DEPARTMENT FOR INTERNATIONAL DEVELOPMENT

STRATEGY FOR RESEARCH ON RENEWABLE NATURAL RESOURCES

NATURAL RESOURCES SYSTEMS PROGRAMME

FINAL TECHNICAL REPORT

DFID Project Number

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Project Title

Development of improved cropping systems incorporating rainwater harvesting/conservation

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Organisation

University of Newcastle upon Tyne
in collaboration with
Sokoine University of Agriculture and
Ukiriguru Agricultural Research Institute

NRSP Production System

Semi-arid

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1. Background

1.1 Context and Justification

The links between poverty and environmental degradation pose a real challenge to any attempt to promote sustainable development in semi-arid Africa. Initiatives to improve management of soil and water offer the means to reverse both processes and should be considered as a key element of any strategy for sustainable livelihoods. Although the project began before the adoption by DFID of the sustainable livelihoods framework, it can be seen that the focus of the project on developing improved cropping systems incorporating rainwater harvesting (RWH) is consistent with this approach. See Box 1.

Box 1: Potential contribution of SWC to sustainable livelihoods

Outcome	Possible contribution of SWC
More income	Increase in water availability allows production of cash crops
Reduced vulnerability	Reduces risks associated with low and erratic rainfall
Improved food security	Improved soil and water management leads to higher yields
Increased well-being	Group approaches to SWC allow development of social and human capital
More sustainable use of the NR base	On-site and off-site benefits

Source: Boyd & Turton, 2000

The terminology that exists in the literature can be confusing, therefore it is necessary to define the key concepts as they have been applied to this project. RWH can be defined as the process of concentrating rainfall as runoff from a larger catchment area to be used in a smaller target area. There are many examples in the literature of attempts to develop a typology of RWH techniques (see for example Box 2). We can identify a continuum of techniques that links in-situ soil-water conservation (SWC) at one extreme to conventional irrigation at the other extreme. These techniques and evidence for their use in semi-arid Tanzania are reviewed by Gowing et al. in Annex 1, paper 4. In principle, RWH can be distinguished from SWC in that it involves spatial separation between the runoff producing area and the runoff receiving area. Likewise, it can be distinguished from irrigation in that the target area is contiguous with the catchment area and that the application to the target area is essentially uncontrolled (both in rate and time).

Although there are numerous documented examples of ancient RWH practices, modern scientific interest is very recent. In sub-Saharan Africa particularly, it can be argued that RWH occupies the knowledge gap between the two extremes that have previously received far greater attention. In a review of soil & water management research in semi-arid areas of

Southern and Eastern Africa, Morse (1996) identified only 15 references to RWH in a total of 500 sources. On one hand, widespread concern over land degradation led to a focus on soil tillage and erosion control that began during the colonial era. On the other hand, efforts to exploit water resources led to a focus on irrigation. The middle ground of RWH has been largely neglected, but arguably represents the best prospect for sustainable intensification and improved livelihoods for the vast majority of dry-land farmers.

Box 2: Typology of RWH for Agriculture (after Prinz,1994)

The research context in Tanzania is reviewed by Mahoo et al, Rwehumbiza et al, Hatibu et al and Gowing et al in Annex 1, paper 1-4. The project is seen as relevant to the needs of the arid and semi-arid zones, which occupy the broad central belt running North-South between the coastal zone (800 - 2000mm annual rainfall) and the elevated Western and Southern plateaux (800 - 1300mm annual rainfall) as shown in Map 1. Within the arid and semi-arid zones, rainfall is typically low (500 - 800mm) and erratic. Nevertheless, some parts have relatively high population density (30 - 70 persons per km^2) as shown in Map 2. Recent research based on in-depth case studies in Kenya (Tiffen et al, 1994) and Nigeria (Mortimore,1993) has indicated that population growth and agricultural intensification may be accompanied by improved rather than deteriorating environmental quality. Since both of these cases relate to semi-arid environments, the question arises: i*s the experience replicable in semi-arid Tanzania?* The two target areas were selected with this question in mind.

The Western Pare Lowlands target area (WPTA) comprises parts of Mwanga and Same districts on the Western flank of the Pare mountain range extending down to the Pangani river. The lowlands fall within the Massai steppe agro-ecological zone, which is characterised by rolling plains with reddish sandy clay soils of relatively low fertility formed on basement complex rocks. Annual rainfall is in the range 500 to 800mm with bimodal pattern. Both districts also include high potential uplands, which are experiencing population pressure. This together with good communications links and employment opportunities in the sisal estates has promoted recent population shifts into the lowlands. Attempts to promote adoption of drought-resistant sorghum have been resisted and there is a strong preference for maize production.

The Lake Zone target area (LZTA) in Maswa district lies in the North of Shinyanga region and is part of the Sukumaland socio-cultural zone, which extends over a large part of North-western Tanzania bordering Lake Victoria. It falls within the extensive central semi-arid agro-ecological zone, which is characterised by gently undulating plains with long slopes to wide valley bottoms. Annual rainfall is in the range 600 to 900mm and is weakly bimodal, such that the season is relatively long with a tendency to split. The land-use pattern, as depicted in Figure 1, is linked to the recurrent topo-sequence of soils, known as the Sukumaland catena and first described by Milne (1936). During the colonial era and continuing into the 1980's cotton was actively promoted together with other drought resistant crops (sorghum, cassava), but farmers have a marked preference for maize and rice as dual-purpose crops. The rain-fed rice cropping system in Sukumaland contributes 35% of total rice production in Tanzania and depends upon RWH techniques involving bunded field known as "majaluba" (see photographs). This system has been adopted apparently spontaneously throughout the area without intervention by NARS research or extension services. There is clear evidence that the system is actively expanding, not only in Shinyanga region, but also throughout the central semi-arid zone.

Figure 1: Sukumaland catena and typical land-use pattern (after Ngailo,1994)

INSERT PHOTOGRAPHS OF MAJALUBA SYSTEM IN LZTA

1.2 Previous Research

DFID funded research into RWH in Tanzania began in 1992 as a collaborative venture between Newcastle University (UNEW) in UK and Sokoine University of Agriculture (SUA) in Tanzania. The primary responsibility of UNEW (under project R5170) was to develop a computer model of the key processes in the RWH cropping system. This work was documented in an interim report (Gowing et al, 1992), two end-of-project reports (Gowing & Young, 1996; Young & Gowing,1996) and numerous working papers. The primary responsibility of SUA (under project R5752) was to conduct researcher-managed field experiments in Tanzania and other complimentary investigations. This work was documented in two interim technical reports (Hatibu et al, 1993 & 1995) and in a separate end-of-project report (Hatibu et al, 1997).

Experimental fieldwork was executed at three sites; Kisangara (Mwanga), SUA campus (Morogoro) and Hombolo (Dodoma). The main site was at Kisangara (in the WPTA). There was no work in the Lake Zone in the first phase of the project. Three main experiments were set out on the Kisangara site:

- The runoff measurement experiment was designed to provide data on runoff response from a small catchment area representative of within-field micro-catchment RWH systems. This was a plot experiment involving combinations of three factors (not replicated): two plot sizes, two plot slopes and four surface treatments.
- The runoff farming experiment was designed to provide data on crop response to varying levels of enhanced water supply derived from an adjacent catchment. The crop was maize in a pure stand. This was a similar experiment involving three factors (replicated): four catchment sizes, two plot slopes and two tillage treatments.
- The soil/water conservation experiment was designed to investigate the effect of in-situ moisture conservation and involved five treatments (replicated); zero tillage, flat cultivation, contour ridges, stone bunds and live barriers.

The site layout can be seen in the photograph, which also shows two additional plots, which were included to demonstrate small external catchments (known as the caag system).

In addition to supporting the field experiments, work at Newcastle focused on development of a process-based computer model. This was seen as a tool to add value to the costly, laborious and time-consuming field experiments. The model was intended to permit extrapolation over a much longer time period by using long-term weather data. Also, the model was intended to permit evaluation of likely performance at other sites by using soils data.

From the outset, development of the model was linked to a separate modelling initiative at the university of Nottingham, which produced the PARCH crop model for simulating growth of sorghum, maize and millet. In order to improve the model's ease of use, a graphical user interface was provided together with other ancillary tools:

- A climate generator allowed for filling gaps in weather data and estimating values for missing parameters;
- A pedotransfer function routine allowed for estimating hydraulic properties of soils using readily available soil physical properties.

The model was validated for maize cropping systems using within-field micro-catchment RWH. Data used for this exercise were obtained from the runoff experiments at Kisangara and Morogoro sites. Satisfactory performance in simulating daily runoff was demonstrated, however, a number of limitations of the model were noted (Gowing & Young, 1996 p.68). In particular, it was noted that up-scaling to deal with external (macro)-catchment RWH systems would require further work to extend and modify the way in which the runoff processes are modelled.

Computational experiments were conducted using the model to simulate performance of the RWH system for conditions representative of the WPLL target area over a 30 year period. It was shown that little yield benefit was obtained in most Masika seasons, but a clear benefit was obtained in approximately half of the Vuli seasons. Nevertheless, consultations with farmers visiting the Kisangara site indicated that they were reluctant to adopt micro-catchment systems and preferred instead to adopt macro-catchment RWH.

INSERT PHOTOGRAPHS OF KISANGARA SITE

Map 1: Land Resource Zones in Tanzania

Map 2: Population and Administration in Tanzania

2. Project Purpose

The current project should be seen as a second phase of the original RWH project. The stated purpose remains essentially the same for both phases:

> *Improved techniques for rainwater harvesting and water conservation developed and promoted.*

The current project aimed to continue and extend the earlier work in several directions:

- the researcher managed experimental work in the original Western Pare target area to be continued and extended to include new work on larger catchments and farmer-managed experiments;
- much of the new off-station experimental work to be directed to improving understanding of farmers' practices and complemented by investigation of factors influencing adoption of RWH innovation;
- transferability of the approach to be assessed in a new target area in the Lake Zone involving collaboration with Ukiriguru Agricultural Research Institute (UARI);
- the existing simulation model to be further developed to include new functionality and simulation studies to be extended;
- the biophysical simulation model to be embedded within a broader decision support framework incorporating other socio-economic factors affecting adoption.

Significant shifts of emphasis compared with earlier work were towards more on-farm experimentation, more farmer participation, consideration of external catchment RWH systems and closer links with NARS and NGO's.

Recognising that farmers in the semi-arid areas of Tanzania already possess some knowledge of SWC/RWH practices and are to varying extents already attempting to adapt their farming systems, the main issue of concern was how to provide effective technical support. Phase 2 activities were therefore directed towards finding answers to the following questions:

- what are the technical constraints on successful promotion of improved cropping systems involving RWH?
- what are the factors influencing farmers' decisions on adoption of RWH?
- what are the needs of NARS research/extension staff in providing technical support and promoting RWH?

3. Research Activities

3.1 Introduction

The research activities conducted under the current phase of the project are discussed within this section. All activities in Tanzania were conducted in close collaboration with in-country counterparts. The lead in all fieldwork in Western Pare target area was taken by SUA, while the lead in all fieldwork in Lake Zone target area was taken by UARI. Both collaborating institutes provided valuable facilities and expertise without which the project activities could not have been delivered.

All planned inputs were achieved. Additional inputs through closely related initiatives have also contributed to the thrust and impact of the research, specifically:

- EU-funded research in the Lake Zone provided an opportunity for in-depth investigation of soil hydrology and indigenous knowledge of soils;
- DFID-funded policy research in collaboration with ODI provided an opportunity for in-depth investigation of policies and structures which influence RWH practices;
- SIDA funding permitted preparation of a comprehensive planners' manual on RWH incorporating case studies.

Some minor modifications to the original workplan have previously been reported in two interim progress reports and have been reflected in the revised logical framework. The only significant deviations from the current (April 1999) version relate to activities 1.5, 4.1 and 4.2, which are all concerned with training activities. They have not been achieved because of resource constraints, as they were dependent upon additional funds being obtained from other sources. It is hoped that they will take place as future dissemination activities.

3.2 Workshops & Conferences

3.2.1 Same Workshop

A workshop was arranged at Same (WPTA) in August 1997 to review farmers' needs with regard to RWH uptake and extension workers' requirements in meeting those needs. Specifically, this involved:

- assessing the extent of knowledge of RWH amongst extension workers at village and district levels;
- identifying and ranking the constraints faced by both farmers and extension workers by formulating a problem tree;
- identifying possible solutions and how these can be implemented.

The participants were drawn from Mwanga (WPTA) and Maswa (LZTA) and included district extension officers, district subject matter specialist (crops) and district irrigation officer, as well as those involved with the project.

Through discussions and field trips, it emerged that extension worker knowledge of RWH techniques is severely limited. Extension activity in the two areas concentrates on a narrow range of techniques mainly oriented towards soil conservation. There is a preoccupation with directing runoff away from crops since it is seen as a hazard rather than as a resource. Participants developed a problem tree by identifying successively more fundamental causes of the problem of low use of RWH. The constraints were then ranked as follows:

Farmer constraints	**Extension constraints**
1. Lack of technical knowledge of RWH	1. Lack of training in RWH
2. Lack of secure land tenure	2. RWH not included in district plans
3. Lack of capital	3. Lack of equipment (eg. surveying)
4. Insufficient labour	4. Lack of transport and incentives
5. Crop-livestock conflicts	
6. Unavailability of runoff source	

A full report on the workshop was prepared and distributed as a working paper. A Kiswahili translation was also prepared and distributed to participants.

3.2.2 Maswa workshop

A workshop was arranged at Maswa (LZ TA) between 30th March to 1st April 1998 to review farmers' needs with regard to RWH uptake and extension workers' requirements in meeting those needs. Specifically, this involved:

- assessing the extent of use of RWH by farmers;
- assessing the extent of knowledge of RWH and involvement amongst extension workers at village and district levels;
- identifying and ranking the needs and constraints of farmers and extension workers ;
- identifying possible solutions and follow-up activities.

The participants included 8 farmers, 9 village executive officers, 11 extension workers and 4 researchers.

The findings of the PRA, which had been conducted earlier in 6 villages of Maswa district, provided a basis for discussion. It was agreed that RWH for rice production is widely practised in the target area, but lack of technical know-how limits the effectiveness. Extension workers are neither trained nor equipped to provide effective technical assistance. A ranked list of constraints is reproduced in Table 2.

The main recommendations of the workshop were that technical training was required and that there was a need to establish village-level structures to coordinate resource management and reduce conflict over access. A full report on the workshop was prepared and distributed as a working paper. A Kiswahili translation was also prepared and distributed to participants.

Table 2: Constraints identified by Maswa workshop participants

3.2.3 Arusha workshop

In order to promote dialogue with NARS scientists a workshop was held in Arusha at an early stage in phase 2 (during February 1998) involving 27 researchers and research managers. Delegates were drawn from various parts of the NARS in Tanzania (including Zonal Directors from Lake, Central and Northern zones) and from Kenya, Uganda and Zimbabwe. Discussions were focussed on the following:

- impact of research on RWH and SWC practices;
- experiences of participatory approach to research;
- role of modelling in the research-extension continuum.

The response of the delegates was encouraging in that the project was seen to be making valuable contributions at two levels. Firstly, by developing strategies for improved land husbandry in two contrasting farming systems; secondly, by developing tools and methodologies with wider implications for improving the effectiveness of the research-extension continuum in relation to land husbandry practices.

Specific recommendations of the workshop were as follows:

1. RWH should be seen as part of the continuum of soil-water management techniques.
2. Within the semi-arid areas of Tanzania, covering the Northern, Central and Lake Zones, soil-water management research is a high priority.
3. Research scientists from the zonal agricultural research institutes should be actively involved in the programme.
4. The model should be introduced into the zones, with UARI leading on rice, SARI leading on maize and Central Zone leading on sorghum.
5. The model should include a socio-economic dimension in view of the influence on adoption.
6. Some adoption studies regarding technologies on wheat, dairy, maize and beans have been done or are in progress. These should be studied and results incorporated.
7. Further adoption studies are required in order to improve understanding of farmers' perceptions and objectives.
8. Extension service staff have a narrow knowledge on soil conservation and lack skills and awareness in SWC and RWH.
9. Training of extension staff and NGO's in RWH techniques should be carried out through district level and zonal level workshops.
10. A strategy for marketing outputs from research is needed in order to spread the message to farmers.

3.2.4 Harare workshop

A workshop devoted to discussion of RWH was held as a special session of the scientific conference of the Southern & Eastern African Society of Agricultural Engineers (SEASAE) in Harare towards the end of phase 2 in September 1999. This provided an opportunity to expose project findings to a wider audience with the following objectives:

- to obtain comments on adoption of RWH techniques in the rest of the region;
- to explore important factors which influence adoption;
- to consider tools that should be developed to help extension services;
- to consider priorities for future RWH research in the region.

A booklet containing three discussion papers was distributed to all participants:
- A review of RWH techniques used in the semi-arid areas of Tanzania
- Actions taken to tackle the problem of transferability
- PARCHED-THIRST- a tool for technology transfer

These were presented in plenary session and discussed by participants.

The workshop delivered the following recommendations for promoting adoption of RWH:
- Hudson (1991) factors influencing success or failure of soil conservation projects provide a guide to best practice;
- Interventions should be build upon existing knowledge and practices, which requires consideration of farmers' capacity, perceptions and priorities;
- Farmers should be involved in assessment/evaluation of technology and cultural preferences should be studied;
- Development of new technology with farmers requires dialogue over an extended time and does not easily fit the short-term project cycle;
- Projects are likely to target the poor, but the poorest of the poor are in no position to innovate;
- There is a need to establish links between researchers in various countries and from various disciplines.

A separate document containing the discussion papers and proceedings was prepared as a working paper.

3.2.5 Morogoro workshop

A project workshop was held in Morogoro between 13th and 15th October. It was attended by 26 participants, who were drawn from both WPTA and LZTA. These included mainly district-level planning and extension officers. The purpose was to explore the constraints on effective utilisation of rainwater in semi-arid areas of Tanzania and to review the findings of the RWH research project.

Four discussion papers were presented in order to provide background for discussions:
- A review of RWH techniques used in the semi-arid areas of Tanzania
- Issues identified by farmers and extension workers
- Research methodologies and results
- Decision support systems - tools for technology transfer

A problem tree was developed and subsequently reformulated as a project outline with the following purpose statement:

Productivity of water in rain-fed agriculture increased through accelerated adoption of rainwater harvesting.

This was then developed into an outline logical framework for a district-level project. Six outputs were identified and through pair-wise ranking it was agreed that the highest priority was considered to be development of effective approaches to promoting RWH. This exercise provided further confirmation of the perceived knowledge gap.

A separate document containing the discussion papers and proceedings was prepared as a working paper.

3.2.6 Morogoro Conference

An end-of-project scientific conference was held in Morogoro on 22nd and 23rd November 1999. Participants were drawn from various departments within SUA, from various NARS institutes in Tanzania, Uganda and Kenya, from various government departments within Tanzania, and from NGO's. The purpose of the meeting was to present the findings of the RWH research project for scientific and technical scrutiny amongst an expert group.

A total of 13 discussion papers were presented under four sub-themes:

Sub-theme 1:	Vulnerability of agricultural production in drylands
Paper 1:	Rainfall variability and drought
Paper 2:	Land characteristics, runoff and erosion
Sub-theme 2:	Critique of past research and development efforts
Paper 3:	Policies and strategies for soil & water conservation
Paper 4:	Relevance of research to poor farmers in semi-arid areas
Sub-theme 3:	Research methodologies and results
Paper 5:	RWH techniques
Paper 6:	Research into in-situ SWC
Paper 7:	Research into micro-catchment RWH
Paper 8:	Research into macro-catchment RWH
Paper 9:	Runoff measurement techniques
Sub-theme 4:	Technology adoption
Paper 10:	Factors affecting adoption of RWH
Paper 11:	Farmers' participation in research
Paper 12:	Computer simulation to assess transferability
Paper 13:	Decision support systems - tools for technology transfer

The discussion papers were subsequently revised for publication as a special issue of the Tanzania Journal of Agricultural Science. They are presented as Annex 1 to this report.

3.3 Socio-Economic Surveys

3.3.1 Western Pare Target Area

Two socio-economic surveys were previously conducted in the first phase of the project. The first, using RRA techniques, established a broad picture of the biophysical and socio-economic conditions of Mwanga district (Hatibu et al, 1993). The second collected specific data from individual farmers regarding their inputs, outputs, assets, cash-flow and household data. In the second phase of the project it was considered to be necessary to extend these studies in order to:

- gain better understanding of local farming systems (in particular the extent of RWH/ SWC practices) and their historical development;
- study the effects of environmental and socio-economic circumstances on the farming systems (particularly adoption of RWH/SWC innovations);
- given the predetermined focus on RWH, to identify target beneficiaries;
- to inform planning of activities, particularly on-farm research.

The first survey was conducted during February 1997 using informal PRA techniques. Six villages within WPTA were included (three each in Mwanga and Same districts). Group meetings were held in each village. Village resource maps showing physical features, water resources and land use were prepared by the farmers and provided the basis for much of the discussion. Transect walks were also done. Farmers selected for interview represented a cross-section of those with and without RWH practices and with plots in different areas of the village. A full report was prepared as a project document.

The first survey provided valuable information on the extent and types of RWH techniques employed by farmers and the factors which limit their use. With the focus of experimental work in Mwanga district it was felt that more detailed data was need on the farming systems in the target villages, particularly Lembeni and Kifaru. In particular, reasons for adoption or non-adoption of RWH required further exploration. To this end, farmers who had been exposed to RWH either through visiting Kisangara site or contacts with the research team were included in a follow-up study. In all, 40 farmers from Lembeni and 32 from Kifaru were interviewed using a structured questionnaire. This second survey focused in particular on an analysis of a number of different characteristics of farmers that might explain adoption or non-adoption of RWH. Earlier consultations at the Arusha workshop had established that very little research on technology adoption had previously taken place in Tanzania. An attempt was made to fit a Tobit model of adoption (See Senkondo et al, Annex 1, paper 9). A full report was prepared as a project document.

Considerable difficulties were encountered in analysing attitudes to RWH adoption because of the nature of the technology. There is a broad continuum of practices and it is impossible to identify any discontinuity between "traditional" and "improved" practice. It was therefore considered necessary to conduct a third study in order to provide more confidence in the findings. The third survey was conducted in Kiruru village (Mwanga) and in Hedaru village (Same). Both informal and formal methods of data collection were used. Farmers' perceptions on RWH were explored in greater depth and consensus was reached on key attributes that distinguished improved practice. An attempt was made to fit a Logit (logistic regression) model of farmer adoption. A full report was prepared as a project document.

3.3.2 Lake Zone Target Area

A team from UARI was first commissioned to undertake a review of secondary data derived from the extensive existing work on farming systems in the Lake Zone. Previously seen as a cotton area, there has been and still is a trend towards rice production for three reasons:

- growing cotton left farmers at the mercy of the official marketing organisation, which was renowned for late payment, whereas rice can be sold on the open market and is also a food crop;
- cotton requires greater labour inputs than rice;
- with falling cotton prices, rice is more profitable.

Four farming systems were identified in Maswa district. Rice is important in three systems and is dominant in one of them. It is grown in bunded fields (known as majaluba), which receive runoff from non-arable land. Indigenous knowledge of soils is well-developed and as a result there are clear distinctions between the crops grown on different soil types as shown in Figure 1. Previous investigations have shown that water and the related problem of weed control are major constraints.

Following the review, further activities focused on evaluating the extent of RWH in the LZTA, based on a focused PRA in six villages in Maswa district (Mwabayanda, Kinamwigulu, Shishiyu, Lali, Dulung'wa and Kidema) which took place in January 1998. The specific aims of the study were to:

- evaluate the nature and extent of RWH practices on different soils
- gain an understanding of the position of rice within the farming system
- assess the socio-economic factors influencing adoption of innovations which intensify and/or extend the rice system (especially RWH)
- assess farmers' technical constraints and identify researchable issues.

The extent of the major farming systems was identified in each case and the importance of rice was assessed. Cotton was the dominant crop in only one village, but even there rice still makes up 20% of the cropped area. A common coping strategy is to mix maize with rice. If rains are good, the rice is harvested, but if they are poor, there is still a crop of maize. A full report was prepared as a project document.

3.4 Experimental Fieldwork

3.4.1 Western Pare Target Area

Work on researcher-managed experimental plots at Kisangara continued from Vuli 1996/7 to Masika 1999. In order to reduce the workload so that experiments could also be established in farmers' fields, the experiment was modified. Monitoring of runoff was continued only on the upper block (8% slope) and monitoring of soil moisture by neutron probe was discontinued. In view of the shift of emphasis towards external (macro) catchment systems, it was necessary to obtain runoff data from instrumented catchments at an appropriate scale. Attempts to locate suitable datasets or previously instrumented small catchments in Tanzania were fruitless. It was therefore necessary to establish small instrumented catchments in and around the Kisangara site as reported by Young et al in Annex 1 (paper 8).

Two external catchments supplying runoff to the caag systems had previously been instrumented in phase 1, however they produced no useful data due to two factors:

- Flumes for measuring runoff were oversized;
- Unmanaged natural vegetation reduced runoff yield.

The flumes were replaced with smaller ones and an attempt was made to encourage local livestock keepers to graze these catchments normally.

Two large catchments were identified above the site as suitable for runoff measurement and flumes were installed. These represent a grazed catchment of 1 to 2 hectares with predominantly rill flow and a larger catchment of 5 to 10 hectares including some bare, rocky ground with gulley flow. The set-up is shown in Figure 2. Other locations for catchment studies were also investigated, but not developed because of resource constraints.

On-farm experiments present a considerable challenge to the collection of data with statistical validity. While it is commonly difficult to control non-treatment variables because of physical differences between farms and diverse management practices, it is usually possible to maintain control over the treatment variable (eg fertiliser application, weed control etc). However, in the case of macro-catchment RWH this is not possible, because the natural catchments cannot be replicated. It is necessary to adopt a split-plot design, but this still presents serious difficulties in controlling and measuring the distribution of runoff. After consideration of various potential sites, it was decided to concentrate on two experimental fields at Kifaru village. New land to the South of the village has been cleared in recent years and attempts have been made by local farmers to adopt RWH practices. They lack the knowledge to do this effectively and there is clear evidence of land degradation through erosion and gulleying.

Farmers were keen to cooperate and two field were selected, which represent the soil variation down the catena. Each field (ie upper and lower) had an identical experiment imposed upon it comprising 9 plots with 3 treatments and 3 replicates:

- T1 = Control (ie. current farmer practice without RWH)
- T2 = External catchment RWH
- T3 = Conservation tillage

Plot size was 15m wide (across slope) and 50m length (down slope) arranged as shown in Figure 3. In order to deliver equal amounts of runoff to each replicate in T2, these plots were all aligned along one side and supplied from a ditch which was lined with bricks to minimise losses. Two raingauges and three flow measurement flumes were installed at the site. The experiment began in Vuli 1997/8 and continued for three seasons. Further details are given by Kajiru et al (Annex 1, paper 7).

Figure 2: Layout of external catchment runoff experiments at Kisangara

Figure 3: Layout of on-farm experiment at Kifaru

Following contacts made during village-level socio-economic surveys and consultations in the Same workshop, a local NGO (SAIPRO) facilitated an attempt to set-up a participatory RWH trial in Hedaru village. The process began with participatory planning in August 1998, which was documented in a separate report. An external catchment system was developed using water diverted from a culvert under the Dar-Moshi highway. The trial ran for only one season, but results were encouraging (see Lazaro et al in Annex 1, paper 10).

3.4.2 Lake Zone Target Area

The existing practices for rainfed rice production (majaluba system) are diverse and complex. Coping strategies and researchable constraints have been documented in outline by the UARI farming systems team, but previous on-farm research has been limited to investigation of response to fertiliser applications. In order to properly identify appropriate interventions on water management, it was considered necessary to limit the fieldwork effort to a programme of monitoring. This was focussed on two sites: Mwabayanda and Shishiyu. Instrumentation was installed in the latter site in 1998 to provide detailed water-balance data, but data were collected for only one cropping season. Further details are given by Young et al in Annex 1 (paper 8).

INSERT PHOTOGRAPHS OF RUNOFF MEASUREMENTS

INSERT PHOTOGRAPHS OF KIFARU SITE

3.5 Modelling activities

3.5.1 Macrocatchment rainwater harvesting

Synthetic unit hydrograph

The original PARCHED-THIRST model (PTv1), which was designed to simulate runoff over distances of no more than 50-100m, assumed that the runoff process was instantaneous. Runoff from the catchment area was transferred to the cropped area on a daily basis and runoff rate was not calculated. With the shift of focus from microcatchment to macrocatchment RWH, it became necessary to rethink this approach for two reasons:

- When rainfall occurs on a catchment larger than a few hectares, it can take some time for any runoff to reach the mouth of the catchment.
- Large catchments can produce large volumes of potentially erosive runoff. We need to be able to quantify the erosivity of this runoff in order to deal with it safely within a farmer's field. Erosivity is related to flow velocity.

Working in collaboration with a visiting fellow from Aristotle University Thessaloniki (Dimitris Papamichail), we adopted to the US Department of Agriculture Soil Conservation Service (USDA-SCS, 1975) Synthetic Unit Hydrograph approach. This assumes that the relationship between runoff and time during a runoff event can be approximated by a dimensionless unit hydrograph whose properties are determined by the nature of the catchment. Those properties are:

The peak discharge, q_p:

$$q_p = \frac{(0.208AR)}{t_p}$$

Where: q_p = the peak discharge (m3/s)
t_p = the time to peak (hr)
A = 0.01 x the area of the catchment (ha)
R = Rainfall exccess (mm)

The time to peak, tp, is calculated by:

$$t_p = \left(D/2\right) + L$$

Where: t_p = time to peak (hr)
D = duration of rainfall excess (hr)
L = the lag time (hr) - time between centroid of rainfall excess and the peak of the hydrograph

The lag time, L, is assumed to equal $0.6\ t_c$ where t_c (the time of concentration of the drainage basin) is given by Kirpich (1940):

$$t_c = 3.97\left(\frac{(0.001Le)^{0.77}}{0.01S^{0.385}}\right)$$

Where: t_c = time of concentration (min)
Le = length of slope of catchment (m)
S = slope of catchment (%)

This procedure was initially implemented as a FORTRAN dynamic link library (DLL) which could be called from Visual Basic on the assumption that, for the large number of floating point calculations needed, FORTRAN would be faster than Visual Basic. However, the process of establishing a connection with an ‘out of process’ server (the DLL) slowed the system down to the extent that any advantage of FORTRAN’s faster floating point maths was lost. The procedure is now incorporated within PARCHED-THIRST v2 in Visual Basic. A hydrograph is calculated at user-defined intervals (default 5 min) within a runoff event. These are summed to give a hydrograph for the whole runoff event.

Multiple profiles

Another consequence of the move from microcatchment to macrocatchment RWH is the need to account for variability in soils, topography and vegetation over the modelled area. In PT, although the two profiles (catchment and cropped area) could have different vegetation cover and soil surface treatments, they were assumed to have the same soil type.

Extensive rewriting of the model was required to allow more than two profiles to be simulated, each with entirely different soil, vegetation ,and topographic properties. RWH systems are now no longer represented simply by a catchment and cropped area. Rather, they may comprise any number of runoff source and sink areas. This not only allows for the variability of catchments to be considered but also, by representing a cropped field with a number of small profiles, the variability of the depth of harvested water and thus variability of crop growth can be simulated.

3.5.2 Other technical improvements

ORYZA-W and LOWBAL

The inclusion of rice systems in the project brought about a need for a rice components within version 2. Rather than re-invent the wheel, a literature review (Gowing and Young, 1997) revealed a number of models which could be included within the DSS. The ORYZA-W model (Wopereis et al., 1996) developed by Wageningen in the Netherlands was eventually chosen for a number of reasons:

- It is based upon the well-known ORYZA model (Kropff et al., 1994) developed in collaboration with IRRI in the Philippines.
- Work was underway by WARDA to calibrate the ORYZA for West African lowland rice.
- The source code was freely available and incorporation was not a problem.

ORYZA-W simulates the growth of rainfed, lowland rice and considers the effects of light and water on the crop. Because of the nature of rice-growing padis or jalubas the existing PT water balance was considered unsuitable. Instead, the LOWBAL water balance model designed specifically for lowland rice soils was adopted.

Both ORYZA_W and LOWBAL were translated from the original FORTRAN code into Visual Basic and incorporated within PTDSS in a modular manner another rice model to be ‘slotted’ in at a future date if necessary. ORYZA_W was designed to be run within a simulation environment which carried out a number of basic modelling functions such as integration and interpolation. This functionality was recreated within Visual Basic.

Pedotransfer Functions

Although pedotransfer functions (PTFs) are widely used in cropping systems, there is evidence to suggest that they are not universally applicable (Young et al., 1999). In order to offer users the choice of which PTFs are most appropriate for local soils, both the Vereecken(1989) and the Rawls and Brakensiek (1989) PTFs have now been incorporated into the model.

In certain circumstances, the user may have observed moisture retention and/or hydraulic conductivity data. While PTv1 did not allow the full use of these data, v2 now allows the user to input parameters of three different functions (Brooks-Corey, 1964; Campbell, 1974; or Van Genuchten, 1980) which can be fitted to these data.

Model Calibration

Recognising the importance of the model being seen to be able to reproduce observed yields, there has been a considerable investment in the parameterisation of the model for locally grown varieties of maize and rice. Two MSc students spent 6 weeks in Tanzania collating data from a number of sources which enabled them to develop improved cultivar files.

Piston Flow

Working closely with the team at Newcastle F-Bauke van der Meer at Silsoe Research Institute has a number of improved components as part of his PhD studies. One of these, a piston flow routine, has now been included in the PTDSS.

The routine was developed in response to the fact that PT could not reproduce the speed with which water moved through sandy soils in field trials in Zimbabwe (van der Meer, 1999). As a result, he developed a routine which replaces the normal finite difference approach for soil moisture movement under wet conditions.

In the Pipeline

While the great majority of the work has now been incorporated into the model, there are a number of components which, despite a considerable investment in time, are yet included. These are:

- Bayesian belief network (BBN). Some effort was made to develop a BBN before the final adoption study in Mwanga district. However, because of the apparent lack of factors influencing adoption, it has not be possible to develop this any further.
- The rainfall disaggregator currently included within the PTDSS is relatively simple. There are a number of other approaches in the literature which might represent the form

of rainfall more realistically. These were examined in late 1996 but time has not permitted their inclusion within the DSS.

- While collaborating with Dimitris Papamichail we attempted to develop an improved infiltration-runoff routine based upon the work of Madramootoo et al. (1989). However, the method was complex and there are still a number of bugs which require ironing out.

3.5.3 User interface improvements

A totally new user interface has been developed for PARCHED-THIRST v2. This is to accommodate both the extra requirements of the multiple profiles, rice, etc. and suggestions from users. Specific changes include:

Excel input, output and analysis

Traditionally cropping systems models are typified by a large manual, MS DOS front ends or command line prompts and the need to manipulate large quantities of data into formats which can be used as input to the model. Output data need to be imported into other packages (such as Excel) before they can be used. As a result of these problems, they are often unusable by any but their authors. Responding to suggestions from user groups polled during workshops, the problems of data manipulation were addressed by developing an Excel-based system.

Using Visual Basic for Applications (the macro language underlying Microsoft Excel), a number of capabilities have been developed:

- Using ActiveX technology (Formerly OLE – Object linking and embedding), the user can open Excel worksheets or text files containing weather data within the DSS and specify the exact location of the different weather variables within the files. This allows weather data from other systems such as DSSAT (Tsuji et al., 1994) to be used without wasting time on data manipulation.
- When the model begins, it also starts up a copy of MS Excel to which all initial parameters are written and all output data are written as the simulation progresses. As a result, rather than ASCII text files, the user is presented with an easy-to-use spreadsheet.
- Using the same automation techniques, we have developed a graphing package which uses Excel's charting components to analyse output data. Rather than having to manipulate data directly, the model provides a number of menu driven analysis options.

Access to parameters

Hess and Stephens (1994) highlight the importance of inexpert users not being offered the opportunity to change the values of parameters which rarely require it. To this end, crop parameters which commonly need altering are easily available, others are hidden behind 'Advanced' buttons.

Windows standards

The ‘feel’ of the model has been brought in line with commercially available Windows packages with such features as context-sensitive ‘right-click’ mouse access to important features, ‘cut and paste’ for repetitive number entry, etc.

Flow diagram

To cope with the almost limitless number of profiles which can be simulated, a third-party component, Lassalle Addflow v3.0, has been incorporated and provides flow charting functionality. This allows the user to ‘draw’ the relationships between profiles and thus the pathway(s) which water will take through the system.

Object-oriented methodology

Visual Basic 5.0 allows the use of an object-oriented approach to programming. This both reduces the number of ‘bugs’ in the code and makes the code easier to maintain. It also makes it easier to slot in new components or replace existing components at a future date.

Object-orientation formed the basis for the new rationale behind the model front end. Each simulation scenario is known as a ‘*system*’. A *system* has a number of properties which include simulation start date, sowing dates, etc. It is also made up of a number of *profiles*. These can be thought of as ‘blocks’ of soil/plant/atmosphere which are assumed to represent an area with homogeneous soils, topography, vegetation , etc. A *profile* is defined by a set of parameters saved in a ‘*.pro’ file. It is possible to have many *profiles* in a *system*, all with the same ‘*.pro’ file. This removes the need to laborious enter the same parameters over and over again. Similarly, a crop cultivar is represented by a ‘*.cul’ file. Many profiles may have the same crop, and thus the same ‘*.cul’ file which again reduces the need to input the same data more than once. Thus the object-oriented approach has been carried through from the underlying methodology to the functionality of the model.

4. Outputs

Output 1: a computer based decision support tool developed in order to assist in problem analysis and screening best-bet options through what-if analysis at farm-level.

Achievements against output 1 are summarised by Gowing et al in Annex 1 (paper 11). Interim reports were presented to the workshops in Arusha, Harare and Morogoro. A paper was presented at an international conference in Spain (Young et al, ??). A revised users' manual is in preparation together with the following scientific papers:

- Developing improved dryland cropping systems in Tanzania: use of computer simulation to extrapolate experimental results. To be submitted to: *Experimental Agriculture.*
- PARCHED THIRST: testing a process-based simulation model with field experiments in Tanzania. To be submitted to: *Computers and Electronics in Agriculture.*

Experimental research into soil-water management, whether on a research station or on farmers' fields is necessarily restricted to specific sites over limited time intervals and meaningful extrapolation is a problem. With this in mind, the Newcastle/SUA/UARI project team pursued a twin-track approach in which the experimental effort was linked to the development of a simulation model designed to permit easy spatial and temporal extrapolation. The model aims to represent the important biophysical processes using data that can be easily measured or estimated to represent crop, soil, weather etc. It comprises various sub-models, which are linked together as shown in Figure 4.

The twin-track approach introduced additional requirements into the experimental effort in order to provide data necessary to validate the model. Particular problems arising from this were:

- the necessity for careful control over experimental conditions at times conflicted with the desire to demonstrate practices that could be adopted by farmers;
- the necessity to first collect experimental data over a number of seasons under highly variable field conditions conflicted with the need to test and validate the model using real data during the life of the project.

The utility of the model as a practical tool to assist in the problem analysis and screening of intervention options was discussed with key NARS representatives in three workshops (Arusha, Harare and Morogoro). Through the life of the project it is clear that the initial scepticism about the role of models was replaced by positive endorsement of the approach.

It should be noted that considerable attention was devoted to important aspects of the model that determine its ease-of-use, viz.

- Graphical user-interface
- Easy data entry
- Easy output interpretation
- Ancillary tools to estimate missing input data

Figure 4: MODEL STRUCTURE

Output 2: optimum systems selected/developed using simulation and on-farm experimentation

Achievements against output 2 are summarised by Hatibu et al and by Kajiru et al in Annex 1 (papers 6 & 7). Interim reports were presented to the workshops previously described. A planners' manual has been prepared and is to be published and distributed by RELMA/Sida later this year. The following scientific papers are in preparation:

- Runoff agriculture in Tanzania: the neglected opportunity to enhance productivity in drylands. To be submitted to: *Land Degradation & Development.*
- Developing improved dryland cropping systems in Tanzania: experimental evidence for benefits of rainwater harvesting. To be submitted to: *Experimental Agriculture.*

Experimental results from micro-catchment RWH plots at Kisangara showed that there was little benefit obtained during Masika season compared with conventional dryland cropping. However, highly significant yield benefits were obtained during Vuli season. Extrapolation over a much longer period using the simulation model, demonstrated that this conclusion would also hold in the longer term. It was evident that yield benefits in Masika can be expected to occur only I year in 10, whereas in Vuli they are expected about 1 year in 2. This indicates that an optimum micro-catchment system for maize involves cropping the full field area in Masika and only one third of the total area in Vuli.

The possibility of spatial extrapolation to other parts of WPTA with lower rainfall was examined in a second computational experiment. As can be seen from Figure 5, in Masika season the benefit is minimal under all three scenarios considered. It can therefore be concluded that the experimental results from Kisangara can be applied throughout WPTA. However, in Vuli season the response can be seen to vary with rainfall regime. This indicates that experimental results from Kisangara cannot be simply extrapolated to drier sites. It appears that a larger catchment area would be necessary at such sites, which translates into lower cropping intensity.

Experimental results from macro-catchment RWH plots at Kifaru demonstrated significant increases in both biomass yield and grain yield. This was also evident for the caag system plots at Kisangara. Again extrapolation was possible using the model and this showed no overall gain in Masika, but significant yield benefits during Vuli, as shown in Figure 6.
The computational experiment was extended to examine three water sharing scenarios. It was shown that incremental yield per hectare was reduced by spreading runoff over a larger area, but total production increased. The decision on the optimum size of cropped area for an external catchment RWH system is problematic. It is often difficult to identify the size of the catchment and it is often difficult to effectively limit the extent of the cropped area receiving runoff. The simulation model allows for better informed planning decisions, but water rights disputes are a recurrent problem with such systems as was seen in Hedaru.

Figure 5: Results of temporal and spatial extrapolation for micro-catchment RWH

Figure 6: Results of computational experiment on macro-catchment RWH

Another aspect of water-sharing strategies was investigated in a computational experiment on the majaluba system in LZTA. Weather data from Ngudu in Maswa district for a 20-year period provided the basis for the simulation. The investigation included three different ratios of catchment to cropped area and two different methods of water distribution within the cropped area. The cropped area in each case was assumed to be 3ha, but the catchment was simulated as 3ha, 10ha and 20ha. Water distribution alternatives were a serial (cascade) system and a parallel (equal division) system. In each case yield was predicted for the top third, middle third and bottom third of the cropped area. The results indicated that a 3ha catchment area is inadequate, but that there is little difference between 10ha and 20ha catchment sizes. Results also clearly show that the parallel system (ie. equal water division) is much better for the middle and bottom plots. Overall performance is increased by 80% over the cropped area taken as a whole, but the trade-off is that the yield from the top plot is reduced by 35%. Clearly, if all three plots down the slope belong to a single farmer, the optimal strategy must be to spread the water equally. In practice there may be different farmers involved and the simulation result may therefore provide a basis for discussion and agreement over water-sharing.

Earlier exploratory simulation studies, which were reported in the 1st Interim Report in March 1997, dealt with another concern over macro-catchment RWH systems. This is the problem of unmanageable high flows, which can damage structures and cause serious erosion. There is clear evidence from both LZTA and WPTA that this is a real problem. There is a need for further investigations to determine the maximum acceptable flowrate and corresponding catchment area. Further technical developments are then required to determine appropriate methods of controlling and limiting flows diverted from external catchments and distributing them safely within the cropped area.

In spite of the apparent risks and conflicts associated with external macro-catchment RWH systems, the evidence from consultative workshops indicates that farmers have a strong preference for these rather than micro-catchment systems. This was further confirmed in a participatory evaluation of RWH experiments which was conducted in WPTA in June 1999. Groups of farmers were selected from Kifaru, Hedaru and Toloha villages for this exercise, which is reported in a separate project document.

Output 3: methodology developed for assessing transferability of RWH techniques to new locales

Achievements against this output are summarised by Senkondo et al. and by Lazaro et al. in Annex 1 (papers 9 & 10). Interim reports were presented to the workshops previously described. One scientific paper has previously been published (Senkondo et al.,1998) and another is in preparation:

- Measuring the impact of efforts to promote rainwater harvesting in semi-arid Tanzania. To be submitted to: *Agricultural Water Management.*

The methodology in relation to assessment of potential performance of RWH techniques in any new locale has been considered under output 1. However, an important additional dimension was explored within the scope of consultative workshops in the two target areas and the socio-economic survey activities previously described. A separate working paper has been produced as an output from each of these activities.

It is clear that there have been few serious attempts previously to investigate factors influencing technology adoption in Tanzania. Particular problems were identified in relation to RWH, because it is not a neatly packaged technology, but is easily divisible and can be adopted incrementally. Two attempts were made to fit predictive models of adoption based on parameters such as age, farm size, available labour, gender and knowledge. Amongst these, it is apparent that knowledge is most significant, but is also very difficult to measure in any meaningful way. Further work is required to establish the reliability and utility of this approach in screening technical options according to socio-economic characteristics of any particular farmer. Ultimately, success in establishing this predictive ability can assist in targeting both technical and policy interventions at particular beneficiary groups and in determining trade-offs between different groups.

Evidence form LZTA shows that farmers are willing to invest considerable amounts of labour in developing RWH systems without assurance of guaranteed benefits every year. In WPTA the preferred crop is maize, which brings lower returns than the rice crop in LZTA, but access to markets is good and conditions appear to favour sustainable intensification. The main constraint on RWH adoption, which was consistently identified in surveys and workshops, was lack of knowledge. Farmers do not know how to do it and extension workers do not know how to help them. This knowledge gap was reflected in the prioritisation of outputs for future district level interventions as defined in the outline logical framework developed in the Morogoro workshop (See Box 3)

INSERT LOGICAL FRAMEWORK

Output 4: adoption of project outputs promoted through workshops and training sessions

Achievements are summarised in preceding sections of this report.and separate documents have been produced in the form of working papers from each workshop. Dissemination and promotion activities have taken place at national, district and local levels.

At national level, weaknesses in policies and strategies for promoting RWH are discussed by Hatibu et al in Annex 1 (paper 3). This critiques is also incorporated as a country case-study by Boyd & Turton (2000). The need for action by various government agencies (ie water, agriculture, forestry, roads) and for improved coordination between them has been ackowledged.

At district level, the knowledge constraint has been recognised. A series of consultations and workshops culminated in the preparation of an outline for a district-level RWH development project. The need for technical training has also been acknowledged as is demonstrated in the requests received from Same and Mwanga districts (see below).

At local level, within the immediate project target areas, considerable effort was devoted to promoting farmer involvement as summarised by Lazaro et al in Annex 1 (paper 10). This included both participatory evaluation of trials in Mwanga district and participatory planning and execution of trials in Same district.

INSERT LETTER FROM SAME

INSERT LETTER FROM MWANGA DISTRICT

5. Contribution of Outputs

The project outputs have individually and collectively contributed to delivering the stated project purpose in a number of ways. Firstly, at the level of immediate impact within the main target area of the project (ie. Western Pare Lowlands) there has been an impact on livelihoods through developing and promoting rainwater harvesting techniques. Secondly, there has been longer-term impact on the effectiveness of the research-extension continuum through developing and promoting new methods. Thirdly, at the broader policy level, there has been an impact through promoting greater awareness of opportunities for sustainable intensification of production through adoption of rainwater harvesting.

Research has shown that under the conditions prevailing in Western Pare target area (WPTA), where maize is the preferred crop, in-situ soil-water conservation techniques provide no significant improvement in yields. Benefits in terms of soil erosion control were apparent and these might be expected to deliver long-term sustainability benefits, but without short-term production gains there is minimal chance of adoption. In contrast, rainwater harvesting has been shown to deliver production benefits, although these are significant only in Vuli season.

In the case of micro-catchment RWH systems only part of the field (typically 1/4 or 1/3) is cropped with the remaining part used as the catchment area. Cropping intensity is reduced, although this would only affect Vuli season since the entire field would be cropped during Masika. The benefit is that assurance of acceptable yield (above 1.5 tonnes per hactare) is greatly increased during Vuli season, therefore return to labour and other inputs is greater and less risky. Nevertheless, farmers have shown a degree of reluctance to adopt micro-catchment RWH.

There is a clear preference for macro-catchment RWH systems and there is abundant evidence that farmers lack the knowledge to do this effectively. Furthermore, there is evidence that extension workers lack the skills necessary to provide technical assistance. Opportunities exist to make better use of runoff from external catchments, but there is greater risk of associated with these RWH systems. Problems are both technical (ie. control of flow diversion and distribution) and social (ie. water-sharing and joint-ownership).

Promotion pathways to the NARS and NGOs have been established, but there is a need for technical training in order to promote good practices. Requests have been received for short-term in-service training within WPTA and this is considered to be a priority for follow-up activity. A technical manual has been prepared for planners, which will help improve district-level development activity, but follow-up is recommended in order to pilot-test strategies to deal with the technical and social problems identified. There is also a need to reform initial training of extension workers, who are currently orientated towards soil-erosion control rather than rainwater harvesting.

Comparison between experiences in the two target areas is informative. In the case of the lake zone (LZTA), a successful techniques was introduced from elsewhere and has spread rapidly without intervention from development agencies. Technical problems still remain to be solved (notably water management and weed control) and there is a strong case for increased technical support given the importance of this system in relation to total rice production in Tanzania. In WPTA there is no evidence of successful introduction of a widely applicable technique. Consequently, there is far greater diversity of current practice and general lack of confidence in existing knowledge. However, there is reason to believe that conditions do favour sustainable intensification of production in WPTA and further development and promotion of RWH is recommended. Socio-economic studies focusing on preconditions for RWH adoption have consistently shown knowledge to be the key constraint and there is no evidence of other major concerns.

Recognising the inherent limitations of experimental research into soil-water management, this project adopted a twin -track approach in which the experimental effort was linked to the development of a simulation model. The model was designed to permit easy spatial and temporal extrapolation of experimental results and was seen as a way of adding value to costly and time-consuming field experiments. Initial scepticism within the NARS was contested through a series of presentations and consultations. The resulting discourse on methodologies for systems research is seen as a significant contribution from the project. Given the re-orientation within the NARS in favour of client-oriented research, there is scope for follow-up action to promote wider adoption of modelling.

The term "model" is used widely and means different things to different people. In this context we are referring to a tool for dynamic simulation of bio-physical processes. PARCHED - THIRST v1.0 was delivered at the end of phase 1 (ie 1996) and has been widely distributed. PARCHED-THIRST v2.0 now incorporates a number of improvements. It was seen as a decision-support tool, rather than simply as a means of describing the system, as in the original PARCH model. In certain respects its capabilities now exceed those of other well-known, state-of-the-art crop simulation models (eg. DSSAT, APSIM). An attempt was made to provide additional capabilities that permit analysis of socio-economic factors that influence the behaviour of farmers. Efforts to understand and quantify these influences were inconclusive and there is a need for further work.

The project has actively promoted adoption of RWH systems through two phases (1992-96 and 1996-99). Over this time, we have sought to stimulate greater awareness of the opportunity afforded by the under-utilised rainfall-runoff resource. There is evidence that in the past, runoff was seen as a threat and "safe disposal" was the priority. The potential value of the resource was not reflected in official policy documents (water, agriculture, forestry etc) nor was it recognised in technical development efforts. It is our contention that the project has contributed to a marked shift in perception and there is now much greater awareness of the potential for RWH as a contributor to sustainable intensification of crop production. There is a need for follow-up actions to draft new policies and strategies at national, district and local levels. In particular, there is an immediate need to examine the implications of widespread adoption of RWH on catchment-level resources both in terms of water and sediment yields.

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