



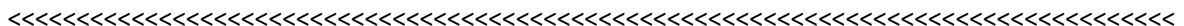
ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
FACULTY OF TECHNOLOGY

IMPACT OF LAND USE/LAND COVER CHANGE ON  
CATCHMENT HYDROLOGY AND WATER QUALITY OF  
LEGEDADI-DIRE CATCHMENTS, ETHIOPIA.

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## **ABSTRACTS**

The main objective of this study was to assess the impact of the environmental changes on the hydrology and water quality of the Lege Dadi-Dire catchments. More specifically, the study analysed the land cover change scenarios that were assumed would have taken place in the catchments, and the effect these changes have had on the hydrology and water quality of the catchment. The Soil and Water Assessment Tool (SWAT) model was used to investigate the impact of land cover change on streamflow, sediment, nitrate, phosphorous, and other considered water quality variables yield of the study area. The model was set up using readily available spatial and temporal data, and calibrated against measured values.

There was good agreement between monthly estimated and simulated variables for the calibration and validation periods. The simulation of sediment was slightly underestimated but overall, the agreement between the estimated and simulated variables was acceptable. Two approaches have been taken to conduct the study. First, historical land use/cover data of 1960, 1980, and 2008 were taken and the impact of land use/cover change over the period was analysed.

Second, the 1990 land use/cover data was used as a base data and scenarios of the future land use/cover were developed. Taking both cases, impacts of land use/cover and their scale were identified in this study.

Accordingly, there has been close correlation between land use/cover, stream flow and turbidity. There has been a considerable increase in runoff of about 8.3% in Lege Dadi catchment which is attributing to land use/cover effect.

Without climate change, land cover changes considered in the scenarios account for an increase in runoff of about 3.4-49.9% and 14.9-15.3% for Lege Dadi and Dire catchments respectively.

Similarly, the sediment yields have also increased more closely with agricultural land use intensification.

In relation to the increase in agricultural land, nitrate, phosphorous and other considered variables have shown considerable increase through the application of agricultural inputs such as fertilizers. This will further escalate the problem of water quality and treatment cost of Lege Dadi water treatment plant. Remedial measures have also been recommended.

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## TABLE OF CONTENTS

ABSTRACTS.....	ii
ACKNOWLEDGMENTS.....	iii
LIST OF FIGURES .....	vi
LIST OF TABLES.....	viii
LIST OF ABBREVIATIONS.....	ix
<b>Chapter 1 INTRODUCTION .....</b>	<b>1</b>
1.1 GENERAL.....	1
1.2 STUDY AREA.....	3
1.3 CLIMATE AND HYDROLOGY .....	5
1.4 PROBLEM DESCRIPTION .....	6
1.5 OBJECTIVE .....	9
1.6 RESEARCH QUESTIONS.....	9
1.7 SIGNIFICANCE OF THE RESEARCH .....	10
<b>Chapter 2 LITERATURE REVIEW .....</b>	<b>11</b>
2.1 INTRODUCTION .....	11
2.2. HYDROLOGIC CYCLE.....	11
2.3. HYDROLOGIC MODELS.....	13
2.3.1 Introduction.....	13
2.3.2. The System concept .....	14
2.4 OVERVIEW OF HYDROLOGIC MODELS .....	17
2.5 PREVIOUS WORKS .....	19
2.6 CONCLUSION.....	21

<b>Chapter 3 METHODS AND MATERIALS.....</b>	<b>22</b>
3.1 HYDROLOGICAL MODEL SELECTION .....	22
3.2 DATA COLLECTION AND ANALYSIS.....	25
3.2.1 Climatic and stream flow data .....	25
3.2.2 Physiographic Data .....	30
3.3 MODEL SET UP .....	37
3.3.1. Watershed delineation.....	37
3.3.2. Land use and Soil Characterization .....	38
3.3.3. Outlet and Inlet Definition.....	39
3.3.4. Weather Data Definition.....	39
3.4 SENSITIVITY ANALYSIS, CALIBRATION AND VALIDATION.....	40
<b>Chapter 4 LANDUSE/LANDCOVER CHANGE SCENARIOS AND IMPACT ASSESSMENT .....</b>	<b>54</b>
4.1 INTRODUCTION .....	54
4.2. EXISTING LANDUSE/COVER.....	55
4.2.1. Land Use and Types of Land Cover in the Legedadi Catchment Area .....	55
4.2.2 Land Use/Land Cover in the Dire Catchment Area.....	58
4.3 LAND USE AND LAND COVER SCENARIOS .....	64
<b>Chapter 5 RESULT AND DISCUSSION .....</b>	<b>68</b>
<b>Chapter 6 Conclusions and Recommendations.....</b>	<b>75</b>
6.1. CONCLUSIONS .....	75
6.2 LIMITATIONS.....	77
6.4. RECOMMENDATIONS.....	78
6.5 FUTURE RESEARCH .....	79
<b>REFERENCES .....</b>	<b>80</b>
<b>APPENDICES .....</b>	<b>80</b>

## LIST OF FIGURES

Fig.1.1 Location of the study area (vertical legend, elevation; horizontal legend, distance scale)....	4
Fig. 1.2 Average Turbidity of Lege Dadi Reservoir Raw Water.....	8
Fig. 2.1: The hydrologic cycle.....	12
Fig. 2.2 The global hydrologic cycle as represented in hydrologic system.....	14
Fig 2.3 The watershed as a hydrologic system.....	15
Fig. 2.4 Hydrologic SYSTEM MODEL Structure.....	16
Fig.2.5 Classification of Hydrologic Models.....	17
Fig. 3.1: Overview of the Modules in SWAT.....	24
Fig. 3.2: Stream flow and sediment discharge correlation for Aleltu gauging station.....	29
Fig.3.3: Landuse/cover classification of Lege Dadi-Dire catchments 1990.....	36
Fig.3.4 Watershed delineation and configuration of the study areas.....	38
Fig.3.5: Comparison between simulated and observed streamflow for the calibration period for Lege Dadi mean monthly streamflow .....	45
Fig,3.6: Comparison between simulated and observed streamflow for the validation period for Lege Dadi mean monthly streamflow.....	45
Fig,3.7: Comparison between simulated and observed streamflow for the calibration period for Dire mean monthly streamflow.....	46
Fig,3.8: Comparison between simulated and observed streamflow for the validation period for Dire mean monthly streamflow.....	46
Fig. 3.9: Comparison between simulated and observed sediment flow for the calibration (a) and validation (b) period for Lege Dadi catchment.....	48

Fig, 3.10: Comparison between simulated and observed sediment flow for the calibration(c)  
and validation (d) period for Dire catchment.....49

Fig 4.1. Legedadi Catchment land use/cover distribution 1990.....55

Fig 4.2. Land use/cover distribution of Legedadi catchment for the years 1960, 1980 and 2008...58

Fig 4.3. Land use/cover distribution of Legedadi catchment for the years 1990.....60

Fig 4.4. Land use/cover distribution of Dire catchment for the years 1960, 1980 and 2008.....63

Fig.4.5: LULC Percentage distribution of the base and each scenario in Lege Dadi  
catchment area.....67

Fig.4.6: LULC Percentage distribution of the base and each scenario in Dire catchment area.....67

Fig.5.1: Percentage change in variables attributed to change in LULC in Lege Dadi catchment.....70

Fig. 5.2: Sediment yield rate for Lege Dadi catchment subbasins.....71

Fig.5.3 Annual mean Nitrate yield rate of subbasins in Legedadi catchment area (KgN/ha/day)....71

Fig.5.3: Percentage change in variables attributed to change in LULC in Dire catchment.....73

Fig. 5.4: Sediment yield rate for Dire catchment subbasins.....74

**LIST OF TABLES**

Table 1.1: Climatic Stations in Proximity to Legedadi and Dire Catchment Areas..... 6

Table 1.2: Actual and Projected Population Density in the Catchment Areas.....7

Table 1.3: Average Turbidity of raw water in Lege Dadi Reservoir, FTU.....8

Table 2.1: The sediment loads for reservoir sites were given as follows.....20

Table 3.1: Climatic Stations within and in the Proximity to Legedadi and Dire Catchment Areas used as source of Precipitation data..... 26

Table 3.2: Climatic Stations within and in the Proximity to Legedadi and Dire Catchment Areas used as source of minimum and maximum temperature data.....26

Table 3.3: summary of monthly climatic data for considered station.....27

Table 3.4: Soil and land use configuration in Lege Dadi catchment.....35

Table 3.4: Soil and land use configuration in Dire catchment.....35

Table 3.5: DEM characterization of the study area.....36

Table 3.6: Parameter sensitivity ranking for Lege Dadi catchment.....42

Table 3.7: Parameter sensitivity ranking for Dire catchment.....42

Table 3.8: Model evaluation statistics for the calibration and validation periods for average monthly flow.....44

Table 3.9: Parameter sensitivity ranking for Lege Dadi catchment for suspended sediment.....46

Table 3.10: Parameter sensitivity ranking for Dire catchment for suspended sediment.....46

Table 3.11: Model evaluation statistics for the calibration and validation periods for average monthly suspended flow .....45

Table 4.1: Land use/cover distribution of Legedadi catchment for the years 1960, 1980 and 2008.....56

Table 4.2: Land use/cover distribution of Dire catchment for the years 1960, 1980 and 2008.....62

Table 4.3 Description of Land use/cover change scenarios developed for the catchment areas.....65

Table 4.4: Detailed Land use/cover type distribution and change scenarios developed for the catchment areas.....66

Table 5.1: Summary table of different variables and their values for actual LULC values.....69

Table 5.1: Percentage change in some variables due to change in landuse/cover as per the scenarios.....69

Table 6.1: Summary table of different variables and their values.....76

## LIST OF ABBREVIATIONS

AGRC- Agricultural Land-Close-grown

CRGR--- Cropland/Grassland Mosaic

CRU-Climatic research unit

CHROMIC L- chromic luvisols

CALCICXER- calcic xerosols

DEM - Digital Elevation Model

DISOX\_OUT Amount of dissolved oxygen transported out of reach during time step (kg O<sub>2</sub>).

FODB - Deciduous Broadleaf Forest

GRAS - Grassland

GIS - Geographical Information Systems

LULC - Land Use and Land Cover

LULC- land use and land cover

LEPTOSOLS- leptosols

MIGS- Mixed Grassland/Shrubland

NO<sub>3</sub>\_OUT Nitrate transported with water out of reach during time step (kg N).

NSURQ - NO<sub>3</sub> in surface runoff (kg N/ha). Nitrate transported with surface runoff.

ORTICSOLO- orthic solonchaks

ORGN\_OUT Organic nitrogen transported with water out of reach during time step (kg N).

ORGP\_OUT Organic phosphorus transported with water out of reach during time step (kg P).

ORGN - Organic N yield (kg N/ha).

ORGP - Organic P yield (kg P/ha)

PELLIC VE-pellic vertisols

SED\_OUT Sediment transported with water out of reach during time step (metric tons).

SC-1- Scenario 1

SWAT - Soil and Water Assessment Tool

SYLD - Sediment yield (metric tons/ha).

WATR- Water body

WYLD - Water yield (mm H<sub>2</sub>O).



## Chapter 1

### INTRODUCTION

#### 1.1 GENERAL

Land use change is an undeniable and significant global, ecological trend. As Agarwal(2000) notes, "Three of the well-documented global changes are increasing concentrations of carbon dioxide in the atmosphere; alterations in the biochemistry of the global nitrogen cycle; and on-going land use/land cover change."

Disasters from land degradation such as deforestation, poor agricultural practices, and inappropriate land use systems, among others, cause devastating effects. They disrupt the socio-economic activities, ecological systems and general development of the region.

The potential effects on water resources due to land use/cover change and global climate change in the past few decades have been of great concern. Land clearing, agricultural activities, construction, mining, urban and industrial development, and similar activities can have a major impact on the quantity and rate of surface runoff, and on the rates of erosion and sediment transport that take place.

Most recent assessments of environmental effects on water resources have taken the form of sensitivity analyses. Water resources sensitivity studies are simplified assessments of how the hydrological regime (usually streamflow) will respond to prescribed or model-simulated climatic conditions (usually temperature, precipitation, and evaporation) and environmental changes.

According to Central Statistical Authority (2005), the total land holding area under different land uses in Ethiopia was estimated to be about 11,047,249 hectares. This area is composed of 98.5% of the rural private holdings and 1.5% of the urban private holdings in the country. Of this land, area under temporary crops accounted for 8,193,391 hectares (74.2%); land under permanent crops estimated to be 667,768 hectares (6%); grazing land amount to be 957,856 hectares (8.7%); fallow land is reported to be 839,949 hectares (7.6%); woodland amounted to be 87,057 hectares (0.8%) and land for other uses is estimated to be 301,232 hectares (2.7%).

This study investigates land use/land cover dynamics and its consequent impacts on stream flow and water quality at Lege Dadi-Dire catchments. Lege Dadi-Dire reservoirs catchment is one and the largest of the three main water supply sources of Addis Ababa city. It is located 22kms to the eastern side of the city and approximately lies in geographic coordinates of 481.3kms east to 507.7kms east of UTM and 996.32kms to 1019.42kms north UTM.

The Dire and Lege Dadi catchments which have catchment areas of 78km<sup>2</sup> and 208km<sup>2</sup> respectively, contribute raw water to the treatment plant located at Laga Dadi dam site. The raw water supplied for the treatment plant from the catchment areas is characterized by high turbidity (TAHAL, 2000). Water quality in the reservoir has deteriorated over the past twenty years. Raw water turbidity has increased considerably since the mid-eighties. Whereas turbidities were previously close to 200 FTU during the rainy season of July-September and even less than 100 FTU in the dry season, turbidity in the rainy season now exceeds 1,000 FTU and declines to about 500 FTU in the dry season.

This has two main adverse impacts, namely, an increase in water treatment costs (higher chemicals demand), and, more critical, the inability of the plant to reach its design production, especially during the rainy season.

## 1.2 STUDY AREA

The two catchment areas, the Legedadi and Dire in which water is harvested for storage in the two existing reservoirs (the Legedadi and Dire) are located in the upper north-western narrow part of the Awash basin.

Lege Dadi-Dire reservoirs catchment is one and the largest of the three main water supply sources of Addis Ababa city. It is located 22kms to the eastern side of the city and approximately lies in geographic coordinates of 481.3kms east to 507.7kms east of UTM and 996.32kms north to 1019.42kms north UTM.

The region is characterized by a range of volcanic mountains rising to elevations range from 2,460 and 3,200 m.a.m.s.l. The major physiographic units found in the catchment area are: mountains, dissected side slopes of mountains, hills, steep to undulating foot-slopes, gullies, valleys, and undulating plains and flat to almost flat plains. The main units of the catchment area are: small villages surrounded by Eucalyptus wood, intensively and moderately cultivated land, Eucalyptus woodland (young and matured), shrub-land, Eucalyptus grass and natural vegetation, Grassland, bare soil and built-up areas (paved road, dam, concrete buildings in Sendafa town, and water bodies).

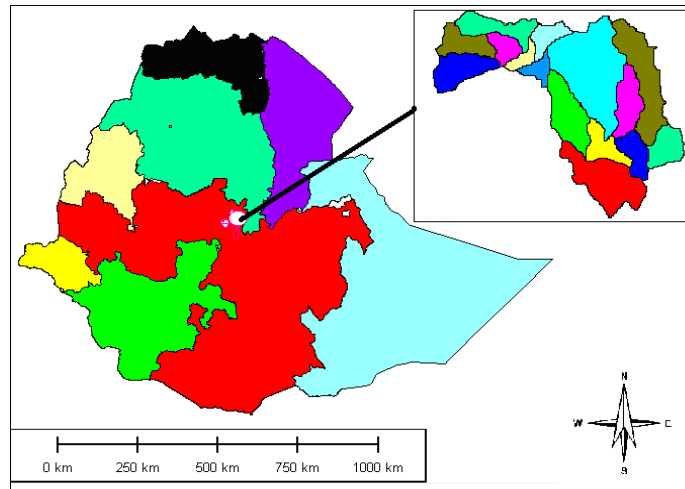


Fig.1.1 Location of the study area (vertical legend, elevation; horizontal legend, distance scale)

The population of the catchment basins, by and large, ekes out its existence from rain fed crops and livestock, which may be categorized as subsistence agriculture.

High population growth and environmental degradation, limited resources, and inadequate land use and water policies have increased raw water degradation in the area.

Surface water stored in the Legedadi and Dire reservoirs is the main source of drinking water for the metropolitan area of Addis Ababa. The Legedadi reservoir constructed in 1970 to harvest run-off water during the rainy seasons for urban water supply, is the principal source of water for the Addis Ababa Metropolitan Area.

The availability of ground water in this region is very limited (TAHAL, 2000). The surface water resource potential of the catchment areas in average rainfall years is well beyond the existing impounding capacity. This study is expected to help concerned sectors in planning, developing and managing water resource projects; and as an input for those who are interested to further research in related area and field of study.

### 1.3 CLIMATE AND HYDROLOGY

High annual rainfalls in the region of Addis Ababa occur when moist winds are forced to rise in order to pass over mountains. Such conditions prevail especially along the mountain ranges that extend early at right angles to the prevailing storm movements. The rainfall patterns in the catchment areas have a bimodal profile with strong peaks in the summer months and minor rainfalls in the months of March and April.

In the summer months, mainly from July to September, a strong air current moves from the southwest towards the northeast. This current brings moisture from the Gulf of Guinea to the Upper Awash and Abay (Blue Nile) watersheds. Thus, there are two seasonal weather patterns in the region of Addis Ababa, and these are clearly observed and reflected by the weather observation records. The weather is relatively cool in the wet season of July to September when the main rains fall, while the more or less rainless season of October to June has warmer temperatures with easterly winds. Rainfall usually occurs in the form of localized thunderstorms due to convective heating of the air masses during the day and rapid cooling at night.

Rainfall stations in the catchments, operated by the Hydrological Division of the Ministry of Water Resources (HDMWR), are located at Legedadi Reservoir and in the Mutinicha catchment area (a watershed of the Akaki River). However, these stations have long periods without data.

For this reason, the long-term records available for five stations operated by NMSA in the Awash and Blue Nile basins (which have relatively complete data and a similar climatic regime to that of the Legedadi-Dire catchment areas), have been taken as the basis for this study.

The locations of the five stations are shown in Table 1.2. which gives their latitude, longitude and elevation, as well as the periods for which records are available. These locations of the stations were found from NMSA and location table was prepared as shown in table n.

Precipitation and temperature data obtained from these stations have been analysed and being checked for quality as shown in annex.

Table1.1: Climatic Stations in Proximity to Legedadi and Dire Catchment Areas.

No	Location	Longitude	Latitude	Elevation (m.a.m.s.l)	Data availability (years)
1	Bole Airport	38°45'	09°02'	2324	1963-2008
2	AA Observatory	38°43'	09°02'	2408	1951-2008
3	Sendafa	39°01'	09°09'	2560	1962-2006
4	Sululta	38°26'	09°01'	2610	1988-2007
5	Entoto	38°80'	09°03'	2900	1988-2008

The time series of discharge at the outlet of a watershed is the most important data to calibrate and validate a hydrological model. A daily stream flow data of the study period was not available at the upstream of the reservoir since there is no station at the entry. Therefore, hydrological calculations based on the hydrology similarity method were performed in order to obtain stream flow and sediment flow for calibration and validation from a nearby gauging station.

#### 1.4 PROBLEM DESCRIPTION

The relationship between land and water is of interest world wide. In many developing countries, changes in land use are rapidly taking place and the largest change in terms of land area, and arguably also in terms of water resource impact arising from afforestation and deforestation activities (Calder, 1993).

The dynamic nature of land use emanating from increasing population, technology and climatic change is of paramount stage in Ethiopia that needs primary concern. Expansion and intensification of agriculture, growth of urban areas, and extraction of timber and other natural resources will likely accelerate over the coming decades to satisfy demands of increasing population (McColl, 2007)

These increase pressure on the indigenous forest resources, and demands for timber and pulp are leading to increasing areas under going commercial afforestation with fast-growing monocultures of often exotic tree species like eucalyptus tree. Those changes and agricultural demands of irrigation water, cattle feeding, hydroelectricity, increasing losses all pose pressure on water availability and quality. It may also result in alteration of stream patterns, altered pattern of global atmospheric circulation, and long term extinction of species.

Table 1.2: Actual and Projected Population Density in the Catchment Areas.

Catchment Basin	Area (km <sup>2</sup> )	1994(Census)		1999(Projection)		2010(Projection)	
		population	Average population Density (Persons/km <sup>2</sup> )	Population	Average population Density (Persons/km <sup>2</sup> )	population	Average population Density (Persons/km <sup>2</sup> )
Lege Dadi	206	20,000	98*	23,000	112	32000	156
Dire	78	6,000	77	7,000	90	9000	116
Total	284	26,000	88	30000	101	41000	136

\*Average population density for all-Ethiopia for the period was 54p/km<sup>2</sup>.

[Source: Tahal consulting engineers ltd, 2000]

The Study area is highly prone to those changes imposing impact on hydrological processes and resulting in degradation of raw water in the reservoir.

Water quality in the reservoir has deteriorated over the past twenty years. Raw water turbidity has increased considerably since the mid-eighties. Whereas turbidities were previously close to 200 FTU during the rainy season of July-September and even less than 100 FTU in the dry season, turbidity in the rainy season now exceeds 1,000 FTU and declines to about 500 FTU in the dry season.

Table 1.3 Average Turbidity of raw water in Lege Dadi Reservoir, FTU

Year	1985	1986	1987	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Average Turbidity, Months 7,8,9	176	230	230	250	316	605	641	530	614	667	772	800	1100
Average Turbidity, Months 1-6,10-12	93	88	88	99	151	132	179	248	264	347	391	430	520

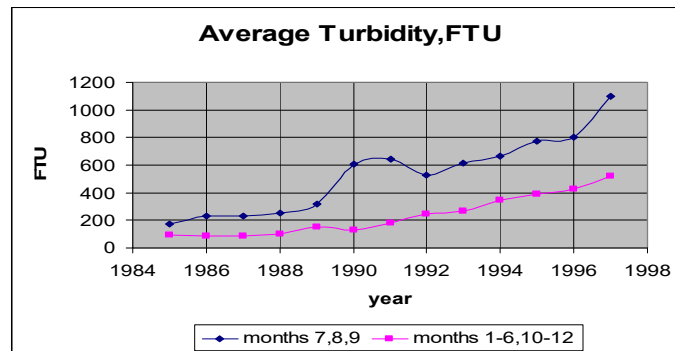


Fig. 1.2 Average Turbidity of Lege Dadi Reservoir Raw Water.

This has two main adverse impacts, namely, an increase in water treatment costs (higher chemicals demand), and, more critical, the inability of the plant to reach its design production, especially during the rainy season.

This escalated the cost of water treatment in recent years.

## **1.5 OBJECTIVE**

The main objective of this study is to identify the scale of impact of land use change on the hydrology and water quality, and suggest remedial measures by using advanced distributed parameter hydrologic model SWAT (Soil and Water Assessment Tool) and available data.

## **1.6 RESEARCH QUESTIONS**

- How much SWAT model is applicable to assessment of land use/land cover change impact on hydrology and water quality in small Ethiopian plateau watershed?
- At a local scale, how does a given change in land use or management affect local runoff generated and water quality? This would give valuable insights into the magnitudes of change and whether they are significant or not.
- How can adverse effect be mitigated using economically and environmentally acceptable measures?
- What would be the projected hydrology of the catchment based on different land cover dynamics scenarios and its implications?

## 1.7 SIGNIFICANCE OF THE RESEARCH

The knowledge how land use/cover change influence watershed hydrology will enable local governments and policy makers to formulate and implement effective and appropriate response strategies to minimize the undesirable effects of future land use/cover change or modifications. Given that impacts of land use/cover change on water resources are the result of complex interactions between diverse site-specific factors and offsite conditions, standardized types of responses will rarely be adequate. General statements about land–water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (Tadele, 2007).

Hydrologic response is an integrated indicator of watershed condition, and changes in land use/cover may affect the overall health and function of a watershed. Such changes vary spatially and occur at different rates through time. Direct and powerful linkages exist among spatially distributed watershed properties and watershed processes (Tadele, K., 2007). To envisage the future effects of land use change on river flow, it is important to have an understanding of the effects of historic land use/cover changes have had on watershed hydrological system. Moreover, detecting and simulating the effects of land use/cover change and management on hydrological processes requires a new and improved procedure to instrument watersheds based on the hydrological sensitivity due to land use/cover changes at sub-watershed levels.

In general, this study is expected to help concerned sectors in planning, developing and managing water resource projects in the study area and be an input for those who are interested to further research in related field and area of study.

## Chapter 2

### LITERATURE REVIEW

#### 2.1 INTRODUCTION

The purpose of this literature review is to provide the reader with a general overview of application of hydrologic modelling for environmental impact assessment. Hydrologic models are increasingly used in hydrology to simulate changes in watershed management, to investigate the impacts of external influences (such as land use and land cover changes) and also to extend data sets. This chapter reviews two topics that are core to this research, namely hydrologic modelling, land use and land cover (LULC) change.

#### 2.2. HYDROLOGIC CYCLE

Water on earth exists in a space called the hydrosphere which extends about 15 km up into the atmosphere and about 1 km down into the lithosphere, the crust of the earth (Chow, 1988).

Water circulates in the hydrosphere through the maze of paths constituting the hydrologic cycle.

As shown schematically in Fig. 2.1, water evaporates from the oceans and the land surface to become part of the atmosphere; water vapour is transported and lifted in the atmosphere until it condenses and precipitates on the land or the oceans; precipitated water may be intercepted by vegetation, become overland flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow, and discharge into streams as surface runoff.

Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge groundwater, later emerging in springs or seeping into streams to form surface runoff, and finally flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continues.

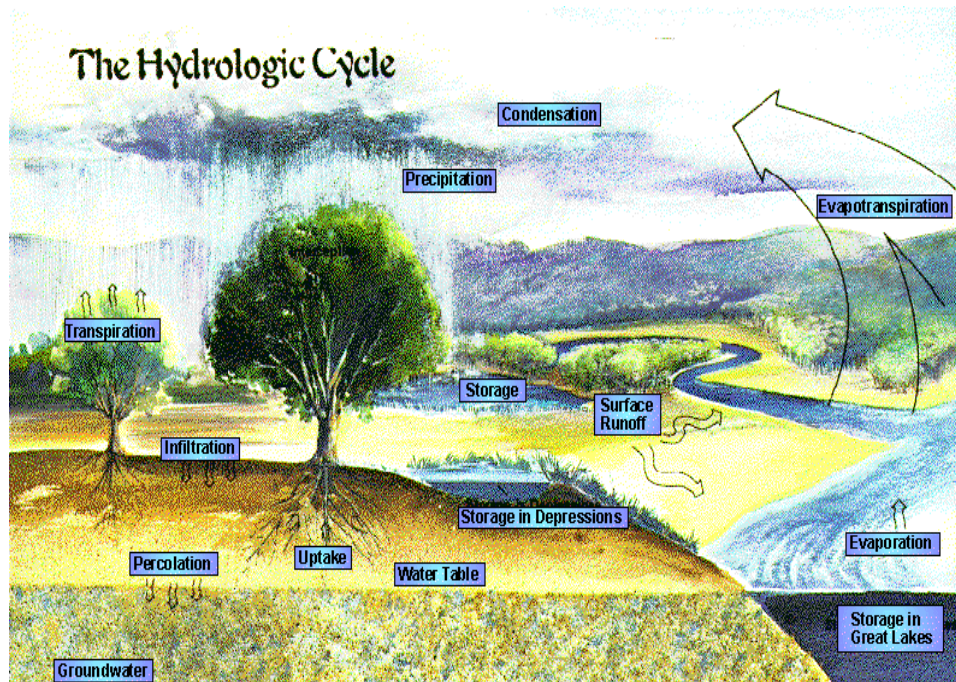


Fig. 2.1: The hydrologic cycle.

[Source: Institute of Water Research, Michigan State University, 1997]

Although the concept of the hydrologic cycle is simple, the phenomenon is enormously complex and intricate. It is not just one large cycle but rather is composed of many interrelated cycles of continental, regional, and local extent. Although the total volume of water in the global hydrologic cycle remains essentially constant, the distribution of this water is continually changing on continents, in regions, and within local drainage basins.

The hydrology of a region is determined by its weather patterns and by physical factors such as topography, geology and vegetation.

Also, as civilization progresses, human activities gradually encroach on the natural water environment, altering the dynamic equilibrium of the hydrologic cycle and initiating new processes and events.

Changes in the distribution, circulation, quality or temperature of earths water which have far reaching effects may be caused by human activities. People till the soil, irrigate crops, fertilize land, clear forests, pumps ground water build dams, dump waste into rivers and lakes, and do many other constructive and destructive things that affect the circulation and quality of water in nature.

## **2.3. HYDROLOGIC MODELS**

### **2.3.1 Introduction**

Hydrological modeling involves the application of mathematical expressions that define quantitative relationships between inputs and outputs. The scope of hydrologic modeling and its applications has broadened dramatically over the past decades. Hydrologic modeling is related to the spatial processes of the hydrologic cycle and is often used to estimate basin water resources as well as for impact assessment or more precisely water resources management. Many hydrologic models have been developed in the past and more are being developed and they are used to determine the performance of watersheds under inevitable land use changes.

### 2.3.2. The System concept

Hydrologic phenomena are extremely complex, and difficult both to measure and understand in full detail. In the absence of perfect knowledge, however, they may be represented in a simplified way by means of the system concept: A system is a set of connected parts that forms a whole (Chow, 1988).

The hydrologic cycle may be treated as a system whose components are precipitation, evaporation, snowmelt, infiltration, runoff and other processes in the hydrologic cycle. The different components can each be grouped together into subsystem or broken down into new sub-processes, depending on the level of detail in the analysis and the purpose of the analysis.

In Figure 2.2 below, the global hydrologic cycle is represented in a system. The dashed lines divide it into three subsystems:

- **The atmospheric water system** containing the processes of precipitation, evaporation, interception and transpiration.
- **The surface water system** containing the process of snow accumulation and melt, overland flow, surface runoff, subsurface and groundwater outflow and runoff to streams and the ocean.
- **The subsurface water system** containing the process of infiltration, groundwater recharge, subsurface flow and groundwater flow.

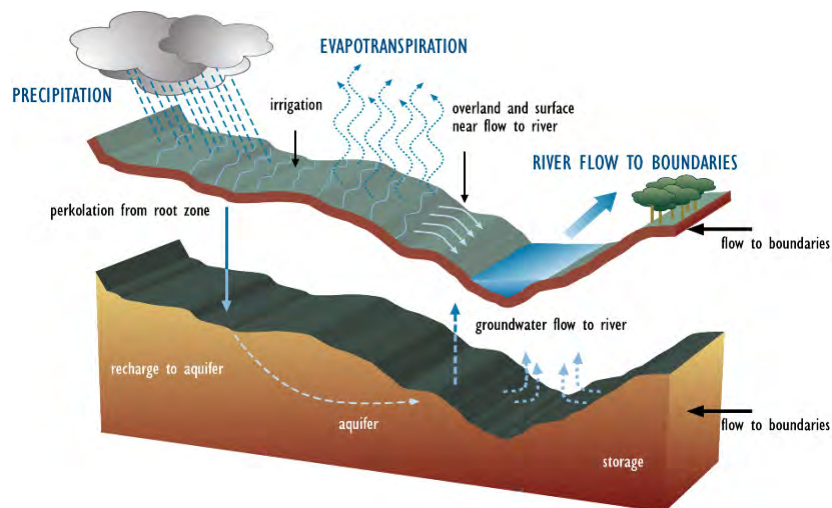


Fig. 2.2 The global hydrologic cycle as represented in hydrologic system.

For most practical applications, only a few processes of the hydrologic cycle are considered at a time, and only for a small part of the earth's surface, usually in a catchment (Godina, 1995).

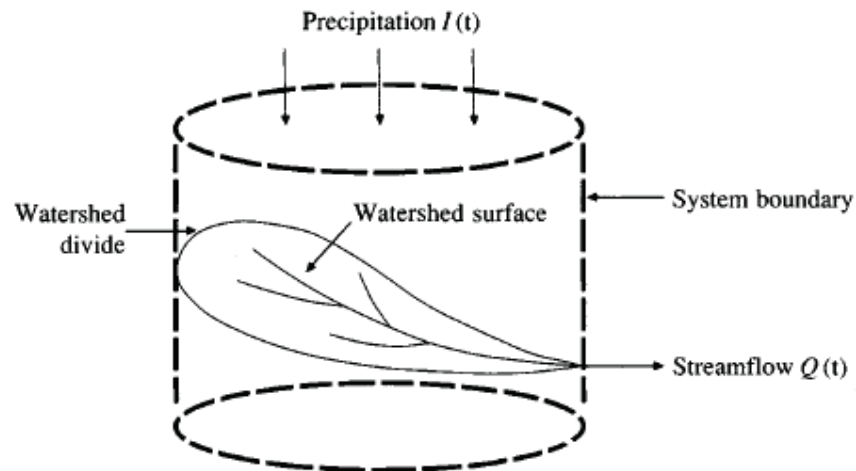


Fig 2.3 The watershed as a hydrologic system.

Water resources systems are characterized by multiple interdependent components that together produce multiple economic, environmental, ecological and social impacts. Planners and managers working to improve the performance of these complex systems must identify and evaluate alternative designs and operating policies, comparing their predicted performance with the desired goals or objectives. These alternatives are defined by the values of numerous design, target and operating policy variables.

The objective of hydrologic system analysis is to study the system operation and predict its output. A hydrologic system model is an approximation of the actual system; its inputs and outputs are measurable hydrologic variables and its structure is a set of equations linking the inputs and outputs. Central to the model structure is the concept of a system transformation.

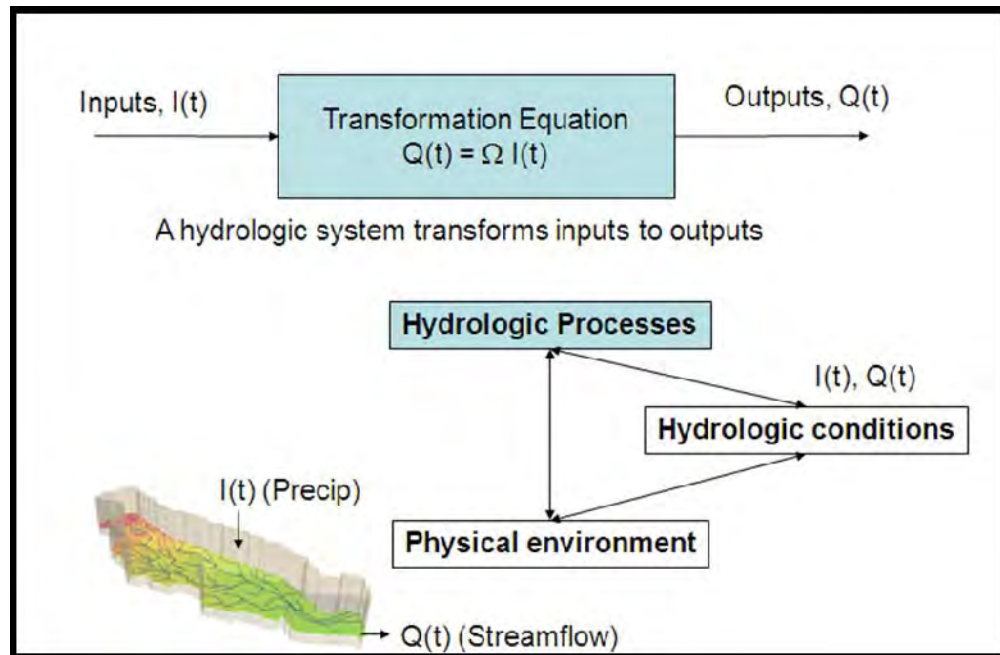


Fig. 2.4 Hydrologic SYSTEM MODEL Structure.

Let the input and output be expressed as functions of time,  $I(t)$  and  $Q(t)$  respectively, for  $t$  belonging to the time range  $T$  under consideration. The system performs a transformation of the input into the output represented by

$Q(t) = \Omega I(t)$ , which is called the transformation equation of the system. The symbol  $\Omega$  is a transfer function between the input and the output.

Constrained optimization together with simulation modelling is the primary way we have of estimating the values of the decision variables that will best achieve specified performance objectives.

## 2.4 OVERVIEW OF HYDROLOGIC MODELS

Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle (Wikipedia, 2009). They are primarily used for hydrologic prediction and for understanding hydrologic processes.

Two major types of hydrologic models can be distinguished:

**Models based on data.** These models are black box systems, using mathematical and statistical concepts to link a certain input (for instance rainfall) to the model output (for instance runoff). Commonly used techniques are regression, transfer functions, and system identification.

**Models based on process descriptions.** These models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated. These models are known as deterministic hydrology models. Deterministic hydrology models can be subdivided into single-event models and continuous simulation models.

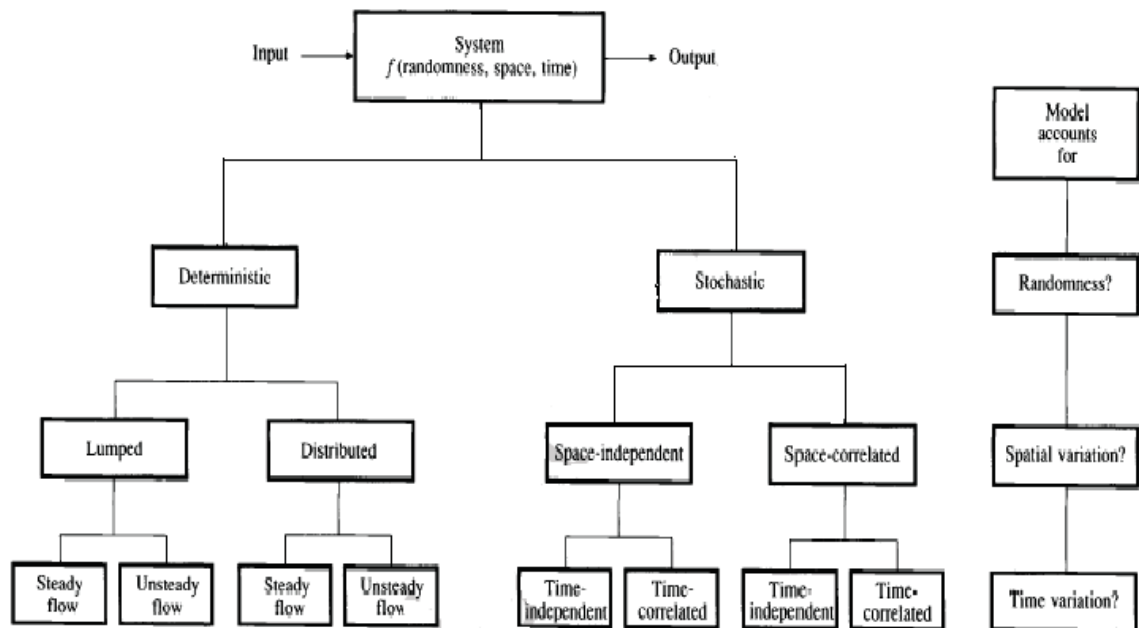


Fig.2.5 Classification of Hydrologic Models.

In a deterministic lumped model, the system is spatially averaged, or regarded as a single point in space without dimensions. In contrast, a deterministic distributed model considers the hydrologic processes taking place at various points in space and defines the model variables as functions of the space dimensions.

Stochastic models are classified as space-independent or space-correlated according to whether or not random variables at different points in space influence each other.

At the third level of the tree, time variability is considered. Deterministic models are classified as steady-flow (the flow rate not changing with time) or unsteady-flow models. Stochastic models always have outputs that are variable in time. They may be classified as time-independent or time-correlated; a time-independent model represents a sequence of hydrologic events that do not influence each other, while a time-correlated model represents a sequence in which the next event is partially influenced by the current one and possibly by others in the sequence.

In this study, emphasis is given to deterministic, physically based, basin-scale, continuous-time model that help to predict the impact of management on water and sediment in watersheds.

## 2.5 PREVIOUS WORKS

### *I. BCEOM 1980 STUDY (BCEOM, 1980)*

The BCEOM study examined the existing LegeDadi and Gafarsa dams and conducted bathometric surveys, meteorologic analysis and reservoirs operations studies. Bathometric maps were produced for the Legedadi and Gafarsa reservoirs, a peak rainfall analysis was calculated and inflows to the reservoirs was calculated from rainfall simulation as there were no gauging data for the period 1958 to 1979. The resulting average annual inflow obtained was 64,000,000m<sup>3</sup>.

### *II. AESL 1984 STUDY (AESL 1984)*

The AESL report was a reconnaissance study which provided the basis for all future Addis Ababa water supply studies. Due to its preliminary nature, certain assumptions were taken regarding unit runoff rates, flood discharges and sedimentation. A sedimentation rate of 370m<sup>3</sup>/km<sup>2</sup>/year (540t/km<sup>2</sup>/year) was assumed based on previous studies.

### *III. AESL 1993 STUDY*

This study reviews SEURECA's previous work as follows: In case of actual sediment information for the reservoir sites; SEURECA examined previous reports (Mac Donald 1986, HALCROW 1989) to estimate sediment yield. This study indicates a sediment yield ranging from 540t/km<sup>2</sup>/year to 600t/km<sup>2</sup>/year. SEURECA inconsistently then decide to use a constant value of 2400t/km<sup>2</sup>/year at all sites.

The AESL (1993) study justifies its approach which was to estimate the sedimentation that has occurred in past of 13 years before the study and fit this data to the HALCROW sediment yield curves. They also conducted a water balance analysis and estimated the sedimentation

from 1979 to 1992 as 4,5Mm<sup>3</sup>. The study derived a curve for suspended sediment yield assuming 25% bed load which is given by;

$$Y=6207A^{-0.23}$$

Where, Y= suspended sediment yield in t/km<sup>2</sup>/yr

A= catchment area in km<sup>2</sup>

Table 2.1 The sediment loads for reservoir sites were given as follows.

Area	Catchment Area (km <sup>2</sup> )	Suspended sediment (t/km <sup>2</sup> /yr)	Sediment bedload (t/km <sup>2</sup> /yr)	Total sediment yield (t/km <sup>2</sup> /yr)
Dire	72	2321	580	2901
Akaki A	409	1560	390	1950
Gerbi	59	2430	608	3038

#### ***IV. SOIL AND WATER LTD, 1994***

The study was initiated by problem of the supply of water to the city which consisted of the fact that the water was negative effected by taste and odour the causes of which were not completely known. Rigorous and vast water quality analysis was conducted and they come to conclude that short- term changes in species composition and abundance of algae in the Lege Dadi Reservoir were possible. These changes are certainly linked to the variability of the level of nutrients and sediment load of the inputs from the rivers that feed the reservoir. The seasonal changes in the amount of rainfall presumably play an important role in determining the nutrient chemistry and physics (eg. light penetration) of the reservoir.

#### ***V. TAHAL 1998***

In 1998 Tahal Consulting Engineers (TAHAL) in association with Metaferia Consulting Engineers (MCE) carried out the Bathymetric survey of the reservoir and the results of a bathymetric survey conducted in 1979 were reconstructed.

A comparison of this result for Lege Dadi reservoir with those from the previous survey indicated an average silt accumulation of 110,000m<sup>3</sup>/year, representing a loss of 0.25% of live storage capacity per year. In terms of soil loss from the catchment area, this amounts to an average of 760tons/km<sup>2</sup>/year (1999 Bathymetric map Report).

## **2.6 CONCLUSION**

In this section, attempt has been made to provide the reader with a general overview of application of hydrologic modelling for environmental impact assessment.

Previous works have also been identified and dealt with. Different approaches and study outputs have been summarized in the preceding sections. The primary emphasis of those previous studies, in one way or the other, was the water in the reservoir.

However, the integrative nature of river basin, in environmental, social and economic aspects and their dynamics temporally and spatially calls for closer study of watershed system components.

## Chapter 3

### METHODS AND MATERIALS

#### 3.1 HYDROLOGICAL MODEL SELECTION

There are numerous criteria which can be used for choosing the “right” hydrologic model.

These criteria are always project-dependent, since every project has its own specific requirements and needs. Further, some criteria are also user-dependent (and therefore subjective), such as the personal preference for graphical user interface, computer operation system (OS), input-output (I/O) management and structure, or user’s add-on expansibility.

Among the various project-dependent selection criteria, there are four common, fundamental ones that must be always answered:

- Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project such as peak flow, event volume and hydrograph, long-term sequence of flows...),
- Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating land use/cover change, regulated reservoir operation, snow accumulation and melt, single-event or continuous processes...),
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?),
- Price (Does the investment appear to be worthwhile for the objectives of the project?).

This study is aimed at assessing the potential impact of land use/cover change on a wide range of hydrologic processes and water quality.

More specifically, the hydrologic model for this study needs to have the capability to:

- Represent variable land use throughout the watershed, and to produce a full hydrograph response from each sub-area.
- Produce a full hydrograph, and must be capable of evaluating variable soils and land use conditions. The model should be able to route hydrographs through different stream reaches, and identify principal runoff source areas at selected points-of interest. The model should also compute sub-area release rates, or provide travel time and peak flow information from which these release rates may be developed.
- Evaluate the hydrologic effects of land use change.

The selected model must be computationally efficient, and its data input requirements must be compatible with data readily obtained for the selected Watershed.

The following hydrologic model outputs are required in order to fulfil the study objectives: simulated flow (Water yield mm H<sub>2</sub>O)-The net amount of water that leaves the sub basin and contributes to stream flow in the reach during the time step. Sediment yield (metric tons/ha/year)-Sediment from the subbasin that is transported into the reach during the time step.), volumes and hydrographs at the outlets of sub basins and water quality related outputs.

The method to evaluate the impacts due to land use/cover changes and land use modifications is through integrating Geographical Information system (ArcView GIS) and Soil and Water Assessment Tool (SWAT) model.

SWAT is a basin - scale, continuous - time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the subwatershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only subwatersheds that are characterized by dominant land use, soil type, and management.

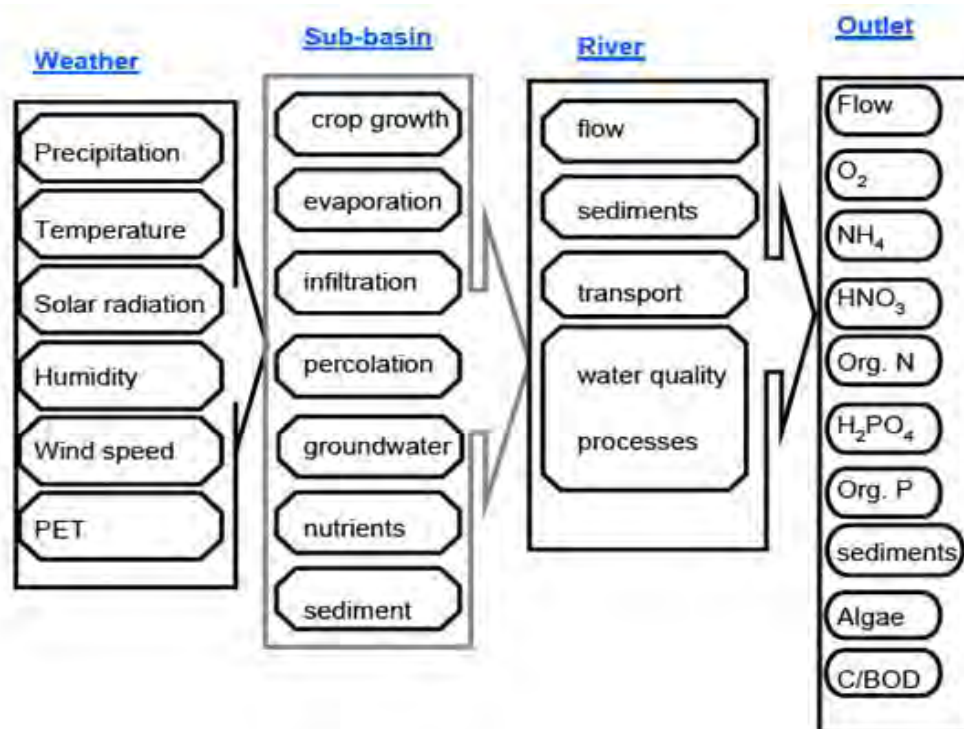


Fig. 3.1: Overview of the Modules in SWAT

Hence, SWAT was used in this study which is an appropriate model in simulating the requirements set earlier using available soil, topography, land use and weather data.

### **3.2 DATA COLLECTION AND ANALYSIS**

The basic data sets that are required to develop an input database for the model are climatic, stream flow, topographic and land use data.

#### **3.2.1 Climatic and stream flow data**

Climatic Inputs and HRU Hydrologic Balance Climatic inputs used in SWAT include daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which can be input from measured records and/or generated.

Daily precipitation, maximum and minimum temperature data were obtained from National Meteorological Service Agency (NMSA) for the nearby weather stations. The locations and available data of the rainfall and temperature stations are given on Tables 3.1 and 3.2.

Solar radiation data, relative humidity, and wind speed data were generated by the model.

SWAT model requires daily weather data; however there are only few meteorological stations in the basin having full and long record of data.

SWAT, unless given read-in climate data, uses a random weather generator that uses information found in weather station WGN files. In this study the weather generator algorithm in SWAT were used to fill in the missing data in monthly rainfall, minimum and maximum temperature. In our case the monthly and daily rainfall, maximum and minimum temperature have missing data as which have been represented by -99 so that SWAT will fill in the gap.

Table 3.1: Climatic Stations within and in the Proximity to Legedadi and Dire Catchment Areas used as source of Precipitation data.

No.	Station name	Station Code	Location			Available Data Duration		No. of Years
			Lat.	Long.	Altit.	starting	end	
1	Addis Ababa Bole	pcp1	476590	993272	2354	1987	2004	17
2	Addis Ababa	pcp2	472710	996727	2408	1987	2008	21
3	Entoto	pcp3	473907	1004831	2964	1989	2007	18
4	Sendafa	pcp4	502651	1011388	2560	1987	2006	19
5	Sululta	pcp5	461654	1015144	2610	1988	2006	18

Table 3.2: Climatic Stations within and in the Proximity to Legedadi and Dire Catchment Areas used as source of minimum and maximum temperature data.

No.	Station name	Station Code	Location			Available Data Duration		No. of Years
			Lat.	Long.	Altit.	starting	end	
1	Addis Ababa Bole	tmp1	476590	993272	2329	1984	2008	24
2	Addis Ababa	tmp2	472710	996727	2362	1984	2008	24
3	Entoto	tmp3	473907	1004831	2964	1988	2008	20
5	Sululta	tmp5	461654	1015144	2686	1988	2008	20

Table 3.3 Summary of Monthly Climatic Data.

Station name	Climate Data	Month												Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Addis Ababa Bole	Precipitation(mm)	13.9	32.8	67.5	91.1	69.0	117.8	234.9	246.3	127.6	36.1	2.4	5.2	1044.6
	Max. Temperature(oC)	23.8	25.2	25.3	25.0	25.4	23.5	21.2	21.0	21.9	23.0	23.2	23.4	23.5
	Min. Temperature(oC)	7.6	8.8	10.5	11.3	10.9	10.6	11.2	11.2	10.4	8.4	5.9	6.4	9.4
Addis Ababa	Precipitation(mm)	15.1	38.5	74.4	90.8	79.7	146.5	273.3	285.0	175.3	36.0	4.7	9.3	1228.3
	Max. Temperature(oC)	23.8	25.2	25.3	25.0	25.4	23.5	21.2	21.0	21.9	23.0	23.2	23.4	23.5
	Min. Temperature(oC)	9.0	10.2	11.5	12.2	12.3	11.4	11.4	11.5	11.2	10.1	8.6	8.2	10.6
Entoto	Precipitation(mm)	15.7	36.6	60.8	84.9	69.4	143.5	307.7	338.6	146.7	25.7	8.8	8.7	1247.0
	Max. Temperature(oC)	19.3	20.2	20.2	19.6	20.1	18.1	16.0	16.0	16.8	18.2	18.8	19.0	18.5
	Min. Temperature(oC)	7.9	8.6	9.0	9.3	9.8	8.8	8.1	8.2	8.4	8.1	7.5	7.4	8.4
Sendafa	Precipitation(mm)	17.5	28.4	51.0	77.6	54.2	104.9	332.3	306.7	120.2	19.9	2.7	2.7	1117.9
	Max. Temperature(oC)	-	-	-	-	-	-	-	-	-	-	-	-	-
	Min. Temperature(oC)	-	-	-	-	-	-	-	-	-	-	-	-	-
Sululta	Precipitation(mm)	19.6	17.0	62.1	64.4	59.0	167.1	313.5	310.4	114.3	19.8	8.3	7.9	1163.4
	Max. Temperature(oC)	23.3	23.7	23.6	24.0	24.1	22.4	20.5	20.3	21.2	22.0	22.5	22.9	22.5
	Min. Temperature(oC)	3.2	3.8	3.8	4.3	4.2	3.7	3.2	3.1	3.1	2.4	2.2	2.7	3.3

The time series of discharge at the outlet of a watershed is the most important data to calibrate and validate a hydrological model. A daily stream flow data of the study period was not available at the upstream of the reservoir since there is no station at the entry. Therefore, hydrological calculations based on the hydrology similarity method were performed in order to obtain stream flow and sediment flow for calibration and validation from a nearby gauging station.

The study area is situated in a nearby catchment of Aleltu River which has similar physio-geographical, soil, and geological conditions as well as other hydrological parameters.

The unknown discharge of the study area was estimated on the basis of known discharges of Aleltu gauging station data obtained from Ethiopian Ministry of Water Resources (MoWR) according to their catchment areas, mean annual rainfall and elevation.

To calculate the daily discharges of Lege Dadi and Dire catchments, the following formula was used:

$$Q_i = Q_j * K_1 * K_2 * K_3$$

Where:

$Q_i$  – daily discharges at  $i^{th}$  ungauged catchment;

$Q_j$  - daily discharges at the gauged hydrologic station used for evaluation of stream flows in the  $i^{th}$  catchment.

$K_1 = A_i/A_j$  – Catchment area comparison coefficient:

$A_i$  – Area of  $i^{th}$  ungauged catchment;

$A_j$  – Catchment Area of the hydrological station;

$K_2 = P_i/P_j$  – mean annual rainfall comparison coefficient;

Where:

$P_i$  - mean annual rainfall over  $i^{th}$  ungauged catchment;

$P_j$  - mean annual rainfall over the basin of the hydrological station;

$K_3 = H_j/H_i$  – groundwater decrement comparison coefficient;

Where:

$H_j$  – Average elevation of the hydrological station catchment;

$H_i$  - Average elevation of the  $i^{\text{th}}$  ungauged catchment;

Since the ungauged study areas and the hydrologic station catchment are close neighbours having nearly the same mean annual precipitation and average elevation,  $K_2$  and  $K_3$  are insignificant ( $K_2 \approx K_3 \approx 1$ ).

The unknown sediment discharge of the study area was estimated on the basis of correlation equation of flow versus sediment discharge developed for Aleltu gauging station from hourly data obtained from Ethiopian Ministry of Water Resources (MoWR).

The correlation equation developed shows stream and sediment flows are correlated at an  $R^2$  value of 0.96.

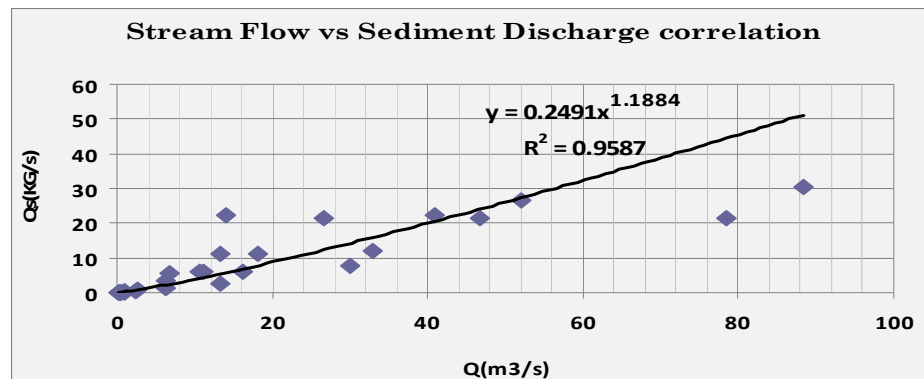


Fig. 3.2: Stream flow and sediment discharge correlation for Aleltu gauging station.

Hence, the unknown daily sediment discharge at Lege Dadi and Dire catchment outlets were compute from the following formula:

$$Q_s = 0.249 * Q^{1.188}$$

Where:

Q – Daily stream flow of the ungauged catchment estimated from gauged

Catchment (Aleltu) earlier ( $m^3/s$ )

Qs –Daily suspended sediment discharge of the ungauged catchment ( $Kg/s$ )

Data generated with this equation was used for calibration and validation of the model.

### **3.2.2 Physiographic Data**

#### ***3.2.2.1 Digital Elevation Map (DEM) and Stream Network (DSN)***

A Digital Elevation Model (DEM) of 90m resolution was obtained from Ministry of Agriculture and Rural Development (MoARD) . It is then resampled to 57m and used for delineation and the topographic characterization of the watershed. It is also used to determine the hydrological parameters of the watershed such as slope, flow accumulation, direction and stream network. The watershed delineated by AVSWAT (Arc view interface) was divided into appropriate number of sub-watersheds in order to capture heterogeneity in physical properties. Each one of the sub-watersheds was partitioned into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics.

Stream Network data was also obtained and used for cross-check against stream network generated from the watershed view by the model.

#### ***3.2.2.2 Soil Data***

The soils data used by SWAT can be divided into two groups, physical characteristics and chemical characteristics. The physical properties of the soil govern the movement of water

and air through the profile and have a major impact on the cycling of water within the HRU. Inputs for chemical characteristics are used to set initial levels of the different chemicals in the soil. While the physical properties are required, information on chemical properties is optional. The soil input (.sol) file defines the physical properties for all layers in the soil.

The soils of the basin reflect the combined effects of the soil formation-geology (primary fine grained, weathering to produce clays); climate (moderate to high rainfall); topography and time, reflecting the long period of stability to produces soils which generally receive much higher rainfall. The highland soils in the area were developed primarily under conditions of forest with a regular cycling of nutrients between the trees and the topsoil, and with the subsoil deeply leached under conditions of high rainfall. However, today the dominant is man who has cleared the forest and placed the land under cultivation but with insufficient management; many (most) soils now truncated profiles due to the impact of erosion BCEOM (1999).

Following is a brief description of the variables in the soil input file used by SWAT.

- SNAM Soil name: The soil name is printed in HRU summary tables.  
Optional.
- HYDGRP Soil hydrologic group (A, B, C, or D).
- SOL\_ZMX Maximum rooting depth of soil profile (mm).  
If no depth is specified, the model assumes the roots can develop throughout the entire depth of the soil profile.
- ANION EXCL Fraction of porosity (void space) from which anions are excluded.  
Optional.
- SOLCRK Potential or maximum crack volume of the soil profile expressed as a fraction of the total soil volume.  
Optional.

- **TEXTURE** Texture of soil layer.  
This data is not processed by the model and the line may be left blank.  
Optional.
- **SOL\_Z(layer #)** Depth from soil surface to bottom of layer (mm).
- **SOL\_BD(layer #)** Moist bulk density (Mg/rn3 or g/cm3).  
The soil bulk density expresses the ratio of the mass of solid particles to the total volume of the soil,  $P_b Ms/VT$ . In moist bulk density determinations, the mass of the soil is the oven dry weight and the total volume of the soil is determined when the soil is at or near field capacity. Bulk density values should fall between 1.1 and 1.9 Mg/rn3.
- **SOL\_AWC(layer #)** Available water capacity of the soil layer (mm H20/rnm soil).  
The plant available water, also referred to as the available water capacity, is calculated by subtracting the fraction of water present at permanent wilting point from that present at field capacity,  $A WC FC - WP$  where A WC is the plant available water content, FC is the water content at field capacity, and WP is the water content at permanent wilting point.
- **SOL\_K(layer #)** Saturated hydraulic conductivity (mm/hr).  
The saturated hydraulic conductivity, 'sat, relates soil water flow rate (flux density) to the hydraulic gradient and is a measure of the ease of water movement through the soil. Ksat is the reciprocal of the resistance of the soil matrix to water flow.
- **SOL\_CBN(layer #)** Organic carbon content (% soil weight).  
When defining by soil weight, the soil is the portion of the sample that passes through a 2 mm sieve.
- **CLAY(layer #)** Clay content (% soil weight).  
The percent of soil particles which are < 0.002 mm in equivalent diameter.
- **SILT(layer #)** Silt content (% soil weight).  
The percentage of soil particles which have an equivalent diameter between 0.05 and 0.002 mm.
- **SAND(layer #)** Sand content (% soil weight).  
The percentage of soil particles which have a diameter between 2.0 and 0.05 mm.

- ROCK(layer #) Rock fragment content (% total weight).  
The percent of the sample which has a particle diameter > 2 mm, i.e. the percent of the sample which does not pass through a 2 mm sieve.
- SOL\_ALB(layer #) Moist soil albedo.  
The ratio of the amount of solar radiation reflected by a body to the amount incident upon it, expressed as a fraction. The value for albedo should be reported when the soil is at or near field capacity.
- USLE\_K(layer #) USLE equation soil erodibility (K) factor (units: 0.0 13 (metric ton m<sup>2</sup> hr)/(m<sup>3</sup> -metric ton cm)).  
Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself.

The dominant soil texture throughout the basin is clay (Pellic Vertisols). In areas of restricted drainage and/or moisture inflow weathering has produced expanding clays which crack deeply and become very hard when dry, but swell and become sticky when wet. These Vertisols are self-mulching in that the repeated shrinking and swelling tends to mix and remix the upper soil layers. This, plus the frequent high water table, reduces leaching and produces a fertile soil with fertility well distributed through the profile. Under the right conditions, these soils are highly productive, and are indeed often favoured by smallholders. However, the soil properties, especially the hardness when dry and the stickiness when wet, make them difficult to cultivate, especially with traditional implements. These are only a narrow window of opportunity when the soils are damp, but not wet, when they can be easily cultivated. That window is broadened with mechanization, but the difficulties remain. They also tend to remain waterlogged for long periods, and are often not cultivated for this reason; however, on such sites in the highlands (generally broad, shallow alleys) they provide favoured grazing land, including critical dry-season forage (BCEOM, 1999).

### **3.2.2.3 Landuse/Landcover Data**

Digital land use/ land cover data of 200m resolution of 1990 was obtained from Ministry of Agriculture and Rural Developments (MoARD). This data was used as a base landuse in developing scenarios about the future conditions.

Other actual land use/cover data of 1960, 1980 and 2008 were obtained from Oromia Water Works Design and Supervision Enterprise and used for analysing the previous land use/cover changes and their impact on water resources in the study area.

According to the 1990 data, the land use/cover types in the catchment areas are distributed by the government and local authorities through “Peasant Associations” as per the farmers’ needs but without being any regional plan necessary to maintain the ecological balance of the catchments.

#### ***I. Lege Dadi Catchment Area (1990)***

The land use/ land cover of this catchment mainly consists of cropland/grassland mosaic (6.86% of the catchment area), grassland (31.46%), Eucalyptus trees and natural vegetation (3.42%), mixed grassland/shrubland (4.94%) and agricultural land-close-grown (53.32%).

The cultivated fields are located in the mid- and lower slopes of the mountains and the hills, foot-slopes, undulating plains, flat to almost flat plain valley sides, and at part of the edge of the perimeter of the reservoir. The cultivated fields situated on the steep and undulating slopes are not protected from water erosion by any soil and water conservation measures.

#### ***II. Dire Catchment Area(1990)***

The Dire catchment area is located adjacent to north-west of the Legedadi catchment area and covers an area of about 78km<sup>2</sup>. The land use and land cover types of the area consists of

moderately cultivated cropland/grassland mosaic (27.68%), range-brush (1.51%), grassland (5.25%), eucalyptus woodland and natural vegetation (9.47%) and intensively cultivated agricultural land-close-grown (56.09%). The percentage of land cover types of Lege Dadi and Dire catchment areas were given in Tables 3.4 and 3.5 below.

Table 3.4: Soil and land use configuration in Lege Dadi catchment.

SWAT MODEL SIMULATION		TUE OCT 20 18:28:51 2009		
MDL				
MULTIPLE HRUS LANDUSE/SOIL OPTION		THRESHOLDS : 3 / 10 [%]		
NUMBER OF HRUS: 28				
NUMBER OF SUBBASINS: 8				
	AREA [HA]	AREA [ACRES]	%WAT.AREA	
WATERSHED:	20938.1804	51739.2907		
LANDUSE:				
CROPLAND/GRASSLAND MOSAIC-->CRGR	1436.45	3549.54	6.86	
GRASSLAND-->GRAS	6587.14	1 6277.17	31.46	
DECIDUOUS BROADLEAF FOREST-->FODB	717.03	1771.81	3.42	
AGRICULTURAL LAND-CLOSE-GROWN-->AGRC	11164.06	27586.96	53.32	
MIXED GRASSLAND/SHRUBLAND-->MIGS	1033.50	2553.82	4.94	
SOIL:				
CALCICXER	2170.39	5363.14	10.37	
LEPTOSOLS	644.96	1593.74	3.08	
ORTICSOLO	1786.7853	4415.24	8.53	
PELLIC VE	16336.0398	40367.17	78.02	

Table 3.5: Soil and land use configuration in Dire catchment.

DETAILED LANDUSE/SOIL DISTRIBUTION		SWAT MODEL CLASS		TUE OCT 13 16:15:36 2009
		AREA [HA]	AREA [ACRES]	
WATERSHED		7837.2380	19366.2070	
CODE	AREA [HA]	AREA [ACRES]	%WAT.AREA	
<b>LANDUSE</b>				
Cropland/Grassland Mosaic --> Crgr	2165.04	5349.92	27.63	
Range-Brush --> Rngb	118.26	292.23	1.51	
Grassland --> Gras	408.69	1009.90	5.21	
Deciduous Broadleaf Forest --> Fodb	736.87	1820.84	9.40	
Agricultural Land-Close-Grown --> Agrc	4405.77	10886.87	56.22	
Mixed Grassland/Shrubland --> Migs	2.61	6.45	0.03	
<b>SOIL</b>				
Calcixer	927.14	2291.01	11.83	
Chromic L	4040.22	9983.58	51.55	
Leptosols	80.23	198.26	1.02	
Orthic solo	2352.66	5813.53	30.02	
Pellic Ve	436.99	1079.83	5.58	

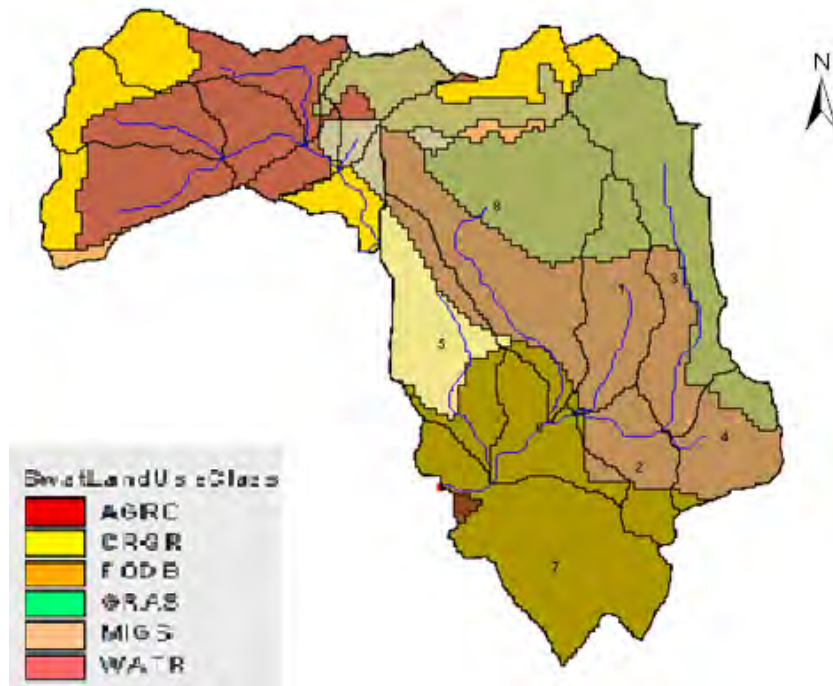


Fig.3.3: Landuse/cover classification of Lege Dadi-Dire catchments 1990.

The average annual surface water potential of the two catchment areas was estimated as: Legedadi catchment, 86 MCM and Dire catchment, 50 MCM, giving a total potential of 136 MCM/year. Since the live volume of the reservoirs is limited, large quantities are lost by downstream spills.

### **3.3 MODEL SET UP**

SWAT is a physically based basin-scale continuous time distributed parameter hydrologic model that uses spatially distributed data on soil, land use, Digital Elevation Model (DEM), and weather data for hydrologic modeling and operates on a daily time step. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management.

#### **3.3.1. Watershed delineation**

The digital elevation model used in this study has a 57m resolution. For spatially explicit parameterization, SWAT subdivides watersheds into sub-basins based on topography, which are further subdivided into hydrologic response units (HRU) based on unique soil and land use characteristics. The DEM of the basins was loaded and the watersheds were masked manually. Stream definition threshold area was set to 600ha. The Legedadi and Dire catchments were divided into eight and seven subbasins respectively setting the same number of corresponding outlets on the streams.

Table 3.5: DEM characterization of the study area.

Watershed	Watershed Elevation (m.a.s.l)			Area(ha)	No. of Subbasins	No. of HRU	Average Slope
	Minimum	Maximum	Mean				
Lege Dadi	2426	3219	2576.7	20938.18	8	28	0.038
Dire	2524	3217	2830.41	7837.238	7	31	0.125

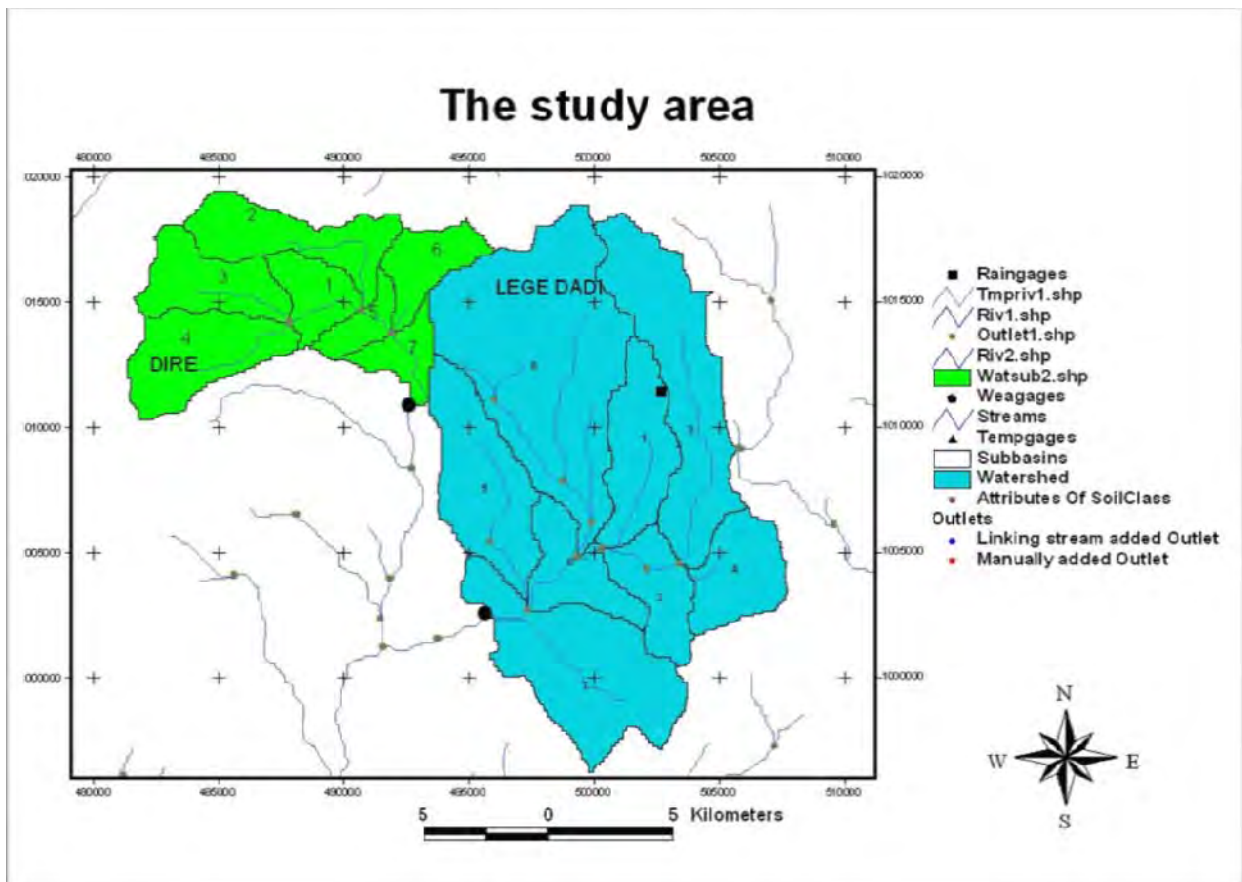


Fig.3.4 Watershed delineation and configuration of the study areas.

### 3.3.2. Land use and Soil Characterization

Data on land use and land cover patterns of an area are essential for gaining an understanding of the problems involved in water harvesting in water catchments, in the development of such areas, and for solving problems of erosion and deterioration of reservoir water quality.

The digital land use/ land cover and soil maps of these catchments were loaded. The land use (3%) and soil (10%) over the subbasin area was set for multiple hydraulic response unit definition.

The catchment area mainly consists of cropland/grassland mosaic, grassland, Eucalyptus trees and natural vegetation, mixed grassland/shrubland and agricultural land-close-grown.

### **3.3.3. Outlet and Inlet Definition**

In this section additional outlet points were added at the place where stream flow measured data are available or estimated and unwanted ones were removed. The two most important ones are at the dam sites of the two catchments, where flow is monitored. These outlets enable finally to calibrate and validate the model output. In this study there was no inlet definition made in the catchment. Finally, after sub basin parameter calculation the each catchments is sub divided in to sub-basins.

### **3.3.4. Weather Data Definition**

In this study global data from climate research unit (CRU) is used in weather data definition in SWAT, which is half-degree climate grid. In order to make use of the CRU half-degree climate grids in SWAT that require station data as weather input, it is first necessary to overlay the climate grids with a SWAT subbasins shape-file and then to aggregate the values in order to obtain one value per month per each subbasin. The overlay and the creation of the subbasin averages of monthly precipitation, minimum and maximum temperature as well as the number of wet days per month, were performed using a semi-automated program within ArcGIS (Schuol, 2005). This program is basically made up of the creation of Thiessen polygons around each value point representing the center of the grid cell, the overlay and intersection of the subbasin layer with the climate grids and finally the computation of the area-weighted average which is then assigned to each subbasin centroid.

The climatic data required for SWAT simulation are: daily precipitation, daily maximum and minimum air temperature, daily solar radiation, daily wind speed, and daily relative humidity. If any of these data is not available, SWAT can generate data using a weather generator. The later three are simulated using the WXGEN in SWAT due to the absence of data. Daily precipitation and temperature data are available for each of the subbasins except for Sendafa station which has only daily precipitation data. The climate and weather station used in this study is attached as annex.

### **3.4 SENSITIVITY ANALYSIS, CALIBRATION AND VALIDATION**

The ability of a watershed model to sufficiently predict constituent yields and streamflow for a specific application is evaluated through sensitivity analysis, model calibration, and model validation. Model input parameters always contain uncertainty to some extent. However, a model user has to assign values to each parameter. The model is then calibrated against measured data to adjust the parameter values according to certain criteria.

Focus on sensitive parameters can lead to a better understanding and to better estimated values and thus reduced uncertainty. The analysis was done by use of the LH-OAT method (van Griensven and Meixner, 2006). This method combines the ‘One-factor-At-a Time’ (OAT) design and the Latin Hypercube (LH) sampling by taking the LH samples as initial points for a OAT design.

#### *i) LH simulations*

The LH simulation is based on the Monte Carlo simulation but uses a stratified sampling approach that allows efficient estimation of the output statistics. The distribution of each parameter is subdivided into N ranges each with a probability of occurrence of 1/N. Each

range is sampled once and random values of the parameters are generated. The model is then run N times with the random combinations of the parameters.

*ii) One-factor-At-a Time sampling*

The OAT design integrates local to global sensitivity method. In each run, only one parameter is changed and thus the changes in the output can be attributed to the input parameter changed. Considering n parameters, n+1 model runs are performed to obtain one partial effect for each parameter. Each input parameter is varied one by one starting from an initial vector. The result of the influence of a parameter may depend on the values chosen for the remaining parameters i.e. a partial effect, thus the process is repeated for several sets of input parameters. The final effect is then calculated as the average of all the partial effects. The variance of this set gives a measure of how uniform the effects are. The elementary effects obtained using this procedure allows the screening of the entire set of input parameters with a low computational requirement.

*iii) LH-OAT sensitivity analysis*

The LH-OAT method combines the two methods described above, thus ensuring that the full range of all parameters has been sampled with the precision of an OAT design. This leads to a robust and efficient sensitivity analysis method. For m intervals in the LH method and p parameters, a total of  $m*(p+1)$  runs are required.

Sensitivity analysis, calibration and validation were conducted for stream flow, suspended sediment and water quality for each catchment prior to the calibration exercise of each one variable.

**a. Stream flow:** The model was run on monthly basis from the period 1990-2004 (using the estimated flow) for the sensitivity analysis of Lege Dadi and Dire catchments; and the results are given in Table 3.6 and Table 3.7 respectively.

Table 3.6: Parameter sensitivity ranking for Lege Dadi catchment.

Rank	Sensitive Parameters Code	Parameter Description	File
1	CN <sub>2</sub>	Initial SCS CN II value	*.mgt
2	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	*.gw
3	RCHRG_DP	Deep Aquifer percolation coefficient	*.gw
4	SOL_AWC	Available water capacity	*.sol
5	GW_REVAP	Groundwater revap coefficient	*.gw
6	SOL_K	Saturated hydraulic conductivity	*.sol
7	ESCO	Soil evaporation compensation factor	*.hru
8	CANMX	Maximum canopy storage	*.hru
9	SOL_Z	Soil depth	*.sol
10	BIOMIX	Biological mixing efficiency	*.mgt

Table 3.7: Parameter sensitivity ranking for Dire catchment.

Rank	Sensitive Parameters Code	Parameter Description	File
1	CN <sub>2</sub>	Initial SCS CN II value	*.mgt
2	SOL_AWC	Available water capacity	*.sol
3	SOL_K	Saturated hydraulic conductivity	*.sol
4	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	*.gw
5	SOL_Z	Soil depth	*.sol
6	ESCO	Soil evaporation compensation factor	*.hru
7	RCHRG_DP	Deep Aquifer percolation coefficient	*.gw
8	SLOPE	Average slope length	*.hru
9	CANMX	Maximum canopy storage	*.hru
10	BIOMIX	Biological mixing efficiency	*.mgt

Parameters identified in sensitivity analysis that influence predicted stream flow were used to calibrate the model. Model calibration is the process by which model is adjusted to more

closely match some observed data. The calibration greatly improved the agreement between estimated and simulated monthly flows.

The model evaluation, both graphically and statistically, shows good agreement between the observed and simulated streamflow. Although some peaks are not captured adequately, in general, the model can be said to have an acceptable performance and that the hydrological processes and streamflow dynamics have been simulated realistically.

The Nash Sutcliffe efficiency (Ens) and the square of the Pearson product moment correlation coefficient ( $R^2$ ) through data points were used for model evaluation.

The Nash Sutcliffe efficiency NSE is defined by (Nash and Sutcliffe, 1970) as:

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

Where  $O_i$  is the observed flow

$\bar{O}$  is the mean observed flow

$S_i$  is the model simulated flow

$n$  is the number of observations

A value closer to unity, means the model explains the variance better. A negative modeling efficiency means that the model prediction is worse than simply using the mean of the observed flows.

The correlation coefficient (r-value) is given by:

$$r = \frac{\sum(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum(O_i - \bar{O})^2 \sum(S_i - \bar{S})^2}}$$

Where  $O_i$  is the observed flow

$\bar{O}$  is the mean observed flow

$S_i$  is the model simulated flow

$n$  is the number of observations

The r-squared ( $R^2$ ) value can be interpreted as the proportion of the variance in simulated flow ( $S_i$ ) attributable to the variance in observed flow ( $O_i$ ).

As it can be seen in Table 3.7 below, the model efficiency measures are in acceptable range ( $R^2 > 0.6$  and  $ENS > 0.5$ ).

Table 3.8: Model evaluation statistics for the calibration and validation periods for average monthly flow.

Watersheds	Simulation	Simulation Period	Monthly Average	
			$R^2$	Ens
Lege Dadi	Calibration	1992-1998	0.77	0.76
	Validation	1999-2004	0.84	0.83
Dire	Calibration	1992-1998	0.88	0.93
	Validation	1999-2004	0.87	0.90

Graphical representation of observed and estimated flows match well for both calibration and validation periods (fig.3.3.).

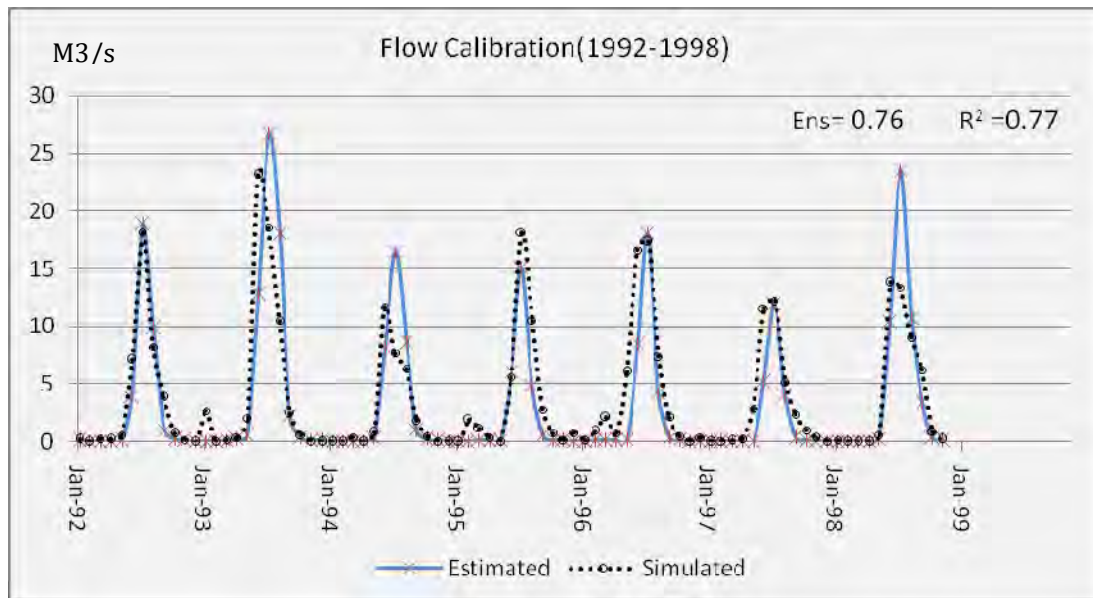


Fig.3.3: Comparison between simulated and observed streamflow for the calibration period for Lege Dadi mean monthly streamflow.

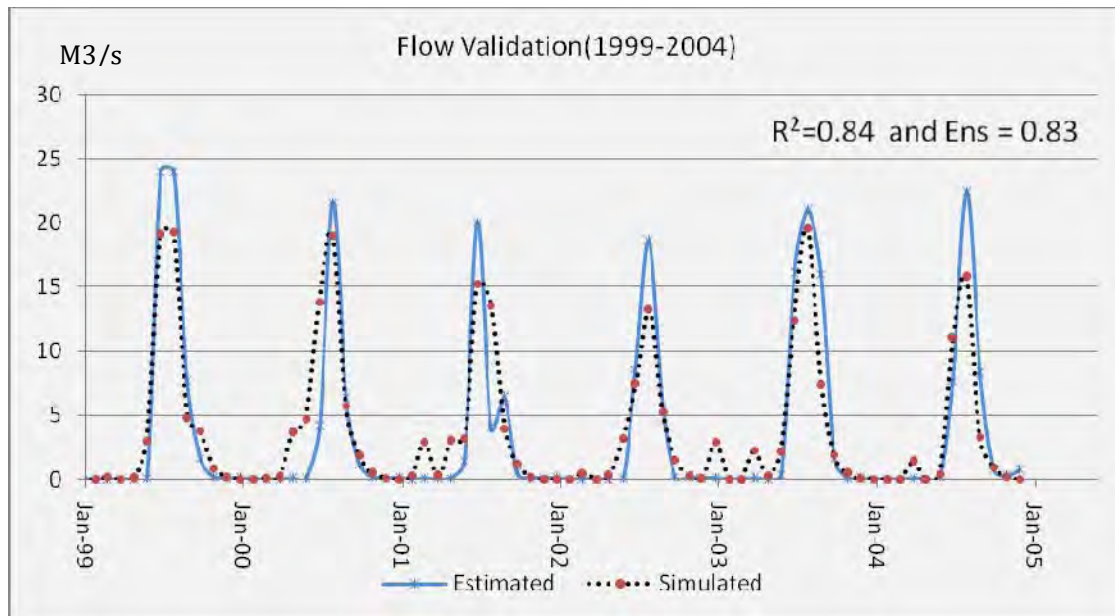


Fig.3.4: Comparison between simulated and observed streamflow for the validation period for Lege Dadi mean monthly streamflow.

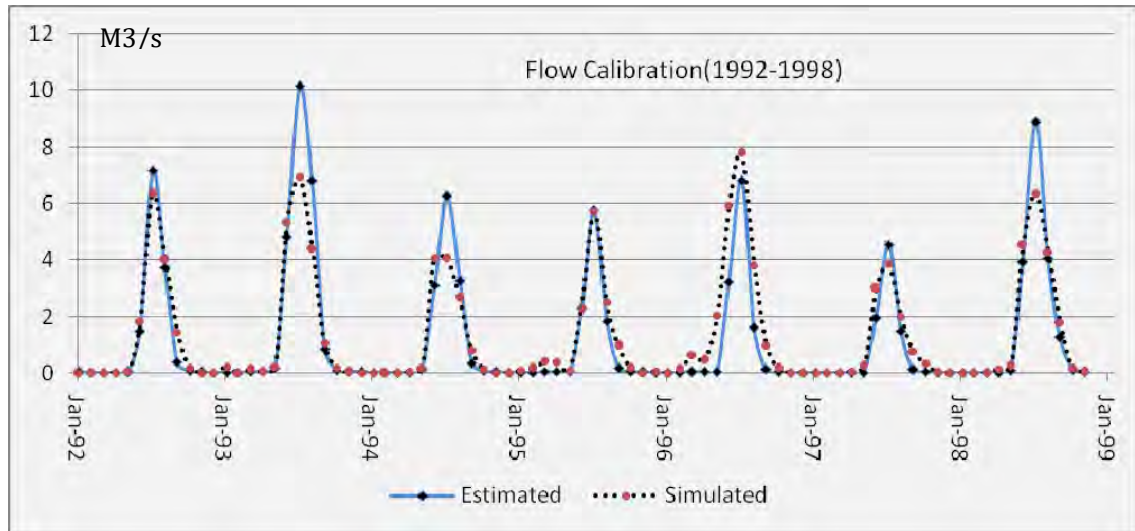


Fig.3.5: Comparison between simulated and observed streamflow for the calibration period for Dire mean monthly streamflow.

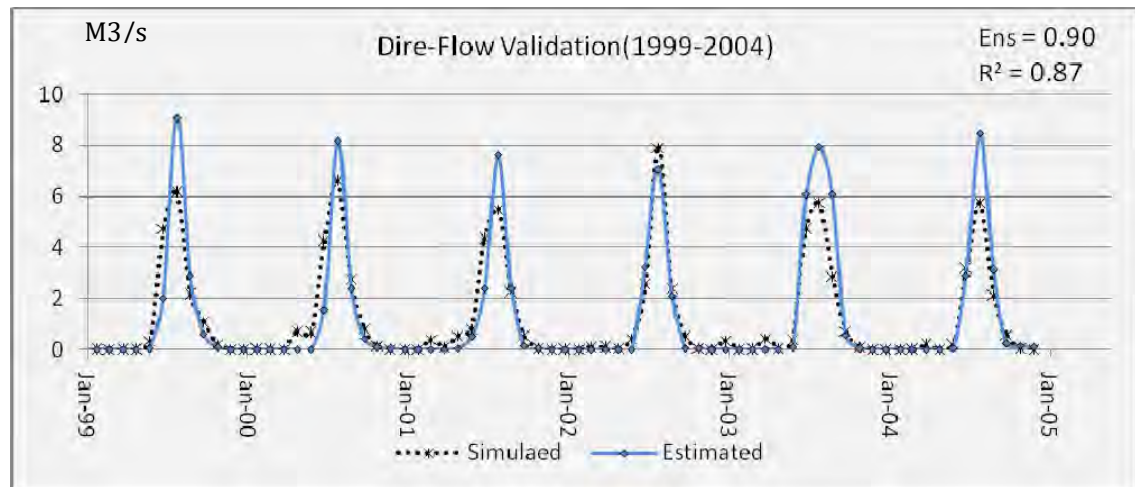


Fig.3.6: Comparison between simulated and observed streamflow for the validation period for Dire mean monthly streamflow.

As demonstrated in preceding figures, the model was set up using readily available data that were quality controlled before being used. Model parameters adjustment was based on the sensitivity analysis as well as those that were deemed needing adjustment because their initial values were not adequately determined. The model parameters were kept at reasonable ranges and this minimized the uncertainty within the model output. Different criteria used to evaluate

the model performance showed that the model was adequately calibrated for use in impact assessment.

**b. Suspended Sediment**

After calibrating and validating for stream flow, the model was calibrated and validated for suspended sediment load at the corresponding outlets of the two watersheds. Sensitive parameters have been identified as tabulated below.

Table 3.9: Parameter sensitivity ranking for Lege Dadi catchment for suspended sediment.

Rank	Parameters Code	Parameter Description	File
1	Surlag	Surface runoff lag coefficient	*.bsn
2	SLOPE	Average slope length	*.hru
3	REVAPMN	Threshold depth of water in the shallow aquifer for 'revap' or percolation to occur	*.gw
4	CN <sub>2</sub>	Initial SCS CN II value	*.mgt
5	ALPHA_BF	Base flow alpha factor	*.gw
6	SOL_Z	Soil depth	*.sol
7	SOL_K	Saturated hydraulic conductivity	*.sol
8	SLSUBBSN	HRU Average slope length	*.hru
9	CANMX	Maximum canopy storage	*.hru
10	ESCO	Soil evaporation compensation factor	*.hru

Table 3.10: Parameter sensitivity ranking for Dire catchment for suspended sediment.

Rank	Sensitive Parameters Code	Parameter Description	File
1	Surlag	Surface runoff lag coefficient	*.bsn
2	SLSUBBSN	HRU Average slope length	*.hru
3	SLOPE	Average slope length	*.hru
4	ALPHA_BF	Base flow alpha factor	*.gw
5	CH_K2	Effective Hydraulic conductivity in main channel alluvium	*.rte
6	SOL_Z	Soil depth	*.sol
7	CANMX	Maximum canopy storage	*.hru
8	CN <sub>2</sub>	Initial SCS CN II value	*.mgt
9	SOL_AWC	Available water capacity	*.sol
10	ESCO	Soil evaporation compensation factor	*.hru

Parameters identified in sensitivity analysis that influence predicted suspended sediment flow were used to calibrate the model. Even though the calibration improved the agreement between estimated and simulated monthly suspended sediment flows, it still underestimated the values.

Table 3.11: Model evaluation statistics for the calibration and validation periods for average monthly suspended flow.

Watersheds	Simulation	Simulation Period	Monthly Average	
			R <sup>2</sup>	Ens
Lege Dadi	Calibration	1992-1998	0.75	0.73
	Validation	1999-2004	0.72	0.77
Dire	Calibration	1992-1998	0.81	0.77
	Validation	1999-2004	0.77	0.77

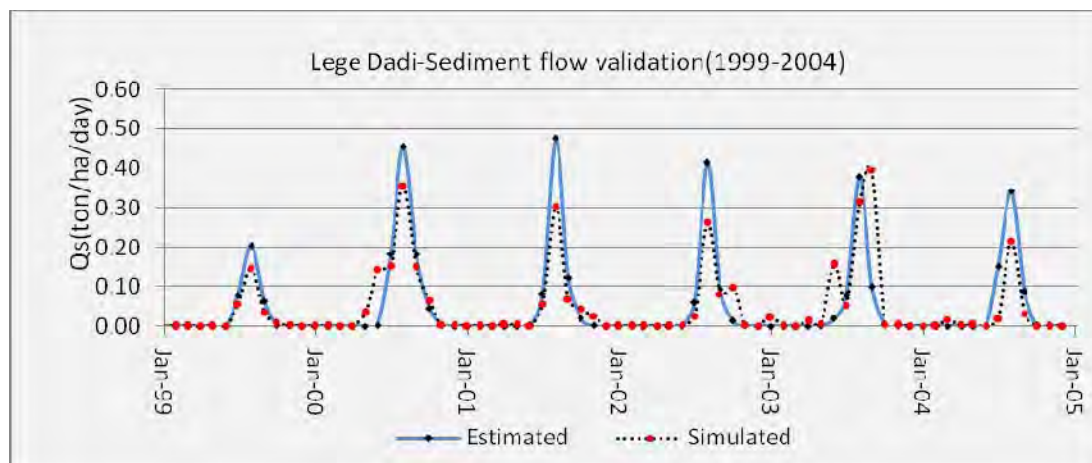
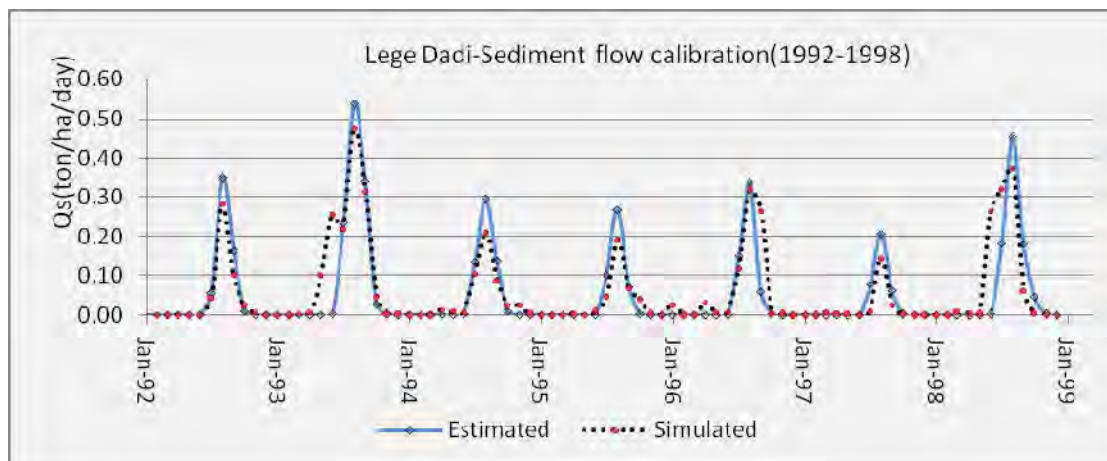
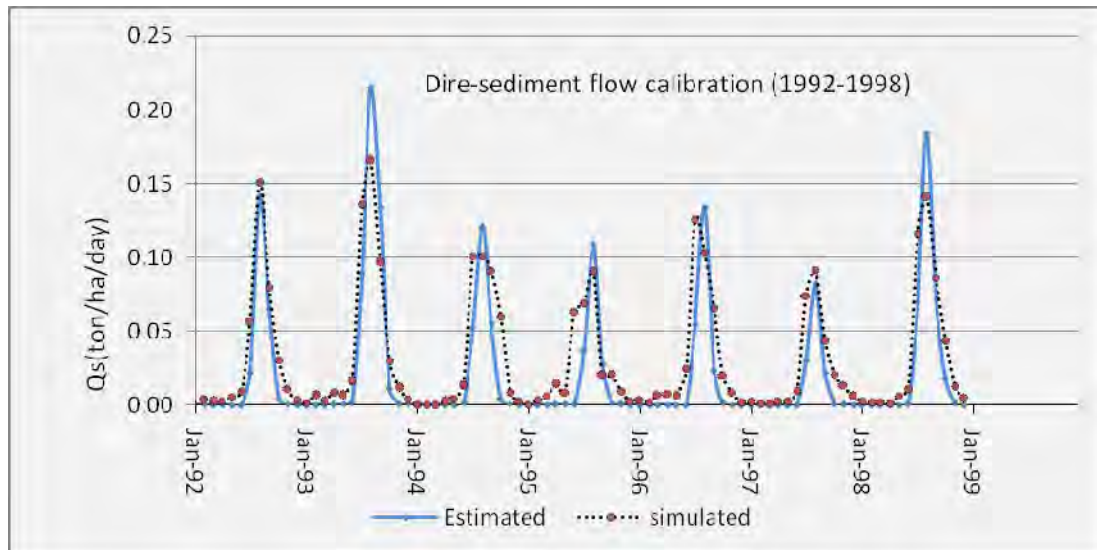


Fig. 3.7: Comparison between simulated and observed sediment flow (tons/ha/day) for the calibration.



(a) and validation (b) period for Lege Dadi catchment.

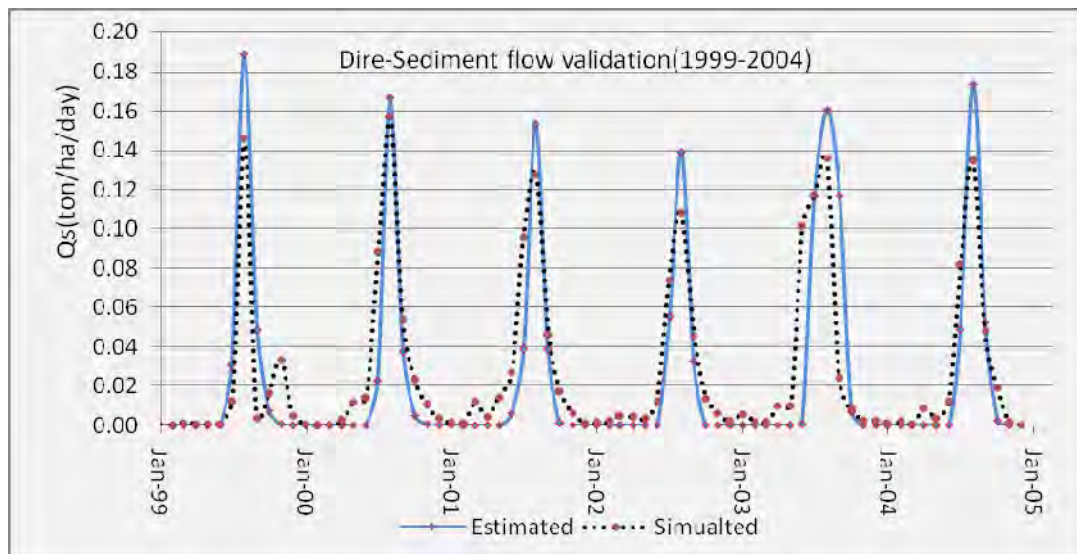


Fig. 3.8: Comparison between simulated and observed sediment flow for the calibration(c) and validation (d) period for Dire catchment.

As it can be observed from the above graphs, the model well simulates the observed data except it is missing the peak sediment discharges especially in validation periods. This may be the result of recent land use/cover changes as the base land use/cover map used was that of 10 years ago.

### **C. Water Quality**

According to the TAHAL (2000) report, raw water for the Legedadi treatment plant was characterized by high turbidity and colour, low alkalinity and low hardness. The suspended solids are very fine and of a colloidal nature. The main components that makeup this water quality deterioration was sediment, nitrate, organic and mineral nitrogen and phosphorous; and dissolved oxygen.

Sensitivity analysis, as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty. It can be achieved if there exists a measured data of the variables of interest over a time series. Sensitivity analysis for this study was conducted using limited data obtained from Addis Ababa Water Supply and Sewerage Authority (AAWSA) and the result was given in tables on next pages.

Table 3.12: Sensitivity analysis of water quality parameters

```

=====
Sensitivity Analysis Inputs and Results
=====
Control parameter are :
number of intervals in Latin Hypercube =          10
parameter change for OAT = 5.000000000000000E-002
random seed number =          2003
=====
Objective functions are (objmet.dat):
OBJECTIVE FUNCTION 1 = SSQ   for flow           (m^3/s) at location 1
OBJECTIVE FUNCTION 2 = SSQ   for sediment load    (T/d ) at location 1
OBJECTIVE FUNCTION 3 = SSQ   for organic N load  (T/d ) at location 1
OBJECTIVE FUNCTION 4 = SSQ   for organic P load  (T/d ) at location 1
OBJECTIVE FUNCTION 5 = SSQ   for nitrate load   (T/d ) at location 1
OBJECTIVE FUNCTION 6 = SSQ   for mineral P load  (T/d ) at location 1
OBJECTIVE FUNCTION 7 = SSQ   for kjel N load    (T/d ) at location 1
OBJECTIVE FUNCTION 8 = SSQ   for total N load    (T/d ) at location 1
OBJECTIVE FUNCTION 9 = SSQ   for total P load    (T/d ) at location 1
    
```

OBJECTIVE FUNCTION 1			OBJECTIVE FUNCTION 2		
parname	rank	mean	parname	rank	mean
ALPHA_BF	2	0.395E+01	ALPHA_BF	2	0.271E+00
ESCO	7	0.937E+00	ESCO	8	0.308E-01
SLOPE	8	0.878E+00	SLOPE	7	0.340E-01
SLSUBBSN	10	0.638E-01	SLSUBBSN	3	0.786E-01
CH_K2	3	0.153E+01	CH_K2	10	0.294E-01
CN2	1	0.882E+01	CN2	4	0.424E-01
SOL_AWC	5	0.124E+01	SOL_AWC	9	0.299E-01
surlag	6	0.103E+01	surlag	1	0.102E+01
sol_k	9	0.767E+00	sol_k	5	0.381E-01
sol_z	4	0.128E+01	sol_z	6	0.342E-01
ch_n	11	0.242E-02	ch_n	12	0.633E-02
			SPCON	11	0.790E-02
			SPEXP	13	0.601E-02

<b>OBJECTIVE FUNCTION</b>	<b>3</b>	<b>OBJECTIVE FUNCTION</b>	<b>7</b>		
ranking		ranking	Not sensitive		
-----		-----			
parname	rank	mean	parname	rank	mean
<b>Not sensitive</b>			<b>OBJECTIVE FUNCTION</b>	<b>8</b>	
<b>OBJECTIVE FUNCTION</b>	<b>4</b>		ranking		
<b>Not sensitive</b>			-----		
ranking			parname	rank	mean
-----			ALPHA_BF	2	0.747E+01
-----			ESCO	9	0.145E+01
parname	rank	mean	SLOPE	6	0.201E+01
<b>Not sensitive</b>			SLSUBBSN	13	0.827E-01
<b>OBJECTIVE FUNCTION</b>	<b>5</b>		CH_K2	5	0.314E+01
ranking			CN2	1	0.104E+02
-----			SOL_AWC	7	0.182E+01
-----			surlag	10	0.139E+01
parname	rank	mean	sol_k	8	0.166E+01
ALPHA_BF	2	0.741E+01	sol_z	4	0.468E+01
ESCO	9	0.142E+01	sol_alb	15	0.318E-02
SLOPE	6	0.199E+01	ch_n	14	0.632E-02
SLSUBBSN	13	0.722E-01	SOL_NO3	3	0.702E+01
CH_K2	5	0.314E+01	<b>OBJECTIVE FUNCTION</b>	<b>9</b>	
CN2	1	0.104E+02	ranking		
SOL_AWC	7	0.180E+01	-----		
surlag	10	0.140E+01	-----		
sol_k	8	0.163E+01	parname	rank	mean
sol_z	4	0.465E+01	ALPHA_BF	3	0.173E+01
sol_alb	15	0.156E-03	ESCO	9	0.497E+00
ch_n	14	0.610E-02	SLOPE	11	0.139E+00
NPERCO	11	0.844E+00	SLSUBBSN	12	0.793E-01
SOL_ORGN	12	0.261E+00	CH_K2	5	0.126E+01
SOL_NO3	3	0.687E+01	CN2	1	0.724E+01
			SOL_AWC	8	0.583E+00
			surlag	4	0.128E+01
			sol_k	10	0.223E+00
<b>OBJECTIVE FUNCTION</b>	<b>6</b>		sol_z	6	0.120E+01
ranking			ch_n	13	0.259E-02
-----			PHOSKD	7	0.103E+01
-----			SOL_LABP	2	0.354E+01
parname	rank	mean			
ALPHA_BF	7	0.896E-01			
ESCO	8	0.891E-01			
SLOPE	12	0.925E-02			
SLSUBBSN	11	0.100E-01			
CH_K2	4	0.194E+00			
CN2	1	0.799E+00			
SOL_AWC	9	0.387E-01			
surlag	5	0.163E+00			
sol_k	10	0.217E-01			
sol_z	3	0.340E+00			
PHOSKD	6	0.152E+00			
SOL_LABP	2	0.501E+00			

There is a shortage of measured data for those water quality variables to utilize for calibration and validation over the study period. Attempt has been taken to calibrate as per the sensitivity analysis using the available data. It is obvious that the result gets closer to measured value as the time series data used gets of shorter period. In addition to calibrating using the measured data, it has been tried to adjust the parameters referring to the water quality study results of TAHAL (2000).

## Chapter 4

### LANDUSE/LANDCOVER CHANGE SCENARIOS

#### AND IMPACT ASSESSMENT

#### 4.1 INTRODUCTION

Land-use change is a locally pervasive and globally significant ecological trend. In Ethiopia, the rate of conversion of forest, grassland and other natural landcover to agricultural and urban areas is at its apex. Globally and over a longer period, nearly 1.2million km<sup>2</sup> of forest and woodland and 5.6 million km<sup>2</sup> of grassland and pasture have been converted to other uses during the last 3 centuries, according to Agarwal, et al, (2000). During this same period, cropland has increased by 12 million km<sup>2</sup>.

These land-use changes have important implications for future changes in the Earth's climate change and, consequently, great implications for subsequent land-use change for the reason that they are interdependent. The effect of these changes is not limited at micro level as the case of the considered Legedadi- Dire catchment rather it is determinant factor of sustainability in overall at national and global level.

According to Lambine et al. (2001), land-use and land-cover changes occur throughout the world and when aggregated can affect the functioning of the Earth's system significantly.

They have a direct impact on the diversity of plants and animals worldwide; they modify the climate at local and regional levels as well as contribute to global climate warming; they are the primary source of soil degradation. Such changes have wider economic and socio-political implications. As stated earlier as a problem, this tracking change is hypothesized to be the cause for Lege Dadi Treatment plant raw water quality degradation and also may influence the hydrology in long run.

## 4.2. EXISTING LANDUSE/COVER

### 4.2.1. Land Use and Types of Land Cover in the Legedadi Catchment Area

#### a) 1990

The land use and land cover types in the Legedadi catchment area are distributed by the government and local authorities through ‘Peasant Associations’ according to the farmers’ needs but without there being any regional plan necessary to maintain the ecological balance of the catchments.

The cultivated fields are located in: the mid- and lower slopes of the mountains and hills, foot-slopes, undulating plains, flat to almost flat plain valley sides, and at part of the edge of the perimeter of the reservoir. The cultivated fields situated on the steep and undulating slopes are not protected from water erosion by any soil and water conservation measures.

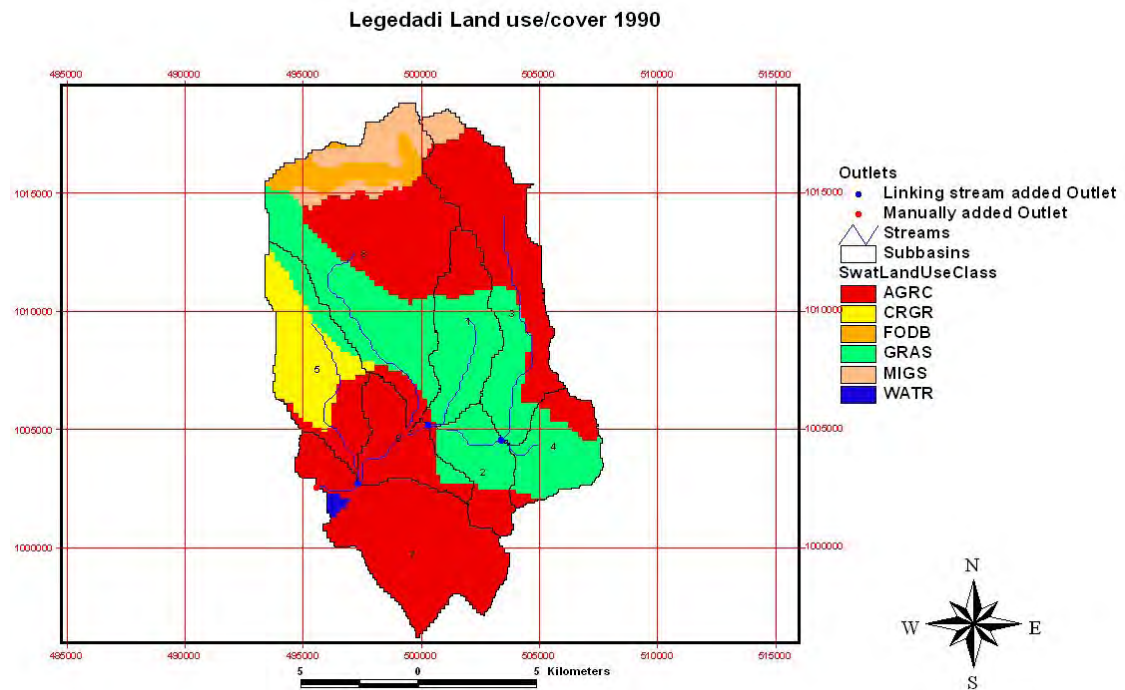


Fig 4.1. Legedadi Catchment land use/cover distribution 1990.

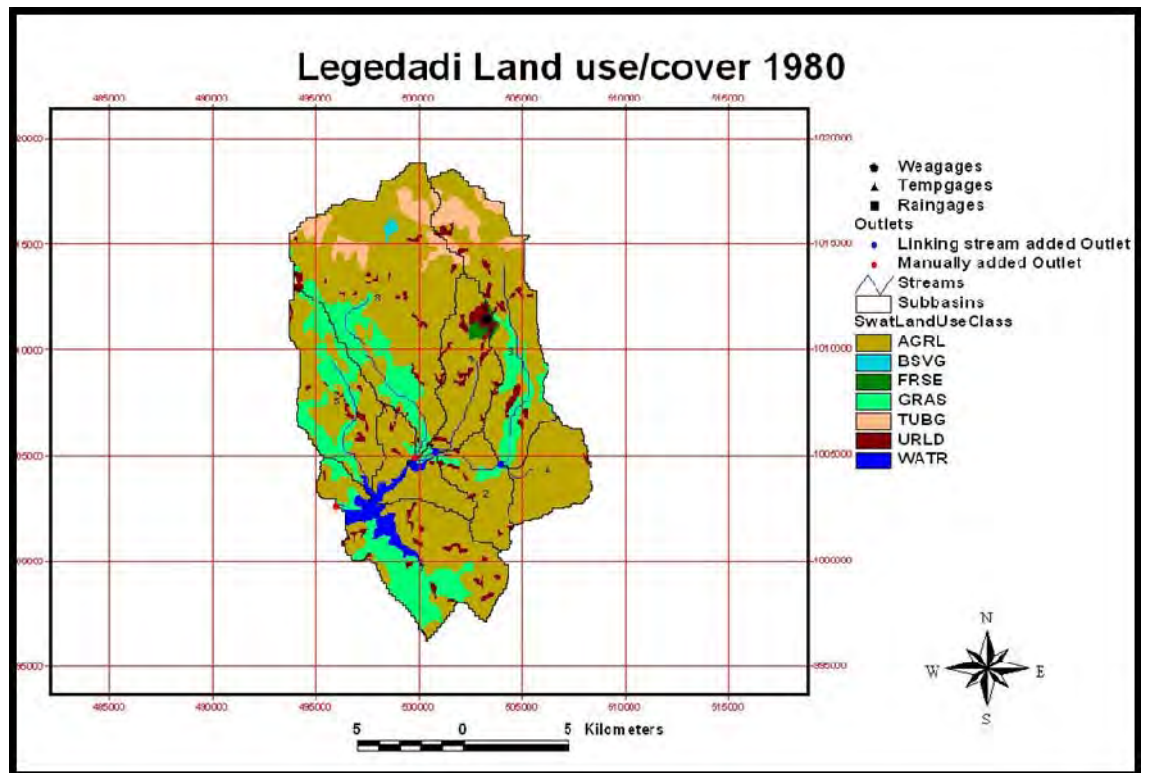
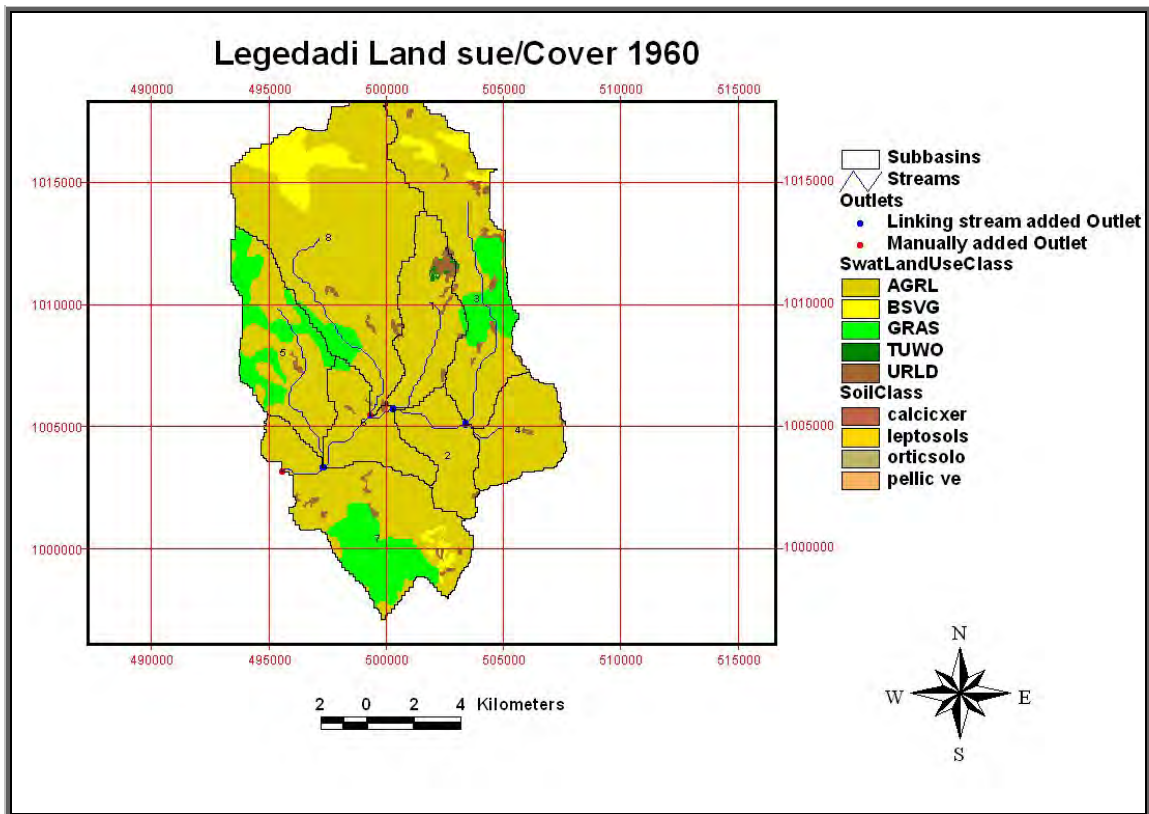
The grassland units in the areas surrounding the Legedadi reservoir are being progressively converted into cropped lands. Soil loss from these cropped lands is very serious and alarming both from the aspect of erosion and from the loss of nutrients which are essential for crop growth. According to TAHAL report (2000), four-fifths of the erosion in the highlands results from crop fields. Crop fields situated on steep slopes in the area surrounding the reservoir are not only sources of soil particles deposited in the reservoir by erosion, but are also sources chemical contaminants resulting from the applied chemical fertilizers.

***b) 1960, 1980 and 2008***

The land use/cover data obtained from Oromia Water Works Design and Supervision Enterprise (OWWDSE) was actual data over longer time which helps in visualizing the change and its consequence impact. Distribution of the land use/cover types have been tabulated below.

Table 4.1: Land use/cover distribution of Legedadi catchment for the years 1960, 1980 and 2008.

Landuse Types	Acronym	1960		1980		2008	
		Area [ha]	%Wat. Area	Area [ha]	%Wat. Area	Area [ha]	%Wat. Area
Flower Farm	URHD	-	-	-	-	6.50	0.03
Water	WATR	-	-	446.91	2.13	417.66	1.99
Bare Ground	TUBG	-	-	1099.83	5.25	277.54	1.33
Baren Or Sparsly Vegetated	BSVG	990.24	4.73	40.64	0.19	95.14	0.45
Grassland	GRAS	2760.87	13.19	3671.84	17.54	744.65	3.56
Forest-Evergreen	FRSE	-	-	73.05	0.35	1847.86	8.83
Wooded Tundra	TUWO	30.18	0.14	-	-	96.59	0.46
Residential-Low Density	URLD	456.01	2.18	899.89	4.30	1758.30	8.40
Agricultural Land-Generic	AGRL	16700.8	79.76	14706.0	70.24	15693.9	74.95
<b>TOTAL</b>		<b>20938.18</b>	<b>100</b>	<b>20938.18</b>	<b>100</b>	<b>20938.18</b>	<b>100</b>



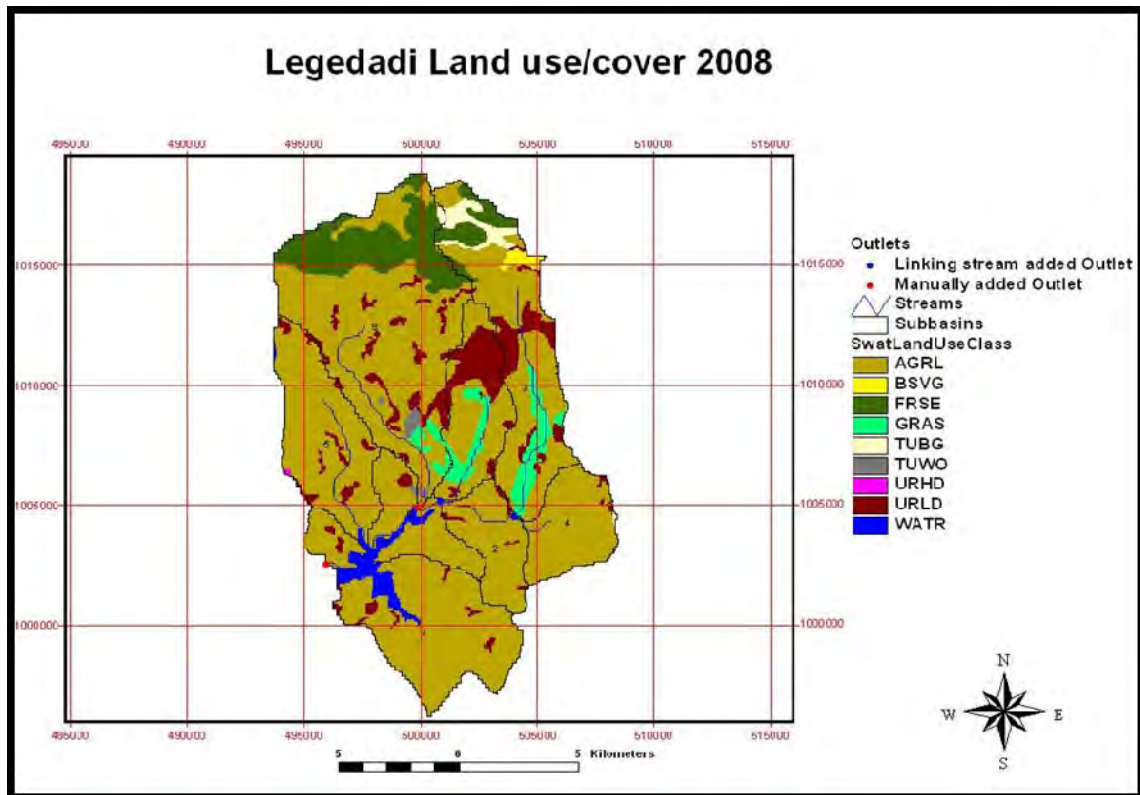


Fig 4.2. Land use/cover distribution of Legedadi catchment for the years 1960, 1980 and 2008

In the course of time, it is observed that settlement areas and planted trees have expanded in the catchment. Water abstracting structure (dam) and flower farm has been introduced. Agricultural land in 1960 is larger than others which is in contrary to the general land use change trend.

#### 4.2.2 Land Use/Land Cover in the Dire Catchment Area

The Dire catchment area is situated adjacent to the north-west of the Legedadi catchment area and covers an area of 78 km<sup>2</sup>. The clay core dam constructed in the catchment area for water harvesting and to supplement water supply to Addis Ababa went into operation in April 1999. The reservoir is connected by pipeline to the Legedadi water treatment plant.

a) 1990

The land use and land cover types in the Dire catchment area consist of: moderately cultivated land, intensively cultivated land, eucalyptus woodland (matured and young); grass and other natural vegetation (woody), shrub land, grassland, bare soil and built-up areas (paved roads, dam, concrete buildings, etc.).

The major physiographic units on which the various land cover types are found are: the mountains of Bereh, Bura and Tnkole, foothills, the foot and side slopes of the mountains and hills, steep stream embankments, and narrow undulating valley bottoms and sides. Tributaries of the Doyo and Yeso rivers on which the Dire dam is constructed have deeply dissected the mountains from the north-west direction to the north-east. Thus, the tributaries of the river form deeply incised gorges in the mountains and undulating and relatively wide valley bottoms at the foot slopes in the northern and southern parts of the catchment area. The altitude in the catchment area ranges from 2,524 to 3,217 m.a.m.s.l. The 693-m elevation difference demonstrates the steepness of the catchment area.

Distribution and Properties of Land Use and Land Cover Classes is as follows:

Eucalyptus woodland of the Addis Bah Fuel Wood Project covers most of the mountains summits and slopes which are currently owned and maintained by the Oromia Natural Resources and Environmental Protection Bureau. The trees when matured are sold by the Bureau for use in Addis Ababa. The farmers are allowed to graze their livestock in matured eucalyptus plantations throughout the year, but they are not allowed to graze in coppices after cutting or in young plantations.

The unit has a fair percentage of ground cover to protect the soil against erosion during rainy seasons. The soil is shallow, stony and rocky which is easily detached during torrential rains if not held by the roots of the grasses and trees planted by the Addis-Bah Project and by remnants of the natural vegetation.

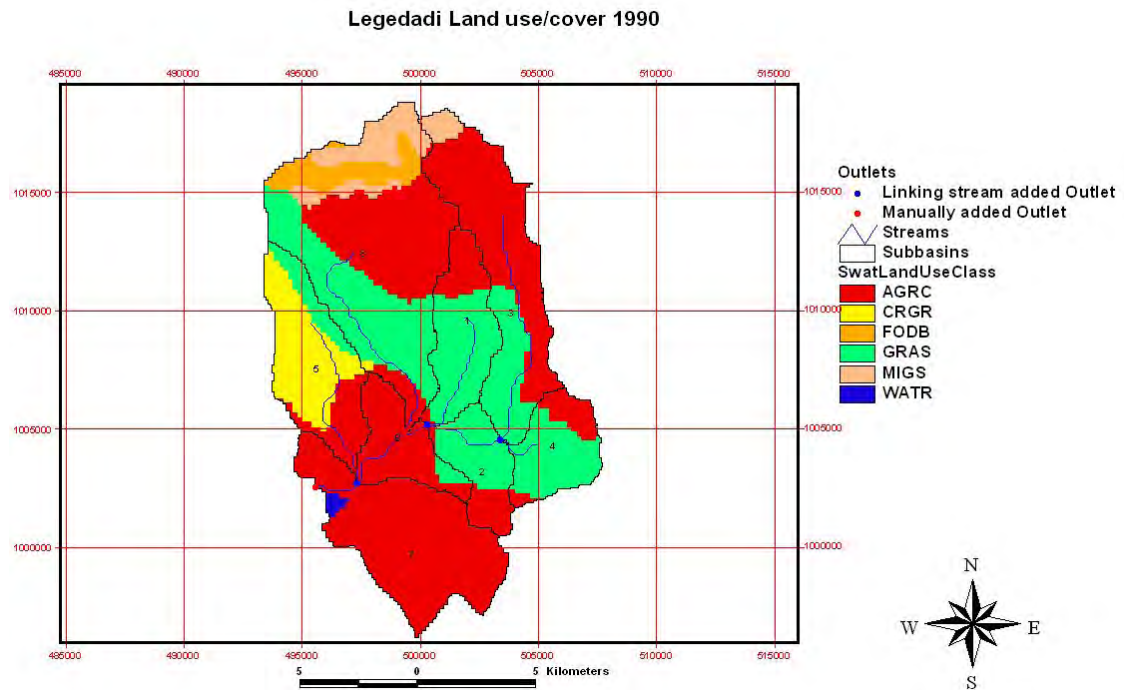


Fig 4.3. Land use/cover distribution of Legedadi catchment for the years 1990.

The steep sides of streams and the steep mountainsides below the eucalyptus plantation (on the mountains) have been left for the farmers as grazing areas for their livestock.

Shrubs with grasses and scattered trees, shrubs and grasses have naturally covered these units.

But farmers have now opened up some parts of these units for cropping. According to TAHAL report (2000), these units are being converted to crop fields owing to the serious shortage of land due to fast population growth and the large portions of their land taken for the eucalyptus plantation and for the Dire reservoir.

Land reallocation came to a halt after the Derg government. Crop yields on the previously cultivated fields are declining from year to year due to severe soil erosion and because the farmers are reluctant to apply fertilizers owing to their high cost.

Large areas of land on the steep sides of hills and streams were opened up for cropping in 1998. This was done in order to allocate land to farmers who were relocated from the

reservoir area and because of the growing number of landless inhabitants of the area. Since the farmers have not been instructed to adopt any soil conservation measures, either physical or biological, large amounts of soil have been carried away.

Grasses covering the undulating narrow and relatively wide valley bottoms and sides provide forage for the livestock. Farmers harvest hay from wet grasslands after the rainy season in November and the livestock directly graze on these grasses during the dry season. Due to the lack of land allocations and the growing number of landless peasants, the area of grasslands is decreasing and the crop fields encroach on to individually-owned grasslands.

The cultivated lands occupy the steep mountain slopes which are deeply incised by the streams, undulating valley sides, foothills, foot slopes and undulating plains. The soils on the mountain sides are relatively shallow, but are deep on the foot slopes and undulating valley bottoms.

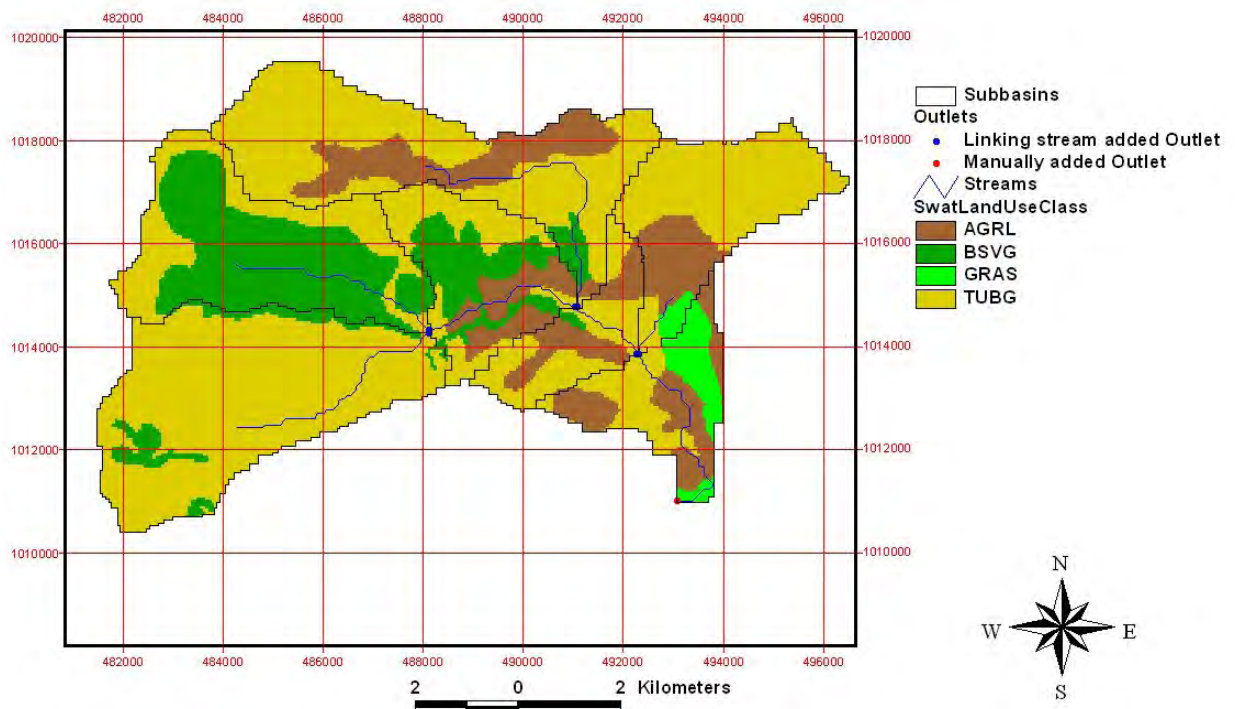
#### ***b) 1960, 1980 and 2008***

The land use/cover data obtained from Oromia Water Works Design and Supervision Enterprise (OWWDSE) was actual data over longer time which help in visualizing the change and its consequence impact. Distribution of the land use/cover types have been tabulated below.

Table 4.2: Land use/cover distribution of Dire catchment for the years 1960, 1980 and 2008.

Landuse Types	Abbr.v.n	1960		1980		2008	
		Area [ha]	%Wat. Area	Area [ha]	%Wat. Area	Area [ha]	%Wat. Area
Water	WATR	-	-	-	-	127.04	1.62
Bare Ground Tundra	TUBG	4849.11	61.87	3927.23	50.11	3290.61	41.99
Baren or Sparsly Vegetated	BSVG	1486.07	18.96	1060.83	13.54	-	-
Grassland	GRAS	201.57	2.57	467.61	5.97	-	-
Forest- Evergreen	FRSE	-	-	-	-	1761.83	22.48
Residential-Low Density	URLD	-	-	53.96	0.69	135.83	1.73
Agricultural Land-Generic	AGRL	1300.49	16.59	2327.62	29.70	2521.93	32.18
<b>Total</b>		<b>7837.24</b>	<b>100.0</b>	<b>7837.24</b>	<b>100.0</b>	<b>7837.24</b>	<b>100.00</b>

### Land use/cover Distribution of Dire Catchment 1960



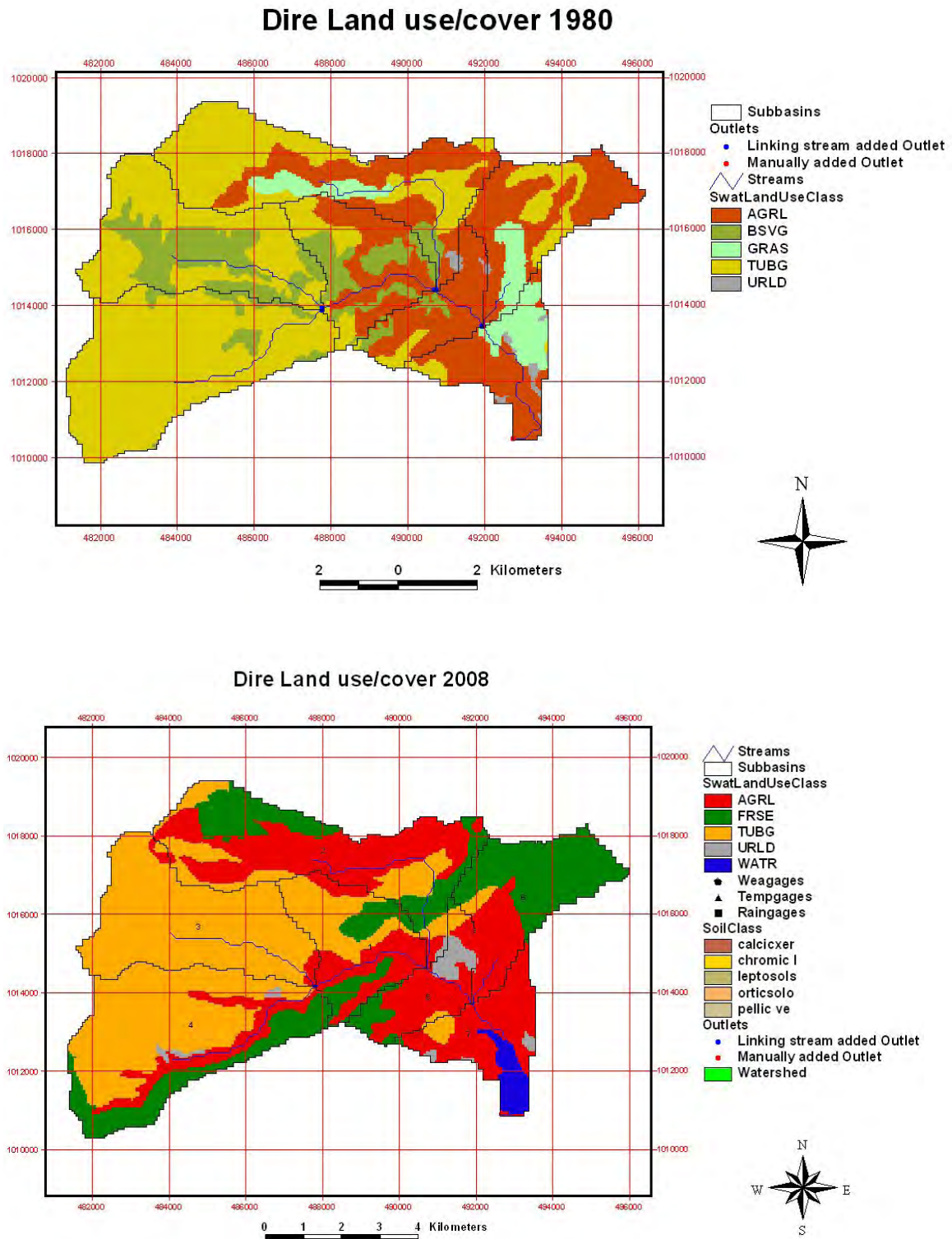


Fig 4.4. Land use/cover distribution of Dire catchment for the years 1960, 1980 and 2008

In the course of time, it is observed that settlement areas and planted trees have expanded in the catchment. Water abstracting structure (dam) and commercial tree plantation has been introduced. Agricultural land increased from 1960 through 2008 by two folds(16.59% to 32.18%).

### **4.3 LAND USE AND LAND COVER SCENARIOS**

It is difficult to derive future land-use scenarios for a region, because of the difficulty of representing the factors responsible for land-use changes. Land-use changes are driven by global change processes, especially by changes of global markets and political reforms and constrained by the given natural characteristics and socio-economic conditions of a region. This complexity gives rise to a wide range of approaches that range from extreme land-use changes such as total deforestation of a watershed, to the development of models that consider regional socioeconomic aspects.

In this study, simple hypothetical scenarios were set considering the current land use trend of the study areas as tabulated below. The 1990 land use/cover data was used as the base data to derive the scenarios.

The first scenario (Sc-1) considers 30% conversion of natural land covers to agricultural land as a result of population pressure in the catchments. The current rate of expansion of agricultural land in the area is nearly 2% every year.

The second land use change scenario (Sc-2) assumed 50% reduction in natural land covers and expansion of agricultural land by 40.07% and 38.92% for Legedadi and Dire catchments respectively keeping the water body constant.

The third and fourth scenarios (Sc-3 and Sc-4) consider the effect of urbanization in Legedadi catchment. The catchment is adjacent to the capital Addis Ababa and bisected by a main road from the capital to northern part of the country. Sendafa town which is undertaking rapid

change is also located in the catchment. Sc-3 is more likely to occur as the current trend in the area implies if no measure is taken.

Table 4.3: Description of Land use/cover change scenarios developed for the catchment areas

Catchment Area	Scenario code	Description
Lege Dadi	SC-1	Reduction by 30% of its base landuse/landcover area in landuse/cover types CRGR, FODB, GRAS. MIGS Keeping WATR (water body constant) and 26.44% increase in AGRC.
	SC-2	Reduction by 50% of its base landuse/landcover area in landuse/cover types CRGR, FODB, GRAS. MIGS Keeping WATR(water body) constant and 44.07% increase in AGRC
	SC-3	reduction by 50% of its base landuse/landcover area in landuse/cover types CRGR, GRAS, MIGS; 30% reduction in FODB; no change WATR landuse/cover types and 42.77% increase in AGRC -URBAN area = 10% of AGRC.
	SC-4	Reduction by 50% of its base landuse/landcover area in FODB, MIGS, 100% reduction in CRGR; no change WATR, GRAS landuse/cover types and 35.15% increase in AGRC. -URBAN Area = 10% of AGRC.
Dire	SC-1	Reduction by 30% of its base landuse/landcover area in CRGR, FODB, GRAS, RNGB, MIGS landuse/cover types and 23.35% increase in AGRC
	SC-2	Reduction by 50% of its base landuse/landcover area in CRGR, FODB, GRAS, RNGB, MIGS landuse/cover types and 38.92% increase in AGRC.
	SC-3	Increase by 50% of its base landuse/landcover area in CRGR, FODB, RNGB, MIGS landuse/cover types, keeping GRAS constant and 34.28% reduction in AGRC.

Table 4.4: Detailed Land use/cover type distribution and change scenarios developed for the catchment areas.

a) Lege Dadi catchment.

Landuse/ cover type	Base	Land use/cover Area Change (%)			
	Landuse/ cover Area (%)	Sc-1	Sc-2	Sc-3	Sc-4
AGRC	52.99	26.44	44.07	+42.77*	-34.15*
CRGR	6.96	-30	-50	-50	100
FODB	3.42	-30	-50	-30	50
GRAS	31.39	-30	-50	-50	0
WATR	0.31	0	0	0	0
MIGS	4.93	-30	-50	-50	50

b) Dire Catchment

Landuse/ cover type	Base	Land use/cover Area Change (%)		
	Landuse/ cover Area (%)	Sc-1	Sc-2	Sc-4
AGRC	56.23	23.35	38.92	-34.28
CRGR	27.61	-30	-50	50
FODB	9.39	-30	-50	50
GRAS	5.22	-30	-50	0
RNGB	1.51	-30	-50	50
MIGS	0.04	-30	-50	50

c) Summary of LULC area distribution in the catchments by hectare (ha).

Catchments	LULC	Base LULC	SC-1	SC-2	SC-3	SC-4
Lege Dadi	AGRC	11095	14029	15984	15842	7306
	CRGR	1457	1020	729	729	4372
	FODB	716	501	358	501	1074
	GRAS	6572	4601	3286	3286	6572
	WATR	65	65	65	65	65
	MIGS	1032	723	516	516	1548
Dire	AGRC	4386	5410	6093		2882
	CRGR	2154	1508	1077		3230
	FODB	732	513	366		1099
	GRAS	407	285	204		407
	RNGB	118	82	59		177
	MIGS	3	2	2		5

The SWAT model was setup for each landuse/cover change scenarios of both catchments and the corresponding output was given in the next chapter.

The land use/cover distribution of the base and each scenario are demonstrated in the following figures. The summation of each LULC makes up the whole catchment area of the study areas that is 100%.

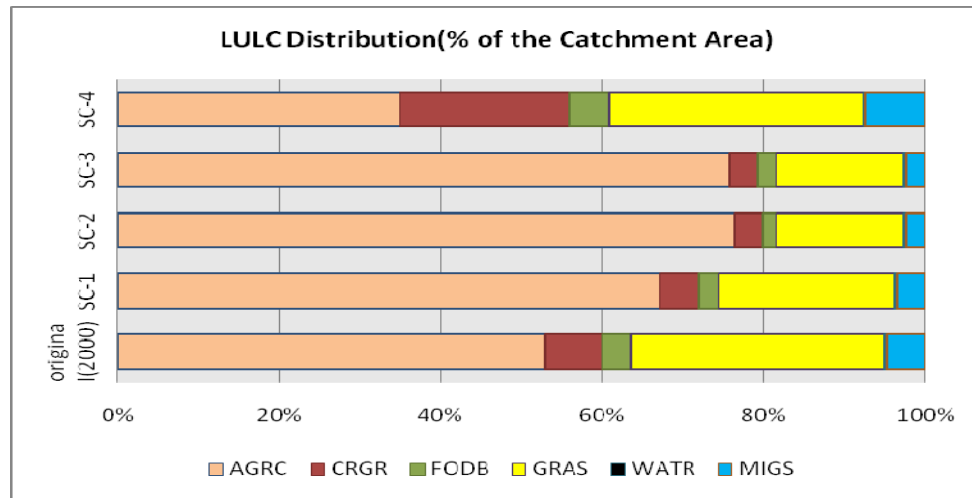


Fig.4.5: LULC Percentage distribution of the base and each scenario in Lege Dadi catchment area.

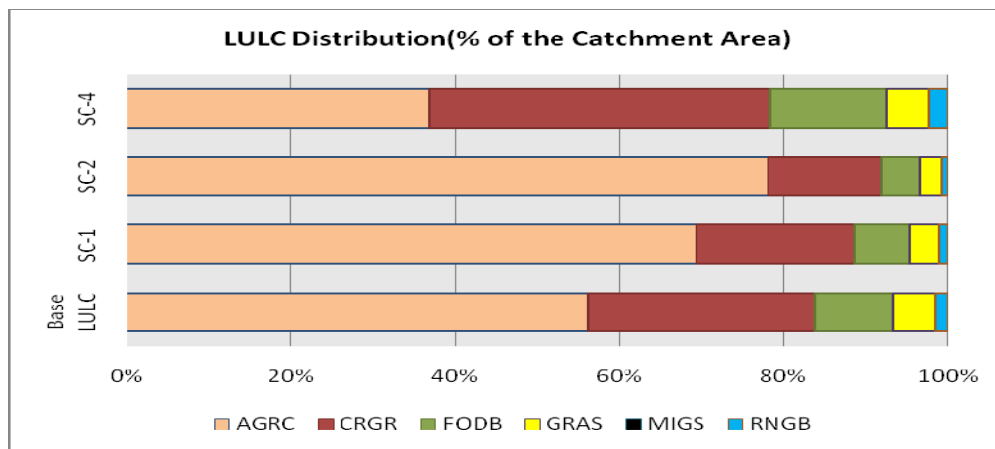


Fig.4.6: LULC Percentage distribution of the base and each scenario in Dire catchment area.

Land use scenarios 1-3 were assumed to be threat to the water supply scheme where as scenario 4 was the counter action that could be taken as mitigation measure.

## Chapter 5

### RESULT AND DISCUSSION

The actual landuse/cover of the study areas and the scenarios were analysed with SWAT to demonstrate their effect on hydrology and water quality. For all model runs, the meteorological input data were the same. The assumption underlying the scenarios is that the climatic components do not change.

Among the various hydrologic processes that take place in a catchment, surface runoff, sediment flow and nutrient transportation are most essentials. The results obtained for these components are characterized by the spatial distribution of the meteorological input variables and the heterogeneities within the subbasins.

This chapter summarizes the important findings and contributions of this study to scientific research, especially in this region of the world. It also discusses some of the limitations of the SWAT model, and recommendations for future research.

#### *i. Lege Dadi Catchment*

##### *a. Observation*

The results of the observations show that, on average, the 1980 yielded more runoff while that of 1960 yielded reduced amounts. Sediment and turbidity in general had the same trend as the stream flow. As shown in previous chapter, there were no considerable landuse changes in the catchment area. The increase in turbidity could be attributed to improper land utilization on the peripheries of the reservoir. Traditional agriculture without erosion controlling measures and over grazing on the peripheries of the reservoir is observed which could be increase turbidity of the reservoir water.

*b. Scenario Analysis*

The changes in LULC over the scenarios sc-1 to sc-4 have been significant and have contributed to a considerable change in the variables of interest such as flow, sediment discharge and nutrient transport as shown in table 5.1 below.

Table 5.2: Percentage change in some variables due to change in landuse/cover as per the scenarios.

Catchment	Scenarios	Variables						
		FLOW	SED	ORGN	ORGP	NO3	MINP	DISOX
Lege Dadi	Sc-1	3.4	8.0	6.2	6.2	20.4	38.6	3.1
	Sc-2	48.1	61.5	57.9	57.9	82.3	40.8	46.9
	Sc-3	49.9	61.4	48.9	17.7	42.6	60.7	48.8
	Sc-4	38.5	52.6	41.7	13.5	29.6	60.7	48.8
Dire	Sc-1	14.9	11.2	36.3	36.3	42.3	0.0	14.5
	Sc-2	15.3	21.5	36.3	36.3	46.3	0.0	17.5
	Sc-3	14.9	17.8	36.3	36.3	42.3	0	16.7

A comparison made between the base LULC and the scenarios shows there has been a considerable increase in all the considered variables. Without climate change, land cover changes accounted for an increase in runoff of about 3.4-49.9%. Looking at the four land cover scenarios, on average, Scenario 3 yielded more streamflow while Scenario 1 yielded reduced amounts. On the other hand, Scenario 2 gave higher mean sediment yield than other Scenarios and this was due to more conversion of 50% of natural land cover to agricultural land, which increased soil erosion. Thus, there was an increase/decrease in sediment yield and

water yield with a decrease/increase in agricultural land use assuming the climatic variables unchanged. Scenario 3 increased streamflow by 49.9% which is attribute of urbanization. Removal of vegetative cover would generally increase the average surface runoff. Thus, the increase in streamflow could also be attributed to a decrease in evapotranspiration. This decrease in evapotranspiration could be attributed to decreased interception as well as transpiration. All other considered variables have shown considerable increase with intensification of agricultural land.

In Scenarios 3 and 4, 10% of the AGRC land use was assumed as occupied by urban area.

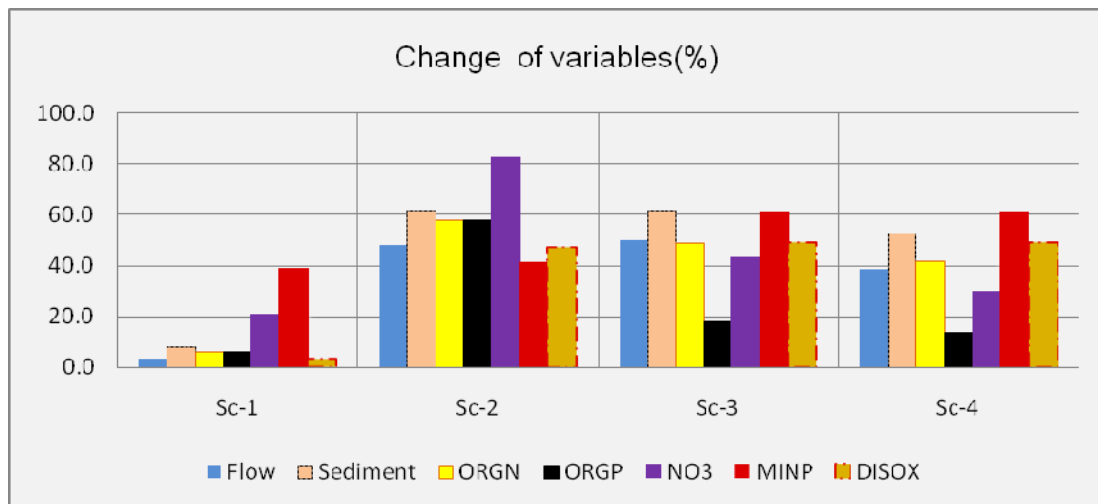


Fig.5.1: Percentage change in variables attributed to change in LULC in Lege Dadi catchment.

Sediment hotspot areas have been identified by subbasins which are closely related to the driving factors such as land use type and the topographic characteristics. Lege Dadi catchment area have an average annual sediment yield rate of 9.92ton/ha.

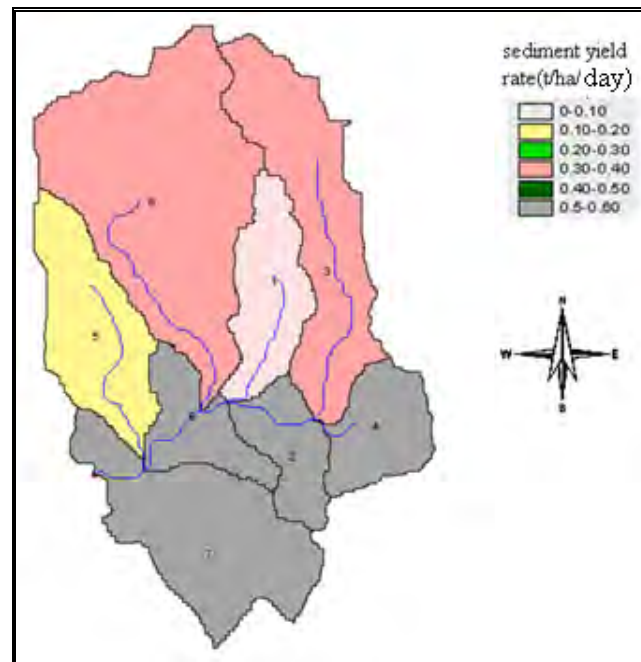


Fig. 5.2: Sediment yield rate for Lege Dadi catchment subbasins.

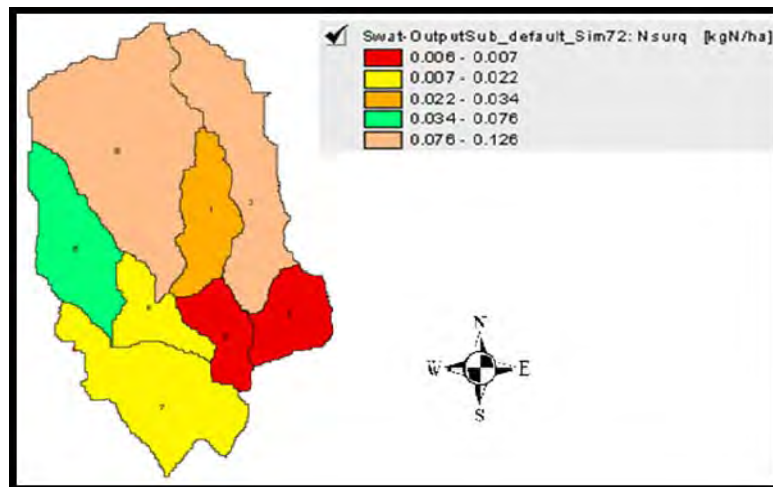


Fig.5.3 Annual mean Nitrate yield rate of subbasins in Legedadi catchment area (KgN/ha/day).

*ii. Dire*

*a. Observation*

The results of the impact on stream flow due to land cover change over the time periods of 1960 to 2008 are significant. On average, 2008 yields more runoff while that of 1980 yielded reduced amounts. Increase in agricultural land would generally increase the average surface runoff. Corresponding water quality parameters respond to the change in LULC as tabulated. In general, there have been increases in runoff and turbidity which may be attributing to increase in agricultural land, decrease in natural vegetation in the catchments.

*b. Scenario Analysis*

The cultivated land (intensively and moderately) in the Dire catchment area occupies about 56.2% of the total land mass as per the base map. Out of this, the intensively cultivated land which falls more or less on undulating slope occupies only 3.5% of the area, while the remaining is situated on slopes (more than 5%). Since crop cultivation in the catchment area is practiced without implementing any soil conservation measures, crop fields are the major sources of sedimentary materials; it is expected that these materials will in the future be deposited in the Dire reservoir. Soils on steep slopes are susceptible to erosion during rainy periods when the soil is pulverized or prepared for sowing of crops. These topographic condition and intensification agriculture contributed to increase of stream flow, sediment and other variables in the scenarios set for this study.

In 1994, the cultivated area was estimated in the report submitted by Soil and Water Ltd. at about 45% of the catchment area, while in the TAHAL study (2000) this area was estimated at about 55%. This increase has been at the expense of the grasslands. This account for about increase of AGRC by 10% of the catchment area in 6 years (1.7%/year) which implies the scenarios 1 and 2 are most likely to undergo if mitigate measures are not taken. Intrusion of the crop land into the woodland without implementing any soil conservation measures leads

to an increase in the rate of soil loss rate and reservoir sedimentation and raw water quality deterioration.

Scenario 3 is omitted in case of dire catchment which accounts for urbanization effect since the catchment area is off-road.

Increase in nitrate and phosphorous in the scenarios is due to application of fertilizer and agricultural chemicals. However, there is no that much difference in response of variables among the scenarios. This may be for the reason that the catchment area is small so as to trace the effects by SWAT model or its topographic characteristics (steep slope).

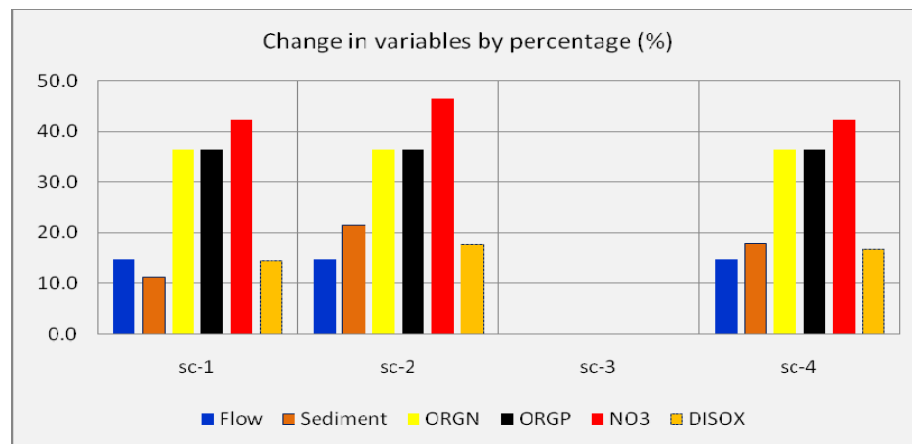


Fig.5.3: Percentage change in variables attributed to change in LULC in Dire catchment.

Currently, bare soil unit is highly susceptible to erosion during the rainy season. This unit, although occupying small part of the catchment area, nevertheless contributes a good deal of eroded soil and gravel to the streams. The model has under estimated the sediment yield even though the catchment exhibits lesser rate of sediment yield (7.60ton/ha/year) than Lege dadi catchment.

Hotspot sediment areas have also been identified which may help in taking remedial measures to reduce the effect of sedimentation. This is shown in the following figures for both catchment areas. Not only sedimentation, but also other factors contributing for the

deterioration of water quality are the results of land use change. Policy regulating land use with especial emphasis and support for local dwellers should be drawn and implemented in order to achieve sustainability of the water supply scheme.

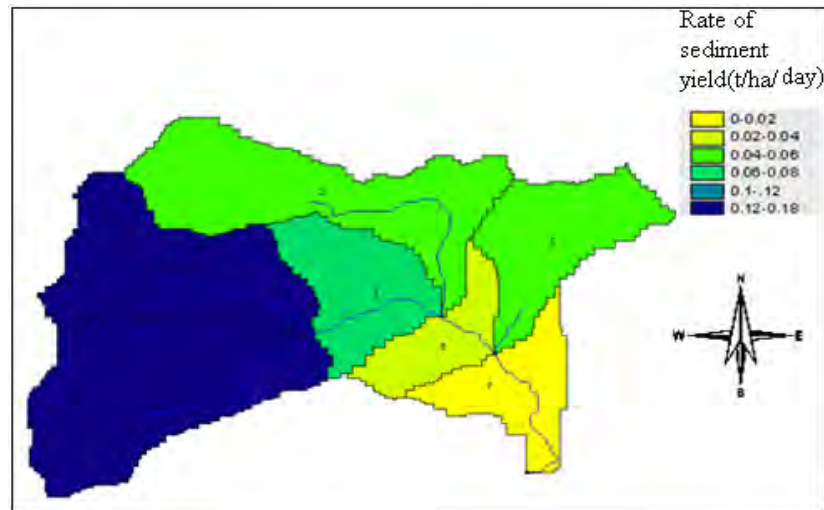


Fig. 5.4: Sediment yield rate for Dire catchment subbasins.

As it can be observed from the figure above, areas with steep slope and agricultural land are more prone to higher rate of sedimentation.

In general, the impacts of human activities on water resources occur through changes in land-use and climate. Those changes affect regional hydrologic balance by altering runoff, soil moisture storage, aquifer levels, stream flow, and water quality. These alterations in turn can cause water supply stresses, floods, draught, ecological imbalance and shift in plant species. Thus, there is a need to address these issues in order to combat possible threats posed on water resources at a catchment scale.

## Chapter 6

### Conclusions and Recommendations

SWAT has been used in this study to analyse the impact of environmental change in the Lege Dadi-Dire catchments and their impacts on hydrology and water quality. The results include hydrological statistics, land cover change scenarios and impact assessment. This chapter summarizes the important findings and contributions of this study to scientific research, especially in this region of the world.

#### 6.1. CONCLUSIONS

The SWAT model was calibrated against stream flow, sediment yield and selected water quality variables where parameters were adjusted based on the sensitivity analysis, as well as those that were deemed needing adjustment because their initial values were not adequately estimated. Keeping the model parameters at reasonable ranges minimized the uncertainty in the simulations. In general, there was good agreement between monthly estimated and simulated ( $Ens > 0.5$ ) and ( $R^2 > 0.60$ ) variables for the calibration and validation periods. The simulation of sediment was slightly underestimated but overall, the agreement between the estimated and simulated variables was acceptable.

The changes in stream flow, sediment yield and other water quality parameters are attributes to change in actual LULC over the periods considered at the basin scale for Dire catchment. For Legedadi catchment, it is attribute to the landuse on the periphery of the reservoir experiencing over grazing and traditional farming. The average flow, sediment yield and other water quality parameters of this study and previous works are summarized as follows.

Table 6.1: Summary of average values of variables.

Catchments:		Legedadi					Dire
Study:		current	BCEOM 1980	AESL 1984	AESL 1993	TAHAL 1998	current
Variables	FLOW (cumecs)	4.85	2.00	-	-	3.00	1.924
	SED_OUT (ton/ha/year)	9.92	-	5.40	24.00	7.60	7.460
	OGRGN (KgN/ha/yr)	3.53	-	-	-	-	0.592
	ORGP (KgP/ha/yr)	1.947	-	-	-	3.79	0.503
	NO3 (KgN/ha/yr)	5.737	-	-	-	-	5.503
	MINP (KgP/ha/yr)	0.502	-	-	-	-	0.593
	DISOX (KgO2/ha/yr)	6.064	-	-	-	2.592	2.427

In general, there have been increases in runoff and turbidity which may be attributing to increase in agricultural land, decrease in natural vegetation in the catchments.

The impacts of landuse change on the hydrology are more localized, since landuse changes tend to aggregate around the same existing land-use types. This analysis has clearly shown the strong effect that LULC change, and especially agricultural land use, has had on the hydrological regime of the Lege Dadi-Dire catchments.

The changes in LULC over the scenarios 1 to 4 have been significant and have contributed to a considerable increase in runoff. Generally runoff was highest from agricultural lands and increase in area of agricultural land increased runoff. There has been a considerable increase in runoff of about 49.9% in scenario 3 of the Lege Dadi catchment which is attributing to consideration of urbanization effect. As considered in the scenarios, without climate change, land cover changes considered in the scenarios account for an increase in runoff of about 3.4-49.9% and 14.9-15.3% for Lege Dadi and Dire catchments respectively.

Similarly, the sediment yields have also increased more closely with agricultural land use intensification. There has been a considerable increase in sediment yield of about 61.5% and 21.5% in Lege Dadi and Dire catchments respectively in scenario 2 of the which is attributing to consideration of 50% increase in agricultural land. The base sediment yield rate of the catchments which is 7.93ton/ha/year and 6.42ton/ha/year for Lege Dadi and Dire may rise to

12.80ton/ha/year and 7.80ton/ha/year respectively.

In relation to the increase in agricultural land, turbidity has shown considerable increase through the application of agricultural inputs such as fertilizers. This will further escalate the problem of water quality and treatment cost of Lege Dadi water treatment plant. Some variables and their corresponding values in different scenarios have been given in Table 6.2 below.

Table 6.2: Summary table of different variables and their values.

Catchment	Scenarios	Variables						
		LOW (cumecs)	SED_OUT (ton/ha/year)	OGRGN (KgN/ha/yr)	ORGP (KgP/ha/yr)	NO3 (KgN/ha/yr)	MINP (KgP/ha/yr)	DISOX (KgO2/ha/yr)
Lege Dadi	Base Value	3.62	7.93	0.41	0.82	0.36	0.44	4.89
	Sc-1	3.74	8.57	0.44	0.87	0.43	0.61	5.05
	Sc-2	5.36	12.80	0.65	1.29	0.66	0.62	7.20
	Sc-3	5.42	12.79	0.61	0.96	0.51	0.71	7.29
	Sc-4	5.01	12.10	0.58	0.93	0.47	0.71	7.29
Dire	Base Value	1.21	6.42	0.17	0.34	0.25	0.13	2.46
	Sc-1	1.21	7.14	0.17	0.34	0.25	0.13	2.82
	Sc-2	1.39	7.80	0.17	0.34	0.25	0.13	2.90
	Sc-3	1.60	7.56	0.17	0.34	0.25	0.13	2.88

## 6.2 LIMITATIONS

The use of scenarios in this study has helped to better understand and visualize how LULC alter catchment hydrologic response. These scenarios have made it possible to explore a range of conditions with respect to landuse/cover within which we can find estimates of the sensitivity of the catchment. This can help stakeholders and policy-makers to assess the impacts of several alternative sets of options to make better informed choices for an improved future. The study has also demonstrated the general potential of integrating spatial data and distributed modeling in impact assessment, which includes assessing vulnerability.

Regardless of those strengths, this study has certain limitations;

- The stream flow and sediment discharge used for calibration and validation were

estimated from a nearby catchment. It is recommended if gauge could be installed and measured data could be used to minimize uncertainty.

- The development of the land-use scenarios is that in reality landuse changes are mostly policy driven, which may not necessarily follow a scientific approach or mere scenario that considers gross change of the portion of the landuse.
- This study was conducted without taking the climatic change into account. However, these phenomena are interdependent and one is the driving factor of the other and vis versa. Therefore, the combined effect of climate and landuse change is likely to have more implication in those areas.
- Long duration time series records of water quality variables is essential in order for a model to be calibrated, validated and used for appropriate simulation. The data used in this study were limited which may have increased uncertainty.

#### **6.4. RECOMMENDATIONS**

If any control measures against increased runoff were to be applied, then clearly agricultural land has to be given priority with emphasis on proper farming practices, where less land is optimized to produce more crop yield rather than the opposite. The extra land could then be utilized to plant trees since forests have the lowest mean sediment, nitrate and other variables yield rate per unit area.

In general, there have been increases in runoff and turbidity which may be attributing to increase in agricultural land and decrease in natural vegetation in the catchments.

Soil Erosion Control indirectly serves improving water quality and water quantity.

Afforestation, by the community or by other bodies with specific emphasis on improved management. Adequate water quality control can be achieved by pollution prevention of the source water, i.e. the run-off from the rivers.

## 6.5 FUTURE RESEARCH

A few recommendations are discussed below for possible future research

- i. There is need to explore the performance of other hydrologic models for the purpose of comparing catchment behaviour and impacts' statistics. In area, little work has been done on distributed hydrologic modeling and much less on related impact assessments. Many studies have concentrated on bathymetric surveys and land use change, and mitigation to their related impacts, and these have taken the form of qualitative assessments. This research work has made a contribution towards this end.
- ii. There are numerous landuse/cover models due to development in computational technology in recent years. It is important to model land use/cover and project to the futures through those models than setting simple hypothetical scenarios.
- iii. There is need to incorporate the impact of climatic change and explore the use of downscaled climate change projections given that hydrological applications require climate/weather information at a higher spatial and temporal resolution.
- iv. It is vital to refine the spatial distribution of measurement sites in order to understand the scale of change that each landuse type contributes.
- v. With regard to parameter and model prediction uncertainties, there is need to use a multi-criteria approach in model calibration where other data, other than streamflow, are used to calibrate the model. This way, the modeler can explore whether or not incorporating the extra data can reduce these uncertainties.

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## **APPENDICES**

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