

**CHEMICAL RUNOFF POTENTIAL OF AGRICULTURE
AROUND LAKE NAIVASHA
KENYA**

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Chemical runoff potential of Agriculture around Lake Naivasha Kenya

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Dedication

***This work is dedicated to my father Mr. Mai Van Mac, my Dearest Doan
Thi Hong Hanh and Mai Thuy Hong***

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ABSTRACT

Chemical runoff, emanating from intensive farming in the riparian zone around lake Naivasha was investigated. Two farm sites were selected based on their representative soil types and farming practices in the area. Rainfall simulation experiments were conducted on several fields, in order to experimentally determine sediment and chemical losses in runoff. Chemical and nutrient extraction parameters from soil to runoff and rainfall were verified using field and laboratory analysis. This information was then used to calibrate and compare a number of nonpoint source pollution models, commonly used to assess environmental impacts of agriculture on water resources. The three models, Agnps v.5, Przm v2.1 and Sesoil v3.0 were compared using a parameter sensitivity technique. Two farm-scale watershed representations of nonpoint source pollution processes were also generated by combining Agnps v.5 with Ilwis in a Geographic Information System approach. In general, it was observed that the major part of chemical mass transport in runoff was linked to sediment losses.

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List of Used Symbols

Most symbols was described in the text and they are particularly represented for each Model, they are briefly described below.

Symbols	Interpretation	Unit
In Rainfall simulation		
Pd	The amount of soil P released in time t (min)	mg/kg
W	Water/soil ratio	l/kg
Pa	Initial available soil P content	mg/kg
K, α, β	Constants for a given soil to calculate Soluble P	[-]
S	Mass of soil per unit area in the zone of interaction between surface soil and rain water	[g]
R	Rainfall rate per unit area	L/min
E	Effective depth of interaction between surf soil and runoff	mm
B	Bulk density of soil in this depth	kg/m ³
T	Duration	min
V	Total amount of rainfall during a runoff event	l
W	was approximated as S/runoff volume.	G/ml
In AGNPS model		
E	Soil loss in	tons/acre
EI	Rainfall energy intensity	100-ft-ton inch/acre hr
Ks	Soil erodibility factor	ton-acre hr/100-acre foot-ton inches
Lf	Slope length factor	[-]
Sf	Slope steepness factor	[-]
Cf	Cover and management factor	[-]
Pf	Support practice factor and	[-]
<i>SSF</i>	A calculated factor to adjust for slope shape	[-]
RF	Runoff	inches
RL	Storm precipitation	inches
S	Retention factor	inches
RO ⁻	N or P concentration in the runoff	ppm
\bar{C}	Mean concentration of the soluble portion of the nutrient in the soil surface during runoff	mg/l
EXK ⁻	An extraction coefficient for movement into the runoff	[-]
RO	total runoff	mm
RON	Soluble N in the runoff	pounds/acre
CZERON	Available soluble N content in the soil	kg/ha
CHECKN	Available N due to the rainfall	kg/ha
XKFN1	Rate constant for downward movement of N into the soil	[-]
EFI	Total infiltration for the storm	mm
XKFN2A	rate constant for N movement in the runoff	[-]
RO	Total storms runoff	mm
COEFF	A porosity factor	[-]
RN	N contribution due to the rain	kg/ha
EFRAIN	Effective rainfall	mm
ROP	Soluble P in the runoff	lbs./acre
CZEROP	Available P due to natural and fertilizer nutrient level	kg/ha
CHECKP	available P due to the initial soil	kg/ha
XKFP1	A rate constant for downward movement of P into the soil	[-]
XKFP2	The rate constant for movement into runoff	[-]

SOLN	Soluble N in the top centimeter of the original soil	kg/ha
SOLP	Soluble P in the top centimeter of the original soil	kg/ha
FN(X)	N fertilizer application in cell X	kg/ha
FP(X)	P fertilizer application in cell X	kg/ha
FA(X)	Fraction of this application remaining in the top cm of the soil	[-]
CSN	Concentration of N in the pore water of the surface cm of soil	ppm
CSP	Concentration of P in the pore water of the surface cm of soil	ppm.
RCN	N concentration in the rainfall	mg/l
EXKN1	Extraction coefficient for N downward movement	[-]
EXKP1	Extraction coefficient for P downward movement	[-]
EXKN2	Extraction coefficient for N movement in to runoff	[-]
EXKP2	Extraction coefficient for P movement into runoff	[-]
Qs(x)	Sediment discharge at the downstream end of the channel reach	lbs./s
Qs(0)	Sediment discharge at the upstream end of the channel reach	lbs./s
Qs1	Lateral sediment inflow rate	lbs./s
X	Downslope distance	feet
Lr	Reach length	feet
D(x)	Sediment deposition rate at point x	lbs/s-ft ²
W	Channel width	feet
Qp	Peak discharge	ft ³ /s
A	Drainage area	acres
Sc	Channel slope	ft/ft
RF	Runoff volume	inches
Lc	Channel length	feet.

In PRZM model

Ju	Uptake of chemical	g/day
F	The fraction of total water in the zone used for transpiration	day-1
ϵ	An uptake efficiency factor or reflectance coefficient	[-]
A	Cross section area of soil column	cm ²
Δz	Depth dimension of compartment	cm
Cw	Dissolved concentration of chemical	g/cm ³
θ	Volumetric soil water content	cm ³ /cm ³
P	Precipitation	cm/day
S	The watershed retention parameter	[-]
RCN	SCS runoff curve number	[-]
J _{QR}	The chemical loss due to runoff	g/day
Q	The daily runoff volume	cm ³ /day
A _w	Watershed area	cm ²
J _{ER}	The chemical loss due to erosion	g/day
X _e	The erosion sediment loss	metric tons/day
.r _{om}	The enrichment ratio for organic matter	g/g
C _s	Solid phase concentration of chemical	g/g
P	a units conversion	g/tons
X _e	The event soil loss	metric tons/day
LS	Length slope factor	[-]
V _r	Volume of event (daily) runoff	m ³
C	Soil cover factor	[-]
Q _p	Peak storm runoff	m ³ /sec
P	Conservation practice factor	[-]
K	Soil erodibility factor	[-]
.a	Units conversion factor	

In SESOIL model

C _{sa}	Pollutant concentration in soil air	µg/mL
.c	Pollutant concentration in soil water	µg/mL
H	Henry's law constant	m ³ atm/mol
R	Gas constant	[8.2*10 ⁻⁵ m ³ atm/(mol ⁰ K)]
T	Soil temperature	⁰ C
S	Pollutant absorbed concentration	µg/g soil
K _d	Pollutant partitioning coefficient	(µg/g soil)/(µg/mL)
.c	Pollutant concentration in soil water	µg/mL
.n	Freundlich constant.	[-]
c _o	Overall (total) pollutant concentration	µg/cm ³
F _a	The air-filled porosity	ml/ml
.n	Soil (total) porosity	ml/ml
θ	Soil moisture (water) content	ml/ml
ρ _b	Soil bulk density	g/cm ³

List of Acronyms

AE	Accelerated Eutrophication
AGNPS	Agriculture Non-point Pollution Source
BD	Bulk Density
DO	District Office
EUT	Eutrophication
E	Evaporation
EC	Electrical Conductivity
ET	Evapotranspiration
GIS	Geographic Information Systems
Ln	Natural Logarithmic
MSM	Mineral Soil Moisture (m ³ /m ³)
N	Nitrogen
R	Rainfall
RO	Runoff
RUSLE	Revised Universal Soil Loss Equation
P	Phosphorus
Bio-P	Bio-available Phosphorus
Bray1-P	Bray 1-Available Phosphorus
OC	Organic Carbon
Olsen-P	Olsen-Available Phosphorus
OM	Organic Matter
OSM	Organic Soil Moisture content (m ³ /m ³)
SED.	Sediment
SESOIL	Seasonal Soil Compartment Model
SP	Soluble Phosphorus
PRZM	Pesticide Root Zone Model
PP	Particulate Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
USLE	Universal Soil Loss Equation

CHAPTER I

INTRODUCTION

This chapter gives a general introduction, research objectives, justification, hypotheses, methodologies and a short overview of literature.

1.1 -/ Background

Surface runoff from agricultural land is a contributor to accelerated eutrophication (AC) in lakes and streams (i.e., an over enrichment of lake water with PO_4^{3-} and NO_3^- ions, that cause excessive growth of algae and aquatic plants, a process called eutrophication). The U.S. Environmental Protection Agency identified agricultural nonpoint source (NPS) pollution as the major source of stream and lake contamination preventing attainment of the water quality goals identified in the Clean Water Act (U.S. Environmental Protection Agency, 1988). Phosphorus (P) and Nitrogen (N) are both nutrients often associated with AC of lakes and streams (Levine and Schindler, 1989).

The use of inorganic fertilizers, though essential for increasing crop production, can also prove to be hazardous to the environment, for example using both (NO_3^-) and (NH_4^+) fertilizers that can be converted to nitrate. NO_3^- is taken up by plant, but high nitrate content in plants is considered unhealthy, especially when the crops are used for the manufacture of the baby food. When not taken up by plants, concern is expressed for contamination of ground water by nitrate ions. Being negatively charged, NO_3^- ions are not adsorbed by the negative charged clay colloids, and hence are subject to washing and leaching.

P is most often the element limiting AC because many blue-green algae are able to utilize atmospheric N_2 . By excessive use of phosphate fertilizers, large amounts of the phosphate (PO_4^{3-}) may reach streams and lakes by surface runoff and leaching (Kim H.Tan 1994).

Previous research (Sharpley et al 1978, 1986, 1994, Sharpley 1981, 1983, 1985, Pote et al 1996, 1999) had proven the correlation between content of N and P pools in soil and in surface runoff water.

In this study, the hypothesis is going to be tested with certain condition. Also applying the models to quantify and simulate pathways of pollutants from non-point pollution areas such as the heavily fertilized agricultural region in the area of Naivasha - Kenya.

1.2-/ Objectives

The study is emphasized on the characterization of chemical runoff, non-point pollution modeling, in the riparian area around Lake Naivasha, more specifically:

- To quantify and qualify Nitrogen and Phosphorus in runoff and sediment, eroded by rainfall and irrigation from fertilized agricultural fields and its pollution potential of the lake water;

mm approximately and repeat every 3 days. Excess waters runoff directly and can enter the lake with fertilizers and pesticides in the wash load and eroded sediment. Estimates for the open Lake standing stocks of Nitrogen and Phosphates in 1974 were given by GauDet and Muthiri (1981) as 77 and 84 tons, while the theoretical annual input from the surrounding draw down area of N and P are 16 and 33 tons respectively.

1.4- The hypothesis

- There is a trend of increasing N and P levels in the lake water as shown in Table 1.2

Table 1-2 Trends in N and P contents of the Lake water

Year	Soluble N (mg/l)	Soluble P (mg/l)	Data source
1984	0.045	0.005	Harper, 1990
1988	0.125	0.012	Harper, 1990
1997	0.452	-	Morgan, 1997
1998	3.6	0.18	Tang, 1998

- Leaching of amended fertilizers (both organic and inorganic) in the agricultural field surround the lake is the reason for increasing N and P contents in the lake water (John Goldson 1993).
- Fertilization before important rainfall events increases N and P concentration in runoff and sediment.
- To analyze and determine interaction of rainfall intensity with soil bulk density, soil aggregate and initial condition of soil N and P contents to N and P contents in the runoff and eroded sediment. The desorption of soil P can be described by the following empirical equation (Sharpley et al 1981a)

$$Pd = K. Pa. t^{\alpha}. w^{\beta} \quad [\text{mg/kg}] \quad (1.1)$$

Where: Pd is the amount of soil P released (mg/kg) in time t (min)
 W water/soil ratio (l/kg)
 Pa initial available soil P content (mg/kg)
 K, α , β are constants for a given soil

Combining this kinetic equation with the concept of a thin soil layer of uniform mixing between rainwater and soil solution, an equation for the concentration of soluble P (SP) in runoff (C_{ro}) during a rainfall, runoff event, can be derived as (Sharpley et al. 1981a)

$$C_{ro} = (K. Pa. S. t^{\alpha-1}. w^{\beta})/ R \quad [\text{mg/l}] \quad (1.2)$$

Where: S mass of soil per unit area in the zone of interaction between surface soil and rain water
 R Rainfall rate (L/min) per unit area

Mean SP concentration of runoff (C_{ro} , mg/L) during a runoff event can be obtained from the following equation

$$\overline{C_{ro}} = (K. Pa. E. B. t^{\alpha}. w^{\beta})/V \quad [\text{mg/l}] \quad (1.3)$$

Where: E Effective depth of interaction between surface soil and runoff (m)
 B Bulk density of soil in this depth (kg/m^3)
 T Duration (min)
 V Total amount of rainfall (l) during a runoff event
 W was approximated as S/runoff volume.

For each runoff event, E (mm) was calculated from soil loss (kg/ha) using the following equation (Sharpley 1985a)

$$\ln(E) = a + b \cdot \ln(\text{soil loss}) \quad (1.4)$$

Where: a and b is constant related to soil texture (Sharpley, 1983). Leonard et al 1979, Sharpley et al 1985) used E as a constant value.

Particulate transport

As soil erosion is a selective process with respect to particle size in favor of finer particles, and chemicals are preferentially sorbed by clay-sized particles, sediment transported in runoff usually has a greater chemical content than the surface soil from which the eroded soil originated. This has led to the concept of enrichment ratios (ER) for P and N, defined as ratio of the nutrient (P or N) content of sediment (eroded soil) to that of source soil. A negative linear relationship between the logarithms of ER and sediment loss has been reported by Menzel (1980); Sharpley (1985b). This relationship was used to calculate the particulated P (PP), bioavailable P (BioP), and total Nitrogen (TN) concentration of runoff from the total P (TP), available P, and TN content of surface soils respectively:

$$\text{Runoff PP} = \text{Soil TP (mg/kg)} * \text{sediment concentration (g/l)} * \text{ER PP} \quad [\mu\text{g/l}] \quad (1.5)$$

$$\text{Runoff BioP} = \text{Soil BioP(mg/kg)} * \text{Sediment concentration (g/l)} * \text{ER BioP} \quad [\mu\text{g/l}] \quad (1.6)$$

$$\text{Runoff TN} = \text{Soil TN (mg/kg)} * \text{Sediment concentration (g/l)} * \text{ER TN} \quad [\mu\text{g/l}] \quad (1.7)$$

Where: PP Particulate P
 BioP Bioavailable P
 TN Total Nitrogen

1.5-/ Methodology

1.5.1-/ Experiment

Field runoff experiments were done using rainfall simulation. Before the rainfall simulation, the soil samples had to be taken and the soil was measured (using TDR). Inverse auger method was used to measure soil permeability of loam soil and sandy loam soil (appendix A-2). Total runoff was measured for every simulation. Runoff samples were collected during simulation in 250 ml plastic bottles for determination of pH, EC, sediment concentration, available P, SP, TN, and SN. After rainfall Soil samples were taken in some simulations, for analyzing soil properties.

- **Soil samples:**

- Surface soil samples were collected (0-50 mm depth) for each unit in the micro watershed, air-dried and sieved through a 2 mm screen

- **Runoff**

- Watershed, plot runoff collected directly from simulated rainfall
- Water samples were collected from simulated rainfall during event

- **Chemical analysis**

In the scale of this study, soil pH, EC, CEC, Base saturation, soil particle distribution, OC, soil TN, soil P-Olsen, Sediment P-Olsen, runoff SP were determined for selected representative samples.

- ***Analysis in ITC Laboratory***

1. $\text{PH}_{\text{H}_2\text{O}}$
2. Electrical conductivity (EC_{25})
3. Sediment concentration of water samples (by drying);
4. SN and SP by Merck Rqflex reflector portable lab.

- ***Analysis in International Soil Reference and Information Centre (ISRIC)***

1. Particle size distribution was determined by Pipette method
2. Soil and Sediment Available P was determined by the Olsen procedure (Olsen and Sommers. 1982, Reeuwijk. 1995)
3. Total Soil and Sediment %N was determined by a semi-micro-Kjeldahl procedure (Bremner 1965, Reeuwijk. 1995)
4. Organic Carbon (%OC) was determined by Walkley-Black method (Reeuwijk. 1995)
5. Soluble P on filtered (0.45 μm) runoff samples and that of total water soluble P following digestion with Dilute acid-Fluoride.

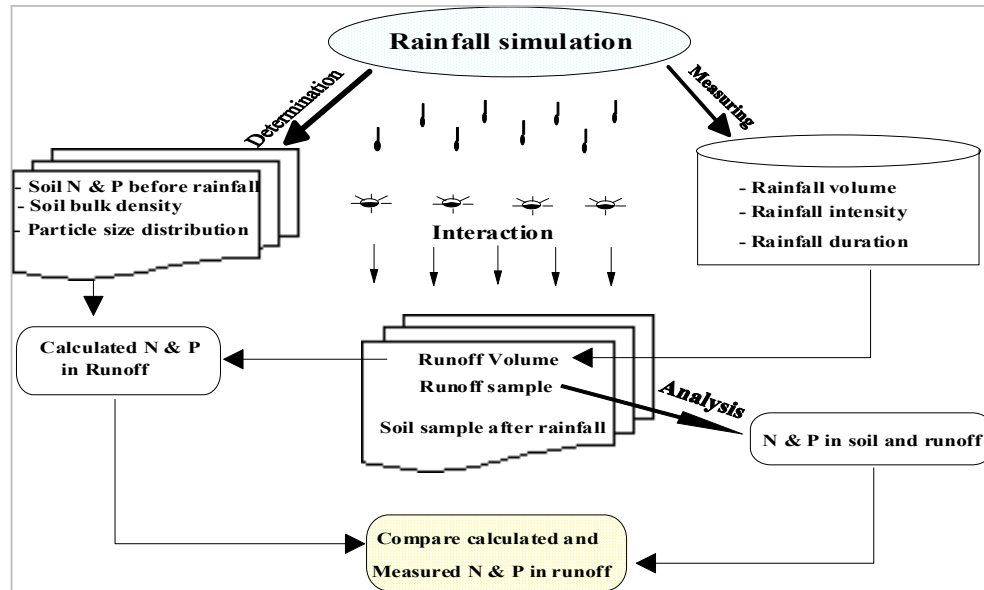


Figure 1-1 Designing scheme for experiment.

Calculated results of N and P in runoff were compared with measured results from the field and laboratory.

Chemical rainfall runoff simulation experiments were done on: Sandy loam soil, loam soil, Uncultivated soil, Cultivated soil, high level of fertilizer, Medium level of fertilizer, Low level of fertilizer (more details will be mentioned in Chapter 4)

1.5.2-/ Model Implementation

- Aerial Photo Interpretation
- Field work: Collection and interpretation of Land use, soil, climate, crop management, and other data.
- GIS: Preparation of input maps for AGNPS model (Watershed boundary, slopes, channels and flow direction) as well as creation of the output maps (sediment and Nutrient losses calculated with AGNPS).
- Use of AGNPS model for watershed in cell basis

A number of selected individual cells from AGNPS were used for PRZM, SESOIL runs using similar input data parameters and the results among three models were compared.

1.6-/ Literature overview

1.6.1 -/ Nitrogen (N) and Phosphorus (P)

1.6.1.1.Nitrogen

Most of N in soils (98%) is in organic form (Bremner 1965), it presents in plant residue barnyard manure, and industrial and domestic waste. Some of these organic N compounds, such as amino acids are soluble in soil water. However most of the N in soil water are in inorganic form e.g. NH_4^+ , NO_3^- and NO_2^- . The later is released in soil water by decomposition of soil organic matter. Inorganic N can also be added to soils by the application of fertilizers.

Nitrite, NO_2^- , Nitrate, NO_3^- which are the products of nitrification of ammonium (NH_4^+). Nitrite is usually quickly converted into nitrate, so that most important inorganic species of N in soil water are the NH_4^+ and NO_3^- forms. In contrast to NH_4^+ , NO_3^- ions are anionic in nature, and consequently will not be attracted by negatively charge clay minerals. Therefore, NO_3^- tends to be leached into the ground water. The presence of nitrate in amounts above 10mg/l is considered to be hazardous for human health by EPA standards and is particularly harmful for babies. When consumed, NO_3^- may not only be carcinogenic, it will also be reduced into NO_2^- in the anaerobic environment of the digestive system. The nitrite reacts with hemoglobin and interferes with its function as an oxygen carrier, causing blue coloring in babies.

1.6.1.2. Phosphorus (P)

In natural environments like water, P will be existed as phosphate (PO_4). In water, orthophosphate mostly exists as H_2PO_4^- in acidic condition or as HPO_4^{2-} in alkaline conditions.

Many phosphate compounds are not very soluble in water ($<0.01 \text{ mg PL}^{-1}$, Sharpley 1999); most of them in the natural systems exist in solid form. However, soil water and surface water (rivers and lakes) usually contain relatively low concentration of dissolved (or soluble) phosphorus. Water bodies may also contain organic P and phosphate attached to small particle of sediment. **Total phosphorus** (TP) in water is all of the P in solution regardless of its form and is often the form reported in water quality studies. **Algal available or Bioavailable P** is P that estimated to be available to organic like algae that are present in a lake or river. This is usually estimated by a chemical test which is designed to measured the **dissolved P** and the **particulate P** that are easily available. This is a measure of the P that is immediate concern to water quality. In soils P may exist in many different forms, in practical terms, however, P in soil can be thought of existing in three "pool"

- **Soluble P**, that is orthophosphate form plants take up and only the pool that has any measurable mobility.
- **Active P pool**, that is in solid phase (inorganic P absorbed to small particle in the soil and organic P that is easily mineralized) relatively easily released to the soil solution
- **Fixed P pool**, which is inorganic very insoluble P and organic compounds that are resistant to mineralization by microorganisms in the soil

1.6.2- Nitrogen (N) and Phosphorus (P) loss

Rony Wallach et al (1988) had done modeling the losses of soil-applied chemicals in runoff, lateral irrigation versus precipitation. Concentration of surface runoff from rainfall depend on resident time distribution while from lateral irrigation case depend on the number of cells that the field is divided into, the concentration are increased from upper stream to the outlet. He pointed out the transfer of chemicals from soil solution to surface runoff process is represented by transfer coefficient describing diffusion-controlled transport through a thin laminar boundary layer, which depend on specific chemical, soil surface physics such as roughness, lateral slope, soil type and runoff discharge, rain intensity and duration. One of that factors provide for that process was a layer of interaction between rainfall and thin layer of surface soil before leaving the field as runoff, so call Effective Depth of Interaction (EDI) (Sharpley 1985b), which range from 1-5 mm in depth. In average 73% of this depth reduced due to munching of 100 kg wheat straw.ha⁻¹ and 80% reduction due to a 0.5 mm² mesh screen. Simulating crop cover (Sharpley 1985) was obtained compare to the control (3.36) all soil loss, the logarithm (ln) of soil loss was linearly related to the ln(EDI) (R intensity, RO energy and aggregation). Differing enrichment ratio (ER) for C, N, Organic P (2.0, 1.61 and 1.47 average for six soils) indicate the erosion may reduce the C/N/Organic P ratio of the remaining surface soil. The logarithm of ER for each P form, N, C and K was related to the logarithm of soil loss, which ranged from 10 - 180 kg/ha. A major of the N lost by surface runoff is organic N fraction (Schuman et al 1973, Kissel et al 1976), which is associated with slit size particles and sediment.

The losses of NO₃-N in water runoff, studied by Lal (1980) on an alfisol in southeast Nigeria for bare fallow, maize-maize (ploughed), cowpea-maize (ploughed), maize-maize (mulched) and maize-cowpea (no-tillage) were 10, 3, 2, 0.5 and 0.6 kg/ha/yr. The enrichment ratio (ER) of eroded sediments was 2:1-5:1 for organic carbon, total nitrogen, Bray-P and exchangeable cations. The mean annual nutrient loss in the eroded soil, for slopes ranging from 1 to 15% was 2540 kg organic carbon, 210 kg N, 11 kg P, 19 kg K 140 kg Ca and 11 kg Mg/ha/yr. The nutrient concentration in runoff and seepage water also depends on the quality of the mulched material used, and on the methods of fertilizer application. While in a high land area of central Kenya Gachere et al (1997). ER was >=1 and sediments were mostly enriched with P and Na. The P and Na concentration were 4 to 10 and 2 to 3 time the source material. Sediment from plots was 247 to 936% richer in P than soil from which it originated. The highest value 10.3 of ER of P was recorded in maize with fertilization. Change in soil pH, %OC, % TN following erosion were significantly correlated with cumulative soil loss. The data indicated that nutrient loss due to erosion is one of the major causes of soil fertility depletion of Kenyan soils.

Distribution of N and P in runoff and leaching were studied and reported by many authors. According to Kunishi Otal (1972) Soluble P concentration of 0.1 - 0.13 mg/l of runoff from fertilized field were reduced to 0.009 mg/l by sorption during movement downstream clearly changes in BioP can occur between the point where it leaves a field to where it enters a water body, $P_{transported} = F(\text{agricultural management})$. The reduction in P loss (Bengtson et al 1988) must be weighted in terms of a potential increase in NO₃- loss in tile drained fields. Phosphorus export in stream, flow from the riparian forest was reduced 80% with similar

amounts exported in surface runoff (0.43 kg/ha/yr.) and ground water (0.3 kg/ha/yr.). P loss also depended on sorption and release P of soil. It was approved by Linsquist et al (1997) with experiment in an ultisols with and without fertilization in different aggregate size fraction, mean aggregate diameter is <0.027, 0.072, 0.12, 0.375, 0.75, 1.5, 2.4 and 3.4 mm. The results shown that total Pi in the +P treatment aggregates size increased from 1590 - 1672 mg P/kg as aggregate size decreased from 3.4 to 0.75 mm. Smaller aggregates with greater reactive mass sorbed more P than larger one.

Soil texture and organic matter (OM) content could have major influence on leaching losses of NO_3^- (Muchovej et al 1994). And there is strong correlation (Steen Voorden et al 1986) between NO_3^- -N leaching to ground water and rate of N fertilizer was observed of intensively manage grassland system in Netherlands, with the highest NO_3^- -N concentration being observed for grass system. At the same levels of N fertilizer applied, NO_3^- leaching is higher in grazed grassland than that from cut grass land.

Gabrielle and Kengni (1996) Used CERES model's soil components for analysis and field evaluation nitrogen transfer and transformations N losses in soil-crop systems with simple and function CERES models and compare with the more complex SLIM (for solute transport) and NCSOIL (for N mineralization) models. When using NCSOIL for simulate mineralization, CERES predict NO_3^- leaching reasonable well with a root mean square error of 6 to 21 kg N/ha, representing 5% of the yearly flux. The SLIM model performed as well and better simulates the intense NO_3^- percolation regime that occurred in wintertime. When link to NCSOIL, the CERES model showed a good potential for estimating N dynamics in soil, even if its piston flow type of NO_3^- transfer was not always relevant.

Meek et al (1995) had compared NO_3^- -N leached follow alfalfa of a conventional tillage bean-bean rotation with a silage corn-winter wheat rotation in a conventional tillage or no-till system in south-central Idaho. Nitrate leaching was determined by: - Sampling the soil solution below the root zone (1.2 and 1.5 m) using ceramic-tipped samples and calculating the N movement from the water balance. Owens et al (1995) set up experiment in six large, undistributed monolith lysimeters (8.1 m² area and 2.1 m deep) to investigate NO_3^- -N leaching in a six year corn-soybean rotation study western Ohio, NH_4NO_3 fertilizer was applied 224 kg N/ha in spring each year. During six year of study, the flow weighted average NO_3^- -N concentration in the percolate was 10.5 and 14.3 mg/l (6% slope and 13% slope). Mean annual NO_3^- -N losses in the percolate were 31.6 to 47.1 kg/ha (for 6% slope and 13% slope). When the water content exceeds field capacity a single equation to predict leaching of top-dressed or incorporated was developed by Burns (1975, 1976), assuming layer-to-layer piston flow. The addition of chemical fertilizer [KNO_3 or $(\text{NH}_4)_2\text{SO}_4$] greatly increased the amount of Nitrogen lost Blondel (1971).

Grant and Heaney use mathematical Modeling in ecosys to simulate of P movement and uptake to represent SP concentration under dynamics boundary conditions. This model is used to explain the temporal and spatial distribution of P among soluble and resin-, NaHCO_3^- , NaOH^- , and HCl^- extractable and Fraction in soils following amendment with KH_2PO_4 . The results of model testing suggest that changes in soluble P concentrations following P

amendments may be represented from concurrent equilibrium reactions for adsorption-desorption, precipitation-dissolution, and ion pairing.

The hypothesis of soil test P correlation to dissolved reactive P and Bioavailable-P in runoff were approved as linear equation by Pote et al (1996, 1999). N, P and Potassium (K) losses in surface runoff in loam soil in west-central Minnesota were determined by Burwell et al (1975). He estimated average N loss in surface runoff base on 1962-1971 water and sediment loss ranged from 0.76 kg/ha to 1.75 kg/ha for $\text{NH}_4\text{-N}$ and from 0.61 kg/ha to 2.29 kg/ha for $\text{N}_3\text{-N}$ depend on soil cover treatment. Average annual P loss in surface runoff (orthor-P in water + available sediment P) ranged from 0.35 to 1.19 kg/ha depending on soil cover treatment. Surface runoff contained more soluble P than was contributed annual by precipitation, soil and/or plant material were major sources of inorganic P lost in runoff.

Kwacha (1998) studied vulnerability of soils to changes in agricultural use around Lake Naivasha, Kenya. A total of 29 pits (includes minipits and auger holes) was described and sampled for analyzing texture, EC, pH, Organic matter content, Nitrogen content, Ca, Mg, K, Na, Mn, and Phosphorus. He reported that Land uses changed soils chemical properties and physiographic unit, the soil has high Ca, Mg and N but P very low. Also he concluded cultivation and soil management modified topsoil properties. While the wetland soils around Lake Naivasha had been studied by Urassa, (1999) and reported that soil had not been polluted by accumulation of salt.

The using of fertilizers, pesticides and sewage are reported by Tang (1999) as main reason for contamination of Lake Water through non-point source pollution. The leaching risk of pesticide was predicted by applying several models for each soil type and crop cover.

CHAPTER II

THE STUDY AREA

This chapter gives overall information about study area and information about in situ current using Agrochemical.

2.1-/ Location

Lake Naivasha is located 100 km Northwest of Nairobi in the Naivasha Division of Nakuru District, Kenya (Figure 2-1). The center of the lake is at latitude $00^{\circ}46'S$ and longitude $36^{\circ}22'E$. It is within the UTM zone 37. Its boundary coordinates are X_{\min} 190000, Y_{\min} 9907000; X_{\max} 221000, Y_{\max} 9934000. Altitude is around 1900m.

2.2-/ Climate

The climate is humid to sub-humid in the highlands and semi-arid in the rift valley. The mean monthly maximum temperature range between $24.6^{\circ}C$ to $28.3^{\circ}C$, and mean monthly minimum temperature between $6.8^{\circ}C$ and $8.0^{\circ}C$. The average monthly temperature ranges between $15.9^{\circ}C$ and $17.8^{\circ}C$.

The average annual rainfall ranges from about 1300mm in Kinangop plateau (South Kinangop Njambini) to about 600mm (Naivasha K.C.C. Ltd.) in the rift floor. The rainy seasons are typically from April to May (sometimes June) and October to November. The April-May rainy season is the main rainy period, known as the 'long rains', while the 'short rains' occur during October-November.

2.3-/ Geology

The geology of the area is characterized by volcanic rocks and Quaternary lacustrine deposits from large ancient lakes, which were formed during pluvial periods, becoming shallow or drying completely during Inter-pluvial (Cole, 1950).

There are two lithologic units in the lake shore area, lacustrine and volcanic origin. The prevailing quaternary deposit is of lacustrine origin, which largely comprises of fine volcanic ashes besides clay and silt. In addition, due to the soil erosion and deposition resulting from the lake levels fluctuations, there appeared also some coarse loamy with occasional fine gravel deposits.

2.4-/ Geomorphology

Three types of landscapes can be identified in the Naivasha catchment: the Kinangop plateau, the Mau escarpment, and the Rift valley floor (Thompson, 1958). The study area is within the Rift Valley floor (figure 2-1). It contains some major units, that are lacustrine plain and volcanic plain as identified by Kwacha (1998). Upper part of Southern part is Volcanic ash and Pumice.

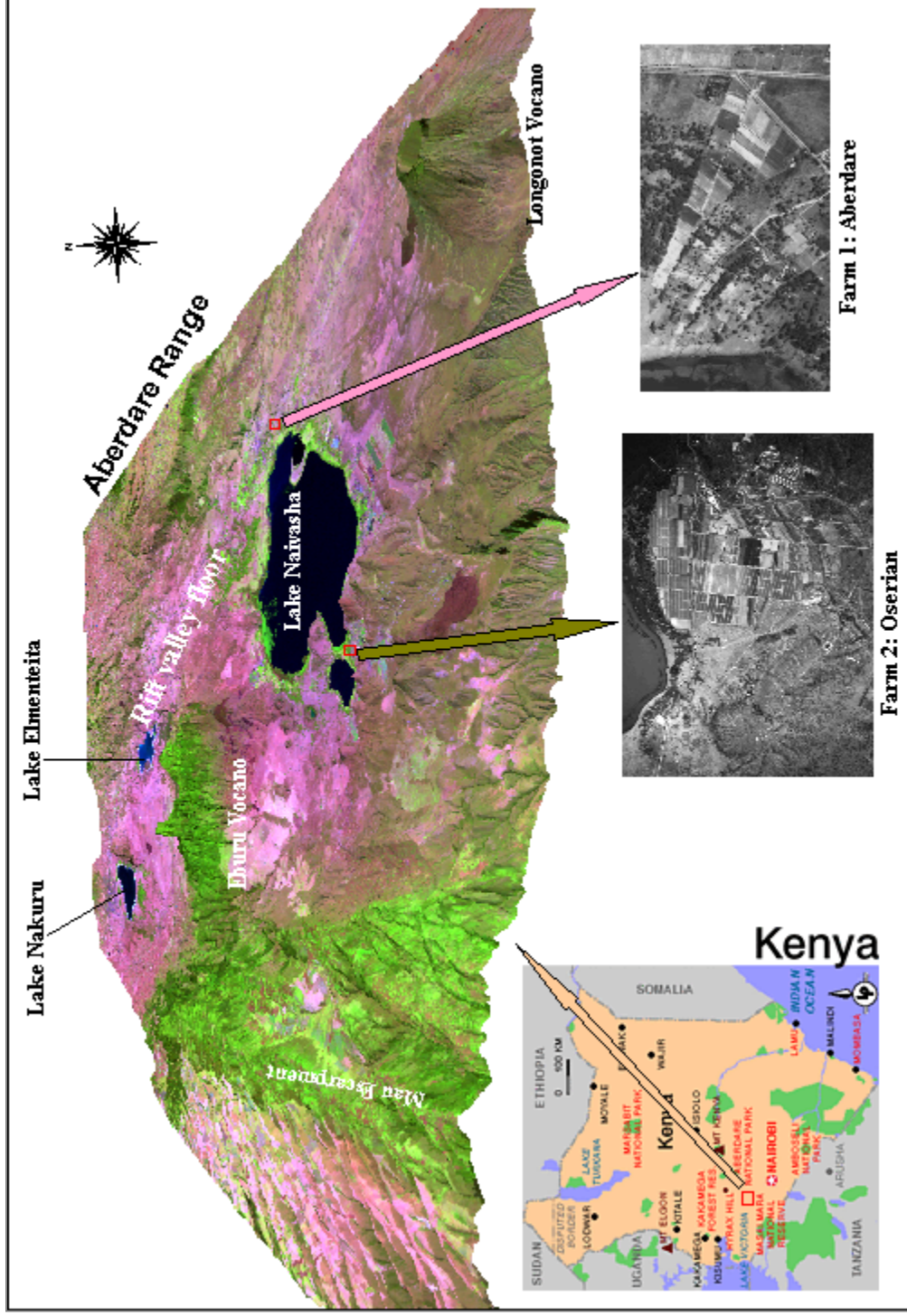


Figure 2-1 Overview Lake Naivasha within Rift valley, color composite TM 96 in 3D view and experiment sites Aberdare and Oserian farms in Aerial Photograph.

The topography near the lake is flat and is part of the recent lacustrine plain. The dominant slopes are within the range 0-2%, in parts 2-5%. Away from the lake the land rises gradually and slopes between 2 to 5% are common.

2.5-/ soil and land use around Lake Naivasha

2.5.1-/ Soil

Soil in the study has been given by KSS (1980), Kamoni (1988), Siderius (1977), Gatahi (1986) and recently Kwacha (1998), Urassa (1998) and Tang (1999). A brief description to study area are given as follow:

- In the site one, Eastern part (Aberdare farm) soil derived from volcanic ashes (323 P(x), m-h) is complex of Ando-haplic Phaeozems, well drained, moderately deep to deep, dark brown, friable and slightly smeary, fine gravelly, sandy clay loam to sandy clay, with humic topsoil. And Gleyic Cambisols, imperfectly drained, moderately deep to deep, strong brown, mottled, firm and brittle, sandy clay to clay. Which are developed on Lacustrine and Longonot Akaria pumice
- In the site two, South part (Oserain farm) most soil is developed on Lacustrine with Solonetz (320 Pi h), Larger part go further to the south is Lithosols and Xerosols (13 H x, m-h), well drained, shallow, dark reddish brown, friable, very calcareous, bouldery or stony, loam to clay loam; in many places saline

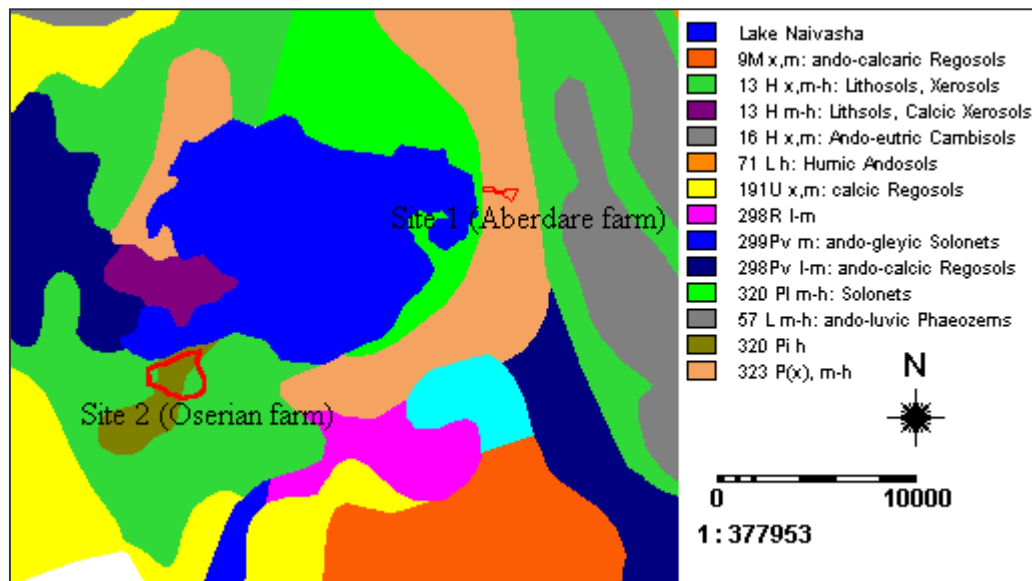


Figure 2-2: Soil map around Lake Naivasha

Source: Soils description and exploratory soil map of Kenya, 1982

2.5.2-/ Land use

There are four major land uses in the area: agriculture, natural vegetation, settlements, and game sanctuaries. The agriculture sector, which includes cereal growing, horticulture, floriculture, viticulture, and dairy farming, is mainly concentrated around the lake. Most of

the floriculture takes place inside greenhouses. The natural vegetation cover surrounding the lake is mainly papyrus swamp vegetation while outside of the lake surrounding, shrub, acacia, and cactus trees are the main natural vegetation covers. Settlement is mainly concentrated in Naivasha town although scattered homes and villages can also be found within the study area.

2.6-/ Water balance of the lake

There are several contributors to the water balance of the lake. The inputs to the lake consist of rainfall, surrounding surface run-off, river flows, and seepage inflow from catchment. The outputs include evaporation from the lake and swamp area, water abstraction, and seepage outflow from the lake. The approximate annual water budget was calculated by LNROA (LNROA, 1996) (Table 2-1). The evapotranspiration amount from swamp has been modified since the values given by LNROA are not certified.

Inputs	Wet condition	Mean condition	Dry condition	Outputs	Wet condition	Mean condition	Dry condition
Rainfall	140.8	72.9	45.0	Evaporation	229	183.5	177.8
Malewa River	378	153	53	Evapotranspiration	27.5	18.3	15.6
Gilgil river	74	24	3.2	Seepage	54	54	32
Karati	6.5	2.1	0.28	Abstraction	33.8	44.6	53.2
Ungauged area	117.8	77.9	34.2				
Seepage	54	54	32				
Sum (Σ)	771.1	383.9	167.7	Sum(Σ)	344.3	300.4	278.6

Table 2-1 Approximate annual lake water budget (unit: 10^6m^3)

Source: LNROA, 1996

2.6.1-/ Inflow to the lake

Rainfall

Long term rainfall for the period 1966-1993 is calculated and presented in Figure 2-3. This rainfall data series are from meteorological station W.D.D (Water Development Department) with coordinates are x: 216173, y: 9918872. There are two rainy seasons, March/April/May and October/November. The rainfall varies from 432-961mm/year. Average rainfall is 669mm/year. The maximum monthly rainfall (117mm) appears in April. It contributes to 17% of total rainfall per annum. A second peak rainfall (57mm) occurs in November.

LNROA (1996) classified rainfall years with three conditions: wet, mean and dry. The corresponding representative annual rainfall is 939mm, 608mm and 442mm per annum. Direct rainfall on the lake surface contributes about 20% of the total lake water inputs in wet and mean condition, and about 26% in the dry condition.

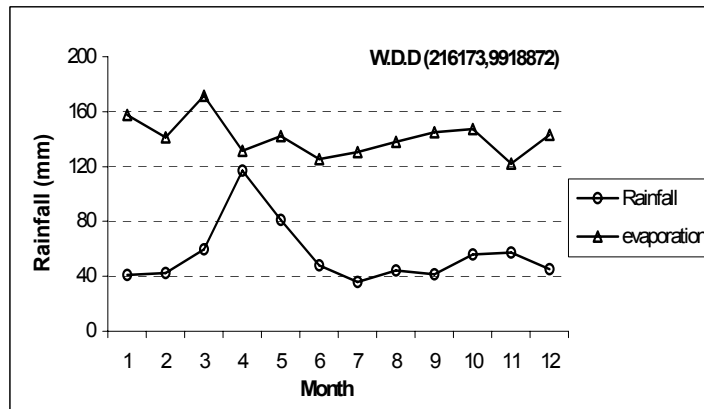


Figure 2-3 Rainfall and Evaporation in W.D.D station, Naivasha

River flows

The lake receives drainage water mainly from two perennial rivers Malewa and Gilgil that account for 90% of the river inflows to the lake. Their drainage areas are 1730 and 420 km² respectively. River Karati also contribute considerable amount of water. Several ephemeral streams flow into the lake in the southern part. Their contributions are insignificant.

Subsurface flow

Many studies since 1922 demonstrate Lake Naivasha catchment has an internal underground drainage system, draining in and out. Most of the water leaving the lake goes out between Olkaria and Longonot, whilst a small portion goes north between Eburru and Gilgil. The outflow from the lake has been traced up to 30 km south (Darling et al., 1990). The inflow was assumed equal to the outflow in the lake water budget (LNROA, 1996).

2.6.2- Outflow from the lake

Outflow from the lake includes Evaporation, Evapotranspiration and water abstraction. Evaporation was counted as 60% of total water losses (LNROA 1996), ranges from 128 mm in dry condition to 181 mm in wet condition.

The evapotranspiration and Lake evaporation rate given by LRONA (1996) are 2141 mm and 1529 mm respectively. Evapotranspiration from the swamps also calculated about 3-5 mm/day (Mekomnen 1999, Hussein Farah 1999). The water abstraction was estimated about 33 to 53*10⁶ m³ /year (Lake management plan 1995). Therefore Lake water balance has big vary, in wet and mean condition, inputs exceed outputs about 430*10⁶ and 85*10⁶ m³/year respectively. While during the dry condition, outputs exceed inputs about 100*10⁶ m³/year.

2.7- Present situation of using Agrochemical in riparian agricultural area

In the preceding sections it was foregoing mentioned that land use around Lake Naivasha where some 4500 ha (Ahmad 1999) which is under intensive cultivation of horticulture. High benefits are getting from Lake Resources and high inputs that are fertile soils with huge

amount of very fresh water as well as a lot of fertilizer and pesticide, insecticide, herbicide and fungicide etc. Regarding fertilizers, the Farmer applied most recommended amount of it to get best yield although it would be amended. While chemical, it was applied not only against insecticides, diseases and for other purposes but also for preventing whether it can threat to the crop or not, hence some time that applied chemical was unnecessary.

Both kind of chemical exist on and inside plants and in the soil. In the soil, it is taken by plant, evaporated into the air, decayed itself by solar radiation, absorbed into the soil, washed by surface runoff to the open water body and deep leaching to ground water by percolation. Schematic presentations for fertilizers and pesticide applications have been shown in appendix A-1.

CHAPTER III

EXPERIMENTAL RESULTS ANALYSIS

This chapter focused main point in rainfall analysis, rainfall - infiltration - runoff relations and chemical runoff, especially N and P due to runoff in scale of point measurement.

3.1 -/ Rainfall analysis

Rainfall is the most important factor for the development of soils (Smiles 1979, Tan 1994), plants (Tan 1994 and Hudson 1996) and environment. For soil erosion, this factor plays a very important role (Morgan 1982, Hudson 1996). Its effects are high rainfall volumes, these rainwater excesses water holding capacity of the soil, or rainfall intensity higher than infiltration rate. Both generate surface runoff, which is potential of transportation of soil materials, nutrients and organic matters.

Understanding rainfall and its distribution in Naivasha (mentioned in chapter 2), the measures for using its provision or avoiding the harmful is necessary.

Frequency distribution of rainfall is one of element show peak rainfall and runoff with certain return period. For the rainfall in Naivasha, frequency distribution was calculated using meteorological data in 37 year (1960 - 1997) and Rankplot program (Donker 1996) for the Naivasha DO. Results are shown in Table 3-1 and Figure 3-1.

Table 3-1: Annual rainfall and its return periods in Naivasha station

Return period	rainfall (mm)	Actual rainfall		Data source for 100 years return period
		Volume (mm)	year	
2	651.6			
5	783.4			
10	870.7			
20	954.5			
30	1002.6			
50	1062.9			
100	1144.0	1018.0	1961	Mai Van Trinh 1999
100	1080.0	1018.0	1961	Lars Erik Ase 1985
100	1156.0	1036.0	1937	Brind and Robertson 1958

According to N.H.W.Donker (personal communication) we could possibly analyze frequency for monthly and maximum rainfall. Results from running Rankplot brought forward a high rainfall volume in April (249 mm) and May (185.6 mm) compare to average value. Highest monthly rainfall was in April while maximum rainfall was in May (Figure 3-2). It is showed in Table 3-2

Irrigation

Most popular irrigation in this area is sprinkler in the open field for agriculture like vegetable, French beans, corn, potato and grass, drip irrigation for greenhouse. Water was extracted from ground water and the lake.

Table 3-2: Monthly and Maximum rainfall in April, May and November in different return period

Return period (year)	Monthly rainfall (mm)			Maximum rain fall (mm)		
	April	May	November	April	May	November
2	104.3	70.5	50.5	23	23.5	15.9
5	158.6	113.7	88.5	35.6	41.7	27.3
10	194.6	142.3	113.7	43.9	53.7	34.9
15	214.9	158.5	128	48.6	60.5	39.2
20	229.1	169.8	137.9	51.9	65.2	42.2
25	240.1	178.5	145.6	54.5	68.9	44.6
30	249	185.6	151.8	56.5	71.9	46.4
Mean	112.1	76.7	55.9			

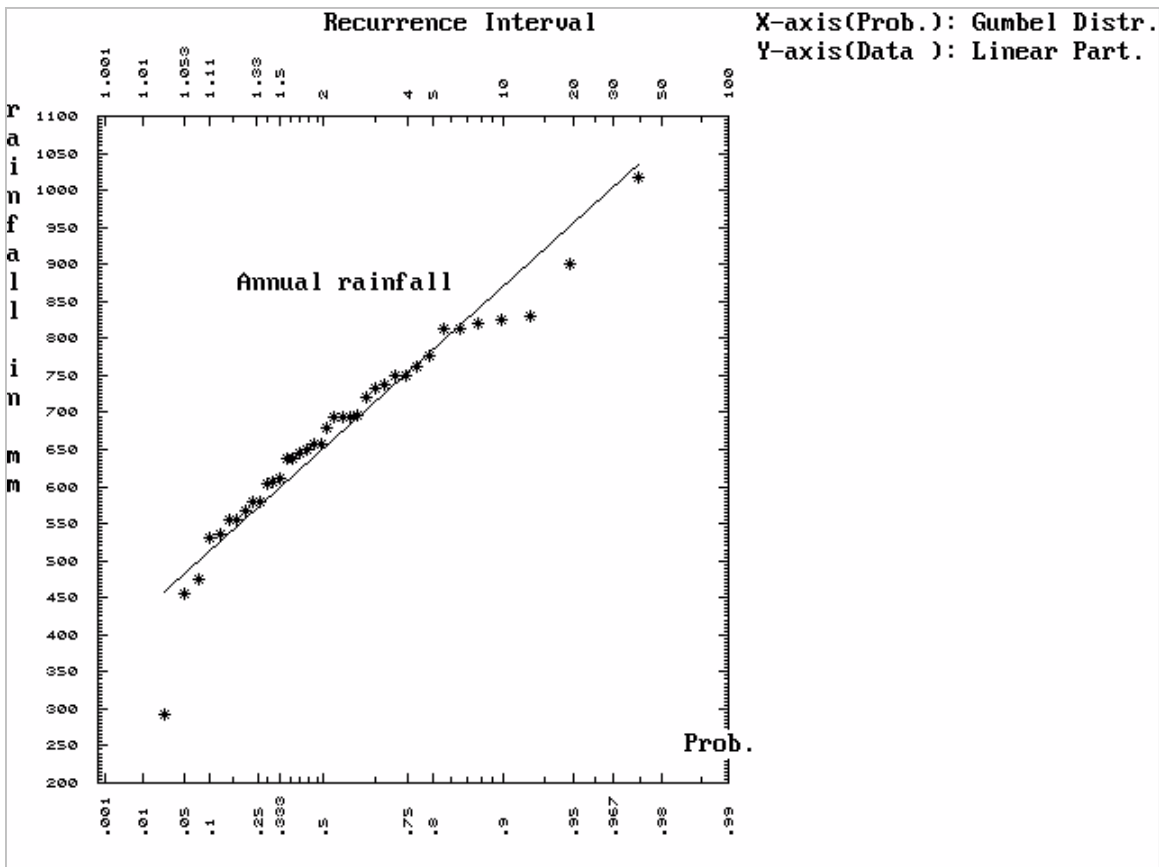


Figure 3-1: Probability and return period for annual rainfall in Naivasha

Figure 3-2: monthly and maximum rainfall Frequency in different return period

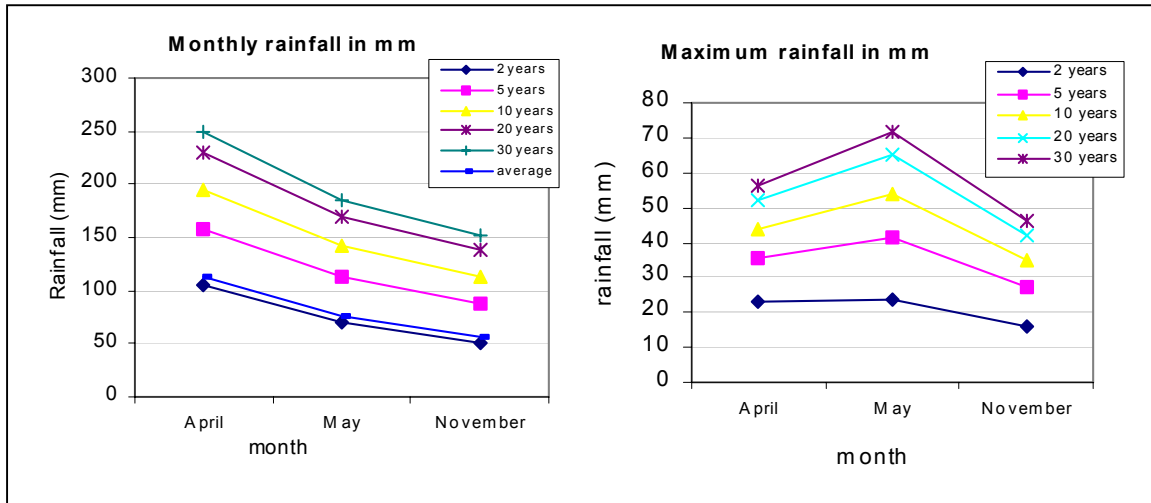


Figure 3-3: Sprinkler irrigation in the Cabbage and modern one in French beans open field in Naivasha

As mentioned in Chapter 1, in the loam soil with permeability $K = 0.7$ to 35.7 cm/day, irrigation is considered as excess infiltration (Appendix A-2). Normally the farmers do irrigate by sprinkler in three hours for every three or four day, even the next irrigation take place while subsoil (10 - 20 cm) still saturated or very wet (Jolicoeur, personal communication, 1999).

Discussion

The potential runoff in riparian of Lake Naivasha is classified as low because of low rainfall and rainfall intensity (Lars-Erik Ase, 1985, Hamududu, 1998). But statistical rainfall data had shown the rainfall distribution in April and May and probability of maximum rainfall in that month may be make up high peak runoff, especially in loam soil with very low permeability. In addition the excess irrigation may cause of surface runoff or makes subsoil always saturated, easily to generate overland flow.

3.2-/ Experiment descriptions

Experiments were carried out mainly in two farms, Aberdare farm in the East of the Lake Naivasha ($36^{\circ}26'07.85''\text{E}$, $0^{\circ}44'49.47''\text{S}$), representing agriculture, production is growing vegetable, corn, potato and beans etc in loam soil. Oserian farm in the South of Lake Naivasha ($36^{\circ}17'47.04''\text{E}$, $0^{\circ}49'13.69''\text{S}$), where represents for a sandy loam, productions are growing flowers, that are roses, carnation, statice etc.

The aims of the experiment is to find out effect of rainfall volume, intensity, soil condition such as soil moisture content, soil bulk density to potential runoff, soil loss and chemical losses (Nitrogen, Phosphorus) in sediment (eroded soil) and runoff waters.

Rainfall and Rainfall simulation

In regular experiments, very good equipment was set up for observing the rain occasion with a trap of sediment and runoff. Because of time consumption and experiments took place in dry season, hence two possibilities existed. The first was using Sprinkler irrigation system as empirical condition. This approach sounds very interesting because most open field was using sprinkler for irrigation and we can control irrigation time as well as rain duration to generate runoff, especially for large plot can be done possibly. Also some disadvantage and difficult were met, they are:

- Rainfall intensity was not uniform or it was difficult to measure rainfall intensity for whole plot, hence rain volume was not known
- Building up plots for measuring and collecting sample on the crop was impossible and not accurate without constructions
- The farmers and the irrigation technical were not willing to incorporate to do experiment on their field, for example in order to generate runoff, the time to irrigate should be lengthened more.

The second was rainfall simulation, this approach has some advantage

- Easy to set up experiment in every where
- Controllable rainfall volume and duration, plot area was known
- Easy to measure runoff and collect the samples

Some disadvantages were the small plot size; hence it doesn't represents for whole field, soil surface, slopes variation and land cover. Rainfall effects were higher because most runoff and sediment go straight to the outlet without deposition and low infiltration rate and short resident time. However, first approach had been tried but was not succeed, therefore the second method had been substituted perfectly by time consumption and measurement. Description of each experiment is shown in Table 3-3

Table 3-3: Experiment descriptions

crop type	Experiment	Point (Replicate)	Area (m ²)	Rainfall volume (ml)	Duration (minute)	Rainfall intensity (mm/hr)	Runoff volume (ml)	M soil ** Moisture (m ³ /m ³)
Loam soil								
French Beans	A1	1	0.0625	2000	10	192	1010	0.21
		2	1	24480	101	14.54	3500	0.22
		3	0.0625	2000	11	174.55	1120	0.24
Cabbage one week	A3	1	0.0625	2000	23	83.48	1330	0.276
		2	0.0625	2000	18	106.67	1190	0.261
		3	0.0625	2000	13	147.69	1060	0.279
Cabbage two weeks	A4	1	0.0625	2000	11.08	173.23	680	0.191
		2	0.0625	2000	9	213.33	750	0.165
		3	0.0625	2000	8	240.00	900	0.197
Cabbage one week	A5	1	0.0625	2000	9	213.33	820	0.215
		5	0.0625	2000	10	192.00	850	0.175
		6	0.0625	2000	10.15	189.16	865	0.173
	A5	2	0.0625	2000	13	147.69	1090	0.211
		3	0.0625	2000	13.58	141.35	1000	0.176
		4	0.0625	2000	12	160.00	750	0.159
	A6	1	0.0625	2000	8	240.00	1060	0.185
		2	0.0625	2000	9	213.33	1170	0.21
		4	0.0625	2000	11.13	172.46	980	0.21
	A6	3	0.0625	2000	12.43	154.42	760	0.178
		5	0.0625	2000	10.07	190.73	820	0.158
		6	0.0625	2000	14.28	134.42	820	0.152
Grass one week	A7	1	0.0625	2000	13.65	140.66	1210	0.244
		2	0.0625	2000	12.63	151.98	500	0.049
one week cabbage	A9	1	0.0625	2000	13.28	144.54	890	0.116
		2	0.0625	2000	10.00	192.00	1110	0.116
Sandy soil								
bare soil	O1	1	0.0625	2000	10	192.00	350	0.005
Carnation	O2	1	0.0625	2000	15	128.00	930	0.096
		2	0.0625	2000	13.25	144.91	1070	0.186
bare soil	O3	1	0.0625	2000	9.23	207.94	86	0.025
Statice	O4	1	0.0625	2000	10.33	185.81	400	0.049
		2	0.0625	2000	13.43	142.93	395	0.102
		3	0.0625	2000	13.31	144.18	670	0.075
Grass	O5	1	0.0625	2000	10.75	178.60	560	0.02

** Mineral Soil Moisture (m³/m³) before rainfall simulation

For rainfall simulation, rainfall volume was constant (32mm) for each watershed has area equal 0.0625 m².

3.3-/ Rainfall simulation analysis

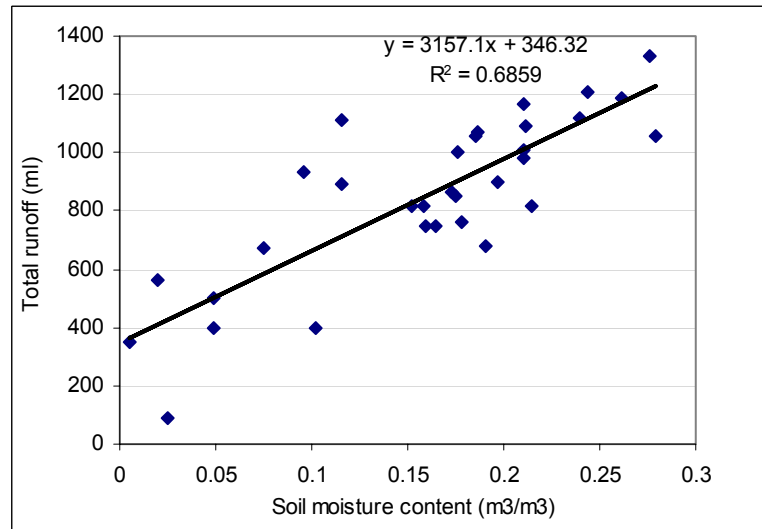


Figure 3-4: Correlation of initial soil moisture and total runoff

3.3.1-/ Rainfall - soil condition - runoff

Brind Robertson (1958), Lars-Erik Ase (1986) found runoff coefficient varied from 0.1 to 0.5, however, there is a big variation of Runoff coefficient c in different simulation. It depends on number of different factors such as soil type (from 0.043 to 0.53 for sandy soil and from 0.25 to 0.665 for Loam soil), rainfall duration, vegetation, slope and soil moisture content. As shown in Figure 3-4 total runoff and soil moisture content have a linear correlation with each other. But for the real effect, runoff was a function of rainfall duration, soil moisture content and soil permeability. The results are shown in the following equation:

$$RO = 3157.1 \cdot MS + 346.32$$

$$R^2 = 0.6859$$

$$RO = 14.7076 \cdot D + 2728.124 \cdot MS - 0.19758 \cdot Per + 262.7768$$

$$R^2 = 0.70689$$

Where:

RO = runoff volume (ml), (constant rainfall volume for every simulation, plot size=625 cm²)

MS = soil moisture content before rainfall simulation (m³/m³)

D = Rainfall Duration (minute)

Per = Permeability (cm/day) (Appendix A-2)

3.3.2-/ Rainfall - soil condition - sediment yield

Sediment in runoff results from detachment and transportation processes. The detachment process is function of rainfall intensity, soil detachability index and interception (Morgan 1982). Morgan (1982) specified transport capacity (T) that was a function of crop factor C,

overland flow Q and slope. The overland flow was mentioned above, in case of rainfall simulation we had crop and slope factor is nearly the same for every simulation. Correlation between soil condition to sediment concentration and sediment yield is lower compare to runoff may be due to the differentiation of soil surface from site to site like stoniness, aggregate fraction and root systems and so on. They are showed in Figure 3-5.

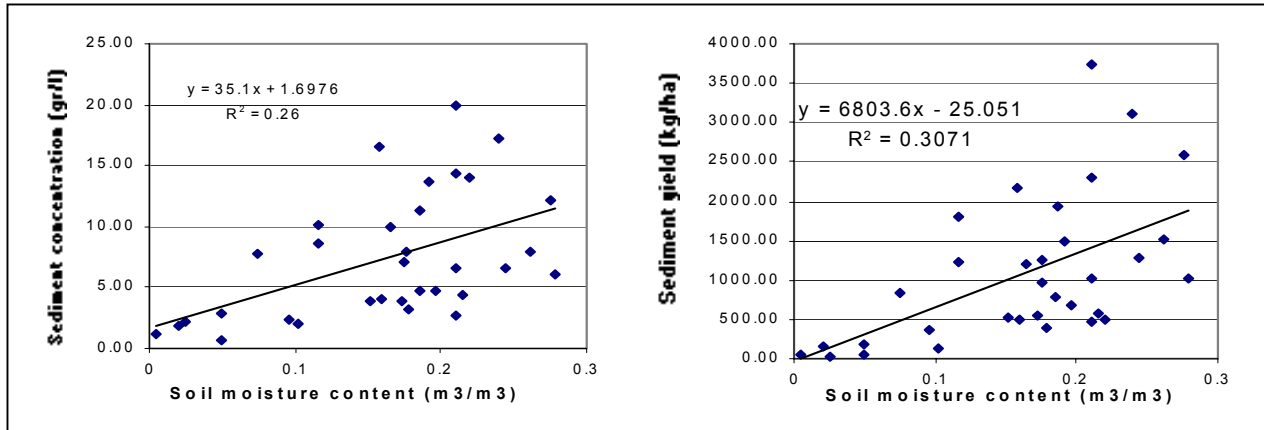


Figure 3-5: influence of initial soil moisture content to sediment concentration and soil loss

Multi-regression equation for sediment concentration and soil loss

$$\text{Sed} = 33.41019 \cdot \text{MS} + 0.001697 \cdot \text{Intensity} - 0.00145 \cdot \text{Per} + 1.855159$$

$$\text{R square} = 0.261162$$

$$\text{Soilloss} = 7999.393 \cdot \text{MS} + 3.94 \cdot \text{Intensity} + 0.4924 \cdot \text{Per} - 924.483$$

$$\text{R square} = 0.3405$$

(Sed. = sediment concentration (gram/l))

Table 3-4: Water erosion impact on loam and sandy loam

Soil type	Permeability (cm/day)	Initial Soil moisture content (m3/m3)	Runoff volume m3/ha	sed. Concentration (g/l)	Soil loss (Kg/ha)
loam	7.9 - 35.7	0.18	151.57	8.45	1268.03
sandy loam	357.7 - 397.4	0.07	89.22	3.95	461.87

Data in Table 3-4 illustrated much higher in runoff volume (1.69 times), sediment concentration (2.14 times) as well as soil loss (2.74 times) in loam than sandy loam. It also can be seen that permeability in loam much lowers than sandy loam (in average, 21.8 compare to 377.55 cm/day), hence rainfall rate higher infiltration rate and overland flow was generated quickly. In addition, average soil moisture content in loam soil higher than in sandy soil to cause soil surface saturated, even sealing effect, therefore runoff water was generated.

3.4- Chemical Runoff Analysis

This part is of major importance in the study, it is not only tests some hypothesizes but also gives quantitative information on potential chemical runoff, provided that those information for the coming chapter.

3.4.1- Experiment and simulation

All simulations have been done the same as mentioned in the fore going part. Because of laboratory costs, hence some experiments were selected for detailed laboratory chemical analysis. Hypothesis and methodology were described in Chapter one. Previously studies such as Sharpley (1981, 1983, 1985), Pote et al (1996, 1999) have done rainfall simulation experiences to find out the effects of soil P test to P content in runoff. To avoid variability of results they had to saturate soil surface for 48 hours prior simulation. In our case, the procedures was not applied, but however, we can see the effects of real surface soil to runoff, soil loss and chemical content in runoff water. Soil properties before rainfall simulation had been shown in Table 3-7.

Table 3-5: Experiment description before simulation

Experiment	Soil properties before simulation									
	Sand	silt	clay	C/N	CEC	pH	EC	OC	P-Olsen	%N
	%	%	%		Cmol/kg		µs/cm	%	.mg/kg	%
A1.1						7.7	573		112	0.16
A3.2						8	251		82	0.14
A4.2	48.5	35.0	16.5	9	31.6	8.1	385	1.43	126	0.17
A5.1						7.7	396		273	0.21
A6.4	41.7	41.1	17.2	5	24.9	7.6	1195	1.42	729	0.26
A7.2						6.8	248		28	0.36
A9.1						7.8	711		103	0.14
O1.1						6	185.7		103	0.12
O2.1	56.3	36.1	7.6	8	20.7	5.3	2950	2.32	353	0.28
O3.1						6.2	121		22	0.15
O4.2	68.8	25.0	6.2	9	13.9	7.3	421	1.17	110	0.13
O5						6.5	171.1		39	0.18

The P-Olsen method (available P extraction by NaHCO_3 , used for non-acid soils (Olsen and Sommers. 1982). Total-P, Bioavailable-P were not analyzed because of budget and TP has less effect to plant available nutrient and releasing of P into runoff (Personal communication with Dr. L.P. van Reeuwijk, ISRIC). One should pay attention is that P-Olsen in bare soil (exp. O3.1) much lower than the others, while P-Olsen in soil that applied grain fertilizer two day before (exp. A5, A6, A9) or applied by drip irrigation (exp. O2, O4) much higher than same normal cropping soil.

Table 3-6: soil condition before simulation

Experiment	Soil condition	Remarks
A1.1	French beans, flowering	Surface was moist
A3.2	2 weeks Cabbage	
A4.2	4 weeks cabbage	Consolidated surface, 8-10 % stone
A5.1,A6.4, A9.1	2 weeks Cabbage,	applied 100, 200 & 150 kg DAP 2 days before in 0-5 cm layer
A7.2, O3.1	Grass and bare soil	Soft surface with grass roots
O1.1	Carnation flower after harvesting	Soft and dried surface
O2.1	Flowering Statice	Drip fertilized every day
O4.2	Young Statice	Drip fertilized every two day

During rainfall simulation, runoff samples were collected and filtering fractionated into two part, sediment (was analyzed in the way like soil sample for P-Olsen and %N) and water (was analyzed in the way like water sample for SP and SN), (see Appendix A-4). Results of runoff samples analysis are shown in Table 3-7

Table 3-7: Chemical analysis results of Runoff samples

Experiment	Sediment P-Olsen (mg/kg)	Runoff water			Field measure	
		pH	EC (us/cm)	SP (mg/l)	PO ₄ (mg/l)	N (NO ₃ +NH ₄) mg/l
A1.1	70	7.8	420	1.35	4	6
A3.2	88	7.8	383	0.71	0.2	0.2
A4.2	118	8.1	398	1.57	1	0.2
A5.1	263	7.7	365	7.57	30	5
A6.4	310	7.6	393	13.4	47	16
A7.2	- *	7.9	417	1	6	2.6
A9.1	159	7.6	396	13.6	60	17
O1.1	-	8	287	0.54	4	1.5
O2.1	-	7.6	343	2.04	10	23
O3.1	-	7.3	281	0.15	1	4.1
O4.2(1)	-	8	320	1.03	6	3.4
O5	-	8.1	1792	1.07	16	71

- *: Sample was not enough for P -Olsen sensitive

- Samples was not enough for TN and SN sensitive in both sediment and water

Some remarks should be taken in to account from Table 3-7 are;

- Most runoff sample has pH higher than original soil, this was explained as dilution and removal of base elements in the soil to the runoff.
- There was a correlation between soil P-Olsen and P-Olsen in sediment and SP in water. It is shown in Figure 3-6 and Figure 3-7. In figure 3-7, the reddish data series showed SP in runoff from the field that had been fertilized two days before rainfall simulation took place much higher one from normal field. Scattering of SP from fertilized field could be explained by fertilization practices, because fertilizer was applied in dry condition. During two days, fertilizer grains was not be able to be desolved to soil solution or

adsorbed on soil particles, therefore rainfall on locally distribution made runoff water with unpredictable chemical content.

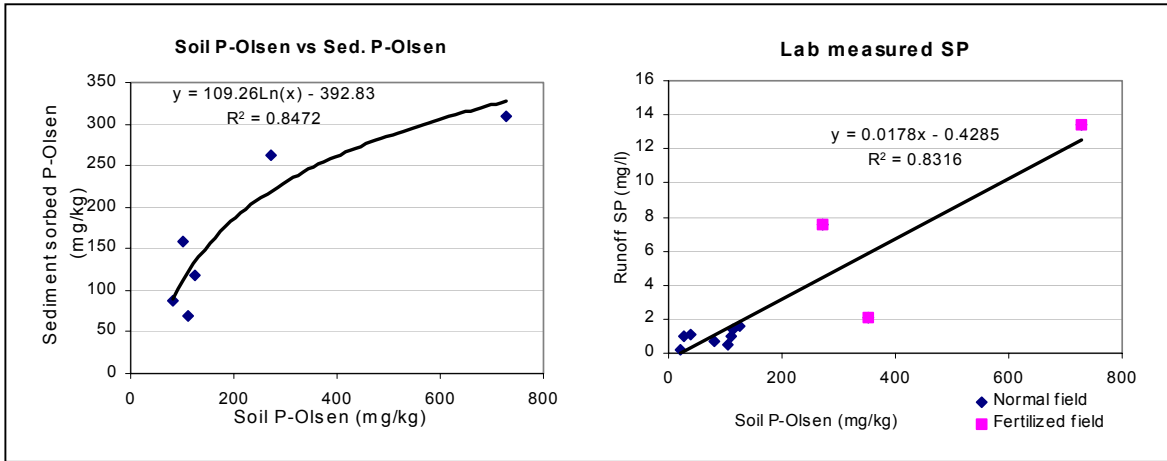


Figure 3-6: Sediment P-Olsen is logarithmic function of Soil P-Olsen

Figure 3-7: Linear correlation of Soil P-Olsen and Soluble P in runoff

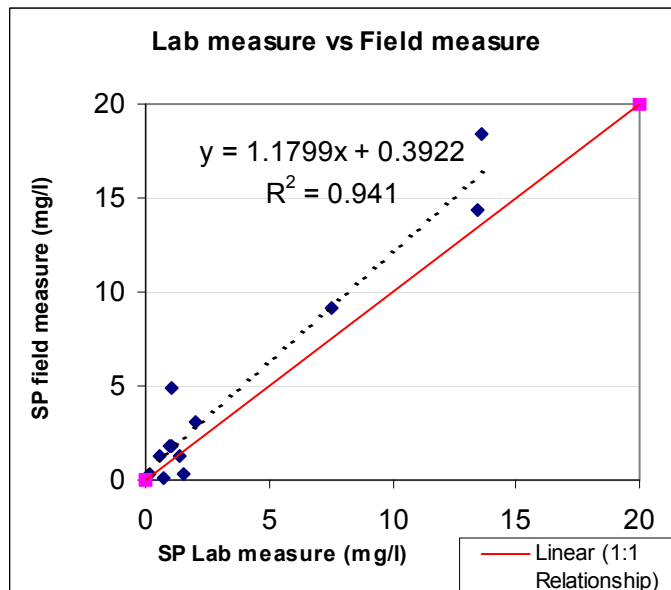


Figure 3-8: Comparison of Laboratory and field measurement SP

- SP in runoff water was also measured in the field by *Merck Rqflex reflexor* Lab. The result almost compatible with the laboratory analysis. It has a linear correlation to the one from the laboratory although the slope of correlation line (1.18) showed SP measured in the field is higher than in the Laboratory (slope=1). It may be due to reduction of SP because of sorption PO_4^- by soil particles, or may be due to a less accurate measurement in the field (Figure 3-8).

3.4.2- Enrichment ratio (ER)

ER is defined as the ratio of the nutrient content (such as N, P, K, OC, OM) of sediment (eroded soil) to that of source soil (Sharpley 1983, 1985). Lan (1980) found ER in generally between 2:1 - 5:1 for OC, TN, Bray-P and Exchangeable cations. Yet, Sharpley (1985) found in silt loam ER for water soluble + pH_{3.0} extractable P was 3.4, for 0.001M H₂SO₄ P was 3.35-1.79 and for Bray-I was 1.82-2.03. He had shown relationship between ER and soil loss as logarithmic function for BioP, BP, TP, OP, TN as follow

$$\begin{aligned} \text{Ln(ER)} &= 1.21 - 0.16 \ln(\text{soil loss - kg/ha}) \\ \text{Ln(ER)} &= 2.48 - 0.35 \ln(\text{soil loss - kg/ha}) \text{ for labile P and K} \\ \text{Ln(ER)} &= 1.63 - 0.25 \ln(\text{soil loss - kg/ha}) \text{ for OC} \end{aligned}$$

While Gachene (1986) stated that ER(available P) in some Kenyan soils was 1.1-2.08, mean equal 1.41, particular for samples from Longonot was 1.48.

In our samples unfortunately, number of samples was small because some sediment samples sizes were not enough for N and P sensitive analysis, hence it was not significant to conclude the figure. However, from the measured samples the ER was found to range from 0.63 to 1.54, ER for P-Olsen was found to be 1.1 on average, also for unanalyzed samples.

3.4.3- Nutrient losses (N and P)

A consequence of excess rainfall is soil erosion, which is a combination of runoff, soil loss, nutrient losses (N, P, K, Ca, Mg etc). Runoff and soil loss results in high peak flood, land degradation and Lake Pollution, channels fulfill. Nutrient loss result in not only decreases of soil fertilities, crop productions but also increasing content of pollutants in water courses and accelerating the eutrophication process of surface waters. Soileau et al (1994) has done experiments in 1988 in Alabama and stated that dissolved and particulate P concentration increased from 0.6 to 7.9 mg/l and from 180 to 1387 mg/kg in runoff before and after fertilization. The summarized of nutrient losses due to excess rainfall is shown in Table 3-8

Table 3-8: Nutrient losses in different field condition of simulation event in kg/ha

	P loss In Sediment	P loss In Runoff	Total P loss	N loss In Runoff	N loss in Sediment	Total N loss
Uncultivated (bare + grass)	0.0013	0.0410	0.04	0.132	0.1447	0.277
Normal crop	0.1105	0.1430	0.25	0.279	2.1746	2.453
Crop with prior fertilization	0.2216	1.6776	1.90	1.862	2.0526	3.914
Flower with irrigated fertilization.	0.0815	0.1847	0.27	1.820	0.6891	2.509
fallow after long term cropping	0.0072	0.0959	0.10	6.362	0.3335	6.695

In all field conditions, P loss in runoff was much higher than in sediment (1.2 - 31.5 times). For the N loss was different, In loam soil, N loss in runoff higher than in sediment (average of 2.19 times), but inversely in sandy loam (average of 0.182). In both sediment and runoff total loss of N (2.28 - 6.69 kg/ha) higher than total loss of P (0.14 - 2.17 kg/ha). Especially the losses of N and P in prior fertilization field whether by broadcasting on the surface, furrow or dripping higher than in normal field and bare soil and uncultivated soil. One remark should be taken into account was N loss much higher than P loss, this can be explained by the way the farmers apply fertilizers. In food and vegetable crops most N: P ratio applied was 2:1, while in flower farms this ratio much higher even though no P fertilizers was applied in some crops (see appendix A-1).

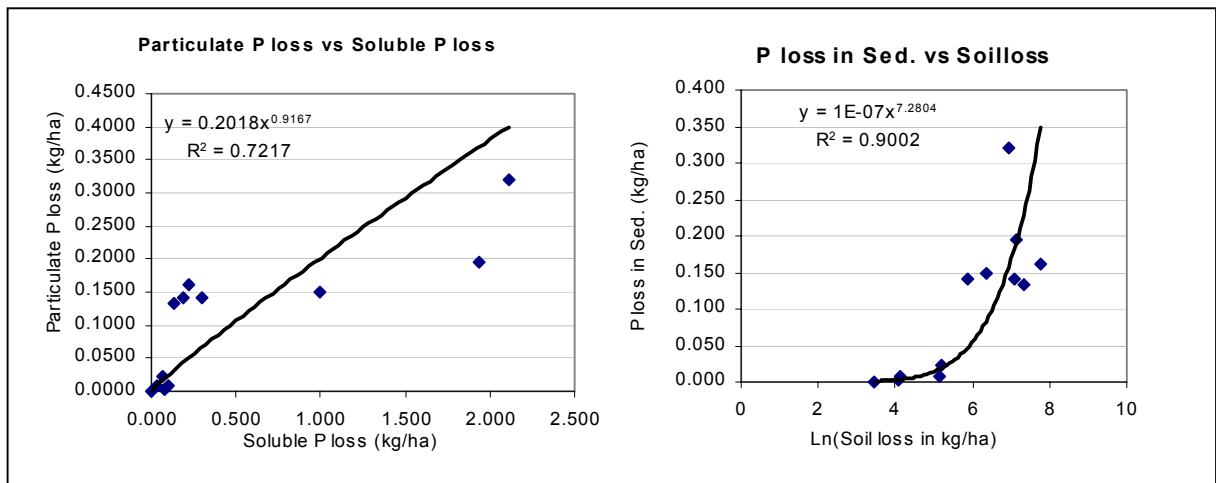
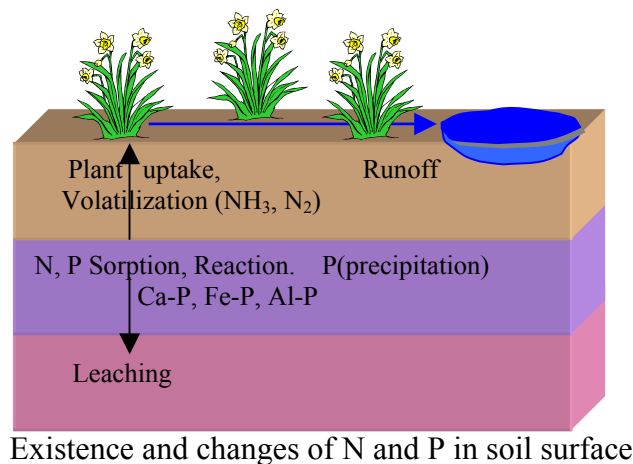


Figure 3-9: Relation ship of Soluble P loss and Particulate P loss

Figure 3-10: Relationship of Particulate P loss and Natural logarithmic of soil loss

3.4.4- Nutrient Extraction out of the medium



The dynamics of N and P in soil surface had been shown above. Nitrogen and Phosphorus exist inside the soil structure, sorbed on the soil particles, diluted in the soil colloids, taken up by plants, reacts with other substances or changes its form. When rain occurs, it is brought downward to the lower horizon by infiltration and percolation processes, the amount of N and P downward depend on sorption of the soil, the cation retaining of soil was shown by Cation Exchange Capacity (CEC) (Denis Baize, 1988). N and P sorption increase with CEC and clay content, in sandy soil (CEC<24 cmol/kg), sorption nearly zeros (Reeuwijk 1993, and personal communication). When rainfall intensity exceeds infiltration rate, N and P was taken away by runoff and sediment in soluble and particulate forms. The fraction of SN and SP depended on content of SN and SP in soil surface, the amount of the particulate forms was a function of soil N, soil P, soil aggregate, OC, rainfall intensity, crop and slope and so on.

Solieau et al (1994) compared N and P loss between two cultivation systems that are conventional tillage and conservation tillage during 1984-1989 and he found out;

Nutrient loss	Conventional tillage	Conservation tillage
Runoff (%)	15	21
Sediment loss (kg/ha)	2979	1311
NH ₄ -N (kg/ha)	0.87	1.18
NO ₃ -N (kg/ha)	3.03	4.40
TN (kg/ha)	4.95	6.39
SP (kg/ha)	0.75	2.62
PP (kg/ha)	0.24	0.3
TP loss (kg/ha/1 cm rainfall)	0.008	0.023

Lal (1980) measured losses of plant nutrients in runoff and eroded soil in different crops. Average Nutrient concentration in water runoff for different crop, fertilized 120 kg N, 13 kg P and 30 kg K were; 8.38 ppm for NO₃-N and 0.92 ppm for PO₄-P respectively.

	NO ₃ -N + NH ₄ -N	P
Leaching losses (kg/ha)	17.46	1.15
Losses in water runoff (kg/ha) N	9.6	2.9
Losses in eroded soil (kg/ha)	3.4	13.1

From the above figure, if we take 5 cm of soil depth, assuming soil N = 0.1%, soil P = 18 mg/kg, bulk density = 1 kg/dm³, the ratios of nutrient losses will be

$$\begin{aligned} \text{N in runoff / N soil} &= 0.026 \\ \text{N leached / N soil} &= 0.035 \\ \text{P in runoff / P soil} &= 0.18 \\ \text{P leached / P soil} &= 0.12. \end{aligned}$$

Burwell et al (1977) studied N and P movement from agricultural watersheds during 1969 - 1974 with annual precipitation was 33 inches

One can see that N losses fraction in order of in Sediment > leaching > surface runoff, but inversely for P losses, P loss in Sediment > in surface runoff > leaching.

Average annual N and P movement in corn watershed (lb/arce)

Movement Pathway	N						P					
	Applied N 155 lb/a		Applied N 400 lb/a		Applied N 306 lb/a		Applied 36 lb/a		Applied N 59 lb/a		Applied N 60 lb/a	
	Lb/a	%	Lb/a	%	Lb/a	%	Lb/a	%	Lb/a	%	Lb/a	%
Sediment	17.8	71.2	24.5	54.7	6.9	17.3	0.4	74.1	0.7	80.0	0.2	40.9
Surface runoff	0.9	3.6	1.7	3.8	1.4	3.5	0.1	20.4	0.1	15.3	0.1	20.5
Subsurface flow	6.3	25.2	18.6	41.5	31.7	79.4	0.0	5.6	0.0	4.7	0.2	38.6
Total loss	25.0	1.0	44.8	1.0	39.9	1.0	0.5	1.0	0.9	1.0	0.4	1.0

Fraction of N, P losses into runoff and leaching were very rarely documented in the world because of very difficult to measure, It was computed base on a thin layer of soil (EDI). According to calculation in the following part, average EDI = 0.8 cm, therefore we can consider the depth as one cm on the top.

$$\text{Soil mass(kg)} = \text{depth(dm)} * \text{Area(dm}^2) * \text{Bulk Density(kg/dm}^3)$$

$$\text{Soil N (P)} = \text{soil mass} * \text{soil N (P) content} \quad [\text{mg}]$$

$$\text{N (P) loss fraction in runoff} = \frac{\text{RunoffN(P)loss}}{\text{SoilN(P)}} \quad [\text{w/w}]$$

$$\text{N (P) loss fract. in leaching} = \frac{\text{N(P)soil_beforerrain} - \text{N(P)soil_afterrain} - \text{RunoffN(P)}}{\text{SoilN(P)}} \quad [\text{w/w}]$$

Table 3-9: Fraction of N, P losses into runoff and leaching

Experiment	P	N	P	N
	Runoff/soil ratio	Runoff/Soil ratio	Leached/soil Ratio	Leached/soil Ratio
A4.2 (normal field)	0.023	0.001	0.008	0.061
A6.4 (fertilized)	0.030	0.010	0.490	0.520
O2.1 (fertilized)	0.011	0.012	0.460	0.261
O4.2 (fertilized)	0.007	0.003	0.029	0.297
Loam	0.051	0.006	0.249	0.290
Sand loam	0.008	0.010	0.245	0.279

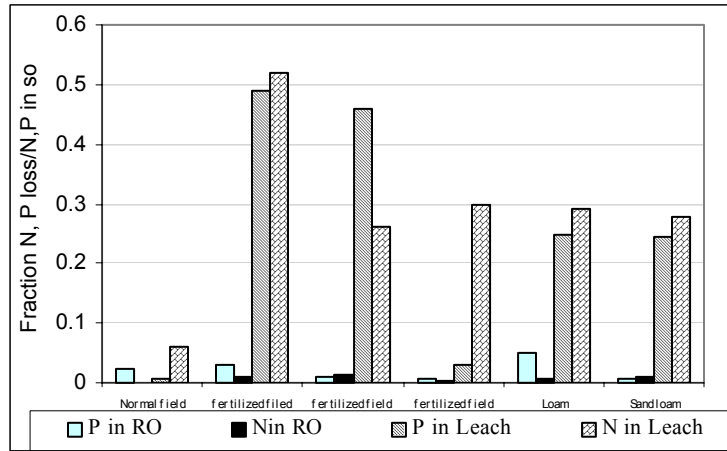


Figure 3-11: Fraction of N, P loss in Runoff and leaching to soil N, P

3.4.5- Prediction of Soluble P in runoff

The propose was to predict SP in runoff by measuring rainfall (volume, duration), soil (available P, soil particle size, bulk density), runoff volume etc. The formulae for this calculation was based on Equation 1.3 (Chapter 1)

- Constant K, α and β was calculated for different soil type. Sharpley (1983) had found out the constants for two soil groups

Table 3-10: Constant K, α and β for acidic and basic calcareous soil

Constant	Acidic soils		Basic calcareous soils	
	Mean	Range	Mean	Range
K_L (Labile P)	0.142	0.021-0.302	0.109	0.033-0.243
K_B (Bray -P)	0.095	0.016-0.262	0.067	0.025-0.106
α	0.177	0.045-0.319	0.146	0.060-0.301
β	0.520	0.204-0.850	0.574	0.329-0.827

Also Sharpley (1983) found out relationship between K, α and β with ratio of percent clay/ organic carbon (OC)

$$K_L = 1.422 * (\% \text{ clay} / \% \text{ OC})^{-0.829} \quad \alpha = 0.815 * (\% \text{ clay} / \% \text{ OC})^{-0.540}$$

$$K_B = 0.630 * (\% \text{ clay} / \% \text{ OC})^{-0.698} \quad \beta = 0.141 * (\% \text{ clay} / \% \text{ OC})^{0.429}$$

Sharpley (1985) gave more detailed calculation for those constants for each soil type

Table 3-11: Constant K, α and β for different soil textures

Soil texture	K	α	β
Loam	0.029	0.094	0.794
Clay	0.071	0.151	0.541
Silt loam	0.061	0.319	0.24
Clay loam	0.075	0.105	0.702
Fine sandy loam	0.035	0.195	0.304

- P_a was initial available P content in soil surface (showed in Table 3-5) in mg/kg

- Effective depth of interaction between surface soil and runoff (E) was determined for different soil texture. Sharley (1985) found relationship between E and soil loss as follow:

Table 3-12: Effective depth of interaction is function of soil loss

Soil texture	Relationship Equation
Loam	$\text{Ln}(E) = -1.676 + 0.594 * \ln(\text{soil loss}^{**})$
Clay	$\text{Ln}(E) = -2.457 + 0.594 * \ln(\text{soil loss})$
Silt loam	$\text{Ln}(E) = -1.307 + 0.542 * \ln(\text{soil loss})$
Clay loam	$\text{Ln}(E) = -2.039 + 0.554 * \ln(\text{soil loss})$
Fine sandy loam	$\text{Ln}(E) = -1.780 + 0.594 * \ln(\text{soil loss})$

** : E in millimeter, Soil loss in kg/ha,

Soil texture sample took for four samples in depth of 0 - 5 cm. In fact E presents in 1-2 cm on top layer only, hence there was some field assessment for soil texture in the thin surface layer to have very good fit. Sub-assessment for soil texture such as soil consolidate, soil compaction, fraction of stone grain or plant root on the surface, all of them have more or less effect to detachment process (some was illustrated in Table 3-6).

- B was soil bulk density in surface soil kg/dm³ (field measure by ring method)
- T was rainfall duration in minute (showed in Table 3-3)
- W was calculated by S/Runoff volume
- S was mass of soil per area in the zone of interaction between soil and water,

$$S = E * \text{plot area} * B \quad [g]$$
- V was total amount of rainfall (32 mm for every simulation)

Plotting of calculated against measured soluble P in runoff is showed in Figure 3-12. The calculation of every parameter had been shown in (appendix A-3)

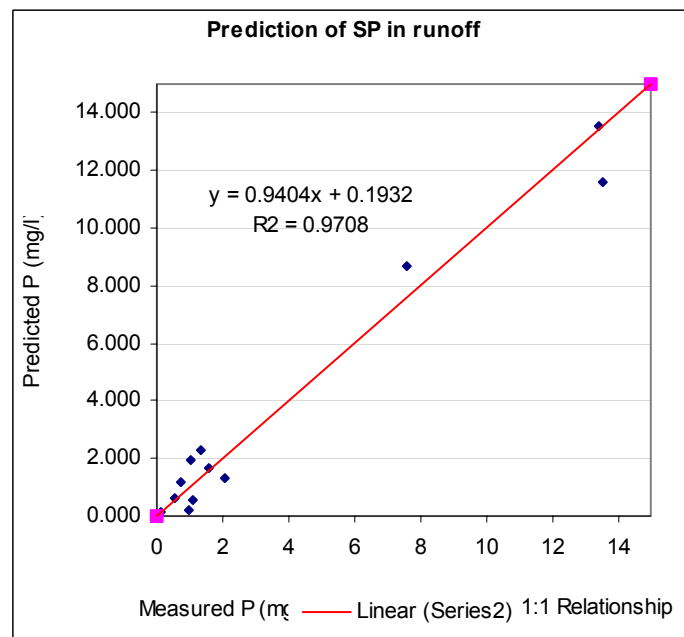


Figure 3-12: Predicted and measured SP

CHAPTER IV

MODEL IMPLEMENTATION

This chapter supposed to implement the modeling to simulate potential chemical runoff in scale of watershed.

4.1-/ AGNPS (Agriculture Non-point Pollution Source)

4.1.1. Description of AGNPS

The agricultural Non-Point Source Pollution Model (AGNPS) presents the means of objectively evaluating non-point-source pollution from agricultural watersheds.

The model had been applied widely throughout of integrated GIS to extract topographic variables to calculate and predict soil erosion (Panuska 1991, Ferrer 1993, Munasinghe 1998, Konanteng 1998 and Abdulrahim 1999). Very few applications for calculating nutrient lost, (Rode 1998, Rode and Frede 1997) because of requirement of detailed soil information and laboratory data.

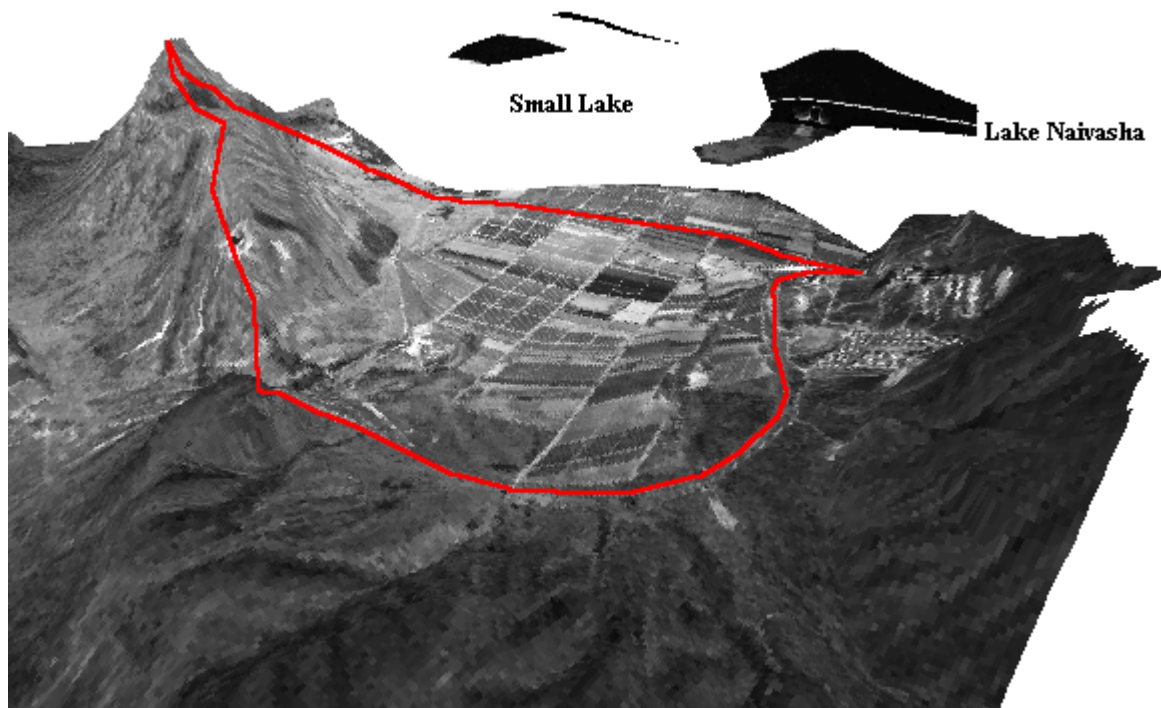


Figure 4-1: Watershed selection for AGNPS (main Oserian farm, Aerial photo_3D 1991)

The model works on a cell basis. These cells are uniform square areas that divide up the watershed. This division makes it possible to analyze any area in the watershed. The basic components of the model are hydrology; erosion; sediment transport; and transport of nitrogen, phosphorus, and chemical oxygen demand. In the hydrology portion of the model, calculations are made for runoff volume and peak concentrated flow. Total upland erosion, total channel erosion and a breakdown of these two sources into five particles size classes (clay, silt, small aggregate, large aggregate and sand) for each of the cells is calculated in the erosion portion. Sediment transport also calculated for each of the cell in the five particle classes as well as the total. The pollutant transport portion is subdivided into one part handling sediment-attached pollutants.

Total detached sediment and the breakdown into the particle-size classes are made on a per cell basic. A modified USLE is used to predict upland erosion for single storm events (Wischmeier and Smith 1978)

$$E = EI * K_s * L_f * S_f * C_f * P_f * SSF \quad [\text{tons/acre}] \quad (4.1)$$

- Where:-
- E= soil loss in tons/acre
 - EI= rainfall energy intensity in hundred foot-ton inch/acre hour
 - K_s= soil erodibility factor in ton-acre hour/hundred- acre foot-ton inches
 - L_f= Slope length factor
 - S_f= Slope steepness factor
 - C_f= Cover and management factor
 - P_f= Support practice factor and
 - SSF= a calculated factor to adjust for slope shape

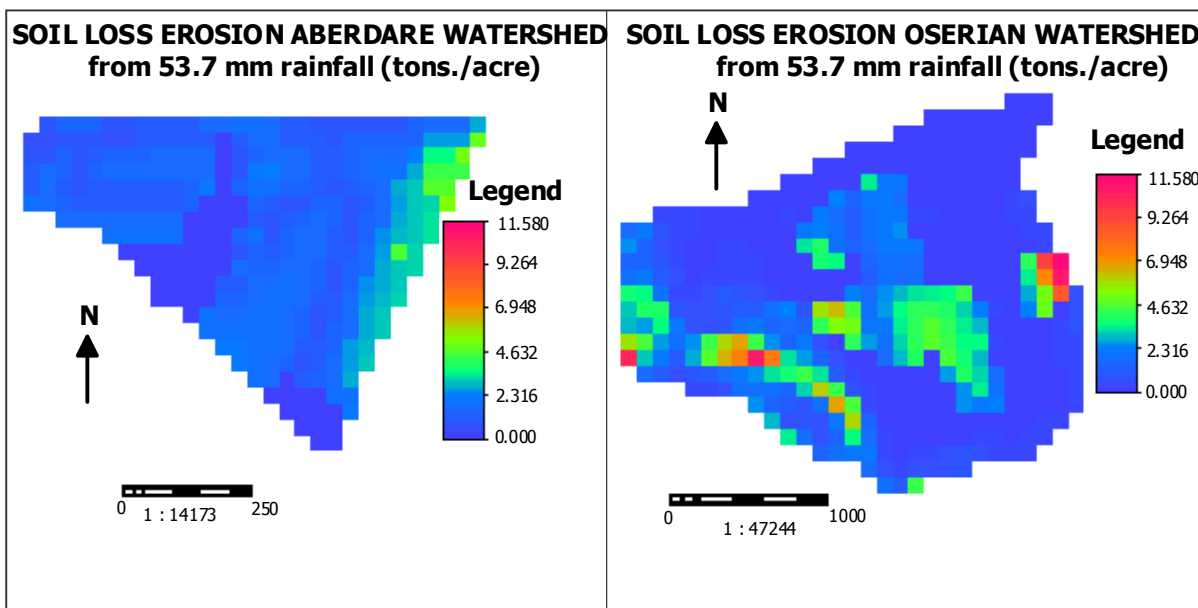


Figure 4-2: Sediment loss from 53.7 mm rainfall in loam soil, Aberdare watershed.

Figure 4-3: Sediment loss from 53.7 mm rainfall in sandy loam soil, Oserian watershed

The runoff volume from each cell is determined using the U.S. Department of Agriculture, soil conservation service (1972) curve number method. The equation is

$$RF = \frac{(RL - 0.2 * S)^2}{RL + 0.8 * S} \quad [\text{inches}] \quad (4.2)$$

Where:- RF = runoff in inches

- RL = Storm precipitation in inches, and

- S = Retention factor in inches, $S = \frac{1000}{CN} - 10$, CN is the curve number.

The basic equation to predict the soluble N and P concentration Frere et al 1980 (in CREAMS) in the runoff is

$$RO^* = \bar{C} * EXK^2 * RO * 0.01 \quad [\text{ppm}] \quad (4.3)$$

RO^{*} = N or P concentration in the runoff

\bar{C} = mean concentration of the soluble portion of the nutrient in the soil surface during runoff

EXK^{*} = an extraction coefficient for movement into the runoff

RO = total runoff in millimeters.

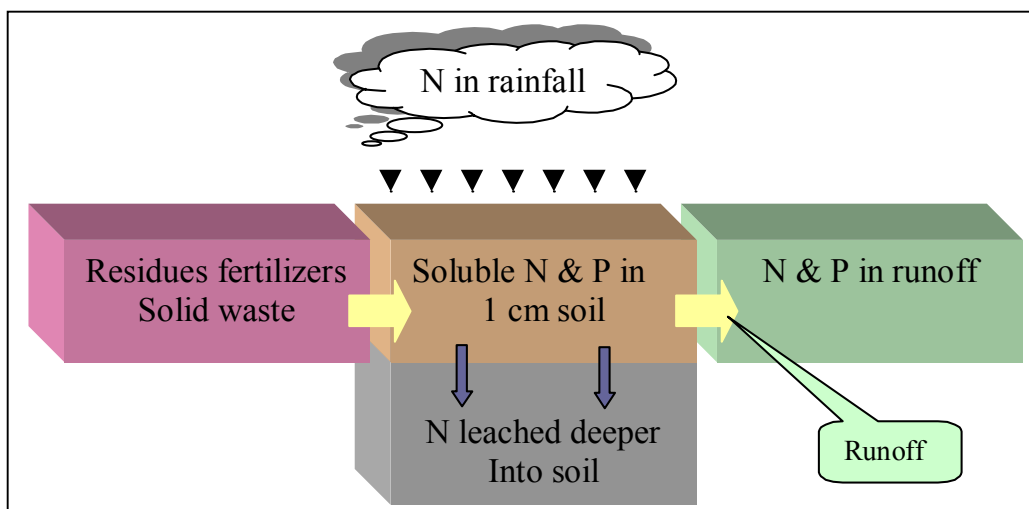


Figure 4-4: Diagram for estimating nutrient losses in runoff.

Soluble N concentration is predicted by the following equation

$$RON = \frac{0.892 * (CZERON - CHECKN) * (e^{(-XKFN1 * EFI)} - e^{(-XKFN1 * EFI - XKFN2 * RO)})}{COEFF + \frac{RN * RO}{EFRAIN}} \quad [\text{lbs/acre}] \quad (4.4)$$

Where:

- RON	Soluble N in the runoff in pounds/acre
- CZERON	Available soluble N content in the soil in kg/ha
- CHECKN	Available N due to the rainfall in kg/ha
- XKFN1	a rate constant for downward movement of N into the soil
- EFI	Total infiltration for the storm in mm
- XKFN2	A rate constant for N movement in the runoff
- RO	Total storms runoff in mm
- COEFF	A porosity factor
- RN	N contribution due to the rain in kg/ha
- EFRAIN	Effective rainfall in mm

The equation to predict soluble P in the runoff is

$$ROP = \frac{0.892 * (CZEROP - CHECKP) * (e^{(-XKFP1*EFI)} - e^{(-XKFP1*EFI - XKFP2*RO)})}{COEFF + \frac{CHECKP * XKFP2 * RO}{COEFF}} \quad [\text{lbs./acre}] \quad (4.5)$$

Where:

- ROP	= Soluble P in the runoff in lbs./acre
- CZEROP	= Available P due to natural and fertilizer nutrient level in kg/ha
- CHECKP	= available P due to the initial soil in kg/ha
- XKFP1	= A rate constant for downward movement of P into the soil
- XKFP2	= The rate constant for movement into runoff

In this case effects of rainfall are omitted. Since very little soluble P is found in rainfall, its net contribution to the runoff is negligible.

The available N in the soil is calculated by accounting for organic matter N, fertilizer N and soil porosity

$$CZERON = (SOLN + FN(X) * FA(X)) * COEFF \quad [\text{kg/ha}] \quad (4.6)$$

The available soluble P in the soil is calculated as

$$CZEROP = (SOLP + FP(X) * FA(X)) * COEFF \quad [\text{kg/ha}] \quad (4.7)$$

Where:

SOLN (SOLP)	Soluble N and P in the top centimeter of the original soil in kg/ha
FN(X)	N fertilizer application in cell X, kg/ha
FP(X)	P fertilizer application in cell X in kg/ha
FA(X)	Fraction of this application remaining in the top centimeter of the soil

The initial soluble N in the top centimeter of the original soil is estimated

$$SOLN = 0.10 * CSN * POR \quad (4.8a)$$

$$\text{SOLP} = 0.10 * \text{CSP} * \text{POR} \quad (4.8b)$$

Where: CSN Concentration of N in the pore water of the surface centimeter of soil in ppm
 CSP = concentration of P in the pore water of the surface centimeter of soil in ppm.

$$\text{Soil porosity is determined by } \text{POR} = 1 - \frac{\text{Bulkdensity}}{2.65} \text{ (Frere et al 1980)}$$

The porosity factor COEFF is solved by using the porosity as $\text{COEFF} = 0.00001/\text{POR}$
 The available N due to the rainfall is solved by using the relation

$$\text{CHECKN} = \text{RCN} * 10^{-6} \quad [\text{mg/l}] \quad (4.9)$$

Where RCN N concentration in the rainfall (0.8 mg/l)

The available P due to initial soil is solved as

$$\text{CHECKP} = \text{SOLP} * \text{COEFF} \quad [\text{kg/ha}] \quad (4.10)$$

The equations for the rate constant for downward movement of soluble N and P are

$$\text{XKFN1} = \frac{\text{EXKN1}}{10 * \text{POR}} \quad [-] \quad (4.11)$$

$$\text{XKFP1} = \frac{\text{EXKP1}}{10 * \text{POR}} \quad [-] \quad (4.12)$$

Where: EXKN1, EXKP1 Extraction coefficient for N, P downward movement

The effective infiltration is defined as $\text{EFI} = \text{EFRAIN} = \text{RO}$ [mm]

Where: RO Total storm runoff in mm

Effective rainfall $\text{EFRAIN} = \text{R} - (10 * \text{POR})$ [mm]

Where: R = storm rainfall in mm

The rate constants for movement of soluble N and P into the runoff are

$$\text{XKFN2} = \frac{\text{EXKN2}}{10 * \text{POR}} \quad [-] \quad (4.13a)$$

$$XKFP2 = \frac{EXKP2}{10 * POR} \quad [-] \quad (4.13b)$$

Where: EXKN2 = extraction coefficient for movement in to runoff
EXKP2 = extraction coefficient for movement into runoff

The N contribution due to the rain is calculated as

$$RN = RCN * R * 0.01 \quad (4.14)$$

The method used for sediment routing involves equation for sediment transport and deposition described by Foster et al. (1981) and Lane (1982). The equation is derived from the steady state continuity equation.

$$Qs(x) = Qs(0) + Qs1 \frac{\Delta x}{Lr} - \int_0^x D(x) * W * dx \quad [lbs./s] \quad (4.15)$$

Where: Qs(x) = Sediment discharge at the downstream end of the channel reach in lbs./s
Qs(0) = Sediment discharge at the upstream end of the channel reach in lbs./s
Qs1 = Lateral sediment inflow rate in lbs./s
X = Downslope distance in feet
Lr = Reach length in feet
D(x) = Sediment deposition rate at point x in lbs/s-ft²
W = channel width in feet

The equation used to determine the peak flow rate was developed by Smith and Williams (1980) for use in SCREAMS

$$Qp = 8.84 * A^{0.7} * Sc^{0.159} * RF^{(0.824 * A^{0.0166})} * \left(\frac{Lc^2}{A * 43560} \right)^{-0.187} \quad [ft^3/s] \quad (4.16)$$

Where:

Qp = Peak discharge in ft³/s
A = Drainage area in acres
Sc = channel slope in ft/ft
RF = runoff volume in inches
Lc = channel length in feet.

AGNPS was also used to compute point source pollution, feedlots, addition erosion and impoundment for certain cell by calculating transport of chemical and organic matter from point to outlet and from cell to cell. In case of our selected watershed, those factors will be subjected.

4.1.2- Application of GIS (Ilwis 2.2 software) for AGNPS

Extracting topographic and variables for running AGNPS (Agriculture Non-point Source Pollution) model is based on Aerial photo interpretation, contour map and drainage map.

Dividing the watershed into equal area cells using aggregate group operation in Ilwis creates the watershed's layout. The slope, slope shape and flow direction in each cell were calculated from contour map with contour interpretation, calculate Dx, Dy, min, max and group aggregate. The channel length, indicator and gradient, and slope length were also calculated from river and contour map with cross operations like cross, min, max, distance and table calculation and so on. The operations are shown in Figure 4-5

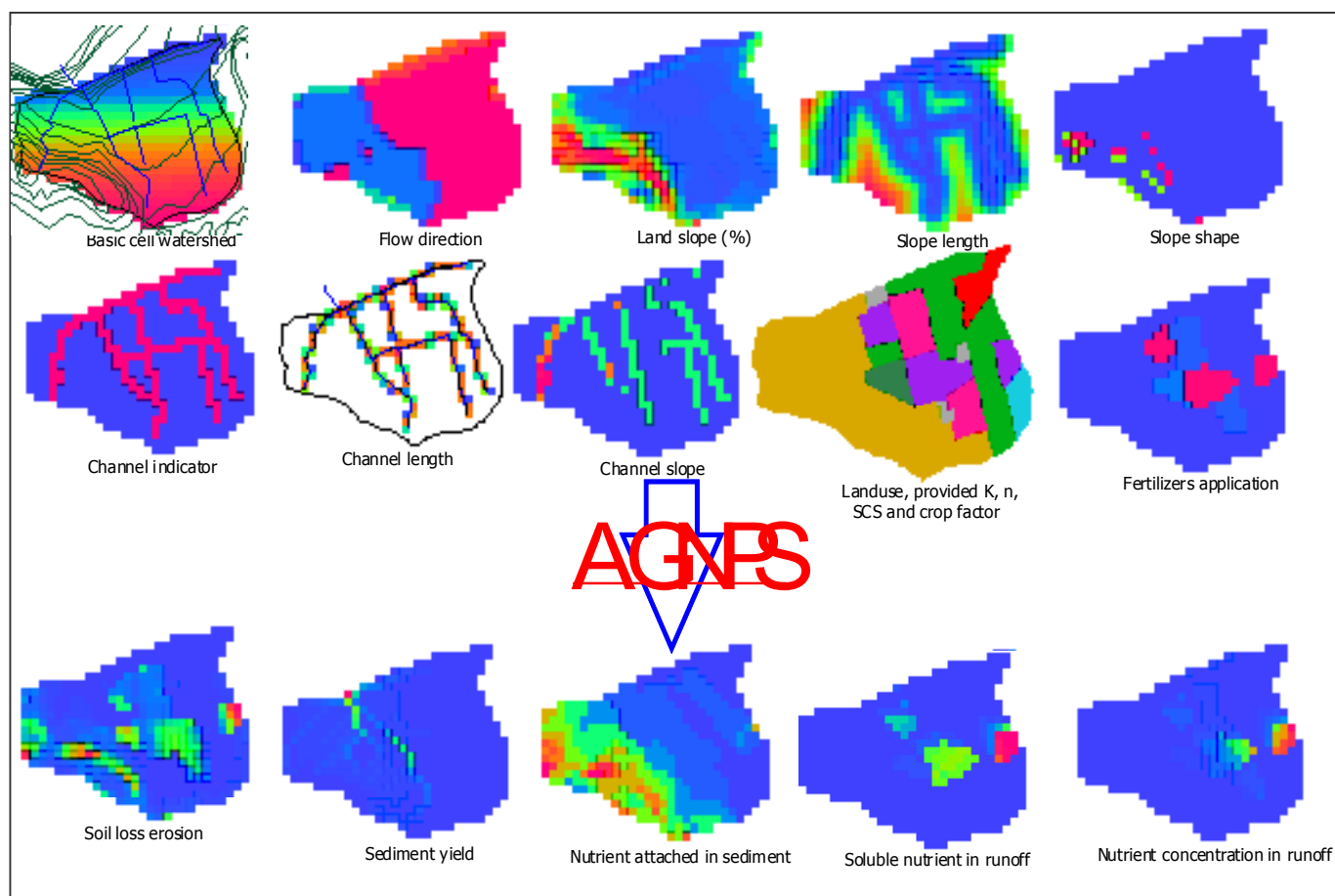


Figure 4-5: AGNPS output maps from AGNPS calculation and GIS output map

The other input factors like K factor, C factor, P factor were calculated by using RUSLE software (Foster et al 1992); and SCS curve number, overland Manning's, Surface condition constant, Chemical Oxygen Demand (COD) are calculated for each land use unit and soil type. By crossing land use and watershed in cell maps, while the cross table was generated, we were able to calculate those factors for each cell by weighted average area method (they are shown in Table 4-1).

4.2-/ Model calibration

Calibration the input parameter is necessary for every model. It reflects how good the model could simulate, through which how the model could be implemented. In the study, the model-input parameters were adjusted by comparing model's output parameters for one single cell area and comparing model output with measurement values (simulation experiments) such as runoff volume, sediment loss, N and P in sediment and runoff in selected cell to such point measurement. The rainfall was 1.26 inches, cell area was 0.1 acre

Table 4-1: Input parameters before and after calibration

Input parameter	Loam		Sandy loam	
	Calculated	Calibrated	Calculated	Calibrated
SCS curve number	85.0	89.45	67.0	85.5
K (Erodibility)	0.428	0.314	0.303	0.305
C (crop factor)	0.248	0.378	0.248	0.310
P (practice factor)	1.00	1.00	1.00	0.80
Soil N (lbs/lbs soil)	0.0016	0.0012	0.0015	0.0002
Soil P (lbs/lbs soil)	0.0004	0.0002	0.0002	0.0001
N extraction coef. For runoff	0.006	0.008	0.01	0.10
P extraction coef. For runoff	0.051	0.035	0.008	0.10
N extraction coef. For leaching	0.249	0.249	0.245	0.245
P extraction coef. For leaching	0.290	0.290	0.279	0.279
Organic matter	2.414	2.414	2.414	2.414

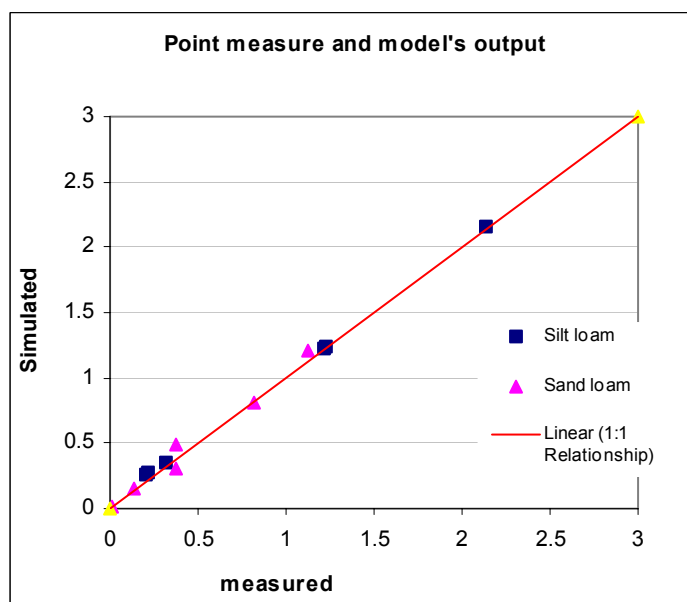


Figure 4-6: Model's output and point measurement

4.2-/ Executing AGNPS model

Table 4-2: Input factors for AGNPS based on AGNPS manual

Landuse	Surface condition	AMC	Manning's η	COD	K factor	C factor	P factor
Bare gr	0.01	85.5	0.04	60	0.305	0.09	0.1
Carnation	0.05	85.5	0.15	170	0.305	0.31	0.8
Fallow	0.15	62.5	0.08	115	0.01	0.09	0.1
Green H	0	100	0.01	20	0.01	0.01	0.01
Office	0.01	61.6	0.03	80	0.01	0.01	0.01
Potato	0.05	85.5	0.15	170	0.305	0.31	0.8
Stalice	0.05	85.5	0.15	170	0.305	0.31	0.8
Grass	0.15	62.5	0.08	115	0.01	0.09	0.1
Cabbage, Beans	0.05	89.45	0.25	170	0.314	0.378	1.0
House, Store, farm	0.01	75.8	0.03	80	0.01	0.01	0.01

Reference was based on R.A. Young et al 1987

For running AGNPS, the input files should be completely entered and computer will check the input file (ranges of parameter, indicators and flow directions). In the Aberdare farm, watershed was divided into 348 equal cells with cell's area is 0.2223 acres. In Oserain farm, watershed was divided into 491 equal cells with cell's area is 0.68 acres. For the rainfall designing, the ten years return period maximum rainfall and maximum rainfall in the third August 1999 was taken with rainfall volume was 53.7 and 34.5 mm respectively. The factors such as receiving cell, flow direction, land slope, slope shape, slope length as well as channel were extracted from Ilwis output files (Figure 4-5) after running script AGNPS (Mannaerts, Dost and Patrono 1997).

Soil information

The model required detailed soil information for each cell, i.e:

1. Soil N (P) in (lbs./lbs. soil): This provide the total nutrient loss in the eroded sediment that refers to a multiplication of sediment and N, P enrichment ratio for the different particle fractions such as clay, silt and sand. The figure of soil N, P had been shown in Table 3-5 by considering P-Olsen.
2. Pore water N (P) concentration (ppm), we used default that is 5 ppm and 2 ppm for N and P respectively because of no facilities to determine.
3. N (P) extraction coefficient for runoff, which provided the amount of Soluble N, P and its concentration in the runoff. From the analysis result of the rainfall simulation showed in Table 3-9, then we had this factor as showed in Table 4-1.
4. N (P) extraction coefficient for leaching also provided the amount of N and P leached deeper into the soil as showed in Table 4-1.

Soil N, P was difference from soil to soil, therefore one should be careful when simulating in large watersheds with different soil type and land cover. For the Pore water N, P and N, P extraction to runoff and leaching, data was very rare in the world because most of authors use

model to simulate runoff and sediment yield or use default to simulate N, P pollution (Rode and Frede 1997; Rode 1998)

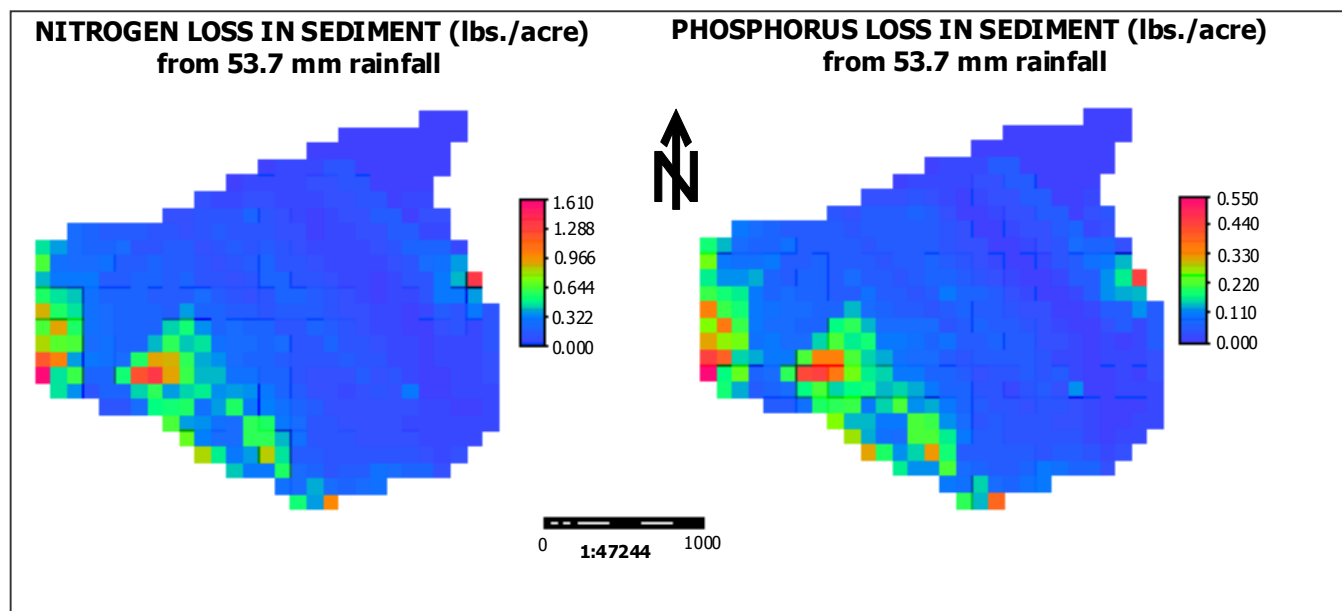


Figure 4-7: N and P loss attached in sediment (lbs./acre) were function of soil loss, in Oserian watershed from 53.7 mm rainfall, soil loss were shown in Figure 4.2.

Fertilizer information

Nitrogen and phosphorus fertilizers are main input factors for agriculture to get high benefit, also they are sources for water pollution when amended to the soil and subsequently is loaded to the water body by rainfall and surface runoff. Fertilizer was applied for every crop, the doses and kinds depended on soil type, crop requirement and investment ability of the farmers. In certain crop within selected watershed, the fertilizer information was indicated in Table 4-3

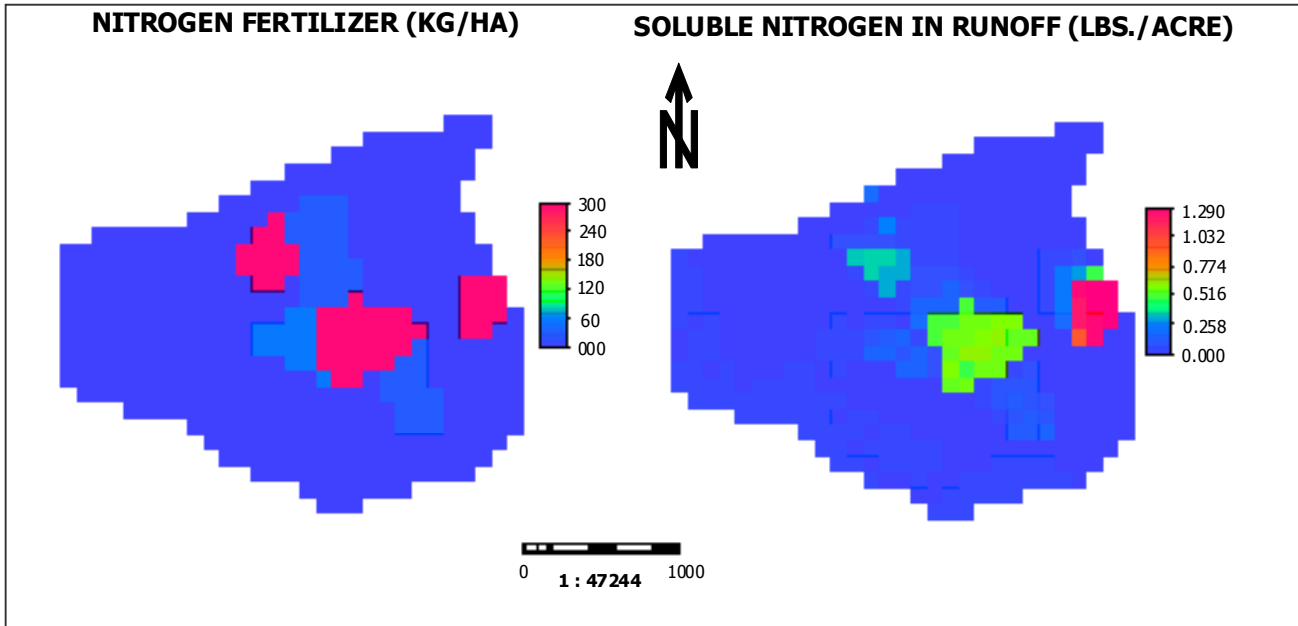
Table 4-3: Fertilizer input for AGNPS

Crop	N fertilizer		P fertilizer	
	Dose Lbs./Acre	Available N (%)	Dose Lbs./Acre	Available P (%)
Cabbage, Beans	57.12	60	17.85	60
Potato, Baby corn	57.12	60	17.85	60
Carnation	300.00	60	187.00	60
Stalice	32.00	60	0	60

Data from Table 4-3 shows that the big a difference in amount of fertilizer between flower crop and vegetable crops, excluding the others kinds of fertilizer such as Mg SO₄, K₂SO₄, Borax, Kcl, and fertilizers contained Ca were applied with rates relatively high.

The consequence of high fertilizer rate is clearly illustrated in Figure 4-8, the higher the Nitrogen fertilizer rate applied, the higher N dissolved and when moved into runoff.

Figure 4-8: SN in runoff was a function of runoff volume and fertilizer application, rainfall of 53.7 mm



The susceptible of the soils to rainfall also influenced to erosion processes and the extraction of chemicals to the runoff.

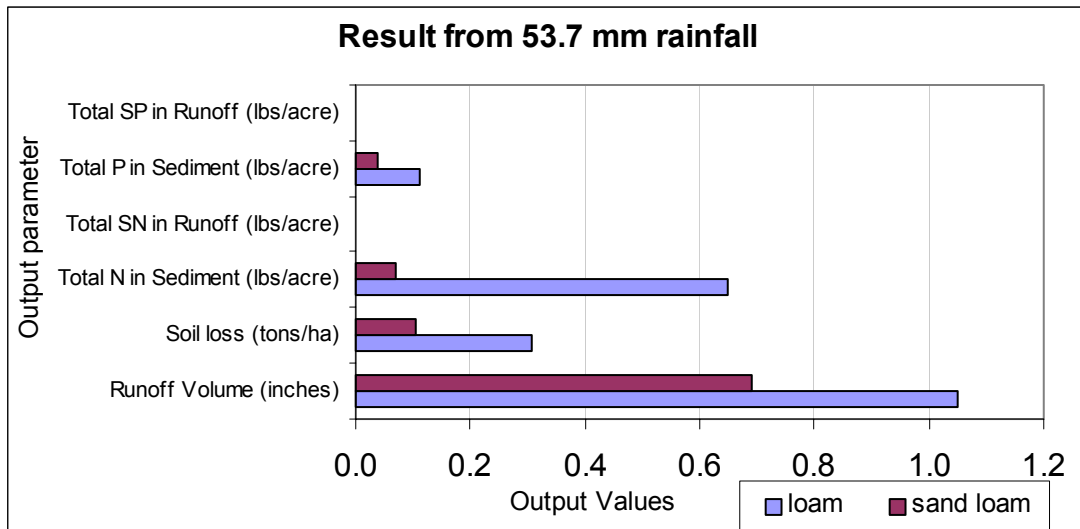


Figure 4-9: Runoff, soil loss and Nutrient losses from loam compare to sand loam

As shown in Figure 4-9, for loam with higher fraction of aggregate particles that includes silt and very fine sand; and clay content (62.2% and 17%) than sandy loam (56% and 6% respectively), those particles have higher OC, Nutrient content, lighter in bulk density, easily to be entrained. Therefore soil loss as well as nutrient loss is higher in loam than sandy loam.

From the calibration, water, soil erosion and nutrient attached in sediment and runoff were calculated for each event and watershed. In this case, a 10-years return period rainfall that was taken for calculation with precipitation of 53.7 mm (Table 4-4).

In order to assess yearly erosion effect, daily meteorology data in one-year period (since 10/1/1998 to 9/31/1999) had been considered for the operation. The limit of AGNPS was event simulation, hence for the simultaneously simulation the user have to work for every event. In terms of excesses rainfall and soil water retention, runoff would be generated when the rainfall volume was high or the rainfall intensity higher than infiltration rate, those belong to the soil retention factor. The U.S Department of Agriculture, Soil Conservation Service (1972) designed a formula for relation of the rainfall, the soil retention and the runoff as showed in the Equation 4.2

It is obviously known that runoff is generated only when rainfall is higher than retention factor. Overall if we have $CN = 89$ (Equation 4.2), then rainfall depth should be greater than 1.17 inches. In other words Foster (1999) recommended that storms less than 0.5 inches are not included in the erosivity computation. According to the empirical condition in the study area, it was daily irrigation, therefore soil condition had a consistently low retention factor, thus 13 storms exceeded 0.5 inches events in one year period 10/1998-9/1999 were taken for the model's calculation. Yearly yield of runoff volume, sediment; N and P in sediment and runoff are shown in Table 4-4.

Table 4-4: Total Yields for Aberdare and Oserian watershed outlet from 53.7 mm event and yearly rainfall in 1999

Output parameter	Unit	53.7 mm event		Yearly rainfall 2000	
		Aberdare	Oserian	Aberdare	Oserian
Watershed area	acre	76.56	1212.77	76.56	1212.77
Runoff Volume	inch	1.05	0.69	2.970	1.66
Soil loss	ton	9.46	52.18	20.22	124.31
Total N in Sediment	kg	22.57	38.51	67.02	132.03
Total SN in Runoff	kg	0.00	0.00	0.00	0.00
Total P in Sediment	kg	3.82	22.00	10.77	60.51
Total SP in Runoff	kg	0.00	0.00	0.00	0.00

Comparing the result between Table 4-4 and Table 3-8 in chapter 3 we can see that most output results were compatible with field simulation and point measurement. One should take into account that total SN and SP in runoff in the watershed outlet were zero, while in the same event (53.7 mm rainfall). It was 13.47 and 11.13 kg in Aberdare watershed and 70.9 and 29.54 kg in Oserian watershed, respectively if we sum up SN and SP from every cell's outlet. An explanation for that is sediment and nutrient routing effect. That means during transport process, P is precipitated; and soluble N and P adsorbed to the sediment particles. There is a transfer from the runoff solution to the fine sediment particles.

Yearly discharge in 1999 which simulated from 13 events ($P > 0.5$ inches), 299.8 mm rainfall volume was not proportion to 53.7 mm event, but lower discharge because some event were near 0.5 inches threshold with low energy of rain drop or detachment.

CHAPTER V

SENSITIVITY ANALYSIS AND MODEL COMPARISON

This chapter describes the sensitivity analysis that was the important of the input parameter to the output one. Assessment of different models implementation through control selected cell and comparison of the output parameters.

5.1- Sensitivity analyses

We performed a sensitivity analysis on the model to determine the relative change in model output with respect to the change in inputs and model variable. After determining standard input variables and computing base output values, we varied the input variables over a range of value and repeat the computation. These show how the model outputs vary with changes in input values. Results show how the model functions and how important each of the variables is in determining the output. The variables used for sensitivity analysis are showed in Table 5-1.

Table 5-1: A summary of the input parameters used in the sensitivity analysis

Parameter	Description
Rain	Storm rainfall, 24-hour design storm were assumed
CN	SCS curve number
LS	Land slope
N	Overland Manning's coefficient
K	Soil erodibility
C	Cropping factor
Avail	Fertilizer availability factor

Table 5-2: A summary of the output parameters at the watershed outlet analyzed in the sensitivity analysis

Parameter	Description
SC	Sediment yield (tons/acre)
Ns	Nitrogen yield associated with the sediment (lb/acre)
Nq	Soluble nitrogen yield (lb/acre)
Ps	Phosphorus yield associated with the sediment (lb/acre)
Pq	Soluble phosphorus yield (lb/acre)
CODq	Soluble chemical oxygen demand yield (lb/acre)

Those output parameters would be compared to the standard file output parameters that were created from the Oserain watershed as discussed in Chapter 4. The ratio of those parameters to the one of standard file is shown in Table 5-3.

Table 5-3: Results of sensitivity analysis (as Ratio of simulated output values to the standard file output value for parameter).

	ava50	ava75	ava125	ava150	n50	n75	n125	n150	k50	k75	k125	k150	scs50	scs75
Runoff Volume	1	1	1	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	0.41
Peak Runoff Rate	1	1	1	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.07	0.43
Total Sediment Yield	1	1	1	1	1.27	1.12	0.91	0.83	0.75	0.89	1.10	1.20	0.30	0.66
Total N in Sediment	1	1	1	1	1.29	1.14	0.93	0.86	0.79	0.93	1.07	1.14	0.43	0.71
Total Soluble N in Runoff	1	1	2	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00
Total P in Sediment	1	1	1	1	1.29	1.14	0.86	0.86	0.86	0.86	1.14	1.14	0.43	0.71
Total Soluble P in Runoff	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Soluble COD	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.50

(Continue)

	Scs	Scs	Cfact	Cfact	Cfact	sl_gr	sl_gr	sl_gr	sl_gr	sl_gr	Rain	Rain	Rain	Rain	control
	125	150	50	75	125	150	50	75	125	150	50	75	125	50	
Runoff Volume	1.57	1.85	1.00	1.00	1.00	1.00	0.92	0.96	1.03	1.06	0.34	0.65	1.37	1.74	1
Peak Runoff Rate	1.53	1.79	0.75	0.89	1.10	1.20	0.65	0.82	1.19	1.38	0.33	0.63	1.44	1.96	1
Total Sediment Yield	1.23	1.27	0.79	0.93	1.07	1.14	0.71	0.86	1.14	1.29	0.43	0.71	1.36	1.79	1
Total N in Sediment	1.21	1.21	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1
Total Soluble N in Runoff	17.00	17.00	1	1	1	1	1	1	1	1	2.50	1.50	1.00	0.50	1
Total P in Sediment	1.14	1.29	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	1
Total Soluble P in Runoff	5.00	5.00	1	1	1	1	1	1	1	1	1.00	1.00	0.00	0.00	1
Total Soluble COD	1.50	1.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.09	1.00	1.00	0.91	1

Where: Avar fertilizer available

N overland manning's

K erodibility

Scs curve number

cfact crop factor

Sl_gr land slope

Rain rainfall volume

50, 75, 125 and 150 are verified 50%, 75%, 125% and 150% of standard Avar, n, k, scs, cfact, sl_gr, rain from Oserian file in chapter 4.

Some observations from Table 5-3 : The SCS curve number and rainfall amount have the most influence on the output values including runoff, soil loss, nutrient loss in sediment and soluble in runoff. The output parameters compare to the standard output parameter range from 6%-185% and 32% - 196% respectively, typically SN and SP were very high compare to standard one. Erodibility (K), crop factor (C) and land slope (SL_gr) had similar influence to the output parameters because they were components of RUSLE equation. The higher K, C and SL_gr the higher of soil loss and nutrient loss in sediment while influence of overland Manning's was inverse. But those factors have influence to the soil loss and the nutrient loss in the sediment only. The factor with least influence was fertilizer availability (ava), the consequence of its changing were the soluble nutrient in the runoff and its concentration.

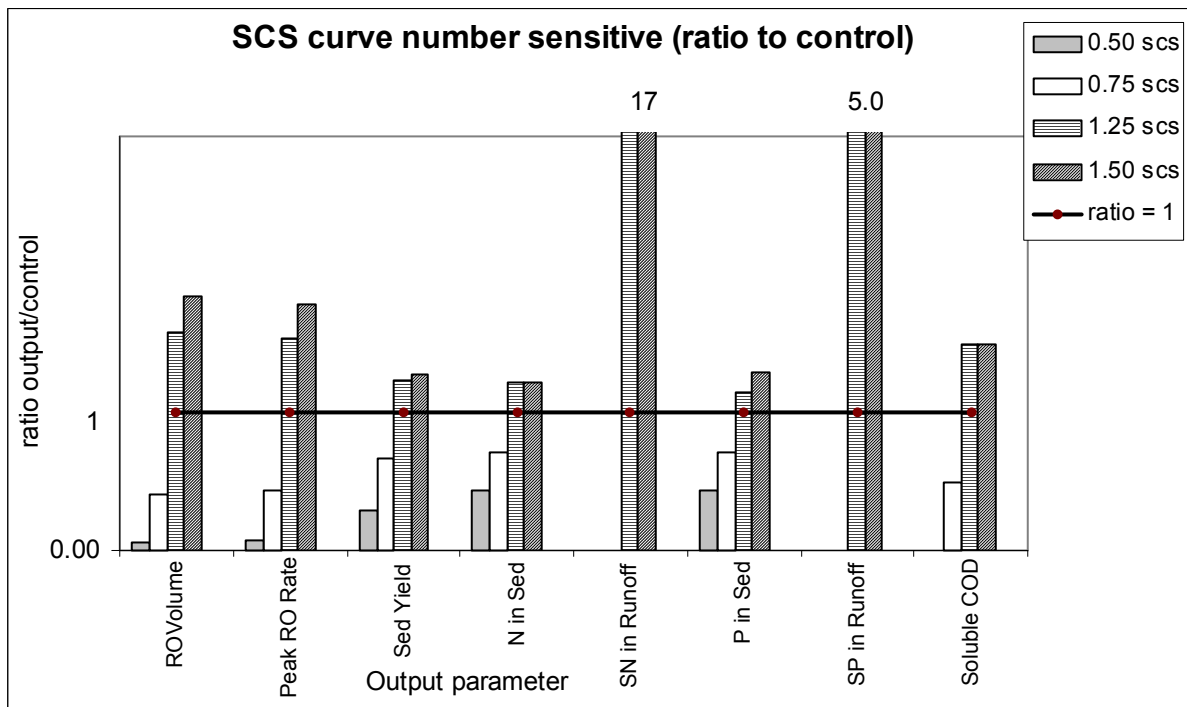


Figure 5-1: Ratio of verified SCS output file to standard SCS output file

5.2-/ Model comparison

Many models have been applied to simulate chemical dynamics to get predictions instead of paying lots of field observations and measurement; and to get good results in areas where it is not possible for field surveys to take place or have an unmeasurable source area such as agricultural non-point pollution. In the case of study area three models were implemented, that are Agricultural Nonpoint Source Pollution model (AGNPS), Seasonal Soil Compartment model (SESOIL) and Pesticide Root Zone Model (PRZM 2). Actually a good comparison between PRZM and SESOIL could be expected, but not really good for all three of them, because PRZM and SESOIL simulate simultaneously fate of chemical in both leaching and wash load in one soil parcel in a time period. While AGNPS simulate the fate of chemical in wash load only in one rainfall event for completed watershed. AGNPS, its calculations and applications have been described in the chapter 4.

PRZM

The mathematical descriptions of the processes simulated by PRZM2 are broken down into five categories that are:

- Transport in soil
- Water movement
- Soil erosion
- Volatilization
- Irrigation.

Mulling et al (1993), David (1990), Mueller (1994) and De Silva (1998) had described overview of the Model's operations. In this study we concentrated on the erosion category. Some descriptions of the model as follow:

The plant uptake of chemicals is modeled by assuming that uptake of chemical by plant is directly related to transpiration rate. The equation is

$$J_u = f * C_w * \theta * \epsilon * A * \Delta z \quad [\text{g/day}] \quad (5.1)$$

Where:

- J_u = Uptake of chemical (g/day)
- f = The fraction of total water in the zone used for transpiration (day⁻¹)
- ϵ = An uptake efficiency factor or reflectance coefficient (dimensionless)
- A = Cross section area of soil column (cm²)
- Δz = Depth dimension of compartment (cm)
- C_w = Dissolved concentration of chemical (g/cm³)
- θ = Volumetric soil water content (cm³/cm³)

Subjective the effect of snowmelt, daily runoff volume is calculated as follow

$$Q = \frac{(P - 0.2 * S)^2}{P + 0.8 * S} \quad [\text{cm}^3/\text{day}] \quad (5.2)$$

$$\text{and } S = \frac{1000}{RCN} - 10$$

Where:

- P = Precipitation (cm/day)
- S = The watershed retention parameter
- RCN = SCS runoff curve number.

The loss of chemical due to runoff is

$$J_{QR} = \frac{Q}{A_w} * C_w * A \quad [\text{g/day}] \quad (5.3)$$

Where:

- J_{QR} = The chemical loss due to runoff (g/day)
- Q = The daily runoff volume (cm³/day)
- A_w = Watershed area (cm²)

And the loss chemical due to erosion is

$$J_{ER} = \frac{P * X_e * r_{om} * C_s * A}{A_w} \quad [\text{g/day}] \quad (5.4)$$

Where:
 J_{ER} = The chemical loss due to erosion (g/day)
 X_e = The erosion sediment loss (metric tons/day)
 r_{om} = The enrichment ratio for organic matter (g/g)
 C_s = Solid phase concentration of chemical (g/g)
 P = a units conversion (g/tons)

The enrichment ratio for organic matter is calculated from

$$\ln(r_{om}) = 2 + 0.2 \ln(X_e/A_w)$$

Removal of sorbed chemical on eroded sediments requires estimates for soil erosion. The modified Universal Soil Loss Equation (MUSLE) as developed by Williams (1975) is used to calculate soil loss as follow

$$X_e = a * (V_r * q_p)^{0.56} * K * LS * C * P \quad [\text{tons/day}] \quad (5.5)$$

Where: X_e = The event soil loss (metric tons/day) - LS = Length slope factor
 V_r = Volume of event (daily) runoff (m^3) - C = Soil cover factor
 q_p = Peak storm runoff (m^3/sec) - P = Conservation practice factor
 K = Soil erodibility factor - a = Units conversion factor

SESOIL

Sesoil is one-dimensional vertical transport model for the unsaturated soil zone. The model is based on mass balance and equilibrium partitioning of the chemical between different phases. It was designed to perform long-term simulations of chemical transport and transformations in the soil. They are included in three cycles:

- **Hydrologic Cycle**
 - Rainfall - Capillary rise
 - Infiltration - Evapotranspiration
 - Groundwater runoff (recharge) - Soil moisture retention (storage)
 - Surface runoff
- **Sediment Cycle**
 - Sediment washload (Erosion due to storms)
- **Pollutant Fate Cycle**
 - Advection
 - Diffusion (air phase) - Washload
 - Volatilization - Surface runoff
 - Sorption - Groundwater runoff (recharge)
 - Cation exchange - Metal complexation
 - Hydrolysis - Chemical degradation/decay

The hydrologic cycle and pollutant fate cycle in Sesoil were described and simulated by Bonasountas et al (1997) Tang (1999), Jolicoeur (2000).

In pollutant transport models, estimates of erosion and sediment yield on watersheds are required in order to compute the removal of sorbed chemicals on eroded sediments. A major factor in this process is the surface runoff, which is part of hydrolysis cycle. Erosion is a function of the rate of surface runoff and several other factors.

The sediment cycle of Sesoil was calculated by EROS, a theoretical sediment yield model (Foster et al. 1980), which is part of CREAMS model (Knisel 1980; Foster et al. 1980). The erosion component considers the basic process of soil detachment, transport and deposition. For the detachment process, the model employs the Universal Soil Loss Equation (USLE; Wischmeier and Smith 1978), modified by Foster et al. (1980) for single storm events.

To model the sediment transport capacity for overland flow, EROS incorporate the Yalin transport equation (Yalin 1963), modified for nonuniform sediment with a mixture of particle sizes and densities.

In short, Pollutant can be removed from the soil area being simulated by SESOIL through surface runoff and washload. The pollutant in surface runoff is simply surface runoff computed in hydrologic cycle (for each month) multiplied by the pollutant concentration in the soil moisture of the surface layer (for each time step).

$$C_{sa} = \frac{cH}{R(T + 273)} \quad [\mu\text{g/ml}] \quad (5.6)$$

Where: C_{sa} = pollutant concentration in soil air ($\mu\text{g/mL}$)

c = Pollutant concentration in soil water ($\mu\text{g/mL}$)

H = Henry's law constant ($\text{m}^3\text{atm/mol}$)

R = gas constant [$8.2 \cdot 10^{-5} \text{ m}^3 \text{ atm}/(\text{mol}^\circ\text{K})$]

T = Soil temperature ($^\circ\text{C}$)

Pollutant loss via washload was computed by taking the sediment yield from the washload cycle and multiplying it by the absorbed pollutant concentration in the surface layer.

$$S = K_d c^{1/n} \quad [\mu\text{g/g soil}] \quad (5.7)$$

Where s = Pollutant absorbed concentration ($\mu\text{g/g soil}$)

K_d = Pollutant partitioning coefficient ($\mu\text{g/g soil}/(\mu\text{g/mL})$)

c = Pollutant concentration in soil water ($\mu\text{g/mL}$) n = Freundlich constant.

The total concentration of the pollutant in the soil is computed as:

$$C_o = f_a * c_{sa} + \theta * c + \rho_b s \quad [\mu\text{g/cm}^3] \quad (5.8)$$

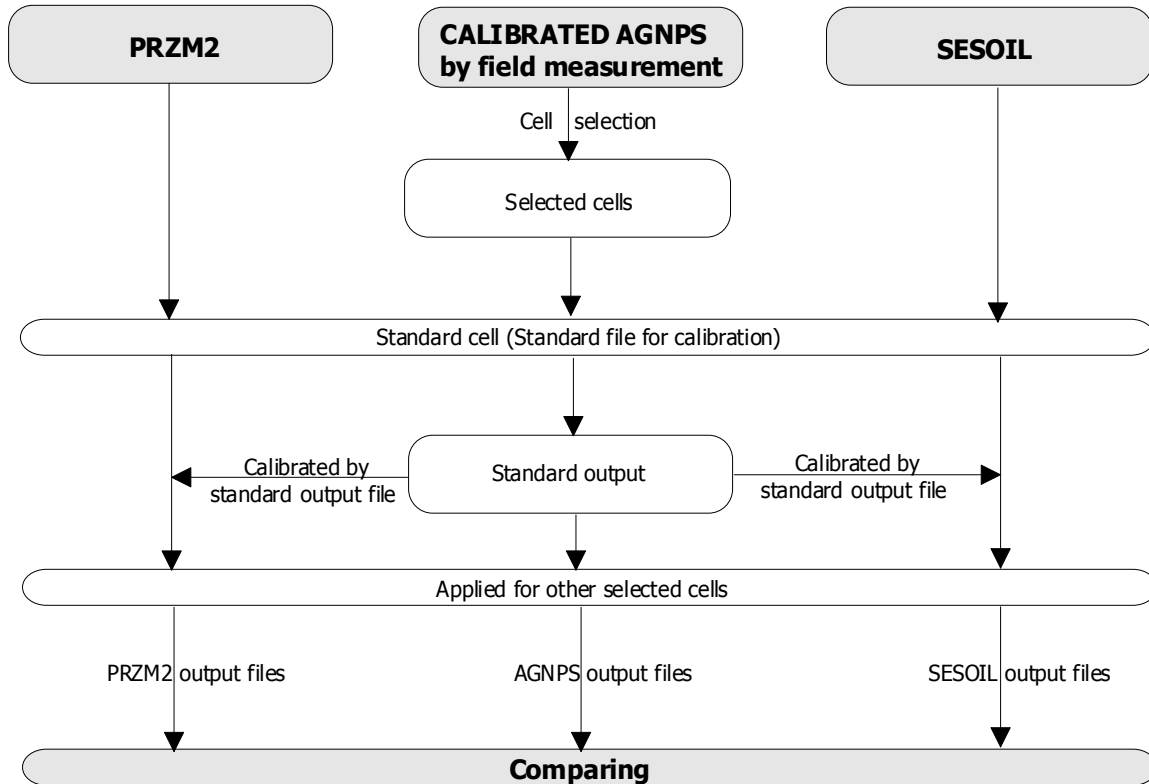
Where c_o = Overall (total) pollutant concentration ($\mu\text{g/cm}^3$)

$F_a = n - \theta$ = the air-filled porosity (ml/ml) n = soil (total) porosity (ml/ml)

θ = Soil moisture (water) content (ml/ml) ρ_b = soil bulk density (g/cm^3).

The aim was comparison of output parameters simulated from three models using different scenarios that had different field condition such as SCS curve number, land slope, slope length, or rainfall duration in the same rainfall volume (daily rainfall recorded in one year period, 10/1988-9/1999 from Longonot station). The scheme is showed in Figure 5-2.

Figure 5-2: Scheme for model calibration and comparison



Results and discussions:

The model's output parameters chosen for comparison were: Runoff volume, sediment yield; chemical (N and P) in the sediment and in the runoff. Because the same chemicals were used in the three models, no changing of the chemical properties in the input files after calibration was necessary. Most factors that influenced the output parameter values were components of RUSLE equation such as rainfall (R), curve numbers (SCS), soil erodibility (K), slope factor (SL) and crop factor (C). K, SL and C in situ provided the sediment yield and particulate chemical while R and SCS verified all runoff volume, sediment yield, and chemical in both sediment and runoff.

5.2.1- AGNPS - PRZM2

The two models have been run on 10-selected cells with different surface conditions, SCS curve number range between 81 to 90. The results showed a good linear correlation for both models in surface runoff and sediment yield (Figure 5-3). The confusion matrix showed, that when SCS higher than 88, surface runoff from PRZM2 was lower than AGNPS, while it was reverse for sediment yield (illustrated by Figure 5.6). This difference could be explained by looking at Equations 4.1 and 5.5 for soil loss. In AGNPS, modified USLE by Wischmeier and Smith (1978) is used while in PRZM, MUSLE by Williams (1975) is used. There is a difference between slope shape factor (SSF) in AGNPS and peak runoff rate (Qp) in PRZM2 for calculation of sediment yield.

$$E=EI*Ks*Lf*Sf*Cf*Pf*SSF \quad \text{[tons/acre]} \quad (4.1)$$

$$X_e = a \cdot (V_r \cdot q_p)^{0.56} \cdot K \cdot LS \cdot C \cdot P \quad [\text{tons/day}] \quad (5.5)$$

(Variables were described in section 4.1 and 5.2)

There is poor correspondence in the above two equations for soil loss calculation, for AGNPS (Equation 4.1) in form of $y=a \cdot x$ (with $x=EI$) while for PRZM (Equation 5.5) the soil loss is power function of runoff volume and peak runoff, equation forms $y=ax^{0.56}$ (see figure 5.12).

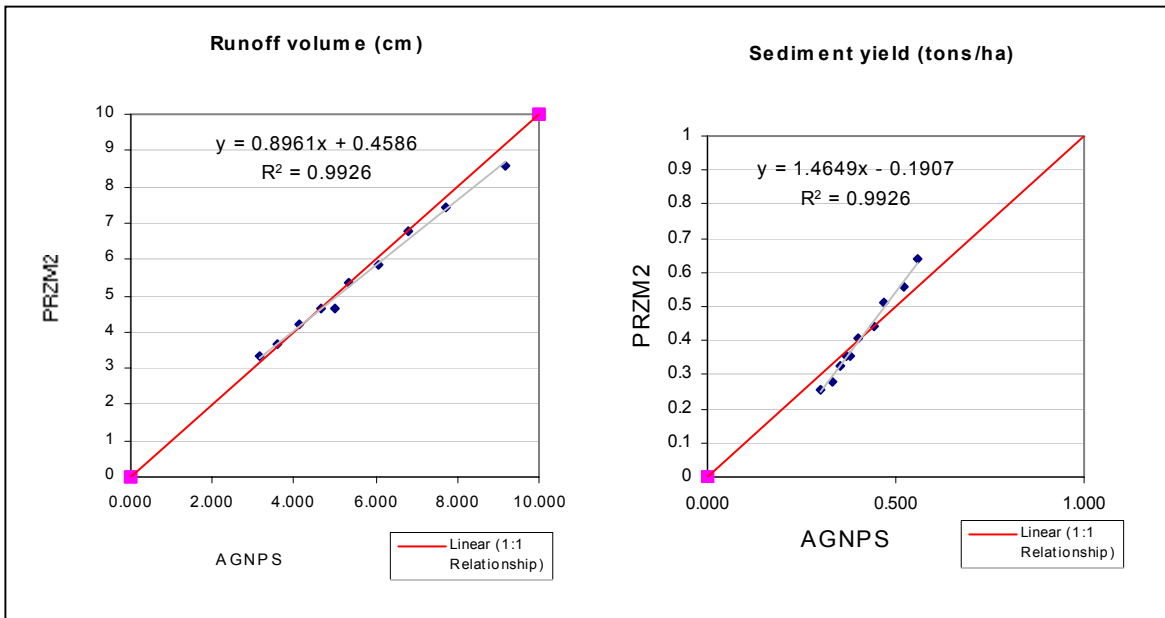


Figure 5-3: Surface runoff and sediment yield in AGNPS against PRZM2

In PRZM, we failed to calibrate chemical sorbed in the sediment because the total chemical in sediment seemed too small compared to AGNPS output (around 10%). This brought a big difference between the two models although they had very high correlation.

Soluble chemical concentrations (SN and SP) in runoff waters between AGNPS and PRZM2 were correlated to each other by a logarithmic equation rather than linear equation (Figure 5-5). When the CN-numbers were higher than 88, AGNPS gave higher values than PRZM2, whereas at lower SCS curve numbers, both models gave similar results. Calculation of SN and SP in runoff in AGNPS is shown in Equations 4.4 and in PRZM by Equation 5.3, they are;

$$RON = \frac{0.892 \cdot (CZERON - CHECKN) \cdot (e^{(-XKFN1 \cdot EFI)} - e^{(-XKFN1 \cdot EFI - XKFN2 \cdot RO)})}{COEFF + \frac{RN \cdot RO}{EFRAIN}} \quad [\text{lbs/acre}] \quad (4.4)$$

$$J_{QR} = \frac{Q}{A_w} \cdot C_w \cdot A \quad [\text{g/day}] \quad (5.3)$$

By taking runoff volume and extraction coefficient as variables, assuming the runoff volume equal for two models. Soluble N and Soluble P in runoff in equation 4.4 is exponential of runoff volume and extraction coefficient to runoff, while SN and SP in runoff in equation 5.3 is linear function of runoff volume and dissolved concentration of N and P (see figure 5.6 and 5.12).

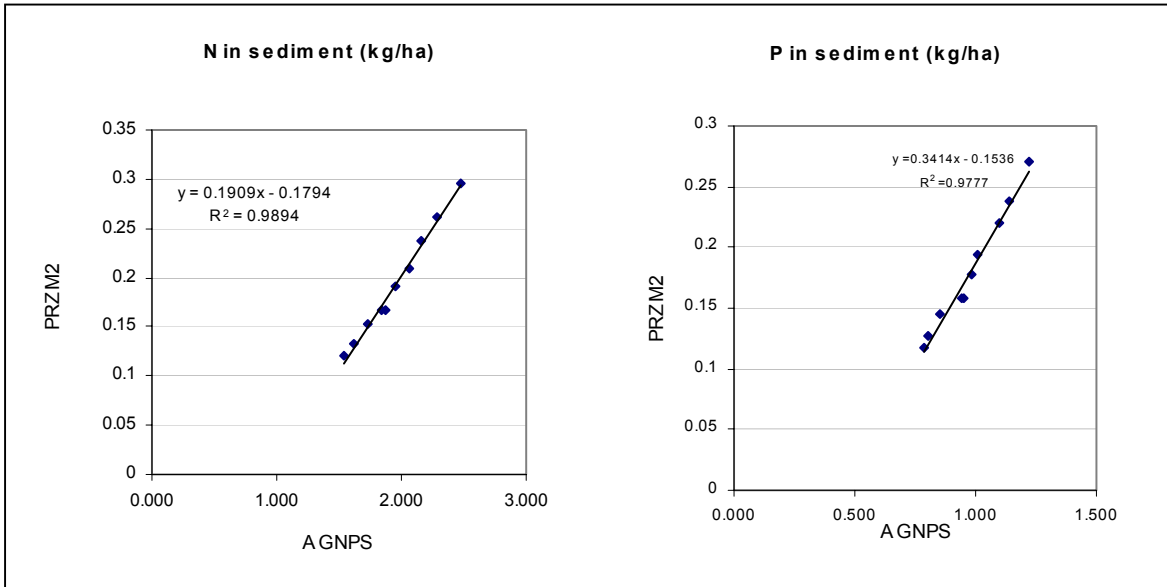


Figure 5-4: Correlation between AGNPS and PRZM2 on N and P in sediment

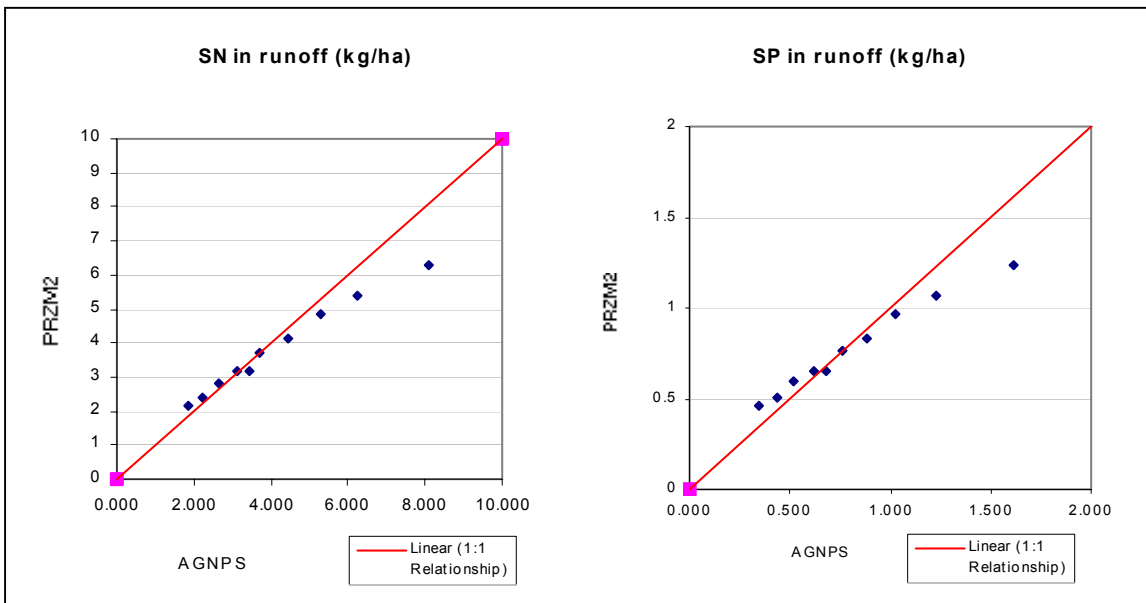


Figure 5-5: SN and SP in runoff calculated by AGNPS against PRZM2

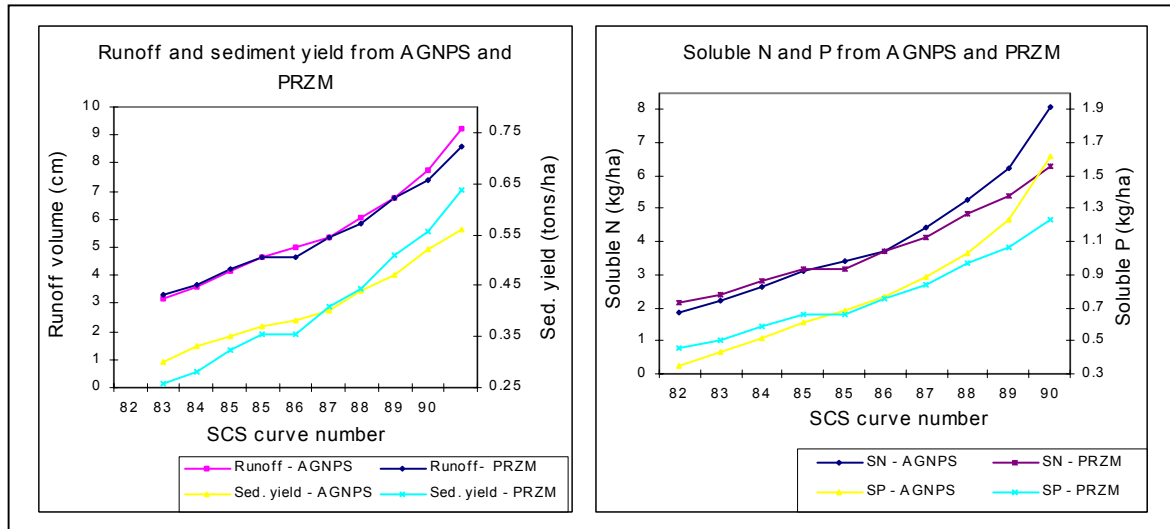


Figure 5-6: Runoff volume (cm), sediment yields (tons/ha), soluble N and soluble P (kg/ha) calculated from AGNPS and PRZM at different SCS curve number.

5.2.2- AGNPS - SESOIL

The principle of comparison applied was the same as the first Agnps-Przm scenario as showed in Figure 5-2. SESOIL model was run for calibrated AGNPS cells and continuously applied for the other selected cells.

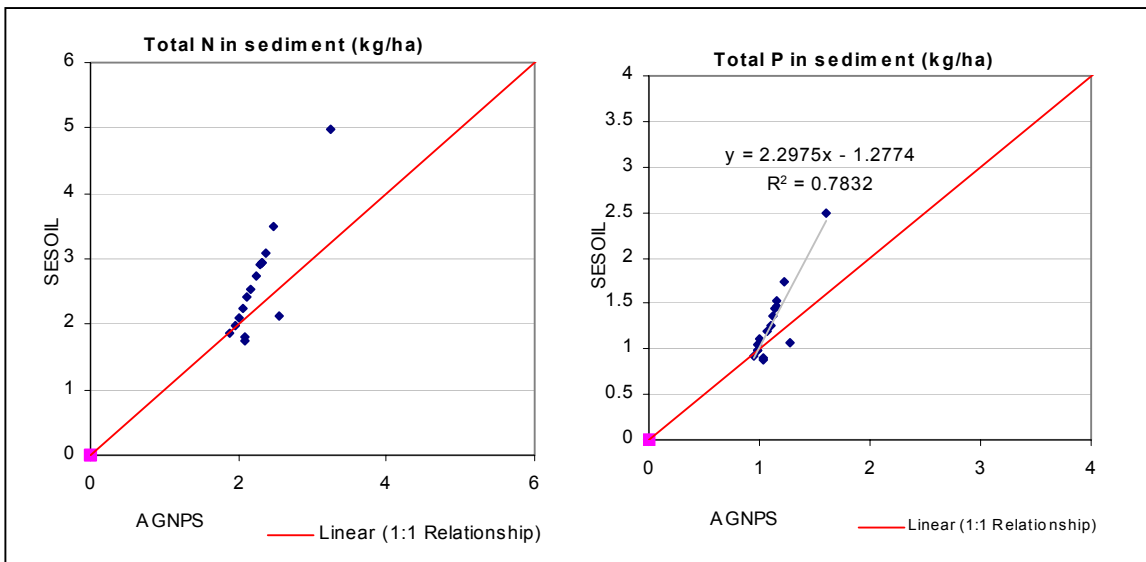


Figure 5-7: Total N and P in sediment (kg/ha) calculated by AGNPS against SESOIL

Figure 5-7 shows a good correlation between AGNPS and SESOIL for N and P loads sorbed in sediment, but it was not close to each other in terms of comparison (values diverted from 1:1 relationship line, slope>2.09), which mean results from SESOIL were higher than from

AGNPS. This trend was similar to the trend of PRZM against AGNPS (Figure 5-3 and 5-4). Explanation could also be based on equations 5.9 and 5.10

$$\text{SED- (Agnps)} = \text{SOIL} * \text{SED} * \text{ER} * 0.892 = \text{SOIL} * \text{SED} * (7.4 * \text{SED}^{-0.2} * \text{Tf}) * 0.892 \quad [\text{lbs./acre}] \quad (5.9)$$

$$\text{Chemical in sediment (in Sesoil)} = \text{Sed} * \text{S} \quad [\mu\text{g}] \quad (5.10)$$

- Where:
- SOIL= N and P concentration in the soil
 - SED= Sediemnt yield (kg/ha)
 - ER= Enrichment ratio
 - Tf= texture correction factor
 - S= Pollutant absorbed concentration ($\mu\text{g/g}$ soil)

In AGNPS, chemical in sediment is power function of sediment, equation form $y = a.x.x^{-0.2}$ while in SESOIL chemical in sediment is linear function of soil loss.

Plotting the output of SESOIL against AGNPS on SN and SP in runoff gave a reversed trend to N and P in sediment (Figure 5-8) because SN (P) in AGNPS was calculated by equation 4.4 that is Exponential equation. While in SESOIL, SN (P) = Runoff volume * Csa, (Csa is N, P concentration in soil air) as a linear equation (illustrated by Figure 5-9).

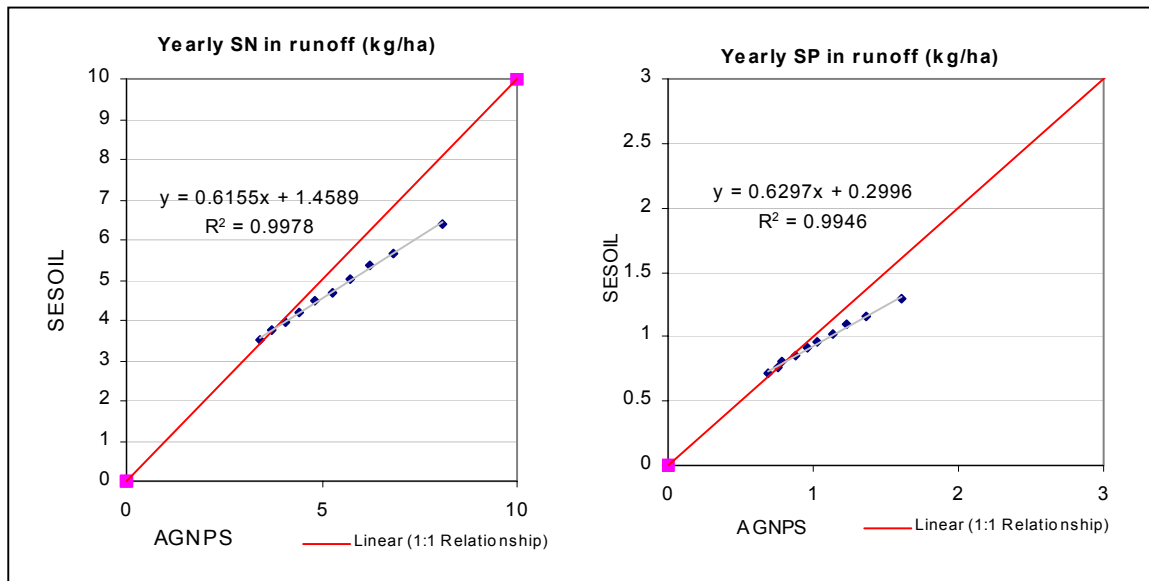
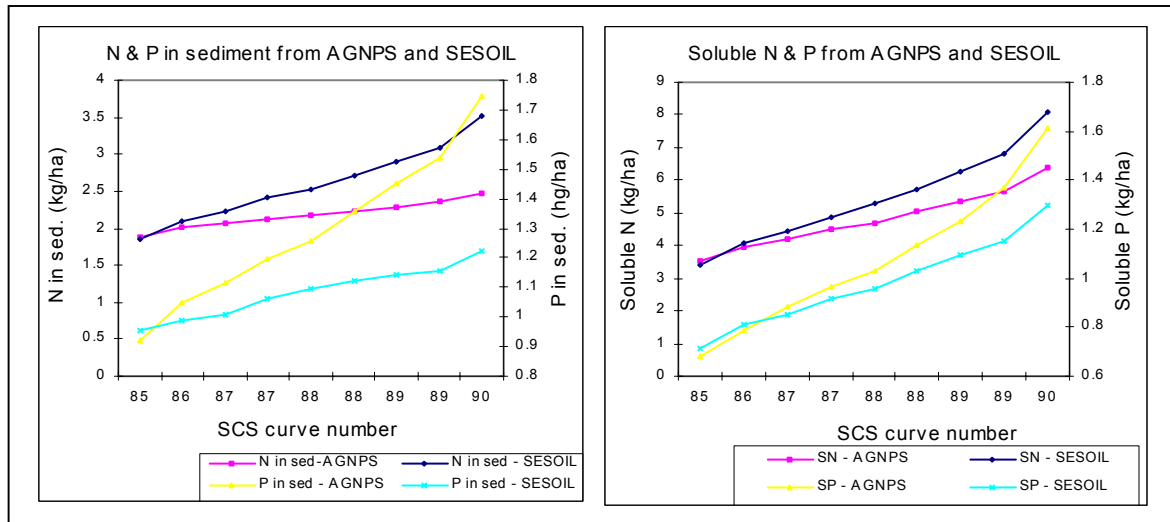


Figure 5-8: SN and SP in runoff, simulated by SESOIL against AGNPS.

The trend from Figure 5-8 was almost similar to the trend from Figure 5-5 Slope from correlation of SN and SP were 0.61 and 0.62 respectively compare to slope =1 from 1:1 line, that mean SESOIL gave lower results than AGNPS from the same input parameters (illustrated by Figure 5-9).

Figure 5-9: N and P in sediment (kg/ha), soluble N and P in runoff calculated from AGNPS and SESOIL (same input file) at different SCS curve number.



5.2.3- PRZM2 - SESOIL

The comparison test was also performed between PRZM and SESOIL with same selected cell outputs that were calculated for above comparisons. The output parameters were SN and SP (Figure 5-10). Slopes of correlation line were 1.025 and 0.94 for SN and SP respectively. In PRZM, SN (P) is calculated by runoff volume multiplying to dissolved N (P) concentration (equation 5.3) and in SESOIL, SN (P) is calculated $SN (P) = \text{Runoff volume} * C_{sa}$ (C_{sa} is N, P concentration in soil air). Both of them are forms of linear equation, hence it can be said that PRZM2 and SESOIL gave similar calculation and results for Soluble N and P in runoff water (Figure 5-11).

Figure 5-10: SN and SP in runoff SESOIL against PRZM2

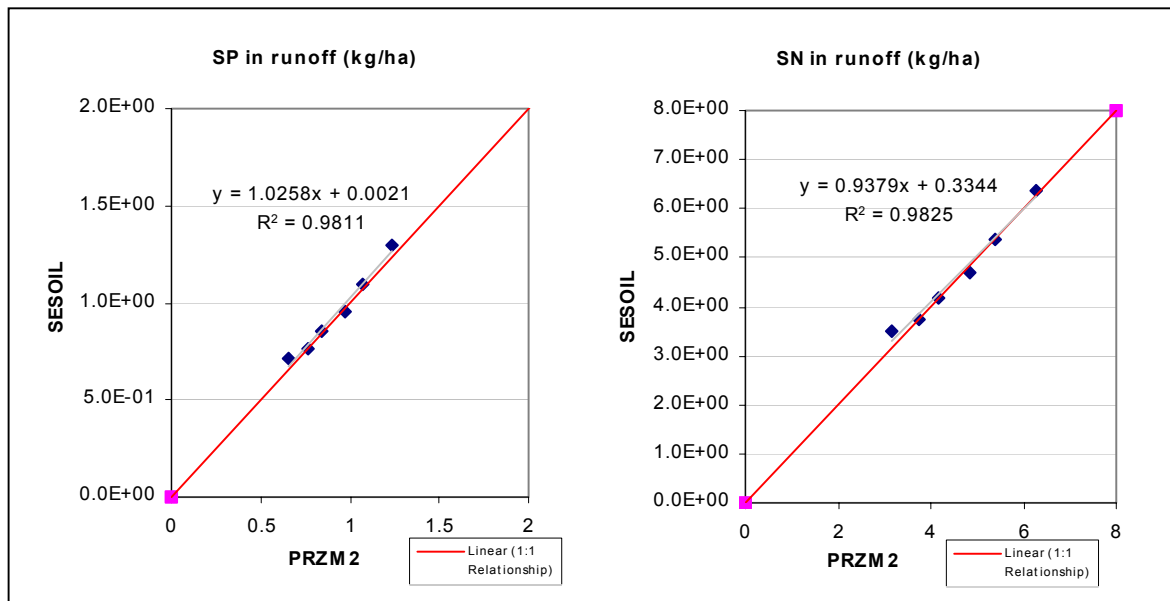


Figure 5-11: Soluble N and P in runoff calculated by PRZM and SESOIL

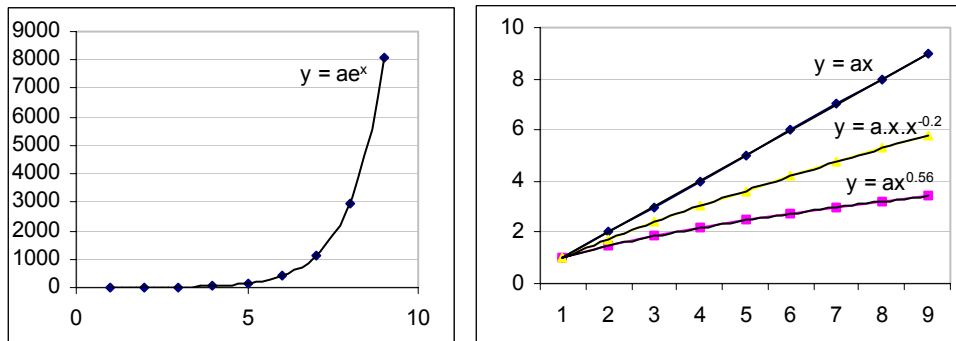
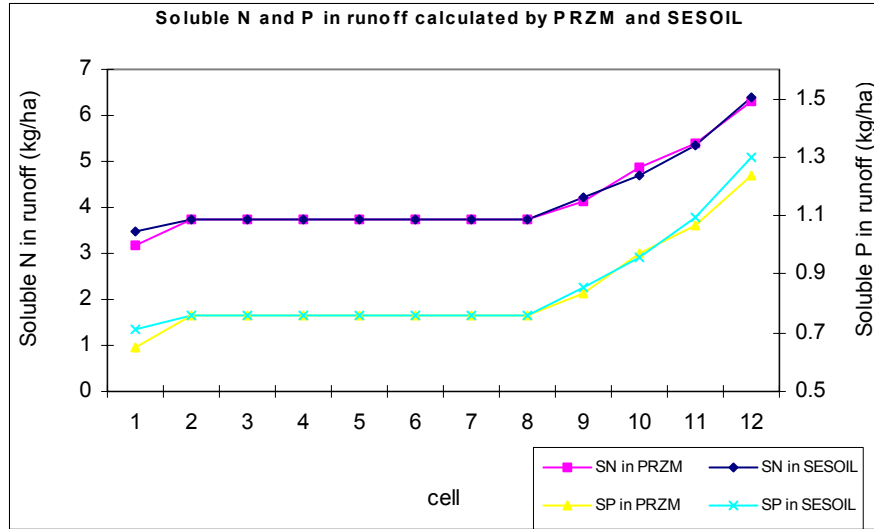


Figure 5-12: Graph from equations formed $y=ax$, $y=ae^x$, $y=ax.x^{-0.2}$ (or $y=a.x^{0.8}$), and $y=ax^{0.56}$

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This chapter gives the conclusions drawn from the study, as well as the recommendations for future study and farm management.

6.1-/ Conclusions

Rainfall analysis and rainfall simulation

From the recorded meteorology data, annual rainfall, monthly rainfall and maximum rainfall for a detailed return period were computed by using a Rankplot technique. Results showed that it was compatible to previous research and indicated the peak rainfall with a 10-year return period and a 100-year return period for maximum rainfall and annual rainfall.

Runoff coefficients for irrigated cropland was much higher than in noncultivated land because of daily irrigation practices and related soil moisture content, especially in the loamy soils with rather low permeability. This condition reveals a risk for high peak runoffs and short of time of concentration for irrigated cropland when additional high rainfall events occur.

We observed (measured using rainfall simulation) a linear correlation between runoff volume, sediment losses and initial soil moisture content. Runoff and soil loss from loam soils were much higher than from sandy loams for a same rainfall volume.

Phosphorus loss in sediments was strongly related to total soil loss, hence both sediment and nutrient chemical losses are an indication of not only degradation of the in-situ soil fertility but also of off-site pollution risk and sedimentation of the Naivasha lake.

From a combination of previous researches and rainfall simulation experiments in the study area, we determined the extraction coefficients of Nitrogen, and Phosphorus into runoff and leaching, which are basic essential data for evaluating nonpoint source pollution with models like the AGNPS, SESOIL or the PRZM models. We could also calculate the depth of interaction between rain water and the soil surface. From the initial Soil-P content, rainfall volume, rainfall duration, soil bulk density, runoff volume and depth of interaction, we could evaluate the average soluble N and P in runoff water. The results showed a good correlation between predicted and measured Soluble-P (SP) in runoff.

Model implementation

By using Agriculture Non-Point Source Pollution Model (AGNPS), it was possible to analyze the nonpoint source impacts of complete farm-sized areas on the Naivasha lake. This was

attempted for the Aberdare farm area and the Oserian estate. We used a Digital Elevation Model, Drainage system to extract topographic variables and create various input parameters for AGNPS.

By combining the results from rainfall simulation experiments, laboratory analysis and GIS modeling, we could create realistic input files for two farm-scale watersheds, one in the loam soil (30.98 ha) and another in the sandy loam area (490.79 ha). A design rainfall of 53.7 mm with a ten years return period and all annual rainfall (all erosive precipitation > 0.5 inches) in one year period (1/10/1998-31/9/1999) was used for simulation. The results shown for the first watershed: yearly discharge of runoff were 2.97 inches; total soil loss were 20.22 tons; total N in sediment were 67.02 kg; and total P in sediment were 10.77 kg. In the second watershed; yearly discharge of runoff were 1.66 inches; total soil loss were 124.34 tons; total N in sediment were 132.03 kg; and total P in sediment were 60.51 kg. These are rough estimates of chemical runoff budgets, which can drain eventually in the Naivasha Lake.

Increase of fertilizer application rates obviously increases available and soluble N, P in soil surface, hence concentration of N and P in runoff water becomes high. Losses of N and P are also increased.

By running a sensitivity analysis on model input – output parameters (and comparison with a created standard file), we obtained differences in model output as a function of input parameters. SCS curve number and rainfall volume were very important input parameters with high sensitivities on the output.

Model comparison

Three models which permit simulation of chemical runoffs were compared, using a small unit runoff or land area (or cell in Agnps). The model AGNPS was employed to simulate runoff, soil loss, N and P in sediment and runoff for a few selected cells (small watershed) that was calibrated by field measurements. Two others models (PRZM and SESOIL) were also employed to simulate same rainfall runoff events. The results obtained were compared to results computed from AGNPS and with each other.

Runoff volume calculated from PRZM was a little lower than from AGNPS, while sediment yield was reversed. Soluble N and P in runoff from PRZM were lower than from AGNPS. The trend was similar for the comparison of AGNPS and SESOIL, SN and SP losses in runoff computed from SESOIL were lower than one from AGNPS. Those differences could be explained as due to differences in sub-models for calculation runoff, soil loss, and chemicals in runoff, soil loss for each model.

Although the comparison between PRZM and SESOIL on soil loss was not very successful and also for particulate N and P, there was very good correlation and fit between soluble N and P that was calculated from both PRZM and SESOIL. Slopes of best-fit line are 1.025 and 0.94, respectively.

The limitation of PRZM was that we are not able to calibrate chemicals sorbed to the sediment for large amounts or high chemical losses attached to sediments. For SESOIL was that we are not able to calibrate for the high soil losses during certain rainfalls.

6.2-/ Recommendations

In order to have a very good assessment of potential chemical runoff and source of Lake water pollution, the following studies are suggested in the future;

1. Determination of Phosphorus in the different pools (total-P, Bio-available P and soluble P) due to rainfall erosion that will have different impact or accelerate Eutrophication as well as pollution of the lake water.
2. Determine N and P in runoff in different crops, levels of fertilizer, kinds of fertilizer and application timing before rainfall.
3. Agricultural Non-point Source Pollution model (AGNPS) is a good tool for evaluating potential chemical runoff in small-scale watersheds. The recommendation is that AGNPS be applied, after further calibration, to the whole riparian are of the Lake Naivasha to simulate potential chemical runoff for larger scale watershed. The present study caters for only a portion of the larger watershed that does not cover all the possible pathways the chemicals may follow into the Lake. Considering that the buffer zone (between the riparian area and the Lake) is narrow and in some places is not existing, the actual attenuation of the chemicals must be considered to be low. But one should take into account the accuracy of the model, cell size should not be too large, result of that will be very high peak runoff, soil loss and chemical losses. Model calibration is very important and should be taken care, because very high differences in output values can arise when using default and non-calibrated input parameters.
4. One should pay more attention in comparing different models in different pathways of pollutants. Using very good field measurement to calibrate the models and find out the agreement between models because each model had employed particular sub-models to compute one factor. Therefore corrections will be very important, otherwise one should apply a given model with careful calibration to have very good results.
5. For the flower and horticulture farms with high fertilizer inputs, they should be aware of the timing, methods of application, because runoff from rainfall that after fertilization with very high N, P content in sediment as well as in runoff water.
6. In order to conserve the Naivasha freshwater environment without putting-off agricultural production, the recommendation is that it is necessary to create or maintain small buffer zones of a forest plantation around the lake shoreline, especially in intensive agricultural farming areas.

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List of Used Symbols

Most symbols was described in the text and they are particularly represented for each Model, they are briefly described below.

Symbols	Description	Unit
In Rainfall simulation		
Pd	The amount of soil P released in time t (min)	mg/kg
W	Water/soil ratio	l/kg
Pa	Initial available soil P content	mg/kg
K, α, β	Constants for a given soil to calculate Soluble P	[-]
S	Mass of soil per unit area in the zone of interaction between surface soil and rain water	[g]
R	Rainfall rate per unit area	L/min
E	Effective depth of interaction between surf soil and runoff	mm
B	Bulk density of soil in this depth	kg/m ³
T	Duration	min
V	Total amount of rainfall during a runoff event	l
W	was approximated as S/runoff volume.	G/ml
In AGNPS model		
E	Soil loss in	tons/acre
EI	Rainfall energy intensity	100-ft-ton inch/acre hr
Ks	Soil erodibility factor	ton-acre hr/100-acre foot-ton inches
Lf	Slope length factor	[-]
Sf	Slope steepness factor	[-]
Cf	Cover and management factor	[-]
Pf	Support practice factor and	[-]
SSF	A calculated factor to adjust for slope shape	[-]
RF	Runoff	inches
RL	Storm precipitation	inches
S	Retention factor	inches
RO ⁻	N or P concentration in the runoff	ppm
\bar{C}	Mean concentration of the soluble portion of the nutrient in the soil surface during runoff	mg/l
EXK ⁻	An extraction coefficient for movement into the runoff	[-]
RO	total runoff	mm
RON	Soluble N in the runoff	pounds/acre
CZERON	Available soluble N content in the soil	kg/ha
CHECKN	Available N due to the rainfall	kg/ha
XKFN1	Rate constant for downward movement of N into the soil	[-]
EFI	Total infiltration for the storm	mm
XKFN2A	rate constant for N movement in the runoff	[-]
RO	Total storms runoff	mm
COEFF	A porosity factor	[-]
RN	N contribution due to the rain	kg/ha
EFRAIN	Effective rainfall	mm
ROP	Soluble P in the runoff	lbs./acre
CZEROP	Available P due to natural and fertilizer nutrient level	kg/ha
CHECKP	available P due to the initial soil	kg/ha
XKFP1	A rate constant for downward movement of P into the soil	[-]
XKFP2	The rate constant for movement into runoff	[-]

SOLN	Soluble N in the top centimeter of the original soil	kg/ha
SOLP	Soluble P in the top centimeter of the original soil	kg/ha
FN(X)	N fertilizer application in cell X	kg/ha
FP(X)	P fertilizer application in cell X	kg/ha
FA(X)	Fraction of this application remaining in the top cm of the soil	[-]
CSN	Concentration of N in the pore water of the surface cm of soil	ppm
CSP	Concentration of P in the pore water of the surface cm of soil	ppm.
RCN	N concentration in the rainfall	mg/l
EXKN1	Extraction coefficient for N downward movement	[-]
EXKP1	Extraction coefficient for P downward movement	[-]
EXKN2	Extraction coefficient for N movement in to runoff	[-]
EXKP2	Extraction coefficient for P movement into runoff	[-]
Qs(x)	Sediment discharge at the downstream end of the channel reach	lbs./s
Qs(0)	Sediment discharge at the upstream end of the channel reach	lbs./s
Qs1	Lateral sediment inflow rate	lbs./s
X	Downslope distance	feet
Lr	Reach length	feet
D(x)	Sediment deposition rate at point x	lbs/s-ft ²
W	Channel width	feet
Qp	Peak discharge	ft ³ /s
A	Drainage area	acres
Sc	Channel slope	ft/ft
RF	Runoff volume	inches
Lc	Channel length	feet.

In PRZM model

Ju	Uptake of chemical	g/day
F	The fraction of total water in the zone used for transpiration	day-1
ϵ	An uptake efficiency factor or reflectance coefficient	[-]
A	Cross section area of soil column	cm ²
Δz	Depth dimension of compartment	cm
Cw	Dissolved concentration of chemical	g/cm ³
θ	Volumetric soil water content	cm ³ /cm ³
P	Precipitation	cm/day
S	The watershed retention parameter	[-]
RCN	SCS runoff curve number	[-]
J _{QR}	The chemical loss due to runoff	g/day
Q	The daily runoff volume	cm ³ /day
A _w	Watershed area	cm ²
J _{ER}	The chemical loss due to erosion	g/day
X _e	The erosion sediment loss	metric tons/day
.f _{om}	The enrichment ratio for organic matter	g/g
C _s	Solid phase concentration of chemical	g/g
P	a units conversion	g/tons
X _e	The event soil loss	metric tons/day
LS	Length slope factor	[-]
V _r	Volume of event (daily) runoff	m ³
C	Soil cover factor	[-]
Q _p	Peak storm runoff	m ³ /sec
P	Conservation practice factor	[-]
K	Soil erodibility factor	[-]
.a	Units conversion factor	[-]

In SESOIL model

C _{sa}	Pollutant concentration in soil air	µg/mL
.c	Pollutant concentration in soil water	µg/mL
H	Henry's law constant	m ³ atm/mol
R	Gas constant	[8.2*10 ⁻⁵ m ³ atm/(mol ⁰ K)]
T	Soil temperature	⁰ C
S	Pollutant absorbed concentration	µg/g soil
K _d	Pollutant partitioning coefficient	(µg/g soil)/(µg/mL)
.c	Pollutant concentration in soil water	µg/mL
.n	Freundlich constant.	[-]
c _o	Overall (total) pollutant concentration	µg/cm ³
F _a	The air-filled porosity	ml/ml
.n	Soil (total) porosity	ml/ml
θ	Soil moisture (water) content	ml/ml
ρ _b	Soil bulk density	g/cm ³

List of Acronyms

AE	Accelerated Eutrophication
AGNPS	Agriculture Non-point Pollution Source
BD	Bulk Density
DO	District Office
EUT	Eutrophication
E	Evaporation
EC	Electrical Conductivity
ET	Evapotranspiration
GIS	Geographic Information Systems
Ln	Natural Logarithmic
MSM	Mineral Soil Moisture (m ³ /m ³)
N	Nitrogen
R	Rainfall
RO	Runoff
RUSLE	Revised Universal Soil Loss Equation
P	Phosphorus
Bio-P	Bio-available Phosphorus
Bray1-P	Bray 1-Available Phosphorus
OC	Organic Carbon
Olsen-P	Olsen-Available Phosphorus
OM	Organic Matter
OSM	Organic Soil Moisture content (m ³ /m ³)
SED.	Sediment
SESOIL	Seasonal Soil Compartment Model
SP	Soluble Phosphorus
PRZM	Pesticide Root Zone Model
PP	Particulate Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
USLE	Universal Soil Loss Equation

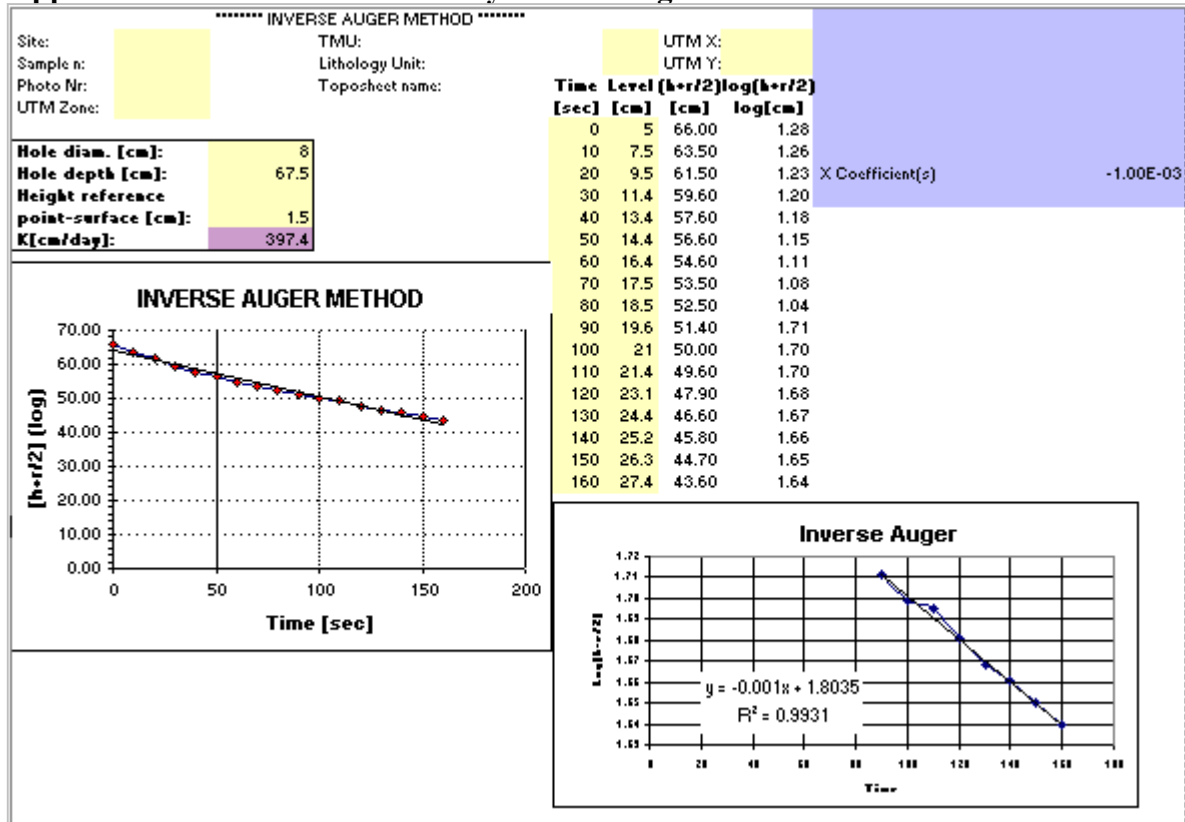
A. APPENDICES

Appendix A-1: Typical Schemes for application of Fertilizers and pesticides for horticulture in Riparian Agriculture area Lake Naivasha

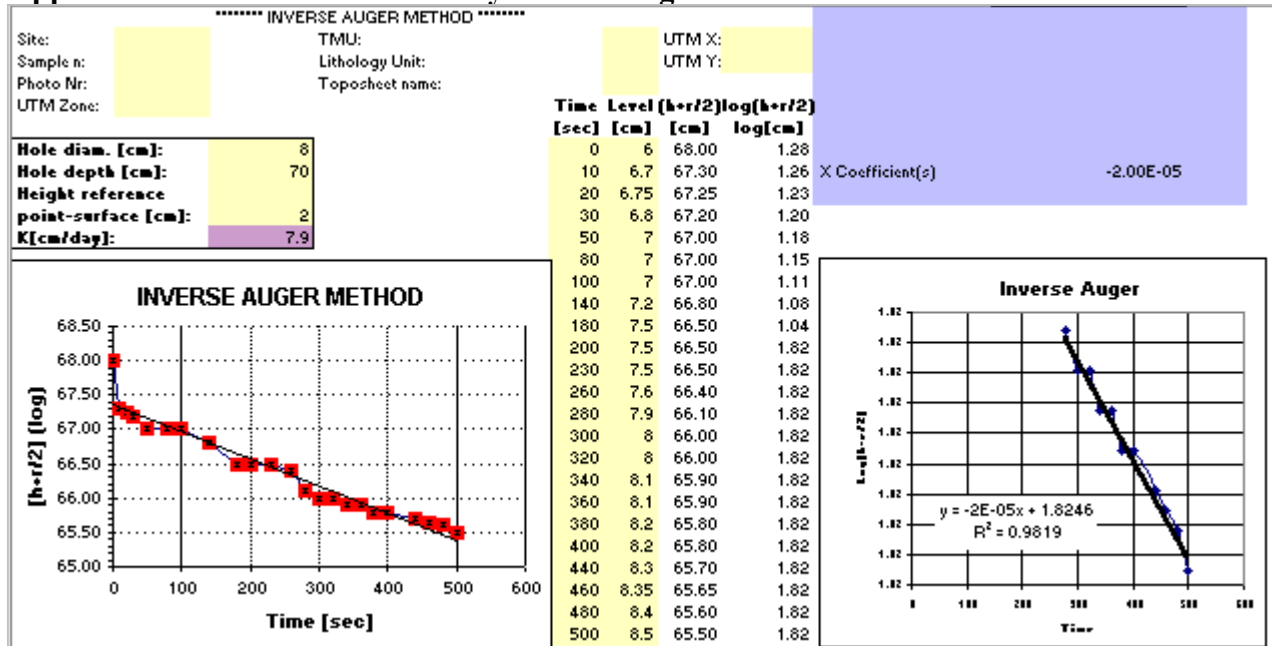
Crop	Fertilizer		Pesticides	
	Kind	Dose	Kind	Dose (ml/ha/crop)
Beans (kg/ha/crop for fertilizer)	Manure	10000	Lasso	1250
	DAP	100	Copper green	750
	Urea	100	Pyrimix	1000
			Coverate	400
			Alto	140
			Sumidicin	1500
			Plintunix	70
			Folieur	125
			Jumidicin	500
			Stroby	100
			Malathium	500
Cabbage (kg/ha/crop for fertilizer)	Manure	10000	Xenteri	500
	DAP	100	Dymix	500
	Urea	100	Coverate	300
			Suger	1000
			Thrizide	250
			Murathium	500
			Pyrimix	500
			Dimu	250
			Jumicidin	500
			Lesseade	200
		Dipen	250	
Rose (kg/ha/every two day)	MgSO4	36.6	ND	
	KSO4	3.3		
	(NH4)2SO4	5		
	KNO3	30		
	Misrosol	1		
	CuSO4	0.03		
	M.A.P	8.3		
	Sodium molipdate	0.025		
	Ca NO3	63.3		
	KNO3	13.3		
	Hamprion	0.5		
UREA	6.6			
Carnation (kg/ha/every two day)	MgSO4	25	ND	
	(NH4)2SO4	20		
	Kcl	15		
	Borax	0.4		
	M.A.P	28		
	Ca(NO3)2	88		
	KNO3	15		
Statice (kg/ha/every two day)	Mg SO4	6.6	ND	
	K SO4	6.8		
	NH4 SO4	6		
	Borax	0.3		
	CaNO3	3.5		
	KNO3	4.5		

ND: Not determine

Appendix A-2a: Calculation of K by inverse Auger method for Sand loam



Appendix A-2b: Calculation of K by inverse Auger method for Silt loam



Appendix A-3: Calculation of mean soluble P of runoff

Simulation	Duration (minute)	Rain (ml)	Rain Intensity (mm/hr)	RO volume (ml)	Sed. Conc. (g/l)	Soil loss (kg/ha)	K const.	P-Olsen (mg/kg)	ln(E)	E (mm)
A1.1	10	2000	192	1010	14.29	2308.94	0.025	112	2.924	18.620
A3.2	18	2000	106.67	1190	7.90	1503.40	0.025	82	2.669	14.431
A4.2	9	2000	213.33	750	9.96	1195.68	0.025	126	2.533	12.596
A5.1	9	2000	213.33	820	4.32	567.31	0.061	273	2.090	8.089
A6.4	11.13	2000	172.46	980	6.58	1031.74	0.035	729	2.342	10.400
A7.2	12.63	2000	151.98	500	0.75	60.16	0.061	28	0.758	2.133
A9.1	13.28	2000	144.54	890	8.65	1231.48	0.109	103	2.550	12.805
O1.1	10	2000	192	350	1.13	63.17	0.109	103	0.683	1.979
O2.1	15	2000	128	930	2.44	363.67	0.029	353	1.722	5.598
O3.1	9.23	2000	207.94	86	2.26	31.04	0.109	22	0.261	1.298
O4.2	10.33333	2000	142.928	400	2.82	180.48	0.109	110	1.306	3.692
O5	10.75	2000	178.60	560	1.88	168.45	0.109	39	1.265	3.544

Simulation	BD (kg/dm ³)	a	b	Rain (mm)	Plot area (cm ²)	E (cm)	soil mass (g)	W	SP (mg/kg)	Measured P (mg/l)
A1.1	1.116	0.06	0.329	32	625	1.862	1298.775	1.286	2.268	1.35
A3.2	1.116	0.06	0.329	32	625	1.443	1006.581	0.846	1.161	0.71
A4.2	1.116	0.06	0.329	32	625	1.260	878.557	1.171	1.663	1.57
A5.1	1.116	0.319	0.240	32	625	0.809	564.203	0.688	8.656	7.57
A6.4	1.116	0.195	0.304	32	625	1.040	725.374	0.740	13.511	13.44
A7.2	1.129	0.319	0.240	32	625	0.213	150.524	0.301	0.216	1
A9.1	1.129	0.319	0.240	32	625	1.281	903.570	1.015	11.617	13.57
O1.1	1.129	0.146	0.574	32	625	0.198	139.645	0.399	0.647	0.54
O2.1	1.129	0.094	0.794	32	625	0.560	394.992	0.425	1.321	2.04
O3.1	1.129	0.146	0.304	32	625	0.130	91.570	1.065	0.155	0.15
O4.2	1.129	0.146	0.304	32	625	0.369	260.525	0.651	1.928	1.03
O5	1.129	0.146	0.304	32	625	0.354	250.064	0.447	0.588	1.07

Appendix A-4: Procedure for soil analysis

I. pH-H₂O and pH-KCl

1) Principle

The pH of the soil is potentiometrically measured in the supernatant suspension of a 1:2.5 soil:liquid mixture. The liquid is either water (pH-H₂O) or a 1 M KCl solution (pH-KCl)

2) Procedure

- Weight 20 g fine earth into a 100 ml polythene wide-mouth type bottle. Include a blank.
- Add 50 ml liquid (water or 1 M KCl solution) and cap the bottle.
- Shake for two hours
- Before opening the bottle for measurement, shake by hand one or twice
- Immerse electrode in upper part of suspension
- Read pH when reading has stabilized (accuracy 0.1 unit)

II. Organic Carbon

1) Principle

The Walkley-Black procedure is followed. This involved a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid at about 125°C. The residual dichromate is titrated against ferrous sulphate. To compensate for incomplete destruction an empirical correction factor of 1.3 is applied in the calculation of the result.

2) Procedure

- Grind approx. 5 g fine earth to pass a 0.25 mm sieve.
 - Weigh 1 g of this material (accuracy 0.01g) into a 500 ml wide-mouth erlenmeyer flask. Include a control sample.
 - Add 10.00 ml dichromate solution. Include two blanks (erlenmeyer flask without soil) to determine the molarity of the ferrous sulphate solution.
 - Carefully add 20 ml sulphuric acid with a measuring cylinder, swirl the flask and allow to stand on a pad for 30 minutes (in fume cupboard)
 - Add about 250 ml water and 10 ml of phosphoric acid with a measuring cylinder and allow to cool.
 - Add 1 ml of indicator solution and titrate with ferrous sulphate solution while the mixture is being stirred. Near the end-point the brown color becomes purple or violet -blue and titration must be slow down. At the end-point the colour changes sharply to green. If more than 8 of the 10 ml dicromate added has been reduced then repeat the determination with less soil
- 3) Calculation

$$\text{Carbon content of the soil \%C} = M * \frac{V1 - V2}{S} * 0.39 * \text{mcf}$$

Where: M= molarity of Ferrous sulphate solution (from blank titration)
V1= ml Ferrous sulphate solution required for blank
V2= ml Ferrous sulphate solution required for sample
S= weight of air dry sample in gram
 $0.39 = 3 * 10^{-3} * 100\% * 1.3$
mcf = Moisture correction factor

Conversion of the % carbon to % organic matter is done by multiplying with the empirical factor 2
%Organic matter = 2*%Carbon.

III. Nitrogen

1) Principle

The Micro-Kjeldahl is followed. The sample is digested in sulphuric acid and Hydrogen peroxide with selenium as catalyst and whereby organic nitrogen is converted to ammonium sulphate. Solution is then made alkaline and ammonia is distilled. The evolved ammonia is trapped in boric acid and titrated with standard acid.

2) Procedure

2a) Digestion

- Grind approx. 5 g fine earth to pass a 0.25 mm sieve.

- Weigh 1 g of this material (accuracy 0.01 g) into digestion tube. Of soils, rich in organic matter (>10%), 0.5 g is weighted in. In each batch, include two blanks and a control sample.
- Add 2.5 ml digestion mixture.
- Add successively 3 aliquots of 1 ml hydrogen peroxide. The next aliquot can be added when frothing has subsided. If frothing is excessive, cool the tube in water.
- Place the tube on the heater and heat for about 1 hour at moderate temperature (200°C)
- Turn up the temperature to approx. 330 °C (just below boiling temp.) and continue heating until mixture is transparent (about 2 hours)
- Remove tubes from heater, allow to cool and add approx. 10 ml water with a wash bottle while swirling.

2b) Distillation

- Add 20 ml boric indicator solution to a 250 ml beaker and place beaker on stand beneath the condenser tip
- Add 20 ml of NaOH 38% to digestion tube and distil for about 7 minutes during which approx. 75 ml distillate is produced
- Remove beaker from distiller, rinse condenser tip, and titrate distillate with 0.01 M HCl until colour changes from green to pink.

3) Calculation

$$\%N = \frac{a - b}{s} * M * 1.4 * mcf$$

Where:

- a= ml HCl required for titration sample
- b= ml HCl required for titration blank
- s= air-dry sample weight in gram
- M= molarity HCl
- 1.4= $14 * 10^{-3} * 100\%$ (14=atomic weight of Nitrogen)
- mcf= moisture correction factor

IV. Particle-size

Separation of the mineral part of the soil into various size fractions and determination of the proportion of the fractions. The analysis applied to the fine earth (<2mm).

Of paramount importance in this analysis is the pretreatment of the sample aimed at complete dispersion of the primary particles. Therefore, cementing materials (usually of secondary origin) such as organic matter and calcium carbonate may have to be removed. In some cases also sesquioxides may need to be removed. It may be argued, however, that for agriculture purposes it is often not relevant or even fundamentally wrong to remove these components.

After shaking with a dispersing agent, sand is separated from clay and silt with a 50 µm sieve**. The sand is fractionated by dry sieving, the clay and silt fractions are determined by the pipette method (Reeuwijk, 1995, page3-2)

V. Phosphorus (Extracting according to Olsen et al)

1) Principle

The sample is extracted with a sodium bicarbonate solution of pH 8.5. Phosphate in the extract is determined colorimetrically with the blue ammonium molybdate method with ascorbic acid as reducing agent. The high pH of the extracting solution renders the method suitable for calcareous, alkaline or neutral soils containing Ca phosphates because the Ca concentration in solution is suppressed by precipitation of CaCO₃. As a result, the phosphate concentration in solution can increase.

The procedure can, in principle, also be applied to acid soils as the relatively high pH of the carbonate buffer suppresses the solubility of Al and Fe and thus allows the phosphate concentration to increase.

2) Procedure

- Weigh 5 g fine earth (accuracy 0.01 g) into a 250 ml polythene shaking bottle. Include two blanks and a control sample.
- Add 100 ml of the extracting solution
- Shake for 30 minutes
- Filter through a hardened filter (e.g Whatman42)
- Pipette into (short) test tubes 3 ml of the standard series, the blanks and the sample extracts
- Slowly add 3 ml of the mixed reagent by pipette and swirl (CO₂ evolution)
- Allow the solutions to stand at least 1 hour for the blue colour to develop its maximum

- Measure absorbance on spectrophotometer at 882 or 720 nm

3) Calculation

Plot a calibration graph of absorbance against concentration

$$P \text{ (mg/kg soil)} = (a-b) * \frac{100}{1000} * \frac{1000}{s} * \text{mcf} = (a-b) * \frac{100}{s} * \text{mcf}$$

Where:
 a= mg/l P in sample extract
 .b= ditto in blank
 s= sample weight in gram
 mcf= moisture correctionfactor

*Conversion factor for P₂O₅ = 2.31 * P*

VI. Cation Exchange Capacity (CEC)

1) principle

This rapid and convenient method is based on the strong affinity of the monovalent silver thiourea complex cation (AgTU) for negatively charged colloid surfaces, mineral and organic alike. This allows a one-step centrifuge extractin with a 0.01 M AgTU solution in which complete exchange is achieved. Thus, the supernatant solution contains all exchangeable cations while the decrease in Ag concentration is a measure for CEC

2) Procedure

- Crush (not grind) approx. 5 g of fine earth to pass a 0.5 mm sieve
- Weigh 1 g of this sample (accuracy 0.005 g) into a 50 ml centrifuge tube include two blank and a control sample
- Pipette 40 ml of the AgTU extractant into the tube and close this with a cap or rubber stopper
- Shake for 4 hours in reciprocating shaking machine
- Centrifugate
- Measure Ca, Mg, K, Na and Ag in the clear supernatant extract
 (for Detailed steps in "Procedure for soil analysis", Reeuwijk 1995)

Appendix A-5: Output parameters for cells calibrated from field measurement in silt loam and sand loam

Output parameter	unit	Silt loam	Sand loam
RO volume	inches	0.48	0.32
Peak Runoff Rate	cfs	0.55	0.54
Total Sediment Yield	tons	0.05	0.02
Total Sediment Yield	tons/ha	1.235	0.494
Total Nitrogen in Sediment	lbs/ha	1.93	0.27
Total Nitrogen in Sediment	kg/ha	2.163	0.303
Total Soluble Nitrogen in Runoff	lbs/ha	0.23	1.08
Total Soluble Nitrogen in Runoff	kg/ha	0.258	1.211
Soluble Nitrogen Concentration in Runoff	ppm	2.16	14.71
Total Phosphorus in Sediment	lbs/ha	0.32	0.13
Total Phosphorus in Sediment	kg/ha	0.359	0.146
Total Soluble Phosphorus in Runoff	ppm	0.25	0.01
Total Soluble Phosphorus in Runoff	kg/ha	0.28	0.011
Soluble Phosphorus Concentration in Runoff	ppm	2.34	0.16

Appendix A-6: Calibrated input file for PRZM (Standard file for Nitrogen)

```

1 CHEMICAL, NO TEMPERATURE CORRECTION, PRZM INPUT FOR ZONE 1
HYDROLOGY PARAMETERS (CROP DATA FROM USDA NO.283 HANDBOOK)
  0.80   0.00   0 15.000   1   3
  1
  0.165  0.489  0.65  1.00  2.5
  1
  1   0.15  20.0 60.000   3 85 86 65 0.1 0.1 0.1 0.0
  1
010199 201099 301299   1
PESTICIDE TRANSPORT AND TRANSFORMATION AND APPLICATION PARAMETERS
 12   1   0
Nitrogen
010199   0   5.0 100.00
010299   0   5.0 100.00
010399   0   5.0 100.00
010499   0   5.0 100.00
010599   0   5.0 100.00
010699   0   5.0 100.00
010799   0   5.0 100.00
010899   0   5.0 100.00
010999   0   5.0 100.00
011099   0   5.0 100.00
011199   0   5.0 100.00
011299   0   5.0 100.00
  1   1
SOILS PARAMETERS
 20.0   1.0   0 0 0 0 0 0 0 0 0
 0.0E00 4.72E2 5.0E00
  1
  1   20.0  1.35  0.250   0.0   0.0
      0.012 0.012 0.000
      2.5   .270   .040   1.0   18.
  0   0
WATR  YEAR   1  PEST  YEAR   1  CONC  YEAR   1
  3  YEAR
RFLX1  TSER   1.0E05
RUNF   TSER
INFL   TSER   12

```

Appendix A-7: Calibrated input file for PRZM (Standard file for Phosphorus)

```

1 CHEMICAL, NO TEMPERATURE CORRECTION, PRZM INPUT FOR ZONE 1
HYDROLOGY PARAMETERS (CROP DATA FROM USDA NO.283 HANDBOOK)
  0.80   0.00   0 15.000   1   3
  1
  0.165  0.49  0.65  1.00  2.5
  1
  1   0.15  20.0 60.000   3 85 86 65 0.1 0.1 0.1 0.0
  1
010199 201099 301299   1
PESTICIDE TRANSPORT AND TRANSFORMATION AND APPLICATION PARAMETERS
 12   1   0
Phosphorus
010199   0   5.0 40.00
010299   0   5.0 40.00
010399   0   5.0 40.00
010499   0   5.0 40.00
010599   0   5.0 40.00
010699   0   5.0 40.00
010799   0   5.0 40.00
010899   0   5.0 40.00
010999   0   5.0 40.00
011099   0   5.0 40.00
011199   0   5.0 40.00
011299   0   5.0 40.00
  1   1
SOILS PARAMETERS
 20.0   1.0   0 0 0 0 0 0 0 0 0
 0.0E00 0.0E00 0.0E00
  1
  1   20.0  1.35  0.250   0.0   0.0
      0.012 0.012 0.000
      2.5   .270   .040   1.0   85.8
  0   0
WATR  YEAR   1  PEST  YEAR   1  CONC  YEAR   1
  3  YEAR
RFLX1  TSER   1.0E05
RUNF   TSER
INFL   TSER   12

```

Appendix A-8: Calibrated input file for SESOIL(Standard file for Nitrogen)

Application and Washload Data			
		<input checked="" type="checkbox"/> Washload simulation	
Application data		Washload	
Number of years	<input type="text" value="1"/>	Number of years of data	<input type="text" value="1"/>
Number of soil layers	<input type="text" value="2"/>	Washload area (cm2)	<input type="text" value="100000000"/>
Application area (cm2)	<input type="text" value="100000000"/>	Silt	<input type="text" value=".41"/>
Latitude of the site (deg N)	<input type="text" value="0.00"/>	Sand	<input type="text" value=".42"/>
Loading Type		Clay	<input type="text" value=".17"/>
<input type="radio"/> Instantaneous (Loading in ug/cm2/day)		Slope Length (cm)	<input type="text" value="2926"/>
<input checked="" type="radio"/> Continuous (Loading in ug/cm2/month)		Average Slope (cm/cm)	<input type="text" value=".04"/>
<input type="checkbox"/> Initial concentration for sublayers	<input type="text"/>		

Appendix A-9: Calibrated climate input file for SESOIL(Standard file for Nitrogen)

Month	Air temp °C	Cloud cover	Humidity	Albedo	Evapotrans Cm/day	Precip cm	Duration days	# of storm	Lenth days
Oct	17.25	0	0	0	0.34	18	0.450986	9.725	30.4
Nov	16.9	0	0	0	0.33	18	0.461854	9.325	30.4
Dec	17.15	0	0	0	0.31	18	1.28077	5.325	30.4
Jan	17.8	0	0	0	0.33	18	1.16435	5.325	30.4
Feb	18.15	0	0	0	0.32	18	1.16435	5.325	30.4
Mar	18.45	0	0	0	0.35	18	0.399755	9.825	30.4
Apr	18.25	0	0	0	0.28	18	0.24451	9.425	30.4
May	17.45	0	0	0	0.23	18	0.334943	9.325	30.4
Jun	16.4	0	0	0	0.24	18	1.16435	5.325	30.4
Jul	15.85	0	0	0	0.23	18	1.16435	5.325	30.4
Aug	16.05	0	0	0	0.24	18	1.16435	5.325	30.4
Sep	16.6	0	0	0	0.37	18	1.16435	5.325	30.4

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