WATER CONTROL FOR RICE CULTIVATION IN SMALL VALLEYS OF WEST AFRICA

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1. Introduction

In many Sub-Saharan West African countries, self-sufficiency in rice decreased from almost 100% in 1950 to 60% in 1980. The shortage of rice and the large import of it has created official government interest in the intensified agricultural use of the small valleys in those countries. Of the small valleys of Sub-Saharan West Africa, those in the humid Equatorial Forest Zone and the sub-humid Guinea Savanna Zone (Figure 1) are suitable for the cultivation of rice. Of the total area of 2.2 million km^2 in these zones, about 10% consist of small valleys. This indicates a huge potential for rice production (Photo 1).

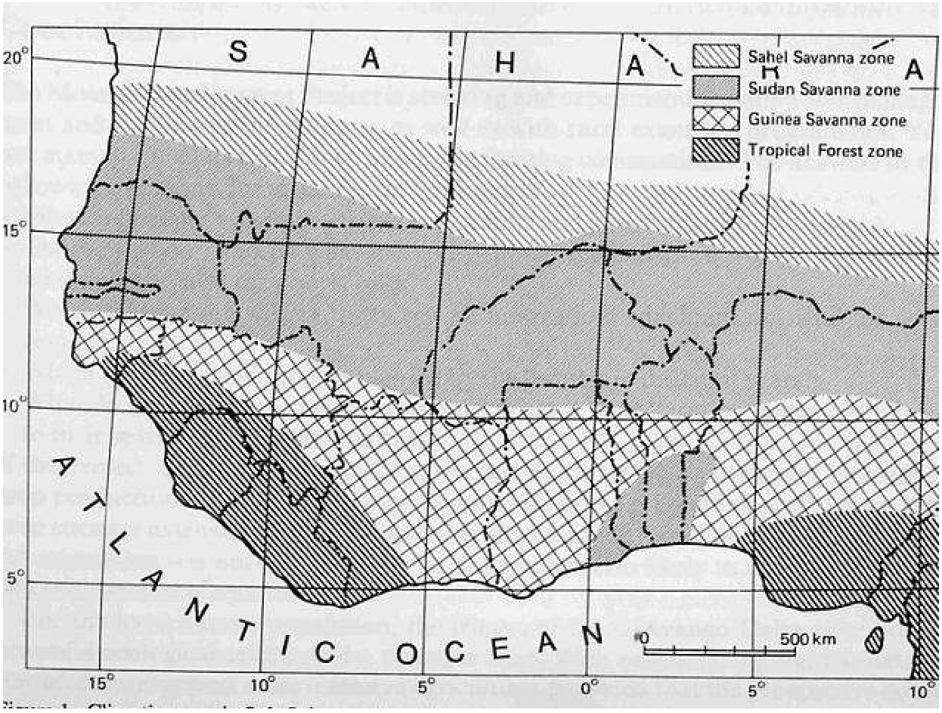


Figure 1. Climatic zones in Sub-Saharan West Africa

The farming families in Sub-Saharan West Africa already make intensive use of most of the small valleys, although the valleys form only a minor part (less than 10%) of the total area farmed by a family. The emphasis of the farming system is on upland cropping. Nevertheless, cultivation in the valleys is an important part of the system, producing rice and vegetables during the rainy season, and vegetable only during the dry season.

The present paddy yields are as a whole rather low (1.3 on/ha). The question arises: can the smallholder farms along the small valleys produce more rice? Answers to this question have to be sought in the mechanisms acting between:

1. – Government policies and farmers' attitudes;
2. – Marketing conditions and farmers' response;
3. – Constraints to agricultural input:, labor and farm economics;
4. – Agricultural intensification, and social or environmental disruptions.

Photo 1. A small valley, under rice, and its upland in the distance.

In view of the decreasing self-sufficiency, it is obvious that the mechanisms as they act at present are not geared to enhancing rice production. For example one may ask the question: *are the rice imports increased as a result of the reduced production or is rice production reduced as a result of the imports*? Hence, if more rice is to be produced, these mechanisms will require adjustments.

Among the technical adjustments that could be made is a better control of the water in the valleys. Whilst not claiming to give the final answer on how to grow more rice in the valleys, this article will discuss some possible ways to improve water control, because, without it, no production increase in productivity per ha is possible.

At present, the farming communities make the greatest use they can of the small valleys by adapting their agricultural practices to the environmental and hydrological conditions prevailing in the valleys. Whether it will be feasible to introduce, on a large-scale, water-control measures that will change these conditions and still result in greater yields will depend on other adjustments in other of the above-mentioned mechanisms.

2. Hydrological characterization of wetlands and small valleys

2.1 Wetlands

In literature, we have found no consistent definitions of the different types of wetlands and of the place that small valleys occupy within them. Feeling the need for a provisional classification, we therefore differentiate between the following wetlands:

1. – Tidal/coastal plains with salty water;
2. Coastal river plains: estuaries and lower delta's, with moving zones of salty and fresh water under the influence of tidal movements and varying river discharges;
3. – Inland tidal river plains: higher parts of the estuaries and delta's with zones of fresh water only, but still under the influence of the tides;

4. – River flood plains: large river valleys, upper parts of coastal delta's, inland delta's, with zones of fresh water under the influence of rainfall and river discharge only;
5. – Dish-shaped inland depressions without distinct river courses, the wetland regime being mainly determined by rainfall, incoming surface runoff, and evaporation;
6. – Small valleys (often called "small inland valleys", although the term "inland" is not strictly necessary, as they are always in the interior). A still better denomination would be "upper valley reaches". In this article, however, we will continue to use the traditional term "small valleys".

Hydrologically, wetlands can be characterized by the relative importance of the following inflow factors (Figure 2):
1. – Local rainfall retained in the wetlands;
2. – Surface runoff from the bordering uplands;
3. – Lateral seepage of groundwater from bordering uplands;
4. – Upward seepage of deep groundwater originating from uplands;
5. – Flooding by river water at high river stages;
6. – Flooding by tidal water (fresh or salt).

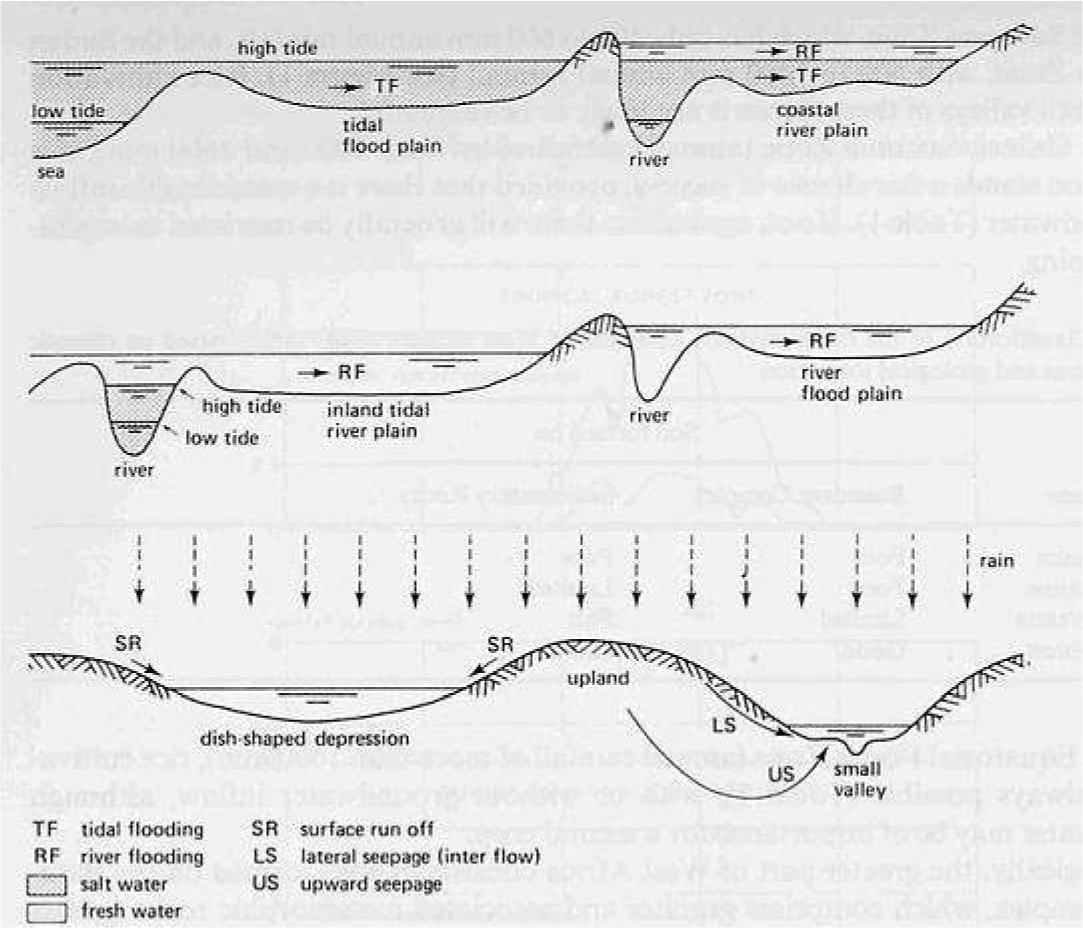


Figure 2. Water resources in wetlands

2.2 Hydrology of small valleys

Figure 3 summarizes the sources of water in a small valley where the traditional water management for rice (random small basins) is practiced. The figure shows the sources to be local rainfall and the upward seepage of groundwater, but that flooding and surface runoff also occur.

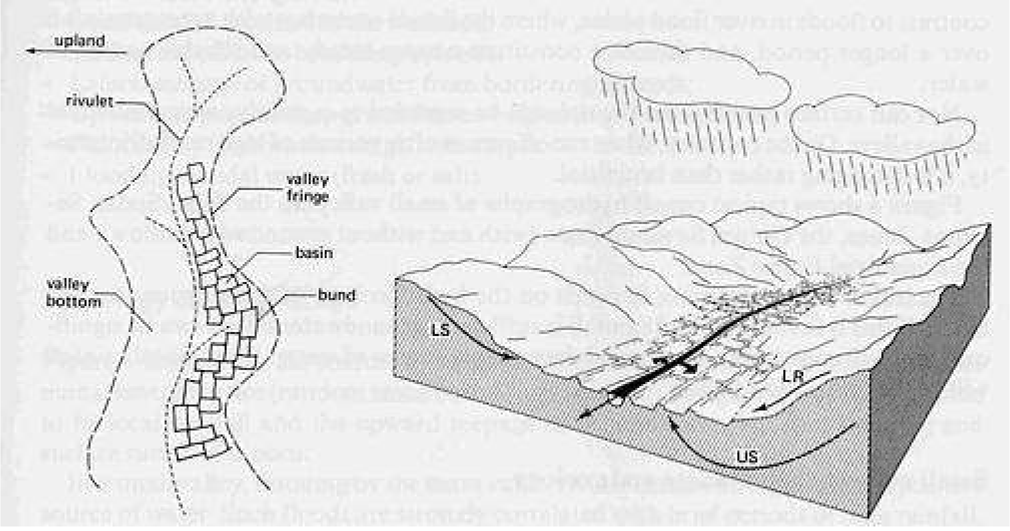


Figure 3. A small valley, with traditional random basins, and its water resources

In a small valley, flooding from the main valley rivulet cannot be regarded as a positive source of water. Such floods are strongly correlated with brief periods of high-intensity rainfall, and are therefore flashy, unreliable, and more of a liability than an asset. This is in contrast to floods in river flood-plains, where the flood correlate with average rainfall over a longer period, and therefore constitute a more steady and reliable source of water.

Nor can surface runoff from the uplands be regarded as a positive source of water in the valleys. On the contrary, when runoff occurs after periods of high rainfall intensity, it is damaging rather than beneficial.

Figure 4 shows typical runoff hydrographs of small valleys in the Sahel/Sudan Savanna Zones, the Guinea Savanna Zone (with and without groundwater inflow) and the Equatorial Forest Zone.

The inflow of groundwater depends on the hydrogeology of the surrounding uplands. If this is favorable and rainfall is sufficient, groundwater inflow can be significant and will constitute a steady and dependable source of water. If not, local rainfall will be the only important inflow factor.

2.3 Small valleys, their climate and geology

Inflowing groundwater will play only a minor role in zones with low rainfall, as in the Sahel Savanna Zone – which has only 400 to 600 mm annual rainfall – and in the Sudan Savanna zone with 600 to 1000 mm annual rainfall (Figure 1).

In the Guinea Savanna Zone (annual rainfall between 1000 and 1600 mm), rice cultivation stands a fair chance of success, provided that there is a considerable inflow of groundwater (Table 1). If not, agriculture will generally be restricted to vegetable cropping.

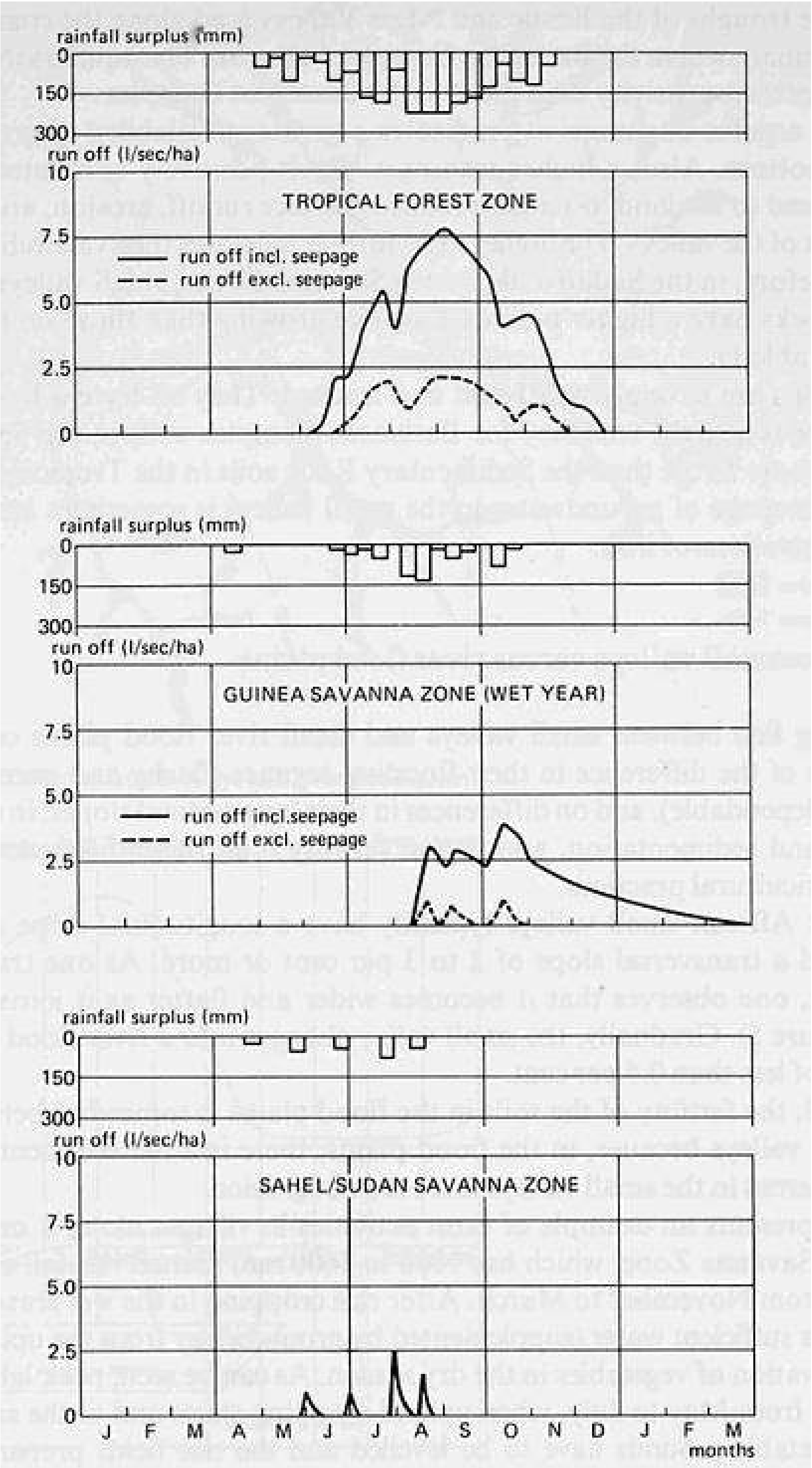


Figure 4. Typical stream-flow hydrographs of small valleys in various climatic zones, with or without groundwater inflow (seepage).

Table 1. Classification of the rice cultivation potential of West Africa's Sub-Saharan small valleys based on climatic zone and geological formation

	Soil formed on	
Climatic Zone	Basement complex	Sedimentary rocks
Sahel Savanna	Poor	Poor
Sudan Savanna	Poor	Limited
Guinea Savanna	Limited	Fair
Tropical Forest	Good	Good

In the Equatorial Forest Zone (annual rainfall more than 1600 mm), rice cultivation is always possible, with or without groundwater (table 1), although the groundwater may be of importance for a second crop.

Geologically, the greater part of Sub-Saharan West Africa consists of soils formed on the Basement Complex, which comprises granites and associated metamorphic rocks (gneiss and schists) of Pre-Cambrian age. The presence of highly transmissive aquifers in these regions is not likely.

A higher transmissivity (the product of hydraulic conductivity and depth of the aquifer) indicates a greater availability of groundwater to the valley-bottom. Also a higher transmissivity is positively correlated to a higher ratio of upland to lowland, because it reduces surface run-off, erosion and subsequent grinding out of the valleys. The higher ratio increases the availability of groundwater, as the catchment area is relatively larger. Therefore, in the Sudan and Guinea Savanna Zones, small valleys on the Sedimentary Rocks have a higher potential for rice growing than those on the Basement Complex, to compare the extremes.

All the soils are strongly weathered and leached. They all have a low fertility, although there is a slight tendency for the Basement Complex soils in the Sahel Savanna zone to be more fertile than the Sedimentary Rock soils in the Tropical Forest zone. The lateral seepage of groundwater into the small valleys is sometimes associated with toxic concentrations of iron.

2.4 Agriculture: small valleys versus river flood-plains

The dividing line between small valleys and small river flood-plains can be drawn on the basis of the difference in their flooding regimes: flashy and unreliable versus steady and dependable, and on the differences in their longitudinal slopes. In the processes of erosion and sedimentation, and in soil fertility – all these differences leading to different agricultural practices.

The small valleys of Sub-Saharan West Africa typically have a longitudinal slope of 0.5 to 1.5% and a transversal slope of 2 to 3% or more. As one travels down a small valley, one observes that it becomes wider and flatter as it joins other small valleys (Figure 5). Gradually, the small valley changes into a river flood plain, which has a slope of less than 0.5%

In general, the fertility of the soils in the flood-plains is somewhat better than in the small valleys, because in the flood-plains there is a net sedimentation of soil particles, whereas in the small valleys there is a net erosion.

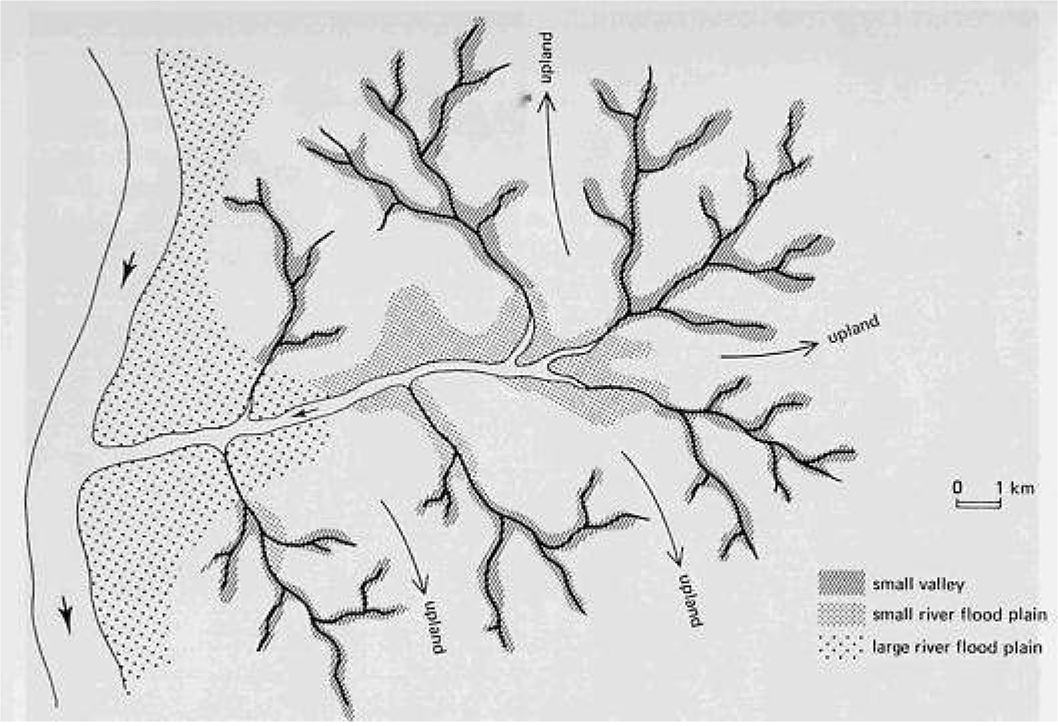


Figure 5. Delimitation of small valleys and river flood-plains

Figure 6 presents an example of farm activities in villages along a small valley in the Guinea Savanna zone, which has 1000 to 1600 mm annual rainfall and a distinct dry period from November to March. After rice cropping in the wet season, the small valley retains sufficient water (supplemented by groundwater from the uplands) to permit the cultivation o vegetable during the dry season. As can be seen in the figure, peak labor requirements occur from May to July, when upland cropping starts and at the same time the lowland vegetable mounds have to be leveled and the rice-fields prepared. Another period of peak labor occurs from November to January, when upland crops and rice are harvested and the mounds for lowland vegetable have to be made (Photo 2).

Photo 2. Mounds prepared for vegetable crops in a small valley

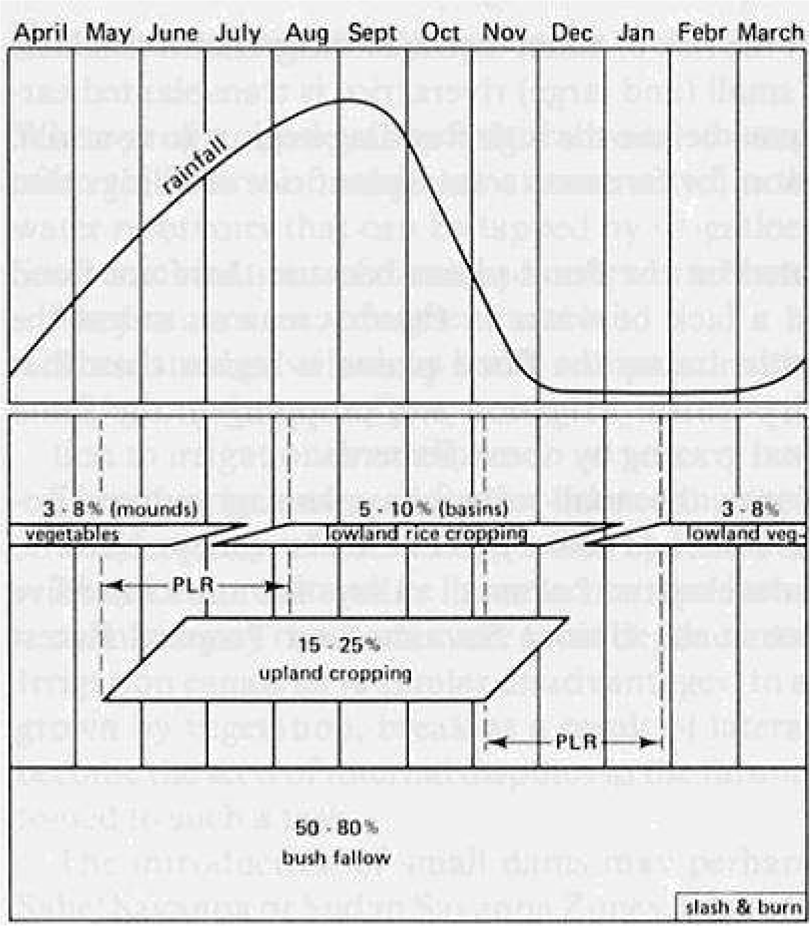


Figure 6. A cropping calendar

As upland cropping has the farmer’s priority, rice in the small valleys is usually transplanted rather late. As can be imagined, working in the swamps of the valley bottoms is arduous and carries with it the risk of water-borne diseases such as malaria and bilharzia. In the flood plains of small and large rivers, rice is transplanted earlier, because this work must be completed before the high flooding begins. In contrast, in the small valleys, it is not uncommon for farmers to transplant rice seedlings that are 3 to 4 months old.

Usually, vegetables are not cultivated on the flood plains because there are flood hazards during the rainy season and a lack of water during the dry season, unless the plains are irrigated. The irrigation potential in the flood plains is higher than that in the small valleys (Table 2), but dry-season irrigation and cropping in the flood plains could conflict with the traditional grazing by nomadic herds.

In the Sahel and Sudan Savanna zones, the small valleys have less agricultural potential than the flood plains (Table 2), because the small valleys have no dependable water supply. Hence, the development of small valleys for intensive rice cultivation stands a better chance in the Guinea Savanna and Tropical Forest zones than in the other two zones.

Table 2. Summary of the characteristics and agricultural potential of small valleys and river flood-plains

Characteristic	Small valleys	Flood plains
Land slope	> 0.5%	< 0.5%
Length of valley stream	< 10 - 25 km	> 10 – 25 km
Dominant source of water	Flooding	Local rainfall + Groundwater
Transport of soil	Net erosion	Net sedimentation
Soil fertility	Poor	Medium

		Agricultural potential	
Season	Zone	Small valleys	Flood plains
Rainy	Sahel+Sudan Savanna	Grazing Water reservoir	Grazing Flood-recession Cropping
Rainy	Guinea Savanna + Tropical Forest	Late rice Vegetables	Early rice (deep water rice)
Dry	Sahel+Sudan Savanna	Grazing Water reservoir Vegetables	Grazing
Dry	Guinea Savanna + Tropical Forest	Vegetables	Grazing Irrigated crops

3. Water-management systems

When people speak of agricultural water-management systems in small valleys, they often think first of small dams in the higher parts of the valleys to form water reservoirs that can be tapped by irrigation canals along the foot of the upland. Such combinations of dams and reservoirs, however, have certain disadvantages:
1. – They cause a loss of agricultural land;
2. – Their storage volume is small compared with the total volume of rainfall, runoff, and groundwater inflow; hence they do little to attenuate floods and their contribution to irrigation is small;
3. – They may be a source of water-related diseases;
4. – The creates problems of operation and maintenance;
5. – They cause costs to be incurred by the farming communities – costs, which they cannot repay or which make them dependent on external agencies.

Irrigation canals have similar disadvantages. In addition, they can easily become overgrown by vegetation, break as a result of lateral runoff, and their management may become the seed of internal disputes in the farming community, because it is not accustomed to such a task.

The introduction of small dams may perhaps be beneficial in some places in the Sahel Savanna or Sudan Savanna zones, where they could provide water for households (drinking, cooking, washing), for animals, and for garden crops. Irrigation canals would then not be needed. The water stored in the reservoirs, however, would probably not last the entire dry season, in which case the traditional system of manually dug wells may be more effective for such water supplies.

In the Guinea Savanna and Equatorial Forest zones, the combination of dams and irrigation canals does not seem necessary, because the rainfall is sufficient to permit the cultivation of rain-fed rice or vegetables during the dry season and, for reasons explained before, irrigation during the dry season would be largely confined to the river flood-plains.

It would thus appear that the water management in small valleys during the rainy season should primarily be a matter of on-farm water conservation and small-scale drainage control or flood protection.

For rice cultivation in small valley-bottoms during the rainy seasons, the following systems of small-scale water management have been indentified:

1. – The traditional random-basin system (widely practiced)
2. – The central-drain system (sometimes used in the humid tropics);
3. – The interceptor-canal system (not often applied);
4. – The head-bund system (sometimes applied in the Savanna zones);
5. – The contour-bund system (not often applied).

3.1 The traditional random-basin system

In the traditional water-management system for rice, small bunds divide the valley bottom and some parts of the valley fringes into approximately rectangular plots (Figure 3). Those bunds that run approximately parallel to the valley axis sometimes form an almost continuous (though not straight) line, which tends to follow the topographic contour lines. In general, however, the bunds give the impression that they have been made at random.

Within the plots, rice is transplanted on ridges of variable height. Sometimes the ridges are absent. Land leveling within the plots is of varying quality, but because the plots are in principle horizontal, they can be called level-basins. When necessary for water control, the bunds are opened to let water in or drain it off.

In the Equatorial Forest zone, where rainfall is plentiful, bunding is sometimes only rudimentary or not done at all, because water need not be conserved on the fields and drainage need not be restricted.

As the farmers have an intimate knowledge of the water regime in their rice plots and adapt their cultural practices accordingly, it will be difficult to develop and alternative water-management system that would be superior to the traditional system and at the same time attractive to the farmers. Also, the alternative system would have to be applied in conditions that vary from valley to valley. This makes it difficult to devise a standard system that would be generally applicable and effective.

3.2 The central-drain system

The central drain system (Figure 7) is sometimes applied in small valleys in the Equatorial Forest zone where rainfall is high (e.g. in Sierra Leone). The advantage of

this system is that the valley bottom is provided with an improved drainage outlet, so that the water levels in the rice fields, especially those near the central drain, can be controlled at a lower level. Possible disadvantages of the system are:
1. – The central drain may require a large cross-section, which constitutes a considerable investment and a loss of cultivable land;
2. – If there are no bunds around the rice fields, the drain may cause a shortage of water during dry spells or at the end of the rainy season;
3. – The drain may increase flood hazards downstream;
4. – The drain may require considerable maintenance, which would necessitate cooperation between the members of the different villages along the valley; there are indications that farmers are not ready to perform the required maintenance because apparently they do not consider the system an improvement. Photo 1 shows a central drain in which rice is planted!

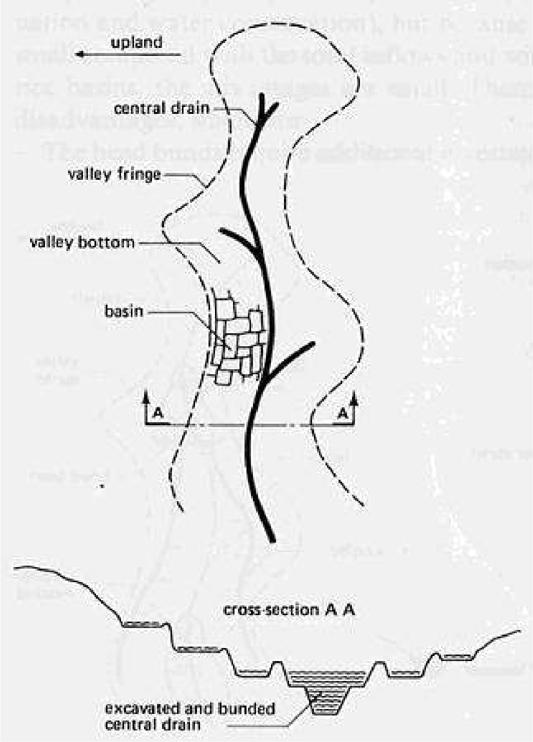
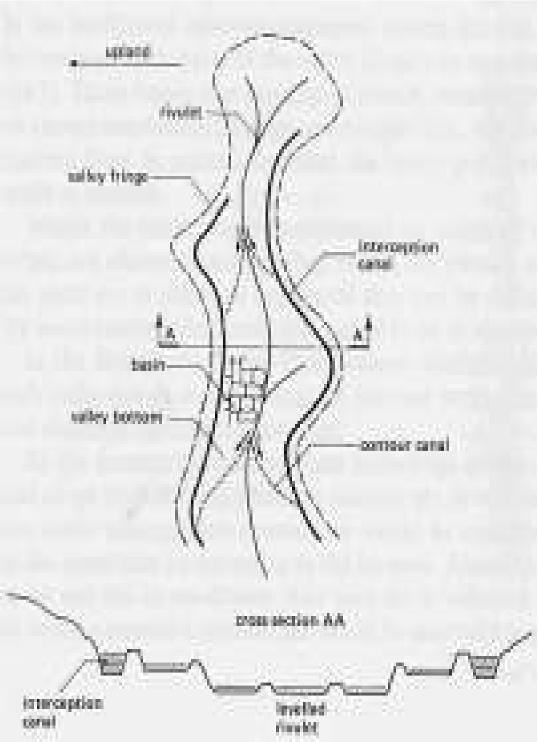
	

Figure 7. A central-drain system	*Figure 8. An interceptor-canal system*

3.3 The interceptor-canal system

The interceptor canal is a channel dug along the valley fringe (Figure 8). At regular intervals along the rivulet, contour drains lead the axial runoff from the rivulet to the canal. The canal also intercepts the lateral runoff from the uplands. Along the canal, take-off structures or small spillways distribute the water over the traditional rice basins.

During periods of high rainfall, the interceptor canal system distributes the water over the entire width of the valley. As a result, extra water is being conserved, axial runoff through the rivulet is reduced, erosion hazards are diminished, and floodings downstream decrease. Also, the paddy fields are better protected from any rapid inflow of water from the rivulet and from lateral runoff from the uplands. During dry spells in the rainy season, the interceptor-canal system can bring to the rice fields the base flow in the rivulet, which consists of the tail recession of the surface runoff and the continuous groundwater inflow.

On account of these effects, more rice fields than otherwise can be brought under cultivation and their yields are probably better. Disadvantages of the system may be:
1. – In dry years, the total runoff will be small and the extra gain of water may be insignificant;
2. - In wet years, the extra conservation of water in the rice fields may be unnecessary and the system loses its significance;
3. – The drains and canals require frequent maintenance, which may not be acceptable to the farmers;
4. – The distribution of water over the spillways of the interceptor canal and into the traditional rice basins requires careful management by the farmers, who may not be in a position to provide it;
5. – The contour drains and the interceptor canal cause a loss of land;
6. – There is a risk of landslides along the interceptor canals.

3.4 The head-bund system

In the head-bund system, a series of head bunds are built across the rivulet, so that behind the bunds the water level in the rivulet is raised and small storage reservoirs or ponds are created (Figure 9). Contour canals lead the water from the reservoirs to the valley fringes. Further, the head-bund system works in much the same way as the interceptor-canal system. The characteristics, advantages, and disadvantages of the two systems are therefore much alike, the main difference between the two being the presence of the ponds.

Hydrologically, the pond may have a few advantages – such as flood attenuation and water conservation – but because the storage of water in the ponds is very small compared with the total inflows and with the storage facilities in the traditional rice basins, the advantages are small. There are however, a number of disadvantages:
1. – The head bunds require additional investment, maintenance and operational care;
2. – The ponds behind the bunds may silt up
3. – During periods of peak discharge in the rivulet, the head bunds may erode and collapse
4. – The ponds cause extra loss of land
5. – The ponds may be a source of water-related disease.

There are indications in some valleys in the Sudan and Guinea Savanna zones that the farmers do not maintain the head-bund system as would be technically desirable. Perhaps the system does not yield them sufficient benefit to offset the additional labor required for its upkeep. Also, the ponds may give rise to clashes between the villagers and the roaming cattle herdsmen attracted to these ponds.

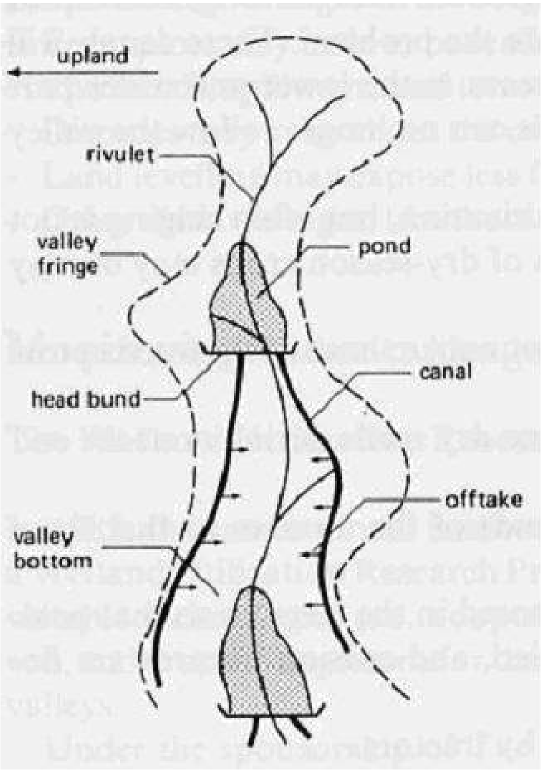


Figure 9. A head-bund system

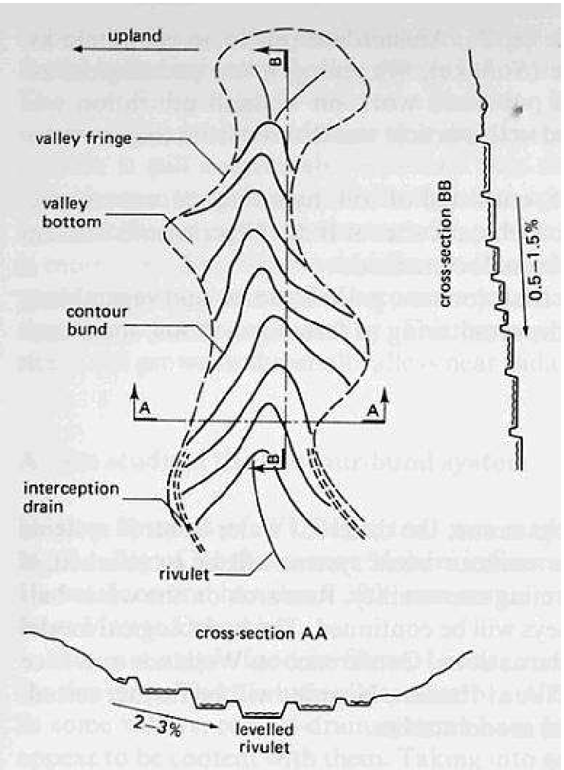


Figure 10. A contour-bund system

3.5 The contour-bund system

The contour-bund system consists of a number of bunds laid across the valley rivulet, following from there the contour line of the valley (Figure 10). Parallel to the bunds, the soil surface is horizontal. Perpendicular to the bunds some land leveling may be required. One thus obtains flat, terraces parcels. The rivulet will have disappeared. The bunds are spaced at a distance corresponding to the usual width of the traditional rice basins or somewhat wider, depending on the longitudinal slope, the amount of land levelling required, the exposure of infertile soil by this levelling, and the water depth needed on the field.

To drain the terraces at the end of the growing season so as to promote the ripening of the crop and to facilitate harvest operations, each terraced parcel is provided with an outlet or spillway to the next parcel. These outlets also prevent the occurrence of high water levels during periods of high rainfall. If, in the downstream parcels, the flow from terrace to terrace becomes to great or lasts too long, interceptor canals can be dug along the valley fringes to alleviate the problem. The canals will ultimately carry the drainage water to the main stream in the lower and wider part of the valley, where other valleys join and the canals can no longer follow the valley fringes. In the terraces the land may be ridged for rice cultivation, but often ridging is not needed. Also temporary mounds for the cultivation of dry-season crops may or may not be formed between the bunds.

The advantages of the contour-bund system are:
1. – Water can be conserved in the terraces to overcome dry spells during or at the end of the rainy season
2. – More water can be diverted towards the fringe ends of the terraces so that these can become more productive
3. – During rainy periods, water can be temporarily stored in the terraces so that peak runoffs are reduced, floodings are better controlled, and erosion hazards are decreased
4. – The land levelling can be done by oxen traction or by tractors.

Possible disadvantages of the contour-bund system are:
1. – Farm plots may have to be re-allocated
2. – The bunds, spillways, and terraced fields have to be maintained
3. – Disputes may arise about the overflow levels of the spillways
4. – Land leveling may expose infertile soil
5. – Other disadvantages, like those of the interceptor-canal system may exist.

4. Monitoring water-management systems

4.1 The Wetland Utilization Research Project (WURP)

In 1982, the International Institute of Tropical Agriculture (IITA) in Nigeria started a Wetland Utilization Research Programme (WURP). WUR's objective is to develop suitable technologies (i.e. adoptable within the existing farming systems) of water, soil and crop management for the more intensive utilization of the West African small valleys.

Under the sponsorship of the Netherlands Directorate General for International Cooperation (DGIS), WURP is being assisted by ILRI (on water management aspects), the Royal Tropical Institute (KIT) on socio-economic aspects, and by the Soil Survey Institute (STIBOKA) on pedological aspects. Under Phase I, an inventory of published work on wetland utilization was completed. Much of the information used in this article was derived from that inventory.

Phase II, which was launched in 1985, consisted of soil, hydrological, agronomic, and socio-economic surveys of selected benchmark sites in Bida (Nigeria) and Makeni (Sierra Leone). These surveys have also been documented.

Phase III will include crop-husbandry trials (on rice, grain, legumes, and vegetables), water and soil management trials, and the monitoring of farming systems, socio-economics, and hydrology.

4.2 Hydrological monitoring

Under the hydrological monitoring programme, the different water-control systems described earlier will be monitored. The contour-bund system will be established, if possible with the cooperation of the farming community. Research on the water balances of the bunded rice fields will be continued. The hydrological model presented by Gunneweg (1985) at the International conference on Wetlands and Rice in Sub-Saharn Africa, organized by IITA at Ibadan, Nigeria, will be further tested. Table 3A and 3B present some results of the model studies.

Table 3A Some results of the hydrological model studies

General Rainfall-runoff studies	Total rainfall (mm)	Ratio of upland to lowland	Average runoff (l/s/ha)	Runoff duration *) (days)
Bida (wet year)	1600	20	1	200
Bida (dry year)	800	20	0	0
Makeni (wet year)	3600	4	4	225
Makeni (dry year)	2800	4	2	175

*) from rice fields with 15 cm bunds, including groundwater contribution

Table 3B Number of days with fully saturated soil in bunded rice fields

	Groundwater contribution	Probability of exceedance (%)			
		50	80	90	95
Bida	included	210	90	9	0
Bida	excluded	80	40	9	0
Makeni	included	280	250	235	225
Makeni	excluded	230	205	195	185

As can be seen from the tables, the quantity of groundwater contributed to the moisture content of the rice fields is much more pronounced in Bida than in Makeni. This is because the aquifers near Bida are larger and have a higher transmissivity, being found in Sedimentary Rocks, whereas thos in Makeni are in the Basement Complex. The runoff duration in Bida in a wet year is nearly the same as in Makeni and it is even higher than in Makeni in a dry year, although the rainfall during a wet year in Bida is still considerably less than during a dry year in Makeni. Similarly, it can be seen that during a wetter than average year in Bida (probability of exceedance less than 50%) the number of days with fully saturated soil in bunded rice fields is more than 200, not much different from the number of days in Makeni. In a dry year, however, this number becomes very small for Bida, indicating that rice cultivation there will be unrewarding. This corresponds with observations that, in dry years, rice is not grown in small valleys near Bida.

4.3 A case study of the contour-bund system

During Phase II of WURP, a trial was made with the contour-bund system in the small valley of Rogbom, near Makeni, Sierra Leone. The valley lies in the Equatorial Forest Zone and has about 3000 mm annual rainfall, but the rainy season is restricted from May to December.

Rice is a staple food in Sierra Leone, and the small valleys are intensively used for this crop. There is little water control and even the random-basin system is absent. In some valleys, central-drain systems have been introduced, but the farmers do not appear to be content with them. Taking into account that the valley swamps presently contribute about 50% of Sierra Leone's total rice production and that 33% of the rice consumed is imported, continued experimentation with water-management systems in the small valleys would appear to be justified.

In discussion with farmers during field visits, we identified the following constraints to rice cultivation:

- Inefficient use of available water
- Poor soil fertility
- Rice diseases
- Pests (birds, monkeys, rodents)
- Weeds
- Iron toxicity
- Scarcity of labour

It was observed that rice yields in the central, wettest, part of the valley were much higher than those in its drier fringes (Table 4). This suggested that it would be worthwhile to study whether yield in the fringe lands could be increased bu introducing the contour-bund system to spread the water over the width of the valley. Not only would this practice increase the water availability in the fringe lands, it might also result in an improved control of pests (e.g. the cutting-grass, a small rodent), weeds, and iron toxicity.

Table 4. Rice yield (paddy) of sample plots in the 1985/86 season (kg/ha)

Cross-Section	West fringe	Centre	East fringe	Average
1	316	2408	833	1185
2	817	1629	150	865
3	455	836	462	585
4	823	2439	265	1175
Mean	603	1828	428	953

During the dry season of1986, five contour bunds were made, covering an area of 1.5 ha. Each bund was 40 cm high and 60 cm wide at the base, and 40 cm wide at the top. Table 5 summarizes the costs of bund construction. The difference in elevation between the successive bunds was 10 cm. Thus a cascade of terrace was created. Outlets with a crest height of 15 cm were made in the bunds near the rivulet. In this small experiment, the rivulet could not be eliminated, but in a larger experiment in which the bed of the rivulet can be leveled (Figure 10), the outlets can be constructed more towards the fringes.

During the 1986 growing season, it was proved that when the outlet gate was removed, the ponded water between the bunds could e drained in three days. After the gate had been replaced, the water could be ponded again in two days. This gives the farmer a certain control over the water level in his parcel, so that he can prepare the soil at his convenience and not when the rainfall dictates it. Further, it enables him to weed more efficiently and to apply fertilizer directly to the soil instead of it being dissolved and possibly washed away.

Monitoring of the water levels in the terraced fields has shown that during the growing season the levels vary only a few centimetres, whereas outside the bunded fields they vary as much as 20 to 40 cm.

Table 5. Construction costs of the contour bunds

Activity	Man-days	Costs in Le
Surveying, pegging and supervision (costs borne by WURP)	-	-
Cutting bunding material	2	20
Constructing reinforcements	5	50
Earth moving	10	100
Spillways	5	50
Finishing	2	20
Total	24	240

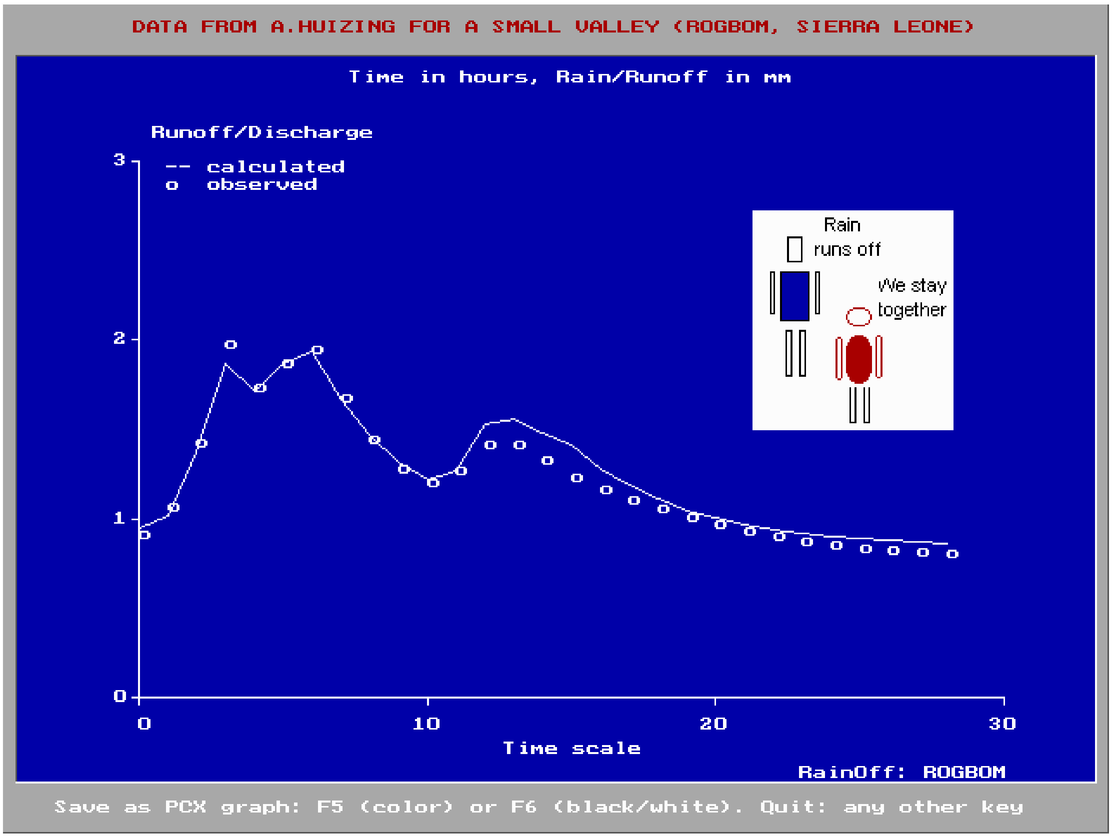
At the time of construction, an unskilled labourer earned Le per day at the nearby gold mines. This wage formed the basis of the conversion of man-days to Le in Table 5. The official exchange rate was 5 Le to U.S. $ 1.

The bunds cost Le 160 per ha. If the increase in rice yield is only 20% (Table 4 suggests hat a higher possible increase), this corresponds to an increase of 200 kg paddy per ha, or 40 kg milled rice per ha. At current market prices, this would amount to Le 216 per ha.

In view of the favourable ratio between expected yield increase and construction cost, a continuation of the water-management trials and the monitoring programme can be recommended.

4.4 Annex: Simulation of rainfall-runoff relation

With the RainOff program, free download from http://www.waterlog.info/rainoff.htm the rainfall runoff relation in the Rogbom valley near Makenni was simulated using a non-linear reservoir. The result is shown in the figure below.



DATA FROM A.HUIZING FOR A SMALL VALLEY (ROGBOM, SIERRA LEONE)

Save as PCX graph: F5 (color) or F6 (black/white). Quit: any other key