

Lui River Valley Model
and some of its applications

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FOREWORD

Most of the methods to describe processes in the hydrological cycle like rainfall-runoff relationships and to assess the magnitude of extreme events and their statistical recurrence period have been developed on data collected in the climatically moderate zones of the earth. Hydrological phenomena of the tropics were frequently described and quantified by techniques developed elsewhere. The lack of appropriate methods lead to over- or underestimation of resources and risks. In this respect the present work of Ir. C.J.M. Bastiaansen is an essential step to avoid this type of errors in resource development.

The application of conceptual hydrological models and their calibration with flood data collected in the Lui river valley in Zambia is providing a sound framework to estimate the feasibility and possible extent of rice cultivation in the valley.

The Department of Water Resources of the Wageningen Agricultural University hosted the author during the preparation phase of this report. The collaboration, especially with Drs. P.J.J.F. Torfs was mutually beneficial.

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Prof. Dr.-Ing. J.J. Bogardi,
Chairman Dept. of Water Resources

Wageningen, February 1995

Summary .

The Lui River Valley is a wetland area in Zambia's Western Province Zambia, within the so-called Barotse Sands which are part of the Kalahari sandplains. Its catchment area consist approximately of 14% wetland and 86% upland. The main land use of the wetland(s) is cattle grazing during the dry season and, more recently, rice cultivation.

There are no flood level records for the Lui river valley, and thus no proper information is available about the Lui river flood regime. In order to evaluate the valley's physical suitability for rice cultivation, a hydrological model has been set up. It could assist in generating simulated data about the flood regime in relation to rice cultivation, i.e. planting date as related to the arrival of the floods, variation in flood depths as related to maximum flood level fluctuations and length of growing season as related to the duration of the flood season.

Rainfall and flood level data have been recorded during four hydrological seasons. During the same period, rating curves have been determined and topographic and soil data were collected.

The model consists of three parts: one for the upland root zone, a second for the upland groundwater reservoir, and a third for the wetland reservoir. The upland root zone model uses the so-called "threshold" concept, while the two reservoir models are based on linear reservoir theory. The whole model has a strongly conceptual approach.

The data (or model variables), obtained from monitoring four hydrological seasons, are used to calibrate the model and to derive its parameters. Wetland reaction factors were derived from the slopes of the recession curves of monitored hydrographs.

Model results can be summarised as follows. The floods start at the beginning of January and they reach their peak either during the last 8 days of February or early in March. Peak flows at Litawa vary between $18.3 \text{ m}^3 \text{ s}^{-1}$ (10% probability of non-exceedance) and $50.4 \text{ m}^3 \text{ s}^{-1}$ (90% probability of non-exceedance). In terms of flood levels, this means a fluctuation of peak flood levels of 0.34 m . For Sasenda, this figure equals 0.30 m . Flood recession depends on the height of the maximum floods and the value of the recession

constant ($e^{-\alpha}$), or α -value and takes between 3 and 5 months.

From the mean annual amount of rainfall of 876 mm at Litawa almost 68% is lost by evapotranspiration from the upland and another 25% by evapotranspiration from the wetland. Only 7% ends up as river discharge and causes the seasonal floods.

Sensitivity analyses proved the model's insensitivity for the variations of model parameters such as maximum soil moisture capacity, upland evapotranspiration coefficients and the upland reservoir reaction factor. However, the upland reservoir reaction factor could not be estimated more precisely than being a value between 0.001 and 0.002 day⁻¹. This means that, though the approximate movements of the upland groundwater table are known, its exact amplitude (i.e. the maximum and minimum groundwater table levels) is not well known. The assumed value for the macro-porosity contributes also to this uncertainty.

Model results, in terms of an evaluation of the possibility to grow rice in the Lui river valley under the simulated flood regime, are summarized below:

- The last possible planting date for rice is the first of December for long-straw varieties and the 10-th of December for short-straw varieties. Farmers have difficulties in meeting the given dates due to either an insufficient capacity for land preparation and row planting, or a late start of the rains to have sufficient time to plant early.
- The fluctuation range in maximum flood levels is sufficiently small to leave (hydrologically) a sufficiently wide range in suitable field levels to plant rice. In this regard, an estimated 24% (more than 10,000 ha) of the valley bottom is hydro-pedological suitable for rice cultivation.
- A major problem for rice cultivation is the long and often variable length of the recession period to drain rice fields. Especially in years with high floods, the recession takes very long. Further down-stream (Senanga district) this problem will become more pronounced.

Mapping of land is not only useful for the identification of suitable rice land but also for the purpose of monitoring the planting exercise and the maximum flood depths. For identification also local information (from farmers) and vegetation types are important sources.

Negative effects on the environment, due to an increase of rice (wetland & cash crop) and cassava (upland & food crop) cultivation, are expected to originate more from changes of the wetland than from those of the upland. More rice cultivation, with an increased use of fertilizers, might result in a lower wetland reaction factor which will result in a further increase of the already long flood season. The effects on the fluctuation range of annual maximum flood levels are however negligible.

Possibilities to influence the flood regime, e.g. to shorten the long recession period in years with high floods and to obtain a more optimum flood depth, are limited and expensive. This is due to a relatively high longitudinal slope of the valley bottom of 0.4 m km^{-1} .

Canalization of the main channel(s) would require regulation structures every 2 to 3 km. In the optimum situation, the suitable area to grow rice will be increased by about 50% and then it will cover an estimated 30% of the total valley bottom. However, in absolute terms, this is only about 60 ha more rice land within each controlled section with a length of approximately 3 km. At least 40 regulation structures will be needed for the whole length of the river valley which makes the intervention economically doubtful and certainly for the present level and intensity of rice cultivation in the Lui Valley, unrealistic.

Maxima (and minima) of dambo water levels fluctuate most likely more than those of upland groundwater tables. This makes that rice cultivation in dambos is (a) limited to its fringes and (b) rather unreliable, especially with respect to droughts.

Acknowledgments

The Land and Water Management Project, a project within the Land Use Planning Section of the Provincial Department of Agriculture, started a hydrological survey in the Lui river valley in 1988/89. In an early stage the possibility to compose a hydrological computer model was explored and a first simple version was built by the end of 1989. The model presented in this paper is based on the same concept.

I gratefully acknowledge the interest and cooperation of the head of the Department of Agriculture, Western Province and the Land Use Planning section. I also want to thank the personnel of the Land Use Section for the huge volume of good work done, especially in surveying and in the recording of flood levels. In addition, I appreciated the assistance in the surveys of many students from the University of Zambia.

Furthermore, I would like to acknowledge the support of all senior staff, zambians and expatriates alike, who co-operated with the Land and Water Management project in the 1988-1993 period. I am grateful to those outside the direct realm of the project, but who supported this study. They are the Irrigation and Land Husbandry Branch of the Ministry of Agriculture in Lusaka, the "Technical Monitoring Team" of the University of Zambia, composed of ir J.A.C. Knops and dr A. Sichinga.

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The final version of the model was produced with assistance from the Department of Water Resources of the Wageningen Agricultural University. In this respect, special thanks go to Prof. dr ing J.J. Bogardi and drs P.J.J. F. Torfs for their guidance and suggestions in composing the model, and to ir K.J. Lenselink for reading the final manuscript.

December 1993, Ir. C.J.M. Bastiaansen.

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1. Introduction

This document deals with a hydrological study, carried out in the Lui River Valley, Western Province, Zambia (see figure 1.a. and 1.b.), during the years 1988 to 1992. Data collection was done by the Land and Water Management Project (LWMP) with the assistance of the Land Use Planning section of the Department of Agriculture, Mongu.

Lui River Valley, in which the study was carried, showed a good potential for rice cultivation under natural flood conditions [Bastiaansen, 1989]. A hydrological model was developed to simulate the flood regime in relation to flood risks for rice cultivation. The same model can be used to evaluate the effects rice cultivation may have on the flood regime. On the basis of the model results dambo water levels were evaluated in relation to the possibility of rice cultivation.

1.1. Description of the study area.

The Lui River, a tributary to the Zambezi river, is located in the upper catchment area of the Zambezi river. The catchment area covers an acreage of about 10.000 km² and the valley bottom about 500 km² or a 5% of the total catchment area. The Lui river valley begins at Luatembo where several minor upland streams merge together into one river. Its confluence with the Zambezi is some 10 km south of the town of Senanga. The total river length is about 130 km and the valley's width varies from a 2 km in the north to almost 4 km in the south.

The catchment area is within the so called Barotse sand region which is part of the Kalahari sandplains [Gils, 1988]. Soils are sands of a medium to coarse texture, deep and very permeable.

The area is inhabited by the Kwanga, a Lozi tribe. The total population along de river is estimated at 16,000 people, who live in some 750 villages. Access to the area is very difficult and poorly developed. In the northern part the Mongu-Lusaka road crosses the area and there is a gravel road from Namushakende to Nakanyaa, a small village on the Lui river. Other places can only be reached with four wheel driven vehicles over sandy bush tracks. During the flood season, the left bank is inaccessible due to the poor state of the wooden bridges at the valley crossings of Sasenda and Litawa.

Agriculture is the main source of subsistence and cash income. Maize and cassava are the most important staples. Others are millet, sorghum and a number of legumes. Cassava is planted on the upland and maize on the seepage zones at the edge upland-wetland. About a third of the families own cattle which gives them a certain wealth, security and a cash income. Fish is an appreciated relish and protein source in the daily dish. Rice cultivation is of a relatively recent date and mainly grown for a cash income.

The climate type is tropical with one single rainfall season from October to April. Heavy rainfall occurs in the months of December, January and February. Average seasonal rainfall varies from a 1,000 mm in the northern part to less than 700 mm in the southern part of the catchment. Rainfall variability is rather high and its coefficient of variation (CV) amounts to over 40% for monthly totals. Severe dry spells are a common feature with devastating effects on rain fed crops.

Mean temperature is high, 25 °C , in the dry hot season (September and October) and low, below 20 °C, in the cold dry season (May, June, July).

More detailed information on the study area can be found in Peters, 1960, Gils, 1988 and Heemskerk 1990.

1.2. Objective of the study.

No historical flood level data, with respect to the onset, annual maxima and recession of floods, are known. In terms of flood risks of rice cultivation under natural flooding conditions, little is known. The onset of the floods relates to the last planting date, the fluctuation in maximum flood levels relates to acceptable flood depths and flood recession to the length of the growing season.

The flood characteristics as mentioned above, can be studied from discharge hydrographs. Long term rainfall data, available from the rainfall gauging stations Kaoma, Mongu and Senanga, can be used to simulate the historical discharge hydrographs of the Lui river.

The study results will also enable the setup of a wetland evaluation system. From topographical data as collected by LWMP in the period 1988-1992, flood levels are translated into flood depths. The study, carried out at different outlets, will give more information about differences in flood regime along the valley.

Depending on the model's validity and accuracy, the future effects of (more) rice cultivation in the valley on the flood regime can be studied. Something can also be said about the suitability of dambos for rice cultivation.

1.3 The hydrology of the area.

The catchment area can be divided into a major part, the wooded uplands and a minor part, the grass covered wetland. The hydrological difference between the two is the position of the ground water table which is very deep on the upland and near or above the surface in the wetland. The term wetland includes pan-¹ and stream dambos¹ and upland river valleys¹.

On the upland, rainfall in excess of the evapotranspiration and soil moisture storage capacity will percolate to the groundwater reservoir. Due to the deep groundwater table, the capillary rise of groundwater to the root zone is insignificant. This means that the whole amount of percolation will once flow into the wetland. Parts of the wetland are permanently and others seasonally flooded. The extent and duration of the floods depend strongly on amount and distribution of rainfall of both the present and previous rainy season(s).

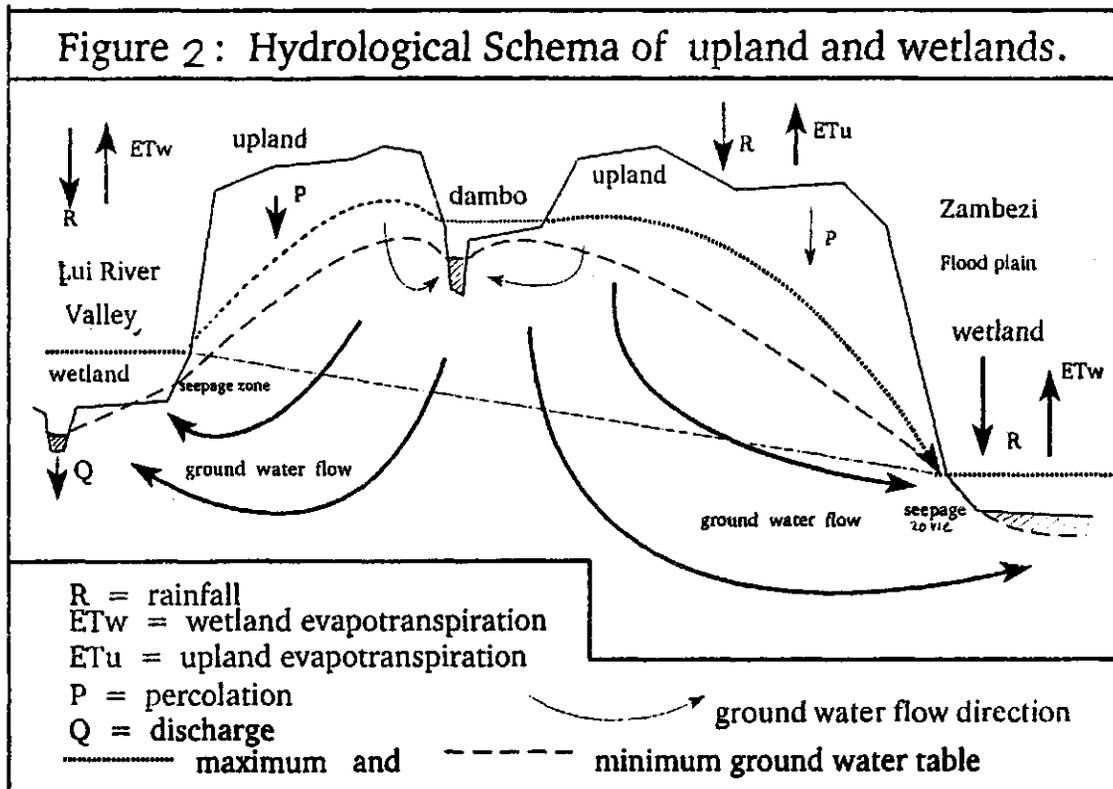
Wetland with a flow outlet, like upland river valleys, will have a discharge during and until a few months after the end of the rainy season. Pan dambos have no outlet and thus no 'open' discharge. Their water levels relate to the position of the nearby upland groundwater tables. A schema of the hydrological processus is given in figure 2.

2. Conceptual aspects of the model.

2.1. Introduction.

To simulate historical discharge hydrographs from historical rainfall data, it is necessary to monitor for several hydrological seasons the model variables, such as rainfall and river discharges. The model is calibrated by means of a fitting procedure in which

¹ See glossary of terms.



calculated hydrographs are fitted to the monitored ones. In this way the model parameters can be derived. Once they are known, historical discharge hydrographs can be simulated from historical rainfall data (Clarke, 1973).

Model parameters describe the geometry of the catchment (upland-wetland ratio), the physical properties of the soils (transmissivity, soil moisture storage capacity, macro porosity etc.) and the evapotranspiration coefficients (vegetation type, rooting depth and for the wetland the flooding pattern).

When the catchment area is sufficiently homogeneous (isotropy) in its characteristics, a number of parameters are lumped into one parameter, the reservoir reaction factor. This factor equals the slope of the recession curve of the discharge hydrograph, plotted on semi-Log or Ln paper. When the curve is a straight line, then the reservoir output is linear with the reservoir contents or with the water height in the reservoir. Linear reservoir theory is then applicable. The generalised equation for a linear reservoir reads [De Zeeuw, 1973]:

$$q_n = q_{(n-1)} \times \exp^{-\alpha + (q_{n-1} - I_n)} + I_n \times (1 - \exp^{-\alpha + (q_{n-1} - I_n)}) \quad (1)$$

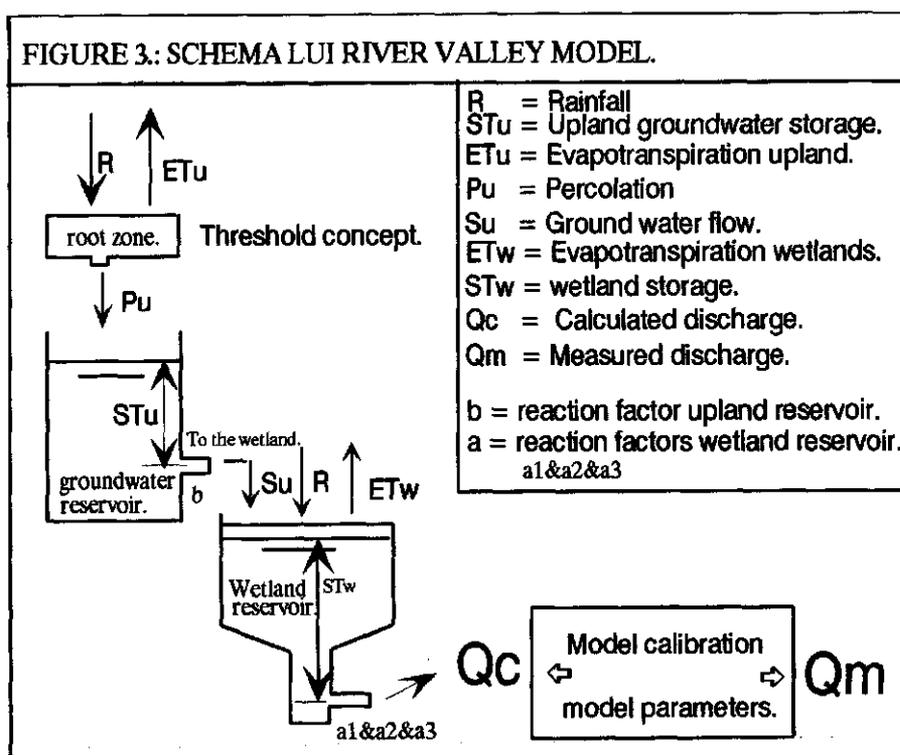
Where: q_n is the discharge and I_n the input during interval t_{n-1} to t_n in days or hours.

When the assumption of parameters is based on physically understood mechanisms, the model approach is called "conceptual" and the model is named a conceptual linear model.

The Lui River Valley model, shown in figure 3, exists of three different reservoirs:

- The upland root zone reservoir.
- The upland ground water reservoir.
- The wetland reservoir.

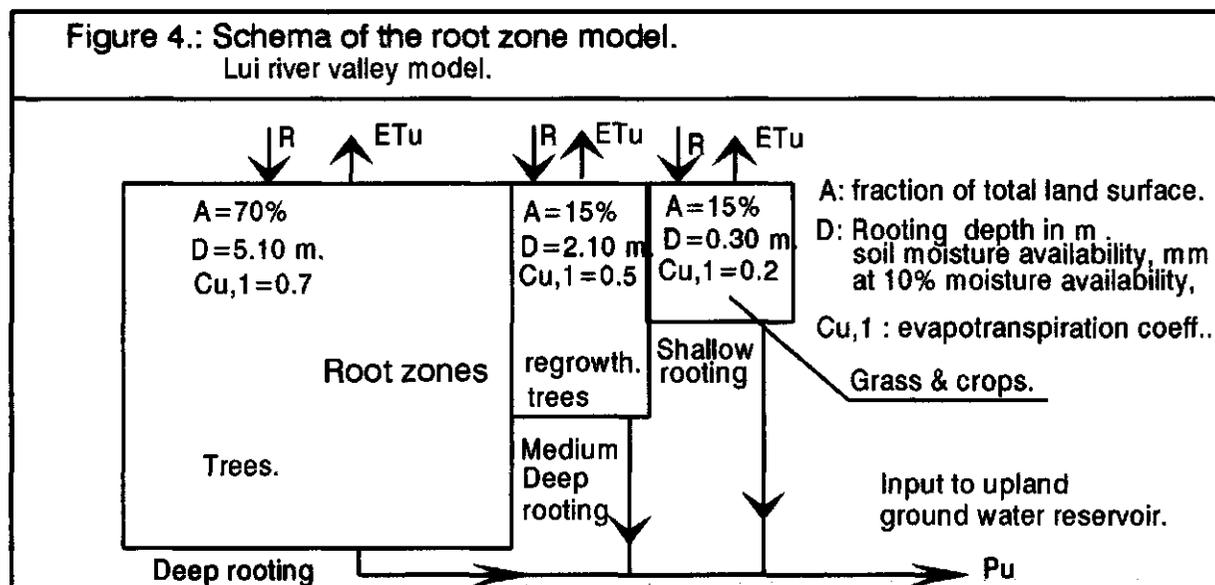
Conceptual aspects of each of the three reservoirs are briefly discussed below.



2.2 The upland root zone.

The upland mainly exists of savanna woodland with an undercover of grass during the rainy season but some parts are cultivated with cassava and millet. With shifting cultivation as a main land use form, another part of the upland is in the stage of regrowth. As a result and as a function of different rooting depths, the upland is divided into three zones, each having its own parameters, see

figure 4 .



The potential upland evapotranspiration $ET_{u,p}$ depends on both (1) the amount of available soil moisture, SM_{act} and (2) the type of vegetation (rooting depth), $C_{u,1}$. The latter is assumed constant for each zone. A shortfall between the actual evapotranspiration ET_a and the potential evapotranspiration ET_p , will develop as soon as the soil moisture availability SM_{act} becomes less than the maximum amount, SM_{max} . Their ratio equals the evapotranspiration coefficient, C_{SM} . In the model, a simple linear relationship is assumed between the ratios of ET_a/ET_p and SM_{act}/SM_{max} .

The evapotranspiration from the upland is calculated by:

$$ET_{u,n} = C_{u,n} \times C_{SM,n} \times ET_{r,n} \quad \text{mm} \quad (2)$$

Where:

- $ET_{u,n}$ = Evapotranspiration of the upland, mm d^{-1} .
- $C_{u,n}$ = coefficient to account for vegetation type and rooting depth.
- $C_{SM,n}$ = coefficient to account for soil moisture status.
- $ET_{r,n}$ = Reference evapotranspiration rate for a given climate and maximum readily available soil moisture, mm d^{-1} . [Doorenbos, 1977 and 1979].
- n = indicates calculation interval, d.

With the known amount of rainfall R as an input and the upland evapotranspiration ET_u as an output, a balance can be kept on the amount of stored soil moisture. When the amount is more than the maximum storable amount SM_{max} , water will percolate to the ground water reservoir, or:

$$P_{u,n} = (SM_{b,n} + 0.5 * R_n - ET_{u,n}) - SM_{max} = SM_{b,n} - SM_{max} \text{ mm} \quad (3)$$

in which:

$$SM_{b,n} = SM_{a,(n-1)} + 0.5 * R_n.$$

$$\text{with } SM_{a,(n-1)} \leq SM_{max}.$$

It is assumed that already half of the received rainfall in the period under consideration will contribute into the soil moisture availability for evapotranspiration. As such, half its quantity is added to the $SM_{b,n}$ -value. It is obvious that percolation, $P_{u,n}$ from the root zones to the ground water reservoir only occurs when $SM_{b,n}$ exceeds the value for SM_{max} .

The equations 2 and 3 have to be applied to each of the three zones. The input $P_{u,n}$ for the upland reservoir model, is found by adding the $P_{u,n}$ -values of the three zones.

2.3 The upland ground water reservoir.

With a known input value P_u , the output S_u can easily be calculated according to equation 1, provided a correct value is assumed for the reaction factor, β day⁻¹. An estimate for β can be obtained from the catchment geometry and transmissivity (KD-value) of the upland, see figure 5. A mathematical expression for β is given by [De Zeeuw, 1966]:

$$\beta = \frac{8 * K * D}{L^2 * (2 - m) * \mu} \quad (4)$$

where:

- K = hydraulic conductivity, m d⁻¹.
- D = thickness of the aquifer, m .
- μ = macro or effective porosity, fraction of 1.
- L = spacing between wetlands, m .
- m = fraction of upland/(upland + wetland) or B/L.

An impression on the KD-value can be obtained from the steady

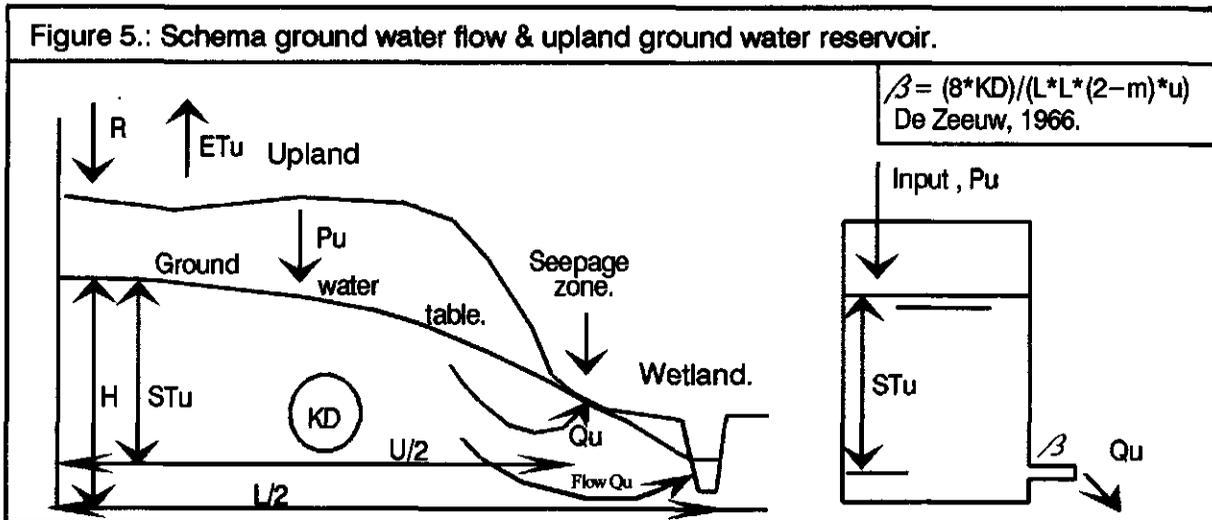
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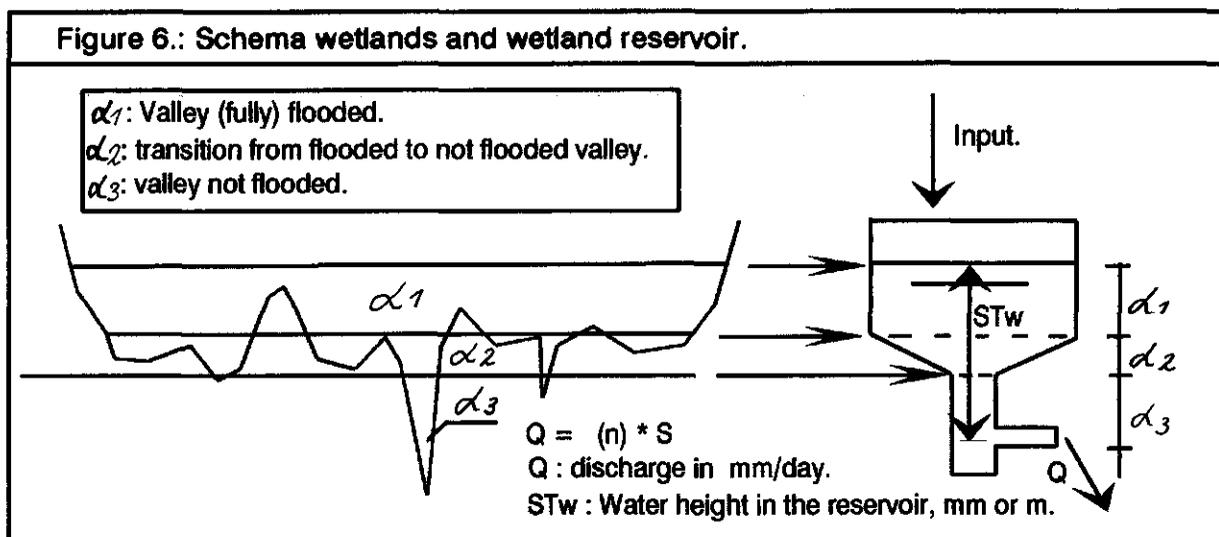
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ground water flow model, see paragraph 3.3.3.. The geometry determines the values for L and m and are studied from maps 1:100,000 , see paragraph 3.3.1.. The maps are also used to get an idea on a possible upland/wetland ration which is needed to translate the output of the upland ground water reservoir into an input for the wetland reservoir.



2.4. The wetland reservoir.

Details on the wetland reservoir are shown in figure 6.. Apart from ground/water of the upland also direct rainfall contributes to the wetland reservoir input. Their sum minus the wetland evapotranspiration gives, as long as a positive value is obtained, an input for the wetland reservoir.



The wetland evapotranspiration ET_w depends strongly on the so called 'wetness'. 'Wetness' is defined as the availability of water for evapotranspiration which includes both free water as well as soil moisture. As such the 'wetness' represents the extent of permanent flooded areas as well as the flood duration of the temporarily or seasonally flooded wetland. A numeric expression for the 'wetness' is given by the 'wetness' coefficient, $C_{w,2}$, which relates the actual 'wetness' to the average 'wetness' of the same period. The coefficient is based on the average 'wetness' of as many hydrological cycles as possible for which the model has simulated the hydrographs.

Thus there are two coefficients which determine ET_w as function of ET_x ; $C_{w,1}$ which takes into account the vegetation and average 'wetness' and a $C_{w,2}$ -coefficient which corrects for differences in flood regime or differences in the actual 'wetness'.

ET_w is calculated according to:

$$ET_{w,n} = C_{w,1,n} * C_{w,2,n} * ET_{x,n} \text{ mm} \quad (5)$$

The $C_{1,w}$ -coefficient is 0.4 to 0.6 in the dry season and its value increases gradually during the flood season to a maximum of 1.0 or more. The average value for one hydrological season will be between 0.6 and 0.8 and thus the $ET_{w,cum}$ will on average amount to $0.7 * ET_{x,cum}$ or to 1500 mm. $C_{w,1}$ -coefficients have a gradual course over the year and are the same every year and for each catchment.

In order to determine the $C_{w,2}$ coefficient, the model keeps a balance on the amount of available water in the wetland system. It should be noted that the balance can be negative due to the depletion of soil moisture at the end of the dry season, prior to the start of the next rainy season. This parameter is also determined by the model and as such not an assumed parameter. A mathematical expression for the $C_{w,2}$ -coefficient reads:

$$C_{w,2,n} = \frac{ST_{w,n} + ST_{w,t}}{ST_{w,n,avg} + ST_{w,t}} \quad (6)$$

where:

- $ST_{w,n} = ST_0 + I^c_{w,n}$
- $I^c_{w,n} =$ Either the input to the reservoir according to equation 7. or the accumulated value of negative inputs (depletion of soil moisture).
- $ST_0 =$ Dischargeable storage, (Q_n / α) .

and

$$ST_{w,t} = -ST_{w,min} + ST_{w,const}.$$

$ST_{w,min}$ = Smallest (most negative) value of ST_w , which occurred in the whole simulation period. (1953-1992).

$ST_{w,const}$ = A constant (mm), positive value between 50 and 100.

and $ST_{w,n,avg}$ = average $ST_{w,n}$ value in period n, for all the years of simulation.

Adding the constant value, $ST_{w,t}$, to both the numerator and denominator of equation 6, makes that no negative $C_{w,2}$ -coefficients are obtained. Adding the constant $ST_{w,const}$ to find $ST_{w,t}$ avoids either too small or too high values for $C_{w,2,n}$ at low $ST_{w,n,avg}$ -values. The latter will be the case either late in the dry season or during the first rains of the next rainy season. In that period $ST_{w,n}$ values can be high or low due to either high or low rainfall as compared with the expected average amount of rainfall in that period.

With a known ET_w value, the input of the wetland reservoir is calculated according to:

$$I_{w,n} = S_{w,n} + R_n - ET_{w,n} \text{ mm} \quad (7)$$

where: $S_{w,n}$ = from upland incoming Seepage, mm.
 R_n = Rainfall, mm.
 $ET_{w,n}$ = Wetland evapotranspiration, mm.
 n = denotes the period; month, decade.

As soon as the $I_{w,n}$ -value becomes negative there will be no input to the wetland reservoir. Succeeding inputs are accumulated until a positive value for $I_{w,n}$ (re)appears again. This will be after the first rains have replaced the depleted soil moisture and after sufficient head has been created to develop interflow. This means that the first rains are not 'effective' in developing discharge while part of the first 'effective' rains, mainly in December, only become effective in a later stage when flood levels are rising (mainly in January and part of February, see also table 4, appendix II.). When the interflow effects are not taken into account, the rising limb of the hydrographs starts too early.

The output of the wetland model is calculated according to equation 1 with the use of the reaction factors α_{1-3} which are derived from the monitored discharge hydrographs, as shown in paragraph 3.2.2. The use of different α 's for the same reservoir is dealt with in paragraph 3.3.4..

2.5. Water balances.

Each reservoir has its proper water balance. For the whole system an overall water balance can be given. The following balances are involved:

Root zone:

$$\sum (R_n - ET_{u,n} - P_{r,n}) = \Delta ST_z = ST_{z,n=0} - ST_{z,n=n} \text{ mm} \quad (8)$$

where: ΔST_z = Change in soil moisture content of the root zone after n-intervals.

Upland reservoir or groundwater reservoir:

$$\sum (P_{u,n} - S_{u,n}) = \Delta ST_u = ST_{u,n=0} - ST_{u,n=n} \text{ mm} \quad (9)$$

where ΔST_u = Change in stored amount of ground water after n-intervals.

Wetland reservoir:

$$\sum (R_n + S_{w,n} - ET_{w,n} - Q_{c,n}) = \Delta ST_w = ST_{w,n=0} - ST_{w,n=n} \text{ mm} \quad (10)$$

where: ΔST_w = Change in stored amount of water in the wetland after n-intervals.

Overall water balance reads:

$$\sum (R_n - ET_{u,n} - ET_{w,n} - Q_{c,n}) = \Delta ST_o = 0 \text{ mm} \quad (11)$$

where ΔST_o = Change in stored amount of soil moisture and water stored in respectively upland root zone(s), ground water reservoir and wetland. Over very long periods its value should be zero.

3. The model.

3.1. Introduction.

In this chapter attention is paid to the model variables and the model parameters, the model calibration and the goodness of fit. Results are presented, followed by a parameter sensitivity analyses.

3.2. Model variables.

Model variables are:

- Rainfall data from the main stations or historical rainfall data and from sub-stations during the monitoring period.
- Climatological data to calculate the reference evapotranspiration ET_r .
- Discharges. This includes the determination of the rating curves and the monitoring of flood levels.

3.2.1. Rainfall data.

3.2.1.1. Rainfall data of the main stations.

Rainfall data of the main stations Mongu, Kaoma and Senanga are used to simulate historical discharge hydrographs. Sufficient data are available for the period 1953-1992. Rainfall input data, as averages of 10 day periods for the three stations, are shown in table 2 of appendix I. Summarised results are shown in table 1.

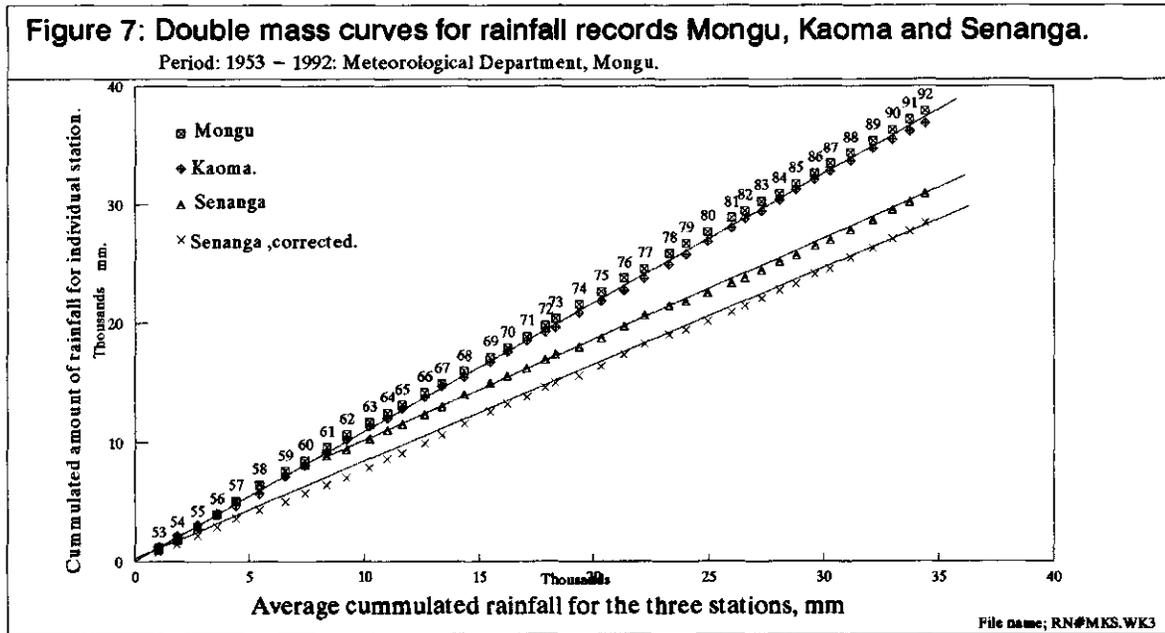
Table 1.: Annual total rainfall for 5%, 50% and 95% of non-exceedance.

Station	R_{avg}	R_{STD}	$R_{5\% \text{ n.e.}}$	$R_{95\% \text{ n.e.}}$	CV %
Mongu	947	189	637	1257	20
Kaoma	911	205	575	1247	23
Senanga	776	215	423	1129	28

An important gradient in amount of rainfall exist in the north-south direction. Rainfall variability is rather high; coefficient of variation (CV) of more than 20% for annual totals and CV of more than 40% for monthly totals.

A check on systematic errors in the rainfall records is shown in

figure 7. The double mass curves for each stations is given. Rainfall for Senanga does not show reliable during the fifties. Only from 1960 onwards, a straight line develops. A simple, linear correction is made for the years 1953 - 1960 as shown in figure 7. The lines for Mongu and Kaoma are almost identical which means that both stations received over a longer period of several years, the same amounts of rainfall.



3.2.1.2. Rainfall substations.

Within the Lui river catchment, 10 rain gauges have been placed early 1988, to collect rainfall data from the study area. Gauges could not be installed ideally distributed over the whole area, due to lack of local skilled manpower and accessibility to perform the daily readings. Gauges were placed at schools where teachers could do the readings.

Missing data of the sub-stations, which amounted to a 20% of the total records, have been replaced by the average values of the three main stations. Data have been arranged and averaged to calculate the rainfall for the different catchment areas, see table 1, appendix I. In the calculation of average rainfall for Litawa catchment area 8 sub-stations contributed. The data are compared with rainfall records of the three main stations, see table 2. Differences in the totals for each rainy season are small and less than 4% of the total amount recorded. In appendix 1, table 1 ,

rainfall figures, as totals for 10 day periods, are presented for the rain seasons of 1988/89 to 1991/92. These figures are used for the calibration of the model.

Table 2.: Comparison between average total seasonal rainfall (mm) for Litawa and for the Mongu/Kaoma/Senanga average.

Season	1988/89	1989/90	1990/91	1991/92	Totals:
Litawa	949	834	808	693	3282
Mongu+Kaoma +Senanga.	969	861	775	686	3291
Difference in mm.	-20	-27	30	7	-7

3.2.2. Reference evapotranspiration.

Reference evapotranspiration is calculated according to the modified Penman equation [Doorenbos, 1977 and 1979]. The calculation of ET_r is given in table 3 of appendix 1. In the lower part of the table, calculated ET_r -values for the years 1986/87 to 1991/92, are given.

ET_r -values depend on temperature, wind speed, relative humidity and sunshine duration. Daily values range from 4 to 6 mm/day. Totals for one complete hydrological year are 2000 mm or slightly more.

3.2.3. Discharge monitoring.

The monitoring of discharge is carried out by recording the flood levels from the water level gauges, every 2 to 3 days. In order to obtain discharges, the readings are translated into discharges by means of rating curves. Rating curves are determined by doing discharge measurements.

3.2.3.1. Rating curves.

For the derivation of a rating curve reference is made to hand books in hydrology [e.g. Maidment, 1992]. The generalised equation reads:

$$Q = b \times H^c \quad (12)$$

$$\ln Q = a \times \ln H + c \quad (12')$$

where Q = discharge in m^3/s
 H = Flood level relative to the zero datum of stream channel, $WL-H_0$.
 a, c = linear regression coefficients

Discharge measurements have been carried out several times at different flood levels during both stages, i.e. for rising and falling flood levels. These measurements are done at places where dike-crossings with bridges exist so that flow measurements are done within a reasonably well defined "control" section.

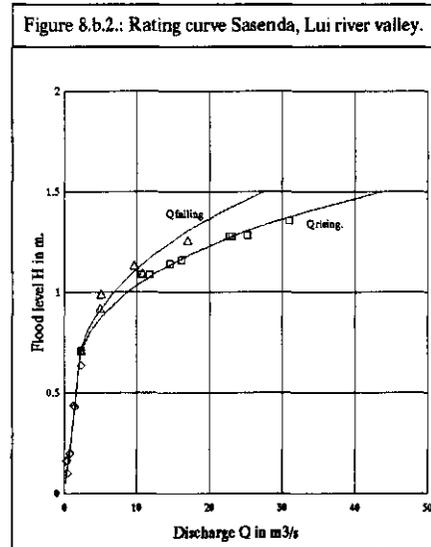
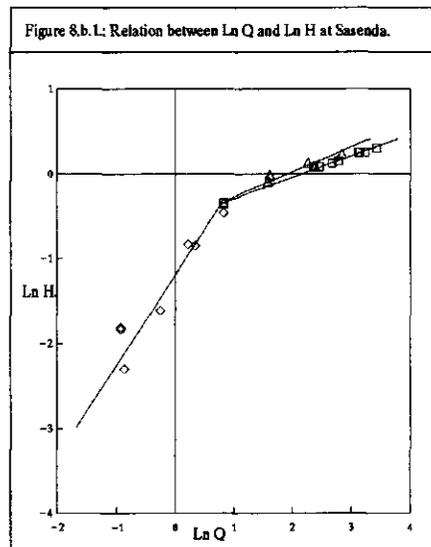
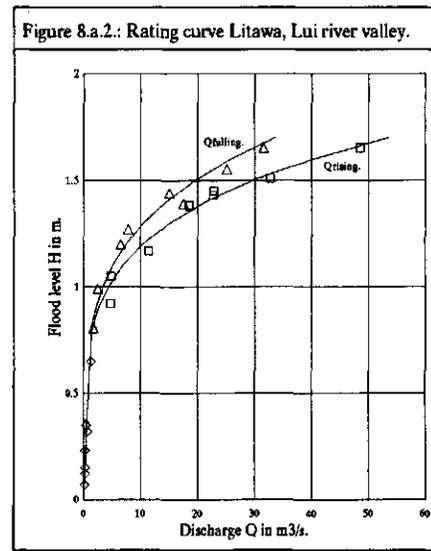
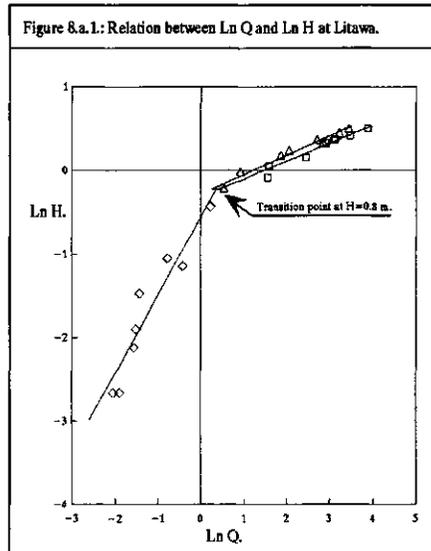
Results of analyses for the gauging stations at Sasenda and Litawa are shown in the figures 8^a and 8^b. H -values, a - and c -coefficients are presented in table 3.

Due to the flooding of the valley and thus the temporary storage of discharge, rating curves show (1) a hysteresis effect and (2) a broken line for $\ln Q$ against $\ln H$. The break-point is located at the point of transition (H_{trs}) whereby the main flow leaves or returns to the (main) river channels. Hysteresis only occurs beyond that point.

Table 3.: H_0 and a and c coefficients for Litawa and Sasenda.

Station/ Q_{type}	Coeff. a	Coeff. c	Rsqrt	No. of obs.
LITAWA: $H_0 = -0.03$ m on GR; $GR_0 = 1027.53$ m. above m.s.l.				
Q_{low} , $H_0 < 0.8$ m.	1.064	0.587	0.93	8
Q_{rising}	4.731	1.472	0.97	7
$Q_{falling}$	4.346	1.212	0.97	8
SASENDA: $H_0 = 0.0$ m on GR; $GR_0 = 1039.95$ m. above m.s.l.				
Q_{low} , $H_0 < 0.7$ m.	0.935	1.115	0.91	9
Q_{rising}	4.007	2.154	0.99	8
$Q_{falling}$	0.461	1.910	0.95	5

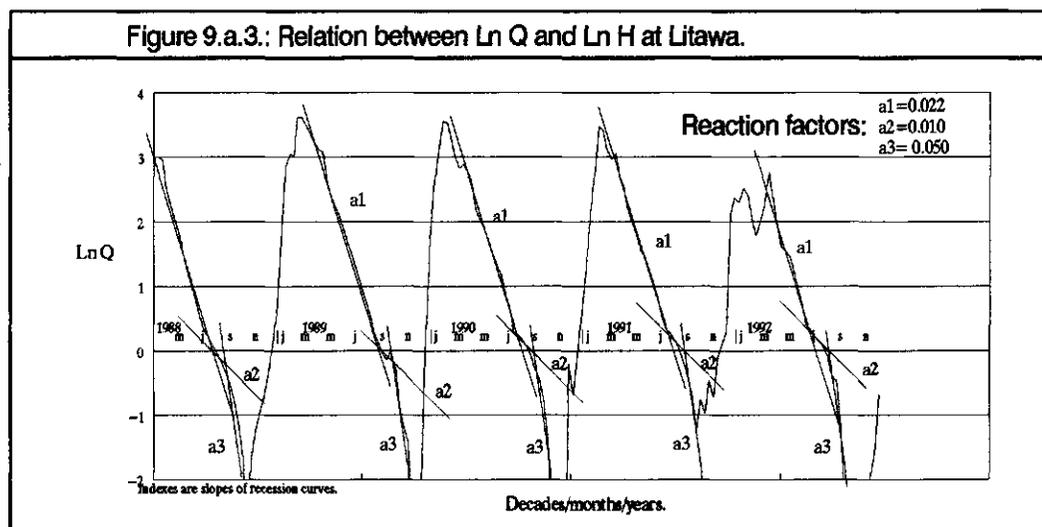
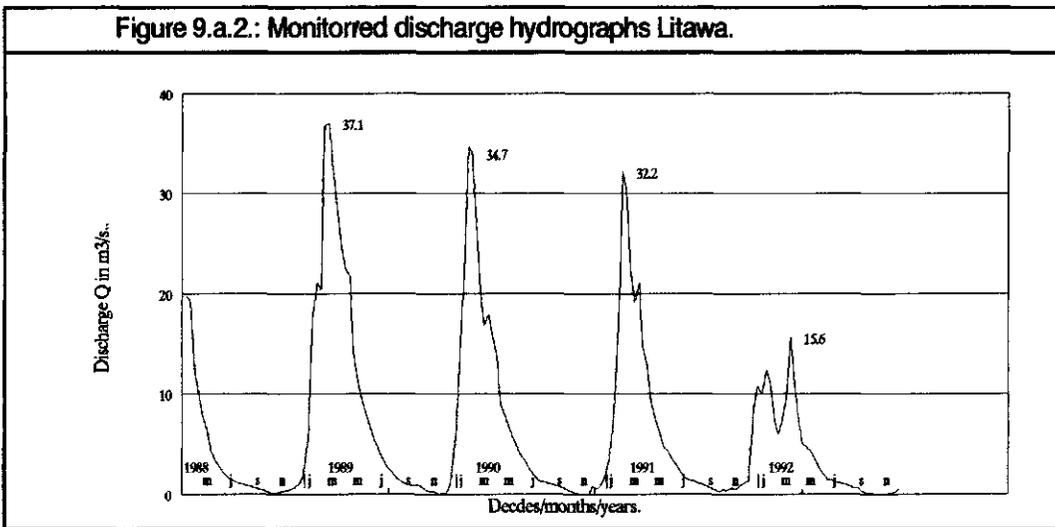
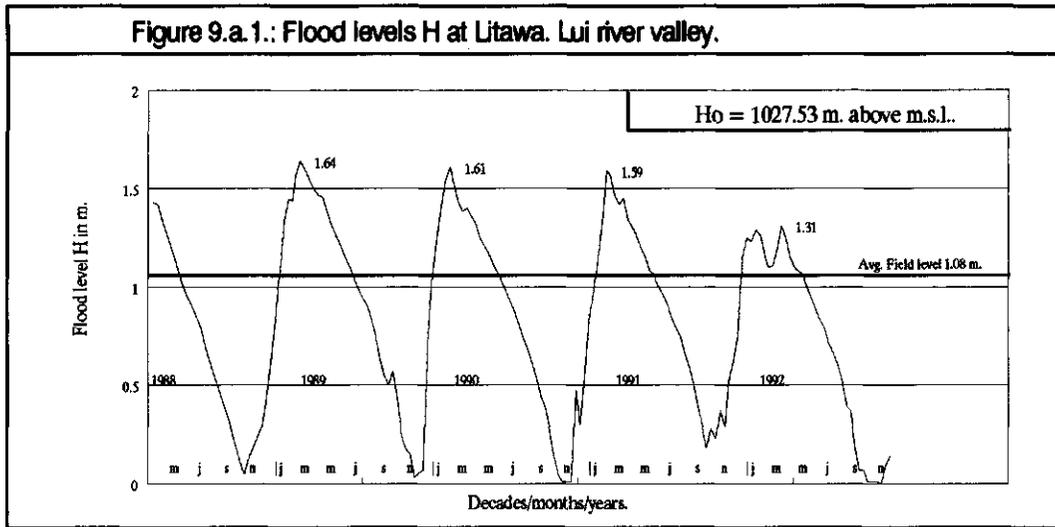
The Lui river carries no bed- and very little suspended load. It is therefore unlikely that significant changes occurred in river bed morphology in the last 40 to 50 years. The derived rating curves have therefore been assumed to be valid for the whole period 1953-1992.

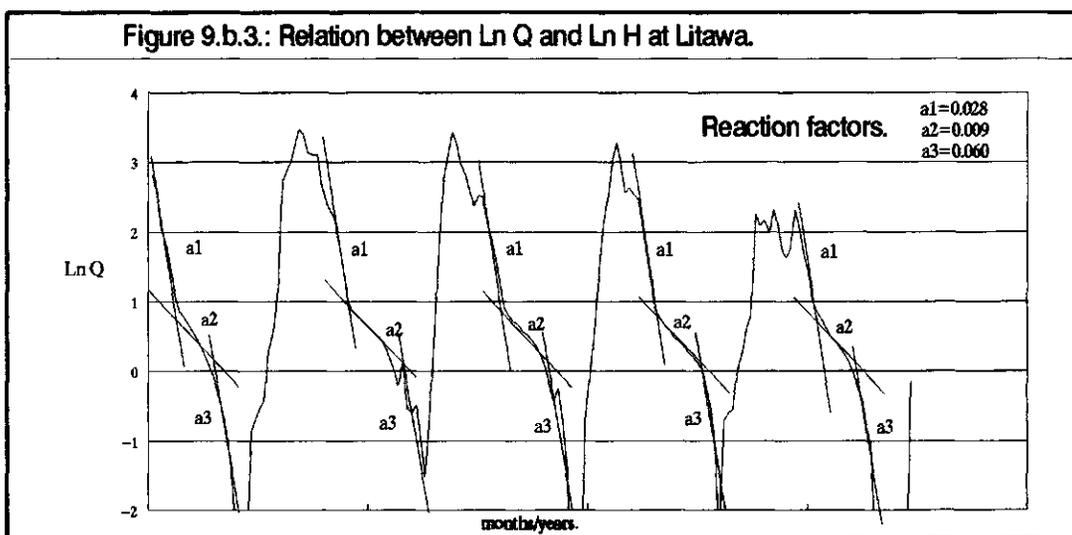
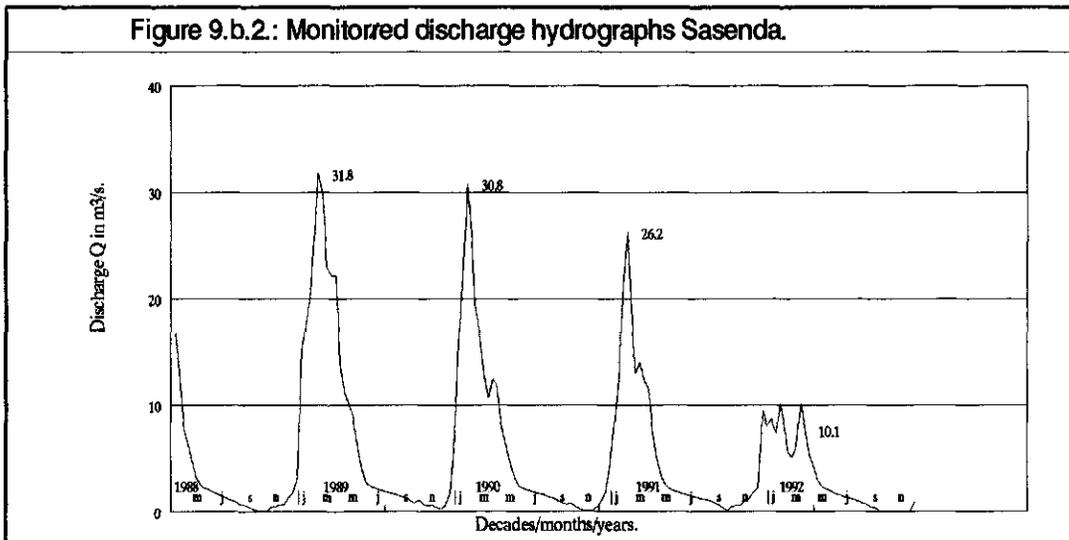
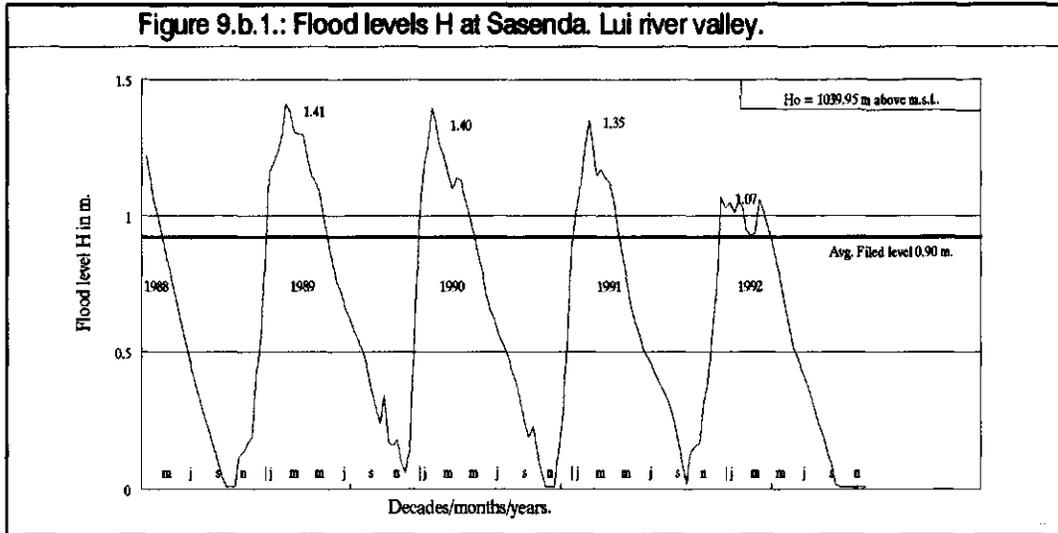


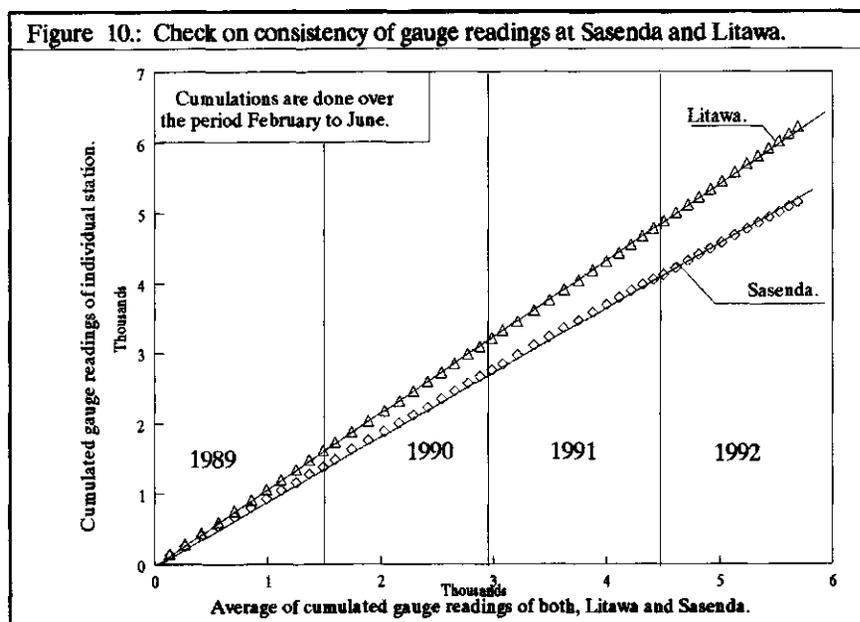
3.2.3.2. Discharge monitoring.

Gauge reading records for Litawa and Sasenda, for four hydrological years of 1988/89 to 1991/92, are given in table 4 of appendix I. The flood level graphs are shown in figures 9^{a.1} and 9^{b.1}. A check on the consistency of the data and on systematic errors, by means of a double mass plot of the gauge readings of Litawa and Sasenda, is shown in figure 10.

Gauge readings are corrected with the H_0 -value in order to find H, which value is substituted in the rating curve equations to convert the flood levels into discharges. The results are discharge hydrographs as shown in figures 9^{a.2} and 9^{b.2}. The Ln Q-t graphs, of which the slopes of the recession curves represent the reservoir







reaction factors (α), are shown in figures 9^a.3 and 9^b.3..

Three different α 's can be derived:

- α_1 The valley is fully flooded. Valley discharge is very significant in the total discharge.
- α_2 The transition phase: there is still water stored in the valley but the valley's contribution in the discharge has become insignificant.
- α_3 Drainage of the river channels.

For the recession of floods from the valley, reaction factors (α_1) of 0.022 and 0.028 day⁻¹ are found for Litawa and Sasenda respectively. More details on the different α 's are given in paragraph 3.3.4.. Table 4 summarises recorded peak flows and derived α -values.

Table 4: Peak discharges and α 's for Litawa and Sasenda.

Year	88/89	89/90	90/91	91/92	α_1	α_2	α_3
Sasenda	31.8	30.8	26.2	10.1	0.028	0.009	0.060
Litawa	37.1	34.7	32.2	15.6	0.022	0.010	0.050

3.3 Model parameters.

Model parameters describing the physical aspects of the model are discussed below.

3.3.1. The geometry of the catchment.

From maps, scale 1:100,000, the catchments areas of Sasenda and Litawa were estimated at 350,000 and 480,000 ha respectively. The wetland covers an estimated 60,000 and 80,000 ha. respectively. Upland/wetland ratios of 4.8 and 5.0 are derived. The given acreage(s) would be correct when all the wetland which classify as liable to floods, are really flooded every season. This may occur in and after a number of wet years. After a number of dry years, the wetland acreage can be considerably reduced which gives higher upland/wetland ratios. From the final model calibration, ratios of 6.22 and 6.28 are found for Sasenda and Litawa catchments respectively. Final results are shown in table 5.

When the average width of the wetland is on average 1.5 km than a U (upland) and L (upland+wetland) values of 9.4 km and 11.0 km are derived. These values can be substituted for $m = U/L$ in equation 4.

Table 5.: Geometry of the catchments Litawa and Sasenda, Ha..

Catchment	Total	Upland	Wetland	Upl/wetl
Litawa	459,000	396,000	63,000	6.28
Sasenda	325,000	280,000	45,000	6.22

3.3.2 Parameters for the upland root zones.

In the present model three different zones are defined as a function of vegetation and rooting depth. Each zone has its own parameter values. Assumed values are given in table 6..

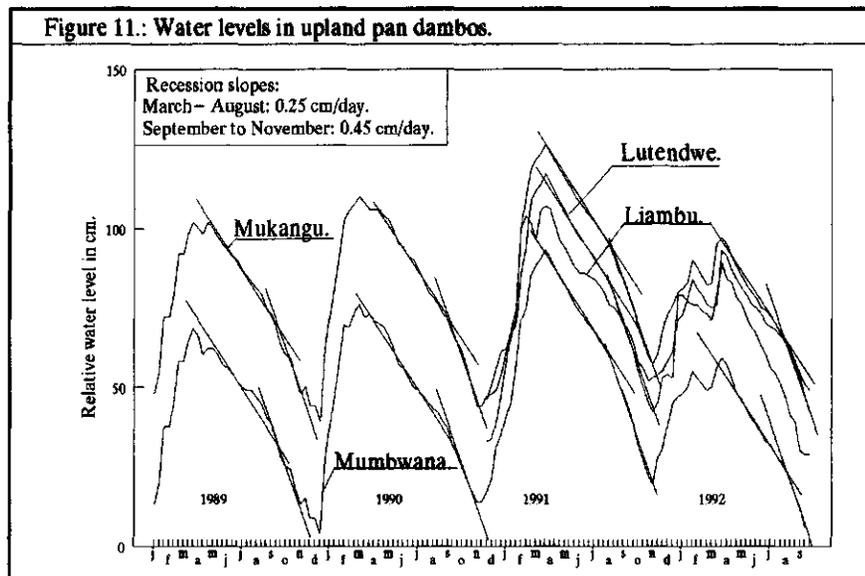
Table 6.: Model parameters for the upland root zone model.

Root depth	zonal %	SM _{max} in mm	ET _{coeff} · C _{u,1}
Shallow	15%	30	0.2
Medium	15%	210	0.5
Deep	70%	510	0.8

The root zone parameters are kept constant for both catchments, Litawa and Sasenda. Parameter values can be varied in a way that the model results are the same. Variation of a single parameter will have an effect on the model results. This is discussed in paragraph 3.6., which deals with sensitivity analyses.

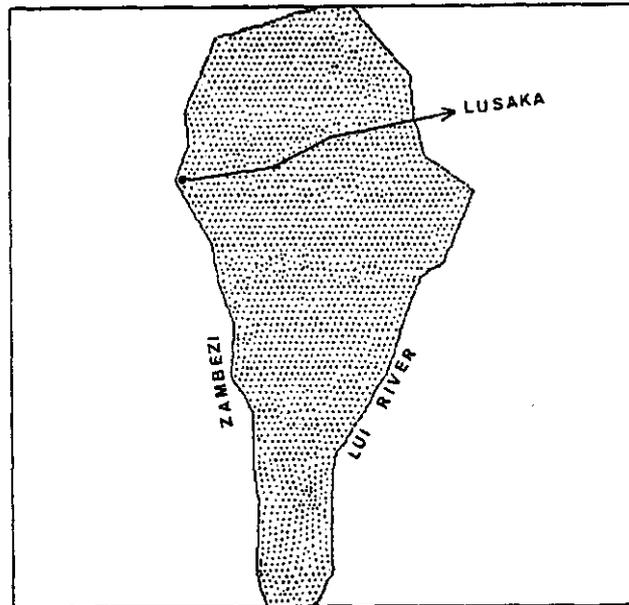
An estimate of the contribution of groundwater flow into the wetland reservoir can be made from tentative annual water balance calculations of the wetland ($R + S_w - ET_w = Q$). With rainfall of 800 to 1,000 mm, a discharge between 300 and 500 mm, and a wetland evapotranspiration of 1,500 to 1,700 mm, the contribution from the upland groundwater is in the order of 1,100 mm. In terms of mm, expressed relatively to the upland area, it amounts to 175 mm per 'average' hydrological year or to 0.5 mm/day.

Another estimate of the amount of groundwater flow is obtained from the analyses of dambo water levels. Water level graphs for different dambos, i.e. Mukangu, Mumbwana, Lutendwe and Liambu show remarkable similarities, see figure 11. This shows the homogeneity (isotropy) of the area. During the groundwater table 'recession' period from April to August, the graphs are rather straight and have the same slopes of about 0.0025 m/day. For a macro porosity of about 20%, this would correspond to a groundwater discharge of 0.5 mm/day. The small reaction factor for the upland reservoir, β (see 3.3.3.) makes that there is little variation in ground water flow over the year. The average total annual upland discharge therefore amounts to about ($365 \times 0.5 \text{ mm/day} =$) 180 mm.



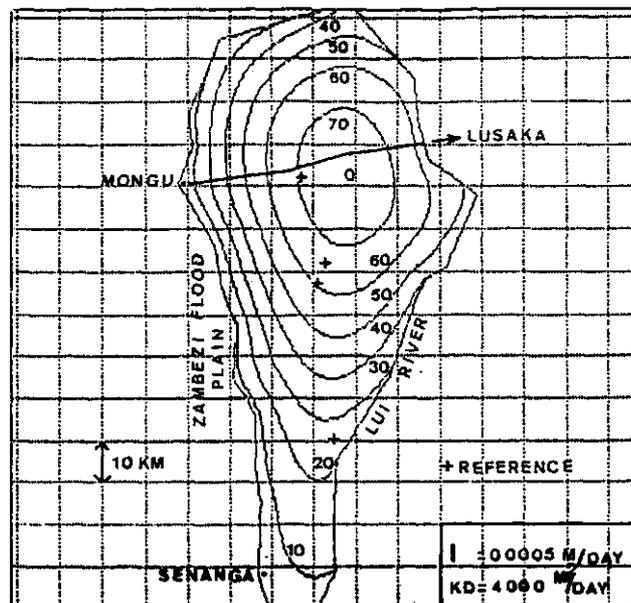
The generated network grid is shown in figure 12.b..

Fig. 12.b : Grid network for groundwater flow modelling.



In the model, different transmissivity or KD-values are used to produce isohyetal maps. The isohyetal map, showing lines of constant head, should fit some of the known water levels of the pan-dambos in the upland. For a proper fit between the isohyetal pattern and dambo water levels, a KD-value of approximately 4,000 is needed, see figure 13.a..

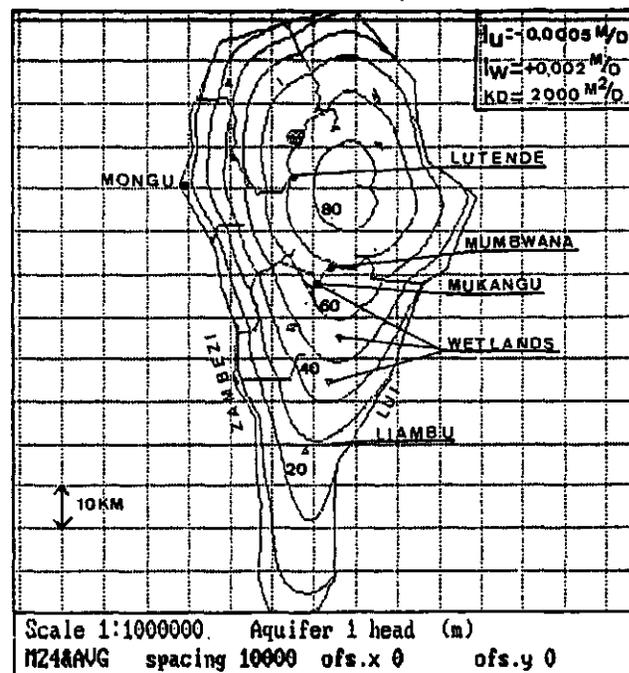
Fig. 13.a : Isohyetal map for area shown in fig. 12.b, without the 'upland wetland' taken into account.



However, the high evapotranspiration from the (pan) dambos and other wetland areas, scattered over the upland, should be taken into account. This wetland areas can be seen as evaporation sinks which do not constitute an input but an output of the groundwater model. Assuming an ET_w of 1500 mm/year and an annual rainfall of 800 mm then the wetland will have a net annual output, through evapotranspiration, of 700 mm or almost 0.002 m/day.

From maps 1:100,000, an area of about 60,000 Ha has been labelled as wetland so that the (average and overall) water balance components (ET_u , ET_w , R and Q) values are close enough to those found with the Lui River Valley model. Results are shown in figure 13.b.. Now a KD-value of about 2,000 $m^2 d^{-1}$ is needed to obtain a fit between the isohyetal pattern and the dambo water levels of Mumbwana, Mukangu and Lutende.

Fig. 13.b : Isohyetal map of area shown in fig. 12.b , with the 'upland wetland taken into account.



From the isohyetal map, slopes in the groundwater table can be derived. They vary from less than 0.5 m/km in the central part of the upland to more than 5 m/km near the fringes with the Lui river valley and the Zambezi Flood Plain edge. In reality the difference in slopes at the central part and those near the fringes is even more pronounced than calculated above because KD-values are not constant but high in the central part of the upland ($D=D_{max}$) and

low(er) near the outflow at the fringes. For this reason and unlike those for Mukangu, Mumbwana and Lutende, the water levels of Liambu dambo did not fit properly to the isohyetal pattern of figure 13.b.. The first ones are all near to one and the same isohyetal line and not that far from the central part of the upland. Liambu dambo is near the fringes of the upland with the Lui River Valley where steeper slopes in the groundwater table can be expected due to lower KD or D values.

For a KD-value of 3,000, a macro porosity of 0.25 (25%) and a geometry of the catchment as described in paragraph 3.3.1. , a β -value of 0.001 day^{-1} is derived, according to equation 5. This small value means that from an unit input (percolation) to the ground water reservoir, only 30% has left after one year.

In the final calibration of the Lui model, β -values of 0.0015 and 0.0020 day^{-1} were used for Litawa and Sasenda catchments respectively. These higher values give, with the rearranged equation 5, average travel distances for groundwater flow (L) of 8.9 and 7.7 km respectively. It are acceptable values if one realises that groundwater flow contributes more to wetland evapotranspiration (25% of total rainfall) than to discharge (7% of total rainfall) and as such the "upland" wetlands (dambos and stream dambos), scattered all over the upland, are as importance as the Lui River Valley itself. This reduces considerably the average distance of the groundwater flow.

3.3.4. Parameters for the wetland reservoir.

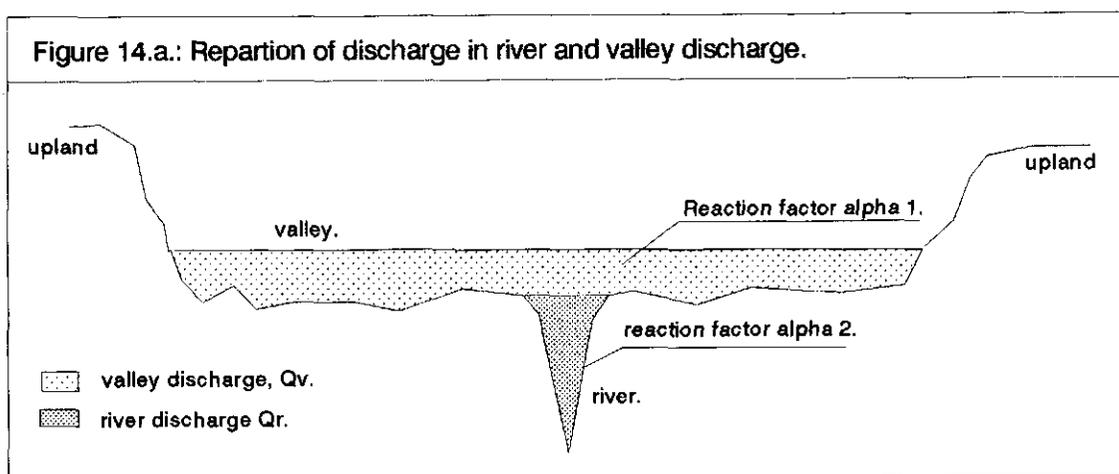
Important parameters for the wetland are the $C_{w,1}$ and $C_{w,2}$ -coefficients which are used to calculate ET_w , as described in paragraph 2.4..

The determination of the $C_{w,2}$ -coefficient requires the assumption of a constant value for $ST_{w,const.}$, to avoid extreme values for this coefficient. A value of 75 mm has been used in the final model calibration. Different $ST_{w,const.}$ -values and their effects on the model performance are discussed in the paragraph 3.6. which deals with sensitivity analyses. For a given $ST_{w,const.}$ -value, the $C_{w,2}$ -coefficient, expressed as an average for a hydrological season, varied between 1.59 (1958/59: a wet season) and 0.67 (1972/73: a dry season). It is noted again that the $C_{w,2}$ is not an normal evapotranspiration coefficient but as explained before, a 'wetness'

coefficient.

The wetland reaction factors α 's are not assumed but derived from the hydrographs monitored as shown in paragraph 3.2.3.2.. Three α 's are derived which gives a complicated calculation of the output.

Below, a situation with two different reservoir reaction factors, α_1 (valley) and α_2 (river channel) is looked upon. The calculated discharge equals $Q_c = Q_v + Q_r$. Figure 14.a. shows the valley and the river channel in a cross-sectional view.



River discharge Q_r : As long as the calculated discharge, according to equation 1 of paragraph 2.1., is smaller than $Q_{r,max}$ then $\alpha = \alpha_2$ is used with eq.1.. As soon as the calculated discharge Q_c becomes more than $Q_{r,max}$, then Q_r becomes equal to $Q_{r,max}$:

$$Q_{r,t} = Q_{r,max} = Q_{r,max} \times e^{-\alpha_2 \times t} + Q_{r,max} \times (1 - e^{-\alpha_2 \times t})$$

Valley discharge Q_v : as long as $Q_r \leq Q_{r,max}$, Q_v develops as a recession curve under its own reaction factor α_1 . But as soon as $Q_r = Q_{r,max}$ then Q_v is calculated according to:

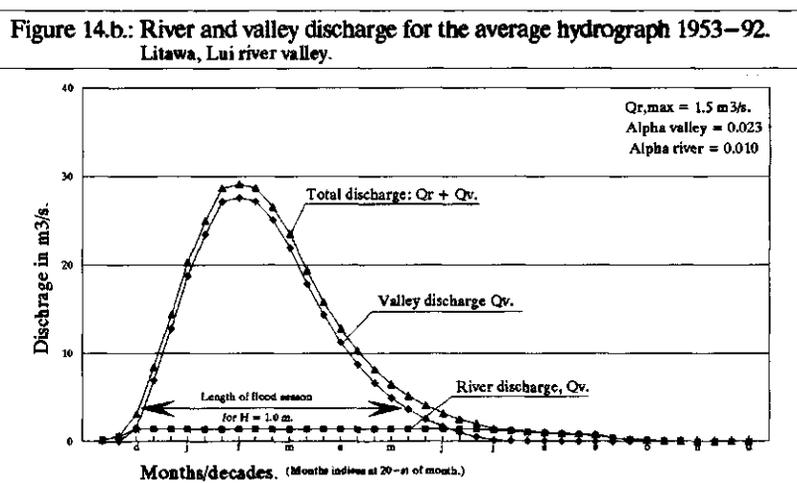
$$Q_{v,t} = Q_{v,t-1} \times e^{-\alpha_1 \times t} + J \times (1 - e^{-\alpha_1 \times t})$$

where J is a corrected input value for I_w , according to:

$$J_n = I_n - \frac{(Q_{r,max} - Q_{r,n-1} \times e^{-\alpha_r t})}{(1 - e^{-\alpha_r t})}$$

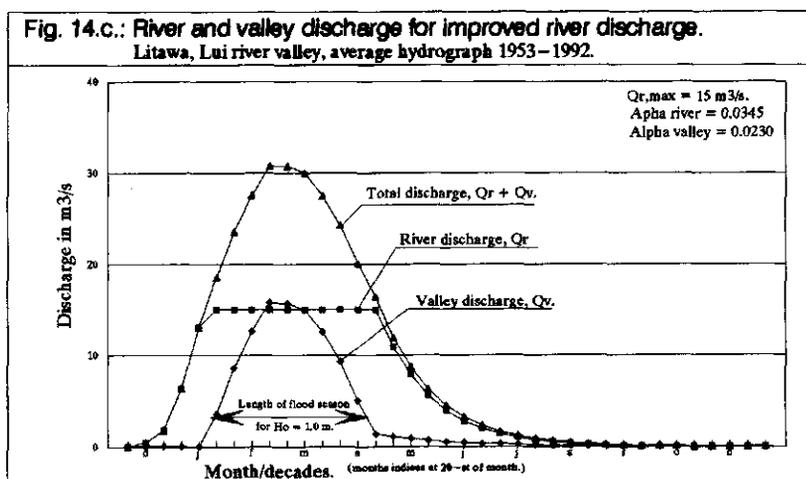
As soon as $Q_{r,n-1} = Q_{r,max}$ than J_n equals $I_n - Q_{r,max}$. The $Q_{r,max}$ is a required input to keep Q_r at a constant rate of $Q_{r,max}$.

The calculated Q_v and Q_r and their addition to Q_c at Litawa, are shown in figure 14.b.. To construct the hydrograph(s), the average input values I_w , of the 40-year's period 1953-92, have been used.



The rather small contribution in the total discharge of the river channels, as compared with the one of the valley, is remarkable.

Figure 14.c. which is similar to figure 14.b., shows the effects of an increased river discharge capacity of the river on the flood regime of the valley. This will be a result of canalization of the main river channel(s), see also paragraph 4.2.4..



Including a third reaction factor, $\alpha = \alpha_3$, for the low and rapidly decreasing discharges, can be done by using an additional "if-statement" which calculates these low(er) discharges according to equation 1 with $\alpha = \alpha_3$. Small errors will result from the transition of α_2 to α_3 and reversely. Although the errors are small because also the contribution of the low discharges in the total discharge is rather insignificant, they can not be disregarded because their values would accumulated over the years, resulting in a divergence between input and output.

An other reason that the input does not exactly equal the output is the fact that the calculation intervals are not constant. Normally the interval is 10 days except for months with 31 days and for the month of February.

The wetland reservoir has a relative short memory. For an overall α -value of 0.02 day^{-1} , an input has left the reservoir for 99.9% after one year. For the above given reason, an annual correction is made on the output so that output equals exactly the input. Table 4 of appendix II gives an example.

3.4. Model calibration and goodness of fit.

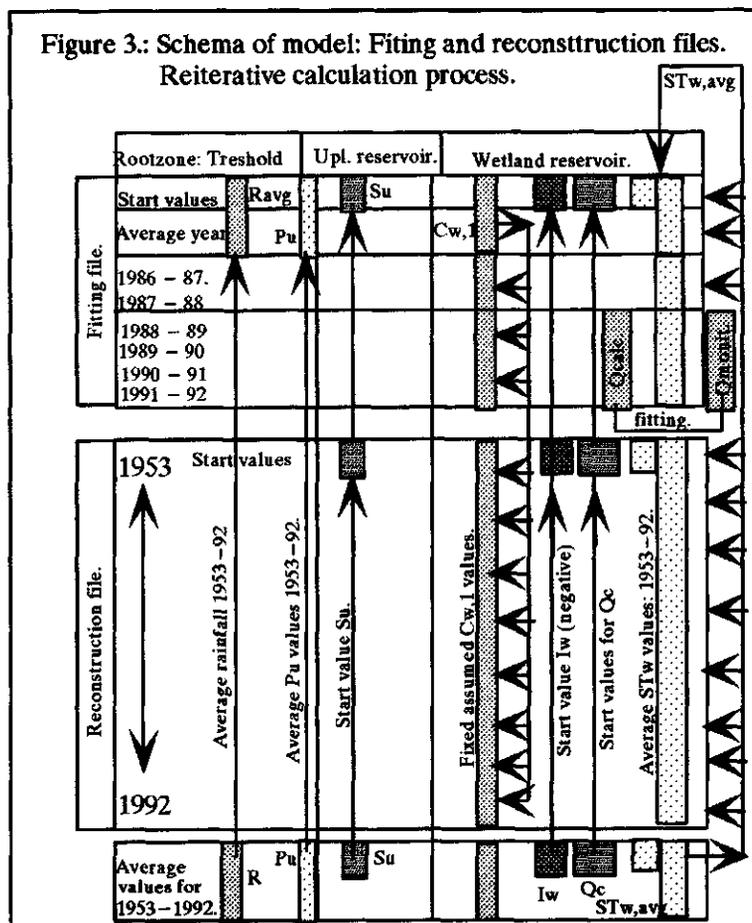
In the model calibration the calculated discharge hydrographs are compared with the four monitored hydrographs of 1988/89 to 1991/92. As long as no proper fit between the two exist, model parameters are reassumed until a good fit between the calculated and monitored discharges is obtained. The goodness of fit can be described by different fitting parameters F_1 to F_3 , see next paragraph.

3.4.1. Model calibration scheme.

The calibration or model fitting is an iterative calculation process, as shown by figure 15. There are two parts, called files. In the fitting file, the hydrographs are calculated and compared with the monitored ones and in the simulation file hydrographs are simulated on historical rainfall data 1953-1992. Due to the slow nature of groundwater flow, an 'average' year and two more hydrological cycles, e.g. 1986/87 and 1987/88 proceed the four monitored years in the fitting file, necessary to avoid errors in the values for the reservoir storage and discharges at the beginning of the monitored period.

Strong links, which exist between the two files, are indicated by

arrows in figure 15. Given a (highest) reaction factor value of about 0.02 day^{-1} for the wetland reservoir and in order to obtain sufficient accuracy in calculated peak discharges, a time interval of 10 to 11 days (monthly decades) is chosen.



Correct initial values in both files are provided from the average of monthly decade values out of the simulation file. Such values, at the start of the ^{first} hydrological year, are required for the available soil moisture storage, SM_0 , of the different root zones, for the upland ground water flow S_u (which has a linear relationship with the upland ground water storage), for the accumulated (negative) value of soil moisture depletion in the wetland I_w , and for the wetland discharge Q_c .

The rainfall input in the 'average' year of the fitting file are the average rainfall data of all the years in the simulation file. The same is done for the percolation figures because average rainfall would not produce the correct but lower percolation figures since they are, as average of many years, too uniform distributed over the rainy season.

A third linkage between the fitting and simulation file is the use of the average wetland storage $ST_{w,avg,n}$ (see equation 6 paragraph 2.4.) to calculate the wetness or $C_{w,2}$ -coefficients in both files.

It is foremost this link which has led to integrate both files in one iterative calculation scheme. The definition of the $C_{w,2}$ -coefficient is an important element in the accurate determination of the wetland evapotranspiration as a function of the flooding.

After the calibration, the model will validate by predicting correctly the discharges. It might be possible that still some adjustments in model parameters or some conceptual changes are needed. It is unknown how good the model predict very high discharges (as a result of very high rainfall) because none of such years occurred during the monitored period of the model calibration. For example, exceptional high and early rainfall might require a more detailed approach for interflow estimations which determines more accurately the onset of the floods.

3.4.2. The goodness of fit.

For a proper fit between the calculated and monitored hydrographs, the area under both graphs should be equal and their ratio near to unity or a 100%. This does not mean a proper fit with respect to the onset, the maximum and recession of the floods.

Goodness of fit can be judged by parameters which are the average value of the square root of the sum of square numbers of the absolute deviations between the measured and calculated discharges. When all discharges are included, the parameter F_1 , describes the overall goodness of fit, as follows:

$$F_1 = \frac{\sqrt{\sum (Q_{m,n} - Q_{c,n})^2}}{N_1} \quad (13)$$

where: $Q_{m,n}$ = Monitored flow at end of interval n.
 $Q_{c,n}$ = Calculated flow at end of interval n.
 N_1 = number of intervals.

For the analyses of the fluctuation in annual maxima, the fit of maximum floods is important. The goodness of fit for maximum floods can be expressed by the F_2 -coefficient:

$$F_2 = \sqrt{\frac{\sum (Q_{m,max} - Q_{c,max})^2}{N_y}} \quad (14)$$

where: $Q_{m,max}$ = Monitored maximum flood.
 $Q_{c,max}$ = Calculated maximum flood.
 N_y = Number of hydrological cycles or years.

The goodness of fit for low discharges is obtained by the substitution of $\ln Q$ instead of Q in equation 13 and which gives a third coefficient F_3 .

3.5 Results of the model calibration.

The model is applied to two catchments, i.e. Sasenda and Litawa. The results of the fitting and simulation are given in the tables 1.a and 1.b , 2.a and 2.b and 3.a and 3.b of appendix 2.

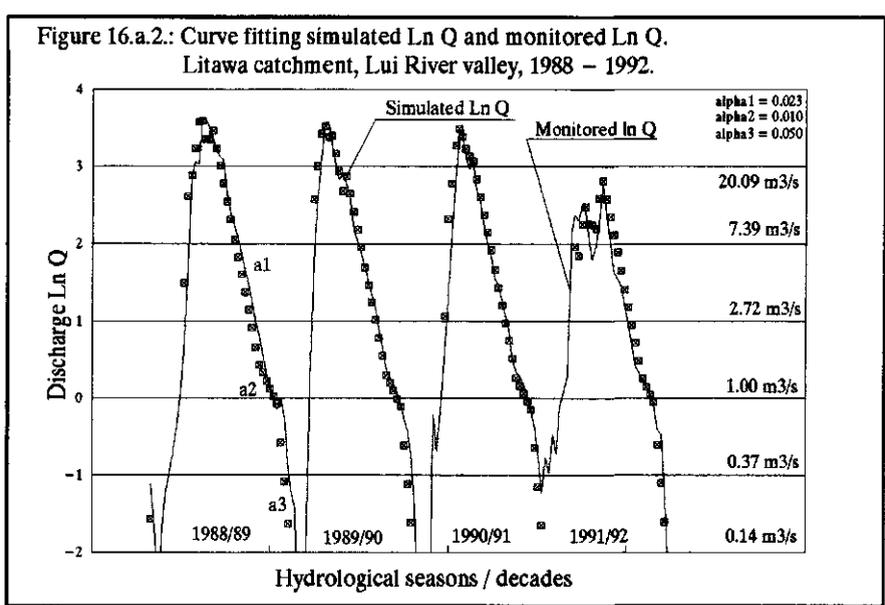
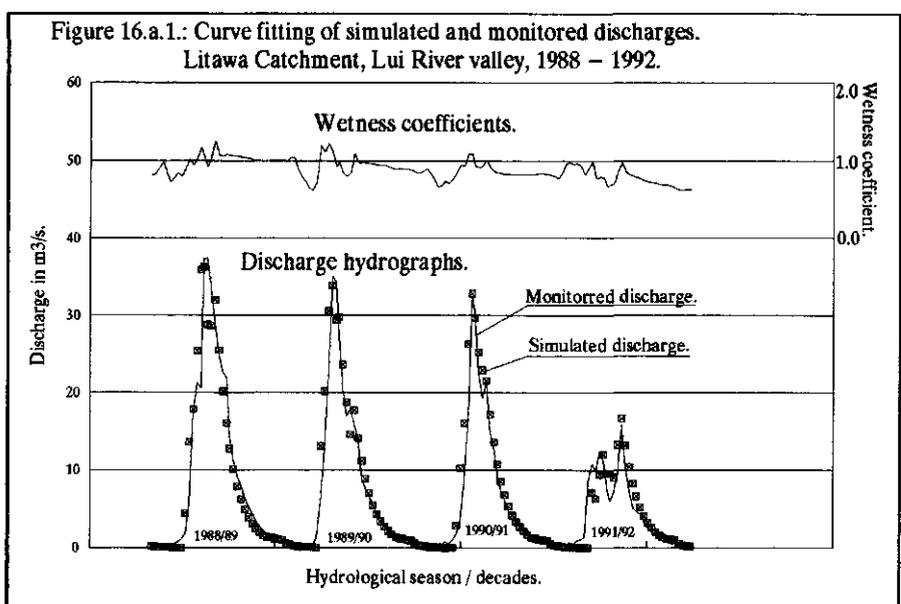
The fit between the calculated and monitored hydrographs is shown in the figures 16^a and 16^b for Litawa and Sasenda respectively. Numerical values on the maxima and the total discharges as well as on the goodness of fit coefficients, are given at the bottom of the figures.

Simulation results for the period 1953 - 1992, are shown in figures 17^a and 17^b, in which also the values for the $C_{w,2}$ -coefficients are shown. Interpretation of these results gives values for the different water balance components.

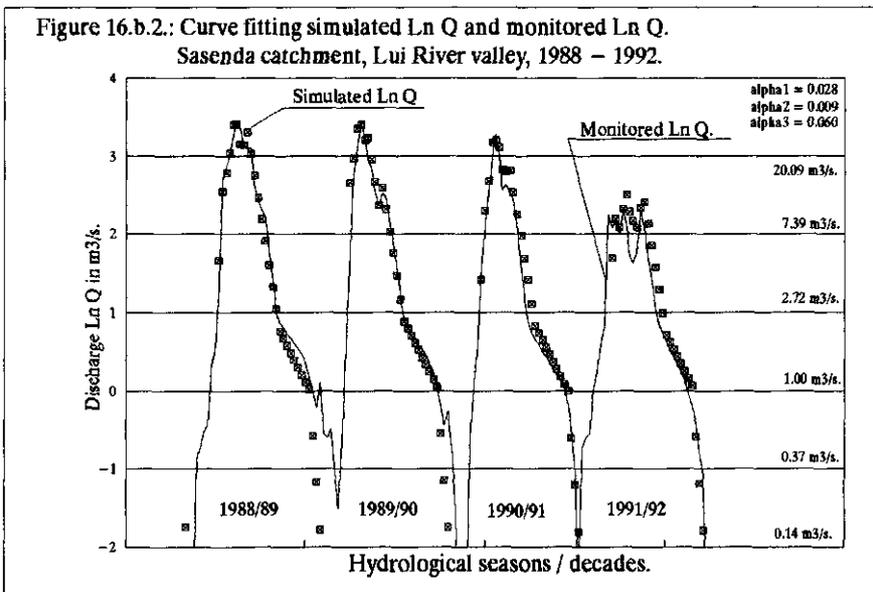
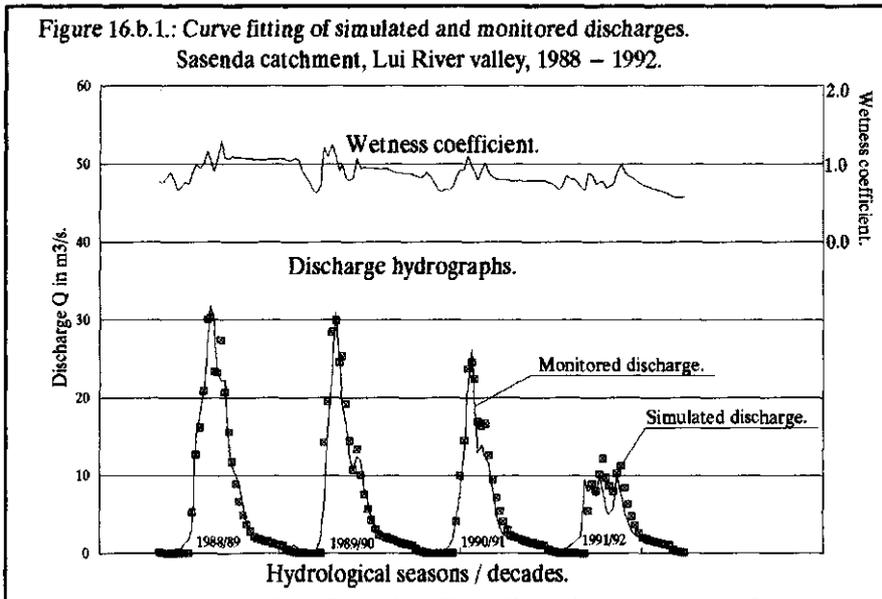
3.5.1. Rainfall.

Total rainfall is near to about average in three out of the four monitored rainy seasons; 1988/89, 1989/90 and 1990/91. Rainfall for the rainy season 1991/92 is well below average.

For the simulation period 1953-1992, the average seasonal rainfall inputs are 876 mm and 898 mm for Litawa and Sasenda respectively. The 10% and 90% probability levels of non-exceedance are 655 and 1088 mm for Litawa and 683 and 1112 mm for Sasenda.



Goodness of fit:	1988/89	1989/90	1990/91	1991/92	1988 – 1992
Qc,max m3/s	36.17	33.86	32.83	16.62	
Qm,max m3/s	37.34	35.07	32.39	15.8	
Qc/Qm * 100%	97%	97%	101%	105%	
Qc mm	65	56	51	30	201
Qm mm	65	52	44	29	191
Qc/Qm * 100%	99%	108%	114%	101%	105%
F1-value m3/s	3.69	2.63	2.49	2.25	2.82
F2-value m3/s	1.16	1.20	0.45	0.82	0.96
F3-value m3/s	1.59	0.98	1.46	2.08	1.58
F1: All decades	F2: peak flows		F3: recession limb.		



Goodness of fit:	1988/89	1989/90	1990/91	1991/92	1988 – 1992
Qc,max m3/s	30.32	29.94	24.54	12.23	
Qm,max m3/s	31.77	30.79	26.24	10.08	
Qc/Qm * 100%	95%	97%	94%	121%	
Qc in mm total area.	73	65	54	34	226
Qm in mm total area	77	62	49	33	221
Qc/Qm * 100%	94%	105%	111%	103%	102%
F1-value m3/s	1.81	2.25	1.54	2.33	2.01
F2-value m3/s	1.46	0.86	1.69	2.15	1.61
F3-value m3/s	2.1	1.78	1.84	2.53	2.08
F1: All decades	F2: peak flows		F3: recession limb.		

Figure 17.a : Simulated hydrographs, Litawa 1953 – 1992. Lui river valley.

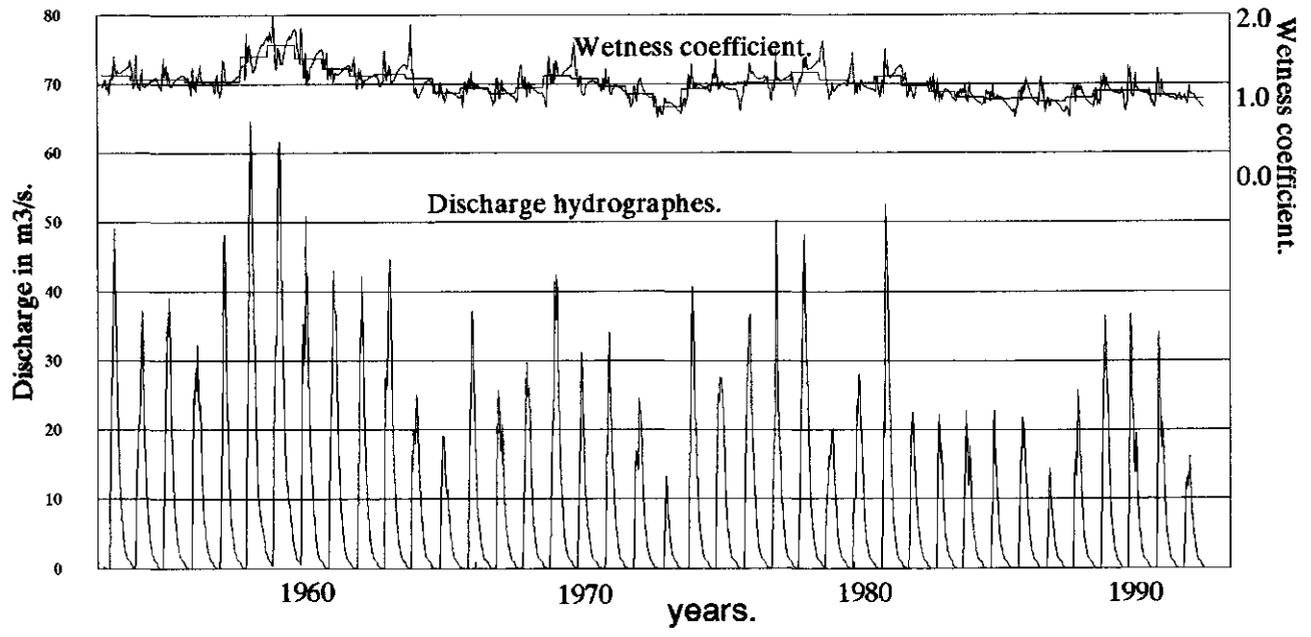
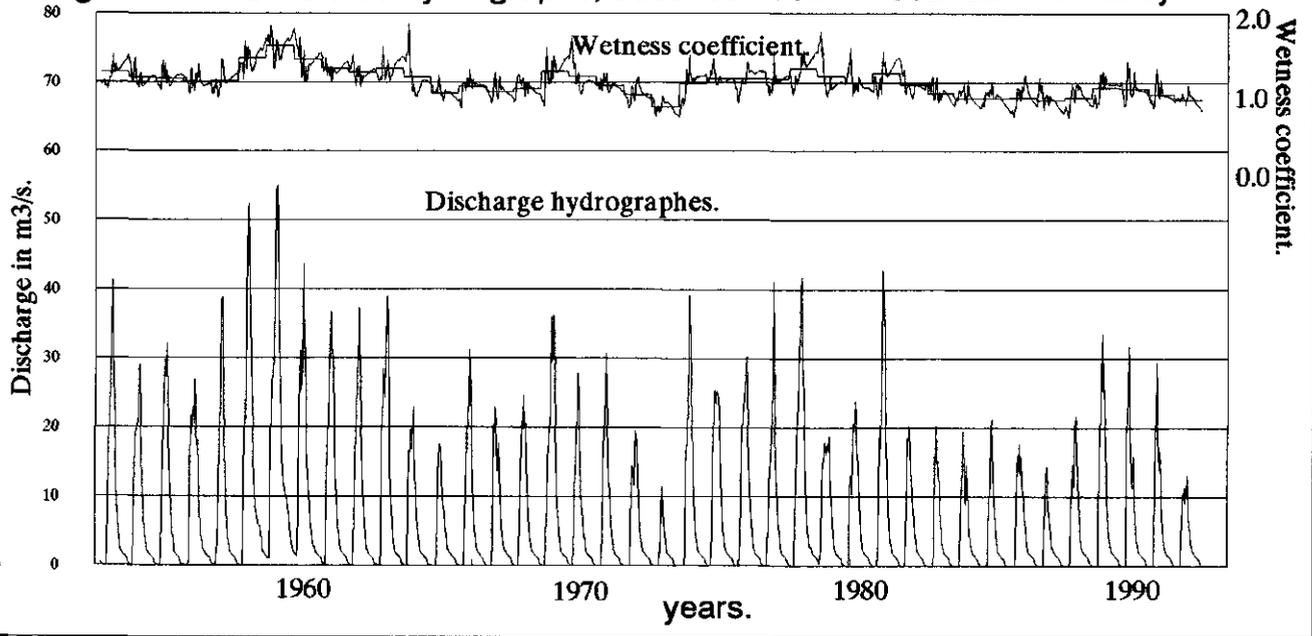


Figure 17.b : Simulated hydrographs, Sasenda 1953 – 1992. Lui river valley.



3.5.2. Evapotranspiration.

The ET_w values are about twice as much as the ET_u values. They are 0.71 and 0.36 times the ET_r , respectively. A summary is given in table 7.

Table 7.: Annual evapotranspiration figures, as averages for the whole period 1953-1992.

Litawa	ET_{avg}	ET 10% n.e.	ET 90% n.e.	CV %
ET_u in mm.	700	603	797	10.8
ET_w in mm.	1573	1222	1924	17.4
Sasenda.				
ET_u in mm.	710	616	804	10.3
ET_w in mm.	1573	1213	1933	17.9

3.5.3. Percolation and groundwater flow.

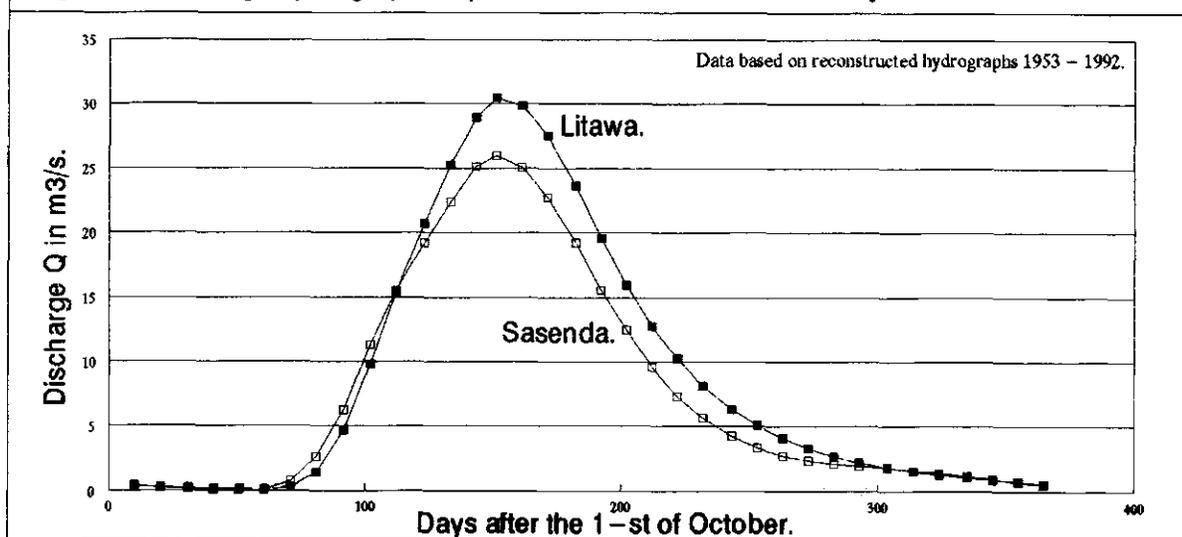
Over a longer period of several years, the amounts of percolation equals the amount of groundwater flow. The groundwater storage fluctuates but they are small as compared with the total amount of groundwater flow during a longer period. Important changes in groundwater storage may however occur between two consecutive hydrological years.

The variability of percolation, in terms of the coefficient of variation (Litawa) of 56.8%, is huge and much higher than the one for groundwater outflow (CV = 29.5%, Litawa). Percolation figures can be obtained from table 7 by subtracting the ET_u -values from the rainfall. For a 80% probability interval the annual groundwater outflow S_u , will be between 112 mm (10% n.e.) and 247 mm (90% n.e.). As an inflow or input into the wetland reservoir (after being multiplied by the Upland/Wetland ratio), its value represents often a more important input than the amount of direct rainfall.

3.5.4. Discharge.

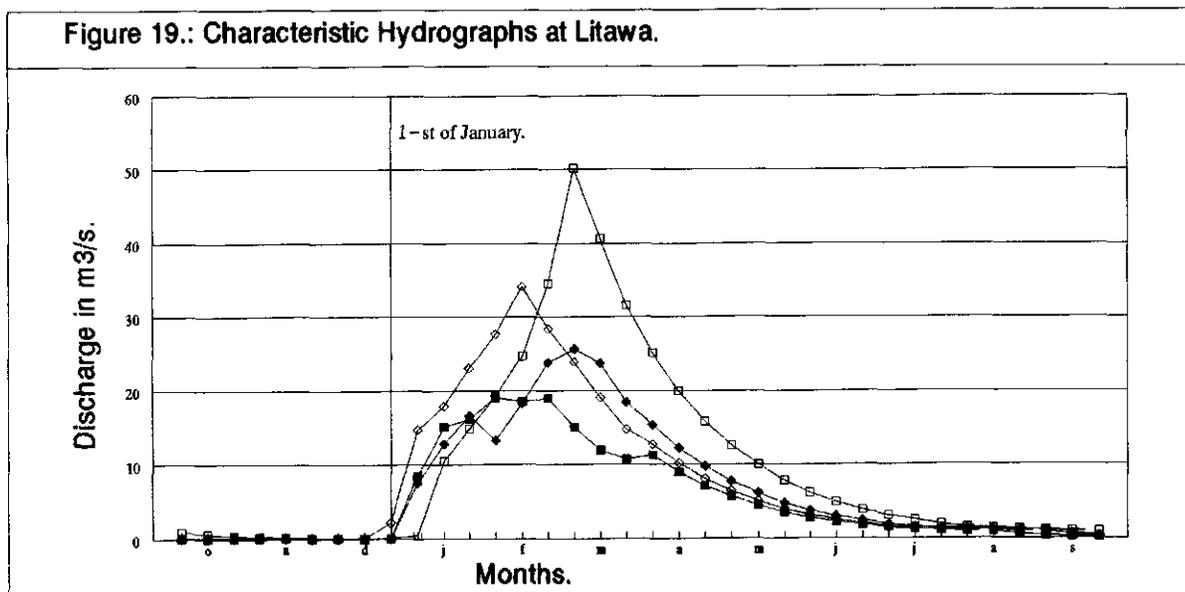
The 'average' hydrographs for Litawa and Sasenda for the whole simulation period 1953-1992 are shown in the figure 18. The 'time lag' between the two hydrographs can be observed, especially for the recession curves.

Figure 18.: Average hydrograph for period 1953–1992. Lui river valley.



Some characteristic simulated hydrographs for Litawa are shown in figure 19. This figure illustrates the differences in onset, maxima and recession of the floods.

Figure 19.: Characteristic Hydrographs at Litawa.



The hydrographs with a 50% (average), a 10% (dry) and a 90% (wet) probability of non-exceedance for Litawa are shown in figure 20.

Flooding of the valley normally starts in the beginning of January, reaches a maximum in the last 8 days of February or early March. For Litawa, the variability in the annual maximum discharge ($\text{m}^3 \text{s}^{-1}$) amounts to a CV% of 36.5% while the variability in total annual discharge (mm) amounts to a CV% of 40.5%. Data on maximum and total annual discharges are summarised in table 8.

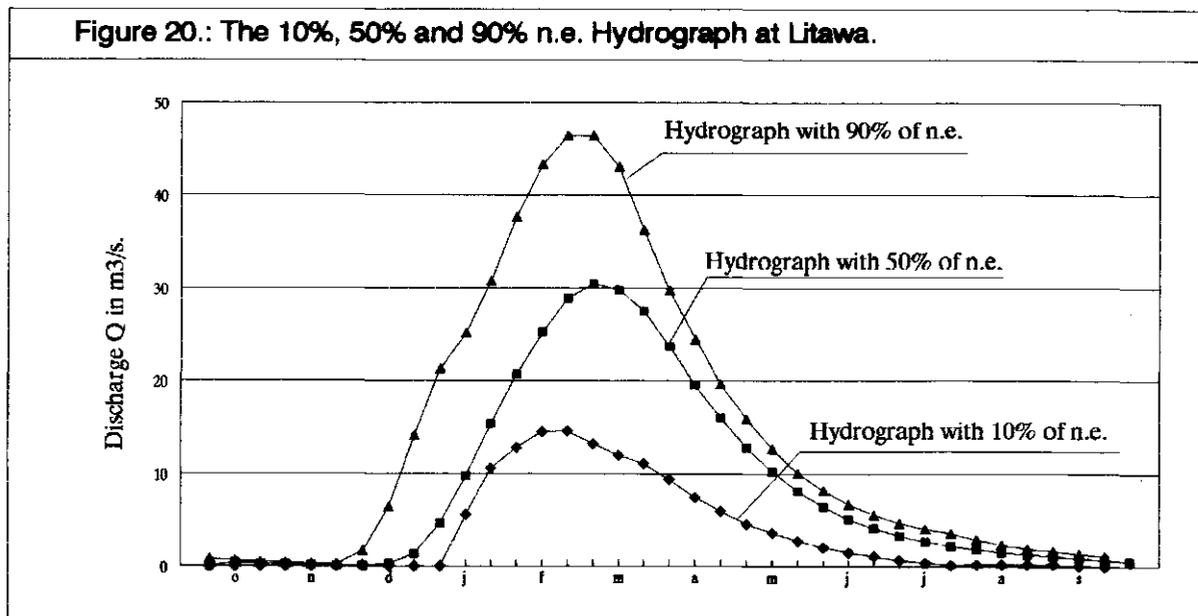


Table 8.: Analyses of reconstructed hydrographs 1953 - 1992.

Location		Average, 50% n.e.	Low values, 10% n.e.	High values 90% n.e.
Litawa	Q_c, max m3/s	34.4	18.3	50.4
Sasenda	Q_c, max m3/s	29.6	16.3	42.9
Litawa	Q_c^1 mm.	59	29	90
Sasenda	Q_c mm	70	33	107

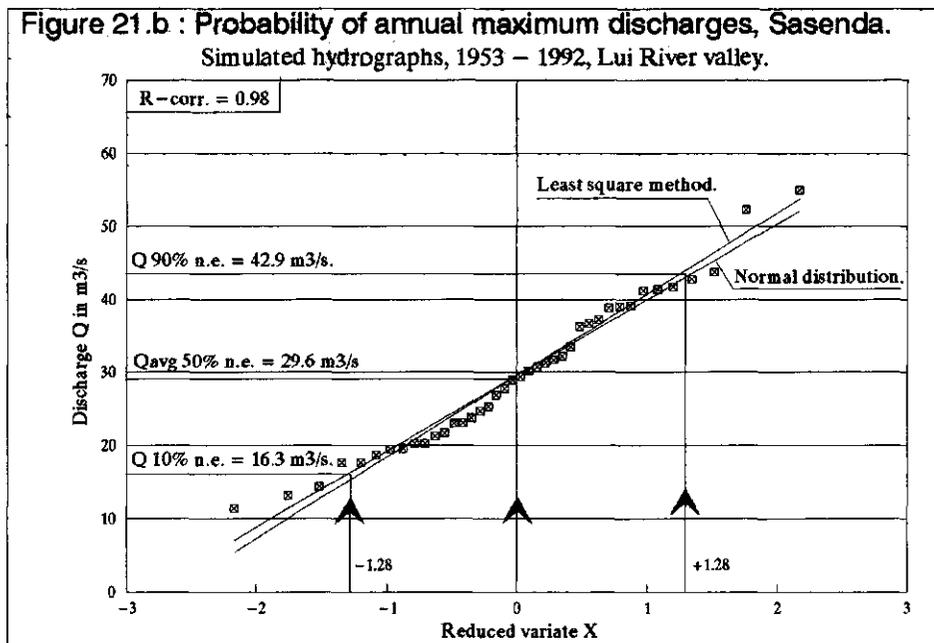
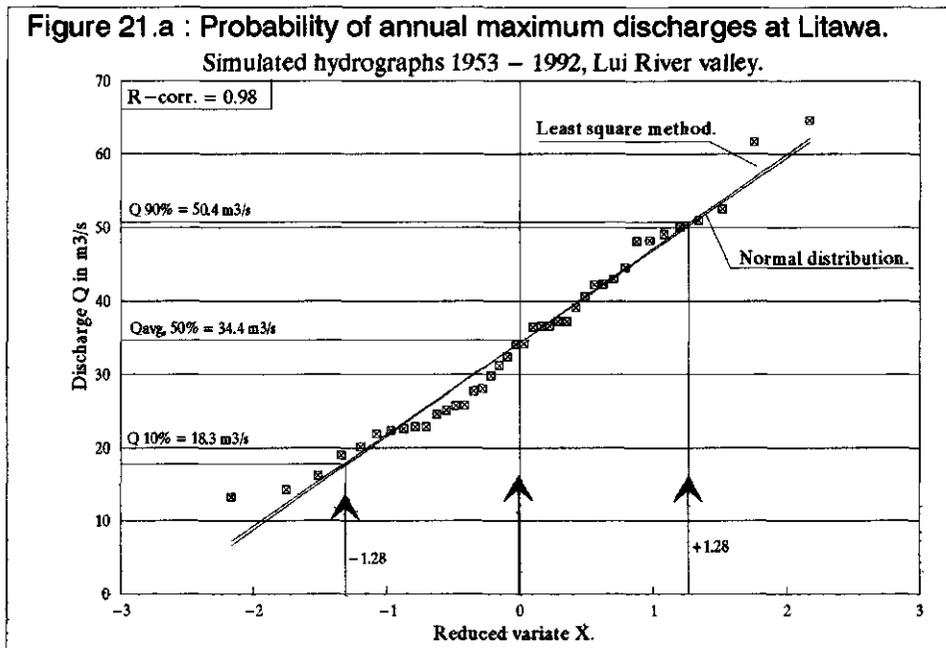
¹ expressed on the total acreage of the catchment.

The standard normal probability distribution of annual peak discharges for both catchments, are given in figure 21. Blom's plotting positions have been used [Maidment, 1992]. High correlations ($R > 0.98$) are obtained between the ordered simulated discharges (x_i) and their corresponding quantiles.

Translation of the maximum discharges, with a 10% and a 90% probability of non-exceedance, into corresponding maximum flood levels gives the fluctuation of maximum flood levels (for a 80% probability interval) of 0.34 m. and 0.30 m. for Litawa and Sasenda respectively. It are rather small fluctuations with a low variability of (CV%) 8.4% for both locations.

3.5.5. Changes in storage.

In and during the wet fifties, the (ground)water storage was more important then at the end of the dry eighties. The amount of



Discharges:	Qmax 50%	Qmax 10%	Qmax 90%	$ P_n - P_k m$	CV %
Litawa	34.39	18.34	50.44	0.096	36.5 %
Sasenda	29.56	16.26	42.86	0.078	35.2 %
Flood levels:	Hmax 50%	Hmax 10%	Hmax 90%	PI 80%	
Litawa	1.6	1.43	1.77	0.34	8.4 %
Sasenda	1.38	1.23	1.52	0.29	8.4 %

storage over the period 1953 to 1992 has decreased. Details can be found in the tables 3.a. and 3.b. of appendix II and in table 9 of the next paragraph 3.5.6.. The major changes in storage occurred, of course, to the upland groundwater reservoir but they are, as a percentage of the accumulated value of the other water balance components, almost insignificant.

3.5.6. Overall balances.

The overall balances show which part of the rainfall will evapotranspire from either the upland or the wetland and which part ends up as discharge. The balance is summarised in table 9.

The higher (discharge) figures for Sasenda as compared with those of Litawa are partly due to higher rainfall in the northern part of the Catchment.

The discharge amounts for a 80% probability interval, 3.3% to 10.3% of the total rainfall (Litawa).

Table 9.: Water balance components as averages for the period 1953-1992, mm/season.

Catchment	Rain	ET _{upl}	ET _{wetl}	Q _c	AST
Litawa	876	603	216	59	-2
Sasenda	898	612	218	70	-2
As % Rain	100%	68.5%	24.5%	7.3%	-0.3%

3.6 Sensitivity analyses.

Sensitivity analyses are done in search for the dependency of the model from its own (and assumed) parameters. Parameters to be evaluated are: (1) the reaction factor for the upland ground water reservoir β , (2) the maximum amount of available soil moisture of the upland SM_{max} , (3) the upland evapotranspiration coefficients $C_{u,1}$ and (4) the constant value $ST_{w,const}$, added to the wetland storage to avoid unrealistic wetness coefficients.

Changes in the parameters β and $ST_{w,const}$ do not affect the total input and thus output of the reservoirs but they affect the time-lag of the system. Different values for the SM_{max} and $C_{u,1}$ parameters

change the input and therefore a re-calibration is first made before the effects on the model performance are studied. In the re-calibration, only an adjustment of the $C_{w,1}$ coefficient to calculate the wetland evapotranspiration, is needed. Effects from a change in the reaction factor α is discussed in chapter 4.

3.6.1. The upland reaction factor β .

A lower β -value gives a stronger attenuation effect on the calculated discharge due to the slower reaction of the upland groundwater reservoir. As a result, the fluctuation in annual maximum discharges as well as in annual maximum flood levels will be less pronounced. For high(er) β -values attenuation will be less and fluctuations in maximum discharges are more important. Results of the sensitivity analysis for several β -values are shown in table 10. A more accurate estimate of the β -parameter is possible when during the calibration period important differences occur in the monitored maximum discharges.

Table 10.: Effects of different β -values on the model output.

Item (Litawa)	Units	0.00075	0.0010	0.0015	0.0020	0.0030
Lag ¹ :→ 0.1 * S _u	Year	8.4	6.3	4.2	3.2	2.1
F1-value	m ³ /s	3.46	3.16	2.82	2.64	2.52
F2-value	m ³ /s	1.53	1.09	0.96	1.15	1.99
F3-value	m ³ /s	1.41	1.42	1.58	1.61	1.70
Q _{avg} , 50% n.e.	m ³ .s	35.2	34.8	34.4	34.1	33.5
Q 10% n.e.	m ³ /s	20.9	19.8	18.3	17.0	14.7
Q 90% n.e.	m ³ /s	49.5	49.8	50.4	51.1	52.3
AH _{max} , 80% PI	m.	0.30	0.32	0.34	0.37	0.42
GWL _{min} , 80% PI	m.	1.41	1.16	0.86	0.67	0.46
GWL _{max} , 80% PI	m.	1.75	1.54	1.29	1.15	0.99

¹ Here, the lag is expressed as the time (years) to reduce the Q_{recession} to a tenth of its original value.

The fluctuation in annual maximum flood levels, for a 80% probability interval, increases from 0.30 m for a β -value of 0.00075 d⁻¹ to 0.42 m for a β = 0.00300 d⁻¹. This is a rather insignificant increase as compared with the change in β -value from 0.00075 d⁻¹ (=100%) to 0.00300 d⁻¹ (400%).

The assumed β -value has a more effect on the fluctuation of the

positions of the upland groundwater table, see table 2. Appendix III : e.g. the fluctuations in the groundwater table are, for a probability interval of 80%, 0.46 m ($\beta=0.00300$) and 1.41 m. ($\beta=0.00075$).

Dambo water levels most likely relate to the position of the nearby ground water table, see chapter 4.3.. Dead tree stumps due to high (ground)water levels in the fifties, as well as regrowth of trees, due to low (ground)water levels in the eighties, are found on the dambo margins with the upland. A period of sufficient length with either high or low groundwater tables, requires a rather small β -value of less than 0.002 d^{-1} .

On the other hand fluctuations of more than 1.16 m in the minimum level of the ground water table are unlikely which excludes β -values lower than 0.001 d^{-1} . The β -value has therefore most likely a value between 0.001 and 0.002 day^{-1} . In the final model fit for Litawa, a β -value of 0.0015 is used.

3.6.2. The wetland storage constant, $ST_{w, \text{const.}}$.

Five different $ST_{w, \text{const}}$ -values have been chosen to study their effects on the model. Results are summarised in table 11.

Table 11.: Effects of the $ST_{w, \text{const}}$ -value on the model performance.

$ST_{w, \text{const.}}$	Units	25	50	75	100	125
F1-value	m3/s	3.22	2.99	2.82	2.68	2.59
F2-value	m3/s	1.26	1.04	0.96	1.02	1.17
F3-value	m3/s	1.40	1.41	1.58	1.64	1.68
ΔH_{max}	m.	0.32	0.33	0.34	0.36	0.37

Different $ST_{w, \text{const}}$ -values have little consequences for the goodness of fit. For a $ST_{w, \text{const}}$ ranging from 25 and 125 mm, the fluctuation in annual maximum flood levels increased from 0.32 m. to 0.37 m (PI 80%). The best fit (F_2 -value) is obtained for a $ST_{w, \text{const}}$ -value of 75.

3.6.3 Maximum soil moisture availability, SM_{max} .

The value for SM_{max} determines the maximum volume of soil moisture in the root zone(s) which is available for the upland evapotranspiration. A higher SM_{max} -value increases the ET_u , resulting in less

percolation and thus less groundwater flow. A re-calibration of the model is therefore needed through the adjustment of $C_{w,1}$ -coefficients to obtain a good fit between the simulated and monitored hydrographs. After re-calibrations, the effects on the simulated hydrographs are studied. The results are summarised in table 12.

Good fits are obtained by multiplication of the $C_{w,1}$ -coefficients with a constant value, see table 12. From the same table, it can be observed that different SM_{max} -values hardly change the model output Q_c . The highest and lowest, average $C_{w,1}$ -values are 0.87 and 0.66. The corresponding values for the total annual ET_w , based on an ET_{ref} of 2200 mm y^{-1} , are 1,450 and 1,900 mm y^{-1} . The range includes all reasonable values for the total annual wetland evapotranspiration.

Table 12.: Effect of different SM_{max} -values on the model output.

Litawa	Units	SM_{max} -low	SM_{max} -avg.	SM_{max} -high
Root zones. Assumed SM_{max} -values.				
Shallow	mm	20	30	40
Medium	mm	140	210	280
Deep	mm	340	510	680
Goodness of fit.				
F1-value	m ³ /s	2.95	2.82	2.80
F2-value	m ³ /s	0.88	0.96	1.27
F3value	m ³ /s	1.40	1.58	1.53
Balance components for the period 1953-1992.				
Rain	mm	876	876	876
ET_{up1}	mm/upl	654	700	727
P_u	mm/upl	222	177	150
ET_w	mm/wetl	1857	1573	1405
$C_{w,1,avg}$		0.87	0.73	0.66
Q_c	mm/wetl	436	433	424
$Q_{c,avg}$ 50% n.e.	m ³ /s	34.4	34.4	34.1
$Q_{c,low}$ 10% n.e.	m ³ /s	17.4	18.3	18.6
$Q_{c,high}$ 90% n.e.	m ³ /s	51.3	50.4	49.6
ΔH_{max} PI 80%	m	0.37	0.34	0.33

Different values of SM_{max} have similar effects on the fluctuations in the upland groundwater table position as different β -values. For a 80% probability interval, the fluctuation in annual minimum ground water tables due to either a high or a low SM_{max} -value, are 0.69 m and 1.09 m respectively. They are within the existing fluctuation ranges due to an unknown β -value between 0.001 and 0.002 day⁻¹, see figure 30 of paragraph 4.3., which shows the relative groundwater table positions as a function of β .

3.6.4. Upland evapotranspiration coefficients, $C_{u,1}$.

The assumed values of $C_{u,1}$ -coefficients influence the amount of ground water flow in more or less the same way as the assumed value

Table 13.: Effects of assumed $C_{u,1}$ coefficients on model output.

Litawa	Units	High $C_{u,1}$	Avg $C_{u,1}$	Low $C_{u,1}$
Root zones. Assumed $C_{u,1}$ -values.				
Shallow	mm	0.3	0.2	0.1
Medium	mm	0.6	0.5	0.4
Deep	mm	0.9	0.8	0.7
Goodness of fit.				
F1-value	m ³ /s	2.76	2.82	2.79
F2-value	m ³ /s	1.07	0.96	1.38
F3value	m ³ /s	1.53	1.58	1.61
Balance components, Averages for the period 1953-1992.				
Rain	mm	876	876	876
ET _{up1}	mm/upl	743	700	656
P _u	mm/upl	143	177	222
ET _w	mm/wetl	1357	1573	1864
$C_{w,1,avg}$		0.63	0.73	0.87
Q _c	mm/wetl	433	433	419
Q _{c,avg} 50% n.e.	m ³ /s	34.4	34.4	33.6
Q _{c,low} 10% n.e.	m ³ /s	18.4	18.2	17.5
Q _{c,high} 90% n.e.	m ³ /s	51.3	50.4	49.6
ΔH_{max} PI 80%	m	0.34	0.34	0.35

for SM_{max} , see table 13. Different $C_{u,1}$ -coefficients have not much effect on the outcome of the model in terms of (peak) discharges, see table 13.

3.6.5. Summary of the sensitivity analyses.

Low β -values and low $ST_{w, const.}$ -values reduce slightly the fluctuation of annual maximum discharges and thus the fluctuation in maximum flood levels. For higher values the contrary is found.

Different values for SM_{max} -values and $C_{u,1}$ -coefficients change the amount of ground water flow from upland to wetland. After a re-calibration of the model, it looks that the changes are mainly compensated for by a change in ET_w and not by a change of the river discharge nor of its maximum levels. The effects are however, as it is the case for different assumptions of β , more pronounced for the position of the upland groundwater table.

IV. Applications of results.

4.1. Introduction.

Some applications of the model, described in chapters 2 and 3, are presented in the following paragraphs. The simulated hydrographs 1953-1992 provide information on the flood regime which defines, amongst other factors, the valley's suitability for rice cultivation. Another application is the study of effects due to a change in the environment of either the wetland (rice cultivation) or upland (more cassava) or both. Possibilities to influence the flood regime are briefly discussed. Finally, the relation between dambo water levels and calculated upland ground water table levels, is discussed. It is notified that the physical aspects, discussed in this chapter, are not the only aspects which play a role in the extent rice can and will be grown in the valley. Socio-economic, infra-structural and marketing policies play an important role as well, but they are outside the scope of this paper.

4.2. Hydrological aspects of rice cultivation.

Whether it is possible to grow rice under natural flood conditions or not, it is important to know more about the flood regime. Flood characteristics such as the onset, the variation in annual maximum flood levels and the recession of floods, define the last possible planting date(s) and the variety choice with respect to flood depth tolerance and possible length of the growing season. In this respect, a choice can be made between long and short straw varieties. Their differences in characteristics are listed in table 14. (De Datta, 1981).

4.2.1. The last possible planting date.

Land preparation and planting.

In order to control weeds, cross ploughing is advised. The first ploughing should be done early (September) so that sufficient time is left between the first- and the cross-ploughing. Land preparation and planting is done under rain fed conditions prior to the arrival of the floods. In reality farmers wait for 'good' rains before they start ploughing which assures a good grazing for their draft-oxen. When these initial rains are late, land preparation and planting of rice also start late. Rice which is planted (too) late might suffer from early floods resulting in either (in the worst

case) drowning of the young rice plants, fish damage and poor tillering. After planting, rice needs a week for germination and at least another 2 weeks to establish before the floods arrive.

Table 14.: Some characteristics of long (deep water) and short straw varieties.

Characteristic.	Long straw	Short straw
Growth duration, days	150 to 210	120 to 150
Flood depth tolerance	up to 1.0 m.	up to 0.5 m.
Flood season, days	100 to 150	60 to 100
Stem length, m.	1.2 to 1.5	0.5 to 0.8
Potential yield, T/Ha	4.0	6 to 7
Fertiliser needs	low	high
Weed tolerance	good	poor
Dormancy	present	absent
Water management	low level	demanding

Farmers, aware of unexpected early floods, choose their rice fields at different elevations to spread risks. However, the optimum field level range to plant is narrow, e.g. 0.36 m. for long straw varieties, see figure 23 while at the beginning of the flood season, the flood levels increase rapidly with about 0.04 m/day (rising limb of the hydrographs).

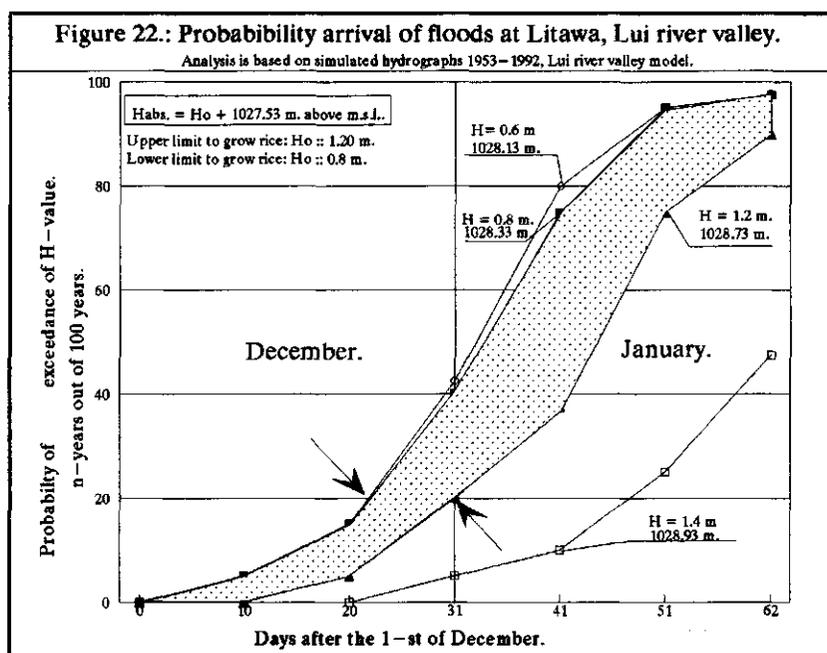
In order to find the last possible planting dates, the discharges hydrographs 1953 - 1992 have been analysed with respect to the onset of the floods. Results for Litawa are shown in figure 22. The results apply to almost every location of the valley since the 'time lag' in the onset of the floods along the valley is very small, as illustrated by figure 18.

For the arrival of floods, the date floods reach the level of the rice fields can be taken. For Litawa, the lower and upper suitable field levels coincide approximately with the H-values of 0.8 to 1.2 m respectively. Translated into absolute field levels, a range from 1028.33 m to 1028.73 m above mean sea level. A detailed topographical survey at Litawa revealed that rice (for a PI of 90%) is planted between the levels 1028.30 and 1028.90 m. (on average at 1028.63 m.) above mean sea level (LWMP, 1989) which constitutes a

much wider range than the given suitability range, especially with regards to the upper limit. Figure 22 shows the dates (x-axis) that floods have arrived at a given H-level and given probability (y-axis). For example, when once every five years ($P=20\%$) a too early onset of the floods is accepted and with the assumption that rice should be planted three weeks prior to the arrival of the floods, then the last planting date can be derived:

- Long straw varieties on the low(er $H=0.8$ m.) fields have to be planted before the 1-st of December.
- Short straw varieties (or long ones planted on the high(er) located fields, $H=1.20$ m.) have to be planted before the 10-th of December. Short straw varieties should however not be planted much earlier otherwise they mature too early.

The possible delay in the planting of higher rice fields compared with the low(er) ones is rather small, and only 10 days, see arrows in figure 22.

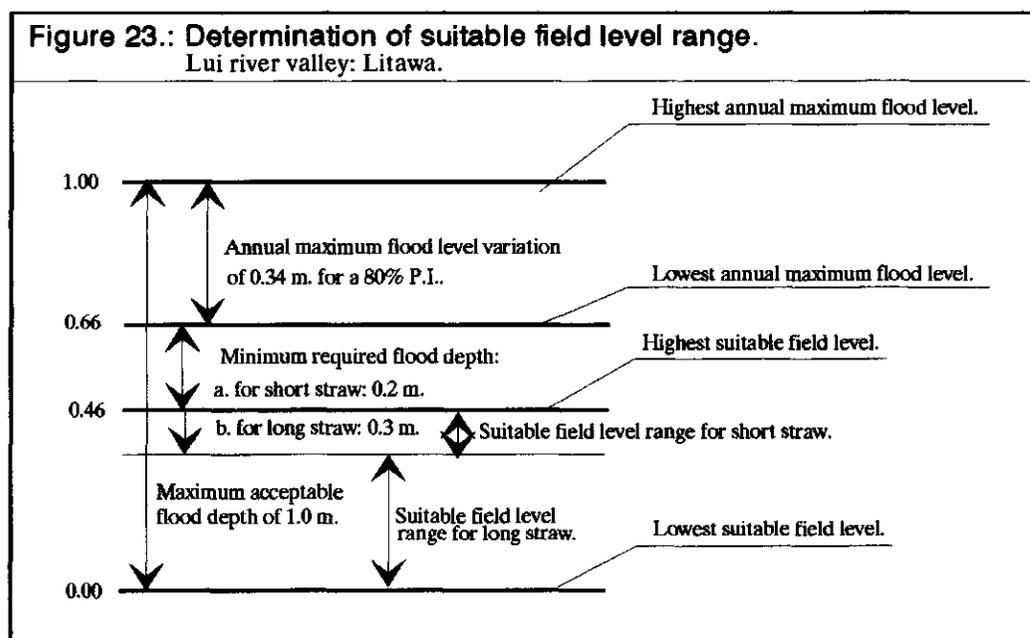


4.2.2. Depth of flooding.

Poor floods (depths) makes the rice crop vulnerable to diseases such as rice blast, brown spot [Bastiaansen, observations] and yields will be reduced. A certain flood depth is also necessary in order to have a sufficiently long flood season. The relationship

between flood level or flood depth and flood duration is obvious. The latter should correspond with the length of the growing season of the chosen rice variety, see paragraph 4.2.3..

Fluctuation of maximum flood levels reflects directly the fluctuation in maximum flood depths. The upper and lower suitable field levels for rice cultivation can be derived and its range depends on the maximum flood level fluctuations, as shown in figure 23. Figure 24 gives the suitable parts for rice cultivation within a given cross section of the valley.

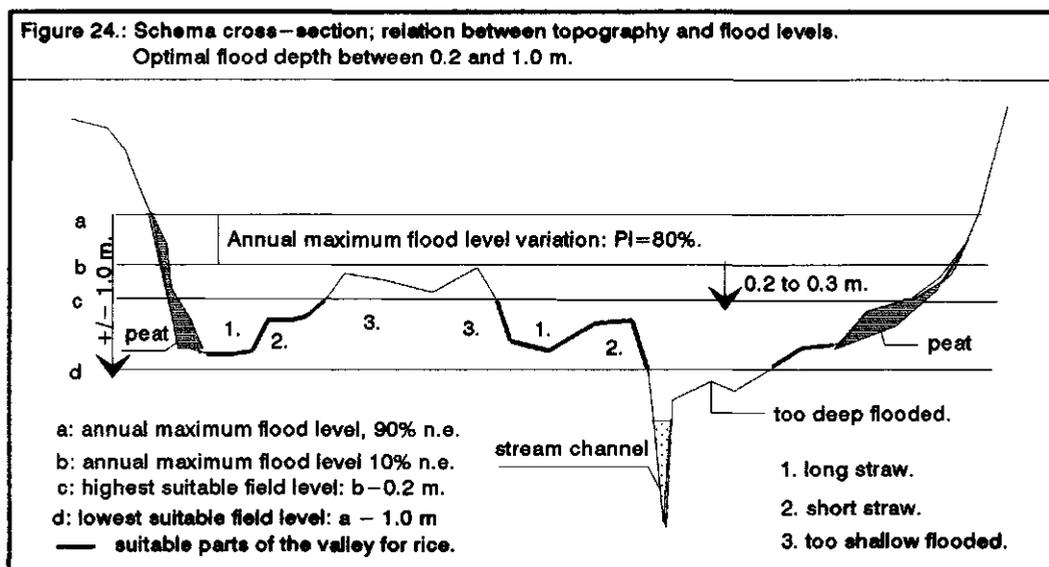


In the determination of the suitable field level range, the following assumptions are used:

- A minimum flood depth of 0.2 (short straw) to 0.3 m. (long straw) is required to assure a flood period of sufficient length.
- Short straw varieties will tolerate a flood depth up to a maximum of 0.6 m while long straw varieties tolerate depths up to 1.0 m [De Datta, 1981].

The highest suitable field level will therefore correspond with the lowest maximum flood level, with a 10% probability of non-exceedance, minus 0.2 to 0.3 m, see lines b and c of figure 24.

Likewise, the lowest suitable field level for rice (long straw) equals the highest maximum flood level, with a 90% probability of non-exceedance, minus the maximum tolerated flood depth of 1.0 m, see lines a and d. of figure 24.



Data analyses on simulated hydrographs 1953 - 1992, show a fluctuation range (for a 80% probability interval) of seasonal maximum flood levels at Litawa of 0.34 m.. Slightly smaller and wider ranges will be found for locations upstream and downstream of Litawa respectively. The resulting suitable field levels are then (see figure 23) 0.36 m and 0.06 for long and short straw varieties respectively. The narrow range for short straw varieties proves the low potential for this variety type in the Lui river valley environment. In fact, short straw varieties are planted up to a much higher field level, i.e. up to 1028.90 m. above m.s.l. at Litawa (LWMP,1989). This has resulted in a disastrous situation during 1991/92 season, when the maximum flood level only reached (see figure 9.a.1. $H_0 + 1.31 =$) 1028.84 m. above m.s.l.. Rice fields were not flooded at all or dried out fully before or during flowering. Even rainfall could not avoid this because of a the prolonged dry spell in January and February 1992. A similar situation would have occurred in 1972/73 and 1986/87 and most likely also in 1964/65 and 1978/79, see the years with a maximum discharge of less than 20 m³/s in figure 17.a .

Besides the inadequate natural flood conditions for short straw

varieties, many other reasons exist to be very careful in the promotion of short straw varieties in the Lui River Valley.

4.2.3. Growing season and annual floods.

Harvesting paddy is easier when rice fields are well drained instead of still flooded. For threshing, dry places are required. However farmers often prefer for reasons of risk spreading and soil fertility, to plant rice in low(er) fields although they are aware of the poor drainage. The topography is however such that higher places are always found nearby.

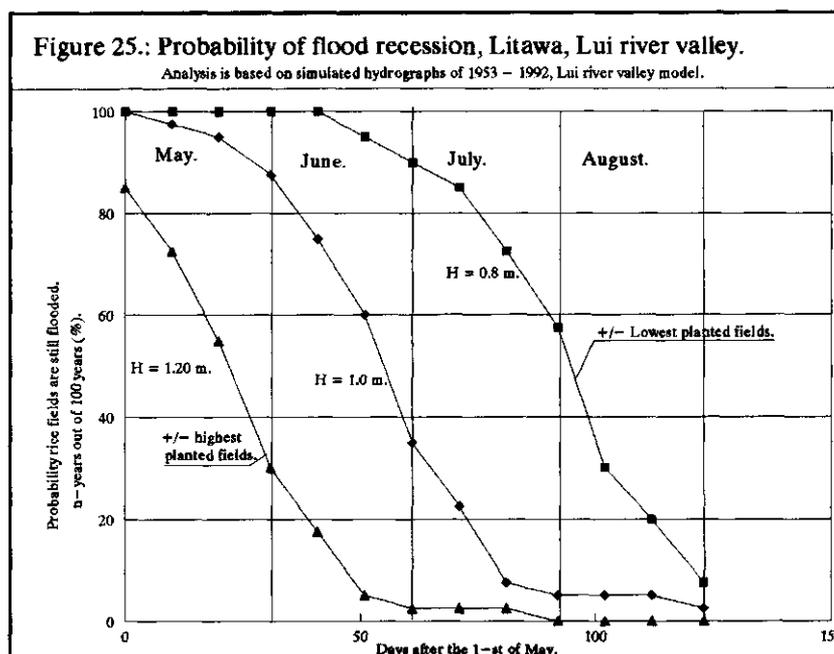
Since long straw varieties have a dormancy period of at least three months, no serious damage will occur to the rice when in water for a short period. However repeatedly wetting and drying will have negative effects the milling quality. For the same reason the harvest should not be delayed, even if the floods recede late because it results in over-mature paddy which increases the percentage of broken rice in the milling.

To study the drainage of the rice fields, the recession curves have to be analysed. Data were only analysed for Litawa though differences in recession clearly exist which means an accelerated and earlier drainage upstream and a delayed one downstream. A difference of about one week has been found between Sasenda and Litawa. A further attenuation of the floods in the downstream direction might cause a delayed drainage by a week or two at the down stream end of the valley, in Senanga district.

Results of the analyses on recession curves 1953-1992 are shown in figure 25. in which the probabilities (as n-years out of 100 on the y-axis) for different H-values curves are given that rice fields are still flooded at a given date (x-axis). For the highest suitable field level (short straw varieties, $H = 1.20$ m.), rice fields are still flooded in 8 out of the 10 years on May, the 1-st. At the end of May, when most of the short straw varieties should be harvested, the fields are still flooded once every three years ($P = 33\%$).

Long straw varieties, with a growing season of 180 to 240 days, are harvested from mid-June to the end of July. At these dates the higher fields will normally be drained but in at least 9 (mid-June) and 6 (the end July) times out of 10 years, the lower ones are still flooded. For fields at an average field level ($H = 1.0$ m or

at an absolute level of 1028.53 m. above m.s.l.) floods have not yet receded in 7 and 1 out of 10 years at mid-June and the end of July, respectively. The analyses are based on a year with an average 'wetness' which means that in 'wet' seasons the recession takes longer and in a 'dry' season shorter than mentioned above.



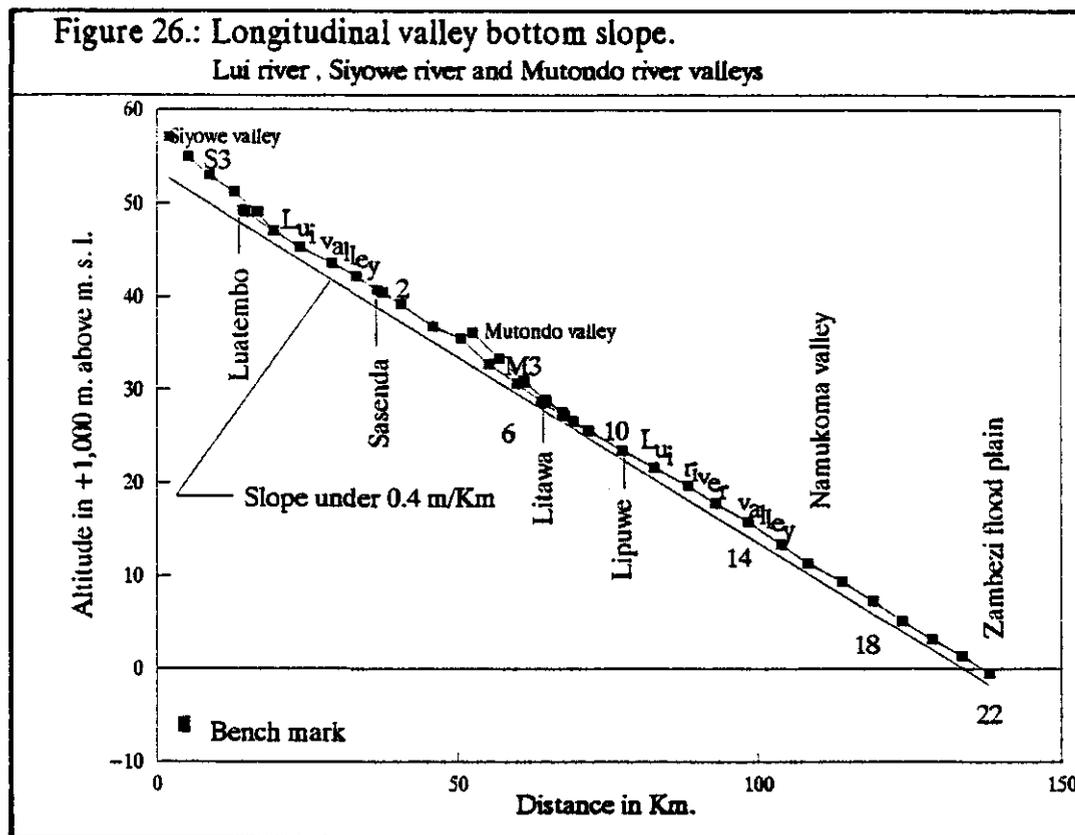
It is clear that harvesting paddy in a flooded field is very common in the Lui river valley. To avoid this situation, better (and artificial) drainage will be needed. However this will not only shorten the recession period but it will also reduce the total flood season and the height of maximum floods or the flood depths. Especially in a 'dry' seasons, the flood season would become too short and flood depths too shallow. Control measures/structures will be needed, see paragraph 4.3.4..

4.2.4. Suitability of the Lui river valley for rice cultivation.

4.2.4.1. Estimates of the suitable area for rice cultivation.

A topographical surveys, which included also the collection of soil data, was carried out. Cross sections of the valley, at equi-distances of about 5 km, were surveyed, see figure 1.b.. From the topographical data of a cross-section (one elevation point every 50 m.), the average valley bottom level was determined and used to

derive the longitudinal valley bottom slope. On average, a slope of 0.4 m km^{-1} was found, see figure 26. Higher slopes exist in areas with a better natural drainage and smaller ones in more water-logged parts of the valley. During the 1990/91 season, flood levels have been recorded to determine the so called 'reference flood level' curve.



With the known flood levels for Sasenda and Litawa, for a 10%, 50% and 90% probability of non-exceedance, the flood level curves for the same probability percentages of non-exceedance have been simulated. In this way, the flood levels for a 10%, 50% (=average) and 90% probability of non-exceedance are known at each cross section and they are used to derive the suitable field level ranges. Then a count is done for each cross section to determine the number of field level points within the suitable range. After a correction for unsuitable soil type(s), the percentage of suitable land for rice cultivation is known. For the whole valley this percentage comes to about 24% or to at least some 10,000 Ha. of suitable rice land. Detailed data for each cross section are given in table 1. of appendix 3.

4.2.4.2. Identification of suitable land for rice cultivation.

Topographic maps can be drafted to see whether the height of a proposed land for rice cultivation lies within the suitable limits, as defined in the previous paragraph or not. However due to the effects of "micro" topography, for example the meandering of the main channel(s), the 'real' suitable field level range could be somewhat different from that found by interpolation of the given limits of two successive cross-sections.

Often, additional information on vegetation and of farmers themselves, are as useful as a topographic mapping. Nevertheless, a topographic map which relates topography to flood levels in order to obtain flood depths, can be useful for the extension staff to advise farmers where to start planting (lower spots/fields) which variety and to monitor flood depth on which data a decision can be made whether to maintain or to shift the location(s) of a rice fields.

4.3. Physical changes in the environment.

Changes that can be foreseen, are a result of an increased number of families, from either inside or outside the area, who want to grow rice. When more people from outside the area want to grow rice (wetland) as a cash crop, it will create the need to grow more cassava on the upland for staple food. Possibilities to grow more maize are very limited while rice does not belong to the staple food.

4.3.1. Effects from within the wetland.

The (increase of) fertilizer use in rice cultivation will improve the nourishing status of the water which at the moment is very poor in both nitrate and phosphate (Rothuis, 1992). Weeds and other water vegetation will then develop more vigorously and this would possibly increase the resistance against water discharge. In the worst case, extensive swamps will develop and flood recession will become very long. A situation might develop in which the valley does not fully drain every season so that and the Lui river becomes perennial. Another reason for a delayed recession of the floods might be the construction of bunds around rice field which would temporarily increase the amount of water stored. The situation can approximately be simulated by using a low(er) α_1 -value in the model e.g. 0.0115 day^{-1} , which is half its original value.

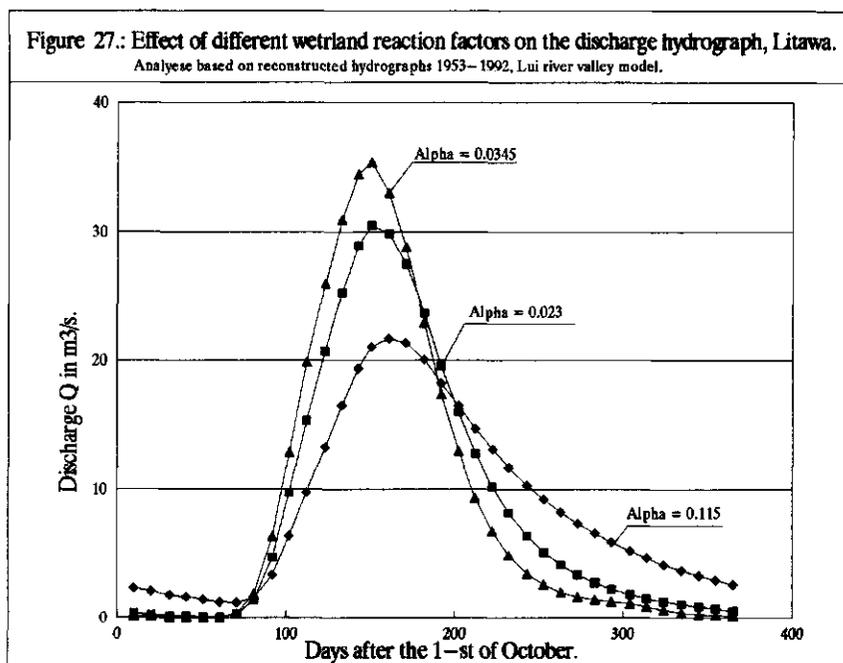
To shorten the flood recession period, the main river channel(s) should be cleaned and cleared (see paragraph 4.2.4.) so that the river discharge contributes significantly more in the total discharge as shown by comparison of the figures 14.b and 14.c . As a result of the cleaning of the main channel(s) and from the excavation of multiples (secondary) drains towards the main channel(s), a recession reaction factor for the valley of 0.0345 day^{-1} instead of 0.023 day^{-1} could be used to calculate the length of the recession. Results for these rather arbitrarily chosen α -values, are shown in figure 27 and a summary is given in table 15.

For higher α_1 -values, higher (maximum) discharges are found as well as a slight increase in the (PI 80%) fluctuation of annual maximum flood levels.

Table 15: Effects of different wetland reservoir reaction factors α on the average flood characteristics.

Reaction factor α_1		$\alpha = 0.0115$	$\alpha = 0.0230$	$\alpha = 0.0345$
Peak discharge ¹	m ³ /s	23.5	34.4	41.0
Flood recession	days	169	101	73
Fluctuation H_{MAX}	m.	0.30	0.34	0.36

- ¹ the given peak flows deviate from those of figure 27 due to the fact that peak flows do not all occur in one and the same calculation interval.



For low α_1 -values peak flows are lower and the recession periods are extremely long, to such an extent that parts of the valley do not dry up any more before the onset of the next flood season.

The definition of the 'average flood recession ends' when rice fields at the average suitable field level are drained. This occurs at Litawa for a H-value of 1.0 m . Then the Q_c equals (use $H=1.0$ in the Q_r -rating equation for Litawa, table 3) $Q_{c,r} = Q_{rec} = 3.36 \text{ m}^3 \text{ s}^{-1}$. The recession periods are then calculated according to (rearrangement of equation 1, without an input):

$$T_{rec} = \frac{\ln Q_{max} - \ln Q_{rec}}{\alpha}$$

Recession periods of 73, 101 and 169 days are found for α_1 -values of 0.0345 , 0.0230 and 0.0115 day^{-1} respectively, see table 16. When recession starts on the 15th of March, 50% of the rice fields ($H \leq 1.0 \text{ m}$) would be drained at approximately the following dates: May, 29th., June 25th. and September, the 1st.. Thus a deterioration of the natural drainage (e.g. a decrease of the Manning coefficient by 50%) would result in a substantial increase of flood season by more than 2 months.

In table 16, the recession periods (in days) are given with regards to the 'wetness of the season', which relates to the value of Q_{peak} for different probabilities of non-exceedance and to the definition 'the valley is drained', which relates to the H-value or the relative position of the rice fields and corresponding value for Q_{rec} .

Table 16.: Flood recession in days (bold) at Litawa for different values of α_1 , H and Q_{peak} .

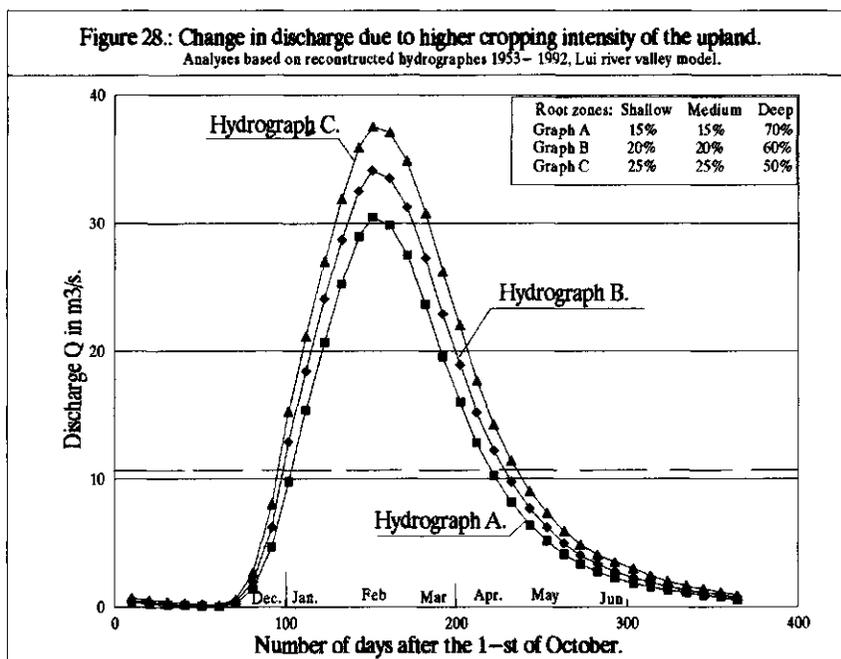
α -value \rightarrow		$\alpha_1 = 0.0115$			$\alpha_1 = 0.0230$			$\alpha_1 = 0.0345$		
Pr. n.e. \rightarrow		10%	50%	90%	10%	50%	90%	10%	50%	90%
fld lvl \downarrow		Q_{peak}	Q_{peak}	Q_{peak}	Q_{peak}	Q_{peak}	Q_{peak}	Q_{peak}	Q_{peak}	Q_{peak}
H \downarrow	$Q_{rec} \downarrow$	13.0	23.5	33.9	18.3	34.4	50.4	21.5	41.0	60.4
0.8	1.3	200	252	284	115	142	159	81	100	111
1.0	3.4	116	169	200	73	101	117	53	73	83
1.2	7.4	49	100	132	39	67	83	31	50	61

Creation of a high α_1 -value will lead to very short recession periods of not more than a month for the high(er) located rice fields in 'dry' years (10% probability of non-exceedance).

4.3.2. Effects of changes in upland cropping.

An increase in the population density will most likely result in an increased number of cassava fields on the upland. The fraction of land with a shallow rooting depth as defined in table 6 of paragraph 3.3.2., will increase, as well as the zone with a medium root depth (shifting cultivation). Both zonal areas might increase from 15% to 20%, leaving only 60% as 'untouched' wooded upland with a deep rooting characteristic. The effects are shown by curve b in figure 28. To study the effects even beyond this point (due to large scale deforestation on the upland) a percentage of 'untouched' wooded upland of 50% is analysed as well (curve c).

The analysis is done by leaving the evapotranspiration coefficients $C_{1,w}$ and the $ST_{w,avg}$ -values, to derive the $C_{w,2}$ coefficients, unchanged. Results are summarised in table 17.



A lower upland evapotranspiration, resulting in an increased groundwater flow towards the wetland, is compensated for by an increase in both, the wetland evapotranspiration and the river discharge.

The increase is relatively more important for the discharge than for the wetland evapotranspiration. Extreme low floods are less likely to occur which means a reduction in the fluctuation of the annual maximum flood levels. The recession period only increases slightly from 101 days to 109 days or by just one week since the α -value is not changed.

Table 17.: Effects of land use intensity of the upland for cassava growing.

Graph:		Graph A	Graph B	Graph C
Deep root zone	%	70	60	50
Peak flow	m ³ /s	34.4	38.1	41.6
Flood recession	days	101	105	109
Max. flood level fluctuation.	m	0.36	0.32	0.30
Water balance components: in mm expressed to the total catchment area.				
Rainfall	mm.	876 (100%)	876 (100%)	876 (100%)
ET upland	mm.	604 (69%)	567 (65%)	530 (60%)
ETwetland	mm.	216 (25%)	243 (28%)	270 (31%)
Discharge, Q	mm.	59 (6.7%)	69 (7.9%)	80 (9.1%)
Q/ETw		0.273	0.284	0.296

Obviously a change in the upland cropping pattern has less influence on the flood regime as a change of the cropping pattern of the wetland. This can be understood from the fact that the wetland reservoir reaction factor α , even a low(er) one, is more than 10-times the reaction factor value for the upland.

4.3.3. Combined effects.

It is likely that both effects of (1) a lower α_1 due to more rice cultivation in the valley and (2) an increase in cassava cultivation on the upland, will occur simultaneously unless people make rice also their staple food so that there is less need for more cassava cultivation.

The most serious effect will be an increased flood season as a result of both a higher maximum discharge (deforestation, 50%) and

a lower reaction factor for the wetland (poorly drained wetland). The recession of floods from the lowest and highest rice fields in a wet year ($Q_{\text{peak,avg}} = 38.1 \text{ m}^3/\text{s}$, curve B, figure 28) and for a low α_1 -value will take 294 and 142 days respectively. No rice fields will be drained in time for harvest while the lower ones are even not drain any more before the arrival of the next flood season.

4.3.4. Possibilities to manipulate the flood regime.

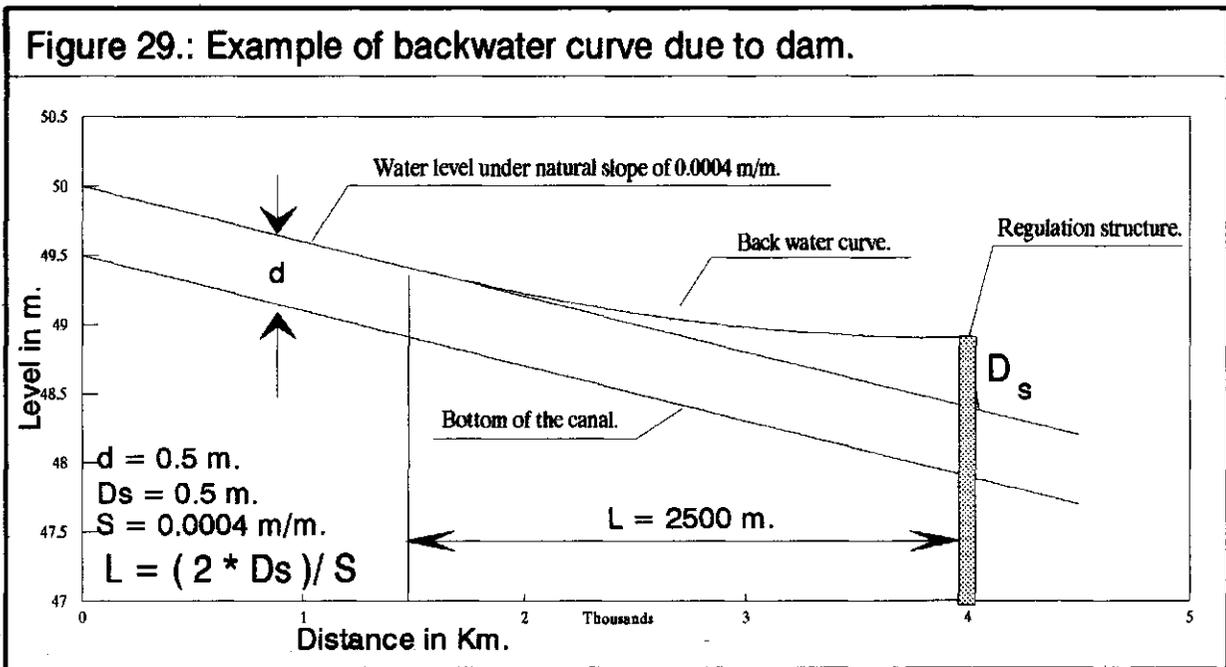
In order to avoid damages from a sudden onset of floods or to shorten the too long recession period, canalization of the (main) channel(s) is needed so that its discharge capacity is substantially increased. The effect of an increased discharge of the main channel(s) by a tenfold (from about 1.5 to 15 m^3/s) is shown in the figures 14.b. and 14.c. The most important change will be a much shorter flood season and a lower flood depths. For a river discharge capacity of 15 m^3/s , the valley will not or hardly be flooded in a dry year.

To eliminate the extreme effects of the canalization on the flood regime, control structures will be needed. These structures will be (partly) closed in dry seasons to dam up the flood level to a constant and optimum level. In a relative 'wet' season the structures are (partly) opened to avoid too high flood levels. Near crop maturity, the structures will be fully open to drain the rice fields within a relatively short period. The latter determines the required discharge capacity and the dimensions of the regulation structures.

To drain the valley bottom upstream of Litawa, an acreage of about 20.000 Ha. with an average flood depth of 0.7 m, within 3 to 4 weeks, a discharge capacity, in addition to the existing one of the valley, of 50 m^3/s will be required. Such a channel capacity, constructed under the natural valley bottom slope of 0.4 m km^{-1} , requires a canal bottom width of 10 to 12 meters and a (water) depth of 3.0 m. The regulation structures in the dike-crossings should have a maximum capacity of 100 m^3/s . This gives a maximum drainage capacity of ($5 \text{ l s}^{-1} \text{ ha}^{-1}$) 43 mm/day.

From above it should be clear that both, channel and structures, are rather voluminous works and they would require skilled manpower for operation and maintenance of system.

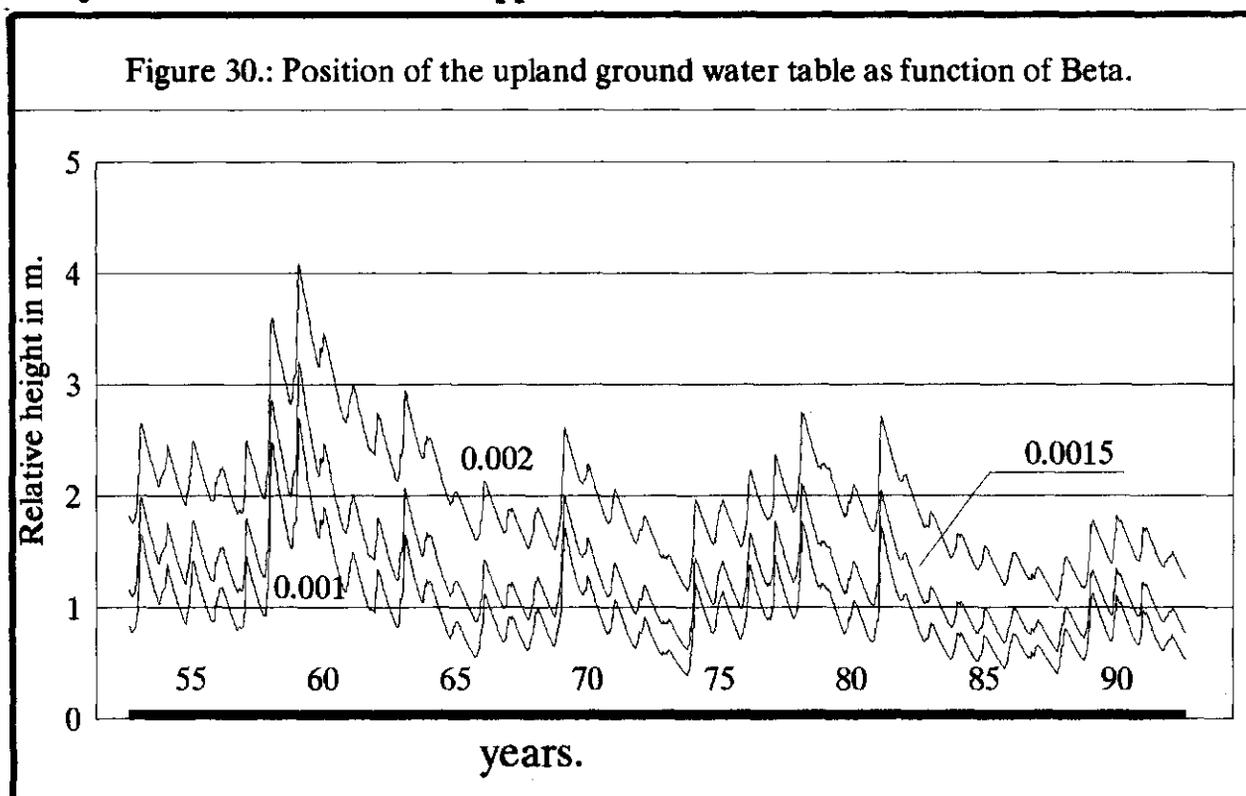
Without further details on the design, something can be said on the number or intensity of these structures which will determine to a large extent the investment costs. Regulation structures, placed in dikes across the valley, will backup up the flood level at the structure with ΔH of 0.5 m above the average maximum flood level. The influence of the back water curve will then be felt up to an upstream distance of $L = 2.5 \text{ km}$. L is calculated according to the simplified formula $L_x = (2 * \Delta H)/S$ (ILACO, 1981) in which $S = 0.0004 \text{ km km}^{-1}$, see figure 29. Only over a distance of about 1.5 to 2.0 km upstream of the structure, a constant and optimum flood depth can be guaranteed. Near the structure with the highest water depth, long straw varieties can be grown. Further upstream from the structure, short straw variety can be planted. The distance L of 2.5 km means that between Sasenda and Litawa, already 13 of these dikes and control structures are needed. The suitable acreage for rice may increased from 24% to 34% of the total area, see table 1., appendix III., in which the maximum suitable acreage is given for the most ideal artificial water/flood levels. Thus an increased acreage by roughly 60 ha towards a total of 200 ha under flood control, are the only benefits, which are rather marginal improvements for the moment.



4.4. Dambos.

Initially it was thought that the model would also give useful

information on the fluctuations of maximum and minimum dambo water levels. Though it is believed that dambo water levels react upon the fluctuations in the nearby ground water table(s), no clear picture could be obtained. This is due to the inaccurate estimate of the β -parameter in the model and the unknown macro-porosity. The β -values will be somewhere between 0.001 and 0.002 day^{-1} . Figure 30 shows the relative positions of the upland ground-water tables for two different β -values, as simulated with the model. Detailed data are given in table 2. of appendix III.



The unknown macro-porosity, influences the position of the ground water table in almost the same way as the β -value. A smaller porosity gives an increased fluctuation (amplitude) of the position of the groundwater table while both, macro-porosity and reaction factor determine the slope of the recession of groundwater table. If a macro porosity of 25% is used, with the standard β -value of 0.0015 d^{-1} (see figure 31.a.) then the 'recession' in groundwater table and dambo water level differ from each other. Also the effects of evapotranspiration (during the dry season) and of rainfall (in the rainy season) seem important. For a much lower macro porosity (see figure 31.b. : 11.4%), the recession slopes for groundwater and dambo water level, are almost identical and effects of rainfall or evapotranspiration seem negligible. A macro porosity of only 11.4 % is however unrealistic low. Macro porosities for

Figure 31.a.: Comparaision between dambo water levels and calculated ground water table by the Lui river valley model and macro porosity of 25 %.

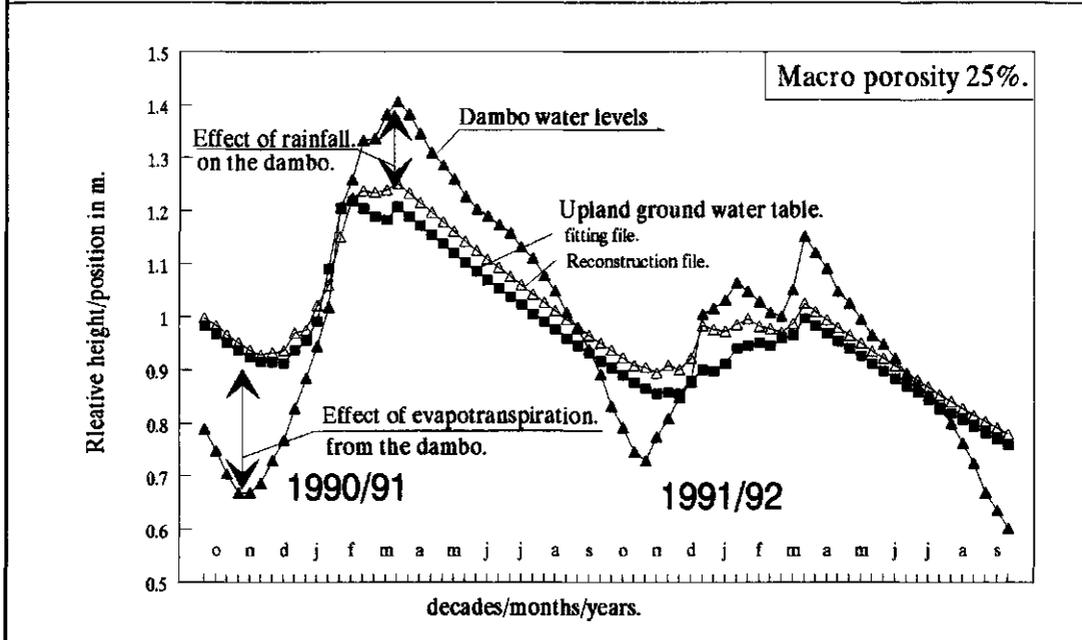
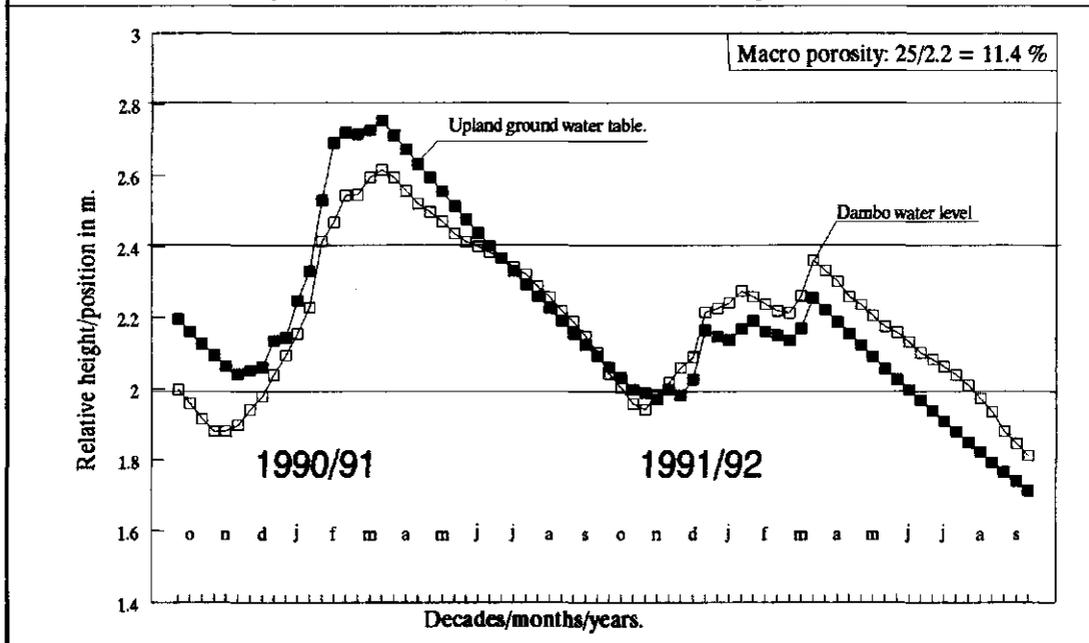


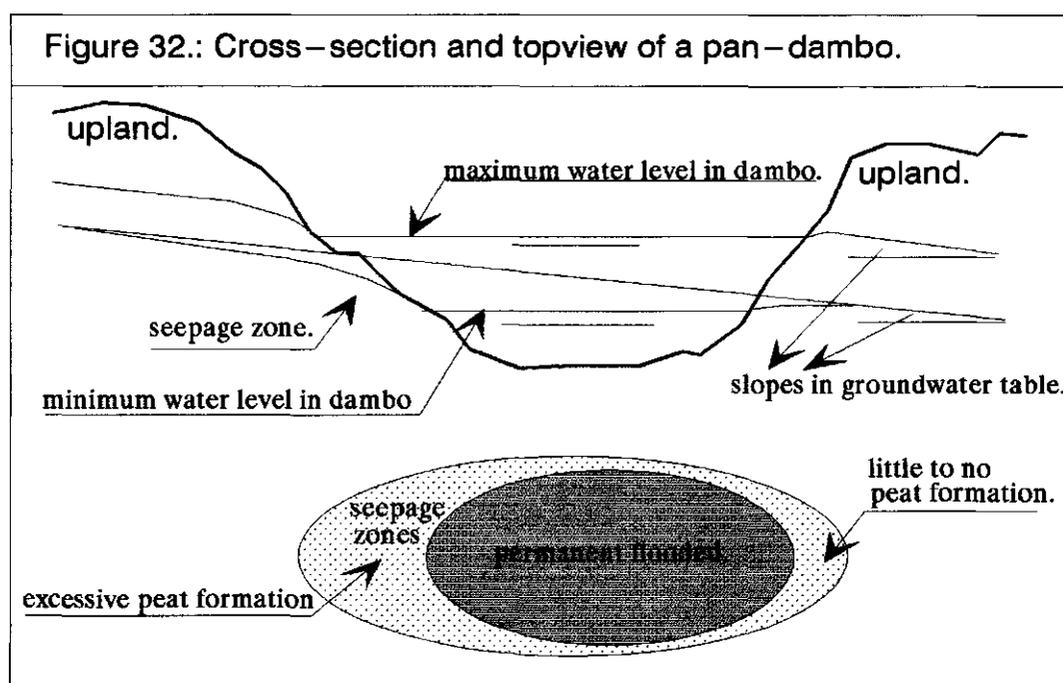
Figure 31.b.: Comparaision between dambo water levels and calculated ground water tables by the Lui river valley model for a macro porosity of 11.4 %.



sandy soils are difficult to determine. The macro-porosity might vary between 15% and 30% .

An almost identical picture, as shown in figure 31.b , for a higher macro-porosity can be obtained by assuming a higher β -value of

0.003 day⁻¹. It is therefore believed that the upland reaction factor for groundwater flow to dambos is higher than the one used in the Lui River Valley model and not necessarily the same for all the dambos, due to differences in shape and diameter in relation to surrounding upland. Also the position of the dambo in the three dimensional groundwater table plane (slopes in the groundwater table) which determines the extent of the seepage zones, as shown in figure 32, might play an important role.



From the figures 31.a. and 31.b , it is expected that the fluctuations in the minimum and maximum annual dambo water levels are equal or more extreme than those of the nearby upland ground water table. The fluctuation range (PI of 80%) in annual maximum ground water table levels is 1.54 m for $\beta=0.001$ and 1.15 m for $\beta=0.002$, see table 2, Appendix III. The fluctuation ranges in seasonal minimum water levels are 1.16 m and 0.67 m respectively. These ranges are such that no good suitable field level range exists.

However, farmers take into account the position of the minimum dambo water level when they choose where to plant their rice; they move down the edge when this level is low and up the edge when this

level is high. In this way, they eliminate as good as possible the long term effects of historical rainfall on the dambo water levels. However, there is still the unknown amount of rainfall resulting in the (unknown) increase of the annual minimum dambo water level to reach its maximum level.

Based on the assumption that dambo water levels follow the upland groundwater table fluctuations the following analysis is made. For the period 1953-1992, the ground water table increased on average 0.48 m over the rainy season. The range limits for a 80% probability interval are 0.05 m (P-10% of n.e.) and 0.90 m (P-90% of n.e.), see the table 2. Appendix III. For this huge variation, amongst others, only long straw varieties can be planted in dambos and not without risks, especially with respect to droughts. As analysed, the increase of the (ground)water table over the rainy season is often too limited, e.g. less than 0.3 m once every three years. The 0.3 m. constitutes a rather small difference with regards to the required position of the (ground)water table depth for ploughing and the desired flood depth during the growing season. Differences of more than 1.0 m only occur in less than once every 10 years. The preliminary conclusion that high rainfall seems to be less of a threat to rice cultivation in dambos than low amounts, certainly for long straw varieties can be drawn.

Glossary

- Upland:** Wooded areas or drylands with the ground water table at great depth. It's altitude is a few to 50 meters above the wetlands.
- Wetland:** Lowlands with the ground water table either near or above the surface. Due to (semi)permanent flooding, these areas are treeless. They include dambos, stream dambos, upland river valleys and flood plains.
- Pan dambos:** Circular treeless depressions in the upland with a diameter of 1 to 6 km. Normally permanently flooded.
- Stream dambos:** Treeless areas in the upland. Semi-permanently flooded areas (during and shortly after the rainy season). They often form a connection between pan dambos (flat bottomed drainage system), or are found in the upper reaches of an upland river valley (head water, valley dambos).
- Upland river valleys:** Small rivers with often broad valleys. These valleys flood during and until a few month after the rainy season.
- Zambezi flood plain and upl. plains:** Zambezi flood plain or Barotse flood plain is a type of rift valley. The Barotse plain and others came into being partly through erosive river action, but mainly by tectonic events. They are bounded by scarps (break points in relatively flat areas).
- Seepage zones:** Small strip along the boundaries between the wetlands and upland. In this strip the ground water table is either near or at the surface ground level during the whole year; water logged areas. As a result, peat soils have developed.
- Hydrological season:** Period with corresponds with one hydrological cycle. In the Zambian case, with one single rainy season in a year, a season corresponds with one year which starts at the beginning of rainy season, e.g. October.
- Monthly decade:** 10 days periods in a month. Except for the last decade of the months with 31 days when the monthly decade equals 11 days. Last decade of February, 8 days.

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List of symbols

A	Acreage or cross sectional area	ha, m ₂
C	Evapo(transpi)ration coefficient	-
C _{u,1}	Evapotr. coefficient of upland vegetation.	-
C _{SM}	Evapotr. coefficient as function of soil moisture availability.	-
C _{w,1}	Evapotr. coefficient wetland vegetation under average flood pattern.	-
C _{w,2}	Evapotr. coefficient wetland as function of the 'wetness' or flood pattern.	-
CV	Coefficient of variation: X _{avg} /STD (*100%)	- or %
D	Thickness of aquifer(s)	m
e	Exponential function.	
ET	Evapotranspiration	mm, mm d ⁻¹ .
	ET _r : Reference evapotranspiration.	mm, mm d ⁻¹ .
	ET _u : Evapotranspiration from the upland	mm, mm d ⁻¹ .
	ET _w : Evapotranspiration from the wetland	mm, mm d ⁻¹ .
F	Coefficient for the goodness of fit.	-
GWL	Ground water level.	m
GR	Gauge reading	m
H	Water or Flood level.	m (m.s.l.).
	H ₀ : Water/Flood level at Q=0 m ³ /s.	m (m.s.l.).
	H _{tr} : Water/floodlevel at which the water leaves the stream channels to flood the valley.	
I	Input value, effective rainfall	mm, mm d ⁻¹ .
K	Hydraulic conductivity	m d ⁻¹ .
L	Spacing between the centers of wetlands.	m or Km.
m	Ratio of upland/(upland+wetland)	-
N	Number of hydrological seasons	-
n.e.	non-exceedance	%
P	P _u : Percolation from upland root zone.	mm, mm d ⁻¹ .
PI	Probability interval.	%
Q	Discharge	mm d ⁻¹ , m ³ s ⁻¹
	Q _m : Monitored discharge.	
	Q _c : Calculated discharge.	
	Q _v : Valley discharge	
	Q _f : Falling stage of hydrograph.	
	Q _r : Rising stage of hydrograph.	
q	Discharge flow rate	mm d ⁻¹ .
R	Rainfall.	mm, mm d ⁻¹ .
	Correlation coefficient.	-
S	Seepage or groundwater flow rate.	mm, mm d ⁻¹ .
	S _u : Groundwater flow, upland	mm d ⁻¹
	S _w : Groundwater flow, wetland	mm d ⁻¹
SM	Soil moisture (content).	mm or %Vol.
ST	Storage or stored amount of (ground)water	mm or m ³ .
STD	Standard deviation (normal distributions)	-
t	Time, period.	day, decade.
α	Reaction factor wetland reservoir.	day ⁻¹
β	Reaction factor groundwater reservoir.	day ⁻¹
μ	Macro or effective porosity, fraction of 1.	

Subscript and superscript - Suffixes:

avg	Main symbol value is an averaged value.
a	X-coefficient in regression analyses.
b	Main symbol relates to the beginning of the period.
c	Main symbol value is a cumulated value or a constant. Constant, in regression analyses.
e	Main symbol relates to the end of the period.
f	Main symbol has a fixed value.
max	Maximum value for main symbol.
min	Minimum value for main symbol.
n	Monthly decades 1, 2 n.
r	Reference value of main symbol.
t	Main symbol value for interval t.
u	Main symbol relates to the upland.
w	Main symbol relates to the wetland.
z	Main symbol relates to the rootzone.
Δ	Delta indicating a difference range in the main symbol.

Appendixes

Appendix I.

Table 1.: Input rainfall for fitting file.

Table 2.: Input rainfall data for simulation file.

Table 3.: Calculation of the reference evapotranspiration, Mongu.

Table 4.: Flood levels 1988 to 1992. Lui River.

Appendix II.

Table A.: Summary on model, Litawa.

1.a Fitting file and goodness of fit.

2.a Averaged values for water balance 1953-1992.

3.a Annual water balances.

Table B.: Summary on model, Sasenda.

1.b Fitting file and goodness of fit.

2.b Averaged values for water balance 1953-1992.

3.b Annual water balances.

Table 4.: Calculation scheme for wetland reservoir.

Appendix 3.

Table 1. Information on levels and suitability percentages at the cross sections, Lui Valley.

Table 2. Annual groundwater levels as a function of the β -value.

Table 1: Input rainfall data for fitting file.			Appendix I							
Month	Year	Luatambo	Sasenda	Lisawa	Llande	Kaoma	Mongu	Senangs	Avg(KMS)	Avg(2KM19)
Oct1	1988	0	0	0	0	0	0	0	0	0
Oct2	1988	6	4	5	8	34	0	102	45	34
Oct3	1988	50	38	40	37	14	17	24	18	17
Nov1	1988	26	22	23	29	50	10	51	37	34
Nov2	1988	0	0	0	0	0	0	0	0	0
Nov3	1988	16	16	17	19	62	30	7	33	38
Dec1	1988	75	79	82	76	20	124	102	82	78
Dec2	1988	56	57	56	61	55	40	7	34	39
Dec3	1988	46	49	47	34	107	33	36	58	63
Jan1	1989	81	78	82	85	93	108	63	88	93
Jan2	1989	105	76	72	59	164	95	47	102	113
Jan3	1989	79	68	64	50	44	55	79	58	55
Feb1	1989	89	80	88	88	126	79	56	87	93
Feb2	1989	125	122	116	111	132	120	88	113	118
Feb3	1989	83	67	62	63	69	120	25	71	81
Mar1	1989	29	21	20	14	9	42	8	20	22
Mar2	1989	52	53	51	35	71	62	47	60	62
Mar3	1989	119	94	84	66	36	64	68	56	53
Apr1	1989	11	12	12	10	0	6	4	22	3
Apr2	1989	1	6	6	12	0	38	1	13	15
Apr3	1989	23	21	20	16	5	10	2	6	6
Totals:1988/89		1070	964	947	873	1089	1051	817	1004	1019
Oct1	1989	4	6	5	5	22	11	6	13	14
Oct2	1989	22	22	23	24	2	29	35	22	19
Oct3	1989	5	5	5	2	11	3	0	5	6
Nov1	1989	13	16	13	8	12	4	12	9	9
Nov2	1989	35	29	28	23	20	16	2	13	15
Nov3	1989	1	2	3	5	4	26	0	10	12
Dec1	1989	35	34	33	34	29	81	27	45	49
Dec2	1989	51	37	33	20	30	49	49	42	41
Dec3	1989	130	113	120	122	133	86	166	129	121
Jan1	1990	148	139	138	145	123	166	144	144	144
Jan2	1990	42	48	45	62	34	90	52	58	60
Jan3	1990	146	142	132	108	39	113	132	96	87
Feb1	1990	73	64	66	97	117	118	108	114	115
Feb2	1990	27	24	28	28	42	35	4	27	32
Feb3	1990	45	49	45	30	23	13	0	12	14
Mar1	1990	12	15	13	9	6	17	13	12	12
Mar2	1990	1	2	1	7	0	22	33	18	16
Mar3	1990	22	33	39	65	24	24	12	20	22
Apr1	1990	44	40	45	49	99	35	84	80	71
Apr2	1990	0	1	3	2	0	0	0	0	0
Apr3	1990	5	6	5	9	21	0	1	7	9
Totals 1989/90:		856	827	822	853	790	937	878	876	866
Oct1	1990	11	17	14	3	22	14	25	20	19
Oct2	1990	18	9	7	0	13	0	0	4	5
Oct3	1990	7	5	7	8	0	10	20	10	8
Nov1	1990	18	10	10	8	0	0	13	4	3
Nov2	1990	1	5	5	3	7	45	28	26	26
Nov3	1990	60	50	58	81	22	26	39	29	27
Dec1	1990	62	55	52	61	36	31	34	34	34
Dec2	1990	34	41	42	31	30	20	38	29	28
Dec3	1990	109	101	102	95	106	101	33	80	89
Jan1	1991	30	39	38	54	59	74	65	66	66
Jan2	1991	59	72	72	62	82	71	37	64	69
Jan3	1991	74	61	61	101	130	94	122	115	114
Feb1	1991	110	109	107	99	75	160	153	129	125
Feb2	1991	83	86	93	78	22	91	20	45	49
Feb3	1991	41	48	45	13	12	2	6	7	7
Mar1	1991	23	20	35	51	11	24	18	18	17
Mar2	1991	56	53	44	56	42	23	25	30	31
Mar3	1991	50	53	45	37	23	98	81	67	64
Apr1	1991	2	1	1	0	0	0	0	0	0
Apr2	1991	0	0	0	0	0	0	0	0	0
Apr3	1991	1	0	0	0	0	0	0	0	0
Totals 1990/91:		846	834	835	841	882	883	755	777	781
Oct1	1991	0	0	0	0	0	2	0	1	1
Oct2	1991	61	48	44	42	36	2	13	17	18
Oct3	1991	17	13	17	16	2	19	4	8	9
Nov1	1991	34	31	31	25	36	9	69	38	32
Nov2	1991	20	24	19	14	12	22	21	18	18
Nov3	1991	67	50	58	66	71	26	28	41	44
Dec1	1991	35	23	21	44	25	57	3	28	33
Dec2	1991	69	70	68	83	38	107	66	70	71
Dec3	1991	91	105	107	94	72	78	73	74	74
Jan1	1992	23	24	22	27	42	15	31	29	29
Jan2	1992	20	35	30	48	23	28	80	43	36
Jan3	1992	41	44	47	64	17	74	82	58	53
Feb1	1992	65	48	41	21	35	45	20	33	36
Feb2	1992	16	13	13	17	30	57	22	36	39
Feb3	1992	23	27	20	6	11	1	38	17	13
Mar1	1992	32	27	24	13	84	17	32	44	47
Mar2	1992	61	55	55	22	24	45	39	36	35
Mar3	1992	71	58	67	85	71	63	48	60	63
Apr1	1992	7	13	10	0	0	7	35	14	10
Apr2	1992	0	0	0	0	0	0	0	0	0
Apr3	1992	3	2	3	3	23	5	10	13	13
Totals 1991/92:		754	708	697	669	652	677	710	680	674

Table 2.: Input data rainfall, reconstruction file. Rainfall in mm/decade. Appendix I.

	October			November			December			January			February			March			April			May			September			
1952/53	0	15	19	41	10	31	78	51	37	83	74	96	78	129	56	129	56	41	14	29	4	0	1	0	0	0	19	
1953/54	0	8	0	6	22	28	77	136	49	55	54	42	51	44	94	75	80	1	0	4	2	0	0	0	0	0	0	
1954/55	0	6	6	24	29	12	80	133	67	62	93	122	60	50	80	48	38	4	5	5	10	1	1	0	0	0	0	
1955/56	7	4	17	37	9	54	38	35	74	119	99	28	72	55	25	91	49	38	39	60	2	0	0	0	0	4	0	
1956/57	0	0	3	46	25	62	79	33	29	25	51	55	80	103	142	113	46	12	0	1	0	0	1	1	0	1	5	
1957/58	9	21	36	20	69	18	33	182	97	98	92	145	144	96	99	49	25	2	3	13	0	0	0	0	0	5	0	
1958/59	0	6	38	57	21	66	96	157	79	89	34	78	112	81	121	96	56	7	12	0	0	10	0	0	0	0	0	
1959/60	0	0	5	18	31	29	43	70	209	51	9	82	50	152	26	7	56	3	3	6	18	13	1	0	0	0	0	
1960/61	0	3	2	22	70	46	21	52	95	67	72	63	110	94	25	56	59	43	22	18	0	0	2	0	0	0	0	
1961/62	1	0	30	30	76	22	50	32	48	30	120	110	60	84	85	7	52	17	12	20	4	0	0	0	0	0	0	
1962/63	1	3	1	32	35	26	64	94	151	109	23	71	91	95	60	91	31	0	0	10	0	0	0	0	0	0	0	
1963/64	6	1	26	47	48	75	151	77	28	97	10	29	49	56	31	14	4	0	0	0	0	0	0	2	0	1	0	
1964/65	0	6	2	24	25	18	82	36	55	105	47	45	50	32	32	11	4	30	35	5	0	0	0	0	1	0	0	
1965/66	14	0	0	14	75	35	92	39	47	57	106	58	96	60	106	84	40	1	42	3	3	0	4	0	0	0	1	
1966/67	0	19	1	16	29	2	51	69	25	98	84	107	57	37	23	15	36	70	10	3	20	0	0	0	0	0	0	
1967/68	0	4	35	62	42	76	83	48	53	54	56	114	52	78	0	86	62	3	3	54	0	0	0	0	7	0	1	
1968/69	0	1	4	4	90	100	105	25	75	98	36	83	67	142	42	56	105	73	23	0	0	0	0	0	0	0	1	
1969/70	2	34	49	51	31	14	61	82	51	28	60	96	83	24	16	18	13	5	0	32	8	0	0	0	0	0	1	
1970/71	3	17	2	21	40	77	9	83	75	106	36	87	70	91	17	25	13	14	22	8	5	13	0	0	0	0	0	
1971/72	0	8	1	37	17	10	29	70	54	93	53	75	27	27	19	73	79	58	45	2	10	1	0	0	1	0	6	
1972/73	7	4	7	8	0	6	47	85	18	19	14	55	2	57	54	44	10	11	4	0	0	4	0	0	0	0	0	
1973/74	0	29	8	51	4	25	76	64	99	105	39	81	85	146	57	82	18	21	25	0	0	18	1	0	6	0	0	
1974/75	0	5	16	37	62	38	60	113	90	55	92	61	38	67	38	57	54	46	11	6	0	0	2	0	0	0	1	
1975/76	1	0	11	3	6	14	73	87	69	54	89	64	78	85	69	76	88	85	46	25	0	21	0	0	0	0	5	
1976/77	9	10	12	47	13	12	60	31	59	2	103	40	61	70	103	170	42	7	28	0	0	1	0	0	0	0	8	
1977/78	0	0	6	4	21	36	60	74	68	54	87	67	87	100	73	114	96	42	31	50	0	0	0	6	0	1	0	
1978/79	1	53	9	74	42	16	75	83	22	58	17	53	19	21	28	49	30	48	0	0	0	0	0	0	0	0	0	
1979/80	2	31	9	44	68	37	120	70	63	10	35	81	69	35	62	64	47	6	49	17	0	0	0	0	0	0	3	
1980/81	0	11	33	51	17	33	25	66	111	32	99	61	29	125	176	81	48	71	0	0	4	0	0	0	0	0	0	
1981/82	0	5	2	13	50	33	13	38	52	80	47	79	36	46	35	20	3	21	10	28	0	5	0	0	16	0	6	
1982/83	1	33	12	4	49	75	53	13	57	26	61	119	48	22	1	55	14	10	17	15	2	13	0	0	0	0	0	
1983/84	0	18	33	11	29	83	40	65	87	31	56	72	86	18	33	18	4	84	18	1	0	0	0	0	0	4	0	
1984/85	14	3	14	80	6	54	51	84	26	45	62	47	95	61	9	30	27	18	19	0	2	0	3	0	0	0	0	
1985/86	0	1	15	18	1	20	57	64	38	88	61	75	57	27	71	20	73	50	6	55	34	0	0	1	0	0	1	
1986/87	11	38	43	39	1	47	116	0	14	13	90	34	59	36	40	1	16	42	0	3	0	1	0	1	0	0	5	
1987/88	13	8	7	17	4	27	109	58	98	55	72	63	14	96	73	72	50	27	32	3	19	0	0	0	0	4	0	
1988/89	0	46	18	37	0	16	82	34	59	88	102	59	87	113	71	20	60	56	4	13	6	0	0	0	0	0	0	
1989/90	13	22	5	9	13	2	45	42	129	144	59	95	114	27	12	12	18	20	73	0	7	0	1	0	0	0	1	
1990/91	20	4	10	4	26	28	34	29	80	66	64	115	129	45	7	18	30	67	0	0	0	0	0	0	0	0	6	
1991/92	1	17	8	37	18	41	28	70	74	29	43	58	33	36	17	44	36	60	14	0	13	0	0	7	0	0	0	
Avg Rain	3	12	14	29	31	36	64	67	66	63	63	74	67	68	63	63	42	30	17	12	4	2	0	0	1	1	1	
STD Rain	5	14	13	19	24	24	31	36	37	33	29	27	31	37	40	38	26	26	17	17	7	5	1	1	3	1	3	
CV Rain				64%	76%	66%	48%	57%	56%	52%	46%	37%	46%	55%	74%	71%	62%	66%										

Table 3.: Calculation of the reference evapotranspiration MONGU

Appendix I.

Latitude 15°15'south, altitude 1053 meter														
Boltzman coeff. 2.02E-09														
AVERAGE YEAR:														
Data	Dimensic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
Mean Temperature	gr. Cels.	26.0	25.5	24.3	23.9	23.9	23.9	23.3	21.0	18.8	18.5	22.0	25.2	23.7
Dew temperature	gr. Cels.	11.0	16.0	18.0	18.0	18.0	17.0	16.0	11.0	6.0	4.0	5.0	7.0	18.0
windspeed	knots	5.46	5.02	4.50	3.83	4.16	4.09	5.03	5.54	5.26	5.80	6.59	6.87	3.2
sunshine hours	hrs/day	8.2	6.6	5.6	5.6	5.9	7.0	9.0	9.8	9.7	9.8	9.9	9.4	5.8
Radiation	langleys	594	544	511	518	511	526	550	513	477	492	549	591	518.0
														0.0
Calc. RH %		50.2	60.8	75.7	79.5	78.5	76.7	68.3	57.7	52.2	46.3	39.3	35.5	79.0
Sat. vap. press	mbar	32.0	32.0	30.8	30.0	30.0	30.0	29.0	24.9	21.7	21.5	26.9	32.0	29.0
act. vapour press.	mbar	16.1	19.5	23.3	23.9	23.6	23.0	19.8	14.4	11.3	10.0	10.6	11.4	23.4
hum. def.	mbar	15.9	12.5	7.5	6.2	6.5	7.0	9.2	10.5	10.4	11.5	16.3	20.6	6.2
f(u)		1.09	1.02	0.95	0.84	0.89	0.88	1.02	1.10	1.06	1.14	1.26	1.30	0.8
W(u)		0.76	0.74	0.73	0.73	0.73	0.73	0.73	0.71	0.68	0.68	0.68	0.75	0.7
(1-W)		0.24	0.26	0.27	0.27	0.27	0.27	0.27	0.29	0.32	0.32	0.32	0.25	0.3
(1-W)*f(u)*(Ea-Ed)		4.17	3.34	1.91	1.40	1.56	1.67	2.54	3.37	3.52	4.21	6.57	6.71	1.3
														0.0
Radiation	mm/day	15.8	16.6	16.7	16.8	16.4	15.2	13.6	11.9	11.0	11.4	12.7	14.4	18.8
Max. daylength	hours	12.5	12.8	13.0	12.9	12.8	12.2	11.8	11.4	11.2	11.3	11.6	12.0	12.9
Rs	mm/day	8.10	7.57	7.05	7.12	7.17	7.29	7.55	7.07	6.56	6.80	7.51	8.11	7.1
Rns, alpha=0.15	mm/day	6.88	6.44	5.99	6.05	6.10	6.20	6.42	6.01	5.58	5.78	6.38	6.90	6.0
f(T)		16.1	16.0	15.8	15.7	15.7	15.7	15.6	15.1	14.8	14.6	15.3	16.0	15.8
f(ed)		0.16	0.15	0.13	0.13	0.13	0.13	0.14	0.17	0.19	0.20	0.20	0.19	0.1
f(n/N)		0.69	0.56	0.49	0.49	0.52	0.62	0.79	0.87	0.88	0.88	0.87	0.81	0.5
Rnl=f(T)*f(ed)*f(n/N)		1.82	1.32	0.98	0.96	1.03	1.25	1.76	2.28	2.47	2.58	2.61	2.46	1.0
Rn=Rns-Rnl		5.06	5.12	5.01	5.09	5.06	4.95	4.65	3.73	3.11	3.20	3.77	4.43	5.1
W*Rn		3.85	3.79	3.66	3.71	3.70	3.61	3.40	2.65	2.11	2.18	2.56	3.32	3.7
Total of horz. +vert.		8.01	7.13	5.57	5.12	5.25	5.28	5.94	6.01	5.63	6.39	9.14	10.04	5.0
c-correction value														0.0
Ref. Humidity		50.17	60.83	75.67	79.50	78.50	76.67	68.33	57.67	52.17	46.33	39.33	35.50	79.0
windspeed	m/sec	2.81	2.59	2.32	1.97	2.14	2.10	2.59	2.85	2.71	2.99	3.39	3.53	1.7
C for Uday/Unight=1.5		0.87	0.86	1.02	1.00	1.00	1.01	0.99	0.94	0.90	0.85	0.80	0.80	1.0
ET reference	mm/day	6.88	6.98	5.68	5.12	5.25	5.34	5.88	5.65	5.07	5.43	7.31	8.03	5.0
number of days		31	30	31	31	28	31	30	31	30	31	31	30	31.0
ET reference	mm/month	216	210	176	159	147	165	176	175	152	168	227	241	2213

Results on ETref Calculations:

Monthly ETref	mm	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Season
1986/87		188	187	193	180	140	168	202	191	149	172	214	241	2224
1987/88		253	224	186	163	158	165	170	165	138	129	188	246	2165
1988/89		224	207	171	154	144	152	153	157	134	156	203	239	2095
1989/90		221	240	182	150	138	179	184	166	142	169	211	265	2226
1990/91		231	224	172	155	159	174	196	173	143	154	204	254	2240
1991/92		244	185	174	171	157	169	196	185	150	166	240	284	2320
Average ETr		227	211	176	162	149	168	180	173	143	158	210	255	2212
ETr in mm/day		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Season
1986/87		6.1	6.2	6.2	5.8	5.0	5.4	6.7	6.1	5.0	5.5	6.9	8.0	6.1
1987/88		8.2	7.5	5.3	5.3	5.6	5.3	5.7	5.3	4.6	4.1	6.1	8.2	5.9
1988/89		7.2	6.9	5.5	5.0	5.1	4.9	5.1	5.1	4.5	5.0	6.5	8.0	5.7
1989/90		7.1	8.0	5.9	4.8	4.9	5.8	5.5	5.4	4.7	5.4	6.8	8.8	6.1
1990/91		7.5	7.5	5.5	5.0	5.7	5.6	6.5	5.6	4.8	5.0	6.6	8.5	6.1
1991/92		7.9	6.2	5.6	5.5	5.8	5.5	6.5	6.0	5.0	5.3	7.8	9.5	6.4
ETr average , mm/day		7.3	7.0	5.7	5.2	5.3	5.4	6.0	5.6	4.8	5.1	6.8	8.5	6.1

Table 4: Flood levels 1988 to 1992. Lui valley Appendix I.

Corrected gauge readings in cm.

Date	Lua	Sas	Lit	20L	Date	Lua	Sas	Lit	20L	Date	Lua	Sas	Lit	20L
31 Mar'88	73	128	140	NA	10 Nov'89	12	16	15	NA	20 Jun'91	36	57	98	35
10 Apr'88	58	114	139	NA	20 Nov'89	24	18	12	NA	30 Jun'91	34	51	94	34
20 Apr'88	49	105	132	NA	30 Nov'89	3	10	0	NA	10 Jul'91	32	48	89	31
31 Apr'88	43	100	125	NA	10 Dec'89	21	6	3	NA	20 Jul'91	31	45	82	25
10 May'88	37	92	118	NA	20 Dec'89	30	15	4	NA	31 Jul'91	29	41	76	19
20 May'88	34	84	112	NA	31 Dec'89	49	56	68	NA	10 Aug'91	26	38	72	14
31 May'88	30	77	103	NA	10 Jan'90	79	94	103	NA	20 Aug'91	24	35	64	11
10 Jun'88	28	70	97	NA	20 Jan'90	85	117	112	NA	31 Aug'91	21	31	56	5
20 Jun'88	27	63	92	NA	31 Jan'90	110	126	138	NA	10 Sep'91	18	25	47	0
30 Jun'88	24	56	87	NA	10 Feb'90	125	140	148	NA	20 Sep'91	15	18	37	NA
10 Jul'88	20	50	82	NA	20 Feb'90	98	134	158	NA	30 Sep'91	11	10	27	NA
20 Jul'88	16	43	76	NA	28 Feb'90	104	126	149	NA	10 Oct'91	7	2	5	NA
31 Jul'88	12	37	67	NA	10 Mar'90	85	122	140	NA	20 Oct'91	9	8	25	NA
10 Aug'88	0	31	59	NA	20 Mar'90	73	115	135	NA	31 Oct'91	9	10	20	NA
20 Aug'88	0	26	53	NA	31 Mar'90	79	110	136	NA	10 Nov'91	10	11	34	NA
31 Aug'88	9	20	45	NA	10 Apr'90	91	114	133	NA	20 Nov'91	23	25	26	NA
10 Sep'88	0	15	39	NA	20 Apr'90	79	115	129	NA	30 Nov'91	22	33	49	NA
20 Sep'88	1	10	32	NA	31 Apr'90	73	107	122	NA	10 Dec'91	30	51	59	NA
30 Sep'88	-3	5	25	NA	10 May'90	70	101	118	NA	20 Dec'91	38	66	72	NA
10 Oct'88	0	0	17	NA	20 May'90	64	94	114	NA	31 Dec'91	56	102	112	NA
20 Oct'88	0	-5	9	NA	31 May'90	61	86	109	NA	10 Jan'92	55	97	122	0
31 Oct'88	-9	-2	2	NA	10 Jun'90	57	79	103	NA	20 Jan'92	54	99	120	8
10 Nov'88	9	12	9	NA	20 Jun'90	52	71	100	NA	31 Jan'92	58	95	126	27
20 Nov'88	3	14	15	NA	30 Jun'90	48	65	96	NA	10 Feb'92	69	100	123	39
30 Nov'88	3	17	20	NA	10 Jul'90	45	62	90	NA	20 Feb'92	59	97	112	38
10 Dec'88	20	19	26	NA	20 Jul'90	42	56	85	NA	28 Feb'92	58	89	107	38
20 Dec'88	12	41	39	NA	31 Jul'90	40	53	78	NA	10 Mar'92	55	87	108	38
31 Dec'88	30	56	59	NA	10 Aug'90	37	49	71	NA	20 Mar'92	52	88	115	47
10 Jan'89	55	82	80	NA	20 Aug'90	34	44	65	NA	31 Mar'92	62	99	128	49
20 Jan'89	94	116	102	NA	31 Aug'90	30	39	58	NA	10 apr'92	60	95	121	52
31 Jan'89	85	120	131	NA	10 Sep'90	26	32	50	NA	20 apr'92	61	88	112	51
10 Feb'89	91	124	141	NA	20 Sep'90	21	24	41	NA	30 apr'92	51	85	107	42
20 Feb'89	122	131	142	NA	30 Sep'90	18	19	35	NA	10 May'92	44	74	105	37
28 Feb'89	110	141	154	NA	10 Oct'90	17	23	26	NA	20 May'92	36	70	103	25
10 Mar'89	104	139	161	NA	20 Oct'90	16	14	12	NA	31 May'92	30	61	97	23
20 Mar'89	98	131	157	NA	31 Oct'90	10	6	1	NA	10 Jun'92	28	53	91	18
31 Mar'89	88	130	152	NA	10 Nov'90	5	-4	-13	NA	20 Jun'92	24	46	86	17
10 Apr'89	98	130	147	NA	20 Nov'90	9	0	-2	NA	30 Jun'92	22	42	80	15
20 Apr'89	73	121	144	NA	30 Nov'90	18	1	-5	NA	10 Jul'92	19	38	77	9
30 Apr'89	82	115	143	NA	10 Dec'90	26	14	44	NA	20 Jul'92	16	34	68	5
10 May'89	73	112	136	NA	20 Dec'90	38	28	27	NA	31 Jul'92	12	29	63	2
20 May'89	67	109	129	NA	31 Dec'90	52	56	51	NA	10 Aug'92	8	23	57	0
31 May'89	58	99	123	NA	10 Jan'91	89	88	80	NA	20 Aug'92	6	18	52	NA
10 Jun'89	55	90	119	NA	20 Jan'91	76	101	93	NA	31 Aug'92	3	13	46	NA
20 Jun'89	52	82	113	NA	31 Jan'91	80	111	112	NA	10 Sep'92	0	7	28	NA
30 Jun'89	49	78	108	NA	10 Feb'91	99	125	130	58	20 Sep'92	0	4	27	NA
10 Jul'89	46	72	103	NA	20 Feb'91	95	135	155	74	30 Sep'92	0	-4	16	NA
20 Jul'89	43	66	98	NA	28 Feb'91	88	127	154	69	10 Oct'92	0	-16	4	NA
31 Jul'89	40	62	92	NA	10 Mar'91	77	115	144	81	20 Oct'92	0	-29	-6	NA
10 Aug'89	34	58	88	NA	20 Mar'91	80	116	138	80	31 Oct'92	0	-33	-14	NA
20 Aug'89	30	54	83	NA	31 Mar'91	83	114	139	86	10 Nov'92	0	-33	-14	NA
31 Aug'89	25	50	72	NA	10 Apr'91	71	112	130	77	20 Nov'92	0	-32	-3	NA
10 Sep'89	20	44	61	NA	20 Apr'91	63	105	122	70	30 Nov'92	0	-31	6	NA
20 Sep'89	13	37	52	NA	30 Apr'91	57	95	121	64	10 Dec'92	7	-29	11	NA
30 Sep'89	6	30	47	NA	10 May'91	51	86	117	59	20 Dec'92	7	23	27	NA
10 Oct'89	12	24	54	NA	20 May'91	47	78	112	46	31 Dec'92	20	33	138	NA
20 Oct'89	8	34	42	NA	31 May'91	40	67	105	42					
31 Oct'89	0	17	21	NA	10 Jun'91	37	61	109	39					

Table 1.a.: SUMMARY ON MODEL: Litawa.

Lui river valley: 1988 – 1992.

Appendix: II.

Model parameters: Parameters according to the fitting of Qcalc. to Qmonit.			
Areal acreages:		Rating curve parameters	
Upland acreage	396000 Ha	Qlow	Qrising
Wetland acreage	63000 Ha	X-coeff.	4.35
Total acreage	459000 Ha	C-value	1.21

Reservoir reaction factors /day		Upland parametres:			
Beta,upl.	0.0015	Rootdepth	Shallow	Medium	Deep
Alpha1	0.023 Q mm/d >	SMmax m	30	210	510
Alpha2	0.01 Q mm/d >	Ratio: %%	15%	15%	70%
Alpha3	0.05 Q mm/d <	Cupl	0.2	0.5	0.8
STw,cons	75 STw,min				208

Water balances: expressed in mm.						
Fitting File: 1988/89 – 1991/92.						
Year	1988/89	1989/90	1990/91	1991/92	1988/92	X-avg
Rainfall	949	834	808	693	3284	821
Upland water bal.: in mm on an area of: 396000 Ha						
STupl,b	186	241	213	198	186	
ETupland	740	702	677	610	2728	682
Percolation	209	132	131	83	556	139
Seepage	158	159	146	126	590	148
STupl,e	241	213	198	155	155	
STe,calc	237	213	198	155	152	3
Wetland water balance, in mm over an area of: 63000 Ha						
STw,b	-161	-136	-162	-166	-161	
Seepage	995	1002	921	793	3710	927
ETwetland	1451	1449	1365	1294	5559	1390
Discharge	470	410	367	216	1464	366
STw,e	-136	-162	-166	-192	-192	
STe,calc	-138	-159	-165	-191	-189	-3
Overall water balance, mm over an area of: 459000 Ha						
STb	139	189	162	148	139	159
Rainfall	949	834	808	693	3284	821
ET	837	804	771	704	3117	779
Discharge	64	56	50	30	201	50
STe	189	162	148	108	108	
STe,calc	186	162	148	108	105	3
Deviation %%	1.7%	-0.2%	-0.1%	-0.1%	2.4%	

"Goodness of fit"	1988/89	1989/90	1990/91	1991/92	1988/92
Total discharge, mm; Volume under hydrograph.					
Q calculated:	65	56	51	30	201
Qmeasured:	65	52	44	29	191
Qc/Qm *100%	99%	108%	114%	101%	105%
Annual maximum discharge: m3/s @sqrt((Qc-Qm)^2)					
Qc,max m3/s	36.17	33.86	32.83	16.62	29.87
Qm,max m3/s	37.34	35.07	32.39	15.80	30.15
F2-value m3/s	1.17	1.20	0.44	0.82	0.96
CV-Coeffient:	3.1%	3.4%	1.4%	5.2%	3.0%
Calculated – measured discharges: @Sqrt(@sum((Qc-Qm)^2/n))					
F1- value Q	3.68	2.63	2.49	2.25	2.82
F3-value Ln Q	1.59	0.98	1.46	2.08	1.58
Goodness of fit recession curve (April to the end of September).					
F1'- valu Q	1.75	0.79	0.78	1.39	1.18
F3'- valu Ln Q	0.22	0.20	0.15	0.29	0.22

Table 1.b.: SUMMARY ON MODEL: Sasenda.

Lui river valley: 1988 – 1992.

Appendix: II

Model parameters: Parameters according to the fitting of Qcalc. to Qmonit.				
Areal acreages:		Rating curve parameters		
Upland acreage	280000 Ha	X-coeff.	Qlow	Qrising
Wetland acreage	45000 Ha		0.935	4.548
Total acreage	325000 Ha	C-value	1.115	2.046
				1.836

Reservoir reaction factors /day				Upland parameters:			
Beta, upl.	0.002			Rootdepth	Shallow	Medium	Deep
Alpha1	0.028	Q mm/d >	0.363	SMmax m	30	210	510
Alpha2	0.009	Q mm/d >	0.190	Ratio: %%	15%	15%	70%
Alpha3	0.06	Q mm/d <	0.190	Cupl	0.2	0.5	0.8
STw, cons	75	STw, min	200	Eff. por.:	25 %		

Water balances: expressed in mm.							
Fitting File: 1988/89 – 1991/92.							
Year		1988/89	1989/90	1990/91	1991/92	1988/92	X-avg
Rainfall		965	834	787	701	3286	822
Upland water balance in mm on an area of: 280000 Ha							
STupl, b		112	176	143	123	112	
ETupland		737	700	662	615	2715	679
Percolation		227	134	124	85	571	143
Seepage		166	167	145	119	597	149
STupl, e		176	143	123	89	89	
STe, calc		173	143	123	89	86	3
Wetland water balance, in mm over an area of: 45000 Ha							
STw, b		-146	-106	-142	-154	-146	
Seepage		1035	1039	900	741	3715	929
ETwetland		1438	1448	1315	1225	5425	1356
Discharge		520	463	385	243	1612	403
STw, e		-106	-142	-154	-182	-182	
STe, calc		-104	-143	-156	-180	-181	-1
Overall water balance, mm over an area of: 325000 Ha							
STb		76	137	103	84	76	100
Rainfall		965	834	787	701	3286	822
ET		834	803	753	700	3090	773
Discharge		72	64	53	34	223	56
STe		137	103	84	51	51	
STe, calc		135	103	84	52	49	3
Deviation %%		1.8%	0.1%	0.4%	-0.7%	5.0%	

"Goodness of fit"	1988/89	1989/90	1990/91	1991/92	1988/92
Total discharge, mm; Volume under hydrograph.					
Q calculated:	73	65	54	34	225
Qmeasured:	77	62	49	33	221
Qc/Qm *100%	94%	105%	111%	103%	102%
Annual maximum discharge: m3/s @sqrt((Qc - Qm) ^ 2)					
Qc, max m3/s	30.32	29.94	24.54	12.23	24.26
Qm, max m3/s	31.77	30.79	26.24	10.08	24.72
F2-value m3/s	1.46	0.86	1.69	2.15	1.61
CV-Coefficient:	4.6%	2.8%	6.5%	21.3%	6.5%
Calculated – measured discharges: @Sqrt(@sum((Qc - Qm) ^ 2/n))					
F1- value Q	1.81	2.25	1.54	2.33	2.01
F3- value Ln Q	2.10	1.78	1.84	2.53	2.08
Goodness of fit recession curve (April to the end of September).					
F1'- valu Q	0.88	0.58	1.00	1.38	0.96
F3'- valu Ln Q	0.21	0.20	0.24	0.33	0.25

Table 2.a.: Water balances, period 1953 – 1992.
Average values, Litawa. Appendix II.

Annual average values 1953 – 1992. Parameters according to the fitting of Qcalc. to Qmonit.									
Decade	ETr	R	ETu	Pu	Sw	Cw,1	ETw	Qc	Cw,2
	73	3	7	0	28	0.54	40	1	1.00
o	73	12	7	0	27	0.55	40	1	1.00
	80	14	9	0	30	0.56	45	0	1.00
	70	29	10	2	27	0.58	41	0	1.00
n	70	31	12	2	26	0.59	42	0	1.00
	70	36	15	3	26	0.61	42	0	1.00
	57	64	15	8	27	0.76	43	0	1.00
d	57	67	19	10	27	0.77	44	2	1.00
	63	68	25	11	31	0.78	49	7	1.00
	52	63	23	12	29	0.86	44	13	1.00
j	52	63	25	13	29	0.88	46	21	1.00
	57	74	30	18	34	0.90	51	31	1.00
	53	67	30	18	32	0.90	48	35	1.00
f	53	68	31	20	33	0.92	48	40	1.00
	42	53	25	21	28	0.96	40	33	1.00
	54	53	33	20	36	0.97	52	41	1.00
m	54	42	33	11	36	0.98	53	38	1.00
	59	30	36	6	40	0.98	58	36	1.00
	60	17	35	1	36	0.91	54	27	1.00
a	60	12	33	1	36	0.91	54	22	1.00
	60	4	30	0	35	0.87	52	17	1.00
	58	2	26	0	35	0.85	49	14	1.00
m	56	0	23	0	34	0.82	46	11	1.00
	62	0	23	0	37	0.76	47	10	1.00
	48	0	16	0	33	0.82	39	7	1.00
j	48	0	14	0	33	0.79	38	6	1.00
	48	0	13	0	32	0.76	36	5	1.00
	51	0	13	0	32	0.67	34	4	1.00
j	51	0	12	0	31	0.64	33	3	1.00
	56	0	12	0	34	0.61	34	3	1.00
	68	0	13	0	30	0.52	36	2	1.00
a	68	0	12	0	30	0.54	37	1	1.00
	75	0	11	0	32	0.56	42	1	1.00
	85	1	11	0	29	0.44	38	1	1.00
s	85	1	10	0	28	0.45	39	1	1.00
	85	1	9	0	28	0.46	39	1	1.00
Total:	2213	876	700	177	1128	0.73	1573	433	1.000

Balance of root zone: mm. Acreage: Ha.		R	ETu	Pu	CECK	ETu,corr	
396000		876	700	177	177	699	
Bal. for ground water reserv.: mm	STu,b	P	Su	STu,e	dSTu		
STu,b + P - Su = STu,e	396000	291	177	180	192	-99	
	459000	251	153	155	165	-86	
Balance for wetland reservoir: mm	STw,b	R	Sw	ETw	Q	STw,e	
	63000	-141	876	1128	1573	433	-178
	459000	-19	120	155	216	59	-24
Grand balance: mm	STb	R	ETu	ETw	Q	STe	
	Yavg	232	876	603	216	59	141
	40 Y's	232	35055	24137	8634	2379	136
	%		100.0%	68.9%	24.6%	6.8%	
Check on water balances:					STe	Diff	
Upland: Rootzone:	R - ETu - Pu				-0	-0	
Upland: Ground water:	STu,b + 40 * (P - Su) =				187	4	
Wetland:	STw,b + 40 * (R + Sw - ETw) =				-185	-7	
Overall balance:	STb + 40 * (R - ETu - ETw - Q) =				136	-5	

Table 2.b.: Water balances, period 1953 – 1992.
Average values Sasenda. Appendix II.

Annual average values 1953 – 1992. Parameters according to the fitting of Qcalc. to Qmonit.										
Decade	ETr	R	ETu	Pu	Sw	Cw,1	ETw	Qc	Cw,2	
	73	4	7	0	28	0.54	40	1	1.00	
o	73	12	8	0	27	0.55	40	1	1.00	
	80	14	9	0	30	0.56	45	0	1.00	
n	70	30	10	2	26	0.58	41	0	0.99	
	70	32	13	2	26	0.59	41	0	0.99	
	70	37	15	3	26	0.61	42	0	1.00	
d	57	66	15	8	27	0.76	43	1	1.00	
	57	67	19	10	27	0.77	44	5	1.00	
	63	69	25	11	31	0.78	49	13	1.00	
	52	64	23	13	29	0.86	44	22	1.00	
l	52	64	25	13	30	0.88	45	29	1.00	
	57	75	30	18	35	0.90	51	40	1.00	
	53	67	30	18	33	0.90	48	42	1.00	
f	53	71	32	23	36	0.92	48	48	1.00	
	42	54	25	23	30	0.96	40	40	1.00	
	54	55	33	21	40	0.97	52	48	1.00	
m	54	42	33	12	40	0.98	53	43	1.00	
	59	32	36	7	44	0.98	58	40	1.00	
	60	18	35	2	40	0.91	54	30	1.00	
a	60	13	33	1	39	0.91	54	24	1.00	
	60	5	31	0	38	0.87	53	18	1.00	
	58	3	27	0	38	0.85	49	14	1.00	
m	56	0	23	0	37	0.82	46	11	1.00	
	62	0	23	0	40	0.76	47	9	1.00	
	48	0	16	0	35	0.82	39	6	1.00	
j	48	0	15	0	35	0.79	38	5	1.00	
	48	0	13	0	34	0.76	37	4	1.00	
	51	0	13	0	33	0.67	34	3	1.00	
j	51	0	12	0	33	0.64	33	2	1.00	
	56	0	12	0	35	0.61	34	2	1.00	
	68	0	13	0	31	0.52	36	2	1.00	
a	68	0	12	0	31	0.54	37	1	1.00	
	75	0	12	0	33	0.56	42	1	1.00	
	85	1	12	0	29	0.44	38	1	1.00	
s	85	1	10	0	29	0.45	39	1	1.00	
	85	2	9	0	28	0.46	39	1	1.00	
Total:	2213	898	710	188	1183	0.73	1573	509	1.000	

Balance of root zone: mm. Acreage: Ha.		R	ETu	Pu	CECK	ETu,corr.	
		898	710	188	188	710	
Balance for upland reservoir: mm		STu,b	P	Su	STu,e	dSTu	
STu,b + P - Su = STu,e	280000	222	188	190	134	-88	
	325000	192	162	164	115	-76	
Balance for wetland reservoir: mm		STw,b	R	Sw	ETw	Q	STw,e
	45000	-113	898	1183	1573	509	-170
	325000	-16	124	164	218	70	-23
Grand balance: mm		STb	R	ETu	ETw	Q	STe
	Yavg	176	898	612	218	70	92
	40 Y's	176	35908	24463	8713	2820	88
	%%		100.0%	68.1%	24.3%	7.9%	
Ceck on water balances:						STe	Diff.
Upland: Rootzone:	R - ETu - Pu					-0	-0
Upland: Ground water:	STu,b + 40 * (P - Su) =					130	4
Wetland:	STw,b + 40 * (R + Sw - ETw) =					-172	-3
Overall balance:	STb + 40 * (R - ETu - ETw - Q) =					88	-4

Table 3.a.: Annual water balances, Litawa, Lui valley, mm. Appendix II.

Parameters according to the fitting of Qcalc. to Qmonit.																	
Season	Rainfa			Rootzone.		Upland res.		Wetland reservoir.				Overall bal.: Upl. + Wetl.				Annual max.	
	R	ETu	P	Su	STu,e	Sw	ETw	Q	STw,e	Cw,2	ETu	ETw	Q	ST	Qmax	Hmax	
1952/53	1089	772	293	210	295	1320	1762	589	-93	1.13	666	242	81	336	49.13	1.75	
1953/54	828	698	158	207	329	1301	1677	498	-125	1.06	602	230	68	264	37.23	1.65	
1954/55	933	726	205	202	332	1270	1679	519	-121	1.07	627	230	71	268	39.11	1.67	
1955/56	954	780	158	187	304	1177	1642	500	-133	1.04	673	225	69	255	32.39	1.60	
1956/57	912	697	227	194	337	1218	1627	490	-118	1.04	601	223	67	276	48.26	1.75	
1957/58	1256	774	485	292	529	1837	2153	863	-37	1.40	668	296	118	451	64.66	1.86	
1958/59	1216	797	420	351	599	2204	2426	976	-21	1.56	687	333	134	513	61.70	1.84	
1959/60	863	711	152	300	451	1886	2129	663	-65	1.36	613	292	91	379	50.95	1.77	
1960/61	944	780	176	243	384	1529	1914	590	-97	1.22	656	263	81	323	43.06	1.70	
1961/62	889	734	162	211	335	1327	1760	483	-120	1.12	633	242	66	271	42.24	1.69	
1962/63	990	719	274	224	385	1410	1787	590	-98	1.15	621	245	81	314	44.64	1.72	
1963/64	754	649	117	201	301	1266	1694	361	-134	1.08	560	233	50	226	25.11	1.51	
1964/65	644	560	81	152	230	954	1374	257	-168	0.87	483	189	35	162	19.00	1.42	
1965/66	949	736	195	156	270	979	1488	422	-151	0.94	635	204	58	214	37.21	1.65	
1966/67	760	658	110	147	233	922	1368	335	-168	0.86	567	188	46	174	25.80	1.52	
1967/68	958	789	158	147	242	926	1494	385	-159	0.95	681	205	53	193	29.80	1.57	
1968/69	1132	792	343	203	382	1278	1748	604	-100	1.12	683	240	83	319	42.37	1.70	
1969/70	763	676	103	194	291	1221	1679	344	-138	1.07	583	230	47	221	31.25	1.59	
1970/71	835	699	129	163	257	1026	1513	364	-155	0.96	603	208	50	196	34.16	1.62	
1971/72	794	666	118	142	233	894	1357	339	-167	0.85	574	186	47	183	24.62	1.51	
1972/73	455	444	43	110	165	692	1067	112	-198	0.67	383	147	15	92	13.27	1.31	
1973/74	1022	741	250	145	270	913	1443	441	-146	0.92	639	198	60	217	40.58	1.68	
1974/75	950	787	164	165	269	1039	1546	448	-152	0.98	679	212	61	214	27.69	1.54	
1975/76	1007	761	233	179	322	1125	1585	517	-125	1.01	656	218	71	276	36.64	1.64	
1976/77	908	713	206	195	333	1225	1648	476	-118	1.05	615	226	65	277	50.15	1.76	
1977/78	1076	769	301	226	408	1423	1820	652	-89	1.16	664	250	90	351	48.19	1.74	
1978/79	698	642	85	199	294	1250	1668	332	-140	1.06	554	229	46	221	20.14	1.44	
1979/80	922	759	143	189	269	1061	1591	400	-151	1.01	655	216	55	214	28.05	1.55	
1980/81	1074	746	330	209	390	1312	1729	602	-98	1.11	643	237	83	324	52.54	1.78	
1981/82	612	552	68	185	274	1161	1530	282	-136	0.97	476	210	39	212	22.56	1.48	
1982/83	700	621	85	142	217	890	1394	234	-173	0.88	536	191	32	153	22.30	1.47	
1983/84	772	657	108	125	201	783	1289	275	-181	0.81	567	177	38	143	22.84	1.48	
1984/85	728	636	98	115	184	722	1240	218	-189	0.78	549	170	30	122	22.82	1.48	
1985/86	834	690	125	114	196	715	1251	291	-184	0.79	595	172	40	150	21.87	1.47	
1986/87	649	597	73	105	163	661	1180	141	-197	0.74	515	162	19	102	14.34	1.34	
1987/88	893	731	141	112	193	702	1264	319	-183	0.80	631	173	44	147	25.70	1.52	
1988/89	969	768	203	142	254	892	1408	429	-161	0.89	664	193	59	201	36.44	1.64	
1989/90	861	715	150	153	251	964	1412	412	-161	0.89	616	194	57	195	36.65	1.64	
1990/91	775	658	123	143	231	897	1326	358	-171	0.84	568	182	49	171	34.07	1.62	
1991/92	686	607	82	122	192	765	1247	219	-187	0.79	524	171	30	132	16.25	1.37	
		CHECK	79	CHECK	192			CHECK	-197	1.00			CHECK	138			
	R	ETu	P	Su	STu	Sw	ETw	Q			ETu	ETw	Q	dST	Qmax	Hmax	
AVG	876	700	177	180	297	1128	1573	433			604	216	59	-3	34.39	1.60	
STD	165	76	97	53	94	333	274	175			65	38	24		12.54	0.13	
P10%	665	603	53	112	177	702	1222	209			520	168	29		18.34	1.43	
P90%	1088	797	301	247	417	1555	1924	658			687	264	90		50.44	1.77	
AVG %	100%	79.8%	20.2%					78.4%	21.6%		68.9%	24.6%	6.8%	*****	PI 80%	0.34	
Cff. Var.	18.9%	10.8%	54.6%	29.5%	31.6%	29.5%	17.4%	40.5%			10.8%	17.4%	40.5%		36.5%	8.4%	
											P10%	59.3%	19.1%	3.3%			
											P90%	78.4%	30.1%	10.3%			

Table 3.b.: Annual water balances, Sasenda, Lui river valley, m Appendix II.

Parameters according to the fitting of Qcalc. to Qmonit.																	
Season	Rainfa			Rootzone.		Upland		Wetland			Overall balance: Upl. + Wet				Annual max.		
	R	ETu	P	Su	STu,e	Sw	ETw	Q	STw,e	Cw,2	ETu	ETw	Q	ST	Qmax	Hmax	
					227				-113					180			
1952/53	1108	779	304	229	302	1425	1786	685	-53	1.15	671	247	95	275	41.31	1.50	
1953/54	839	707	159	217	244	1352	1689	556	-102	1.07	609	234	77	193	29.00	1.39	
1954/55	941	728	210	207	247	1291	1653	575	-98	1.05	627	229	80	198	32.20	1.42	
1955/56	948	776	156	186	217	1158	1592	538	-115	1.01	669	220	74	182	26.86	1.36	
1956/57	917	697	231	197	251	1224	1594	522	-95	1.02	600	221	72	205	38.87	1.48	
1957/58	1223	770	457	308	400	1917	2080	973	-11	1.35	663	288	135	343	52.19	1.58	
1958/59	1262	797	465	384	481	2389	2393	1229	8	1.54	686	331	170	417	54.91	1.60	
1959/60	885	723	161	312	330	1940	2090	788	-45	1.34	623	289	109	281	43.74	1.52	
1960/61	983	773	214	252	293	1565	1893	696	-66	1.21	666	262	96	249	36.75	1.46	
1961/62	950	754	203	229	267	1424	1796	602	-66	1.14	650	249	83	218	37.28	1.47	
1962/63	1027	730	302	254	315	1578	1861	697	-55	1.20	629	258	96	262	39.00	1.48	
1963/64	754	649	117	212	221	1318	1693	440	-114	1.08	559	234	61	161	23.04	1.31	
1964/65	671	579	90	149	161	929	1344	312	-157	0.85	499	186	43	104	17.60	1.24	
1965/66	978	748	212	164	209	1018	1477	485	-125	0.94	644	204	67	166	31.20	1.41	
1966/67	780	671	115	152	173	944	1365	389	-151	0.86	578	189	54	125	22.94	1.31	
1967/68	939	778	153	149	176	928	1437	435	-145	0.91	671	199	60	135	24.71	1.34	
1968/69	1169	803	366	228	314	1416	1785	704	-52	1.15	692	247	97	267	36.29	1.46	
1969/70	793	698	110	207	217	1286	1703	437	-118	1.08	602	238	61	162	27.79	1.37	
1970/71	879	729	141	168	191	1044	1500	438	-136	0.95	628	208	61	144	30.69	1.40	
1971/72	793	667	118	141	168	879	1317	370	-152	0.83	574	182	51	130	19.55	1.27	
1972/73	467	456	44	102	109	637	1023	123	-193	0.64	393	142	17	45	11.35	1.12	
1973/74	1102	765	306	173	242	1078	1521	566	-98	0.98	659	211	78	199	39.09	1.48	
1974/75	987	794	194	200	236	1248	1664	579	-107	1.06	684	230	80	192	25.34	1.34	
1975/76	1013	766	233	205	264	1278	1663	598	-87	1.06	660	230	83	231	30.23	1.40	
1976/77	901	719	192	206	249	1281	1660	521	-96	1.05	619	230	72	210	41.17	1.50	
1977/78	1137	787	344	253	340	1572	1873	778	-40	1.20	678	259	108	302	41.67	1.50	
1978/79	768	689	105	218	228	1355	1733	461	-114	1.10	593	240	64	172	18.65	1.25	
1979/80	954	785	151	177	202	1100	1588	482	-131	1.00	676	220	67	163	23.76	1.32	
1980/81	1090	756	339	226	312	1420	1763	667	-58	1.14	651	244	92	265	42.75	1.51	
1981/82	639	570	74	189	197	1178	1534	343	-120	0.97	491	212	47	153	20.24	1.28	
1982/83	713	632	89	136	150	849	1339	265	-164	0.84	544	185	37	100	20.26	1.28	
1983/84	780	663	111	120	141	746	1229	305	-171	0.77	571	170	42	97	19.47	1.26	
1984/85	766	663	109	115	134	717	1224	267	-175	0.77	571	170	37	86	21.21	1.29	
1985/86	847	700	128	116	147	722	1232	333	-168	0.78	603	171	46	113	17.67	1.24	
1986/87	686	622	83	108	122	672	1175	199	-184	0.74	536	163	28	72	14.32	1.18	
1987/88	895	734	142	116	147	725	1240	365	-165	0.78	632	172	51	112	21.66	1.30	
1988/89	1000	767	235	164	218	1021	1459	518	-121	0.93	661	202	72	177	33.47	1.43	
1989/90	858	718	144	168	194	1048	1445	478	-138	0.91	618	200	66	150	31.67	1.41	
1990/91	779	661	125	147	171	916	1312	401	-154	0.83	569	182	55	123	29.42	1.39	
1991/92	680	603	81	118	134	736	1200	245	-178	0.75	520	166	34	83	13.11	1.16	
CHECK			77	CHEC	134			CHEC	-186	1.00			CHEC	90			
	R	ETu	P	Su	STu	Sw	ETw	Q			ETu	ETw	Q	dST	Qmax	Hmax	
AVG	898	710	188	190	228	1183	1573	509			612	218	70	-2	29.56	1.38	
STD	168	73	101	60	78	372	281	209			63	39	29		10.39	0.11	
P10%	683	616	58	114	128	707	1213	242			531	168	33		16.26	1.23	
P90%	1112	804	318	267	328	1659	1933	776			692	268	107		42.86	1.52	
AVG %	*****	79.1%	20.9%					75.6%	24.5%		AVG %	68.2%	24.3%	7.9%	*****	PI 80%	0.29
Coeff. V	18.7%	10.3%	54.0%	31.4%	34.4%	31.4%	17.9%	41.0%			Coeff.	10.3%	17.9%	41.0%		35.2%	8.4%
											P10%	59.2%	18.7%	3.7%			
											P90%	77.1%	29.8%	12.0%			

Table 4.: Calculation schema for wetland reservoir. App.: II.

Calculations based on data for an 'average' season of period 1953-1992.

Symbol	ETr	R	Sw	Cw,1	ETw	lw	lw,cum	lw > 0	lw,m	Driver	Qvalley	Qtotal	Qtotal	Qt.corr	Qt.corr	Qc	STw	
Units	days	mm/dec	mm/d	mm/d	mm/d	mm/d	mm/dec	mm/d	mm/dec	M3/s	mm							
o	10	73	12	27	0.55	40	-11	-134	0	0.0	0.02	0.00	0.00	0	0.02	0	0.1	-139
8	11	80	14	30	0.56	45	-2	-141	0	0.0	0.01	0.00	0.01	0	0.01	0	0.1	-141
10	10	70	29	27	0.58	41	6	-134	0	0.0	0.01	0.00	0.01	0	0.01	0	0.1	-133
n	10	70	31	26	0.59	42	15	-119	0	0.0	0.00	0.00	0.00	0	0.00	0	0.0	-119
12	10	70	36	26	0.61	42	17	-102	0	0.0	0.00	0.00	0.00	0	0.00	0	0.0	-102
13	10	57	84	27	0.76	43	33	-88	0	0.0	0.00	0.00	0.00	0	0.00	0	0.0	-88
14	10	57	87	27	0.77	44	49	-20	0	0.0	0.00	0.00	0.00	0	0.00	0	0.0	-20
15	11	63	88	31	0.78	49	49	29	2.8	0.18	0.21	0.39	4	0.40	4	2.9	29	
16	10	52	83	29	0.88	44	56	56	5.6	0.18	1.28	1.48	15	1.50	15	10.9	56	
17	10	52	83	29	0.88	46	53	53	5.3	0.18	2.07	2.25	22	2.31	23	18.8	53	
18	11	57	74	34	0.90	51	60	60	6.0	0.18	2.79	2.97	33	3.06	34	22.2	60	
19	10	53	87	32	0.90	48	59	59	5.9	0.18	3.39	3.57	38	3.66	37	26.7	59	
20	10	53	88	33	0.92	48	59	59	5.9	0.18	3.67	4.05	41	4.16	42	30.3	60	
21	8	42	53	28	0.98	40	41	41	5.1	0.18	4.06	4.23	34	4.34	35	31.8	41	
22	10	54	53	36	0.97	52	37	37	3.7	0.18	3.64	4.12	41	4.22	42	30.8	37	
23	10	54	42	36	0.98	53	25	25	2.5	0.18	3.61	3.79	36	3.89	39	28.4	26	
24	11	59	30	40	0.98	58	13	13	1.2	0.18	3.02	3.20	35	3.29	36	24.0	13	
25	10	60	17	38	0.91	54	-1	-1	0	0.0	0.18	2.37	2.55	25	2.61	26	19.1	-1
26	10	60	12	36	0.91	54	-6	-6	0	0.0	0.18	1.84	2.02	20	2.08	21	15.1	-7
27	10	60	4	35	0.87	52	-13	-21	0	0.0	0.18	1.43	1.61	16	1.65	18	12.0	-21
28	10	56	2	35	0.85	49	-12	-33	0	0.0	0.18	1.10	1.28	13	1.31	13	9.8	-33
29	10	56	0	34	0.82	46	-11	-44	0	0.0	0.18	0.83	1.01	10	1.04	10	7.8	-44
30	11	82	0	37	0.78	47	-10	-54	0	0.0	0.18	0.81	0.79	9	0.81	9	5.9	-53
31	10	48	0	33	0.82	39	-8	-60	0	0.0	0.18	0.45	0.63	6	0.64	6	4.7	-60
32	10	48	0	33	0.79	38	-5	-66	0	0.0	0.18	0.32	0.50	5	0.51	5	3.7	-66
33	10	48	0	32	0.78	36	-4	-69	0	0.0	0.18	0.22	0.40	4	0.41	4	3.0	-69
34	10	51	0	32	0.67	34	-3	-72	0	0.0	0.18	0.13	0.31	3	0.32	3	2.3	-72
35	10	51	0	31	0.64	33	-2	-73	0	0.0	0.18	0.07	0.25	2	0.26	3	1.9	-73
36	11	56	0	34	0.61	34	-1	-74	0	0.0	0.18	0.01	0.17	2	0.18	2	1.3	-74
37	10	88	0	30	0.52	36	-6	-80	0	0.0	0.15	0.01	0.16	2	0.16	2	1.2	-80
38	10	68	0	30	0.54	37	-7	-87	0	0.0	0.13	0.01	0.14	1	0.14	1	1.1	-87
39	11	75	0	32	0.58	42	-10	-96	0	0.0	0.12	0.01	0.12	1	0.13	1	0.9	-96
40	10	85	1	29	0.44	35	-8	-104	0	0.0	0.07	0.01	0.08	1	0.08	1	0.6	-104
41	10	85	1	28	0.45	39	-10	-114	0	0.0	0.04	0.00	0.05	0	0.05	0	0.4	-114
42	10	85	1	28	0.48	39	-10	-124	0	0.0	0.03	0.00	0.03	0	0.03	0	0.2	-124
43									0	0.03	0.00	0.03						
44	Totals:		2213	876	1128		1573		432					421		432		
45									R+Sw E	432						97.43		of Input

Calculations: If statements: @R(Condition, R-value), R represents the equation to calculate the result.
\$ sign indicates the absolute addressing of either column or row or both.

ETw = ETr * Cw,1 * Cw,2 with Cw,2 = 1.0 in this example for an 'average' season.

lw : to end of december: 0.5*D15+0.5*D14+E15-G15 (interflow effect)
 then: January 1 0.8*D16+0.5*D15+E16-G16 (interflow effect)
 January 2 0.7*D17+0.4*D16+E17-G17 (interflow effect)
 January 3 0.8*D18+0.3*D17+E18-G18 (interflow effect)
 February 1 0.9*D19+0.2*D18+E19-G19 (interflow effect)
 February 2 +D20+0.1*D19+E20-G20 (interflow effect)
 February 3 +D21+E21-G21

lw: March to September R+Sw-ETw

lw,cum: Cell i8 @F(i7<0,+i7+H8,H8)
 Driver: Cell i8 @F(L7<=SD\$4#AND#K6=0,L7*EXP(-SB\$4*B8),@F(+L7*EXP(-SB\$3*B8)+K6*(1-@EXP(-SB\$3*B8))<=SD\$3
 #AND#M8<0.2*SD\$3,+L7*EXP(-SB\$3*B8)+K6*(1-@EXP(-SB\$3*B8))+SD\$3)
 Qvalley: Cell m8 @F(L7*EXP(-SB\$3*B8)+K6*(1-@EXP(-SB\$3*B8))<=SD\$3#AND#M7<=0.2*SD\$3,+M7*EXP(-SB\$2*B8)+M7*EXP(-SB\$2*B8)+(K6-((SD\$3-L7*EXP(-SB\$3*B8))/(1-@EXP(-SB\$3*B8)))*(1-@EXP(-SB\$2*B8)))
 Qtotal: Cell n8 +i8+m8
 Qtotal: Cell o6 +n8*b8
 Qt.corr: Cell p6 +o6*(SB\$44/5.0544)
 Qt.corr: Cell q6 +p6*b8
 Qc: Cell r6 +p6*SD\$2*10000/(1000*24*3600)
 STw: Cell s8 @F(P8<D3,i8+N8/53,i8+P8/32)

Table 1.: Information on levels and suitability percentages at the cross-section, Lui river valley.								
Appendix: III.		levels in m. above m.s.l.			Suitab. limits valley		Suitability 0.25/0.95 m.	
BM	BM-zero	Avg. V.b. lvl.	ref. FLd Lvl	Avg Fld lvl	Lower	upper	actual %	max. %
96L	1050.49	1049.28	1050.02	1050.24	1049.39	1049.84	22	27
97L	1048.58	1047.06	1047.59	1047.81	1046.96	1047.41	45	45
98L	1046.72	1045.36	1045.82	1046.04	1045.19	1045.64	22	38
99L	1044.67	1043.49	1043.97	1044.19	1043.34	1043.79	30	40
100L	1044.26	1042.24	1042.25	1042.47	1041.62	1042.07	14	32
1L	1043.07	1040.77	1041.11	1041.33	1040.48	1040.93	41	48
2L	1042.25	1039.19	1039.45	1039.67	1038.82	1039.27	34	31
3L	1038.74	1036.90	1037.37	1037.84	1036.16	1037.07	17	24
4L	1037.01	1035.59	1036.06	1036.52	1034.85	1035.75	-	-
5L	1035.61	1032.73	1033.34	1033.81	1032.13	1033.04	25	41
6L	1032.56	1030.60	1030.41	1030.66	1029.83	1030.23	23	38
7L	1030.52	1028.72	1028.88	1029.13	1028.30	1028.71	26	47
8L	1030.98	1027.17	1027.53	1027.78	1026.95	1027.36	34	36
9L	1027.44	1025.58	1026.19	1026.44	1025.61	1026.02	27	32
10L	1026.13	1023.52	1023.97	1024.22	1023.39	1023.80	36	39
11L	1023.00	1021.59	1021.72	1021.97	1021.14	1021.55	10	
12L	1022.94	1019.59	1019.85	1020.10	1019.27	1019.68	24	28
13L	1020.90	1017.78	1018.19	1018.44	1017.61	1018.02	25	33
14L	1018.25	1015.75	1016.33	1016.58	1015.75	1016.16	31	42
15L	1016.51	1013.36	1013.91	1014.16	1013.33	1013.74	33	40
16L	1012.76	1011.30	1011.87	1012.12	1011.29	1011.70	20	20
17L	1011.35	1009.39	1009.52	1009.77	1008.94	1009.35	21	29
18L	1008.58	1007.26	1007.72	1007.97	1007.14	1007.55	27	27
19L	1006.71	1005.17	1005.77	1006.02	1005.19	1005.60	17	42
20L	1004.99	1003.07	1003.63	1003.88	1003.05	1003.46	14	24
21L	1002.47	1001.30	1001.25	1001.50	1000.67	1001.08	32	57
22L	999.96	999.28	998.42	998.67	997.84	998.25	4	32
						Average %:	24	34

	Annual maximum ground water level					Annual minimum ground water level					Seasonal increase: WLmax - WLmin				
0.001*8	0.75	1.00	1.50	2.00	3.00	0.75	1.00	1.50	2.00	3.00	0.75	1.00	1.50	2.00	3.00
1952/53	3.32	2.65	1.99	1.66	1.32	2.65	1.99	1.33	1.01	0.64					
1953/54	3.16	2.47	1.76	1.39	1.00	2.62	1.92	1.21	0.84	0.48	0.51	0.48	0.43	0.38	0.36
1954/55	3.19	2.49	1.78	1.41	1.04	2.65	1.95	1.23	0.87	0.51	0.58	0.58	0.57	0.57	0.57
1955/56	2.97	2.26	1.55	1.19	0.82	2.54	1.84	1.14	0.79	0.45	0.32	0.32	0.31	0.31	0.32
1956/57	3.20	2.50	1.80	1.45	1.12	2.62	1.92	1.23	0.89	0.56	0.65	0.66	0.66	0.67	0.67
1957/58	4.32	3.60	2.86	2.48	2.09	3.60	2.83	1.99	1.53	1.01	1.70	1.67	1.63	1.59	1.52
1958/59	4.89	4.08	3.20	2.70	2.13	4.04	3.16	2.18	1.63	1.00	1.28	1.25	1.21	1.17	1.13
1959/60	4.35	3.46	2.47	1.91	1.29	3.58	2.67	1.67	1.14	0.61	0.31	0.30	0.29	0.28	0.29
1960/61	3.91	3.00	2.02	1.50	0.99	3.28	2.37	1.43	0.96	0.52	0.34	0.34	0.34	0.35	0.38
1961/62	3.65	2.75	1.81	1.34	0.92	3.02	2.13	1.24	0.82	0.44	0.37	0.37	0.38	0.38	0.40
1962/63	3.83	2.95	2.07	1.65	1.27	3.21	2.34	1.46	1.04	0.64	0.81	0.82	0.83	0.83	0.83
1963/64	3.42	2.54	1.67	1.25	0.86	2.77	1.92	1.10	0.72	0.38	0.20	0.21	0.21	0.21	0.21
1964/65	2.88	2.04	1.24	0.88	0.55	2.40	1.60	0.87	0.54	0.27	0.11	0.12	0.14	0.15	0.17
1965/66	2.92	2.14	1.43	1.12	0.85	2.42	1.67	0.99	0.68	0.41	0.52	0.54	0.56	0.57	0.58
1966/67	2.63	1.89	1.22	0.92	0.65	2.24	1.53	0.89	0.61	0.35	0.21	0.22	0.24	0.24	0.24
1967/68	2.60	1.90	1.27	0.99	0.73	2.19	1.52	0.91	0.64	0.38	0.36	0.37	0.38	0.39	0.38
1968/69	3.29	2.61	2.00	1.71	1.42	2.51	1.84	1.24	0.97	0.71	1.09	1.10	1.09	1.07	1.04
1969/70	2.98	2.29	1.62	1.28	0.91	2.44	1.75	1.09	0.75	0.42	0.47	0.45	0.38	0.31	0.20
1970/71	2.74	2.06	1.40	1.07	0.75	2.23	1.57	0.93	0.63	0.34	0.31	0.31	0.31	0.32	0.33
1971/72	2.48	1.83	1.20	0.90	0.62	2.06	1.43	0.84	0.57	0.31	0.25	0.26	0.27	0.28	0.29
1972/73	2.17	1.52	0.92	0.63	0.39	1.74	1.15	0.62	0.39	0.20	0.10	0.09	0.07	0.06	0.07
1973/74	2.55	1.97	1.45	1.21	1.01	2.06	1.48	0.96	0.73	0.50	0.82	0.82	0.83	0.83	0.81
1974/75	2.55	1.96	1.41	1.14	0.86	2.12	1.54	0.98	0.70	0.42	0.49	0.48	0.45	0.41	0.35
1975/76	2.81	2.23	1.66	1.37	1.08	2.34	1.76	1.19	0.88	0.55	0.69	0.69	0.68	0.67	0.66
1976/77	2.97	2.37	1.77	1.46	1.13	2.47	1.85	1.22	0.89	0.54	0.64	0.62	0.58	0.58	0.58
1977/78	3.37	2.75	2.11	1.77	1.41	2.89	2.07	1.44	1.11	0.75	0.91	0.90	0.88	0.88	0.87
1978/79	2.96	2.30	1.61	1.23	0.81	2.48	1.81	1.12	0.76	0.40	0.27	0.23	0.17	0.12	0.08
1979/80	2.77	2.10	1.41	1.06	0.72	2.33	1.67	1.01	0.68	0.38	0.29	0.29	0.29	0.30	0.32
1980/81	3.38	2.72	2.05	1.72	1.40	2.50	1.85	1.19	0.87	0.58	1.05	1.05	1.04	1.03	1.01
1981/82	2.92	2.24	1.54	1.17	0.79	2.39	1.71	1.03	0.69	0.36	0.42	0.40	0.35	0.30	0.21
1982/83	2.53	1.86	1.18	0.86	0.55	2.09	1.44	0.81	0.52	0.27	0.14	0.15	0.16	0.17	0.19
1983/84	2.30	1.66	1.05	0.77	0.53	1.95	1.33	0.76	0.51	0.29	0.21	0.22	0.24	0.25	0.26
1984/85	2.15	1.55	0.99	0.74	0.53	1.77	1.19	0.67	0.45	0.25	0.21	0.22	0.23	0.24	0.24
1985/86	2.06	1.49	0.99	0.78	0.56	1.79	1.25	0.76	0.54	0.34	0.29	0.30	0.31	0.32	0.32
1986/87	1.90	1.36	0.88	0.67	0.47	1.56	1.05	0.60	0.40	0.22	0.11	0.11	0.12	0.13	0.13
1987/88	1.96	1.45	1.01	0.81	0.62	1.65	1.16	0.72	0.52	0.32	0.40	0.40	0.41	0.41	0.40
1988/89	2.27	1.78	1.33	1.12	0.90	1.89	1.39	0.92	0.69	0.44	0.62	0.62	0.61	0.60	0.57
1989/90	2.32	1.82	1.35	1.11	0.85	1.92	1.41	0.92	0.66	0.40	0.43	0.43	0.43	0.42	0.41
1990/91	2.22	1.72	1.22	0.97	0.70	1.87	1.36	0.86	0.61	0.35	0.31	0.31	0.30	0.30	0.30
1991/92	2.00	1.50	1.00	0.75	0.51	1.75	1.25	0.77	0.53	0.30	0.13	0.14	0.14	0.15	0.16
	Annual maximum ground water level					Annual minimum ground water level					Seasonal increase: WLmax - WLmin				
0.001*8	0.75	1.00	1.50	2.00	3.00	0.75	1.00	1.50	2.00	3.00	0.75	1.00	1.50	2.00	3.00
WLavg	2.92	2.25	1.58	1.25	0.93	2.41	1.74	1.09	0.77	0.46				0.48	
Std	0.68	0.60	0.50	0.45	0.39	0.55	0.45	0.33	0.26	0.18				0.33	
P10% ne	2.05	1.48	0.94	0.68	0.44	1.70	1.16	0.66	0.43	0.23				0.05	
P90% ne	3.80	3.02	2.23	1.83	1.42	3.12	2.32	1.52	1.11	0.69				0.90	
PI 80%	1.75	1.54	1.29	1.15	0.99	1.41	1.16	0.86	0.67	0.46				0.86	
Highest and lowest GWL for period 1953-1992.															
WLmax	4.89	4.08	3.20	2.70	2.13	4.04	3.16	2.18	1.63	1.01				1.63	
WLmin	1.90	1.36	0.88	0.63	0.39	1.56	1.05	0.60	0.39	0.20				0.07	
Max - min	2.99	2.72	2.32	2.07	1.75	2.48	2.11	1.59	1.24	0.81	Years dGWL < 0.30 m			13	33%
Highest and lowest GWL for period 1963-1992.															
WLmax	3.83	2.95	2.11	1.77	1.42	3.21	2.34	1.46	1.11	0.75				1.09	
WLmin	1.90	1.36	0.88	0.63	0.39	1.56	1.05	0.60	0.39	0.20				0.07	
Max - min	1.93	1.59	1.23	1.14	1.03	1.65	1.29	0.86	0.72	0.55					