ASSESSMENT OF NON-POINT SOURCE POLLUTION IN LAKE AWASSA WATERSHED USING THE ANNUALIZED AGRICULTURAL NON-POINT SOURCE (AnnAGNPS) MODEL

MSc. Thesis

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July 2008

Addis Ababa

Assessment of Non-Point Source Pollution in Lake Awassa Watershed
Using the Annualized Agricultural Non-Point Source (AnnAGNPS) Model

A Thesis Submitted to the Faculty of Technology Department of Chemical Engineering,

School of Graduate Studies

Addis Ababa University

In Partial fulfillment of the requirements for the Degree of

MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING

By

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July 2008

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for the acceptance by the Addis Ababa University a thesis entitled: **Assessment of Non-Point Source Pollution in Lake Awassa Watershed Using the Annualized Agricultural Non-Point Source (AnnAGNPS) Model** in partial fulfillment of the requirements for the Degree of Masters of Science in Environmental Engineering.

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Dr. Ababu Teklemariam

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Date……..

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I, Demelash Amare Shamo, declare that this thesis is my own original work and it has not been presented and will not be presented by me to any other university for the similar or any other degree award.

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Signature

Date……..

DEDICATION

This thesis is dedicated to my parents Assegedech Asfaw Dabula and Amare Shamo Genta for their unequalled support and encouragement. With out their support, attaining this degree would not have been possible.

ACKNOWLEDGEMENTS

I would like to express my deepest and sincere gratitude to my advisor Dr. Ababu T/Mariam for his support, constructive evaluation of my work and flexibility working on my paper during odd hours and late hour discussions at his residence; my thanks also goes to his family.

My deepest thanks go to Ato Kassa Oyicha for his devotion, critical and insightful comments and suggestions through out my thesis work. I would like to thank his family for their lovely welcoming and comforting treatment during my visits.

I am indebted to Bisrat Gugssa of the Awassa Ethio-Tech for his friendly help and professional solutions he gave me whenever I asked him.

Special thanks go to Eshetu Eltamo and his wife Hanna Zeleke, Wondosen Kasaye, Deneke Madebo, Girma Timer, Zewde Afework, Girmay Fekadu, Yemane G/ Egziabher and all PCDP staff at Awassa.

I would like to forward my gratitude to Dr. Tora Abebe & his family, Demekech Dagne & her family, Tegenu Zerfu, Nardos Tilahun, Yonas G/ Tsadik, Yechale Kebede, Abren Gelaw, and other best friends of AMU.

I would like to extend my sincere gratitude to South Ari Wereda Rural Development Coordination office for the financial support during the entire study period.

I would like to appreciate all my friends and family members who contributed in one way or the other during my study.

January 2008

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ABSTRACT

Lake Awassa watershed is a Closed-watershed located in the Central Main Ethiopia Rift valley (MER). Despite its ecological, social, and economical functions and values, the lake and its watershed have been and being inflicted by non-point sources of pollution associated with deleterious anthropogenic activities. Better management of the environment to halt the existing problem of pollution and possibly to restore the ecosystem, requires informed decision on the root causes of the problem as well as on alternative management measures.

In this study, the Annualized Agricultural Non-Point Source (AnnAGNPS) model has been used for relative assessment of non-point source pollution, prioritization of the sources of pollution and formulation and evaluation of alternative management measures.

The relative comparison of the AnnAGNPS model average annual output, with respect to land use, for the year 2004 showed that cultivated land with Maize and Coffee, mono-cropped Maize land, and Bare land are leading sources in terms of runoff yield. In addition, Bare land, Pasture poor condition and mono-cropped Maize land are top yielding in terms of sediment. Based on nutrient yield mono-cropped Maize land, cultivated land with Maize and Coffee, and cultivated land with Maize and 'Chat' are principal sources in terms of Nitrogen. Bare land, Shrub land with poor condition, and Pasture poor condition are leading in terms of Organic Carbon. Mono-cropped Maize land and cultivated land with Maize and Coffee are chief sources in terms of Phosphorous. Accordingly, the study identified mono-cropped Maize land, Bare land and cultivated land with Maize and Coffee as priority areas that need alternative management option to control the non-point source pollution.

The study also showed that a change from mono-cropped Maize land to mixed cultivation of Maize and 'Chat' would result a decrease up to 78% for water and Organic Carbon, 91% for sediment and more than 95% for Phosphorus yields, while Nitrogen yield remain unchanged. A change from Bare land to mixed cultivation of Maize and 'Chat' would result a decrease up to 99%, 94% and 78% for sediment, Organic Carbon and water yield, respectively, while an increase up to 100% for Nitrogen. A switch from the mixed cultivation of Maize and Coffee to mixed cultivation of Maize and 'Chat' would result a decrease up to 81%, 75%, 60% and 35% for water, Nitrogen, sediment and Organic carbon yield, respectively, as well as a decrease of more than 85% for Phosphorus yield.

Comparison of 1965 and 2004 scenarios showed that a decrease of watershed runoff by about 28%, while there is a decrease of sediment yield by about 73%. Similarly, there were a decrease of around 32%, 50% and 35% for Nitrogen, Organic Carbon and Phosphorus yields, respectively, for the 1965 scenario from that of 2004.

The result of the study showed that a change in land use system can bring about significant reduction in non-point source pollution and the spatial distribution of areas in the watershed that need immediate attention.

1. INTRODUCTION

A watershed is an area of land that sheds water to a lake or river. It is a logical way to divide landscapes and ultimately the most appropriate analytical and management units for water quality improvement. Understanding them is the first step in protecting the water and other natural resources. The watershed is a dynamic and complex web of resources: soil, water, air, plants, animals and human beings. Its features depend on its size, boundary, terrain, and soil type. It is crucial to understand watersheds and their dynamic nature before decisions are made or actions are taken that may affect important watershed structural or functional characteristics.

The pollution of water resources is of foremost concern today. It has a direct impact on the health of people and the environment. From spatial perspective, the sources of pollution can be divided as point and non-point sources. As the name implies, point source pollution represents those activities where wastewater is routed directly into receiving water bodies by, for example, discharge pipes, where they can be easily measured and controlled. In contrast, non-point source pollution arises from a broad group of human activities for which the pollutants have no obvious point of entry into receiving watercourses.

Agriculture is only one among various causes of non-point sources of pollution; however, it is generally regarded as the largest contributor of pollutants of all the categories. Agricultural pollution has characteristics that pose particular problems. It is dispersed geographically over large areas, it usually discharges as a component of natural runoff into surface waters and the underlying groundwater, and it is extremely difficult to collect and treat. The serious nature of the agricultural water pollution problem is becoming evident in most developed and many developing countries (Susanne, 1995).

The ecological impact of agricultural non-point source pollutants, range from simple nuisance substances to severe ecological impacts involving fish, birds and mammals, and on human health. Sediment, nutrients and pesticides occupy the first four categories of

non-point source pollutants impacting surface waters, and are significantly associated with agriculture (Glenn, 2002).

Land degradation; directly linked to agricultural non-point source pollutants of surface waters, seriously affects livelihoods and food security of millions in Ethiopia and threatens the livelihood of many more. The main land degradation; and the associated impairment of surface water quality, accelerated sedimentation in reservoirs, lakes and ponds, lowered storage capacity of dams and, flooding hazards, arises from high soil erosion rates as a result of steep slopes, continuous encroachment and cultivation of marginal lands; and a long history of deforestation, over grazing and others (MoARD, 2005).

Clearing of forests, animal grazing, and other reductions in the vegetation of the catchment areas of the Ethiopian lakes, which have expanded considerably during recent years, increased the silt and nutrient load of the water. The present level of deforestation in Ethiopia (about 150,000 to 200,000 hectares of forest per year) poses a serious environmental problem. Most of the factors that encourage soil erosion (depleted forest, inadequate plant cover, organically poor soils, improper farming methods, etc.) are very common in Ethiopia, and some of its lakes have suffered from the consequences of the linked processes of plant cover removal, erosion, and sedimentation (Zinabu, 1998).

In this regard, it has been identified that Lake Awassa and its wetland system including the Tikur Wuha River and Cheleleka Swamp were being inflicted by deleterious anthropogenic activities in the watershed resulting in non-point source pollution. The leading causes of the pollution were identified to be human activities associated, particularly, with poor agricultural practices, clearing of forest, use of fertilizers, herbicides and pesticides, rapid and unplanned urbanization, poor waste management and industrial effluent from within the watershed (Zerihun, 2003).

The degradation and deterioration of the ecosystem should have been given immediate attention to curb the situation and possibly efforts backed by research findings should have been made to restore and preserve the environment. On the other hand, scientific

research with systematic and holistic approach would be of crucial importance with regard to indicating appropriate paradigms for sustainable management of overall socioeconomic activities; i.e. human activities dictated by the potentials and limitations of the environment.

Accordingly, this thesis, basically focuses on assessment of runoff, erosion, sediment and other pollutant sources, transport and deposition of pollutants, prioritization of pollutant sources, and formulation of alternative management options, by application of appropriate modeling tool, for the Lake and its watershed with the impetus of supplying scientific background and direction for the management of the watershed.

2. LITERATURE REVIEW

2.1 Previous Relevant studies on Lake Awassa Watershed

Many studies have been carried out by different agencies since early 1970's with respect to the development of water resource projects, hydrology and hydrogeology, natural resource management, and environmental impact assessment and pollution in the study area.

The earliest official study on water resources of the area was conducted by the British Land Resources Division (LRD) Ministry of Overseas Development, which was operating in close collaboration with the Executive Organ of the Ethiopian National Water resources Commission (NWRC) in 1973. The study was restricted to land and surface water resources and socio-economic factors affecting their exploitation. According to the review of this study by AG Consults, it has noticed the changes in the level of Lake Awassa, its relation to climatic changes and the impacts from changes in the watershed due to human impact. Some of the major recommendations; as stated by AG Consults, were establishment of Awassa catchment Development board to exercise control over land and water use, establishment of soil and water conservation office, and designation of protective forest above altitude 2000 m. a.m.s.l. (AG Consult, 2007)

In 1992, the pervious Ethiopian Valleys Development Studies Authority commissioned the Rift Valley Lakes Basin Integrated Natural Resources Development Master Plan Study, which was conducted by Sir William Halcrow & Partners of UK. Water and Power Consultancy Services (WAPCOS) of India to conducted the countrywide Water Resources Development Master Plan Study in 1990. Water Works Design and Supervision Enterprise (WWDSE) also carried out the study of Lake Awassa Level Rise in 2000. The Geological Survey of Ethiopia has carried out the Hydrogeology and Engineering Geology of Awassa Lake Catchment Study in 2003. A Master's Thesis study by Yemane Gebreegziabher in 2004 was also conducted at a watershed level.

The most recent study on Pollution of Lake Awassa commissioned by South Nations Nationalities and Peoples Region (SNNPR) Water Resources Development Bureau (WRDB) and conducted by AG Consult Consulting Hydrogeologists & Engineers Plc. in 2007 is the most relevant to this research among the different studies carried out previously.

Awassa Lake Level Rise Study

The Awassa Lake Level Rise study was carried out by Water Works Design and Supervision Enterprise (WWDSE) in 2000. The major purpose of the study was to investigate the causes of lake level rise, to forecast future conditions of lake level rise, and to propose remedial measures that could curb the situation in the short-term and long-term plans.

According to the study report by WWDSE (2001), the lake catchment area including the surface area of the lake is about 1440 km^2 and the lake surface area based on 1:10,000 scale map was about 100 km^2. Thus, the effective catchment area of the lake is about 1340 km^2. The surface area of Lake Awassa occupies about 7% of the total lake catchment area. The town of Awassa lies in an area of about 1% of the total lake catchment area. The relatively compacted surface of the Awassa town and the roof catchments have resulted in generating higher magnitude of runoff and associated with it, the problem of drainage in the urban area founded along the shoreline of Lake Awassa.

A bathymetric survey of the Lake Awassa was carried out to produce bathymetric map of the lake and to develop depth- area as well as depth-volume curves of the natural lake reservoir. The bathymetric map of the lake with a scale of 1:10,000 and contour interval of 2 m was prepared. From this map, the area-capacity-elevation curves of the lake were made and used for computing change in storage (WWDSE, 2001).

According to the report, during the study, the lake periphery was traversed and benchmarks were set at prominent places and tied to elevation above mean sea level. During the course of the survey, the non-recording staff gauge reading of the lake level

has been tied to elevation above mean sea level so that future reading could easily be referred in this way.

The annual water balance of Lake Awassa had been calculated from 1970-1998, which consists of high and low rainfall years with small and big cycles in the data set. Accordingly, it was reported that during dry years, storage changes are in decline trends and the groundwater component likewise decreases, and during wet years, storage changes are in increasing trends and correspondingly the groundwater component increases. There could probably be anomalous individual events contrary to the above facts that might be explained by relating to change in meteorological elements.

The study has concluded that the outflow from the lake in the form of groundwater is of lesser magnitude as compared with the inflow to the lake in the form of rainfall on the lake surface. This clearly indicates that wet years have overwhelming influence in generating high runoff volume on the Lake Surface and effective catchment also partly contribute to lake level rise.

Similarly, based on the results of the bathymetric survey, it was concluded that the 1998/1999 surface area of Lake Awassa was about 100 km^2 and that of Lake Cheleleka was practically zero. About 30 years back the surface area of Lake Awassa and Lake Cheleleka were about 88 km^2 and 12km^2 respectively. The transformation of Lake Cheleleka to swampy area has completely changed the aquatic ecosystem. Tall papyrus like grasses grow in the swampy area indicating that the deposition of transported sediment from the uplands has been in a continuous process of filling the natural reservoir of lake Cheleleka (WWDSE, 2001).

As stated by WWDSE (2001), the transformation of Lake Cheleleka to swampy area has dramatically resulted in the complete depletion of its regulating capacity, which in natural condition controlled the surface runoff since its existence as lake. Accordingly, the expansion of Lake Awassa by an equal magnitude (about 12km^2) to that of the surface area of Lake Cheleleka 30 years ago clearly shows the disappearance of Lake Cheleleka

and rise in the level of Lake Awassa in recent years is a major threat to the town of Awassa.

Assessment of the Water Balance of Lake Awassa Catchment

This study was conducted using the Thornthwaite and Mather soil water balance procedure and spreadsheet model for the period of 1981-1998 (Yemane, 2004). According to Yemane (2004), evaporation, rainfall, surface runoff and constant groundwater outflow from the lake constitute 131, 106, 83 and 43 Mm^3 respectively, of the annual average water balance, and the freshness of the lake water is attributed to the constant groundwater outflow. As Yemane (2004) reported, the results of the catchment water balance showed that long-term mean annual values of rainfall, actual evapotranspiration, and catchment runoff constitute 1398, 916 and 482 Mm^3 respectively.

In this study, Yemane (2004) compared catchment runoff for different scenarios with that of 1998 condition and reported a Change of -22% and 4% for the 1965 and 2004 land use situations, respectively. In accordance, he concluded, the combined effect of climatic and land use changes during the past 25 years most likely resulted in an increase of the catchment runoff and so the lake level (Yemane, 2004).

Study of Pollution of Lake Awassa

The main purpose of the study; by AG Consult Consulting Hydrogeologists & Engineers Plc., was to conduct complete environmental impact and detailed water quality assessment, for the lake water and water resources of the Lake Awassa catchment. The study presented results of the investigations carried out on the physical settings of the Lake and its Catchment including detailed and up to date data on hydrology, hydrogeology, hydrometeorology, water quality, soils, and land use and land cover. It also included data on the biological environment of the lake and their interactions as well as on the social environment.

The study of AG Consult (2007) indicated that there were high land cover changes in the past 30 years. Accordingly, it presented the rate of change between 2000 and 2005 with the highest being 91% and 81% for Urban and shrub land respectively, followed by 33% and 31% for wooded grass and dense shrub in that order, similarly a 26% for both open forest and bare land. The Water body area (that includes Lake Awassa and Lake Cheleleka) has remained almost constant in its total area coverage, i.e. 100.78, 102.34 and 99.59 sq km for the years 1976, 2000 and 2005 respectively. As per the study, when the two lakes area separately analysed, Lake Awassa showed a slight rate of increase, which is almost 9 %, while Lake Cheleleka significantly decreased by about 75% in the last 30 years. Urban Built-up area has been increased by 202 % in the same period while Marsh area has progressively declined in the three periods to cumulative rate of greater than 39%.

In this study, the outcome of analysis of erosion using the Universal Soil Loss Equation (USLE) was given to be 702,062 ton/year of soil loss for 2007 from 136,217 hectares of land. The amount of soil loss in the catchment was reported to range from 0 to 1099 ton/ha/year, and average soil loss of 5.2 ton/ha/year was specified, acknowledging the lower effectiveness of the USLE used for the analysis, due to the application of smaller number of parameters or variables, intrinsic limitations of the model. In addition to that, the existence of erosion problem and its causes were presented for specific localities in the watershed, despite the heavy reliance on qualitative data (AG Consult, 2007).

The Study report of Pollution of Lake Awassa rendered the output of the detailed survey on previous pertinent studies carried out and their findings on Lake Awassa and its watershed as well as other relevant studies, the literature review of the report was used as a key information source in the current study.

The study was found to be of potential relevance for the current study both as a data source and to substantiate the results of the model simulation with its findings, since both studies have a closely related objective and data requirement. Accordingly, the data from the report as well as the results were used comprehensively in this research.

2.2 Model Application in Watershed level Pollution Assessment

Understanding site and watershed hydrology is essential to understanding non-point source problems and the impacts of management measure implementation may have on water quality. Each action taken on a farm has the potential to affect hydrology. The extent to which management decisions influence hydrology needs to be understood and estimated since hydrology is so important to the detachment, transport, and delivery of pollutants.

In agricultural watersheds, hydrology can be affected by a number of elements. The combined effects of all management measures and management practices on the watershed hydrology should be considered both at the farm level and watershed scale in order to estimate the impacts on the quality of receiving water bodies.

Field-scale and watershed-scale models can aid analysis of the impacts on hydrology, and thus decisions on appropriate selection and placement of measures and practices in the watershed. In some cases, a thoughtful discussion or simple analysis will provide the answers regarding impacts to hydrology, but some form of modeling will usually be needed to integrate the various small and large impacts that management measures and practices are likely to have on watershed hydrology.

Models are simplified mathematical representations of real systems, processes, or objects. They are often created to test hypotheses, aid data acquisition, allow for simulation or prediction, improve a quantitative understanding of a system and enhance communications. Hydrologic models aid decision making and planning in several different ways. Models provide forecasts of current and alternative impacts on water quality, detail NPS processes, establish critical areas, rank alternative measures and are often the only means of predicting water quality impacts for non-monitored sites (Novotny and Olem, 1993). However, models often have many limitations. Therefore, a thorough understanding of the hydrology of the area gained through monitoring or experience is usually needed to interpret model results properly.

If the watershed within which agricultural management measures will be implemented includes land uses other than agriculture, then planners will need to consider agriculture's role within the watershed. In other words, the degree to which agricultural lands control watershed hydrology should be investigated and understood to enable analysis of the potential impacts that management measures and practices will have on watershed hydrology. Once again, some sort of watershed modeling capability will usually be needed to aid this analysis.

2.2.1 History of Watershed Level Modeling

According to a review of watershed modelling history, (Latif K. *et al*., 2003), Sing and Woolhiser (2002) provide a historical perspective of hydrologic modelling, and discussed new developments and challenges in watershed models. In their paper, Latif K. *et al.* (2003), date the origin of mathematical modelling back to the rational method developed by Mulvany (1850) and an event model by Imbeau (1982) that relates the peak runoff rate to runoff intensity. The work of Streeter and Phelps (1925) may be treated as the first effort in water quality modelling where the authors tried to address the relationship between dissolved oxygen in rivers and streams, and input from domestic wastewater. The works of Velz (1938) and O'Connor (1960, 1962) are among the other early attempts in water quality modelling. The earliest attempt in sediment modelling originated from relating soil loss from field plots to slope and steepness (Zingg, 1940). This work was extended by several researchers (Smith, 1941; Browning et al., 1947) which led to the development of the USLE (Wischmeire and Smith 1958; 1965; 1978).

Early models were based on simple one-dimensional, steady-state conditions. Advances in the theory of flow and transport phenomenon, and in computer technology elevated the art of sediment transport and water quality modelling as time constraints was not a factor anymore. Development of fully dynamic, steady state and three dimensional water quality models become feasible. The computational capability allowed the coupling of water quality models with watershed and hydrodynamic models (Latif K., *et al*., 2003).

As a result, varieties of models become available, and the choice of the right model become a challenge. Selecting the right model for a specific application depends on

factors like type of the stressors considered, economic constraints such as time and labour, hardware, personal experience and preferences, hydrologic considerations, and scientific rigor and data availability (Latif K., *et al*., 2003).

2.2.2 Non Point Source (NPS) Modeling

The diffuse nature of Non-Point Source (NPS) Pollution and the high expense of monitoring and research, made solutions to NPS pollution difficult to formulate and evaluate. Also, the often-complex data necessary for reliable management decisions have not always been readily available. Consequently, hydrologic models and decision support systems have gained wide acceptance as cost-effective tools for predicting NPS loadings, developing and evaluating the effects of Best Management Practices (BMPs) and establishing Total Maximum Daily Loads (TMDLs) (Tim *et al*., 1994).

A major difficulty with NPS water quality modelling is the spatially variable characteristics of watershed systems. Therefore, practicable but accurate, water quality modelling requires that the spatial elements within a watershed system, such as elevation, slope, soil characteristics, land-use, and climatic conditions, be a generalized representation of the real-world features. Data availability, scale and procedural limitations inherent to watershed modelling clearly necessitate this simplification. Until recently, hydrologic models have been unable to adequately manage and represent this required spatial component. Now, proper management of NPS pollution and watershed data is becoming increasingly feasible via the use of a Geographic Information System (GIS) and increasingly available spatial data.

The integration of a GIS and water quality model allows for establishing relationships between watershed parameters and their spatial attributes. Some GIS/Model systems are fully integrated, with all functions processed within the GIS platform. Unfortunately, the majority of available GIS/Model systems contain only a linked integration. This involves stand-alone components (GIS and Model) that create, support and share relevant information. It should be noted that most GIS platforms allow for supplemental integration through the construction of function-specific extensions and script plug-ins.

In recent years, the number of available water quality models has increased. The capabilities and scope of these models range from the simple empirical (minimum data required, hydrology independent, export coefficient based) model to the complex mechanistic (large data required, hydrology dependent) model.

2.2.3 Model Uncertainty

A cause of concern in modern modelling is the lack of uncertainty analysis. Uncertainty, a condition of incomplete or unreliable knowledge, exists in scientific projections of future conditions because of induction and is an essential component of planning and decision-making (Chapra and Reckhow, 1983). Hydrologic model uncertainty, in particular, is related to the relationship among the variables characterizing the dynamic behaviour of systems, including uncertainty about the value of the parameters representing system behaviour, uncertainty associated with predictions of the future behaviour of the system, the design of uncertainty reducing programs (Beck, 1987) and size of watershed (Novotny and Olem, 1993).

Uncertainty can be estimated and reduced by use of standard statistical software and through model calibration and validation. Model calibration is the process of varying uncertain model input over likely ranges of values until a satisfactory match between simulated and measured data is obtained. Validation is the process of demonstrating that the calibrated model is an adequate representation of the physical system (Bhuyan *et al.*, 2000). In addition to model uncertainty, the processing and simplification of data with a GIS can potentially contribute to uncertainty. One method of reducing GIS related uncertainty is to use the most applicable and comprehensive data sets available.

Obviously, according to Snyder (1973), due to the uncertainties inherent in deterministic-conceptual simulation sole reliance on computer modelling is not a wise course for predicting the nuances of hydrologic response. However, modelling has come a long way in the last 25 yrs, and remarks have been given to balance between observation and simulation for better understanding and interpretation of modelling results, as no longer are environmental models of little or no practical value. Such models can be helpful tools for planning the implementation of management measures to achieve water quality goals,

but the limitations of models and appropriate interpretation of modelling results should be fully understood before implementation decisions are made (Flynn, 2000).

Clearly, the key task in any modelling study is the analysis and interpretation of the model outputs. Since models are simply tools for a quantitative, systematic analysis of specific environmental problems or issues, they do not provide simple “yes” or “no” answers to managers, regulators or decision-makers. Rather, they usually provide detailed information about the expected response of the system to a given perturbation in order that a more informed, objective decision can be made.

The computer output generated by a model must be analyzed and interpreted in a logical and consistent fashion to answer the decision-maker’s questions, “What do the results mean?” and “How accurate and reliable are they?” To understand the true meaning of modelling results within a decision-making framework, both the assumptions of the analysis and accuracy of expectations (i.e., reliability) must be clearly defined. Both of these considerations are difficult, if not impossible, to discuss in general terms without discussing the specific characteristics of the particular model. However, assumptions usually are included, and required, in both how the model is configured or designed and how it is applied. Thus, a model may be used in many applications, with the same set of model assumptions common to all applications, while the application assumptions may differ from one case to another. The decision maker or analyst must be aware of both kinds of assumptions and their associated limitations to appreciate the validity of the modelling results.

According to Flynn (2000), the accuracy associated with the results of modelling studies depends on the model used, the accuracy of the input data, the characterization of the environmental system being simulated, and the expertise/experience and resources available to the model user. Decision-makers must understand that all these factors determine the ultimate accuracy and reliability of the model results. Even under the best circumstances, the model results should be considered estimates or approximations, since the model itself is an approximation of a real environmental system. This does not detract from the utility of models; it simply emphasizes the use of models as tools. It is also a

valuable tool for understanding the critical factors determining the behaviour of the simulated system. With this knowledge, the system can be better managed.

Most models are often more accurate in a relative sense, than in an absolute sense. That is, when models are used to compare alternatives, the relative differences predicted between alternatives are sometimes more reliable than an absolute value predicted for any one alternative. Models are often used to evaluate these relative differences (Flynn, 2000).

Literature by Susan *et al.* (1996), on the applicability of models and modelling states that, the complexity and dynamic nature of environmental processes make simulation particularly attractive. The use of computer simulation models is increasing despite controversy over their validity and applicability. The controversy arises from opposing views of how models should be used. At one extreme, there are those who feel that models should contain only processes that have been proved valid, and that they should not be applied outside a range of situations for which they are applicable. At the other extreme are those who would apply models even though the processes or data are known to be inapplicable to the situation under study. Useful applications probably lie between these two extremes, especially when combined with a critical and insightful evaluation of the output. Hauhs (1990) suggests that models should be applied until they are shown to be invalid, as they represent the current level of knowledge. However, if evidence from measurement, monitoring or experience suggests that the model is deficient or inappropriate, then the scientific foundation of the model should be re-examined and improved.

2.2.4 Evaluation of the AnnAGNPS Model

The single event Agricultural Non-Point Source (AGNPS) model was developed in the early 1980's by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency, and the Natural Resource Conservation Service (NRCS) in USA (Young *et al.*, 1989; Young et al., 1995). The model was developed to analyze and provide estimates of runoff water quality resulting from single storm events from agricultural watersheds ranging in size from a few hectares to 20,000 ha. Because of

its ease of use, flexibility, and relative accuracy, AGNPS is widely applied throughout the world to investigate various water quality problems.

AGNPS is a single-event model. Early in its development, this was recognized as a serious model limitation. In the early 1990's, a cooperative team of ARS and NRCS scientists was formed to develop an annualized continuous-simulation version of the model, AnnAGNPS. Coordination of the effort was originally supervised by the ARS, North Central Soil Conservation Laboratory in Morris, Minnesota, and later was transferred to the NRCS, National Water and Climate Centre, Water Science and Technology Team in Beltsville, Maryland. Research and development leadership was assumed by the ARS, National Sedimentation Laboratory in Oxford, Mississippi. NRCS in Beltsville provides technology transfer support for AnnAGNPS.

AnnAGNPS is the pollutant-loading component for a suite of models referred to as AGNPS 2001. AGNPS 2001 is a tool for use in evaluating the effect of management decisions affecting a watershed system. AGNPS 2001 includes GIS routines for developing model input and analysis of model output, a synthetic weather generator (GEM), AnnAGNPS for pollutant loading, in-stream modeling routines, and routines to examine salmon development. The tool automates many of the input data preparation steps needed for use with large watershed systems.

2.2.4.1 Intended Uses and Process modeled

AnnAGNPS is a continuous-simulation, watershed-scale model intended for use as a tool to evaluate non-point source pollution from agricultural watersheds ranging in size up to 300,000 ha. It is an expansion of the capabilities of AGNPS and as such shares many similarities to the original model. The watershed is subdivided into homogenous land areas (cells) with respect to soil type, land use, and land management. These areas can be of any shape from the original square grid cells of AGNPS to more appropriate hydrologic boundaries generated by terrain-following Geographical Information System (GIS) software. AnnAGNPS simulates surface water, sediment, nutrients, and pesticides leaving the cells and their transport through the watershed. The model can be used to examine current conditions or to compare the effects of implementing various

conservation alternatives over time within the watershed. Alternative cropping and tillage systems, fertilizer, pesticide, irrigation application rates, point source loads, and feedlot management can be evaluated.

2.2.4.2 Target Audience

The primary target audiences for the AnnAGNPS model were the state and field offices of the NRCS in the USA. Other agencies involved in natural resource planning will also find the model useful. The model remains the most practical means to examine the flow of water and water transported pollutants on a watershed scale in a manner allowing planners to determine the effects of treatments over long time periods (risk analysis), and to examine the treatments needed based on landscape and watershed location. AGNPS allow natural resource planners to identify high priority treatment areas, a valuable tool for optimizing limited resources.

2.2.4.3 Model Availability and Source

AnnAGNPS is currently available via the AGNPS 2001 web site. Additional features are being added and more are planned for the future. Ground water is planned for a future release. Executable files are available to convert AGNPS input files to AnnAGNPS input file format, to generate flow nets, to develop input files, and to examine output.

AnnAGNPS is available as a 32-bit version for Windows 98, NT, 2000, and XP. AnnAGNPS could also be used on other platforms that have a compiler for ANSI standard FORTRAN 95. The executable program is approximately 2 MB. A Pentium or higher PC with a minimum of 32 MB of memory is recommended because of Windows requirements. There is no memory limitation for AnnAGNPS because it includes a memory manager with virtual memory capabilities. Additional free disk storage considerations should include input file and output file needs (and virtual memory if used).

Table 1 Summary of the Components of AnnAGNPS Model

Characteristics	Incorporated in Model	Comments
Spatial Scale	Watershed	Limited by data availability and computer memory, drainage areas up to 300,000 ha
Discretization	Cells	Square grid or hydrologic boundaries
Temporal Scale	Daily time step	Unlimited number of years
Water		
Surface runoff	Yes	SCS curve number and extended TR55
Irrigation	Yes	Water with dissolved chemicals and sediment with attached chemicals
Groundwater	Future development	
Sediment		
Sheet and Rill Erosion	Yes	RUSLE technology
Gully Erosion	Yes	Function of surface runoff volume
Stream-Bed and Bank Erosion	Yes	By transport capacity
Transport	Yes	Einstein deposition equation with Bagnold transport capacity
Impoundments	Yes	Settling time and dilution due to permanent storage
Particle Size Classes	Yes	Five
Nutrients		
Nitrogen	Yes	Dissolved and attached
Phosphorous	Yes	Dissolved and attached
Organic carbon	Yes	Dissolved and attached
Pesticides	Yes	Unlimited number, dissolved and attached
Feedlots	Yes	dissolved nutrients only
Point Sources	Yes	Water and dissolved nutrients
Gullies	Yes	Sediment and attached chemicals
Snow-Melt	Under development	Based upon thermodynamic balance of snow-pack with surrounding environment
Frozen Soils	Under development	Thermodynamic balance and heat transfer within soil column, includes effect on USLE soil "K" factor
Economics	Under development	Minimization of pollutant loadings

2.2.4.4 Verified Applications and Tests

AnnAGNPS technology was based upon science found in AGNPS (Young *et al.*, 1994), Groundwater Loading Effects of Agricultural Management System (GLEAMS) (Knisel, 1993), Erosion-Productivity Impact Calculator (EPIC) (Williams *et al.*, 1989), Water

Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995), and RUSLE (Renard *et al*., 1997) models which have undergone sensitivity analyses (Young *et al*., 1987). Other references pertaining to testing and application of the AGNPS model are Hession et al. (1988), Park and Kim (1995), Parson *et al*. (1996), Prasher *et al.* (1995), Sathyakumar and Farrell-Poe (1995), Young *et al*. (1989), and Young *et al*. (1995).

2.2.4.5 Model Characteristics

AnnAGNPS perform calculations on a daily time step. AnnAGNPS simulates water, sediment, nutrients, and pesticide transport at the cell and watershed levels. Special components are included to handle concentrated sources of nutrients from feedlots and point sources, concentrated sediment sources with attached chemicals from gullies, and irrigation (water with dissolved chemicals and sediment with attached chemicals).

1. Methods

The model partitions soluble nutrients and pesticides between surface runoff and infiltration. Sediment-transported nutrients and pesticides are also calculated and equilibrated within the stream system. Sediment is subdivided into five particle size classes (clay, silt, sand, small aggregate, and large aggregate). Particle sizes are routed separately in the stream reaches.

2. Surface Runoff and Soil Moisture

For purposes of runoff generation and soil water storage, the soil profile is divided into two layers. The top 200 mm are used as a tillage layer whose properties can change (bulk density, etc.). The remaining soil profile comprises the second layer whose properties remain static. A daily soil moisture budget considers applied water (rainfall, irrigation, and snowmelt), runoff, evapotranspiration, and percolation. Runoff is calculated using the SCS Runoff Curve Number equation (Mockus, 1972), but is modified if a shallow frozen surface soil layer exists. Curve numbers are modified daily based upon tillage operations, soil moisture, and crop stage. Actual evapotranspiration is a function of potential evapotranspiration calculated using the Penman equation (Penman, 1948) and soil moisture content.

Time of concentration in each cell can either be input or calculated by the model. If calculated, cell time of concentration is the sum of the travel times from the hydraulically most distant point for overland flow, shallow concentrated flow, and concentrated flow within the cell. Calculations for the three flow types are based upon the NRCS TR-55 (SCS, 1986) procedures, modified by Theurer and Cronshey (1998). The first 50 m of flow length are treated as overland flow. The next 50 m are treated as shallow concentrated flow, while the length beyond this is treated as concentrated flow.

3. Erosion

Overland erosion of sediment is determined using the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997) and was modified to work at the watershed-scale in AnnAGNPS (Geter and Theurer, 1998). RUSLE is an erosion model predicting long time average annual loss resulting from raindrop splash and runoff from specific field slopes in specified cropping and management systems and from rangeland. However, it is currently considered the best sheet and rill technology suited for continuous simulation of watershed sediment yield. RUSLE is used to determine the delivery ratio for the sheet and rill erosion for each cell. The delivery ratio for the individual particle-size classes is proportioned according to their respective fall velocities. The resulting sediment is called the sediment yield to the stream system.

4. Nutrients

A daily mass balance for nitrogen (N), phosphorous (P), and organic carbon (OC) is calculated for each cell. Major components considered are plant uptake of N and P, fertilization, residue decomposition, and N and P transport. Soluble and sediment adsorbed N and P are calculated. N and P are further partitioned into organic and mineral phases. Plant uptake of N and P are modeled through a simple crop-growth stage index.

5. Pesticides

A daily mass balance adapted from GLEAMS (Leonard *et al.*, 1987) is computed for each pesticide. AnnAGNPS allows for any number of pesticides, each with their own independent chemical properties. Each pesticide is treated separately, independent

equilibration is assumed for each pesticide. Major components of the pesticide model include foliage wash-off, vertical transport in the soil profile, and degradation. Soluble and sediment adsorbed fractions are calculated for each cell on a daily basis.

6. Reach Routing

Peak flow for each reach is calculated using an extension of the TR-55 graphical peak discharge method (Theurer and Cronshey, 1998). Sediment routing is calculated based upon transport capacity relationships using the Bagnold stream power equation (Bagnold, 1966). Sediments are routed by particle size class where each particular size class is deposited; more entrained, or transported unchanged depending upon the amount entering the reach, availability of that size class in the channel and banks, and the transport capacity of each size class. If the sum of all incoming sediment is greater than the sediment transport capacity, then the sediment is deposited. If that sum is less than the sediment transport capacity, the sediment discharge at the downstream end of the reach will include bed and bank material if the user has indicated that it is an erodible reach.

Nutrients and pesticides are subdivided into soluble and sediment attached components for routing. Attached P is further subdivided into organic and inorganic. Each nutrient component is decayed based upon the reach travel time, water temperature, and an appropriate decay constant. Soluble nutrients are further reduced by infiltration. Attached nutrients are adjusted for deposition of clay particles. Equilibrium concentrations are calculated at both the upstream and downstream points of the reach. A first-order equilibration model is used.

2.2.4.6 Calibration

As with all physical-process models, the model input can be refined by comparing model simulations to observed data. The selection of the curve number largely controls runoff volume in models that use SCS curve number technology. Because of the impact of runoff volume on all other hydrologic processes, it is expected that the curve number may be one of the most sensitive parameters in the AnnAGNPS model.

2.2.4.7 Input / Output

AnnAGNPS includes 34 different categories of input data (Cronshey and Theurer, 1998). These can be further grouped into the following major classifications:

- climate,
- land characterization,
- field operations,
- chemical characteristics, and
- Feedlot operations.

The climatic data consist of precipitation, maximum and minimum air temperature, relative humidity, sky cover, and wind speed. Land characterization data include soil characterization, curve number, RUSLE parameters, and watershed drainage characterization. Field operation data include tillage, planting, harvest, rotation, chemical operations, and irrigation schedules. Feedlot operations include daily manure production rates, times of manure removal, and residual amount from previous operations.

There are over 400 separate input parameters necessary for model execution. Some of these parameters are repeated for each cell, soil type, land use, feedlot, and/or channel reach. Separate parameters are necessary for the model verification section. Default values are available for some of the input parameters. The daily climate data input set includes 22 parameters, eight of which are repeated for each day simulated. A climate generator, GEM, can be used to generate the precipitation and min/max air temperatures for AnnAGNPS. The development of other input data can be simplified because of duplication over a given watershed. Some of the geographical inputs including cell boundaries, land slope, slope direction, and land use, can be generated by GIS and digital elevation models.

Input is facilitated by an input editor, which is currently available with the model. The input editor provides for data input in a page type format, with each of the 34 major data categories on a separate input page. Input and output can be in either all English or all metric units. Separate input files for watershed and climate data allows for quick

changing of climatic input. Extensive data checks (with appropriate error messages) are performed as data are read and, to a lesser extent, after all data are read. Brief explanations of the input parameters are provided in the editor.

Output is expressed on an event basis for selected stream reaches and as source accounting from land or reach components over the simulation period. Output parameters are selected by the user for the desired watershed source locations (specific cells, reaches, feedlots, point sources, and gullies) for any simulation period. Source accounting indicates the fraction of a pollutant-loading passing through any reach in the stream network that came from the user identified watershed source location. Multiple watershed source and reach locations can be identified. Additionally, event quantities for user-selected parameters can be output at desired stream reach locations. Output analysis can be simplified by using the output editor.

2.2.4.8 Interfaces

Current interfaces for the model include:

- A Windows-based flow network generator (using Digital Elevation Model data) which can be used to subdivide the watershed into hydrologically-derived cells and to provide basic land information such as areas, slopes, and elevation;
- A Windows-based input editor for inputting or modifying AnnAGNPS input data.
- A Windows-based post processor for examining model output;
- Input data converter for old AGNPS data to AnnAGNPS input. AnnAGNPS can be run on an event basis after converting the AGNPS input file;
- A set of reference databases to assist with developing the input parameters.

2.2.4.9 Limitations and Applicability

The following limitations to the model are acknowledged by the developers:

- All runoff and associated sediment, nutrient, and pesticide loads for a single day are routed to the watershed outlet before the next day simulation begins (regardless of how many days this may actually take);

- There is no tracking of nutrients and pesticides attached to sediment deposited in stream reaches from one day to the next;
- Point sources are limited to constant loading rates (water and nutrients) for entire simulation period;

2.2.5 Application History

For more than a decade, AGNPS has been used worldwide for water quality and NPS pollution predictions. The following articles were selected as case studies since they show the progress that the model has made, and address the issues imperative to successful integrated AGNPS/GIS predictions. These projects include: Validation Study Using an Integrated AGNPS/GIS System (Mitchell *et al*., 1993), Sediment Yield Predictions (Perrone and Madramootoo, 1999), Evaluation of AnnAGNPS (Yuan, *et al.*, 2005) , and Soil Erosion Assessment (Muleta *et al*., 2005).

2.2.5.1 Validation of AGNPS for Small Watersheds Using an Integrated System

Mitchell *et al.* (1993) evaluated the suitability of a GIS/AGNPS integrated model system for predicting runoff and sediment yield from small, mildly slopping central Illinois watersheds. Half of the fifty sediment yielding runoff events were used to calibrate the model and averaged calibrated input was used for the remaining events to validate the model. The resulting simulated total annual runoff varied from 65 to 151%, and total annual sediment yield varied from 29 to 557% of the observed data. The model algorithms were unable to describe the watersheds small slope and area accurately. Despite their discrepancies, Mitchell *et al.* (1993) concluded the model is a valuable tool for water quality management, but required further work to improve accuracy and applicability.

2.2.5.2 Sediment Yield Prediction Using AGNPS

Perrone and Madromootoo (1999) evaluated the ability of the AGNPS model to predict sediment yield for a small Quebec watershed. The model was calibrated using adjusted NRCS curve numbers and USLE factors for twelve runoff events. The model averaged an error of 28% and a coefficient of performance of 0.01 for all sediment yield predictions.

Six of the twelve events were over-predicted, six events were under predicted, but eight among these predicted to within ±15% of the observed yield. The results indicated that though AGNPS was fairly reliable for surface runoff, careful attention should be given to the selection of seasonally adjusted USLE C factors and particle size distribution.

2.2.5.3 Evaluation of AnnAGNPS on Mississippi Delta MSEA Watershed

Yuan, *et al.* (2005) assembled all necessary data from the Mississippi Delta Management System Evaluation Area (MDMSEA) Deep Hollow watershed, to validate the AnnAGNPS model, and used the validated AnnAGNPS to evaluate the effectiveness of BMPs for sediment reduction. The study compared AnnAGNPS predictions with three years of field observations from the MDMSEA Deep Hollow watershed.

The study reported, using no calibrated parameters, AnnAGNPS underestimated observed runoff for extreme events, but the relationship between simulated and observed runoff on an event basis was significant (R^2 = 0.9). In contrast, the lower R^2 of 0.5 for event comparison of predicted and observed sediment yields demonstrated that the model was not best suited for short-term individual event sediment prediction; may be due to the use of Revised Universal Soil Loss Equation (RUSLE) within AnnAGNPS, and soil loss parameters were derived from long-term average annual soil loss estimates. The agreement between monthly average predicted sediment yield and monthly average observed sediment yield had an R^2 of 0.7. Three–year predicted total runoff was 89% of observed total runoff, and three-year predicted total sediment yield was 104% of observed total sediment yield. Alternative scenario simulations showed that winter cover crops and impoundments are promising BMPs for sediment reduction.

Eventually, Yuan, *et al.* (2005) concluded that, Watershed models are the most cost-effective tools to aid in the decision-making process of selecting the BMP that is most effective in reducing the pollutant loadings and The Annualized Agricultural Non-Point Source Pollutant Loading model (AnnAGNPS) is one such tool.

2.2.5.4 Soil Erosion Assessment of Lake Alemaya Catchment, Ethiopia

Muleta *et al.* (2005) integrated the Agricultural Non-point Source Pollution Model (AGNPS) and the technique of the Geographic Information System (GIS) to quantify soil erosion in the Lake Alemaya catchment. The result indicated that 66 per cent of the catchment has a soil erosion rate of 10 to more than 80 ton/ ha/ yr. The annual soil loss has been estimated at 31 ton /ha, which is more than the permissible value of 1-16 t/ ha for different agro-ecological zones of Ethiopia. The sediment yield of the catchment was about 10,148 ton with a delivery ratio of 6.82 %.

As Muleta *et al.* (2005) sited, Nigussie and Fekadu (2003) tested the AGNPS model on Augucho catchment, Western Hararghe, in the same region with a similar agro-ecology and farming system as the Lake Alemaya catchment, and found that sediment yield was well predicted with a correlation coefficient of 0.97 between the observed and predicted values. The observed sediment yields for erosive storms were 1225.5 tonnes in 1988 and 217.2 tonnes in 1990. Similarly, Hassen *et al.* (2004) validated the model on Kori gauged watershed, located in the Northern Ethiopian Highlands, and found that there was a strong linear association between measured and predicted values of sediment yield with a correlation coefficient of 0.98.

According to Muleta *et al.* (2005), the AGNPS model has produced realistic estimates of soil loss and sediment yield in the Lake Alemaya catchment, showed an appreciable spatial variation of soil loss in the catchment. The model also has the capability to identify areas within a watershed with high erosion and sediment yield, which could help to prioritize and formulate development and conservation plans in order to use available economic resources optimally. They also concluded that although the AGNPS model is a valuable tool in characterizing the spatial and temporal variation of soil erosion and sediment yield in watersheds, it is essential to develop a link between the model and GIS to process and analyse the necessary input data so that the efficiency of the model can be improved.

Ultimately, models have been essential tools for reducing or managing NPS pollution. As modelling becomes more commonly used, it must be remembered that models contain

uncertainties and limitations and should not be used as a NPS end-point. Among various water quality models, however, AnnAGNPS (aside from minor shortcomings) has proven accurate in simulating watershed systems and NPS pollution in different parts of the world including Ethiopia. Successful implementation of the integrated AnnAGNPS/GIS could be used as a decision support system for water quality planning and management.

3. OBJECTIVES

General Objective

The general objective of the study is evaluation of non-point pollutant sources in Lake Awassa watershed and evaluation of environmental risks using appropriate environmental model.

Specific Objectives

- Identify the various sources of pollutant loadings and their relative contribution to the lake pollution;
- Prioritize the various sources of pollutant loadings according to the environmental risks they pose and manageability;
- Propose environmental management plan and evaluate its effectiveness on reducing the pollutant loadings.

4. MATERIALS AND METHODS

4.1 Description of the Study Area

4.1.1 Location, Topography and Drainage

Lake Awassa watershed is located in the Central Main Ethiopia Rift valley (MER) and lies between latitude 6˚48'45"- 7˚14'49"N, and longitude 38˚16'34"- 38˚43'26"E. The lake watershed falls in two administrative regions, Oromia and Southern Nations Nationalities and Peoples Region (SNNPR) and has a total area of 1407.23 Km^2 of which 112.78 Km^2 (around 8.1% of the total area) is the Lake surface. Elevation of the area generally ranges from 1680m.a.s.l. to 2940m.a.s.l. comprising escarpments, ridges, plateau, undulating to rolling and dissected plains, depressions, and swamps.

Lake Awassa is a Closed-watershed Lake with no surface water outflow. It is located at about 275Km from Addis Ababa in SNNPR bordering the capital of the region Awassa in the west. It stretches 16 km NE-SW (the longest axis) and 6 km NW-SE (the shortest axis) with a maximum depth of 21 meter at its NE part and decrease in depth to the shores (Yemane, 2004). The lake is fed both by few ephemeral streams on the north-west and western side of the catchment and by the Tikur Wuha River, which is the only perennial river, enters Lake Awassa draining the Cheleleka swamp on the northeast side. Cheleleka swamp receives surface runoff from the headwaters of the eastern rift escarpment and from groundwater upstream.

The lake watershed mainly is characterized by a flat-lying topography with scattered small hills. Elevation of the rift escarpments and ridges in the east and west of the watershed range from 2000 to the maximum of 2940 m.a.s.l. It is known that the uplands on either side of the flat lowlands are deforested and denudated. The steeply sloping and deforested uplands are likely to produce high runoff to the lowlands shortly after individual storms. The continuous erosion process on the eastern highlands have resulted on filling Cheleleka Lake with sediment load and transformed it to a swamp (Yemane, 2004).

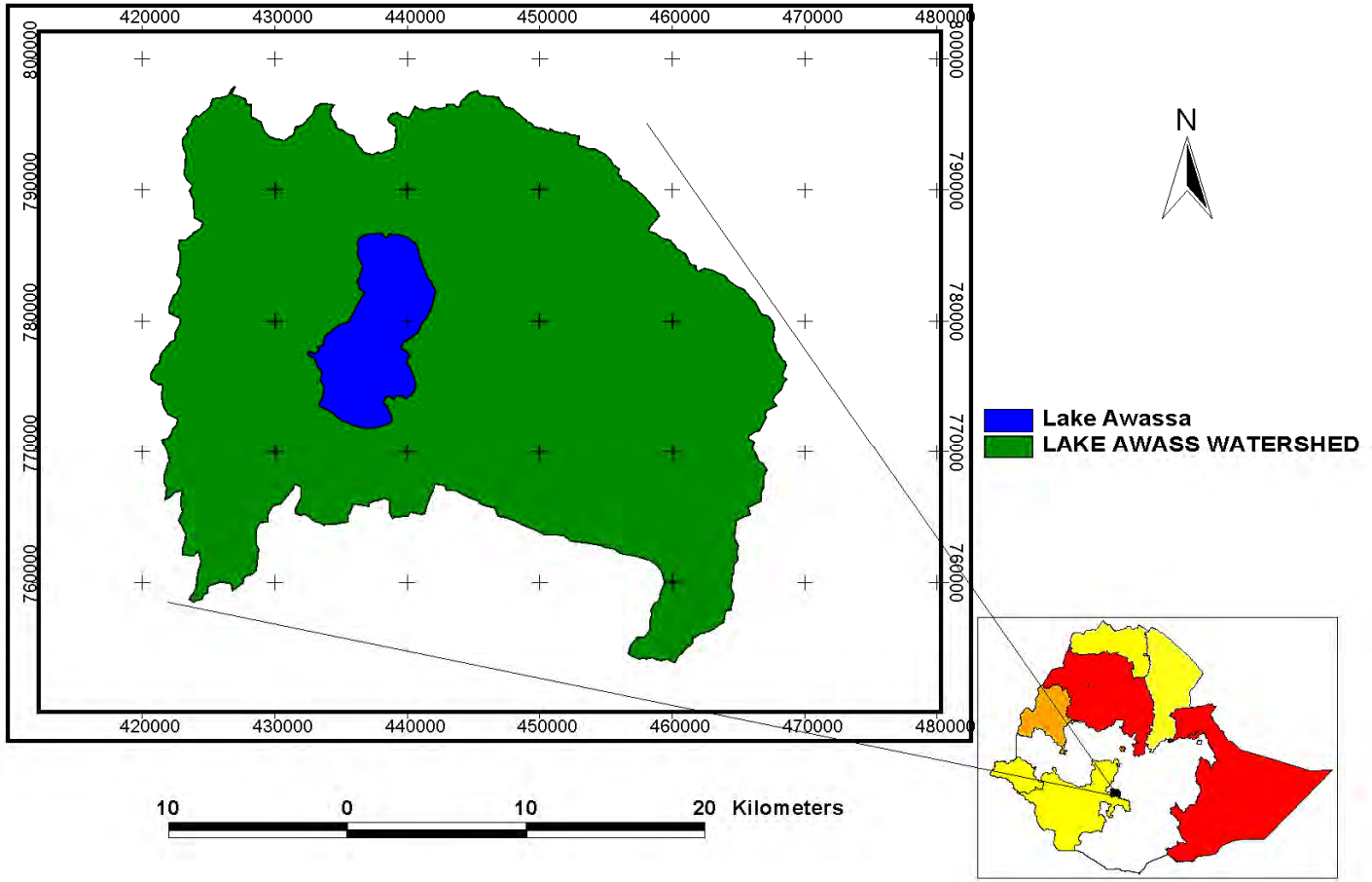

Figure 1 Lake Awassa Watershed Location Map

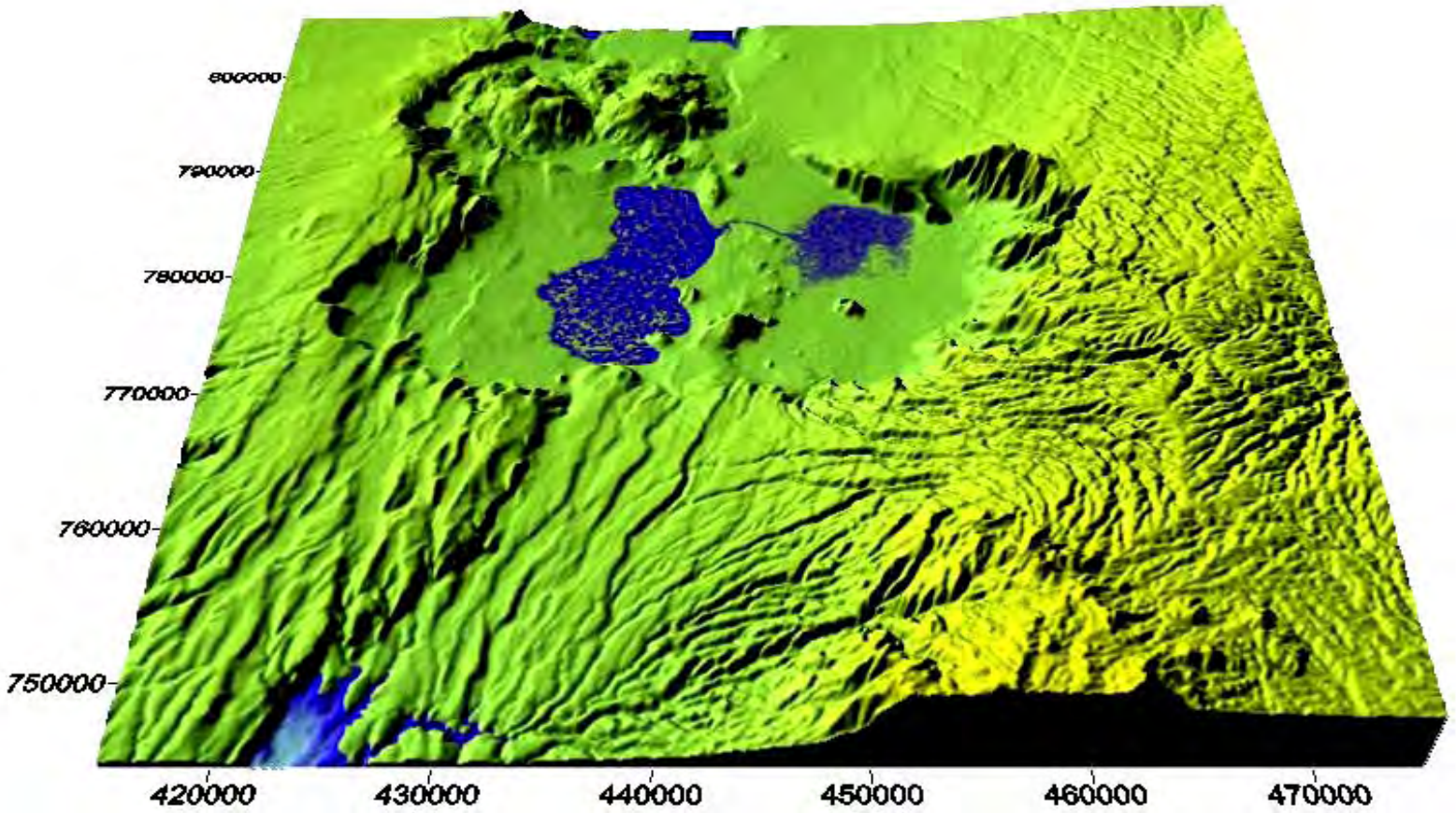

Figure 2 DEM of Lake Awassa Watershed

4.1.2 Climate

Lake Awassa watershed has extended period of wet season (March-October with mean monthly rainfall varying from 85 to 133mm). June to September rainfall contributes 44% to the mean annual precipitation in the watershed. The climate in the area is dry to sub-humid according to the Thornthwaite's system of defining climate or moisture regions (Dessie, 1995). The mean annual rainfall on bases of 12 to 30 years of record of five rainfall stations that contribute to the watershed is estimated to be 1028mm. Though there is no other station in the watershed that records temperature to compare with, it can be concluded from Awassa station that, the lowland part of the catchment annual temperature ranges from 9^0C to 29^0C, while mean monthly temperature is 19.7^0C (Yemane, 2004).

4.1.3 Land Use and Vegetation

According to Yemane (2004) land use and vegetation description for the year 2004, the eastern highlands of the watershed were moderately vegetated. The lowlands close to the foot of the escarpment have been relatively well covered with mixed type vegetation, while the poorly drained western part of the watershed was devoid of vegetation and lack of vegetation cover has been more severe in the high lands. The North Western mountainous area of the watershed was covered with dense bush. The land cover map of the study area made by Yemane (2004) based on October 2004 satellite images and field observations as well as that of 1965 made by WWDSE and modified by Yemane were used in this study. To adequately represent the effect of land use types in the modeling and simulation of runoff and erosion for the watershed the major land cover units modified by Yemane (2004), were classified in to 14 land cover units in the current study.

Accordingly, cultivated land covered with various types of crops was classified in to five sub classes namely: CL1 (Maize), CL2 (Maize + Coffee), CL3 (Maize + 'Chat'), CL4 (Maize + Potato), CL5 (Maize + 'Enset'), and CL6 (Maize + Haricot Bean). Grassland, shrubby grassland and swampy grassland were categorized in to two pasture sub classes

PAS1 (Pasture poor condition) and PAS2 (Pasture good condition). Bush land and bushy woodland are grouped under two rangeland subclasses RANGE1 (Shrub poor condition) and RANGE2 (Shrub good condition). Similarly, dense bushy woodland, open forest, dense forest and plantation forest were put under two forest sub classes FORES1 (Forest with high canopy cover) and FORES2 (Forest with low canopy cover). Lake and Swamp area (WATER), built-up (URB) and bare rocks (CL0) are considered as stand-alone sub classes and used in the current study (Fig. 3, Annex 9 and Annex 10).

4.1.4 Soil Classification

The soil map of the study area originally produced by WWDSE (2001) and modified by Yemane (2004) was adapted and used in this study (Fig. 4 and Annex 9).

4.1.5 Population

The total population of the catchment reported for the year 2007 is 757,496 of which 384,104 are male and 373,399 are female (AG Consults, 2007). Most of the population depends on agriculture that directly or indirectly is related to the water resources of the catchment including Lake Awassa, feeder rivers and groundwater.

4.2 Study Period

The period from 2000 - 2004 was used for this study because the required daily climate data available from the National Meteorological Services Authority (NMSA) is up to the year 2005. Model initialization was carried out using two years synthetic daily climate data (that of 1998 and 1999) and simulation running was carried out using historic daily climatic data of the years 2000 - 2004.

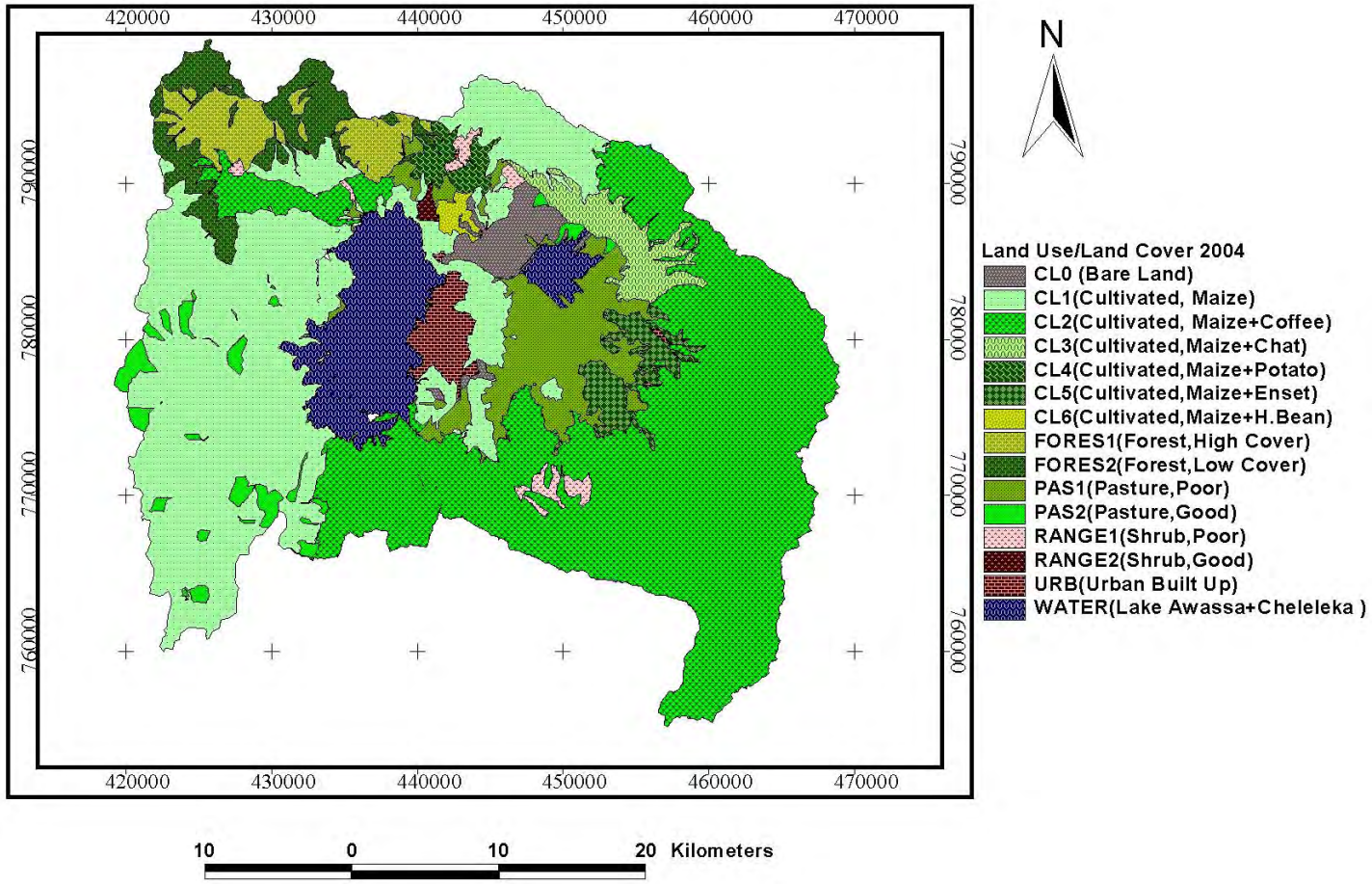

Figure 3 Land Use Map of 2004

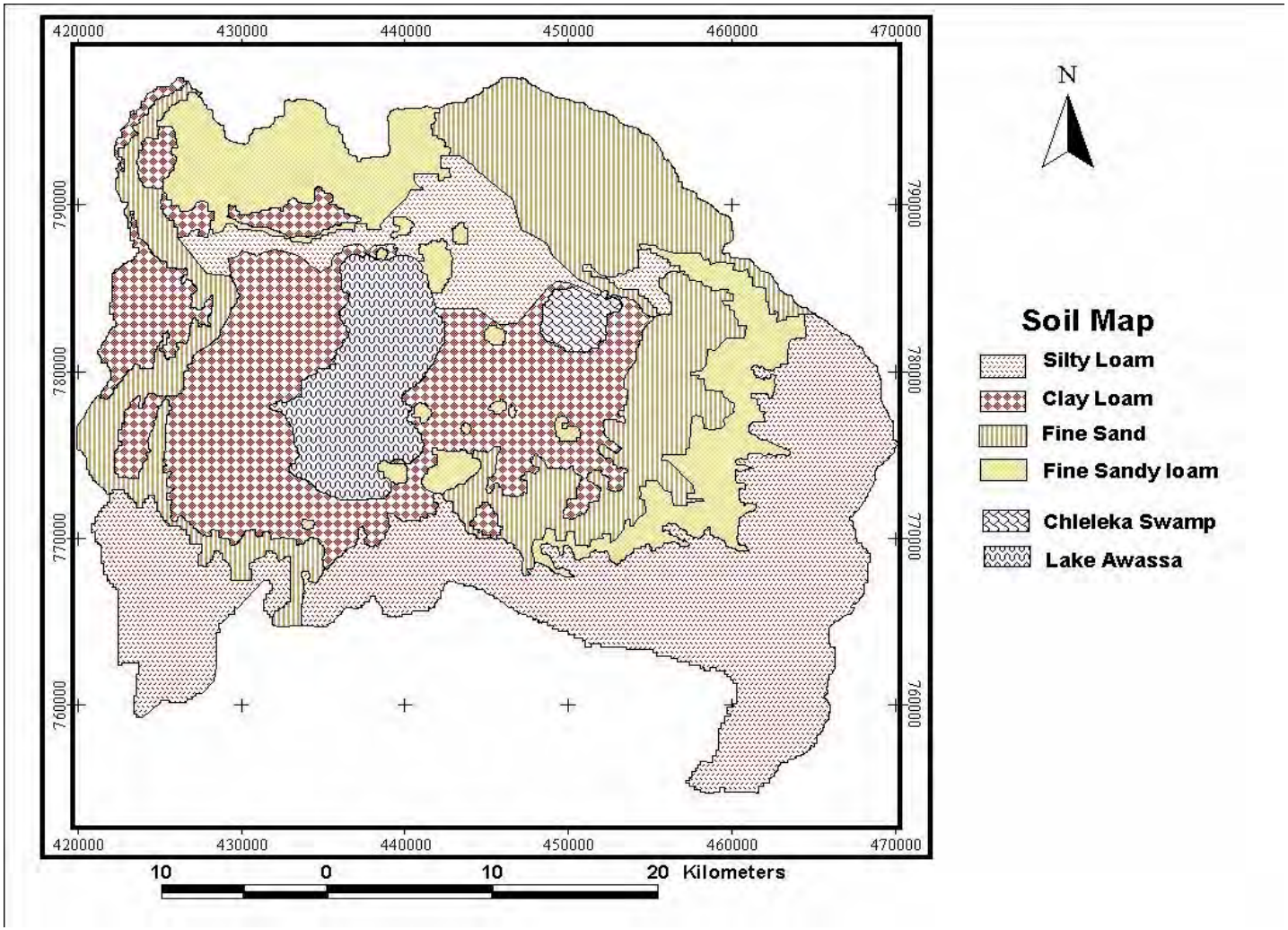

Figure 4 Soil Map of the Study Area

4.3 Methodological Framework

For this study, activities on collection of both primary and secondary data, data pre-checking and pre processing, input data preparation, model simulation and out put analysis were carried out using different measuring instruments including meter tape, clinometers, and Geographic Positioning System(GPS) as well as different Geographic Information System (GIS) softwares and downloaded AGNPS pollutant model.

4.3.1 Types and Sources of Data

The sources and details of the Primary Data Collected and used for the purpose of the study includes:

- Physical characteristics of the watershed (Cell and Reach related data) with Clinometers, Meter tape (2m and 50m), Global Positioning System (GPS, model GARMIN etrex venture), and topographic maps(Scale of 1:50,000);
- Field Management Practices like crop calendar, crop rotation, tillage, fertilizer application, pesticides application etc were collected by interviewing farmers and Sidama Zone and Awassa Zuria Wereda Rural Development Coordination Office experts as well as key informants ;
- Point Source identification and location using GPS and topographic maps of the watershed;
- General observation of the watershed based on available soil and land use/cover maps.

The sources and particulars of Secondary Data used include data on:

- Daily, monthly and long term mean annual climate data (Temperature, Rainfall, Wind Speed and Sky Cover) from the NMSA for the years 2000-2005;
- Digital Elevation Model (DEM) 90 m resolution of the watershed;
- Land Use/Land Cover maps of 1965, 1994 and 2004(initially produced by WWDSE and updated and used by Yemane G.(Yemane, 2004));

- Topographic Maps from National Mapping Agency (Scale 1:50000);
- Watershed Physical Characteristics including soil properties and water quality from different literature and Laboratory analysis report conducted for AG Consult Consulting Hydrologists and Engineers Plc. by Debub University, Ministry of Water Resources and SNNPR Soil Laboratories.

4.3.2 Data Pre-processing, organization and Analytical Techniques

- Geographic Information System (GIS) software;
    - DEM of the study area was extracted from Shuttle Radar Topographic Mission (SRTM) data (ETH.hgt 90m resolution) using Global Mapper 7, designed for visualization and utilization of the SRTM data of the USA, Export Raster and Vector Data Command;
    - Processing of topographic related data from the exported DEM of the area was done using ArcView GIS 3.3 with its Spatial Analysis and Hydro extensions loaded including the processing of DEM, Flow Direction and Flow Accumulation determination, Stream Network generation and Watershed and Sub Watershed delineation;
    - Digitizing and Processing of soil and Land use/cover scanned maps to the format needed by the AnnAGNPS model was done using ILWIS Academic 3.3 Software Create Segment Map, Polygonize and Export commands;
- Major input data preparation, pollution simulation and output analysis & formatting was carried out using the AnnAGNPS v3.5 (Release date April 2005) AGNPS/Arc View interface, aided by the Technical Documentation and User's Guide of the model;
- Qualitative analysis of simulation Output and plotting of scenarios involving Averages has been conducted by using Arc View 3.3, Surfer 8 Worksheet, and Microsoft Excel 2003 Spreadsheet.

5. RESULT

The AnnAGNPS pollutant-loading model simulation output, with watershed land cover map of 2004(adapted from Yemane, 2004) and model initialization and simulation using two and five years synthetic and historic daily climate data, respectively; has a recorded rainfall events of 789 and average rainfall events per year of 157.8. The ensuing out put for the year 2004; with average annual precipitation of 792.410mm, from the runoff events recorded in the average annual output table is summarized and given below:

5.1 Accumulated Average Annual Surface Water Yield

Model output for the accumulated landscape & watershed water yield (Mass per Unit Area per Annum); given as average annual loading rate at Lake Awassa, equals 53.32mm/ha/yr, with its components being, subsurface direct yield of 0.21, and surface direct yield of 53.11. The summary by Intensity and Land Use Classes and the respective area coverage and contribution of each class to the total annual water yield presented in Table 2 and Figure 5, in that order.

Table 2 Average Annual Surface Water Yield by Intensity Class

Intensity Class (mm/ha/hr)	Area (ha)	% Area	Average[1] Yield (mm/ha/hr)	Actual[2] Yield (Mm^3)	% Total Yield
< 1.0	19447.85	13.82	0.17	9.12	0.08
1.0- 15.0	39064.57	27.76	8.68	643.59	5.80
15.0- 50.0	38431.31	27.31	30.95	2268.58	20.44
50.0- 100.0	4489.05	3.19	60.00	441.21	3.97
> 100.0	39289.72	27.92	146.73	7738.20	69.71
Total	140722.50	100.00	53.32	11100.70	100.00

[1] Average for contributing cells in that intensity class (Same for the subsequent Tables and Figures).

[2] Sum of the annual water yield from each contributing cell (Same for the subsequent Tables and Figures).

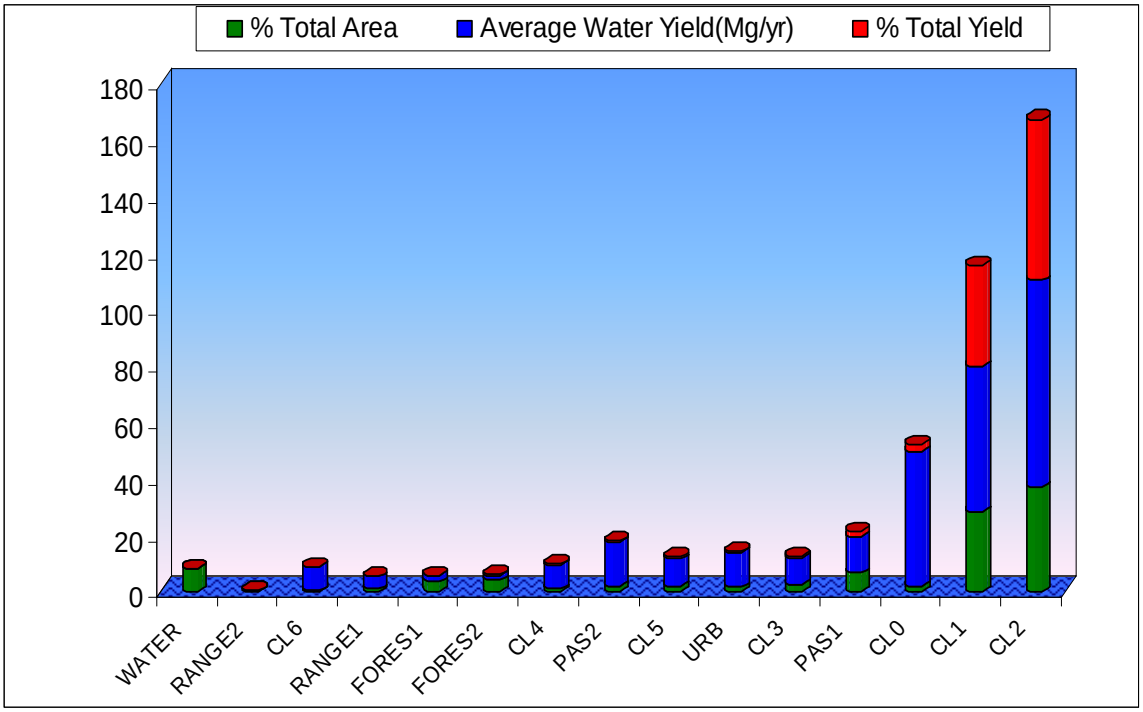

Figure 5 Average Annual Surface Water Yield by Land Use Class

Note: The legend for the land use classes used represent

CL0 = Bare Land,
CL1 = Cultivated (Maize),
CL2 = Cultivated (Maize + Coffee),
CL3 = Cultivated (Maize + 'Chat'),
CL4 = Cultivated (Maize + Potato),
CL5 = Cultivated (Maize + 'Enset'),
CL6 = Cultivated (Maize + Haricot Bean),
FORES1= Forest (High Cover),
FORES2 = Forest (Low Cover),
PAS1 = Pasture (Poor),
PAS2 = Pasture (Good),
RANGE1 = Shrub (Poor),
RANGE2 = Shrub (Good),
URB = Urban Built-up,
WATER = Lake Awassa and Cheleleka Swamp

(Legend the same for the subsequent Tables and Figures)

5.2 Accumulated Average Annual Sediment Yield

The annual average landscape and watershed erosion for each cell in the watershed differentiated and aggregated by particle size class and accumulated for the simulation period is zero for Bed and Bank for all reaches. The watershed totals, for sheet and rill erosion; by particle size class in Ton/ha/yr is 0.073, 0.106, 0.167 for clay, silt and sand, respectively. The output for small and large aggregates is 0.251 and 0.428 correspondingly. Watershed total annual average for landscape and watershed erosion amounted to 1.024 Ton/ha/yr.

Table 3 Average Annual Sediment Erosion by Intensity Class

Intensity Class	Area (ha)	% Area	Average Yield (Mg/yr)	Total Yield (Mg)	% Total Yield
< 1.0	115538.03	82.10	0.22	1069.39	25.14
1.0- 15.0	24223.78	17.21	2.91	2222.48	52.24
15.0- 50.0	599.83	0.43	30.57	275.14	6.47
50.0- 100.0	360.82	0.26	76.36	687.21	16.15
> 100.0	0.00	0.00	0.00	0.00	0.00
Total	140722.47	100.00	0.74	4254.21	100.00

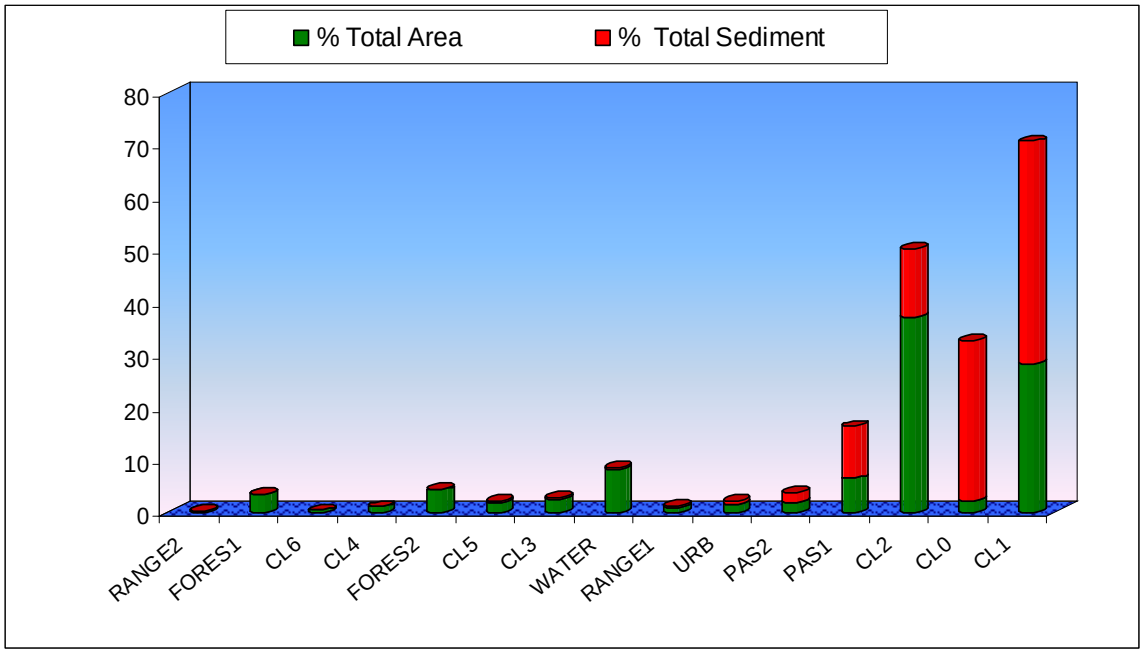

Figure 6 Average Annual Sediment Erosion by Land Use Class

5.3 Accumulated Average Annual Nitrogen Yield

The above simulation run out put average annual file for Nitrogen yield to the stream system (unit area) showed values of 0.019, 0.172, and 0.191 Kg/ha/yr for Attached, Dissolved and Subtotals respectively, and summarized by intensity and land use class as presented in Table 4 and Figure 7 correspondingly.

Table 4 Average Annual Nitrogen Yield by Intensity Class

Intensity Class	Area (ha)	% Area	Attached N (Kg/ yr)	Dissolved N (Kg/ yr)	Total N (Kg/ yr)	% Total N
< 1.0	133185.82	94.64	55.59	515.42	581.89	43.07
1.0 -2.0	0.00	0.00	0.00	0.00	0.00	0.00
2.0 - 3.0	0.00	0.00	0.00	0.00	0.00	0.00
3.0 - 4.0	0.00	0.00	0.00	0.00	0.00	0.00
4.0 - 5.0	7536.66	5.36	0.04	768.60	769.04	56.93
Total	140722.47	100.00	55.63	1284.02	1350.93	100.00

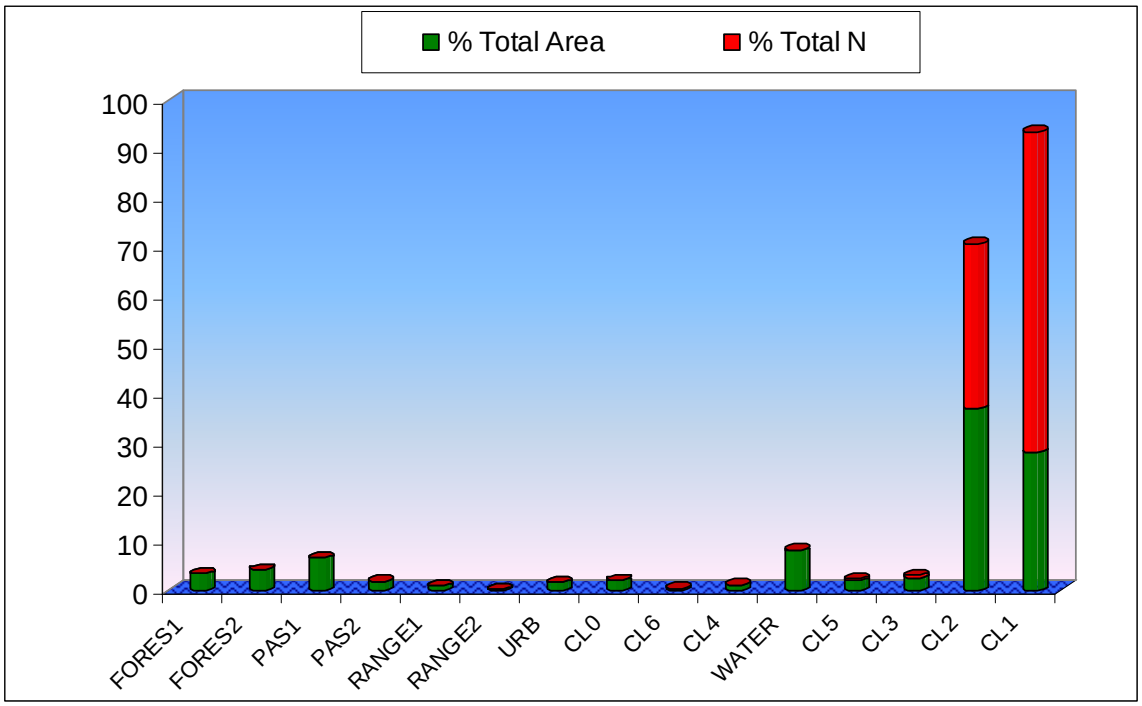

Figure 7 Average Annual Nitrogen Yield by Land Use Class

5.4 Accumulated Average Annual Organic Carbon (OC) Yield

The Average Annual File for OC showed Attached, Dissolved, and Subtotal Yield to the Stream System to be 0.922, 0.000, and 0.922 Kg/ha/yr respectively. Each cell's contribution, recapitulated by Intensity and Land Use Class is presented in Tables 5 and Figure 8.

Table 5 Average Annual Organic Carbon (OC) Yield by Intensity Class

Intensity Class	Area(ha)	% Area	OC (Kg/yr)			% Total OC
			Attached	Dissolved	Total	
< 1.0	114813.71	81.59	973.16	0.00	973.16	22.78
1.0 - 15.0	24977.98	17.75	2207.95	0.00	2207.95	51.68
150 - 50.0	777.29	0.55	651.28	0.00	651.28	15.24
50.0 - 100.0	153.49	0.11	439.88	0.00	439.88	10.30
> 100.0	0.00	0.00	0.00	0.00	0.00	0.00
Total	140722.47	100.00	4272.27	0.00	4272.27	100.00

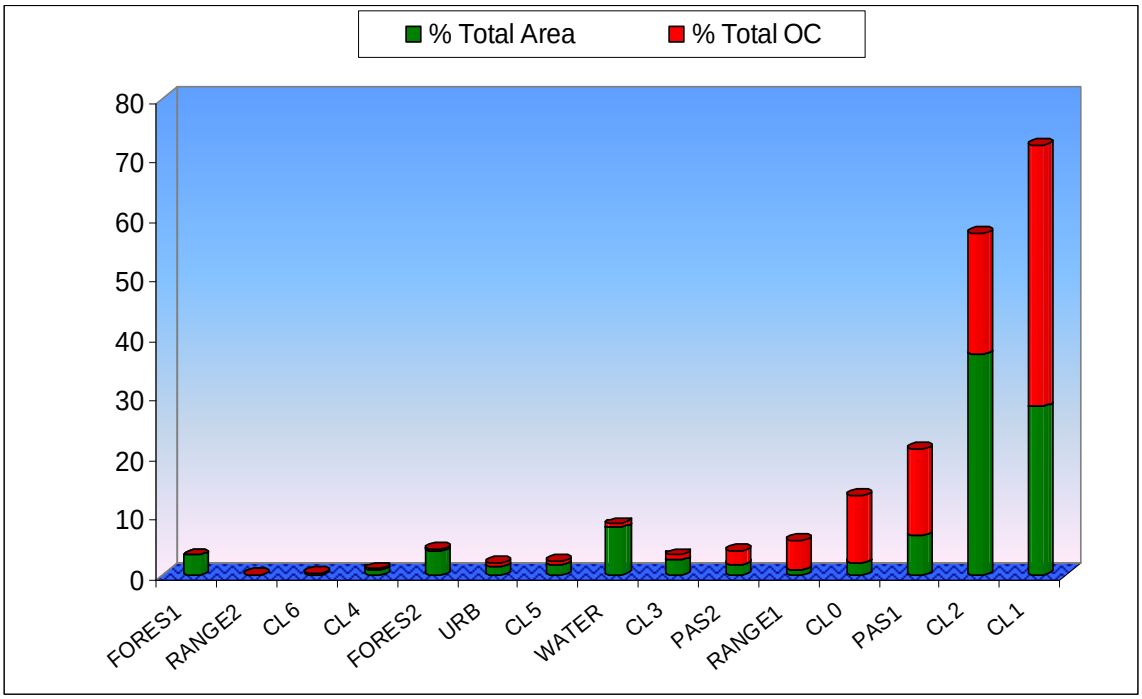

Figure 8 Average Annual Organic Carbon (OC) Yield by Land Use Class

5.5 Accumulated Average Annual Phosphorous (P) Yield

The Attached and Dissolved components of Phosphorous average annual yield per unit area to the stream system are recorded to be 0.029Kg and 3.170Kg, with the overall subtotal of 3.199 Kg/ha/yr. The summary by Intensity and Land Use Class of contributing cells is given in Tables 6 and Figure 9, respectively.

Table 6 Average Annual Phosphorous (P) Yield by Intensity Class

Intensity Class	Area (ha)	% Area	Attached P (Kg)	Dissolved P (Kg)	Total P (Kg)	% Total P
< 1.0	103347.45	73.44	2.99	154.73	157.72	0.03
1.0 - 15.0	866.30	0.62	9.04	818.33	826.80	0.15
150 - 50.0	591.48	0.42	28.38	5505.01	5533.38	0.99
50.0 - 100.0	2153.57	1.53	68.20	14132.90	14201.09	2.55
> 100.0	33763.67	23.99	7230.76	529830.92	537061.69	96.28
Total	140722.47	100.00	7339.37	550441.89	557780.68	100.00

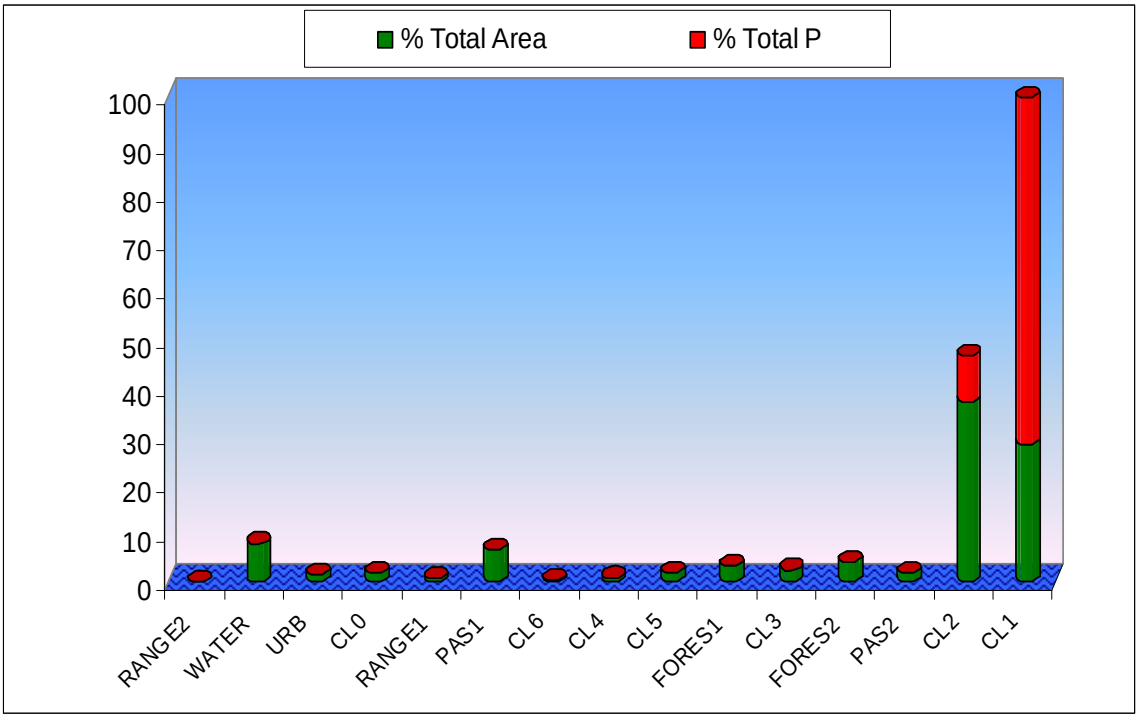

Figure 9 Average Annual Phosphorous (P) Yield by Land Use Class

6. DISCUSSION

6.1 Accumulated Average Annual Surface Water Yield

The Accumulated Landscape and watershed water yield to the stream; given as annual average loading rate per unit area, ranges between 0.00 to 183.31 mm/yr. The mean loading rate for the whole watershed equals 53.32 mm/yr with a subsurface direct yield of 0.21, and surface direct yield of 53.11. The sub-surface component's contribution to the total loading is only 0.39% (Table 2).

Rearranging and classifying the model out put by intensity classes the volume area relationship existing has been clearly observed. Nearly 70% of the Accumulated Landscape and watershed water yield has originated from cells covering only 30% of the effective catchment area (Southern and Eastern parts of the watershed with higher slope gradient and comprising Cultivated Land with Maize (CL1) and Maize + Coffee (CL2)). The area coverage of cells with annual loading rates of 1.0-15.0, 15.0-50.0, and above 100.0 Kg/ha/yr is nearly equal each around 30%. Where as, the percentage contribution from these intensity classes have significant difference at about 15% between the first and the second and around 50% between the second and the third (the relative output from the 1.0-15.0 class is 28.43 and 8.32% of the 15.0-50.0 and the >100.0 class outputs, respectively). Similarly, cells yielding under 1.0mm/yr; at about 6% of the effective catchment contributed to only 0.08%, while those cells yielding between 50.0 and 100.0mm/yr covering around 3% contributed nearly 4% to the total water yield (50 fold of the under 1.0mm/yr class contribution which has double its size) (Table 2, Fig.3 and Fig. 5).

Further analysis of the Accumulated Landscape and watershed water yield to the stream in terms of land use/land cover revels that, it ranges from 0.09 to 73.03mm/yr in the effective catchment area, the least being for RANGE2 (Shrub land, Good Condition) and the highest for that of CL2 (Cultivated land with Maize + Coffee). In addition to that, the analysis based on land use/land cover indicates CL1 (Cultivated land, Maize) with a rate

of 51.4 tons/yr and CL0 (Bare Land) with a rate of 47.57 tons/yr followed the highest rate of CL2. The contribution of these three top yielding classes is more than 95% of the total annual water yield in the watershed from combined effective catchment area coverage of around 73% (Fig. 5 and Annex 2).

In this result, the higher water yield from CL2 than from that of CL1 and CL0 most probably is due to the higher altitude and slope condition where Maize and Coffee mixed farming system is practiced. In this context the land use/land cover type such as CL2, CL1 and CL0 are the most critical land use classes, followed by PAS2 (Pasture, Poor Condition), PAS1(Pasture, Good Condition) and URB (Urban Built-up) regarding water yield, in that order. This result is consistent with previous reports conducted regarding water yield and with the well-founded research outcomes of hydrological phenomenon, i.e. facts of rainfall-runoff inter linkage with land use/land cover.

Comparison of runoff generated for the study period (2004) land use/land cover condition to that of 1965 scenario shows an increase of runoff by about 28% (Annex 8). Similar comparison made by Yemane (2004) reported a change of 26% using the Thornthwaite and Mather soil water balance procedure and spreadsheet model for the same period(-22% for 1968-1998 and 4% for 1998-2004). Moreover, the mean annual water yield simulated by the current study has only a 7% difference between long-term mean annual catchment runoff reported by Yemane (2004). The slight deviation between the results is insignificant for comparing scenarios at a watershed level. The slight magnitudinal deviation could be the cumulative effect of several uncontrolled factors. However, most likely; the most important factors could be those associated and controlled by the critical land use categories considered and time steps used for the analysis in the current and the previous study, for which the decisions are dictated by the methodology followed and the complex and dynamic socioeconomic and socio-cultural conditions prevail in the watershed.

The individual difference and spatial distribution of The Accumulated Annual Average Water Yield simulation out put at a cell level from the AnnAGNPS model and summarized in Table 2 and Annex 2 is shown in Figure 10.

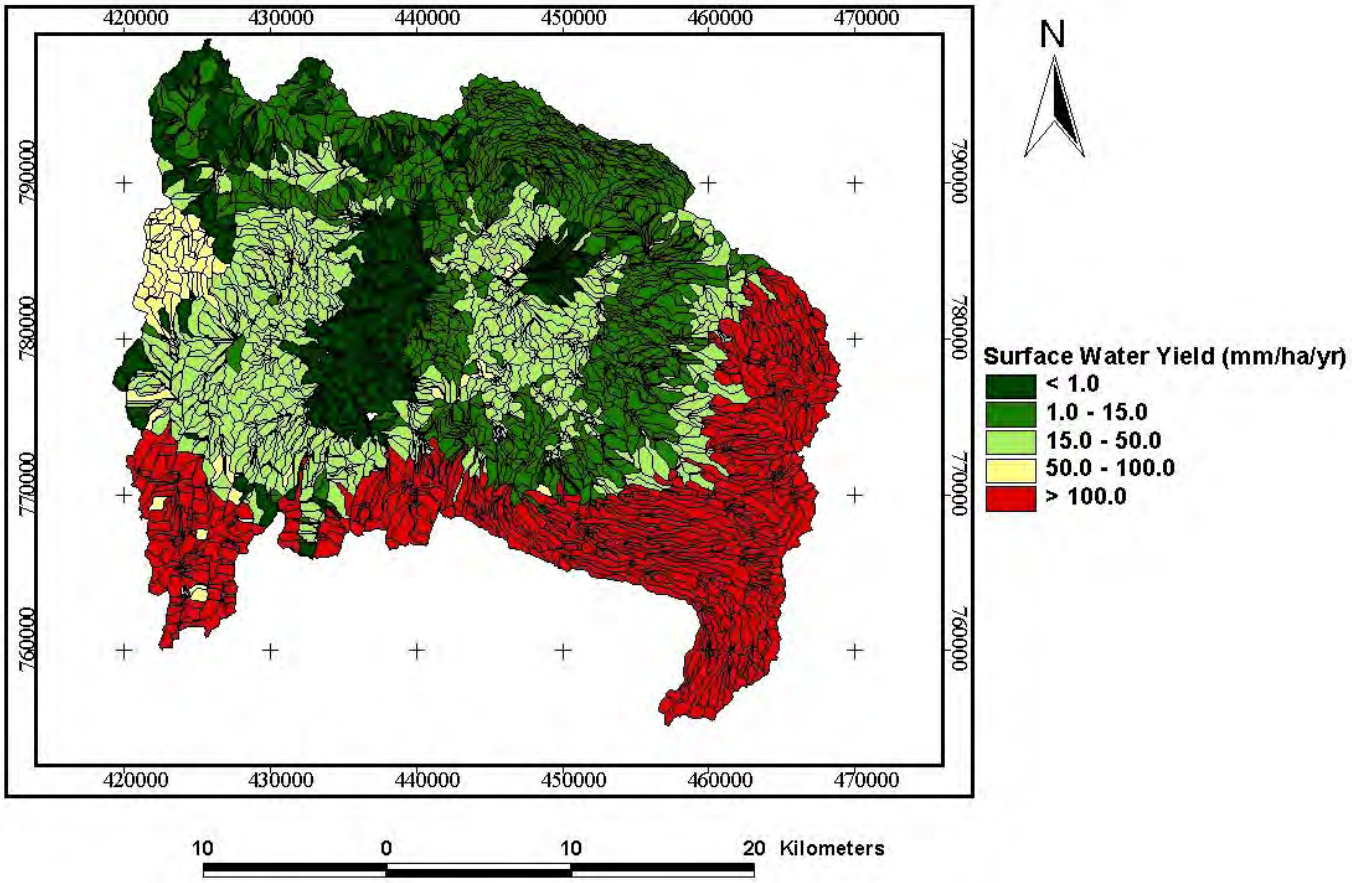

Figure 10 Accumulated Average Annual Surface Water Yield

6.2 Accumulated Average Annual Sediment Yield

The Accumulated Landscape and Watershed Erosion; given as annual average loading rate per unit area, ranges between 0.00 to 86.85 Mg/yr. The mean loading rate for the whole watershed equals 1.02Mg/ha/yr.

Further classification in to different intensity classes showed that around 80% of the effective catchment area has a loading rate less than 1Mg/yr and contributed to nearly 25% of the total load. More than 50% of the total load originated from 18% of the watershed having intensity between 1 and 15Mg/yr (Eastern and South Eastern areas around Lake Awassa predominantly cultivated with maize, Northern areas of Cheleleka Swamp bare land and cultivated with maize and 'chat' and scattered areas at eastern parts of the watershed cultivated with maize and coffee) . The remaining nearly 25% of the load comes from an area covering less than 2% of the effective catchment (Southern parts of Awassa town cultivated with maize, Pasture poor and bare land, as well as Northern parts of Cheleleka Swamp cultivated with maize and bare land) (Fig.3, Fig. 6 and Table 3). This result and the areas identified as critical erosion sources by the current study highly agree to that reported by WWDSE (2001), Yemane (2004) and AG Consults (2007) despite the high variability between the reported volumes both for the rate and total volume of erosion between each other and with the current study. This inconsistency might possibly originate from the methodological difference between the procedures followed in each of the studies and the time scale difference between the analyses as mentioned earlier. In addition to that, the subjective difference associated with characterizing the dynamic behaviour of systems, including uncertainty about the value of the parameters representing system behaviour and size of watershed (Novotny and Olem, 1993) could be potential sources for the observed difference.

Analysis of the sediment yield with respect to land use/land cover shows the first three most contributing land use/land cover classes are CL1, CL0 and CL2. Analysis of the relative sediment yield with standardized area coverage shows the most yielding land use/land cover classes to be CL0, PAS1 and CL1 with a magnitude of 15.4, 1.54 and

1.50, respectively, accordingly identified as critical classes in terms of sediment yield. The critical area identified and ranked in the current study is in absolute harmony with that reported by WWDSE (2001) for the study area, as well as consistent with the hydrologic principles of runoff and sedimentation (Fig. 6 and Annex 3).

More over, despite the higher water yield from CL2 than CL1(Annex 2), as discussed in the previous section most likely due to topographic factors; the relative rate of sedimentation of CL2 at about 0.35 is lower than that of CL1 (Annex 3). This can be substantiated by the cover available through out the year under the agro-forestry/mixed farming practice of CL2, which has its contribution in the reduction of different forms of detachment and transport of soil particles than that of seasonal and strip crop cover under the homogeneous maize cultivation. The same reasoning can be forwarded for the highest rate of sedimentation observed for CL0 (Bare Land), which is devoid of cover to protect the soil.

The individual difference and spatial distribution of the accumulated annual average sediment yield simulation out put at a cell level from the AnnAGNPS model and summarized in Table 3, Figure 6 and Annex 3 is shown in Figure 11.

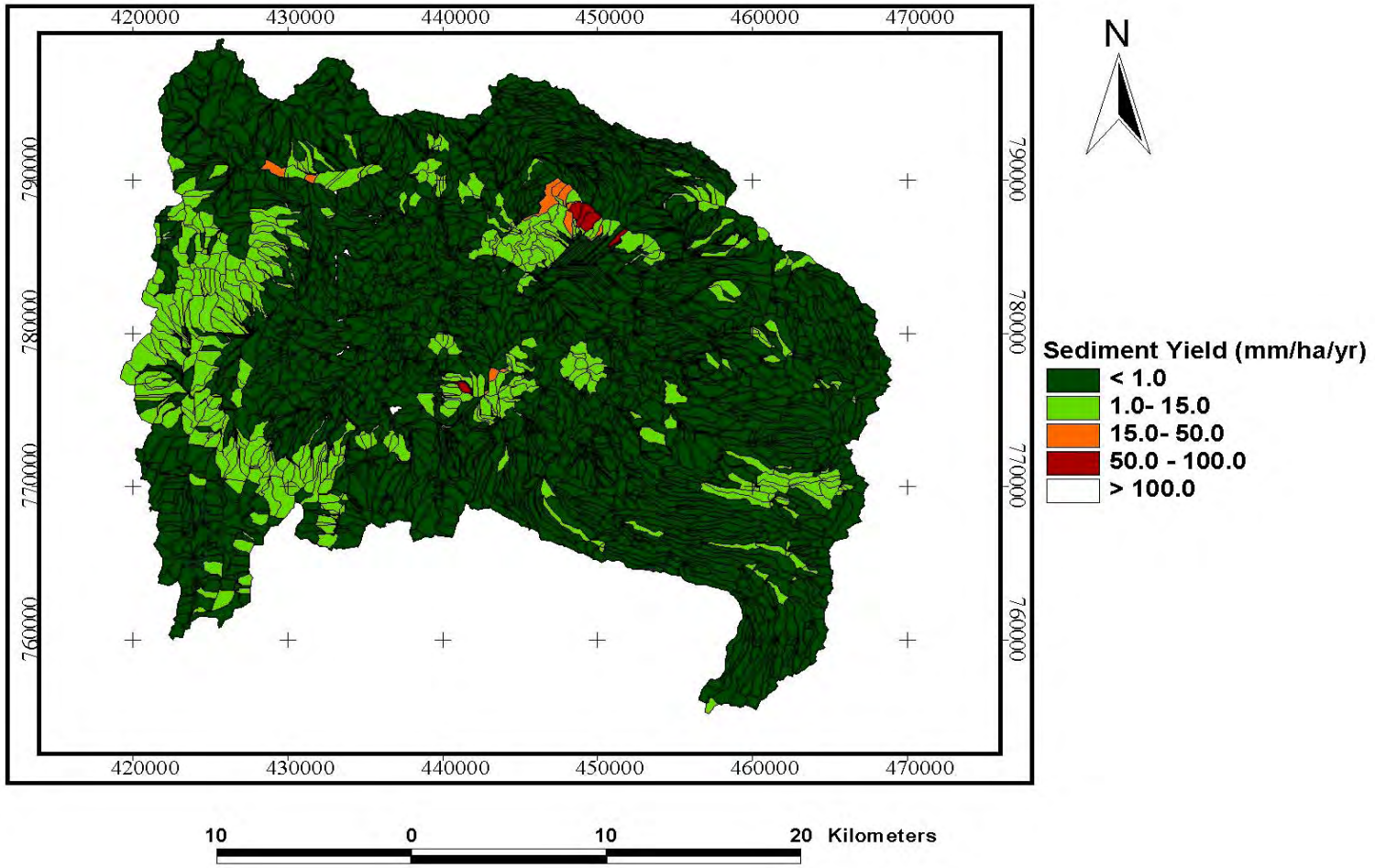

Figure 11 Accumulated Average Annual Sediment Yield

6.3 Accumulated Average Annual Nitrogen Yield

The accumulated average annual nitrogen yield to the stream given as mass per unit area ranges between 0.0 and 4.14 Kg/ha/yr. The mean value for the attached and dissolved components equals 0.019 and 0.172 Kg/ha/yr respectively, resulting in a total loading rate of 0.191 Kg/ha/yr.

Classification in to different intensity classes exhibit that around 43% of the total Nitrogen load was from 95% of the total watershed having a loading rate of < 1.0 Kg/ha/yr while the remaining 5% of the total area contributed nearly 57% of the total load and has an intensity of > 4.0 Kg/ha/yr (Table 4 and Fig.7).

Further analysis in terms of Land use/Land cover shows almost 99% of the total load originated from only two Land Use/Land Cover classes. CL1 contributed about 65% and CL2 contributed nearly 34% of the total N load (Fig.7 and Annex 4). From this it can be shown that the primary source for the N load is fertilization and the output depends on the water yield from the land use/land cover class since the N is dominantly transported as dissolved. Accordingly, CL1 and CL2 are selected as critical land use/land cover classes with respect to Nitrogen yield for the watershed.

This result, even though there is no detailed study regarding the sources and contribution of chemical pollution in the watershed to compare with, perfectly reflects the eutrophic condition of the lake portrayed through various studies in the past. It also clearly shows the origin and contribution of the N pollution and N pollutant sources as there is, according to (Seelig and Nowatzki, 2001), a positive correlation between amount of agricultural land in a watershed and the concentration of N in watershed streams.

The individual difference and spatial distribution of the accumulated annual average Nitrogen yield simulation out put at a cell level from the AnnAGNPS model and summarized in Table 4, Figure 7 and Annex 4 is shown in Figure 12.

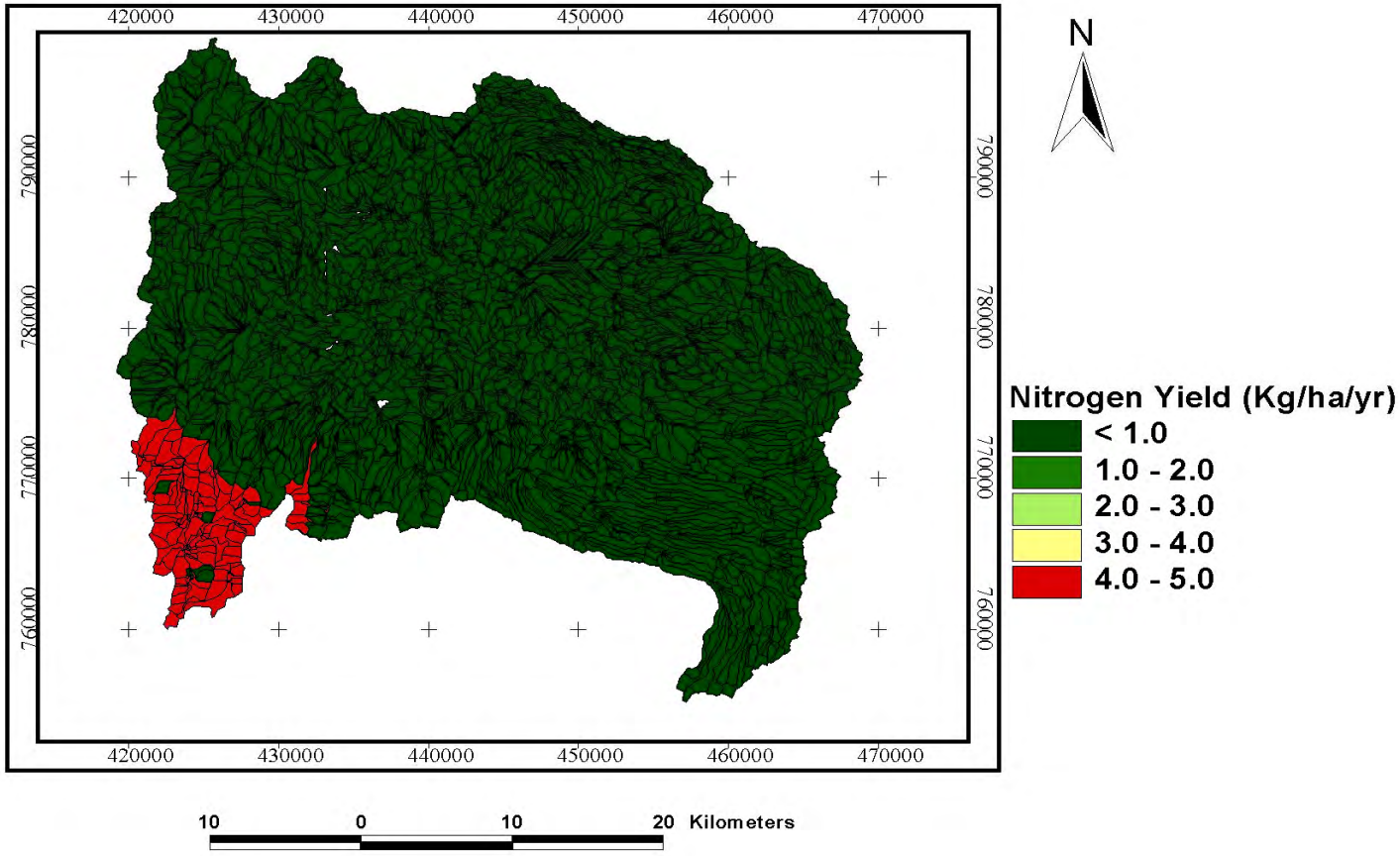

Figure 12 Accumulated Average Annual Nitrogen Yield

6.4 Accumulated Average Annual Organic Carbon (OC) Yield

The accumulated average Organic Carbon (OC) yield to the stream given as mass per unit area ranges between 0.0 and 73.59 Kg/ha/yr. The mean value for the attached and dissolved components equals 0.922 and 0.000 Kg/ha/yr respectively, resulting in a total loading rate of 0.922 Kg/ha/yr. The OC load to the stream system was completely transported in the attached form, which depends on the amount of sediment yield from the respective cell for its transport in addition to its production.

Nearly 75% of the total OC loading comes from cells having intensity less than 15.0 Kg/ha/yr and the remaining 25% originated from intensity classes between 15.0 and 100.0. Cells having intensity less than 1.0 Kg/ha/yr and contributing around 23% of the total OC load cover nearly 82% of the watershed total area. Accordingly, cells having intensity greater than 1.0 kg/ha/yr and contributing to more than 77% of the total load were identified as critical areas in terms of OC loading covering an area of 18% of the total watershed (Table 5).

The analysis based on Land use/Land cover shows that CL0, RANGE1, PAS1, and CL1 are the leading sources for the OC load having standardized intensities of 5.71, 5.7, 2.2 and 1.6 correspondingly, followed by PAS2, CL2, CL3, and CL5 with respective standardized loading intensities of 1.2, 0.54, 0.35, and 0.3 (Fig. 8 and Annex 5).

The individual difference and spatial distribution of the accumulated annual average Organic Carbon (OC) yield simulation out put at a cell level from the AnnAGNPS model and summarized in Table 5, Figure 8 and Annex 5 is shown in Figure 13.

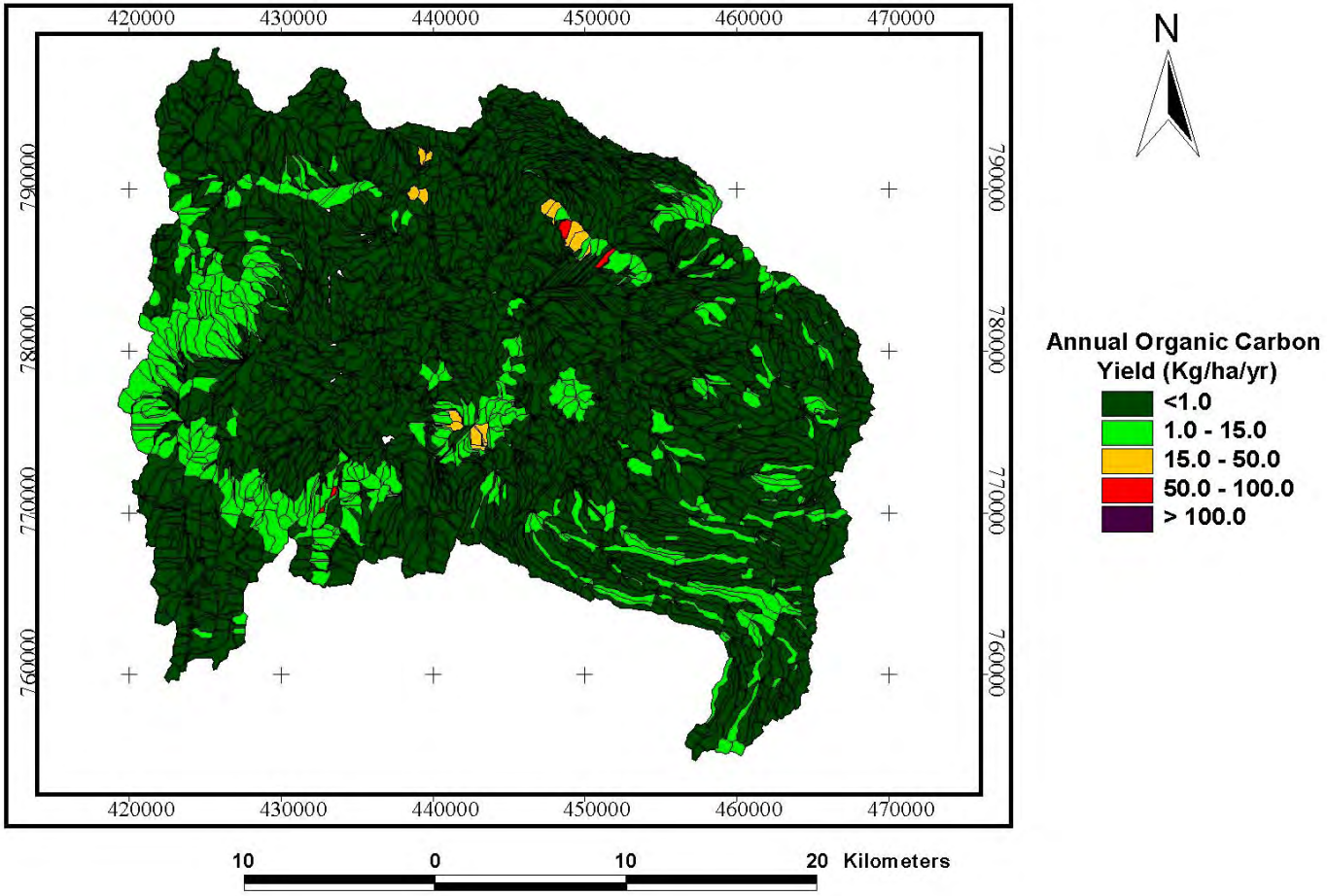

Figure 13 Accumulated Average Annual Organic Carbon (OC) Yield

6.5 Accumulated Average Annual Phosphorous (P) Yield

The accumulated average Phosphorous (P) yield to the stream given as mass per unit area ranges between 0.0 and 2961.9 Kg/ha/yr. The mean value for the attached and dissolved components equals 0.029 and 3.17 Kg/ha/yr respectively, resulting in a total loading rate of 3.199 Kg/ha/yr.

More than 96% of the total P loading comes from cells having intensity greater than 100.0 Kg/ha/yr covering nearly 25% of the watershed area and only the remaining 4% originated from intensity classes less than 100.0 from 75% of the total area. Accordingly, cells having intensity greater than 100.0 kg/ha/yr and contributing to more than 96% of the total load were identified as critical areas in terms of P loading covering 25% of the total watershed area (Table 6).

The analysis based on Land use/Land cover shows that CL1 is the leading source for the P load having standardized intensity of 3.2 and contributing 90.5 of the total load, CL2 followed CL1 with a value of 0.26 and 9.5% for the standardized intensity and contribution to the total loading. Accordingly, CL1 is identified as a critical Land Use/Land cover class in terms of P loading covering 28.3% of the watershed (Fig.9 and Annex 6).

The individual difference and spatial distribution of the accumulated annual average Phosphorus (P) yield simulation out put at a cell level from the AnnAGNPS model and summarized in Table 6, Figure 9 and Annex 6 is shown in Figure 14.

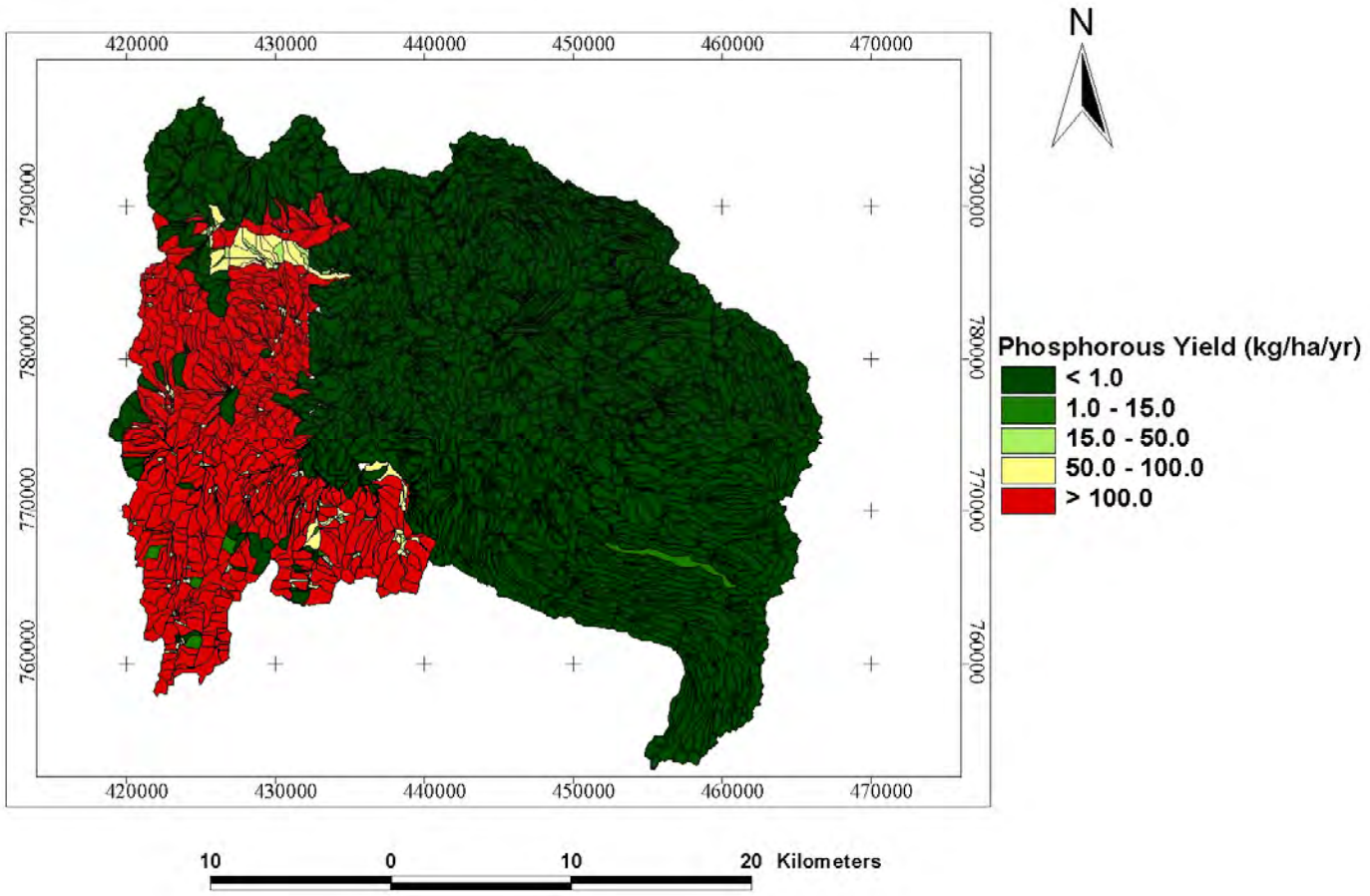

Figure 14 Accumulated Average Annual Phosphorus (P) Yield

7. CONCLUSION

Non-point source pollutants from agricultural lands associated with deleterious anthropogenic activities are responsible for the impairment of the water quality of Lake Awassa. Very little research has been done to assess the non-point source pollutants in Lake Awassa watershed even though they often are the major contributors to onsite degradation of agricultural lands and offsite pollution of Lake Awassa. In addition, there is little information on sources, impacts and possible management options of non-point source pollution

Realizing the above fact, this study has been conducted to identify the primary sources of the non-point source pollution and assessed the relative contribution of each source using the Annualized Agricultural Non-Point Source (AnnAGNPS) Pollutant loading model. Evaluation of the relative intensity of yield with respect to average annual runoff, sediment, Nitrogen, Organic Carbon and Phosphorus elucidated the leading land use/land cover classes for the pollution.

The result showed that cultivated land with Maize and Coffee (CL2), mono-cropped Maize land (CL1), and Bare land (CL0) are leading sources in terms of water yield. In addition, Bare land CL0, Pasture poor condition (PAS1) and mono-cropped Maize land (CL1) are top yielding in terms of sediment. Based on nutrient yield mono-cropped Maize land (CL1), cultivated land with Maize and Coffee (CL2), and cultivated land with Maize and 'Chat' (CL3) are principal sources in terms of Nitrogen (N). Bare land (CL0), Shrub land with poor condition (RANGE1), and Pasture poor condition (PAS1) are leading in terms of Organic Carbon (OC). Mono-cropped Maize land (CL1) and cultivated land with Maize and Coffee (CL2) are chief sources in terms of Phosphorous (P). Accordingly, the study identified mono-cropped Maize land (CL1), Bare land (CL0) and cultivated land with Maize and Coffee (CL2) as priority areas that need alternative management option to control non-point source pollution.

The study also showed that a change from mono-cropped Maize land (CL1) to mixed cultivation of Maize and 'Chat' (CL3) would result a decrease up to 78% for water and Organic Carbon, 91% for sediment and more than 95% for Phosphorus yields, while the Nitrogen yield more or less remain unchanged. A similar change from Bare land (CL0) to mixed cultivation of Maize and 'Chat' (CL3) would result a decrease up to 99%, 94% and 78% for sediment, Organic Carbon and water yield, respectively, while an increase up to 100% would result for Nitrogen yield as expected due to the fertilization assumed during the change. A switch from the mixed cultivation of Maize and Coffee (CL2) to mixed cultivation of Maize and 'Chat' (CL3) most likely lead to a decrease up to 81%, 75%, 60% and 35% for water, Nitrogen, sediment and Organic carbon yield, respectively, as well as a decrease of more than 85% for Phosphorus yield.

Ultimately, the simulation result to determine the effectiveness of best management practices using the 1965 and 2004 scenarios showed that a decrease of watershed runoff by about 28%, while there is a decrease of sediment yield by about 73%. Similarly, there were a decrease of around 32%, 50% and 35% for Nitrogen, Organic Carbon and Phosphorus yields, respectively, for the 1965 scenario from that of 2004. Indeed, the out come of this study has vividly indicated the significant reduction in non-point source pollution, thus implying that land use system change is the main area of focus for future sustainable agricultural practices, which is in harmony with the existing socioeconomic and socio-cultural conditions prevalent in the study area to be implemented with ease.

8. RECOMMENDATIONS

Except for the possible uncertainty associated with models and modeling, the AnnAGNPS model applied in this study, has facilitated better assessment of non-point source pollutants, evaluation of alternative management options with the outputs consistent with previous studies in Lake Awassa watershed, as well as in accord with the well-founded hydrological phenomenon. Moreover, the model's algorithm based on the RUSLE and SCS Curve Number methods, which are validated and widely applicable procedures; corroborate the usefulness of the study result. However, it should be further substantiated to be used as a final decision support tool; until then, it can potentially be used as a planning aid with the necessary precaution.

Among the sound management options that should be implemented to curb the existing problem of non-point source pollution and possibly, to restore the ecosystem a change in land use system towards mixed farming and agroforestry is the principal. Specifically, a land use/land cover change from bare land (CL0) to shrub (RANGE1 and RANGE2), and a change from mono cropped maize (CL1) to agroforestry and mixed farming practice of Maize and Coffee(CL2), Maize and 'Chat' (CL3), Maize and Potato(CL4), and Maize and 'Enset' (CL5) are believed to relive the environment from the man made burden.

Furthermore, there are also alternatives that should be looked into, including:

- ✓ area closure to restore the poor grazing areas (PAS1 and RANGE1) to better condition,
- ✓ limiting the quality and quantity of commercial fertilizers and other agricultural inputs,
- ✓ soil fertility management to improve the physical and chemical properties of the soil that made it susceptible to erosion.

Integration of physical soil and water conservation structures with the mentioned options and/or as stand-alone measures may also result in the reduction of the non-point source pollutant loadings. Immediate or near future attention and decisive action towards better

management of the watershed based on well thought plan aided by scientific and objective information is crucial for the effectiveness of the options.

Ways shall be devised to incorporate objective findings of different studies in the planning and management of projects to preserve the social, economical and environmental values and functions of the lake and the watershed at large. Moreover, means to complement the usefulness of previous and current studies in protecting the ecosystem from further degradation and, possibly, to restore it shall be looked into, to utilize the scarce resources available for the management and restoration of the fragile ecosystem effectively.

The model's integration with geo spatial analysis tool ArcView GIS that facilitate handy input data preparation can be one of the major uncertainty sources, the availability, accuracy and quality of the geographic data should be thoroughly investigated and means of harmonizing and supplying these data should be assessed for future more reliable and wider application of the AnnAGNPS model. In addition to that, the format used in the daily climate data section, which is one of the challenges during input data preparation for application outside the USA; needs enhancement for versatile utilization of the model like by linking it with other flexible database application software such as the Microsoft Spreadsheet.

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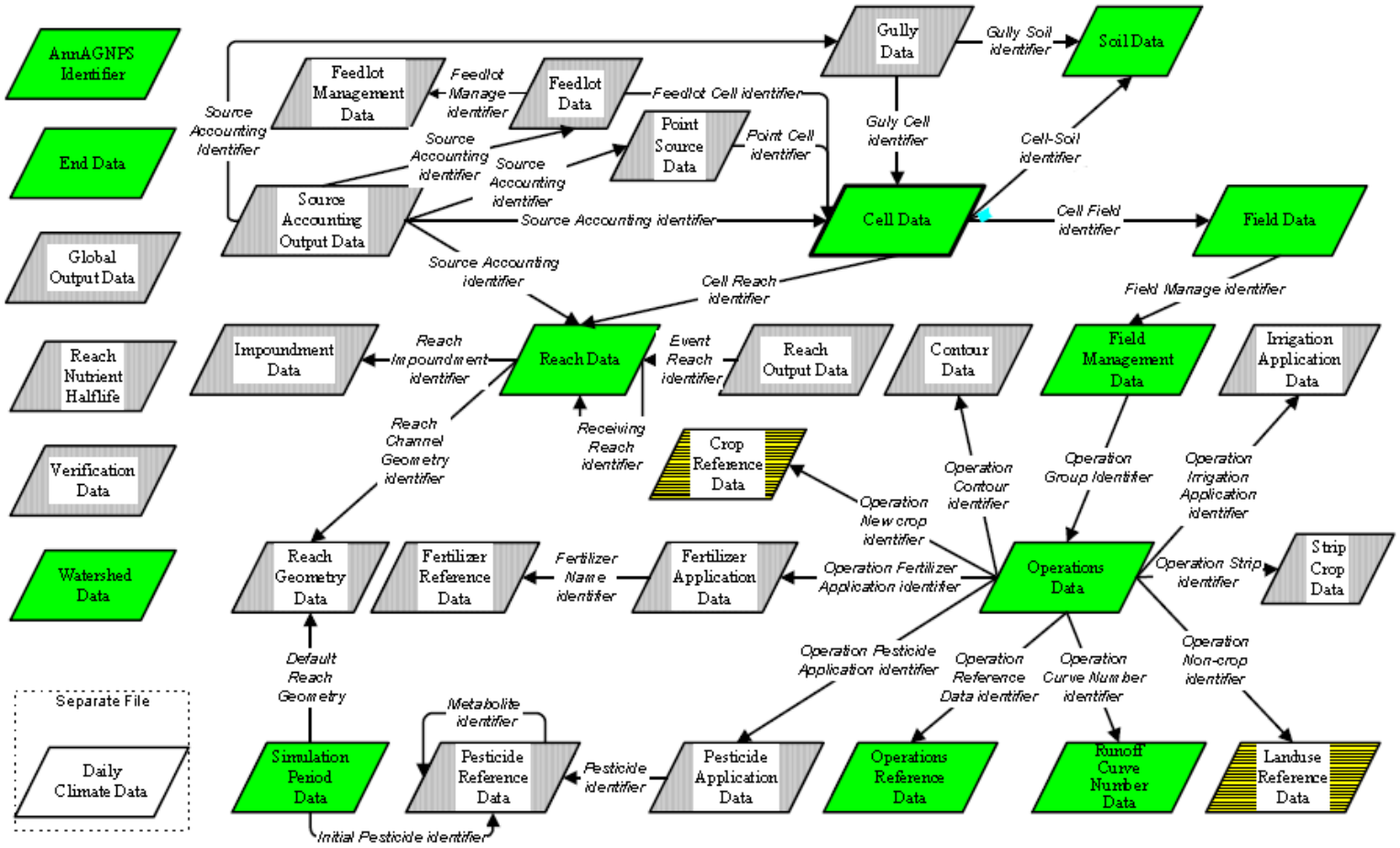
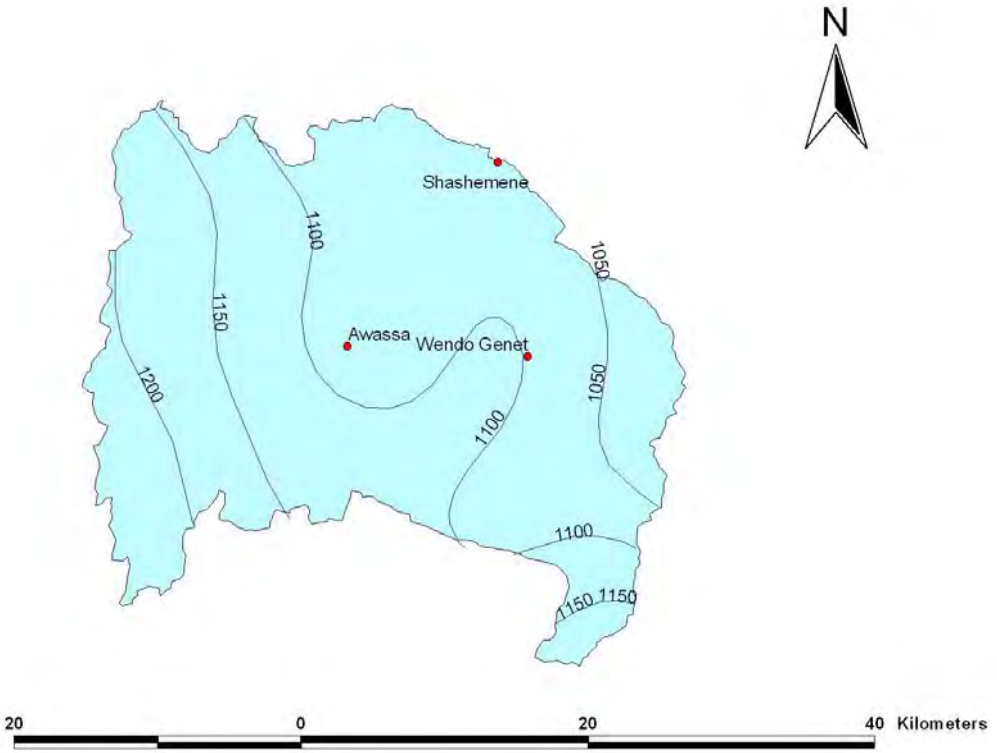
APPENDICES

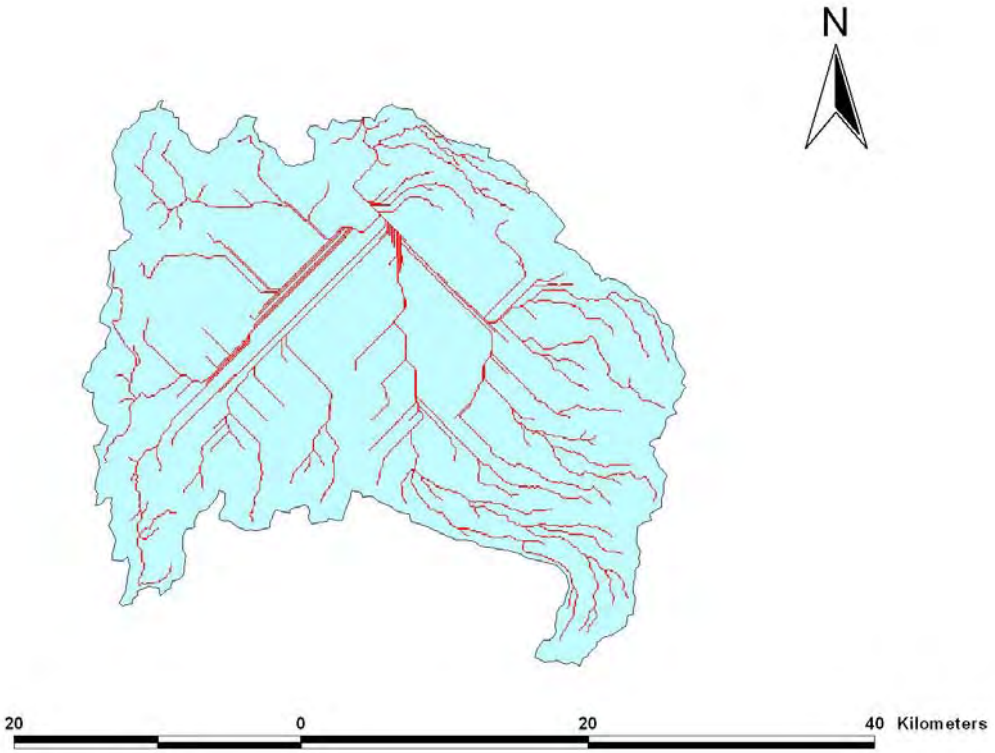
Annex 1 AnnAGNPS Input Header Section Links



Annex 2 Isohytal Map of Lake Awassa Watershed



Annex 3 Drainge Network of Lake Awassa Watershed



Annex 4 Average Annual Surface Water Yield by Land Use Class

Land Use[3] Class	Area (ha)	% Total Area	Average		Average Yield (Mg/yr)	Total Yield (Mg)	% Total Yield
			Land Slope	LS Factor			
CL0	2816.41	2.00	0.03	0.74	47.57	277.24	2.50
CL1	39773.58	28.26	0.04	0.91	51.40	3981.33	35.87
CL2	52217.97	37.11	0.14	4.45	73.03	6344.45	57.15
CL3	3542.72	2.52	0.08	1.77	9.47	77.98	0.70
CL4	1455.46	1.03	0.02	0.43	8.48	26.57	0.24
CL5	2707.82	1.92	0.06	1.63	9.76	46.63	0.42
CL6	548.62	0.39	0.03	0.77	8.46	7.18	0.06
FORES1	4749.09	3.37	0.11	3.05	2.14	13.86	0.12
FORES2	5943.84	4.22	0.13	3.62	1.50	16.17	0.15
PAS1	9290.66	6.60	0.03	0.68	12.97	209.64	1.89
PAS2	2658.29	1.89	0.12	3.23	15.59	37.12	0.33
RANGE1	1220.56	0.87	0.20	5.73	4.44	8.21	0.07
RANGE2	224.75	0.16	0.07	1.59	0.09	0.02	0.00
URB	2294.99	1.63	0.03	0.57	12.09	54.28	0.49
WATER	11277.70	8.01	0.01	0.19	0.00	0.00	0.00
Total	140722.47	100.00			17.13	11100.70	100.00

[3] CL0 = Bare Land, CL1 = Cultivated (Maize), CL2 = Cultivated (Maize + Coffee), CL3 = Cultivated (Maize + 'Chat'), CL4 = Cultivated (Maize + Potato), CL5 = Cultivated (Maize + 'Enset'), CL6 = Cultivated (Maize + Haricot Bean), FORES1= Forest (High Cover), FORES2 = Forest (Low Cover), PAS1 = Pasture (Poor), PAS2 = Pasture (Good), RANGE1 = Shrub (Poor), RANGE2 = Shrub (Good), URB = Urban Built-up, WATER = Lake Awassa and Cheleleka Swamp (Legend the same for the subsequent Tables and Figures)

Annex 5 Average Annual Sediment Erosion by Land Use Class

Land Use Class	Area (ha)	% Area	Average		Sediment Yield	% Sediment Yield
			Land Slope	LS Factor		
CL0	2816.41	2.00	0.03	0.74	1310.12	30.80
CL1	39711.62	28.22	0.04	0.91	1805.98	42.45
CL2	52217.97	37.11	0.14	4.45	552.67	12.99
CL3	3542.72	2.52	0.08	1.77	14.89	0.35
CL4	1455.46	1.03	0.02	0.43	1.62	0.04
CL5	2707.82	1.92	0.06	1.63	6.28	0.15
CL6	548.62	0.39	0.03	0.77	0.60	0.01
PAS1	9050.68	6.43	0.03	0.69	421.15	9.90
PAS2	2654.56	1.89	0.12	3.31	76.81	1.81
RANGE1	1220.56	0.87	0.20	5.73	19.26	0.45
RANGE2	224.75	0.16	0.07	1.59	0.00	0.00
FORES1	4749.09	3.37	0.11	3.05	0.00	0.00
FORES2	5943.84	4.22	0.13	3.62	2.27	0.05
URB	2254.24	1.60	0.03	59.02	27.18	0.64
WATER	11624.12	8.26	0.01	0.19	15.38	0.36
TOTAL	140722.5	100.00	0.07	5.86	4254.21	100.00

Annex 6 Average Annual Nitrogen Yield by Land Use Class

Land Use Class	Area(ha)	% Area	Average		Total N (Kg/yr)	% Total N
			Land Slope	LS Factor		
CL0	2816.41	2.00	0.03	0.74	0.00	0.00
CL1	39773.58	28.26	0.04	0.91	880.69	65.19
CL2	52217.97	37.11	0.14	4.45	454.04	33.61
CL3	3542.72	2.52	0.08	1.77	7.40	0.55
CL4	1455.46	1.03	0.02	0.43	1.52	0.11
CL5	2707.82	1.92	0.06	1.63	4.81	0.36
CL6	548.62	0.39	0.03	0.77	0.34	0.03
FORES1	4749.09	3.37	0.11	3.05	0.00	0.00
FORES2	5943.84	4.22	0.13	3.62	0.00	0.00
PAS1	9290.66	6.60	0.03	0.68	0.00	0.00
PAS2	2658.29	1.89	0.12	3.23	0.00	0.00
RANGE1	1220.56	0.87	0.20	5.73	0.00	0.00
RANGE2	224.75	0.16	0.07	1.59	0.00	0.00
URB	2294.99	1.63	0.03	0.57	0.00	0.00
WATER	11277.70	8.01	0.01	0.19	2.13	0.16
Total	140722.47	100.00			1350.93	100.00

Annex 7 Average Annual Organic Carbon (OC) Yield by Land Use Class

Land Use Class	Area(ha)	% Area	Average		Total OC	% Total OC
			Land Slope	Slope Length Factor		
FORES1	4749.09	3.37	0.11	3.05	0.00	0.00
RANGE2	224.75	0.16	0.07	1.59	0.00	0.00
CL6	548.62	0.39	0.03	0.77	0.35	0.01
CL4	1455.46	1.03	0.02	0.43	2.28	0.05
FORES2	5943.84	4.22	0.13	3.62	9.61	0.22
URB	2294.99	1.63	0.03	0.57	19.72	0.46
CL5	2707.82	1.92	0.06	1.63	24.67	0.58
WATER	11277.70	8.01	0.01	0.19	26.13	0.61
CL3	3542.72	2.52	0.08	1.77	37.89	0.89
PAS2	2658.29	1.89	0.12	3.23	95.34	2.23
RANGE1	1220.56	0.87	0.20	5.73	211.91	4.96
CL0	2816.41	2.00	0.03	0.74	487.76	11.42
PAS1	9290.66	6.60	0.03	0.68	619.71	14.51
CL2	52217.97	37.11	0.14	4.45	862.47	20.19
CL1	39773.58	28.26	0.04	0.91	1874.44	43.87
Total	140722.47	100.00			4272.27	100.00

Annex 8 Average Annual Phosphorous (P) Yield by Land Use Class

Land Use Class	Area (ha)	% Area	Average		Total P	% Total P
			Land Slope	LS Factor		
CL0	2816.41	2.00	0.03	0.74	0.05	0.00
CL1	39773.58	28.26	0.04	0.91	504935.84	90.53
CL2	52217.97	37.11	0.14	4.45	52812.15	9.47
CL3	3542.72	2.52	0.08	1.77	3.19	0.00
CL4	1455.46	1.03	0.02	0.43	1.43	0.00
CL5	2707.82	1.92	0.06	1.63	1.61	0.00
CL6	548.62	0.39	0.03	0.77	0.48	0.00
FORES1	4749.09	3.37	0.11	3.05	2.82	0.00
FORES2	5943.84	4.22	0.13	3.62	8.39	0.00
PAS1	9290.66	6.60	0.03	0.68	0.09	0.00
PAS2	2658.29	1.89	0.12	3.23	14.54	0.00
RANGE1	1220.56	0.87	0.20	5.73	0.07	0.00
RANGE2	224.75	0.16	0.07	1.59	0.00	0.00
URB	2294.99	1.63	0.03	0.57	0.01	0.00
WATER	11277.70	8.01	0.01	0.19	0.00	0.00
Total	140722.47	100.00			557780.68	100.00

Annex 9 Land Use Change between 1965 and 2004

Land Use	% Total Area		% Change	
	1965	2004	Increase	Decrease
Cultivated +Bare + Exposed	6.00	1.82		-69.70
Cultivated Land	29.25	43.40	48.36	
Dense Bushy Woodland	12.55	3.33		-73.49
Dense Bushy Woodland + Open Grassland	21.33	26.07	22.24	
Dense Shrub Land	1.20	0.21		-82.04
Dense Woodland	6.27	1.05		-83.17
Lakes	7.07	7.30	3.23	
Open Bushy Woodland	9.01	4.51		-49.91
Open Grassland	5.24	7.04	34.22	
Open Shrub + Bare +Exposed	1.64	3.20	95.68	
Plantation Forest	0.09	0.36	303.69	
Urban Built up	0.36	1.71	380.05	

Annex 10 Comparison of model output for 1965 and 2004 scenario

Accumulated Annual Yield	1965	2004	Change	% Change
Total Water(Mg)	8663.4	11100.7	2437.3	+28.1
Sediment (tones)	2386.1	4254.2	1868.1	+78.3
Nitrogen (Kg)	1023.4	1350.9	327.5	+32.0
Organic Carbon(Kg)	2844.2	4272.3	1428.1	+50.2
Phosphorus(Kg)	414652.9	557780.7	143127.8	+34.5

Annex 11 Soil Erodibility Factor Based on Soil Texture for Lake Awassa Watershed

Textural Class	Erodibility Factor		
	Average	Slope<2%	Slope>2%
Clay Loam	0.30	0.33	0.28
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Silty Loam	0.38	0.41	0.37
Cheleleka Swamp	0.00	0.00	0.00
Lake Awassa	0.00	0.00	0.00

Annex 12 Run of Curve Number Data

Land use/Cover Type	Runoff Curve Number Code	Hydrologic soil Group			
		A	B	C	D
Bare land	C0	77.0	86.0	91.0	94.0
Maize	C1	60.0	72.0	80.0	83.0
Maize + Coffee	C2	59.0	74.0	82.	86.0
Maize + ‘Chat’	C3	59.0	74.0	82.0	86.0
Maize + Potato	C4	60.0	72.0	80.0	83.0
Maize + ‘Enset’	C5	59.0	74.0	82.0	86.0
Maize + H.Bean	C6	60.0	72.0	80.0	83.0
Pasture(Poor)	P1	49.0	69.0	79.0	84.0
Pasture(Good)	P2	39.0	61.0	74.0	80.0
Range(Poor)	R1	30.0	62.0	74.0	85.0
Range(Good)	R2	30.0	48.0	65.0	73.0
Forest(High)	F1	30.0	55.0	70.0	77.0
Forest (Low)	F2	36.0	60.0	73.0	79.0
Urban Built up	U1	51.0	68.0	79.0	84.0