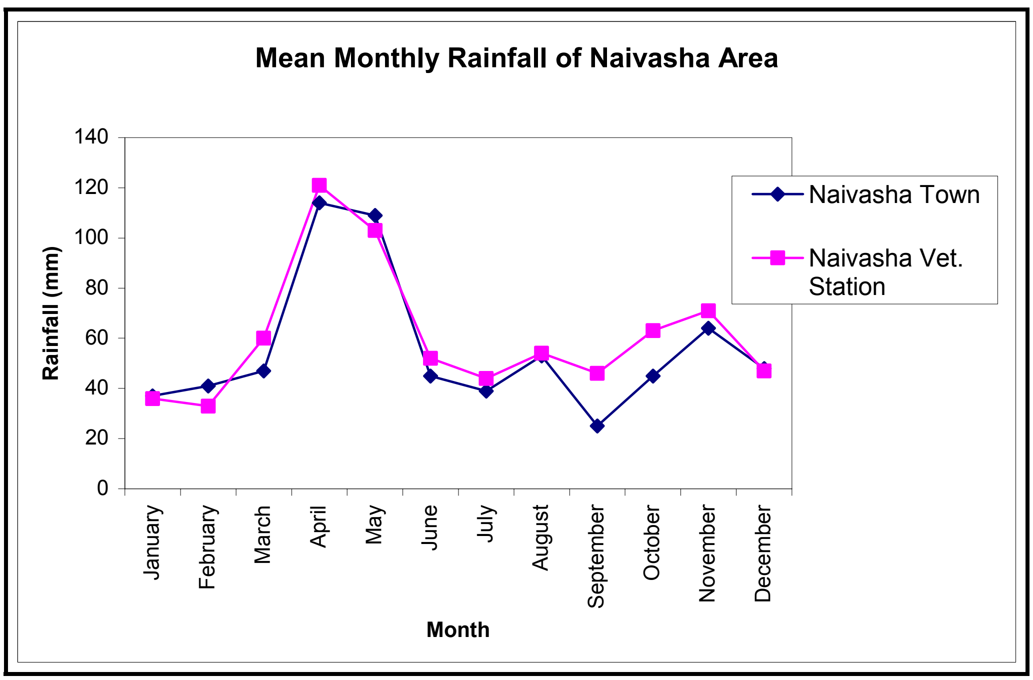


Figure 2-4: Average rainfall distribution of two stations around Lake Naivasha

2.2 Natural Resources

Lake Naivasha has important natural resources. In some cases they are unique within a wide area (LNRA, 1999)
Some of them are;

- Fresh water
- Geothermal power
- Diverse habitats
- Wide variety of mammals and birds
- Productive fishery
- Natural beauty and mild climate

2.3 Geology

According to the papers of Thompson and Dodson (1963) Clark et. al (1990), and McCall (1967) general geology of the area is described as follows. The Rift Valley, which is the most remarkable feature of the Earth's crust, forms a more or less continuous scar from Israel and Jordani South western Asia all the way to Mozambique in south-eastern Africa. One of the most prominent parts of the valley system is the so-called "Gregory Rift Valley" in Kenya. It is flanked by Nyandarua Range on eastern side and the Mau Escarpment on its western side (Ase, 1986).

Volcanic rocks and quaternary lacustrine deposits cover the study area. The lake Naivasha basin, stretching over an area of 3292 km^2, lies in the East African Rift valley, major basin covers just over 2% of the continent and spread over seven countries, namely Djibouti, Eritrea, Ethiopia, Sudan, Uganda, Tanzania and including Kenya. Based on detailed core analysis and radio carbon dating, Richardson and Richardson (1972) suggest that, in the period 9200 BC to 5700 BC, Naivasha was about four times as extensive and 58 m higher as it was in 1960.

Sediments cover much of the Rift Valley floor. These are Pleistocene in age; Quaternary era some 1.5 to 2.0 million years ago; and were laid down in lacustrine (lake) environments. The bulk of faults, scarps and fissures are linked with the Pleistocene movements. The volcanic rocks are a mixture of acid and basic larva's such as Tephrites, Rhyolites and Sodic Rhyolites.

The Rift valley was formed through many episodes of faulting and volcanism some 30M years ago. In geologic terms, the lake is very young, and there is still much evidence of volcanic activities. The geological information for Lake Naivasha area is available on a map at scale of 1:100,000, which have been surveyed by Clarke et.al (1998) and at scale 1:250 000 (Clarke et.al, 1990).

2.4 Topography

The topographic map shows that the area near the lake where most of the agricultural activities take place is flat and part of the recent lacustrine plain. Lacustrine plain is one of the subdivisions of major landscape, which identified in terms of geopedological soil survey terminology. Other subdivision is volcanic plain. The volcanic plain occurs in close association with the lacustrine plain.

2.5 Soils

Soils on the lacustrine plains around the lake have developed on sediments from volcanic ashes. Soils can vary from well to poorly drained, fine to sandy silts and clay loams of varying colour, but often pale. Fertility is variable and in some areas the soil can be sodic or saline. Generally the soils are easy to work, but very powdery when dry.

Soils in the catchment area are generally developed from volcanic activity, of moderate to low fertility, deep clayish loams, greyish brown to black in colour, often with drainage problems. Soils often degenerate into black cotton soils with impeded drainage in low-lying areas (LNROA, 1993).

2.6 Hydrology

Lake Naivasha with a total area of 13,255 hectares receives the discharge of the major rivers of Malewa, Giligil and Karati. The flow from Karati is seasonal. Almost 80% of the inflow in to the lake drained from Malewa with drainage area of about 1730 km^2 and Turasha sub catchments. Hydro geologically the lake Naivasha catchment is divided in to 11 sub basins namely Malewa, Gilgil, Karati, Turasha, Marmonet, Murukai, Kitiri, Wanjoni, Simba, Ngathi and Dundori.

Other sources of water input in to the lake include rainfall that occurs directly over the lake through underground movements (groundwater flow) from the catchment. The outputs from the lake are direct evaporation from the lake surface, transpiration from the swamp and other aquatic vegetation, underground seepage and water extraction by human activities.

Water balance of Lake Naivasha is complicated because of no accurate estimate of how much water goes in and out of the lake underground and how much is evaporating in to atmosphere. Lake Naivasha catchment has no surface outlet. It has underground water inflows and outflows. The freshness of the water can only result of underground outflows, otherwise the lake water has been saline.

2.7 Economy and Environment

The lake has always been an important ecological site to Kenya because of the diversity of flora and fauna in the range of vegetation zone associated with the lake (Salah, 1999). Due to its exceptional water quality this lake confers a paramount striate. There has been tremendous agricultural and geothermal power development based on extraction of water from the lake with the cultivation of flowers and vegetables for the export market in Europe. In the 1980’s a considerable expansion of Kenya’s cut flower industry brought Kenya to a point where the country was reorganized as one of the most important “Off season” supplier to Western Europe (Konijn, 2000). Plate-2 shows the cultivation of flower in a green house.

Powerful extensive horticulture farms are located around the lake, producing 75% of Kenya’s horticulture exports (Gorroxategi, 2001). There has been a rapid expansion of green houses mainly for flower cultivation around Lake Naivasha (Plate-3). The expansion of irrigated agriculture in this area took place after mid 1980.

At the moment over 100 large and small commercial farms are running irrigated floriculture, vegetables are produced mainly for exports to international markets and they are leading in the regional economy with net yearly return of US$ 63.02 million (Ahammad, 2001).

The birds of the lake are world famous, and it plays host to over 350 species. The diversity of wild life contributes to this area being an important tourist destination. The type of wildlife that are predominantly observed in the study area are Giraffe, Zebra, Hippopotamus, Impala, Water buck, Monkey, Buffalo and Warthog (Plate-4). These wildlife animals are mainly concentrated around the lake (riparian zone) and watering points. Also lake Naivasha is an important site for commercial fisheries. Introduced species are predominantly Or-eochroms leucostrictus, Tilapia zilli and Micropterus salmoides. The yearly net return from tourism and fisheries are US$ 6.58 and 44,322 million respectively as estimated by Salah, 1999.

2.8 Landuse / Vegetation

The catchment has been classified into the following land-use classes; lake, forest, irrigated agriculture, rain fed agriculture, rangeland and wet lands (Salah, 1999). The landuse types include fishing, residential area, agriculture land (Irrigated and non-irrigated), dairy farming, rangeland, natural vegetation, and out crop rocks (mountain climbing).

The Massai tribe pastoralists who were using the land for grazing and the lake water for watering their cattle formerly used to occupy the lake Naivasha area, but now the situation is drastically changing (Harper et al., 1990). With the arrival of white settlers in the area, considerable changes in the landuse had occurred. Among these: they introduced beef and diary farming, high tech irrigated agriculture with horticultural crops and flowers. Flowers (roses, carnation) and horticultural (vegetable) productions for export are the main agricultural activities that are dominating the shore of Lake Naivasha area and the sector absorbs the highest number of employees.

In the study area, three main types of semi-natural vegetation can be observed. These are papyrus mixed with grassland, acacia woodland and wooded grassland (Plate-5). A large part of natural vegetation has been removed and replaced by agricultural farming and pasture. Except for some parts, the increasing population of human being in the area has disturbed most part of the natural ecosystem.

Plate 2: View of a Green House

Plate 3: View of the Flower Farms Around the Lake

Plate 4: Gathering of Hippopotamus in the lake

Plate 5: Natural Vegetation such Papyrus and grassland in the lakeshore.

CHAPTER 3 : INFORMATION SYSTEM ANALYSIS (INFORMATION ANALYSIS)

3.1 Introduction

This chapter describes the method of design a Hydro-Environmental-Economic information system. Information analysis is a detailed appraisal of the existing system and includes finding out how the system works and what it does. It also includes what users require. The following analysis was carried out in the context of the development of Hydro-Environmental-Economic modelling information system. A system has both static (data) and dynamic (processes and flows) components. The static component describes the structure of the system, and dynamic component describes the processes in the system. More specifically, the statistic properties of a system are concerned with the abstraction of objects and concept involved, their properties (attributes) and their relationships. The properties are defined in a schema using same form of data description language. The dynamic aspects of the system are concerned with operations on objects and properties required by transaction and queries. Thus, the dynamic model abstracts the behaviour of the system and takes the form of specifications.

This chapter mainly focuses on the design and development of a conceptual (data and process) model of Hydro-Environmental-Economic modelling system. The process and data modelling will employ use of Data Flow Diagrams (DFDs), which is one of the most important tools used to model the system components, and data dictionaries with detailed description.

3.2 Dataflow Diagrams

Data flow diagrams use symbols, which represent system components. System components are processes; data used by the process and data stored and any external entities that interact with the system. The symbols represent the direction of data flow, processes, data stores and terminators (external entities) as shown in Fig 4.1.

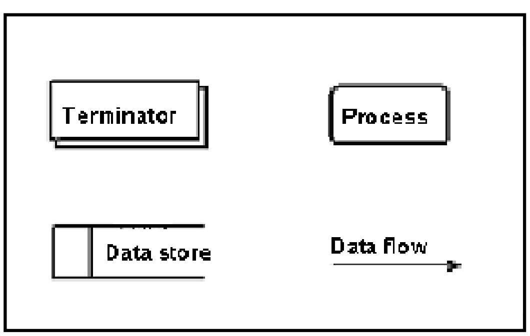


Figure 3-1: shows symbols use for data flow diagrams.

1. Terminator /External Entities

Terminators are outside the system, but they either supply input data into the system or use the system output. They are the entities over which the designer has no control. External entities that supply data into a system are sometimes called sources, and those that use data are sometimes called sinks.

2. Process

Processes show what systems do. Each process has one or more data inputs and produces one or more data outputs. Processes are represented by rectangles in a DFD. Each process has a unique name and number, which appear inside the rectangle that represents the process in a DFD.

3. File or Data stores

A file or a store is a repository of data. It contains data that is retained in the system. Processes can enter data into a data store or retrieve data from the data store. Each data store has a unique name.

4. Data flows

Data flows model the passage of data in the system and are represented by lines joining system components. An arrow indicates the direction of the flow and the line is labelled by the name of the data flow.

Flow of the data in the system can take place:

Between two processes;

From a data store to a process;

From a process to a data store;

From a source to a process; and

From a process to a terminator

A process can usually be split into several sub processes until a level is reached which is simple (Benyon, 1990). Process at lower levels can be checked to ensure that their inputs and outputs constitute exactly the data that appear at the higher level. The process of Hydro-Environmental-Economic modelling will be discussed in two levels:

1.Top level

2.Lower levels

The top-level processes describe the main process involved in the Hydro-Environmental-Economic modelling, the data inputs and outputs of the processes. Throughout process modelling, the symbol presented in figure 3-1 will be used.

3.3 Process modelling

The process modelling technique has a main objective to structure the information system functions and thus to enable defining the functional specifications of the system to be developed. The technique is mainly concerned with the definition of a top-down approach such the context data flow diagram (DFD) and its decomposition in to Low-level diagrams. Elementary functions are included (DD) to complement the documentation of DFD's.

The process modelling makes design of the Context Data Flow diagram (DFD) and its decomposition into Low-level diagrams. The Top-level diagram of Hydro-Environmental-Economic modelling system showing the sub systems such data collection & irrigated area mapping, economic modelling, crop-hydrological Processing, and analysis). Overall process-modelling structure is presented in figure 3-2.

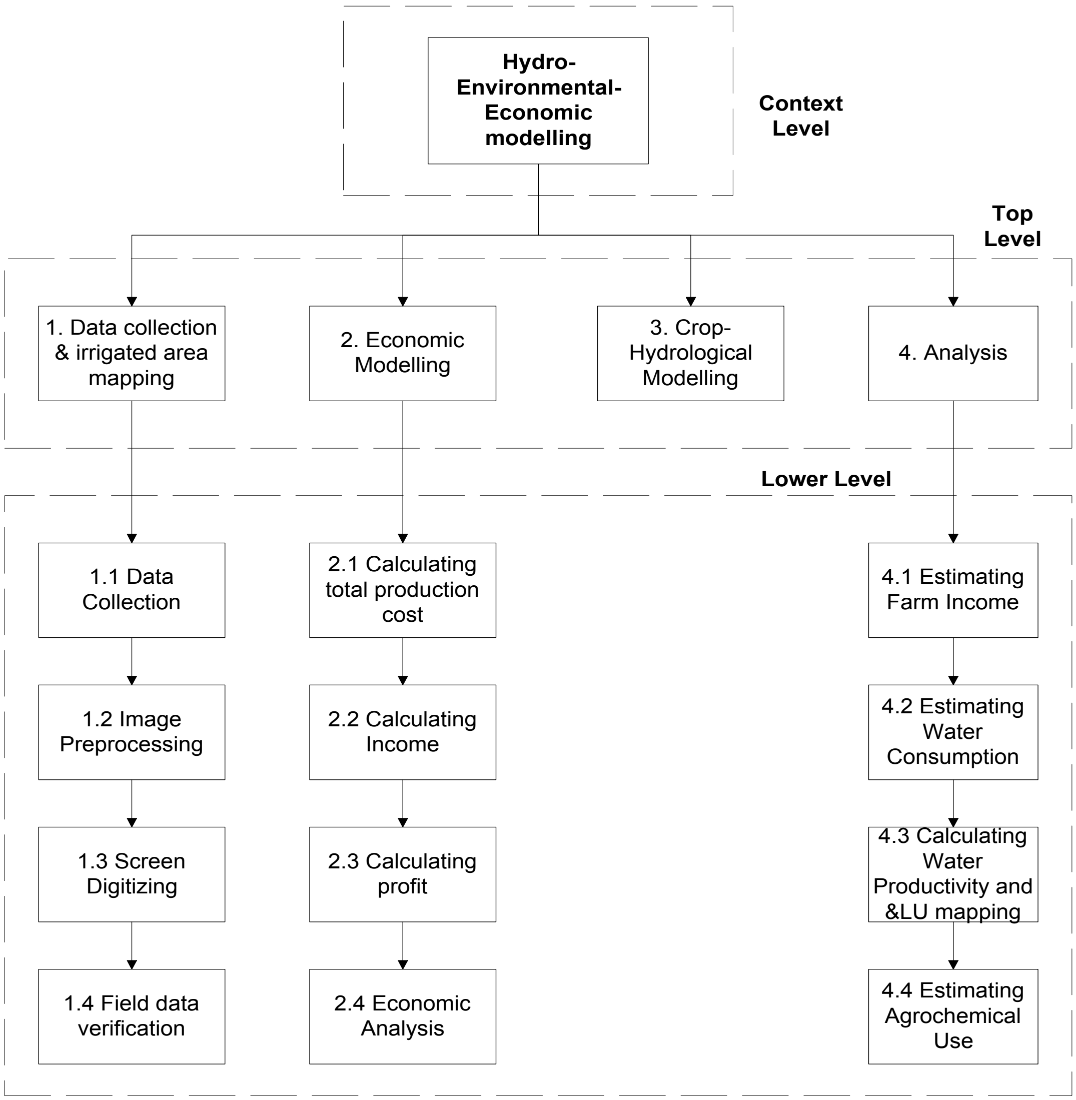


Figure 3-2: Overall process modelling structure.

3.4 Context Diagram

The common way to start the design is to model the whole system as one process and identifying the main information sources of the system so-called external entities. The Hydro environmental-Economic modelling system, when modelled by one process, consists of seven main external entities. They are ITC database, Ministry of Land and Settlement, Meteorology Department, Farmers, Lake Naivasha Lake Riparian Owners Association and Researchers as shown in the fig 3-3.

The Hydro-Environmental-Economic modelling system receive requests for Researchers, ITC database, Farmers and Lake Naivasha Riparian Owners Association. The system receives data from Lake Naivasha Riparian Owners Association, ITC database, Ministry of Land & Settlement, Meteorology Department, Farmers and Ministry of Water Resources for the Hydro-Environmental-Economic modelling. The system processes and analyses the data and produces the required user information.

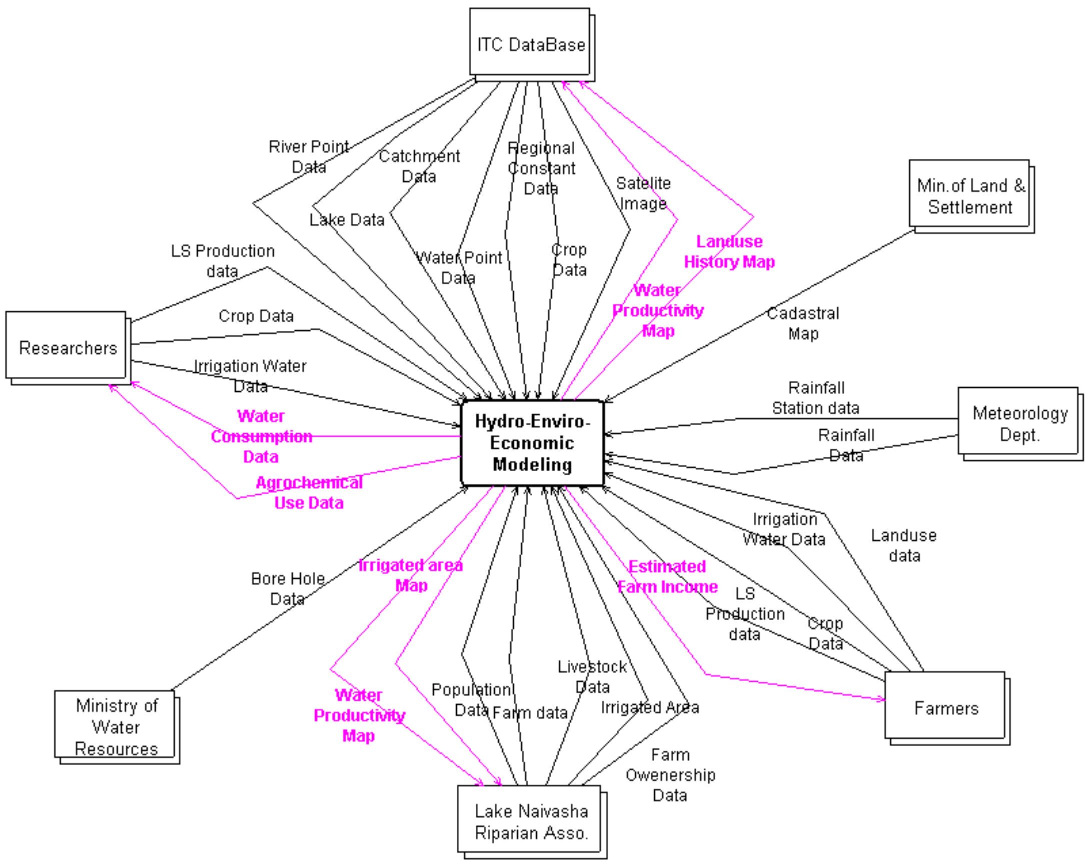


Figure 3-3: Context diagram of the Proposed System

3.5 Top Level Diagram

A model like that shown in fig. 3-3 does not describe the system in detail. For further detail it is necessary to identify the major system processes and draw a DFD made up of these processes and the data flow between them. The DFD that shows the major system processes is called the top level DFD as shown in fig 3-4 which shows the various processes involved in the proposed system. Proposed Hydro-Environmental-Economic modelling system has four main processes that are Data collection & Irrigated area mapping, Economic modelling, Crop-Hydrological Processing, and Analysis. The activities, requirements and descriptions of each process are explained separately in the coming sections.

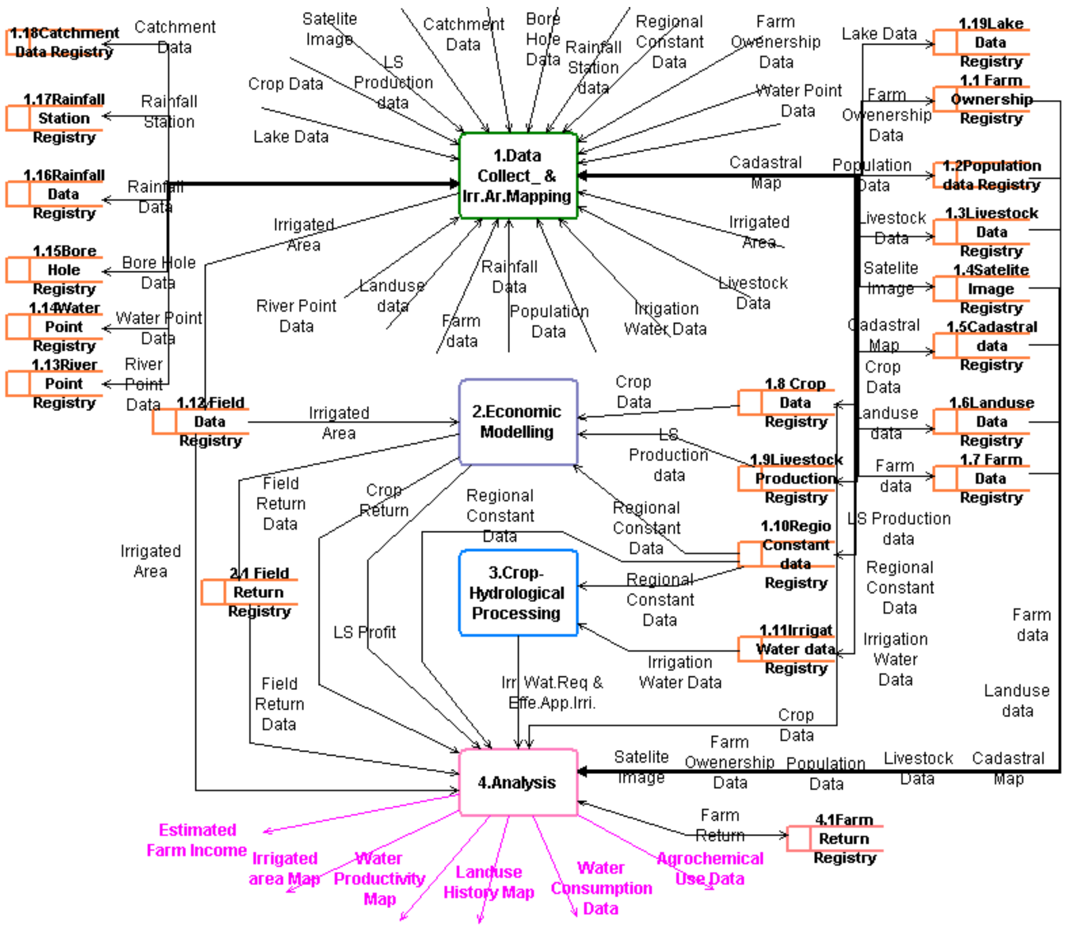


Figure 3-4: Data Flow Diagram

3.5.1 Data Collection & Irrigated Area mapping

This is the main process of the Hydro-Environmental-Economic modelling. This process is mainly responsible for collection of data and tracing irrigated area with the aid of satellite images and field verification.

Functions

Collecting and storing all data in stores

Image pre-processing and tracing the irrigated area by screen digitising and

Calculating irrigated area.

All calculations in connection with these functions are described in section 3.11.1.

<u>Sub processes</u>:

-Data collection

-Image pre processing

-Screen digitizing

-Field data verification

All these sub processes are described in section 3.6.1.

Input flows:

-Regional constants data
-Satellite image
-Farm data
-Borehole data
-Landuse data
-Cadastral Map
-Rainfall Station data
-Livestock data
-Crop data
-Rainfall data
-Population data
-Irrigated area data
-Farm Ownership data
-LS production data
-Lake data
-River point data
-Water point data
-Irrigation water data
-Catchment data

Output flows:

-Irrigated area

Accessed stores:

-Field Data Registry (Write), Satellite image registry, Farm ownership registry, Crop data registry, Population data registry, Livestock data registry, Cadastral data registry, Landuse data registry, Farm data registry, Livestock production registry, Regional constant data registry, Irrigation water data registry, Catchment data registry, Rainfall station registry, Bore hole registry, Water point registry, River point registry and Lake data registry (Read, Write and Update).
Description of these data stores is given in appendix-5.

3.5.2 Economic modelling

This process is mainly responsible for economic calculation in terms of Livestock profit, Crop return and Field return. Economic modelling mainly consists of assessing net returns of each crops and livestock profit. Net return of crop and livestock is the difference of total return and total production cost of crops and livestock. In calculating total production cost of crops, parameters such use and cost of labour, fertilizer and pesticide, cost of seeds, preservation, freight and cooling, and crop rotations are considered. In calculating net returns of crops, parameters such crop yield, crop rotation, yield return co-efficient and farm gate price are considered. Parameters such labour requirements, labour cost, fodder cost and dry matter intake (DMI) are considered for calculation of total production cost of livestock. Production of milk, price of milk, production days and percentage of productivity are considered for calculation of livestock profit.

Most of the calculations done in economic modelling are based on the study of Sayeed, 1999. He developed a dynamic economic model using excel spreadsheet to show the individual farm outputs together with crop and diary net returns. The economic model has been developed to supply instantly outputs such water productivity of farms when necessary changes done in input parameters. In addition to that, this new model was added the time series. So, without changing the structure and existing data of the model, we can add relevant data of any particular year and visualize different scenarios.

Functions:

Calculating of crop return
Calculating of profit of livestock

Calculating field return
Calculating crop return
All equations in order to perform above functions are described in section 3.11.2.

Sub processes:
-Calculating total production cost
-Calculating Income
-Calculating profit
-Economic analysis.
All these sub processes are described in section 3.6.2.

Input flows:
-Irrigated area
-Crop Data
-Livestock Production Data
-Regional Constant data

Output flows:
-Field Return Data
-Crop Return
-Livestock Profit

Accessed stores:
-Regional Constant data Registry (Read)
-Field Data Registry (Read)
-Field Return Registry (Write)
-Crop data registry (Read)
-Livestock Production registry (Read)
Description of these data stores is given in appendix-5.

3.5.3 Crop-Hydrological processing

This process is mainly responsible for calculating Irrigation water requirements and the Effective Applied irrigation. Mekonen, 1999 calculated supplementary irrigation water requirement that used for these calculations.

Functions:
Calculating Irrigation water requirement and effective applied irrigation
All equations in order to perform above functions are described in section 3.11.3.

Sub processes:
There are no sub processes.

Input flows:
-Irrigation water data.
-Regional constant data

Output flows:
-Irrigation water requirements and Effective applied irrigation.

Accessed stores:
-Irrigation water data registry (Read)
-Regional constant data registry (Read)

3.5.4 Analysis Process

This process, which is very important, is mainly responsible to compose reports and maps in accordance with Agrochemical use, Land history, Water productivity, Irrigated areas, Water consumption and Economy based on user requirements.

Functions:
Produce agrochemical, landuse history, water productivity and irrigated area maps.
Produce reports on water consumption, agrochemical use, water productivity on farm and field basis.
All equations in order to perform above functions are described in section 3.11.4.

Sub processes:
-Estimating farm income
-Estimating water consumption
-Calculating water productivity and LU mapping.
-Estimating agrochemical use
All these sub processes are described in section 3.6.3.

Input flows:
-Population data
-Landuse data
-Irrigated area
-Livestock data
-Cadastral map
-Livestock Profit
-Regional constant data
-Farm data
-Farm Ownership data
-Satellite Image
-Crop data
-Crop Return
-Field return data
-Irrigation water require and Effective Applied Irrigation

Output flows:
-Estimated Farm Income
-Water Productivity Map
-Irrigated area map
-Landuse history map
-Agrochemical use data
-Water Consumption data

Accessed stores:
-Field data Registry (Read)
-Field Return Registry (Read)
-Crop Data Registry (Read)

3.6 Lower Level Diagrams

The model represented by the top-level model in fig 3-4 also, does not describe the system in detail. For a detail description of the system, it is necessary to expand each identified major process (except crop hydrological processing). As we expand the major processes of the top-level model into more detail, a detailed description of the system can be obtained, which is represented by a so-called low-level diagram. So, in this section, each of the major processes identified in the top-level is expanded and described briefly.

3.6.1 Data collection and irrigated area mapping sub processes

This sub process consists of data collection, image pre-processing, screen digitising and field data verification process as shown in fig 3-5 below.

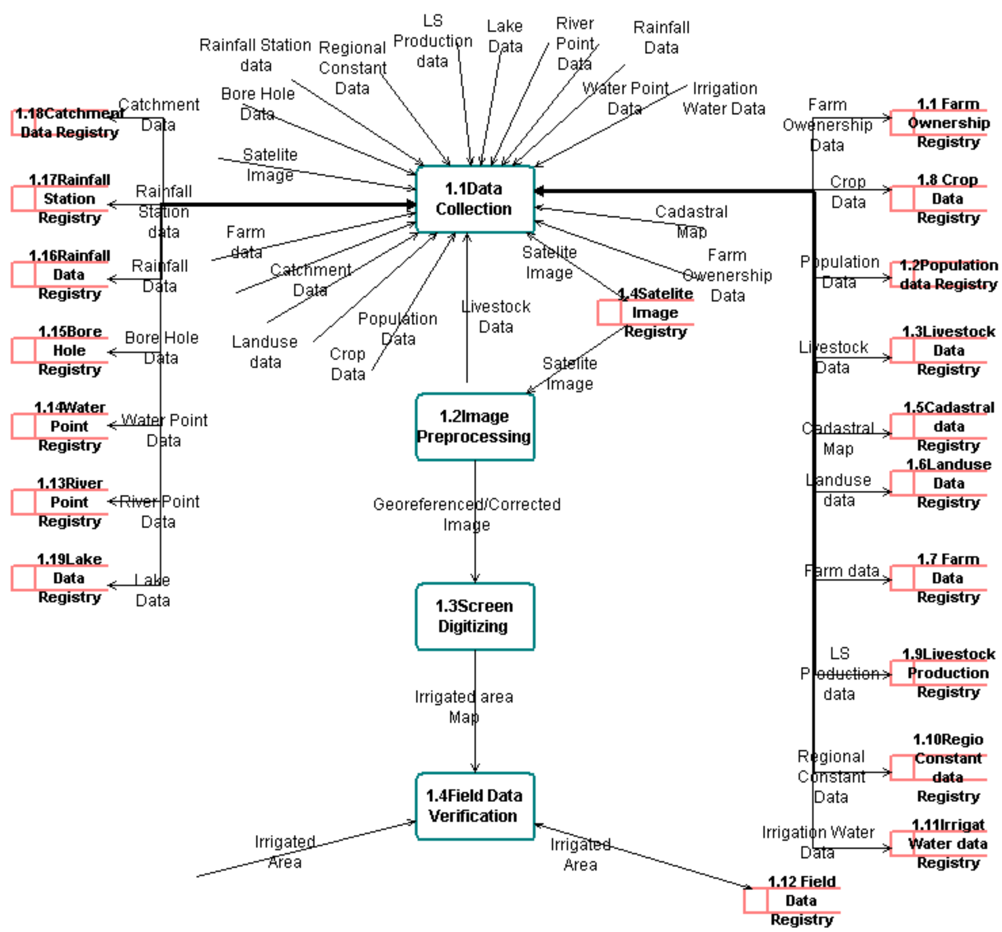


Figure 3-5: Low-level diagram of data collection and irrigated area mapping

The names of sub processes of Data collection and Irrigated area mapping and their activities are explained in the table 3-1 below. Data dictionary for data stores is given in appendix-5.

Table 3-1: Showing names of sub processes of data collection and irrigated area mapping and their activities

Sub process No	Name of the Process	Description of Activities
1.1	Data Collection	• Collection data on Regional constant, Satellite image, Farm, Livestock, Livestock production, Crop, Rainfall, Borehole, Population, Landuse, Catchment, Water point, Cadastral, Farm ownership, Irrigation water, Lake and River point data.
1.2	Image Pre-processing	• Return satellite image to image pre-processing process for Georeferencing and correcting • Georeferencing and Correcting of image.
1.3	Screen digitizing	• Return the image to screen digitizing process • Screen digitizing the irrigated area. • Return the image and digitized polygon map to field verification process.
1.4	Field data verification	• Cross check, correct and update digitized irrigated area map with aid of field data. • Store irrigated area data in a Field data Registry (No.1.12)

3.6.2 Economic modeling sub processes

This process consists of calculating total production cost, calculating income, calculating profit and economic analysis processes as shown in fig 3-6 below.

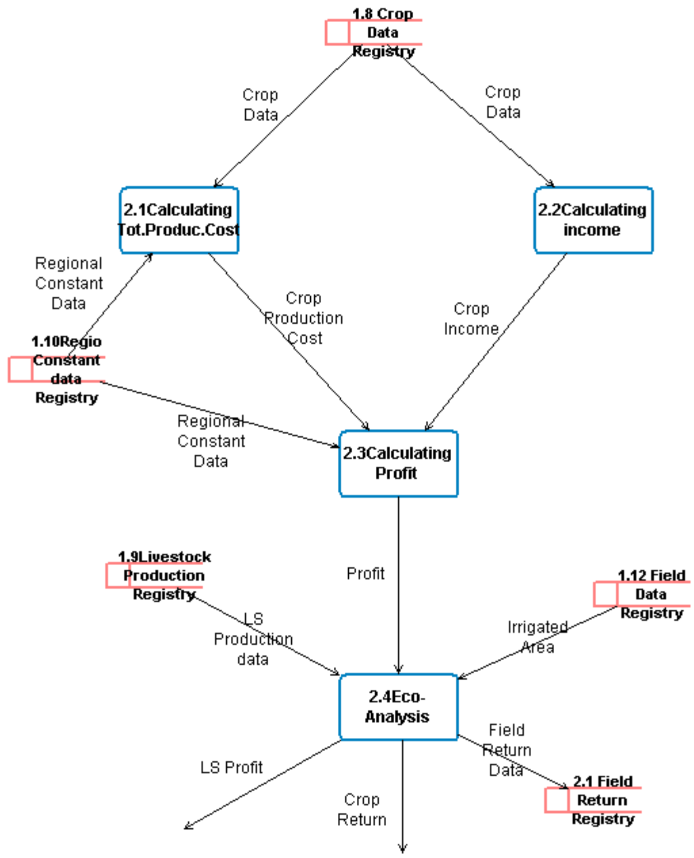


Figure 3-6: Low level Diagram of economic modelling

The name of sub process of Economic modelling and their activities are explained in the table 3-2 below. Data dictionary for data stores is given in appendix-5.

Table 3-2: Showing names of sub processes of economic modelling and their activities.

Sub process number	Name of the process	Description of activities
2.1	Calculating total production cost	• Receive data on regional constant and crop. • Return the crop production cost to calculating profit process.
2.2	Calculating income	• Receive data on crop. • Return crop income to calculating profit process.
2.3	Calculating net profit	• Receive regional constant data, crop production cost and crop income. • Return profit to Economic analysis process
2.4	Economic analysis	• Receive data on Livestock production, irrigated area and profit.

Sub process number	Name of the process	Description of activities
		• Store the Field return data in Field return Registry no.2.1 • Return Crop return and Livestock Profit to Analysis Process no.4

3.6.3 Analysis sub processes

This process consists of estimating farm income, estimating water consumption, calculating water productivity and LU mapping and estimating agrochemical use.

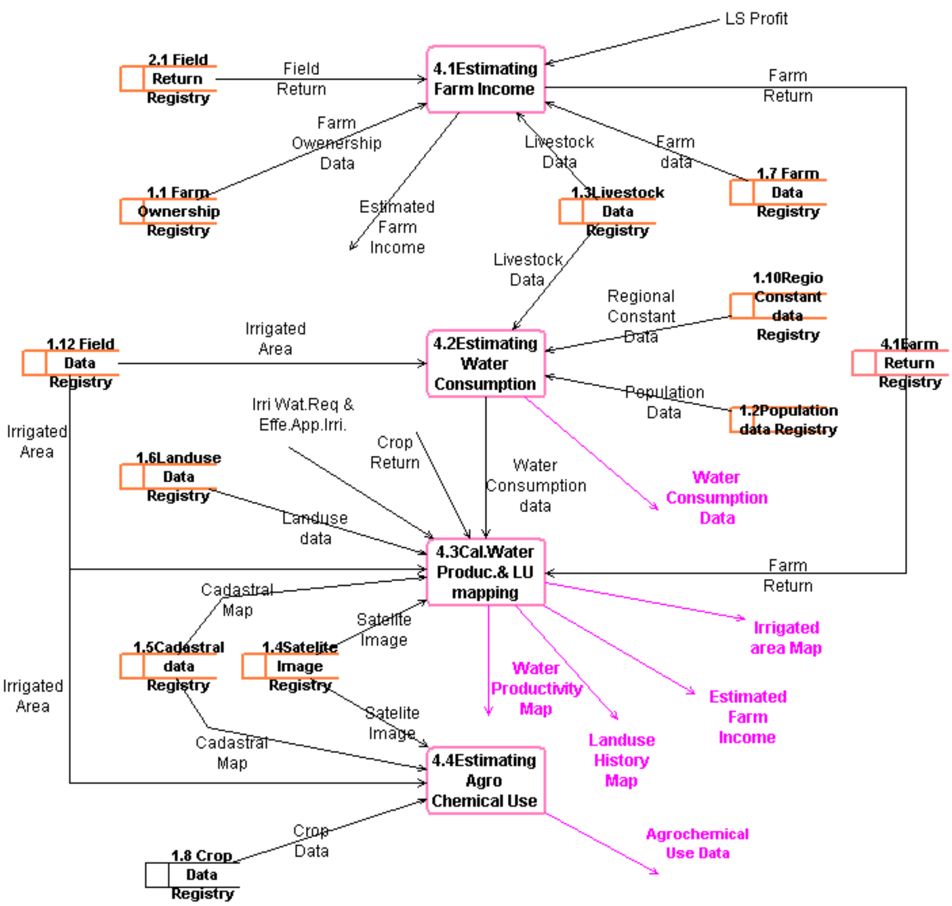


Figure 3-7: Low level Diagram of analysis process

The sub processes of Analysis and their activities are explained in the table 3-3 below. Data dictionary for data stores is given in appendix-5.

Table 3-3: Showing names of the processes of analysis and their activities

Sub process No	Name of the process	Description of Activities
4.1	Estimating Farm Income	• Collection data on Field return, Farm ownership, Livestock, Farm and Livestock profit. • Return Estimated Farm Income • Store farm return in the farm return registry
4.2	Estimating Water Consumption	• Collection data on Livestock, Irrigated area, Regional constant and Population • Return water consumption data.
4.3	Calculating Water Productivity and LU mapping	• Collection data on Landuse, Irrigation water req. and Effective Applied Irrigation, Crop return, Water consumption, Farm return, Satellite image, Cadastral map and Irrigated area. • Produce Irrigated area map, Estimated farm income, Landuse history map and Water productivity map
4.4	Estimating Agro Chemical Use	• Collection data on Cadastral map, Satellite image, crop and Irrigated area. • Produce Agrochemical use of Farms.

3.7 Defining Information Requirement

The identification of information requirements can contribute to solve the problems of different interest groups. Information system should be developed, if they can in someway meet the requirements and need of the organization. Correct and complete identification and definition of the information requirements are therefore the key ingredients of successful information system development (Sushil Pradhan, 1998).

Information requirements are key elements in developing the overall information system structure and in specifying databases and applications. The information requirements are determined by the strategies, goals, objectives and procedures of the analysis of the current problem.

Based on the analysis of the results of interviews and the existing problems, the following categories of information requirement are identified to generate the Hydro-Environmental-Economic modelling new information system.

- Information on Farm

- Information on Climate
- Information on Irrigated area
- Information on Landuse
- Information on Economy
- Information on Crops

3.8 Information Analysis

Information analysis defines the actual content of the information system. On the basis of the information requirements of the system and study of outputs, major processing functions and inputs of the system were defined. Information analysis defines the conceptual view of the system and describes what the system should contain and what it should be able to do.

Definition of information type required by users from the new system is very important. It is also important to know the new system's proposed functions, its data structure and data quality concepts.

Results of information analysis and indication of requirements of input and output within the information system is presented in table 3-4.

Stakeholders	Requirements & Responsibilities	Input Requirements	Output Requirements	Quality Parameters for information
Lake Naivasha Riparian Owners Association	To manage existing human activities in the Lake ecosystem through voluntarily adopted sustainable wise use principles to ensure conservation of the fresh water resources. To improve the standard of living of the people through regional development and Economic growth.	Statistical data a) Livestock b) Population c) Water abstraction d) Farm e) Irrigated area & Farm ownership	Water productivity map. Irrigated area map	Completeness Regularity Consistency
Researchers	Contribute to research activities conducted by ITC	**Crop data** a) Fertilizer pesticide requirement. b) Yield **Irrigation water data** a) Irrigation requirements days b) Act. Evapotransrira.	Agrochemical use data Water consumption data	Completeness Regularity Consistency
ITC Data base	Collect and provide raw and analysed data to the research activities	**Regional Constant** a) Currency exchange rate b) Casual labour cost c) Cost of fertilizer d) Cost of pesticide e) Rainfall f) Water requirement for livestock and farm population. **Crop data** **Bore hole data** **Farm gate price** **Satellite image** **Water Point Data** **Catchment data** **Lake data**	Landuse history map Water productivity map Agrochemical use map Farm income distribution map	Completeness Lineage Regularity
Farmers	Contribute to the regional development and Economic growth	**Landuse data** **Irrigation water data** a) Applied irrigation **Crop data** **LS Production data**	Estimated farm income	Completeness

Table 3-4: Shows the requirements of input and output of the system

3.9 User Requirement Analysis

Base on the above analysis the proposed system should provide the following information. These can be grouped as

- Agrochemical use information
- Water productivity information
- Landuse history information
- Farm/Field economic information
- Water consumption information

3.10 Overall System Structure

Based on the results of the analysis, problem definition and information requirement analysis, Hydro-Environmental-Economic modelling information system is designed to meet all the requirements.

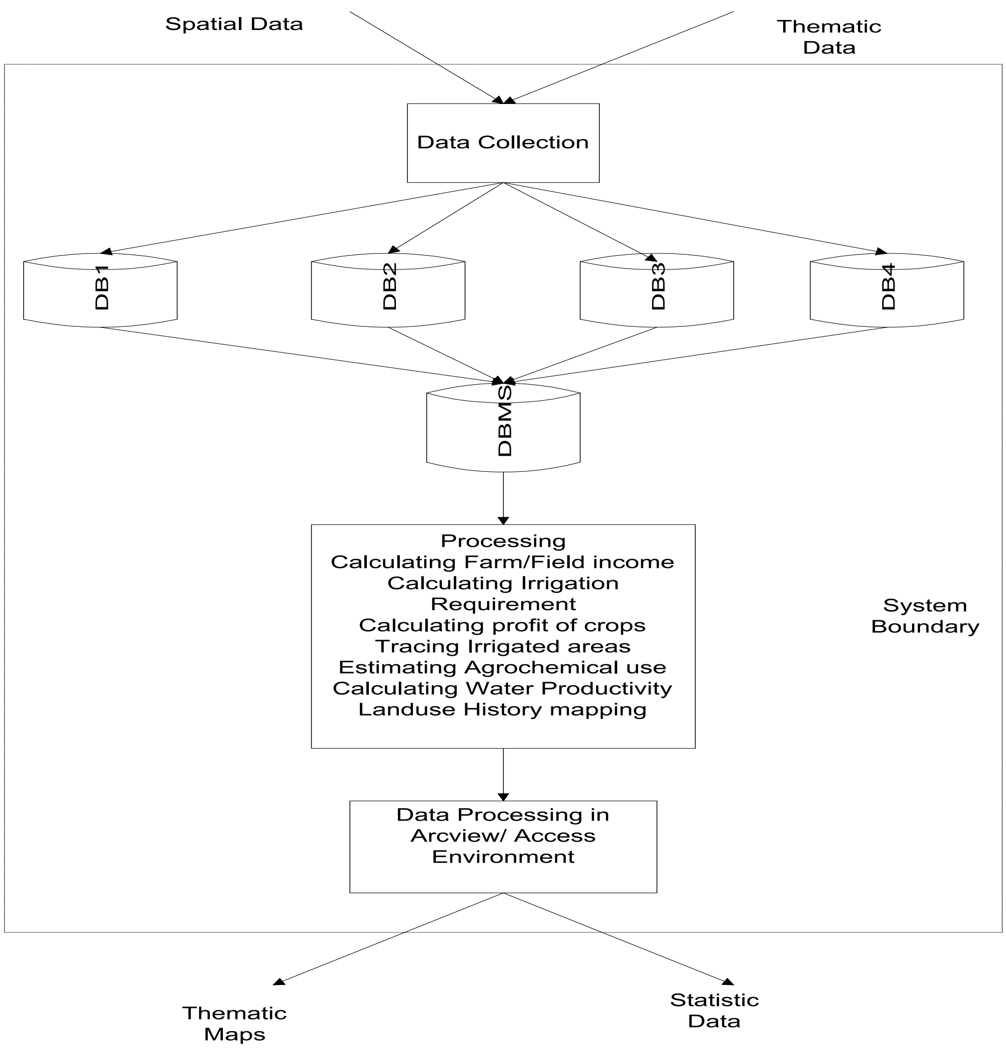


Figure 3-8: Global representation of Hydro-Environmental-Economic Modelling Information System

3.11 Data Processing in MS Access and Arcview Environments

This section describes all calculations done in process modelling.

3.11.1 Data Collection & Irrigated Area mapping

In this process following equation is used to calculate irrigated area in ArcView environmental.

Equation 3-1: Irrigated area =Return. [Area]

3.11.2 Economic Modelling

In this process, following equations and relevant queries are used to calculate crop return, profit of livestock, field return and crop return in MS Access environment.

Calculating crop return

Equation 3-2: Tot_Pro_Cost: ((([Cost_L_F_P]+([Cost_L_F_P]*0.1*[Factor_Seed])) +([Cost_L_F_P] +([Cost_L_F_P]*0.1*[Factor_Seed]))*0.05*[Factor_Preser])+[Farm_G_P]*0.5*27.5*[Factor_Frieght])*0.01*[Factor_Cooling]+((([Cost_L_F_P]+([Cost_L_F_P]*0.1*[Factor_Seed]))+([Cost_L_F_P]+([Cost_L_F_P]*0.1*[Factor_Seed]))*0.05*[Factor_Preser])+[Farm_G_P]*0.5*27.5*[Factor_Frieght])

Equation 3-3: Cost_L_F_P = [Labour_use]*[L_Cost]+[Fer_use]*[C_F_A]+[Pes_use]*[Pes_Price]

Following query has been designed to calculate total production cost and cost for labour, fertilizer and pesticide in connection with above equation 3-2 and 3-3.

Query

SELECT Crop.Crop_id, Crop.Labour_use, Crop.Fer_use, Crop.Pes_use, Crop.Pes_Price, Regional_Constant.L_Cost, Regional_Constant.C_F_A, [Labour_use]*[L_Cost]+[Fer_use]*[C_F_A]+[Pes_use]*[Pes_Price] AS **Cost_L_F_P**, ((([Cost_L_F_P]+([Cost_L_F_P]*0.1*[Factor_Seed]))+([Cost_L_F_P]+([Cost_L_F_P]*0.1*[Factor_Seed]))*0.05*[Factor_Preser])+[Farm_G_P]*0.5*27.5*[Factor_Frieght])*0.01*[Factor_Cooling]+((([Cost_L_F_P]+([Cost_L_F_P]*0.1*[Factor_Seed]))+([Cost_L_F_P]+([Cost_L_F_P]*0.1*[Factor_Seed]))*0.05*[Factor_Preser])+[Farm_G_P]*0.5*27.5*[Factor_Frieght]) AS **Tot_Pro_Cost**, Crop.Factor_Seed, Regional_Constant.Year, Crop.Factor_Preser, Crop.Farm_G_P, Crop.Factor_Frieght, Crop.Factor_Cooling

FROM Regional_Constant INNER JOIN Crop ON Regional_Constant.Year = Crop.Year

GROUP BY Crop.Crop_id, Crop.Labour_use, Crop.Fer_use, Crop.Pes_use, Crop.Pes_Price, Regional_Constant.L_Cost, Regional_Constant.C_F_A, Crop.Factor_Seed, Regional_Constant.Year, Crop.Factor_Preser, Crop.Farm_G_P, Crop.Factor_Frieght, Crop.Factor_Cooling;

Equation 3-4: Crop_Y = [Crop_Rotation]*[Yield]

Equation 3-5: Effect_Y = [Yield_R_Coe]*[Crop_Y]

Equation 3-6: Effect_Return = [Effect_Y]*[Farm_G_P1]

Equation 3-7: Profit = [Effect_Return]-[Tot_Pro_Cost]

Equation 3-8: Net_Profit = [Profit]/[Ex_Rate]

Where

Tot_Pro_Cost	-Total Production cost (Ksh/hec)
Cost_L_F_P	-Cost of labour, fertilizer and pesticide (Ksh/hec)
Factor_Seed	-Factor for seedling (0 or 1)
Factor_Preser	-Factor for preservation (0 or 1)
Factor_Frieght	-Factor for freight (0 or 1)
Factor_Cooling	-Factor for cooling (0 or 1)
Farm_G_P	-Farm gate price (Ksh/Ton)
Labour_use	-Labour use (Workdays/ha.crop)
L_Cost	-Cost of labour (Ksh/day)
Fer_use	-Use of fertilizer (Tons/ha.crop)
C_F_A	-Cost of fertilizer all crops (Ksh/Ton)
Pes_use	-Use of pesticide (Tons/ha.crop)
Pes_Price	-Price of pesticide (Ksh/Ton)
Crop_Y	-Yield of crop (Tons/ha.crop)
Crop_Rotation	-Crop rotation per year (None)
Yield	-Total yield (Tons/ha.yr)
Effect_Y	-Effective yield (Tons/ha.yr)
Yield_R_Coe	-Yield return co-efficient (None)
Effect_Return	-Effective return (Ksh/ha.yr)
Farm_G_P1	-Farm gate price (same as Farm_G_P) (Ksh/Ton)
Profit	-Profit in Ksh (Ksh/ha.yr)
Net_Profit	-Net profit in Us$ (US$/ha.yr)
Ex_Rate	-Exchange rate of Kenyan Shilling & Us$ (None)

Calculating field return

Equation 3-9: Tot_Profit = [Area_Irri]*[Net_Profit]

Where

Tot_Profit	-Total profit of field (Us$)
Area_Irri	-Irrigated area (ha)
Net_Profit	-Profit of crop (Us$/ha)

Calculating Livestock Profit

Equation 3-10: Total_Cost = ([Labor_req]*[Labor_Cost]+[Fodder_Price]*[D_M_I])

Equation 3-11: Return_Lu = [Production]*[Price]*[Produc_Days]*[Produc_Per]

Equation 3-12: Net_Return = ([Return_Lu]-[Total_Cost])/[Ex_Rate]

Where

Total_Cost	-Total cost of livestock production (Ksh/LU)
Labor_req	-No of labours required for livestock unit (Workdays/LU.yr)
Labor_Cost	-Labour cost (Ksh/day)
Fodder_Price	-Market price of fodder (Ksh/Ton)
D_M_I	-Dry Matter Intake (Tons/LU)
Return_Lu	-Return per LU (Ksh/LU)
Production	-Production of milk (Liters/LU.day)
Price	-Price of milk (Ksh/litre)
Produc_Days	-Effective number of production days (Days/LU.day)
Produc_Per	-Percentage of productivity of LU (%)
Net_Return	-Profit of LU (US$/LU.yr)

3.11.3 Crop-Hydrological processing

In this process following equations are used to calculate irrigation water requirement and effective applied irrigation.

Calculating irrigation water requirement

Equation 3-13: ETact(y) = [AvgOfIrri_Re_D]*[AvgOfET_act]*10

Equation 3-14: Asu_E_RF = [AvgOfIrri_Re_D]*[R_F]*10*[AvgOfFactor_R]/365

Equation 3-15: Irri_W_Re = ([ETact(y)]-[Asu_E_RF])*[AvgOfFactor_Iri_wa]

Calculating effective applied irrigation

Equation 3-16: App_Irri = [AvgOfApp_irri]*[AvgOfIrri_Re_D]*10

Equation 3-17: Effe_Ap_Irri = ([App_Irri]-[Asu_E_RF])*[AvgOfFactor_E_A_I]

Where

ETact(y)	-Actual Evapotranspiration (m^3 /ha.yr)
AvgOfIrri_Re_D	-Irrigation required days (Days/yr)
AvgOfET_act	-Actual Evapotranspiration (mm/day)
Asu_E_RF	-Assumed effective rainfall (m^3 /ha.yr)
R_F	-Rainfall (mm)

AvgOfFactor_R	-Factor of effective rainfall (or rainfall) (1 or 0)
Irri_W_Re	-Irrigation water requirement (m^3 /ha.yr)
Asu_E_RF	-Assumed effective rainfall (m^3 /ha.yr)
AvgOfFactor_Iri_wa	-Factor of irrigation water requirement (1 or 0)
App_Irri	-Applied irrigation (m^3 /ha.yr)
AvgOfApp_irri	-Applied irrigation (mm/day)
AvgOfFactor_E_A_I	-Factor of effective applied irrigation (1 or 0)
Effe_Ap_Irri	-Effective applied irrigation (m^3 /ha.yr)

3.11.4 Analysis Process

In this process following equations are used to calculate estimated farm income, water consumption, agrochemical use and water productivity on farm and field basis.

Estimating farm income

Equation 3-18: Tot_Income_L = [Units]*[Net_Return]

Equation 3-19: Tot_Profit = [Area_Irri]*[Net_Profit]

Equation 3-20: Tot_Profit(OA) = [SumOfTot_Profit]+[SumOfTot_Income_L]

Where

Tot_Income_L	-Total income from livestock (Us$)
Units	-Livestock units (No)
Net_Return	-Return from livestock (Us$/LU.yr)
Tot_Profit	-Total profit from crops (Us$/yr)
Area_Irri	-Irrigated area (ha)
Net_Profit	-Profit from crop (Us$/ha)
Tot_Profit(OA)	-Overall total profit (Us$/yr)

Estimating Water consumption

Equation 3-21: Tot_App_Irri = [Area_Irri]*[Effe_Ap_Irri]

Equation 3-22: Water_Consu_LS_FP = ([W_R_L]*[Units]+[W_R_FP]*[People])

Equation 3-23: Total_Water_Cons = [SumOfTot_App_Irri]+[Water_Consu_LS_FP]

Where

Tot_App_Irri	-Total applied irrigation (m^3 /yr)
Area_Irri	-Irrigated area (ha)
Effe_Ap_Irri	-Effective applied irrigation (m^3 /ha.yr)
Water_Consu_LS_FP	-Water consumption for livestock and farm people (m^3 /yr)
W_R_L	-Water requirement for livestock (m^3 /LU.yr)
Units	-No.of livestock units (None)

W_R_FP	-Water requirement for farm people (m^3 /person.yr)
People	-No.of people (None)
Total_Water_Cons	-Total water consumption (m^3 /yr)

Calculating water productivity (Field water productivity)

Equation 3-24: Tot_Irri_w_Req = [Area_Irri]*[Irri_W_Re]

Equation 3-25: Water_Pro_Ex = [Tot_Profit]/[Tot_Irri_w_Req]

Equation 3-26: Tot_App_Irri = [Area_Irri]*[Effe_Ap_Irri]

Equation 3-27: Water_Produc_Ac = [Tot_Profit]/[Tot_App_Irri]

Where

Tot_Irri_w_Req	-Total irrigation water requirement (m^3 /yr)
Area_Irri	-Irrigated area (ha)
Irri_W_Re	-Irrigation water requirement (m^3 /ha.yr)
Tot_Profit	-Total profit from crop (Us$/yr)
Water_Pro_Ex	-Expected water productivity (Us$/ m^3)
Tot_App_Irri	-Total applied irrigation (m^3 /yr)
Effe_Ap_Irri	-Effective applied irrigation (m^3 /ha.yr)
Water_Produc_Ac	-Actual water productivity (Us$/yr)

Farm water productivity

Equation 3-28: Farm_Wat_Produc(OA) = [Tot_Profit(OA)]/[Total_Water_Cons]

Equation 3-29: Farm_Wat_Produc (Irri) = [Tot_Profit]/[Tot_App_Irri]

Where

Farm_Wat_Produc(OA)	-Overall farm water productivity (Us$/ m^3)
Tot_Profit(OA)	-Overall total profit (Us$/yr)
Total_Water_Cons	-Total water consumption (m^3 /yr)
Farm_Wat_Produc	-Farm water productivity –only irrigation water (Us$/ m^3)
Tot_Profit	-Total profit –only from irrigation (Us$/yr)
Tot_App_Irri	-Total applied irrigation (m^3 /yr)

Estimating Agrochemical use

Equation 3-30: Tot_Agro_Che = ([Fer_use]+[Pes_use])*[Area_Irri]

Where

Tot_Agro_Che	-Total agrochemical use (Tons/yr)
Fer_use	-Fertilizer use (Tons/yr)
Pes_use	-Pesticide use (Tons/yr)
Area_Irri	-Irrigated area (ha)

CHAPTER 4 : SYSTEM DESIGN

4.1 Introduction

This chapter mainly focuses on the data modelling. This will be based on information analysis and process modeling (chapter-3). The data modelling steps consist from Entity-Relationship Diagrams (ERD).

4.2 Data Modelling

The earth's surface can be considered as a spatio-temporal continuum in which process of different kinds take place. Geo-information systems are used to store and process data referring to the earth surface. These data contain both thematic and geometric (spatial) information (Molenaar, 1998).

For most applications the thematic aspects of a terrain description are of prime importance. This means that the data querying and processing will be organized and formulated primarily from a thematic perspective. The structuring and formulation of the geometric aspects of the data will be secondary.

According to Molenaar, two types of spatial processes such as field and object oriented approach can be considered in structuring for linking thematic and geometric data. In this study object oriented approach will be considered (fig.4-7). It assumes that terrain features or objects can be defined which each has location or position and a shape and non-geometric characteristics. These objects are represented in an information system by means of an identifier to which the thematic and geometric data are linked. This is called the terrain feature oriented approach or (terrain object oriented) approach.

Data modeling is a process of representing and manipulating information within the framework of a database system. It is actually done in three levels- conceptual level, logical level and physical level modeling.

One of the best-known models at this level is the relational model, which organizes data in tables. These tables can be manipulated by a relational database management system (RDBMS). (Molenaar, 1998)

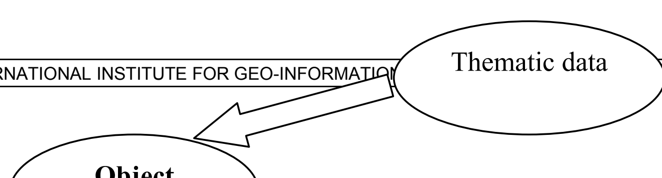


Figure 4-1: Object structured data organization (Source; Molenaar, 1998)

4.7.1 Modelling Techniques

The data modelling techniques has main objective to determine the logical structures (models) of the system to be developed. As mentioned above it is actually done in three levels: conceptual level, logical level and physical level modelling. During this activity it will be decided which information is important to the system and how this information can be obtained from the data. The approach is bottom –up: from the information needs to information needs structure, to a data storage structure.

Several techniques are used in combination during the data modelling activity, namely

- Entity Relation Diagram (ERD) to define the logical file structure
- Normalization
- Data Dictionary (DD) set up

In this research data will be modelled by using Entity Relationship (E-R) method. This method is chosen because of its capacity of offering a solution to problems of scale and practicability, by modelling the relationships between the groups of data elements rather than individual data elements (Benyon, 1990) The entity-relationship approach, based on entity-relationship model was introduced by Chen in 1976. Entity-relationship (E-R) method uses major abstractions to describe data. These are

- Entities: is anything real or conceptual that is of interest to the enterprises. This can be an object (a product, farm), a person (customer, trader), an event (purchasing, manufacturing, a plan)
- Relationship: These are associations or links between two or more entities. The relationship must have particular significance. There may be more than one relationship between the same entities.
- Attributes: These are the properties of entities and relationships. Attribute values that describe each entity become a major part of data store in the database.

4.7.2 Conceptual data modelling

The conceptual model is the first level of abstraction from reality and consists of describing how thematic and geometric data can be linked in a database, and how the data about terrain objects can be abstracted and represented in a database.(Pradhan, 1998) It is the conceptual model, which represents the information system as it must accommodate all the external or users views. (Benyon, 1990) Occasionally this level is called semantic analysis, because it should capture the semantics of the data. (Hawryszkiewycz, 1997). The conceptual data model is concerned with analyzing the information requirements, and once all requirements are collected and analyzed the next step is to create a conceptual schema for the database using a high-level conceptual model (Assefa, 1994). The conceptual model is a concise description of the data requirements of the users and includes detailed description of the data types, relationships and constraints but does not include any implementation details.

4.7.3 Logical Data modelling

The logical data model is the intermediate level of data representation and is the process of database design to implement the conceptual data models, in which storage structures are specified. It follows the conceptual data model and is completed when a particular database structure is chosen based on detail design of the conceptual model. It translates the conceptual model into a format that is compatible to specific computer software. There are different database structures such as hierarchical, relational, object oriented and network or record database structure (Benyon, 1990). In this study relational database structure is chosen to form the logical data model design, which is related to how the data are processed and stored in computer software.

The logical data modelling represent map of associations among entities through their entity identifier. There are three degrees of relationships between objects: one-to-one, one-to-many and many-to-many. The transformation of each of those relationship degrees needs different methods depending on the classification of their relationship whether obligatory or non-obligatory.

The results of the transformation are presented in the form of skeleton tables that contain the key attributes. The data model shows only the important attributes of entities, which represent entity association. The relations between entities that contain geometric data will be performed by means of geo-information processing. The basic skeleton tables of the proposed system, given in section 4.7.6, indicate attributes of the objects.

4.7.4 Physical Data Modelling

The mapping of data on to structures is called the physical data model or implementation model. This is the last step whereby internal storage structure and file organisations are specified. Physical data models describe how to put data items into storage locations so that they can be retrieved. This level deals with system configuration: hardware devices (storage, display, peripherals and so forth), file structures, access methods and location of data. In order to complete this phase the accomplishments of several operational tasks have to be reached as for instance the selection of the DBMS in particular from a large variety of software available in the market. The definition of the type of fields (string or character, integer, real, logical. etc) and its extension, the establishment of relations, creation of views, pre-defined queries etc (Trujillo, 1994)

4.3 Modelling of Hydro-Environmental-Economic database

4.7.5 Conceptual model of Hydro-Environmental-Economic Database

This part explains the entities to be included and relationship among the entities. Entities are chosen depending on the system requirements. Different data need to be organized in one database so as to allow queries.

Relations are fundamental to the provision of information. In this case relationship between entities will be represented as follows.

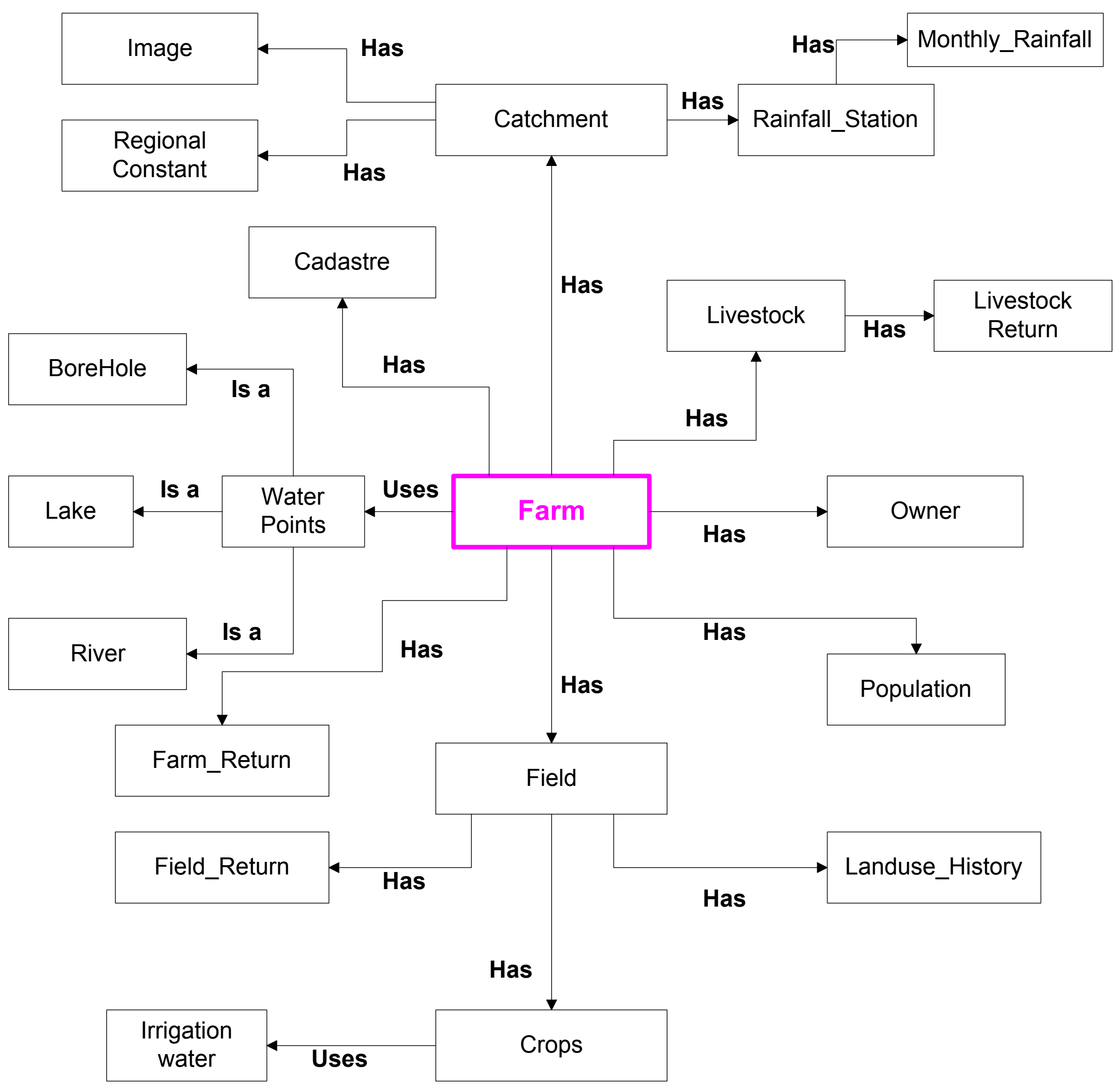


Figure 4-2: Conceptual model for Hydro-Environmental-Economic modelling

- Degree: The number of entities participating in the relationship. A binary relationship has degree=2, ternary relationship has degree=3.
- Complexity (or cardinality) This may be 1:1 relationship, M:1 or M:M
- Membership class : This indicates whether it is obligatory or non-Obligatory for an entity to participate in a relationship

The designed conceptual model would accommodate all the information requirements from terminators as explained in chapter-3.

Cardinality Constraints for Hydro-Environmental-Economic modelling

These are the rules that try to capture the meaning of the data in system. A cardinality constraint defines the relation and specifies the number of relationships in which an entry can appear or participate. Figure 4.7 shows the entities and their relationship. Cardinality constraints of the conceptual modelling are elaborated as follows.

The catchment has one or many images	The catchment has many rainfall stations
A rainfall stations have many monthly rainfall.	The catchment has many regional constants
The catchment has many farms	A farm should have only one owner
A farm uses one or many water points	An owner can have one or many farms
A farm has many livestock	A livestock has a return
A water point can be a borehole	A water point can be a Lake
A water point can be a river	A farm has one or many fields
A farm can be sited in one or many cadastral	A cadastral has one or many farms.
A farm has many returns	A field has many returns
A field has many landuse	A field has only one crop
A crop uses irrigation water	A farm has the catchment.

4.7.6 Logical model of the Hydro-Environmental-Economic database

The logical data modelling involves the normalization of the Entity-Relationship diagram and the description of the skeleton tables. Normalization involves:

- Eliminating repeating groups
- Checking that all attributes depend on their (single or composite) identifier
- Checking that there is no dependency between the attributes.
- Checking that there is no hidden dependency between the attributes

In this case normalization is used in many to many relationships. The entities concerned are;

- Farm and Cadastral.

A new table (Cad_Farm) is created having the composite identifiers.

Skeleton tables

The Entity-Relationship diagram describes many of the important features without showing the attributes associated. This additional information can be conveniently represented in the form of a set of fully normalized table types (Howe, 1989). Skeleton table is a set of tables that shows entities with their corresponding attributes in normal form. It helps to transform the Entity-Relationship diagram into computer compatible format, by mapping entities and relationships with their corresponding attributes in the forms of tables. Skeleton tables have identifiers and foreign keys. Identifiers are attributes whose values uniquely identify entities or relationships. The attribute whose value is uniquely identifying an entity is called a primary key for that entity. A primary key could be single if it has only one identifier and composite if it has two identifiers.

The basic skeleton tables for the entities and their attributes in normal form of the proposed system are indicated below. The primary keys are bold and underlined and the foreign keys are bold italicized.

Catchment	[**Catchment_Id**, Area]
Image	[**Image_Id**, Catchment_Id, Co-ord_N, Co-ord_S, Co-ord_W, Co-ord_E, Sensor_Mode, Sensor, Platform, Date]
Rainfall	[**Rainfall_st_Id**, Catchment_Id, Station_Name, Co_or_X, Co_or_Y, Latitude, Longitude, HEI_T]
Monthly_Rainfall	[**Monthly_Rain_Id**, ***Rainfall_st_id***, Year, Month, Rain_fall]
Livestock	[**L_stock_R_Id**, ***Livestock_id***, Farm_Id, Year, Units]
Livestock_Return	[**Livestock_id**, **Year**, Production, Price, Produc_Days, Produc_per, Labor_req, Labor_Cost, Fodder_Price, D_M_I]
Cad_Farm	[**Cad_Farm_Id**, ***Cad_Id***, Farm_Id]
Cadastre	[**Cadastral_Id**, Cadaster_code, Area]
Farm	[**Farm_Id**, Catch_id, F_Name, Owner_Id, F_Address, Tot_F_Area]
Farm_Return	[**Return_id**, ***Farm_id***, Year, Return]
Owner	[**Owner_Id**, O_Name, Address, Tel_no]
Water_Point	[**Water_P_Id**, WELL_Id, Co-or_X, Co-or_Y, Farm_id, Source_Type_ID, Source_Name]
Bore_Hole	[**BorHole_Id**, ***Water_P_ID***, Source_ID, Altitude, Tot_Dep, W_Level, Yield, Cons_Year]
Lake	[**ID**, ***Water_P_id***, L_Area, Source_Type_ID, Year, Level]
River_Point	[**River_P_ID**, ***Water_P_ID***, Source_Type_Id, Name]
Population	[**Population_id**, ***Farm_id***, Year, People]
Field	[**Field_id**, ***Farm_id***, Field_name, Year, Crop_id, Area, Area_Irri, NAI_II_FAR]
Field-Return	[**Return_ID**, ***Field_ID***, Year, Profit]
Crop	[**Crop_id**, **Year**, Crop_name, Crop_Rotation, Labour_use, Fer_use, Pes_use, Pes_Price, Yield, Yield_R_Coe, Farm_G_P, Farm_G_P1, Factor_Seed, Factor_Preser, Factor_Frieght, Factor_Cooling]
Irrigation water	[**Irri_Wat_id**, ***Crop_id***, Year, Irri_Re_D, ET_act, App_irri, Factor_W_R, Factor_E_A_I, Factor_Iri_wa]
History	[**History_id**, ***Field_id***, Farm_id, Land_use]
Regional_Constant	[**Reg_C_id**, Catchment_id, Year, L_Cost, Ex_Rate, C_F_A, R_F, W_R_L, W_R_FP]

The data organized in the table are fully normalized to avoid redundancy to make an efficient DBMS, which is presented in fig 4-3.

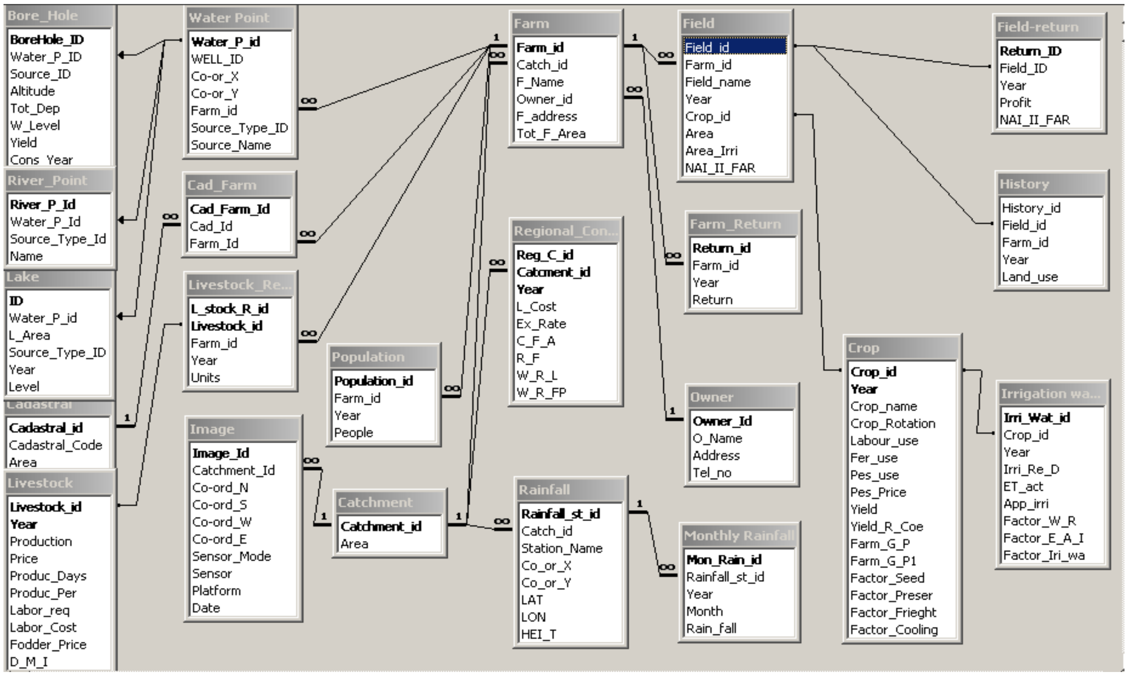


Figure 4-3: Logical data model to be implemented in the proposed system.

CHAPTER 5 : IMPLEMENTATION OF AN INFORMATION SYSTEM FOR HYDRO-ENVIRONMENTAL-ECONOMIC MODELLING

5.1 Introduction

After designing a process and data model in chapter 4, this chapter will mainly focus on the implementation of the hydro-environmental-economic modeling information system.

System implementation is aimed at turning to fruition all that has been put down on paper in previous phase. In this study, ArcView package and Microsoft Access are mainly used to implement the system. The hydro-environmental-economic model is design in Microsoft Access 2000 in PC environmental. Set of spatial data of hydro-environmental-economic modeling is organized in ArcView.

Question such what are the water points located in a particular farm and farm water productivity are considered in to implementation in this section as sample products.

Overview of the system implementation of sample products is given as shown in figure 5.1.

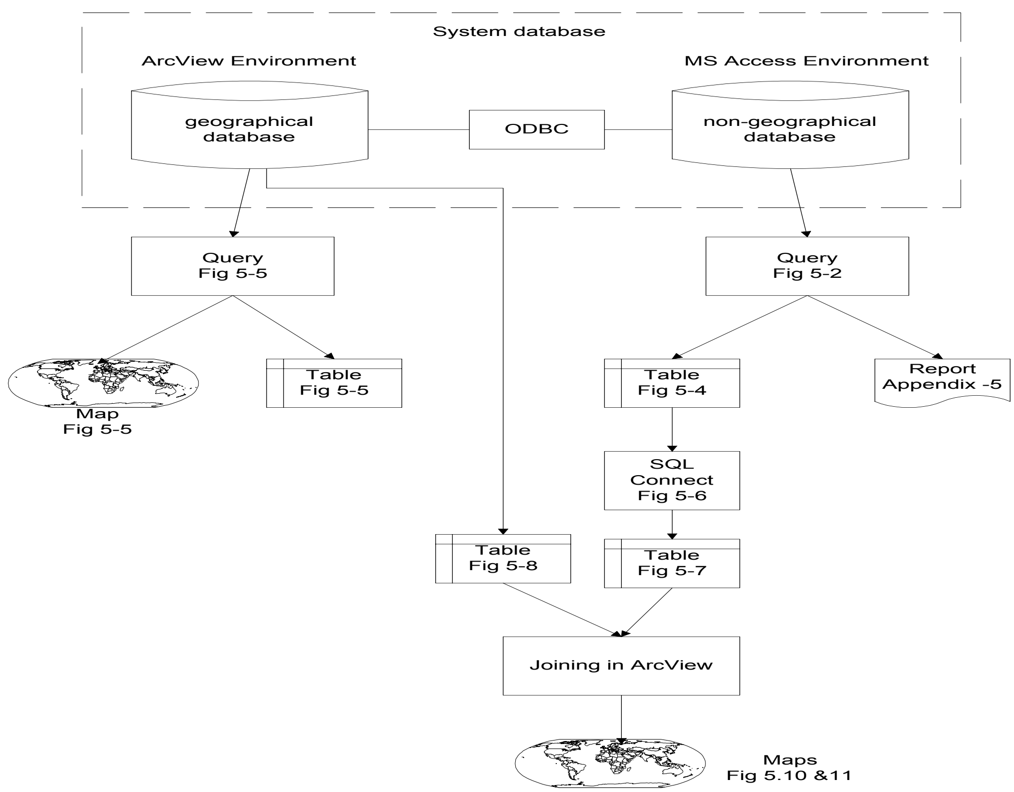


Figure 5-1: Overview of the system implementation

5.2 Software packages

The software packages were used in system implementation is ArcView, Microsoft Access, ILWIS and ERDAS imagine.

5.2.1 General Introduction to ArcView

Arcview is one of the most used commercial GIS package developed by Environmental System Research Institute (ESRI). It provides powerful tools for visualization, query and analyzing data spatially. ArcView user interface includes views, tables, charts, layouts and scripts, all of them are stored in one file called project.

VIEW is a collection of themes. A theme represents a distinct set of geographic features in a particular spatial data source. For example, a view of a study area might have one theme representing irrigated area (area feature), one theme representing borehole (point feature), and one theme representing roads (line feature).

CHART is a graphic representation of tabular data. It has provides a powerful additional visual representation of the attribute associated with the geographic features. Chart can be used to display, compare and query geographic and tabular data effectively.

LAYOUT is a map that let the user can display views, charts, tables, imported graphics primitives.

SCRIPT is a macro program language of ArcView. With ArcView scripts, the user can add new capabilities to ArcView and build complete applications.

In this study, all graphical information is organized in ArcView environment.

5.2.2 Microsoft Access

This software is used in non-spatial data modeling, which includes database development and management activities. It has the capabilities to retrieve, store and query non-spatial/attributes information efficiently. This software allows enforcing key constraints and referential integrity constraints. The attribute tables can be linked through unique identifier i.e. primary key and foreign key concept.
In this study, non-graphical database of hydro-environmental-economic modeling were organized by using Microsoft Access.

5.2.3 General introduction to ILWIS

ILWIS (Integrated Land and Water Information System) software is a GIS package with image processing capabilities. It allows inputting, managing, analyzing, displaying and presenting geographical data. ILWIS can work with a number of data types eg. Vector raster maps, attribute tables and images.

In this study preprocessed TM and MSS satellite images are in the ILWIS environment and this images are exported to ArcView through ERDAS imagine software.

5.2.4 General introduction to ERDAS imagine

ERDAS also has image processing capabilities in GIS. Due to unavailability facility of direct exporting ILWIS images to ArcView, ERDAS software were used.
In this study images in ILWIS format has been exported to ERDAS imagine. Then re-sampling with new co-ordinate system and sub setting were performed. Finally it saved in the .lan format and retrieved from the ArcView.

5.3 Generating the system database

Irrigated area, borehole, road etc. can be put into the system database by digitizing the existing maps and images. In ArcView environment the command ADDITEM is used to add new item to the theme attribute table. For assigning the value to the item of the table we use command CALCULATE (for numeric item) or MOVE (for character item)

As shown in the conceptual model hydro-environmental-economic modeling inventories were carried out. So decomposition of objects can be assign to the attributes tables. This is done in Access. To access the data from a table to other table of the system, the relationship must be established. (see logical data modeling) The relations among database tables can be created by the command RELATE. In figure 4.8 (chapter 4), the database tables and their relationship and common items are clearly presented.

5.4 Querying in MS Access

Querying of non-geographical data in MS Access is done in this study. Expression builder in Access is used to calculate water productivity as shown in fig. 5.2

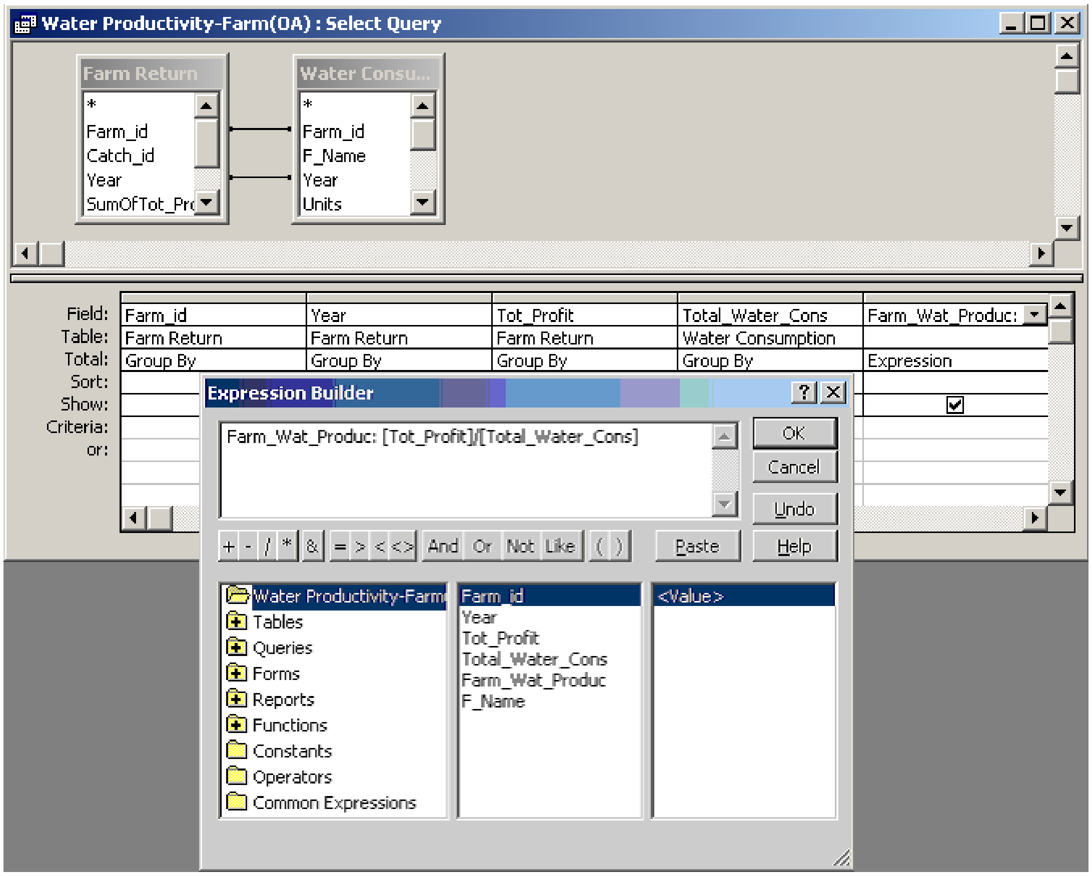


Figure 5-2: Use of expression builder in Access.

Query in connection with calculating water productivity of farms is given as shown in the fig 5.3.

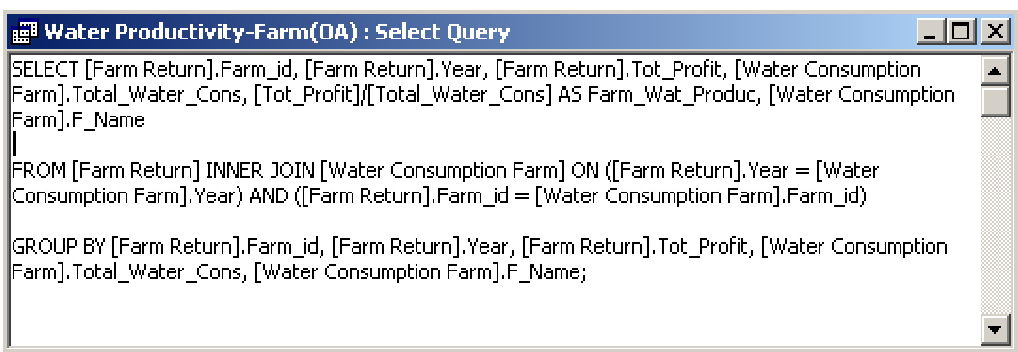


Figure 5-3: Shows the query of calculating farm water productivity

Results of the above query can be given in the forms of table or report. Table and report are as shown in the fig 5.4 and appendix 5 respectively.

Water Productivity-Farm(OA) : Select Query

Farm_id	Year	Tot_Profit	Total_Water_Con	Farm_Wat_Prod	F_Name
100	1986	272568.32	249958.71	1.09	Aberdare_Estate
100	2000	243612.17	308273.13	0.79	Aberdare_Estate
101	1986	7726.20	6602.07	1.17	Bees_Garden
101	2000	9214.57	12147.72	0.76	Bees_Garden
102	1986		666.30		Boffer_Farm
102	2000	182500.05	238354.54	0.77	Boffer_Farm
103	1986	883928.40	870606.19	1.02	Brixia_Mario
103	2000	625082.17	879271.67	0.71	Brixia_Mario
104	1986	947150.93	301159.89	3.15	Gold_Smith
104	2000	1026303.05	538679.10	1.91	Gold_Smith
105	1986				Green_Planet/Amoroso
105	2000	118545.91	144004.73	0.82	Green_Planet/Amoroso
106	1986				Herneth_(Kenya)_Ltd
106	2000	626848.62	330332.90	1.90	Herneth_(Kenya)_Ltd
107	1986	1495421.72	486874.80	3.07	Homegrown
107	2000	6930295.69	4573323.57	1.52	Homegrown
108	1986				Lake_Flowers
108	2000	870290.05	328878.20	2.65	Lake_Flowers
109	1986				Korongo_Farm

Record: 19 of 84

Figure 5-4: Query result in the form of table

5.5 Querying in ArcView

In this section two types of querying in ArcView are described as follows.

5.5.1 Querying of geographical data

In order to answer a question like what are the water points located in Manera farm (Farm_id=137), query can be design in ArcView environment and results are as shown in fig 5-5. For this purpose (spatial data) query builder is used in the ArcView.

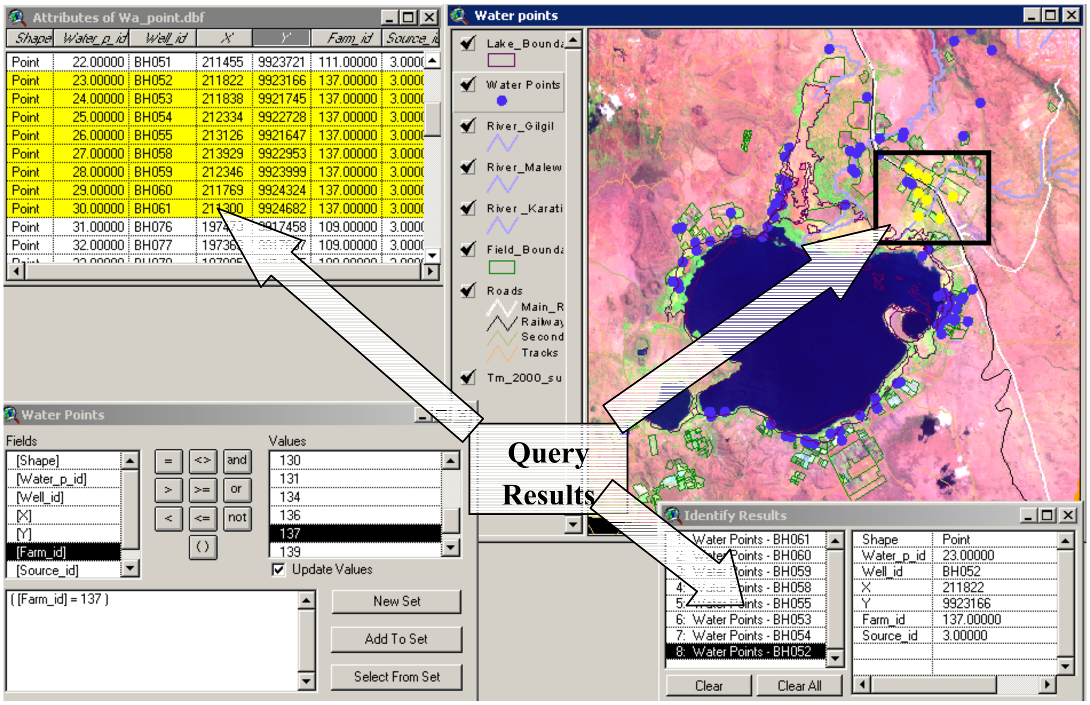


Figure 5-5: Results and graphical visualization of the query in ArcView

5.5.2 Querying of non-geographical data

Querying of non-geographical data in ArcView can be done. For this purpose SQL connect and ODBC that is provided by MS window 2000/windowNT are needed. As shown in the fig 5-6, SQL connect is used to abstract necessary data which is going to link with graphical part and results table are saved as .dbf file in ArcView. Results of the query of SQL connect is given as shown in fig 5-7.

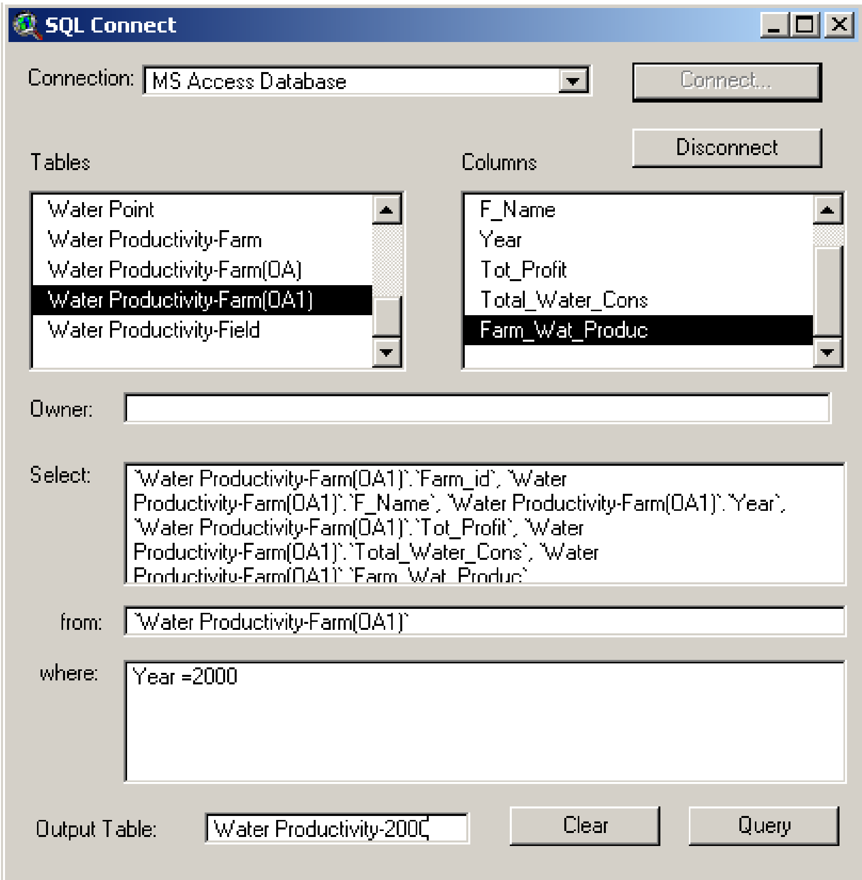
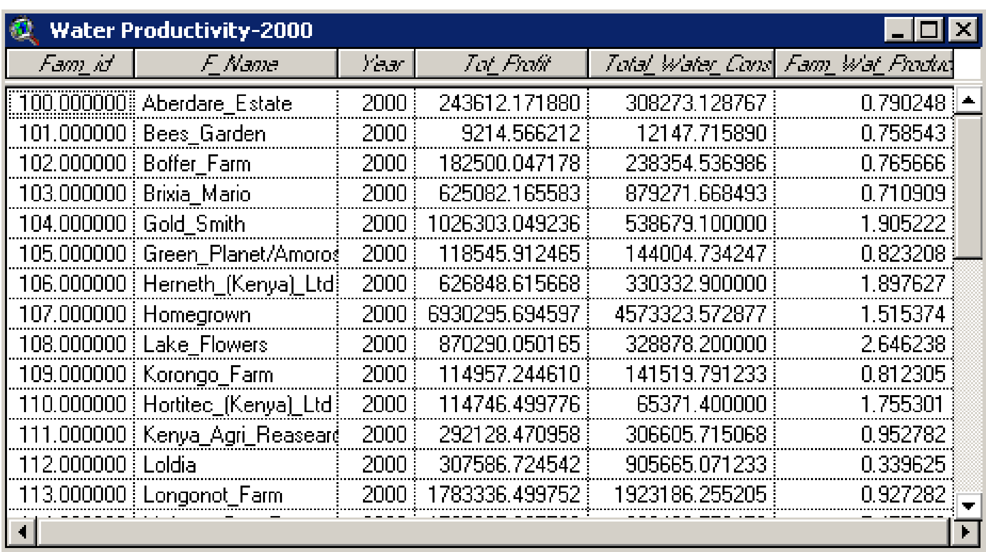


Figure 5-6: SQL connect in ArcView



Water Productivity-2000

Farm_id	F_Name	Year	Tot_Profit	Total_Water_Cons	Farm_Wat_Produc
100.000000	Aberdare_Estate	2000	243612.171880	308273.128767	0.790248
101.000000	Bees_Garden	2000	9214.566212	12147.715890	0.758543
102.000000	Boffer_Farm	2000	182500.047178	238354.536986	0.765666
103.000000	Brixia_Mario	2000	625082.165583	879271.668493	0.710909
104.000000	Gold_Smith	2000	1026303.049236	538679.100000	1.905222
105.000000	Green_Planet/Amoros	2000	118545.912465	144004.734247	0.823208
106.000000	Herneth_(Kenya)_Ltd	2000	626848.615668	330332.900000	1.897627
107.000000	Homegrown	2000	6930295.694597	4573323.572877	1.515374
108.000000	Lake_Flowers	2000	870290.050165	328878.200000	2.646238
109.000000	Korongo_Farm	2000	114957.244610	141519.791233	0.812305
110.000000	Hortitec_(Kenya)_Ltd	2000	114746.499776	65371.400000	1.755301
111.000000	Kenya_Agri_Reaseard	2000	292128.470958	306605.715068	0.952782
112.000000	Loldia	2000	307586.724542	905665.071233	0.339625
113.000000	Longonot_Farm	2000	1783336.499752	1923186.255205	0.927282

Figure 5-7: Results of the query of SQL Connect

5.6 Linking of geographical and non-geographical data

The next step of implementation of system is to link geographical data (fig 5-8) and non-geographical data (fig 5-7). To achieve this there should be a common field in both tables. It can be identified as farm_id. For joining of these two tables, JOIN command in ArcView is used. Result of the joining is shown in the fig. 5-8.

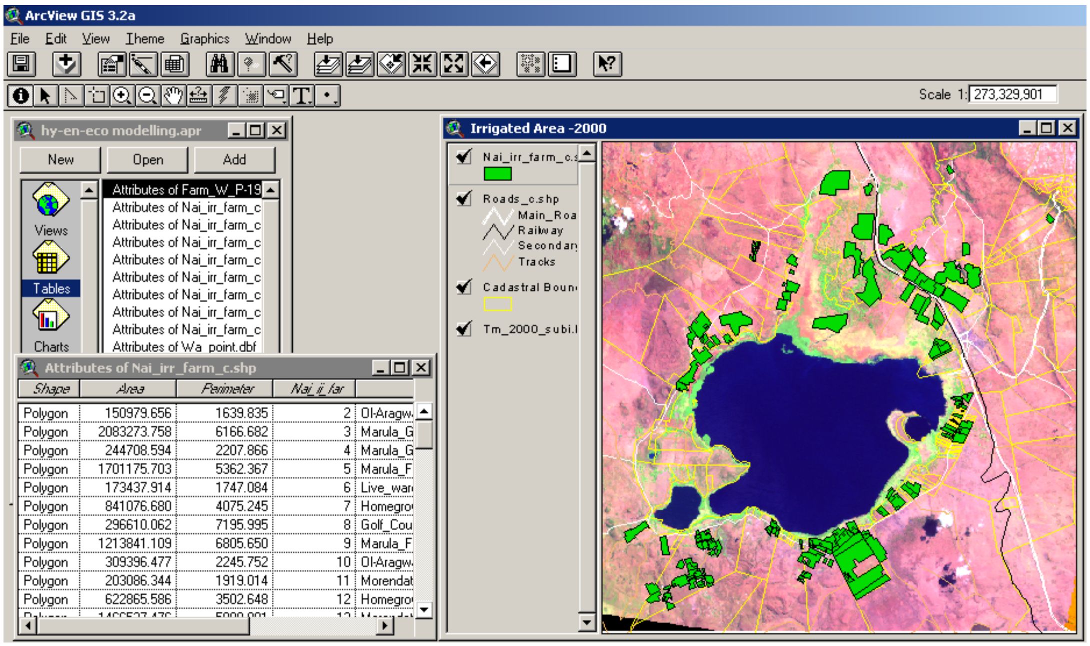


Figure 5-8: Geographical data in ArcView

Shape	Area	Perimeter	Nai_ii_fa	Landclas	Farm_Id	F_Name	Year	Water_Prod
Polygon	150979.656	1639.835	2	Ol-Aragwai_Farm	122	Ol-Aragwai_Farm	2000	0.713487
Polygon	2083273.758	6166.682	3	Marula_Grass	139	Marula	2000	0.106416
Polygon	244708.594	2207.866	4	Marula_Grass	139	Marula	2000	0.106416
Polygon	1701175.703	5362.367	5	Marula_Fodder	139	Marula	2000	0.106416
Polygon	173437.914	1747.084	6	Live_ware_Ltd_GH	133	Live_Ware_Ltd	2000	2.213136
Polygon	841076.680	4075.245	7	Homegrown_Marula	107	Homegrown	2000	1.385863
Polygon	296610.062	7195.995	8	Golf_Court-Malewa	135	Golf_Court-Malewa	2000	
Polygon	1213841.109	6805.650	9	Marula_Fodder	139	Marula	2000	0.106416
Polygon	309396.477	2245.752	10	Ol-Aragwai_Farm	122	Ol-Aragwai_Farm	2000	0.713487
Polygon	203086.344	1919.014	11	Morendat_Fodder	116	Morendat	2000	0.149160
Polygon	622865.586	3502.648	12	Homegrown_KARI	107	Homegrown	2000	1.385863

Figure 5-9: Results of the joining in ArcView

5.7 Visualization

After joining two tables (geographical and non-geographical data) information such water productivity can be visualized in ArcView as shown in fig 5-10.

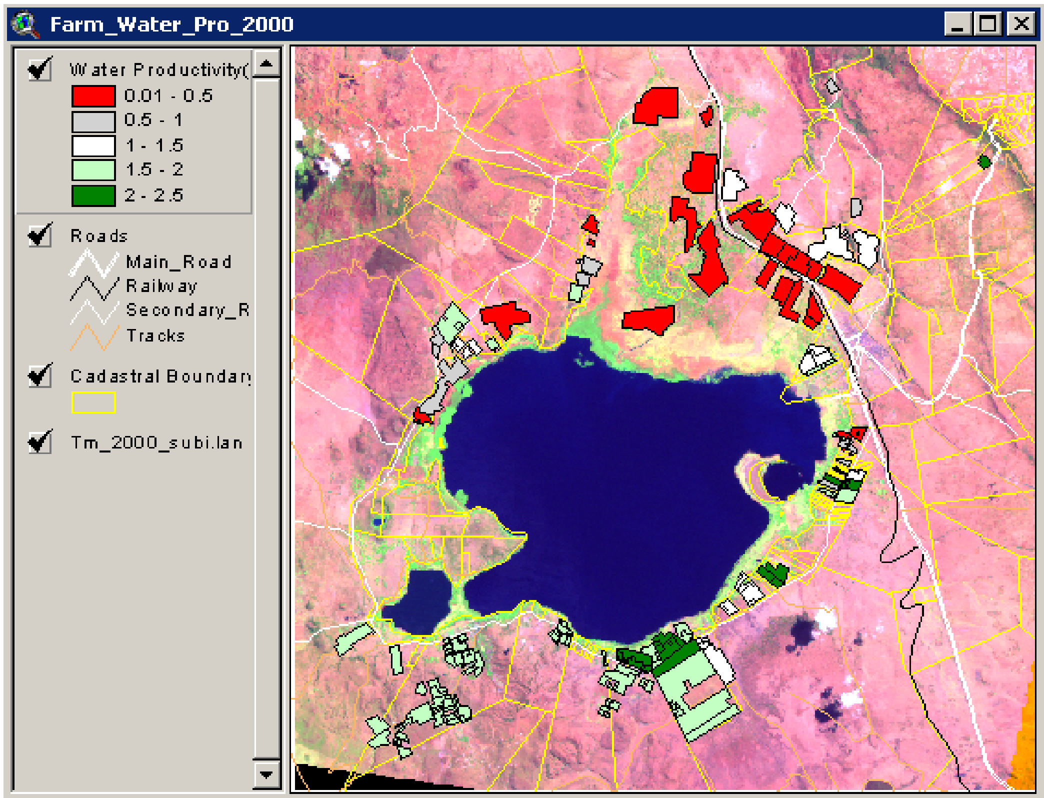


Figure 5-10: Shows the farm water productivity distribution

Since the time series is added to the hydro-environmental-economic model above same procedure can be applied to the data of year 1986. So the results of farm water productivity of year 1986 is shown in fig 5-12.

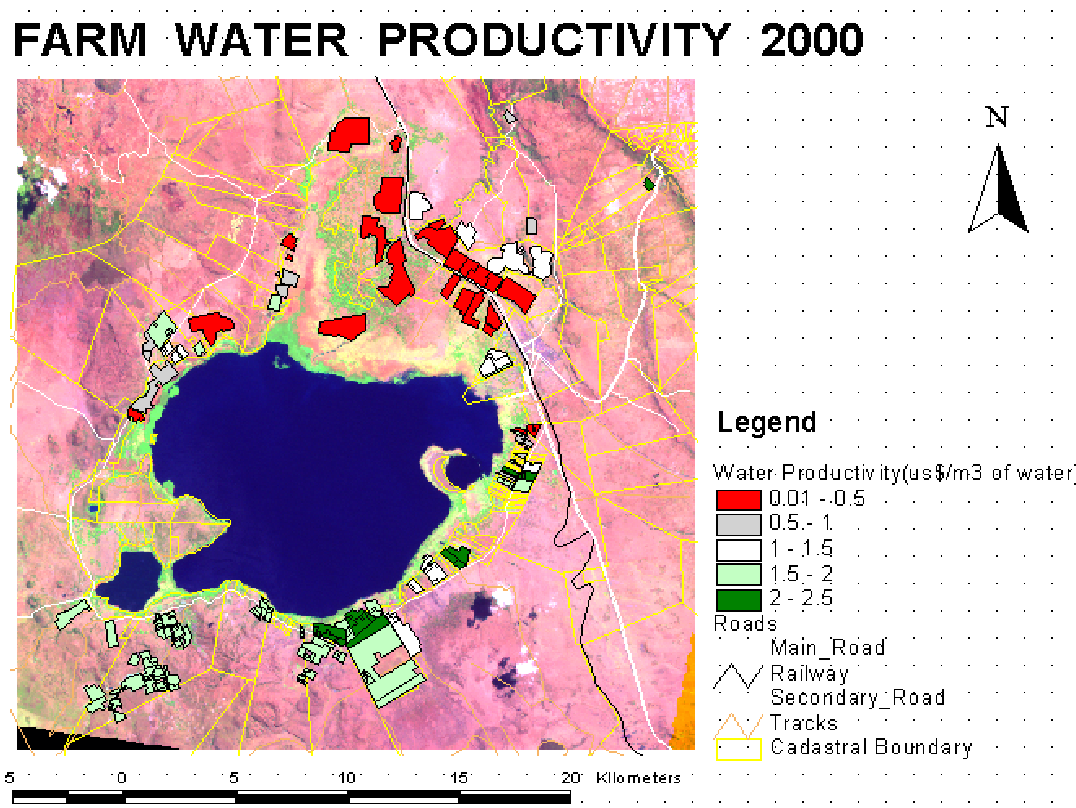


Figure 5-11: Farm water productivity map of year 2000

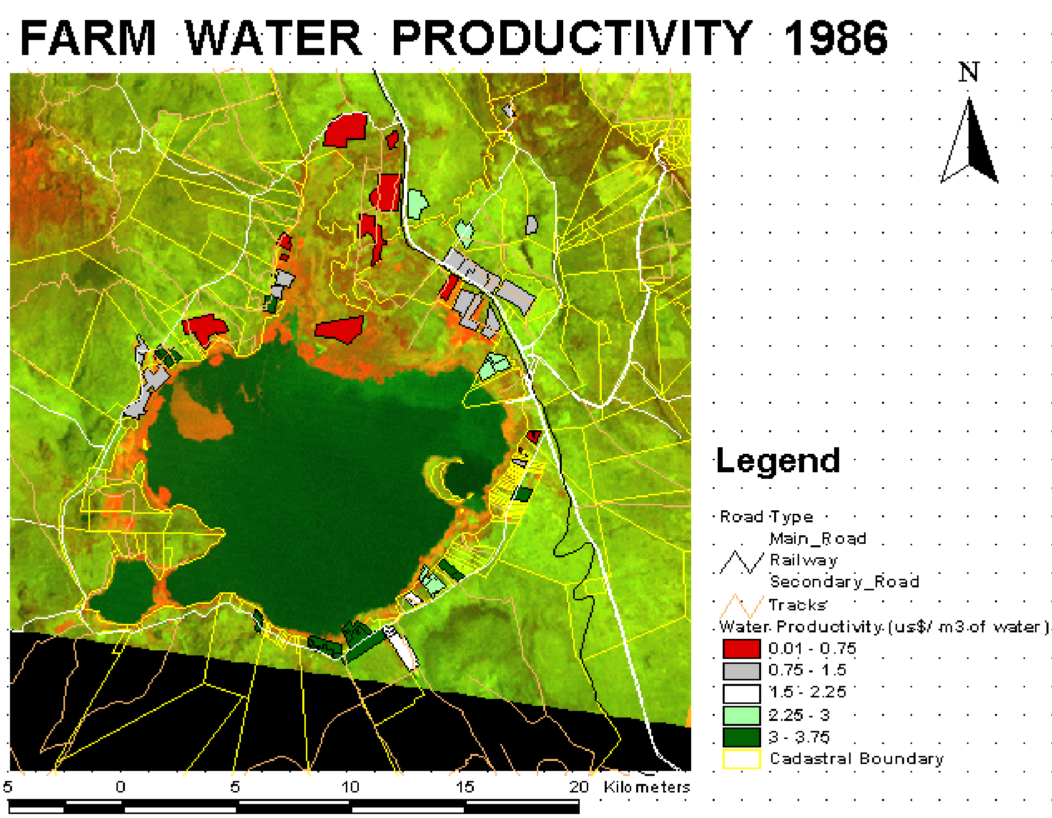


Figure 5-12: Farm water productivity of year 1986

CHAPTER 6 : OVERVIEW OF USER INTERFACE MENU

6.1 Introduction

Design of a good user interface menu is one of the most important activities in system design. Nowadays, user simply want a toll which is very simple and easy to handle, and can solve their problems just by clicking a mouse button on a menu driven system. Certainly, a user interface menu helps a user to achieve his task, but in fact, it cannot be guaranteed that every user interface menu system will be helpful. There are criteria to evaluate this kind of system whether they are really helpful to the user. Actually, a user interface menu driven system should be easy to understand, handle and user friendly. Further, the most important aspect is that it should be effective and efficient. An interface is effective if it is produce good quality of output, i.e. the best solution to a problem, depending upon the users' requirement. An interface is efficient if it produces the results in least time with least errors (Pradhan, 1998).

6.2 Hydro-Environmental-Economic modelling information system

The hydro-environmental-economic modelling information system developed for assessing of farm water productivity, agrochemical use, farm water consumption, farm return and landuse history. It was developed in a PC environmental using the Microsoft Access 2000 database programme. Using Microsoft, we can manage all information in a single database file. Within the file, we can divide data into separate storage containers called tables. We can view, add and update table data using online forms.

6.3 Design of User Interface

For designing of user interface, forms and switchboard in the Microsoft Access are used. Also the tool such command which is linked to the visual basic programming, is also used for designing. The start menu was designed in a form and it linked to the switchboard page in order to add and edit data and visualizes results in the form of reports and maps.

The schematic representation of the flow of the user interface as implemented in MS Access is presented in fig 6-1.

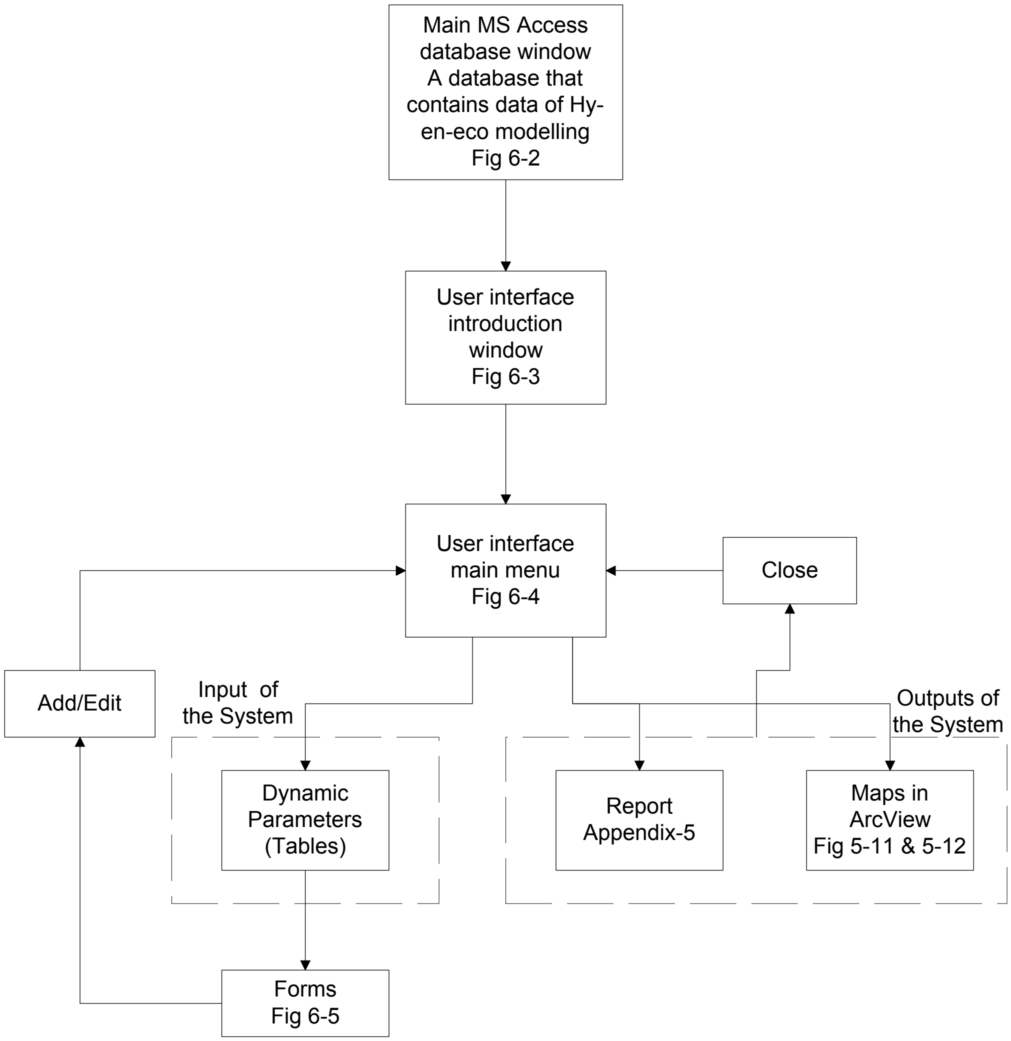


Figure 6-1: Schematic representation of the user interface.

6.4 How to start?

To run the hydro-environmental-economic information system, the user should first active Microsoft Access 2000 programme and open the hydro-enviro-economic.mdb. Once this file is opened, the main Access database window as shown in fig 6-2, starts. Then by double clicking start menu form in the form list of Access database window, the introduction menu is opened as shown in fig 6-3.

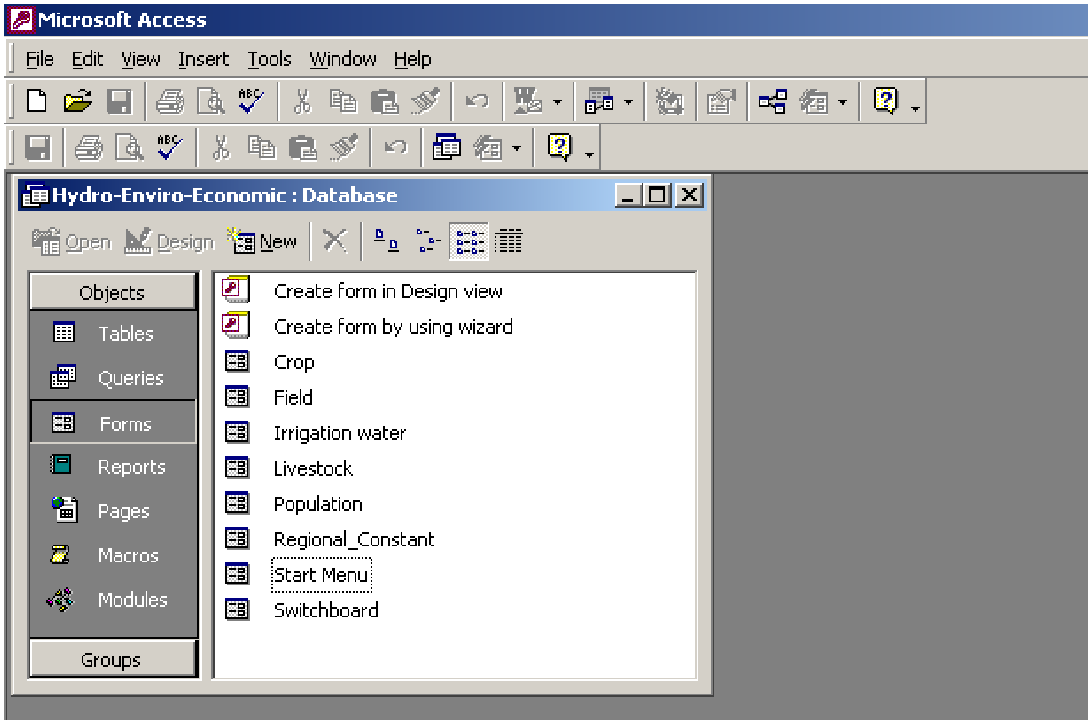


Figure 6-2: Main Access database window of hydro-environmental-economic modelling information system

Then user has options whether to proceed with next menu by clicking the <start> button, close the menu by clicking <close> button or exit the Access programme by clicking the <stop> button. The user can enter into the main menu (fig 6-4) by clicking the <start> button. This main menu includes three aspects such dynamic parameters, reports and maps.

6.4.1 Dynamic Parameters

These are the inputs of the system. They are in forms of the MS Access (fig 6-5). We can add or edit parameters in the forms and subsequently results can be shown in reports or maps by clicking the buttons in main menu. Queries are the main core part of the system where all analysis is done in between inputs and outputs of the system.

6.4.2 Report

This is one of the outputs of the system. Each time when parameters change in the forms, system runs the query and updated results in the reports. In the user interface reports can preview and click the <print> button then send report to a print.

6.4.3 Map

This is also output of this system. When click the <view maps in ArcView> button, maps in hydro-enviro-economic ArcView project opens. In this project, all maps based on user requirements can be visualized. The results of maps are based on the changes done in forms.

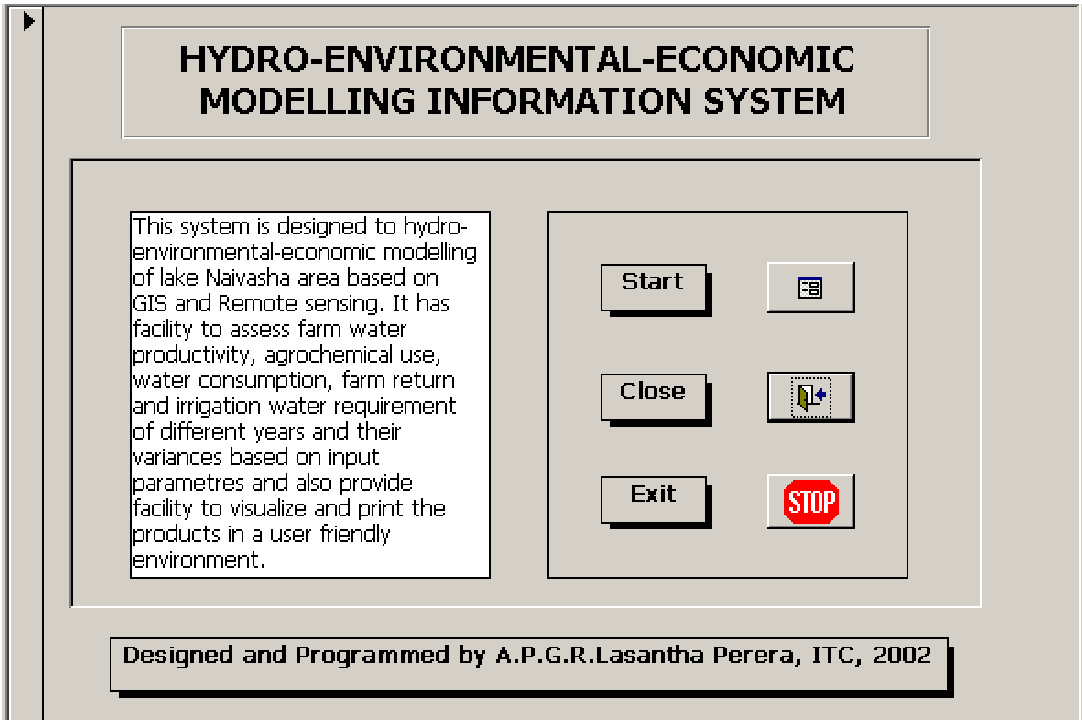


Figure 6-3: Introduction menu of hydro-environmental-economic modelling information system

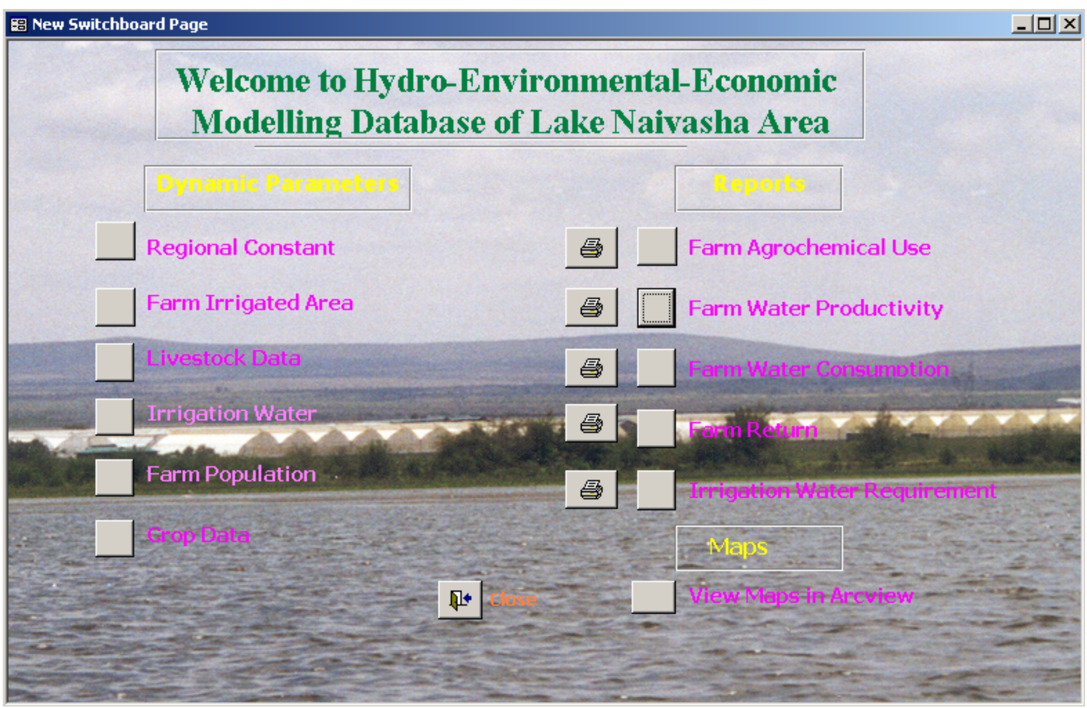


Figure 6-4: Main menu of hydro-environmental-economic modelling information system

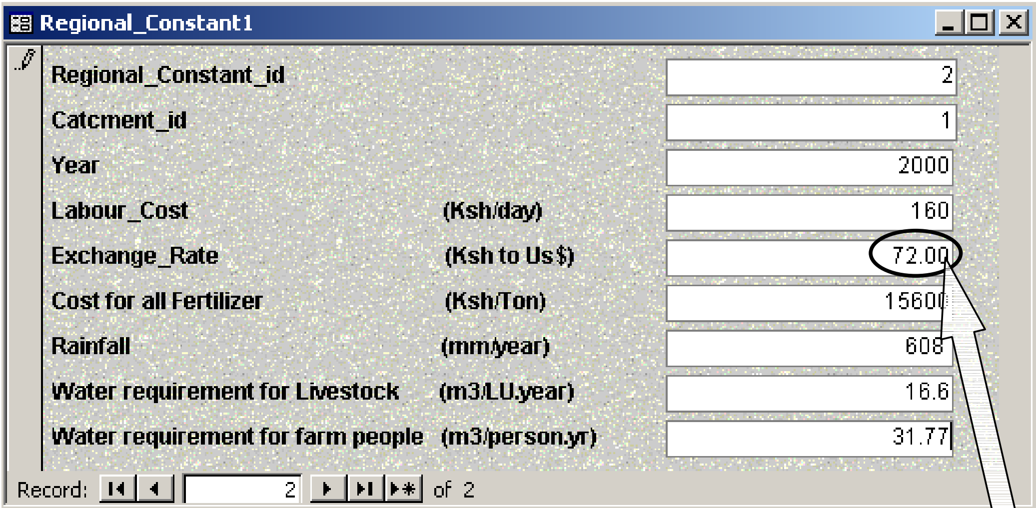


Figure 6-5: Form of regional constant parameters with the exchange rate of 72.

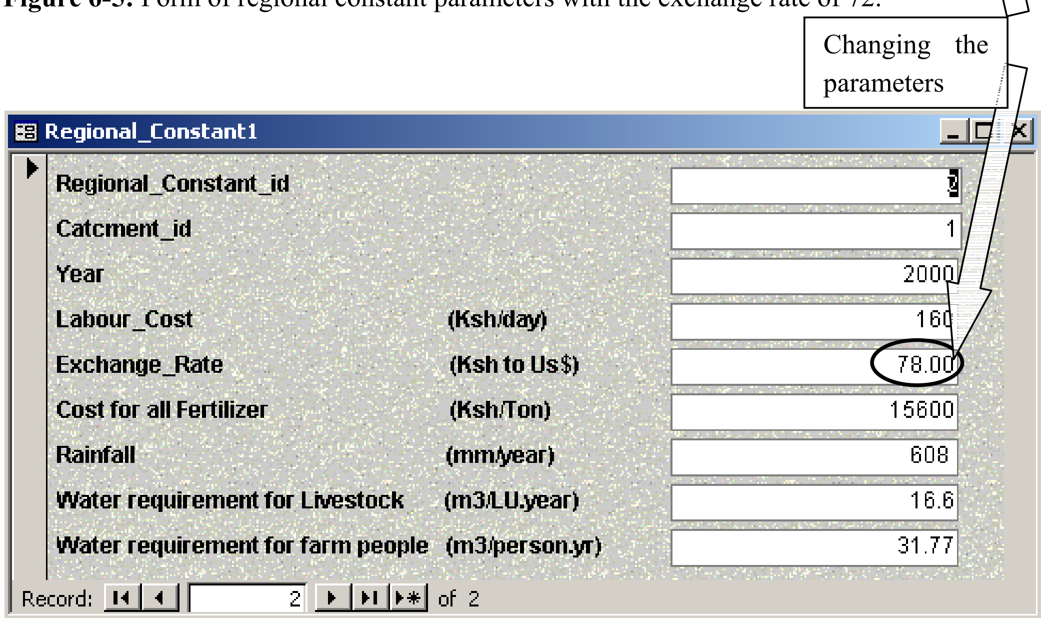


Figure 6-6: Form of regional constant parameters with the exchange rate of 78.

Changes of exchange rate (Ksh to Us$) have been made in the forms of user interface (fig 6-5 and fig 6-6). Due to these changes, results can be visualized in maps or reports. Results in the form of report are shown in fig 6-7 and fig 6-8.

Farm Water Productivity 1986 and 2000-(Over All)

Farm_id	*Farm Name*	*Year*	*Water_Productivity (US$/m3 of water)*
100	Aberdare_Estate	1986	1.09
100	Aberdare_Estate	2000	0.67
101	Bees_Garden	1986	1.16
101	Bees_Garden	2000	0.64
102	Boffer_Farm	1986	
102	Boffer_Farm	2000	0.65
103	Brixia_Mario	1986	1.01
103	Brixia_Mario	2000	0.60

Figure 6-7: Report of the farm water productivity in accordance with the exchange rate of 72.

Farm Water Productivity 1986 and 2000-(Over All)

Farm_id	*Farm Name*	*Year*	*Water_Productivity (US$/m3 of water)*
100	Aberdare_Estate	1986	1.09
100	Aberdare_Estate	2000	0.62
101	Bees_Garden	1986	1.16
101	Bees_Garden	2000	0.59
102	Boffer_Farm	1986	
102	Boffer_Farm	2000	0.60
103	Brixia_Mario	1986	1.01
103	Brixia_Mario	2000	0.56

Figure 6-8: Report of the farm water productivity in accordance with the exchange rate of 78.

It seems that the exchange rate of Ksh to Us$ is inversely proportional to the water productivity of farms. As shown above, we can edit any parameter in the regional constant forms and can visualize results accordingly.

CHAPTER 7 : CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The main aim of the study was to develop an information system that integrates hydro-environmental-economic parameters that can be used by various decision makers for better management of water and environmental in the Lake Naivasha Catchment. This study included the following main activities.

- Review and analysis of information, which included design of a conceptual process model and defining information requirement based on user requirements (Chapter-3).
- The design of a data model of the system that integrates information from various sources (Chapter-4).
- Implementation of the system by employing and processing of data of the study area. This system was successfully implemented by using MS Access and ArcView packages (Chapter-5).
- Develop an effective and efficient user interface system that enabled management of dynamic parameters and presentation of results in map and report form (Chapter-6).

The first specific objective is to design the hydro-environmental-economic information system that integrates the three components based on land field information. Three components such hydro relates to water productivity, environmental relates to landuse history and use of agrochemical loads and finally economy relates to farm returns. The system was designed with the help of process and data modelling techniques. Process modelling is described in Chapter-3 and data modelling describes in chapter-4. In the process modelling, top-down approach was used. The process modelling made design of the context data flow diagram (DFD) and it was decomposed into four sub processes (fig 3-4). In data modelling, the conceptual and logical data models were designed. In conceptual data modelling, the important entities for hydro-environmental-economic modelling in the Lake Naivasha catchment were distinguished. In this study, main entity was identified as a farm (fig 4-2). The designed system has the capability to produce information in forms of reports, tables and maps depending on user requirement.

The second specific objective is identifying stakeholders of the system, information requirement, data flows and data stores. It was achieved by conducting interviews and process modelling. Researchers, Ministry of Water Resources, Lake Naivasha Riparian Association, Farmers, Metrological Department, Ministry of Land and Settlement and ITC database are identified as main stakeholders of the system (chapter-3). Designed processes and data stores in the system are described in the section 3.6 and appendix-5.

The third specific objective is to design a prototype system and the fourth specific objective is to implement information system in a GIS software. They were achieved in Chapter-5.

The fifth specific objective is to design a user interface for geographical information system. It will help the user when using the system. The introduction menu and main menu allow the user to interact with the system more easily. The system is successfully implemented by using MS Access and ArcView packages (chapter-6).

The final specific objective is to evaluate the system products by user. The user evaluated the system products when run the test programme of the system. Based on that evaluation, quality of the products has been increased.

Based on the above research objectives the following conclusions can be drawn.

Hydro-Environmental-Economic information system has been designed. The modelling processes played an important role for the successful outcome of this study.

The interviewing the stakeholders of the hydro-environmental-economic modelling information system has been important to the research. It resulted in understanding and identifying the information requirement, how the system should be and what is expected to do.

The hydro-environmental-economic database structure for the system has been designed. The thematic data are stored in forms of tables. The spatial data are stored in the forms of vector formats that can be linked with the thematic data through their key-identifier. The entity relational methodology acts as a useful tool for describing the data models. The data structure was developed for the implementation in to relational database management systems. So data can be easily accessed within the tables by means of relation ships, which has been created between them.

Economic model of assessing water productivity has been redesigned in order to add data of lake Naivasha area of any respective year without changing the structure of the model.

Hydro-Environmental-Economic model has been made solid link to GIS.

User friendly interface for the system processes has been designed and it help the system user to visualize different scenarios based on the changes in input parameters of the system.

7.2 Recommendation

The hydro-environmental-economic modelling information system is powerful geo-information system, which integrates water, environmental and economy of lake Naivasha area. There still possibility for the improvement in the formalization, conceptualisation and integration of processes of related phenomena. For further development of this system, it is recommended to work on the following areas and topics.

The quality assessment of remote sensing data and ground-surveyed data is recommended for the further study.
The query viewing and updating system in user interface is also recommended.

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APPENDIX

Appendix 1: Mean Rainfall figure (mm) for selected stations

Details	Naivasha Town	Naivasha Vet. Station
Years	42	39
Average(mm)	666	729
Altitude(m)	1900	1829
Month		
January	37	36
February	41	33
March	47	60
April	114	121
May	109	103
June	45	52
July	39	44
August	53	54
September	25	46
October	45	63
November	64	71
December	48	47

Source: Jaetzeld R. and Schmidt H. (1983), LNROA, 1993

Appendix 2: Temperature data of Naivasha

Month	Temperature, C (1973-54)				
	Max	Mean Max	Mean	Mean Min.	Min
January	30.8	27.7	17.9	8.1	1.9
February	32.1	28.3	18.3	8.2	3.1
March	32.6	27.3	18.5	9.8	2.8
April	30.5	25.1	18.3	11.5	5.6
May	27.6	23.8	17.5	11.3	6.1
June	27.6	23	16.5	9.9	4.4
July	26.8	22.5	15.9	9.3	4.6
August	27.2	22.9	16.1	9.4	4.4
September	28.4	24.5	16.7	8.8	2.2
October	30.3	25.6	17.3	9.1	3.9
November	28.9	24.7	17	9.3	3.9
December	30.1	25.8	17.3	8.7	3.3

Source East African Metrological Dept. 1964.
Climatologically statistics Naivasha (00 43 S, 36 26 E; 1900 m above sea level)

Appendix 3: Standard Interview Questionnaires

1. Questionnaire for user needs assessment of Hydro-Environmental-Economic information system

- To identify users of Hydro-Environmental-Economic modelling information system
- To assess user needs of Hydro-Environmental-Economic modelling of Lake Naivasha area
- To identify the type and quality of information mostly required by users

1. Date of interview: ……………………………………………………………………………… …
2. Name of Interviewer:……………………………………………………………………………….
3. Interviewee 3.1. Name: ………………………………………………………...……………………
3.2. Occupation……………………………………………………………………………
4. Name of Organization/Association/Farm: …………………………………………………………
5. Does your organization/Association/Farm have an experience in using water, economic and environmental data/information? Yes/No. ……………………………………………………………..
6. If Yes for question 5, what kind of information? ……………………..…………………………….
7. For what purpose do you use the data/information? ………………………………………………… ………………………………………………………………………………………………………....
8. Where do you get the data/information? …………………………………………………………… ……………………………………………………………………………………………………...
9. How do you get the data/information? …………………………………………………………… ……………………………………………………………………………………………………
10. In what form do you receive the data/information?……………………………………………….

- ✓ In the form of map (Digital)? Yes/No……………………………….…………………………..
- ✓ In the form of map (Analogue)? Yes/No……………………………….………………………..
- ✓ In the form of statistic data? Yes/No…………………………………….………………………
- ✓ In the form of tables? Yes/No……………………………………..…………………………..
- ✓ In the form of reports? Yes/No………………………………….…………………………

11. Does your Organization/Association/Farm share data/information with others? Yes/No…………..

If Yes, With whom?………………………………………………………………………………

In which form?………………………………………………………………………………

- ✓ In the form of map (Digital)? Yes/No………………………………………………………..
- ✓ In the form of map (Analogue)? Yes/No………………………………………………………..
- ✓ In the form of statistic data? Yes/No……………………………………………………………
- ✓ In the form of tables? Yes/No…………………………………………………………………..
- ✓ In the form of reports? Yes/No………………………………………………………………

12. Does your Organization/Association/Farm need data/information in future? Yes/No.……………
13. If your answer is yes for question 12, what type of data/information does your farm needs? …….
    - ✓ Do you need raw/unprocessed data/information? Yes/No…………………………………….
    - ✓ Do you need processed data/information? Yes/No…………………………………………….
    - ✓ Do you need both raw/and processed? Yes/No…………………………………………………
14. In what form do you need them? ……………………………………………………………………
    - ✓ In the form of map (Digital)? Yes/No…………………………………………………………..
    - ✓ In the form of map (Analogue)? Yes/No……………………………………………………..
    - ✓ In the form of statistic data? Yes/No……………………………………………………………
    - ✓ In the form of tables? Yes/No…………………………………………………………………..
    - ✓ In the form of reports? Yes/No………………………………………………………………

15. What are the parameters you prefer in determining the quality of data? ……………………………
    - a) Accuracy………………………………………………………………………………
    - b) Completeness………………………………………………………………………….
    - c) Timeliness…………………………………………………………………………….
    - d) Correctness……………………………………………………………………………
    - e) Others…………………………………………………………………………………
16. For what purpose does your Organization/Association/Farm needs data/information? ………… …………………………………………………………………………………………………
17. Which parameters/characteristics are most relevant to your Organization/Association/Farm? … …………………………………………………………………………………………………
18. Which data information format is convenient for your Organization/Association/Farm? …………
    - ✓ Do you prefer digital format i.e. in computer system? Yes/No………………………………..
    - ✓ Do you prefer analogue format i.e. in paper format? Yes/No…………………………………
    - ✓ Do you prefer both formats? Yes/No…………………………………………………………..

      If your answer is yes, rank them according to your preference………………………………..
19. Would you explain why you choose above format(s)? ……………………………………………. …………………………………………………………………………………………………

Appendix 4: Spatial /Non spatial data recording formats

2.Farm data sheet

The objective of this farm data sheet is

- To collect primary data on farms in order to design or update Hydro-Environmental-Economic database

1. Date of Surveying: …………………………………………………………………………………
2. Name of Surveyor: …………………………………………………………………………………
3. Farm Identification No: ……………………………………………… ………………………….
4. Name of the Farm: …………………………………………………………………………………
5. Cadastral No: ………………………………………………………………………………………
6. Name of the owner: ………………………………………………………………………………
7. Address: ……………………………………………………………………………………………
8. Total farm area (ha): ………………………………………………………………………………

In details

Crop	Field Identification No.	Area (ha)
Flower-Open Flower-GH Vegetable Fodder Wheat Grass Macadamia Nuts Others… Total		

9. No. of LS units: …………………………………………………………………………
10. No. of farm people: ……………………………………………………………………
11. Water source details: ……………………………………………………………

Identification Name or Number	Type	Co-ordinates X,Y	Total water abstraction (m^3/Yr)	Remarks
	Borehole River point Lake point			

12. Details of landuse history

Field Identification Number	Year	Landuse

Landuse type: Natural, Cultivated, Uncultivated or build-up

13. Sketch map of the farm & co-ordinates of the farm boundaries. (To delineate any farm boundary changes)…………………………………………………………………………………………………

Appendix 5: Data Dictionary

Store No	**Store Name**	**Description of data stored**	**Used by process**	**Update by process**
1.1	Farm Owner ship Registry	Farm Ownership data	4.1 Estimating Farm Income	Data collection No.1.1
1.2	Population data Registry	Farm Population data	4.2 Estimating Water Consumption	Data collection No.1.1
1.3	Livestock data Registry	Farm Livestock data	4.1 and 4.2	Data collection No.1.1
1.4	Satellite image Registry	Satellite images are stored in this store	4.Analysis	Data collection No.1.1
1.5	Cadastral data	Cadastral data are stored in this store.	4.Analysis	Data collection No.1.1
1.6	Landuse data Registry	Landuse data are stored in this store	4.3 Calculating water productivity and LU mapping	Data collection No.1.1
1.7	Farm data Registry	All farm data such farm id, name, owner of the farm, and irrigated farm area are stored in this store	4.1 Calculating Tot Production Cost	Data collection No.1.1
1.8	Crop Data Registry	Data relevant to crop are stored in this store.	2.1 Calculating Tot. Production cost 2.2 Cal. Income 4.4 Est. Agro.C. Use	Data collection No.1.1
1.9	Livestock production Registry	Data relevant to livestock production are stored in this store	2.4 Eco-Analysis	Data collection No.1.1
1.10	Regional constant data Registry	Data on labour cost, Currency exchange rate, Cost for fertilizer, rain fall, Water requirement for livestock and farm population.	2.1 Calculating Tot Production cost 2.3 Calculating Profit 3.Crop Hyd. Process.	Data collection No.1.1

Store No	Store Name	Description of data stored	Used by process	Update by process
1.11	Irrigation water data Registry	Data on Irrigation requirement days, Actual evapotranspiration, and applied irrigation Data on irrigated area	4.2 Estimating water Consumption 3. Crop Hydrological Processing	Data collection No.1.1
1.12	Field data Registry	Data on lake level	4.3 Calculating water Production 4.4 Est. Agroc Use 4.1 Estimating water Consumption	Field data verification No.1.4
1.13	Lake data Registry	Data on water abstraction points		Data collection No.1.1
1.14	Water point Registry	Data on bore hole		Data collection No.1.1
1.15	Bore Hole Registry	Yearly rainfall data		Data collection No.1.1
1.16	Rainfall Data Registry	Data on rain fall stations		Data collection No.1.1
1.17	Rainfall Station Registry	Data on Catchment		Data collection No.1.1
1.18	Catchment Data Registry	Data on field return		Data collection No.1.1
2.1	Field Return Registry	Income of Farms	4.1 Estimating Farm Income	2.4 Economic Analysis
4.1	Farm Return Registry			4.1 Estimating Farm Income

Appendix 6: Query result in the form of report

Farm Water Productivity 1986 and 2000-(Over All)

Farm_id	Farm Name	Year	Water_Productivity (US$/m3 of water)
100	Aberdare_Estate	1986	1.09
100	Aberdare_Estate	2000	0.79
101	Bees_Garden	1986	1.17
101	Bees_Garden	2000	0.76
102	Boffer_Farm	1986	
102	Boffer_Farm	2000	0.77
103	Brixia_Mario	1986	1.02
103	Brixia_Mario	2000	0.71
104	Gold_Smith	1986	3.15
104	Gold_Smith	2000	1.91
105	Green_Planet/Amoroso	1986	
105	Green_Planet/Amoroso	2000	0.82
106	Herneth_(Kenya)_Ltd	1986	
106	Herneth_(Kenya)_Ltd	2000	1.90
107	Homegrown	1986	3.07
107	Homegrown	2000	1.52
108	Lake_Flowers	1986	
108	Lake_Flowers	2000	2.65
109	Korongo_Farm	1986	
109	Korongo_Farm	2000	0.81
110	Hortitec_(Kenya)_Ltd	1986	
110	Hortitec_(Kenya)_Ltd	2000	1.76
111	Kenya_Agri_Reasearch_Ins	1986	0.62
111	Kenya_Agri_Reasearch_Ins	2000	0.95
112	Loldia	1986	0.24
112	Loldia	2000	0.34
113	Longonot_Farm	1986	1.30
113	Longonot_Farm	2000	0.93
114	Malewa_Bay_Estate	1986	0.21
114	Malewa_Bay_Estate	2000	5.48
115	Mbegu	1986	
115	Mbegu	2000	2.04

Monday, January 21, 2002 Page 1 of 3