# Matter fluxes in the Turasha Catchment, Kenya

## An exploratory Analysis

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March, 2001

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By

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What is more important, thanks to God, thanks.

Raul

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# ABSTRACT

The Turasha catchment is one of the main contributors to Lake Naivasha together with the Upper Malewa. Therefore what happen within the Turasha Catchment: Kinangop Plateau, Kipipiri Mountain and Aberdares Ranges will have a direct impact in the water quality of Lake Naivasha.

This study tries to integrate the biological aspects in the estimation of stocks and fluxes, not only as an additional topic but also as an always-present element that has to be considered; hence the terminology of ecosystems is used. Because vegetation, rocks, water, the so called compartments, need to be integrated in order to quantify their stocks and fluxes, it was an essential part of this work to present the theoretical background linking all of them.

There are several studies about biogeochemistry in undisturbed ecosystems, they have something in common: the availability of detailed data. This is not the case of the Turasha catchment where the long-term precipitation and discharge data are available but water quality parameters specific for the area are almost nonexistent. However, it does not mean that data from areas around Lake Naivasha (Malewa River for example), from literature and those collected during fieldwork can not be used. This work also shows some indirect methods for the estimation of stocks when all the data are not available.

The first attempt to deal with the lack of data was to present the proposal of a sampling scheme that will provide enough data with the less number of visits to the field as possible. For this case, a study of the patterns of rainfall and discharge was analyzed, making use of the long-term data collected from the gauging stations Turasha, Kitiri and Muruaki; and from the rainfall stations Geta, North Kinangop and North Kinangop Mawingo. For the proposal of the sampling scheme, the area was divided in subcatchments (Kianjogu, Mkungi, Kitiri, Tulasha, Muruaki) and in addition recommendations for the characterization and estimation of matter fluxes are given, making special emphasis in the use of GIS and Remote Sensing. After the analysis, the months of February and May were selected as the more suitable. A preliminary sampling was carried out in the very beginning of this study, the sampling was executed in September when the rains were very local and erratic.

After presenting a proposal to get the required data for estimate fluxes within the Turasha catchment, an overview of the status in stocks and fluxes is showed. In this case indirect methods to calculate stocks using information from literature and studies for Malewa River were used. With the aid of the analysis of the preliminary sampling some of these values were confirmed. Estimations of stocks in standing biomass for tropical forest (1285700 - 5142800 tons of dry matter in an area of 12857 ha) and for grass (kikuyu/pennisetum-clandestinum with 164261 tons of dry matter in an area of 45628 ha) were calculated. Input and output to the ecosystem were also obtained. The mean weight of total dissolved solids in rainfall is 2015 tons/year and in the Turasha River is 13496 tons/year. This indicates that atmospheric precipitation is an important source of solutes in the Turasha catchment (14%). Values for major ions are presented for each estimation. Finally the rocks compartment was also studied, beginning with the lithology that had to be extracted from geological reports for areas around Lake Naivasha. Fieldwork data was used also to have a better idea of the rocks and mineralogy presented in the area, in this case, for each subcatchment.

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# Chapter 1 Introduction

## 1.1 Introduction

Lake Naivasha is distinctive among the lakes lying the rift valley of central Ethiopia, Kenya and Tanzania because its water is fresh. A large fraction of the water supplied to the lake comes from dilute rivers and rain. The lake does not lie in a closed catchment, but loses water and solutes via seepage. The fresh water provides a habitat suitable for a diverse avifauna and a commercial and sport fishery.

The Naivasha catchment lies between the two flanks of the Eastern or Gregory Rift Valley, with the Aberdare Mountains and Kinangop plateau on the east and the Mau Escarpment on the west. The highlands surrounding the drainage catchment receive more rain than the lake and valley floor and provide most of the water that maintains the lake therefore what happen in the upper areas have a big impact in the lake and surroundings.

The Malewa River accounts for about 90% of the river discharge into Lake Naivasha. Flows in the Karati River and other stream courses are seasonal and often do not reach the lake as surface water. Perennial flow is maintained in the Malewa River (1730 km2 watershed) by rains on the Aberdare Mountains and Kinangop Plateau. Rains on the Bahati highlands keep perennial flow in the Gilgil River (420 Km2 watershed) to at least the 2100 m contour, but consumption for irrigation and natural losses often eliminate the flow before the lake is reached.

It is important for the water quality of Lake Naivasha to quantify the import of solutes from the catchment. Because the Malewa River accounts for the majority of the water discharged into the lake, this is an area of interest to study, however because of the complexity of the system and its considerable size, an alternative is to select one of its subcatchments. In the future, the results obtained in the selected subcatchment would be extended to the rest of the Lake Naivasha Catchment.

The Turasha catchment with an area of 770 $Km^2$ represents almost the half of Malewa catchment (1730 $Km^2$) and contributes with 50 % of the discharge in the Malewa River. This catchment is a good candidate to initiate a program of monitoring to estimate the export of solutes from the catchment into the lake.

There was not previous work in the Turasha catchment related to its water quality, but information about discharge and rainfall is available. Additional information can be gathered and/or processed hence analyses of the export of solutes would be feasible. Also some water quality parameters for the Malewa River from whom the Turasha River is a tributary could be used in this study.

Because of the complexity of the area of study and the scarcity of previous works in its water quality, it is necessary to initiate an exploratory analysis in order to depict the factors that should be considered and the feasible approach to get the result pursued.

The study will try to cover the geological, chemical and biological aspects that influence the water quality, specifically the export of solutes from the Turasha catchment, area that representatively accounts for what happen in the whole Naivasha catchment.

## 1.2 Objectives

The objective of this study is to make an exploratory analysis of the Turasha catchment in order to identify the factors and information necessary to compute its matter fluxes and stocks. In order to achieve this main objective, two sub-objectives will be pursued:

- To evaluate and design a sampling scheme for the computing of matter fluxes in the Turasha River and its tributaries after carrying out a preliminary sampling during fieldwork.
- To estimate fluxes and stocks with the information already available for areas around Lake Naivasha (Malewa River for example).

The first sub-objective is justified by the lack of data for the Turasha catchment and is presented here with the intention that future studies will take advantage of it. Also with the first sub-objective the influential factors will be determined. The second sub-objective tries to depict the status of the catchment in what fluxes and stocks is related. It is intended to include biological aspects also, therefore ecosystems terminology is used in this study.

## 1.3 Methodology

### 1.3.1 Literature review on ecosystems approach

From the beginning of this study, it was intended to include some biological aspects to the traditional study of water quality. This led to the review of literature in biogeochemical aspects in water quality that would be important for the Turasha catchment. This literature review will be included in chapter 3.

### 1.3.2 Analysis of available data prior to fieldwork

Because no previous study was carried out in the study area, the data available is either processed with other purposes or not processed at all. The more availability of data, the more accurate the preliminary sampling will be.

### 1.3.3 Processing of available data

As preparation for the preliminary sampling all the information available for mobility on fieldwork has to be prepared. Maps of drainage and roads are printed in this stage, also satellite images. The data used was the processed by MSc students in previous years. It is important to highlight that some corrections have to be made to this data after fieldwork.

### 1.3.4 Design of a preliminary sampling scheme

Because this is the first attempt to take samples of water in the Turasha catchment and because the main streams were not well identified, it was decided to gather samples according to just a few requirements. All the data collected and experience acquired will be later used in the design of an improved sampling scheme. This data will be used also in the estimation of stock and fluxes.

### 1.3.5 Sampling on field according to preliminary sampling scheme

This will be carried out during fieldwork in the month of September, just at the beginning of the second rainy season for the Turasha catchment.

### 1.3.6 Gathering of additional information on field

Additionally to the water samples, information about geology, soils, land cover, etc, will be collected, if available, during fieldwork.

### 1.3.7 Analysis of samples collected on field

Some parameters will be measured on field and also the samples will be stored for further analysis on laboratory.

### 1.3.8 Processing of additional data in order to compute and characterize fluxes

Initially only the data that will be used for the preliminary sampling is processed. In this stage, all the data required for the computing of annual fluxes and its characterization is processed: rainfall, discharge, geology, land cover, satellite images, etc.

### 1.3.9 Study of methods to compute annual fluxes

In this study some methods available in literature will be evaluated. They will be presented and described for later evaluation in order to find which one fits more with the characteristics of the Turasha Catchment.

### 1.3.10 Proposal of a sampling scheme and method to compute fluxes

According to the previous step, the data available and the constraints found during fieldwork the more adequate sampling scheme together with the method to compute annual fluxes is presented. The procedure to characterize the fluxes according to geology, land cover, etc using Remote Sensing and GIS will be also presented.

### 1.3.11 Preliminary estimate of stocks and fluxes

Until this point the lack of data has been diminished with the presentation of a sampling scheme. However from the point of view of "results" just few will be obtained so far. With the preliminary sampling and with the proposal of the optimum one, only an overview of the ecosystem will be captured and of course the main factors also will be identified.

Even with the lack of data, some interesting estimates would be calculated if information from literature and areas surrounding Lake Naivasha were used. It is intended to estimate stocks for the main compartments found during the previous stages of this work.

The possibility to estimate stocks in some compartments (biomass and rocks for example) will be evaluated and what is more important the input and the output to the ecosystem will be analized.

# Chapter 2 Study Area

The Turasha catchment is situated in Nyandarua District, Central Province of Kenya; it is bound by latitudes 0°23'46"S - 0°45'16"S and longitudes 0°36'24"E - 0°36'42"E. In its western boundary is the Karati escarpment, the Kipipiri Mountain to the Northeast and Kinangop plateau to the south. In the East, the Aberdare's range is located. The total area of the Turasha catchment is 770 Km$^2$.

## 2.1 Geology and Parent Material

The geological information of the area is extracted from geological report Nos. 12 (Shackleton, 1945), 55 (Thompson et al, 1958), 67 (Thompson, 1964) and 78 (Mc Call, 1967). The geology comprises rocks of volcanic origin, some of which date back to the Miocene period.

Recent superficial volcanic deposits mainly cover the northern part of the area. This is underlain by Pliocene tuff formations. The tuff formations include vitric pumice tuffs, ignimbrites and welded tuffs with lacustrine sediments, graded tuffs and lake sediments containing varying amount of diatomite.

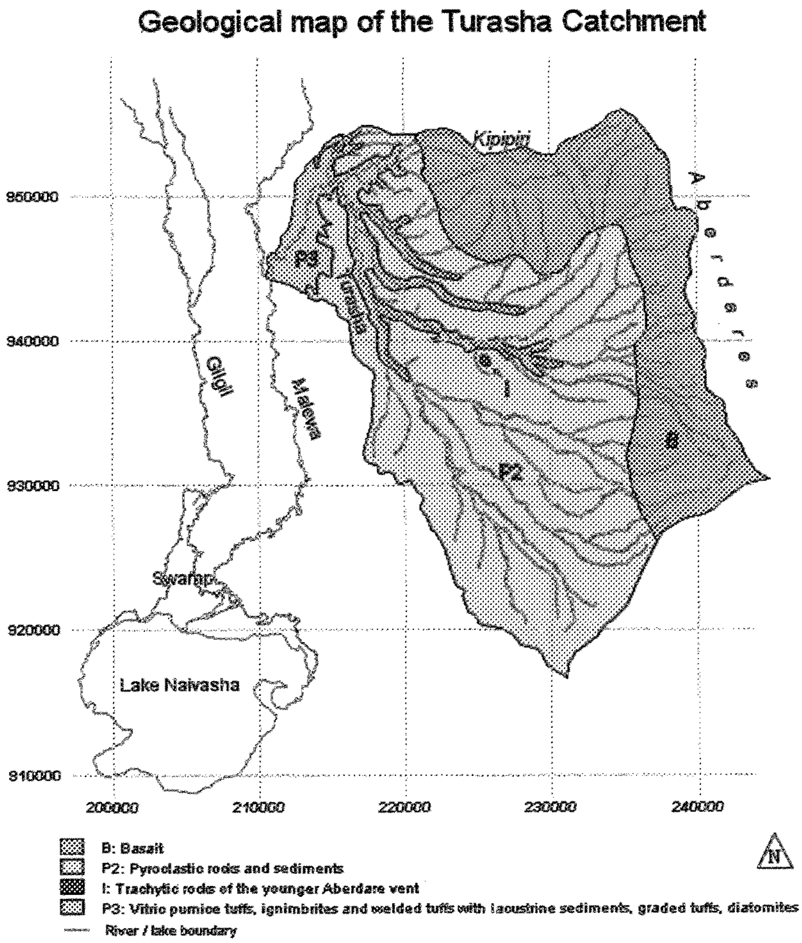



Figure 2.1 Geological map of the area (Kenya Soil Survey, 1977)

The Kipipiri and Aberdare Mountains consists mainly of Basalts: vesicular olivine basalt of Pliocene-Miocene age and olivine basalts of Miocene age, basalt and Agglomerate of Simbara series (predominantly in Kipipiri Forest area) and the Laikipian type of Basalt in the lower eastern fringes of Kipipiri Mountain all of which belong to period ranging from

Miocene to Pleistocene. The other rocks found in the area include Trachytic tuffs (Miocene-Pleistocene). Alluvium covers some parts along the rivers. Pyroclastic rocks and sediments of Upper to Middle Pleistocene periods cover the remaining central and southern part. Others include Trachytic rocks of the younger Aberdare vents and Kijabe type Basalt both of Upper to Middle Pleistocene periods. See Figure 2.1 for the geology of the Turasha catchment.

## 2.2 Topography

The combined geomorphological phenomena of volcanicity and other tectonic activities together with climate has resulted in the formation of extensive areas of plateaus and scarps, mountains and hills including huge vents in the area.

To the south of the catchment is found the Kijabe hill, which is of basaltic origin. Immediately north of the slopes of the Kijabe hill, starts the Kinangop plateau, which has an elevation of approximately 2500m in average. Although this landform is normally referred to as plateau, it is a "step" on the side of the Rift Valley forming a plain of platform which is approximately 16 Km wide (Rachilo, 1978). The surface of the Kinangop is conpicuosly smooth. It is the marginal strip of a plain of accumulation which formerly extended from the foot of the Aberdare and Kipipiri across the Rift Valley region, and probably also eastwards across the northern end of the Aberdare (Shackleton, 1945).

The plain is deeply dissected in the north-western part of the area by the Mkungi, Kitiri and Muruaki rivers all of them tributaries of the Turasha that later reaches the Malewa which ultimately discharges into lake Naivasha. This part of the plateau is characterized by a number of steps, which eventually form plateaus and scarps.

To the North is the Kipipiri hill, which rises some 914m above the surrounding plains to 3347m. It stands apart from the main Aberdare Range on the east, from which it is separated by a saddle deeply trenched by the streams draining either side.

## 2.3 Rainfall

The Kinangop Plateau is situated in the rain-shadow of the Aberdare. The rains therefore are diminishing rapidly from 1300 – 1400 mm per year on the eastern side to 700 – 800 mm in the western (Jaetzold, 1976). It is not therefore surprising that within one settlement scheme there are differences of up to 400mm. In certain years the differences in rainfall are even much higher (Rachilo, 1978).

The variations of rainfall likewise are also increasing from East to West though they are not very large on an annual basis. Expected rainfall in four out of five years ranges between 1000 mm on the eastern side to 800 mm on the western, and even the driest year has more than 400 mm (Rachilo, 1978)

The distribution of rainfall - Kinangop Forest Station - is presented in Figure 2.2. The daily values were smoothed with a moving average of 10 days.

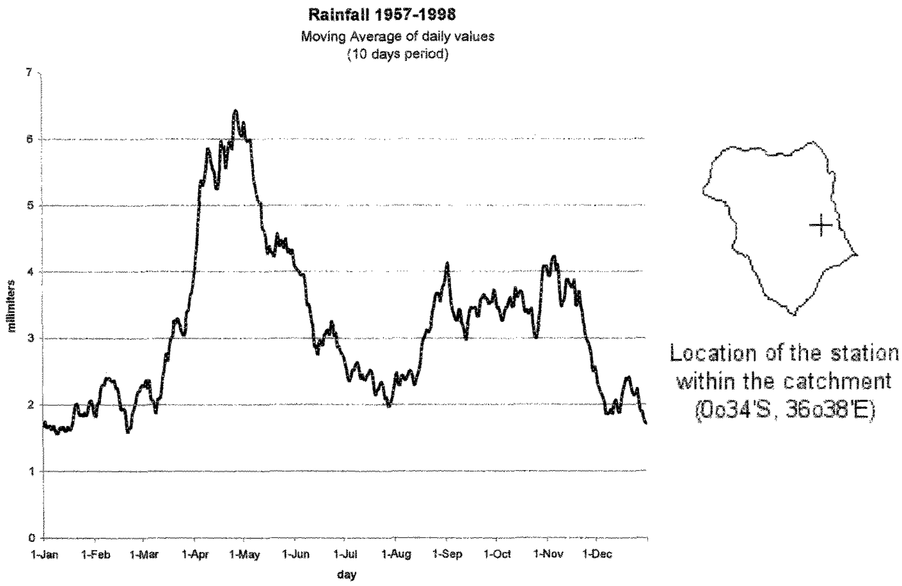



Figure 2.2 Distribution of rainfall, Kinangop Forest Station

A more detailed analysis of rainfall for the area is showed in chapter 5.

## 2.4 Evapotranspiration: Humid and arid months

In addition to precipitation, it is important to know how much of it is lost through evaporation and transpiration. This then will help in determining approximately the differences in water balance.

In the Kinangop area the annual potential evaporation (Eo) ranges from 1400-1700 mm from East to West (Jaetzold, 1976). This puts the annual evapotranspiration (0.8Eo) to approximately 1100-1400mm. On the eastern side of the plateau, the rainfall and evapotranspiration pattern is such that the growing period for most crops is from the end of March to December. The annual rainfall/evaporation ratio varies from near 100% in the east to somewhat less than 50% in the west. The insufficient rainfall in the period June – September can be offset by the excess of rainfall in the period March May, provided that the soil is deep enough to utilize this moisture. To the western rim of the plateau, the main rainy season (March – May) becomes so short that even the soil moisture is not sufficient to reach further than June. In this side, the second rains from November to January are on average not heavy to base cultivation on.

## 2.5 Temperatures

A main climatic problem is the low night temperature, which is brought about by the cold air that flows from the Aberdare down to the Kinangop Plateau during clear nights causing night frosts nearly every month in the area. In general, the mean temperature ranges from 12 °C in the east to 15 °C in the west (Jaetzold, 1976). Frosts occurs frequently in the east and rarely in the west.

## 2.6 Vegetation

Most parts of the area have been cleared for cultivation and the vegetation is predominantly secondary. The majority of the area is grassland apart from the western fringes of the Aberdare and Kipipiri Mountains. Some parts of the area are under swamp grasses. According to Scott et al, (1971) the Kinangop Plateau is under Pennisetum clandestinum grassland (kikuyo grass). Along the western fringes of the Aberdare and Kipipiri Mountains mixed bamboo forest in addition to undifferentiated Combretum types or broad-leaved vegetation mainly on ridge tops. Whereas the valley sides in this area are covered mostly with undifferentiated Acacia species, the valley bottoms are mainly Pennisetum clandestinum grassland with scattered trees and shrubs (Scott et al, 1971). In the north there is also the presence of Leleswa shrub and grassland, the former occurring predominantly in plateaus and scarps and the latter in footslope areas.

## 2.7 Hydrology

The survey area in general is very much dissected by drainage ways, the majority of which have their sources in Aberdare and Kipipiri Mountains. To the north-western part of the catchment is the Malewa River into which the Turasha River discharges their waters. The Malewa River eventually leads its water into Lake Naivasha to the west. In the central and to the south of the area are the drainage ways that generally have flat valleys. There are quite a number of dams built to retain water along some of the rivers. The drainage in the area can be seen in Figure 2.1.

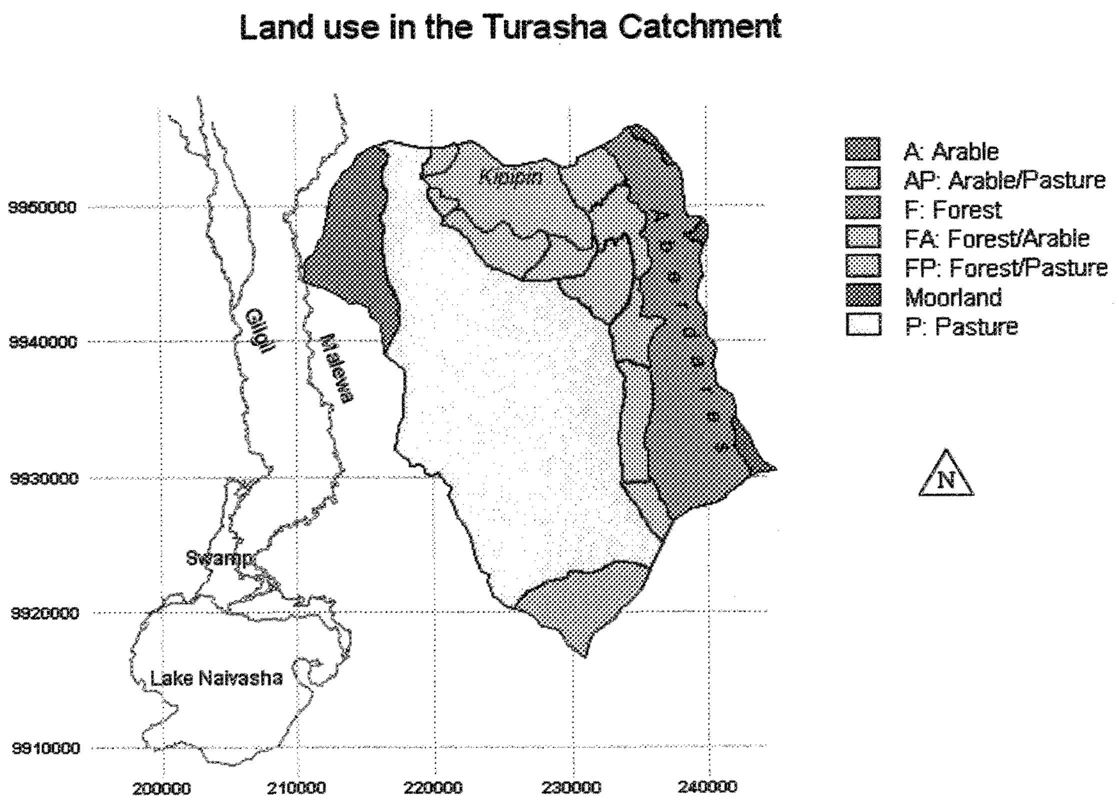



Figure 2.3 Landuse of the Turasha Catchment

## 2.8 Land Use

The land use in the area according to visual interpretation of the Landsat 7 Images of the area and the checkpoints collected during field work, is depicted in Figure 2.3

# Chapter 3 Literature Review

The Turasha catchment comprises two main land covers: agricultural and forest. The Forest area comprises The Aberdare National Park but also the tree plantations on the foot of the range. The Kinangop Plateau is mainly agricultural.

Chemical flux and cycling are linked to the hydrologic cycle. Hence one cannot measure the input and output of nutrients without simultaneously measuring the input and output of water; the problem usually is that subsurface flows of water, which can be a significant fraction of the hydrologic cycle, are almost impossible to measure. The interaction of the nutrient cycle and the hydrologic cycle could be turned to good advantage in the quantitative study of an ecosystem (Likens, 1977).

This study pursue the identification of the main factors influencing the water quality in the streams of the Turasha catchment, therefore the biological aspects has to be mentioned.

## 3.1 The Ecosystem Concept

A basic functional unit of nature, an ecosystem comprises a group of living organisms and the physical and chemical environment in which they live. The ecosystem can be thought of as being made up of plants, animals, organic debris, available nutrients, soil minerals, water and gases, all linked by food webs, and flows of energy and nutrients. Producing and consuming organisms interact in a self-regulating manner, usually in relation to the total amount of energy available in the ecosystem (Gosz, 1978)

By the 1950s, the ecosystem concept had fully pervaded ecological thinking and spawned a new branch of ecology in which the **cycling of matter** and the associated flux of energy through the ecosystem provided a basis for characterising the system's structure and function.

A first concept of ecosystem was the realization that feeding relationships link organisms into a single functional entity, the **biological community**. That these feeding relationships define an ecological unit was a novel idea of Charles Elton during the 1920s.

A second concept, developed forcefully a decade later by A.G. Tansley, took Elton's idea an important step further by regarding animals and plants in associations, together with the physical factors of their surroundings, as a fundamental ecological system. Tansley called this the **ecosystem**. He envisioned the **biological and physical parts of nature together**, unified by the dependence of animals and plants on their physical surroundings and by their contribution to the maintenance of the physical world.

### 3.1.1 Lotka's thermodynamic view of the ecosystem

Working independently of the ecologists of his day, Alfred J. Lotka developed ecosystem concepts from considerations of energetics. He was the first treating population and communities as **thermodynamic** systems. In principle, he said, each system can be represented by a set of equations that govern **transformations of mass among its components.** Such transformations include the assimilation of carbon dioxide into organic carbon compounds by green plants and the consumption of plants by herbivores and of animals by carnivores.

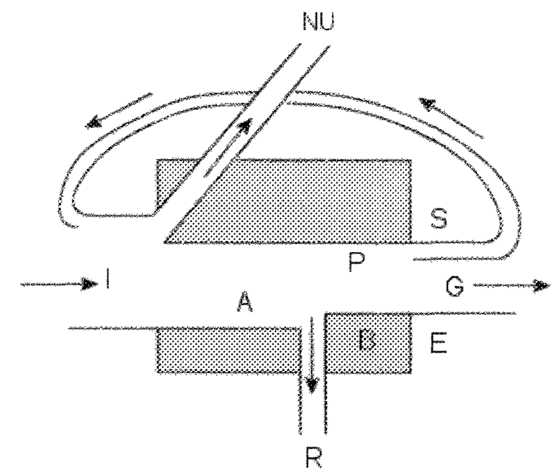



Figure 3.1 Odum's "universal" model of ecological energy flow, which can be applied to any organism: I=ingestion; A=assimilation; P=production; NU=not used; R=respiration; G=growth; E=excreta; S=storage and B=biomass

Not all the energy of sunlight enters biological pathways of transformations. In fact, most of it drives the circulation of winds and ocean currents and the evaporation of water, which make up a large, physical thermodynamic system. But part of the energy of sunlight that plants do assimilate by photosynthesis ultimately fuels all biological processes and therefore establishes the overall rate of transformation within the ecosystem.

In 1942 Raymond Lindeman adopted Tansley's notion of the ecosystem as the fundamental unit in ecology and Elton's concept of the food web, including inorganic nutrients at the base, as the most useful expression of ecosystem structure. The food chain has many links (primary producer, herbivore, and carnivore) which Lindeman referred to as trophic levels (in Greek trophic means food). Furthermore, Lindeman visualized a **pyramid of energy** within the ecosystem. He argued that less energy reaches each successively higher trophic level because of the work performed and because of the inefficiency of biological energy transformations on the next lower trophic level. The ratio of production on one trophic level to that on the level below it constitutes the ecological efficiency of that link in the food chain.

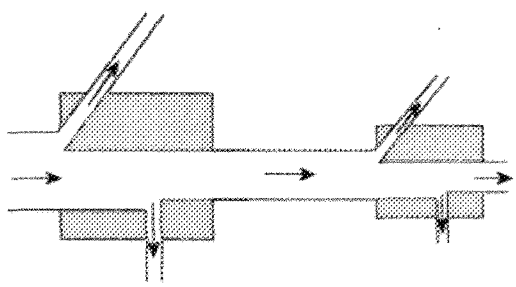


Figure 3.2 Representation of a food chain by Odum's energy flow models. The net production of one trophic level becomes the ingested energy of the next higher level. After E.P. Odum, Am. Zool. 8:11-18 (1968)

**Energy provides a common idiom for ecological description, and the masses of elements (such as carbon) made possible the direct comparison of plants, animals, microbes, and abiotic sources of energy and elements in the ecosystem (Ricklefs, 1993).**

With a clear conceptual framework for the ecosystem and a **"currency"** of energy to describe its structure, **ecologists began to measure energy flow and the cycling of nutrients in the ecosystem**. One of the strongest proponents of this approach has been Eugene P. Odum. From 1953 Odum depicted ecosystems as energy flow diagrams (Figure 3.1). For any trophic level, such a diagram consisted of a box representing the biomass (or its energy equivalent) at any given time **and pathways through the box representing the flowing energy**. Feeding relationships linked energy flow diagrams into a food web, as shown in Figure 3.2.

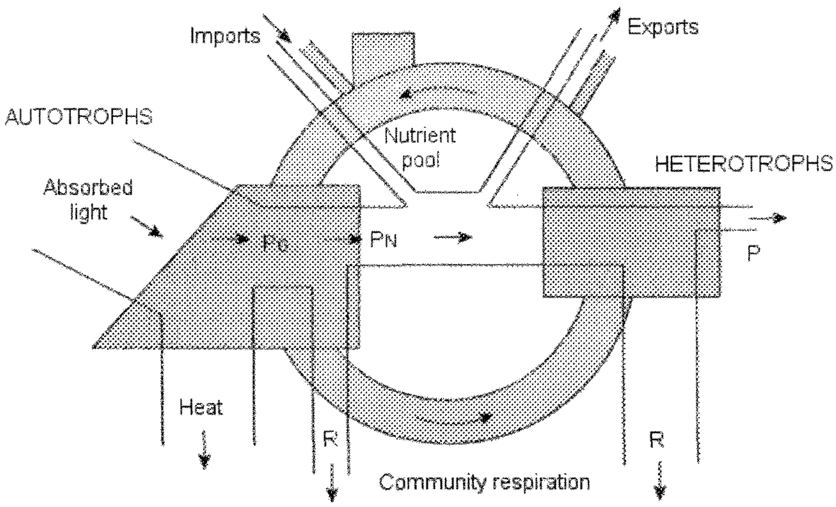



Figure 3.3 Odum's flow diagram of an ecosystem showing the one-way flow of energy and the recycling of materials. $P_G$ = gross production, $P_N$ = net production, P = heterotrophic production, and R = respiration.

Unlike energy, which ultimately comes from sunlight and leave the ecosystem as heat, **nutrients are regenerated and retained within the system**. Odum elaborated energy flow diagrams to include this cycling of elements (Figure 3.3). In the development of ecosystem studies, **the cycling of elements has assumed equal standing with the flow of energy.** One reason for this prominence is that the amounts of elements and their movement between components can provide a convenient index to the flow of energy, which is difficult to measure directly. Carbon, in particular, bears a close relationship to energy content because of its intimate association with the assimilation of energy via photosynthesis.

A second reason for the prominence of nutrient cycling is the fact that the levels of certain nutrients regulate primary production. In deserts, plant growth in most areas reflects the amount of water rather than the amount of sunlight or minerals in the soil. By contrast, the open oceans are deserts by virtue of their scarce nutrients, particularly nitrogen. Understanding how elements cycle between components of the ecosystems seems crucial to understanding the regulation of ecosystem structure and function.

### 3.1.2 Primary production

Plants capture light energy and transform it into the energy of chemical bonds in carbohydrates. Glucose and other organic compounds (starch and oils, for example) may be transported throughout the plant or stored conveniently for later release of their energy by respiration. Photosynthesis chemically unites two common inorganic compounds, carbon dioxide ($CO_2$) and water ($H_2O$), to form glucose ($C_6H_{12}O_6$), with the release of oxygen ($O_2$). The overall chemical balance of the photosynthetic reaction is

$$6\ CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Photosynthesis transforms carbon from an oxidized (low-energy) state in CO2 to a reduced (high-energy) state in carbohydrate. Because work is performed on carbon atoms, photosynthesis requires energy. This is provided by visible light. **For each gram of carbon assimilated, the plant gains 39 kJ of energy**. But because of inefficiencies in the many biochemical steps of photosynthesis, no more than a third (and usually much less) of the light energy absorbed by photosynthetic pigments eventually appears in carbohydrate molecules (Ricklefs, 1993)

Photosynthesis supplies the carbohydrate building blocks and energy that the plant needs to synthesize tissues and grow. Rearranged and joined together, glucose molecules become fats, oils, and cellulose. Combined with **nitrogen, phosphorus, sulfur, and magnesium, simple carbohydrates derived ultimately from glucose provide and array of proteins, nucleic acids, and pigments**. Plants cannot grow unless they have all these basic building materials. Remember that chlorophyll contains an atom of **magnesium**; even thought all other necessary elements might be present in abundance, a plant lacking magnesium cannot produce chlorophyll and thus cannot grow. Ecologists distinguish two measures of assimilated energy: **gross production, the total energy assimilated by photosynthesis**, and **net production, the accumulation of energy in plant biomass** (including plant growth and reproduction). **Because plants occupy the first position in the food chain, ecologists refer to these measures as gross or net primary production**. The difference between gross and net production is the energy of respiration, the amount used for maintenance and biosynthesis.

## 3.2 The Flow of Energy in an Ecosystem

Ecology, like economics, concerns itself with the movement of valuable commodities through a complete network of producers and consumers. Just as economy runs on money, so does an ecosystem run on energy, all of which comes initially from the sun (Gosz, 1978).

Although the natural world would seem to receive a virtually limitless influx of energy capital in the form of solar radiation, its energy budget is actually quite small. Thus paradox can be explained by the fact that **living organisms do not utilise solar energy directly; they have access to only the small portion of it that is converted by green plants** into a stored chemical form through the process of photosynthesis. The organic matter fixed by plants is utilised by animal consumers; the plants are also consumers to the extent that they utilise some of the energy stored in their tissues for their own maintenance. Animals are associated with a grazing food web (in which living plant tissue is the source of energy) or a detritus food web (in which dead tissues are the source).

**There are several ways to investigate the dynamics of energy in nature, but the broadest approach is ecosystem analysis, in which the amount of energy transferred between the consumer compartments in an ecosystem is quantified.** Since the inputs and outputs of each compartment can be calculated, this approach makes it possible to draw up a balance sheet for energy flow.

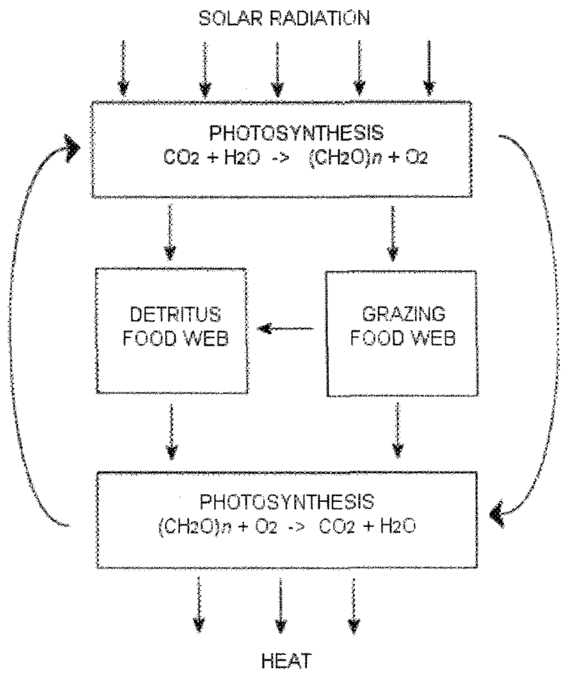



Figure 3.4 Basic pathways of energy flow

To provide a bookkeeping structure for the balance sheet topographical boundaries are defined for the ecosystem under investigation, so that energy flow can be expressed per unit of land or water per unit of time. However, **energy** containing organic matter **can be transported across ecosystem boundaries by meteorological forces** such as precipitation or wind, **by geological forces** such as running water and by **biological vectors** such as the movement of animals. All these avenues of transport must be taken into account in quantitatively describing the flow of energy through the ecosystem.

Measuring the movement of energy across ecosystem boundaries is usually a difficult task, but it can be simplified by several factors.

The basic pathways of "energy flow" through an ecosystem all originate with solar radiation (Figure 3.4), a small percentage of which is converted by green plants into organic material through the process of photosynthesis. This organic material may be consumed either as living plant tissue by herbivores in the grazing food web or as dead tissue by decomposers in the detritus food web; these animals in turn provide the food base for a variety of carnivores. **Assimilated organic matter** that is not utilised for the growth of individual organisms or populations is **"burned" by the process of respiration to power the metabolism of plants of plants and animals**. Because respired energy is ultimately lost as heat, an ecosystem requires a continual influx of solar energy.

## 3.3 The relationship between the movement of elements and flow of energy

Assimilatory processes are those referred to the transformations that result in the production of organic forms of a particular element. For example, photosynthesis by which "inorganic" (oxidized) carbon (carbon dioxide) is reduced to the "organic" carbon of carbohydrates, is the most obvious assimilatory transformation of an element. In the cycling of carbon, photosynthesis is balanced by respiration, a complementary dissimilatory process that involves the oxidation of organic carbon with the accompanying release of energy and the return of carbon to its available inorganic form.

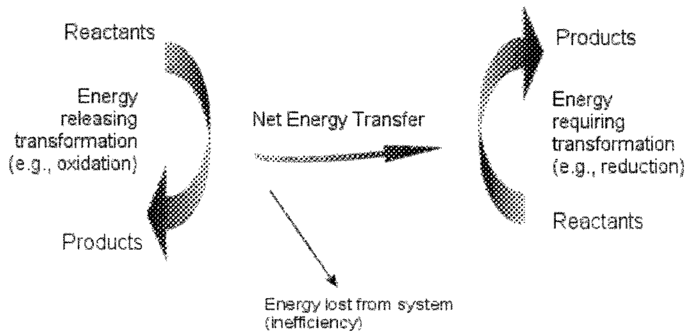



Figure 3.5 Coupling of energy transformations and flow of energy

But what is more important, **not all transformations of elements in the ecosystem are biological, nor all involve the net assimilation or release of useful quantities of energy**. <u>Weathering of bedrock releases certain elements (potassium, phosphorus, and silicon, for example) to the ecosystem.</u>

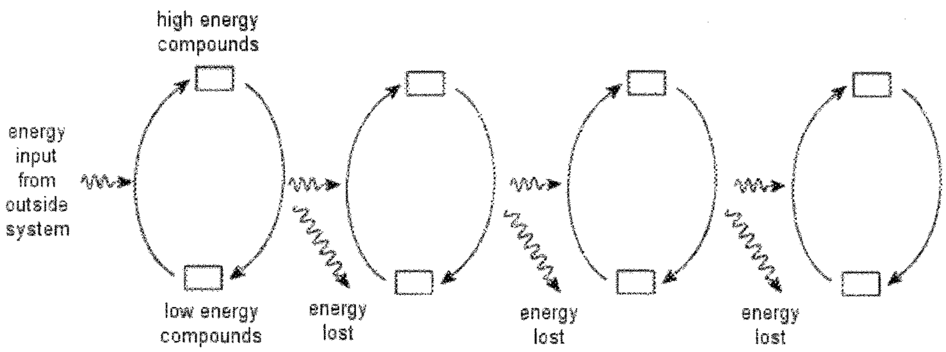



Figure 3.6 Energy flowing trough the ecosystem

**Most energy transformations are associated with biochemical oxidation and reduction of carbon, oxygen, nitrogen, phosphorus, and sulphur**. An energy-releasing transformation is coupled with and energy-requirement transformation, so that energy is transferred from the reactants in the first to the products in the second (Figure 3.5). When more energy is released by the first than required by the second, the balance is lost as heat (hence the thermodynamic inefficiency of life processes) (Ricklefs, 1990).

The initial input of energy into the ecosystem is accomplished by an assimilatory transformation (the reduction of carbon) in which the source of energy is light rather than a coupled dissimilatory process (one releasing energy). A portion of that energy is lost with each subsequent transformation.

**The cycling of elements <u>between living and physical parts of the ecosystem</u> is related to energy flow by the coupling of the dissimilatory part of one cycle to the assimilatory part of another (Figure 3.6)**

## 3.4 Cycling of elements between compartments of the ecosystem

**<u>Each form of an element can be thought of as occupying a separate compartment in the ecosystem. In this context, biochemical transformations are fluxes of the elements among the compartments.</u>**

For example carbon occurs as carbon dioxide both in the atmosphere and dissolved in water, as carbonate and bicarbonate ions dissolved in water, as calcium carbonate (limestone) in sediments, and in all organic molecules (Figure 3.7). Photosynthesis moves carbon from the carbon dioxide compartment to that containing organic forms of carbon (assimilation); respiration brings it back (dissimilation). The compartment of organic carbon has many subcompartments: animals, plants, microorganisms, and detritus. Herbivory, predation, and detritus feeding move carbon among these subcompartments.

The movement of an element between living organisms and the inorganic forms of the element that organisms both produce and use occurs over periods ranging from a few minutes to the life span of the organism and its subsequent existence as organic detritus. Both organic and inorganic forms of elements may leave the rapid circulation within the ecosystem for compartments not readily accessible to transforming agents. For example coal, oil, and peat contain vast quantities of carbon that has been removed from circulation in the ecosystem.

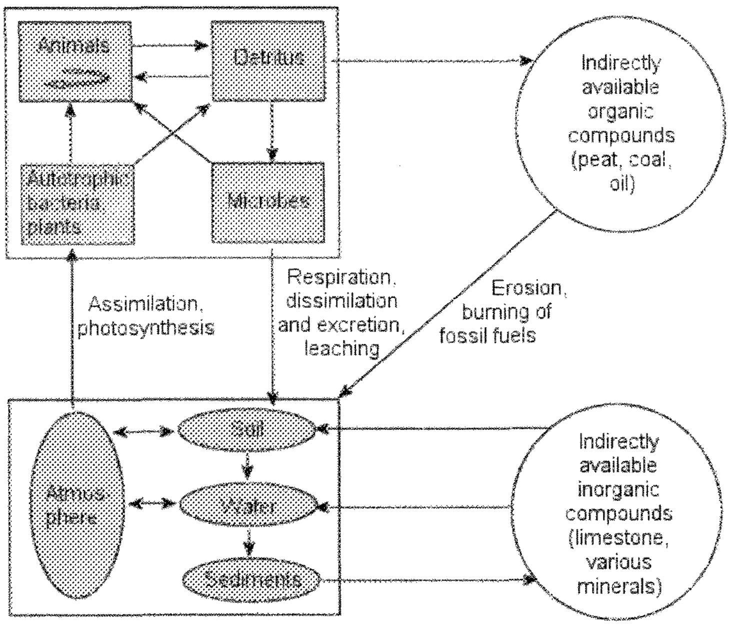



Figure 3.7 A generalised compartment model of the ecosystem (for carbon)

## 3.4 The water cycle and cycling of elements in the ecosystem

Evaporation and condensation resemble photosynthesis and respiration thermodynamically. In this context, the clouds, the ocean, etc, are compartments. Evaporation, not precipitation, determines the flux of water through the ecosystem. The absorption of radiant energy by liquid water couples an energy source to the hydrological cycle. Evaporation and precipitation are closely linked because the atmosphere has a limited capacity to hold water vapor; any increase in evaporation of water into the atmosphere creates an excess of vapor and results in an equal increase in precipitation.

At many points, nutrient cycles may be strongly geared to the hydrologic cycle. Nutrient input and output are directly related to the amounts of water. Biologic uptake of nutrients by plants and release of nutrients by biological decomposition are closely related to the pattern of water availability. Potential levels of biomass within the system are determined in large measure by precipitation characteristics. Similarly, the nature and rate of weathering and soil formation are influenced by the hydrologic regime, since water is essential to the **major chemical weathering processes (ion exchange, hydrolysis, solution, diffusion, oxidation-reduction, and adsorption and swelling).**

## 3.5 The watershed as an ecosystem

Life on our planet is dependent upon the cycle of elements in the biosphere. Atmospheric carbon dioxide would be exhausted in a year or so by green plants were not the atmosphere continually recharged by $CO_2$ generated by respiration and fire (Cole, 1958).

Of no less importance to life are the elements with **sedimentary cycles**, such as phosphorus, calcium, and magnesium. With these cycles, there is a continual loss from biological systems in response to erosion, with ultimate deposition in the sea. Replacement or return of an element with a sedimentary cycle to terrestrial biological systems is dependent upon such processes as **weathering of rocks**, addition from volcanic gases, or the biological movement from the sea to the land. According to Odum, **sedimentary cycles are less perfect and more easily disrupted by man than carbon and nitrogen cycles.** The disruption of local cycling patterns by the activities of man could reduce existing "pools" of an element in local ecosystems, restrict productivity, and consequently limit human population. Recognition of the importance of these biogeochemical processes to the welfare of mankind has generated intensive study of such cycles.

The rate of **release of nutrients from minerals by weathering, the addition of nutrients by erosion**, and the **loss of nutrients by erosion are three primary determinants of structure and function in terrestrial ecosystems**. Further, with this information it is possible to develop total chemical budgets for ecosystems and to relate these data to the larger biogeochemical cycles (Bormann, 1967).

It is largely because of the complex natural interaction of the **hydrologic cycle** and nutrient cycles that it has not been possible to establish these relationships. In many ecosystems this interaction almost hopelessly complicates the measurement of weathering or erosion. Under certain conditions, however, these apparent hindrances can be turned to good advantage in an integrated study of biogeochemical cycling in **small watershed ecosystems** (Likens, 1977)

## 3.6 The watershed and the Biogeochemical Cycling

The terrestrial ecosystem participates in the various larger biogeochemical cycles of the earth through a system of input and outputs. Biogeochemical input in forest or field ecosystems may be derived from three major sources: geologic, meteorologic, and biologic. Geologic input is here defined as dissolved or particulate matter carried into the system by moving water or colluvial action, or both. Depositions of the products of erosion or mass wasting and ions dissolved in incoming seepage water are examples of geologic input. Meteorologic input enters the ecosystem through the ecosystem through the atmosphere and is composed of additions of gaseous materials and of dissolved or particulate matter in precipitation, dust, and other wind-borne materials. Biological input results from animal activity and is made up depositions of materials originally gathered elsewhere; examples are fecal material of animals whose food was gathered outside the system, or fertilizers intentionally added by man (Boorman, 1967).

Chemicals may leave the ecosystem in the form of dissolved or particulate matter in moving water or colluvium or both **(geologic output)**; through the diffusion or transport of gases or particulate matter by wind **(meteorologic output)**; or as a result of the activity of animals, including man **(biologic output).**

Nutrients are found in four compartments within the terrestrial ecosystem: in the atmosphere, in the pool of available nutrients in the soil, in organic materials (biota and organic debris, and in soil and rock minerals (Fig. 3.8)

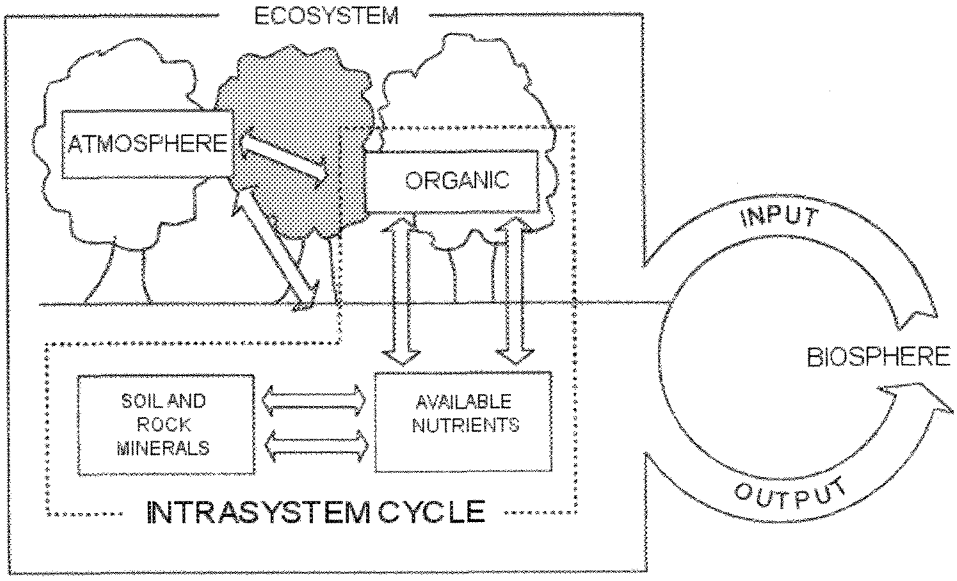



Figure 3.8 Nutrient relationships of a terrestrial ecosystem, showing sites of accumulation and major pathways. Input and output may be composed of geologic, meteorologic, and biologic components (Boorman 1967)

The **atmospheric** compartment includes all atoms or molecules in gaseous form in both the below-ground and the above-ground portions of the ecosystem. The pool of **available nutrients** in the soil **consists of all ions** adsorbed on the clay-humus complex or dissolved in the soil solution. The **organic** compartment includes all atoms incorporated in living organisms and their dead remains. The soil-rock compartment is comprised of elements incorporated in primary and secondary minerals, including the more readily decomposable minerals that enter into equilibrium reactions with the available nutrients (Boorman 1967).

Elements without a prominent gaseous phase may show considerable intrasystem cycling between the available-nutrient, organic, and soil-rock compartments (Figure 2.5). **This internal cycle results from** (i) **the uptake of nutrients by plants**, (ii) **the release of nutrients from plants by direct leaching,** (iii) **the release of nutrients from organic matter by biological decomposition**, and (iv) **equilibrium reactions that convert insoluble chemical forms in the soil-rock compartment to soluble forms in the available-nutrient compartment, and vice versa.**

Available nutrients not only enter the ecosystem from outside but are added by the action of physical, chemical, and biological weathering of rock and soil minerals already within the system. Although some ions are continually withdrawn from the available nutrient compartment, forming secondary minerals in the soil and rocks, for most nutrient elements there is a net movement out of the soil-rock compartment. As the ecosystem is gradually lowered in place by erosion or by the downward growth of roots, new supplies or residual rock or other parent material are included.

## 3.7 Nutrients inputs and outputs

The lack of information on the nutrient-input, nutrient-output relationships of ecosystems is apparently related to two considerations: (i) integrated studies of ecosystems tend to fall into an intellectual "no man's land" between traditional concepts of ecology, geology, and pedology; (ii) more important, the measurement of nutrient input and output requires measurement of hydrologic input and output.

Unquestionably this lack of quantitative information is related to the difficulties encountered in measuring nutrients entering or leaving an ecosystem in seepage water or in sheet or rill flow, and to the high cost, in time and money, of obtaining continuous measurements of the more conventional hydrologic parameters of precipitation and stream flow. **In many systems the problem is further complicated by the fact that much water may leave by the way of deep seepage, eventually appearing in another drainage system;** direct measurement of loss of water and nutrients by this route is virtually impossible (Boorman, 1967).

## 3.8 Small Watershed Approach

An example of a successful aplication of the ecosytem approach aplied to the study of elements in a watershed is detailed below.

In some ecosystems the nutrient-cycle, hydrologic cycle interaction can be turned to good advantage in the study of nutrient budgets, erosion and weathering. This is particularly so if an ecosystem, meets two specifications:

If the ecosystem is a watershed, and
If the watershed is underlain by a tight bedrock or other impermeable base, such as permafrost.

Given these conditions, for chemical elements without a gaseous form at biological temperatures, it is possible to construct nutrient budgets showing input, output, and net loss or gain from the system. These data provide estimates of weathering and erosion (Likens, 1977).

If the ecosystem were a small watershed, input would be limited to meteorologic and biologic origins. Geologic input, as defined above, need not be considered because there would be **no transfer of alluvial or colluvial material between adjacent watersheds**. Although materials might be moved within the ecosystem by alluvial or colluvial forces, these materials would originate within the ecosystem.

When the input and output of dust or windblown materials is negligible, **meteorologic input can be measured from a combination of hydrologic and precipitation-chemistry parameters**. From periodic measurements of the elements contained in precipitation and from continuous measurements of precipitation entering a watershed of known area, one may calculate the temporal input of an element in terms of grams per Hectare (Boorman, 1967).

Losses from this watershed ecosystem would be limited to geologic and biologic output. Given an impermeable base, geologic output (losses due to erosion) would consist of dissolved and particulate matter in either stream water or seepage water moving downhill above the impermeable base. Although downhill mass movement may occur within the system, the product of this movement are delivered to the stream bed, whence they are removed by erosion and stream transportation. **Geologic output can be estimated from hydrologic and chemical measurements**. A weir anchored to the bedrock, will force all drainage water from the watershed to flow over the notch, where the volume and rate of flow can be measured. These data, in combination with periodic measures of dissolved and particulate matter in the outflowing water, provide an estimate of geologic output which may be expressed as gram of an element lost per hectare of watershed.

The nutrient budget for a single element in the watershed ecosystem may be expressed as follows: **(meteorologic input + biologic input) – (geologic output + biologic output) = net loss or gain**. This equation may be further simplified if the ecosystem meets a third specification, if it is part of a much larger, more or less homogeneous vegetation unit. Biological output would tend to balance biological input if the ecosystem contained no special attraction or deterrent for animal populations moving at random through the larger vegetation system, randomly acquiring or discharging nutrients. On this assumption, the nutrient budget for a single system would **become (meteorologic input per hectare) – (geologic output per hectare)= net gain or loss** per hectare. This fundamental relationship provides basic data for an integrated study of ecosystem dynamics (Likens, 1977).

Weathering, or the rate at which an element bound in soil and rock minerals is made available, can be estimated from net losses of that element as calculated by the nutrient-budget method. Within the ecosystem (watershed), atoms of an element (one that lacks a gaseous form at ecosystem temperatures) may be located in (i) soil and rock minerals, (ii) the biota and organic debris, and (iii) the pool of available nutrients (Figure 3.8). There is an intense intrasystem cycling between categories (ii) and (iii) as large quantities of ions are taken up by the vegetation by the vegetation each year and released by direct leaching or stepwise decomposition in the food chain. Ions are continually released to the intrasystem cycle by weathering of soil and rock material. Some of these ions, however are reconstituted as secondary minerals. **If an ecosystem is in a state of dynamic equilibrium, as the presence of climax forest would suggest, ionic levels in the intrasystem cycle must remain about the same for many years. Thus in the climax ecosystem, net ion losses (output minus input) must be balanced by equivalent additions derived from weathering of soil and rock materials.** Thus, net ionic losses from an undisturbed, relatively stable terrestrial ecosystem are a measure of weathering within the system (Boorman, 1967). In a successional ecosystem (in which nutrients are accumulating in biomass and organic debris over the course of years, the rate at which an ion is released by weathering must equal its rate of net loss from the ecosystem plus it rate of net accumulation in the biota and organic debris.

# Chapter 4 Preliminary Sampling

## 4.1 The tasks carried out

During fieldwork, a preliminary sampling was carried out taken into account the data available at that moment. The first step before going to field was to process or adequate this data. Another important issue was the validation of the data (drainage mainly). The tasks performed just before, during and just after fieldwork are detailed in this chapter.

## 4.2 Examination of data available

Initially a literature review and an examination of data available for the study area were carried out. Maps using existing data sets were mapped out delineating the subcatchments within the Turasha basin. In this stage the data identified as relevant to the study were:

### 4.2.1 Topographic maps

| Sheet | Code | Date | Scale | Publisher |
|---|---|---|---|---|
| Naivasha | 133/2 | 1975 | 1:50000 | UK, Directorate of Overseas Surveys |
| Kinangop | 134/1 | 1975 | 1:50000 | UK, Directorate of Overseas Surveys |
| Gilgil | 119/4 | 1975 | 1:50000 | UK, Directorate of Overseas Surveys |
| Nyeri | SA-37-1 | 1981 | 1:250000 | Survey of Kenya |

Table 4.1 Topographic maps

The sheet Kipipiri also required for the study was obtained during fieldwork (See section 4.3.3).

### 4.2.2 Geologic maps

Initially no geology map for the Turasha catchment was available, therefore it had to be requested to who correspond in Kenya during fieldwork (See section 4.3.3).

### 4.2.3 Satellite images

| Image | Date | Format | Bands | Area of study covered |
|---|---|---|---|---|
| Lake Naivasha | 18-May-2000 | ERDAS LAN | 1,2,3,4,5,6 | Western Part |
| Mount Kenya | 21-Feb-2000 | ERDAS LAN | 1,2,3,4,5,6 | Eastern Part |

Table 4.2 Satellite Images

### 4.2.4 References

During the literature review and in later stages, a few research papers, MSc theses and journal articles from past works in Lake Naivasha and surroundings were collected. Also several books and journal articles related to this field of study were selected. This literature is detailed in the References.

## 4.3 Field data collection

The main task during fieldwork was the collection of water samples to be analyzed for major ions. But also the collection of some land cover information by visual observation was carried out. Soil and geology maps were also necessary to be collected.

### 4.3.1 Water samples collection

Water samples were collected from twenty locations, sixteen of them in rivers within the Turasha catchment, moreover two in the Malewa River and two in the Gil-Gil River. The samples for the last four locations were selected for reasons of comparison, even thought they are outside the study-area. In each location at least one sample was taken, in the important locations (outlet of a subcatchment) two or three samples were taken in different days. The sampling was done between September 13 and September 26 of the year 2000 at the end of the second dry season in the Turasha catchment.

The criteria used to select the locations were:

- Water flow
- Subcatchments
- Land cover
- Accessibility

Figure 4.1 shows the streams in the area and the distribution of the sampling points. It is necessary to highlight that not all the streams in the area are perennial and that the sampling was done during September when some streams are not flowing. Also the presence of dams for local water supply in the dry season stops the flow of water in some streams.

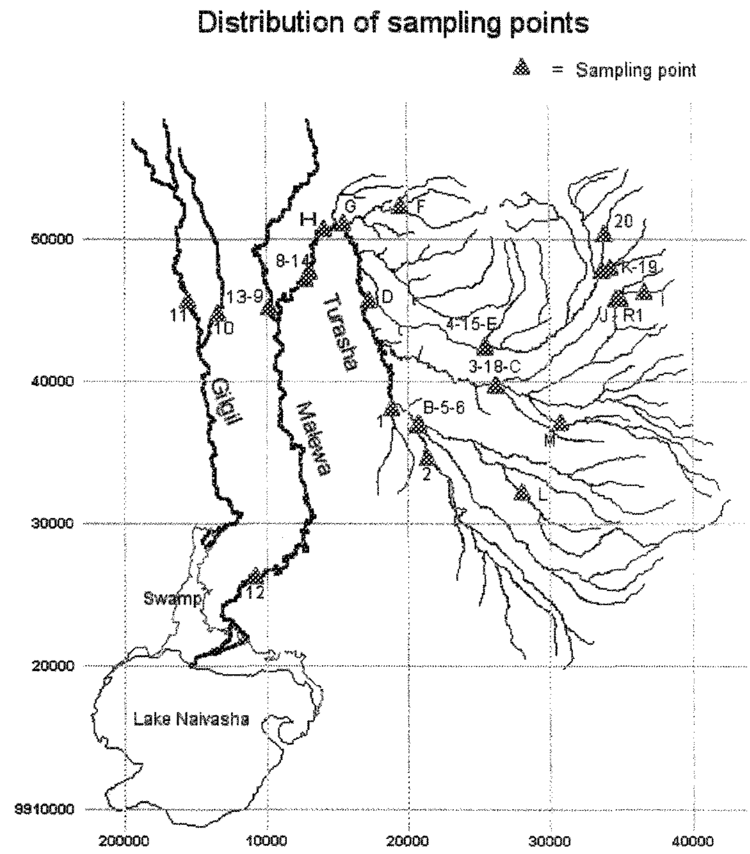


Figure 4.1 Distribution of sampling points

Therefore only the streams with flowing water were considered in the sampling scheme. In Figure 4.2, the flowing streams are presented in blue while the dry streams are presented in red. It is easy to see that the rivers with water are mainly those that born on top of the Aberdare and Kipipiri mountains.

The next criterion to select the locations for sampling was the position according to the subcatchments of the Turasha catchment. The main goal was to take samples in the outlet of each subcatchment.

The study area was divided in 5 subcatchments named: Kianjogu, Mkungi, Kitiri, Tulasha and Muruaki. Each name corresponds to the main stream in the subcatchment except in the case of the Tulasha subcatchment were the main stream has the name Turasha. The name Tulasha corresponds to the name of the main stream when it born in the Aberdare. This name is used to avoid confusion.

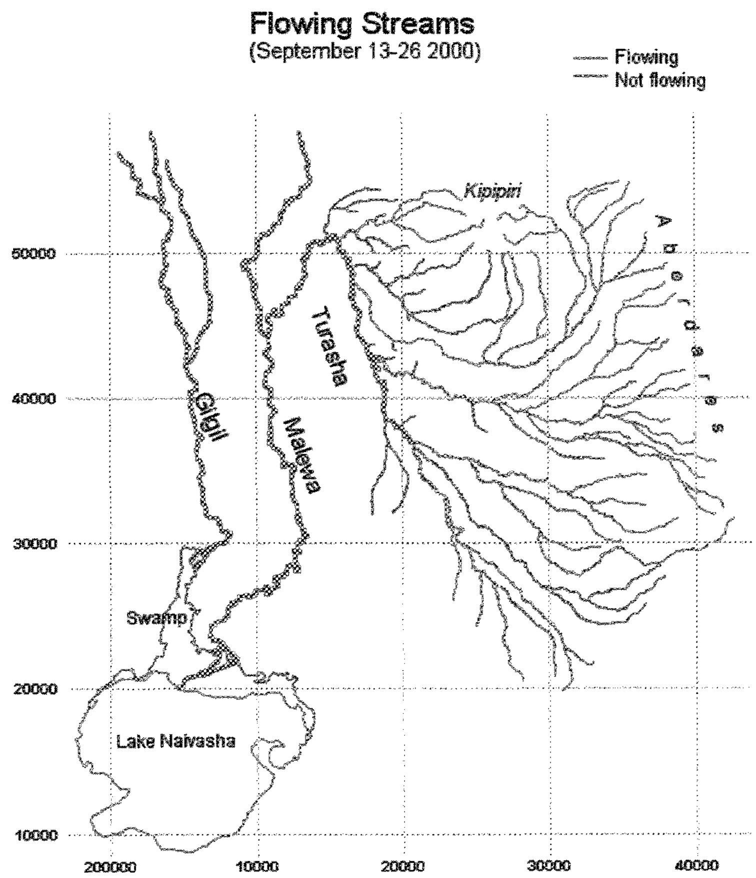



Figure 4.2 Flowing streams

Some samples were taken as near as possible (limitation due to accessibility) to the outlet of the subcatchment, Figure 4.3 shows this samples in red color.

Once each subcatchment was well defined, the next step was to take additional samples, not only in the outlet but also upstream. It was of special interest to take samples in the undisturbed areas of the subcatchments: the forests in the Kipipiri and Aberdare Mountains. Samples in the forest were taken for the Kianjogu, Mkungi and Kitiri. Access to the Tulasha Forest was not possible; the new coming rains made the road impassable. In Figure 4.3 the samples in undisturbed forest are represented in green. In the subcatchments where sampling on the forest was not possible, samples were taken upstream, as near to as possible to the Aberdare, these are presented in yellow in Figure 4.3

Additionally a longitudinal transect along the Turasha River was carried out with samples after each tributary and also downstream near the Malewa River. These samples are represented in blue in Figure 4.3

Finally, extra samples were taken out of the Turasha catchment in the Malewa and Gilgil Rivers, grey symbols in Figure 4.3.

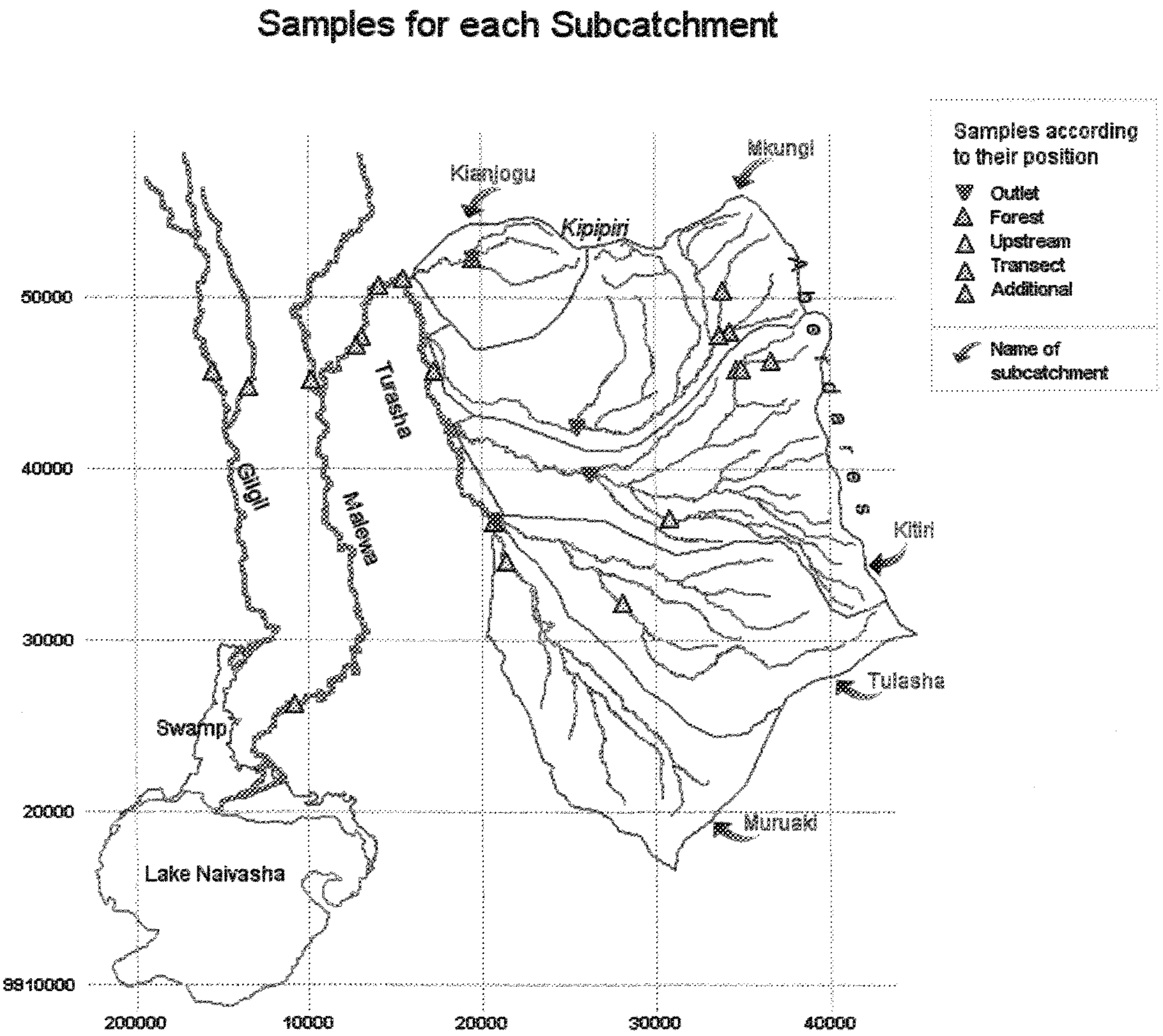



Figure 4.3 Subcatchments and sample points

Each sample was taken using a plastic bucket and two 250-ml polyethylene bottles. Bottles were filled with sample water, agitated and then decanted. This procedure was followed prior each sample collection. The same day of collection, pH and conductance were measured in unfiltered samples, also chloride and alkalinity were analyzed but in filtered samples. Filtration was carried out using filter of 0.45 µm pore size. The results of these preliminary measurements are showed in Table 4.3.

The samples were stored in polyethylene bottles at room temperature. Acid was added to the samples as a preservative the same day of collection or one or two days later. One rainwater sample was collected in the north-east of the Turasha catchment (Kitiri subcatchment); it was treated as the other samples.

These samples were carried back to the Netherlands for the analysis of major ions.

Table 4.3 shows the analysis of the samples only in chronological order, as they were collected on field. After fieldwork they were classified according to its subcatchments; this classification is presented in table 4.4. The distribution of the sampling points can be seen in Figure 4.1

| Sample Code | X* | Y* | Z** | Date | pH | EC*** US/cm | Alk mmol/l | Cl mg/l |
|---|---|---|---|---|---|---|---|---|
| 2 | 221313 | 9934592 | 2422 | 13-Sep-00 | 7.65 | 291.0 | 1.7 | 12.0 |
| 3 | 226210 | 9939723 | 2409 | 13-Sep-00 | 8.03 | 278.0 | 0.9 | 4.0 |
| 4 | 225416 | 9942461 | 2414 | 13-Sep-00 | 8.12 | 280.0 | 1.0 | 4.0 |
| 5 | 220778 | 9936994 | 2421 | 13-Sep-00 | 8.10 | 164.2 | 1.1 | 4.0 |
| 6 | 220751 | 9936881 | 2421 | 13-Sep-00 | 7.80 | 290.0 | 1.3 | 12.0 |
| 8 | 213033 | 9947763 | 2023 | 13-Sep-00 | 8.21 | 220.0 | 0.9 | 8.0 |
| 9 | 210214 | 9945248 | 2000 | 13-Sep-00 | 8.23 | 151.7 | 1.0 | 8.0 |
| 10 | 206535 | 9944786 | 1980 | 13-Sep-00 | 8.17 | 286.0 | 1.6 | 6.0 |
| 11 | 204506 | 9945707 | 1990 | 13-Sep-00 | 8.23 | 150.2 | 0.9 | 8.0 |
| 12 | 209144 | 9926344 | 1915 | 13-Sep-00 | 8.18 | 105.6 | 1.0 | 6.0 |
| 13 | 210203 | 9945242 | 2000 | 15-Sep-00 | 7.91 | 80.4 | 0.7 | 4.0 |
| 14 | 212801 | 9947255 | 2022 | 15-Sep-00 | 8.22 | 102.1 | 0.9 | 6.0 |
| 15 | 225441 | 9942473 | 2415 | 15-Sep-00 | 7.95 | 92.5 | 0.9 | 4.0 |
| 18 | 226150 | 9939697 | 2408 | 15-Sep-00 | 8.00 | 103.3 | 1.0 | 4.0 |
| 19 | 234198 | 9948050 | 2578 | 18-Sep-00 | 7.90 | 124.8 | 1.0 | 4.0 |
| 20 | 233869 | 9950441 | 2704 | 18-Sep-00 | 7.93 | 93.2 | 0.8 | 4.0 |
| 21 | 226001 | 9959342 | 2612 | 18-Sep-00 | 8.15 | 80.9 | 0.8 | 4.0 |
| B | 220628 | 9936910 | 2421 | 21-Sep-00 | 7.45 | 135.0 | 1.2 | 4.0 |
| C | 226151 | 9939701 | 2408 | 21-Sep-00 | 7.95 | 94.5 | 1.0 | 5.0 |
| D | 217219 | 9945687 | 2256 | 21-Sep-00 | 8.02 | 102.5 | 1.1 | 4.0 |
| E | 225433 | 9942460 | 2416 | 21-Sep-00 | 7.95 | 89.3 | 0.9 | 4.0 |
| F | 219496 | 9952305 | 2264 | 21-Sep-00 | 8.18 | 123.4 | 1.1 | 4.0 |
| G | 215437 | 9951067 | 2144 | 22-Sep-00 | 8.30 | 103.5 | 1.1 | 4.0 |
| H | 214018 | 9950750 | 2164 | 22-Sep-00 | 7.74 | 108.6 | 0.9 | 4.0 |
| I | 236687 | 9946313 | 2670 | 23-Sep-00 | 8.45 | 112.6 | 1.4 | 4.0 |
| J | 234635 | 9945803 | 2564 | 23-Sep-00 | 7.81 | 85.8 | 0.8 | 4.0 |
| K | 233666 | 9947798 | 2560 | 23-Sep-00 | 8.05 | 97.4 | 0.8 | 4.0 |
| R1 | 234987 | 9945786 | 2571 | 23-Sep-00 | 7.20 | 31.4 | 0.3 | 4.0 |
| L | 228044 | 9932214 | 2456 | 23-Sep-00 | 7.82 | 108.8 | 1.0 | 4.0 |
| M | 230725 | 9937146 | 2460 | 26-Sep-00 | 7.90 | 90.0 | 1.5 | 4.0 |

Table 4.3 Field measurements of the water samples

* X, Y in meters, Projection UTM, Spheroid Clarke 1880, Zone number 37 south, Datum Arc 1960

** Z taken from DEM (interpolation of contour lines, topomap 1975)

***EC measurements during day 13 are not used because of problems with the instrument

| Location | Day | Sample Code | EC uS/cm | pH | Alk mmol/l | Cl mg/l |
|---|---|---|---|---|---|---|
| Gilgil River - Little Gilgil tributary | 13 | 10 | - | 8.17 | 1.6 | 6 |
| Gilgil River - Murindati tributary | 13 | 11 | - | 8.23 | 0.9 | 8 |
| Kianjogu subcatchment - Outlet | 21 | F | 123.4 | 8.18 | 1.1 | 4 |
| Kitiri subcatchment - Forest | 23 | I | 112.6 | 8.45 | 1.4 | 4 |
| Kitiri subcatchment - Forest plantation | 23 | J | 85.8 | 7.81 | 0.8 | 4 |
| | | R1 | 31.4 | 7.20 | 0.3 | 4 |
| Kitiri subcatchment - Middle | 26 | M | 90.0 | 7.90 | 1.5 | 4 |
| Kitiri subcatchment - Outlet | 13 | 03 | - | 8.03 | 0.9 | 4 |
| | 15 | 18 | 103.3 | 8.00 | 1.0 | 4 |
| | 21 | C | 94.5 | 7.95 | 1.0 | 5 |
| Malewa River - Downstream/outlet | 13 | 12 | - | 8.18 | 1.0 | 6 |
| Malewa River - Upstream | 13 | 09 | - | 8.23 | 1.0 | 8 |
| | 15 | 13 | 80.4 | 7.91 | 0.7 | 4 |
| Mkungi subcatchment - Forest plantation | 18 | 19 | 124.8 | 7.90 | 1.0 | 4 |
| | | 20 | 93.2 | 7.93 | 0.8 | 4 |
| | 23 | K | 97.4 | 8.05 | 0.8 | 4 |
| Mkungi subcatchment - Outlet | 13 | 04 | - | 8.12 | 1.0 | 4 |
| | 15 | 15 | 92.5 | 7.95 | 0.9 | 4 |
| | 21 | E | 89.3 | 7.95 | 0.9 | 4 |
| Muruaki subcatchment - Middle | 13 | 02 | - | 7.65 | 1.7 | 12 |
| Muruaki subcatchment - Outlet | 13 | 06 | - | 7.80 | 1.3 | 12 |
| Tulasha subcatchment - Middle | 23 | L | 108.8 | 7.82 | 1.0 | 4 |
| Tulasha subcatchment - Outlet | 13 | 05 | - | 8.10 | 1.1 | 4 |
| Turasha River - Transect after Kianjogu | 22 | G | 103.5 | 8.30 | 1.1 | 4 |
| Turasha River - Transect after Kianjogu - DAM | 22 | H | 108.6 | 7.74 | 0.9 | 4 |
| Turasha River - Transect before Kitiri | 21 | B | 135.0 | 7.45 | 1.2 | 4 |
| Turasha River - Transect before Mkungi | 21 | D | 102.5 | 8.02 | 1.1 | 4 |
| Turasha River - Transect outlet | 13 | 08 | - | 8.21 | 0.9 | 8 |
| | 15 | 14 | 102.1 | 8.22 | 0.9 | 6 |

Table 4.4 Field measurements by subcatchment and day of sample (September 2000)

The complete analysis of water samples together with the laboratory results are presented in section 4.5 – Table 4.7.

Each time a sample was taken there was a little variation in its coordinates, because of the GPS precision or because the second or third sample were taken a few meters away from the original point. The coordinates for each location are presented in table 4.5. A sample of rain is also included (R1). It is classified within the area it was taken.

| Location | X* | Y* | Z** |
|---|---|---|---|
| Kianjogu subcatchment – Outlet | 219496 | 9952305 | 2264 |
| Kitiri subcatchment – Forest | 236687 | 9946313 | 2660 |
| Kitiri subcatchment - Forest plantation | 234635 | 9945803 | 2559 |
| Kitiri subcatchment – Middle | 230725 | 9937146 | 2460 |
| Kitiri subcatchment – Outlet | 226150 | 9939697 | 2408 |
| Mkungi subcatchment - Forest plantation | 233666 | 9947798 | 2560 |
| Mkungi subcatchment – Outlet | 225416 | 9942461 | 2414 |
| Muruaki subcatchment – Outlet | 220751 | 9936881 | 2399 |
| Tulasha subcatchment – Middle | 228044 | 9932214 | 2457 |
| Tulasha subcatchment – Outlet | 220778 | 9936994 | 2399 |
| Turasha River - 1 Transect before Kitiri | 220628 | 9936910 | 2399 |
| Turasha River - 2 Transect before Mkungi | 217219 | 9945687 | 2242 |
| Turasha River - 3 Transect after Kianjogu | 215437 | 9951067 | 2140 |
| Turasha River - 4 Transect after Kianjogu – DAM | 214018 | 9950750 | 2138 |
| Turasha River - 5 Transect outlet | 212801 | 9947255 | 2023 |
| Gilgil River – Little Gilgil Tributary | 206535 | 9944786 | *** |
| Malewa River – After Turasha River | 209144 | 9926344 | *** |
| Malewa River – Before Turasha River | 210214 | 9945248 | *** |

Table 4.5 Coordinates for each location

* X, Y in meters, Projection UTM, Spheroid Clarke 1880, Zone number 37 south, Datum Arc 1960

** Taken from DEM (interpolation of contour lines, topomap 1975)

*** Out of the Turasha Catchment

### 4.3.2 Tree species

It was of interest to collect some information about land cover in the area, especially in the forests of the Kipipiri and Aberdare Mountains. Some data was provided at Geta Station situated in the north-east of the catchment near to the Aberdare National Park.

The subcatchments Mkungi and Kitiri have two different forests: Plantation and Indigenous. They are remarkable different in tree species. The forest of subcatchments Kianjogu and Turasha are mostly indigenous. Subcatchment Muruaki does not have forest area. Some control points in forest areas were taken for further classification.

The trees in the plantation are for commercial purposes; the main species are Pinus Patula, Cypressus Lusitanica and Red Cedow. Pinus Patula is the predominant in the area. Parts of the plantations are cultivated under the Shamba System, so it is possible to find other crops in these fields. All these plantations are localized mainly between the piedmonts of the Aberdare and Kipipiri Mountains.

Olea Africanus is the predominant tree specie in the indigenous forest. The indigenous Dombea burgessiae and Dombea Groetzenii are also present, but in less quantity. However, the higher the altitude the more notorious is the presence of Bamboo spp.

### 4.3.3 Additional information and maps

Additional information was collected from Nairobi related to soil in the Kinangop Area. This information is compiled in the booklet "Soil Conditions in the Kinangop Area - Site Evaluation report no.34 - January 1978". Also the following maps were obtained:

| Sheet | Code | Date | Scale | Publisher |
|---|---|---|---|---|
| Kipipiri (topomap) | 120/3 | 1975 | 1:50000 | UK, Directorate of Overseas Surveys |
| Geological map of Kinangop Area | Drawing No 77082 | November 1977 | 1:250000 | Kenya Soil Survey |
| Soil map of the Kinangop Area | Drawing No 77059 | November 1977 | 1:100000 | Kenya Soil Survey |

Table 4.6 Topographic maps collected during fieldwork

## 4.4 Geographic data processing

This was carried out after fieldwork having enough knowledge of the area and also ground control points. The main task was to geo-reference the two TM 2000 images (eastern and western part of the Turasha catchment). Also during fieldwork it was observed that the drainage maps available were not accurate enough to be used in the study so this work had to be redone.

### 4.4.1 Geo-reference of Landsat 7 images

Two Landsat 7 scenes were necessary to cover the whole Turasha catchment. The scene dated May 18 covers most of the western part of the catchment and the scene dated February 21 covers most of the eastern part. Some control points were collected on field but also more were necessary to geo-reference the catchment. After field work all the topographic sheets (scale 1:50000) covering the catchment were available and ready to be used in the geo-referencing. The main tasks are detailed below:

- Scanning of topographic maps (Naivasha, Kinangop, Gilgil and Kipipiri)
- Geo-reference of scanned maps (using corner coordinates)
- Gluing of georeferenced scanned maps to get one geo-referenced topographic map
- Geo-reference of L7 2000 February scene (using topographic image to get reference points)
- Geo-reference of L7 2000 May scene (using topographic image to get reference points)
- Additionally the two geo-referenced L7 images were glued together for presentation purposes

In the process ERDAS Imagine 8.4 was used. The results were later exported to ILWIS 2.2. The following projection parameters were used:

- Projection: UTM
- Spheroid: Clarke 1880
- Zone number: 37
- Datum: Arc 1960

The control points used to georeference this images are presented in Appendix A.

### 4.4.2 Digitalisation of streams

An accurate streams map was obtained using the same scanned topographic map. The process was as follow:

- Identification of main streams in the catchment
- On screen digitalisation of main streams using the scanned topographic map
- Classification of streams in perennial and no perennial
- On screen digitalisation of subcatchments using the new streams map and the contours map

The streams were digitized using ERDAS Imagine 8.4 while the subcatchments were digitized using ILWIS 2.2

## 4.5 Analysis of Preliminary sampling data

The samples collected on fieldwork, during the preliminary sampling were sent to the laboratory for the corresponding analysis. The results obtained from the laboratory together with the field measurements are presented in Table 4.7.

Some checks were carried out on the results received; they are detailed in the following sections. Eventually, some water quality data for the area from Gaudet and Melack (1981), that will be used in this study are jointly analyzed.

The tests executed are: pH calculated vs. observed, hydrological profiles along the main streams and source rock deduction.

| Location | day | Code | EC | pH | HCO3 (Alk) | | Cl | | Na | | Mg | | K | | Ca | | Fe | | S | SO4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | uS/cm | | mg/l | meq/l | mg/l | meq/l | mg/l | meq/l | mg/l | Meq/l | mg/l | meq/l | mg/l | meq/l | mg/l | meq/l | mg/l | mg/l | meq/l |
| Gilgil River – Little Gilgil tributary | 13 | 10 | - | 8.2 | 97.6 | 1.6 | 6 | 0.17 | 26.63 | 1.158 | 0.90 | 0.074 | 10.82 | 0.277 | 6.89 | 0.344 | 0.71 | 0.0254 | - | - | - |
| Gilgil River - Murindati tributary | 13 | 11 | - | 8.2 | 54.9 | 0.9 | 8 | 0.23 | 9.40 | 0.409 | 0.57 | 0.047 | 4.55 | 0.116 | 2.96 | 0.148 | 0.64 | 0.0229 | - | - | - |
| Kianjogu subcatchment - Outlet | 21 | F | 123.4 | 8.2 | 67.1 | 1.1 | 4 | 0.11 | 13.50 | 0.587 | 1.53 | 0.126 | 2.81 | 0.072 | 9.00 | 0.449 | 0.01 | 0.0004 | 16.64 | 49.92 | 1.039 |
| Kitiri subcatchment - Forest | 23 | I | 112.6 | 8.5 | 85.4 | 1.4 | 4 | 0.11 | 4.44 | 0.193 | 5.12 | 0.421 | 1.58 | 0.040 | 11.42 | 0.570 | 0.00 | 0.0000 | 0.30 | 0.90 | 0.019 |
| Kitiri subcatchment - Forest plantation | 23 | J | 85.8 | 7.8 | 48.8 | 0.8 | 4 | 0.11 | 4.13 | 0.18 | 2.86 | 0.235 | 1.47 | 0.038 | 8.29 | 0.414 | 0.03 | 0.0011 | 0.40 | 1.20 | 0.025 |
| Kitiri subcatchment - Forest plantation | 23 | R1 | 31.4 | 7.2 | 18.3 | 0.3 | 4 | 0.11 | 2.67 | 0.116 | 0.15 | 0.012 | 0.89 | 0.023 | 1.74 | 0.087 | 0.09 | 0.0032 | 0.60 | 1.80 | 0.037 |
| Kitiri subcatchment - Middle | 26 | M | 90 | 7.9 | 91.5 | 1.5 | 4 | 0.11 | 4.81 | 0.209 | 4.03 | 0.332 | 2.37 | 0.061 | 12.35 | 0.616 | 0.13 | 0.0047 | 0.50 | 1.50 | 0.031 |
| Kitiri subcatchment - Outlet | 13 | 03 | - | 8.0 | 54.9 | 0.9 | 4 | 0.11 | 7.29 | 0.317 | 2.95 | 0.243 | 3.24 | 0.083 | 9.31 | 0.465 | 0.31 | 0.0111 | - | - | - |
| Kitiri subcatchment - Outlet | 15 | 18 | 103.3 | 8.0 | 61.0 | 1.0 | 4 | 0.11 | 5.04 | 0.219 | 3.22 | 0.265 | 2.32 | 0.059 | 8.95 | 0.447 | 0.00 | 0.0000 | - | - | - |
| Kitiri subcatchment - Outlet | 21 | C | 94.5 | 8.0 | 61.0 | 1.0 | 5 | 0.14 | 4.58 | 0.199 | 3.12 | 0.257 | 2.25 | 0.058 | 8.67 | 0.433 | 0.13 | 0.0047 | 2.20 | 6.60 | 0.137 |
| Malewa River - Downstream/outlet | 13 | 12 | - | 8.2 | 61.0 | 1.0 | 6 | 0.17 | 6.10 | 0.265 | 1.60 | 0.132 | 2.88 | 0.074 | 6.77 | 0.338 | 0.10 | 0.0036 | - | - | - |
| Malewa River - Upstream | 13 | 09 | - | 8.2 | 61.0 | 1.0 | 8 | 0.23 | 6.29 | 0.274 | 1.20 | 0.099 | 2.51 | 0.064 | 4.91 | 0.245 | 0.22 | 0.0079 | - | - | - |
| Malewa River - Upstream | 15 | 13 | 80.4 | 7.9 | 42.7 | 0.7 | 4 | 0.11 | 6.41 | 0.279 | 1.30 | 0.107 | 2.54 | 0.065 | 5.26 | 0.262 | 0.11 | 0.0039 | - | - | - |
| Mkungi subcatchment - Forest plantation | 18 | 19 | 124.8 | 7.9 | 61.0 | 1.0 | 4 | 0.11 | 4.35 | 0.189 | 3.28 | 0.270 | 1.81 | 0.046 | 12.21 | 0.609 | 0.06 | 0.0021 | - | - | - |
| Mkungi subcatchment - Forest plantation | 18 | 20 | 93.2 | 7.9 | 48.8 | 0.8 | 4 | 0.11 | 3.83 | 0.167 | 2.95 | 0.243 | 1.09 | 0.028 | 9.64 | 0.481 | 0.09 | 0.0032 | - | - | - |
| Mkungi subcatchment - Forest plantation | 23 | K | 97.4 | 8.1 | 48.8 | 0.8 | 4 | 0.11 | 4.47 | 0.194 | 2.87 | 0.236 | 1.52 | 0.039 | 9.13 | 0.456 | 0.03 | 0.0011 | 0.70 | 2.10 | 0.044 |
| Mkungi subcatchment - Outlet | 13 | 04 | - | 8.1 | 61.0 | 1.0 | 4 | 0.11 | 4.48 | 0.195 | 2.34 | 0.192 | 2.13 | 0.054 | 7.82 | 0.390 | 0.16 | 0.0057 | - | - | - |
| Mkungi subcatchment - Outlet | 15 | 15 | 92.5 | 8.0 | 54.9 | 0.9 | 4 | 0.11 | 4.42 | 0.192 | 2.37 | 0.195 | 2.01 | 0.051 | 7.87 | 0.393 | 0.12 | 0.0043 | - | - | - |
| Mkungi subcatchment - Outlet | 21 | E | 89.3 | 8.0 | 54.9 | 0.9 | 4 | 0.11 | 4.49 | 0.195 | 2.47 | 0.203 | 2.40 | 0.061 | 8.08 | 0.403 | 0.00 | 0.0000 | 1.11 | 3.33 | 0.069 |
| Muruaki subcatchment - Middle | 13 | 02 | - | 7.7 | 103.7 | 1.7 | 12 | 0.34 | 18.48 | 0.804 | 3.91 | 0.322 | 13.96 | 0.357 | 14.66 | 0.732 | 6.66 | 0.2385 | - | - | - |
| Muruaki subcatchment - Outlet | 13 | 06 | - | 7.8 | 79.3 | 1.3 | 12 | 0.34 | 9.37 | 0.408 | 3.10 | 0.255 | 10.15 | 0.260 | 11.41 | 0.569 | 4.84 | 0.1733 | - | - | - |
| Tulasha subcatchment - Middle | 23 | L | 108.8 | 7.8 | 61.0 | 1.0 | 4 | 0.11 | 3.60 | 0.157 | 3.49 | 0.287 | 3.30 | 0.084 | 11.86 | 0.592 | 0.06 | 0.0021 | 0.40 | 1.20 | 0.025 |
| Tulasha subcatchment - Outlet | 13 | 05 | - | 8.1 | 67.1 | 1.1 | 4 | 0.11 | 3.98 | 0.173 | 3.04 | 0.250 | 3.16 | 0.081 | 10.52 | 0.525 | 0.08 | 0.0029 | - | - | - |
| Turasha River - Transect after Kianjogu | 22 | G | 103.5 | 8.3 | 67.1 | 1.1 | 4 | 0.11 | 6.33 | 0.275 | 2.87 | 0.236 | 2.82 | 0.072 | 9.10 | 0.454 | 0.09 | 0.0032 | 0.61 | 1.83 | 0.038 |
| Turasha River - Transect after Kianjogu - DAM | 22 | H | 108.6 | 7.7 | 54.9 | 0.9 | 4 | 0.11 | 6.83 | 0.297 | 2.86 | 0.235 | 2.97 | 0.076 | 9.30 | 0.464 | 0.07 | 0.0025 | 0.50 | 1.50 | 0.031 |
| Turasha River - Transect before Kitiri | 21 | B | 135 | 7.5 | 73.2 | 1.2 | 4 | 0.11 | 4.94 | 0.215 | 3.19 | 0.262 | 5.28 | 0.135 | 13.04 | 0.651 | 0.13 | 0.0047 | 5.99 | 17.97 | 0.374 |
| Turasha River - Transect before Mkungi | 21 | D | 102.5 | 8.0 | 67.1 | 1.1 | 4 | 0.11 | 5.85 | 0.254 | 3.13 | 0.257 | 2.69 | 0.069 | 8.86 | 0.442 | 0.00 | 0.0000 | 0.96 | 2.88 | 0.060 |
| Turasha River - Transect outlet | 13 | 08 | - | 8.2 | 54.9 | 0.9 | 8 | 0.23 | 6.10 | 0.265 | 2.34 | 0.192 | 2.86 | 0.073 | 7.77 | 0.388 | 0.24 | 0.0086 | - | - | - |
| Turasha River - Transect outlet | 15 | 14 | 102.1 | 8.2 | 54.9 | 0.9 | 6 | 0.17 | 6.25 | 0.272 | 2.49 | 0.205 | 2.86 | 0.073 | 8.23 | 0.411 | 0.20 | 0.0072 | - | - | - |

Table 4.7 Water quality data of preliminary sampling (classified by subcatchments)

### 4.5.1 pH observed vs. pH calculated

For calculation of pH, in order to be compared with the observed value, the software PREEQC (Parkhurst and Appelo, 1999) was used. For pH evaluation, the charges are balanced and equilibrated with the $CO_2$ from the air. For the calculation, the carbon was taken from $HCO_3$. The input file for PREEQC is presented in Appendix D. Figure 4.4 plots the calculated vs. the observed pH Values.

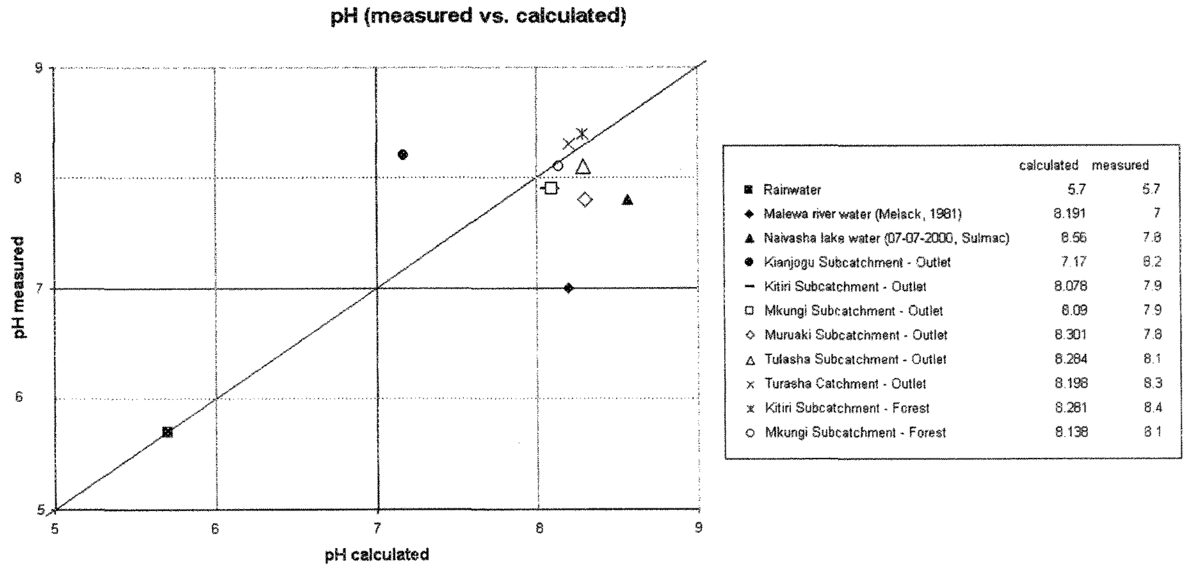


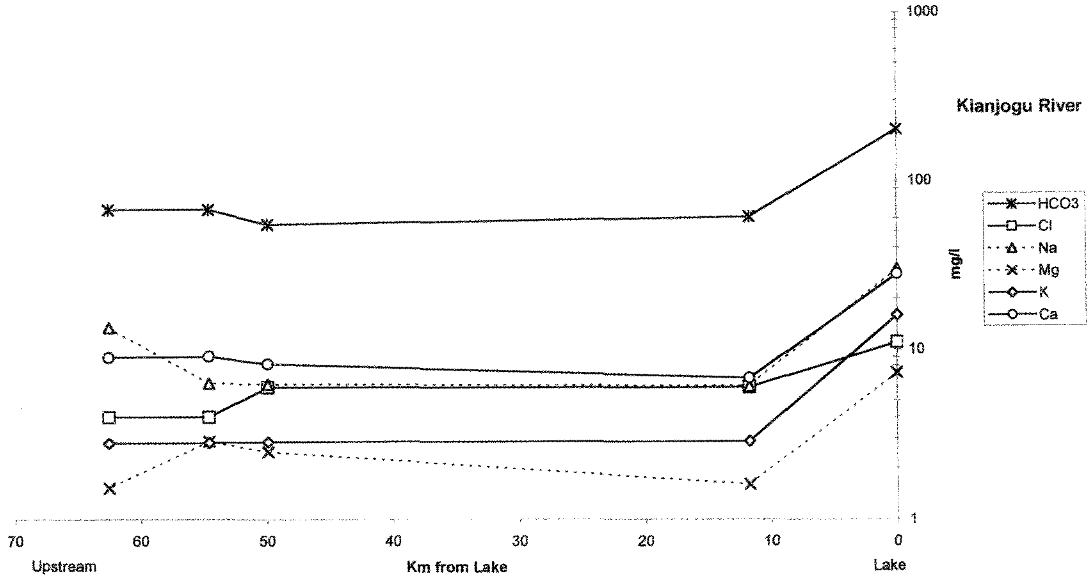

Figure 4.4 pH calculated vs. pH observed

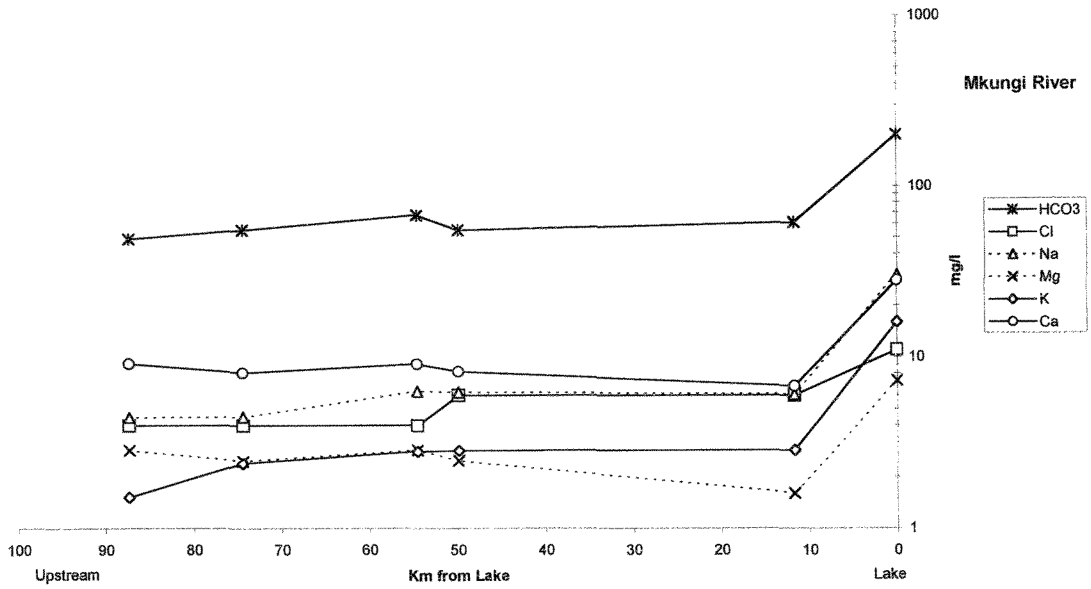
In this way the measurements performed by the laboratory can be evaluated. As can be seen in Figure 4.4, the samples for the main streams in the area have a calculated pH very close to the measured on field (near to the diagonal). The Kianjogu subcatchment is an exception; it presents a high concentration in SO4.

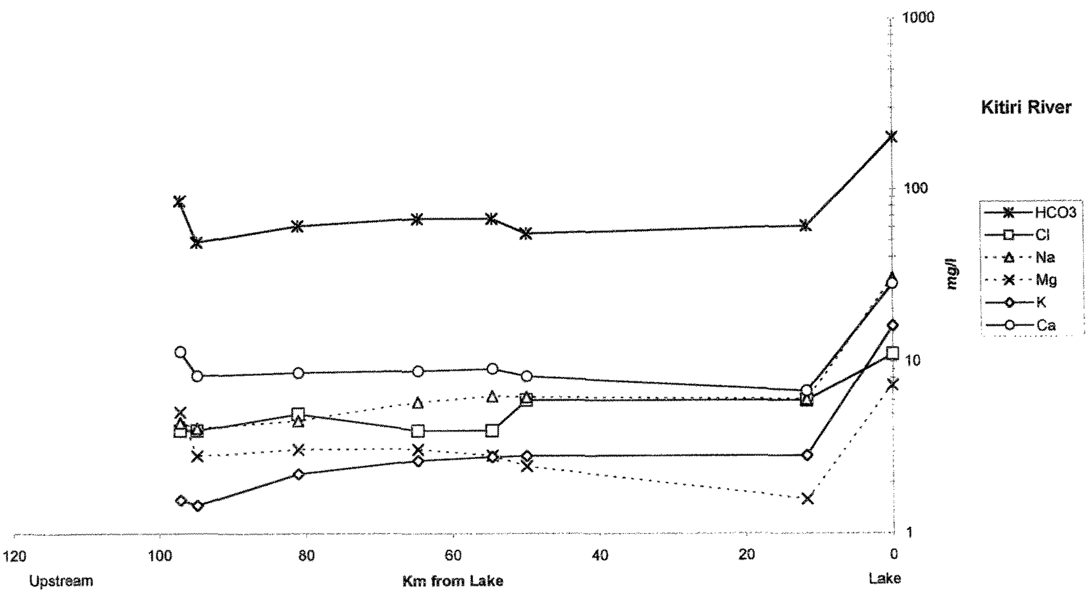
### 4.5.2 Hydrochemical profiles along the drainage network

The chemical composition of the Malewa River varies seasonally from its headwaters to its mouth. During the dry season a gradient of increasing concentration from the headwater until the mouth occurred for all major ions except chloride. On the other hand, during a wet season no regular trend in concentration existed (Gaudet, 1981). With this precedent it is convenient to see if the same pattern is found in the Turasha catchment.

Figure 4.5 shows the hydrochemical profiles along the drainage network Turasha – Malewa – Lake Naivasha. The distance between the lake and the sample points was computed by ILWIS with the distance map option.


Kianjogu River
1000
100
10
1
mg/l
HCO3
Cl
Na
Mg
K
Ca
70
60
50
40
30
20
10
0
Upstream
Km from Lake
Lake


Mkungi River
1000
100
10
1
mg/l
HCO3
Cl
Na
Mg
K
Ca
100
90
80
70
60
50
40
30
20
10
0
Upstream
Km from Lake
Lake


Kitiri River
1000
100
10
1
mg/l
HCO3
Cl
Na
Mg
K
Ca
120
100
80
60
40
20
0
Upstream
Km from Lake
Lake

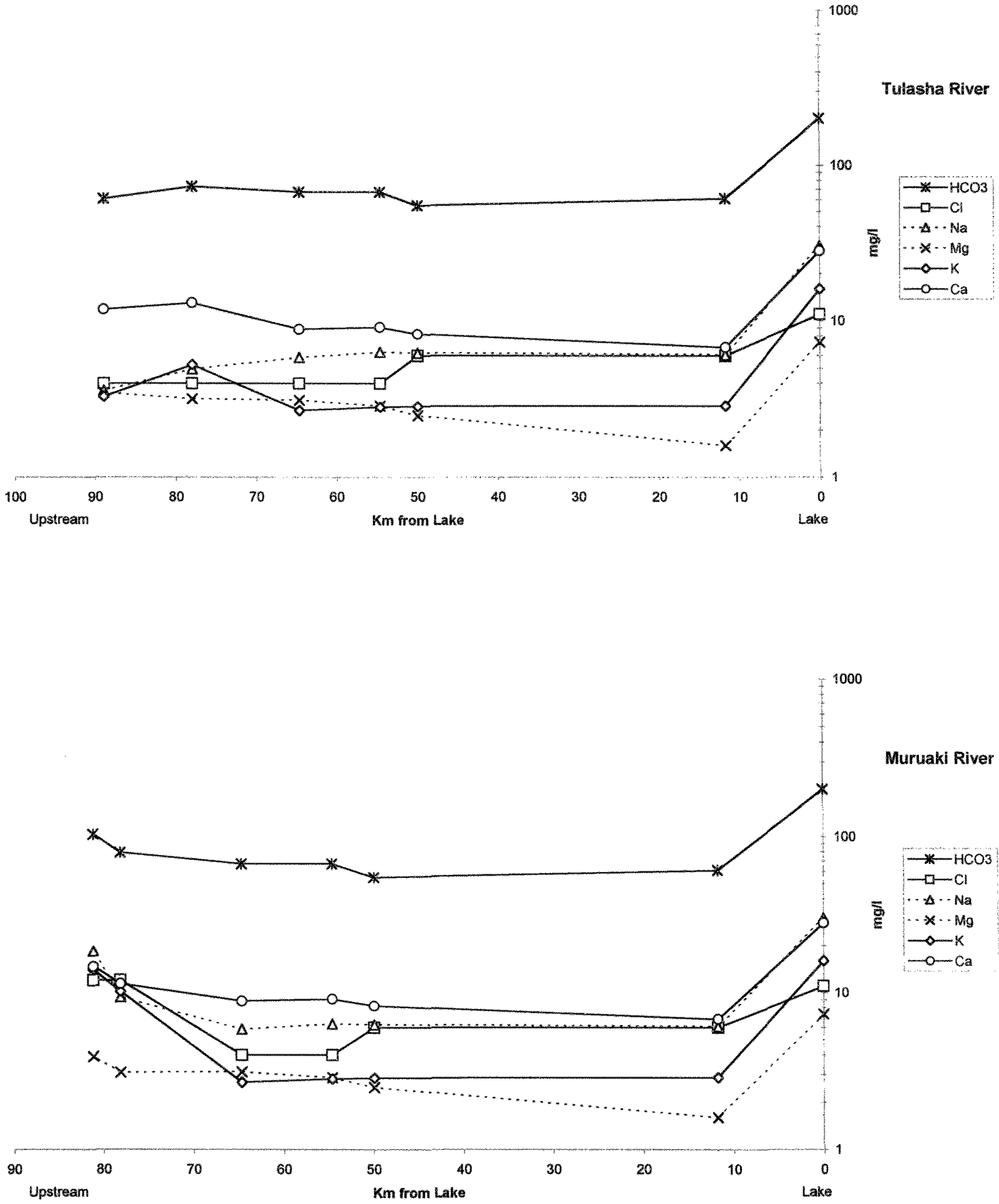



Figure 4.5 Hydrochemical profiles along the drainage network Turasha – Malewa – Lake Naivasha

# LIST OF FIGURES

At a first look the concentrations does not present the pattern found by Gaudet in the Malewa River where the concentrations increase with catchment area. It is very important to highlight that the samples were taken when some local rains were present near to the Aberdare Range. Therefore the pattern of higher concentrations downstream is not clear in Figure 4.5.

Moreover it is possible to see that some ions decrease concentration downstream (the variation is small) downstream. A good example of decreasing concentration downstream is the Muruaki River. The Muruaki subcatchment does not have influence of the shadow rains of the Aberdares in its headwater, therefore the sample taken in this catchment (kilometer 81 from the Lake) was basically base flow and that is why the higher concentrations at that point.

The samples were not taken in the same day thus they have the influence of the erratic and local rains presented near to the Aberdares. The rains in the Mkungi and Kitiri contributed with diluted water affecting the pattern along rivers. However it is possible to see that the concentration measurements are consistent along the streams (there are not remarkable outliers) for the water quality parameters plotted.

In following chapters an analysis of the rain pattern along the year in the Turasha Catchment will be presented in order to suggest the period more suitable to sample, getting in that way a clearer pattern.

### 4.5.3 Source Rock deduction

With the water quality data of Table 4.7, the possible origin (source rocks) was derived, using graphical plotting and 'source rock deduction reasoning – ratio tests' (Hounslow, 1995).

In Figure 4.6 the piper diagram for the samples taken in the main streams of the Turasha catchment is presented, additionally two samples taken in the Aberdare range are included (Forest). The corresponding classification is presented in Table 4.8.

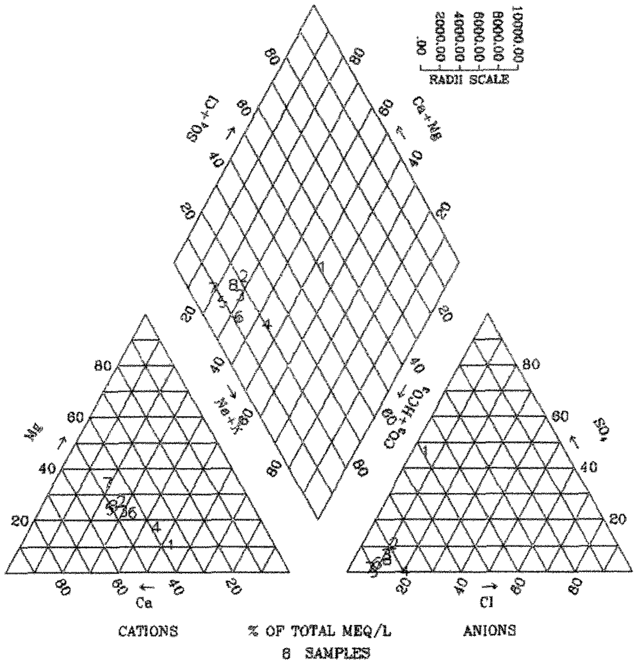



Figure 4.6 Piper diagram for preliminary samples

| Water sample from: | Possible origin |
|---|---|
| 1 Kianjogu Outlet | Rhyolite (high SO4) |
| 2 Kitiri Outlet | Basalt |
| 3 Mkungi Outlet | Basalt |
| 4 Muruaki Outlet * | Rhyolite |
| 5 Tulasha Outlet * | Basalt |
| 6 Turasha Outlet | Basalt/Rhyolite |
| 7 Kitiri Forest | Basalt/Calcite |
| 8 Mkungi Forest | Basalt |

Table 4.8 Classification according to Piper diagram
*$SO_4$ not measured

Now the same exercise, but looking similarities with the Stiff diagrams of Hounslow (1995). This plot is presented in Figure 4.7 with the corresponding interpretation in Table 4.9

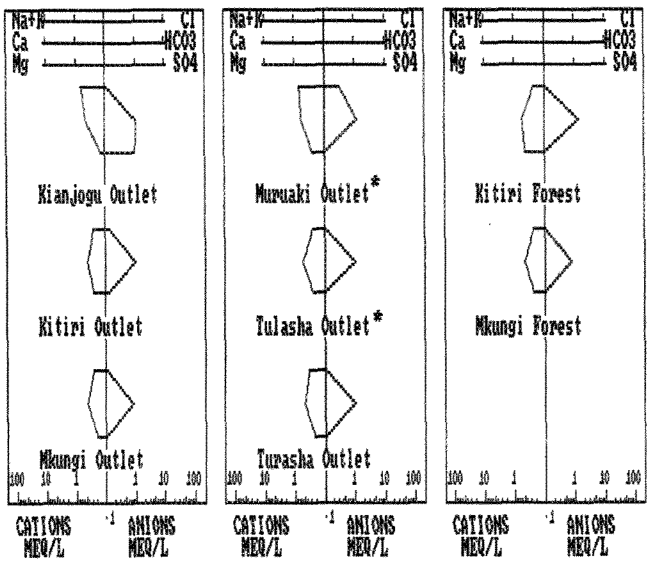



Figure 4.7 Stiff diagram for preliminary samples

| Water sample from: | Possible origin |
|---|---|
| 1 Kianjogu Outlet | Rhyolite (high SO4) |
| 2 Kitiri Outlet | Basalt |
| 3 Mkungi Outlet | Basalt/Rhyolite |
| 4 Muruaki Outlet * | Rhyolite |
| 5 Tulasha Outlet * | Basalt |
| 6 Turasha Outlet | Basalt/Rhyolite |
| 7 Kitiri Forest | Basalt/Calcite |
| 8 Mkungi Forest | Basalt |

Table 4.9 Classification according to Stiff diagram
*$SO_4$ not measured

And finally, the possible origin of the water samples is derived using source-rock deduction reasoning (ratio tests). The ratios and its interpretation are presented in Table 4.10

According to Figure 4.7, all the subcatchments (including the sample for the whole Turasha catchment) have a similar signature where $HCO_3$ and Ca are predominant, typical characteristic of African waters (Mannaerts, pers. communication). However the Kianjogu subcatchment (60% of its area underlaid by basalt) presents a different signature where $SO_4$ is the predominant.

| | Kianjogu | Kitiri | Mkungi | Muruaki | Tulasha | Turasha | Kitiri Forest | Mkungi For. |
|---|---|---|---|---|---|---|---|---|
| (Na+K-Cl)/ (Na+K-Cl+Ca) | 0.71 Plagioclase Weathering Possible | 0.35 Plagioclase weathering possible | 0.42 Plagioclase weathering possible | 0.54 Plagioclase Weathering Possible | 0.35 Plagioclase weathering possible | 0.51 Plagioclase weathering possible | 0.30 Plagioclase weathering possible | 0.35 Plagioclase weathering possible |
| Na/(Na + Cl) | 0.84 Albite Or ion Exchange | 0.59 Albite or ion exchange | 0.63 Albite or ion exchange | 0.55 Albite or ion exchange | 0.61 Albite Or ion exchange | 0.71 Albite or ion exchange | 0.63 Albite or ion exchange | 0.63 Albite or ion exchange |
| Mg/(Mg+Ca) | 0.22 Granitic Weathering | 0.37 Granitic weathering | 0.34 Granitic weathering | 0.31 Granitic Weathering | 0.32 Granitic Weathering | 0.34 Granitic weathering | 0.42 Granitic weathering | 0.34 Granitic weathering |
| Ca/(Ca + SO4) | 0.30 Ca removal Ion exchange or calcite precipitation | 0.76 Ca source other than gypsum Carbonates or silicates | 0.85 Ca source other than gypsum Carbonates or silicates | - | - | 0.92 Ca source other than gypsum Carbonates or silicates | 0.97 Ca source other than gypsum Carbonates or silicates | 0.91 Ca source other than gypsum Carbonates or silicates |
| (Ca + Mg)/SO4 | 0.6 Dedolomitization unlikely | 5.0 Dedolomitization unlikely | 8.7 Dedolomitization unlikely | - | - | 18.1 Dedolomitization unlikely | 52.9 Dedolomitization unlikely | 15.8 Dedolomitization unlikely |
| TDS calculated | 148 mg/l Silicate weathering possible | 91 mg/l Silicate weathering possible | 80 mg/l Silicate weathering possible | 130 mg/l Silicate weathering possible | 92 mg/l Silicate weathering possible | 94 mg/l Silicate weathering possible | 113 mg/l Silicate weathering possible | 73 mg/l Silicate weathering possible |
| Cl/sum anions | 0.05 Silicate or carbonate weathering | 0.11 Silicate or carbonate weathering | 0.1 Silicate or carbonate weathering | - | - | 0.09 Silicate or carbonate weathering | 0.07 Silicate or carbonate weathering | 0.12 Silicate or carbonate weathering |
| HCO3/ sum anions | 0.49 | 0.78 | 0.83 Silicate or carbonate weathering | 0.79 | 0.49 | 0.88 Silicate or carbonate weathering | 0.91 Silicate or carbonate weathering | 0.84 Silicate or carbonate weathering |
| Langelier Index | -0.39 Undersaturated with respect to calcite | -0.39 Undersaturated with respect to calcite | -0.73 Undersaturated with respect to calcite | -0.59 Undersaturated with respect to calcite | -0.38 Undersaturated with respect to calcite | -0.24 Undersaturated with respect to calcite | 0.10 Oversaturated with respect to calcite | -0.63 Undersaturated with respect to calcite |

Table 4.10 Source-rock deduction reasoning for the main streams in the Turasha catchment.

In this case (see Table 4.10) most of the ratios are similar for all the subcatchments. The Kianjogu subcatchment presents slightly different ratios explained by the higher concentration of $SO_4$.

# Chapter 5 Proposal of a Sampling Scheme

This chapter consists in the proposal of a sampling scheme for the generation of hydrogeochemical loads and the examining of the relationship between flux, lithology and land use.

## 5.1 Sampling Locations

The best positions for sampling are at the outlet of the subcatchments. On field there were identified seven subcatchments (one for each main tributary of the Turasha River) but only five of them have flowing water in the dry season. A location in the outlet of the Turasha catchment is also compulsory. Additionally to this locations (outlet) it is recommended to sample along the Turasha river (transect) which means between each two outlets of subcatchment: 3 locations in the dry season and 5 locations in the rainy season (remember that two subcatchments do not have flowing water in the dry season). The "transect" locations are very important in case of using the EC routing technique (Appelo et al, 1982) for the estimation of discharges.

Other extra locations to be sampled, not for estimation of fluxes but for characterization according to land cover, geology, area of subcatchment, etc., are those in the Aberdare and Kipipiri Mountains.

### 5.1.1 Accessibility to proposed locations

The main drawback to sample in the proposed locations is the accessibility, especially if the sampling period must be short. All the "outlet" and "transect" locations, except for the Tulasha and Muruaki subcatchments (see Figure 4.1), are located in big scarps far from any passable road. These locations are even more difficult to reach during the rainy season.

The locations in the Aberdare also have the problem of accessibility, there is one road all along the Aberdare, which allows the sampling in undisturbed forest, but in the rainy season, this road is impassable.

### 5.1.2 Frequency of sampling

More than one sample for each location is recommended, especially when the variation on discharge can be affected easily for rains in the Aberdare. This could be seen frequently during fieldwork, when at the joint of two rivers one of them has discharge due to rain upstream and the other is almost dry. Once again the accessibility to some locations limits the number of samples that can be taken.

In the joint of two rivers, tree locations have to be sampled almost simultaneously (two "outlet" locations and one "transect") otherwise they cannot be related to each other, in the estimation of fluxes (by addition) and also in case of EC routing. Evaluation of how fluxes from contributing watersheds add up and compare with the larger composite watershed encompassing them will let to test the accuracy of a mass balance approach (Richards, 1997).

### 5.1.3 Sampling scheme used during fieldwork

As an example it is presented the sampling scheme used during fieldwork at the beginning of the second rainy season. It is important to highlight that this is an approximation to the right sampling scheme, specially when the area was not well known and when the data available in that moment (drainage and flowing rivers) was not well defined. This sampling was carried out during the beginning of the second rainy season (September) therefore two subcatchments were not taken into account because they were dry. It will be seen later on that this period is not the optimal for the purposes pursued.

The area was divided in five subcatchments (see Figure 5.1); "outlet", "transect" and "forest" locations were selected. The criteria to choose these locations were presented in chapter 4.

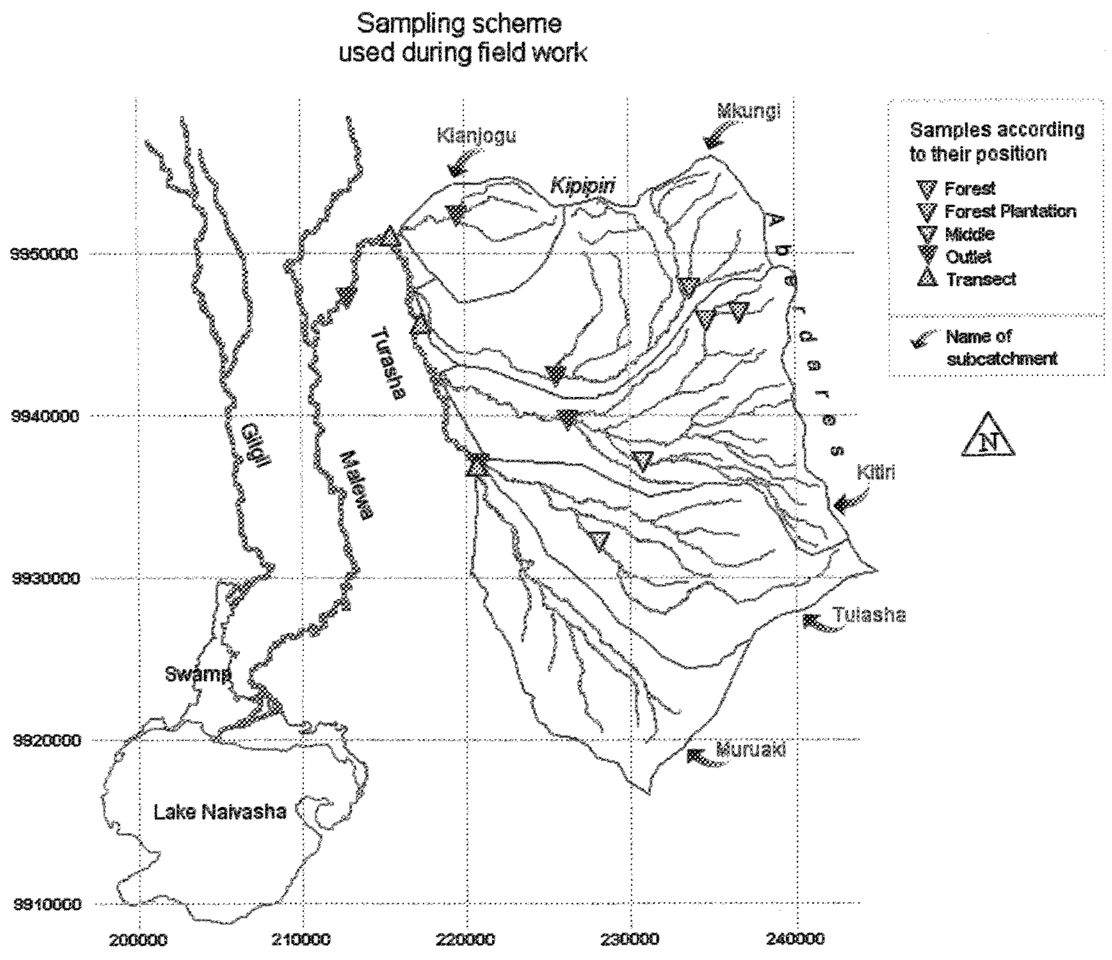



Figure 5.1 Sampling scheme used during fieldwork (locations are plotted)

Notice that the subcatchments presented in Figure 5.1 are only for operational purposes, the true subcatchments corresponding to each location will be defined later. The list of locations within the Turasha catchment, its coordinates and height are presented in Table 5.1

| Location | X* | Y | Z** |
|---|---|---|---|
| Kitiri subcatchment – Forest | 236687 | 9946313 | 2660 |
| Mkungi subcatchment - Forest plantation | 233666 | 9947798 | 2560 |
| Kitiri subcatchment - Forest plantation | 234635 | 9945803 | 2559 |
| Kitiri subcatchment – Middle | 230725 | 9937146 | 2460 |
| Tulasha subcatchment – Middle | 228044 | 9932214 | 2457 |
| Kianjogu subcatchment – Outlet | 219496 | 9952305 | 2264 |
| Mkungi subcatchment – Outlet | 225416 | 9942461 | 2414 |
| Kitiri subcatchment – Outlet | 226150 | 9939697 | 2408 |
| Tulasha subcatchment – Outlet | 220778 | 9936994 | 2399 |
| Muruaki subcatchment – Outlet | 220751 | 9936881 | 2399 |
| Turasha River - Transect before Kitiri | 220628 | 9936910 | 2399 |
| Turasha River - Transect before Mkungi | 217219 | 9945687 | 2242 |
| Turasha River - Transect after Kianjogu | 215437 | 9951067 | 2140 |
| Turasha River - Transect outlet | 212801 | 9947255 | 2023 |

Table 5.1 List of locations used during fieldwork. X and Y
*X, Y in meters, Projection UTM, Spheroid Clarke 1880, Zone number 37 south, Datum Arc 1960
** Taken from DEM (interpolation of contour lines, topomap 1975)

From now and so on it will be presented the proposed sampling scheme, but the fieldwork data will be used as an example to show the process.

## 5.2 Delineation of subcatchments for each location

The subcatchments presented previously were used for operational purposes only; they do not represent the subcatchments covered for each location. The divides of subcatchment for the locations in Table 5.1 were delineated by plotting in ILWIS the points selected together with the contour lines and with an automatically generated subcatchment layer that was created using WMS. The software WMS can generate a subcatchment at any point using a DTM of the area (the DTM was obtained by interpolation of the digitized contour lines – topomaps 1977: see Table 3.4). Judging the position of topographic highs from contours and with the aid of the WMS layer, a subcatchment for each location was delineated.

The delineation of subcatchments for the locations selected in the preliminary sampling, carried out during fieldwork, is showed in Figure 5.2. For each type of location, a map is presented.

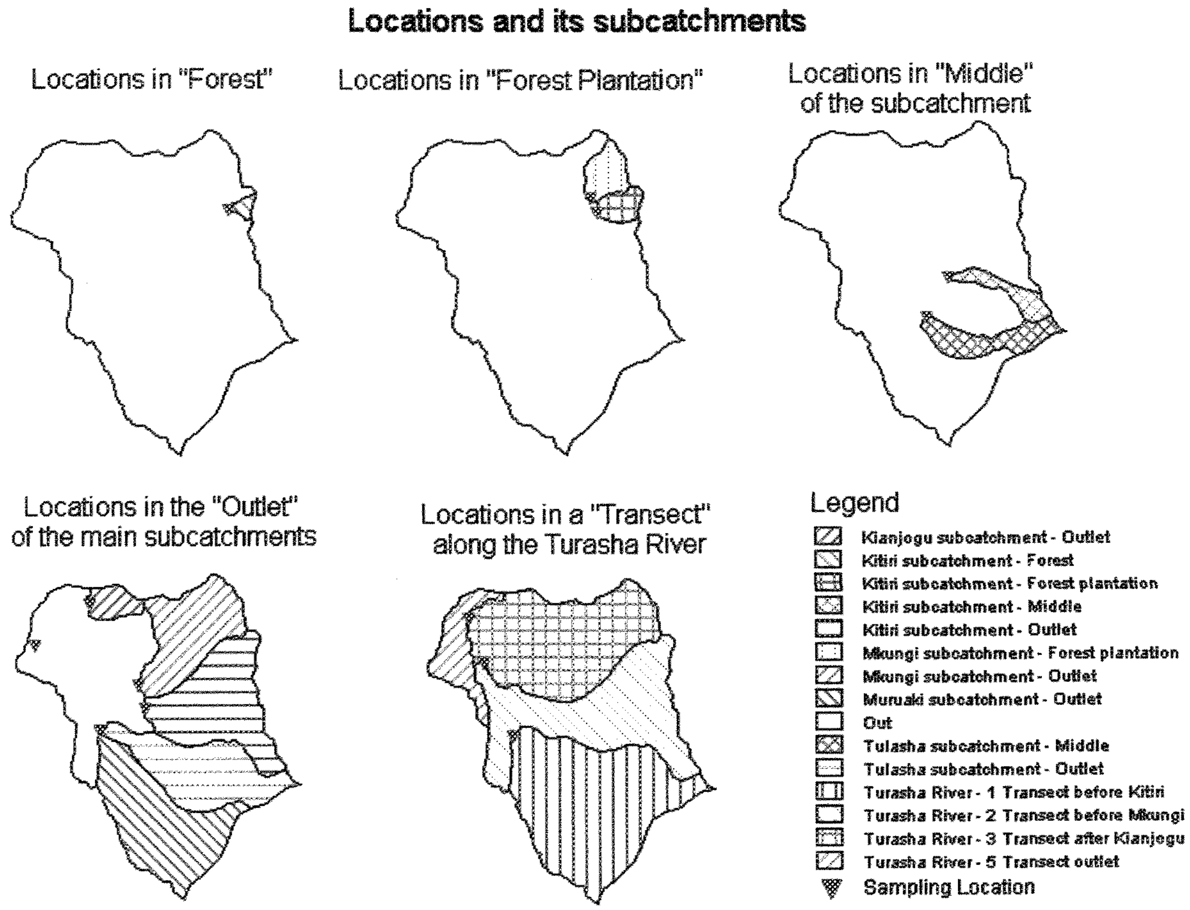



Figure 5.2 Locations and its subcatchments

The "divide" maps were digitized on screen using ILWIS 2.1, then this vector maps were converted in

| Location | Area ($m^2$) | Area ($Km^2$) |
|---|---|---|
| Kitiri subcatchment - Forest | 5504400 | 5.5 |
| Kitiri subcatchment - Forest plantation | 17543700 | 17.5 |
| Mkungi subcatchment - Forest plantation | 27796500 | 27.8 |
| Kitiri subcatchment - Middle | 23346900 | 23.3 |
| Tulasha subcatchment - Middle | 45188100 | 45.2 |
| Kianjogu subcatchment - Outlet | 21634200 | 21.6 |
| Kitiri subcatchment - Outlet | 144088200 | 144.1 |
| Mkungi subcatchment - Outlet | 109043100 | 109.0 |
| Muruaki subcatchment - Outlet | 158793300 | 158.8 |
| Tulasha subcatchment - Outlet | 121436100 | 121.4 |
| Turasha River - Transect before Kitiri | 280229400 | 280.2 |
| Turasha River - Transect before Mkungi | 211590900 | 211.6 |
| Turasha River - Transect after Kianjogu | 226084500 | 226.1 |
| Turasha River - Transect outlet | 51949800 | 51.9 |

Table 5.2 Area for each location

polygons and finally transferred to raster format. From the histogram of each map, the corresponding area for each subcatchment was obtained (Table 5.2)

## 5.3 Characterizing geology for each location

A geology coverage for each location's catchment can be obtained trough the overlapping of the subcatchments map (Figure 5.2) and the geology map (Figure 2.1). The function "CROSS" of ILWIS 2.2 was used with both maps in raster format; areas for each subcatchment with different geology was extracted from the histogram of the resulting map.

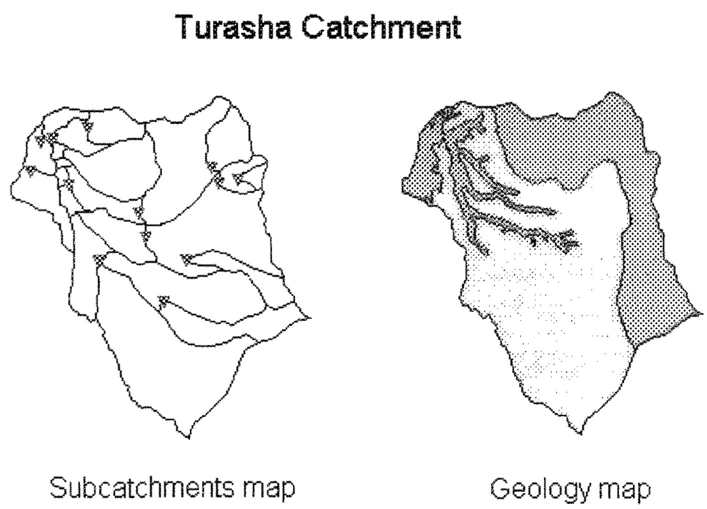



Figure 5.3 Crossing maps: subcatchments and geology.

| | Pyroclastic rocks and sediments | | Trachytic rocks of the younger Aberdare vent | | Vitric pumice tuffs, ignimbrites and welded tuffs with lacustrine sediments, graded tuffs, diatomites | | Basalt | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | $Km^2$ | Frac | $Km^2$ | Frac | $Km^2$ | Frac | $Km^2$ | Frac | $Km^2$ | Fr |
| Kianjogu subcatchment - Outlet | 5.74 | 0.27 | - | - | 1.05 | 0.05 | 14.84 | 0.69 | 21.63 | 1 |
| Kitiri subcatchment – Forest | - | - | - | - | - | - | 5.50 | 1.00 | 5.50 | 1 |
| Kitiri subcatchment – Forest plantation | 1.47 | 0.08 | - | - | - | - | 16.06 | 0.92 | 17.53 | 1 |
| Kitiri subcatchment – Outlet | 72.31 | 0.50 | - | - | 4.72 | 0.03 | 67.03 | 0.47 | 144.07 | 1 |
| Mkungi subcatchment-Forest plantation | 0.95 | 0.03 | - | - | - | - | 26.84 | 0.97 | 27.79 | 1 |
| Mkungi subcatchment - Outlet | 25.32 | 0.23 | - | - | 1.50 | 0.01 | 82.22 | 0.75 | 109.04 | 1 |
| Muruaki subcatchment – Outlet | 155.43 | 0.98 | - | - | - | - | 3.33 | 0.02 | 158.76 | 1 |
| Tulasha subcatchment – Outlet | 81.64 | 0.67 | - | - | - | - | 39.80 | 0.33 | 121.44 | 1 |
| Kitiri subcatchment – Middle | 7.46 | 0.32 | - | - | - | - | 15.89 | 0.68 | 23.34 | 1 |
| Tulasha subcatchment – Middle | 24.26 | 0.54 | - | - | - | - | 20.93 | 0.46 | 45.19 | 1 |
| Turasha River-Transect before Kitiri | 237.07 | 0.85 | - | - | - | - | 43.13 | 0.15 | 280.20 | 1 |
| Turasha River-Transect before Mkungi | 126.13 | 0.60 | 0.36 | 0.00 | 17.89 | 0.08 | 67.03 | 0.32 | 211.42 | 1 |
| Turasha River-Transect after Kianjogu | 76.74 | 0.34 | - | - | 27.21 | 0.12 | 122.12 | 0.54 | 226.08 | 1 |
| Turasha River-Transect outlet | 24.59 | 0.48 | - | - | 26.67 | 0.52 | - | - | 51.25 | 1 |
| Total | 839.12 | 0.58 | 0.36 | 0.00 | 79.04 | 0.05 | 524.72 | 0.36 | 1443.23 | 1 |

Table 5.3 Geology by subcatchments

The area and later the fraction of catchment area encompassed by each geological class was calculated for all the locations. The results are presented in Table 5.3.

The geology map was obtained from the report "Soil conditions in the Kinangop Area" (Rachilo, 1978). A description of these units is presented in Section 2.1. The map included in the report was scanned and later georeferenced for on screen digitizing. A polygon map was created for each type of location (Figure 5.2) and then all of them were crossed with the geology map. A summary of the maps crossed is showed in Figure 5.3. Detailed versions of these maps are in Figure 2.1 and Figure 5.2.

## 5.4 Characterizing land use for each location

As in the characterization of geology, once selected the locations to be sampled, it is possible to generate subcatchments for each of them. A crossing of the subcatchment map and the land use map was carried out in ILWIS 2.2 and then the corresponding areas were calculated from the resulting histogram.

The land use map was obtained by visual interpretation and "on screen digitizing". Several control points were collected on field in order to interpret each land use unit on the satellite images of the area (see section 4.4.1). Table 5.4 shows the land use within each subcatchment corresponding to the locations sampled during fieldwork. Remember that these results are for the preliminary sampling scheme, however the same procedure can be followed for any sampling scheme as the recommended in this study.

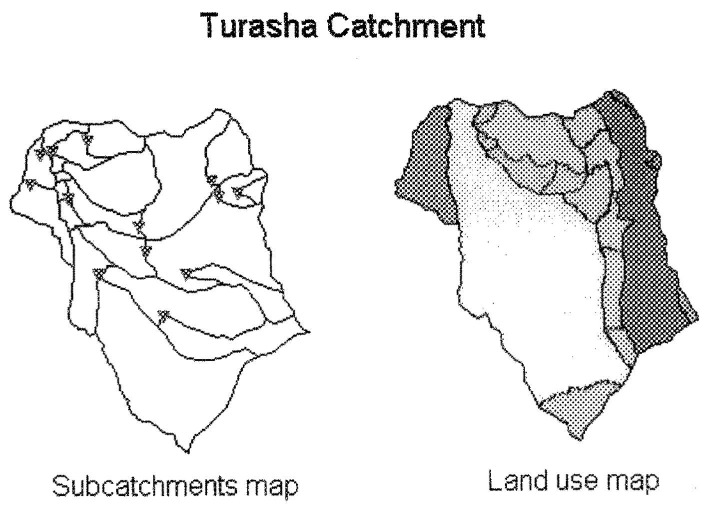



Figure 5.4 Crossing maps: subcatchments and land use

| | | Arable | Arable/ Pasture | Forest | Forest/ Arable | Forest/ Pasture | Moor-land | Pasture | Total |
|---|---|---|---|---|---|---|---|---|---|
| AREA (Km2) | Kianjogu subcatchment - Outlet | - | - | - | 4.48 | 16.36 | - | 0.80 | 21.63 |
| | Kitiri subcatchment - Forest | - | - | 4.60 | - | - | 0.90 | - | 5.50 |
| | Kitiri subcatchment - Forest plantation | - | - | 13.38 | 2.56 | - | 1.60 | - | 17.54 |
| | Kitiri subcatchment – Middle | - | - | 14.20 | 3.92 | - | 1.73 | 3.49 | 23.34 |
| | Kitiri subcatchment – Outlet | - | - | 66.26 | 32.90 | - | 3.32 | 41.59 | 144.08 |
| | Mkungi subcatchment - Forest plantation | - | - | 18.61 | 8.20 | - | 0.98 | - | 27.80 |
| | Mkungi subcatchment – Outlet | - | - | 24.17 | 48.51 | 20.70 | 2.30 | 13.37 | 109.04 |
| | Muruaki subcatchment – Outlet | - | 33.85 | 2.33 | 4.34 | - | - | 118.23 | 158.75 |
| | Tulasha subcatchment - Middle | - | - | 17.83 | 4.46 | - | 2.50 | 20.40 | 45.19 |
| | Tulasha subcatchment - Outlet | - | - | 35.81 | 16.62 | - | 2.50 | 66.50 | 121.44 |
| | Turasha River - 1 Transect before Kitiri | - | 33.85 | 38.14 | 20.96 | - | 2.50 | 184.73 | 280.19 |
| | Turasha River - 2 Transect before Mkungi | 1.73 | - | 66.26 | 32.90 | - | 3.32 | 107.37 | 211.58 |
| | Turasha River - 3 Transect after Kianjogu | 5.39 | - | 24.17 | 70.83 | 50.96 | 2.30 | 72.43 | 226.08 |
| | Turasha River - 5 Transect outlet | 44.99 | - | - | - | - | - | 6.94 | 51.93 |
| | Total | 52.12 | 67.71 | 325.76 | 250.68 | 88.02 | 23.96 | 635.85 | 1444.09 |
| | | | | | | | | | |
| FRACTION | Kianjogu subcatchment - Outlet | - | - | - | 0.21 | 0.76 | - | 0.04 | 1.00 |
| | Kitiri subcatchment - Forest | - | - | 0.84 | - | - | 0.16 | - | 1.00 |
| | Kitiri subcatchment - Forest plantation | - | - | 0.76 | 0.15 | - | 0.09 | - | 1.00 |
| | Kitiri subcatchment - Middle | - | - | 0.61 | 0.17 | - | 0.07 | 0.15 | 1.00 |
| | Kitiri subcatchment - Outlet | - | - | 0.46 | 0.23 | - | 0.02 | 0.29 | 1.00 |
| | Mkungi subcatchment - Forest plantation | - | - | 0.67 | 0.30 | - | 0.04 | - | 1.00 |
| | Mkungi subcatchment - Outlet | - | - | 0.22 | 0.44 | 0.19 | 0.02 | 0.12 | 1.00 |
| | Muruaki subcatchment - Outlet | - | 0.21 | 0.01 | 0.03 | - | - | 0.74 | 1.00 |
| | Tulasha subcatchment - Middle | - | - | 0.39 | 0.10 | - | 0.06 | 0.45 | 1.00 |
| | Tulasha subcatchment - Outlet | - | - | 0.29 | 0.14 | - | 0.02 | 0.55 | 1.00 |
| | Turasha River - 1 Transect before Kitiri | - | 0.12 | 0.14 | 0.07 | - | 0.01 | 0.66 | 1.00 |
| | Turasha River - 2 Transect before Mkungi | 0.01 | - | 0.31 | 0.16 | - | 0.02 | 0.51 | 1.00 |
| | Turasha River - 3 Transect after Kianjogu | 0.02 | - | 0.11 | 0.31 | 0.23 | 0.01 | 0.32 | 1.00 |
| | Turasha River - 5 Transect outlet | 0.87 | - | - | - | - | - | 0.13 | 1.00 |
| | Grand Total | 0.04 | 0.05 | 0.23 | 0.17 | 0.06 | 0.02 | 0.44 | 1.00 |

Table 5.4 Land use by subcatchments

## 5.5 Computing annual fluxes

The sampling scheme considers the computing of annual fluxes and the subsequent characterization of these fluxes according to geology, land use and other factors. Flux is calculated as the product of discharge and concentration. However, stream samples for water chemistry are not typically collected as frequently as discharge data. Several approaches have been used to rectify this problem. They differ in how discharge and concentration data are mathematically reduced to obtain a simple product between discharge and concentration (Richards, 1977).

Dann et al. (1986) review some of the advantages and disadvantages between the various techniques, including the period-weighted method, discharge-weighted method, estimating concentration directly from discharge and simple averaging.

The main limiting factor in the case of the Turasha catchment is the frequency of sampling along the year. If the objective is to compute annual fluxes, it is desirable a sampling scheme distributed all along the year. However this is not possible because there is no staff/equipment to perform that kind of activities in the area several times during the year. The sampling period is reduced to very short periods, 3 weeks as maximum, which was for example the time granted for the fieldwork of this study. Even having 3 weeks it is not possible to sample all the selected locations each day. The person sampling has to move long distances and therefore no more than 7 samples can be taken for day (number of samples in average during fieldwork: grabbing the sample and measuring the discharge).

Another important factor is the availability of discharge records. There are locations with discharge records but most of them do not have any information about discharge other than the measured when the sample is taken.

Below, the different kind of sampling schemes are presented; they are reduced to its simple mathematical representation.

### 5.5.1 Grab samples along the year: concentration and discharge measured

Flux is the product of discharge and concentration. In the case that measurements of solute concentration are available together with the corresponding discharge, the instant flux is obtained only multiplying these two values. Later if these instant fluxes are added up within a specific period, the total flux for the period (one year for example) is obtained. The mathematical expression for this calculation is:

$$L = \sum_{i=1}^{n} \frac{1}{2}\left(C_i Q_i + C_{i+1} Q_{i+1}\right)\left(t_{i+1} - t_i\right)$$

*Equation 1*

Where:
L: Flux
Ci: Concentration at time i
Qi: Discharge at time i
ti: time i
n: number of discharge/concentration measurements

And the corresponding geometrical interpretation is depicted in Figure 5.5. The total flux in the period is nothing else that the area under the line. Then, the formula above is the numerical integration under a curve using the Trapezoid method. In this case the curve is a segmented line. The concentration between $t_i$ and $t_{i+1}$ is unknown under this sampling scheme (a lineal interpolation is assumed) therefore the frequency of sampling is very important.

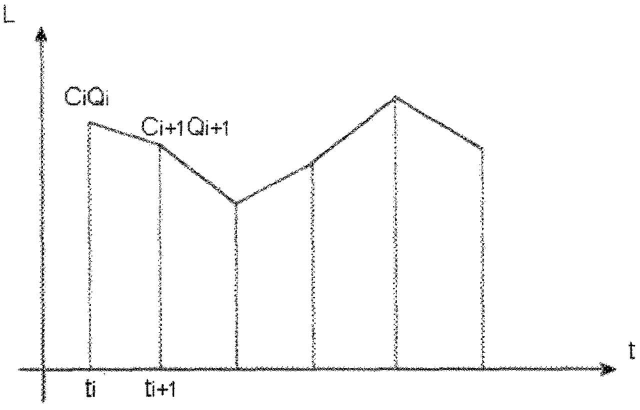



Figure 5.5 Instantaneous fluxes and total flux

Any additional information about discharge (without the corresponding concentration) under this scheme is not used, only the discharge measured at the time the sample was taken is considered.

In the case of the Turasha catchment there are only three gauging stations with daily measurements: 2GC4 (1950-1999) in the outlet of the catchment, 2GC7 (1950-1992) in the outlet of the Muruaki subcatchment and 2GC5 (1958-1994) that is not really in the outlet of the Kitiri subcatchment but upstream. See Figure 4.3 for the location of this subcatchments.

### 5.5.2 Grab samples along the year: concentration and discharge measured; additional discharge data available

This scheme differs from the previous one in that it is not necessary a concentration measurement for each discharge measurement. It means that the "extra" discharge measurements (as is the case of the locations with gauging stations) can be involved within the calculation of fluxes. This is of special interest when there are a few solute concentration measurements and several discharge readings. The mathematical expression is:

$$L = \left\{ \sum_{i=1}^{n} \frac{1}{2} (Q_i + Q_{i+1})(t_{i+1} - t_i) \right\} * \frac{1}{k} * \sum_{j=1}^{k} C_j$$

with n>>k

*Equation 2*

Where:
L: Flux
Cj: Concentration measurement
Qi: Discharge at time i
ti: time i
n: number of discharge measurements
k: available concentration measurements

This equation can be reduced to the same form of the previous one, and then it can be interpreted geometrically in the same way:

$$\bar{C} = \frac{1}{k} * \sum_{j=1}^{k} C_j$$

$$L = \sum_{i=1}^{n} \frac{1}{2}\left(\bar{C} Q_i + \bar{C} Q_{i+1}\right)(t_{i+1} - t_i)$$

*Equation 3*

Where:
C: Average of concentrations
L: Flux
Cj: Concentration measurement
Qi: Discharge at time i
ti: time i
n: number of discharge measurements
k: available concentration measurements

It can be seen that in this case the instantaneous flux is obtained multiplying the discharges by the mean concentration for the period. The mean concentration is obtained from the available concentration measurements. Not all the discharge readings need a corresponding concentration reading. In this case, concentration and discharge do not have to be measured at the same time.

For the Turasha catchment, this sampling scheme look interesting, but at least monthly grab samples are required (Swistock, 1997). As was mentioned earlier, to grab samples all along the year is something not feasible because there is not a continuous monitoring program for the area. Studies in the area, like field work for ITC's MSc students are usually carried during short periods of time (usually one month). Weekly grab samples are not feasible at all.

### 5.5.3 Estimating fluxes from discharge; grab samples in specific periods

Much of the previous work (e.g. Langbein and Dawdy, 1964; Peters, 1984; Bluth and Kump, 1994) demonstrates that fluxes for most water quality parameters are highly correlated with discharge. If there is a correlation between the solute concentration of an element and the discharge, the following can be applied:

$$L = \sum_{i=1}^{n} \left\{ \frac{1}{2} \left[ f(Q_i) + f(Q_{i+1}) \right] (t_{i+1} - t_i) \right\}$$

$$f(Q_i) = L_i = a + bQ_i + cQ_i^2$$

*Equation 4*

Where:
L: Total flux
Li: instantaneous flux at time i
Qi: Discharge at time i
ti: time i
n: number of discharge/concentration measurements
a,b,c: fitting parameters

In this scheme, the instantaneous flux is a function of the discharge. This function is a regression applied to some known instantaneous fluxes at different discharges (see Figure 5.6).

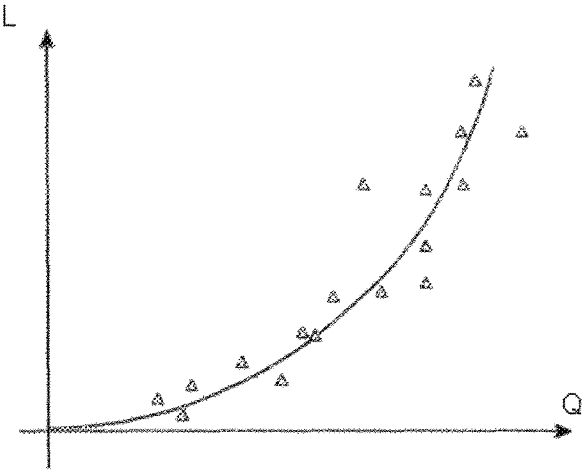


Figure 5.6 Polynomial regression to instantaneous fluxes

Having a direct relationship between instantaneous flux and discharge, the total flux for the period can be estimated by integrating the time series of fluxes over the period. The concentration measurements are only used for the calculation of the regression line. Once the regression curve is obtained the resulting function is applied to all the discharge measurements available.

This approach allows the use of all the discharge data without having concentration measurements for each discharge reading. However as in the previous scheme, several points are required, distributed along the possible values of discharge (see Figure 5.6), which is not possible to carry out in short periods of time.

## 5.6 Computing annual fluxes in the Turasha Catchment

Once presented the methods that can be used to compute annual fluxes, the proposed scheme for the Turasha catchment is detailed together with the required data.

### 5.6.1 Number of locations

It is important to recall that short visits to the area are the only way the samples can be taken because there is not a continuous monitoring program established. This is the main limiting factor to study the export of elements in the Turasha catchment. The samples grabbed would have two purposes: computing of annual fluxes and the characterization of these fluxes according to factors as geology, land use and others. The numbers of locations proposed are presented in Table 5.5.

Depending on the time available, it would be feasible to sample all the locations or at least the locations for computing the fluxes. Even without sampling the upper areas of the subcatchments it is still possible to characterize land use, geology, etc between some subcatchments. If samples for characterization are also taken, this can be analyzed as was showed in sections 5.3 and 5.4.

| | Location type | Position | Remark |
|---|---|---|---|
| **Computing annual fluxes (13 locations)** | Outlet | Turasha's tributaries (7 locations)<br><br>Turasha River (1 location – outlet of catchment) | 5 subcatchments with flowing water in dry season (these 5 subcatchments were sampled during fieldwork) |
| | Transect | In the Turasha River, after the outlet of each subcatchment. (5 locations) | Only 3 locations in the dry season |
| **Characteriza-tion (8 locations)** | Forest | Subcatchment Mkungi (1 location)<br>Subcatchment Kitiri (1 location)<br>Subcatchment Kianjogu (1 location) | |
| | Forest Plantation | Subcatchment Mkungi (1 location)<br>Subcatchment Kitiri (1 location) | |
| | Plateau | Subcatchment Mkungi (1 location)<br>Subcatchment Kitiri (1 location)<br>Subcatchment Tulasha (1 location) | To characterize land use |

Table 5.5 Proposed locations

### 5.6.2 Periods of sampling

The main periods of sampling must be the dry season and the rainy season, later we will explain why these periods are the most important according to the method of computing fluxes selected. Rains in the area are bimodal according to the traditional analysis of rain using monthly averages (Jaetzold, 1976). In this study because of the long-term daily values of rain available, a slightly different but more accurate procedure was applied: moving average of daily values. The rains in the area have different distribution depending in how far they are from the Aberdare and Kipipiri Mountains. Figure 5.7 shows the long-term daily values (smoothed with a 10 days moving average) for the three rainfall stations installed in the area: North Kinangop Forest Station (0°35'S, 36°38'E), Geta Forest Station (0°28'S, 36°37'E) and North Kinangop Mawingo Scheme (0°30'S, 36°31"E).

Kenya Meteorological Department provided the daily values of rainfall. This data was received in tabulated format within an Excel file, however this format is not adequate for computing averages. Therefore a program was developed in 'C' language to transfer the tabulated data into row-column format in order to be processed in a database. The program developed is showed in Appendix B. The data was processed using SQL language to compute the averages and also to depurate it (some wrong values of precipitation were found). Once the data was processed using SQL in an Access database, it was plotted in Excel.

Using daily values the bimodal distribution of rainfall that is frequently attributed to the Kinangop Plateau (Rachilo, 1978) is not so clear. The daily analysis shows a different picture than the "classical" monthly analysis.

Looking at Figure 5.7 it can be seen:

- A dry season for ½ December, January, February and March
- A rainy season for ½ April – ½ June
- A short dry season for July – ½ August
- An intermediate season for ½ August – November

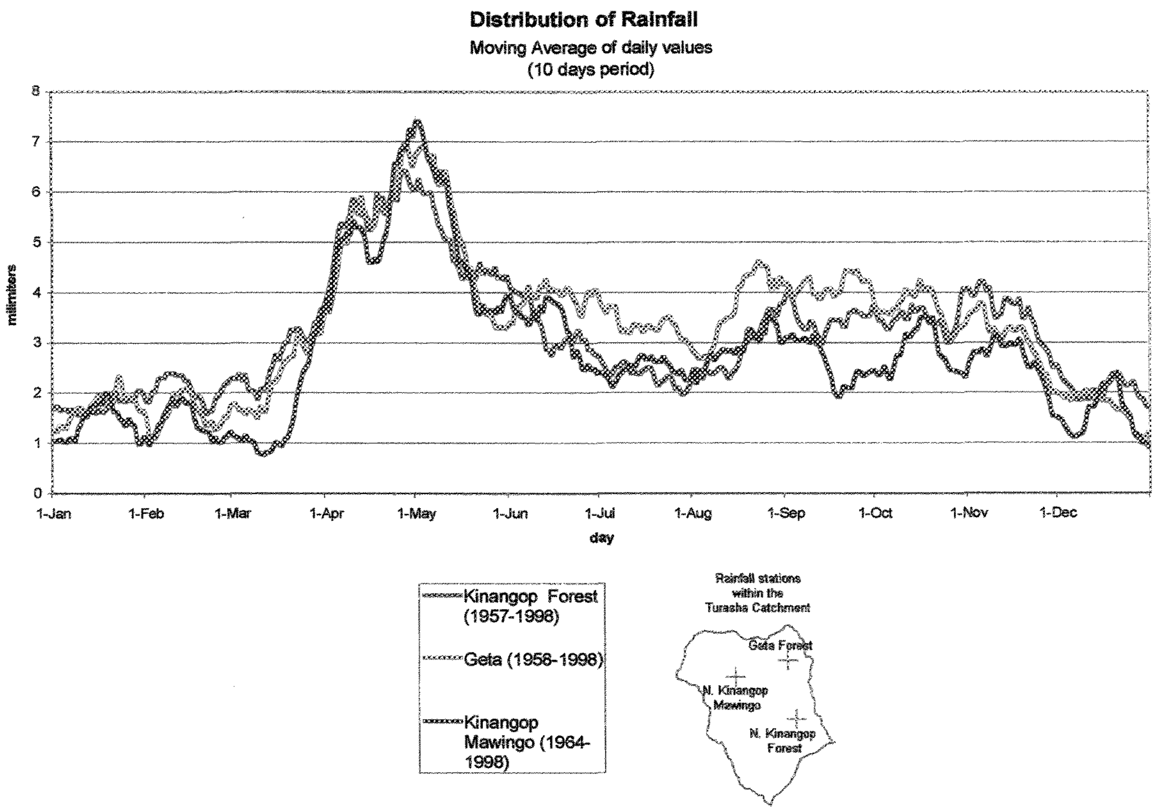



Figure 5.7 Distribution of rainfall in the Turasha Catchment; daily values smoothed with moving average

It is important to highlight that the rains in the intermediate season are local and erratic according to Figure 5.7; there are some peaks and gaps that does not match among stations, this would make difficult the sampling in the area, specially at the beginning of this period (August, September). This was observed during fieldwork in the month of September: in the joint of two streams, one of them was almost dry and the other was with considerable discharge depending in the place the river born (Aberdares/Kipipiri or Kinangop plateau). Table 5.6 show the periods selected for sampling of streams in the Turasha catchment according to this analysis.

Taking a look to the long-term discharge, it can be seen more or less the same pattern as in the rainfall. Three gauging stations are available within the area: Turasha River (0°28’36”S, 36°25’11”E) with records from 1950 to 1997, Muruaki River (0°34’13”S, 36°29’27”E) with records from 1958 to 1994 and Kitiri River (0°33’02”S, 36°33’30”E) with data from 1950 until 1992.

The peak discharge for the catchment (Turasha River) is in the beginning of May (see Figure 5.8), but also there is a considerable discharge in the beginning of November. Low discharges are recorded for January, February and March.

| Season | **Optimal** | **Possible** |
|---|---|---|
| **Dry Season** | February | January, March |
| **Rainy Season** | May | April (second half) |
| **Average discharge** | November | October |

Table 5.6 Periods to sample in the Turasha catchment

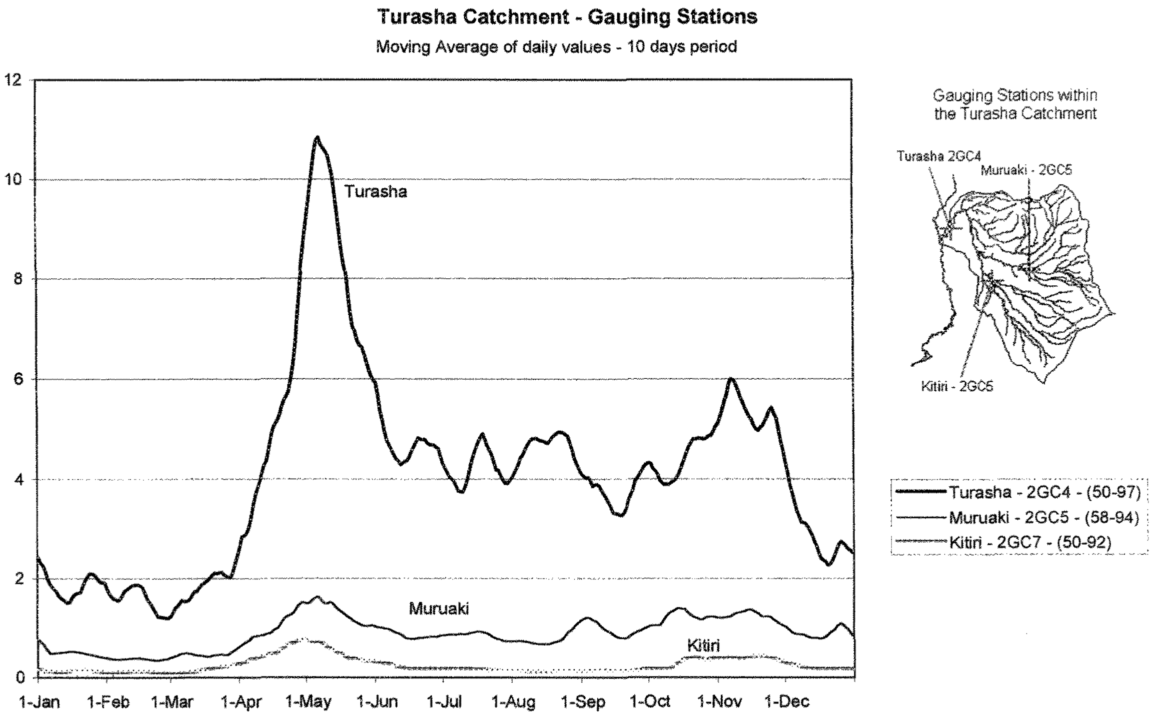



Figure 5.8 Long-term discharge in the Turasha catchment; daily values smoothed with moving average

In Table 5.6 it is considered also the period to sample when the discharges are medium; this will be explained later. Figure 5.9 shows the aerial precipitation and the discharge for the Turasha catchment, the lag between them can be appreciated.

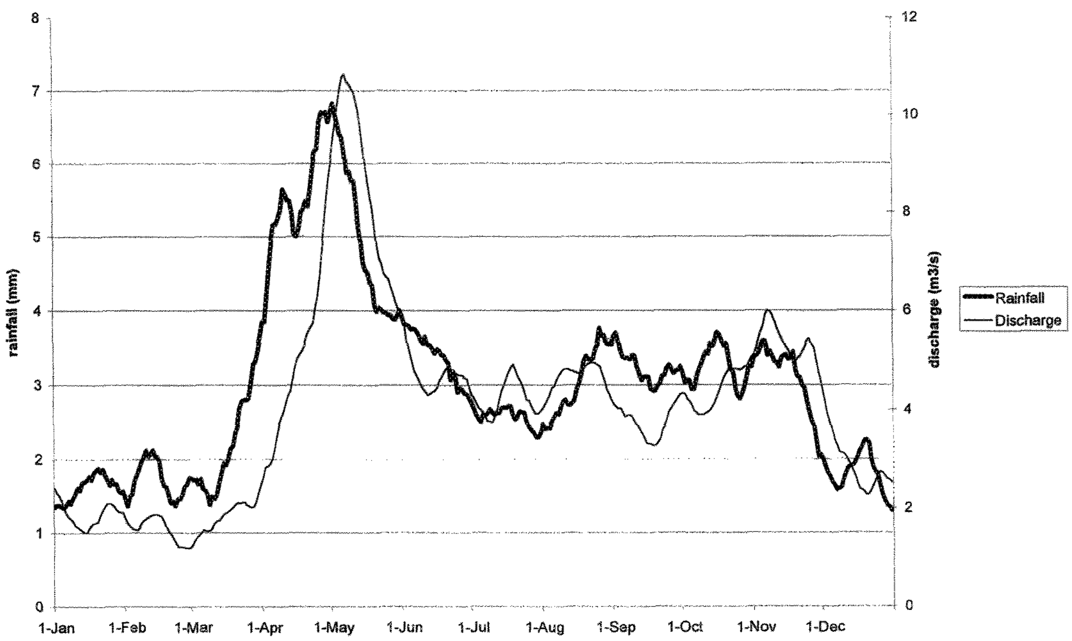



Figure 5.9 Daily values of discharge and precipitation (smoothed with 10 days moving average) for the Turasha Catchment

### 5.6.3 Method selected for computing annual fluxes

Gaudet (1981) showed evidence of relationship between the discharge of the Malewa River (where Turasha River discharge its waters) and the concentration of solutes trough regression analysis; conductance and two major constituents (sodium and bicarbonate) have strong inverse relations with discharge, while magnesium, sulphate and specially chloride show a weak inverse relation. Silica has a weak direct relation with discharge.

Because the grabbing of samples along the year is not possible, the best alternative to calculate fluxes is trough its estimation from discharge according to some measurements carried out during short periods of time: rainy season, dry season and when the discharge is medium. A function relating flux and discharge would be (Langbein and Dawdy, 1964; Peters, 1984; Bluth and Kump, 1994):

$$f(Q_i) = L_i = a + bQ_i + cQ_i^2$$

*Equation 5*

Where:
a, b, c: fitting parameters
Li: instantaneous flux at time i
Qi: discharge at time i

This function is obtained trough polynomial regression to the instantaneous fluxes measured during the periods of sampling (dry, rainy and medium). If these three periods are sampled, a representative curve can be fitted, and later on according to the daily measurements of discharge available (Rivers Turasha – 2GC4, Kitiri – 2GC7, Muruaki – 2GC5) annual fluxes can be estimated.

If at least three samples are grabbed for each location during each period (two samples were taken for the main locations during fieldwork), a regression line like the one presented in Figure 5.10 should be obtained.

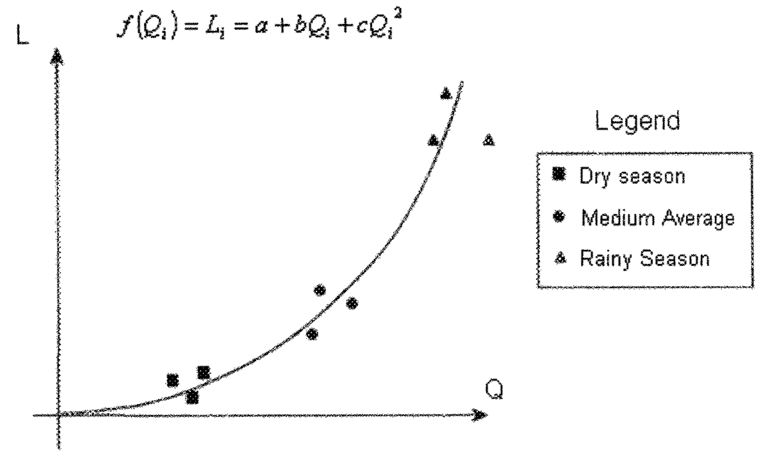



Figure 5.10 Polynomial regression to instantaneous fluxes in three periods of sampling

The estimation of annual fluxes having the regression line and the daily discharge measurements, is obtained trough the integration of instantaneous fluxes according to the formula (see section 5.5.3):

$$L = \sum_{i=1}^{n} \left\{ \frac{1}{2} [f(Q_i) + f(Q_{i+1})](t_{i+1} - t_i) \right\}$$

*Equation 6*

Where:
L: Total flux
f(Qi): Instantaneous flux from regression line at time i
ti: time i
n: number of discharge measurements

In summary, this is the proposed method to be applied in the locations were there are gauging stations. In this way it is possible to get an estimation of the total flux in the outlet of the Turasha Catchment (gauging station 2GC4) and also in two of the 7 subcatchments: Kitiri and Muruaki (gauging stations 2GC5 and 2GC7).

It would be also possible to consider only two periods of sampling, rainy and dry season, in which case a linear regression can be fitted. The disadvantage with this approach is that a constant concentration is being assumed (slope of the lineal interpolation) independently of the discharge.

#### 5.6.3.1 Annual fluxes in locations without gauging stations

The method presented above requires extra discharge readings to those collected during sampling, this is possible in those locations with gauging stations (rivers Turasha, Muruaki and Kitiri). However there are 5 more locations in other streams within the catchment without discharge recordings. From those 5 rivers, only 3 are perennial and should be considered within the calculation of fluxes, these rivers are: Kianjogu, Mkungi and Tulasha (see Figure 4.3).

It is possible to obtain a rough estimation of discharges for those subcatchments without gauges using the data available for the Turasha, Muruaki and Kitiri. The subcatchments are relatively homogeneous therefore using the specific discharge of the three subcatchments gauged, a rough estimation of the unknown discharges can be obtained. The area of the subcatchments with measurement and those without records is detailed in Table 5.7

| Turasha-2GC4 | Kitiri-2GC5 | Muruaki-2GC7 | Mkungi (no gauge) | Tulasha (no gauge) | Kianjogu (no gauge) |
|---|---|---|---|---|---|
| 769854600 | 144088200 | 158793300 | 109043100 | 121436100 | 21634200 |

Table 5.7 Area of catchment for each gauging station ($m^2$)

Using these areas and the monthly discharge (long-term average), the specific discharge (Q/A) is calculated:

| | Turasha-2GC4 | Kitiri-2GC5 | Muruaki-2GC7 |
|---|---|---|---|
| January | 2.41E-09 | 3.35E-09 | 8.21E-10 |
| February | 2.03E-09 | 2.53E-09 | 7.30E-10 |
| March | 2.40E-09 | 3.17E-09 | 1.04E-09 |
| April | 6.28E-09 | 7.06E-09 | 3.28E-09 |
| May | 1.14E-08 | 9.31E-09 | 3.23E-09 |
| June | 6.06E-09 | 5.99E-09 | 1.32E-09 |
| July | 5.56E-09 | 5.91E-09 | 1.02E-09 |
| August | 6.07E-09 | 5.39E-09 | 8.33E-10 |
| September | 4.87E-09 | 6.73E-09 | 9.03E-10 |
| October | 5.66E-09 | 8.46E-09 | 1.87E-09 |
| November | 7.12E-09 | 8.69E-09 | 2.56E-09 |
| December | 3.72E-09 | 6.33E-09 | 1.28E-09 |

Table 5.8 Specific discharge for each subcatchment with gauging station (m/s)

Now there are three possibilities to get a rough estimation of discharge in the ungauged stations: to use the specific discharge of the whole catchment (Turasha-2GC4), to use the specific discharge of a catchment with similar characteristics to that one to be estimated (Kitiri-2GC5 for example) and, to use the average of the three gauging stations. Subcatchments Tulasha and Mkungi are similar to Kitiri and also all of them have the Aberdare in the east where most of the rain come from. Table 5.9 shows the discharges recorded in Turasha, Kitiri and Muruaki together with the estimation for Mkungi, Tulasha and Kianjogu. The specific discharge of Kitiri subcatchment was used for the estimation.

| | Turasha-2GC4 $m^3/s$ | Kitiri-2GC5 $m^3/s$ | Muruaki-2GC7 $m^3/s$ | Mkungi (estimated) $m^3/s$ | Tulasha (estimated) $m^3/s$ | Kianjogu (estimated) $m^3/s$ | Total (gauged+estimation) $m^3/s$ |
|---|---|---|---|---|---|---|---|
| January | 1.856 | 0.482 | 0.130 | 0.365 | 0.406 | 0.072 | 1.457 |
| February | 1.563 | 0.365 | 0.116 | 0.276 | 0.308 | 0.055 | 1.120 |
| March | 1.849 | 0.457 | 0.165 | 0.346 | 0.385 | 0.069 | 1.423 |
| April | 4.837 | 1.018 | 0.521 | 0.770 | 0.858 | 0.153 | 3.320 |
| May | 8.804 | 1.342 | 0.513 | 1.015 | 1.131 | 0.201 | 4.202 |
| June | 4.665 | 0.864 | 0.210 | 0.654 | 0.728 | 0.130 | 2.585 |
| July | 4.279 | 0.851 | 0.162 | 0.644 | 0.718 | 0.128 | 2.503 |
| August | 4.675 | 0.777 | 0.132 | 0.588 | 0.655 | 0.117 | 2.269 |
| September | 3.748 | 0.970 | 0.143 | 0.734 | 0.817 | 0.146 | 2.810 |
| October | 4.356 | 1.219 | 0.298 | 0.923 | 1.028 | 0.183 | 3.650 |
| November | 5.480 | 1.252 | 0.406 | 0.947 | 1.055 | 0.188 | 3.848 |
| December | 2.862 | 0.912 | 0.204 | 0.690 | 0.768 | 0.137 | 2.710 |

Table 5.9 Long-term monthly average of discharge ($m^3/s$)

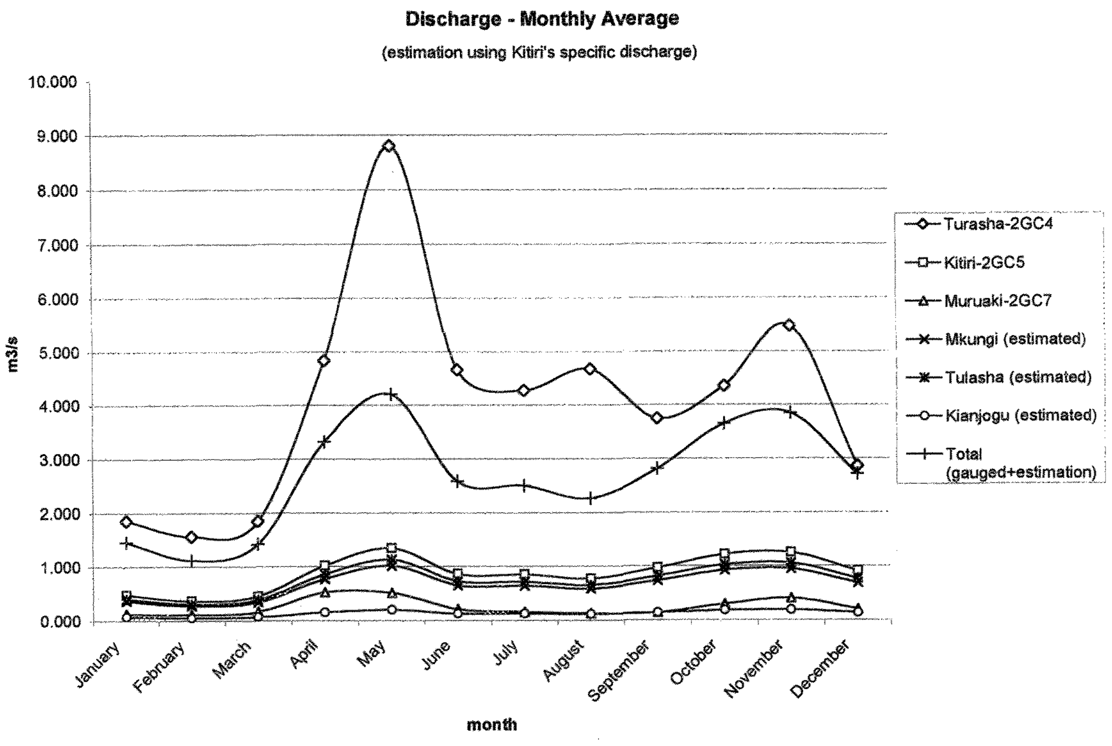



Figure 5.11 Estimated discharges

Figure 5.11 shows the recorded and the estimated discharges for the subcatchments in the area of study. It is important to highlight that the addition of discharges in the subcatchments is less than the total discharge registered in the outlet of the catchment (Turasha – 2GC4). This can be because only the perennial streams were considered (two small subcatchments were left out) and because the recordings of level in the gauging stations are taken in the early morning and late in the afternoon, and possibly much of the short rains are not registered. This will require a further analysis.

In this way a rough estimation of the discharges for the ungauged subcatchments can be obtained and later on the same method for computing annual fluxes presented previously can be applied.

# Chapter 6 Preliminary Estimate of Stocks and Chemical Fluxes in the Turasha Catchment

Until this point it has been presented a preliminary sampling and, using this as a first approximation, a new sampling scheme has been proposed. However the situation of the Turasha Catchment as such is not presented yet, aspect that will be analyzed in this chapter. Moreover the biological aspects are not touched yet.

Studies in the area are mainly related to Lake Naivasha or the Malewa Catchment what means that the availability of information is partial, very limited or gathered with other purposes than matter fluxes computing.

However even with the limited amount of data collected during fieldwork, rough estimates of amount of matter can be computed using indirect methods, which are presented in this chapter.

## 6.1 The vegetation compartment

In an ecosystem, nutrients are accumulated in biomass. The fluxes between the vegetation and the soil/rocks compartments (see Section 3.6) are difficult to quantify. It is easier when there is a perfect cycling of nutrients, in which case what goes out of the ecosystem is due to weathering. Another example is when the production of a crop (maize for example) in the ecosystem is known then the total amount of elements going out of the ecosystem can be determined (according to its biomass and chemical composition).

Because of the heterogeneity of the Turasha Catchment a precise determination of total biomass is not possible, but for the predominant types of vegetation it is feasible to get rough estimates, not only for biomass but also for elements/nutrients, which is the issue in this study.

The stock of elements in grassland and forest are roughly estimated. These estimates are calculated using general data from existing databases. Issues as chemical composition depends on species and environmental condition.

The first step is to estimate the total amount of biomass in the Turasha ecosystem for the selected land covers. Pasture areas cover almost 60% of the catchment with 45628 ha distributed in the land use classes: Arable/Pasture (7%), Forest/Pasture (11%) and Pasture (82%) (see Figure 2.3). The percentage of pasture for these areas is 80% (Becht, pers. communication).

The tons per hectare of dry matter above ground for grass in the Naivasha area is 3, with an estimated dry matter below ground of 50% of the above mentioned value. These results in a total weight of dry matter for grass of 4.5 ton/ha (Becht, pers. communication) (see Table 6.1).

| Grassland | Area with Pasture ha | % of pasture | Pasture only Area ha | Dry matter per hectare ton/ha | Total Dry Matter ton | % of ash content | Total ash ton |
|---|---|---|---|---|---|---|---|
| Kikuyu grass (Pennisetum clandestinum) | 45 628 | 80 | 36 502 | 4.5 | 164 261 | 9.35% | 15 358 |

Table 6.1 Preliminary estimate of dry matter for grass

From this point, general information from literature was used: BIOBIB, a database of Biomass Analyses from the University of Technology Vienna (Reisinger et al.,1996) that is available on internet. BIOBIB includes data of the ultimate analysis of the elements, the proximate analysis, the analysis of the minor and trace elements, data about the melting behaviour of the ash and much more. BIOBIB does not only cover information about different types of wood, straw and energy crops but also waste-wood samples and biomass-waste-assortments of different biomass-treating industries. Currently the database contains 331 different fuels.

| Ash analysis | % in ash | Weight Ton | **Element of interest** | Fraction of element (molecular weight ) | Weight of element Ton |
|---|---|---|---|---|---|
| SO3 | 3.46% | 531 | **S** | 2.50 | 1 329 |
| Cl | 6.06% | 931 | **Cl** | 1.00 | 931 |
| P2O5 | 7.57% | 1163 | **P** | 4.58 | 5 326 |
| SiO2 | 29.50% | 4531 | **Si** | 2.14 | 9 709 |
| Fe2O3 | 0.56% | 86 | **Fe** | 2.86 | 246 |
| Al2O3 | 0.97% | 149 | **Al** | 3.78 | 563 |
| CaO | 9.97% | 1531 | **Ca** | 1.40 | 2 144 |
| MgO | 2.77% | 425 | **Mg** | 1.67 | 709 |
| Na2O | 0.36% | 55 | **Na** | 2.70 | 149 |
| K2O | 28.00% | 4300 | **K** | 2.41 | 10 365 |
| Total | 89.22% | 13 703 | | | 31 469 |

Table 6.2 Ash analysis for grass (from BIOBIB database) and elements of interest

Using the ash analysis of this database (for grassland) it is possible to get a rough estimate of the elements in stock for this vegetation compartment. Once again this is only a rough estimate, because the composition of elements in grass is dependent on the soil type, altitude and even rain season (Toxopeus, pers. communication).

The ash analysis from this database is used now to calculate in a straightforward way the amount of each element in this vegetation compartment (See Table 6.2). It is important to highlight that his rough estimate corresponds to standing biomass.

A similar procedure was followed for the Forest in the catchment, which covers the Aberdare ranges and Kipipiri mountain. Forest covers 17% of the area and is specifically located in the Aberdares and Kipipiri. It is almost impossible to determine the amount of standing biomass for any tropical forest only from literature but at least boundary limits can be established. It can be considered that the standing biomass for a tropical forest is between 100 and 400 ton/ha (A. de Gier, pers. communication and Proctor J,1983).

The following calculations are similar to those used in the computations for grass, but in this case, upper and lower limits are presented.

| Forest | Area with Forest | Dry matter Per hectare | Total Dry Matter | % of ash content | Total Ash |
|---|---|---|---|---|---|
| | hectare | Ton/ha | Ton/ha | | Ton |
| Upper Limit | 12857 | 100 | 1285700 | 0.30% | 3857.1 |
| Lower Limit | 12857 | 400 | 5142800 | 0.30% | 15428.4 |

Table 6.3 Preliminary estimate of dry matter for forest

Once again the BIOBIB database is used to get a general chemical composition of ash from this biomass in order to compute the elements in stock for the forest compartment.

It is important to notice that not all the element remains in the ash but most of them (see the total percentages in Table 6.4 and Table 6.2). There are many parameters that can deviate these values for the true ones as was indicated previously (this are only general values).

It is interesting to make a brief comparison between the stocks for each element in the two vegetation types. The stock for each element in forest and grass differs significantly, but of course the area for grass is almost three times the area of forest in the Turasha catchment.

This data could be used in several ways as for example the impact of the changes of forest areas by grass or the burning of patches of forest, events that will affect the water quality in the area.

| Ash analysis | % in ash | Weight Upper Limit Ton | Weight Lower Limit Ton | **Element of interest** | Fraction of element (molecular weight ) | **Weight of Element (range)** Tons |
|---|---|---|---|---|---|---|
| CO2 | 2.63% | 101 | 406 | **C** | 3.67 | **372 - 1 488** |
| SO3 | 3.46% | 133 | 534 | **S** | 2.50 | **334 - 1 335** |
| Cl | 6.06% | 234 | 935 | **Cl** | 1.00 | **234 - 935** |
| P2O5 | 7.57% | 292 | 1168 | **P** | 4.58 | **1 337 - 5 350** |
| SiO2 | 29.50% | 1138 | 4551 | **Si** | 2.14 | **2 438 - 9 753** |
| Fe2O3 | 0.56% | 22 | 86 | **Fe** | 2.86 | **62 - 247** |
| Al2O3 | 0.97% | 37 | 150 | **Al** | 3.78 | **141 - 565** |
| CaO | 9.97% | 385 | 1538 | **Ca** | 1.40 | **538 - 2 153** |
| MgO | 2.77% | 107 | 427 | **Mg** | 1.67 | **178 - 712** |
| Na2O | 0.36% | 14 | 56 | **Na** | 2.70 | **37 - 150** |
| K2O | 28.00% | 1080 | 4320 | **K** | 2.41 | **2 603 - 10 412** |
| Total | 91.85% | 3 543 | 14 171 | | | 8 275 - 33 100 |

Table 6.4 Ash analysis for forest (from BIOBIB database) and elements of interest

## 6.2 Output from the Turasha catchment

Now an estimation of exports or output from the ecosystem will be estimated (see Figure 3.8). Again the lack of data drives what is possible to quantify. In this case, a previous work from Gaudet and Melack (1981) is used to roughly estimate the outputs from the Turasha catchment. The long-term data available for discharge in the Turasha River (station 2GC4) is also used.

| | Mean Concentration mg/l |
|---|---|
| Na | 9.0 |
| K | 4.3 |
| Ca | 8.0 |
| Mg | 3.0 |
| HCO3 | 70.0 |
| CO3 | 0.0 |
| SO4 | 6.2 |
| Cl | 4.3 |
| F | 0.4 |
| SIO2 | 17.2 |
| $EC_{25}$ | 88-179 |

Table 6.5 Mean concentration of ions for Malewa River according to Gaudet and Melack (1981)

According to Gaudet and Melack, the Malewa River (major inflow to Lake Naivasha) has the mean concentrations presented in table 6.5.

Because of the homogeneity of the Malewa Catchment (volcanic rocks – main source of ions according to Gaudet-Melack), and because the Turasha and Upper Malewa Catchments contributes with approximately the same discharge (50% each one); it is possible to get a first approximation of fluxes using the assumption that the concentrations in the Turasha outlet are similar to those in the Malewa outlet.

The values in Table 6.6 corresponds to a mean annual discharge of 4.08 m3/s which gives a year volume of water of 128 776 590 m3 (based in the long-term discharge data for the station 2GC4).

| | Assumed mean Concentration In Turasha ( from Gaudet and Melack, 1981) Kg/m3 | Mean export from Turasha Kg/year | Mean export from Turasha tons/year |
|---|---|---|---|
| Na | 0.009 | 1158989.3 | 1159.0 |
| K | 0.0043 | 553739.3 | 553.7 |
| Ca | 0.008 | 1030212.7 | 1030.2 |
| Mg | 0.003 | 386329.8 | 386.3 |
| HCO3 | 0.07 | 9014361.3 | 9014.4 |
| CO3 | 0 | 0.0 | 0.0 |
| SO4 | 0.0062 | 798414.9 | 798.4 |
| Cl | 0.0043 | 553739.3 | 553.7 |
| F | 0.0004 | 51510.6 | 51.5 |
| SIO2 | 0.0172 | 2214957.3 | 2215.0 |
| Total | | 15762255 | 15762.2 |

**Table 6.6 Preliminary estimates of Turasha catchment exports using mean concentrations from Gaudet and Melack-1981**

There would be deviations from these estimated values due to factors as:

- Major drainage area for the Malewa River than for the Turasha River
- Probably, there is a presence of bigger concentrations in Turasha River than in Upper Malewa River (EC in Upper Malewa is lower than the EC in the Turasha River according to the measurements carried out during fieldwork and the EC measurements of Angella Graham – 1998; see table 4.4, ECs for Malewa Upstream, Turasha outlet and Malewa downstream/outlet).

It is difficult to adjust the above-presented values, but with the analyses of the samples taken during fieldwork it is possible to see at least if they fall within the range of the estimated values. Gaudet and Melack, additionally to the annual mean concentrations, presented regressions for the concentration of some ions. These regressions however have a low $r^2$ with the exception of conductance, sodium and bicarbonate.

| Y = a + b * log_10 X | | | | |
|---|---|---|---|---|
| | a | b | $r^2$ | F |
| Conductance | 153 | -75 | 0.84 | 88.34 |
| SiO2 | 13.7 | 8.1 | 0.25 | 5.97 |
| Na | 0.48 | -0.22 | 0.61 | 28.79 |
| K | 0.24 | -0.04 | 0.45 | 14.98 |
| Ca | 0.47 | -0.17 | 0.46 | 15.37 |
| Mg | 0.32 | -0.16 | 0.25 | 5.95 |
| HCO3 | 1.39 | -0.56 | 0.74 | 51.16 |
| SO4 | 0.16 | -0.07 | 0.26 | 6.21 |
| Cl | 0.14 | -0.04 | 0.15 | 3.12 |

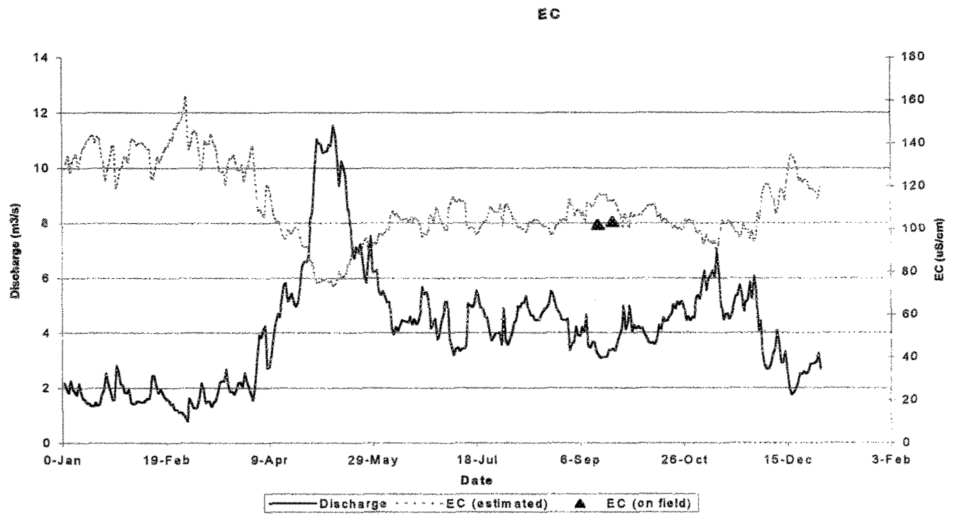
Table 6.7 Value of constants a and b, the coeficient of determination (r^2) and the variance ratio (F) for regressions (Y=a+b log10 X) of the chemical composition of Malewa River (Y) on discharge (X), where Y is the chemical concentration in me-quiv/l except for SiO2 (mg/l) and conductance (uS/cm) and X is the discharge in m3/s; n=20 for each solute (Gaudet and Melack, 1981).

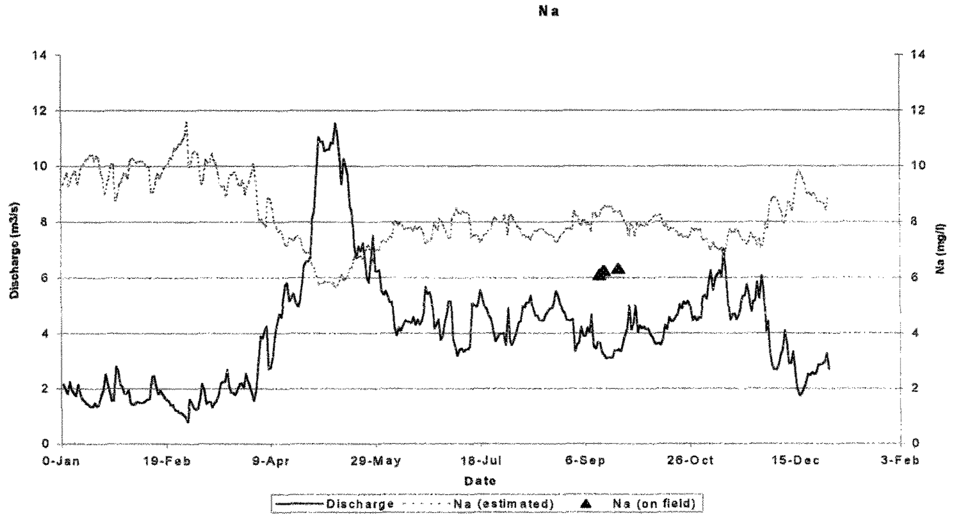
According to this regression analysis, conductance and two major constituents (sodium and bicarbonate) have strong inverse relations with discharge, while magnesium, sulphate and specially chloride show a weak inverse relation. Using the long-term daily average discharges for the Turasha outlet (station 2GC4), a daily flux for each element was computed, which is presented in table 6.8

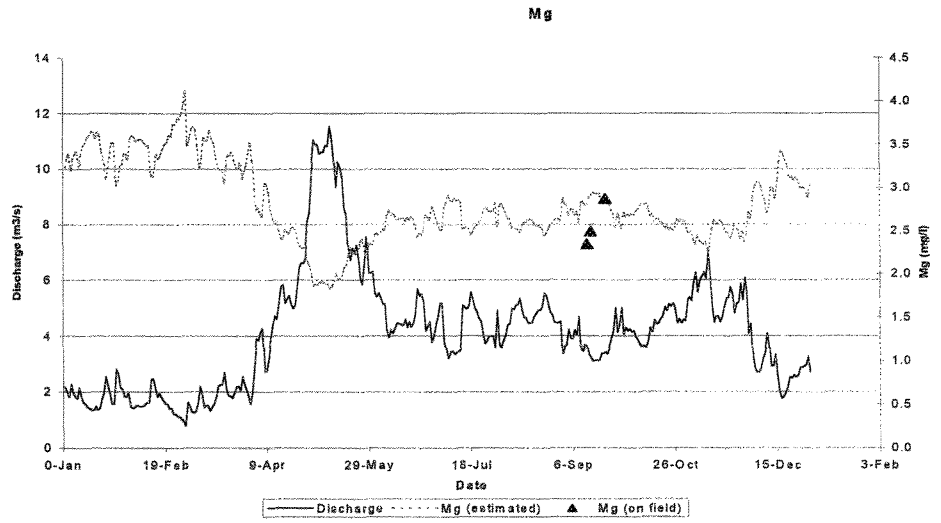
| | Using Mean Concentration | Using Gaudet-Melack's Regressions | Difference |
|---|---|---|---|
| | ton/year | ton/year | |
| SiO2 | 2215 | 2465 | 11% |
| Na | 1159 | 991 | -15% |
| K* | 554 | 1078 | 95% |
| Ca | 1030 | 924 | -10% |
| Mg | 386 | 335 | -13% |
| HCO3 | 9014 | 8018 | -11% |
| SO4 | 798 | 704 | -12% |
| Cl | 554 | 519 | -6% |
| Total | 15711 | 15032 | |

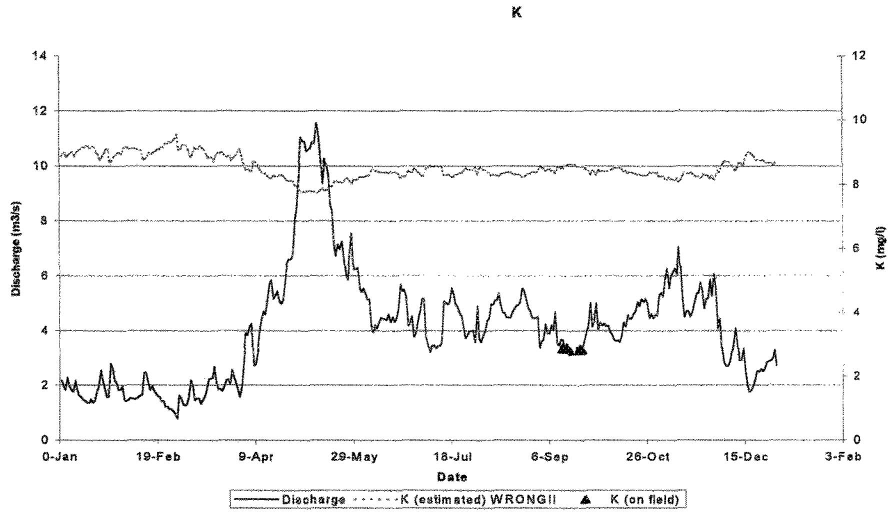
Table 6.8 Comparison between estimations using mean concentration and regression with daily average.
*Wrong estimation with regression

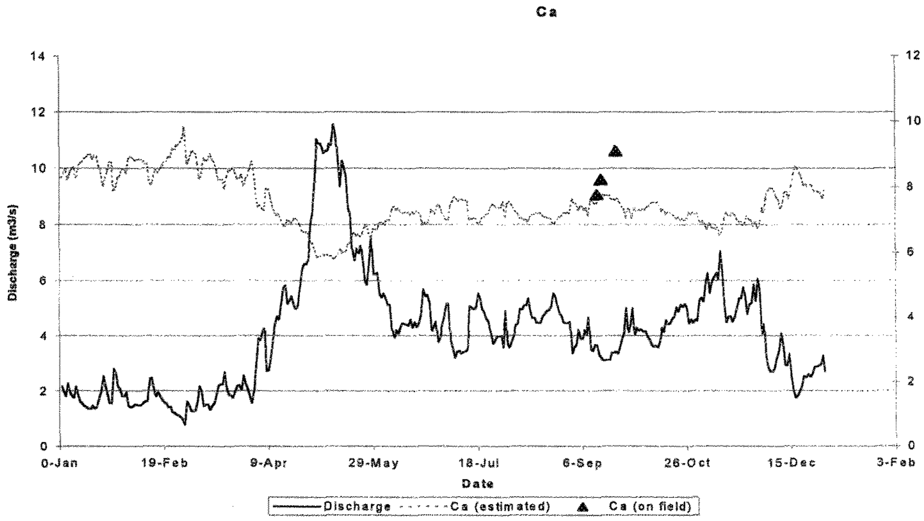
It can be seen in Table 6.8 that the two methods used to compute annual fluxes differ in around 10%. In the case of potassium obviously there is an error in the constants used in the regression, this will be confirmed plotting the field measurements (Figure 6.1) in the following pages.

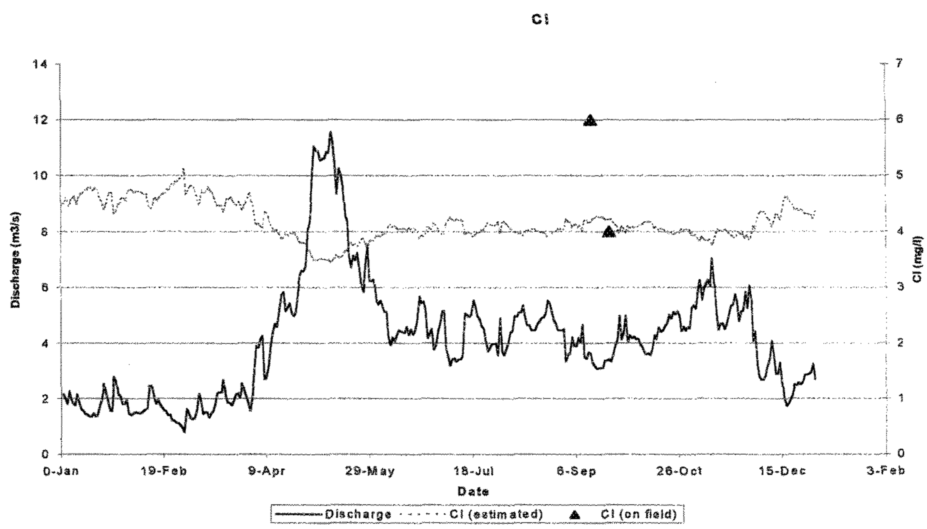

EC
Discharge (m3/s)
EC (uS/cm)
Date
0-Jan 19-Feb 9-Apr 29-May 18-Jul 6-Sep 26-Oct 15-Dec 3-Feb
Discharge EC (estimated) EC (on field)


Na
Discharge (m3/s)
Na (mg/l)
Date
0-Jan 19-Feb 9-Apr 29-May 18-Jul 6-Sep 26-Oct 15-Dec 3-Feb
Discharge Na (estimated) Na (on field)


Mg
Discharge (m3/s)
Mg (mg/l)
Date
0-Jan 19-Feb 9-Apr 29-May 18-Jul 6-Sep 26-Oct 15-Dec 3-Feb
Discharge Mg (estimated) Mg (on field)


K
Discharge (m3/s)
K (mg/l)
0-Jan
19-Feb
9-Apr
29-May
18-Jul
6-Sep
26-Oct
15-Dec
3-Feb
Date
Discharge
K (estimated) WRONG!!
K (on field)


Ca
Discharge (m3/s)
Ca (mg/l)
0-Jan
19-Feb
9-Apr
29-May
18-Jul
6-Sep
26-Oct
15-Dec
3-Feb
Date
Discharge
Ca (estimated)
Ca (on field)


Cl
Discharge (m3/s)
Cl (mg/l)
0-Jan
19-Feb
9-Apr
29-May
18-Jul
6-Sep
26-Oct
15-Dec
3-Feb
Date
Discharge
Cl (estimated)
Cl (on field)

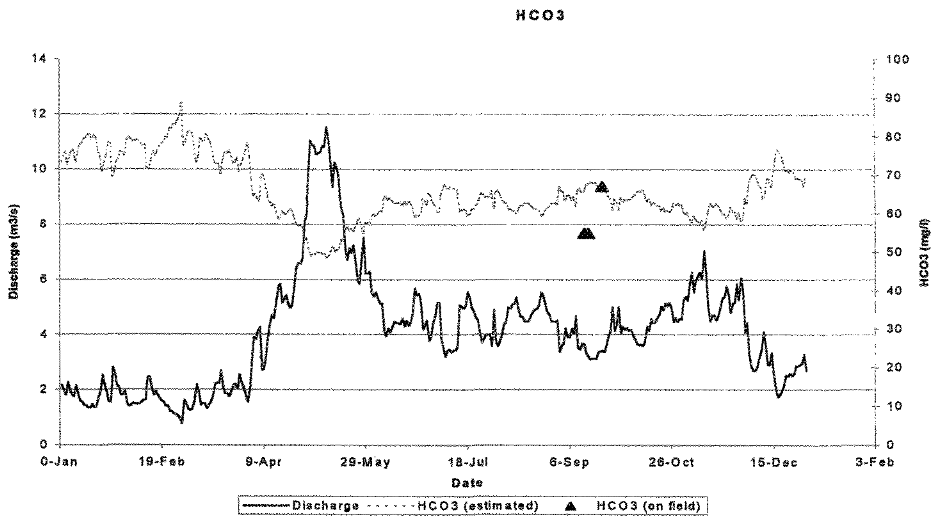



Figure 6.1 Fieldwork values and estimated values according to Gaudet-Melack's regressions

As can be seen in Figure 6.1, the concentration of the samples taken during fieldwork are very close to the estimated values the regressions of Gaudet and Melack. It is clear that the parameters in the regression for Potassium are wrong, the field values are closer to the mean concentration reported by Gaudet-Melack. However it is important to remember that the correlation coefficient for EC is good enough (0.84) to be considered as reliable. Therefore this parameter would be used to ratio the concentrations in the Turasha River calculated using the concentrations in the Malewa River.

The EC measurements during fieldwork were taken the days 15 and 22 of september. The average estimated EC during the month of September is 110.3 uS/cm and the average EC measurements is 102.8 which gives a ratio of 0.93 which means that the above presented estimations are close to the fieldwork measurements.

## 6.3 Input to the Turasha Catchment

An estimation of the input to the ecosystem is also possible. The long-term data of daily rainfall from the stations Kinangop Forest, Geta and Kinangop Mawingo was used to compute the daily aerial rainfall for the catchment. The weight for each station was obtained using the corresponding Thiessen map. The total volume of rainfall for the catchment using this data is presented in Table 6.8.

| Rainfall mm/year | Catchment Area m2 | Total Volume m3/year |
|---|---|---|
| 1109 | 769 854 600 | 853 603 273 |

Table 6.9 Volume of rainfall water per year

The estimation of inputs to the Turasha catchment is straightforward if the mean concentration in rainwater is known. Data relating to the ionic composition of rainwater in East Africa are rare. A few analyses are reported by Gaudet and Melack (see Table 6.10) based on 27 samples in Kenya.

| | Mean (Gaudet- Melack) mg/l | Std. dev. |
|---|---|---|
| Na | 0.48 | 0.25 |
| K | 0.33 | 0.37 |
| Ca | 0.19 | 0.15 |
| Mg | 0.14 | 0.09 |
| Cl | 0.41 | 0.36 |
| SO4 | 0.69 | 0.77 |
| HCO3* | 0.12 | - |

Table 6.10 Ionic composition of rain based on 27 samples in Kenya
*Estimated based on pH of 5.7 assuming equilibrium with pCO2 at atmosphere

According to the previously estimated volume of rainwater, and the mean concentrations from Gaudet, the estimated inputs are presented in Table 6.11.

| | Mean concentration Gaudet-Melack | Estimated amount | |
|---|---|---|---|
| | Kg/m3 | Kg/year | Ton/year |
| Na | 0.00048 | 409730 | 410 |
| K | 0.00033 | 281689 | 282 |
| Ca | 0.00019 | 162185 | 162 |
| Mg | 0.00014 | 119504 | 120 |
| Cl | 0.00041 | 349977 | 350 |
| SO4 | 0.00069 | 588986 | 589 |
| HCO3 | 0.00012 | 102432 | 102 |

Table 6.11 Preliminary estimates of Turasha catchment inputs
using mean concentrations from Gaudet and Melack-1981

Finally what is very interesting is to compare the inputs and output to the Turasha ecosystem (see Table 6.12). But first of all it is important to highlight that the dry precipitation is not considered, which can be a very important vector for some elements, topic that should be considered in further studies.

| | Input ton/year | Output ton/year | Input/Output |
|---|---|---|---|
| Na | 410 | 1159 | 0.35 |
| K | 282 | 554 | 0.51 |
| Ca | 162 | 1030 | 0.16 |
| Mg | 120 | 386 | 0.31 |
| Cl | 350 | 554 | 0.63 |
| SO4 | 589 | 798 | 0.74 |
| HCO3 | 102 | 9014 | 0.01 |
| Total | 2015 | 13496 | 0.15 |

Table 6.12 Comparison between inputs and outputs in the Turasha Catchment

It is easy to see that what is going out of the catchment is more than what is going in. However, most of the sulphate, potassium and chloride would be derived from precipitation, which indicates that an important input vector in the Turasha catchment is the rainwater. It is important to highlight the considerable presence of bicarbonate (big difference between input and output). As is typical for the incongruent solution of aluminosilicate rocks, the atmosphere and respiration of soil biota are sources of bicarbonate (Stumm and Morgan, 1970).

When there is a perfect nutrient cycling, as is the case of forest in the climax stage, the difference between input and output can be explained by weathering of the underlying rocks. However this is not the case of the Turasha catchment, which is a disturbed ecosystem, far from a forest with perfect cycling of nutrients as is the Amazon for example. Erosion, uptake of crops, forest in agradation stage (the Turasha catchment has trees plantation in the piedmont of the Aberdares and Kipipiri mountains), high weathering rates (vesicular basalts allowing free movement of water), all combined together have a big impact in the original input to the ecosystem.

Now an important concept arises if we try to relate the stocks and fluxes: the residence time [stock(ton)/flux(ton/year)]. Looking at the estimates obtained, only input/output fluxes to the ecosystem have been calculated but no estimates for fluxes between compartments. For example, it is not possible to associate the input flux (rain) with the stocks in vegetation. However only for appreciation purposes we can assume that all the flux from rain goes to grass and then obtain the time a nutrient from rain would stay in the compartment before it goes to another one; using this assumption, it was obtained the times for the nutrients in grass: Na (5 months), K (37 years), Ca (13 years), Mg (6 years), Cl (3 years), $SO_4$ (2 years). This exercise can be applied if the fluxes among compartments are known, however here it is only presented as an example.

## 6.4 The rocks compartment

During rock weathering, $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$, $SO_4^{2-}$, $HCO_3^-$, $SiO_2$ and others are added to the water. The amount of each is dependent on the rock mineralogy (Hounslow, 1995). Kilham and Hecky (1973) emphasized the importance of chemical weathering of the rocks as the source of major solutes in Lake Naivasha. Gibbs (1970) calculated the contribution from rocks simply as the difference between river discharge and precipitation.

If it is necessary to talk about minerals, not only the geological map for the Turasha catchment (Figure 2.1) is enough to quantify the stocks in the rock compartment. A description of the mineralogy for the rocks in the Turasha catchment is presented in this study. No studies of weathering rate are available but it is possible to depict the minerals present in the rocks that can be moved from these compartments to others. In this section more than a quantification of stocks in the rocks compartment, a description of the minerals available in this compartments was carried out. To reach this objective a detailed study of the geology descriptions around Lake Naivasha was executed.

Although there is no detailed petrologic map of the Turasha catchment, it was possible to describe the lithology of the area using the geologic map presented in Table 2.1 and two geological reports: "Geology of the Kijabe Area" by Dr. E. P. Saggerson (1962) and "Geological, volcanological and hydrogeological controls on the occurrence of geothermal activity in the area surrounding Lake Naivasha" by M.C.G. Clarke (1990).

The resulting lithological description obtained from these reports is detailed in Appendix C.1. Also the elemental composition of rock types occurring in the Eastern Rift Valley is detailed by Saggerson (1970); this table is presented in Appendix C.2.

Additionally to the information collected from literature, a source rock deduction was carried out using the water samples taken during fieldwork (see section 4.5.3). In this case, not only the source-rock deduction for the outlet of the catchment was determined but also for each main subcatchment and for samples taken in forest (in the Aberdare range). For a description of each subcatchment, see section 5.2. The purpose here is to gain insight into the origin of the water analysis and to corroborate the descriptions given by the geological reports (Appendix C.1 and C.2). The classification obtained from the source rock deduction is compared with the areas calculated from the Geological Map (see Table 6.13).

| | According to diagrams | According to Geological map (%) | | |
|---|---|---|---|---|
| | | Basalt | Pyroclastic rocks and sediments | Pumice tuff / lacustrine sediments |
| Kianjogu Outlet | Rhyolite (high SO4) | 69% | 27% | 5% |
| Kitiri Outlet | Basalt | 47% | 50% | 3% |
| Mkungi Outlet | Basalt/Rhyolite | 75% | 23% | 1% |
| Muruaki Outlet | Rhyolite | 2% | 98% | - |
| Tulasha Outlet | Basalt | 33% | 67% | - |
| Turasha Outlet | Basalt/Rhyolite | 30% | 60% | 10% |
| Kitiri Forest | Basalt/Calcite | 100% | - | - |
| Mkungi Forest | Basalt | 97% | 3% | - |

Table 6.13 Source-rock deduction according to Stiff and Piper diagrams

As a first step it is convenient to examine the samples taken on forest, belonging to the subcatchments Mkungi and Kitiri. The forest samples are particularly interesting because they catch the water weathering only basalt (see brown areas of subcatchments Mkungi and Kitiri in Figure 6.2). All the other samples plotted on the stiff and piper diagrams were taken in the outlet of each subcatchment. The forest samples confirm what is indicated in the geological map from the Kenya Soil Survey (1977) with one exception: the presence of a high content of Calcium (11.4 mg/l). This sample was taken almost in the border of the basalt formation, therefore it is possible that there are some interbedded lake sediments near the area containing $CaSO_4$ (gypsum) and $CaCO_3$ (lime).

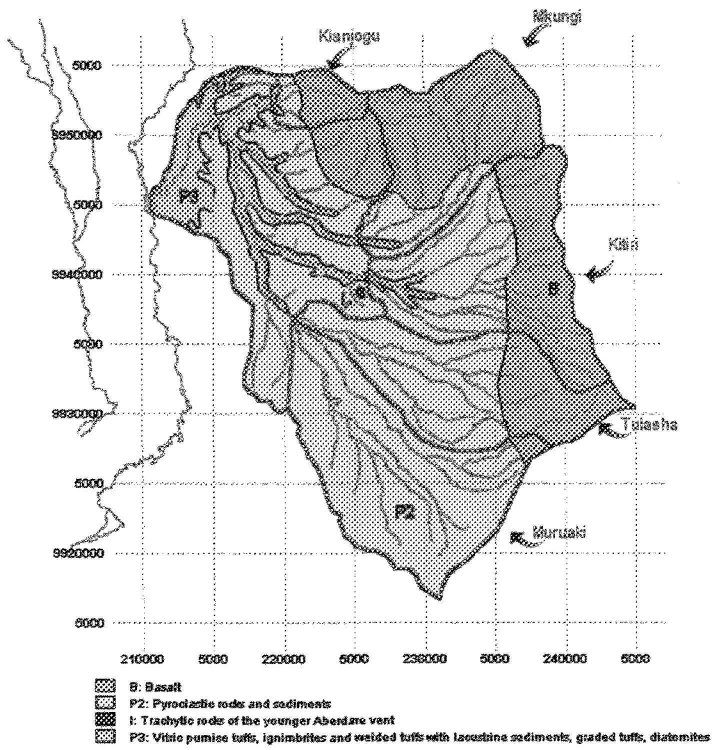



Figure 6.2 Geological map (Kenya Soil Survey, 1977) and subcatchments according to preliminary sampling

Continuing with the samples at the outlet of the subcatchments. Muruaki is almost 100% pyroclastic rocks (unit P2 in the geological map – yellow color – Figure 6.2). It does not have the presence of basalt as can be seen in Figure 6.2, in fact, it is confirmed in the interpretation of the Stiff and Piper diagrams: Rhyolite signature. Now, coming to the other extreme, 60% of the Kianjogu subcatchment is underlaid by Basalt. Again with a particular signature characterises this subcatchment, Rhyolite – an acid rock; in this case the chemical signature is not supported by geology.

# Chapter 7 Conclusions and Recommendations

The objective of this study was to make an exploratory analysis of the Turasha Catchment in order to identify the factors and information necessary to quantify its stocks and fluxes. This work, being an exploratory analysis, does not try to go in deep into specific fields of geology, chemistry or ecology but instead this study tries to integrate all this disciplines in a meaningful result even when the resources or amount of data are limited. It was never forgotten the use of Geographical Information Systems (GIS) and Remote Sensing (RS) in most of the tasks carried out. Even when the procedures followed in the processing of geographic data are not completely detailed in the description of this work, GIS and RS were heavily used.

The next sections present a description of what was obtained after the realization of this study and the recommendations in case a similar study is accomplished in the future. The results obtained are not only quantitative, methodological issues were tested and are considered also as a contribution.

## Conclusions

- The ecosystem approach

From the very beginning, the ecosystem approach was inserted within the methodology used in this study as a tool to integrate entities as vegetation, rocks, water, etc. More than a tool for quantification of stocks dividing the environment in compartments, the ecosystem approach was used as a tool for understanding the functioning of the catchment as a whole. After the realization of this work it can be said that this tool is applicable even when the amount of data is limited or when programs of monitoring are absent, a situation that is typical of rural catchments of many development countries.

- The sampling scheme

The main issue in this part of the research was the identification of the more suitable periods for sampling when the frequency of visits to the field has to be limited. February was selected as the more suitable month to sample base-flow water, and May as the month to sample in the rainy season. In fact to sample in the months of September, October and November is not recommended and it was confirmed with the sampling during fieldwork when local and erratic rains were present.

- The stocks

Another contribution from this study is the methodology used to estimate stocks in vegetation for the Turasha. Even when the estimates are based in general information from literature, they can give a better idea of what is happening within the ecosystem. It is possible at least to compare where the stocks are bigger, for example between grass and forest. Estimations of stocks in standing biomass for tropical forest (1285700 - 5142800 tons of dry matter in an area of 12857 ha) and for grass (kikuyu/pennisetum-clandestinum with 164261 tons of dry matter in an area of 45628 ha) were calculated using general information. The estimates for each element was derived from chemical analyses of ash (BIOBIB Database), the resulting values give an idea of where the elements are and if comparing with fluxes it is possible to understand the functioning of the ecosystem. Only the stocks for the main compartments were estimated but others can be also computed as for example crops.

- The fluxes

Input and output to the ecosystem were estimated. To know if the behaviour of the Turasha catchment is similar to that of the Malewa catchment was one of the main issues in the estimation of input and output. The data collected during fieldwork even being limited could be used to evaluate how deviated the estimates are from the real values. The estimated concentrations for Na, Mg, Ca, HCO3 for the month of September corresponded to those of the water samples taken during the same month. This gives the impression that the use of data from Malewa River for preliminary estimates in the Turasha River are not remarkably deviated, concluding that Turasha has a similar behaviour than Malewa in the export of solutes.

- Fluxes between compartments

After this study it is concluded that if fluxes between some compartments have to be estimated more field data is required. Uptake and release of nutrients between the vegetation compartment and the soils/rock compartment for example are difficult to estimate even with general information (if it is available). The mineralization or decay or organic matter that would be called release of nutrients in ecosystems terminology is possible to estimate, but later the problem of estimation for the uptake of those minerals again from vegetation cannot be determined without the enough amount of data. Nutrient cycling only, would be a topic for another research.

- The data collected during fieldwork

Definitely if estimations are the main issue, measurements of water quality during one month cannot be used as the representative values for the whole year, however they can be used to evaluate how well data from the outer catchment fits in the area of study. The data collected in the preliminary sampling has the problem of being collected during different days at different times when one day was rainy and the other one dry, or when most of the mornings lack rains and most of the afternoons had short showers. To avoid this problem another sampling scheme in a different month was proposed.

## Recommendations

- The period of sampling

It was already explained the necessity of sampling during periods with more homogeneous distribution of rainfall in the catchment. February is recommended for the dry season and May for the rainy season

- The Biomass estimation

Where possible some estimates of biomass can be carried out if plots of vegetation are taken during fieldwork. Because of the importance of vegetation in this kind of studies participation of students in the area from the ACE Division and Forest Division at ITC would be advisable.

- The study of an smaller subcatchment

With the analysis of the water quality data it can be seen that the Turasha subcatchment is relatively homogeneous. In a way or other it can be concluded that some Malewa River data can be applied to the Turasha River, additionally Turasha catchment is relatively homogeneous according to the data collected during fieldwork. Therefore it would be advisable to take a smaller subcatchment that is representative of the Turasha watershed and then try to expand the results obtained to the whole Malewa catchment. Having a smaller subcatchment to study, a more intense program of monitoring can be implemented in the selected area, may be with the use of automatic loggers for the measurement of some parameters.

Mkungi, Kitiri and Tulasha are the main contributors to the Turasha River and they also present similar characteristics in geology, topography, meteorology and land use. One of this subcatchments would be a good candidate to be monitored with the purpose to estimate matter fluxes. With the data acquired in this way it would be possible to extrapolate the information to the whole Malewa catchment which is the most important contributor to Lake Naivasha.

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# Appendix A

The satellite images were georeferenced using ERDAS Imagine 8.4. The next tables show the coordinates in the ERDAS file (image coordinates) and the corresponding UTM coordinates. The coordinates were obtained from the scanned topographic maps of the area. The control points correspond to the Turasha Catchment only, but they can also be used to georeference a bigger area as for example the whole Malewa catchment. The image coordinates corresponds to the files available at IPL in ITC. The geometrical model used is:

Projection UTM, Spheroid Clarke 1880, Zone number 37 south, Datum Arc 1960

## A.1 Control points for Landsat 7, February image

| X input* | Y input | X ref.* | Y ref. |
|---|---|---|---|
| 6230.132 | -4955.55 | 220160.4 | 9929996 |
| 6446.758 | -4613.5 | 228030.5 | 9939199 |
| 6263.877 | -4687.44 | 222288.2 | 9937766 |
| 6179.297 | -4864.35 | 219038.4 | 9932909 |
| 5930.02 | -5117.62 | 210620.6 | 9926423 |
| 5643.328 | -5111.78 | 202145.9 | 9927802 |
| 5750.634 | -4907.76 | 206230.2 | 9933419 |
| 6036.149 | -5020.78 | 214174.2 | 9928849 |
| 5634.855 | -5230.23 | 201430.2 | 9924369 |
| 5868.156 | -4606.3 | 210978.7 | 9941895 |
| 5887.453 | -4764.6 | 210872.7 | 9937096 |
| 5928.528 | -4821.66 | 211832 | 9935222 |
| 5876.657 | -4871.4 | 210111.3 | 9933950 |
| 5743.924 | -4843.38 | 206292.4 | 9935359 |
| 5570.971 | -4657.54 | 201947.1 | 9941595 |
| 5882.556 | -4449.35 | 212070.4 | 9946478 |
| 5919.962 | -4321.03 | 213697.3 | 9950126 |
| 6428.923 | -5008.29 | 225808.3 | 9927585 |
| 6218.495 | -5335.19 | 218196.8 | 9918746 |
| 6313.7 | -4487.25 | 224622.8 | 9943510 |
| 6385.38 | -4600.22 | 226274.6 | 9939863 |
| 6463.437 | -4616.11 | 228483.5 | 9939052 |
| 6119.966 | -4426.56 | 219132.3 | 9946091 |
| 6153.639 | -4578.97 | 219482.3 | 9941472 |
| 6100.573 | -4222.27 | 219439.2 | 9952288 |
| 6446.577 | -4471.18 | 228609 | 9943428 |
| 6439.429 | -4049.12 | 230156.6 | 9955957 |
| 6318.63 | -4832.57 | 223293.7 | 9933221 |
| 6149.008 | -4693.58 | 218857.8 | 9938083 |

* "Input" corresponds to image file and "Reference" correspond to UTM coordinates

## A.2 Control points for Landsat 7, May image

| X input* | Y input* | X ref. | Y ref. |
|---|---|---|---|
| 229.3639 | -5262.67 | 212070.4 | 9946478 |
| 234.6174 | -5577.52 | 210872.7 | 9937096 |
| 265.5574 | -5134.89 | 213697.3 | 9950126 |
| 272.5966 | -4870.8 | 215068.6 | 9957902 |
| 275.4019 | -5635.15 | 211832 | 9935222 |
| 277.2394 | -5932.06 | 210620.6 | 9926423 |
| 462.4773 | -5241.17 | 219132.3 | 9946091 |
| 496.6282 | -5392.8 | 219482.3 | 9941472 |
| 521.4586 | -5677.91 | 219038.4 | 9932909 |
| 572.9236 | -5769.2 | 220160.4 | 9929996 |
| 591.5238 | -5210.14 | 223084.2 | 9946453 |
| 604.7804 | -5501.39 | 222288.2 | 9937766 |
| 654.6425 | -5299.64 | 224622.8 | 9943510 |
| 687.228 | -5322.51 | 225452.9 | 9942731 |
| 777.4128 | -4862.44 | 230156.6 | 9955957 |
| 827.0327 | -5546.33 | 228647.8 | 9935499 |
| 850.0424 | -5740.3 | 228501.3 | 9929625 |
| 871.5116 | -5006.93 | 232295.7 | 9951308 |
| 889.8428 | -5315.13 | 231537.1 | 9942055 |
| 949.038 | -5106.49 | 234154.1 | 9948026 |
| 1027.386 | -5778 | 233606.2 | 9927759 |
| 1078.702 | -5868.84 | 234737.6 | 9924823 |
| 1080.669 | -5498.82 | 236406.5 | 9935821 |
| 1088.466 | -5413.83 | 237011.1 | 9938293 |
| 1130.858 | -5259.83 | 238921.3 | 9942693 |
| 1209.51 | -5686.32 | 239425.8 | 9929680 |

* "Input" corresponds to image file and "Reference" correspond to UTM coordinates

# Appendix B

## B.1 'C' program to import data into Microsoft Access (field-record) from Microsoft Excel (tabulated data)

This program was developed to import the historical data of rainfall and discharge, which is in tabulated format: 1 table for each station at each month. The data was imported into Microsoft Access in the format field-record: three fields (station, date, value) and n records (1 record for each measurement of rainfall or discharge)

```
/* Program to convert the metereological data file to a field-record format */
/* The new format will be:  station_id, date, value   */

#include <stdio.h>
#define maximum 150   /* line maximum size */


main()
{
  char inname[80], outname[80];  /* Names of the files */
  FILE *input, *output;          /* File - handlers  */

  int i, howmany;

  char line[maximum];   /* one line of text from the archive */
  char nothing[10];
  int lenght;                /* length of the line read */

  char station[80], year[80], day[80];
  char january[20], february[20], march[20], april[20], may[20], june[20],
     july[20], august[20], september[20], october[20], november[20],
     december[20];

  char lineout[80];

  /* Set the main variables  */
  /* The folder and names of files of input and output  */
  strcpy(inname, "C:\\windows\\desktop\\naivasha.txt");
  strcpy(outname, "C:\\windows\\desktop\\naivaout.txt");

  /* Open the file with the data */
  input = fopen(inname,"r");
  output = fopen(outname,"w");

  /* A line can be:
         - A label of the station
         - A line with measurements

    So first reading, and then identification

   */
  i=0;  /* lines counter */
```

```
while (!feof(input))
{
  fgets(line, maximum, input);
  lenght=strlen(line);

  /* According to the length of the line, it is identified  */

  if (lenght>1)  /* lenght 1 are blank lines  */
  {

    if (lenght<=25)
    {
      /* It is a station line */

      /* A station line contains:
          -station ID
          -tab
          -Year
       */

      sscanf(line,"%s\t%s", station, year);
    }
    else
    {
      /* It is a line with measurements */

      /* In a measurement line the day is read and the elements in the right are measurements
         for each month
      */
      howmany = sscanf(line, "%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s",
            day, january, february, march, april, may,  june, july,
            august, september, october, november, december);

      if (howmany!=13)
      {
        printf("Error: this line doesn't have the right format\n");
        exit(1);
      }

      i++;
      printf("Formatting line: %d\n", i);


      /* Now that everything is read and identified, it is written using the new format:
       *    -station, date, mesurement
       */


      fprintf(output, "%s\t01/%s/%s\t%s\n", station, day, year,january);
      fprintf(output, "%s\t02/%s/%s\t%s\n", station, day, year,february);
      fprintf(output, "%s\t03/%s/%s\t%s\n", station, day, year,march);
      fprintf(output, "%s\t04/%s/%s\t%s\n", station, day, year,april);
      fprintf(output, "%s\t05/%s/%s\t%s\n", station, day, year,may);
      fprintf(output, "%s\t06/%s/%s\t%s\n", station, day, year,june);
      fprintf(output, "%s\t07/%s/%s\t%s\n", station, day, year,july);
      fprintf(output, "%s\t08/%s/%s\t%s\n", station, day, year,august);
      fprintf(output, "%s\t09/%s/%s\t%s\n", station, day, year,september);
      fprintf(output, "%s\t10/%s/%s\t%s\n", station, day, year,october);
      fprintf(output, "%s\t11/%s/%s\t%s\n", station, day, year,november);
      fprintf(output, "%s\t12/%s/%s\t%s\n", station, day, year,december);
```

```
      }

    }
    else { /* No information in the line */ }
  }

  fclose(input);
  fclose(output);

  exit(0);

}
```

# Appendix C

## C.1 Lithology according to Geological Reports

| Unit | Label | Description<br>(from Geological Reports) | Lithology | Petrology | |
|---|---|---|---|---|---|
| B | Basalt | Vesicular Olivine Basalt<br>Agglomerate of Simbara Series<br><br>Basalt of Laikipian Type | Olivine Basalt | Olivine | $(Mg, Fe)_2SiO_4$<br>(see also composition below)<br>- Basalt that lies on the plane of critical silica saturation, containing normative olivine and diopside with neither nepheline nor hypersthene (Yoder and Tilley, 1962). |
| P2 | Pyroclastics rocks and<br><br>sediments | Kinangop Tuff Series:<br><br>mostly welded tuffs,<br><br>palaesols & weathered zones at top of most beds | Pyroclasts, pyrogenic cristals and lithics which occur in<br><br>a matrix which is often either semi-opaque or opaque<br><br>-Pyroclasts: alkali feldspar, amphibole, quartz<br><br>-Pyrogenic cristals: alkali feldspar, green clinopyroxene, aenigmatite<br>-Lithycs: alkali feldspar, amphibole pyroxene and aenigmatite | Alkali feldspar<br><br>Amphibole<br><br>Quartz<br><br>Green Clinopyroxene<br><br>Aenigmatite | Potassium feldspar (Or, or $KAlSi_3O_8$) and sodium feldspar (Ab, or $NaAlSi_3O_8$) in any ratio<br>$A_{2-3}B_5(Si, Al)_8O_{22}(OH)_2$, where A = Mg, $Fe^{+2}$, Ca, or Na, and B = Mg, $Fe^{+2}$, $Fe^{+3}$, or Al<br>$SiO_2$<br><br>Contains considerable calcium: $ABSi_2O_6$, where A = Ca, Na, Mg, or $Fe^{+2}$, and B = Mg, $Fe^{+2}$, $Fe^{+3}$, Fe, Cr, Mn, or Al<br>$Na_2Fe_5TiSi_6O_{20}$ |
| P3 | Vitric pumice tuffs,<br><br>ignimbrites and welded tuffs with lacustrine sediments, graded tuffs, diatomites | Pumice<br><br>(commonly having composition of rhyolite)<br>Diatomites | Rhyolite<br><br>-Phenocrysts of quartz and alkali feldspar in a glassy to<br><br>cryptocrystalline groundmass<br>Diatomite<br><br>-light-colored soft friable siliceous sedimentary rock | Alkali feldspar<br><br>Quartz<br><br><br>Silica | Potassium feldspar (Or, or $KAlSi_3O_8$) and sodium feldspar (Ab, or $NaAlSi_3O_8$) in any ratio<br>$SiO_2$<br><br><br>$SiO_2$ |
| I | Trachytic rocks of the younger Aberdare vent | Trachytic tuffs | Volcanic rocks in which feldspar microlites of the groundmass have a subparallel arrangement corresponding to the flow lines of the lava from which they were formed. | Feldspar microlites | $(Na, Ca)_2(Ta, Nb)_2O_6(O, OH, F)$ |

## C.2 Elemental composition of rock types occuring in the Eastern Rift Valley

Values expressed as percentages and elements/Na weight ratios calculted from Saggerson (1970). Saggerson sample number in parentheses.

| | Malewa River | Quartz trachyte (96) | Welded tuff (202) | Obsidian (78) | Rhyolite obsidian (73)* | Kataphorite trachyte (92)* | Phonolite (111)* | Olivine Basalt (174)* | Basalt (148)* |
|---|---|---|---|---|---|---|---|---|---|
| Na % | - | 4.900 | 4.700 | 5.000 | 3.400 | 4.900 | 4.900 | 0.300 | 3.200 |
| | | | | | | | | | |
| K % | - | 3.100 | 2.300 | 3.700 | 3.900 | 3.900 | 4.700 | 0.400 | 1.300 |
| K/Na | 0.500 | 0.600 | 0.500 | 0.700 | 1.200 | 0.800 | 1.000 | 1.600 | 0.400 |
| Ca % | - | 1.700 | 1.700 | 0.200 | 0.160 | 0.700 | 1.300 | 2.200 | 5.600 |
| Ca/Na | 0.900 | 0.400 | 0.400 | 0.400 | 0.500 | 0.100 | 0.300 | 8.300 | 1.800 |
| Mg % | - | 0.500 | 0.200 | 0.040 | 0.020 | 0.200 | 0.500 | 18.500 | 1.400 |
| Mg/Na | 0.300 | 0.100 | 0.040 | 0.010 | 0.010 | 0.050 | 0.100 | 68.400 | 0.500 |
| S % | - | 0.000 | 0.000 | 0.020 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 |
| S/Na | 0.200 | 0.000 | 0.000 | 0.004 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 |
| Cl % | - | 0.000 | 0.000 | 0.400 | 0.210 | 0.000 | 0.000 | 0.000 | 0.000 |
| Cl/Na | 0.500 | 0.000 | 0.000 | 0.080 | 0.060 | 0.000 | 0.000 | 0.000 | 0.000 |
| F % | - | 0.000 | 0.000 | 0.170 | 0.280 | 0.000 | 0.000 | 0.000 | 0.000 |
| F/Na | 0.040 | 0.000 | 0.000 | 0.030 | 0.080 | 0.000 | 0.000 | 0.000 | 0.000 |
| SiO2 % | - | 59.200 | 59.700 | 70.400 | 75.600 | 60.700 | 57.300 | 40.700 | 48.200 |
| SiO2/Na | 1.900 | 12.100 | 12.600 | 14.100 | 22.400 | 12.400 | 11.700 | 150.700 | 15.300 |

* Sample from Lake Naivasha Area

# Appendix D

## D.1 PREEQC input file with the water quality data

```
TITLE  Simple Hydrochemical evaluations - Turasha basin, Naivasha lake, Kenya
# Some simple hydrochemical evaluations and tests,
# forward geochemical modelling of rainfall, mixing & rock interaction,
# and comparison with groundwater chemistry in Turasha basin.
# Ps. Inverse modelling approach not attemped due to low measurement
# data accuracy (see field determinations) and large amount of unknowns.
# i.e. thermodynamic data on certain minerals, lithology, missing data.
SOLUTION 1 Rainfall chemistry, Kenya (Gaudet & Melack, 1988)
        temp     25
        pH       5.8
        pe       4         O2(g)    -0.68
        units    ppm
        density  1.000
        Ca                 0.19
        Mg                 0.14
        Na                 0.48
        K                  0.33
        Alkalinity         0.12 as HCO3
#       C(4)                                 0.023
        Cl                 0.41
        S(6)               0.64
        N(5)               0.05
END
SOLUTION 2 Rainwater (equilibrated with the air CO2 for alkalinity & pH evaluation)
        temp     25
        pH       7.0 charge
        pe       4         O2(g)    -0.68
        units    ppm
        density  1.000
        Ca                 0.19
        Mg                 0.14
        Na                 0.48
        K                  0.33
        Cl                 0.41
        S(6)               0.64
        N(5)               0.05
EQUILIBRIUM_PHASES
        CO2(g)             -3.46
END
SOLUTION 3 Kianjogu Subcatchment - Outlet (fieldwork 2000)
        temp     25
        pH       8.2 charge
        pe       4         O2(g)    -0.68
        units    ppm
        density  1.000
        Ca                 9.0
        Mg                 1.53
```

```
        Na              13.5
        K               2.81
#       Alkalinity 67.1 as HCO3
        C(4)                            13.205
        Cl              4.0
        S(6)            49.92
        Fe                              0.01
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
PRINT
SOLUTION 4 Kitiri Subcatchment - Outlet (fieldwork 2000)
        temp    25
        pH      7.9 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              8.7
        Mg              3.1
        Na              4.6
        K               2.3
#       Alkalinity 61.0 as HCO3
        C(4)                            12.004
        Cl              5.0
        S(6)            6.6
        Fe                              0.1
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
SOLUTION 5 Mkungi Subcatchment - Outlet (fieldwork 2000)
        temp    25
        pH      7.9 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              8.1
        Mg              2.5
        Na              4.5
        K               2.4
#       Alkalinity 54.9 as HCO3
        C(4)                            10.804
        Cl              4.0
        S(6)            3.3
        Fe                              0.0
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
SOLUTION 6 Muruaki Subcatchment - Outlet (fieldwork 2000)
        temp    25
        pH      7.8 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              11.4
        Mg              3.1
        Na              9.4
        K               10.1
#       Alkalinity 79.3 as HCO3
        C(4)                            15.606
        Cl              12.0
```

```
        S(6)            0.0
        Fe                              4.8
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
SOLUTION 7 Tulasha Subcatchment - Outlet (fieldwork 2000)
        temp    25
        pH      8.1 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              10.5
        Mg              3.0
        Na              4.0
        K               10.1
#       Alkalinity 67.1 as HCO3
        C(4)                            13.205
        Cl              4.0
        S(6)            0.0
        Fe                              0.1
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
SOLUTION 8 Turasha Catchment - Outlet (fieldwork 2000)
        temp    25
        pH      8.3 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              9.1
        Mg              2.9
        Na              6.3
        K               2.8
#       Alkalinity 67.1 as HCO3
        C(4)                            13.205
        Cl              4.0
        S(6)            1.8
        Fe                              0.1
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
SOLUTION 9 Kitiri Subcatchment - Forest (fieldwork 2000)
        temp    25
        pH      8.4 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              11.4
        Mg              5.1
        Na              4.4
        K               1.6
#       Alkalinity 85.4 as HCO3
        C(4)                            16.806
        Cl              4.0
        S(6)            0.9
        Fe                              0.0
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
SOLUTION 10 Mkungi Subcatchment - Forest (fieldwork 2000)
```

```
        temp    25
        pH      8.1 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              9.1
        Mg              2.9
        Na              4.5
        K               1.5
#       Alkalinity 48.8 as HCO3
        C(4)                            9.603
        Cl              4.0
        S(6)            2.1
        Fe                              0.0
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
SOLUTION 11 Malewa river water (Melack, 1981)
        temp    25
        pH      7.0 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              8.0
        Mg              3.0
        Na              9.0
        K               4.3
        C(4)                            18.4
        Cl              4.3
        S(6)            6.2
        F                               0.4
        Si                              8.02
EQUILIBRIUM_PHASES
        CO2(g)          -3.46
END
SOLUTION 12 Naivasha lake water (07-07-2000, Sulmac intake, v.d.Sprong lab)
        temp    25
        pH      7.8 charge
        pe      4       O2(g)   -0.68
        units   ppm
        density 1.000
        Ca              28.0
        Mg              7.3
        Na              30.0
        K               16.0
        Fe                              0.050
        C(4)                            39.54
        Cl              11
        S(6)            35
        N(5)                            6.2
        Si                              2.8
EQUILIBRIUM_PHASES
        CO2(g)          -3.46  #(equilibrated with the air CO2)
END
```