WATER BALANCE OF SECTIONS OF NARO MORU RIVER

BY

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DECLARATION

I declare that this thesis is my work and has not been submitted for a degree in any other university.

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24.1.92

DATE

This thesis has been submitted to the University of Nairobi with our approval as University supervisors.

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SYMBOLS AND ABBREVIATIONS

A	abstractions of water from river
asl	above sea level
C	concentration or conductivity
Cap	capillary rise
cfs	cubic feet per second
cm	centimetre
CP	channel precipitation
DR	local direct runoff flowing into reach from adjacent catchment area and not from the upstream reach
E	evaporation
Eo	Average annual potential evapotranspiration
Et	evapotranspiration
ft	foot
FZ,fz	footzone
g	gramme
g/l	grammes per litre
GW	net groundwater discharge into reach when positive and net transmission losses from reach when negative
h	gauge height
H	water stage
ha	hectare (10,000 m^2)
hr	hour
I	inflow
Inf	infiltration into soil
kg	kilogramme
km	kilometre
km^2	square kilometres
KSh	Kenya shilling
LRP	Laikipia Research Programme
l/s	litres per second
m	metre
m^2	square metres
m^3/s	cubic metres per second
min	minute
ml	millilitres
mm	millimetre
MoW	Ministry of Works
MoWD	Ministry of Water Development
No.	number
O	outflow
Pr	precipitation
Q	water discharge
Qc	discharge computed from the rating curve
Qdr	groundwater outflow to open water courses and streams
Qi	measured discharge
Qinf	infiltration through riverbed
r	average annual rainfall
RGS	River gauging station
Ri	interflow
RI	river inflow into reach

SYMBOLS AND ABBREVIATIONS

Ro	Runoff in large stream channels
RO	river outflow from reach
Roff	runoff
Se	standard error
Smr	standard error of the mean rating curve
SZ,sz	savannah zone
t	time
USDI	United States Department of Interior
V	velocity
WMO	World Meteorological Organisation
Δ SW	change of water in channel storage
Δ S	change of water in storage
Δ Q	change in streamflow within reach after abstractions have been accounted for

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ABSTRACT

This water balance study is directed towards the solution of problems resulting from the utilization of river water resources for domestic purposes and for irrigation by small-scale farmers living on the semi-humid to semi-arid footzone and the semi-arid savannah regions of Naro Moru river basin and its effect on the residual discharge reaching river Ewaso Ng'iro. The study was carried out in two reaches of Naro Moru river located in the footzone and savannah areas of the basin.

The study entailed making an inventory of water supply points along Naro Moru river, determining the amount of water abstracted from each water supply point over a period of six months, comparing the actual abstractions with the authorized abstractions, measuring river discharge at the river gauging stations marking the ends of each reach, and using a river reach water balance to estimate groundwater inflow into reach, transmission losses within reach and direct runoff contribution to reach. The aim of the study was to find out how streamflow is affected by each of the factors mentioned above as a prerequisite for recommending ways of improving the water allocation and management.

On a monthly basis, the amount of water abstracted from each reach as a percentage of river inflow into reach was about 10 % in the footzone and savannah during the short rains season (November and December) and rose during the dry season up to 35 % in February and 47 % in March for the footzone and savannah reaches respectively. Community water supply projects which increased by four over the six year period from 1984 were responsible for about 97 % of the water abstracted from the river. Authorized abstractions constituted about 8 % of the measured dry season abstractions and 30 % of the measured wet season abstractions.

During the short rains in November and December, the footzone river reach received additional flow from groundwater sources and from direct runoff while the savannah river reach lost water on transmission possibly due to infiltration into the riverbed and sides during high flows. Release of groundwater into the footzone river reach continued into the dry month of January and transmission losses for both reaches were lower over the ensuing dry season (January to March). The long rains season resulted in the addition of direct runoff into the two reaches but the effect was more pronounced in the savannah than in the footzone. This may be explained by the fact that the soils in the savannah region swell on wetting thus reducing the rate of infiltration while those in the footzone have generally higher rates of infiltration.

Proper assessment, allocation and management of the available river water may be achieved by installing simple structures to measure the amount of water diverted especially at the head of community water supply conveyance systems, maintaining a stricter control over the issuing and renewal of water permits and improving the efficiency of water use.

1 INTRODUCTION

1.1 Background

Naro Moru river is one of the nine perennial tributaries of river Ewaso Ng'iro draining the western and northwestern slopes of Mount Kenya and forming the Mount Kenya sub-catchment of upper Ewaso Ng'iro river basin. The main sources of these rivers are to be found within the forested areas of Mount Kenya.

Small-scale mixed farming in the area west and northwest of Mount Kenya, which is now the dominant land-use system, evolved after independence following the process of Africanisation. A representative sample of plot size distribution showed that about 70 % of the plots in the small-scale farming sector are 1 - 4 acres and have been found to be too small to ensure survival at subsistence level for an average household size of 5 - 6 persons (Kohler, 1987; Flury, 1987; Kohler and Speck, 1983).

The immigrant population originated from neighbouring high potential, densely populated districts (Kohler, 1987) and lack knowledge on dryland farming techniques like water conservation (Liniger, 1988). They are faced with a challenge of small farm sizes in a dry environment. Their perception of intensification of agriculture is through irrigation (Kohler, 1987). Water is cited by many farmers as of utmost priority to development (Kohler and Speck, 1983). According to Decurtins (1990) and Decurtins et al (1988), the water resources available in the rivers are sufficient only for domestic and livestock consumption and irrigation of kitchen gardens.

The need to be self-sufficient in food, to reduce the risk in food production, and to produce surplus food for cash to satisfy the rapidly increasing population (due to natural increase and immigration) has resulted in an increased demand for river water first for domestic purposes but also for irrigation (Wiesmann, 1990b, Flury, 1987). There is an increasing number of water supply schemes (Decurtins et al. 1988).

Increased dry season abstraction from the Mount Kenya tributaries of river Ewaso Ng'iro already causes periodic water shortages in the lower parts of the Ewaso Ng'iro river thus denying the pastoral communities living in the semi-arid areas further downstream of one of their most important sources of water during the dry season (Decurtins, 1990; Decurtins et al 1988).

These conflicts of interest between users and uses of river water has prompted a number of studies to be carried out in the Ewaso Ng'iro basin. The studies were mainly aimed at assessing the available water resources with a view to improving the allocation and management of water. During these studies, the importance of different ecological belts around the mountain in relation to their contribution and utilization of streamflow has been recognized.

Jones cited in MoW (1961), studied the low flows of Naro Moru river in relation to areas of recharge and discharge and found that only a small percentage of the flow at river gauging station 5BC2 is derived from melt from the glaciers of Mount Kenya. The Ministry of Works, (MoW, 1961), which carried out an investigation into the water resources of Ewaso Ng'iro basin in 1958-1961 found that the records of Naro Moru at river gauging station 5BC2 were unlikely to give a true position of the river regime because a number of farms were taking water from the river above the gauging station. Abstractions were also heavy below the gauge and therefore the flows recorded bore no relationship to that reaching the Ewaso Ng'iro.

A water resources assessment study by the Ministry of Water Development, (MoWD, 1987) in the upper Ewaso Ngiro basin attempted to include abstractions by carrying out a water permit inventory to obtain information on legal water abstractions. It was found that the available low flows, even after accounting for abstractions, decreased gradually in a downstream direction. This was attributed to the fact that baseflow originates from the higher parts of the catchment and that part of it infiltrates into the riverbed and swamps along the lower reaches. It was also felt that illegal abstractions increased in a downstream direction but no reliable estimate of their magnitude was available.

Since 1981, hydrological studies on the perennial streams west to north of Mount Kenya have been carried out mainly to determine the amount of surface water and response to rainfall (Decurtins et al, 1988; Leibundgut, 1986; Decurtins, 1990). More recently, an integrated approach combining climatological investigations, land-use and vegetation mapping, and soil studies to determine actual evaporation rates, infiltration rates and available soil water storage capacity, and hydrological measurements to assess rainfall and runoff was used by Liniger and Decurtins (1990) to carry out a water balance for five subcatchments located in different ecological zones of the Naro Moru river basin starting from the alpine zone of Mount Kenya down to the semi-arid savannah. The aim of the water balance was to determine how rainfall on the different zones of the basin, contributes to surface flow and groundwater storage over the wet and dry seasons after accounting for evapotranspiration loss and change in soil water storage.

The results showed that the forest zone is the area of highest contribution to surface runoff and to groundwater recharge. River flow during the dry season is mainly derived from the local groundwater sources in the lower forest belt. Below the forest belt, water use due to legal and illegal abstractions was felt to be a more important element of the water balance compared to surface runoff. No further deductions for two subcatchments below the forest (footzone and savannah) could be drawn because abstractions were not included in the water balance measurements.

1.2 Objectives

This study was carried out in two sections (reaches) of Naro Moru river which are situated in two different ecological zones: footzone (below the forest) and savannah. The analysis was done for a period of six months starting from November 1990.

The objectives of the study were:

(1) To determine the daily mean discharge at the river gauging stations marking the beginning and end of each reach;

(2) To carry out a water supply inventory for Naro Moru river;

(3) To assess changes in river water diversion since 1984;

(4) To assess the nature and extent of illegal abstractions on streamflow;

(5) To undertake a river reach water balance study to assess direct runoff into reach, ground water discharge into reach, and losses during transmission;

2. THE STUDY AREA

2.1 Location

The Naro Moru river basin spreads westwards from the peak of Mount Kenya to the Laikipia plateau between latitudes 0^0 03' and 0^0 11' South and longitude 36^0 55' and 37^0 15' East. The altitude ranges from 5199 m a.s.l. at the peak of the mountain to 1800 m a.s.l. near the confluence with the river Ewaso Ngiro. The area of the basin is 169.2 km^2.

The upper half of the basin which is sub-humid to humid is under forest reserve and Mount Kenya National Park while in the other half, small-scale farming predominates. This study concentrates on this lower half of the basin which lies between 1800 m a.s.l. and 2300 m a.s.l. (Leibundgut, 1986; Sombroek et al, 1980).

Figure 2.1 shows Naro Moru river in relation to the other rivers forming the upper Ngiro subcatchment.

2.2 Physical setting

In previous studies (Liniger and Decurtins,1990; Decurtins, 1990; Leibundgut, 1986) Naro Moru river basin has been divided into five geographic and hydrographic zones as shown in Figure 2.2. These are:

1.	The Alpine/peak zone	4160-5199 m a.s.l.
2.	Moorland	3540-4160 m a.s.l.
3	Forest	2300-3540 m a.s.l
4.	Footzone	1980-2300 m a.s.l
5.	Savannah	1800-1980 m a.s.l

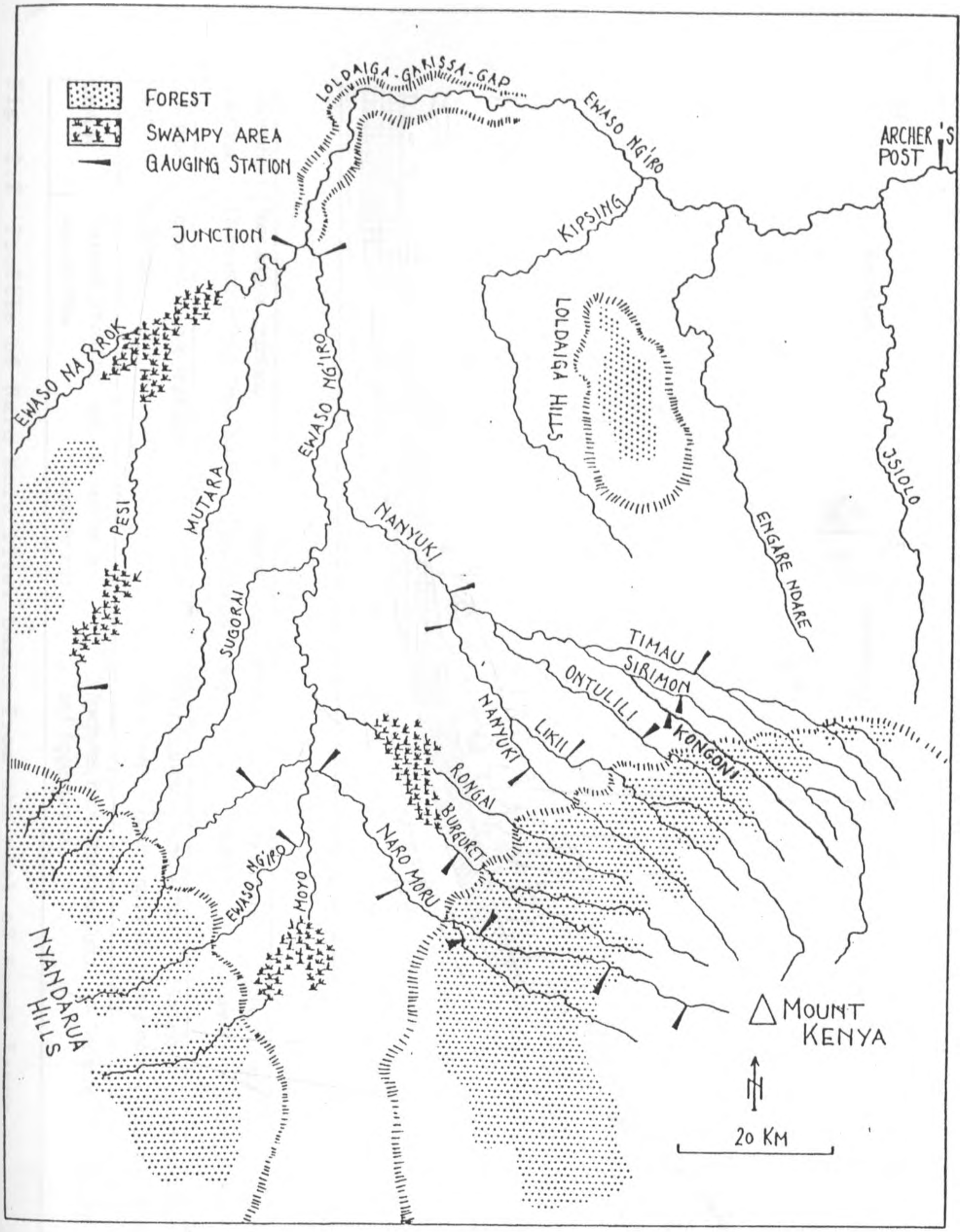
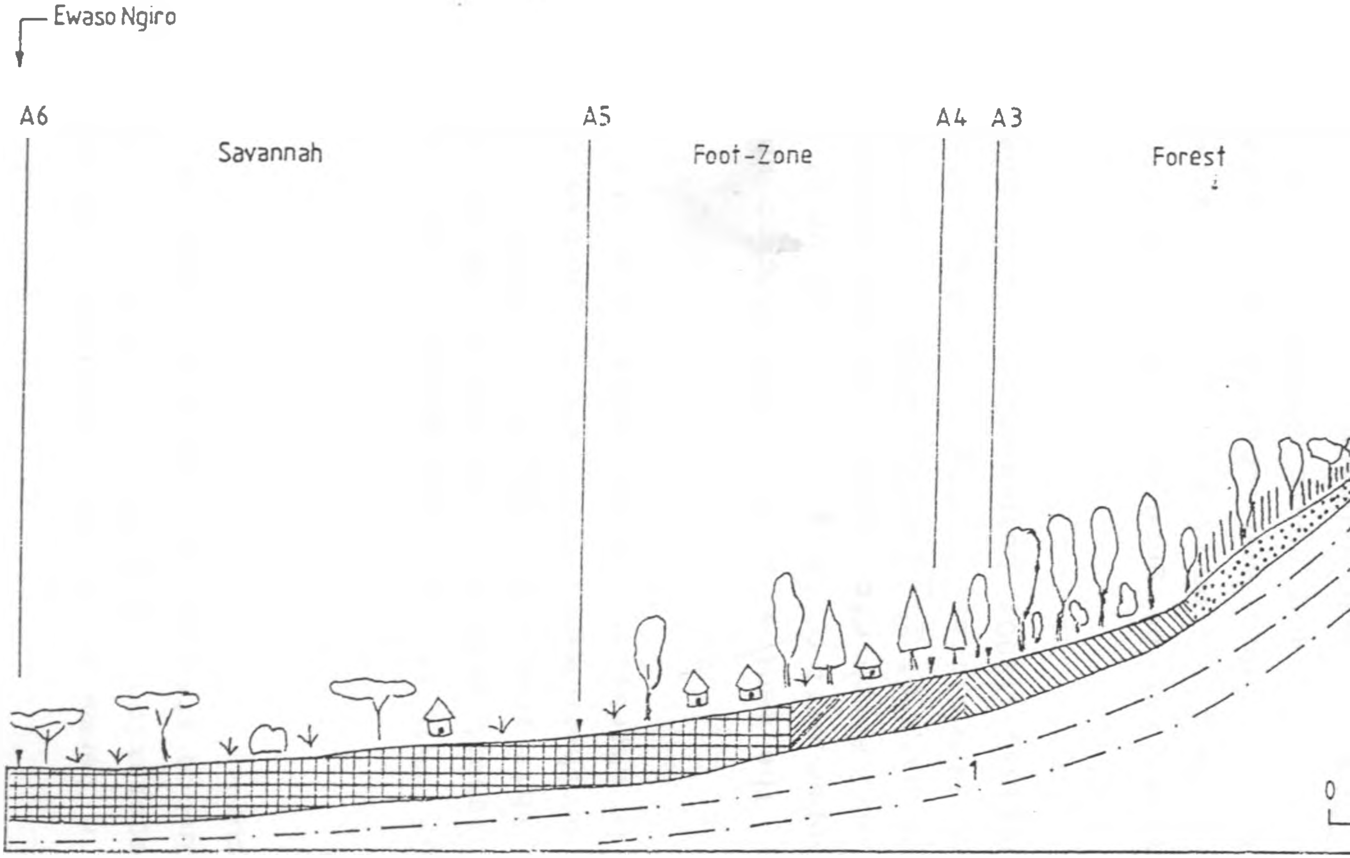


Fig. 2.1 Naro Moru river in relation to other rivers in the upper Ewaso Ng'iro catchment (upstream from Archer's Post).

(Source: Decurtins, 1990)



Vegetation / Land Use	Open accacia - grassland Large scale grazing, Small-holder	Forest (Open / Plantation) Small-holder (mainly crops)		Dry montane Forest	Mixed bamboo/ Forest
Soil type / Depth	Verto-luvic, Luvic Phaeozem Very deep		Ferric Luvisol Very deep	Humic Acrisol Deep - very deep	Andosol Deep-moder-ate
Geology	1. Porphyric Phonolites and Agglomerates	2. Kenytes and Agglomerates	3. Trachytes, Fissile Phonolites, Tuffs and Agglomerates		4. Nepheline

Fig. 2.2 Profile of Naro Moru river basin from the peak of Mount Keny
to the semi-arid Laikipia plateau (Source: Liniger, 1990)

The zones differ in terms of relief, drainage, geology, soils, climate, vegetation, land use and socio-economy. These factors influence streamflow within and outside the zone where they occur.

2.2.1 Alpine zone

Relief and drainage: This is the highest zone of Naro Moru river basin. The highest peak of Mount Kenya, Batian lies on the boundary of this zone and rises to a height of 5199 m a.s.l. The Northern Naro Moru river originates from this region which is characterized by tarns, glaciers and snowfields.

Geology and soils: The central plug of the volcano which is located on the upper part of this zone is made up of two intrusive rock masses, Porphyric, Phonolites and Nepheline Syenites. The lower part of the subcatchment is formed by Trachytes, Fissile Phonolites, Turfs and Agglomerates (Liniger and Decurtins, 1990; Leibundgut, 1986; Speck, 1983; Baker, 1967).

Predominant soil types can be grouped into three types: Lithosols and dystric Regosols on rock outcrops and sorees; Lithosols and Rankers on ridges and moraines; and Rankers, dystric Fluvisols, dystric and humic Gleysols in valley bottoms. Regosols, Luvisols and Rankers are well drained. The soils in this zone are generally shallow and the soil water capacity is low and does not exceed 50 mm (Liniger and Decurtins, 1990; Liniger, 1990; Speck, 1983).

Vegetation and land-use: Vegetation cover is only apparent in the lower part of the zone. The major part of the alpine zone is made up of bare rock, steep slopes, snow and ice. Tussock grasses are found on the marshy valley bottoms and giant groundsels (*Senecio Keniodendron*) are found on the drier better drained areas (Decurtins, 1990, Baker, 1967).

Climate and hydrology: Based on short term studies, the annual rainfall ranges from 600-1000 mm (Decurtins, 1990). Evapotranspiration rates are low. The average potential evapotranspiration during the dry season (Jan-March; July-Sept) is 0.4 mm/day and during the rainy season (April-June; Oct-Dec) it is 0.1 mm/day as calculated by Liniger (1990) following a short duration of measurements in 1990.

The two most important sources of Northern Naro Moru are the Lewis and Tyndal glaciers but springs and tarns also make substantial contribution to perennial streamflow (Decurtins, 1990).

2.2.2 Moorland

Relief and drainage: This zone extends from an elevation of about 3500 m to 4200 m above sea-level. The Northern Naro Moru passes through a wide U-shaped glacial formed valley which then changes into a steep deeply incised fluvial formed gorge below 4000 m. The Southern Naro Moru also originates from this zone. The valley sides are drained by small tributaries and by many diffuse groundwater outflows from the moorland (Decurtins, 1990; Speck,1983).

Geology and soils: The geological structure consists of Kenytes and Agglomerates in the upper part and Porphyric Phonolites and Agglomerates in the lower part. Dominant soils are medium to shallow Histosols and Andosols. The soils are well drained in the upper part of this subcatchment while in the lower parts, soils on the flat ridges are poorly drained and those on the valleys have variable drainage. The soil water capacity in the upper half of the zone is below 50 mm while in the lower half it ranges from 50-100 mm (Liniger, 1990; Speck, 1983).

Vegetation and land-use: Giant groundsels on the valley sides and Tussock grasses on the valley floor are found in the upper part. The lower part of the zone is dominated by the heather vegetation, mostly Erica and Philippia (Decurtins, 1990).

Climate and hydrology: The annual rainfall is higher than in the Alpine zone and it varies between 1000 mm and 1500 mm. The lower part of the moorland receives more rainfall than the upper part (Decurtins, 1990; Berger, 1989). The average rates of potential evapotranspiration are low and are similar to those in the Alpine zone (Liniger, 1990).

Decurtins (1990) found that the moorland had the highest groundwater recharge per unit area which he attributed to the high rainfall, low evapotranspiration rates and limited soil water capacity. The lower part of the moorland had the highest amount of excess water thus contributing greatly to the surface flow in the river.

2.2.3 Forest zone

Relief and drainage: This zone is located between 2300 m and 3540 m above sea level approximately. The relief changes from an area with one deep incised main drainage line with few minor incised tributaries to an area with a dense network of tributaries feeding the main stream. The drainage density is highest in this zone and the Naro Moru river receives the greatest contribution of surface flow from this zone (Decurtins, 1990; MoW, 1961).

The upper part of the forest is a zone of recharge to groundwater. The water later emerges at lower altitudes from the local and regional groundwater aquifers to feed springs and tributaries of the river (Schotterer and Muller, 1985).

<u>Geology and soils:</u> The geologic structure consists of Porphyric Phonolites and Agglomerates. Soil types include Histosols and Andosols of medium to shallow depth in the upper part, Andosols of moderate depth in the middle and deep to very deep humic Acrisols in the lower region. The soil drainage varies in the valley bottoms but soils in the valley sides are well to moderately-well drained (Liniger, 1990; Speck, 1983; Leibundgut, 1986). The soil water capacity is especially high in the lower half of this zone and it exceeds 200 mm (Liniger, 1990).

<u>Vegetation and land-use:</u> The vegetation found in this zone is Heath in a narrow belt in the upper part, Mixed Bamboo Forest in the middle region and Dry Montane Forest in lower region (Liniger and Decurtins, 1990; Baker, 1967). The area forms part of Mount Kenya Forest Reserve which was established in 1932. The influences of man on vegetation are first seen here. Indigenous trees species in the lower gentler parts have been replaced by exotic ones during the period when crop production by small-scale farmers was alternated by forest plantations (Kohler, 1986).

<u>Climate and hydrology:</u> The highest rainfall in Naro Moru river basin is experienced in the upper part of this zone at an altitude of 3200 m a.s.l. approximately (Decurtins, 1990). Rainfall in the forest zone ranges from 950 mm to 1600 mm per year (Decurtins, 1990; Berger, 1989). Average rates of potential evapotranspiration are 1.7 - 2.8 mm/day during the dry season (Jan-March; July-Sept) and 0.6 - 1.7 mm/day during the rainy season (April-June; Oct. Dec) (Liniger, 1990).

The combination of high rainfall, low rates of evapotranspiration, and well drained soils make this zone an area of considerable groundwater recharge (Liniger, 1990; Liniger and Decurtins, 1990).

2.2.4 Footzone

Relief and drainage: The footzone is a transitional zone situated between the volcanic slopes and the Central Laikipia plateau at an altitude range of 1980 m - 2300 m a.s.l. The river has a well marked course. The upper part of this zone still reflects the characteristics of the forest zone. The transition into the savannah zone is marked by the first dry river valley.

Geology and soils: The geologic structure is similar to that of the forest zone. The soils vary from very deep well-drained ferric Luvisols in the upper part to very deep, well to moderately-well drained verto-luvic Phaeozems in the lower regions of this zone and some planosols on plateaus (Liniger, 1990; Speck, 1983).

Vegetation and land-use: The landscape exhibits a humid appearance in the upper part and a semi-humid to semi-arid look in the lowest parts according to decreasing rainfall. A small part of the Mount Kenya Forest Reserve having an area of about 15 km^2 extends into this zone. The upper part of the footzone is intensively used for rainfed agriculture. Potatoes, peas, beans and vegetables are grown. In the lower part small-scale mixing farming is the major land-use type. Small acreages of irrigated agriculture exist (Kohler, 1990; Liniger and Decurtins, 1990; Leibundgut, 1986; Jaetzold and Schmidt, 1983).

Climate: The average annual rainfall increases with altitude from 800 mm at the lower part of the footzone to 900 mm at the upper part (Berger, 1989).

The upper part of this zone is semi-humid with an r/E_0 value of 50-65%, where r = average annual rainfall and E_0 = average annual potential evaporation. Rainfall therefore is not the major limitation to maximum production. Risks of crop failure is fairly low. The lower part of the zone is semi-humid to semi-arid with an r/E_0 ratio of 40-50% (Sombroek et al, 1980).

The average potential evapotranspiration is given by Liniger (1990) as 4.5 mm/day during the dry season (Jan-March; July-Sept) and 3.3 mm/day during the rainy season (April-June; Oct-Dec). Decurtins (1990) adds that due to the high evapotranspiration rates, water stress may be experienced during the dry season.

2.2.5 Savannah zone

Relief and drainage: The savannah is part of the Central Laikipia Plateau. It lies between 1800 m and 1980 m a.s.l. in Naro Moru river basin. The topography is almost flat to gently undulating with some few dry river valleys. The mean groundwater level lies more than 30 m below the surface as estimated from the groundwater contours (MoWD, 1987) and the ground surface contours.

Episodic streams are the characteristic type of river channel in the savannah. The density of intermittent streams in the savannah zone of Naro Moru river basin is 0.51 km/km^2 and is higher than that of perennial streams which is 0.33 km/km^2 (Leibundgut, 1986).

Geology and soils: The geologic structure consists of Porphyric Phonolites and Agglomerates. The soils on the plateau are very deep (120-180 cm) vetro-luvic and luvic Phaeozems of imperfect to moderate drainage. Soils in the valley sides consist of well drained Lithosols and ferric Luvisols while the valley bottoms consist of imperfectly rained gleyic Cambisols and dystric Histosols (Speck, 983).

limate: The savannah zone is semi-arid. The average nnual rainfall is frequently below 700 mm (Berger, 1989; aetzold and Schmidt, 1983). It comes in two seasons: long ains March-May and short rains October to December. Some ntermediate rains (continental) may be experienced in the onths of June-August.

he ratio of r/E_0 is 25-40 % (Sombroek et al, 1980). The verage rate of potential evapotranspiration is given by iniger (1990) as 5.8 mm/day during the dry season (Jan-arch; July-Sept) and 4.7 mm/day during the rainy seasons. he savannah is therefore an area of considerable water tress (Decurtins, 1990). Rainfall is the major limitation o maximum agricultural production (Sombroek et al,1980).

egetation and land-use: The deeply incised river valley s accompanied by typical valley vegetation which consists ainly of thorny bushes and trees. The plain has open rassland vegetation alternating with bushlands (mainly cacia species).

he 750 mm isoline represents the theoretical limit of ainfed agriculture for areas characterized by two rainy eason regimes (Jaetzold and Schmidt, 1983). The risk of rop failure in this zone is therefore high (Flury, 1987; ombroek et al,1980). Small-scale mixed farming is the ajor land-use type. Crops grown include maize, beans, otatoes. Horticultural crops are grown where ossibilities of irrigation exist. These crops include abbages, tomatoes, onions and carrots.

3. Socio-economic aspects

e Alpine and moorland zones are part of Mount Kenya tional Park and are important for tourism. One of the portant touristic activity is mountain climbing.

e forest zone is part of Mount Kenya Forest Reserve. ough human occupation is prohibited in this zone, the rest river reach is open for river water abstraction. e reach offers excellent sites for river water diversion d some large gravity fed systems supplying water to the otzone have their intakes here.

man settlement in Naro Moru river basin commences just low the lower forest line. The upper half of Naro Moru ver basin which contains the headwaters of Naro Moru ver is in Nyeri District while the lower half is in ikipia District. Naro Moru river is the main source of ter both within the basin and outside it. The growth of ro Moru town just next to the river is associated with ailability of water from this river. Out of the nine ibutaries of river Ewaso Ng'iro, Naro Moru river has the ghest yield (Leibundgut, 1986) and therefore its flow is portant for augmenting the flow in river Ewaso Ng'iro ring the dry season.

e average population density for the savannah during the 79 census was 5 persons per km^2 with an average household ze of 3.77 persons. The footzone had average population nsity 15 times higher than this. It stood at 73 persons r km^2 with an average household size of 4.14 persons aetzold and Schmidt, 1983).

e current population density in the savannah region of ro Moru river basin ranges from 25-200 persons per km^2 iesmann, 1990). There are no recent figures for the otzone. Kohler and Speck (1983) give the average amount

of water needed daily by a household as vary
20 - 60 litres for the general area west and
Mount Kenya. The rate of consumption is much
that used by the Ministry of Water Dev
planning purposes in a rural area which is
person per day. The major limitation is the d
water source.

Plot sizes in the semi-arid area west and
Mount Kenya are typically 1-5 acres. It is
an average family of 5-6 persons without
income needs at least 20 acres (8 ha) of la
reliant on food and income needs (Kohler and

Kohler (1990, 1987) who studied the economy
farming in Matanya which is representative of
and in Mwichwiri which is located in the semi
the footzone just below the lower forest bo
some information which sheds some light o
respond to these environmental challenges.
the earlier study are based on a survey do
while those of the more recent study are bas
farm survey done in 1985/86 covering 20 h
therefore the results are preliminary in nat

In Mwichwiri which receives about 900 mm
annually, the household economy is based m
production, particularly on potatoes which a

mainly based on livestock production and more important, on off-farm income.

Major crops grown in Matanya are maize, beans and potatoes. These are dual purpose crops; providing the family with both food and the much needed income. In addition farmers in Matanya were found to keep 3 head of cattle and 10 small stock on average in 1981. Kohler (1987) adds that irrigation is practised along the furrows but the irrigated acreage is small (less than 300 m^2). Returns from horticultural crops was found to be higher than for field crops. Irrigation is therefore highly desired by most farmers in the savannah. Farmers in Matanya meet the basic house-hold food and income requirements by grazing their flock on unoccupied plots and by off-farm income (Kohler, 1990).

3 LITERATURE REVIEW

3.1 Hydrologic cycle and streamflow

The hydrologic cycles refers summarily to the cycling of water from the ocean to the land and back again, including all the pathways and processes connected with the storage and movement of water in its three states (Hewlett, 1982). Figure 3.1 shows all the elements of the hydrologic cycle and how they are inter-related by the various moisture inputs and outputs.

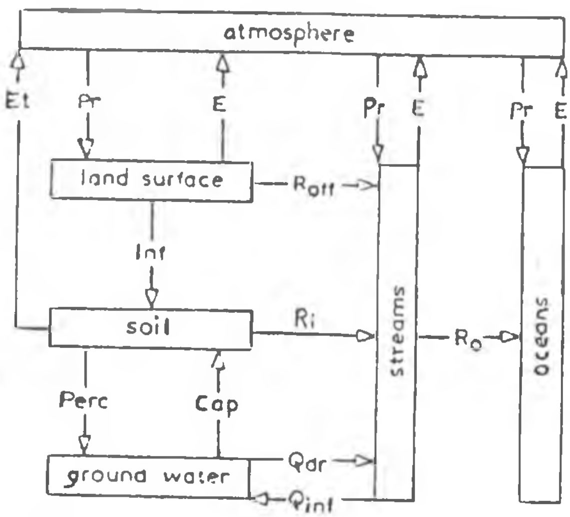


Fig. 3.1 Elements of the hydrologic cycle
(Source: Kessler and Ridder, 1980)

where,

Pr = precipitation
Roff = overland flow
Inf = infiltration into soil
Perc = percolation
E = evaporation
Et = evapotranspiration
Qinf = infiltration through river bed
Cap = capillary rise

Qdr = groundwater outflow to open water sources and streams
Ro = runoff in large stream channels
Ri = interflow

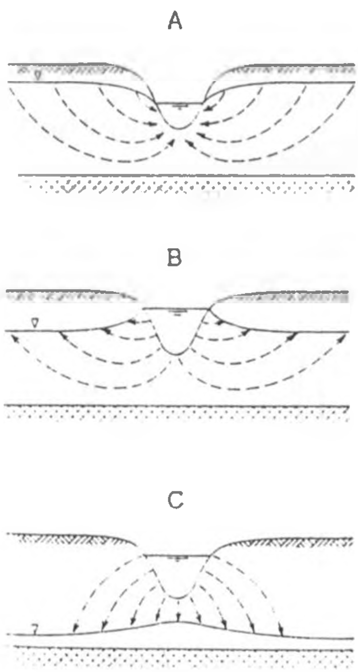
The stream subsystem can be isolated from the hydrologic cycle. The components and sources of streamflow are:

(a) direct precipitation on the stream channel and its tributaries,
(b) surface runoff: the water that flows over the ground surface and finds it way by means of small depressions and rivulets into the more permanent tributary channels,
(c) subsurface runoff or interflow: which percolates through the soil surface and moves laterally to a stream channel, and
(d) groundwater flow or baseflow (Bruce and Clark, 1966).

The four elements mentioned above may be regarded as the inputs into the stream subsystem. From Figure 3.1, it can be seen that streamflow may be lost directly to:

(a) the atmosphere through evaporation
(b) the oceans as runoff
(c) the groundwater and stream banks through infiltration or seepage.

The water of a stream is either fed by the groundwater, the stream thus acting as a drainage channel (effluent stream), or the stream may feed the groundwater, in which case it acts as a recharge channel (influent stream) as shown in Figure 3.2.



g. 3.2 Effluent (gaining) stream (A) and influent (losing) stream with shallow water table (B) and with deep water table (C) (Source: Ridder,1980)

2 Hydrology of Naro Moru river basin

e hydrology of Naro Moru river basin has been presented Liniger (1991) as shown in Fig. 3.3. The five zones in e profile are shown together with the corresponding ailable soil water capacity, infiltration rate, rainfall, il water change, surface runoff, and ground water change r the wet season (April-June; October-December) and the y season (January-March; July-September).

e highest rainfall is received in the lower moorland and per forest zone where high infiltration rates and low ailable soil water capacity allow the highest ntribution to surface runoff and ground water recharge ring the wet season. Ground water discharge takes place the forest zone during the dry season and becomes the jor source of surface runoff during this season.

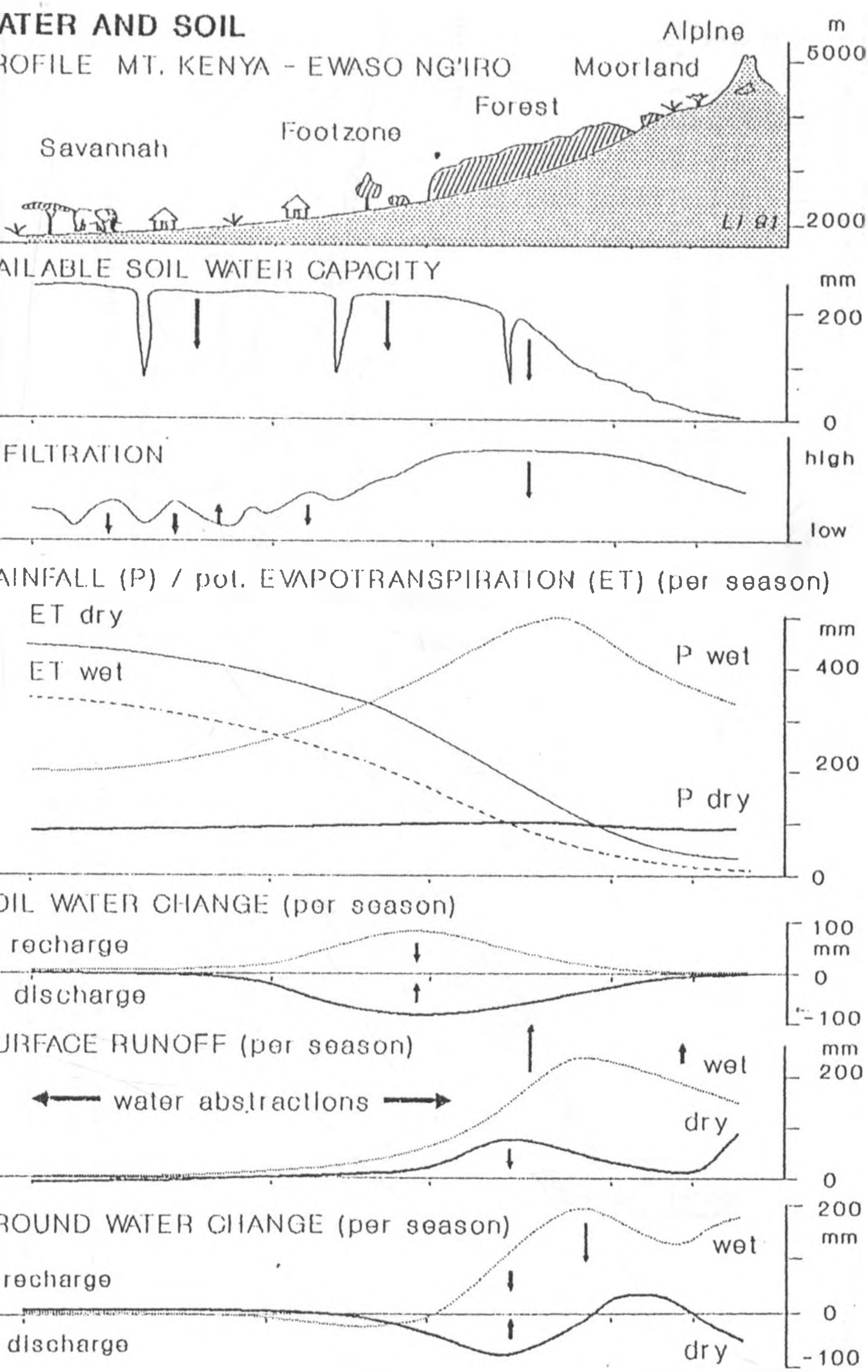
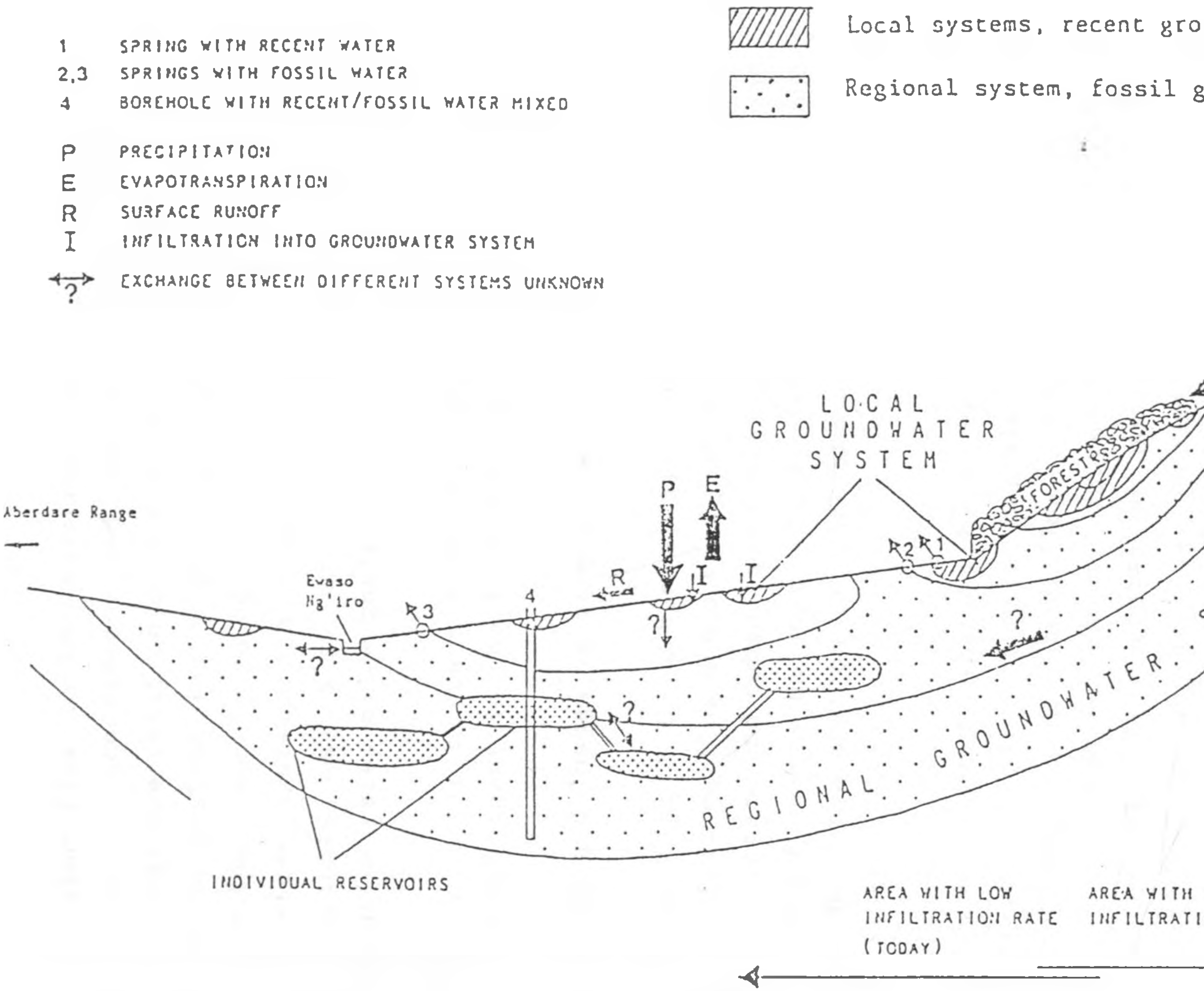


Fig. 3.3 Water balance of Naro Moru river basin
(Source: Liniger, 1991)



.g. 3.4 Hypothetical outline of the two groundwater systems (Source: Sch

Ground water flow in the savannah zone is less clearly understood. Schotterer and Muller (1985) give a hypothetical presentation of the local and regional ground water flow systems for a profile from the top of Mount Kenya to the river Ewaso Ng'iro as seen in Fig. 3.4. Local ground water systems are common in the forest zone but small pockets may also appear in the savannah where infiltration rates allow their formation.

Water abstractions start from the lower forest zone and become significant in the footzone and savannah.

3.3 Gains and losses in streamflow

In the section 3.1 it has already been shown that the sources of streamflow are direct precipitation on the river channel, surface and subsurface runoff and groundwater, and that streamflow may be lost through infiltration into the channel bed, evaporation into the atmosphere and flow into the oceans.

Apart from the modification by other subsystems of the hydrological cycle, streamflow may also be modified by man. Hewlett (1982) defines streamflow as the flow of water past any point in a natural channel above the bottom and sides of the channel. Chow (1984) defines it specifically as "virgin flow" which is the streamflow unaffected by artificial diversions, storage or other works of man in or on the stream channels or in the drainage basin or watershed. Consequently streamflow records should be adjusted by making a quantitative assessment of the artificial effect before any use can be made of such data.

3.3.1 Transmission losses

Although streams can be classified as influent (losing) or effluent (gaining), conditions within a basin may be so variable that a stream can be influent in some reaches and effluent in others (Linsley et al, 1949). Furthermore influent channels may be become effluent and effluent channels may become influent under some storm and flood conditions (Sharp and Saxton, 1962). Abstractions from surface flow resulting from infiltration into the riverbed and banks have been referred to as transmission losses especially with reference to ephemeral streams whose water surface elevations do not represent the groundwater levels (Jones, 1981; Jordan, 1977; Sharp and Saxton, 1962; Keppel and Renard, 1962).

Sharp and Saxton (1962) list three major categories of flood-water storage in valleys that may contribute to transmission losses. These are:

(1) Storage beneath the channel bottom in streams with the groundwater at some depth below channel bottom. Such water does not reappear immediately as streamflow.
(2) Bank storage: that water entering, more or less horizontally, the banks of the channel as the stream stage rises. Some of this water will return to the channel as the stream stage recedes.
(3) Storage in the valley alluvium away from the channel (essentially down-soak and "pot-hole" storage) when overbank flows occur. Some of this may eventually return to the channel, the quantity depending on antecedent soil moisture and the position of the water table relative to the channel bottom.

In many cases, transmission losses may reach the regional water table and therefore, constitute an important source of recharge. In others direct evaporation and transpiration by riparian vegetation remove a large portion of the transmission loss water (Keppel and Renard, 1962).

ordan (1977) working in Western Kansas found that vaporation from the stream surface and from the temporary ools on the flood plain formed only a small proportion of he transmission loss.

mong the more important factors affecting the channel osses are: size and sequence of floods; geology and soils f the valley; the gradient, depth, size, continuity, eander, and number of channels; riparian and phreatophytic egetation along the channels and in the valleys; soil rost conditions; depth to the water table; soil moisture ontent; gross and gravitational pore space in the soil; an-made structures and alterations; antecedent and current ainfall; and the content and nature of the sediment in the treamflow (Sharp and Saxton, 1962).

.3.2 Direct runoff

irect runoff is the sum of overland flow, interflow and hannel precipitation. It is that part of runoff which nters the stream promptly after the rainfall or snow elting (Hewlett, 1982). Channel precipitation is usually mall and is ignored (Garg, 1987) or included in the verland flow term (Chow, 1964).

he runoff generated by rainfall falling on a catchment is ffected by the characteristics of the precipitation and he drainage basin. Precipitation characteristics include ype of precipitation, rainfall intensity, duration of ainfall, distribution of rainfall and direction of revailing storm. Drainage basin characteristics include ize and shape of the basin, antecedent moisture onditions, elevation of the basin and the type and rrangement of stream channels (Garg, 1987). Other factors f importance include types of soil and vegetation cover nd slope and orientation of the catchment.

.3.3 Baseflow

aseflow is defined as outflow into a river channel from xtensive groundwater aquifers which are recharged by water ercolating vertically through the soil mantle to the water able. But baseflow is also sustained by the slow drainage f unsaturated soil into the zone of aeration particularly n steep areas (Hewlett, 1982).

aseflow is composed of groundwater runoff but in certain rocedures of hydrograph analysis, baseflow is assumed ither to include or exclude interflow but not any portion f it (Chow, 1964). During extended dry periods, all treamflow may be contributed by baseflow (Todd, 1980).

roundwater moves to the surface where it occurs in the orm of seepage areas and springs. Todd (1980) defines a pring as a concentrated discharge of groundwater appearing t the ground surface as a current of flowing water. He urther states that gravity springs result from water lowing under hydrostatic pressure and lists the following ypes as the ones generally recognized:

. Depression springs: formed where the ground surface intersects the water table.
. Contact springs: created by a permeable water bearing formation overlying a less permeable formation that intersects the ground surface.
. Artesian springs: resulting from release of water under pressure from confining aquifers either at an outcrop of the aquifer or through an opening in the confining bed.
. Impervious rock springs: occuring in tubular channels or fractures of impervious rock.
. Tubular or fracture springs-issuing from rounded channels, such as lava tubes or solution channels, or fractures of impermeable rock connecting with groundwater.

eyboom (1961) working in Alberta recognized three sources f groundwater which contributed to the baseflow of Elbow iver as contact springs, artesian leakage and bank torage. He adds that bank storage was probably the most mportant contribution of groundwater to streamflow. uring flood periods, the river became influent thus orcing water to enter the gravel deposits along the tream. It has been shown by Todd (1980) that large hanges in magnitude and direction of groundwater movement re brought about during periods of river influency. When he river level drops below the adjoining water table, the tream becomes effluent again and water held in bank torage is released gradually,

nder humid climates where the infiltrated water supply xceeds the evapotranspiration, the soil mantle will rovide baseflow over a long period of time. Dynamic aseflow sources expand during the wet season and shrink luring drought. In drier climates the limited rainfall tored in the catchment usually evaporates leaving little o move towards the stream channel. In such areas the ource of baseflow is often limited to the intermittent hannel and its banks. In steep terrain, narrow roundwater aquifers along the stream channel serve both as imited storage body, and as a conduit through which water s fed to baseflow (Hewlett, 1982).

.4 Separation of streamflow components

he components of streamflow are channel precipitation, verland flow, baseflow and interflow. Channel recipitation and overland flow are usually grouped ogether as direct runoff. Opinions vary in the lassification of interflow. Chow (1964) states that for ractical purposes of runoff analysis, total runoff in a tream is generally classified as direct runoff and aseflow.

several analytical techniques used to separate baseflow and direct runoff from the total streamflow have been documented. While most procedures are based on physical reasoning, the quantitative elements of the separation techniques are essentially arbitrary. The techniques are tools for achieving an approximate separation of baseflow. Although they are recognized as arbitrary, they at least have the merit of consistency (Nathan and McMahon, 1990; Shaw, 1983; Wilson, 1974). The methods differ in their treatment of baseflow response after the start of a rainfall event and in the determination of the cessation of surface runoff.

The beginning of the surface runoff is easily identified in the runoff hydrograph. One simple method of determining the cessation of the runoff event which is not subjective and gives consistent results is given in Shaw (1983) who also suggests that baseflow may be separated from the total stream hydrograph by joining the starting and the ending point of surface runoff with a straight line as illustrated in Fig. 3.5 below

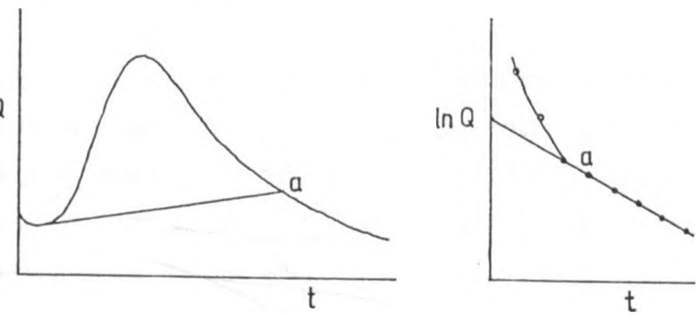


Fig. 3.5 Hydrograph separation (Source: Shaw,1983)

3.5 Definition of water balance

The meaning of the term "water balance" varies according to discipline and application. In brief, it is the determination and coordination of all elements of income and expenditure of water and of water storage variations with the system under study during the assumed design period (Bochkov and Zavodchikov, 1970). The water balance is a valuable tool on the analysis of water problems in an area. Its main objective is the evaluation of water resources. The characteristic features of a water balance can be summarized as follows:

1. A water balance can be assessed for any subsystem of the hydrologic cycle, for any size of area and, for any period of time;
2. A water balance can serve to check whether all the flow components involved have been quantitatively accounted for;
3. A water balance can be regarded as a model of the complete hydrological processes under study and consequently can be used to predict the effect that changes imposed on certain components will have on other components of the system or subsystems;
4. A water balance can serve to calculate the unknown members of the equation provided the other members are quantitatively known with sufficient accuracy (Kessler and Ridder, 1980; Storr, 1970)

Any subsystem is characterized by an inflow and an outflow and an amount of water stored; quantities which change with time (Kessler and Ridder, 1980). The water balance equation for a subsystem that is in balance can be expressed in its simplest form as:

$$I - O = \Delta S \qquad [3.1]$$

Where I is inflow during a given period of time, O is outflow, and ΔS is the change of water in storage. This equation of hydrologic equilibrium can be assessed for any subsystem isolated from the hydrologic cycle. The inflow and outflow are considered over a period of record which is normally chosen in such a manner that, with the exception of one, all the numerical values are known (Kessler and Ridder, 1980).

3.6 River reach water balance

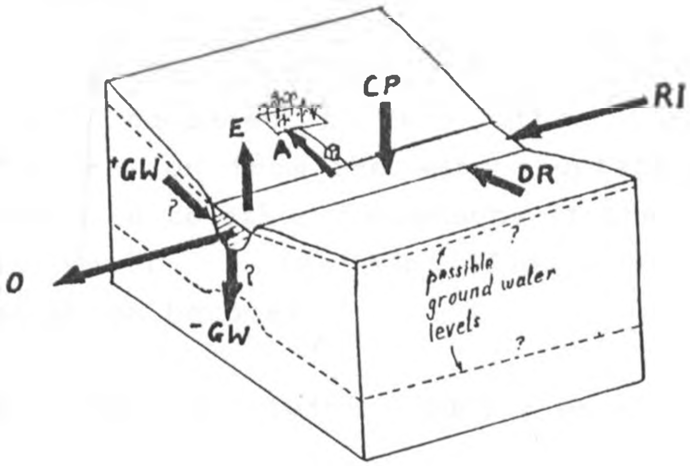
The setting up of a water balance equation starts with the identification of the inflow, outflow and storage components of the system under study. Kessler and Ridder (1980) have expressed the water balance of surface-water systems such as streams and lakes as:

$$(Iinf - Outf) - (Qinf - Qdr) = \Delta SW \qquad [3.2]$$

where
- ΔSW = change of water in channel storage
- Qinf = seepage from surface water body
- Qdr = groundwater outflow to the surface water body
- Iinf = inflow of surface water
- Outf = outflow of surface water

Equation 3.2 has been written with reference to a groundwater balance. The change in storage, (ΔSW) will be positive when surface water recharges groundwater. The inflow and outflow of surface water can be determined by streamflow measurements and the resulting balance will show the quantity that enters the surface water systems minus the quantity that is lost. The change in surface water storage can usually be neglected if the water level in the channel network or lake remains approximately the same during the considered time period. For extensive bodies of surface water and for long time periods, evaporation from the open water surfaces cannot be neglected (Kessler and Ridder, 1980).

Based on this simple equation of a surface water body, a river reach water balance equation can be developed (see Fig. 3.6).



RI = river inflow
RO = river outflow
CP = channel precipitation
DR = local direct runoff
A = abstractions
E = evaporation loss
GW = net groundwater flow into reach when positive or net transmission loss when negative

Fig. 3.6 Schematic representation of a river reach showing the inflow and outflow elements of streamflow

For a river reach the inflow of surface water comes from direct runoff generated locally from rain falling in the area adjacent to the reach (DR), the river inflow from upstream reach (RI) and the direct precipitation on the channel (CP). The outflow of surface water occurs through river outflow at the exit of the reach (RO), losses due to evaporation from the surface (E), and abstractions of river water for use (A).

Referring to equation 3.2. and Fig. 3.6, it can be seen that for a river reach,

$$Iinf = DR + RI + CP \qquad [3.3]$$

$$Outf = RO + E + A \qquad [3.4]$$

ere the meaning of the terms are as described above. The uation for the river reach water balance therefore comes

$$+ RI + CP - RO - E - A - (Qinf-Qdr) = \Delta SW \qquad [3.5]$$

annel precipitation, **CP** may be neglected because it is all compared to the other terms of the equation. aporation from the water surface, E becomes negligible mpared to other components if the surface area of a river small. The simplified river reach water balance uation becomes:

$$- RO - A = (Qinf - Qdr) - DR + \Delta SW \qquad [3.6]$$

en the term **(Qinf-Qdr)** is positive, it represents the net ss in streamflow during transmission and when negative, represents net groundwater inflow into reach. We can ll this term **GW** and change its sign and that of Δ **SW** in uation 3.6 such that:

$$- RI + A = DR + GW + \Delta SW \qquad [3.7]$$

ere the term **GW** is positive when the groundwater flows to the reach and negative when streamflow is dissipated ring transmission in other ways other than abstraction. e term Δ **SW** is positive when water stored in the in the rface body increases.

anmission losses consist of direct evaporation from the ter surface and infiltration (seepage) losses. It is not sy to identify what proportion of the river water that filtrates into the soil is taken up by plants or goes to oundwater.

the amount of water stored in the channel reach does not
ange for the time period over which the water balance is
aluated the term Δ **SW** can be excluded from the equation
7

e terms on the left-hand side of equation 3.7 can be
asured directly. If change in channel storage, Δ **SW** can
neglected, the net effect of direct runoff and ground
ter on streamflow can be evaluated. If periods can be
olated when the local direct runoff, **DR** is zero, the
oundwater inflow to reach and tramsmission losses can can
assessed.

7 Estimation of discharge

ere are several ways of classifying the methods of
timating discharge. The most practical way of estimating
ischarge in a stream whose stage-discharge relation is
own is to use the stage-discharge method. Stage refers to
e water surface elevation at a point along a stream,
asured above an established datum plane. The term gauge
ight is often used interchangeably with stage but it is
re appropriate when used to refer to the reading on a
uge (Herschy, 1985).

ischarge is determined at various stages so as to define
e stage-discharge relation for the cross-section at the
uging site. This process is called calibration and
quires the use of other instruments to obtain discharge.
e most commonly used instrument is the current meter.
termination of discharge can subsequently be made by
asuring stage only and using the stage-discharge
lation to compute the corresponding discharge.

e physical element or combination of elements that
ntrols the relationship between stage and discharge is
own as a control. One classification differentiates

tween natural and artificial controls. An ideal control ould be stable and permanent so as to ensure a fixed and nstant relationship between stage and discharge . An eal gauging site is rarely obtained and changes in ntrol usually result from changes in channel geometry d/or channel roughness (Herschy, 1985; Shaw, 1983; WMO, 80a)

e reliability of the stage-discharge relationship can be eatly improved if the streamflow can be controlled by a gid indestructible cross-channel structure of andardized shape and specification. For a structural ntrol, eg. a weir built to standard specifications, the age-discharge relation is known. Discharge is obtained by asuring stage at one or more specified points and using e stage-discharge relation to compute the discharge haw, 1983; WMO, 1980a). The use of standard structures ch as weirs and flumes is essentially a stage-discharge thod.

selecting any structure for flow measurement one should nsider the required full energy head to obtain modular ree) flow, the range of discharges to be measured, nsitiveness, sediment discharge capability, passing of oating and suspended debris, undesirable change in scharge (eg. through damage), minimum water level in the stream channel and the required accuracy of measurement os, 1976). Other factors which should be considered are se of fabrication and portability (Walker, 1989).

tificial controls built in natural streams are usually oad-crested weirs that conform to the general height and ape of the streambed. In canals and drains where the nge of discharge is limited, thin plate weirs and flumes e controls commonly built.

her ways of obtaining stream discharge include the locity-area method, salt dilution method, float method, ope-area method, stage-fall-discharge method, moving boat thod, ultrasonic method, and electromagnetic method. They e well described in Herschy (1985).

7.1 Stage-discharge method

7.1.1 Operational requirements

natural stream channels, an ideal gauging site should tisfy the following criteria:

) The general course of the stream should be straight for about 100 m upstream and downstream from the gauge site;

) The total flow should be confined to one channel at all stages and no flow should bypass the site as subsurface flow;

3) The streambed should not be subject to scour and fill and should be free of weeds;

4) Banks should be permanent, high enough to contain floods and free of brush;

5) An unchanging natural control should be present in the form of bed-rock outcrop or other stable riffle for low flow and a channel constriction for high flow or a falls or cascade that is unsubmerged at all stages;

6) A pool should be present upstream of the control at extreme low stages to ensure a recording of stage and extremely low flow and to avoid high velocities at the streamward end of stage recorder intakes during periods of high flow;

7) The gauge site should be far enough upstream from confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gauge;

A satisfactory reach for measuring discharge should be available within reasonable proximity of the gauge site but it is not necessary for low and high flows to be measured at the same cross-section;

The site should be easily accessible for ease of installation and operation of the gauging station (WMO, 1980a).

.ributes desired in an artificial control include the .lowing:

) The control should have structural stability and should be permanent. Excessive seepage under and around the control should be prevented by sheet piling or concrete cut-off walls and adequate abutments;

) The crest of the control should be as high as practicable to eliminate, if possible, the effects of variable downstream conditions or to limit those effects to high stages only;

) The profile of the crest of the control should allow sensivity at low stages and extrapolation of the rating curve to peak discharges;

) The passage of the water through the control should create no undesirable disturbances in the channel upstream or downstream of the control;

) If the stream carries a heavy sediment load, the artificial control should be designed to be self-cleaning.

umes require a lower operating head than weirs and erefore can be used where the water level in the stream annel should be kept minimum. Weirs are more easily structed by sediment and floating debris; flumes are latively better in discharging sediment and floating bris. Flumes cannot be used in close coupled combination ructures consisting of turn-outs, control and measuring vices. Triangular sharp-crested weirs are very accurate d sensitive over low flows (Kraatz and Mahajan, 1975).

ker (1989) recommends the cutthroat flume, the tangular sharp-crested weir and the triangular sharp-sted weir because they have general ratings, are easily ricated and are highly portable. Standard cutthroat mes have rating tables and equations which are well umented in Kraatz and Mahajan (1975) and Walker (1989). y can operate with relatively small head loss and are atively insensitive to velocity of approach. They have capability of making good measurements with no mergence and with submergence not exceeding 90%. Their ocity of flow is sufficiently high to virtually minate sediment deposition within the structure during ration, (Walker, 1989; Kraatz and Mahajan, 1975).

rs and flumes have an upper limit in their ability to sure the stream flow. Usually as the flow rate reases, downstream channel control causes such an reased downstream water level that a flume or a weir is wned out; the unique relationship hitherto existing ween stage or upstream water level and discharge in the called `modular' range is thereafter lost. These uctures are therefore only suitable for measuring low medium flows; flood flows are not usually measurable h flumes and weirs (Shaw, 1983; Bos, 1976).

.1.2 Equipment

the stage-discharge relation is known, the only other ormation required is the stage. According to the essity, stage readings can be required as single tantaneous measurements taken at intervals by an erver or as a continuous record by an automatic trument. The instruments for measuring stage apply for uctural and artificial controls.

age indication instruments may be broadly categorized to direct reading gauges and indirect reading gauges. me of either types of instruments are suitable to be tended to become either an analog or digital recording ter-stage recorder (Somer, 1984).

rect reading gauges include: (1) The staff gauge which a graduated plate fixed vertically or inclined to a able structure such as a pile, a bridge pier, a wall or sloping river bank. Staff gauges are read manually and ould be placed where they are easily visible and where ow disturbances are at a minimum. (2) Flood crest-stage uges which are used if the only aim is to determine top ages during flood. (3) Needle gauge which consists of a tal rod and a device to determine the exact vertical sition of the point of the rod. These have a high asuring accuracy but have the disadvantage of a narrow asuring range (usually 1 m). (3) Wire weight gauge which nsists of a drum wound with one layer of a light-weight ble, a bronze weight attached to the end of the cable and metering counter by which the amount of lowered cable can determined. (4) Electrical tape gauge which consists of cable drum with a polyamid-coated steel tape graduated in ntimetres and numbered in decimeters and equipped at the ee end with a measuring feeler housed in a probe.(5) A oat-gauge which consists of a float, a graduated steel pe, a pulley, a counter-weight and an index pointer omer, 1984; Jansen et al, 1979).

direct reading gauges include these devices where the ter height above or beneath a transducer is converted to a pressure, an electric quantity or a time interval ich is related to the water level. These include: (1) essure gauges which are based on the law of hydrostatics ich permits the static pressure head at fixed point below e water level to be converted into a stage. Several rieties exist all differing in the way the pressure is ansmitted to the pressure sensor. (2) Acoustic level uges which operate on the same principle as the echo unders (Somer, 1984; Jansen, et al, 1979).

arly any type of gauge can be adapted for automatic cording except the staff gauge and flood crest gauge ich require direct observations. The recorders can be assified either as analog or digital recorders. The alog recorder provides a graphic record of the stage with spect to time while a digital recorder provides a coded merical output at preselected time intervals (Somer, 84). The most reliable means of recording water level is ovided by a float operated chart recorder (Shaw, 1983).

art from the pressure gauges, recording gauges are ually placed in a stilling well which dampens the uctuations caused by waves and turbulence. The nnection of the stilling well with the stream called illing well intake, should allow water to enter and leave e stilling well so that the well is maintained at the me stage as that of the stream under all conditions of ow. It should also not be subject to plugging by diment (Somer, 1984; Jansen et al, 1979). An independent ference gauge should be set up close to the recorder MO, 1980a).

r structural controls such as flumes and weirs, the age-discharge relation is established from laboratory or eld calibration. The discharge is subsequently derived om the rating equations so obtained. Some countries do t accept laboratory ratings and require that any ructure installed in the field be calibrated in situ MO, 1980a)

3.7.1.3 Methodology

In natural stream channels, the stage-discharge relation should be defined before stage can be used to calculate the discharge. Standard weirs and flumes are defined in USDI (1984) as structures which are fully described, accurately calibrated, correctly installed and sufficiently maintained during the period of flow measurement. Discharge is computed directly by using rating tables or equations. The determination of the stage-discharge relation for natural stream channels is decribed below.

Determination of the stage-discharge relation

The stage discharge relation for a cross-section is obtained by plotting the results of discharge measurements, Q, and the corresponding stages H as points in a Q-H diagram with Q being plotted as abscissae and H as ordinates. One then usually tries to fit a curve (or several portions of curves) expressed by the equation

$$Q = A\ (H-H_0)^B \qquad [3.8]$$

through the data points,

with Q = water discharge

H = corresponding stage

H_0 = stage at zero discharge ($H-H_0$= water depth h)

and constants A,B,H_0 = station parameters yet to be determined.

Theoretically two analytical methods can be considered to determine these parameters. These are a computer method using non-liner least squares method, and a simpler method consisting of two steps, first the determination of H_0 secondly the determination of A and B by log-transformation. The latter method is discussed below in detail.

determine H_0, three values of discharge, Q_1, Q_2 and Q_3 are elected from a smooth curve drawn by visual estimation ch that

$$Q_2^2 = Q_1 Q_2 \qquad [3.9]$$

the corresponding values of stages are H_1, H_2 and H_3, it n be verified that based on the equation 3.9

$$H_0 = (H_1H_3-H_2^2)/(H_1+H_3-2H_2) \qquad [3.10]$$

ter determination of H_0, the values of Q plotted against $-H_0$) on log-log scale will lie approximately on a straight ne between shifts in control. The location of shifts in ntrol can be detected by visual inspection and the rtions of the curve to be treated separately become ear. Logarithmic transformation of equation 3.8 yields

$$\log Q = \log A + B \log (H-H_0) \qquad [3.11]$$

d substituting a = log A, b = B and h = $H-H_0$, yields

$$\log Q = a + b \log h \qquad [3.12]$$

substituting Y = log Q and X = log h,

$$Y = a + b X \qquad [3.13]$$

e parameters a (and therefore also A) and b, valid for ch continuous portion of the curve, are calculated using e least squares method. Substitution of the values found r H_0, A and B in equation 3.8 then yields the mathematical del of the rating curve over the portion considered. The rious portions are connected and thus the rating curve is tained in the linear Q-H plane (Troch, 1984; Shaw, 1983; nsen _et al_, 1979).

harp break in the contour of the cross-section such as overflow plain will cause a break in the slope of the ing curve. Commonly, however, a break in slope is due the low water control being drowned out by a downstream tion control becoming effective or by a channel control oming effective (WMO, 1980b).

ension of rating curve

charge measurements are carried out over the range of ge variation in order to establish the rating curve as ckly as possible. Normally the lower and medium stages sent little difficulty but discharges at higher stages take some time and resort may require to be made to eful extrapolation until such a time as the higher charges are available to be measured (Herschy,1985).

re are several techniques that can be adopted to assess discharge at stages beyond the measured limit of the ing curves, but all extensions are strictly only valid the same shape of cross-section and the same boundary ghness (Troch,1984). Four methods are discussed below.

Logarithmic extrapolation - which is applied when a ing curve plots satisfactorily as a straight line on -log paper. The rating curve is simply extrapolated to her stages or the rating equation fitted to logarithmic ing curve is used to calculate higher discharges. This hod ignores all physical factors and should only be used re hydraulic control does not change and the channel metry is continuous. It should be checked with other hods if the extrapolation exceeds 20% of the largest ged discharge (Troch, 1984; Shaw, 1983). If the river ss section at the site of the gauge is a uniform section even approximates a uniform section) to which can be ted either a segment of a circle or of a parabola or of ectangular or trapezoidal section, then this method can ily be adopted (Garg, 1987).

Velocity-area method - which involves separate
ensions of the stage - area curve and the stage - mean
ocity curve. The overall mean velocity across the
nnel is calculated from

$$Q = A\ V \qquad [3.14]$$

e Q = discharge, A = area of cross-section, and V =
velocity, within the range of measured stages. The
ge area curve is extrapolated reliably using survey
. The stage-mean velocity curve can normally be
ended with little error. Then the higher values of
charge can be calculated for the required stage from the
duct of the corresponding V and A. This method although
ely used has some drawbacks.

- Splitting the Q = A V relation into two separate relations ie. stage-mean area relation and stage-mean velocity relation results in a larger confidence interval than when the single relationship is used.

- The stage-mean area curve may be extrapolated reliably by survey methods but the stage-mean velocity curve cannot be extrapolated with the same reliability. Calculating mean velocity from discharge and area is purely theoretic.

he stage area curve changes abruptly (by inundation of
flood plains for example) one has to accept that the
ge-mean velocity relationship will change also and it is
permitted to extrapolate relationship observed for
er stages while ignoring geometric and/or hydraulic
racteristics of the river reach (Troch, 1984; Shaw,
).

) Stevens method which is based on the assumption of the lidity of the Chezy formula

$$Q = C A \sqrt{RS_f} \qquad [3.15]$$

ere Q = discharge

C = Chezy friction coefficient

A = cross-sectional area

R = hydraulic mean depth

S_f = friction slope

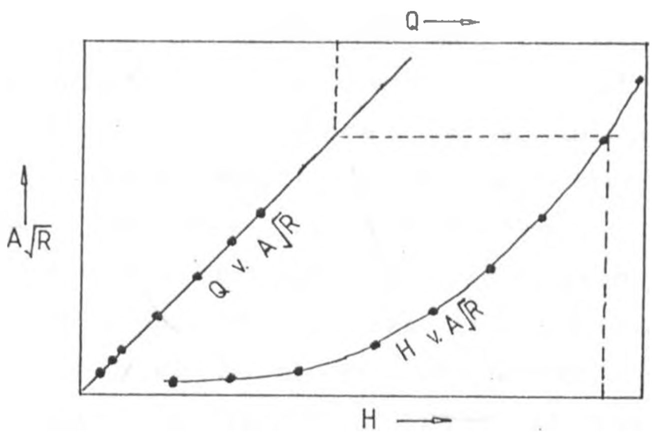


Fig. 3.7 The Stevens method. (Source: Shaw,1983)

e hydraulic mean depth is obtained for all required ages from $R = A/P$ where P is the wetted perimeter. If S_f is taken to be a constant (k) then Q versus $kA\sqrt{R}$ plots a straight line. For gauged stages values of H, rresponding values of $A\sqrt{R}$ and Q are obtained and plotted. e extended straight line can then used to give discharges r higher stages (see Fig. 3.7). This method relies on e doubtful assumption of C remaining constant for all age values (Shaw, 1983; Francis, 1962).

) Mannings Formula method - which is basically the same Stevens method except that the Chezy formula is replaced Mannings formula

$$Q = 1/n(A\ R^{2/3}\ S_f^{1/2}) \qquad [3.16]$$

here Q, R, A, and S_f are the same as in Stevens method and is Mannings roughness coefficient.

he expression $AR^{2/3}$ (sometimes called the conveyance actor) replaces $A\sqrt{R}$ and is assumed to be constant or nown. It is generally accepted that the Manning equation s superior to the Chezy equation since n changes less than as R varies (Shaw, 1983).

he basic hydraulic mechanism applied in all measuring lumes and weirs is the setting up of critical flow onditions for which there is a unique and stable elationship between depth of flow and discharge. Flow in he channel upstream is subcritical, passes through ritical conditions in a constricted region of the flume or eir and enters the downstream channel as supercritical low. It is better to ensure the water level (stage) is easured a short distance upstream of the critical flow ection, this stage having a unique relationship to the ischarge (Shaw, 1983).

<u>lumes and weirs:</u> The basic equations for flumes and ectangular sharp crested weirs are of the general form

$$Q = K\ b\ H^{3/2} \qquad [3.17]$$

here b is the width of the throat for a flume or width of rest for a weir and H is the measured head. For flumes K s a coefficient based on analysis and experiment. For the ectangular sharp-crested weirs, K, also incorporates the ffect of channel geometry and end contractions. More etailed information on the theory of measuring structures ike flumes and weirs is given in Bos, (1976) and Kraatz nd Mahajan, (1975). The cutthroat flume is described elow.

<u>Cutthroat flume:</u> The basic discharge equation for a cutthroat flume operating under free flow conditions is given in Walker (1989) as :

$$Q = K_f W^{1.025} h_u^{nf} \qquad [3.18]$$

where Q = discharge in cubic feet per second (1 cfs=0.0283 m^3/s)

K_f = flume length coefficient (see Fig. 3.8)

W = throat width in feet

h_u = upstream flow depth in feet (1 foot = 0.3048 m)

nf = free flow exponent (see Fig. 3.8)

This equation applies when the ratio of upstream to downstream water depths (h_d/h_u), called the transition submergence St, does not exceed the value shown in figure 3.8 for the flume length in use.

Under submerged conditions, Equation 3.18 is modified to

$$Q = K_s W^{1.025} (h_u - h_d)^{nf}/(-\log S)^{ns} \qquad [3.19]$$

where

Q = discharge in cubic feet per second

K_s= submerged flume length coefficient (see Fig. 3.8)

W = throat width in feet

h_u= upstream flow depth in feet

h_d= downstream flow depth in feet

S = submergence (h_d/h_u)

nf= free flow exponent (see Fig. 3.8)

ns= submerged flow exponent (see Fig. 3.8)

The ratio h_{umax}/L should not exceed 0.4, where h_{umax} is the maximum water depth measured and L is the length of the flume (Kraatz and Mahajan, 1975). Walker (1989) adds that

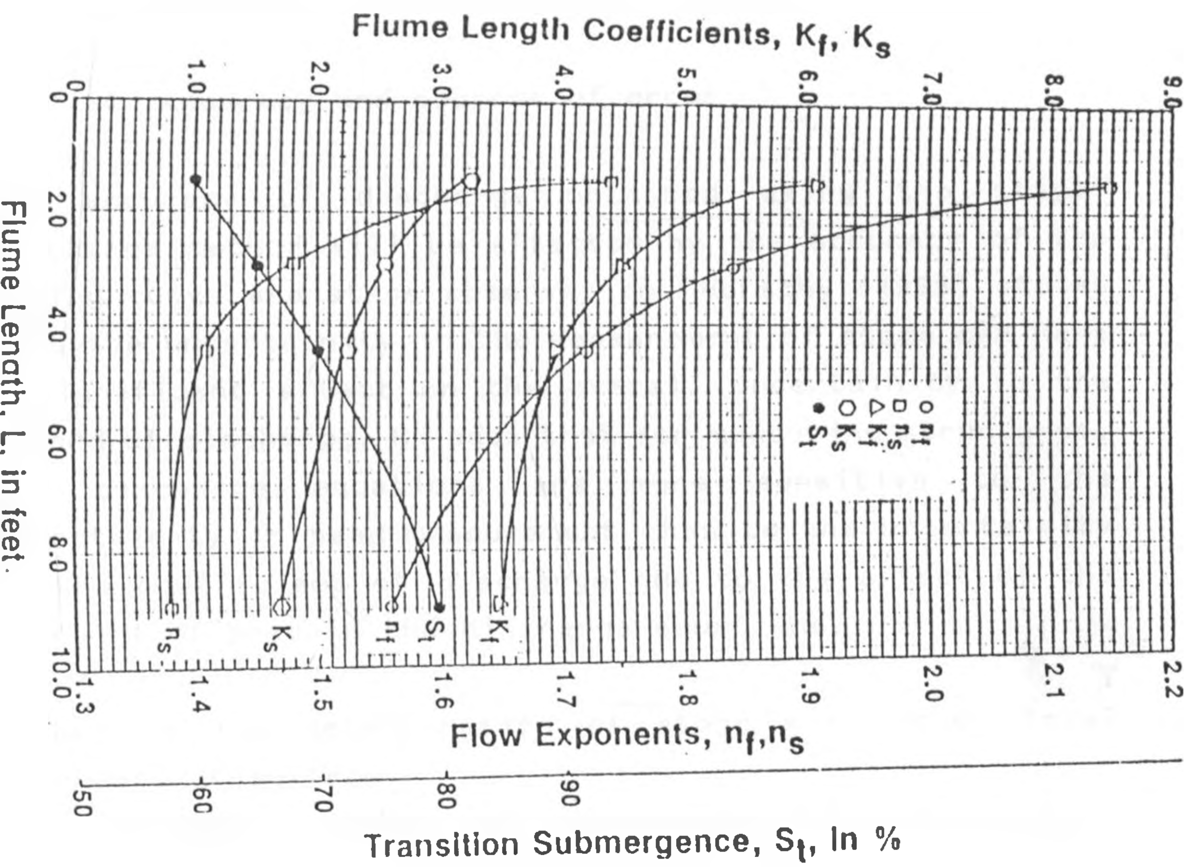


Fig. 3.8 The cutthroat flume rating curves (Source: Walker, 1989)

enever possible, a cutthroat flume should operate under ee flow conditions. However, if it must operate in the bmerged flow regime, Eqn. 3.19 yields accurate readings. en the submergence approaches 90 %, it becomes difficult make sufficient accurate gauge readings in the field.

7.1.4 Accuracy and sources of error

e accuracy of discharge obtained using the stage-scharge method will be affected by the accuracy of the ting curve and stage observation. Herschy (1985) states at the uncertainity in the measurement of stage can have significant effect on the overall uncertainity in the cord of discharge. He adds that for measuring structures, e discharge equations are more sensitive to the certainity in head measurement than to the uncertainity the coefficient of discharge due to the effect of the ponent of head in the discharge equations.

rors in the determination of stage with water level corders arise from:

) Inadequate design and construction of float pulley, gears, pen carriage etc.

) Poor maintenance of instruments, which may manifest itself in friction in the mechanism, siltation of wells, obstruction of pen carriage or float etc.

) Changes in temperature, humidity etc. which may affect the instrumentation and thus the accuracy of the recorder charts.

) Human inaccuracy such as incorrect reading, inaccurate setting of pen or pencil, incorrect attachment of floats or recording charts, etc.

th the exception of pressure gauges which are not placed a stilling well, an accuracy of 1 to 2 cm can easily be tained with most of the gauges, especially those placed stilling wells. Staff gauges can be read with an racy between 1 and 3 cm, depending on the location and ial devices (Jansen et al, 1979).

rtainity in the stage-discharge relationship usually lts from observational and computational procedures. rally the scatter of individuals discharge measurements t the mean curve should be less than 5%. If the ter is greater, the it may be the result of an unstable ion, faulty measurements, the effect of varying water or weed growth in the channel (Bruce and Clark,).

rs in discharge measured by standard structures may e from inaccurate design, fabrication and installation from lack of maintenanace (USDI,1984). Herschy (1985) es the percentage uncertainity at 95% level of thin e weirs and flumes as ranging from 1-5%.

2 Velocity-area method

ctly stated, all methods of streamflow measurement ept salt dilution gauging which is the only absolute charge measurement technique, are velocity-area methods. monly however, this term is used to refer to the use of current meter to measure the mean velocity of flow and direct measurement of the cross-sectional area to ermine the discharge (Herschy,1985). The float method be used to give approximate values of the mean flow ocity where the current meter may be inapplicable chael, 1978). The velocity-area method is discussed ow.

.2.1 Selection of site

site selected for current meter gauging has as far as sible to satisfy the following requirements: the channel uld be straight and of uniform cross-section and slope, depth of the water should be sufficient to provide for effective immersion of the current meter or float, and measuring site should be clear and unobstructed (Shaw, 3; Jansen et al, 1979).

.2.2 Equipment

cross-section area is determined by measuring the width depths in various verticals across the section. The th of the stream or distance between verticals may be ained by measuring from a fixed reference point. For th measurement, a graduated steel tape may be used. ths of various verticals are usually measured by a duated rod or a drum wire-weight system (Ostensson, 5).

velocities on the surface or at selected points in a tical can be measured with a float or more accurately n a current meter. Floats may classified as surface and surface floats with the latter being preferred because y give velocity values closer to the mean stream ocity and are not affected by wind. The conversion tors of the various floats vary from 0.84-1.00 and are luenced not just by the type of float used by also by width, depth and roughness of the channel section ner, 1984; Jansen et al, 1979). The most reliable and ely used current meters are rotating element current ers. These current meters can be either of the propeller e or cup type.

.2.3 Methodology

rent meter gaugings are taken in a number of different s. The manner in which the current meter is held in ition in the water and the manner in which the meter is ported constitute the criteria for the different ways. the wading method the current meter is carried on a rod hich may also be graduated to measure depth) and held in sition by a gauger standing on the stream bed a little to e side and downstream of the instrument. This method is ly practicable in small streams with low or moderate locities. The bridge method is applicable where there is clear span bridge aligned straight across the river near e gauging station. The current meter is lowered on a ne from a gauging reel carried on a trolley. For very de rivers, gaugings may have to be made from a boat ther held in position along a fixed wire or under power ross the section. The gauger may also travel across the ver in a cable car hung from an overhead cable, with the rrent meter suspended on a steel line. Alternatively the uger may remain on the bank but wind the current meter ross the section on a cableway, lowering it to the sired depth by remote mechanical control (Shaw, 1983).

en locating the verticals the following points should be nsidered: the width of the river should be divided into out 20 sub-sections so that no sub-section has more than % of the flow, the verticals should be chosen so that pid changes in the elevation of the river bed are shown rrectly, and where the flow is subject to rapid changes, e number of verticals should be few so as to complete the uging exercise before any significant changes in flow ve occurred.

e mean velocity in the vertical can be determined by one the following methods depending on the time available d having regard to local conditions of the cross-section omer, 1984).

) Velocity distribution method which involves measuring the velocity at a number of points along the vertical between the surface of the water and the bed of the channel, plotting the velocity at each position and determining the mean velocity by means of the mean value theorem. This method is time consuming and is therefore unsuitable for routine discharge measurements.

) Reduced point method in which the velocity observations are made at each vertical at 0.2 and 0.8 of the depth below the surface (two points method) or at 0.6 of the depth from the surface (one point method). In the two point method, the mean velocity in the vertical is given by the mean of the two velocities measured

) Integrated method in which the current meter is raised and lowered through the entire depth at each vertical at a uniform rate. This method is used only in water having a depth greater than 1 m.

general, a measurement time of 30 seconds is sufficient obtain a fair approximation of the true mean velocity at e point considered. When the number of measurement ints in the vertical is four or more, this time may be ortened taking 10 seconds as a minimum (Jansen et al. 79)

e calculation of discharge from the velocity and depth asurements can be made in several ways. Two of the most mmon methods are the mean section method and the mid ction method. It has been found that the mid-section thod gives slightly more accurate results (Somer, 1984; aw, 1983).

7.2.4 Accuracy and sources of error

ing the velocity area method, three quantities are asured, namely width, depth and flow velocity. The asurements of width and depth are subject to random mpling errors. The error in the mean flow velocity is t only due to a random sampling error but also to locity fluctuations and to calculation methods for termination of the mean flow velocity from point asurements.

rors may arise if the flow is unsteady, if there is a eat concentration of suspended material, if the direction the flow is not parallel to the axis of the propeller-pe current meter or is oblique to the plane of the cup-pe current meter, if the current meter is working outside e range established by calibration, if the set up for asurement is different from that used during the libration of the current meter, if there is a significant sturbance of the water surface by wind and if the current ter is not held steadily in the correct plane during asurement.

ow velocities can be determined with an accuracy of the der of ± 2% with propeller-type current meter and ± 5 % th cup-type current meter in the range of velocities tween 0.15 and 4 m/s (Herschy,1985; Somer, 1984; Shaw, 83; Jansen et al, 1979).

7.3. Dilution method

suitably selected chemical solution or tracer of a known ncentration is injected at the start of the measurement ach of the stream. In a downstream sampling section, mples are taken at regular intervals, The discharge of e stream can be deduced from the amount of tracer jected and the concentration of the tracer measured at e downstream end of the reach. At that point the tracer ould be uniformly distributed throughout the cross-ction (Shaw, 1983).

7.3.1 Principle

or the constant rate method, a tracer of concentration C_1 introduced into the water with a background oncentration C_0 at a constant rate q. The flow rate in the tream is Q. The well mixed flow attains a sustained final oncentration C_2. Thus

$$QC_0 + qC_1 = (Q+q)\ C_2 \qquad [3.20]$$

ence

$$Q = ((C_1-C_2)/(C_2-C_0))q \qquad [3.21]$$

or the sudden injection method, also called gulp injection ethod, a known volume of tracer V, of concentration C_1 is dded in bulk to the stream and at the sampling point, the arying concentration, C_2, is measured regularly during the assage of the tracer cloud. Then:

$$VC_1 = Q\int(C_1-C_2)\,dt \qquad [3.22]$$

th the unknown Q easily calculated. (Shaw, 1983).

7.3.2 Materials and equipment

o structures need to be installed in the field neither are ne dimensions of the stream necessary for the computation f discharge with the salt dilution method. Equipment is equired for preparation of the solution, for the injection f the tracer either at a sudden rate or at a contrast rate nd for measuring the concentration of the tracer in the ater at the downstream sampling station (Michael, 1978).

ne various substances chosen as tracers are selected for neir properties which provide ease of detection at low ncentrations. An ideal tracer should should have high lubility, be stable in water, be easily detected at low ncentrations, be non-toxic to fish and other forms of uatic life and be unaffected itself by sediment and other tural chemicals in the water. The three main types of acers used in dilution gauging are chemical, fluorescent d radioactive tracers. Chemicals favoured include sodium loride, sodium dichromate, lithium chloride, sodium trate and manganese sulphate. The cheapest and most nvinient tracer to use is common salt (NaCl). Fluorescent es like green dye fluorescein and radioactive tracers ke tritium and bromine-82 are also used (Herschy,1985; aw,1983; Michael,1978; Replogle et al, 1966).

7.3.3 Methodology

e tracer solution is prepared prior to the field plication. A suitable location for the measurement is osen. There should be sufficient turbulence to ensure a od mixing action of the tracer solution with the water, ving a homogeneous tracer concentration throughout the ole cross-section of the stream at the measuring point. rough approximation of the discharge ought to be made to rve as a guide in estimating the amount of tracer to be ded. Herschy (1985), Bjerve and Groterud (1980) and plogle et al (1966) suggest formulas which can be used estimate the amount of tracer to be added to the water. rschy (1985) gives a rate of 0.2 kg of salt per m^3/s of scharge for natural waters with a low background nductivity as a rule of thumb.

r the constant rate injection method, a solution of acers is injected into the flow at a constant rate over e cross-section. At the downstream end samples are taken regular time intervals. As soon as the concentration of e added tracer has attained a constant value, the rate of e flow can calculated using equation 3.21.

e length of the measuring reach should be as short as ssible so as to limit the duration of injection and the antity of tracer to be injected but long enough to ensure equate mixing of the tracer (Jansen et al, 1979). Several tempts are reported for determining adequate mixing ngth but reports from several approaches produce lculated required mixing lengths differing by as much as o magnitudes (Replogle et al, 1966). Studies are derway in many parts of the world to determine the length the canal or river necessary to obtain satisfactory xing (Michael, 1978). Herschy (1985) who lists two of the uations, states that there are a number of empirical uations which can be used for estimating the mixing stance but that all of them are approximate and are rmally used for preliminary surveys of the reaches ailable or the reach selected.

r the integration or sudden injection method, the lution of the tracer is injected for a short time only. e rate of flow is determined by using equation 3.22. The tegral can be determined by direct measurement of the ncentrations. Sampling of the tracer cloud should start fore the arrival of the tracer and last until all the jected tracer has passed the sampling point. Another ssibility is to sample continuously over the period and e it as an average sample (Jansen et al, 1979).

ll cited in Replogle et al (1966) recognized that the ncentration of the tracer does not have to be measured rectly. In the case of radio-active tracers, a geiger unter may be used to record counts resulting from the ssage of the tracer cloud and for salt dilution method, e conductivity of water may be measured instead of the ncentration (Bjerve and Groterud, 1980; Replogle, et al, 66).

.3.4 Accuracy and sources of error

ors can result from inadequate mixing of the tracer with water. They can also be introduced during the paration of tracer solutions or during the injection of tracer in the field. Adsorption of the tracer by the ks will also lower the accuracy. The sudden injection hod is more reliable than the constant rate injection ce it does require the precise determination of ection rates (Replogle et al, 1966).

re a high degree turbulence can be achieved, very urate results can be obtained (Jansen et al. 1979; ensson, 1976). Herschy (1985) gives an uncertainity of % at 95% level for dilution methods which is equal to t obtainable with the current meter or with the flume.

.3.5 Applicability

method is applicable in streams which are turbulent to ow adequate mixing of the tracer. It is especially ful in natural streams where the current meter cannot be d easily due to the roughness of the bed or sinuosity of channel. Equipment can be carried by one or two sons hence the method is recommended for survey work in ote areas. The method becomes costly for large rivers high discharges but can be usefully applied to the ibration of gauging structures (Shaw, 1983).

n the flow rate is changing rapidly or when the tracer e passage time is excessively long, as it may be in ge river, the continuous injection system is preferred. steady open channel flows of less than a few cubic ers per second, the sudden addition of tracer is ferred (Replogle et al, 1966).

MATERIALS AND METHODS

Selection of site

earlier hydrological studies, (Decurtins 1990; Liniger Decurtins 1990), Naro Moru river basin had been chosen a representative catchment whose results could be rapolated to all other tributaries of river Ewaso Ngiro ginating from the western and northern slopes of Mount ya. The main elements of representativeness are agro-matic zones, soil types, land-use and relief or dform.

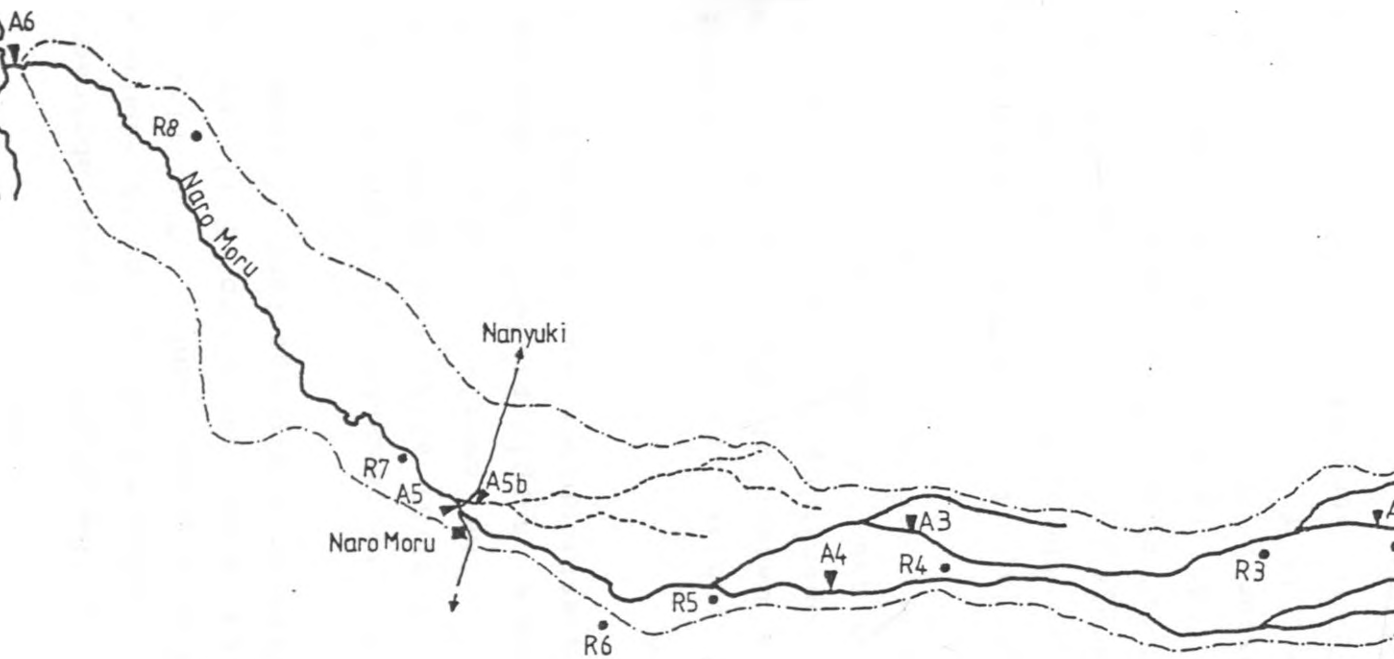
basin is well equipped for hydrological studies (Fig.) and data collection and maintenance of the rometeorological network is one of the tasks routinely ried out by Laikipia Research Programme since 1985.

Water supply inventory

.1 Field work

st field visit: A preliminary field visit to the sites re water is abstracted along Naro Moru river was carried from 20/09/90 to 30/09/90. The objectives of this ld visit were (1) to identify the points where water is tracted, (2) to assess the amounts of water abstracted each point and (3) to obtain information that would lead choice of appropriate methods of measuring the tracted flows.

sites were identified in the field by using the map pared by Leibundgut (1986) following a water supply entory for the area done in 1984. Information on other traction points not existing in 1984 was obtained from local leaders and from the MoWD staff.



KEY

R1 • Rainfall measuring station
A2 River gauging station
Perennial river
Intermittent stream
Catchment boundary

Fig. 4.1 Hydrometeorological network in Naro Moru river basin ing these visits, the amount of water abstracted using ed systems was measured at the point where water is ivered into the storage tank. The flow rate was ermined by the time taken to fill an 18 litre calibrated bucket or a storage tank of known capacity.

<u>ond field visit:</u> The second field visit was carried out m 10/12/90 to 20/01/91 after the cutthroat flumes had n installed in the canals. Detailed information cerning each water supply project was obtained during s period. A questionnaire was used and is shown in endix I.

private and public projects, the information was ained from the owners of the projects or from those ponsible for operating and maintaining it. For munity projects the information was obtained from the ders of the water users associations.

private projects, it was not easy to get access to er permits from the field visits because the people ponsible for projects were in most cases not the owners mselves. Even for community projects it was not easy to ain information on the authorized abstractions from the ders of the water projects. Due to these reasons, the t of water permits for all authorized water users was ained from the Ministry of Water offices in Nyeri and kipia districts.

.2 Data compilation and analysis

location of each water supply project was entered onto :50,000 scale map prepared earlier by Leibundgut (1986). comparison was made between the two inventories to ntify the number of new projects since 1984.

was necessary to set a common basis for the comparison the amounts of water abstracted from the river for tems that operate intermittently and for those that rate continuously. The intermittent flows were verted into the equivalent continuous discharges that ld deliver the same amount of water to user if the tems were operated all the time.

__Measurement of abstractions__

main methods of diverting water were identified during first field visit and the methods of flow measurement discussed with reference to these two methods. These : (1) by use of weirs and open channels where the flows olved usually exceed 15 l/s and the flow variations are ge and (2) by use of pipes flowing under gravity or ped pressure where the flows involved are relatively ll and in some cases intermittent.

liminary information obtained on the different methods d to abstract water from Naro Moru river and the methods sen to measure the flow is presented in Table 4.1.

.1 Discharge measurement in canals

ee canals were identified: one in the footzone and two the Savannah zone. A standard cutthroat flume was talled in each of them.

independent staff gauge was installed at a suitable site the canal to supplement the flume measurements and to ck for possible leakage under or around the flume.

Methods used to measure abstracted flows

) OF DIVERSION ONVEYANCE	TYPE OF PROJECT	MODE OF OPERATION	VARIATION OF FLOW	FLOW MEASUREMENT METHOD
ind canal	community	continuous	high	cutthroat flume, staff gauge, current meter, salt dilution.
gravity	community	continuous	low	volumetric method (18 litre bucket and stop watch or time taken to fill storage tank)
, plata pump, ulic ram	private	mainly continuous	low	"
, diesel or ric pump	private	intermittent	low	"

1.1 Site selection

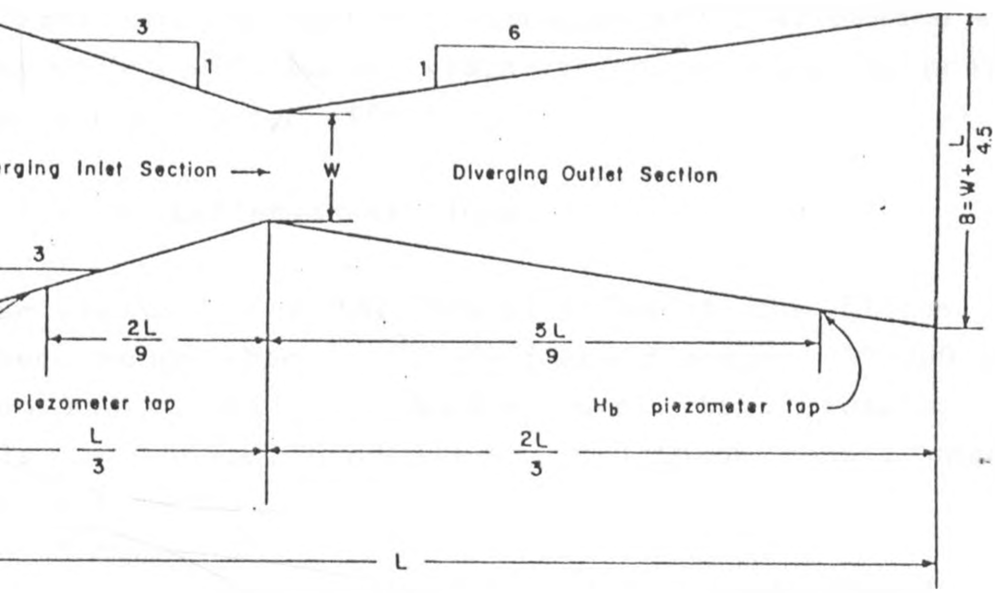
rmation relevant to the design, installation and ation of the cutthroat flume was obtained during the t field visit. This included measurements of width, h, sideslopes, and shape of the channel; stability of banks; anticipated effect of backwater; silt and debris ied in the water; security of the structure against ge; expected extreme flows that would lead to flooding he structure; and accessibility for both maintenance installation purposes. The sites selected had to be on traight stretch of the canal and be upstream of any ake. Based on this information, a qualitative ssment of the different sites was made and the most l site for flume installation was chosen.

ible sites for the installation of staff gauge were ssed. The sites selected had to be stable and anent, be on the upstream side of the flume site, be e to the diversion point, be upstream of any offtake the canal and be free of disturbances that would ct the reading. It had to be visible to an observer be easily accessible by track.

allation of a staff gauge should have preceded the allation of the flumes, but in this case, the staff es were installed about 10 days after the cutthroat es because they were not available in time.

1.2 Design and fabrication of flumes

design of the flumes was done following the procedure ined in Walker (1989) and Kraatz and Mahajan (1975). geometry of the cutthroat flume is in general as shown igure 4.2.



re 4.2 The geometry of the cutthroat flume with a broken plane transition. (Source: Kraatz and Mahajan, 1975).

flumes were fabricated locally under the supervision of author. They were made out of 16 gauge sheet metal and m x 25 mm x 6 mm angle iron bars and painted first with oxide primer and then with black bituminous paint to vent rusting. A centimetre scale was marked with white nt at the appropriate place for measuring the upstream downstream water depths (see Fig. 4.2). The specific ensions of the three flumes were as shown in Table 4.2.

e 4.2 Dimensions of the cutthroat flumes

	Footzone	Savannah
oat width, W in cm	50	40
al length, L in cm	90	180
ne depth, D in cm	60	60
imum capacity, Q in l/s	284	420
oer of flumes	1	2
: per flume (KShs.)	5650	3600

canal in the footzone was wide and shallow and so a me with a wide throat width was chosen so as to prevent essive backwater effect.

.1.3 Installation of flumes

erials used for the installation of the flumes were ber, rough stones, (approximate diameter 150-300 mm), on sacks, soil, carpenters level, tape measure, saw, ls, galvanized iron sheets, polythene paper, spades, el-barrow etc.

flow in the canal was reduced by placing bags filled h soil on the upstream site of the flume installation e. It was difficult to stop the water off completely as er flows in October 1990 were high as is usual during short rains.

cut-off walls were erected at a distance apart equal to length of the flume. The purpose of the cutoff walls to prevent seepage under and around the flume so they e embedded into the bottom and sides of the channel. A tangular section just enough to fit the entry and exit ls of the flume was left in the cut-off wall.

nes were laid on the canal bed between the cutoff walls. flume was fixed in place and levelled longitudinally transversely using a carpenter's level. The flume was gned parallel to the direction of flow.

er levelling, a piece of galvanized iron sheet was led on the timber cutoff wall to seal off any leakage. nes and soil were packed firmly on either side of the me to hold it in place and a bed of stones placed on the tream and downstream sides to prevent scour. The sacks soil blocking the flow were removed and water allowed to w. For the first few days after installation, the flume inspected for leakage. One of the flumes in operation shown in Plate 4.1. (see also Appendix II for the actual pe of the finished flume).

te 4.1 40 cm wide cutthroat flume installed in abstraction point No. 25 in operation.

1.4 Data collection and analysis

data collected daily included the gauge height on the ‑, the upstream and downstream water depths in the e, the time of observation and any remarks concerning activities taking place like cleaning of canals, ing of weir, floods etc. Readings were taken at 09:00 and 15:00 hrs daily.

ulation of discharge was done by applying equations and 3.19 in section 3.7.1.3. The coefficients, nents and submergence limits used are listed in Table

e 4.3 Flume coefficients, exponents and submergence limits.

FLUME LENGTH	S_t	K_f	K_s	n_f	n_s
180 cm	0.74	3.71	2.04	1.64	1.39
90 cm	0.65	4.52	2.56	1.84	1.46

2 Discharge measurement in piped systems

rate of abstraction was assessed at the outlet point of system either directly by measuring the time taken for system to fill a known volume (bucket or storage tank) ndirectly by noting the average time taken to fill the ge tank as reported by the owner or operator.

tional information on the average number of hours of operation for each pumping day, the number of days of ing per week and the months of pumping per year was ined to help in assessing the average rate of raction over the period of study.

surements of rate of abstraction in piped systems was le on three occasions: from 20/9/90 to 30/9/90; from 12/90 to 18/3/91; and from 2/4/91 to 5/4/91. The erage of the three measurements thus obtained was taken be the average rate of abstraction for the period ember 1990 to June 1991.

. Measurement of river flow

e stage discharge method was used to obtain the mean ly discharge at each of the river gauging stations A3, A5, A5b and A6 for the period November 1990 to June 91 and is discussed immediately below. The next two ctions are devoted to the salt dilution method and the rrent meter method which were used to calibrate the river ging stations.

.1 Stage-discharge method

.1.1 River gauging stations

gure 4.1 shows the river gauging network for Naro Moru ver consisting of stations A1 to A6 which were installed 1982 and are maintained by Laikipia Research Programme RP). River gauging station A5 is also Ministry of ter's river gauging station 5BC2 for the upper Ewaso 'iro catchment and has been in operation since 1931.

ation A5b is a newer station belonging to LRP. It was stalled on 18/3/91 on a periodic tributary of Naro Moru ver which discharges its water just downstream of station .

e river gauging stations used during this study are sted in Table 4.4.

able 4.4 River gauging stations used during the study

UGING ATION	LOCATION	ALTITUDE (m a.s.l.)	CATCHMENT AREA (sq. km)
	On Northern Naro Moru river Lower forest boundary	2295	38.7
	On Southern Naro Moru river Lower forest boundary	2295	22.8
	On the main river near Naro Moru town also MoWD RGS 5BC2	1958	84.4
b	On seasonal tributary of Naro Moru river Near station A5 (installed 18/03/91)	1958	17.6
	Just before the confluence of Naro Moru and Ewaso Ng'iro rivers	1795	169.1

: See Fig.4.1 for location of stations

.4.1.2 Equipment and methods

river gauging station should be equipped to measure stage nd should have a suitable reach for measurement of ischarge.

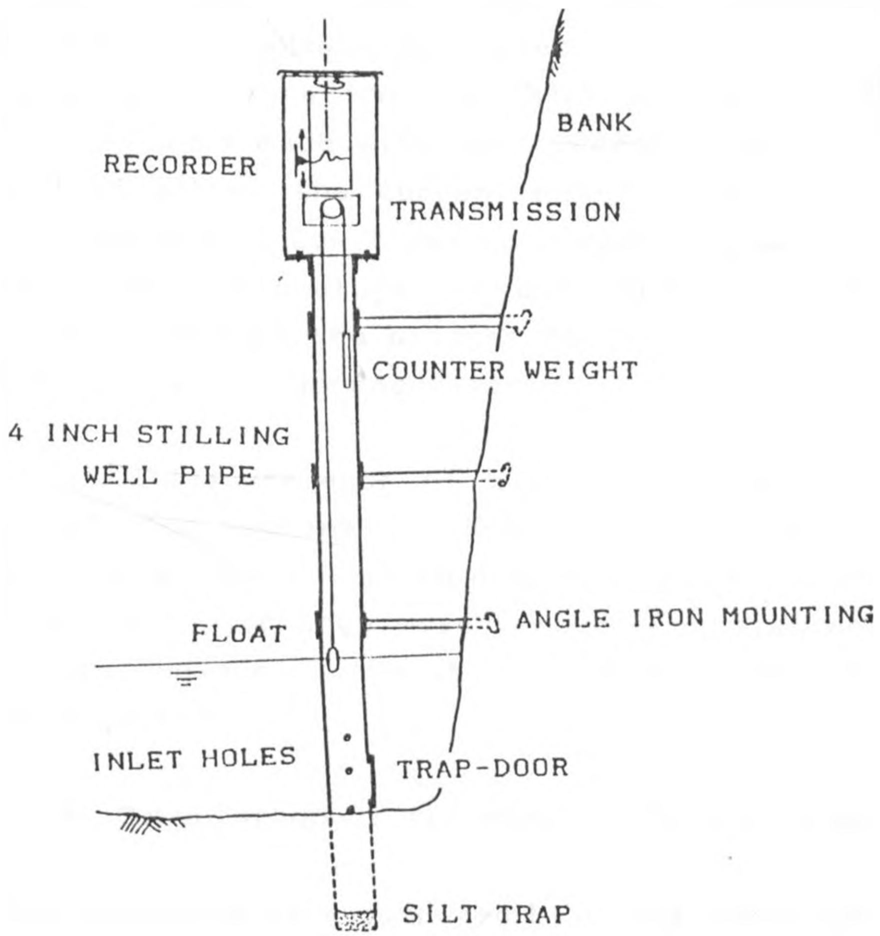
tage in each of the stations mentioned above was measured sing A.OTT R16 vertical water level recorders. The ecorders are float-actuated. A spring or battery powered lock rotates a vertical drum and the water level luctuations are recorded as displacements along the drum xis. The clocks can normally run for 32 days unattended. he height reduction ratio (vertical scale) is 1:10 and the en advance 1 mm on the chart every 2 hours.

he float operates in a stilling well which is a vertically ounted galvanized iron pipe with a nominal internal iameter of 4 inches. For stations A3, A4, A5 and A5b, the ipes are mounted directly in the stream and water gets nto the stilling well through holes on the sides.

r station A6, the stilling well pipe is mounted on the ft bank and water gets into it through two horizontal let pipes at the bed of the river.

ation A5b has a trap-door through which one can remove diment accumulating in the stilling well. The other ations do not experience problems with sediment. For corders at A3, A4 and A5b an independent value of stage obtained by measuring with a tape from a reference point the stilling well pipe.

ations A5 and A6 have a reference staff gauge nearby. e set-up of the water level recorder installed at A5b is shown in Fig. 4.3. It illustrates also the general setup the vertical water level recorders.



g. 4.3 Float actuated water level recorder installed at A5b utine activities needed for the proper operation of the corder stations consisted of:

) Checking the float and water surface elevation with the recorded elevation on the chart, and adjusting the recorder or float mechanism where necessary so as to agree with the reference gauge height,
) Changing the recorder charts once every month,
) Changing the recorder pens when necessary,
) Winding the clock or changing the batteries when necessary,
) Inspecting and cleaning the intake pipes or holes to the recorder stilling well, and
) Inspecting and removing any logs or floating debris obstructing the float near the recorder site.

e equipment and methods used for calibration measurements om 1982 - 1986 is documented in Decurtins (1990). The lt dilution method was used for all the discharge asurements in station A4. Most of the measurements in ation A6 were made with the current meter. For station and A5 either the current meter or the salt dilution thod was used. Low flows were measured using the wading thod with a miniature current meter while flood flows re measured from the bridges for stations A3, A4, A5 and with a normal current meter.

ditional measurements of discharge were made with the lt dilution machine in 1990/91 at all the stations and th a Braystroke miniature propeller-type current meter at ation A5. Discharge measurements for station A5b which s installed during the study were obtained with the salt lution method.

4.1.3 Computation of the mean daily discharge

ting equations were computed by using the stage-discharge ta from LRP' for each of the stations A3, A4, A5 and A6 ected from 1982-1986 and additional data obtained ng the current study.

highest gauged stage was exceeded for all stations ng the period study (Nov - June 1990/91) and hence it necessary to extrapolate the rating curves. Cross-ions were taken at each of the river gauging stations stablish the shape of the section.

rds of stage were obtained in the form of continuous e hydrographs (charts) for each station.

ompute the daily mean discharge from the charts, stage es over each day were read off at 4 hr intervals on the ograph pen trace starting from 02.00 hrs to 22.00 hrs. of the six values of stage obtained for each day was erted to discharge using the rating equation and the harges averaged to obtain the mean daily discharge as n in Appendix III.

2 Salt dilution method

e are two steps involved in using the salt dilution od for discharge measurement in a river. These are:

Calibration - which means establishing the concentration conductivity curve for the salt to be used, and

Discharge measurement in the river.

2.1 Salt dilution equipment

salt dilution machine used is an Epson HX20 Hand-held uter with connections for attaching a conductivity r. The conductivity meter was also used to measure erature. The computer is powered by internal argeable batteries. The calibration and discharge asurements processes are user-interactive and the program written in BASIC. Data is input through a full ASCI yboard and is displayed and edited on a liquid-crystal splay. The raw and processed data is printed on a paper ll but may be issued on a cassette drive. The computer so prints the date and time for each calibration or scharge measurement operation. The tracer used is common lt (NaCl) which is easily obtained from local shops.

4.2.2. Calibration

e materials used for the calibration were the Epson HX20 mputer with the conductivity meter, 1000 ml of distilled ter in a beaker, a 0.5 ml pipette, one packet of salt lected from the batch to be used, a weighing balance curate to 0.01 g, 250 ml of river water in a beaker and stirring rod

salt solution of concentration 10 g/l was prepared by ding exactly 10 g salt into 1000 ml of stilled water and irring until all the salt dissolved. The computer and e conductivity meter were connected. The electrode was aced in the river water and the machines switched on.

e following information was entered into the computer: itial volume of river water (250 ml was used), amount of lt solution added stepwise (0.5 ml was used), and ncentration of the salt solution (10 g/l). It is needed r the computation of calibration coefficient.

e first conductivity measurement was made which gives the ckground conductivity of the river water. Using the pette, 0.5 ml of the salt solution was transferred to the ver water. The river water was stirred and the second nductivity measurement was made. Additional measurements re made by first adding 0.5 ml of the salt solution into e river water and stirring. This was repeated 7 or 8 mes. The computer obtains the value of the calibration efficient through regression analysis and prints the lue obtained. This value is automatically saved by the mputer and is recalled for use during field measurement. can also be altered

4.2.3 Measurement of discharge

e materials used for measuring discharge by the salt lution method were 18 litre buckets; salt (NaCl) packed packets of 1/4 kg, 1/2 kg and 1 kg; Epson HX20 portable mputer and the conductivity meter (see Plate 4.2). A libration coefficient should be available for each batch salt used.

ate 4.2 Current meter and Salt dilution machine and accessories.

suitable site was selected for injecting the salt lution and another site downstream for sampling the ssage of the tracer cloud. Adequate mixing of the salt lution with the water was ensured by choosing a river ach where the flow is turbulent and avoiding pools and ctions with backwater flow. An assessment of discharge s made as to estimate the amount of salt to use. Salt lution was prepared by adding known weights of salt into ver water in the buckets and stirring thoroughly. The mputer and the conductivity meter are connected at the wnstream measuring station. The electrode for the meter s placed in the stream where it could be steady. After itching the machines on, the following information was tered into the computer: the calibration coefficient for e salt being used; name of the measuring station; name of ver; initial gauge height (cm); water temperature (^{0}C); stance from the injection site to the sampling site (m); ount of salt used (kg); and sampling time interval (s).

e salt solution was poured into the water and the mputer started measuring the conductivity every second (a mpling time interval of 1 s was adopted) on pressing the ace bar key. Thus the background conductivity of the ter was measured before the influence of the salt lution was felt at the sampling site.

e conductivity of the river water was measured every cond until all influence of the salt solution has passed e sampling site. It is possible to know when the salt lution has passed through the sampling site because the mputer displays the initial conductivity of the river ter as well the conductivity values obtained every cond. Measurement of conductivity is continued until the rst few stable values of conductivity which are close to e initial conductivity are obtained after which it is lted by pressing the RETURN key. The final gauge height entered into the computer. The computer then would int the discharge obtained and all the information put to it. In addition it would also print the date; time; itial, final, maximum, and average conductivities; total me taken for the measurements to be made and the flow te obtained. A graphical print-out showing the ductivity time curve is printed from which one can judge quality of the measurement. A repeat measurement would made if the output was doubtful.

.3 Current meter gauging

.3.1 Gauging sites

current meter method was used to measure discharge in tion A5 and in the canals. Station A5 has a good site re current meter gauging can be done. The riverbed in tions A3 and A4 consists of cobblestones and some lders. In station A6 the channel bed is free of rocks the flows are less turbulent. The channel is more uous and logs sometimes obstruct the flow in some tions. In station A5b the current meter cannot be lied because the channel is irregular and is vegetated.

..3.2 Current meter gauging equipment

propeller type miniature current meter of the type eport Braystroke 1178 series with a digital counter and graduated wading rod 1 m long was used to measure the er discharge. Other materials needed were a 30 m tape sure, stop watch and a staff gauge (see Plate 4.2). ge was obtained by reading from the reference staff ge.

..3.3. Gauging method

channel cross-section was divided into verticals. The th of the river and the distances between the various ticals were obtained by measuring from fixed reference nt on the bank. Depth at the various verticals was sured with the graduated wading rod. The wading method used. The mean velocity in each vertical was ermined at a point 0.6 of the depth from the water ace. The mid-section method was used to compute the charge.

Daily rainfall data

location of the rainfall measuring stations in Naro river basin are shown in Figure 4.1. Daily rainfall ies for the stations R3, R4, R5, R6, R7 and R8 for the od of January 1990 to June 1991 were obtained. Some ormation on each of these rainfall station is given in e 4.5.

e 4.5 List of the rainfall measuring stations

LL N	LOCATION	TYPE	ALTITUDE (m a.s.l.)	OWNER
	Met station	Daily rain gauge	3040	MoWD
	Naro Moru Park Gate	Daily rain gauge	2440	MoWD
	Naro Moru Chief's home	Daily rain gauge	2180	PRIVATE
	Naro Moru children's home	Helmann siphon type recorder (from 6.4.91)	2070	LRP
	Satima farm	Daily rain gauge	1950	PRIVATE
	LRP station, Matanya	Helmann siphon type recorder	1840	LRP

See Fig. 4.1 for location of the stations

. River reach water balance analysis

.1 General equations and assumptions

seen in Equation 3.7, the basic water balance equation a river reach on a daily basis may be written as

$$DR + GW + \Delta SW = RO - RI + A \qquad [4.1]$$

where,

RO = river outflow from reach

RI = river inflow into reach

A = abstractions from reach

DR = local direct runoff into reach

GW = net movement of groundwater into reach (positive) or net loss during transmission (negative)

Δ SW = change in channel storage

Local direct runoff is that runoff coming from the catchment area adjacent to the reach and should be distinguished from upstream direct runoff which has already reached the channel by the time it enters a particular reach. Transmission losses include infiltration into the channel bed and sides and evaporation. The units used in this analysis are those of discharge i.e m^3/s.

The analysis was first carried out on a daily basis to show the trend and finally on a monthly basis. On a daily basis changes in channel storage cannot be ignored because the time taken for a wave to travel through the reaches is estimated to be less than 6 hrs for the footzone reach and less than 10 hrs for the savannah reach (Chow et al, 1988). The estimates are based on an average slope of 0.74% and a length of 22 km for the savannah reach and 2.2% slope and a length of 13 km for the footzone river reach (Leibundgut, 1986). On a monthly basis changes in channel storage can be excluded because no flood wave will be retained within the reach longer than a day.

The terms on the right hand side of Equation 4.1 are known while those on the left hand side are unknown. The following simplifying assumptions are made in order to reduce the number of unknowns:

(1) If there is no rainfall in the catchment area contributing local runoff into a reach, **DR** becomes zero.

(2) If the river flow is steady, change in channel storage Δ **SW** becomes zero even on daily water balance analysis.

(3) For periods when baseflow is the major constituent of streamflow (i.e negligible local or upstream runoff), any change in amount of streamflow occuring within a reach is attributed to net groundwater outflow into reach or net transmission loss. Thus during the dry season, **DR** is zero, Δ **SW** is zero also because river flow is steady and the only unknown is **GW**. During the wet season, short periods when **DR** and Δ **SW** may be neglected are chosen so as to assess **GW**.

The procedure outlined above is carried out graphically and therefore the results are only fair estimates. The water balance analysis for the footzone and savannah zone reaches is discussed more specifically in the following section.

4.6.2 Footzone river reach

Referring to Fig. 4.4, the water balance equation for the footzone reach on a daily basis may be written as:

$$DR_{fz} + GW_{fz} + \Delta SW_{fz} = RO_{fz} - RI_{fz} + A_{fz} \qquad [4.2]$$

where,

DR_{fz} = local direct runoff into footzone reach

GW_{fz} = net movement of groundwater into footzone reach (positive) or net transmission loss from footzone reach (negative)

ΔSW_{fz} = change in channel storage in footzone reach

RO_{fz} = river outflow from footzone reach which is the discharge through A5

RI_{fz} = river inflow into footzone reach which is the sum of flows through A3 and A4

A_{fz} = abstractions from footzone reach

Rainfall was measured in stations: R4, R5 and R6 (Fig. 4.4) and the areal rainfall was calculated using the Thiessen polygon method.

4.6.3 Savannah zone river reach

Again referring to Figure 4.4, the water balance for the savannah zone reach on a daily basis is

$$DR_{sz} + GW_{sz} + \Delta SW_{sz} = RO_{sz} - RI_{sz} + A_{sz} \qquad [4.3]$$

where,

DR_{sz} = local direct runoff into savannah zone reach

GW_{sz} = net movement of groundwater into savannah zone reach (positive) or net transmission loss from reach (negative)

$\Delta SWsz$ = change in channel storage in savannah zone

RO_{sz} = river outflow from savannah reach which is the discharge through station A6

RI_{sz} = river inflow into savannah reach which is the discharge through stations A5 and A5b.

A_{sz} = abstractions of water from savannah zone reach

Rainfall was measured in stations R7 and R8 and areal rainfall was calculated using the Thiessen polygon method.

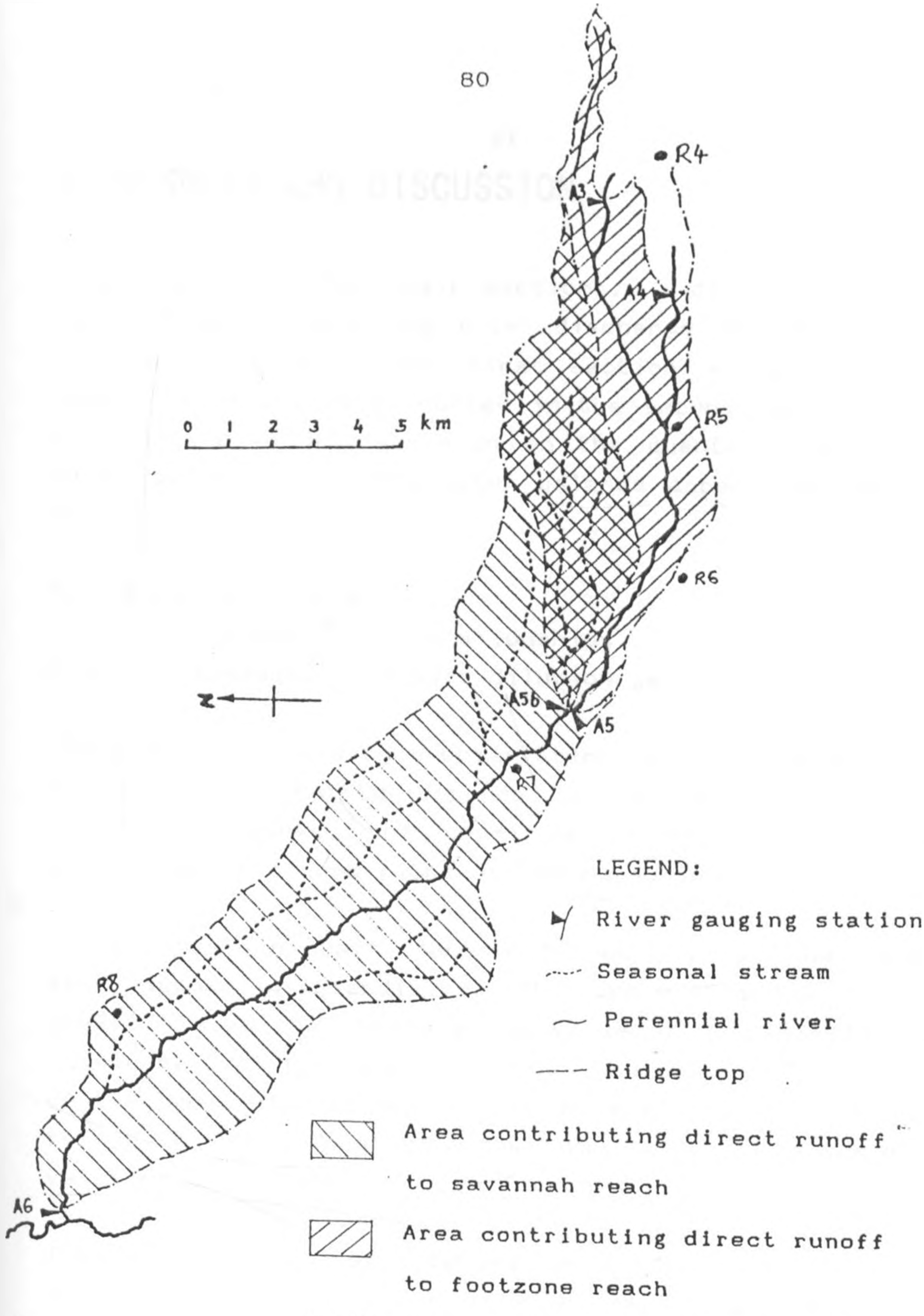


Fig. 4.4 Footzone and savannah reaches of Naro Moru river

5 RESULTS AND DISCUSSION

This chapter has four main sections. A discussion on the methodology of obtaining river discharge and the results obtained appears in the first section while the water supply inventory is discussed in the second section. This is followed by a discussion on the quantities of river water abstractions. The water balance appears in section four.

5.1 River discharge

5.1.1 Stage discharge relationships

5.1.1.1 Evaluation of salt dilution gauging

The accuracy of a single observation of discharge with the salt dilution method depends on the accuracy of the calibration curve, the condition of the salt dilution machine and the conditions of the measuring reach.

The calibration coefficients obtained and used during the study appear in Appendix IV. They are 0.55 and 0.54. Garg (1985) states that the average value of this coefficient should be 0.65 for common salt but the exact value depends on the types of salt present in the water. It is important to repeat the calibration a few times to ensure an accurate value of the calibration coefficient.

The amount of salt used during the study is shown in Fig. 5.1 together with the corresponding discharge measurement obtained. Herschy (1985) recommends the use of 0.2 kg per m^3/s of discharge for natural waters with low background conductivity as a rule of thumb. For the conditions experienced it was observed that this rate is too low. A rate of 6 - 10 kg per m^3/s of discharge would probably be more appropriate (Fig. 5.1). A lower rate can be applicable if the measuring reach was reduced but this

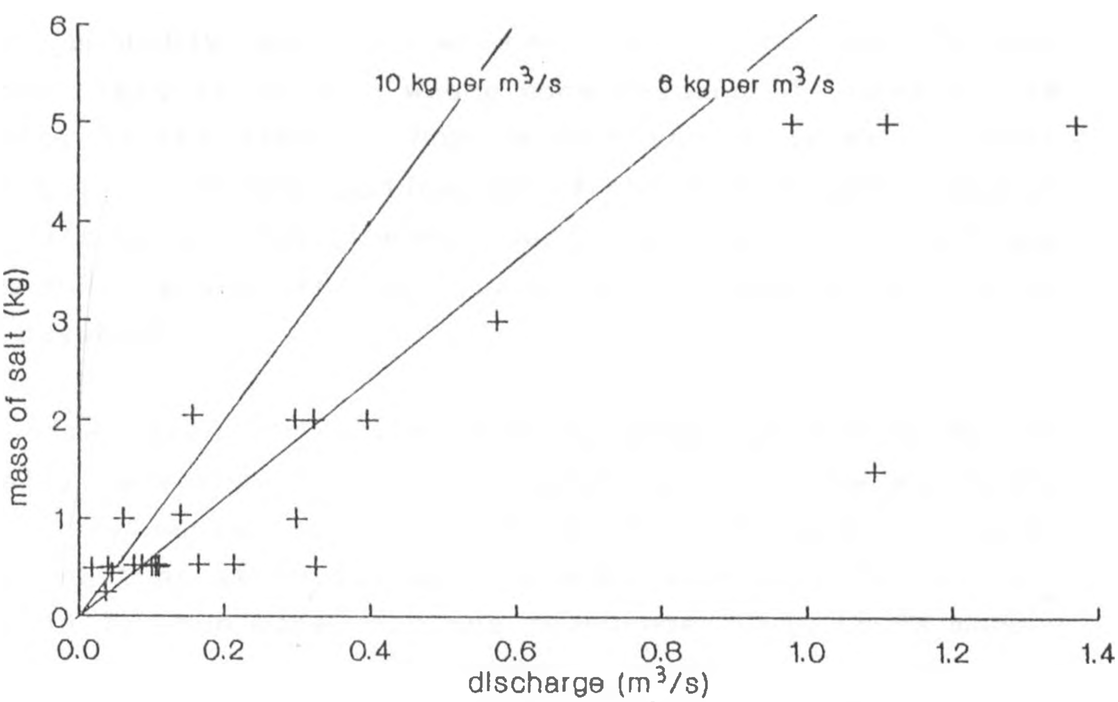


Fig. 5.1 Amount of salt required per m^3/s of discharge

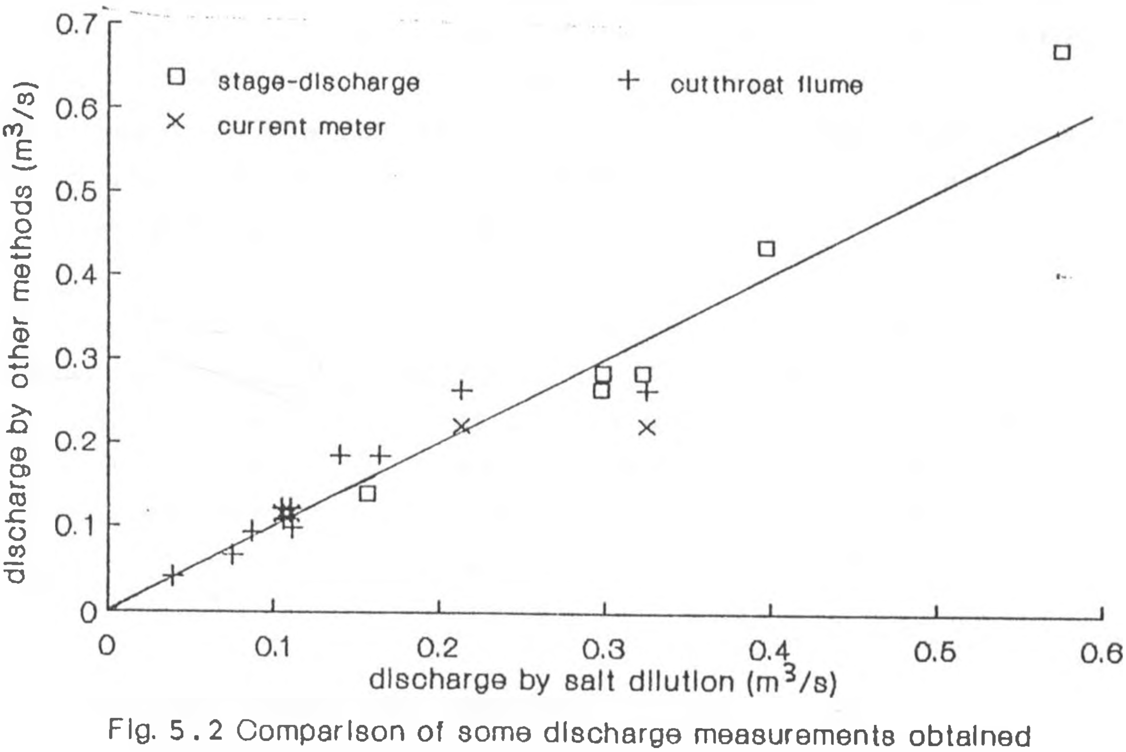


Fig. 5.2 Comparison of some discharge measurements obtained by salt dilution against those obtained by other methods

would probably give poorer results due to insufficient mixing. This is an area where more research is needed. The quality of the sites in Naro Moru river in terms of their suitability for the application of the salt dilution method for discharge measurement declines from the footzone downwards because the quality of mixing becomes poorer in the savannah.

The time taken for a single measurement of discharge was usually less than 30 minutes (Appendix IV). The equipment is easily portable. The amount of salt needed however requires that at least two people be available for the job especially when more than one measurement has to be made.

When conditions were good, the results of the salt dilution method were comparable to those of the current meter or cutthroat flume. In Figure 5.2 some results obtained with the salt dilution method are compared with other methods. The stage-discharge values used here are for medium flows as extreme low and high flows are not accurately determinable with the existing rating equations. For flow measurement in the canals, the salt mixture was injected at the flume site where exit conditions create reasonable turbulence to allow adequate mixing.

The length of measuring reach adopted ranged from 50-100 m as may be seen in Appendix IV. The length of measuring reach should be as short as possible to limit the amount of tracer needed but should be long enough to ensure adequate mixing (Herschy, 1985). More experiments need to be done to ascertain the most appropriate length of the measuring reach.

5.1.1.2 Developing the rating equations

The data used to determine the stage discharge relationship at each of the five river gauging stations is shown in

Appendix IV. Results of measurements of stage and discharge made in 1990/91 with the salt dilution method are presented also in Appendix IV.

The rating curves obtained from the regression between log Q and log H are drawn on double logarithmic scales in Figures 5.3(a), 5.4(a), 5.5(a), 5.6(a) and 5.7(a) for the river gauging stations A3, A4, A5, A6,and A5b respectively. The cross-sections at the river gauging stations are presented together with the rating curves for purposes of discussion.

The river gauging stations A3, A4, and A6 have no artificial controls and the cross-sections shown were taken in line with the water level recorders. It is observed that the stage discharge relations plot fairly linear and no curvature can be ascertained from the available data. The discharge was therefore taken to be zero when the stage is zero.

There is a compound rectangular weir at station A5 and the cross-section was taken on the weir. The zero point of the staff gauge coincides with the weir crest. The zero point of the reference gauge coincides with the bottom of the channel at the cross-section for station A4 (Fig. 5.4(b)).

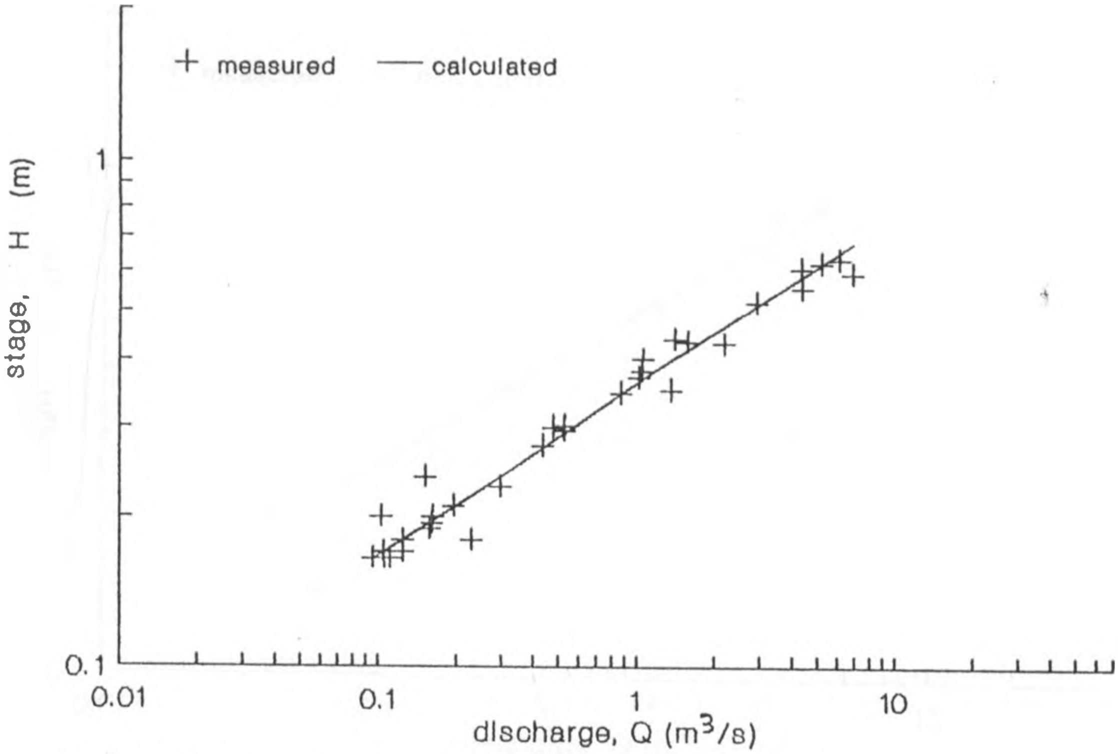


Fig.5.3(a)Rating curve for station A3 on log-log scale

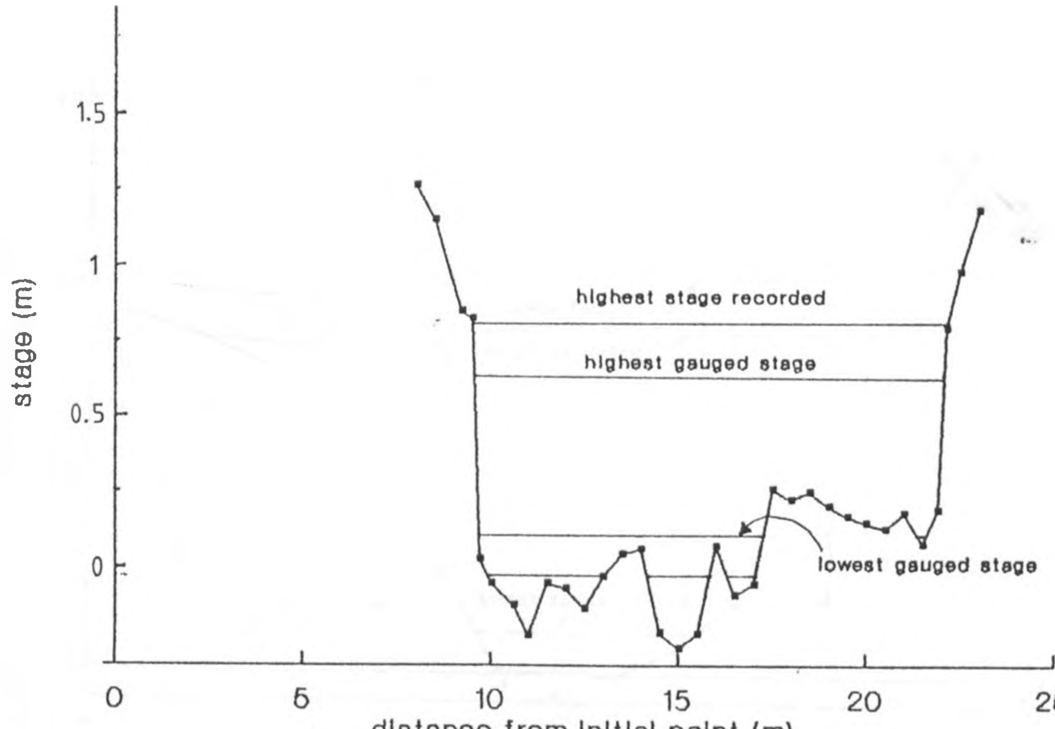


Fig.5.3(b) Cross-section at RGS A3 taken on 7th May,1991

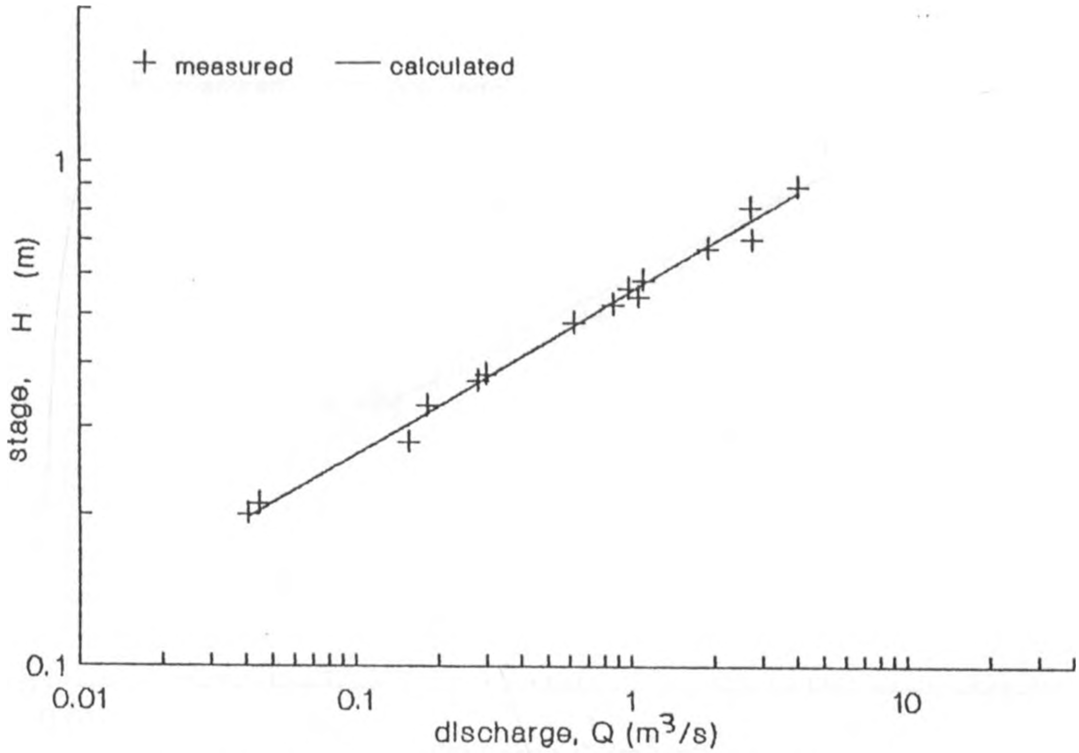


Fig. 5.4(a) Rating curve for station A4 on log-log scale

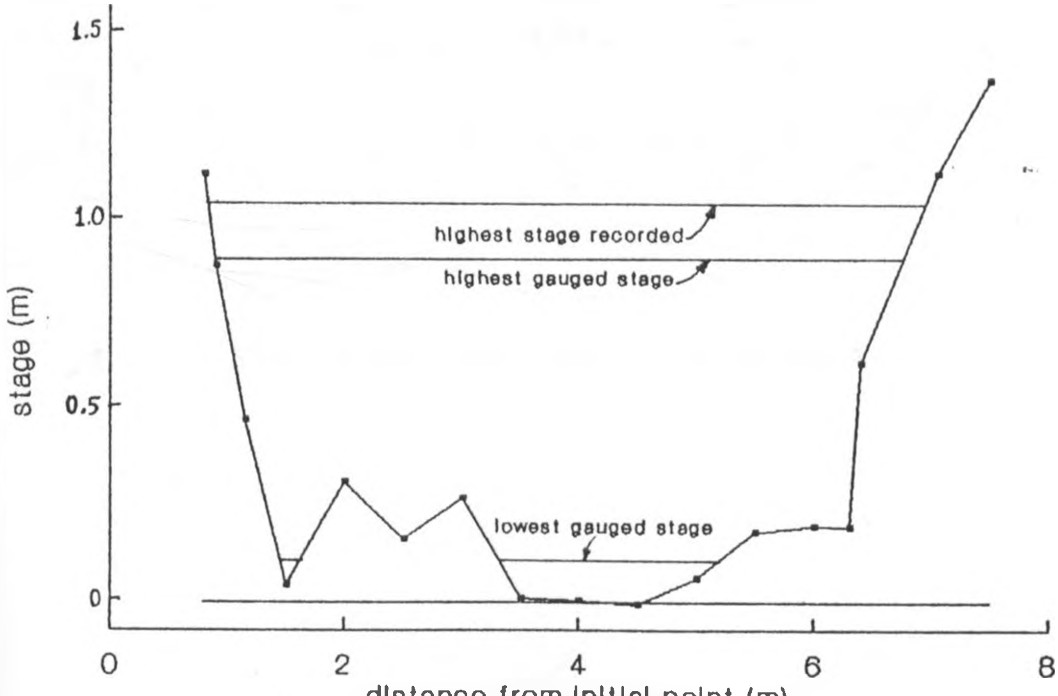


Fig. 5.4(b) Cross-section at RGS A4 taken on 7th May 1991

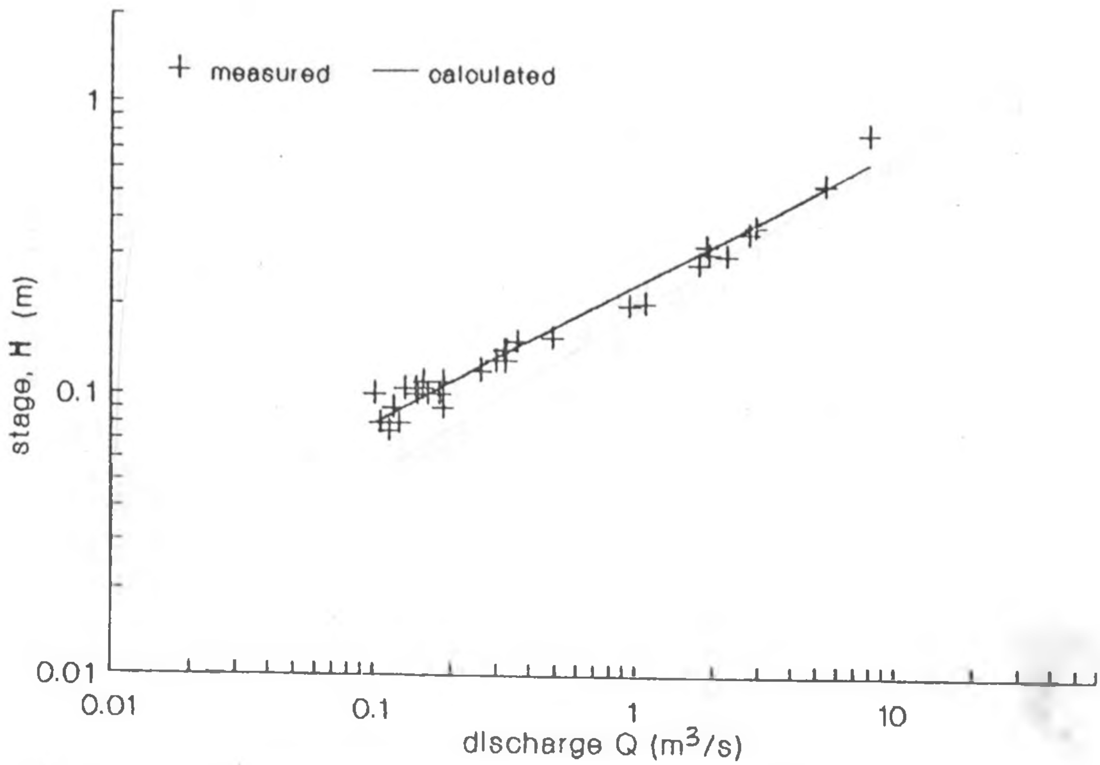


Fig. 5.5(a) Rating curve for station A5 on log-log scale

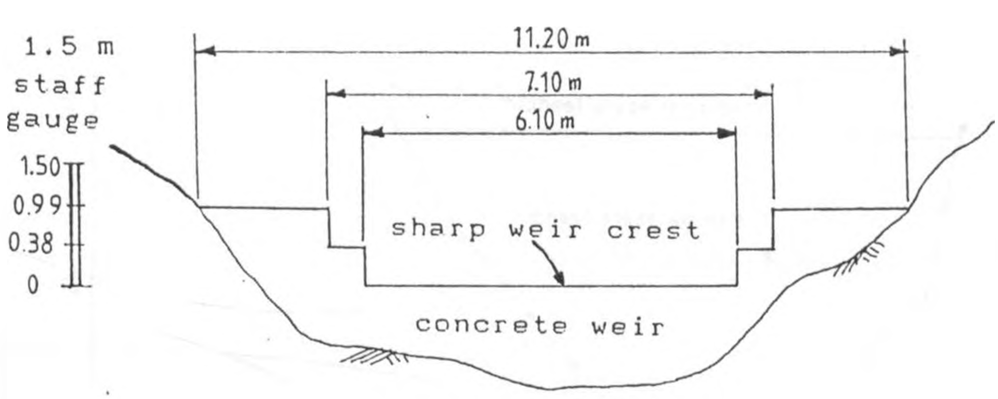


Fig. 5.5(b) Cross-section for station A5

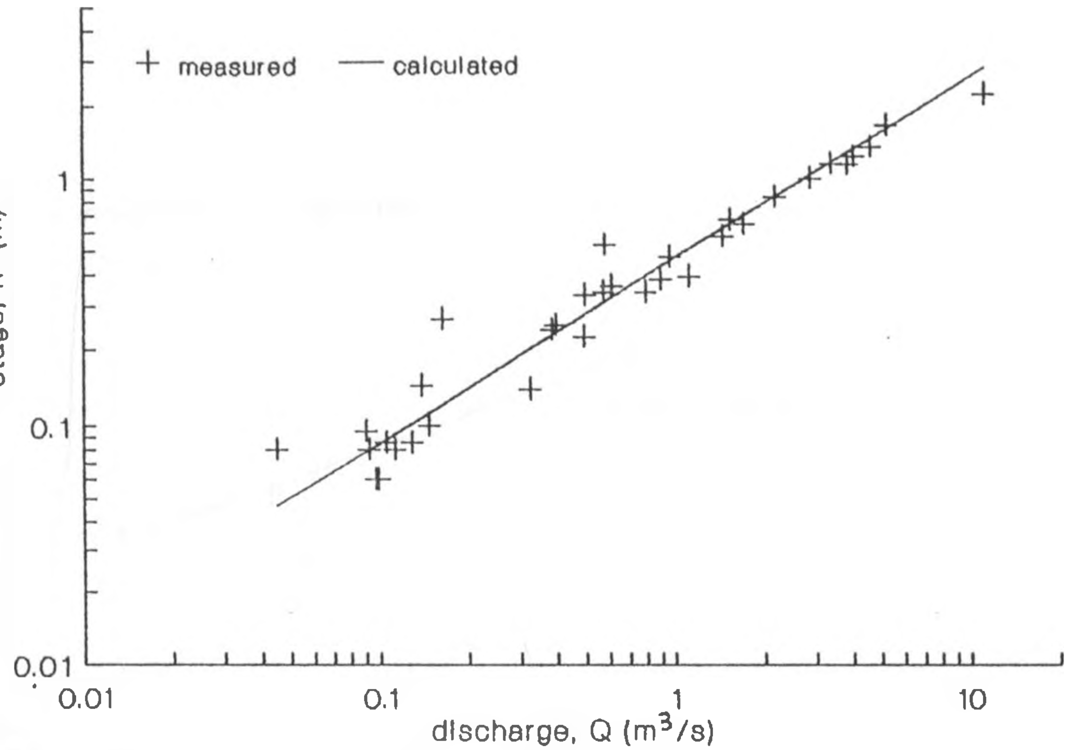


Fig. 5.6(a) rating curve for station A6 on log-log scale

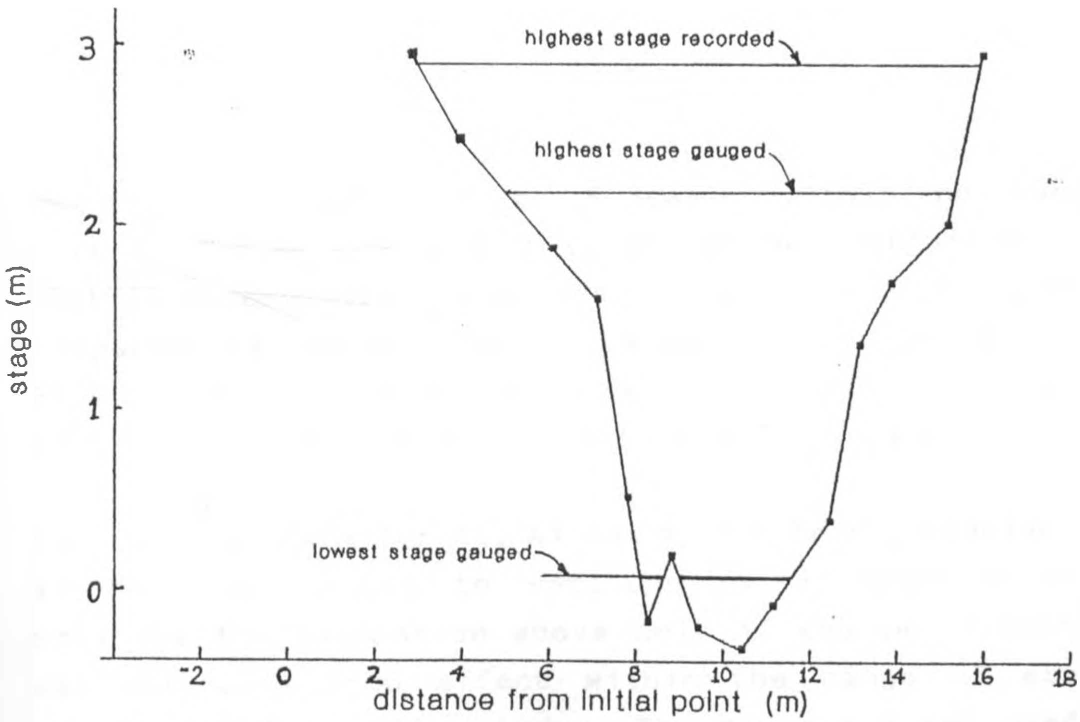


Fig. 5.6(b) Cross-section at RGS A6 taken on 9th May 1991

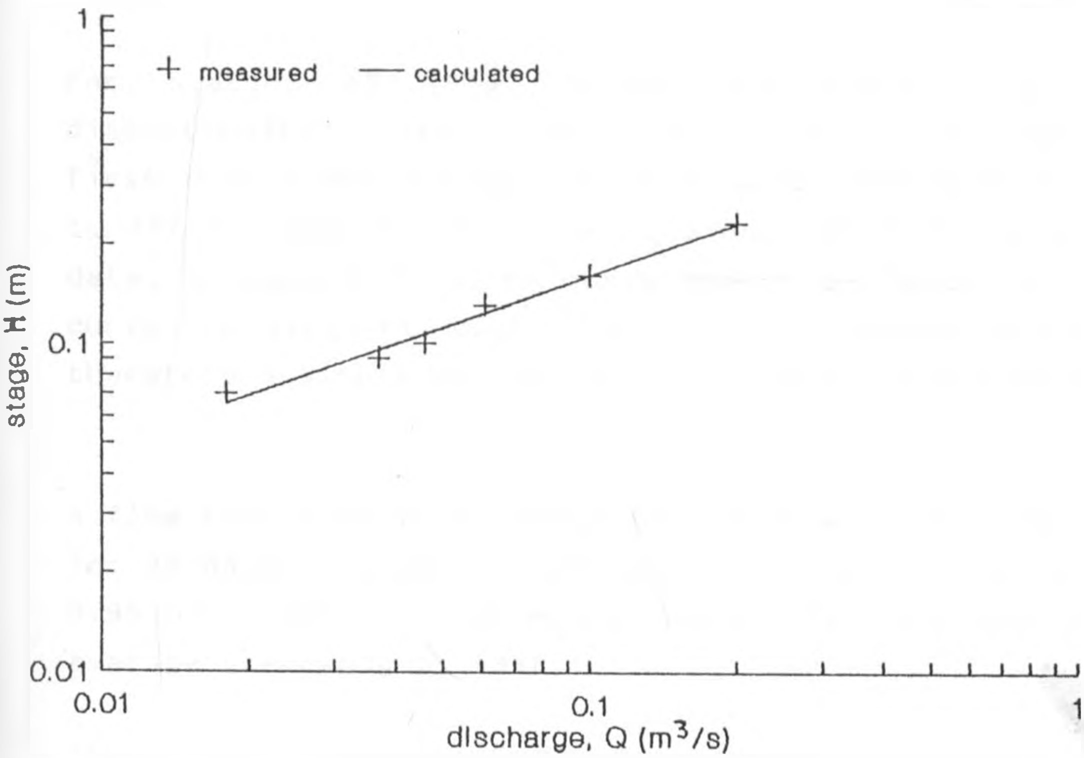


Fig. 5.7 (a) Rating curve for station A5b on log-log scale

From the rating curves (Figs. 5.3(a) - 5.7(a)), no changes in control over the gauged stage can be identified. At least 30 observation points are needed in order to justify a separate rating equation for a range of stage (Herschy, 1985). Due to the paucity of data, a single rating curve has been assumed to hold for all ranges of stage.

The cross-sections for A3, A4 and A6 are fairly regular and can be approximated to sections of a parabola which justifies the assumption above only if change in control does not come into effect within the range of stages experienced during the study. The river did not overtop the banks for those stations during the period of study

(Fig. 5.3(b), 5.4(b) and 5.6(b)). The rating curves also plotted satisfactorily as straight lines over the gauged stage.

For station A5 (Fig. 5.5(a) and 5.5(b)), a minor discontinuity in the rating curves is expected beyond the first 0.38 m and a bigger discontinuity beyond 0.99 m due to the changes in the cross-section. With the available data, a segmented rating curve cannot be justified. The curve is straight over the range of gauged stage and therefore a single rating curve has been assumed to apply.

A flow that exceeds the stage of 0.38 m will be experienced for 30 days in a year on the average, and one that exceeds 0.99 m will be experienced for about 3 days per year on the average (Leibundgut, 1986).

The rating equations obtained are shown in Table 5.1.

Table 5.1 Rating equations for the river gauging stations

STATION	RATING EQUATION	NO. OF OBSERVATIONS	r^2
A3	$Q=21.424*H^{2.998}$	33	0.972
A4	$Q= 6.303*H^{3.104}$	15	0.992
A5	$Q=21.489*H^{2.117}$	32	0.972
A5b	$Q= 3.431*H^{1.928}$	6	0.984
A6	$Q= 2.799*H^{1.348}$	34	0.948

r is the correlation coefficient

5.1.1.3 Extrapolation of rating curves

In all cases the highest measured limits of the rating curves were exceeded during the period of study (Nov. 1990 - June 1991) as shown in Table 5.2 below.

Table 5.2 Highest gauged stage (Hmg) and highest stage recorded (Hmr) in the period Nov-June 1990/91

STATION	HIGHEST GAUGED STAGE Hmg (m)	HIGHEST STAGE NOV-JUNE (m) Hmr (m)	EXCEEDANCE Hmr-Hmg (m)
A3	0.64	0.88	0.24
A4	0.89	1.08	0.19
A5	0.79	1.54	0.75
A5b	0.23	0.83	0.60
A6	2.21	2.88	0.67

Discharge at stages beyond the gauged limits were assessed by extending the rating equations over the whole range of stages measured. This is justifiable for stations A3, A4 and A6 because no change in control is indicated by the data as discussed in section 5.1.1.2. The level of exceedence is below 40%.

For station A5 the highest rated stage was highly exceeded. However, this happened for only one day (15th June 1991) during which time the flow went beyond the maximum weir height (Fig. 5.5(b)). At all other times the flow was confined below the first 0.99 m of stage (Fig. 5.5(b)) and therefore the rating equation obtained has been assumed to apply for all measured stages. The discharge for the day when the river overtopped the weir, (15/06/91) will therefore be underestimated.

There are no discharge measurements at stages beyond 0.23 m for station A5b. The highest stage recorded was 0.83 m. The control for station A5b is a corrugated circular road culvert about 1 m downstream of the recorder and the rating curve may be assumed to be straight even for higher stages. More data is required to verify this assumption.

It is characteristic of Naro Moru catchment for peak flows to last for short periods. They also tend to occur more frequently at night. This makes the gauging of such flows problematic as they also occur less frequently compared to medium and low flows as can be observed from the flow duration curves (Leibundgut, 1986).

5.1.1.4 Statistical analysis of the rating curves

The standard error of the mean relations, Smr, also called the standard error of discharge computed from the rating curve has been calculated at 95% level as described in Herschy (1985) and the results are presented in Tables 5.3 - 5.6 for the river gauging stations A3, A4, A5 and A6. The standard error of the mean confidence limits defines the uncertainty in regression, the stage discharge relation, that is the uncertainty of estimates of discharge from stage from the rating equation.

The results show that the uncertainty in the stage-discharge relation ranges from ±8.1 % in the centroid of the regression to ±22.7 % at the extreme ends of the regression. The uncertainty is highest for station A6 and lowest for station A4.

According to ISO standards, an uncertainty of ±5 % at 95% level is attainable for a single measurement of discharge while using either the salt dilution method or the current meter to measure average flows. This level of uncertainty may need to be modified for conditions of extreme low flows or floods (Herschy, 1985).

The rating curve yields values of discharge that are more accurate than single measurements of discharge. Therefore a level of uncertainty less than ±5 % may be attained in the centroid of the regression.

Table 5.3 Standard error of discharge (at 95% level) computed from the rating curve for river gauging station A3

Date	No.	h (m)	H (m)	log H	$[(\log H-\overline{\log H})]^2$	Qi (gauging) (m^3/s)	Q c (rating) (m^3/s)	$\left[\frac{100(Qi-Qc)}{Qc}\right]^2$	2Smr (± %)
11.04.84	1	1.54	0.17	-0.783	0.061	0.106	0.097	96.47	14.1
24.02.84	2	1.54	0.17	-0.783	0.061	0.111	0.097	225.07	14.1
02.04.84	3	1.54	0.17	-0.783	0.061	0.096	0.097	0.29	14.1
30.03.84	4	1.53	0.17	-0.770	0.055	0.125	0.106	339.24	13.6
25.05.84	5	1.53	0.17	-0.770	0.055	0.105	0.106	0.28	13.6
07.03.84	6	1.53	0.17	-0.770	0.055	0.105	0.106	0.28	13.6
15.02.84	7	1.52	0.18	-0.745	0.044	0.230	0.125	6984.28	12.8
02.03.84	8	1.52	0.18	-0.745	0.044	0.125	0.125	0.05	12.8
19.03.84	9	1.51	0.19	-0.724	0.035	0.158	0.145	79.99	12.1
09.04.84	10	1.51	0.19	-0.712	0.031	0.162	0.157	10.82	11.8
09.04.84	11	1.50	0.20	-0.699	0.027	0.163	0.172	26.45	11.4
03.02.86	12	1.50	0.20	-0.699	0.027	0.103	0.172	1604.80	11.4
24.04.84	13	1.49	0.21	-0.678	0.020	0.196	0.199	2.14	10.8
30.01.91	14	1.47	0.23	-0.638	0.010	0.297	0.261	186.84	9.9
11.02.86	15	1.46	0.24	-0.620	0.007	0.153	0.297	2348.24	9.6
26.04.84	16	1.43	0.28	-0.561	0.001	0.436	0.446	5.51	8.9
05.06.84	17	1.41	0.30	-0.530	0.000	0.526	0.551	20.73	8.8
19.12.84	18	1.40	0.30	-0.526	0.000	0.477	0.568	256.99	8.8
27.04.84	19	1.40	0.30	-0.523	0.000	0.530	0.580	73.16	8.8
26.10.84	20	1.36	0.35	-0.462	0.005	0.876	0.881	0.36	9.4
02.05.91	21	1.35	0.35	-0.456	0.006	1.370	0.920	2390.72	9.5
02.11.84	22	1.33	0.37	-0.432	0.011	1.025	1.087	32.47	10.0
12.10.84	23	1.32	0.38	-0.420	0.013	1.052	1.177	113.46	10.2
28.11.84	24	1.30	0.40	-0.398	0.019	1.060	1.373	520.11	10.7
10.10.84	25	1.27	0.43	-0.367	0.029	2.177	1.706	763.56	11.6
29.11.84	26	1.27	0.44	-0.362	0.030	1.572	1.766	120.50	11.7
26.10.85	27	1.26	0.44	-0.357	0.032	1.409	1.827	524.22	11.9
16.04.85	28	1.18	0.52	-0.284	0.064	2.898	3.016	15.20	14.3
16.04.85	29	1.15	0.56	-0.256	0.079	4.349	3.666	347.12	15.3
16.04.85	30	1.11	0.60	-0.225	0.096	6.825	4.517	2612.07	16.4
12.12.84	31	1.09	0.61	-0.215	0.103	4.317	4.867	127.58	16.8
25.10.85	32	1.08	0.63	-0.204	0.110	5.176	5.234	1.25	17.2
15.04.85	33	1.07	0.64	-0.197	0.115	6.045	5.490	102.37	17.4
			$\overline{\log H}$ =	-0.536	Σ 1.304			Σ 19932.59	
							Se=	±50.714 %	

Table 5.4 Standard error of discharge (at 95 % level) computed from the rating curve for river gauging station A4

Date	No.	h (m)	H (m)	log H	$[(\log H-\overline{\log H})]^2$	Qi (gauging) (m^3/s)	Q c (rating) (m^3/s)	$\left[\frac{100(Qi-Qc)}{Qc}\right]^2$	2Smr (± %)
11.02.86	1	1.50	0.20	-0.699	0.129	0.041	0.043	14.97	17.0
03.02.86	2	1.49	0.21	-0.678	0.114	0.045	0.050	86.84	16.2
30.01.91	3	1.42	0.28	-0.553	0.046	0.156	0.121	824.41	12.0
09.04.85	4	1.37	0.33	-0.481	0.020	0.183	0.202	87.07	10.0
10.04.85	5	1.33	0.37	-0.432	0.009	0.278	0.288	11.79	8.9
19.12.84	6	1.32	0.38	-0.420	0.007	0.298	0.313	22.19	8.7
02.04.85	7	1.22	0.48	-0.319	0.000	0.621	0.646	14.74	8.1
26.10.85	8	1.18	0.52	-0.284	0.003	0.865	0.828	20.04	8.4
08.11.84	9	1.16	0.54	-0.268	0.005	1.064	0.931	204.66	8.6
02.05.91	10	1.14	0.56	-0.252	0.008	0.979	1.042	36.63	8.8
02.05.91	11	1.12	0.58	-0.237	0.011	1.110	1.162	20.02	9.1
11.04.85	12	1.03	0.67	-0.174	0.027	1.891	1.818	16.00	10.6
11.04.85	13	1.00	0.70	-0.155	0.034	2.748	2.083	1018.90	11.1
15.04.85	14	0.89	0.81	-0.092	0.062	2.704	3.277	305.62	13.1
25.10.85	15	0.81	0.89	-0.051	0.083	4.019	4.390	71.28	14.5
			$\overline{\log H}$ =	-0.340	Σ 0.56			Σ 2755.18	
							t(13 df)=	2.14	
							Se=	±31.15	%

Table 5.5 Standard error of discharge (at 95% level) computed from the rating curve for river gauging station A5

Date	No.	h (m)	H (m)	log H	$[(\log H-\overline{\log H})]^2$	Qi (gauging) (m^3/s)	Qc (rating) (m^3/s)	$\left[\frac{100(Qi-Qc)}{Qc}\right]^2$	2Smr (± %)
02.04.84	1	0.08	0.08	-1.125	0.098	0.116	0.089	894.01	12.2
29.03.84	2	0.08	0.08	-1.097	0.081	0.126	0.102	532.69	11.6
11.02.86	3	0.08	0.08	-1.097	0.081	0.107	0.102	20.43	11.6
03.02.86	4	0.09	0.09	-1.046	0.055	0.120	0.131	74.80	10.5
30.03.84	5	0.09	0.09	-1.046	0.055	0.186	0.131	1730.10	10.5
22.05.84	6	0.10	0.10	-1.000	0.035	0.102	0.164	1434.48	9.6
27.02.84	7	0.10	0.10	-1.000	0.035	0.148	0.164	97.16	9.6
31.08.90	8	0.10	0.10	-1.000	0.035	0.180	0.164	92.80	9.6
25.02.84	9	0.10	0.10	-1.000	0.035	0.162	0.164	1.77	9.6
15.03.84	10	0.11	0.11	-0.979	0.028	0.134	0.182	696.59	9.3
14.04.84	11	0.11	0.11	-0.979	0.028	0.156	0.182	204.73	9.3
15.03.84	12	0.11	0.11	-0.979	0.028	0.133	0.182	725.89	9.3
15.03.84	13	0.11	0.11	-0.979	0.028	0.146	0.182	392.09	9.3
03.03.84	14	0.11	0.11	-0.959	0.021	0.186	0.201	54.92	8.9
09.04.84	15	0.11	0.11	-0.959	0.021	0.157	0.201	477.29	8.9
30.01.91	16	0.12	0.12	-0.921	0.012	0.260	0.242	58.56	8.4
09.04.91	17	0.13	0.13	-0.886	0.005	0.322	0.286	157.34	8.1
09.04.91	18	0.13	0.13	-0.886	0.005	0.298	0.286	17.26	8.1
04.06.84	19	0.14	0.14	-0.854	0.002	0.324	0.335	10.24	7.9
18.01.91	20	0.14	0.14	-0.854	0.002	0.319	0.335	22.03	7.9
06.02.90	21	0.15	0.15	-0.824	0.000	0.358	0.387	57.39	7.8
31.10.84	22	0.16	0.16	-0.810	0.000	0.485	0.415	282.76	7.8
26.04.84	23	0.20	0.20	-0.699	0.013	0.953	0.712	1143.68	8.5
22.05.91	24	0.21	0.21	-0.688	0.015	1.092	0.750	2072.72	8.6
25.10.84	25	0.28	0.28	-0.553	0.067	1.761	1.452	453.50	11.0
14.05.91	26	0.30	0.30	-0.523	0.084	2.237	1.680	1098.55	11.7
12.10.84	27	0.31	0.31	-0.516	0.088	1.909	1.740	94.38	11.8
13.10.84	28	0.33	0.33	-0.488	0.105	1.873	1.990	34.77	12.5
25.10.85	29	0.36	0.36	-0.444	0.136	2.748	2.472	125.16	13.5
08.11.84	30	0.38	0.38	-0.420	0.154	2.901	2.771	21.94	14.1
16.04.85	31	0.53	0.53	-0.276	0.288	5.432	5.605	9.48	17.9
11.12.84	32	0.79	0.79	-0.102	0.504	8.092	13.047	1442.30	22.7
			$\overline{\log H}$ =	-0.812	Σ 2.14			Σ 14531.81	

Se= ± 44.02 %

Table 5.6 Standard error of discharge (at 95% level) computed from the rating curve for river gauging station A6

Date	No.	h (m)	H (m)	log H	$[(\log H - \overline{\log H})]^2$	Qi (gauging) (m^3/s)	Qc (rating) (m^3/s)	$\left[\frac{100(Qi-Qc)}{Qc}\right]^2$	2Smr (± %)
14.04.84	1	0.06	0.06	-1.222	0.515	0.099	0.063	3224.20	19.6
29.03.84	2	0.06	0.06	-1.222	0.515	0.097	0.063	2874.54	19.6
10.02.86	3	0.08	0.08	-1.097	0.351	0.045	0.093	2666.55	17.2
27.09.84	4	0.08	0.08	-1.097	0.351	0.113	0.093	459.70	17.2
24.02.84	5	0.08	0.08	-1.097	0.351	0.092	0.093	1.27	17.2
17.02.84	6	0.09	0.09	-1.071	0.321	0.105	0.101	15.92	16.7
06.08.84	7	0.09	0.09	-1.071	0.321	0.129	0.101	770.58	16.7
15.03.84	8	0.10	0.10	-1.022	0.268	0.090	0.117	541.64	15.9
03.05.84	9	0.10	0.10	-1.000	0.246	0.147	0.126	287.31	15.5
26.02.83	10	0.14	0.14	-0.854	0.122	0.325	0.198	4134.36	13.2
07.03.84	11	0.15	0.15	-0.839	0.112	0.139	0.207	1087.44	13.0
06.06.84	12	0.23	0.23	-0.648	0.021	0.494	0.375	1008.75	11.0
31.03.82	13	0.24	0.24	-0.620	0.013	0.385	0.409	34.41	10.8
09.05.91	14	0.25	0.25	-0.602	0.010	0.396	0.432	69.88	10.7
03.03.82	15	0.27	0.27	-0.577	0.005	0.163	0.467	4241.65	10.6
20.05.83	16	0.33	0.33	-0.481	0.001	0.498	0.628	429.58	10.5
15.03.91	17	0.34	0.34	-0.469	0.001	0.574	0.654	149.61	10.5
19.12.84	18	0.34	0.34	-0.469	0.001	0.797	0.654	478.16	10.5
30.05.83	19	0.36	0.36	-0.444	0.004	0.613	0.706	174.69	10.5
24.11.84	20	0.38	0.38	-0.420	0.007	0.898	0.760	331.12	10.6
21.07.83	21	0.39	0.39	-0.409	0.009	1.118	0.787	1771.69	10.7
23.04.82	22	0.47	0.47	-0.328	0.031	0.963	1.012	23.23	11.2
15.06.82	23	0.53	0.53	-0.276	0.052	0.582	1.190	2608.72	11.7
26.10.83	24	0.57	0.57	-0.244	0.068	1.452	1.312	113.60	12.0
25.10.84	25	0.64	0.64	-0.194	0.096	1.715	1.534	139.51	12.7
18.10.83	26	0.67	0.67	-0.174	0.109	1.540	1.632	31.46	12.9
09.11.84	27	0.83	0.83	-0.081	0.179	2.196	2.177	0.73	14.3
28.11.84	28	0.99	0.99	-0.007	0.248	2.881	2.742	25.53	15.5
29.11.84	29	1.13	1.13	0.053	0.311	3.847	3.300	274.76	16.6
02.11.83	30	1.14	1.14	0.057	0.315	3.407	3.339	4.10	16.7
13.12.84	31	1.22	1.22	0.086	0.349	4.052	3.659	115.34	17.2
15.11.84	32	1.34	1.34	0.127	0.399	4.631	4.152	132.98	17.9
30.11.84	33	1.65	1.65	0.217	0.521	5.246	5.496	20.75	19.7
11.12.84	34	2.21	2.21	0.344	0.720	11.216	8.149	1416.43	22.2
				$\overline{\log H}$ = -0.504	Σ 6.94			Σ 29660.20	
							Se=	±60.89 %	

The high uncertainty in the stage discharge relations for the stations in Naro Moru river may have been contributed by the uncertainty in measurement of discharge or stage, instability of the station control, scour or deposition in the channel or changes in the flow regime of the river.

Although most of the measurements in A3 and A4 have been done with the salt dilution machine, the rating curve for station A4 shows a higher accuracy than that for station A3. Station A3 has a channel 12 m wide near the gauge while A4 has a 6 m wide channel while the flows normally conveyed in the two channels are not significantly different. The narrower channel, A4, has better mixing properties compared to a wider one, A3, and would therefore yield more reliable results with the salt dilution method.

In general, low and high flows are less accurately determined either with the salt dilution method or with the current meter as seen in the rating curves (Fig. 5.3(a) - 5.7(a)). With the salt dilution, turbulence becomes poorer at low discharges. With the current meter, the number of revolutions of the propeller for the same exposure time decreases. The roughness of the channel bed also lowers the accuracy with which the cross-sectional area may be determined at low flows.

For peak flows, the flow regime is bound to change substantially during the course of a single measurement. In Naro Moru river for instance, the rising limb of the stage hydrographs is usually almost vertical. The fall is very fast since the peak flows are contributed mainly by runoff. This rapidly changing flow regime may affect the accuracy of determination of peak discharges.

The discharge measurements were taken over a period of time from 1982 to 1991. It is possible that the controls may have been changing with time. Cobble-stones were observed to be deposited above the weir in station A5 especially after a storm. This would alter the control.

It is clear from the rating curves that salt dilution gauging compares well with the current meter gauging where site conditions are suitable for each method. The discharge measurements for A4 and A5b have been obtained solely with the salt dilution method and they show very little scatter.

However the choice of a method to use for discharge measurement should take into consideration the conditions of the site. In station A6, the salt dilution method would be less preferable because the flow is usually non-turbulent. For the measurements taken in 1991 with the salt dilution, it was found difficult to find a suitable site for injecting the salt mixture and the tracer wave took an average of 30 minutes to move through a reach which was only 60-70 m long (see Appendix IV). Under such low flow velocities, complete mixing is doubtful. The discharge measurements obtained were found to be about 12 % lower than those suggested by the previously existing rating curves.

5.1.2 Daily mean discharge

The procedure for computing the daily mean discharge has been outlined in section 4.4.1.3. The results for the five stations are presented in Tables in Appendix V. The monthly discharge has been computed by averaging the daily flows for the month.

The mean monthly discharge for river gauging station A5 is compared with the long term average in Fig. 5.8. The data appears in Appendix X.

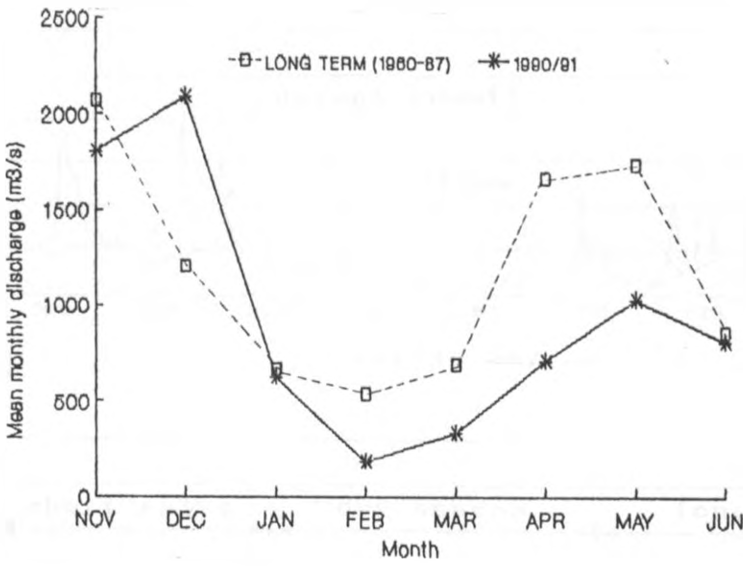


Fig. 5.8 1990/91 Mean monthly discharge for station A5 compared with long term (1960-87) average flows.

The month of December had higher flows than average while the months of February, March, April and May had lower than average flows.

The seasonal nature of streamflow can be seen in Fig. 5.9. Peak flows occur during the rain season and low flows during the dry season. Fig. 5.9(a) represents the river inflow into the footzone reach which is composed of the discharge through the two stations A3 and A4. Figure 5.9(b) and 5.9(c) show the outflow from the footzone and the savannah zone respectively. The inflow into the savannah zone consists of flow through A5 and A5b combined. Fig. 4.4 shows the locations of the gauging stations.

From Fig. 5.9(b) and 5.9(c), it appears that the amount of water passing through the savannah reach decreases during the dry season. This may be due to one or more of the following reasons:

1. Abstractions
2. Seepage through the riverbed
3. Evaporation

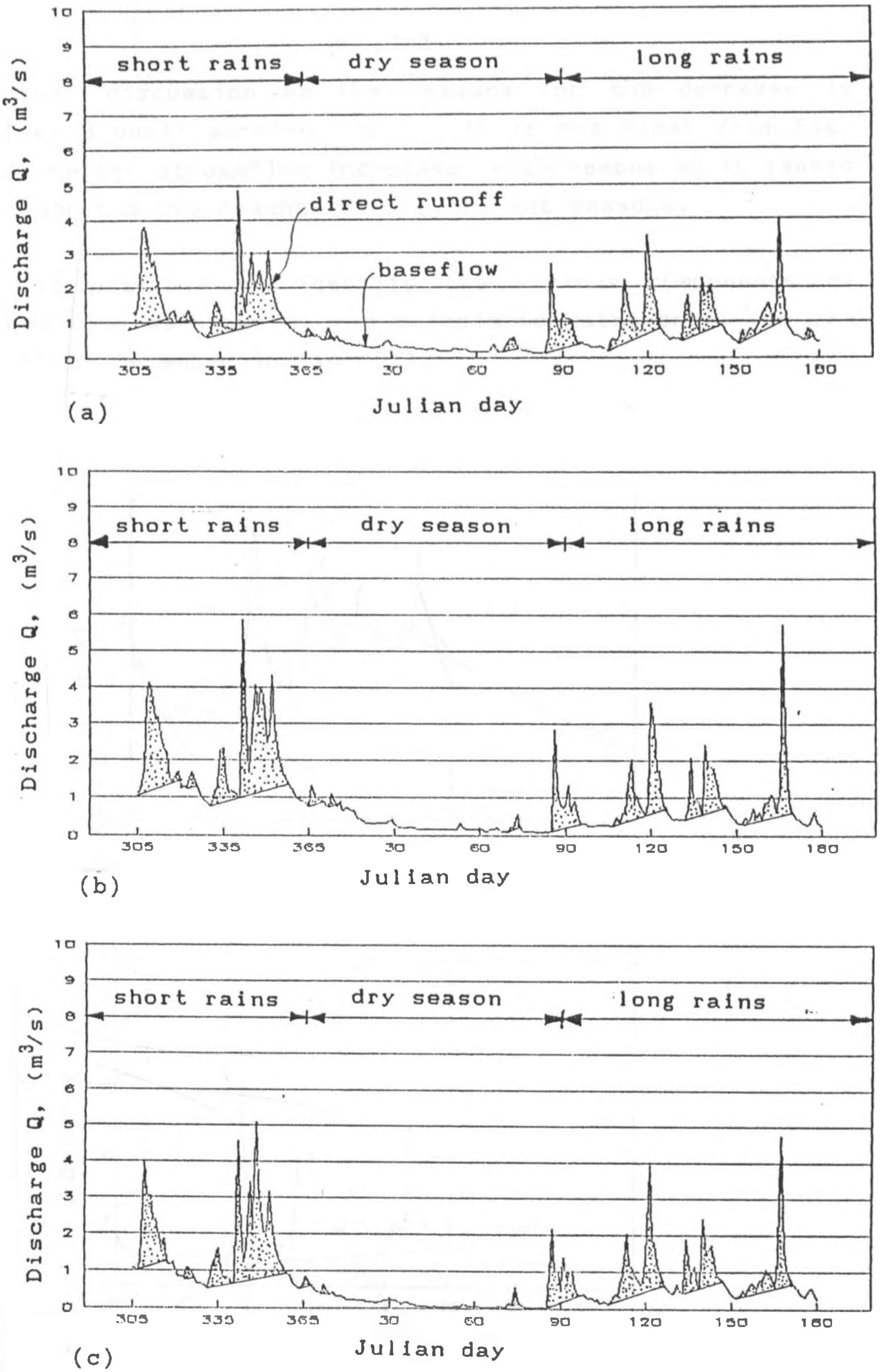


Fig. 5.9 Daily mean discharge for (a) station A3 and A4 combined, (b) station A5 and (c) station A6

Further discussion on the reasons for the decrease is deferred until section 5.4. It is not clear from Fig. 5.9 whether streamflow increases or decreases as it passes through the two reaches during the wet seasons.

It is possible to identify the various components of streamflow as shown in the example for station A4 for the month of December in Fig. 5.10.

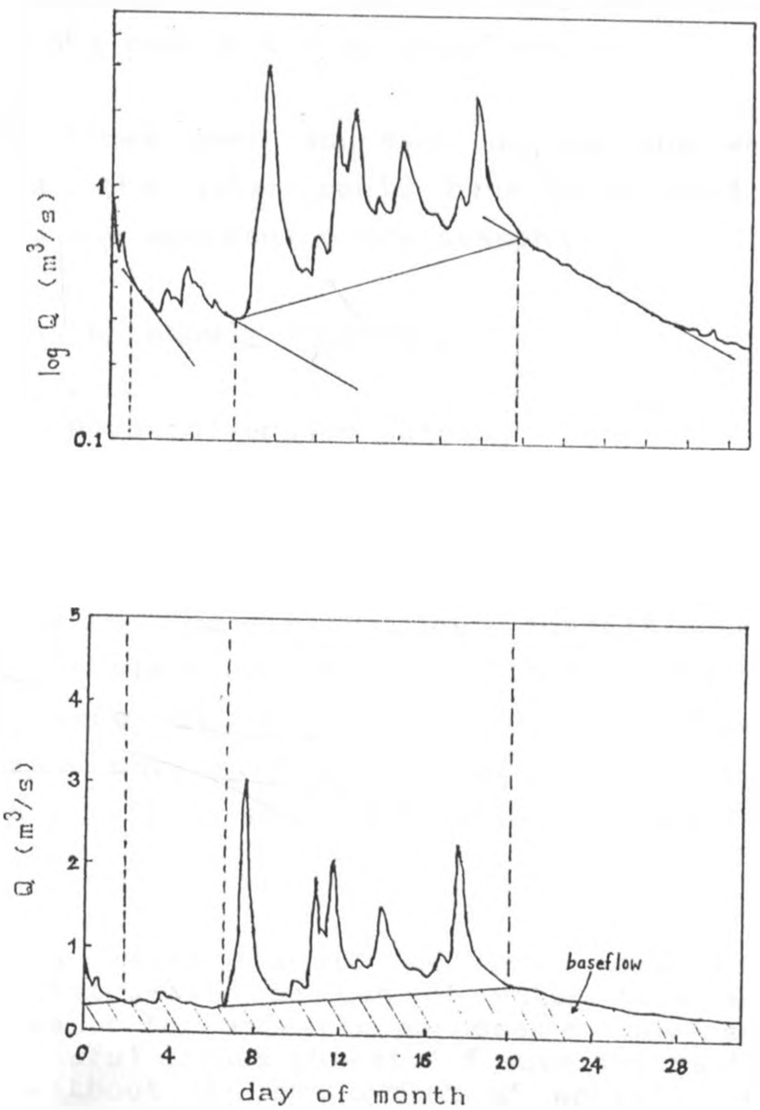


Fig. 5.10 Separation of streamflow into direct runoff and baseflow

From Fig. 5.10, direct runoff stopped after the end of the short rains and streamflow during the dry season was generated purely from groundwater. Streamflow components (baseflow and groundwater) are shown graphically in Fig. 5.9.

During the dry season, flow was derived almost entirely from groundwater. This gradually depleted the groundwater storage. Consequently the low flows are seen to decrease with time during the dry season (January to March). Any abstraction of river water during the dry season therefore must have been met from baseflow.

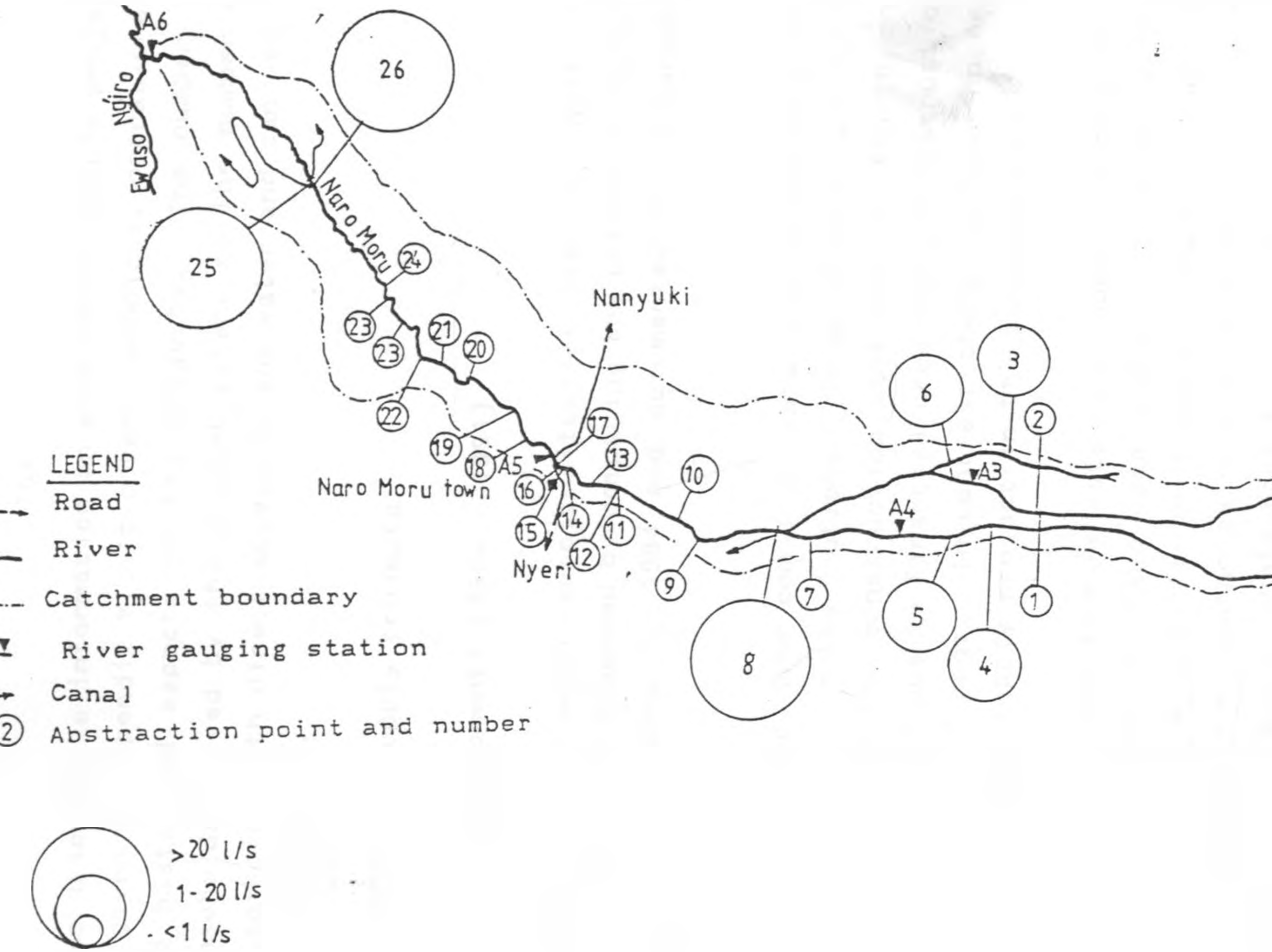
Flood flows were abundant during the wet season. If stored, the water could have been used for irrigation during the succeeding dry season.

5.2 Water supply inventory

5.2.1. River diversion points

The points along Naro Moru river from which water is abstracted are shown in Fig. 5.11. The total number of water supply points that were identified were 26. Places where people draw water for domestic use or where animals drink were not included in this inventory. Only points where a physical water supply installation exists are shown. This in accordance with the Water Act which states that:

> "a water permit is not required for the abstraction or use of water from any body of water for domestic purposes by any person having lawful access thereto if such abstraction is made without the employment of works", (Republic of Kenya 1972).



g. 5.11 Water abstraction (sites and amount) for Naro Moru river.

Some descriptive information on each water supply project is given in Appendix VI. It covers technical, operational, and historical aspects of the projects. The number of households served by the project refers to the number of house-holds with direct access to the water and can use it for irrigation.

5.2.2 Water supply projects

5.2.2.1 Developments (1984 - 1991)

Changes in the water supply situation over the past six years have been assessed by comparing the present inventory with the one done in 1984 and documented in Leibundgut (1986).

Over this period, four community water supply projects have been established in the footzone. Three of these are fully operational and the construction work for the fourth one has been delayed due to financial problems and destruction of the weir by floods. In contrast there has been no new community water supply project in the savannah zone.

In the footzone some four private water supply systems were abandoned. Three of these used hydraulic rams while the fourth one used a canal for conveyance. Hydraulic rams in the footzone were abandoned either due to maintenance problems or the owners preference for the reliable and well established community water supply systems over the low capacity hydraulic rams. Some of the pumping plants in the footzone have also changed hands following sale of land by the former owners.

5.2.2.2 Developments (November 1990 - August 1991)

Remarkable changes in the water supply situation were observed over the 10 months starting from November 1990.

These changes may serve to illustrate the differences between the two zones (footzone and savannah) and the rate at which water supply systems were being increased or improved.

Two permanent diversion weirs in the footzone (Abstraction point Nos. 6 and 8) and one in the savannah (Abstraction point No. 26) were completed. Construction work was in progress for two other weirs in the footzone (Abstraction point Nos.2 and 5). These permanent weirs replaced older temporary structures which were constructed by using loose rocks collected from the river bed. These temporary weirs are usually washed away during the rainy season. Their temporary nature helps to limit the amount of water that can be diverted.

If the trend mentioned above continues, there will be a greater need to ensure that diversion structures have facilities to control the diverted flows otherwise the status of water allocation is bound to deteriorate further.

5.2.3 Comparison of footzone and savannah

A comparison of the water supply situation in the footzone and the savannah is presented in Table 5.7.

The footzone receives water from 16 water supply systems four of which abstract water from the forest belt upstream of the river gauging stations A3 and A4. The savannah zone has 9 water supply systems. About 38% of the water supply systems in the footzone and 33% in the savannah are community owned and serve over 200 house-holds.

Table 5.7 Comparison of water supply projects in the footzone and savannah in Naro Moru river basin.

CRITERIA	FOOTZONE	SAVANNAH	TOTAL
No. of projects in 1991	16**	9	25*
No. of projects in 1984	13	7	20
New community projects since 1984	4	0	4
New private projects since 1984	3	2	5
Abandoned community projects since 1984	0	0	0
Abandoned private projects since 1984	4	0	4
Community projects (percent) 1991	38	33	36
Private projects (percent) 1991	63	67	64
Canals (percent) 1991	6	22	12
Piped water projects (percent) 1991	94	78	88
Projects used for irrigation (percent)	63	78	68
Average abstraction rates for 1990/91			
less than 1 l/s	12	7	19
1 to 5 l/s	1	0	1
6 to 10 l/s	1	0	1
10 to 20 l/s	2	0	2
over 20 l/s	1	2	3

* The total number of projects is 26 but one of the projects abstracts water from the forest river reach and supplies it to the same zone

** Four projects supplying water to the footzone abstract water from the forest river reach by gravity piped systems

About 94% of the systems in the footzone and 78% of those in the savannah use piped conveyance systems. There are two unlined canals in the savannah and one in the footzone. About 70% of the water supply systems are used for irrigation purposes in the footzone and savannah.

Based on the current status of water supply and the changes that have taken place over the last six years, it appears that the footzone is more favourable for the financing, construction, operation and maintenance of water supply infrastructure, Technical, economic and organizational reasons suggested for this are:

(1) Hydraulic and topographical requirements for river diversion sites are more easily met in the footzone than in the savannah. The footzone has a stable bed-rock controlled river channel and steeper slopes which ensures easier construction of the weir and shorter conveyance length. In the savannah, the almost flat topography and the sandy-loam riverbed demands more expensive weirs and long conveyance lengths. The situation in the savannah is further aggravated by a few large farms which may need to be crossed by the water conveyance line. Good sites for storage and distribution tanks are also inadequate in the savannah zone.

(2) Streamflow is more abundant and reliable in the upper reaches of the river than in the lower reaches. Sources of surface water occur in the upper forest zone and lower moorland zone. Abstractions and other losses decrease the available river water from the footzone down to savannah especially during the dry season.

3) Preliminary results from a small-scale farm survey showed that small-scale farming is more economically viable in the footzone than in the semi-arid savannah. (Kohler, 1990). Farmers in the footzone are therefore in a better position to finance water supply projects.

(4) The population density in the footzone is higher than that in savannah zone. The 1979 population census gives a population density of 73 persons per km^2 for the footzone and 5 persons per km^2 for the savannah (Jaetzold and Schmidt, 1983). Although these figures applied for bigger regions ("Division" in Kenyan administrative terms) in which each of the zone falls, they serve to indicate the big difference in population density between the two zones. Population

has been increasing rapidly since the 1979 census. The average population in the savannah part of Naro Moru basin now ranges from 25-200 persons per km^2 (Wiesmann, 1990a). The low population density and the high rate of migration in the savannah have been responsible for the low degree of community organisation (Wiesmann, 1990a), which may explain why community water supply projects have developed more slowly here. However the greater population density also means that a more intensive water supply network is expected in the footzone than in the savannah. A higher population density reduces the relative cost of conveyance as more farms will be reached by a network of specific length if they are located closer to one another.

(5) The footzone lies wholly in the Nyeri District where the headwaters of the river are found, while the savannah zone lies mainly in Laikipia District. Allocation of water within the two zones is administered from the two district headquarters. Decisions concerning water supply issues are also made independently. This situation limits the cooperation between users in the upper reach who are in command of the water and those in the lower reach who must depend on the residual river flow from the upper zones.

(6) From the results of the interviews of farmers (see Appendix VI), it appears that community water supply projects in the footzone have benefited from government and non-government organizations (N.G.O.s) funds to supplement their income during the construction phase.

(7) Community organisation dealing with water supply problems seems to have a longer history in the footzone than in the savannah. The most extensive

water supply system in the footzone was started in 1972 while farmers in the savannah started rehabilitating the canals in the 80's.

5.3 Amount of water abstracted

5.3.1 Evaluation of cutthroat flumes

The cutthroat flumes used for measuring flow in the canals were found to be suitable on the following grounds:

The fabrication was easy and could be done locally. The sheet metal flumes are portable. They could easily be reset and readjusted in the field as needed.

The canals were prone to siltation. Using the stage discharge method would have required frequent ratings at the sections due to the frequent cleaning and desilting operations by the farmers. Weirs are also ruled out because of their inability to discharge sediment.

Current meter measurements were sometimes complicated by low flow velocities and/or shallow depths or irregular channels especially when one had to confine himself to the area near the intake prior to any offtake. Once installed cutthroat flumes do not suffer from the above problems.

Calibration measurements would have been difficult because there are no structures to regulate the flow at the diversion points. This would interfere with the flow in the canals to the dissatisfaction of users. It is also difficult to gauge low and high flows due to their low probability of occurence. Highs flow were observed to occur more frequently at night. Standard precalibrated structures do not require calibration.

The low channel gradients especially in the savannah plateau require instruments that have a low operating head. Flumes fall in this category. Daily readings of stage are easily done even by a relatively unskilled person.

Problems experienced with the cutthroat during their fabrication, installation and operation are:

(1) Constant supervision during fabrication was found to be necessary to ensure that accuracy is maintained.

(2) Ensuring water tight conditions is difficult soon after installation before the fill-up materials have settled. It is important to have an independent staff gauge already in place so as to make corrections for periods when leakage occurs by comparing the discharge obtained in the flume at similar stages when there is no leakage.

(3) The flumes are not suitable for measuring extremely high flows. Increasing the throat width makes the flume uneconomical and reduces the sensivity at low flows. Depth cannot be increased alone as the ratio of h_{umax}/L should not exceed 0.4 (Kraatz and Mahajan, 1975). Raising the flume level with respect to the channel bed level is limited by the maximum allowable upstream head. In one incident farmers complained that a flume was too high and it had to be reset. Lowering the flume is done at the risk of operating it under submerged conditions for high flows. This makes the discharge inaccurate (Kraatz and Mahajan, 1975). One should therefore strike a good compromise bearing in mind the cost, allowable accuracy and possible operating head.

(4) It was difficult to find a site where the canal was straight, stable, deep, narrow and had no offtakes upstream, all at the same time. Materials to fill up the

bank had to be hauled from other sites when a narrow section of the channel was not obtainable.

(6) At high flows turbulence in the outlet diverging section makes the readings of downstream water depth inaccurate (see Plate 5.1). A stilling well would be suitable but this complicates the design. The problem was solved by reading the maximum and minimum water levels and taking the average of the two readings.

(7) The cost of a cutthroat flume is not prohibitive. For 300 farmers, each farmer would need to contribute only KSh. 20.00 to have the flume made. Installation costs are minimal if the farmers provide labour.

Plate 5.1 Turbulent conditions at the downstream diverging section of a cutthroat flume during high flow.

5.3.2 Average rate of abstraction

Systems used for abstracting water from Naro Moru river operate either intermittently or continuously. The amount of water abstracted from each water supply point was assessed for the period November 1990 to June 1991. The results are presented in Table 5.8 for systems that operate intermittently and in Table 5.9 for systems that operate continuously. In Fig. 5.12, the cumulative rate of abstraction along the river profile for each abstraction point is shown. Only where canals or communal gravity pipes exist is a big increase noticed. Piped abstractions were found to take a total of 14 l/s from the river on average and 2 l/s for the footzone and savannah zones respectively for the period November 1990 to June 1991.

Canals are only 12 % of the total number of water supply installations yet they accounted for 88 % of the water that was abstracted from the river over the period Nov-June 1990/91. The total daily rate of abstraction was determined by adding the rate of abstraction for the pipe systems to that for the canals in the same zone. Data on canal abstractions appears in Appendix VII.

Community owned projects accounted for 98 % of the water that was abstracted from the river and they form 36 % of the total number of water supply projects. It is evident from Tables 5.7, 5.8 and 5.9 that community water projects and especially those using canals for conveyance of water take the largest share of water from the river. Private projects have very little effect on river flow because pumps have low capacities and are operated intermittently.

Table 5.8 Average rate of abstraction for systems that operate intermittently (November 1990 - June 1991)

ABST. PT. No.	TYPE OF PROJECT	TYPE OF PUMP	PUMP CAPACITY (L/S)	NORMAL PUMPING SCHEDULE HRS/DAY	DAYS/MONTH	AVERAGE CONTINUOUS RATE (L/S)
1	PRIVATE	DIESEL	0.6	8	12	0.08
7	PRIVATE	ELEC. GEN.	1.9	6	2	0.03
10	PRIVATE	DIESEL	1.0	8	6	0.07
13	PRIVATE	ELECTRIC	1.3	2	4	0.01
14	PRIVATE	ELECTRIC	1.0	4	9	0.05
15	PUBLIC	DIESEL	1.1	15	30	0.70
16	PRIVATE	DIESEL	0.5	6	8	0.03
17	PRIVATE	DIESEL	1.5	4	2	0.02
18	PRIVATE	ELECTRIC	3.1	3	30	0.39
19	PRIVATE	PLATA	0.2	24	28	0.20
20	PRIVATE	PLATA	0.2	24	28	0.20
21	PRIVATE	PLATA	0.2	24	28	0.23
22	COMMUNAL	DIESEL	4.4	8	13	0.64
23	PRIVATE	DIESEL	2.3	7	8	0.17
24	PRIVATE	ELEC. GEN	1.5	6	8	0.10

Table 5.9 Average rate of abstraction for systems that operate continuously (November 1990 - June 1991)

ABST. PT. No.	TYPE OF PROJECT	METHOD OF DIVERSION	AVERAGE RATE OF ABSTRACTION (NOV-JUNE) LITRES/SECOND
2	COMMUNAL	GRAVITY PIPE	NOT OPERATIONAL
3	COMMUNAL	GRAVITY PIPE	1.7
4	COMMUNAL	GRAVITY PIPE	15.0
5	COMMUNAL	GRAVITY PIPE	7.0
6	COMMUNAL	GRAVITY PIPE + CANAL	11.0
8	COMMUNAL	WEIR AND CANAL	90.0
9	PRIVATE	HYDRAM	0.9
11	PRIVATE	HYDRAM	0.1
12	PRIVATE	GRAVITY PIPE	0.7
25	COMMUNAL	WEIR AND CANAL	80.0
26	COMMUNAL	WEIR AND CANAL	125.0

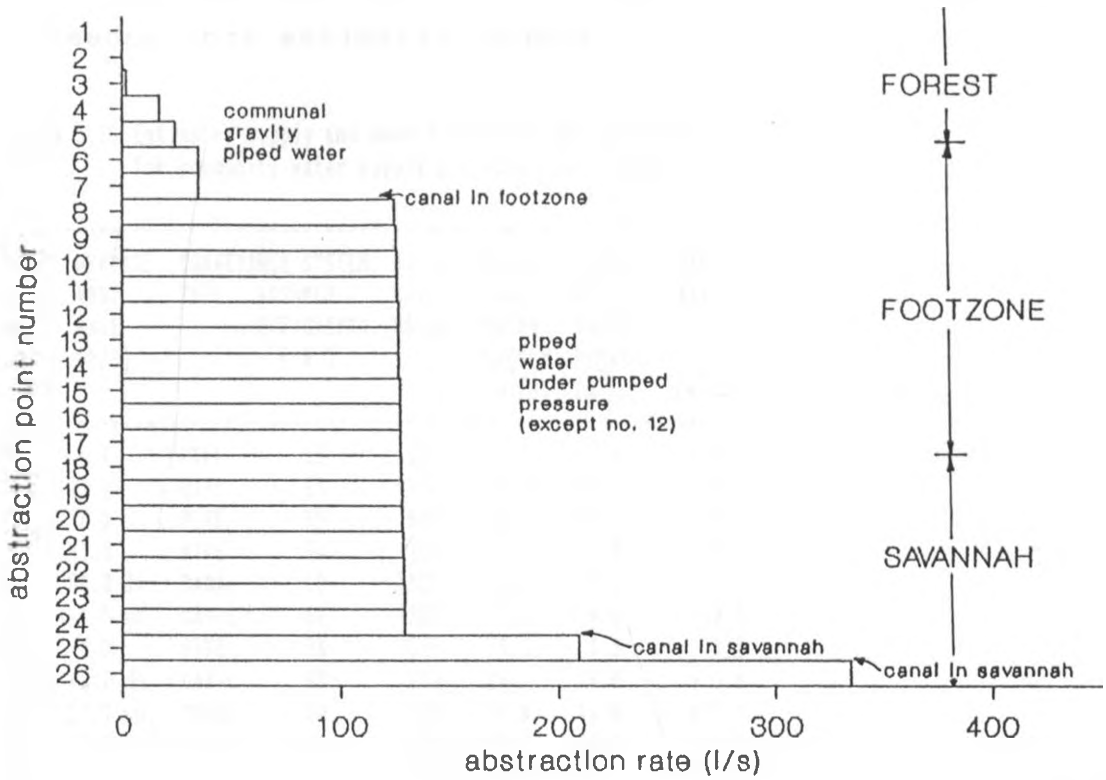


Fig. 5.12 Cumulative rate of abstraction of water along Naro Moru river.

Community water supply projects in Naro Moru river basin serve over 200 households. It is therefore inappropriate to compare community projects on the basis of amount of water abstracted without considering the number of beneficiaries and the uses to which the water is put. Any water management strategy that is going to have a significant impact on the allocation of water resources must be focused on improving the water use efficiency in community water supply projects because these are the ones that take the greatest amount of water from Naro Moru river.

The water demand and supply per household per day for community water projects is shown in Table 5.10. The demand is estimated by assuming 7 persons, 3 livestock units and 0.2 hectares under irrigation per house-hold. It can be seen that most community water projects supplied with piped water would not have been able to irrigate even 0.2 hectares per house-hold whereas for the two canals in the footzone the amount of water abstracted would have exceeded this estimated demand.

Table 5.10 Estimated supply and demand of water per household for community water supply projects (Nov -June)

ABST. PT. No.	AVERAGE ABST. RATE (L/S)	CONVEYANCE SYSTEM TYPE	ASSUMED EFFICIENCY (%)	NO. OF HOUSE-HOLDS	HOUSE-HOLD WATER SUPPLY (m^3/d)	HOUSE-HOLD WATER DEMAND (m^3/d)	EXCESS WATER (m^3/d)
3*	1.7	PIPE	95	500	0.3	0.5	- 0.2
4	15.0	PIPE	95	4000	0.3	14.8	-14.5
5	7.0	PIPE	95	900	0.7	14.8	-14.1
6	11.0	PIPE	70	300	2.4	14.8	-12.4
8	86.0 dm	CANAL	60	1200	3.7	14.8	-11.1
8	121.0 wm	CANAL	60	1200	5.2	14.8	- 9.6
22*	1.0	PIPE	95	325	0.3	0.5	- 0.2
25	80.0 dm	CANAL	60	200	20.7	14.8	+ 5.9
25	123.0 wm	CANAL	60	200	31.9	14.8	+17.1
26	77.0 dm	CANAL	60	300	13.3	14.8	- 1.5
26	126.0 wm	CANAL	60	300	21.8	14.8	+ 7.0

NOTES:

* water used for domestic and livestock purposes only
dm = dry month (March 1991)
wm = wet month (Dec 1990)

House-hold water demand is estimated as follows:

Domestic: 7 persons each at 0.050 m^3/day = 0.330 m^3
Livestock: 3 livestock units each at 0.050 m^3/day = 0.150 m^3

Irrigation:
Irrigated area is 0.2 hectares per household
Irrigation requirement is 5 mm/day
Assumed irrigation efficiency is 70 %
Volume of water required = (10*5*0.2)/0.7 = 14.3 m^3/day

Total house-hold water demand per day is 0.50 m^3/day for domestic purposes only and 14.8 m^3/day for domestic and irrigation combined.

The farmers are coping with the differences in demand and supply in the following ways:

(1) Expanding and improving water supply systems - A good example is abstraction No. 4 which at present has 4000

dependents. A new intake (abstraction point No.5), was constructed in 1984 to supplement the one made in 1972 and at present an additional intake is under construction in another river with the same purpose. Farmers heading the project remarked that the main cause for increasing demand for water is the increasing population as single households are split into two or more after sons get married. The 1984 project started with a membership of 300. At present it has 900 members. Farmers have therefore been forced to erect a permanent weir in place of the temporary one to improve the reliability of supply. Other improvements in the water supply works have been mentioned in section 5.2.1.2.

(2) Excess water in abstraction point No. 25 (Fig. 5.11) is allowed to flow back to the river just beyond station A6. In some cases excess water runs into dams and is used for stock watering (abstraction points No. 12 and 26 in Fig. 5.8). Such stagnant pools of water may be excellent areas for ground water recharge but the soils (verto-luvic Phaeozems) in the semi-arid savannah have very low permeability (Speck, 1983) and evaporation rate is high such that most of this water is lost through evaporation.

(3) For canals, the farmers are able to increase the supply by adjusting the height of the weirs. This reduces the margin between demand and supply as seen in Table 5.11 for abstraction points No. 25 and 26. Canal No. 25 has a more favourable water supply than canal No. 26 because it has a better weir (permanent) and it is upstream of the intake for canal No. 26.

5.3.3 Temporal variations in abstracted flows

Variation in the amount of water abstracted from the river is governed by the method of diversion, conveyance and storage of river water, the water level at the diversion point, the energy requirement for water delivery, the state of the diversion weir and conveyance system, uses of the water and changes in demand over time.

The methods of water diversion and conveyance in Naro Moru river may be classified as follows:

1. Diversion weir and canal
2. Diversion weir or direct abstraction and pipe
    (a) gravity flow
    (b) pumped flow
        (i) water turbine or hydraulic ram
        (ii) diesel or electric pump

The abstraction of water is continuous if:

(1) The water is supplied "on demand" to the users and there is not adequate storage to cover the period when there is no pumping: Canals and gravity flow piped systems fall in this category.

(2) There is no commercial energy requirements: Hydrams fall in this category. Water turbines (plata pumps) are also operated for longer hours subject to the demand.

In contrast, abstraction of water is intermittent if there are energy costs involved (e.g with diesel or electric pumps: Table 5.8) and/or if there is sufficient storage to meet the demand during the rest periods. Most privately owned water supply systems fall in this class (see Table 5.8). Intermittent systems may be operated daily if the capacity of the pumps and storage cannot satisfy the daily water demand. An example of this is abstraction points numbers 15 and 18 which supply water to the town centre and lodge respectively (Table 5.8). As a general remark intermittent systems tend to have low capacities and therefore little effect on the river flow as shown in Table 5.8 and 5.9.

For systems that operate continuously there should be a way of returning excess water to the river. Except for abstraction point number 25 (canal in savannah) where excess water returns to the river just downstream of river gauging station A6, all other systems have no such facility. Water gets lost through seepage inside or outside the Naro Moru river basin or goes into dams where it is used or evaporates. Abstraction points number 12 and 26 are good examples where excess water finally goes into dams.

One of the basic functions of an intake structure is to abstract and control the diverted river flow and direct it to the conveyance entrance (Razvan, 1989). A standard intake block should therefore have openings which ensure the withdrawal of the required discharge. For the three canals in Naro Moru river (abstraction points No. 8,25 and 26)), there are no structures for controlling the amount of water abstracted. Water therefore continues to flow through the canals even when it may not be required.

During the dry season, the high demand for irrigation water forces the farmers to increase the height of the weirs in order to allow more water into the canals. The canals are also desilted and cleared of weeds. This reduces resistance to flow and ensures that more water is admitted into the canals. Sometimes the farmers lowered the height of the weir when the water level rose suddenly. Increasing the height of the weir was achieved by piling more stones or sacks of soil on the weir. The variations in the amount of water abstracted in relation to the river flow and the farmers activities can be seen in Figs. 5.13, 5.14 and 5.15.

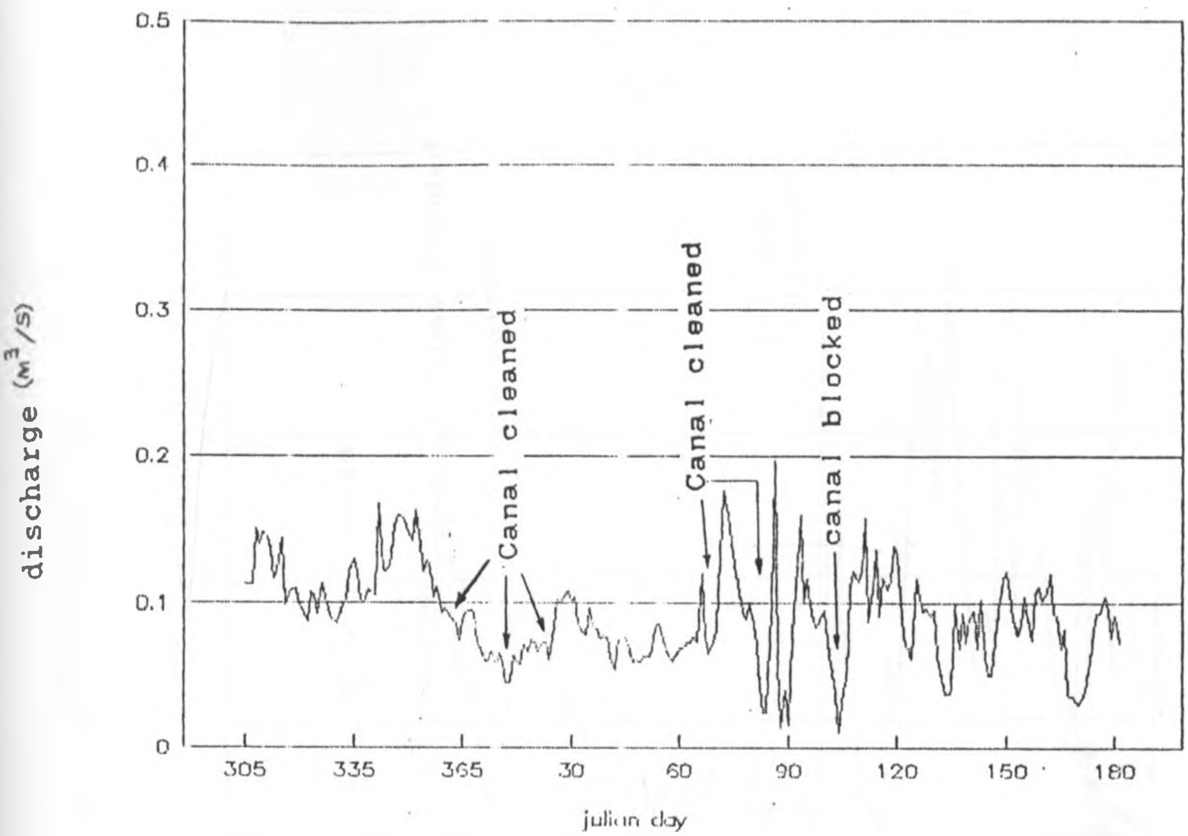


Fig. 5.13 Daily rate of abstraction through canal in footzone (Abstraction point No.8) for Nov-June 1990/91.

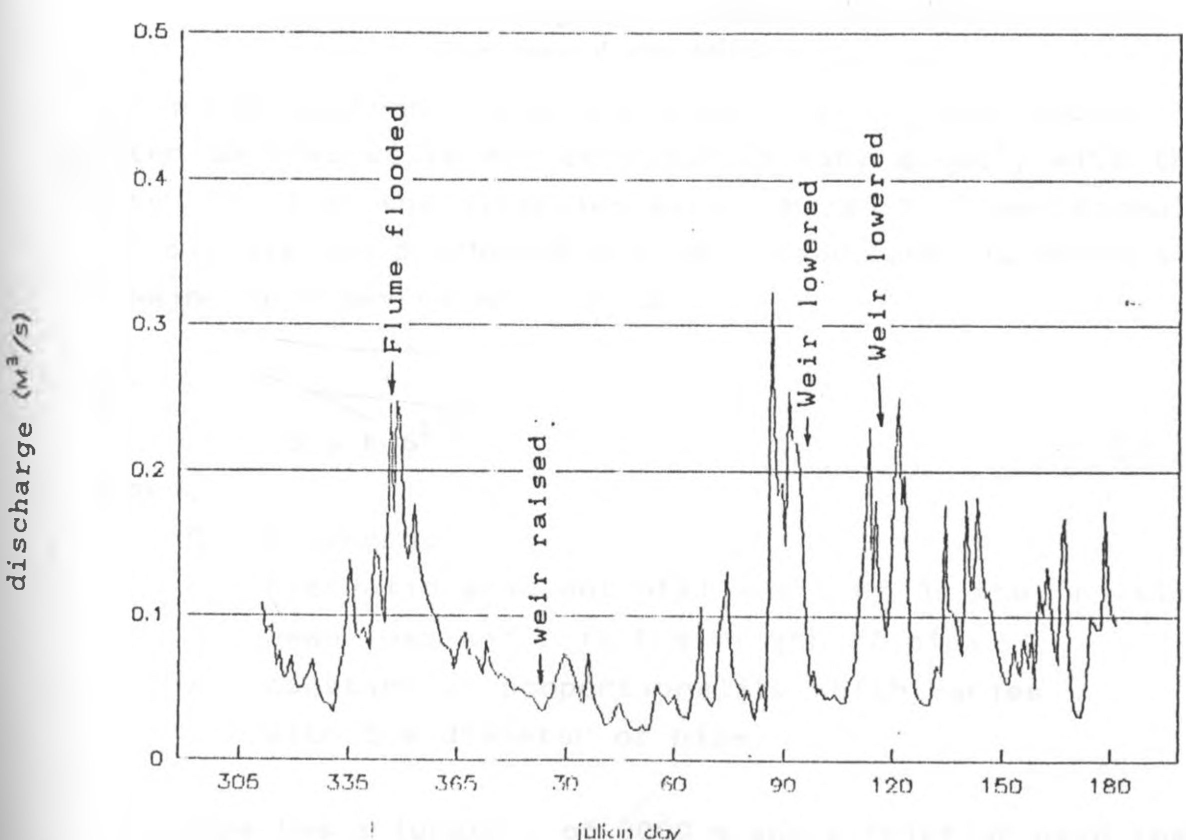


Fig. 5.14 Daily rate of abstraction through canal in savannah (Abstraction point No.25) for Nov-June 1990/91.

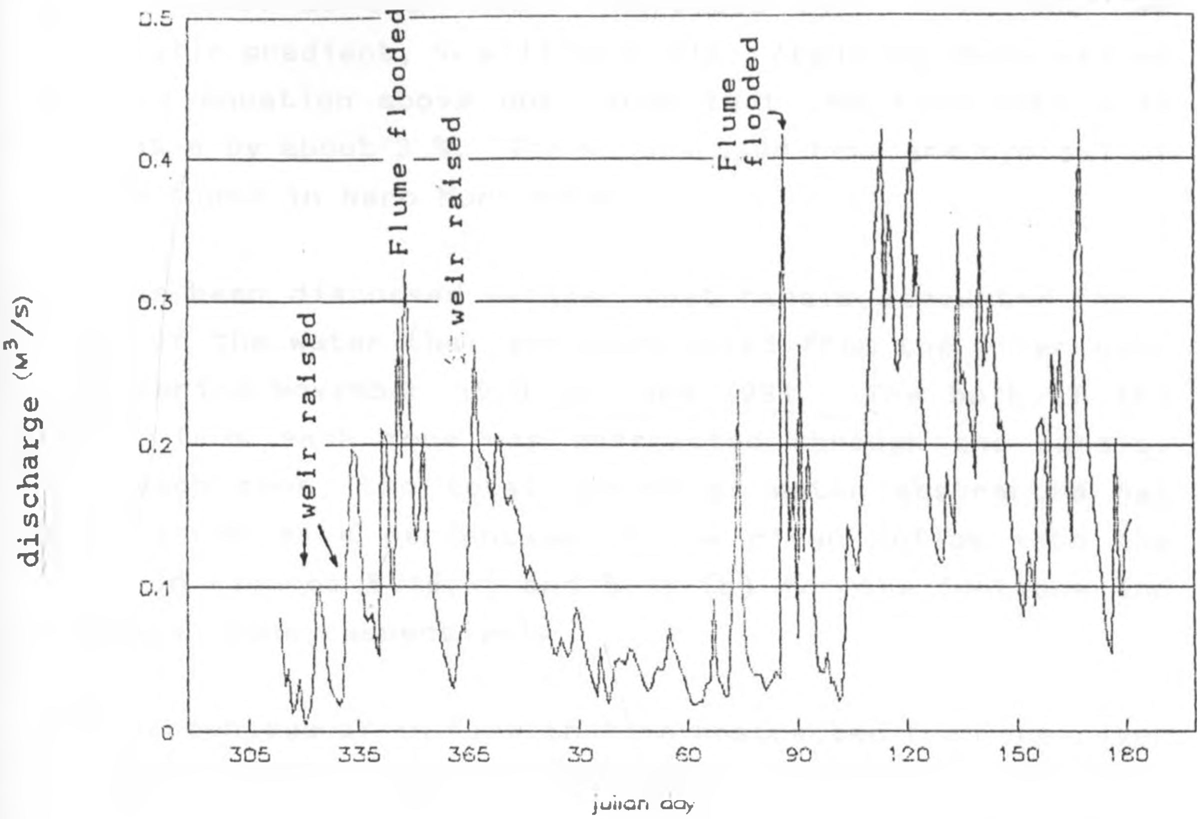


Fig. 5.15 Daily rate of abstraction through canal in savannah (Abstraction point No.26). For Nov-June 1990/91

For piped systems operating under gravity, the amount of water abstracted is not expected to vary greatly with the water level at the diversion site. Hazen-Williams formula for calculating discharge through closed conduits which are flowing full may be written as:

$$Q = K\ S^{0.54} \qquad [5.1]$$

where,

Q = discharge

S = hydraulic gradient hf/l where hf is the friction head loss and L is the length of pipe

K = constant of proportionality which varies with the diameter of pipe.

If a pipe has a length L of 2000 m and a friction head loss hf of 20 m the hydraulic gradient, S_1, will be 0.01. If the water level at the intake increases by 1 m, the new hydraulic gradient, S_2 will be 0.015. Applying these values on the equation above one finds that the flow rate will increase by about 3 %. The values used here are typical of those found in Naro Moru river.

It has been discussed earlier that canals accounted for 88 % of the water that was abstracted from the river over the period November 1990 to June 1991. The bulk of the water from each zone was abstracted through the canals. For each zone, the total amount of water abstracted has been shown as a percentage of the river inflow into the zone in Figures 5.16(a) and 5.16 (b) for the footzone and savannah zone respectively.

The percentage of in flow that is abstracted from the river was about 10 % during the short rains (November - December) in both zones but it rose steadily during the dry months (January - February), and reached about 60% for the footzone reach and almost 100 % for the savannah reach by the end of March. It dropped again during the long rains (April - May) and began to rise again at the middle of June. In the savannah zone, the abstractions nearly dried up the river and only a flow of 14 l/s remained in the river for five days at the beginning of March as may be seen in Appendix V station A6.

In Fig. 5.16(b), the percentage of water abstracted during the month of March appears to exceed the inflow for a few days. The reason is that there was some flow entering the savannah reach through station A5b but it was not accounted for because the station had not been put up. Rainfall data for station R7 shows that 37.1 mm of rain was received on 15/03/91 and 40.4 mm on 27/03/91 (see Appendix VIII).

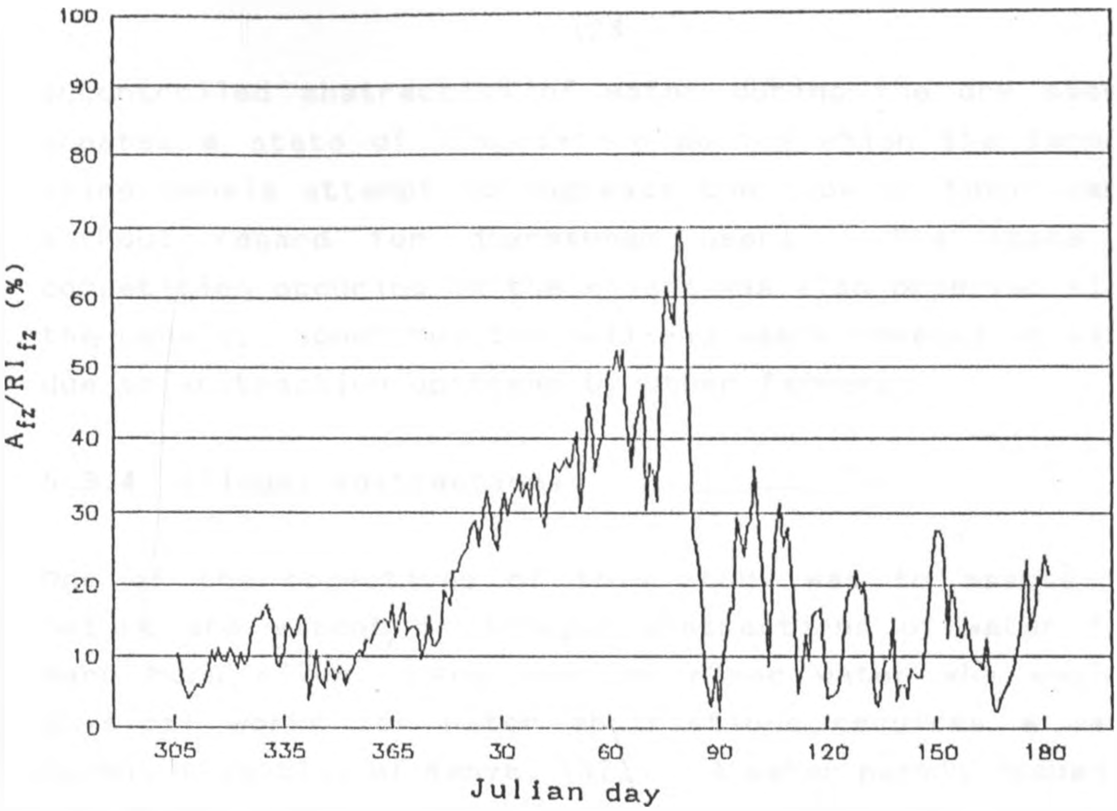


Fig. 5.16(a) Total abstractions from footzone reach (A_{fz}) as a percentage of river inflow into reach(RI_{fz}).

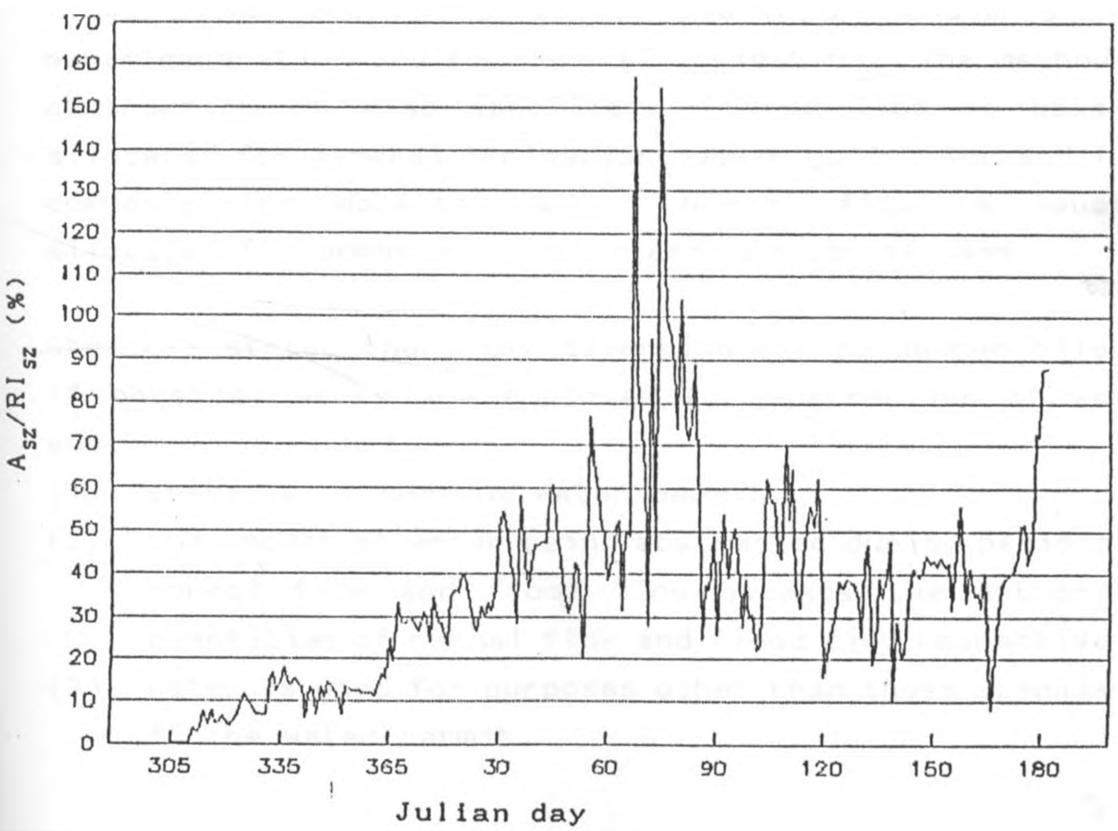


Fig. 5.16(b) Total abstractions from savannah reach (A_{sz}) as a percentage of river inflow into reach(RI_{sz}).

Uncontrolled abstraction of water during the dry season creates a state of competition during which the farmers using canals attempt to increase the flow in their canal without regard for downstream users. The state of competition occuring in the rivers was also observed along the canals. Sometimes the tail-end users receive no water due to abstraction upstream by other farmers.

5.3.4 Illegal abstractions

One of the objectives of this study was to assess the nature and extent of illegal abstractions of water from Naro Moru river. Any user of river water who employs physical works for water abstractions requires a water permit (Republic of Kenya, 1972). A water permit issued by the Water Apportionment Board of the Ministry of Water Development usually bears the following information: name of permit holder, permit number, date of issue and expiry, land registration number, quantities of normal and flood flows authorized for domestic, public or industrial use power generation and for general irrigation. The method of abstraction is also specified. Flood flow is usually allocated for general irrigation, power generation and less commonly for domestic use. Normal flow is usually allocated for domestic, public and industrial uses.

Strictly stated then, any diversion may be deemed illegal if physical works are employed for abstraction of water and:

(1) there is no current water permit,

(2) the amount of water being abstracted during periods of normal flow and flood flow exceeds the authorized quantities of normal flow and flood flow respectively,

(3) water is used for purposes other than those stipulated in the water permit.

It may be unjustified to classify water users with expired permits as illegal users especially when it is known that renewal of permits may sometimes take longer time than anticipated. The greatest difficulty arises in trying to define periods of normal flow. In legal terms normal flow is defined as:

> "ordinary flow at any particular point of a stream as certified by the Water Apportionment Board from time to time to be normal flow at that point", (Republic of Kenya, 1972).

Normal flow is therefore a subjective term and its value changes with time.

Table 5.11 lists the abstraction points identified along Naro Moru river together with the authorized normal and flood flows as obtained from records of the Ministry of Water. The current rate of abstraction is also shown. For canals (No. 8,25,26) the rate of abstraction during low flows (January- March) and high flows (Nov-Dec, April-June) is shown but for piped abstractions it was only possible to state the average rate of abstraction over the period November 1990 to June 1991. It is assumed that the variation in abstraction rate is small.

The column headed "UP" (unknown permits) shows the abstraction points for which no information was available in the list from MoWD. The users claimed they had permits but it was not possible to get access to them. The list of water permits also bears numerous other persons who were not identified in the field visit. Some are former land owners who have sold land to other people (for example in the case of the canals) or people with applications for permits but have not yet installed their plants or users who at one time had pumps but have abandoned them either to breakdown or because they have switched to public or communal water supply projects.

Table 5.11 Measured abstractions compared with authorized abstractions

ABST. PT. NO.	WATER CP	EP	PERMIT NP	UP	A.N.F. m³/d	M.L.F. m³/d	REMARK	A.F.F. m³/d	M.F.F. m³/d	REMARK
1	x	.	.	.	7.0	6.9	ok	9.0	6.9	ok
2	.	x	.	.	-	n/o	n/o	-	n/o	--
3	.	x	.	.	837.8	146.9	ok	2249.6	146.9	ok
4	x	.	.	.	361.9	1296.0	**	-	1296.0	--
5	x	.	.	.	-	604.8	--	583.7	604.8	**
6	x	.	.	.	61.1	950.4	**	881.8	950.4	ok
7	x	.	.	.	-	2.6	--	-	2.6	--
8	x	.	.	.	3.2	6710.3	**	2249.6	8467.2	**
9	.	.	.	x	-	78.6	--	-	78.6	--
10	x	.	.	.	0.6	6.0	**	18.2	6.0	ok
11	x	.	.	.	12.4	11.2	ok	130.2	11.2	ok
12	.	x	.	.	89.0	56.2	ok	-	56.2	ok
13	.	.	.	x	-	0.9	--	-	0.9	--
14	.	.	.	x	-	4.3	--	-	4.3	--
15	x	.	.	.	190.8	60.5	ok	-	60.5	ok
16	.	.	.	x	-	2.6	--	-	2.6	--
17	x	.	.	.	-	1.7	--	-	1.7	--
18	.	x	.	.	3.6	33.7	**	2.3	33.7	**
19	x	.	.	.	2.7	17.3	**	45.2	17.3	ok
20	x	.	.	.	2.7	17.3	**	45.2	17.3	ok
21	.	x	.	.	2.9	19.9	**	60.1	19.9	ok
22	.	x	.	.	72.6	55.3	ok	389.8	55.3	ok
23	.	.	.	x	-	14.7	--	-	14.7	--
24	.	x	.	.	6.3	8.6	**	486.7	8.6	ok
25	.	x	.	.	95.4	5011.2	**	204.9	8363.5	**
26	x	.	.	.	86.3	7084.8	**	297.3	12960.0	**
	50%	31%		19%	1836.3	22202.7		7653.6	33187.1	

CP = current permit
NP = no permit
EP = expired permit
UP = unknown permit
n/o = not operational

A.N.F. = authorized normal abstraction
M.L.F. = measured low flow abstraction
A.F.F. = authorized flood flow abstraction
M.F.F. = measured flood flow abstraction
\- = no information available

REMARKS:

ok = measured abstraction < authorized abstraction
** = measured abstraction > authorized abstraction
-- = information not sufficient to justify a remark

It is felt that the records of water permits lag behind developments in the field. The problem is partly due to the changes in land ownership that have been taking place over the last 40 years. The oldest permits date back to 1950s and some were issued for periods of upto 96 years and are therefore still `current'. Recently issued permits have shorter periods of expiry.

All irrigation should be done during flood flow periods unless there is sufficient storage to reserve flood flows for use in dry season. However it was found that irrigation is practised mainly during the dry season and water is drawn directly from the river.

Apart from the authorized normal flow abstraction, all other abstraction from the river during the dry season may be classified as illegal. From Table 5.11, the total quantity of authorized normal flow is 1836.3 m^3/day. There are 8 abstraction points with no information on authorized normal flow abstractions. All of them are private projects (Appendix VI). As discussed earlier, these private points have capacities which are smaller compared to canals and piped abstractions. This can also be seen in Table 5.11 for other private projects whose information is known (Nos. 1,10,11,18,19,20,21,23). If an extra 5.0 m^3/day is allowed for these unknown abstractions, an estimated total quantity of authorized abstraction of 1841.3 m^3/day is obtained during the dry season which converts to 21 l/s on continuous basis.

The current rate of abstraction during the low flow period (January-March) was found to be 22 203 m^3/day (Table 5.11) which means that only 8% of the abstractions in the dry season were legal. This includes users with expired permits. The assumption here is that the flows in January - March were normal. It has been shown already (Fig. 5.8) that the average flow for these months was below the long term average for station A5. Canals taken together account for 98 % of the illegal abstractions.

During the wet season, the total authorized rate of abstraction is the sum of all authorized flood flows and normal flows. This was 9489.9 m^3/day for Naro Moru river (110 l/s continuous basis). Allowing 5% for the unknown authorized abstraction yields 9964.4 m^3/day. The amount of water abstracted was found to be 33187.1 m^3/day on the average for the months of Nov - Dec, April - June. This means that 70% of the abstractions were illegal.

Illegal abstractions result from users who exceed the amounts of low (normal) and flood flows allowed in the water permits. It can be seen from Table 5.11 that canals exceed by far the authorized abstractions during low and high flows. One way of curbing illegal abstractions in canals is to have separate conveyance system for domestic water use and for irrigation. Piped conveyance for domestic use would reduce the costs involved and a canal for irrigation water would ensure adequate water for all users during flood flows and the possibility of shutting or reducing the flow during the dry season. However not many irrigation users are likely to benefit from water that is only available during the wet season.

It was not possible to know how many of the water users have expired water permits except for those already shown in Table 5.11. All users claimed that they had water permits. Except for abstraction points No. 12 and 15, all other water permits are given for domestic water use and general irrigation. Abstraction points number 12 and 15 serve Naro Moru town and the railway station. No other uses were identified apart from domestic water use and irrigation. Water used for running hydraulic rams and turbine pumps is returned to the river. The results are summarized below in Table 5.12.

Table 5.12 Legal abstractions from Naro Moru river

	A. N. F.		A. F. F.		A. T. F.		M.T.F		%
	m^3/day	l/s	m^3/day	l/s	m^3/day	l/s	m^3/day	l/s	legal
DRY SEASON	1841	21	0	0	1841	21	22203	257	8
WET SEASON	1928	22	8123	94	9964	115	33187	384	30

A.N.F. = authorized normal flow abstraction
A.F.F. = authorized flood flow abstraction
A.T.F. = authorized total flow abstraction
M.T.F. = measured total flow abstraction (average Nov - June)

5.4 River reach water balance

5.4.1. Daily water balance

5.4.1.1 Footzone river reach

In section 4.6.2, the daily water balance equation for the footzone reach has been presented. River discharge (daily mean inflow and outflow) and daily mean abstractions are known and have already been discussed in section 5.1 and 5.3 respectively. The amount by which river flow increases or decreases as it flows down the footzone river reach was calculated on a daily basis according to the equation:

$$\Delta Q_{fz} = RO_{fz} - RI_{fz} + A_{fz} \quad [5.2]$$

and $$\Delta Q_{fz} = DR_{fz} + GW_{fz} + \Delta SW_{fz} \quad [5.3]$$

where,

ΔQ_{fz} = increase or decrease in streamflow after accounting for abstractions
RO_{fz} = river outflow from footzone reach
RI_{fz} = river inflow to footzone reach
A_{fz} = abstractions from footzone reach.
DR_{fz} = local direct runoff to footzone reach
ΔSW_{fz} = change in channel storage in the footzone reach

GW_{fz} = net ground water outflow to footzone reach when positive and net transmission losses when negative.

The results obtained for ΔQ_{fz} are presented graphically in Figure 5.17(a) for the months of November to February and in Figure 5.18(a) for the months of March to June. The values appear in Appendix VIII together with the daily rainfall at each of the stations R4-R8. A net increase in river discharge (positive values in Fig. 5.17(a) and 5.18(a) may be observed when the sum of groundwater outflow into the reach, direct runoff into the reach, and release from channel storage exceeds the sum of transmission losses (recharge of groundwater by reach, bank storage, overbank spill, etc.) and entry into channel storage. The converse result would also be true when losses exceed gains.

In the absence of abstractions and local inflow from direct runoff, subtracting the inflow hydrograph from the outflow hydrograph would show a sharp loss when water is entering channel storage and a sharp gain when water is leaving channel storage (Linsley, et al,1949). This effect is observed in Figures 5.17(a) and 5.18(a) (see for instance 21st-23rd April in Appendix VIII). Whenever a transitory flood wave passed through the footzone reach, a sharp drop in river discharge would be observed. This would be followed by a sharp rise of almost equal magnitude.

It was observed from the stage hydrographs that a flood wave took 4 to 5 hours to pass through the footzone reach. This travel time agrees closely with that estimated as shown in Chow et al (1988) which is less than 6 hours for a channel reach with a gradient of about 2.2% and a length of 13 km. The sharp rises and falls resulting from changes in channel storage, Δ **SW** have been smoothed by applying a 4-day centered moving average formula on the values obtained from equation 5.2.

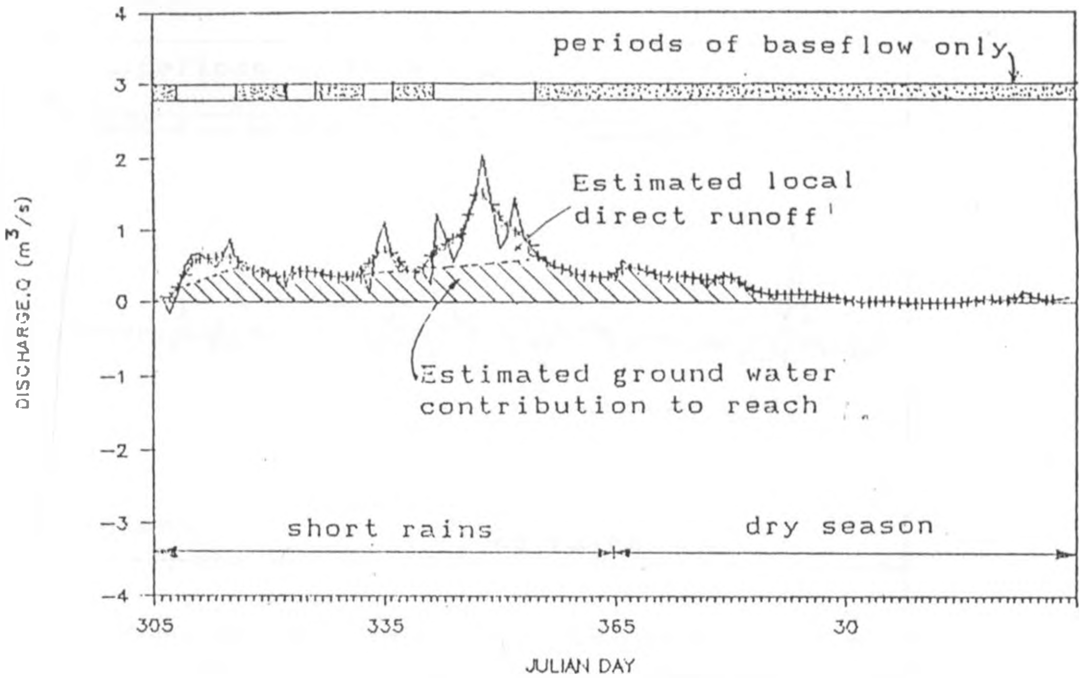


Fig. 5.17(a) Change in streamflow after abstractions have been accounted for (Footzone reach: Nov-Feb 1990/91)

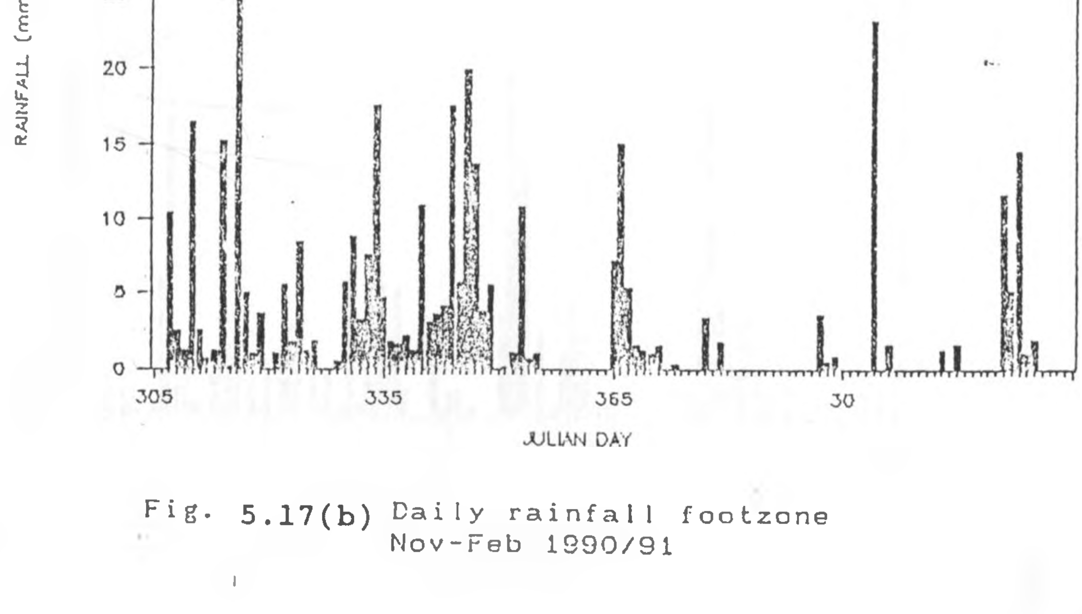


Fig. 5.17(b) Daily rainfall footzone Nov-Feb 1990/91

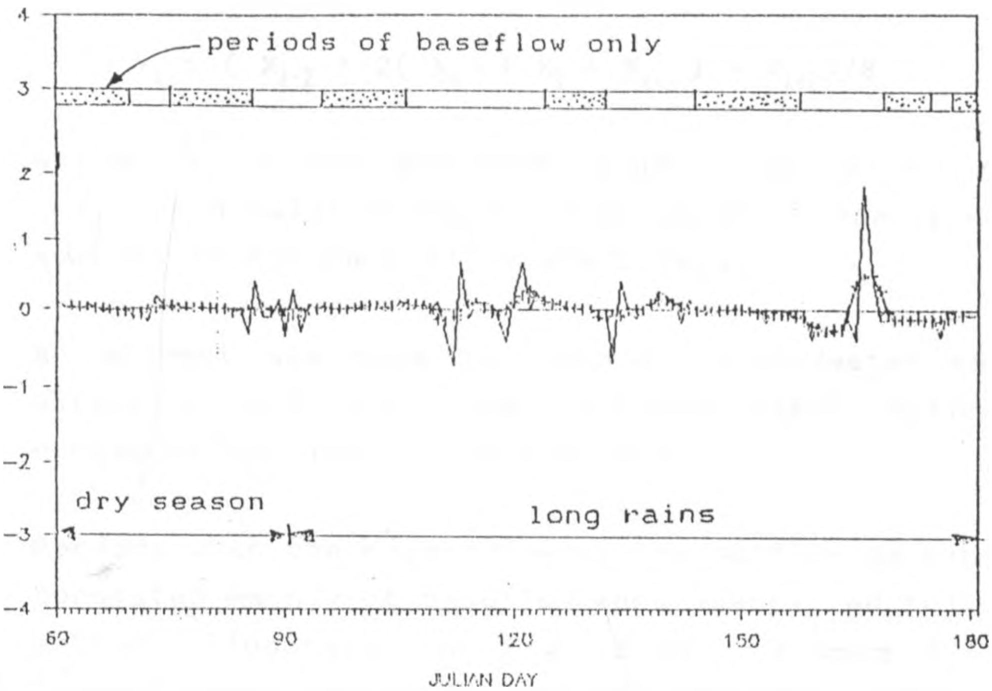


Fig. 5.18(a) Change in streamflow after abstractions have been accounted for (Footzone reach: March - June 1991)

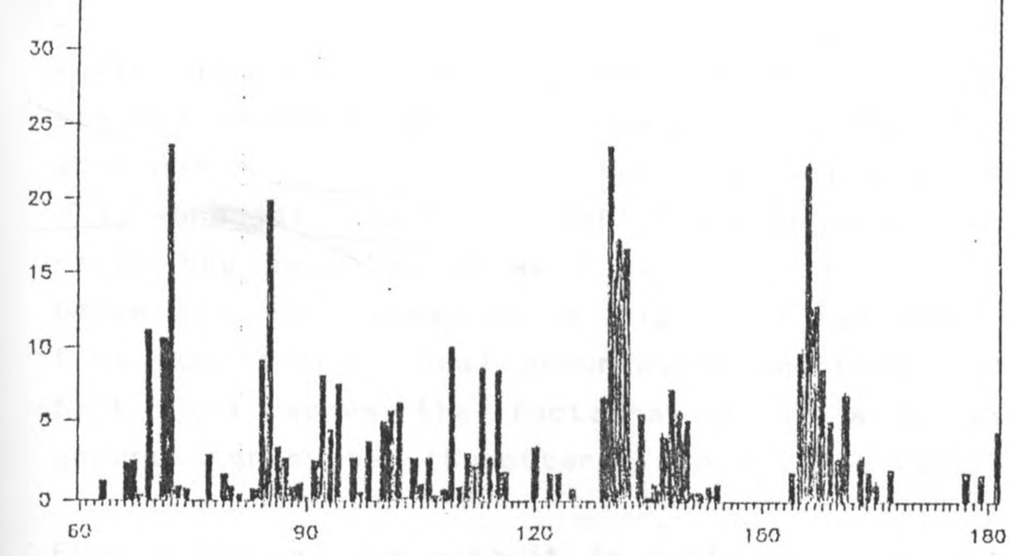


Fig. 5.18(b) Daily rainfall footzone March - June 1991

The smoothing equation is used is

$$Y_k = (X_{k-2} + 2(X_{k-1} + X_k + X_{k+1}) + X_{k+2})/8 \qquad [5.4]$$

where Y_k is the smoothed value on day k and X_k is the unsmoothed value on day k. The smoothed line is shown with symbols in Figure 5.17(a) and 5.18(a).

An attempt was made to identify groundwater runoff and direct runoff into the footzone reach following the procedure outlined in section 4.6.3.

Periods when the river flow at the outflow gauging station consisted mainly of baseflow were identified following the method illustrated in Fig. 5.10. Figure 5.17(b) and 5.18(b) show that such periods occurred when the daily rainfall was low (<10 mm). For such periods, change in channel storage is negligible because there are no waves moving through the river reach. Local direct runoff is negligible. Any increase in river flow occurring within such a period is attributed to groundwater outflow into the footzone river reach (Figure 5.17(a) and 5.18(a)).

Since ground water is released into the river reach more steadily compared with the direct runoff, the line segments obtained for periods when river flow comprises of baseflow only were joined with straight lines to cover periods when river has baseflow as well as direct runoff. The area below the line (hatched in Fig. 5.17(a)) represents the flow coming from local groundwater aquifers. The forest belt just above the footzone is an area with local groundwater system (Schotterer and Muller, 1985).

From graphical analysis it is estimated that the footzone reach received 400 l/s from groundwater during the months of November and December after which the groundwater outflow declined steadily reaching zero at the end of

January. Small streams which may be outlet points for local groundwater aquifers were observed in the upper part of the footzone. The largest one is the perennial stream just downstream of river gauging station A3. About 30% of flow added to the footzone reach during the months of November - January comes from direct runoff and 70 % from groundwater (Fig. 5.17(a)).

If groundwater outflow into the footzone reach ceased after the month of January, then it may be stated that the footzone river reach has an impermeable channel as suggested by Fig. 5.17(a) and 5.18(a) for the months of February and March. There was no net loss in streamflow during these two months. The riverbed material consists of cobbles and boulders overlying the bedrock. The potential evapotranspiration for the dry season is given by Liniger (1990) as 4.5 mm/day but evaporation losses do not seem to affect streamflow appreciably.

During the long rains and intermediate continental rains (April-June) the footzone river reach does not lose or gain water when abstractions have been accounted for. Soil and groundwater storages are depleted during the dry season (January-March) and are replenished during the long rains and the intermediate continental rains season (Liniger and Decurtins, 1990;Decurtins 1990). A greater proportion of the short rains (October-December) is therefore expected to contribute to streamflow compared with the long rains. Long term data show that the monthly mean discharge is highest in November (2.070 m^3/s) and not in May (1.730 m^3/s) for river gauging station A5 (Republic of Kenya, 1990). This shows the importance of the short rains season in terms of their contribution to the surface flow in Naro Moru basin.

Groundwater recharge and discharge takes place mainly in the upper forest and lower moorland zones (Liniger and

Decurtins, 1990). However, the footzone reach is a transitional zone bordering the forest and some groundwater discharge takes place in the upper part of the footzone during the dry season as seen in Fig. 3.3 (Liniger, 1991).

5.4.1.2 Savannah river reach

The daily water balance equation for the savannah zone river reach is presented in section 4.6.3. The water balance analysis was carried out in the same way as for the footzone river reach. Increase or decrease in streamflow for the savannah reach was calculated according to the equation

$$\Delta Q_{sz} = RO_{sz} - RI_{sz} + A_{sz} \qquad [5.5]$$

and

$$\Delta Q_{sz} = DR_{sz} + GW_{sz} + \Delta SW_{sz} \qquad [5.6]$$

where,

Δ Qsz = increase or decrease in streamflow after accounting for abstractions

RI_{sz} = river inflow into reach

RO_{sz} = river outflow from savannah reach

A_{sz} = abstractions from savannah reach

DR_{sz} = local direct runoff

GW_{sz} = net ground water outflow into zone when positive or net transmission loss when negative

ΔSW_{sz} = change in channel storage in savannah reach

The change in river discharge was calculated from known values of river inflow, river outflow and abstractions. The results are of ΔQ_{sz} obtained are presented graphically in Figure 5.19(a) and 5.20(a) for the months of November to February and March to June respectively. Values appear in Appendix VIII together with the daily rainfall at the stations R4-R8.

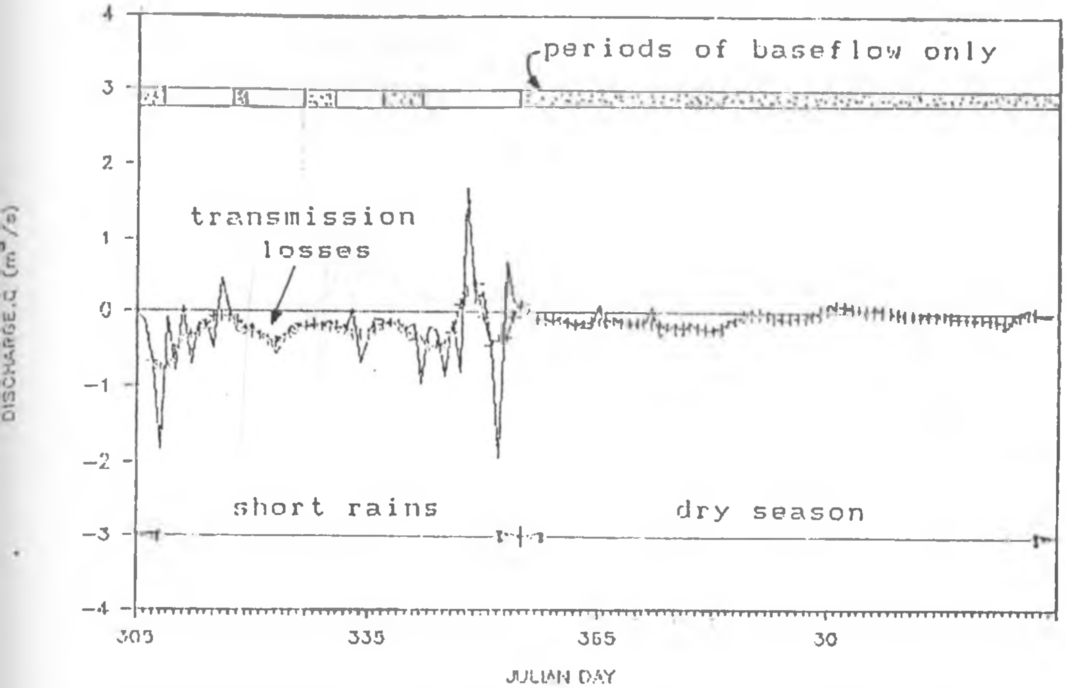


Fig. 5.19(a) Change in streamflow after abstractions have been accounted for (Savannah zone reach: Nov - Feb 1990/91)

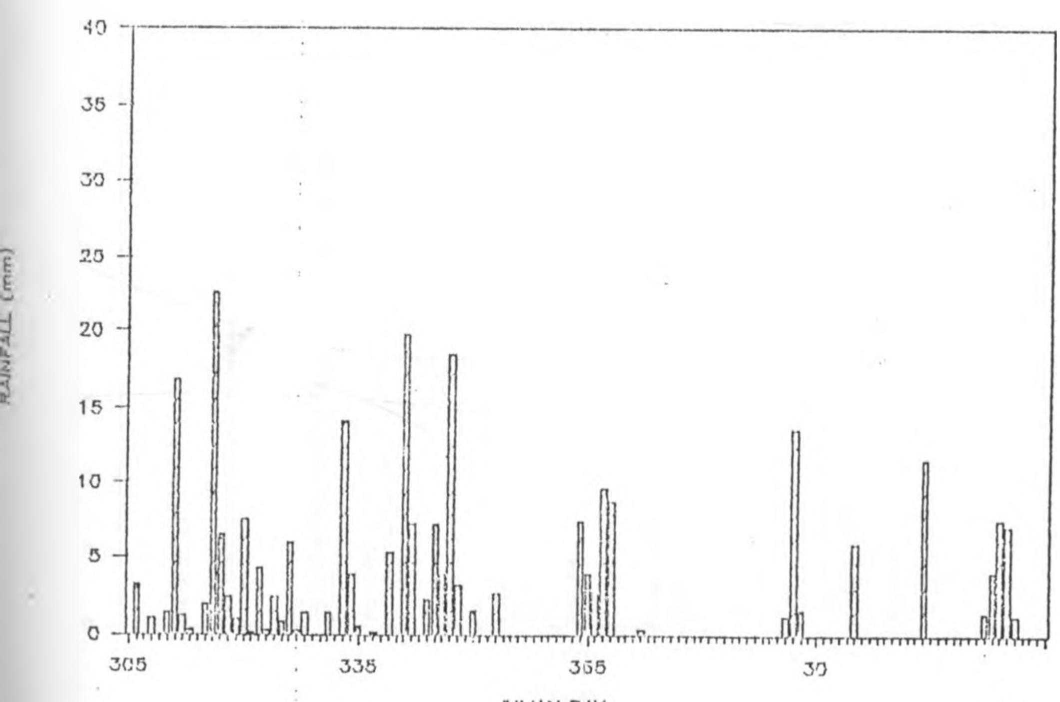


Fig. 5.19(b) Daily rainfall savannah Nov-Feb 1990/91

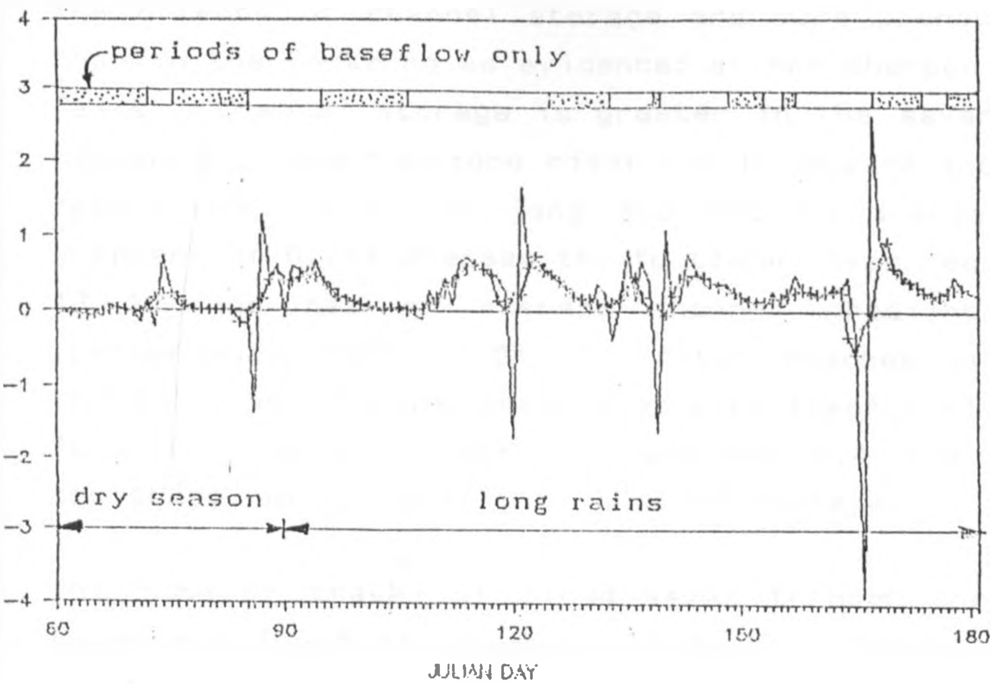


Fig. 5.20(a) Change in streamflow after abstractions have been accounted for (Savannah zone reach: March - June 1991)

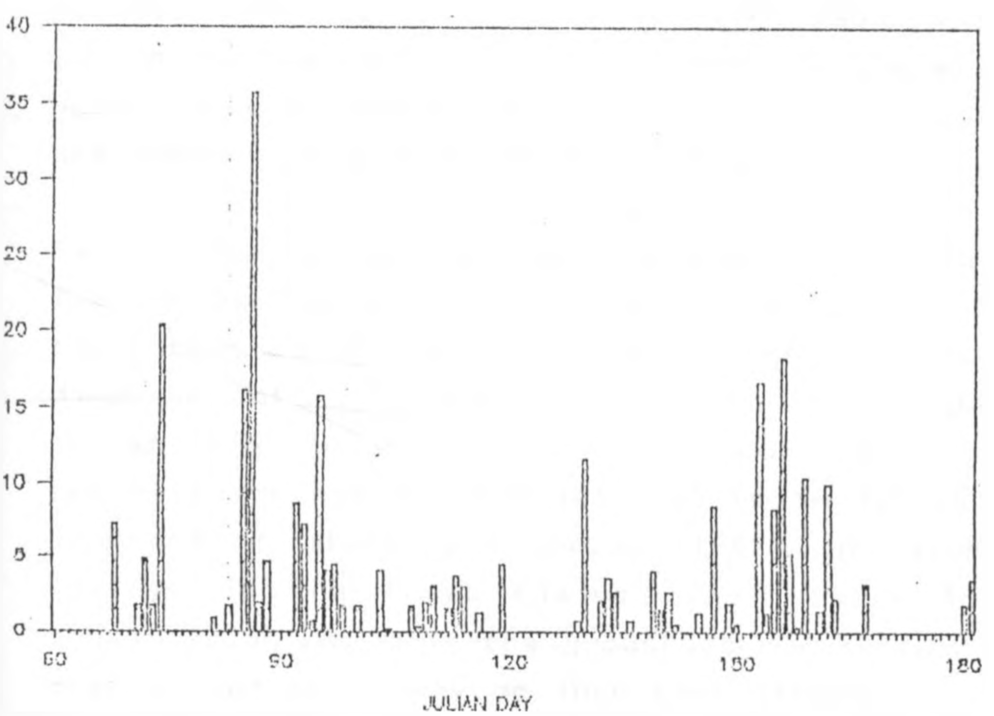


Fig. 5.20(b) Daily rainfall savannah March - June 1991

The effects of channel storage are more pronounced here than in the footzone as evidenced by the sharper rises and falls. Channel storage is greater in the savannah reach compared to the footzone river reach because the savannah zone reach is 22 km long and has an average channel gradient of 0.74% whereas the footzone river reach is only 13 km and has an average channel gradient of 2.2% (Leibundgut, 1985). Shorter river reaches and steeper channel gradients are associated with lower valley storage (Linsley, et al, 1949). Equation 5.4 was used for smoothing out the effect of channel storage.

The time of travel of flood waves through the savannah reach was found to be about 12 hours. This travel time slightly exceeds the estimate in Chow et al (1988) of less than 10 hours for a river reach with a length of 22 km and an average gradient of 0.74 %.

Periods when the river flow at river gauging station A6 (which is the outlet for the reach) consisted mainly of baseflow were identified as illustrated in Figure 5.10 and are shown in Fig. 5.19(a) and 5.20(a).

Fig. 5.19(a) shows that the river reach lost on average 160 l/s during the short rain season (Nov-Dec). This means that about 8% of the flow entering the savannah reach was disposed of in other ways other than abstraction. Transmission losses amounting to about 40% of flood flows for 18 river reaches averaging 85 km in length have been reported in Sharp and Saxton (1962) in natural stream valleys in the Great Plains USA. Water lost during transmission may join the groundwater reservoir below the channel bed or it may go into bank storage or storage in the valley alluvium if overbank spill occurs.

The loss in streamflow in November and December would have been compensated by runoff produced in the savannah zone over these months which fall in the short rains season (see Fig. 5.19(a)). This was observed to happen to a limited extent on 12th November (Julian day 316) and 13th December (Julian day 348) 1990 (see Appendix VIII).

The runoff produced from the rains in November and December was very low for the savannah area. This was attributed to low rainfall intensities, low antecedent soil moisture conditions and losses due to evaporation (Ondieki, 1991). In a smaller representative catchment located in a dry river valley in the savannah zone, no runoff was recorded for these two months even when daily rainfall reached a maximum of 16.5 mm and 23.1 mm for the November and December respectively. This rainfall was measured in station R8 (Fig. 4.1) which is in Naro Moru river basin.

In contrast, runoff was reported in the same catchment on 26th March, 2nd June, and 6th June 1991 when the corresponding daily rainfall was 21.1 mm, 37.4 mm and 10.3 mm respectively (Ondieki, 1991). The total rainfall received during November and December 1990 for rainfall station R8 was twice that received in April and May 1991 (See Fig. 5.21 and Appendix IX). Rainfall amounts alone cannot be used to explain whether runoff is likely to be produced in the savannah zone.

The following factors would support the possibility that the amount of water lost actually recharges groundwater: (1) the riverbed material changes from cobbles overlying bedrock in the upper part of the reach to sandy loam in the lower parts (Leibundgut, 1986); (2) the position of the groundwater table for the savannah reach, as estimated from the groundwater contours (MoWD, 1987) and the ground surface elevations is probably more than 30 m below the ground level. The depth to the water table affects the available storage capacity beneath the channel bottom. The riverbed material affects the rate of infiltration (Sharp and Saxton, 1962).

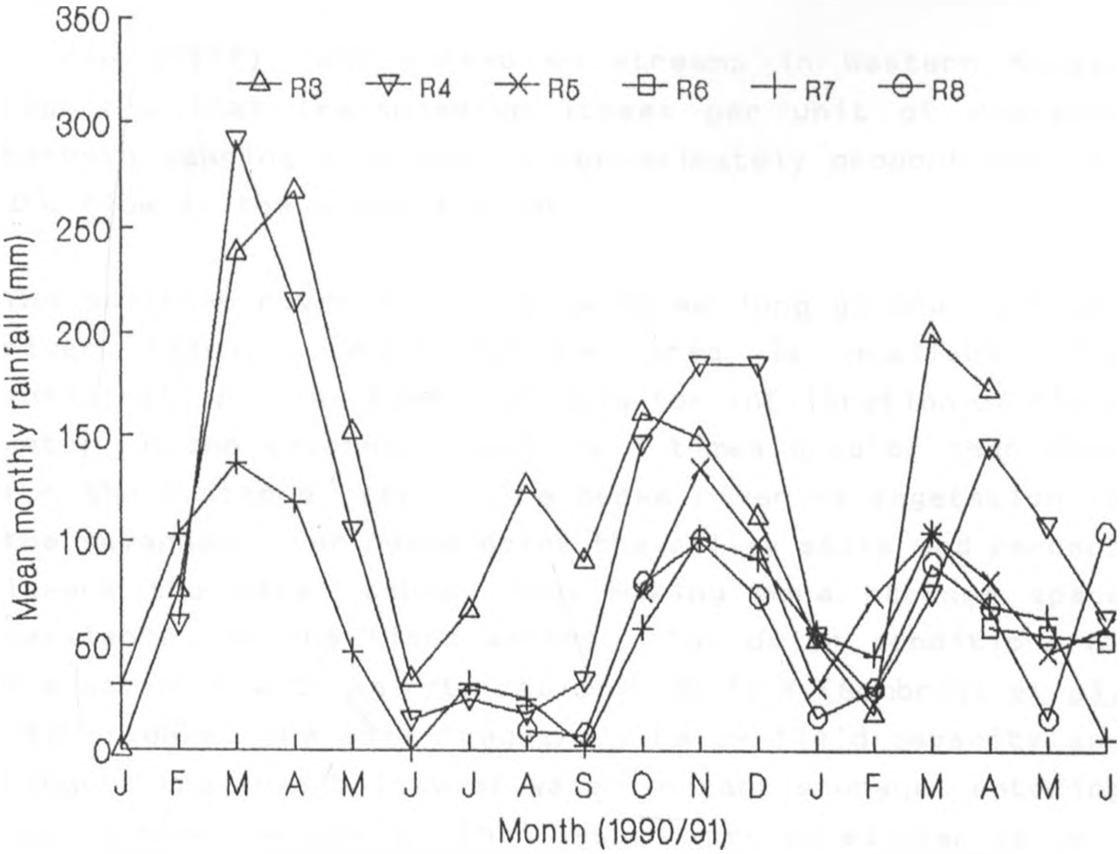


Fig. 5.21 Mean monthly rainfall for the lower Naro Moru river basin. The rain gauges R3 - R8 are shown in Fig. 4.1.

Overbank spill was not observed in this river reach for the period under consideration. However during peak flows the amount of water diverted at the two canals increased sometimes even flooding the flumes. This water would then spill out of the canals into the farms downslope. Readings at the flumes were taken at 9.00 am and 3.00 pm everyday. Peaks could therefore be omitted thus giving a mean daily rate of abstraction lower than the actual one.

It is possible that bank storage may account for the river influency observed during the short rains season. The peaks that occurred in November and December were in general higher than those for April, May and June. Bank storage results from water infiltrating more or less horizontally into river banks and therefore would increase as the water level rises.

Jordan (1977), who worked on streams in Western Kansas reported that transmission losses per unit of distance between gauging stations is approximately proportional to the flow at the upper station.

The savannah river reach is twice as long as the footzone river reach. More surface area is available for infiltration. The time available for infiltration of flood water in the savannah reach is 3 times greater than that for the footzone reach. The dense riverine vegetation in the savannah river reach dries the valley soils and perhaps lowers the water table, thus making more storage space available for the flood waters. The drier conditions of the savannah with an r/E_0 ratio of 25-40 % (Sombroek et al, 1980) leaves the soil frequently below field capacity and reduces the possibility of water in bank storage entering into streamflow again. The losses experienced over January are smaller in absolute terms but amount to about 15 % of the discharge at A5.

While it is likely that transmission losses actually do occur, the possibility of a systematic error in discharge measurement is not ruled out. Overestimating the discharge at A5 and/or underestimating the discharge at A6 may have the same result as a loss in streamflow. As discussed in section 5.1.1.4, the accuracy of the rating equations decreases when the discharge being measured approaches or exceeds the gauged limits as was the case for the peaks flows in November and December.

Observations of the discharge hydrographs for November and December showed that a reduction in river discharge which exceeds the measured abstractions, took place consistently during low and high flows and occurred even when the discharge did not exceed 2 m^3/s which should have been estimated fairly accurately (± 13%) with the rating curves shown in Figure 5.3 and 5.4.

Greater accuracy in the rating curves can be obtained by further measurements especially at the extremes of the rating curves. Another source of error which could have affected the results such that a loss is indicated when it does not take place in reality is a systematic error in measurement of stage.

During the dry months of February and March, streamflow in the savannah reach zone does not increase or decrease after abstractions have been accounted for. Some little runoff is added to the savannah reach in mid March following some rain falling in the upper part of the savannah zone.

In rain gauge R7, 37.1 mm was recorded on 15th March. The total rainfall in station R7 for the period 13th - 19th March (Julian day 71-77) was 45.2 mm while in station R8 which is the lower part of the savannah zone only 4.4 mm was recorded for the same period and it fell on one day, 13th March. This illustrates the extreme spatial variability in daily rainfall amounts experienced in the savannah. Storms may be highly localized even over very short distances.

The other rainfall events in February (Fig. 5.19(b)) do not result in runoff of any appreciable amount possibly due to the low antecedent soil moisture and the high evapotranspiration rates.

During the wet months of April, May and June, the savannah river reach experienced periodic increases in flow. These increases occurred when the river had runoff from the upper parts of the catchment which means that some rain was falling in these areas and was producing runoff. Rain is also recorded at stations in the savannah zone (R7 and R8, Appendix VIII, see also Fig. 5.20(b)). The areal rainfall as shown in Figure 5.20(b) may in some cases seem too little to justify such runoff but it must be taken into consideration that the two rainfall stations in the savannah are not fully representative especially in an area where the spatial variability in rainfall is very high.

Some of the runoff produced from rainfall in the savannah was observed to cause distinct peaks in the stage hydrographs for station A6 which did not appear in station A5 upstream. This together with the rainfall at least confirms presence of runoff.

The runoff episodes are disjoint even when they are following each other closely and they continue for not more than 5 days after rainfall. This shows that the savannah zone has poor storage and/or low infiltration rates and reacts to rainfall by producing direct runoff rather than first filling the soil storage and groundwater storage reservoirs as is the case for the footzone. The occurence of episodic streams is evident in the savannah and is also discussed in Leibundgut (1986).

When direct runoff ceases, the river experiences no increase or decrease in discharge when abstractions have been accounted for. This seems to indicate that low flows during the long rains are not subject to large transmission losses. The transmission losses experienced during the short rains (November - December) can therefore be attributed to (1) the high water levels in the river channel and the low antecedent soil moisture conditions in the stream banks and flood plains, (2) peaks missed in the flumes installed in the canals, (3) unreliability of discharge measurements at high flows for station A5 and (4) systematic errors in stage measurement.

It is felt that the first three reasons in that order are the most likely ones to explain the loss in streamflow. The subject of transmission losses cannot be pursued further unless more detailed investigations are done especially with regard to the infiltration rates of the valley and channel alluvium.

5.4.1.3 Experimental errors

Referring to Equation 5.2 and 5.5, ΔQ is a function of the measured quantities RO, RI and A. The uncertainity in the measurement of streamflow has been calculated at 95% level of confidence in Tables 5.3-5.6 and varies from about 10-20% depending on where the predicted discharge lies on the rating curve. The uncertainity at 95 % in the measurement of abstractions using a cutthroat flume would have been $\pm$ 5% but due unsuitable site conditions and averaging of abstraction data, the accuracy could have dropped to $\pm$ 10%.

If Q is a function of several measured quantities a, b, c,..., the percentage standard deviation of Q is given in Herschy (1985:485) by the formula

$$X_Q = \pm (X_a^2 + X_b^2 + X_c^2 ...)^{1/2} \quad [5.7]$$

where X_Q is the percentage standard deviation of Q, and X_a, X_b, X_c,... are the percentage standard deviations of a,b,c,...etc. Applying the values mentioned above to Equation 5.7 gives a value for the percentage standard deviation of ΔQ of about $\pm$ 17-30 %. The accuracy of determining ΔQ is influenced by the accuracy of the rating curves and the abstraction data.

5.4.2 Monthly water balance

A summary of the monthly water balance is presented in Table 5.13 for the footzone reach and Table 5.14 for the savannah zone reach. The monthly mean abstractions are shown in relation to reach inflow and outflow for the footzone and savannah in Table 5.15 and Table 5.16.

The amount of water abstracted as a percentage of the inflow was highest during the dry months of January February and March. This is because the amount of water available in the river was lowest during these months while abstractions did not decrease to match the flows. Comparison of the monthly mean flow obtained at A5 with long term data showed that the discharge obtained for these months was below average (Fig. 5.8).

Apart from abstractions, groundwater inflow to reach transmission losses and local direct runoff affect the river outflow from the reach. Loss of streamflow due to other causes apart from abstractions has been referred to as transmission loss because it is not always clear whether the water lost goes into groundwater or bank storage or to storage in the valley alluvium (through overbank spill). In this discussion, a net loss of flow is represented by a negative value of (GW+DR) in Tables 5.13 and 5.14.

In Table 5.13 and 5.14, the net effect of groundwater outflow to reach, transmission losses and local direct runoff, (GW+DR), is shown in the last columns. It shows how streamflow increased or decreased within a reach when abstractions were accounted for. Results show that footzone river reach was mainly gaining over the period of study. The savannah zone river was losing during the short rains (Nov-Dec) and also in January. It gained during the long and intermediate rains (April-June).

Table 5.13 Monthly water balance for footzone river reach

MONTH	ROfz	Rlfz			Afz			ESTIMATED		
	A5 (l/s)	A3 (l/s)	A4 (l/s)	A3+A4 (l/s)	Abst.8 (l/s)	PIPES (l/s)	TOTAL (l/s)	GW (l/s)	DR (l/s)	GW+DR (l/s)
NOV	1806	1013	527	1540	112	14	126	322	70	392
DEC	2090	836	667	1503	121	14	135	400	322	722
JAN	623	272	200	472	75	14	89	200	40	240
FEB	184	133	111	244	72	14	86	0	26	26
MAR	337	217	216	433	86	14	100	0	4	4
APR	708	404	402	806	98	14	112	0	14	14
MAY	1027	569	496	1065	80	14	94	0	56	56
JUN	809	434	508	942	79	14	93	-40	0	-40

Table 5.14 Monthly water balance for savannah river reach

MONTH	ROsz	Rlsz			Asz				ESTIMATED		
	A6 (l/s)	A5 (l/s)	A5b (l/s)	A5+A5b (l/s)	Abst.25 (l/s)	Abst.26 (l/s)	PIPES (l/s)	TOTAL (l/s)	GW (l/s)	DR (l/s)	GW+DR (l/s)
NOV	1417	1806	-	1806	62	55	2	119	?	?	-270
DEC	1793	2090	-	2090	123	126	2	251	?	?	- 46
JAN	323	623	-	623	58	126	2	186	-114	0	-114
FEB	75	184	-	184	36	43	2	81	- 28	0	- 28
MAR	238	337	-	337	80	77	2	159	0	60	60
APR	654	708	30	738	109	184	2	295	0	211	211
MAY	1082	1027	45	1072	102	215	2	319	0	329	329
JUN	805	809	19	824	88	170	2	260	0	237	237

Notes for Tables 5.13 and 5.14

ROfz, ROsz = River outflow: from footzone (ROfz), and from savannah reach (ROsz)
RIfz, RIsz = River inflow: to footzone (RIfz), and to savannah reach (RIsz)
Afz, Asz = Abstractions: from footzone reach (Afz) and from savannah reach (Asz)
GW = When positive means ground water outflow to reach, when negative means transmission losses from reach.
DR = Direct runoff to river reach
GW+DR = Net contribution from the two elements GW and DR.
A3,A4,A5,A5b,A6 are the river gauging stations.
Abst.8 is abstraction point No.8 etc.

Table 5.15 Monthly abstractions from the footzone reach (Afz) in relation to river inflow into reach (RIfz).

MONTH	RIfz (l/s)	ROfz (l/s)	Afz (l/s)	Afz / RIfz (%)	Afz / (ROfz-RIfz) (%)
NOV	1540	1806	126	8	x
DEC	1503	2090	135	9	x
JAN	472	623	89	19	x
FEB	244	184	86	35	x
MAR	433	337	100	23	x
APR	806	708	112	14	x
MAY	1065	1027	94	9	x
JUN	942	809	93	10	70

RIfz = River inflow to footzone reach
ROfz = River outflow from footzone reach
Afz = Abstractions from footzone reach
x: no loss in streamflow for this month, ROfz + Afz > RIfz

Table 5.16 Monthly abstractions from savannah reach (Asz) in relation to river inflow into reach (RIsz)

MONTH	RIsz (l/s)	ROsz (l/s)	Asz (l/s)	Asz / RIsz (%)	Asz / (ROsz-RIsz) (%)
NOV	1806	1417	119	7	31
DEC	2090	1793	251	12	85
JAN	623	323	186	30	62
FEB	184	75	81	44	74
MAR	337	238	159	47	x
APR	738	654	295	40	x
MAY	1072	1082	319	30	x
JUN	824	805	260	32	x

RIsz = River inflow to savannah reach
ROsz = River outflow from savannah reach
Asz = Abstractions from savannah reach
x: no loss in streamflow for this month, ROsz + Asz > RIsz

Abstractions alone cannot explain the losses that are experienced in the footzone reach during the month of June and in the savannah reach during the months of November to February. In the last columns of Tables 5.15 and 5.16, the percentage of the losses which could be explained by abstractions have been calculated for these months only.

An attempt was made to identify the sources and amounts of water contributed to each reach and also to identify the amounts of transmission loss. Detailed discussion of the analysis has been presented in section 5.4.1. For the footzone reach it was possible to estimate roughly by graphical methods the sources of additional flow over the months of November-January. Results appear in Table 5.13.

Over the short rains season, the savannah river reach consistently lost water. It is suspected that when streamflow increases the amount of water lost increases both in absolute terms and also as a percentage of flow at the upper gauging station in the savannah zone. However the results were complicated by local direct runoff flowing into the reach over the same period.

There is too much uncertainty involved in estimating runoff inflow from the area of catchment between river gauging stations A5 and A6. The most practical way of estimating transmission losses is to utilize storm events that are confined to the area above the upper river gauging station in a reach. The water lost during transmission may be beneficial if it recharges the groundwater storage.

Over the long rains (April-May) both reaches receive additional water which is attributed mainly to runoff. It is noteworthy that the savannah reach received more runoff during this period than in November-December even though the monthly rainfall indicates that the short rains were only slightly better than the long rains (station R7 and

R8, Fig. 5.21). This difference is attributed mainly to differences in rainfall intensity and antecedent moisture conditions (Ondieki, 1991). There is obviously a host of other factors which complicate this situation.

Abstractions in the dry season became critical because very little flow was generated in the two zones to compensate for the amount that is used. It has been shown earlier that only 8% of the abstractions from Naro Moru river during the dry season may be termed as `legal' when both current and expired permits are considered.

6. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions may be drawn from the observations made during this study:

The footzone river reach received additional flow over the months of November to January 70 % of which may be attributed to ground water outflow into the reach and 30 % to direct runoff resulting from the rain falling in this zone over the short rains season. Flow added to the footzone river reach over the months February to May was much smaller in comparison and in June a slight loss in streamflow was experienced after abstractions had been accounted for.

The monthly rate of abstraction from the footzone reach as a percentage of river inflow was below 10 % in November and December but it rose to 19 %, 35 %, 23 % and 14 % for the months of January, February, March and April and fell again to below 10 % for the months of May and June.

Abstractions from the footzone river reach over the months of November-January were more than compensated for by the additional flow generated within this zone over the same months and the river inflow did not exceed the outflow. Over the ensuing months (February-June), abstractions constituted a bigger percentage of the available streamflow. There was little flow produced within this zone. Therefore river flow decreased on passing through the reach mainly due to the abstractions.

The role of abstractions in reducing streamflow is expected to continue to increase in future. The number of communal water supply schemes increased from 2 to 6 over the period 1984-1991 and there is a tendency for private water supply schemes to be abandoned in favour of communal water projects which operate under gravity flow. The increasing number of water projects is attributed to the increasing population and increased demand for irrigation water. It has been shown that communal water projects were responsible for 97 % of the water that abstracted from the river and used in the footzone over the period of study.

In the savannah zone river reach, water was lost during the months of November - February in other ways apart from abstraction. It is suggested that during the peak flows experienced during these months, the river was influent thus forcing some water to infiltrate into the river banks and bed. The water thus lost did not rejoin streamflow later and was probably lost in soil and ground water storage or through evapotranspiration by riverine vegetation. Nevertheless, even during these four months, abstractions formed 60 % of the decrease in streamflow and only 40 % of the decrease may be attributed to the other transmission losses.

During the months of March - June, the savannah zone reach gained water mainly in the form of direct runoff over short time periods. In contrast, very little runoff was produced in this zone over the months of November and December which fall in the short rain season.

During the months of April - June, the total amount of water abstracted from the savannah river reach was almost equal to the amount produced by runoff and therefore the monthly river discharge at the inflow and outflow sections of the river reach did not decrease.

The monthly rate of abstraction as a percentage of river inflow into the savannah river reach was below 10 % only during the month of November. It rose to 12 % in December, 30 % in January, 44 % in February and reached a maximum of 47 % in March. It dropped to 40 %, 30 % and 32 % in April, May and June respectively.

In the savannah, more than 98 % of the water was abstracted through the two canals, and piped water supply systems have negligible effect on streamflow. Socio-economic and technical factors in this zone do not favour the development of communal water supply infrastructure compared to the footzone.

The following recommendations are suggested as ways of improving water management in the footzone and savannah river reaches:

(1) Intakes for canals should be equipped with standard water measuring devices and a means for shutting or controlling the amount of water diverted. The costs for such structures are not prohibitive if they are distributed equally among the beneficiaries. Water measuring structures would assist in estimating how efficiently water is used. Records of the amount of water abstracted would be used to correct streamflow data to better reflect the available water resources.

(2) Dry season flows are derived from baseflow. Extensive irrigation should not be allowed during the dry season (eg. January to March) as irrigation requirements are usually supposed to be derived from flood flow. Since the need for irrigation water during the high flows is not as great, some form of water storage should be practiced.

(3) Efficient use of water should be promoted in the irrigated areas.

(4) Water permits need to be reviewed from time to time to reflect conditions in the field and illegal abstractions curbed especially during the critical low flow periods.

(5) Excess water that is not used should be allowed to flow back to the river.

(6) Farmers in the savannah should be assisted to improve their water supply infrastructure to enhance efficient use of water.

The following recommendations are made for further studies:

(1) There is need to study closely the existing practices of water utilization for communal systems especially those using canals so as to find where effort needs to be placed to improve on water use efficiency.

(2) In view of the importance of streamflow records of Naro Moru river, there is need to regularly calibrate the river gauging stations so as to improve the streamflow data.

(3) The subject of transmission losses should be studied further. In particular the infiltration rates of riverbed material needs to be investigated.

(4) Further research is needed on the appropriate ways of utilizing flood waters for irrigation.

(5) A population census should be done in the upper half of Naro Moru river basin and more detailed socio-economic studies related to water demand conducted in the entire river basin so as to explain the differences observed in the status of water supply infrastructure.

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APPENDIX I WATER SUPPLY INVENTORY QUESTIONNAIRE

MOWD/LRP: WATER SUPPLY INVENTORY OF LAIKIPIA DISTRICT

ID./MU.:
REL.ID.:

NAME :
SUB.LOC:
COORD. : /
DATE : 1990
R.PERS.:

DAM | PAN | BORE HOLE | W.AB DIR. | 1. PIPE | 2. PIPE
SUB. DAM | ROCK CATC | WELL | W.AB WEIR | 1. FURR | 2. FURR
SPR-ING | 1. TANK | 2. TANK

OTHERS: ....

1. TECHNICAL DESCRIPTION:

1.1. MEASUREMENTS: Length [ ] Width [ ] Depth [ ] Diameter [ ] Others [ ] ......

1.2. CAPACITY: a. Storing capacity (m3): [ ] b. Flowing capacity (l/sec): [ ]

1.3. ACT. AMOUNT: a. Storing a. amount(m3): [ ] Date: .... b. Flowing act. amount (l/s) [ ] Date: ....

1.4. MACHINE: a. Make: .... b. Capac.(l/s): .... c. Remarks: ....

1.5. WATER ABSTR: a. permit: ▬ no perm: ▬ b. use>perm: ▬ use=perm: ▬ use<perm ▬
c. permitted amount [ ] used amount [ ] Date: ....

1.5. SPECIFICATION/REMARKS: ....

2. ACTUAL CONDITION, OPERATION AND MAINTAINANCE:

2.1. PERIODS OF FUNCTIONING: year ▬ Seas. ▬ MONTHS: J F M A M J J A S O N D ....

2.2. ACTUAL WORKING CONDIT.: not ▬ part ▬ full ▬ ....

2.3. DEGREE OF DEVELOPMENT: not ▬ wish ▬ plan ▬ start ▬ part ▬ full ▬ ......

2.4. DEGREE OF DEGRADATION: not ▬ part ▬ full ▬ To rehab: ....

2.5. DEGREE OF PROTECTION: not ▬ part ▬ full ▬ MEANS: ....

2.6. OPERATIONAL TECHNIQ.: hand dies elec turb wheel ram wind solar grav oth.

2.7. WATER QUALITY: good ▬ poll. ▬ h.po. ▬ salt. ▬ Treated ▬ Comb: ....

2.8. RESPONSIBILITY FOR O/M: GOK ▬ Comm. ▬ priv. ▬ NGOs ▬ .... Comb: ....

2.9. REMARKS: ....

3. HISTORY OF THE PROJECT:

3.1. YEARS OF WORKING: Constructed [ ] work.from [ ] to [ ] break [ ]

3.2. CONSTRUCTION BY: GOK ▬ Comm. ▬ priv. ▬ NGOs ▬ ...... nat. ▬ Comb: ....

3.3. FINANCED THROUGH: GOK ▬ Comm. ▬ priv. ▬ NGOs ▬ oth. ▬ ...... Comb: ....

3.4. CONSTR. TECHNIQ.: mec. ▬ hand ▬ Comb. ....

3.5. ORIGINAL PURPOSE: a. LSF: ▬ SSF: ▬ Cent ▬ b. Irr. .... Dom. .... Lst .... Oth. ....

3.6. CHANGES: No: ▬ a. LSF: ▬ SSF: ▬ Cent ▬ b. Irr. .... Dom. .... Lst .... Oth. ....

4. ACTUAL AND FUTURE UTILISATION:

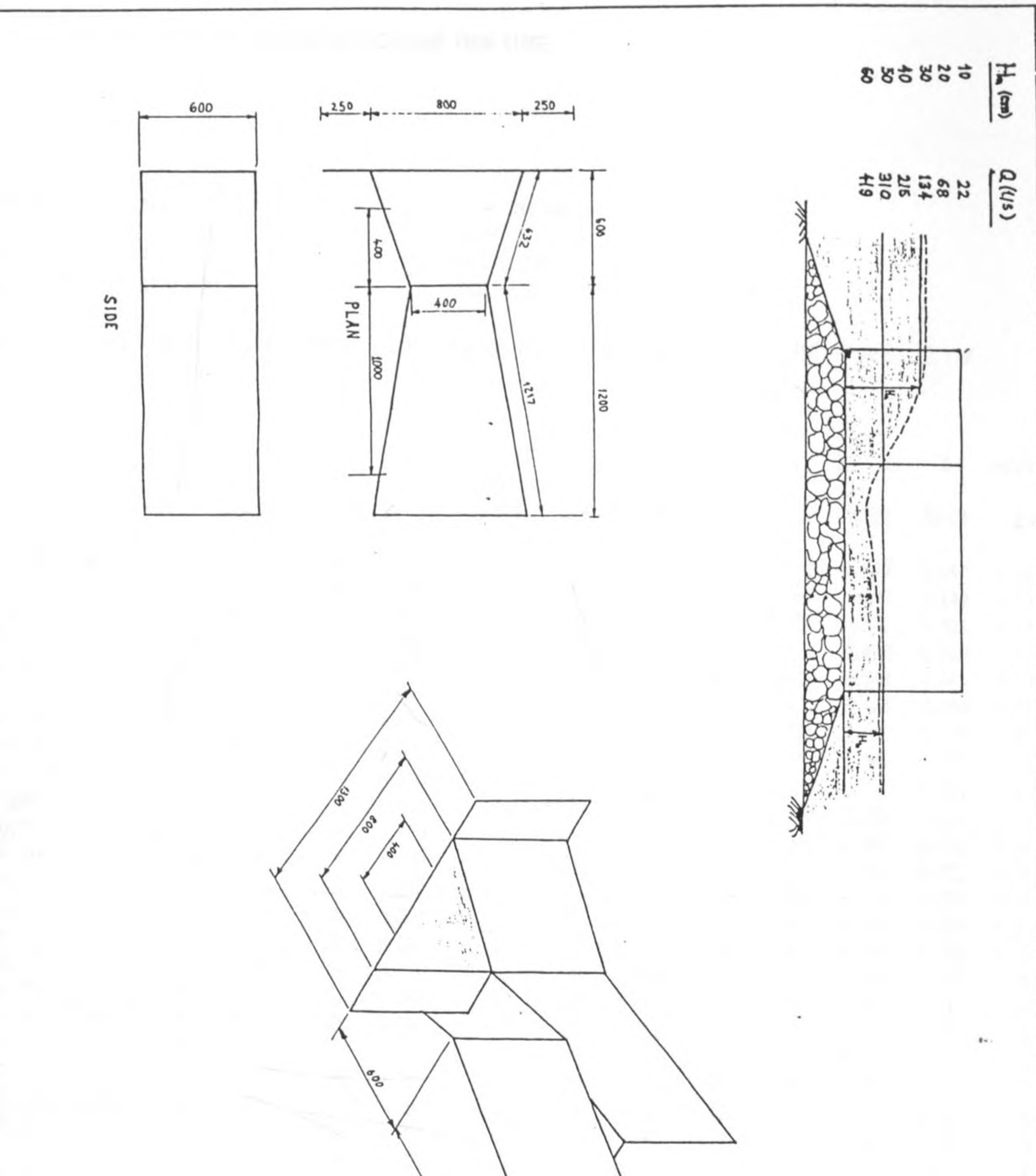
4.1. WATER USED FOR (%): Irr: .... Kga: .... Dom: .... Lst: .... % Wlf: .... Evp: .... Sep: .... %

4.2. ACT. NO. OF BENEFIC.: Area irr: .... Area kga: .... Livestock: .... Pop: ....
AFTER REHABILITATION: Area irr: .... Area kga: .... Livestock: .... Pop: ....
AFTER EXTENSION: Area irr: .... Area kga: .... Livestock: .... Pop: ....

4.3. TECHNIQUES OF IRRIGATION
flood ▬ sprkl ▬ hand ▬ other ....
Condition: not ▬ part ▬ full ▬

TECHNIQUES OF KITCHEN GARDENING:
flood ▬ sprkl ▬ hand ▬ other ....
Condition: not ▬ part ▬ full ▬

APPENDIX II THE 40 CM WIDE CUTTHROAT FLUME



PENDIX III SAMPLE WORKSHEET FOR CALCULATING DISCHARGE FROM STAGE

age - Discharge Calculation (4 hours basis)
ar: 1990
nth: NOV
ation:A5 River: NARO MORU

ting eqn. Q=A*H^B Coeff: 21.489 Index: 2.117

S T A G E. H (m)

Day	Hours 0-4	4-8	8-12	12-16	16-20	20-24
1	0.250	0.260	0.250	0.250	0.240	0.240
2	0.280	0.260	0.250	0.240	0.240	0.250
3	0.240	0.240	0.240	0.230	0.230	0.520
4	0.390	0.340	0.320	0.310	0.330	0.720
5	0.540	0.450	0.390	0.370	0.480	0.490
6	0.450	0.400	0.370	0.360	0.550	0.500
7	0.440	0.390	0.380	0.420	0.400	0.370
8	0.350	0.350	0.400	0.410	0.480	0.420
9	0.390	0.370	0.350	0.350	0.350	0.410
10	0.400	0.370	0.350	0.340	0.330	0.310
11	0.310	0.310	0.310	0.310	0.450	0.320
12	0.310	0.290	0.290	0.280	0.280	0.280
13	0.270	0.270	0.270	0.290	0.270	0.270
14	0.270	0.280	0.300	0.280	0.280	0.320
15	0.330	0.310	0.300	0.290	0.280	0.280
16	0.270	0.270	0.260	0.260	0.260	0.260
17	0.250	0.250	0.270	0.280	0.280	0.260
18	0.260	0.250	0.250	0.250	0.290	0.280
19	0.270	0.270	0.280	0.290	0.290	0.310
20	0.300	0.290	0.280	0.280	0.330	0.310
21	0.290	0.280	0.280	0.270	0.280	0.280
22	0.260	0.260	0.260	0.260	0.250	0.250
23	0.250	0.240	0.240	0.240	0.240	0.230
24	0.230	0.230	0.230	0.230	0.230	0.230
25	0.230	0.230	0.220	0.220	0.220	0.220
26	0.220	0.220	0.210	0.210	0.210	0.210
27	0.210	0.210	0.210	0.210	0.220	0.250
28	0.260	0.230	0.220	0.220	0.280	0.290
29	0.280	0.270	0.260	0.250	0.240	0.300
30	0.370	0.320	0.300	0.280	0.300	0.460
31						

River Discharge
Year: 1990
Month: NOV
Station:A5 River: NARO MORU

Rating eqn. Q=A*H^B Coeff: 21.489 Index: 2.117

D I S C H A R G E. Q (m3/s)

Day	Hours 0-4	4-8	8-12	12-16	16-20	20-24	MEAN
1	1.142	1.241	1.142	1.142	1.047	1.047	1.127
2	1.452	1.241	1.142	1.047	1.047	1.142	1.179
3	1.047	1.047	1.047	0.957	0.957	5.383	1.740
4	2.928	2.190	1.926	1.801	2.055	10.720	3.603
5	5.830	3.963	2.928	2.619	4.544	4.746	4.105
6	3.963	3.089	2.619	2.471	6.061	4.954	3.860
7	3.779	2.928	2.771	3.425	3.089	2.619	3.102
8	2.328	2.328	3.089	3.254	4.544	3.425	3.161
9	2.928	2.619	2.328	2.328	2.328	3.254	2.631
10	3.089	2.619	2.328	2.190	2.055	1.801	2.347
11	1.801	1.801	1.801	1.801	3.963	1.926	2.182
12	1.801	1.564	1.564	1.452	1.452	1.452	1.547
13	1.344	1.344	1.344	1.564	1.344	1.344	1.381
14	1.344	1.452	1.680	1.452	1.452	1.926	1.551
15	2.055	1.801	1.680	1.564	1.452	1.452	1.667
16	1.344	1.344	1.241	1.241	1.241	1.241	1.275
17	1.142	1.142	1.344	1.452	1.452	1.241	1.295
18	1.241	1.142	1.142	1.142	1.564	1.452	1.280
19	1.344	1.344	1.452	1.564	1.564	1.801	1.511
20	1.680	1.564	1.452	1.452	2.055	1.801	1.667
21	1.564	1.452	1.452	1.344	1.452	1.452	1.452
22	1.241	1.241	1.241	1.241	1.142	1.142	1.208
23	1.142	1.047	1.047	1.047	1.047	0.957	1.048
24	0.957	0.957	0.957	0.957	0.957	0.957	0.957
25	0.957	0.957	0.871	0.871	0.871	0.871	0.900
26	0.871	0.871	0.790	0.790	0.790	0.790	0.817
27	0.790	0.790	0.790	0.790	0.871	1.142	0.862
28	1.241	0.957	0.871	0.871	1.452	1.564	1.159
29	1.452	1.344	1.241	1.142	1.047	1.680	1.318
30	2.619	1.926	1.680	1.452	1.680	4.152	2.251
31							

Mean discharge

1 st decade	2.683
2 nd decade	1.536
3 rd decade	1.197
Monthly	1.806

APPENDIX IV STAGE - DISCHARGE DATA

Table A4.1 Stage-discharge data for station A3

Station: A3
River: NAROMORU

DATE	NO.	STAGE H (m)	DISCHARGE Q (m^3/s)	METHOD	SOURCE
15.02.84	1	0.180	0.230	Salt dilution	LRP
24.02.84	2	0.165	0.111	Current meter	LRP
02.03.84	3	0.180	0.125	Current meter	LRP
07.03.84	4	0.170	0.105	Current meter	LRP
19.03.84	5	0.189	0.158	Salt dilution	LRP
30.03.84	6	0.170	0.125	Salt dilution	LRP
02.04.84	7	0.165	0.096	Salt dilution	LRP
09.04.84	8	0.200	0.163	Salt dilution	LRP
09.04.84	9	0.194	0.162	Salt dilution	LRP
11.04.84	10	0.165	0.106	Salt dilution	LRP
24.04.84	11	0.210	0.196	Salt dilution	LRP
26.04.84	12	0.275	0.436	Salt dilution	LRP
27.04.84	13	0.300	0.530	Salt dilution	LRP
05.06.84	14	0.295	0.526	Salt dilution	LRP
25.05.84	15	0.170	0.105	Salt dilution	LRP
10.10.84	16	0.430	2.177	Salt dilution	LRP
12.10.84	17	0.380	1.052	Salt dilution	LRP
26.10.84	18	0.345	0.876	Salt dilution	LRP
02.11.84	19	0.370	1.025	Salt dilution	LRP
28.11.84	20	0.400	1.060	Current meter	LRP
29.11.84	21	0.435	1.572	Current meter	LRP
12.12.84	22	0.610	4.317	Current meter	LRP
19.12.84	23	0.298	0.477	Salt dilution	LRP
15.04.85	24	0.635	6.045	Salt dilution	LRP
16.04.85	25	0.520	2.898	Salt dilution	LRP
16.04.85	26	0.555	4.349	Salt dilution	LRP
16.04.85	27	0.575	6.825	Salt dilution	LRP
26.10.85	28	0.440	1.409	Salt dilution	LRP
25.10.85	29	0.625	5.176	Salt dilution	LRP
03.02.86	30	0.200	0.103	Salt dilution	LRP
11.02.86	31	0.240	0.153	Salt dilution	LRP
30.01.91	32	0.230	0.297	Salt dilution	OWN
02.05.91	33	0.350	1.370	Salt dilution	OWN

APPENDIX IV STAGE - DISCHARGE DATA

Table A4.2 Stage - discharge data for station A4

Station: A4
River: NAROMORU

DATE	NO.	STAGE H (m)	DISCHARGE Q (m3/s)	METHOD	SOURCE
08.11.84	1	0.54	1.064	Salt dilution	LRP
19.12.84	2	0.38	0.258	Salt dilution	LRP
02.04.85	3	0.48	0.621	Salt dilution	LRP
09.04.85	4	0.33	0.193	Salt dilution	LRP
10.04.85	5	0.37	0.278	Salt dilution	LRP
11.04.85	6	0.70	2.748	Salt dilution	LRP
11.04.85	7	0.67	1.891	Salt dilution	LRP
15.04.85	8	0.81	2.704	Salt dilution	LRP
25.10.85	9	0.89	4.019	Salt dilution	LRP
26.10.85	10	0.52	0.865	Salt dilution	LRP
03.02.86	11	0.21	0.045	Salt dilution	LRP
11.02.86	12	0.20	0.041	Salt dilution	LRP
30.01.91	13	0.28	0.156	Salt dilution	OWN
02.05.91	14	0.58	1.110	Salt dilution	OWN
02.05.91	15	0.56	0.979	Salt dilution	OWN

Table A4.3 Stage - discharge data for station A5b

Station: A5b
River: SEASONAL TRIBUTARY TO NAROMORU

DATE	NO.	STAGE H (m)	DISCHARGE Q (m3/s)	METHOD	SOURCE
22.04.91	1	0.09	0.037	Salt dilution	OWN
20.04.91	2	0.10	0.046	Salt dilution	OWN
20.04.91	3	0.16	0.100	Salt dilution	OWN
09.04.91	4	0.07	0.018	Salt dilution	OWN
15.03.91	5	0.13	0.061	Salt dilution	OWN
14.05.91	6	0.23	0.200	Salt dilution	OWN

APPENDIX IV STAGE - DISCHARGE DATA

Table A4.4 Stage - discharge data for station A5

Station: A5
River: NAROMORU

DATE	NO.	STAGE H (m)	DISCHARGE Q (m3/s)	METHOD	SOURCE
25.02.84	1	0.10	0.162	Current meter	LRP
27.02.84	2	0.10	0.148	Current meter	LRP
03.03.84	3	0.11	0.186	Current meter	LRP
15.03.84	4	0.11	0.146	Current meter	LRP
15.03.84	5	0.11	0.134	Current meter	LRP
15.03.84	6	0.11	0.133	Salt dilution	LRP
29.03.84	7	0.08	0.126	Salt dilution	LRP
30.03.84	8	0.09	0.186	Salt dilution	LRP
02.04.84	9	0.08	0.116	Salt dilution	LRP
09.04.84	10	0.11	0.157	Salt dilution	LRP
14.04.84	11	0.11	0.156	Salt dilution	LRP
26.04.84	12	0.20	0.953	Salt dilution	LRP
22.05.84	13	0.10	0.102	Salt dilution	LRP
04.06.84	14	0.14	0.324	Salt dilution	LRP
12.10.84	15	0.31	1.909	Salt dilution	LRP
13.10.84	16	0.33	1.873	Salt dilution	LRP
25.10.84	17	0.28	1.761	Salt dilution	LRP
31.10.84	18	0.16	0.485	Salt dilution	LRP
08.11.84	19	0.38	2.901	Salt dilution	LRP
11.12.84	20	0.79	8.092	Salt dilution	LRP
25.10.85	21	0.36	2.748	Current meter	LRP
16.04.85	22	0.53	5.472	Salt dilution	LRP
03.02.86	23	0.09	0.120	Current meter	LRP
11.02.86	24	0.08	0.107	Current meter	LRP
31.08.90	25	0.10	0.180	Current meter	MoWD
30.01.91	26	0.12	0.260	Current meter	MoWD
18.01.91	27	0.14	0.319	Current meter	OWN
06.02.90	28	0.15	0.358	Current meter	OWN
22.05.91	29	0.21	1.092	Salt dilution	OWN
09.04.91	30	0.13	0.322	Salt dilution	OWN
09.04.91	31	0.13	0.298	Salt dilution	OWN
14.05.91	32	0.30	2.237	Salt dilution	OWN

APPENDIX IV STAGE DISCHARGE DATA

Table A4.5 Stage - discharge data for station A6

Station: A6
River: NAROMORU

DATE	NO.	STAGE H (m)	DISCHARGE Q (m3/s)	METHOD	SOURCE
03.03.82	1	0.27	0.163	Current meter	LRP
31.03.82	2	0.24	0.385	Current meter	LRP
23.04.82	3	0.47	0.963	Current meter	LRP
15.06.82	4	0.53	0.582	Current meter	LRP
25.02.83	5	0.14	0.325	Current meter	LRP
30.05.83	6	0.36	0.613	Current meter	LRP
20.05.83	7	0.33	0.498	Current meter	LRP
21.07.83	8	0.39	1.118	Current meter	LRP
18.10.83	9	0.67	1.540	Current meter	LRP
26.10.83	10	0.57	1.452	Current meter	LRP
02.11.83	11	1.14	3.407	Current meter	LRP
17.02.84	12	0.09	0.105	Current meter	LRP
24.02.84	13	0.08	0.092	Current meter	LRP
07.03.84	14	0.15	0.139	Current meter	LRP
15.03.84	15	0.10	0.090	Current meter	LRP
29.03.84	16	0.06	0.097	Current meter	LRP
14.04.84	17	0.06	0.099	Current meter	LRP
03.05.84	18	0.10	0.147	Current meter	LRP
06.06.84	19	0.23	0.494	Current meter	LRP
06.09.84	20	0.09	0.129	Current meter	LRP
27.09.84	21	0.08	0.113	Current meter	LRP
25.10.84	22	0.64	1.715	Current meter	LRP
09.11.84	23	0.83	2.196	Current meter	LRP
15.11.84	24	1.34	4.631	Current meter	LRP
24.11.84	25	0.38	0.898	Current meter	LRP
28.11.84	26	0.99	2.881	Current meter	LRP
29.11.84	27	1.13	3.847	Current meter	LRP
30.11.84	28	1.65	5.246	Current meter	LRP
11.12.84	29	2.21	11.216	Current meter	LRP
13.12.84	30	1.22	4.052	Current meter	LRP
19.12.84	31	0.34	0.797	Current meter	LRP
10.02.86	32	0.08	0.045	Salt dilution	LRP
09.05.91	33	0.25	0.396	Salt dilution	OWN
15.03.91	34	0.34	0.574	Salt dilution	OWN

APPENDIX IV STAGE-DISCHARGE DATA

Table A4.6 Stage-discharge measurements for 1990/91 obtained by salt dilution method

STATION	A3	A3	A4	A4	A4	A5	A5	A5	A5	A6	A6	A5b	A5b	A5b	A5b	A5b	A5b
DATE	30/1	2/5	30/1	2/5	2/5	9/4	9/4	22/4	14/5	15/3	9/5	15/3	9/4	20/4	20/4	22/4	14/5
TIME (hrs)	1:49	17:20	12:53	18:16	19:12	9:37	10:02	16:57	-	15:03	14:43	17:26	11:22	16:32	17:20	17:25	-
ho (cm)	147	135	140	118	110	13	13	20.5	30	34	25	13	7	9	16	9	23
hf (cm)	147	135	140	111	113	13	13	20.5	30	34	25	13	7	10	16	9	23
Tw (°C)	11.4	11.2	12.9	11.9	11.7	14.1	14.3	13.8	-	18.6	18.6	16.3	15.8	16.7	16.7	16.5	-
Dm (m)	90	70	70	75	75	70	70	60	-	60	70	60	50	50	50	50	-
Wsalt (kg)	2.000	5.000	2.045	5.000	5.000	1.000	2.000	1.500	-	3.000	2.000	1.000	0.495	0.436	0.500	0.250	-
Scoeff	0.547	0.540	0.547	0.540	0.540	0.540	0.540	0.540	-	0.540	0.540	0.540	0.540	0.540	0.540	0.540	-
Ts (s)	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	-
Co (μS/cm)	23.5	15.7	37.8	9.5	10.1	36.0	34.7	21.9	-	50.4	30.3	81.1	79.9	99.1	95.2	97.3	-
Cf (μS/cm)	23.8	16.2	23.7	10.3	10.8	35.7	36.9	23.0	-	52.3	31.9	84.2	82.5	96.8	95.9	100.4	-
Cmax (μS/cm)	77.6	71.8	231.0	109.4	106.9	73.2	104.5	42	-	103.5	67.4	192.4	412.6	430.2	141.6	259.3	-
Tm (min)	4.7	12.6	9.3	10.5	10.4	15.5	18.2	10.5	-	29.4	24.9	21.8	18.8	14.8	14.1	12.8	-
Qsd (l/s)	297	1370	156	979	1110	298	322	1092	2237	574	396	61	18	46	100	37	200

APPENDIX IV STAGE - DISCHARGE DATA

Table A4.7 Discharge measurements in canals obtained by salt dilution method, current meter and flume.

ABST. PT. NO.	8	8	8	25	25	26	26	26	26	26	26
DATE	3/1	10/1	30/1	2/1	16/4	19/12	19/12	2/1	2/1	16/4	16/4
TIME (hrs)	10:13	13:37	13:43	15:41	14:48	16:10	16:59	13:03	13:35	12:16	12:44
ho (cm)	65	63	66	47	14.5	99	99	106	106	28	28
hf (cm)	65	63	66	47	14.5	99	98	106	106	28	28
Tw (°C)	10.9	14.3	14.8	16.8	17.3	14.8	14.9	16.5	16.6	16.7	16.7
Dm (m)	80	80	80	80	50	30	50	25	60	55	55
Wsalt(kg)	0.521	0.520	0.523	0.518	0.500	0.527	1.035	0.508	0.523	0.500	0.500
Scoeff	0.547	0.547	0.547	0.547	0.540	0.647	0.647	0.547	0.547	0.540	0.540
Ts (s)	1	1	1	1	1	1	1	1	1	1	1
Co (μS/cm)	24.4	25.2	24.7	48.5	51.8	33.5	25.3	59.4	50.5	48.9	48.5
Cf (μS/cm)	26.6	25.9	25.6	51.0	52.7	29.5	27.6	49.8	50.4	49.2	49.6
Cmax (μS/cm)	92.3	101.6	83.5	105.0	159.7	184.4	201.7	153.8	139.6	114.7	11.6
Tm (min)	11.8	12.2	13.9	11.5	16.4	3.4	5.5	3.9	5.8	11.1	11.1
Qsd (l/s)	87	75	106	111	39	164	140	325	213	110	105
Qcm (l/s)	-	-	-	-	-	-	-	220	220	113	113
Qf (l/s)	93	66	107	97	40	184	184	264	264	119	119

ho = initial gauge height
hf = final gauge height
Tw = water temperature
Dm = length of measuring reach
Wsalt = mass of salt used
Scoeff = salt calibration coefficient
Ts = sampling time interval
Co = initial conductivity
Cf = final conductivity
Cmax = maximum conductivity
Tm = total measurement time
Qsd = discharge obtained by salt dilution

APPENDIX V DAILY MEAN DISCHARGE

Table A5.1 Daily mean discharge for RGS A3 (1990/91)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	0.861	0.750	0.481	0.199	0.088	0.551	1.286	0.216
2	0.821	0.535	0.400	0.156	0.094	0.612	0.947	0.241
3	1.317	0.497	0.343	0.156	0.094	0.574	0.815	0.228
4	2.202	0.492	0.357	0.183	0.107	0.344	0.481	0.335
5	2.494	0.448	0.323	0.178	0.103	0.234	0.364	0.364
6	2.196	0.438	0.297	0.160	0.127	0.209	0.297	0.260
7	1.695	0.472	0.335	0.169	0.161	0.209	0.285	0.223
8	1.961	3.042	0.440	0.152	0.112	0.176	0.261	0.332
9	1.621	1.148	0.323	0.160	0.100	0.191	0.303	0.357
10	1.251	0.764	0.297	0.147	0.100	0.147	0.280	0.542
11	0.948	1.073	0.352	0.129	0.106	0.136	0.288	0.432
12	0.820	1.521	0.291	0.140	0.165	0.156	0.268	0.430
13	0.715	0.993	0.261	0.133	0.254	0.172	0.592	0.345
14	0.860	1.156	0.229	0.136	0.288	0.152	0.784	0.953
15	0.809	1.306	0.229	0.126	0.164	0.116	0.455	2.212
16	0.640	1.065	0.251	0.106	0.126	0.106	0.733	0.998
17	0.729	1.165	0.224	0.106	0.110	0.161	0.482	0.521
18	0.894	1.505	0.214	0.106	0.106	0.226	0.393	0.414
19	0.809	1.165	0.219	0.103	0.103	0.237	0.987	0.353
20	0.918	0.907	0.209	0.103	0.088	0.324	0.877	0.307
21	0.750	0.759	0.181	0.113	0.080	0.547	1.207	0.302
22	0.600	0.708	0.176	0.130	0.075	0.819	1.276	0.265
23	0.498	0.641	0.172	0.119	0.073	0.676	0.775	0.237
24	0.471	0.553	0.172	0.119	0.073	0.592	0.571	0.229
25	0.439	0.498	0.190	0.112	0.080	0.570	0.526	0.519
26	0.378	0.444	0.210	0.106	0.231	0.450	0.498	0.417
27	0.401	0.420	0.231	0.097	1.320	0.387	0.431	0.292
28	0.461	0.383	0.268	0.088	0.721	0.310	0.364	0.244
29	0.956	0.370	0.307		0.531	0.588	0.303	0.233
30	0.888	0.349	0.229		0.372	2.141	0.267	0.214
31		0.333	0.209		0.575		0.229	
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
1st decade	1.642	0.859	0.360	0.166	0.109	0.325	0.532	0.310
2nd decade	0.814	1.186	0.248	0.119	0.151	0.178	0.586	0.696
3rd decade	0.584	0.496	0.213	0.110	0.376	0.708	0.586	0.295
day max.	2.494	3.042	0.481	0.199	1.320	2.141	1.286	2.212
day min.	0.378	0.333	0.172	0.088	0.073	0.106	0.229	0.214
monthly	1.013	0.836	0.272	0.133	0.217	0.404	0.569	0.434

APPENDIX V DAILY MEAN DISCHARGE

Table A5.2 Daily mean discharge for RGS A4 (1990/91)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	0.422	0.604	0.361	0.139	0.078	0.575	1.059	0.179
2	0.401	0.389	0.297	0.130	0.075	0.459	0.840	0.493
3	0.707	0.353	0.270	0.123	0.073	0.457	0.744	0.273
4	1.457	0.409	0.297	0.131	0.069	0.343	0.474	0.330
5	1.301	0.382	0.246	0.122	0.070	0.212	0.361	0.440
6	1.166	0.330	0.225	0.121	0.082	0.202	0.310	0.439
7	0.892	0.378	0.215	0.114	0.209	0.202	0.267	0.563
8	0.775	1.787	0.396	0.108	0.102	0.175	0.236	0.604
9	0.666	0.690	0.254	0.103	0.084	0.175	0.258	0.804
10	0.633	0.510	0.215	0.105	0.084	0.150	0.253	0.811
11	0.518	0.931	0.278	0.110	0.207	0.146	0.251	1.087
12	0.396	1.488	0.218	0.133	0.236	0.148	0.238	0.916
13	0.360	0.917	0.205	0.116	0.275	0.141	0.848	0.505
14	0.423	0.984	0.178	0.110	0.260	0.128	0.936	0.646
15	0.515	1.178	0.169	0.101	0.161	0.115	0.450	1.767
16	0.367	0.820	0.166	0.096	0.125	0.108	0.498	1.206
17	0.353	0.825	0.162	0.094	0.097	0.242	0.371	0.591
18	0.311	1.534	0.153	0.096	0.084	0.312	0.307	0.435
19	0.341	1.000	0.150	0.093	0.080	0.224	1.249	0.352
20	0.433	0.738	0.146	0.088	0.075	0.312	0.873	0.305
21	0.413	0.619	0.136	0.142	0.072	0.571	0.565	0.288
22	0.324	0.560	0.130	0.132	0.068	1.353	0.759	0.286
23	0.280	0.505	0.128	0.105	0.066	0.793	0.651	0.274
24	0.261	0.459	0.123	0.103	0.070	0.564	0.441	0.233
25	0.230	0.419	0.137	0.122	0.068	0.544	0.390	0.258
26	0.207	0.374	0.140	0.090	0.324	0.402	0.422	0.337
27	0.282	0.337	0.136	0.085	1.341	0.363	0.347	0.222
28	0.311	0.311	0.181	0.082	0.772	0.469	0.295	0.202
29	0.358	0.294	0.181		0.459	0.826	0.248	0.203
30	0.697	0.278	0.154		0.283	1.352	0.227	0.193
31		0.261	0.150		0.644		0.210	
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
1st decade	0.842	0.583	0.277	0.120	0.092	0.295	0.480	0.494
2nd decade	0.402	1.042	0.183	0.104	0.160	0.187	0.602	0.781
3rd decade	0.336	0.401	0.145	0.108	0.379	0.724	0.414	0.250
day max.	1.457	1.787	0.396	0.142	1.341	1.353	1.249	1.767
day min.	0.207	0.261	0.123	0.082	0.066	0.108	0.210	0.179
monthly	0.527	0.667	0.200	0.111	0.216	0.402	0.496	0.508

APPENDIX V DAILY MEAN DISCHARGE

Table A5.3 Daily mean discharge for RGS A5 (1990/91)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	1.127	2.305	1.323	0.221	0.196	1.319	2.920	0.302
2	1.179	1.405	1.083	0.214	0.128	0.642	1.734	0.488
3	1.740	1.132	0.959	0.201	0.102	0.934	1.732	0.412
4	3.603	1.181	0.958	0.232	0.102	0.620	0.960	0.463
5	4.105	1.132	0.886	0.229	0.164	0.380	0.720	0.726
6	3.860	1.038	0.817	0.189	0.164	0.310	0.564	0.498
7	3.102	0.979	0.790	0.164	0.196	0.310	0.481	0.641
8	3.161	5.856	1.095	0.164	0.128	0.272	0.444	0.432
9	2.631	2.630	0.872	0.176	0.102	0.264	0.454	0.882
10	2.347	1.684	0.790	0.164	0.102	0.271	0.445	0.902
11	2.182	2.636	0.888	0.164	0.102	0.286	0.471	1.108
12	1.547	4.067	0.659	0.164	0.247	0.286	0.441	1.013
13	1.381	3.294	0.738	0.164	0.189	0.286	0.711	0.622
14	1.551	4.007	0.712	0.164	0.552	0.286	2.095	1.121
15	1.667	3.753	0.663	0.164	0.241	0.286	0.840	5.734
16	1.275	2.449	0.675	0.164	0.142	0.264	1.020	2.697
17	1.295	2.712	0.487	0.164	0.117	0.306	0.807	0.938
18	1.280	4.310	0.435	0.164	0.102	0.494	0.593	0.685
19	1.511	2.884	0.406	0.164	0.102	0.362	2.432	0.551
20	1.667	2.149	0.361	0.164	0.102	0.621	1.860	0.467
21	1.452	1.846	0.343	0.164	0.077	0.621	1.819	0.425
22	1.208	1.664	0.327	0.330	0.077	1.361	1.797	0.356
23	1.048	1.494	0.327	0.235	0.077	2.015	1.454	0.327
24	0.957	1.367	0.335	0.164	0.103	0.903	0.954	0.299
25	0.900	1.246	0.343	0.164	0.099	1.059	0.803	0.339
26	0.817	1.069	0.343	0.164	0.128	0.833	0.839	0.636
27	0.862	0.993	0.335	0.164	2.846	0.700	0.719	0.365
28	1.159	0.948	0.380	0.164	1.312	0.537	0.565	0.302
29	1.318	0.906	0.445		0.867	0.857	0.454	0.273
30	2.251	0.863	0.305		0.737	3.559	0.378	0.269
31		0.782	0.249		0.829		0.337	
1st decade	2.685	1.934	0.957	0.195	0.139	0.532	1.045	0.575
2nd decade	1.536	3.226	0.602	0.164	0.190	0.348	1.127	1.494
3rd decade	1.197	1.198	0.339	0.194	0.650	1.244	0.920	0.359
daily max.	4.105	5.856	1.323	0.330	2.846	3.559	2.920	5.734
daily min.	0.817	0.782	0.249	0.164	0.077	0.264	0.337	0.269
monthly	1.806	2.090	0.623	0.184	0.337	0.708	1.027	0.809

APPENDIX V DAILY MEAN DISCHARGE

Table A5.4 Daily mean discharge for RGS A5b (1990/91)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1						0.012	0.011	0.011
2						0.011	0.011	0.011
3						0.136	0.011	0.010
4						0.130	0.011	0.009
5						0.024	0.011	0.015
6						0.014	0.011	0.017
7						0.037	0.010	0.014
8						0.037	0.010	0.044
9						0.018	0.010	0.063
10						0.015	0.183	0.036
11						0.015	0.082	0.032
12						0.018	0.051	0.053
13						0.017	0.342	0.030
14						0.023	0.266	0.022
15						0.021	0.062	0.016
16						0.019	0.024	0.024
17						0.031	0.020	0.027
18						0.035	0.020	0.017
19						0.023	0.020	0.014
20					0.013	0.066	0.020	0.012
21					0.011	0.070	0.022	0.012
22					0.011	0.026	0.022	0.011
23					0.011	0.020	0.020	0.010
24					0.011	0.018	0.020	0.010
25					0.011	0.014	0.020	0.009
26					0.011	0.011	0.020	0.008
27					0.143	0.011	0.017	0.007
28					0.061	0.011	0.015	0.006
29					0.018	0.011	0.015	0.006
30					0.015	0.011	0.014	0.009
31					0.011		0.013	
					Mean	Mean	Mean	Mean
1st decade					---	0.044	0.028	0.023
2nd decade					---	0.027	0.091	0.025
3rd decade					0.028	0.020	0.018	0.009
daily max.					0.143	0.136	0.342	0.063
daily min.					0.011	0.000	0.010	0.000
monthly					---	0.030	0.045	0.019

APPENDIX V DAILY MEAN DISCHARGE

Table A5.5 Daily mean discharge for RGS A6 (1990/91)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	1.118	1.600	0.865	0.198	0.049	1.382	3.911	0.307
2	1.069	1.071	0.650	0.186	0.049	0.862	1.859	0.354
3	1.009	0.851	0.578	0.126	0.026	1.014	1.789	0.518
4	1.775	0.842	0.508	0.141	0.014	1.057	1.240	0.408
5	4.038	0.810	0.432	0.176	0.014	0.592	0.931	0.575
6	3.086	0.680	0.409	0.126	0.014	0.413	0.753	0.715
7	3.056	0.686	0.635	0.126	0.014	0.382	0.599	0.626
8	2.385	4.548	0.488	0.081	0.014	0.413	0.512	0.564
9	2.401	2.102	0.372	0.049	0.059	0.331	0.437	0.782
10	2.068	1.236	0.430	0.049	0.049	0.295	0.459	0.837
11	1.623	1.580	0.357	0.049	0.020	0.285	0.675	1.063
12	1.853	3.406	0.320	0.041	0.014	0.247	0.505	1.016
13	1.321	2.120	0.320	0.037	0.149	0.250	0.459	0.856
14	1.199	5.116	0.277	0.037	0.091	0.149	1.885	0.606
15	1.266	3.349	0.237	0.043	0.582	0.204	1.346	1.397
16	1.044	2.410	0.217	0.037	0.220	0.170	0.858	4.763
17	0.885	1.980	0.217	0.037	0.087	0.126	1.151	1.613
18	0.876	2.050	0.217	0.037	0.043	0.204	0.708	1.092
19	0.849	3.156	0.204	0.037	0.037	0.391	0.592	0.884
20	1.085	2.022	0.201	0.037	0.037	0.358	2.432	0.746
21	1.084	1.621	0.201	0.037	0.037	0.684	1.487	0.658
22	0.946	1.375	0.182	0.051	0.037	0.954	1.599	0.544
23	0.757	1.235	0.161	0.049	0.037	2.015	1.738	0.414
24	0.685	1.100	0.161	0.042	0.037	1.223	1.139	0.370
25	0.685	0.968	0.137	0.113	0.037	1.152	0.886	0.343
26	0.641	0.893	0.170	0.066	0.037	0.945	0.832	0.560
27	0.556	0.760	0.182	0.049	0.911	0.805	0.798	0.575
28	0.698	0.637	0.204	0.049	2.144	0.681	0.692	0.399
29	1.135	0.561	0.208		0.997	0.733	0.515	0.286
30	1.308	0.544	0.268		0.979	1.317	0.405	0.267
31		0.680	0.217		0.545		0.351	
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
1st decade	2.201	1.443	0.537	0.126	0.030	0.674	1.249	0.569
2nd decade	1.200	2.719	0.257	0.039	0.128	0.238	1.061	1.403
3rd decade	0.850	1.074	0.190	0.057	0.527	1.051	0.949	0.442
daily max.	4.038	5.116	0.865	0.198	2.144	2.015	3.911	4.763
daily min.	0.556	0.544	0.137	0.037	0.014	0.126	0.351	0.267
monthly	1.417	1.793	0.323	0.075	0.238	0.654	1.082	0.805

APPENDIX VI WATER SUPPLY PROJECTS ALONG NARO MORU RIVER IN 1990/91

ABS. PT. NO.	OWNER	TYPE OF PROJ-ECT	NO. OF HOUSE HOLDS	METHOD OF DIVERSION	OPER STAT	FLOW CHAR.	CONTI. ABSTR. RATE (L/S)	USES OF WATER: DOM	IRR	LIVE STOC	OTHER	SOURCE OF CAPITAL: INITI	OPER.	YEAR OF START	OPER. & MAINT COND
1	MT.K.N.PARK	PRIV	60 #	DIES PUMP	FULL	INTERM	0.08				*	1	4	1967	GOOD
2	M.GITERO W.P	COMM	600	GRAV PIPE	NOT	CONTIN	0.00	n/a				1&2	2	1986	n/a
3	KIBURUGUTU	COMM	500	GRAV PIPE	FULL	CONTIN	1.70	*	*	*	*	2&3	2	1984	GOOD
4	N.MORU W.P.	COMM	4000	GRAV PIPE	FULL	CONTIN	15.00	*	*	*	*	3	2	1972	GOOD
5	MANY.-GITWE	COMM	900	GRAV PIPE	PART	CONTIN	7.00	*	*	*	*	1&2	2	1984	GOOD
6	KABENDERA	COMM	300	GRAV PIPE	PART	CONTIN	11.00	*	*	*	*	1&2	2	1985	GOOD
7	PRIVATE	PRIV	1	ELEC PUMP	FULL	INTERM	0.03	*	*	*		4	4	1990	GOOD
8	AGUTHI CANAL	COMM	1200	GRAV CANAL	FULL	CONTIN	90.00	*	*	*	*	4	2	1963	FAIR
9	N.M.CATHOLIC	PRIV		HYDRAM	FULL	CONTIN	0.91	*	*		*	4	4		GOOD
10	PRIVATE	PRIV	1	DIES PUMP	FULL	INTERM	0.07	*	*	*		4	4	1978	GOOD
11	PRIVATE	PRIV	1	HYDRAM	FULL	INTERM	0.13	*		*		4	4	1954	GOOD
12	N.M.RAIL.STN	PRIV	9 @	GRAV PIPE	FULL	CONTIN	0.65				*	1	4	1926	GOOD
13	PRIVATE	PRIV	1	ELEC PUMP	FULL	INTERM	0.01	*	*	*		4	4	1989	GOOD
14	PRIVATE	PRIV	1	ELEC PUMP	FULL	INTERM	0.05	*	*			4	4	1989	GOOD
15	N.MORU TOWN	PRIV	97 ##	DIES PUMP	FULL	INTERM	0.70				*	1	1	1980	GOOD
16	N.M.TREE NUR	PRIV		DIES PUMP	FULL	INTERM	0.03		*			1	1	1980	GOOD
17	PRIVATE	PRIV	1	DIES PUMP	FULL	INTERM	0.02	*		*		4	4	1946	GOOD
18	N.M.R.LODGE	PRIV		DIES PUMP	FULL	INTERM	0.39		*	*	*	4	4	1966	GOOD
19	PRIVATE	PRIV	1	PLATA PUMP	FULL	INTERM	0.20	*	*			4	4		GOOD
20	PRIVATE	PRIV	2	PLATA PUMP	FULL	INTERM	0.20	*	*	*		4	4	1985	GOOD
21	PRIVATE	PRIV	1	PLATA PUMP	FULL	INTERM	0.23	*	*	*		4	4		FAIR
22	TIGITHI W.P.	COMM	325	DIES PUMP	FULL	INTERM	0.62	*		*		1&2	2	1983	FAIR
23	PRIVATE	PRIV	1	DIES PUMP	FULL	INTERM	0.10	*		*		4	4	1972	GOOD
24	PRIVATE	PRIV	1	DIES PUMP	FULL	INTERM	0.10	*	*	*		4	4	1957	GOOD
25	THOME W. P.	COMM	200	GRAV CANAL	FULL	CONTIN	80.00	*	*	*	*	4	2	1930	FAIR
26	MATANYA W.P.	COMM	300	GRAV CANAL	FULL	CONTIN	125.00	*	*	*	*	4	2	1940	POOR

REMARKS
- # MEANS ABOUT 60 OFFICERS OF KENYA WILDLIFE SERVICES
- ## MEANS 97 CONNECTIONS IN NARO MORU TOWN
- @ MEANS 9 CONNECTIONS IN NARO MORU TOWN

OTHER USES ARE: SCHOOLS, CENTRES, HOTELS, CATTLE DIPS, HEALTH CENTRES

1=GoK
2=COMM
3=NGO
4=PRIV

APPENDIX VII ABSTRACTIONS THROUGH CANALS

Table A7.1 Canal in footzone: Abstraction point No. 8

Ks = 2.56	Ks = 4.52	Remark:
nf = 1.84	St = 0.65	0=free flow
ns = 1.46	W = 0.50 m	1=submerged flow

DATE	h (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q(l/s)		Qavg
	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	(l/s)
01-Nov			24.0	24.5	21.5	20.5	0.90	0.84	1.0	1.0	105	123	114
02-Nov	staff		24.5	24.0	21.5	21.0	0.88	0.88	1.0	1.0	114	111	112
03-Nov	not		24.5	23.5	21.0	20.5	0.86	0.87	1.0	1.0	119	107	113
04-Nov	installed		26.5	33.0	23.5	30.5	0.89	0.92	1.0	1.0	129	172	150
05-Nov			28.5	29.5	26.5	26.5	0.93	0.90	1.0	1.0	128	153	140
06-Nov			28.5	29.5	25.5	26.5	0.89	0.90	1.0	1.0	145	153	149
07-Nov			26.5	28.5	20.0	26.0	0.75	0.91	1.0	1.0	153	137	145
08-Nov			27.5	27.5	24.5	24.5	0.89	0.89	1.0	1.0	137	137	137
09-Nov			26.5	26.5	25.0	23.5	0.94	0.89	1.0	1.0	105	129	117
10-Nov			27.5	25.5	25.0	23.0	0.91	0.90	1.0	1.0	130	116	123
11-Nov			25.5	27.5	22.5	20.0	0.88	0.73	1.0	1.0	122	166	144
12-Nov			24.5	22.5	21.5	21.0	0.88	0.93	1.0	1.0	114	82	98
13-Nov			23.5	23.5	20.5	21.0	0.87	0.89	1.0	1.0	107	102	104
14-Nov			23.5	23.5	20.5	20.0	0.87	0.85	1.0	1.0	107	111	109
15-Nov			24.5	22.5	21.5	19.0	0.88	0.84	1.0	1.0	114	104	109
16-Nov			22.0	22.5	19.0	19.5	0.86	0.87	1.0	1.0	96	100	98
17-Nov			21.5	21.5	18.5	18.0	0.86	0.84	1.0	1.0	93	97	95
18-Nov			21.5	21.0	19.0	18.5	0.88	0.88	1.0	1.0	89	85	87
19-Nov			22.5	24.0	19.5	20.5	0.87	0.85	1.0	1.0	100	115	108
20-Nov			25.6	20.5	21.4	18.5	0.84	0.90	1.0	1.0	133	77	105
21-Nov		65.0	21.0	23.5	19.5	20.0	0.93	0.85	1.0	1.0	73	111	92
22-Nov	66.0	66.0	23.5	24.0	20.0	20.5	0.85	0.85	1.0	1.0	111	115	113
23-Nov	65.0	64.5	23.5	22.5	20.5	19.5	0.87	0.87	1.0	1.0	107	100	103
24-Nov	64.0	64.0	22.0	22.0	19.0	19.0	0.86	0.86	1.0	1.0	96	96	96
25-Nov	63.5	63.0	21.5	21.5	19.5	18.5	0.91	0.86	1.0	1.0	83	93	88
26-Nov	62.5	62.0	21.0	20.5	18.0	18.0	0.86	0.88	1.0	1.0	90	82	86
27-Nov	62.5	64.5	20.5	22.0	18.0	18.5	0.88	0.84	1.0	1.0	82	100	91
28-Nov	62.5	76.5	21.5	22.5	18.5	19.0	0.86	0.84	1.0	1.0	93	104	98
29-Nov	64.5	63.0	23.0	21.5	19.5	18.0	0.85	0.84	1.0	1.0	108	97	102
30-Nov	70.5	70.0	26.0	25.0	23.0	22.0	0.88	0.88	1.0	1.0	125	118	122
01-Dec	72.5	71.0	26.5	25.5	23.0	22.0	0.87	0.86	1.0	1.0	135	127	131
02-Dec	68.5	68.0	24.5	24.0	20.5	20.0	0.84	0.83	1.0	1.0	123	119	121
03-Dec	66.5	66.5	22.5	22.5	19.5	19.0	0.87	0.84	1.0	1.0	100	104	102
04-Dec	66.5	69.0	22.0	23.5	19.5	20.5	0.89	0.87	1.0	1.0	92	107	99
05-Dec	69.5	68.5	24.5	24.0	22.0	21.0	0.90	0.88	1.0	1.0	109	111	110
06-Dec	67.5	68.0	23.5	24.0	21.0	21.0	0.89	0.88	1.0	1.0	102	111	106
07-Dec	67.0	67.0	23.5	23.0	20.5	20.0	0.87	0.87	1.0	1.0	107	103	105
08-Dec	87.0	88.0	32.5	35.5	30.5	33.5	0.94	0.94	1.0	1.0	156	179	168
09-Dec	77.5	74.5	28.5	27.0	26.5	25.0	0.93	0.93	1.0	1.0	128	118	123
10-Dec	72.5	72.0	26.0	26.0	23.5	23.0	0.90	0.88	1.0	1.0	119	125	122
11-Dec	73.4	72.0	26.5	26.5	24.0	23.5	0.91	0.89	1.0	1.0	123	129	126
12-Dec	79.0	78.5	30.0	30.0	27.5	27.0	0.92	0.90	1.0	1.0	148	157	153
13-Dec	77.0	74.5	30.5	29.5	27.0	26.5	0.89	0.90	1.0	1.0	168	153	160

AFFENDIX VII ABSTRACTIONS THROUGH CANALS

Table A7.1 Abstraction point No. 8 : canal in footzone (conti..)

DATE	h (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q(l/s)		Qavg
	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	(l/s)
14-Dec	77.5	76.5	29.5	29.5	26.0	26.0	0.88	0.88	1.0	1.0	159	159	159
15-Dec	80.5	79.5	32.0	30.0	29.5	27.5	0.92	0.92	1.0	1.0	164	148	156
16-Dec	75.5	75.5	29.0	29.5	26.5	26.5	0.91	0.90	1.0	1.0	141	153	147
17-Dec	75.0	74.5	28.5	29.0	26.0	26.0	0.91	0.90	1.0	1.0	137	149	143
18-Dec	76.0	83.0	29.5	32.0	26.5	29.0	0.90	0.91	1.0	1.0	153	173	163
19-Dec	78.0	76.5	29.5	29.0	27.0	26.0	0.92	0.90	1.0	1.0	145	149	147
20-Dec	74.5	75.0	23.5	27.0	20.0	24.0	0.85	0.89	1.0	1.0	111	133	122
21-Dec	72.5	72.0	27.0	26.0	24.0	23.0	0.89	0.88	1.0	1.0	133	125	129
22-Dec	71.5	72.0	25.5	26.0	22.5	23.0	0.88	0.88	1.0	1.0	122	125	124
23-Dec	70.5	70.0	24.5	24.0	22.5	21.5	0.92	0.90	1.0	1.0	102	105	103
24-Dec	69.0	69.0	24.0	24.0	21.0	21.0	0.88	0.88	1.0	1.0	111	111	111
25-Dec	68.0	68.0	23.5	23.5	20.0	22.5	0.85	0.96	1.0	1.0	111	76	94
26-Dec	67.0	67.0	22.5	21.5	19.5	18.5	0.87	0.86	1.0	1.0	100	93	96
27-Dec	66.5	66.0	21.5	21.0	18.0	18.0	0.84	0.86	1.0	1.0	97	90	93
28-Dec	65.5	65.0	21.0	20.5	18.0	17.0	0.86	0.83	1.0	1.0	90	89	89
29-Dec	65.0	64.5	20.5	20.0	17.0	17.0	0.83	0.85	1.0	1.0	89	83	86
30-Dec	64.0	63.5	20.0	19.0	18.0	16.5	0.90	0.87	1.0	1.0	74	73	74
31-Dec	64.0	64.0	20.0	20.5	16.5	17.0	0.83	0.83	1.0	1.0	86	89	88
01-Jan	65.0	67.0	21.0	22.0	18.0	19.0	0.86	0.86	1.0	1.0	90	96	93
02-Jan	67.0	66.0	22.0	21.5	19.0	18.5	0.86	0.86	1.0	1.0	96	93	95
03-Jan	65.0	65.0	21.5	21.5	18.5	18.5	0.86	0.86	1.0	1.0	93	93	93
04-Jan	66.0		21.0	20.5	19.5	19.0	0.93	0.93	1.0	1.0	73	71	72
05-Jan	64.5	65.0	19.5	20.0	18.0	18.5	0.92	0.93	1.0	1.0	66	68	67
06-Jan	64.0	64.0	19.0	19.5	18.0	18.0	0.95	0.92	1.0	1.0	55	66	60
07-Jan	63.0	64.0	19.0	19.5	18.0	18.0	0.95	0.92	1.0	1.0	55	66	60
08-Jan	64.0	63.5	18.5	19.0	16.0	17.5	0.86	0.92	1.0	1.0	70	63	66
09-Jan	65.5	61.0	20.0	19.5	19.5	18.0	0.98	0.92	1.0	1.0	47	66	56
10-Jan	64.0	65.0	19.5	19.5	18.0	18.0	0.92	0.92	1.0	1.0	66	66	66
11-Jan	66.0	65.0	19.0	18.0	18.0	16.0	0.95	0.89	1.0	1.0	55	63	59
12-Jan	64.0	64.0	17.0	18.0	16.5	17.0	0.97	0.94	1.0	1.0	37	51	44
13-Jan	64.0	63.0	17.0	16.0	16.0	15.0	0.94	0.94	1.0	1.0	47	43	45
14-Jan	62.0	62.0	17.0	17.0	13.0	14.5	0.76	0.85	1.0	1.0	67	61	64
15-Jan	61.0	61.5	17.0	17.0	14.5	15.0	0.85	0.88	1.0	1.0	61	58	59
16-Jan	61.0	62.0	17.0	17.0	15.0	15.0	0.88	0.88	1.0	1.0	58	58	58
17-Jan	62.0	62.0	18.0	18.0	14.5	15.0	0.81	0.83	1.0	1.0	72	70	71
18-Jan	60.0	61.5	17.0	18.0	14.0	15.0	0.82	0.83	1.0	1.0	64	70	67
19-Jan	59.0	60.0	18.0	18.5	14.5	15.0	0.81	0.81	1.0	1.0	72	76	74
20-Jan	61.0	63.0	18.0	19.0	15.0	16.0	0.83	0.84	1.0	1.0	70	76	73
21-Jan	61.0	62.0	18.0	18.5	16.0	16.0	0.89	0.86	1.0	1.0	63	70	67
22-Jan	60.0	62.0	18.0	18.5	15.0	15.0	0.83	0.81	1.0	1.0	70	76	73
23-Jan	60.0	61.0	18.5	18.0	15.0	15.0	0.81	0.83	1.0	1.0	76	70	73
24-Jan	60.0	60.5	17.0	17.0	14.5	14.5	0.85	0.85	1.0	1.0	61	61	61
25-Jan	62.5	65.0	18.5	24.0	16.0	22.0	0.86	0.92	1.0	1.0	70	98	84
26-Jan	66.0	65.0	25.0	24.0	23.0	22.0	0.92	0.92	1.0	1.0	105	98	102
27-Jan	67.0	64.5	25.0	24.5	23.0	23.0	0.92	0.94	1.0	1.0	105	93	99
28-Jan	68.5	68.0	25.0	25.0	23.0	23.0	0.92	0.92	1.0	1.0	105	105	105
29-Jan	69.0	68.0	26.0	25.0	24.0	23.0	0.92	0.92	1.0	1.0	111	105	108
30-Jan	65.0	67.0	24.5	24.5	22.0	23.0	0.90	0.94	1.0	1.0	109	93	101

APPENDIX VII ABSTRACTIONS THROUGH CANALS

Table A7.1 Abstraction point No. 8 : canal in footzone (conti..)

DATE	h (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q(l/s)		Qavg
	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	(l/s)
31-Jan	64.0	66.0	23.5	25.0	21.5	22.5	0.91	0.90	1.0	1.0	95	112	104
01-Feb	62.5	63.5	22.0	22.0	20.0	20.0	0.91	0.91	1.0	1.0	86	86	86
02-Feb	61.0	61.0	20.0	20.0	17.5	17.5	0.88	0.88	1.0	1.0	79	79	79
03-Feb			20.0	20.0	17.0	18.0	0.85	0.90	1.0	1.0	83	74	79
04-Feb			21.0	23.0	18.0	20.0	0.86	0.87	1.0	1.0	90	103	97
05-Feb		60.0	21.0	23.0	19.5	21.0	0.93	0.91	1.0	1.0	73	92	83
06-Feb	59.0	60.0	20.3	21.0	18.0	18.5	0.89	0.88	1.0	1.0	79	85	82
07-Feb	58.0	61.0	19.0	21.0	17.0	19.0	0.89	0.90	1.0	1.0	69	80	74
08-Feb	61.0	59.5	21.0	19.5	19.0	17.0	0.90	0.87	1.0	1.0	80	76	78
09-Feb	54.0	54.0	19.0	19.0	16.0	16.0	0.84	0.84	1.0	1.0	76	76	76
10-Feb	57.0	53.0	18.0	18.0	16.0	16.0	0.89	0.89	1.0	1.0	63	63	63
11-Feb	54.0	55.5	17.5	18.0	16.0	17.0	0.91	0.94	1.0	1.0	56	51	53
12-Feb	59.0	58.5	20.5	19.0	18.0	17.0	0.88	0.89	1.0	1.0	82	69	75
13-Feb	56.5	55.0	19.0	18.0	16.5	15.5	0.87	0.86	1.0	1.0	73	67	70
14-Feb	56.0	58.0	18.5	20.0	16.0	17.0	0.86	0.85	1.0	1.0	70	83	76
15-Feb	54.0	53.0	19.0	18.0	16.0	16.5	0.84	0.92	1.0	1.0	76	58	67
16-Feb	52.5	52.0	17.0	17.0	15.0	14.5	0.88	0.85	1.0	1.0	58	61	59
17-Feb	52.0	52.0	17.5	17.0	15.0	15.0	0.86	0.88	1.0	1.0	64	58	61
18-Feb	52.0	52.0	17.0	17.0	15.0	14.5	0.88	0.85	1.0	1.0	58	61	59
19-Feb	53.0	53.0	17.0	17.0	14.0	14.5	0.82	0.85	1.0	1.0	64	61	62
20-Feb	52.0	52.0	17.0	17.0	14.0	14.0	0.82	0.82	1.0	1.0	64	64	64
21-Feb	53.0	53.0	17.0	17.0	14.5	14.0	0.85	0.82	1.0	1.0	61	64	62
22-Feb	59.0	56.0	21.5	19.0	19.0	16.0	0.88	0.84	1.0	1.0	89	76	82
23-Feb	55.0	57.0	19.0	22.0	16.0	19.0	0.84	0.86	1.0	1.0	76	96	86
24-Feb	56.0	55.0	20.0	19.0	17.0	16.0	0.85	0.84	1.0	1.0	83	76	80
25-Feb	56.5	54.0	19.1	18.0	17.0	15.0	0.89	0.83	1.0	1.0	70	70	70
26-Feb	53.0	53.0	17.0	17.0	14.5	14.0	0.85	0.82	1.0	1.0	61	64	62
27-Feb	53.0	52.5	17.0	16.0	14.0	13.5	0.82	0.84	1.0	1.0	64	56	60
28-Feb	52.0	56.0	17.5	17.0	14.0	15.0	0.80	0.88	1.0	1.0	69	58	63
01-Mar	56.0	55.0	18.0	17.0	14.5	14.0	0.81	0.82	1.0	1.0	72	64	68
02-Mar	56.5	55.0	18.0	18.0	15.0	15.0	0.83	0.83	1.0	1.0	70	70	70
03-Mar	54.0	54.5	19.0	18.0	16.0	15.0	0.84	0.83	1.0	1.0	76	70	73
04-Mar	40.0	49.0	19.0	18.0	16.0	15.0	0.84	0.83	1.0	1.0	76	70	73
05-Mar	49.0	48.0	19.0	19.0	16.0	16.0	0.84	0.84	1.0	1.0	76	76	76
06-Mar	46.0	44.0	18.0	19.0	15.0	16.0	0.83	0.84	1.0	1.0	70	76	73
07-Mar	66.5	58.5	28.5	25.0	26.5	22.5	0.93	0.90	1.0	1.0	128	112	120
08-Mar	44.0	42.0	20.0	18.0	17.0	15.5	0.85	0.86	1.0	1.0	83	67	75
09-Mar	42.0	44.0	18.0	17.0	14.2	15.0	0.79	0.88	1.0	1.0	73	58	66
10-Mar	42.0	43.0	18.0	19.0	16.0	14.5	0.89	0.76	1.0	1.0	63	83	73
11-Mar			17.0	22.0	15.5	16.0	0.91	0.73	1.0	1.0	53	110	82
12-Mar	64.5	66.5	28.5	30.0	26.5	28.0	0.93	0.93	1.0	1.0	128	138	133
13-Mar	60.0	64.0	28.5	32.0	16.5	29.0	0.58	0.91	0.0	1.0	179	173	176
14-Mar	80.0	84.0	35.5	35.5	33.5	34.5	0.94	0.97	1.0	1.0	179	141	160
15-Mar	64.0	64.0	30.5	30.5	28.5	28.5	0.93	0.93	1.0	1.0	142	142	142
16-Mar	63.0	63.0	30.5	26.0	28.5	24.0	0.93	0.92	1.0	1.0	142	111	127
17-Mar	62.5	63.5	26.0	25.5	23.5	23.5	0.90	0.92	1.0	1.0	119	108	114
18-Mar	61.5	62.0	24.5	25.0	23.0	23.5	0.94	0.94	1.0	1.0	93	96	94

APPENDIX VII ABSTRACTIONS THROUGH CANALS

Table A7.1 Abstraction point No. 8 : canal in footzone (conti..)

DATE	h (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q(l/s)		Qavg
	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	(l/s)
19-Mar	62.5	66.5	25.0	22.5	23.5	21.0	0.94	0.93	1.0	1.0	96	82	89
20-Mar	61.5	58.0	24.5	22.5	22.5	20.0	0.92	0.89	1.0	1.0	102	95	98
21-Mar	56.5	56.5	22.0	22.0	19.5	19.5	0.89	0.89	1.0	1.0	92	92	92
22-Mar	52.0	51.0	19.0	18.0	16.0	15.5	0.84	0.86	1.0	1.0	76	67	72
23-Mar	51.0	39.0	18.0	10.0	16.5	7.0	0.92	0.70	1.0	1.0	58	26	42
24-Mar	39.0	38.0	10.0	9.0	7.0	6.0	0.70	0.67	1.0	1.0	26	22	24
25-Mar	37.0	38.0	9.0	10.0	5.0	6.0	0.56	0.60	0.0	0.0	21	26	24
26-Mar	54.5	58.0	20.0	24.0	17.0	21.0	0.85	0.88	1.0	1.0	83	111	97
27-Mar	79.0	76.0	34.0	32.0	31.0	26.5	0.91	0.83	1.0	1.0	190	203	197
28-Mar	52.0	46.0	19.0	16.0	16.5	4.0	0.87	0.25	1.0	0.0	73	45	59
29-Mar	35.0	33.0	8.0	6.0	4.5	2.5	0.56	0.42	0.0	0.0	17	9	13
30-Mar	45.0	39.0	13.0	12.0	9.5	7.0	0.73	0.58	1.0	0.0	42	36	39
31-Mar	29.0	27.0	9.0	6.0	5.5	2.5	0.61	0.42	0.0	0.0	22	9	15
01-Apr	51.5	46.0	22.5	18.0	20.0	16.5	0.89	0.92	1.0	1.0	95	58	77
02-Apr	54.0	56.5	24.5	26.0	22.0	24.0	0.90	0.92	1.0	1.0	109	111	110
03-Apr	57.0	72.0	30.5	34.0	28.0	32.0	0.92	0.94	1.0	1.0	152	167	160
04-Apr	50.0	68.5	20.0	27.0	18.0	24.5	0.90	0.91	1.0	1.0	74	126	100
05-Apr	56.0	53.5	25.5	25.0	23.0	22.0	0.90	0.88	1.0	1.0	116	118	117
06-Apr	52.0	52.0	23.5	23.5	21.5	21.0	0.91	0.89	1.0	1.0	95	102	99
07-Apr	51.0	49.5	22.0	22.5	21.0	19.5	0.95	0.87	1.0	1.0	69	100	84
08-Apr	52.0	48.5	22.9	22.0	21.5	19.9	0.94	0.90	1.0	1.0	82	87	85
09-Apr	52.0	50.0	23.0	21.0	20.5	18.5	0.89	0.88	1.0	1.0	98	85	92
10-Apr	51.5	50.0	22.5	21.5	20.0	18.5	0.89	0.86	1.0	1.0	95	93	94
11-Apr	50.0	50.5	16.0	18.0	13.0	15.0	0.81	0.83	1.0	1.0	58	70	64
12-Apr	44.0	43.0	16.0	15.0	14.0	12.0	0.88	0.80	1.0	1.0	52	52	52
13-Apr	39.0	38.0	13.0	12.0	11.0	9.0	0.85	0.75	1.0	1.0	38	36	37
14-Apr			0.0	0.0	0.0	0.0							10
15-Apr	39.0	38.0	13.0	12.0	9.0	8.5	0.69	0.71	1.0	1.0	42	36	39
16-Apr	34.5	44.0	12.0	16.0	9.0	13.0	0.75	0.81	1.0	1.0	36	58	47
17-Apr	53.5	50.0	26.0	24.0	23.5	21.5	0.90	0.90	1.0	1.0	119	105	112
18-Apr	53.5	53.0	27.5	26.5	25.5	24.0	0.93	0.91	1.0	1.0	121	123	122
19-Apr	46.5	45.5	23.0	25.0	20.5	20.5	0.89	0.82	1.0	1.0	98	130	114
20-Apr	55.5	39.0	31.5	12.0	24.5	9.0	0.78	0.75	1.0	1.0	208	36	122
21-Apr	55.5	53.5	31.5	25.5	24.5	23.5	0.78	0.92	1.0	1.0	208	108	158
22-Apr	56.5	54.5	18.5	27.5	17.5	25.5	0.95	0.93	1.0	1.0	53	121	87
23-Apr	55.5	56.5	26.0	25.5	24.0	23.5	0.92	0.92	1.0	1.0	111	108	110
24-Apr	53.5	55.0	27.0	30.0	25.0	27.0	0.93	0.90	1.0	1.0	118	157	137
25-Apr	52.0	53.5	24.0	24.5	22.5	23.0	0.94	0.94	1.0	1.0	90	93	91
26-Apr	53.5	53.5	27.0	27.0	25.0	25.0	0.93	0.93	1.0	1.0	118	118	118
27-Apr	52.5	62.5	26.5	25.0	24.5	23.0	0.92	0.92	1.0	1.0	115	105	110
28-Apr	61.0	59.0	26.0	24.5	24.0	21.0	0.92	0.86	1.0	1.0	111	119	115
29-Apr	70.5	72.5	27.0	29.5	24.5	26.5	0.91	0.90	1.0	1.0	126	153	139
30-Apr	71.0	84.0	27.0	34.0	25.0	32.5	0.93	0.96	1.0	1.0	118	152	135
01-May	59.5	62.5	20.5	22.5	18.0	20.0	0.88	0.89	1.0	1.0	82	95	89
02-May	54.0	55.0	19.0	19.5	17.0	17.5	0.89	0.90	1.0	1.0	69	71	70
03-May	46.0	46.0	18.0	20.0	16.0	18.0	0.89	0.90	1.0	1.0	63	74	69
04-May	35.0	46.0	14.0	20.0	9.5	18.0	0.68	0.90	1.0	1.0	49	74	61

APPENDIX VII ABSTRACTIONS THROUGH CANALS

Table A7.1 Abstraction point No. 8 : canal in footzone (conti..)

DATE	h (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q(l/s)		Qavg
	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	(l/s)
05-May	56.0	53.5	25.5	25.0	23.0	22.0	0.90	0.88	1.0	1.0	116	118	117
06-May	52.0	54.0	23.5	25.0	21.5	22.5	0.91	0.90	1.0	1.0	95	112	104
07-May	52.5	53.5	23.5	22.0	21.0	20.0	0.89	0.91	1.0	1.0	102	86	94
08-May	49.5	48.5	22.5	22.0	19.5	19.5	0.87	0.89	1.0	1.0	100	92	96
09-May	52.0	50.0	23.0	21.0	20.5	18.5	0.89	0.88	1.0	1.0	98	85	92
10-May	51.5	50.0	22.5	21.5	20.0	18.5	0.89	0.86	1.0	1.0	95	93	94
11-May	50.0	50.5	16.0	18.0	13.0	15.0	0.81	0.83	1.0	1.0	58	70	64
12-May	44.0	43.0	16.0	15.0	14.0	12.0	0.88	0.80	1.0	1.0	52	52	52
13-May	39.0	38.0	13.0	12.0	11.0	9.0	0.85	0.75	1.0	1.0	38	36	37
14-May	39.0	38.0	13.0	11.0	9.0	8.0	0.69	0.73	1.0	1.0	42	31	37
15-May	39.0	38.0	13.0	12.0	9.0	8.5	0.69	0.71	1.0	1.0	42	36	39
16-May	45.5	52.0	22.5	24.0	20.3	21.5	0.90	0.90	1.0	1.0	92	105	98
17-May	44.5	44.0	19.0	18.0	16.5	16.0	0.87	0.89	1.0	1.0	73	63	68
18-May	48.0	49.9	20.5	21.9	17.5	18.5	0.85	0.84	1.0	1.0	85	99	92
19-May	40.5	42.5	18.5	19.0	15.5	16.5	0.84	0.87	1.0	1.0	73	73	73
20-May	46.0	44.5	22.5	19.0	19.5	15.5	0.87	0.82	1.0	1.0	100	79	89
21-May	50.5	52.0	21.5	22.5	18.5	20.0	0.86	0.89	1.0	1.0	93	95	94
22-May	48.0	48.5	18.0	18.5	15.6	16.0	0.87	0.86	1.0	1.0	66	70	68
23-May	50.0	52.0	21.5	22.0	17.5	18.0	0.81	0.82	1.0	1.0	99	103	101
24-May	39.0	38.0	17.0	16.0	14.0	13.0	0.82	0.81	1.0	1.0	64	58	61
25-May	40.0	41.0	15.5	16.0	13.5	14.0	0.87	0.88	1.0	1.0	50	52	51
26-May	43.0	35.0	15.5	16.0	13.5	14.0	0.87	0.88	1.0	1.0	50	52	51
27-May	0.0	0.0											75
28-May	45.0	48.0	19.5	22.5	16.5	18.0	0.85	0.80	1.0	1.0	80	110	95
29-May	59.0	58.0	22.5	25.5	19.0	21.5	0.84	0.84	1.0	1.0	104	131	117
30-May	61.5	62.5	27.0	28.5	25.5	26.0	0.94	0.91	1.0	1.0	108	137	122
31-May	59.5	67.0	26.5	22.5	24.5	19.5	0.92	0.87	1.0	1.0	115	100	107
01-Jun	65.5	65.0	21.0	20.5	18.0	17.0	0.86	0.83	1.0	1.0	90	89	89
02-Jun	63.5	64.0	19.0	20.0	16.5	17.0	0.87	0.85	1.0	1.0	73	83	78
03-Jun	58.0	60.0	22.5	24.0	21.5	22.0	0.96	0.92	1.0	1.0	71	98	85
04-Jun	68.5	68.0	23.0	23.5	20.5	20.0	0.89	0.85	1.0	1.0	98	111	105
05-Jun	66.5	65.0	21.0	20.5	18.0	17.0	0.86	0.83	1.0	1.0	90	89	89
06-Jun	68.0	67.0	23.5	21.0	22.5	19.5	0.96	0.93	1.0	1.0	76	73	75
07-Jun	60.0	59.5	25.5	25.0	23.5	23.0	0.92	0.92	1.0	1.0	108	105	106
08-Jun	59.0	61.0	24.0	26.0	21.0	24.0	0.88	0.92	1.0	1.0	111	111	111
09-Jun	62.5	61.0	25.0	24.0	23.0	22.0	0.92	0.92	1.0	1.0	105	98	102
10-Jun	53.5	53.5	25.5	25.5	23.5	23.5	0.92	0.92	1.0	1.0	108	108	108
11-Jun	58.5	58.0	25.5	25.0	22.5	22.0	0.88	0.88	1.0	1.0	122	118	120
12-Jun	58.0	61.5	22.0	24.5	20.0	22.5	0.91	0.92	1.0	1.0	86	102	94
13-Jun	56.5	56.5	22.0	22.0	19.5	19.5	0.89	0.89	1.0	1.0	92	92	92
14-Jun	51.5	51.5	18.0	19.0	16.0	16.5	0.89	0.87	1.0	1.0	63	73	68
15-Jun	57.5	57.0	21.5	21.0	19.5	19.0	0.91	0.90	1.0	1.0	83	80	82
16-Jun	45.0	45.5	12.0	12.5	9.0	9.5	0.75	0.76	1.0	1.0	36	38	37
17-Jun	35.0	35.0	12.0	12.0	9.5	9.0	0.79	0.75	1.0	1.0	35	36	35
18-Jun	34.0	34.0	11.5	11.0	8.5	8.0	0.74	0.73	1.0	1.0	33	31	32
19-Jun	25.0	24.0	11.5	10.0	8.5	8.0	0.74	0.80	1.0	1.0	33	25	29
20-Jun	38.0	37.0	12.0	11.0	9.0	8.0	0.75	0.73	1.0	1.0	36	31	33

APPENDIX VII ABSTRACTIONS THROUGH CANALS

Table A7.1 Abstraction point No. 8 : canal in footzone (conti..)

DATE	h (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q(1/s)		Qavg
	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	9.00 am	5.00 pm	(1/s)
21-Jun	39.0	38.0	13.0	12.0	9.0	8.2	0.69	0.69	1.0	1.0	42	37	39
22-Jun	44.0	43.0	14.0	15.0	16.0	12.0	1.14	0.80	1.0	1.0		52	60
23-Jun	55.0	55.5	22.5	23.0	20.5	22.0	0.91	0.96	1.0	1.0	89	74	81
24-Jun	54.0	54.5	22.0	22.5	19.5	20.0	0.89	0.89	1.0	1.0	92	95	93
25-Jun	56.5	56.0	23.0	22.0	20.5	20.0	0.89	0.91	1.0	1.0	98	86	92
26-Jun	55.0	55.6	23.0	23.0	20.5	19.0	0.89	0.83	1.0	1.0	98	111	105
27-Jun	54.5	55.0	21.5	22.0	18.5	19.0	0.86	0.86	1.0	1.0	93	96	95
28-Jun	56.0	54.0	23.0	22.0	22.0	20.5	0.96	0.93	1.0	1.0	74	79	76
29-Jun	55.5	55.0	21.5	21.0	18.5	18.0	0.86	0.86	1.0	1.0	93	90	91
30-Jun	50.5	52.5	18.0	20.0	16.0	17.0	0.89	0.85	1.0	1.0	63	83	73

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.2: Canal in savannah - Abst. point no. 25

Cutthroat flume	Kf=3.71	ns=1.39	Remark
Specifications	Ks=2.04	St=0.74	0=free flow
	nf=1.64	W=0.40 m	1=submerged flow

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
01-Nov													
02-Nov													
03-Nov													
04-Nov													
05-Nov													
06-Nov			28.5		8.8		0.31	ERR	0	ERR	120	ERR	ERR
07-Nov			28.0	25.5	8.0	7.0	0.29	0.27	0	0	116	100	108
08-Nov			23.5	23.5	6.5	6.0	0.28	0.26	0	0	87	87	87
09-Nov			25.0	23.5	7.0	6.5	0.28	0.28	0	0	97	87	92
10-Nov			25.5	23.0	7.0	6.0	0.27	0.26	0	0	100	84	92
11-Nov			20.0	19.0	4.5	4.5	0.23	0.24	0	0	67	62	64
12-Nov			22.5	20.0	6.0	4.5	0.27	0.23	0	0	81	67	74
13-Nov			18.5	17.5	4.0	4.0	0.22	0.23	0	0	59	54	56
14-Nov			18.0	18.0	4.0	4.0	0.22	0.22	0	0	56	56	56
15-Nov			21.0	20.5	5.0	5.0	0.24	0.24	0	0	73	70	71
16-Nov			18.0	17.5	4.0	4.0	0.22	0.23	0	0	56	54	55
17-Nov			17.0	16.5	4.0	3.5	0.24	0.21	0	0	51	49	50
18-Nov			17.0	16.5	4.0	3.5	0.24	0.21	0	0	51	49	50
19-Nov			18.5	17.5	4.0	4.0	0.22	0.23	0	0	59	54	56
20-Nov	51.0	50.0	17.5	19.5	5.0	5.5	0.29	0.28	0	0	54	64	59
21-Nov	52.0	50.0	21.0	19.5	5.5	5.0	0.26	0.26	0	0	73	64	68
22-Nov	49.0	47.0	18.0	17.0	4.5	4.0	0.25	0.24	0	0	56	51	54
23-Nov	46.0	45.0	16.0	16.0	4.0	4.0	0.25	0.25	0	0	46	46	46
24-Nov	44.0	43.0	15.0	14.5	3.5	3.5	0.23	0.24	0	0	42	40	41
25-Nov	43.5	43.5	14.5	14.5	3.5	3.5	0.24	0.24	0	0	40	40	40
26-Nov	42.5	42.0	14.5	13.0	3.5	3.5	0.24	0.27	0	0	40	33	36
27-Nov	42.0	41.5	13.0	13.0	4.0	4.0	0.31	0.31	0	0	33	33	33
28-Nov	49.0	45.0	19.0	16.0	4.5	4.0	0.24	0.25	0	0	62	46	54
29-Nov	51.0	48.5	21.0	19.0	5.0	6.0	0.24	0.32	0	0	73	62	67
30-Nov	56.0	51.5	24.0	21.0	7.5	5.5	0.31	0.26	0	0	90	73	81
01-Dec	58.0	53.0	33.0	29.0	6.5	6.0	0.20	0.21	0	0	152	123	138
02-Dec	52.0	50.0	29.0	27.0	6.0	5.0	0.21	0.19	0	0	123	110	116
03-Dec	47.0	46.0	24.0	23.0	5.0	5.0	0.21	0.22	0	0	90	84	87
04-Dec	46.0	46.0	23.0	23.0	5.0	4.0	0.22	0.17	0	0	84	84	84
05-Dec	47.0	46.5	24.0	24.0	4.0	4.0	0.17	0.17	0	0	90	90	90
06-Dec	45.5	45.0	23.0	22.0	4.0	4.0	0.17	0.18	0	0	84	78	81
07-Dec	44.0	43.6	22.0	21.0	4.0	4.0	0.18	0.19	0	0	78	73	75
08-Dec	46.4		24.0		4.5		0.19		0		90	0	145
09-Dec											0	0	140
10-Dec											0	0	105
11-Dec											0	0	95

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.2: Canal in savannah - Abst. point no. 25 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
12-Dec	70.0	64.0	49.0	39.0	35.0	28.0	0.71	0.72	0	0	291	200	246
13-Dec	62.0	58.0	37.0	34.0	25.0	20.0	0.68	0.59	0	0	184	160	172
14-Dec	77.0	63.0	50.0	38.0	42.0	27.0	0.84	0.71	1	0	303	192	248
15-Dec	71.0	66.2	45.0	40.0	35.0	29.0	0.78	0.73	1	0	264	209	236
16-Dec	57.5	56.5	33.0	32.0	18.0	15.5	0.55	0.48	0	0	152	145	149
17-Dec	56.0	55.0	32.0	30.7	15.5	14.0	0.48	0.46	0	0	145	135	140
18-Dec	58.5	56.5	33.5	32.0	19.0	17.0	0.57	0.53	0	0	156	145	150
19-Dec	62.5	59.0	37.0	35.0	25.0	20.0	0.68	0.57	0	0	184	168	176
20-Dec	55.5	55.0	31.0	31.0	14.0	14.0	0.45	0.45	0	0	137	137	137
21-Dec	53.5	53.0	29.5	29.0	12.0	11.0	0.41	0.38	0	0	127	123	125
22-Dec	52.0	51.0	28.0	28.0	10.0	10.0	0.36	0.36	0	0	116	116	116
23-Dec	50.0	50.0	27.0	27.0	9.0	9.0	0.33	0.33	0	0	110	110	110
24-Dec	50.0	49.0	26.0	26.0	8.0	7.5	0.31	0.29	0	0	103	103	103
25-Dec	48.5	47.0	25.0	25.0	7.0	7.0	0.28	0.28	0	0	97	97	97
26-Dec	46.0	46.0	24.0	23.0	6.5	6.5	0.27	0.28	0	0	90	84	87
27-Dec	45.0	45.0	22.5	22.0	6.0	6.0	0.27	0.27	0	0	81	78	80
28-Dec	45.0	44.0	22.0	22.0	6.0	6.0	0.27	0.27	0	0	78	78	78
29-Dec	44.0	44.0	21.5	21.0	6.0	6.0	0.28	0.29	0	0	75	73	74
30-Dec	43.0	43.0	21.0	22.0	6.0	21.5	0.29	0.98	0	1	73	52	62
31-Dec	43.0	44.5	22.0	20.5	6.0	6.0	0.27	0.29	0	0	78	70	74
01-Jan	43.0	46.0	23.5	22.0	5.0	6.5	0.21	0.30	0	0	87	78	83
02-Jan	50.5	47.5	25.0	22.0	9.0	7.0	0.36	0.32	0	0	97	78	87
03-Jan	45.0	44.0	21.0	21.0	6.0	5.0	0.29	0.24	0	0	73	73	73
04-Jan	44.0	43.0	21.0	21.0	6.0	5.0	0.29	0.24	0	0	73	73	73
05-Jan	43.0	43.0	21.0	20.0	5.0	5.0	0.24	0.25	0	0	73	67	70
06-Jan	42.0	41.0	20.0	19.0	5.0	5.0	0.25	0.26	0	0	67	62	64
07-Jan	41.0	40.0	19.0	18.0	5.0	5.0	0.26	0.28	0	0	62	56	59
08-Jan	40.0	47.0	24.0	21.0	5.0	7.0	0.21	0.33	0	0	90	73	81
09-Jan	43.0	42.0	20.0	19.0	6.0	5.0	0.30	0.26	0	0	67	62	64
10-Jan	41.0	40.0	19.0	19.0	5.0	5.0	0.26	0.26	0	0	62	62	62
11-Jan	40.0	40.0	18.0	18.0	4.0	4.0	0.22	0.22	0	0	56	56	56
12-Jan	41.0	40.0	19.0	18.0	5.0	4.0	0.26	0.22	0	0	62	56	59
13-Jan	40.0	39.0	18.0	18.0	4.0	4.0	0.22	0.22	0	0	56	56	56
14-Jan	39.0	39.0	18.0	17.5	4.0	4.0	0.22	0.23	0	0	56	54	55
15-Jan	38.0	38.0	17.0	16.5	4.0	3.5	0.24	0.21	0	0	51	49	50
16-Jan	38.0	37.0	17.0	16.0	4.0	3.5	0.24	0.22	0	0	51	46	49
17-Jan	39.0	37.0	17.0	16.5	4.0	3.5	0.24	0.21	0	0	51	49	50
18-Jan	38.0	37.0	16.5	16.0	4.0	3.5	0.24	0.22	0	0	49	46	48
19-Jan	38.0	36.0	16.0	15.5	4.0	3.5	0.25	0.23	0	0	46	44	45
20-Jan	37.0	36.0	16.0	15.0	4.0	3.5	0.25	0.23	0	0	46	42	44
21-Jan	36.0	36.0	16.0	15.0	3.5	3.5	0.22	0.23	0	0	46	42	44
22-Jan	35.0	35.0	14.0	14.5	3.5	3.5	0.25	0.24	0	0	37	40	38
23-Jan	34.0	35.0	13.0	14.0	3.0	3.5	0.23	0.25	0	0	33	37	35
24-Jan	34.0	34.0	13.0	13.5	3.0	3.0	0.23	0.22	0	0	33	35	34
25-Jan	35.0	34.0	15.5	15.0	3.5	3.5	0.23	0.23	0	0	44	42	43

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.2: Canal in savannah - Abst. point no. 25 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
26-Jan	35.0	38.0	14.0	16.5	3.5	4.0	0.25	0.24	0	0	37	49	43
27-Jan	40.0	40.0	18.0	18.0	4.0	4.0	0.22	0.22	0	0	56	56	56
28-Jan	41.0	41.0	19.0	18.5	5.0	5.0	0.26	0.27	0	0	62	59	60
29-Jan	44.0	43.0	21.5	20.5	6.0	5.0	0.28	0.24	0	0	75	70	73
30-Jan	44.0	42.0	21.0	20.0	6.0	5.0	0.29	0.25	0	0	73	67	70
31-Jan	43.0	43.0	20.0	20.0	5.0	5.0	0.25	0.25	0	0	67	67	67
01-Feb	41.0	41.0	19.0	18.0	5.0	4.5	0.26	0.25	0	0	62	56	59
02-Feb	38.0	39.0	16.0	17.0	3.5	4.0	0.22	0.24	0	0	46	51	49
03-Feb	37.0	36.0	15.0	15.0	3.5	3.5	0.23	0.23	0	0	42	42	42
04-Feb	36.0	35.0	15.0	14.0	4.0	3.5	0.27	0.25	0	0	42	37	40
05-Feb	46.0	43.0	22.0	20.0	6.0	5.0	0.27	0.25	0	0	78	67	73
06-Feb	38.0	39.0	15.5	17.0	3.5	4.0	0.23	0.24	0	0	44	51	48
07-Feb	36.0	35.0	14.5	14.0	3.5	3.5	0.24	0.25	0	0	40	37	38
08-Feb	35.0	35.0	14.0	13.5	3.5	3.0	0.25	0.22	0	0	37	35	36
09-Feb	34.0	31.0	14.0	11.0	3.0	2.5	0.21	0.23	0	0	37	25	31
10-Feb	31.0	30.0	11.0	10.0	2.5	2.5	0.23	0.25	0	0	25	21	23
11-Feb	31.0	31.0	10.5	12.0	2.5	3.0	0.24	0.25	0	0	23	29	26
12-Feb	31.0	31.0	11.0	12.5	2.5	2.5	0.23	0.20	0	0	25	31	28
13-Feb	33.0	34.0	13.0	14.5	3.0	3.0	0.23	0.21	0	0	33	40	36
14-Feb	36.0	33.0	16.0	13.0	3.0	3.0	0.19	0.23	0	0	46	33	40
15-Feb	33.0	32.0	12.5	11.5	3.0	3.0	0.24	0.26	0	0	31	27	29
16-Feb	32.0	31.0	12.0	11.0	3.0	2.5	0.25	0.23	0	0	29	25	27
17-Feb	31.0	30.0	10.5	10.0	2.5	2.5	0.24	0.25	0	0	23	21	22
18-Feb	30.0	29.0	10.0	9.5	3.0	2.5	0.30	0.26	0	0	21	20	21
19-Feb	30.0	29.0	10.0	9.5	2.5	2.5	0.25	0.26	0	0	21	20	21
20-Feb	30.0	29.0	10.5	11.0	2.5	2.5	0.24	0.23	0	0	23	25	24
21-Feb	30.0	28.0	11.0	8.5	2.5	2.0	0.23	0.24	0	0	25	16	21
22-Feb	30.0	30.0	10.0	10.0	2.5	2.5	0.25	0.25	0	0	21	21	21
23-Feb	35.0	32.5	15.0	12.5	4.0	3.0	0.27	0.24	0	0	42	31	36
24-Feb	38.0	36.0	18.0	16.0	4.5	4.0	0.25	0.25	0	0	56	46	51
25-Feb	37.0	35.0	17.0	15.0	4.0	4.0	0.24	0.27	0	0	51	42	47
26-Feb	36.0	35.0	15.5	15.0	4.0	4.0	0.26	0.27	0	0	44	42	43
27-Feb	33.0	24.0	13.0	15.5	3.0	13.0	0.23	0.84	0	1	33	44	38
28-Feb	24.5	24.0	15.5	15.0	14.0	13.0	0.90	0.87	1	1	40	41	40
01-Mar	24.0	24.0	16.0	16.0	14.0	13.5	0.88	0.84	1	1	45	46	45
02-Mar	21.5	21.0	13.5	13.0	11.0	11.0	0.81	0.85	1	1	36	33	34
03-Mar	20.5	20.5	12.5	12.5	10.5	10.5	0.84	0.84	1	1	31	31	31
04-Mar	20.5	20.0	13.0	12.0	11.0	10.0	0.85	0.83	1	1	33	29	31
05-Mar	20.0	20.0	12.0	12.0	10.0	10.0	0.83	0.83	1	1	29	29	29
06-Mar	22.5	23.0	15.0	18.5	12.0	17.0	0.80	0.92	1	1	43	52	48
07-Mar	23.0	24.5	18.0	20.0	16.0	18.0	0.89	0.90	1	1	53	62	58
08-Mar	33.0	30.0	28.5	28.0	27.0	18.5	0.95	0.66	1	0	97	116	107
09-Mar	25.0	25.0	16.5	16.0	14.0	14.0	0.85	0.88	1	1	48	45	46
10-Mar	24.0	23.0	15.0	15.0	13.0	12.0	0.87	0.80	1	1	41	43	42
11-Mar	22.0	22.0	14.0	14.0	11.5	11.0	0.82	0.79	1	1	38	38	38

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.2: Canal in savannah - Abst. point no. 25 (Conti..)

DATE 1990/91	GHT (cm) 9.00 am	GHT (cm) 3.00 pm	Hu (cm) 9.00 am	Hu (cm) 3.00 pm	Hd (cm) 9.00 am	Hd (cm) 3.00 pm	Hd/Hu 9.00 am	Hd/Hu 3.00 pm	Remark 9.00 am	Remark 3.00 pm	Q (l/s) 9.00 am	Q (l/s) 3.00 pm	Qavg (l/s)
12-Mar	23.0	24.0	14.0	16.0	11.5	14.0	0.82	0.88	1	1	38	45	41
13-Mar	32.0	31.0	25.0	24.0	23.0	21.0	0.92	0.88	1	1	86	87	86
14-Mar	36.0	37.0	28.0	28.5	25.0	26.0	0.89	0.91	1	1	109	108	109
15-Mar	45.0	40.0	36.5	32.0	35.0	30.0	0.96	0.94	1	1	139	123	131
16-Mar	32.0	31.0	25.0	23.0	22.0	21.0	0.88	0.91	1	1	93	76	84
17-Mar	28.0	28.0	20.0	19.0	18.0	17.5	0.90	0.92	1	1	62	54	58
18-Mar	26.0	24.0	18.5	17.0	16.0	15.0	0.86	0.88	1	1	57	49	53
19-Mar	24.0	23.0	17.0	16.0	15.0	13.5	0.88	0.84	1	1	49	46	47
20-Mar	23.0	22.0	16.0	15.0	14.0	13.0	0.88	0.87	1	1	45	41	43
21-Mar	24.0	24.0	18.0	17.5	16.5	16.0	0.92	0.91	1	1	50	48	49
22-Mar	20.0	20.0	15.0	14.0	13.5	13.0	0.90	0.93	1	1	39	32	35
23-Mar	19.0	19.0	12.0	12.0	10.0	10.0	0.83	0.83	1	1	29	29	29
24-Mar	23.0	23.0	18.0	17.5	17.0	16.0	0.94	0.91	1	1	46	48	47
25-Mar	24.0	25.0	16.0	20.5	14.0	19.0	0.88	0.93	1	1	45	61	53
26-Mar	22.0	19.0	16.5	11.0	15.0	8.5	0.91	0.77	1	1	44	26	35
27-Mar	56.0	69.0	44.0	59.0	32.0	49.0	0.73	0.83	0	1	244	401	323
28-Mar	52.0	55.0	42.0	45.0	37.0	38.0	0.88	0.84	1	1	217	254	236
29-Mar	46.5	45.0	37.0	36.0	30.0	29.0	0.81	0.81	1	1	188	180	184
30-Mar	50.0	46.0	40.0	37.0	35.0	32.0	0.88	0.86	1	1	202	180	191
31-Mar	41.0	42.0	32.0	32.0	25.0	26.0	0.78	0.81	1	1	150	148	149
01-Apr	57.0	51.0	47.0	42.0	38.0	35.0	0.81	0.83	1	1	280	229	254
02-Apr	45.0	46.5	35.0	47.0	28.5	30.0	0.81	0.64	1	0	171	272	222
03-Apr	51.0	48.0	42.0	39.0	34.0	32.0	0.81	0.82	1	1	232	204	218
04-Apr	49.0	46.0	40.0	36.0	32.0	29.0	0.80	0.81	1	1	215	180	198
05-Apr	41.0	40.0	32.0	31.0	25.0	24.0	0.78	0.77	1	1	150	143	146
06-Apr	28.0	26.0	29.5	18.0	22.0	11.0	0.75	0.61	1	0	132	56	94
07-Apr	25.0	26.0	17.0	17.5	10.0	11.0	0.59	0.63	0	0	51	54	53
08-Apr	27.0	26.0	20.0	18.0	12.0	11.0	0.60	0.61	0	0	67	56	62
09-Apr	24.0	23.5	16.5	16.0	9.0	10.0	0.55	0.63	0	0	49	46	48
10-Apr	24.5	24.5	17.0	16.5	9.5	10.0	0.56	0.61	0	0	51	49	50
11-Apr	23.0	23.0	15.5	15.0	9.0	8.5	0.58	0.57	0	0	44	42	43
12-Apr	23.0	23.0	15.0	16.0	9.0	9.0	0.60	0.56	0	0	42	46	44
13-Apr	23.0	22.5	15.5	15.0	8.0	8.5	0.52	0.57	0	0	44	42	43
14-Apr	22.0	24.0	15.0	17.0	8.0	10.0	0.53	0.59	0	0	42	51	47
15-Apr	22.0	22.0	15.0	15.0	9.0	9.0	0.60	0.60	0	0	42	42	42
16-Apr	22.0	22.0	15.0	14.5	8.0	8.0	0.53	0.55	0	0	42	40	41
17-Apr	21.5	22.0	14.5	15.0	8.0	8.0	0.55	0.53	0	0	40	42	41
18-Apr	24.0	26.0	17.0	18.5	10.0	12.0	0.59	0.65	0	0	51	59	55
19-Apr	27.0	26.0	19.0	18.0	12.0	12.0	0.63	0.67	0	0	62	56	59
20-Apr	33.0	32.0	25.0	24.0	17.5	17.0	0.70	0.71	0	0	97	90	93
21-Apr	34.0	39.0	26.0	30.0	19.0	23.0	0.73	0.77	0	1	103	135	119
22-Apr	44.5	39.0	35.0	30.0	28.0	23.5	0.80	0.78	1	1	173	135	154
23-Apr	56.0	46.0	46.0	37.0	37.0	30.0	0.80	0.81	1	1	270	188	229
24-Apr	36.5	36.0	28.0	27.0	21.0	21.0	0.75	0.78	1	1	121	113	117
25-Apr	45.0	41.0	36.0	36.5	29.0	25.0	0.81	0.68	1	0	180	180	180

APPENDIX VII: ABSTRACTIONS THROUGH CANALS

Table: A7.2: Canal in savannah - Abst. point no. 25 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
26-Apr	37.0	37.0	28.0	28.0	22.0	22.0	0.79	0.79	1	1	120	120	120
27-Apr	34.0	34.0	25.5	25.0	19.0	19.0	0.75	0.76	1	1	104	100	102
28-Apr	31.0	31.0	23.0	23.5	13.0	13.0	0.57	0.55	0	0	84	87	86
29-Apr	31.0	40.0	23.0	31.0	13.0	25.0	0.57	0.81	0	1	84	141	113
30-Apr	49.0	43.0	40.0	34.0	33.0	22.0	0.83	0.65	1	0	212	160	186
01-May	58.0	50.0	48.0	40.0	40.0	32.0	0.83	0.80	1	1	285	215	250
02-May	46.5	43.0	37.0	34.0	30.0	26.0	0.81	0.76	1	1	188	167	177
03-May	43.0	39.0	41.0	35.0	34.0	28.0	0.83	0.80	1	1	220	173	196
04-May	38.0	28.0	35.0	20.0	28.0	13.0	0.80	0.65	1	0	173	67	120
05-May	26.5	26.0	19.0	18.0	12.0	11.0	0.63	0.61	0	0	62	56	59
06-May	25.0	24.0	17.0	16.0	10.0	9.0	0.59	0.56	0	0	51	46	49
07-May	23.0	22.5	15.5	15.0	8.5	8.0	0.55	0.53	0	0	44	42	43
08-May	22.0	22.0	15.0	14.5	8.0	7.0	0.53	0.48	0	0	42	40	41
09-May	22.0	22.0	14.0	15.0	8.0	9.0	0.57	0.60	0	0	37	42	40
10-May	22.0	22.0	15.0	14.0	8.5	8.0	0.57	0.57	0	0	42	37	40
11-May	24.0	27.0	16.0	19.0	9.5	12.5	0.59	0.66	0	0	46	62	54
12-May	28.0	27.5	20.0	19.5	13.0	13.0	0.65	0.67	0	0	67	64	66
13-May	27.0	26.5	18.5	18.5	12.0	12.0	0.65	0.65	0	0	59	59	59
14-May	48.5	42.0	38.5	32.5	32.0	26.0	0.83	0.80	1	1	198	153	176
15-May	36.0	33.5	27.0	25.0	20.0	18.0	0.74	0.72	1	0	114	97	105
16-May	34.0	34.0	26.0	26.0	19.0	20.0	0.73	0.77	0	1	103	107	105
17-May	33.0	32.0	25.0	24.0	19.0	18.0	0.76	0.75	1	1	100	94	97
18-May	31.0	30.5	23.5	22.0	18.0	16.0	0.77	0.73	1	0	91	78	84
19-May	29.0	29.0	21.0	21.0	14.0	14.0	0.67	0.67	0	0	73	73	73
20-May	48.0	42.5	38.0	34.0	32.0	26.0	0.84	0.76	1	1	192	167	180
21-May	36.5	37.0	27.5	28.0	21.5	22.0	0.78	0.79	1	1	117	120	118
22-May	38.0	38.0	28.5	28.0	23.0	23.0	0.81	0.82	1	1	123	118	120
23-May	48.0	44.0	38.0	35.0	32.0	29.0	0.84	0.83	1	1	192	170	181
24-May	39.0	38.0	30.5	29.0	24.0	23.0	0.79	0.79	1	1	138	127	133
25-May	36.0	36.0	27.0	27.0	21.0	21.0	0.78	0.78	1	1	113	113	113
26-May	37.5	37.0	28.0	28.0	20.0	20.0	0.71	0.71	0	0	116	116	116
27-May	34.5	35.0	25.5	26.0	18.0	18.5	0.71	0.71	0	0	100	103	101
28-May	33.0	31.5	24.0	23.0	15.0	14.5	0.63	0.63	0	0	90	84	87
29-May	29.0	28.0	21.0	20.0	13.5	13.0	0.64	0.65	0	0	73	67	70
30-May	27.0	26.5	19.0	18.5	12.0	12.0	0.63	0.65	0	0	62	59	60
31-May	26.0	25.5	18.0	17.0	12.0	10.5	0.67	0.62	0	0	56	51	54
01-Jun	25.0	25.0	18.5	20.0	16.5	19.0	0.89	0.95	1	1	55	54	55
02-Jun	25.5	34.0	21.0	24.5	19.0	17.0	0.90	0.69	1	0	67	93	80
03-Jun	28.0	29.0	19.0	20.5	12.0	13.0	0.63	0.63	0	0	62	70	66
04-Jun	25.0	26.0	18.0	19.5	11.0	10.0	0.61	0.51	0	0	56	64	60
05-Jun	35.0	36.5	22.0	24.0	14.5	17.0	0.66	0.71	0	0	78	90	84
06-Jun	28.5	29.0	19.0	20.0	11.5	12.0	0.61	0.60	0	0	62	67	64
07-Jun	38.0	34.5	25.0	22.0	17.5	14.5	0.70	0.66	0	0	97	78	87
08-Jun	30.0	30.5	17.0	17.0	10.0	10.0	0.59	0.59	0	0	51	51	51
09-Jun	43.0	42.0	29.0	28.0	23.0	24.0	0.79	0.86	1	1	127	115	121

APPENDIX VII: ABSTRACTIONS THROUGH CANALS

Table: A7.2: Canal in savannah - Abst. point no. 25 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
10-Jun	39.0	41.5	25.0	27.5	23.0	20.0	0.92	0.73	1	0	86	113	99
11-Jun	46.5	42.0	32.0	28.0	25.0	20.0	0.78	0.71	1	0	150	116	133
12-Jun	41.0	42.5	26.5	28.0	19.0	21.0	0.72	0.75	0	1	106	121	114
13-Jun	37.0	35.0	23.5	22.0	17.0	15.0	0.72	0.68	0	0	87	78	83
14-Jun	33.0	32.0	20.5	19.5	13.0	12.5	0.63	0.64	0	0	70	64	67
15-Jun	52.0	46.0	36.0	30	30.0	24	0.83	0.80	1	1	177	134	156
16-Jun	58.0	51.0	40.0	30	35.0	24	0.88	0.80	1	1	202	134	168
17-Jun	43.0	42.0	22.0	19	16.0	14	0.73	0.74	0	0	78	62	70
18-Jun	39.0	38.0	16.0	15	10.5	9	0.66	0.60	0	0	46	42	44
19-Jun	35.0	36.0	13.0	13.5	8.0	8	0.62	0.59	0	0	33	35	34
20-Jun	35.0	35.0	13.0	12	8.0	7	0.62	0.58	0	0	33	29	31
21-Jun	35.0	35.0	13.0	12	8.0	7	0.62	0.58	0	0	33	29	31
22-Jun	32.0	37.0	11.5	22.0	5.5	16.5	0.48	0.75	0	1	27	81	54
23-Jun	38.0	37.0	25.5	25.0	18.5	18.0	0.73	0.72	0	0	100	97	98
24-Jun	37.0	37.0	25.0	25.0	17.0	17.0	0.68	0.68	0	0	97	97	97
25-Jun	36.5	36.0	24.5	24.0	17.0	17.0	0.69	0.71	0	0	93	90	92
26-Jun	36.5	36.0	24.5	24.0	17.0	17.0	0.69	0.71	0	0	93	90	92
27-Jun	49.5	49.0	35.5	35.0	29.0	29.0	0.82	0.83	1	1	175	170	172
28-Jun	42.0	41.0	29.0	28.0	23.0	21.4	0.79	0.76	1	1	127	121	124
29-Jun	38.5	37.0	26.0	25.0	19.5	19.0	0.75	0.76	1	1	107	100	104
30-Jun	36.0	36.0	24.0	24.0	18.0	18.0	0.75	0.75	1	1	94	94	94

APPENDIX VII: ABSTRACTIONS THROUGH CANALS

Table A7.3: Canal in savannah - Abst. point no. 26

Cutthroat flume	Kf=3.71	ns=1.39	Remark:
Specifications	Ks=2.04	St=0.74	0=free flow
	nf=1.64	W=0.40 m	1=submerged flow

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
01-Nov													
02-Nov													
03-Nov													
04-Nov													
05-Nov													
06-Nov													
07-Nov													
08-Nov													
09-Nov													
10-Nov			24.0	20.0	6.0	4.0	0.25	0.20	0	0	90	67	79
11-Nov			13.0	12.0	1.5	1.0	0.12	0.08	0	0	33	29	31
12-Nov			17.0	13.5	3.5	2.5	0.21	0.19	0	0	51	35	43
13-Nov			8.0	5.5	1.0	0.5	0.13	0.09	0	0	15	8	11
14-Nov			7.5	9.0	1.0	1.0	0.13	0.11	0	0	13	18	16
15-Nov			14.0	13.5	2.5	2.5	0.18	0.19	0	0	37	35	36
16-Nov			6.0	5.0	0.5	2.0	0.08	0.40	0	0	9	7	8
17-Nov			4.0	4.0	1.5	1.5	0.38	0.38	0	0	5	5	5
18-Nov			6.5	11.0	2.0	2.5	0.31	0.23	0	0	11	25	19
19-Nov			15.0	17.0	4.0	4.0	0.27	0.24	0	0	42	51	47
20-Nov	92.0	92.0	26.0	25.0	7.5	7.0	0.29	0.28	0	0	103	97	100
21-Nov	94.0	92.0	27.5	22.5	8.0	6.0	0.29	0.27	0	0	113	81	97
22-Nov	90.0	88.0	20.5	18.0	5.0	4.5	0.24	0.25	0	0	70	56	63
23-Nov	86.5	80.5	14.5	14.0	4.0	3.5	0.28	0.25	0	0	40	37	38
24-Nov	85.0	83.0	12.0	11.0	3.0	3.5	0.25	0.32	0	0	29	25	27
25-Nov	84.0	83.5	10.5	10.5	4.5	4.5	0.43	0.43	0	0	23	23	23
26-Nov	82.5	82.0	9.0	8.5	4.5	4.0	0.50	0.47	0	0	18	16	17
27-Nov	81.0	85.0	7.5	14.0	4.0	4.0	0.53	0.29	0	0	13	37	25
28-Nov	95.0	90.0	31.0	24.0	10.0	6.5	0.32	0.27	0	0	137	90	114
29-Nov	96.0	94.0	34.0	31.0	12.0	10.0	0.35	0.32	0	0	160	137	149
30-Nov	102.0	96.5	42.0	35.0	30.0	20.0	0.71	0.57	0	0	226	168	197
01-Dec	101.5	97.5	41.0	34.5	30.0	20.0	0.73	0.58	0	0	217	164	191
02-Dec	95.5	93.0	32.5	28.5	10.5	8.5	0.32	0.30	0	0	149	120	134
03-Dec	89.5	88.0	23.0	22.0	6.0	6.0	0.26	0.27	0	0	84	78	81
04-Dec	89.0	88.0	22.5	21.0	6.0	5.5	0.27	0.26	0	0	81	73	77
05-Dec	90.0	88.5	23.0	22.0	6.5	6.0	0.28	0.27	0	0	84	78	81
06-Dec	87.0	86.0	19.0	18.5	5.0	5.0	0.26	0.27	0	0	62	59	60
07-Dec	86.0	85.2	17.5	17.0	4.5	4.5	0.26	0.26	0	0	54	51	53
08-Dec	88.8	135.0	21.0	54.0	6.0	44.0	0.29	0.81	0	1	73	350	211
09-Dec	103.0	98.0	42.0	35.5	33.0	22.0	0.79	0.62	1	0	235	172	203
10-Dec	92.2	91.0	27.0	24.9	8.0	7.0	0.30	0.28	0	0	110	96	103
11-Dec	89.2	92.2	22.0	27.0	6.0	8.0	0.27	0.30	0	0	78	110	94
12-Dec	112.0	104.5	51.5	43.5	42.0	33.0	0.82	0.76	1	1	324	250	287

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.3: Canal in savannah - Abst. point no. 26 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
13-Dec	102.0	97.5	40.5	35.0	29.0	20.0	0.72	0.57	0	0	213	168	190
14-Dec	123.0	103.0	60.0	42.0	48.0	30.0	0.80	0.71	1	0	420	226	323
15-Dec	113.0	105.5	50.0	44.9	40.0	34.0	0.80	0.76	1	1	311	264	287
16-Dec	96.5	95.0	33.0	31.5	15.0	10.0	0.45	0.32	0	0	152	141	147
17-Dec	95.0	93.6	31.0	29.5	10.0	9.0	0.32	0.31	0	0	137	127	132
18-Dec	97.0	95.0	35.0	32.0	19.5	14.0	0.56	0.44	0	0	168	145	156
19-Dec	102.5	99.0	41.5	37.0	31.0	24.0	0.75	0.65	1	0	232	184	208
20-Dec	95.0	94.0	31.0	30.0	10.0	9.5	0.32	0.32	0	0	137	130	134
21-Dec	92.5	92.0	27.0	26.0	8.0	8.0	0.30	0.31	0	0	110	103	106
22-Dec	90.0	90.0	24.0	23.0	7.0	6.5	0.29	0.28	0	0	90	84	87
23-Dec	89.0	88.0	21.0	21.0	6.0	6.0	0.29	0.29	0	0	73	73	73
24-Dec	86.0	86.0	19.0	18.0	5.0	5.0	0.26	0.28	0	0	62	56	59
25-Dec	85.0	84.0	16.0	16.0	4.5	4.0	0.28	0.25	0	0	46	46	46
26-Dec	83.0	83.0	14.0	14.0	4.0	3.5	0.29	0.25	0	0	37	37	37
27-Dec	82.0	82.0	12.0	12.0	4.0	4.5	0.33	0.38	0	0	29	29	29
28-Dec	81.0	88.5	10.5	21.0	5.0	6.0	0.48	0.29	0	0	23	73	48
29-Dec	88.0	88.0	21.0	21.0	6.0	6.0	0.29	0.29	0	0	73	73	73
30-Dec	88.0	88.0	20.0	20.5	5.0	6.0	0.25	0.29	0	0	67	70	68
31-Dec	88.0	98.0	20.5	34.0	6.0	21.0	0.29	0.62	0	0	70	160	115
01-Jan	97.0	101.0	34.0	36.5	22.0	25.0	0.65	0.68	0	0	160	180	170
02-Jan	108.5	105.0	48.0	44.5	29.0	35.0	0.60	0.79	0	1	282	258	270
03-Jan	100.0	99.0	40.0	38.0	29.0	28.0	0.73	0.74	0	0	209	192	200
04-Jan	99.0	99.0	38.0	38.0	27.0	27.0	0.71	0.71	0	0	192	192	192
05-Jan	99.0	98.0	38.0	37.0	7.0	25.0	0.18	0.68	0	0	192	184	188
06-Jan	98.0	97.0	36.0	35.0	24.0	22.0	0.67	0.63	0	0	176	168	172
07-Jan	96.0	96.0	34.0	33.0	21.0	19.0	0.62	0.58	0	0	160	152	156
08-Jan	96.0	105.0	33.0	45.0	19.0	35.0	0.58	0.78	0	1	152	264	208
09-Jan	100.0	99.0	39.0	38.0	29.0	28.0	0.74	0.74	1	0	210	192	201
10-Jan	96.0	96.0	35.0	34.0	21.0	19.0	0.60	0.56	0	0	168	160	164
11-Jan	96.0	95.0	34.0	33.0	20.0	20.0	0.59	0.61	0	0	160	152	156
12-Jan	97.0	95.0	35.0	34.0	25.0	22.0	0.71	0.65	0	0	168	160	164
13-Jan	95.0	95.0	34.0	32.0	21.0	19.0	0.62	0.59	0	0	160	145	152
14-Jan	95.0	94.0	32.0	31.5	19.0	18.0	0.59	0.57	0	0	145	141	143
15-Jan	93.0	92.0	28.5	28.0	19.5	18.0	0.68	0.64	0	0	120	116	118
16-Jan	92.0	91.0	27.0	26.0	15.0	10.0	0.56	0.38	0	0	110	103	106
17-Jan	93.0	92.0	29.0	26.5	21.0	16.0	0.72	0.60	0	0	123	106	115
18-Jan	92.0	91.0	27.5	25.5	18.5	11.0	0.67	0.43	0	0	113	100	106
19-Jan	91.0	90.0	26.0	24.0	14.0	7.0	0.54	0.29	0	0	103	90	97
20-Jan	91.0	90.0	26.0	24.0	19.0	17.0	0.73	0.71	0	0	103	90	97
21-Jan	90.0	89.0	24.0	23.0	17.0	15.0	0.71	0.65	0	0	90	84	87
22-Jan	88.0	88.0	19.5	20.5	5.5	8.0	0.28	0.39	0	0	64	70	67
23-Jan	86.0	87.0	16.0	19.0	4.5	5.5	0.28	0.29	0	0	46	62	54
24-Jan	86.0	86.0	16.5	18.0	4.5	5.0	0.27	0.28	0	0	49	56	53
25-Jan	88.5	87.0	20.0	19.0	14.5	6.0	0.73	0.32	0	0	67	62	64
26-Jan	88.0	85.0	20.0	16.0	14.0	4.5	0.70	0.28	0	0	67	46	57
27-Jan	86.0	85.0	18.0	16.0	6.0	4.5	0.33	0.28	0	0	56	46	51
28-Jan	87.0	86.0	19.0	17.0	9.0	5.0	0.47	0.29	0	0	62	51	56

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.3: Canal in savannah - Abst. point no. 26 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
29-Jan	91.0	89.0	24.0	22.0	20.0	16.5	0.83	0.75	1	1	91	81	86
30-Jan	90.0	88.0	24.0	21.0	7.0	6.0	0.29	0.29	0	0	90	73	81
31-Jan	88.0	87.0	20.0	19.5	5.0	5.0	0.25	0.26	0	0	67	64	66
01-Feb	86.0	86.0	17.0	18.0	4.5	5.0	0.26	0.28	0	0	51	56	54
02-Feb	84.0	84.0	14.0	15.0	3.5	4.0	0.25	0.27	0	0	37	42	40
03-Feb	82.0	81.0	13.0	12.5	4.0	4.0	0.31	0.32	0	0	33	31	32
04-Feb	82.0	80.0	11.0	10.0	5.0	5.0	0.45	0.50	0	0	25	21	23
05-Feb	89.0	89.0	15.0	21.0	4.0	15.0	0.27	0.71	0	0	42	73	57
06-Feb	82.0	83.0	11.0	13.0	4.0	3.5	0.36	0.27	0	0	25	33	29
07-Feb	80.0	79.0	10.0	8.5	5.0	5.0	0.50	0.59	0	0	21	16	19
08-Feb	80.0	84.0	8.5	15.0	5.0	4.0	0.59	0.27	0	0	16	42	29
09-Feb	83.0	85.0	14.5	18.0	4.0	4.5	0.28	0.25	0	0	40	56	48
10-Feb	85.0	85.0	17.0	16.5	4.0	4.0	0.24	0.24	0	0	51	49	50
11-Feb	85.0	84.0	17.0	16.0	4.0	4.0	0.24	0.25	0	0	51	46	49
12-Feb	84.0	85.0	16.0	16.0	4.0	4.5	0.25	0.28	0	0	46	46	46
13-Feb	85.0	85.0	18.0	18.5	4.5	4.5	0.25	0.24	0	0	56	59	58
14-Feb	87.0	84.0	19.5	16.5	5.0	4.5	0.26	0.27	0	0	64	49	57
15-Feb	84.0	84.5	17.0	15.0	4.5	4.0	0.26	0.27	0	0	51	42	47
16-Feb	83.0	83.0	15.0	14.5	4.0	4.0	0.27	0.28	0	0	42	40	41
17-Feb	82.0	82.0	13.0	13.0	3.5	4.0	0.27	0.31	0	0	33	33	33
18-Feb	81.0	81.0	12.0	11.0	6.0	5.0	0.50	0.45	0	0	29	25	27
19-Feb	81.0	82.5	11.5	13.5	5.5	3.5	0.48	0.26	0	0	27	35	31
20-Feb	83.0	84.0	14.0	16.0	4.0	4.5	0.29	0.28	0	0	37	46	42
21-Feb	84.0	83.0	16.0	15.0	4.0	4.0	0.25	0.27	0	0	46	42	44
22-Feb	83.5	83.5	15.0	15.0	4.0	4.0	0.27	0.27	0	0	42	42	42
23-Feb	86.0	84.0	18.5	16.5	4.5	4.0	0.24	0.24	0	0	59	49	54
24-Feb	88.0	86.0	21.5	20.0	5.5	5.0	0.26	0.25	0	0	75	67	71
25-Feb	86.0	85.0	19.5	17.5	5.0	4.0	0.26	0.23	0	0	64	54	59
26-Feb	84.0	84.0	17.0	17.0	4.0	4.0	0.24	0.24	0	0	51	51	51
27-Feb	82.0	82.0	15.0	15.0	3.5	3.5	0.23	0.23	0	0	42	42	42
28-Feb	81.0	81.0	14.5	14.0	3.5	3.5	0.24	0.25	0	0	40	37	38
01-Mar	80.0	80.0	12.0	11.0	5.5	5.5	0.46	0.50	0	0	29	25	27
02-Mar	78.0	79.0	8.0	10.0	4.0	5.0	0.50	0.50	0	0	15	21	18
03-Mar	79.0	79.0	9.0	9.0	5.0	5.0	0.56	0.56	0	0	18	18	18
04-Mar	78.0	80.0	9.0	10.0	5.0	5.5	0.56	0.55	0	0	18	21	20
05-Mar	79.0	79.0	9.5	9.5	5.0	5.0	0.53	0.53	0	0	20	20	20
06-Mar	80.0	78.0	12.0	13.5	5.5	3.5	0.46	0.26	0	0	29	35	32
07-Mar	78.0	79.0	13.0	14.0	4.0	4.0	0.31	0.29	0	0	33	37	35
08-Mar	88.0	84.0	26.5	22.0	23.0	6.5	0.87	0.30	1	0	103	78	91
09-Mar	79.0	78.0	14.0	14.5	4.0	4.0	0.29	0.28	0	0	37	40	38
10-Mar	77.0	77.0	13.0	12.0	3.5	6.0	0.27	0.50	0	0	33	29	31
11-Mar	76.0	76.0	10.5	11.0	5.5	5.0	0.52	0.45	0	0	23	25	24
12-Mar	76.0		11.0		5.5		0.50		0		25	0	25
13-Mar				24.0		7.0		0.29		0	0	90	90
14-Mar			31.0	32.0	10.0	11.0	0.32	0.34	0	0	137	145	141
15-Mar	106.0	99.0	46.5	40.0	34.0	26.0	0.73	0.65	0	0	267	209	238
16-Mar			27.0	23.5	8.0	7.0	0.30	0.30	0	0	110	87	98

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.3: Canal in savannah - Abst. point no. 26 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
17-Mar			17.5	18.0	5.0	4.5	0.29	0.25	0	0	54	56	55
18-Mar			15.0	15.0	4.0	4.0	0.27	0.27	0	0	42	42	42
19-Mar			15.0	14.0	4.0	3.5	0.27	0.25	0	0	42	37	40
20-Mar			15.0	14.0	4.0	3.5	0.27	0.25	0	0	42	37	40
21-Mar			15.0	14.0	4.0	3.5	0.27	0.25	0	0	42	37	40
22-Mar			12.0	11.0	4.0	5.0	0.33	0.45	0	0	29	25	27
23-Mar			12.0	13.0	4.0	3.5	0.33	0.27	0	0	29	33	31
24-Mar			14.0	13.0	4.0	3.5	0.29	0.27	0	0	37	33	35
25-Mar			15.0	15.0	4.0	4.0	0.27	0.27	0	0	42	42	42
26-Mar			14.0	14.0	4.0	5.0	0.29	0.36	0	0	37	37	37
27-Mar	120.0	136.0	59.0	60.0	45.0	48.0	0.76	0.80	1	1	414	420	417
28-Mar	102.0	110.0	43.0	49.0	31.0	38.0	0.72	0.78	0	1	235	304	269
29-Mar			32.0	28.5	15.0	9.0	0.47	0.32	0	0	145	120	132
30-Mar			40.0	31.0	28.0	13.0	0.70	0.42	0	0	209	137	173
31-Mar			19.0	20.0	4.5	5.0	0.24	0.25	0	0	62	67	64
01-Apr	105.0	102.5	49.0	43.0	38.0	31.0	0.78	0.72	1	0	304	235	269
02-Apr			27.5	31.0	8.0	11.0	0.29	0.35	0	0	113	137	125
03-Apr	100.0		41.0	36.0	29.0	22.0	0.71	0.61	0	0	217	176	197
04-Apr			36.0	29.5	21.0	9.0	0.58	0.31	0	0	176	127	151
05-Apr			19.0	17.0	5.0	4.0	0.26	0.24	0	0	62	51	56
06-Apr			14.0	16.0	3.5	4.0	0.25	0.25	0	0	37	46	42
07-Apr			14.5	15.0	3.5	4.0	0.24	0.27	0	0	40	42	41
08-Apr			19.0	16.0	5.0	4.0	0.26	0.25	0	0	62	46	54
09-Apr			14.0	12.0	4.0	3.5	0.29	0.29	0	0	37	29	33
10-Apr			13.0	13.5	3.5	3.5	0.27	0.26	0	0	33	35	34
11-Apr			10.0	10.0	5.0	5.0	0.50	0.50	0	0	21	21	21
12-Apr			10.0	11.0	5.0	4.0	0.50	0.36	0	0	21	25	23
13-Apr			10.0	29.5	5.0	10.0	0.50	0.34	0	0	21	127	74
14-Apr			28.0	35.0	9.0	23.0	0.32	0.66	0	0	116	168	142
15-Apr			30.0	30.0	10.0	10.0	0.33	0.33	0	0	130	130	130
16-Apr			29.0	27.0	9.0	8.0	0.31	0.30	0	0	123	110	116
17-Apr			27.0	27.0	8.0	8.0	0.30	0.30	0	0	110	110	110
18-Apr			35.0	36.0	24.0	24.0	0.69	0.67	0	0	168	176	172
19-Apr	100.0		40.5	38.0	30.0	27.0	0.74	0.71	1	0	223	192	208
20-Apr	109.0	110.0	44.0	48.0	32.5	38.0	0.74	0.79	0	1	244	292	268
21-Apr	112.0	117.0	49.0	54.0	40.0	45.0	0.82	0.83	1	1	298	346	322
22-Apr	121.0	116.0	58.0	53.0	47.0	43.0	0.81	0.81	1	1	395	340	368
23-Apr	130.0	122.0		58.0		44.0		0.76		1	0	403	420
24-Apr	112.5	111.0	49.0	48.0	35.0	35.0	0.71	0.73	0	0	291	282	286
25-Apr	120.0	116.0	58.0	52.0	45.0	37.0	0.78	0.71	1	0	401	321	361
26-Apr	112.0	122.0	49.0	58.0	35.0	43.0	0.71	0.74	0	1	291	404	347
27-Apr	109.0	108.5	46.0	45.0	30.0	30.0	0.65	0.67	0	0	263	253	258
28-Apr	105.0	105.0	45.0	44.5	28.0	27.0	0.62	0.61	0	0	253	249	251
29-Apr	104.0	114.0	43.0	51.0	25.0	38.0	0.58	0.75	0	1	235	326	281
30-Apr	124.0	116.0	58.0	53.0	45.0	39.0	0.78	0.74	1	0	401	331	366
01-May	130.0	120.0		54.0		40.0		0.74		1	0	359	420
02-May	117.0	113.0	51.5	49.0	38.0	34.0	0.74	0.69	0	0	316	291	304
03-May	117.0	110.0	55.0	50.0	44.0	35.0	0.80	0.70	1	0	364	301	332

APPENDIX VII: ABSTRACTIONS THROUGH CANALS

Table: A7.3: Canal in savannah - Abst. point no. 26 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
04-May	107.0	105.0	45.0	43.5	27.0	25.0	0.60	0.57	0	0	253	240	246
05-May	0.0	0.0	40.0	39.0	20.0	15.0	0.50	0.38	0	0	209	200	205
06-May	0.0	0.0	36.0	35.0	12.0	11.0	0.33	0.31	0	0	176	168	172
07-May	0.0	0.0	32.0	31.0	10.0	10.0	0.31	0.32	0	0	145	137	141
08-May	0.0	0.0	30.0	29.5	9.5	8.5	0.32	0.29	0	0	130	127	128
09-May	0.0	0.0	28.0	28.0	8.0	8.0	0.29	0.29	0	0	116	116	116
10-May	0.0	0.0	28.5	28.0	8.5	8.0	0.30	0.29	0	0	120	116	118
11-May	0.0	0.0	36.0	37.0	12.0	10.0	0.33	0.27	0	0	176	184	180
12-May	0.0	0.0	35.0	33.0	11.0	10.0	0.31	0.30	0	0	168	152	160
13-May	0.0	0.0	31.0	31.0	10.0	10.0	0.32	0.32	0	0	137	137	137
14-May	123.5	116.0	58.0	50.0	45.0	36.0	0.78	0.72	1	0	401	301	351
15-May	107.0	103.0	44.0	43.0	27.0	35.0	0.61	0.81	0	1	244	241	242
16-May	103.0	106.0	45.0	44.0	37.0	37.0	0.82	0.84	1	1	258	245	252
17-May	0.0	0.0	42.0	41.0	35.0	34.0	0.83	0.83	1	1	229	220	224
18-May	0.0	0.0	40.0	38.0	33.0	30.0	0.83	0.79	1	1	212	199	205
19-May	0.0	0.0	36.0	35.0	29.0	28.5	0.81	0.81	1	1	180	171	176
20-May	124.0	116.5	59.0	53.5	53.0	37.0	0.90	0.69	1	0	371	336	353
21-May	108.0	108.0	45.5	45.0	38.5	38.0	0.85	0.84	1	1	258	254	256
22-May	110.0	109.0	46.5	46.0	39.0	38.0	0.84	0.83	1	1	269	267	268
23-May	117.0	113.0	52.0	49.0	45.0	41.0	0.87	0.84	1	1	316	294	305
24-May	106.0	104.0	48.5	42.0	36.0	35.0	0.74	0.83	1	1	301	229	265
25-May	102.0	102.0	40.0	40.0	33.0	33.0	0.83	0.83	1	1	212	212	212
26-May	103.5	103.0	41.0	41.0	34.5	35.0	0.84	0.85	1	1	218	216	217
27-May	0.0	0.0	37.5	38.0	30.0	31.0	0.80	0.82	1	1	193	196	195
28-May	0.0	0.0	35.0	33.5	27.0	24.0	0.77	0.72	1	0	174	156	165
29-May			30.0	29.0	16.0	11.0	0.53	0.38	0	0	130	123	127
30-May			27.0	26.0	8.0	7.5	0.30	0.29	0	0	110	103	106
31-May			24.5	23.5	7.0	6.5	0.29	0.28	0	0	93	87	90
01-Jun			22.0	22.5	6.0	6.0	0.27	0.27	0	0	78	81	80
02-Jun			23.0	34.5	6.0	20.0	0.26	0.58	0	0	84	164	124
03-Jun			27.0	27.0	8.0	8.0	0.30	0.30	0	0	110	110	110
04-Jun			24.0	23.0	7.0	6.5	0.29	0.28	0	0	90	84	87
05-Jun			39.0	41.0	31.0	35.0	0.79	0.85	1	1	207	216	211
06-Jun			41.5	41.0	35.0	35.0	0.84	0.85	1	1	222	216	219
07-Jun			40.0	38.0	33.0	31.0	0.83	0.82	1	1	212	196	204
08-Jun			29.0	27.0	26.0	25.0	0.90	0.93	1	1	115	96	106
09-Jun	110.5	110.0	49.0	48.0	44.0	44.0	0.90	0.92	1	1	273	254	263
10-Jun		105.0	40.0	44.0	34.5	38.0	0.86	0.86	1	1	205	240	223
11-Jun	112.0	106.0	51.0	44.0	45.0	39.0	0.88	0.89	1	1	299	233	266
12-Jun	103.0	106.0	42.5	44.0	37.0	39.0	0.87	0.89	1	1	225	233	229
13-Jun			36.0	34.5	30.0	27.0	0.83	0.78	1	1	177	170	174
14-Jun			30.5	30.0	21.0	19.0	0.69	0.63	0	0	134	130	132
15-Jun			56.5	48.0	51.0	42.0	0.90	0.88	1	1	342	273	308
16-Jun	130.0	121.0		59.0		54.0		0.92		1	0	358	420
17-Jun			48.5	47.5	44.0	43.0	0.91	0.91	1	1	264	256	260
18-Jun			44.0	40.0	38.0	35.0	0.86	0.88	1	1	240	202	221

APPENDIX VII: ABSTRACTIONS THROUGH CANALS
Table: A7.3: Canal in savannah - Abst. point no. 26 (Conti..)

DATE	GHT (cm)		Hu (cm)		Hd (cm)		Hd/Hu		Remark		Q (l/s)		Qavg
1990/91	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	9.00 am	3.00 pm	(l/s)
19-Jun			38.0	36.5	33.0	31.0	0.87	0.85	1	1	187	179	183
20-Jun			34.0	33.0	28.5	26.5	0.84	0.80	1	1	161	156	159
21-Jun			32.0	30.0	24.5	20.0	0.77	0.67	1	0	151	130	140
22-Jun			27.5	25.0	12.5	9.0	0.45	0.36	0	0	113	97	105
23-Jun			22.0	20.0	6.0	13.5	0.27	0.68	0	0	78	67	73
24-Jun			19.0	18.5	13.5	13.0	0.71	0.70	0	0	62	59	60
25-Jun			18.0	17.0	10.0	6.5	0.56	0.38	0	0	56	51	54
26-Jun			40.0	39.0	26.0	25.0	0.65	0.64	0	0	209	200	205
27-Jun			25.0	23.5	20.0	18.0	0.80	0.77	1	1	99	91	95
28-Jun			19.0	29.5	14.0	24.0	0.74	0.81	0	1	62	129	95
29-Jun			30.0	31.5	24.5	26.0	0.82	0.83	1	1	133	143	138
30-Jun			32.5	31.5	27.0	25.5	0.83	0.81	1	1	150	144	147

APPENDIX VIII: RIVER REACH WATER BALANCE

REACH 1. FOOTZONE (FZ) FROM RGS A3 AND A4 TO A5
REACH 2. SAVANNAH ZONE (SZ) FROM RGS A5 AND A5b TO A6

ELEMENTS CONSIDERED

1. River inflow to reach, RI.
2. River outflow from reach, RO.
3. Abstractions from reach, A.
4. Direct runoff to reach, DR, indicated by rainfall.
5. Gains (+GW) and losses (-GW) in river flow within reach, unknown.
6. ΔQ = RO - RI + A ,represents the increase or decrease in streamflow after abstractions have been accounted for.

1990/91 DATE	JULIAN DAY	RIfz A3+A4	ROfz A5	RIsz A5+A5B	ROsz A6	ABSTRACTIONS Afz	Asz	RAINFALL R4	R5	R6	R7	R8	AREAL RAINFALL FZ	SZ	ΔQ fz	ΔQ sz
		(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(m3/s)	(m3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
01-Nov	305	1.283	1.127	1.127	1.110	0.128	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.028	-0.014
02-Nov	306	1.222	1.179	1.179	1.061	0.125	0.003	0.0	0.0	0.0	0.0	7.2	0.0	3.2	0.083	-0.114
03-Nov	307	2.025	1.740	1.740	1.002	0.127	0.003	8.0	11.1	0.0	0.0	0.0	10.4	0.0	-0.158	-0.735
04-Nov	308	3.660	3.603	3.603	1.764	0.164	0.003	10.2	0.0	0.0	1.5	0.6	2.4	1.1	0.108	-1.836
05-Nov	309	3.794	4.105	4.105	4.013	0.154	0.003	5.1	0.0	0.0	0.0	0.0	1.2	0.9	0.465	-0.089
06-Nov	310	3.362	3.860	3.860	3.066	0.163	0.003	7.2	19.4	0.0	0.0	3.2	16.5	1.4	0.660	-0.791
07-Nov	311	2.587	3.102	3.102	3.037	0.159	0.111	5.8	1.5	0.0	19.8	13.2	2.5	16.8	0.674	0.046
08-Nov	312	2.735	3.161	3.161	2.370	0.151	0.090	2.5	0.0	0.0	0.0	2.7	0.6	1.2	0.577	-0.701
09-Nov	313	2.287	2.631	2.631	2.386	0.131	0.095	4.8	0.0	0.0	0.0	0.7	1.2	0.3	0.474	-0.150
10-Nov	314	1.884	2.347	2.347	2.054	0.137	0.174	3.3	19.0	0.0	0.0	0.0	15.2	0.0	0.600	-0.119
11-Nov	315	1.466	2.182	2.182	1.612	0.158	0.098	0.3	0.0	0.0	0.0	4.3	0.1	1.9	0.874	-0.472
12-Nov	316	1.216	1.547	1.547	1.841	0.112	0.120	46.8	17.5	0.0	33.0	9.7	24.5	22.5	0.443	0.415
13-Nov	317	1.075	1.381	1.381	1.313	0.118	0.071	3.0	5.5	0.0	8.9	3.5	4.9	6.5	0.424	0.003
14-Nov	318	1.284	1.551	1.551	1.191	0.123	0.075	3.9	0.0	0.0	3.3	1.4	0.9	2.4	0.390	-0.285
15-Nov	319	1.325	1.667	1.667	1.257	0.123	0.110	8.1	2.0	0.0	0.0	2.2	3.5	1.0	0.466	-0.300
16-Nov	320	1.007	1.275	1.275	1.036	0.112	0.066	0.0	0.0	0.0	0.0	16.5	0.0	7.4	0.381	-0.173
17-Nov	321	1.082	1.295	1.295	0.879	0.109	0.058	4.1	0.0	0.0	0.0	0.3	1.0	0.1	0.322	-0.358
18-Nov	322	1.205	1.280	1.280	0.870	0.101	0.071	0.0	7.2	0.0	5.3	3.0	5.5	4.3	0.176	-0.339
19-Nov	323	1.150	1.511	1.511	0.843	0.122	0.106	0.0	2.2	0.0	0.0	0.6	1.7	0.3	0.483	-0.562
20-Nov	324	1.351	1.667	1.667	1.077	0.119	0.162	14.8	6.3	0.0	4.3	0.0	8.3	2.4	0.435	-0.428
21-Nov	325	1.162	1.452	1.452	1.076	0.106	0.169	4.8	0.0	0.0	1.5	0.0	1.2	0.8	0.396	-0.207
22-Nov	326	0.924	1.208	1.208	0.940	0.127	0.120	7.3	0.0	0.0	0.0	13.2	1.8	5.9	0.411	-0.148
23-Nov	327	0.778	1.048	1.048	0.751	0.117	0.088	0.0	0.0	0.0	0.5	0.0	0.0	0.3	0.388	-0.209
24-Nov	328	0.732	0.957	0.957	0.680	0.110	0.071	0.0	0.0	0.0	0.0	3.2	0.0	1.4	0.335	-0.207
25-Nov	329	0.669	0.900	0.900	0.680	0.102	0.066	1.7	0.0	0.0	0.0	0.0	0.4	0.0	0.333	-0.154
26-Nov	330	0.584	0.817	0.817	0.637	0.100	0.057	0.0	7.4	0.0	0.0	0.0	5.6	0.0	0.332	-0.123
27-Nov	331	0.682	0.862	0.862	0.552	0.105	0.061	0.0	11.6	0.0	2.5	0.0	8.8	1.4	0.285	-0.248
28-Nov	332	0.772	1.159	1.159	0.693	0.112	0.171	13.2	0.0	0.0	0.0	0.0	3.2	0.0	0.500	-0.295
29-Nov	333	1.313	1.318	1.318	1.128	0.116	0.219	9.3	7.0	0.0	18.3	9.1	7.6	14.2	0.120	0.029
30-Nov	334	1.586	2.251	2.251	1.299	0.136	0.281	21.0	16.5	0.0	2.5	5.4	17.6	3.8	0.801	-0.671
01-Dec	335	1.354	2.305	2.305	1.600	0.145	0.331	19.5	0.0	0.0	0.0	1.2	4.7	0.5	1.095	-0.374
02-Dec	336	0.924	1.405	1.405	1.071	0.135	0.254	7.4	0.0	0.0	0.0	0.0	1.8	0.0	0.616	-0.081
03-Dec	337	0.851	1.132	1.132	0.851	0.116	0.172	0.6	1.9	0.0	0.0	0.3	1.6	0.1	0.397	-0.110
04-Dec	338	0.901	1.181	1.181	0.842	0.113	0.164	9.0	0.0	0.0	0.0	0.0	2.2	0.0	0.394	-0.175

APPENDIX VIII: RIVER REACH WATER BALANCE (CONTI..)

1990/91 DATE	JULIAN DAY	RIfz A3+A4 (m3/s)	ROfz A5 (m3/s)	RIsz A5+A5B (m3/s)	ROsz A6 (m3/s)	ABSTRACTIONS Afz (m3/s)	Asz (m3/s)	RAINFALL R4 (mm)	R5 (mm)	R6 (mm)	R7 (mm)	R8 (mm)	AREAL RAINFALL FZ (mm)	SZ (mm)	ΔQ fz (m3/s)	ΔQ sz (m3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
05-Dec	339	0.830	1.132	1.132	0.810	0.124	0.175	5.2	0.0	0.0	9.7	0.0	1.2	5.3	0.426	-0.148
06-Dec	340	0.768	1.038	1.038	0.680	0.120	0.145	2.4	13.6	0.0	0.0	0.0	10.9	0.0	0.389	-0.213
07-Dec	341	0.850	0.979	0.979	0.686	0.119	0.131	0.5	3.7	0.0	17.0	23.1	2.9	19.8	0.248	-0.162
08-Dec	342	4.829	5.856	5.856	4.548	0.182	0.359	14.5	0.0	0.0	4.3	10.6	3.5	7.1	1.208	-0.948
09-Dec	343	1.838	2.630	2.630	2.102	0.137	0.346	4.5	4.0	0.0	0.0	0.0	4.1	0.0	0.929	-0.183
10-Dec	344	1.274	1.684	1.684	1.236	0.136	0.211	7.0	21.0	0.0	1.3	3.4	17.6	2.2	0.546	-0.238
11-Dec	345	2.005	2.636	2.636	1.580	0.140	0.192	7.7	5.0	0.0	9.7	4.0	5.6	7.1	0.771	-0.864
12-Dec	346	3.010	4.067	4.067	3.406	0.167	0.536	14.9	21.7	0.0	5.6	1.5	20.1	3.9	1.223	-0.125
13-Dec	347	1.910	3.294	3.294	2.120	0.174	0.365	3.3	17.1	0.0	25.4	9.9	13.8	18.4	1.558	-0.809
14-Dec	348	2.141	4.007	4.007	5.116	0.173	0.574	14.2	0.3	0.0	4.8	1.3	3.6	3.2	2.039	1.683
15-Dec	349	2.484	3.753	3.753	3.349	0.170	0.527	17.7	1.6	0.0	0.0	0.0	5.5	0.0	1.440	0.122
16-Dec	350	1.885	2.449	2.449	2.410	0.161	0.298	0.0	0.0	0.0	0.0	3.4	0.0	1.5	0.724	0.260
17-Dec	351	1.990	2.712	2.712	1.980	0.157	0.275	0.5	0.0	0.0	0.0	0.0	0.1	0.0	0.979	-0.457
18-Dec	352	3.039	4.310	4.310	2.050	0.177	0.310	4.3	0.0	0.0	0.0	0.0	1.0	0.0	1.448	-1.951
19-Dec	353	2.165	2.884	2.884	3.156	0.161	0.387	45.2	0.0	0.0	0.0	5.9	10.8	2.7	0.880	0.659
20-Dec	354	1.645	2.149	2.149	2.022	0.136	0.274	2.7	0.0	0.0	0.0	0.0	0.6	0.0	0.640	0.148
21-Dec	355	1.378	1.846	1.846	1.621	0.143	0.234	4.0	0.0	0.0	0.0	0.0	1.0	0.0	0.611	0.009
22-Dec	356	1.268	1.664	1.664	1.375	0.138	0.207	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.534	-0.083
23-Dec	357	1.146	1.494	1.494	1.235	0.117	0.185	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.465	-0.073
24-Dec	358	1.013	1.367	1.367	1.100	0.125	0.165	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.479	-0.102
25-Dec	359	0.917	1.246	1.246	0.968	0.108	0.146	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.437	-0.132
26-Dec	360	0.818	1.069	1.069	0.893	0.110	0.128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.361	-0.048
27-Dec	361	0.757	0.993	0.993	0.760	0.107	0.112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.343	-0.121
28-Dec	362	0.694	0.948	0.948	0.637	0.103	0.129	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.358	-0.182
29-Dec	363	0.664	0.906	0.906	0.561	0.100	0.150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.342	-0.196
30-Dec	364	0.628	0.863	0.863	0.544	0.088	0.134	0.0	0.0	0.0	13.5	0.0	0.0	7.4	0.323	-0.185
31-Dec	365	0.594	0.782	0.782	0.680	0.102	0.192	0.0	9.3	0.0	0.0	8.7	7.1	3.9	0.290	0.090
01-Jan	1	0.842	1.323	1.323	0.865	0.107	0.256	6.6	17.9	0.0	0.0	6.2	15.2	2.8	0.588	-0.202
02-Jan	2	0.697	1.083	1.083	0.650	0.109	0.360	22.6	0.0	0.0	17.5	0.0	5.4	9.6	0.494	-0.072
03-Jan	3	0.613	0.959	0.959	0.578	0.107	0.276	0.0	2.0	0.0	11.4	5.4	1.5	8.7	0.453	-0.106
04-Jan	4	0.654	0.958	0.958	0.508	0.086	0.268	5.1	0.0	0.0	0.0	0.0	1.2	0.0	0.390	-0.183
05-Jan	5	0.569	0.886	0.886	0.432	0.081	0.261	0.6	1.2	0.0	0.0	0.0	1.1	0.0	0.397	-0.193
06-Jan	6	0.522	0.817	0.817	0.409	0.074	0.239	0.0	2.0	0.0	0.0	0.0	1.5	0.0	0.369	-0.169
07-Jan	7	0.550	0.790	0.790	0.635	0.074	0.218	0.0	0.0	0.0	0.0	0.8	0.0	0.4	0.314	0.064
08-Jan	8	0.836	1.095	1.095	0.488	0.080	0.292	1.3	0.0	0.0	0.0	0.0	0.3	0.0	0.340	-0.315
09-Jan	9	0.577	0.872	0.872	0.372	0.070	0.268	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.365	-0.232
10-Jan	10	0.512	0.790	0.790	0.430	0.080	0.228	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.357	-0.131
11-Jan	11	0.630	0.888	0.888	0.357	0.073	0.215	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.331	-0.315
12-Jan	12	0.509	0.659	0.659	0.320	0.058	0.226	1.0	4.1	0.0	0.0	0.0	3.4	0.0	0.208	-0.113
13-Jan	13	0.467	0.738	0.738	0.320	0.059	0.212	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.330	-0.206
14-Jan	14	0.406	0.712	0.712	0.277	0.078	0.201	7.6	0.0	0.0	0.0	0.0	1.8	0.0	0.384	-0.234
15-Jan	15	0.398	0.663	0.663	0.237	0.073	0.171	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.339	-0.255
16-Jan	16	0.417	0.675	0.675	0.217	0.072	0.158	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.330	-0.300
17-Jan	17	0.386	0.487	0.487	0.217	0.085	0.168	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.185	-0.102

APPENDIX VIII: RIVER REACH WATER BALANCE (CONTI..)

1990/91 DATE	JULIAN DAY	RIfz A3+A4 (m3/s)	ROfz A5 (m3/s)	RIsz A5+A5B (m3/s)	ROsz A6 (m3/s)	ABSTRACTIONS Afz (m3/s)	ABSTRACTIONS Asz (m3/s)	RAINFALL R4 (mm)	RAINFALL R5 (mm)	RAINFALL R6 (mm)	RAINFALL R7 (mm)	RAINFALL R8 (mm)	AREAL RAINFALL FZ (mm)	AREAL RAINFALL SZ (mm)	ΔQ fz (m3/s)	ΔQ sz (m3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
18-Jan	18	0.367	0.435	0.435	0.217	0.081	0.157	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.149	-0.061
19-Jan	19	0.370	0.406	0.406	0.204	0.088	0.145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.125	-0.057
20-Jan	20	0.355	0.361	0.361	0.201	0.087	0.144	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.093	-0.016
21-Jan	21	0.317	0.343	0.343	0.201	0.081	0.134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.107	-0.008
22-Jan	22	0.307	0.327	0.327	0.182	0.087	0.108	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.106	-0.036
23-Jan	23	0.300	0.327	0.327	0.161	0.087	0.092	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.113	-0.074
24-Jan	24	0.295	0.335	0.335	0.161	0.075	0.090	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.114	-0.084
25-Jan	25	0.327	0.343	0.343	0.137	0.098	0.110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.115	-0.096
26-Jan	26	0.350	0.343	0.343	0.170	0.116	0.103	0.0	0.0	0.0	2.0	0.0	0.0	1.1	0.109	-0.070
27-Jan	27	0.368	0.335	0.335	0.182	0.113	0.111	4.3	3.2	0.0	22.4	3.1	3.5	13.7	0.080	-0.042
28-Jan	28	0.450	0.390	0.390	0.204	0.119	0.120	2.2	0.0	0.0	2.5	0.5	0.5	1.6	0.049	-0.056
29-Jan	29	0.488	0.445	0.445	0.208	0.122	0.162	3.5	0.0	0.0	0.0	0.0	0.8	0.0	0.080	-0.076
30-Jan	30	0.383	0.305	0.305	0.268	0.115	0.154	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.036	0.117
31-Jan	31	0.359	0.249	0.249	0.217	0.118	0.136	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.007	0.104
01-Feb	32	0.338	0.221	0.221	0.198	0.100	0.116	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.017	0.092
02-Feb	33	0.286	0.214	0.214	0.186	0.093	0.091	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.021	0.063
03-Feb	34	0.279	0.201	0.201	0.126	0.093	0.077	0.0	30.6	0.0	0.0	0.0	23.3	0.0	0.014	0.002
04-Feb	35	0.314	0.232	0.232	0.141	0.111	0.066	0.0	0.0	0.0	8.1	3.0	0.0	5.8	0.028	-0.025
05-Feb	36	0.300	0.229	0.229	0.176	0.097	0.133	6.7	0.0	0.0	0.0	0.0	1.6	0.0	0.025	0.081
06-Feb	37	0.281	0.189	0.189	0.126	0.096	0.080	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.005	0.016
07-Feb	38	0.282	0.164	0.164	0.126	0.088	0.060	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.030	0.022
08-Feb	39	0.260	0.164	0.164	0.081	0.092	0.068	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.004	-0.015
09-Feb	40	0.263	0.176	0.176	0.049	0.090	0.082	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.003	-0.045
10-Feb	41	0.253	0.164	0.164	0.049	0.077	0.076	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.011	-0.038
11-Feb	42	0.239	0.164	0.164	0.049	0.067	0.078	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.008	-0.037
12-Feb	43	0.273	0.164	0.164	0.041	0.089	0.078	5.2	0.0	0.0	0.0	0.0	1.2	0.0	-0.019	-0.046
13-Feb	44	0.249	0.164	0.164	0.037	0.084	0.097	0.0	0.0	0.0	21.1	0.0	0.0	11.6	0.000	-0.031
14-Feb	45	0.247	0.164	0.164	0.037	0.090	0.099	6.7	0.0	0.0	0.0	0.0	1.6	0.0	0.008	-0.028
15-Feb	46	0.227	0.164	0.164	0.043	0.081	0.079	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.018	-0.043
16-Feb	47	0.202	0.164	0.164	0.037	0.073	0.071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.036	-0.057
17-Feb	48	0.200	0.164	0.164	0.037	0.075	0.058	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.039	-0.069
18-Feb	49	0.202	0.164	0.164	0.037	0.073	0.051	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.036	-0.077
19-Feb	50	0.196	0.164	0.164	0.037	0.076	0.055	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.044	-0.073
20-Feb	51	0.191	0.164	0.164	0.037	0.078	0.069	0.0	15.5	0.0	0.0	0.0	11.8	0.0	0.051	-0.059
21-Feb	52	0.255	0.164	0.164	0.037	0.076	0.068	0.0	6.8	0.0	0.0	3.1	5.2	1.4	-0.014	-0.060
22-Feb	53	0.262	0.330	0.330	0.051	0.096	0.066	1.9	18.8	0.0	0.0	8.9	14.7	4.0	0.164	-0.212
23-Feb	54	0.224	0.235	0.235	0.049	0.100	0.093	1.2	1.0	0.0	2.3	13.7	1.0	7.4	0.111	-0.093
24-Feb	55	0.222	0.164	0.164	0.042	0.094	0.126	5.2	0.8	0.0	12.2	0.6	1.9	7.0	0.036	0.003
25-Feb	56	0.235	0.164	0.164	0.113	0.084	0.109	0.0	0.0	0.0	2.3	0.0	0.0	1.3	0.014	0.057
26-Feb	57	0.195	0.164	0.164	0.066	0.076	0.097	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.045	-0.001
27-Feb	58	0.182	0.164	0.164	0.049	0.074	0.083	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.056	-0.032
28-Feb	59	0.170	0.164	0.164	0.049	0.077	0.082	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.072	-0.033
01-Mar	60	0.166	0.196	0.196	0.049	0.082	0.075	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.112	-0.071
02-Mar	61	0.169	0.128	0.128	0.049	0.084	0.055	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.043	-0.023

APPENDIX VIII: RIVER REACH WATER BALANCE (CONTI..)

1990/91 DATE	JULIAN DAY	RIfz A3+A4	ROfz A5	RIsz A5+A5B	ROsz A6	ABSTRACTIONS Afz	ABSTRACTIONS Asz	RAINFALL R4	RAINFALL R5	RAINFALL R6	RAINFALL R7	RAINFALL R8	AREAL RAINFALL FZ	AREAL RAINFALL SZ	ΔQ fz	ΔQ sz
		(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(m3/s)	(m3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
03-Mar	62	0.167	0.102	0.102	0.026	0.087	0.052	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.023	-0.025
04-Mar	63	0.176	0.102	0.102	0.014	0.087	0.054	0.0	1.6	0.0	0.0	0.0	1.2	0.0	0.013	-0.034
05-Mar	64	0.172	0.164	0.164	0.014	0.090	0.052	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.082	-0.098
06-Mar	65	0.209	0.164	0.164	0.014	0.087	0.083	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.043	-0.067
07-Mar	66	0.370	0.196	0.196	0.014	0.134	0.096	9.7	0.0	0.0	0.0	0.0	2.3	0.0	-0.040	-0.086
08-Mar	67	0.215	0.128	0.128	0.014	0.089	0.201	0.0	3.2	0.0	0.0	0.0	2.4	0.0	0.002	0.087
09-Mar	68	0.183	0.102	0.102	0.059	0.080	0.088	0.0	0.5	0.0	0.0	15.9	0.4	7.2	-0.001	0.044
10-Mar	69	0.183	0.102	0.102	0.049	0.087	0.076	0.0	14.7	0.0	0.0	0.0	11.2	0.0	0.006	0.023
11-Mar	70	0.313	0.102	0.102	0.020	0.096	0.065	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.115	-0.017
12-Mar	71	0.401	0.247	0.247	0.014	0.147	0.069	9.8	10.8	0.0	0.0	4.0	10.6	1.8	-0.007	-0.163
13-Mar	72	0.529	0.189	0.189	0.149	0.190	0.179	9.3	28.2	0.0	5.1	4.4	23.7	4.8	-0.150	0.140
14-Mar	73	0.548	0.552	0.552	0.091	0.174	0.253	3.2	0.0	0.0	3.0	0.0	0.8	1.7	0.178	-0.208
15-Mar	74	0.325	0.241	0.241	0.582	0.156	0.372	3.1	0.0	0.0	37.1	0.0	0.7	20.4	0.072	0.713
16-Mar	75	0.251	0.142	0.142	0.220	0.141	0.186	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.032	0.263
17-Mar	76	0.207	0.117	0.117	0.087	0.128	0.116	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.037	0.087
18-Mar	77	0.190	0.102	0.102	0.043	0.108	0.098	0.0	3.8	0.0	0.0	0.0	2.9	0.0	0.021	0.039
19-Mar	78	0.184	0.102	0.102	0.037	0.103	0.090	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.021	0.024
20-Mar	79	0.163	0.102	0.115	0.037	0.112	0.085	6.7	0.0	0.0	0.0	0.0	1.6	0.0	0.052	0.007
21-Mar	80	0.152	0.077	0.088	0.037	0.106	0.092	0.0	1.2	0.0	0.0	0.0	0.9	0.0	0.031	0.040
22-Mar	81	0.143	0.077	0.088	0.037	0.086	0.065	1.1	0.0	0.0	0.0	1.9	0.3	0.9	0.020	0.014
23-Mar	82	0.138	0.077	0.088	0.037	0.056	0.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.005	0.012
24-Mar	83	0.143	0.103	0.114	0.037	0.038	0.085	3.1	0.0	0.0	2.3	0.9	0.7	1.7	-0.002	0.008
25-Mar	84	0.148	0.099	0.110	0.037	0.038	0.097	0.0	11.9	0.0	0.0	0.0	9.0	0.0	-0.011	0.024
26-Mar	85	0.555	0.128	0.138	0.037	0.111	0.075	1.8	25.5	0.0	12.2	21.1	19.8	16.2	-0.317	-0.026
27-Mar	86	2.662	2.846	2.989	0.911	0.211	0.743	14.0	0.0	0.0	40.4	30.2	3.4	35.8	0.395	-1.335
28-Mar	87	1.493	1.312	1.373	2.144	0.073	0.508	8.4	0.9	0.0	3.6	0.0	2.7	2.0	-0.108	1.279
29-Mar	88	0.990	0.867	0.885	0.997	0.027	0.320	0.0	1.2	0.0	0.0	10.4	0.9	4.7	-0.096	0.432
30-Mar	89	0.655	0.737	0.752	0.979	0.053	0.367	4.3	0.0	0.0	0.0	0.0	1.0	0.0	0.135	0.595
31-Mar	90	1.219	0.829	0.839	0.545	0.029	0.216	0.6	0.0	0.0	0.0	0.0	0.1	0.0	-0.361	-0.078
01-Apr	91	1.127	1.319	1.331	1.382	0.091	0.526	0.0	3.3	0.0	0.0	0.0	2.5	0.0	0.283	0.577
02-Apr	92	1.070	0.642	0.653	0.862	0.124	0.350	3.3	9.5	0.0	12.7	3.7	8.0	8.7	-0.304	0.559
03-Apr	93	1.030	0.934	1.070	1.014	0.174	0.418	11.4	2.3	0.0	13.0	0.0	4.5	7.1	0.078	0.362
04-Apr	94	0.687	0.620	0.750	1.057	0.114	0.352	31.1	0.0	0.0	1.3	0.0	7.5	0.7	0.047	0.658
05-Apr	95	0.446	0.380	0.404	0.592	0.131	0.206	0.0	0.0	0.0	1.3	33.5	0.0	15.8	0.064	0.393
06-Apr	96	0.411	0.310	0.324	0.413	0.113	0.139	3.5	3.7	0.0	0.0	8.9	2.7	4.0	0.012	0.228
07-Apr	97	0.411	0.310	0.348	0.382	0.098	0.096	2.2	0.0	9.4	7.6	0.4	0.5	4.4	-0.002	0.131
08-Apr	98	0.351	0.272	0.309	0.413	0.099	0.119	12.0	1.8	0.0	3.3	0.0	3.8	1.8	0.019	0.223
09-Apr	99	0.366	0.264	0.282	0.331	0.106	0.084	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.003	0.133
10-Apr	100	0.298	0.271	0.286	0.295	0.108	0.087	6.3	6.7	0.0	3.0	0.0	4.9	1.7	0.082	0.096
11-Apr	101	0.282	0.286	0.301	0.285	0.078	0.067	4.2	3.0	4.1	0.0	0.0	5.6	0.0	0.082	0.051
12-Apr	102	0.303	0.286	0.304	0.247	0.066	0.070	1.6	9.5	0.4	0.0	0.0	6.2	0.0	0.049	0.014
13-Apr	103	0.312	0.286	0.303	0.250	0.051	0.120	0.2	0.0	4.8	0.0	8.9	0.0	4.0	0.024	0.068
14-Apr	104	0.280	0.286	0.309	0.149	0.024	0.192	11.1	0.0	0.0	0.0	0.3	2.7	0.1	0.030	0.031
15-Apr	105	0.230	0.286	0.307	0.204	0.053	0.175	0.0	2.0	0.0	0.0	0.0	1.0	0.0	0.109	0.073

APPENDIX VIII: RIVER REACH WATER BALANCE (CONTI..)

1990/91 DATE	JULIAN DAY	RIfz A3+A4 (m3/s)	ROfz A5 (m3/s)	RIsz A5+A5B (m3/s)	ROsz A6 (m3/s)	ABSTRACTIONS Afz (m3/s)	ABSTRACTIONS Asz (m3/s)	RAINFALL R4 (mm)	R5 (mm)	R6 (mm)	R7 (mm)	R9 (mm)	AREAL RAINFALL FZ (mm)	SZ (mm)	ΔQ fz (m3/s)	ΔQ sz (m3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
16-Apr	106	0.214	0.264	0.282	0.170	0.061	0.160	0.0	3.2	1.3	0.0	0.0	2.7	0.0	0.111	0.048
17-Apr	107	0.402	0.306	0.337	0.126	0.126	0.153	1.6	0.0	9.0	3.0	0.0	0.4	1.7	0.029	-0.058
18-Apr	108	0.538	0.494	0.529	0.204	0.136	0.230	2.5	0.0	1.1	0.5	0.0	0.6	0.3	0.092	-0.095
19-Apr	109	0.460	0.362	0.385	0.391	0.128	0.270	2.3	12.5	1.0	3.6	0.0	10.1	2.0	0.029	0.275
20-Apr	110	0.637	0.621	0.686	0.358	0.136	0.364	3.8	0.0	8.8	5.3	0.3	0.9	3.1	0.120	0.036
21-Apr	111	1.119	0.621	0.690	0.684	0.172	0.444	12.3	0.0	0.0	0.0	0.0	3.0	0.0	-0.326	0.438
22-Apr	112	2.172	1.361	1.388	0.954	0.101	0.524	0.5	3.2	0.5	0.0	3.3	2.2	1.5	-0.710	0.091
23-Apr	113	1.469	2.015	2.035	2.015	0.124	0.652	3.5	10.8	0.8	6.6	0.0	8.5	3.6	0.670	0.632
24-Apr	114	1.156	0.903	0.922	1.223	0.151	0.407	0.0	2.2	2.7	5.3	0.0	2.6	2.9	-0.101	0.709
25-Apr	115	1.114	1.059	1.073	1.152	0.105	0.544	10.5	1.8	10.9	0.0	0.0	8.3	0.0	0.050	0.623
26-Apr	116	0.851	0.833	0.844	0.945	0.132	0.471	2.5	1.8	0.5	2.3	0.0	1.7	1.3	0.114	0.572
27-Apr	117	0.750	0.700	0.710	0.805	0.124	0.363	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.074	0.458
28-Apr	118	0.779	0.537	0.548	0.681	0.129	0.340	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.113	0.472
29-Apr	119	1.414	0.857	0.868	0.733	0.153	0.396	0.0	0.0	0.3	0.5	9.2	0.0	4.4	-0.404	0.261
30-Apr	120	3.492	3.559	3.569	1.317	0.149	0.555	14.0	0.0	0.0	0.0	0.0	3.4	0.0	0.215	-1.698
01-May	121	2.345	2.920	2.930	3.911	0.103	0.673	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.677	1.654
02-May	122	1.787	1.734	1.744	1.859	0.084	0.484	6.6	0.0	1.7	0.0	0.0	1.6	0.0	0.030	0.598
03-May	123	1.559	1.732	1.742	1.789	0.083	0.532	6.5	0.0	0.0	0.0	0.0	1.6	0.0	0.256	0.579
04-May	124	0.955	0.960	0.970	1.240	0.075	0.369	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.080	0.639
05-May	125	0.724	0.720	0.731	0.931	0.131	0.267	0.0	1.2	0.1	0.0	0.0	0.6	0.0	0.126	0.467
06-May	126	0.607	0.564	0.575	0.753	0.118	0.224	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.075	0.402
07-May	127	0.552	0.481	0.491	0.599	0.108	0.187	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.037	0.295
08-May	128	0.497	0.444	0.454	0.512	0.110	0.172	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.056	0.230
09-May	129	0.561	0.454	0.464	0.437	0.106	0.159	2.3	7.9	1.0	1.0	0.3	6.6	0.7	-0.001	0.132
10-May	130	0.533	0.445	0.627	0.459	0.109	0.161	2.6	8.1	9.3	20.3	1.0	23.6	11.6	0.020	-0.009
11-May	131	0.539	0.471	0.552	0.675	0.078	0.237	16.3	7.3	5.3	0.0	0.0	17.3	0.0	0.009	0.359
12-May	132	0.505	0.441	0.491	0.505	0.066	0.229	11.4	6.1	7.2	3.8	0.0	16.8	2.1	0.001	0.242
13-May	133	1.440	0.711	1.053	0.459	0.051	0.199	10.0	0.0	2.9	3.6	3.6	2.4	3.6	-0.678	-0.395
14-May	134	1.719	2.095	2.361	1.885	0.051	0.530	23.0	0.0	4.4	3.0	2.2	5.5	2.7	0.426	0.054
15-May	135	0.905	0.840	0.903	1.346	0.053	0.351	0.5	0.0	0.0	0.0	0.0	0.1	0.0	-0.012	0.794
16-May	136	1.231	1.020	1.044	0.858	0.112	0.360	4.4	0.0	0.0	1.3	0.0	1.1	0.7	-0.099	0.174
17-May	137	0.853	0.807	0.827	1.151	0.082	0.325	0.0	5.4	1.0	0.0	0.0	4.1	0.0	0.036	0.648
18-May	138	0.700	0.593	0.613	0.708	0.106	0.293	0.0	3.8	5.5	0.0	0.0	7.2	0.0	-0.001	0.388
19-May	139	2.236	2.432	2.453	0.592	0.087	0.251	9.1	2.5	3.5	6.9	0.5	5.6	4.0	0.284	-1.609
20-May	140	1.750	1.860	1.880	2.432	0.103	0.536	5.3	3.4	2.6	2.3	0.6	5.2	1.5	0.213	1.088
21-May	141	1.773	1.819	1.841	1.487	0.108	0.377	2.1	0.0	4.4	3.6	1.6	0.5	2.7	0.154	0.023
22-May	142	2.035	1.797	1.819	1.599	0.082	0.391	1.7	0.0	0.2	0.0	1.0	0.4	0.5	-0.156	0.172
23-May	143	1.427	1.454	1.475	1.738	0.115	0.489	3.4	0.0	0.0	0.0	0.0	0.8	0.0	0.143	0.753
24-May	144	1.013	0.954	0.975	1.139	0.075	0.400	2.0	1.0	0.1	0.0	0.0	1.0	0.0	0.017	0.564
25-May	145	0.916	0.803	0.824	0.886	0.065	0.329	0.0	0.0	0.7	2.0	0.3	0.0	1.3	-0.047	0.391
26-May	146	0.920	0.839	0.859	0.832	0.065	0.336	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.016	0.310
27-May	147	0.778	0.719	0.736	0.798	0.089	0.299	0.0	0.0	0.0	11.7	4.3	0.0	8.4	0.029	0.361
28-May	148	0.659	0.565	0.580	0.692	0.109	0.256	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.015	0.367
29-May	149	0.552	0.454	0.469	0.515	0.131	0.200	0.0	0.0	0.0	3.6	0.0	0.0	2.0	0.034	0.245

APPENDIX VIII: RIVER REACH WATER BALANCE (CONTI..)

1990/91 DATE	JULIAN DAY	RIfz A3+A4 (m3/s)	ROfz A5 (m3/s)	RIsz A5+A5B (m3/s)	ROsz A6 (m3/s)	ABSTRACTIONS Afz (m3/s)	ABSTRACTIONS Asz (m3/s)	RAINFALL R4 (mm)	RAINFALL R5 (mm)	RAINFALL R6 (mm)	RAINFALL R7 (mm)	RAINFALL R8 (mm)	AREAL RAINFALL FZ (mm)	AREAL RAINFALL SZ (mm)	ΔQ fz (m3/s)	ΔQ sz (m3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
30-May	150	0.494	0.378	0.392	0.405	0.136	0.170	0.0	0.0	0.0	0.8	0.0	0.0	0.4	0.020	0.183
31-May	151	0.439	0.337	0.350	0.351	0.121	0.147	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.019	0.148
01-Jun	152	0.395	0.302	0.313	0.307	0.103	0.137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.011	0.131
02-Jun	153	0.735	0.488	0.499	0.354	0.092	0.207	0.0	0.0	0.0	0.0	37.4	0.0	16.8	-0.154	0.062
03-Jun	154	0.500	0.412	0.422	0.518	0.099	0.178	0.0	3.5	0.0	0.0	2.5	1.8	1.1	0.010	0.274
04-Jun	155	0.666	0.463	0.472	0.408	0.119	0.151	0.0	6.4	4.0	8.1	8.2	9.7	8.1	-0.084	0.086
05-Jun	156	0.805	0.726	0.741	0.575	0.103	0.299	15.0	5.8	10.9	27.4	7.2	22.4	18.3	0.025	0.133
06-Jun	157	0.699	0.498	0.514	0.715	0.089	0.286	4.0	9.6	2.9	1.0	10.3	12.8	5.2	-0.113	0.487
07-Jun	158	0.786	0.641	0.655	0.626	0.120	0.295	0.0	2.5	11.7	0.5	0.0	8.6	0.3	-0.024	0.265
08-Jun	159	0.935	0.432	0.475	0.564	0.125	0.160	0.0	6.7	1.0	14.7	4.9	5.1	10.3	-0.379	0.248
09-Jun	160	1.161	0.882	0.945	0.782	0.116	0.387	10.7	0.0	4.0	0.0	0.0	2.6	0.0	-0.163	0.224
10-Jun	161	1.353	0.902	0.938	0.837	0.122	0.325	2.0	12.5	0.0	0.0	2.9	6.9	1.3	-0.329	0.224
11-Jun	162	1.519	1.108	1.140	1.063	0.134	0.402	0.0	0.0	7.5	5.3	15.6	0.0	9.9	-0.278	0.325
12-Jun	163	1.346	1.013	1.066	1.016	0.108	0.346	10.7	0.0	0.0	0.0	4.9	2.6	2.2	-0.225	0.296
13-Jun	164	0.851	0.622	0.652	0.856	0.106	0.259	0.0	3.3	0.0	0.0	0.0	1.7	0.0	-0.123	0.463
14-Jun	165	1.599	1.121	1.142	0.606	0.082	0.202	0.0	2.0	0.0	0.0	0.0	1.0	0.0	-0.396	-0.334
15-Jun	166	3.979	5.734	5.750	1.397	0.096	0.466	0.0	0.0	3.4	0.0	0.0	0.0	0.0	1.851	-3.887
16-Jun	167	2.204	2.697	2.721	4.763	0.051	0.591	8.3	0.0	0.4	1.5	5.3	2.0	3.2	0.544	2.633
17-Jun	168	1.112	0.938	0.965	1.613	0.049	0.333	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.124	0.981
18-Jun	169	0.849	0.685	0.703	1.092	0.046	0.268	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.117	0.657
19-Jun	170	0.705	0.551	0.565	0.884	0.043	0.220	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.111	0.539
20-Jun	171	0.612	0.467	0.479	0.746	0.047	0.193	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.098	0.459
21-Jun	172	0.590	0.425	0.437	0.658	0.053	0.174	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.111	0.396
22-Jun	173	0.551	0.356	0.367	0.544	0.074	0.162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.120	0.339
23-Jun	174	0.511	0.327	0.337	0.414	0.095	0.174	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.089	0.251
24-Jun	175	0.462	0.299	0.309	0.370	0.107	0.160	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.056	0.221
25-Jun	176	0.777	0.339	0.348	0.343	0.106	0.149	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.331	0.144
26-Jun	177	0.754	0.636	0.644	0.560	0.119	0.299	7.4	0.0	0.0	0.0	0.0	1.8	0.0	0.001	0.216
27-Jun	178	0.515	0.365	0.372	0.575	0.109	0.270	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.041	0.473
28-Jun	179	0.446	0.302	0.308	0.399	0.090	0.222	0.0	3.0	0.0	0.0	0.0	1.5	0.0	-0.054	0.313
29-Jun	180	0.436	0.273	0.279	0.286	0.105	0.245	0.0	0.0	5.1	0.0	4.2	0.0	1.9	-0.058	0.252
30-Jun	181	0.407	0.269	0.277	0.267	0.087	0.244	4.8	3.8	1.5	6.4	0.0	4.5	3.5	-0.051	0.234

APPENDIX IX: Mean monthly rainfall for lower Naro Moru river basin (1990/91)

STATION MONTH	R3	R4	R5	R6	R7	R8
JAN	0.0	-	-	-	31.5	-
FEB	76.7	59.9	-	-	103.1	-
MAR	238.2	291.3	-	-	136.7	-
APR	267.2	214.6	-	-	118.6	-
MAY	151.9	104.5	-	-	47.2	-
JUN	34.2	14.3	-	-	0.0	-
JUL	66.8	24.6	-	-	31.8	-
AUG	126.2	17.7	-	-	24.9	9.2
SEP	90.1	33.3	-	-	2.0	7.2
OCT	161.4	146.0	75.5	-	58.7	79.5
NOV	149.4	185.2	134.2	-	101.6	100.0
DEC	111.5	185.1	99.2	-	91.4	73.3
JAN	52.7	54.8	30.4	-	55.9	16.0
FEB	17.6	26.9	73.5	-	46.0	29.3
MAR	200.0	75.1	103.5	-	103.6	88.8
APR	172.7	145.1	81.1	58.9	69.3	68.5
MAY	-	107.2	46.7	55.5	63.8	15.4
JUN	-	62.9	59.1	52.4	5.3	103.4

Note: Location of rain gauges is shown in Fig. 4.1

APPENDIX X: 1990/91 Mean monthly discharge (m^3/s) for station A5 compared with long term average flows

MONTH	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1960-1987*	2.070	1.200	0.665	0.534	0.688	1.660	1.730	0.855
1990/91	1.806	2.090	0.623	0.184	0.337	0.708	1.027	0.809

* Source: Republic of Kenya, 1990