Operational Research and Capacity Building for Food Security and Sustainable Livelihoods Project

Report MHH/4: Water Balance Studies

Report on visits to Debre Kidan, Begasheka, Beresa and Umbulo Wacho project areas, Ethiopia,

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M.H. Hollingham, CAZS, University of Wales, Bangor

LL57 2UW, Wales, UK

Telephone: +44 1248 382316

Fax: +44 1248 364717

Email: m.hollingham@bangor.ac.uk

http://www.bangor.ac.uk/~azs808.

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Summary

This report is a summary of the fourth visit of the Hydrology TA to the DCI capacity building and operational research project areas in March 2005. All raingauges that were installed are still in good physical condition. Farmers had kept records of the rains and DAs had collated some records in all project areas. Rainfall records for 2004 have been retrieved from the farmers and DAs.

Hydrological research in the project areas has yet to commence and there were some discussions with researchers as to how best to obtain hydrological measurements, and the direction of future hydrological research.

The visit was part sponsored by the British Council Link Program. The terms of reference for the BC Link Program visit to Mekelle University were to:

- check the raingauges and the rainfall recording procedures,
- assist with the computerization of rainfall records and develop hydrological research proposals.

Additional funding was secured from DCI to visit Debub University and check on rainfall recording in the Umbulo and Beresa project areas.

The Mekelle Consortium has selected two catchments Debre Kidan and Begasheka. In both three collecting raingauges have been installed. The Debub Consortium have installed five collecting raingauges in the Umbulo Wacho project area, and another four in Beresa. These are read daily by farmers. In all project areas, recording raingauges have been installed at the DAs' office with a counter for the DAs to record daily rainfall and datalogger to record the time of rainfall events.

All raingauges in all project areas were visited with the assistance of Fasil Ejigu of MUC in Mekelle and Feto Esino of Debub University in Awassa. The original Ethiopian researchers who had installed the raingauges and initiated rainfall recording were not available.

In all project areas farmers had kept recording daily rainfall throughout the rains in 2004. In Begasheka and Debre Kidan the rains had not yet started and the majority of farmers had removed the raingauges for safe keeping. In Beresa rainfall recording had not recommenced with the start of rain, only in Umbulo were the majority of farmers still recording rainfall on a daily basis.

The DA rainfall records and their collated records of farmer rainfall records in Begasheka were not available for inspection and the records for Debre Kidan were only available for part of the rains. In Beresa and Umbulo, the DA rainfall records and their collated records of farmer rainfall records were up to date. In none of the project areas were DAs' transcriptions of the farmers' records without error.

In neither consortium had researchers collated farmer or DA records, nor had farmers and DAs been supplied with new record sheets. The dataloggers attached to the recording raingauges contained no records apart from the one in Beresa which had not been visited by university researchers.

The TA collated available farmer, DA and datalogger rainfall records and conducted a preliminary analysis of the data. In all the project areas rainfall was less than average, however crop yields were not affected as feared by the farmers. The TA created a spreadsheet for researchers and DAs to record rainfall on their computers. This calculates dekad, monthly and annual totals. The TA also prepared and gave new record books to

farmers and DAs in Umbulo and Beresa. New record books translated into Tigrinya need to be given to the farmers and DAs in Begasheka and Debre Kidan.

Methods for estimating the water balance in the project areas were discussed with researchers at MUC and Debub University. Discussions concentrated on:

- using existing climate records kept by the meteorological stations near to the project sites;
- encouraging farmers to take measurements of flood flows and water levels in wells; soil moisture and hydraulic property measurements;
- GPS surveys to delineate areas of different soil and rock type;
- synthetic hydrographs and computer modelling.

As a result of discussions three farmers who were already recording rainfall were asked to record observations of flow in gullies adjacent to their farms. The concerns of farmers, farmer indigenous knowledge and the approach of water balance research in the project areas were also discussed.

Researchers were provided with copies of the transcribed rainfall records in Excel spreadsheets, hydrological reference materials, computer programs and Excel spreadsheets to model other hydrological parameters.

Itinerary

Saturday March 5th 2005: The TA departed Bangor 5.30am. Arrived late in Addis 23:30.

Sunday March 6th 2005: The TA stayed in the Addis Hilton

Monday March 7th 2005: The TA visited the Irish Embassy and met with Nuala O Brien to discuss the mission, and then travelled to the British Council offices and met Amsalu Abebe. Later that day the DA flew to Mekelle.

Tuesday March 8th 2005: The TA met Dr. Mebrahtom Mesifin the Mekelle Consortium's coordinator and agreed a rough program. The TA also met Fasil Ejigu in the afternoon and discussed how best to measure the parameters needed for a water budget calculation.

Wednesday March 9th 2005: The TA and Fasil Ejigu travelled to Debre Kidan and inspected the raingauges and rainfall records there.

Thursday March 10th 2005: The TA and Fasil Ejigu travelled to Begasheka and inspected the raingauges and rainfall records there.

Friday March 11th 2005: The TA reported back to Dr. Mebrahtom on the visits and went to see the DAs to ask about their records with Dr Mebrahtom. The TA gave the circuit breaker to Dr. Mebrahtom. The TA visited Desta Gebremichael and Kourum at the REST office.

Saturday March 12th and Sunday March 13th 2005: the TA wrote his report, outlined the research proposal for hydrological research, and collated farmer rainfall records, materials and references for use by the Ethiopian researchers.

Monday March 14th 2005: The TA met with Dr Mebrahtom, Dr. Fasil Ejigu, Abdulagig Mohammed (MSc Student), and Gebreegirabhel Lemma and presented a preliminary report and the outline for hydrological research in the project areas. The TA also received a copy of an MUC hydrological research proposal. Later that day the TA flew to Addis.

Tuesday March 15th 2005: The TA was met by an Irish Embassy vehicle and taken to Awassa. Later that evening he met with Dr Girma, Nuala O'Brien, Garvin Mc Cann (DCI).

Wednesday March 16th 2005 The TA met with Dr Girma, Tewodros Tefera and Shemalis Gebriye and an outline programme for the visit was agreed. The TA made new record books and bought watches for the farmers in Umbulo and Beresa.

Thursday March 17th 2005: The TA visited the Boricha side of the Umbulo catchment to the Yirba and Korangoge DAs offices with Berhanu Abate (DU Plant sciences), Feto Esino (DU Agricultural Engineering) Mesfin Asefa (Korangoge DA Head), Dessalean Danna and Sintayehu Nigusie (Korangoge DAs).

Friday March 18th 2005: The TA, Tewodros and Shemalis went to Beresa and met with Mohammed Mosel head of Natural resources and Agriculture. The TA, Tewodros, Shemalis also went to Beresa DA office met with the DAs there and inspected the DA raingauge.

Saturday March 19th 2005: The TA, Tewodros, Shemalis went to the Beresa project area and met with Habtamua, the Beresa DA in charge of rainfall recording. All farmer raingauges and record were inspected.

Sunday March 20th 2005: The TA visited the Awassa side of the Umbulo catchment with Feto, picking up the Awassa DA Fanage Watan on the way. Visited farmers R1, R2, R4 and R5.

Monday March 21st 2005: The TA went to Yirba and Korangoge, inspected the DA raingauge and farmer raingauge R3.

Tuesday March 22nd 2005: The TA spent in discussion with Feto. Later that day the TA met with Jemal Adem Yasin and Biruck Desalegm of the Environmental Health department of Debub University and discussed environmental health issues in rural Ethiopia.

Wednesday March 23rd 2005: The TA was driven to Addis and compiled notes.

Thursday March 24th 2005: The TA caught the plane back to the UK.

People met:

Person	Position
Nuala O Brien	Programme Officer, DCI Ethiopia
Garvin Mc Cann	(DCI)
Amsalu Abebe	BC LINK Coordinator, British Council
Dr. Mebrahtom Mesifin	Coordinator, Mekelle Consortium Dean of Natural Resources, MUC
Fasil Ejigu	Hydrology Lecturer, MUC
Assefa Kassar	Electrical Engineering Lecturer at MUC
Nigussu Haregewyn	PhD student, MUC
Abdulagig Mohammed	MSc Student, MUC
Desta Gebremichael	Engineer REST, Mekelle
Dr Girma	Chairman, Debub Consortium. Dean, DU
Tewodros Tefera	Coordinator, Debub Consortium Lecturer, DU
Feto Esino	Agricultural Engineering, DU
Shemalis Gebriye	Lecturer, DU.
Jemal Adem Yasin	Dean, Environmental Health, DU
Biruck Desalegm	Environmental Health Lecturer, DU
Mohammed Mosel	Head, Natural Resources and Agriculture, BoA, Butijura
Mesfin Asefa	Head of DAs, Korangoge
Sintayehu Nigusie	Korangoge DA
Dessalean Danna	Korangoge DA
Habtamua Ambawu	Beresa DA
Fanage Watan	Awassa DA

Recommendations

General recommendations

- The project coordinators should take responsibility to ensure that recording and collation is proceeding in the project areas and that once a year farmers and DAs receive new record books and their old record sheets are collated.
- Research should be directed at solving farmers concerns of water insecurity instead of addressing the water balance directly.
- Reports of hydrological research are presented to the farmers and the DAs.
- Farmers and DAs should be trained to make scientific measurements where ever possible and are provided with training, materials and information to enable them to do so.
- Visits to the study areas and activities there should be logged and form part of each consortium's annual report.
- There should be active communication and debate between researchers of both consortia.
- The calendar and time systems used in rainfall records and reports must be clearly stated (i.e. Ethiopian or International).

Recommendations for research

- Farmers' indigenous knowledge of agriculture and climate should be recorded and tested against scientific observations.
- Hydrological research in the project areas should try to obtain measurements of rainfall, evaporation and where appropriate stream flow and groundwater levels, using the methods described in this document.
- Where possible, water harvesting structures should be used to measure runoff and calculate runoff coefficients, time of concentration, runoff curves and the probable maximum flow.
- Later research should estimate the aquifer properties by analyzing groundwater levels, rainfall measurements and aquifer tests (Fetter, 1994). Groundwater levels should be monitored for use in later research and for comparison.
- Researchers should model expected flows in Beresa using the Rational and SCS methods and the rainfall record from the datalogger.
- Hydrological modelling should be carried out in Begasheka and Debre Kidan with existing GIS models. GIS thematic layers of elevation, slope, aspect, land use, soil properties, and aquifer properties should be produced for Beresa and Umbulo. This information should then be used to model the catchment processes using a watershed modelling computer program like WMS (http://www.emrl.byu.edu), a demonstration copy is on CD 2 accompanying this report or the hydrological packages of Arcview. Such catchment models are calibrated by matching simulated catchment responses to actual flood measurements.

- Researchers should submit their projects to the 'Predictions in Ungaged Basins' working group of the International Hydrological Association http://cee.uiuc.edu/research/pub/default.asp

Rainfall

- Farmers and DAs should be provided with new record sheet booklets for the forthcoming year that are translated into local languages. They should also be asked to record the start and finish times of rain storms and be provided with watches (Mekelle). Rainfall recording forms should have additional columns to write this information (Appendix 1).
- Ladders should be provided for all the recording raingauges at the DA offices so they can be easily inspected.
- DAs should be retrained how to collate farmer rainfall records and how to present this data to the farmers.
- DAs in Begasheka and Debre Kidan should be given copies of the rainfall recording Excel spreadsheet on CD 1 of this report, to use on their computers (Mekelle) and to help them collate farmers' rainfall records and produce graphs and tables of rainfall totals in dekads
- Regular monthly or bimonthly visits should be made to the project areas by operational researchers to inspect the raingauges and check the recording of rainfall measurements by farmers and DAs. Totals recorded by farmers and DAs should be checked in the field with them.
- Copies of farmer and DA records should be made by researchers in Dec-Jan every year. New record sheet booklets should be given out then.
- Researchers should analyse rainfall data and produce annual reports which analyse the frequency and duration of rainfall events and the distribution of rainfall. Researchers could use the excel spreadsheets on CD 1 of this report for some of these analyses.
- Annual reports produced by researchers should be presented to the DAs and farmers.
- The areal distribution of rainfall should be calculated by researchers using the average or Thiessen polygon method.
- Nearby meteorological station data should be collated and analysed and then compared against the rainfall for the project areas.

Evapotranspiration

- Researchers should estimate Potential Et using the nearest Meteorological station data using both the Blaney Criddle and Penman methods. The results from these two methods should then compared, and correction factors for the Blaney Criddle method determined for use with Blaney Criddle field calculations used by farmers.
- Literate farmers should be given maximum and minimum thermometers and asked to record daily temperatures for use with the Blaney Criddle field calculations. Farmers should be given tables to convert temperature measurements into Potential Et themselves.

- o Soil properties, infiltration, saturated and unsaturated hydraulic conductivity, should be determined by researchers or trained farmers or DAs.
- o The extent of soil and vegetation types should be mapped by researchers, trained farmers or DAs.
- o Researchers should model soil moisture and Actual Et using computer programs CROPWAT or Water mod, copies of which are on CD 2 with this report.

Stream flow

- o Farmers near gullies should be asked to record *in order of priority:*
  1. whether there were floods in the gullies near to them.
  2. peak flow height in gullies, especially at the exit point of the catchment.
  3. the flow of water in the gulley every morning after a flood event
  4. the start time of rainstorms and the duration of rainfall.
  5. the start time of flow in gullies, the time of peak flow and the time flood flow stopped.

  Record sheets should be provided to the farmers for this purpose. Record sheets should contain columns for date, time, daily water level, peak water level, time of initial flow, time of peak flow, time that flood cease (return to original levels before the rains) and comments (Appendix 16). If all these measurements are obtained hydrographs should be plotted and unit hydrographs constructed by researchers.
- o Researchers should determine channel dimensions, roughness coefficients, and slope, of measurement points to use in Manning's equation. Alternatively artificial spillways should be constructed in the gullies at the gauging points. Farmers should be provided with measuring sticks calibrated in flow rate or conversion tables so farmers can interpret the measurements for themselves.
- o Water levels in the water harvesting ponds in Begasheka should be measured after rainfall, by farmers, so that researchers can calculate subcatchment runoff and runoff coefficients.
- o In the absence of flow measurements, discharge should be calculated by researchers using both the rational and the NRCS curve methods. Synthetic triangular hydrographs are constructed by researchers using the NRCS method. Computed runoff to particular rainfall events should be compared to flood measurements, and model parameters like the curve number and time to peak adjusted accordingly. Excel spreadsheets of the NRCS method are provided on CD1 with this report.

Groundwater

- o At minimum farmers should take measurements of water levels in wells, first thing every morning, in a similar way to rainfall recording. Record sheets should contain columns for Date, Time, Waterlevel (m) and comments (Appendix 16). This data could be used to identify periods when the water table is at the same level and a water balance can be calculated ignoring groundwater storage.

- Surveys of water use by cattle, irrigation and domestic purposes should be conducted by researchers to determine abstractions.

Further recommendations for groundwater

- GPS ground surveys should be carried out by researchers or trained farmers or DAs to identify hard rock areas and map the extent of the aquifers.
- Topological surveys of ground levels adjacent to wells heights should be conducted by researchers or trained farmers or DAs using barometers or digital GPS.
- Slug test and auger hole tests to determine hydraulic conductivity and storativity should be conducted in the base of dry wells. Farmers or DAs may conduct the tests if trained, but researchers should collate and process the results.
- Flood recession curves should be analysed by researchers to estimate recharge. This is only possible if farmers record flow at the catchment exit every day following a flood event (see stream flow recommendations above).
- Computer models should be built by researchers using GMS (a copy of which is on CD 2 of this report) and various estimates of the aquifer properties are calibrated against the recorded water levels.

1 Introduction

1.1 Background to project

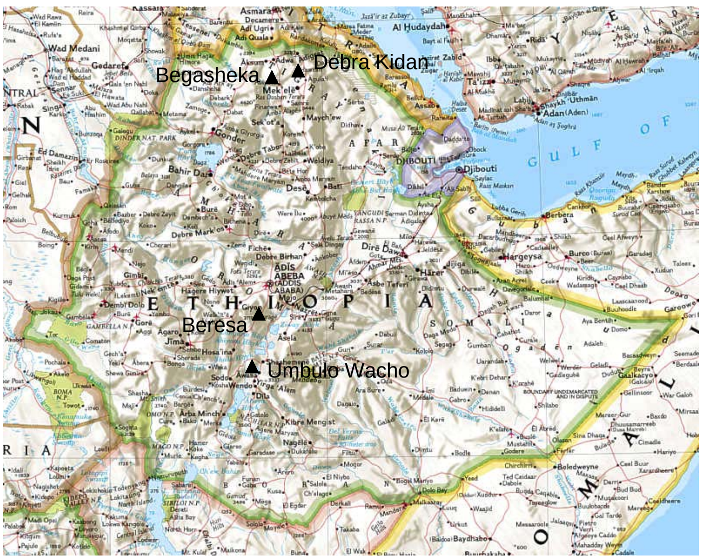
Development Corporation Ireland (DCI) area-based activities in Ethiopia were reviewed (Robinson, 2002) from which the need to support, and collaborate with local institutions working in the area of food security was identified. As a result of this and other reviews, a support program for operational research and capacity-building was developed for both Tigray Regional State and Southern Nations Nationalities and People's Region (SNNPR). Supporting International partners are; the Department of Food Business and Development, University College Cork, Ireland, and CAZS, University of Wales Bangor, UK. The operational research and capacity building program began in mid 2003.

In the SNNPR, the institutions involved are the Awassa College of Agriculture, Faculty of Technology Debub University (DU); the Southern Agricultural Research Institute (SARI), Awassa; the Bureau of Agriculture (BoA) at Zonal and Woreda levels; and the Food Security Unit (all hereafter referred to as the Debub Consortium, coordinated and chaired by the University). The institutions involved in the Tigray Regional State are the Mekelle University (MUC); Bureau of Agriculture at Zonal and Woreda levels; Agricultural research Bureau (TARI) and the Relief Society for Tigray (REST). All these are hereafter referred to as the Mekelle Consortium, also coordinated and chaired by the University.

1.2 Background to mission

Both the Mekelle and the Debub Consortia have chosen 2 project areas each in which to conduct the operational research projects. These are, for the Mekelle Consortium, Debre Kidan and Begasheka; and for the Debub Consortium, Umbulo Wacho and Beresa (Figure 1). Development in these four project areas is based on the catchment approach in order to facilitate and underpin progress of the water component of the operational research program. A stated objective of the research is to calculate the catchment water balance for each of the project catchments. To this end, a request was received from both consortia for technical assistance to install raingauges and design appropriate rainfall recording procedures, first in Umbulo Wacho in March 2004 (Hollingham, 2004a) and then the remaining project catchments in June 2004 (Hollingham, 2004b).

Figure 1: Map of the locations of the Operational research project sites



2 Terms of Reference

The terms of reference for the hydrology TA are for each project area:

1. Establish at least 4 raingauges and daily monitoring procedures for farm families and DAs /HAs.

2. Using appropriate participatory recording procedures based on time achievement of preset level;
    - flows between markers,
    - sample flow rates;
    - estimates of daily groundwater use,
    - measure inflow to and outflow from the watershed,
    - area/volume change of residual water bodies,
    - determine methods to continually monitor the water balance of the watershed.

1. Input to include the design of system, frequency of record taking, format of returns, training of HAs/DAs in implementing, analysis and interpretation of results plus the physical establishment of the study.

3 Response to terms of reference

The first and third terms of reference have been achieved with regard to the setting up of a raingauge network and recording procedures in each of the project areas. However, there have been some problems and in general this is because of researchers and DAs other responsibilities. Some farmers are committed to recording although they cannot see direct benefits yet. DAs are recording and collating rainfall records, but they are also trying to fulfil BoA targets, there are frequent staff changes and some DAs lack training. Researchers are very supportive, but have not fully followed up the management and collation of rainfall records. They are hard pressed with teaching and administrative duties and often leave Debub to pursue their studies elsewhere.

The second term of reference relates to the design of appropriate participatory recording procedures, all directed at calculating a water balance, to estimate ground water flow, stream flow and the measurement of water bodies in the catchment areas. Researchers in both consortia are keen to commence additional hydrological monitoring and there does not appear to be a lack of knowledge in either Debub or Mekelle Universities about the various methods and principles used in hydrological monitoring.

Researchers asked the TA to suggest appropriate hydrological monitoring techniques. Advice, references, computer modelling software and discussions of methods were provided by the TA. Researchers appear to lack the confidence to instigate the new recording procedures. The researchers need to apply the lessons learnt from rainfall recording, identify suitable monitoring sites, prepare and provide recording materials, and approach the DAs to identify recorders help with the collation of records. Researchers should submit budgets for this work.

Both consortia have some information on soils and GIS models for the project areas and are submitting proposals for further hydrological research. Some proposals are directed at solving the water balance; however the focus on the water budget as an overriding objective may hinder the collection of hydrological data as understanding the catchment processes requires many observations taken over several years. There is a danger that the farmers will not see the point of the measurements they make. To counter this, research proposals should address other farmer water related problems and the information gained from such projects should be used to calculate a water balance.

Sections 3.1-3.6 will look first at the assistance requested by researchers during the TAs visit, then at the direction of research proposals and ways to direct research to farmers' concerns and indigenous knowledge, and finally at possible hydrological measurement methods and recommendations for monitoring. Section 3.7 looks at the management of rainfall recording, the condition of every raingauge and set of rainfall records; for each project area and consortium. An analysis of the rainfall records for each of the project areas and notes on the condition of the project computers are also presented.

3.1 Discussions with researchers

Methods for estimating the water balance in the project areas were discussed with Debub and Mekelle researchers. This concentrated largely on using existing climate records kept by the meteorological stations near to the project sites, and encouraging farmers to take measurements of flood flows and water levels in wells. A result was agreement that only very crude estimates of the water balance could be made by relying on farmer observations alone and additional work such as soil moisture and hydraulic property measurements, GPS surveys to delineate areas of different soil and rock type, topological surveys, synthetic hydrographs and computer modelling, would be required. A detailed discussion of the methods to be employed is given in section 3.1.5.

As an immediate response to the researchers' requests, the decision was made to encourage all farmers to record start times and finish times of rainfall; and where a farmer was near a gulley he was asked to observe flow.

3.1.1 Materials given to researchers

The electronic materials referred to below were given to the researchers at the time of the visiton a CD. These with any other computer files mentioned in this report are included with 2 CDs accompanying this report.

- Copies of the transcribed rainfall records in Excel spreadsheets which produced daily (in both (Ethiopian and international date systems), dekads and monthly totals, with the exception of the Debre Kidan DA records. These were given to the TA the day he left for Awassa. A spreadsheet template was also made for the researchers and DAs to transcribe the rainfall data.
- A copy of Ward and Trimble (2004) Environmental Hydrology was given to DCI operational research library at Mekelle another copy will be sent to Tewodros Tefera the Debub consortium administrator with this report.
- Excel spreadsheets to calculate
    - o discharge, peak discharge, time to peak, lag time and recession time using the NRSC synthetic hydrograph method
    - o potential evapo-transpiration using the Blaney Criddle, and simplified Penman's formulae.
    - o monthly rainfall records was prepared in Awassa and given to Feto Esino.
- Electronic photos of farmer and DA record sheets
- Trial versions or freeware computer software. CROPWAT, WaterMod, WMS, GMS, TNT and others
- GIS data files and scanned maps
- Previous hydrologist's reports in Acrobat pdf format.
- References. (See Reference list)

3.1.2 Research proposals

Debub and Mekelle researchers both have research proposals directed at GIS catchment modelling which are based on surveys of the soils, measurement of flow in gullies and where appropriate groundwater levels (Appendix 7). Little information was given on the progress of the Debub consortium's proposals.

These are for Mekelle consortium:

1. *Water Resources Investigation: A Case Study in Begasheka Watershed* by Gebreegziabher Lemma (M.Sc. student, Faculty of Dryland Agriculture, Mekelle University) advised by Dr. Nata Tadesse, Assistant Professor of Hydrogeology:

plans to monitor gulley flows, investigate soil and groundwater, record rainfall and evaporation.

and for Debub consortium;

2. *Assessment of soil erosion and sedimentation in Umbulo Wacho watershed using a GIS based survey*. Researchers: Shimelis Gebriye, Alemayehu Muleneh, Tazebe Kiros and Awdenegest Moges. This plans to build a GIS model of the catchment, classifying soil erosion risks and model the hydrology. This proposal will address farmers' concerns of soil erosion.
3. *Water balance of different production systems (the case of the Umbulo Wacho watershed)*'. Researchers; Ashenafi Madebo, Abrehem Woldemicheal, Awdenegest Moges and Asegide Cherenet. This is a plan to conduct water balance studies of farmers' fields and will measure soil moisture, and evaporation on site. This project partially addresses farmers' concerns to identify appropriate agricultural techniques.
4. *Study on the feasibility of water harvesting practices integrated with small scale low cost drip irrigation systems for household food security*. Researchers: Tazebe Kiros and Shemelis Gebriye. This plans to trial simple irrigation systems based on the water harvesting ponds built by the BoA. The proposal will also examine the relationship between catchment size and pond size, and runoff coefficients. The raingauge at Tenkaka will be useful in this regard. The project will address farmers concerns by helping improve the efficiency of the water harvesting and irrigation systems.

All these proposals require a highly technical approach reliant on equipment or modelling. Although proposal 1 directly addresses the water balance, it is long term and requires several years of measurement before useful results could be presented to the farmers. Because of this researchers would be conducting activities which would seem to the farmers to have little relevance to their needs. The focus of the research proposals should be on solving the farmers' water problems using methods that farmers suggest, and then adapting the necessary scientific methodologies so that they can be used and understood by farmers.

The farmers' main concern is water (see below). Farmers should be asked what they want to do to improve water supplies, and then scientific measurements should be directed at solving the farmers' questions. In this way the farmers can see the relevance of the measurements being taken. An example would be the design of a water harvesting system like the ponds in Debre Kidan and Begasheka and the proposed roof water harvesting system at the church at Yosef's (R5) at Umbulo. Without rainfall frequency analysis it is difficult to judge the right size of tank or pond. Building such a system encourages rainfall recording and would also develop the idea of catchment area and runoff coefficient amongst the local population. Proposals 2, 3 and 4 listed above address some of the farmers' concerns.

As research addressing farmers' concerns in the project areas progresses, more information necessary to calculate a water balance would be collected, however there will still be some hydrological parameters that will not recorded unless the farmers are made aware of sustainable water resource use. There is a danger that communal water supplies, especially groundwater, will be used profligately and suffer the tragedy of the commons; i.e. higher levels of technology will be used to exploit the water resource eventually placing access to water in the hands of a few at the expense of the many. If the concepts of sustainability and community are developed, then hopefully a larger awareness of the environment will arise. Farmers will then ask questions concerning the sustainable yield of water resources in the catchment areas, to which research could then be directed. Another benefit of promoting sustainability and environmental awareness would be that it would encourage grazing control, reforestation and soil conservation work.

3.1.3 Farmer concerns

The only PRA document available to the TA is that for Umbulo (Debub, 2003). The main five concerns relating to water resources out of ten listed are presented below. It is likely that there are similar concerns in the other project areas. The primary concerns of the people of Umbulo relate to the quantity and quality of water supplies for agriculture and domestic purposes as well as erosion. Suggestions to increase water supplies mentioned in concerns one and two, apply equally to one another.

Farmers concerns connected to water resources	Farmer suggestions	Researcher suggestions
1. Unreliable rains affecting crop yields (especially in May) and water supplies for humans and cattle.	Borehole - has been tried and failed Piped from water harvesting reservoir – large community project?	Roof water harvesting Improve crop yields by choosing appropriate crop varieties Irrigation
2. Main sources of water are water harvesting ponds which are seasonal. In dry season lake Awassa is the principle source of water which farmers believe is of poor quality.	Water harvesting ponds	Deeper bigger, less leaky ponds Use plastic, cement or animal manure to line ponds Sediment traps Artificial groundwater reservoirs
3. Disease; malaria and possibly liver disease.	Improved water supplies	Simple water treatment, filters, solar disinfection, coagulation.
4. Erosion. There are large numbers of gullies and sheet erosion which in farmers' perceptions is reducing crop yields. 5. Lack of trees and wildlife.		Grazing control Reforestation Soil conservation structures

The Umbulo PRA highlights water security (the supply of water of adequate quality and quantity). Water supplies for agriculture and domestic were both highly prioritized problems. The current focus on developing techniques to record the water balance in the project areas is directed at increasing water supplies and making more efficient use of water, but little is being done to improve water quality. Water borne disease is causing ill health amongst the population and affecting their ability to work. Yosef and Gudeta, farmers recording rainfall at gauges R3 and R4 in the Umbulo project area were asked about drinking water during the visit.

- Gudeta reported human drinking water is collected from surface pools or a hand pump outside of the catchment. Water quality from pools is poor and sometimes smells. This water causes diarrhoea, typhoid and weakens their resistance to malaria. Well water is of better quality but frequently needs clearing.
- Yosef reported that drinking water is obtained from locally made ponds designed to trap runoff. When asked about the water quality, he said that local people were accustomed to the taste, but that they did not like to present this water to their guests from outside the area, but there is no other option. So many people have come and asked questions about their water supply and its quality. To the local population it is a priority issue and interviewers usually then ask what the local people would like to do to improve the water supplies, but the community has no idea of the options available.

The TA suggested 2 options to Yosef, one of sand filters for use with existing water collecting ponds and rainwater harvesting. There is a church near to Yosef which has a corrugated iron roof of $40m^2$. Based on 2004 rainfall, this could supply 80 litres/ day if combined with a $6m^3$ tank and guttering. This would make a useful demonstration site.

A chance meeting with Jemal Adem Yasin (a lecturer in Envionmental Health) and Biruck Desalegm of Debub University informed the TA of government initiatives to raise environmental health awareness as well as to educate the local population, were being run by the Bureau of Health through the HAs (Household Assistants). HAs were being asked to promote water treatment technologies like sand filters, clay pot filters and solar disinfection which are cheap, well proven methods of improving health. So far there seems little evidence that these technologies have reached the people of the Umbulo project area.

3.1.4 Indigenous Knowledge

An additional topic of discussion with Shemalis Gebriye and Tewodros Tefera of Debub University was moving away from conventional water balance studies to a more participatory approach, focussed on farmers' indigenous knowledge of the climate, crops and soils and comparing this with the results of hydrological research. This would enable researchers to identify strengths and weaknesses in the indigenous knowledge of farmers. This discussion was prompted by the observation that farmers know when their crops are moisture stressed. By asking farmers how long certain crops can survive between periods of rain, a comparison of the water holding capacity of the soils can be made. This can then be verified by scientific study of the soil properties.

Research of this kind needs to be designed carefully so as to ask several non leading questions that can crosscheck the answers elicited from farmers. The extent of areas of indigenous knowledge might lie outside the expectations of researchers and will need to be identified. Below are listed some areas of indigenous knowledge that the TA expects the farmers to hold. This is not an exhaustive list and other areas may come to light.

- How dry /wet has the weather been?
- Yields of crops in good average and bad years of rainfall
- How long can crops go without rain during various stages of crop growth on certain fields or soils?
- Which crops require the most water?
- Which soils/ fields are best for which crops, and why?
- Areas of the catchment that are wetter/drier
- Direction of rainstorms
- Which parts of the catchment produce the greatest runoff?
- When is runoff greatest?
- What is the effect of enclosure and soil conservation works?
- Height and frequency of flood events

This knowledge will provide researchers with additional information to incorporate and calibrate catchment models.

3.1.5 Proposed research methods for water balance studies in DCI project areas.

Researchers in both Mekelle and Debub universities were keen to commence measurement of other water balance parameters. Discussions of the various methods and their applicability within the constraints of the project (minimal equipment and reliance on farmer recording) then ensued. Water balance studies are problematic even with the best equipment and researchers, largely because hydrological processes are complex affected by spatial and temporal variation, with the result that similar rainfall events do not necessarily cause similar catchment responses. The methods outlined will lead to 'ball park' estimates of the water balance.

The methods proposed concentrate on collection of rainfall, evaporation, stream discharges and groundwater levels by farmers. There is a need for constant checking of data collection and recording methods, especially when observations are made by several observers. The constraints of minimal equipment mean that observation and data collection will be labour intensive. Observers will require training, equipment, recording sheets in their own language and perhaps incentives to make time consuming observations.

Researchers are required to train farmers in observation techniques, to collect the farmer records and to gather additional information such as the physical characteristics of the catchment, (size, slope, soils) and the number, location, and dimensions of hydrological features within the catchment area. Researchers will use this information to convert farmer measurements into estimates of the water balance components and report this back to farmers via the Ministry of Agriculture extension workers (DAs). Researchers and farmers will be able to use this information to assess soil and water conservation structures and appropriate cropping patterns.

The proposed techniques suggested in this document will need refinement and calibration in the field. It is proposed that the study is kept as simple as possible, and that hydrological measurements are directed at farmer concerns. Rainfall and evaporation estimates can be used to calculate water use of crops in the catchment, while stream flow and groundwater measurements estimates can be used to estimate the amounts of water available for irrigation. To design soil conservation and water harvesting structures, hydrographs, runoff coefficients, rainfall intensity and duration probabilities, and rainfall event frequency analysis are required.

3.2 Calculating a water Balance

The water balance is used to estimate available water resources. Sustainable water use concentrates on maintaining groundwater levels to ensure water levels do not diminish.

The water balance equation is

$Q=P-Et \pm \Delta S$

Where Q = Stream flow discharge

P = Rainfall

Et =Evapotranspiration

S = Groundwater

All parameters can be considered as volumes of water. Rainfall and evaporation are generally measured as depth and applied across the area of the catchment. Stream flow is measured as volume directly and in the project areas takes the form of ephemeral flows in gullies. The groundwater term is considered as a change in volume over the period of consideration. Groundwater volume is difficult to measure and often the errors made in taking other water balance parameters are included in this parameter.

3.3 Measurement of water balance components

3.3.1 Precipitation (P)

3.3.1.1 Measurement

Daily rainfall is already being recorded in the project areas by farmers using collecting raingauges. This information is useful but measurements of rainfall intensity and duration are needed to calculate peak discharges with the Rational or NRSC methods (see stream flow section below).

Rainfall records have many uses.

- Daily, dekad and monthly rainfall: water input into the catchment, crop water requirements, drought return frequency, soil moisture and groundwater studies
- Real time rainfall records: rainfall intensity duration curves, storm return frequency, flood event modelling, water harvesting and soil conservation structures

Recording raingauges from which rainfall intensities can be calculated have been installed; however there have been problems with the dataloggers and only records for Beresa are available for the 2004-2005 (1996-1997 (E.C.)) hydrological year. If the problems with the dataloggers persist then research will have to rely on farmers' records of the start and finish times of rain storms.

3.3.1.2 Analysis

At present there is too little rainfall data for researchers to construct rainfall intensity duration curves (Ward and Trimble (2004) p 41), two or more years data would give more reliable results. Some preliminary rainfall intensity duration analyses can be done on the full record of the data logger at Beresa, which contains enough of a record to simulate expected peak flows using the Rational and SCS methods. The daily rainfall record combined with the start times and finish times that farmers are now being asked to record, can be used with the Rational and SCS methods.

New rainfall recording forms have been given to the farmers in Umbulo and Beresa, but new rainfall recording sheets are required for Begasheka and Debre Kidan. The Mekelle researchers should translate these into Tigrinya. For the farmers and DAs booklets of sheets should be made up out of the 13 daily sheets, a dekad sheet, and a monthly total sheet from Appendix 1.

Analysis of monthly or annual rainfall return periods (Ward and Trimble (2004) p 45) is possible where there are several years of record. This is the case in Begasheka and Umbulo. Some preliminary analyses are presented in section 3.7.

A spreadsheet template has been created into which farmer rainfall records can be pasted directly to produce daily, dekad and monthly totals and cumulative graphs. This was given to Debub and Mekelle researchers and installed on the DAs' computers in Beresa and Umbulo, but also needs to be demonstrated to the DAs in Debre Kidan and Begasheka and installed on the computers there.

A spreadsheet has been produced which analyses monthly total rainfall for several years of record and produces tables of monthly rainfall frequencies and can also compare an annual monthly rainfall record to the average monthly rainfall. This can be used to choose appropriate monthly rainfall for water harvesting and soil conservation structures. This spreadsheet has been given to Debub researchers. Mekelle researchers can find it on the CD1 accompanying this report.

The total rainfall input into the catchment (areal distribution of rainfall) should be calculated by researchers using the arithmetic mean of all raingauges or the Thiessen polygon method (Ward and Trimble (2004) p43).

3.3.2 Evapotranspiration (Et)

There are two types of evapotranspiration, potential and actual. Potential Et estimates are useful to predict actual Et, measure open water evaporation and crop-water requirements, whilst actual rates are useful for judging the overall impacts in changes in vegetation landuse and cropping methods and calculating the water balance.

Formulae methods use climate data to predict potential Et. Evaporation pans measure potential Et, while soil moisture measurements and lysimeters measure actual Et. Computer models based on soil properties and climate data can calculate the soil moisture balance and actual Et rates.

3.3.2.1 Formulae methods

Formulae methods like the Modified Blaney Criddle (Appendix 8) ((Ward and Trimble (2004) p103; Doorenbos and Pruit (1993)) and the simplified Penman's method (Ward and Trimble (2004) p108) could be used, however there is limited available data with which to work. Solar radiation, sunshine hours, relative humidity and temperature might be available from nearby meteorological stations to the project areas. Maximum and minimum temperatures for the Blaney Criddle Method could easily be recorded by farmers in the field. Meteorological station Penman Et and Blaney Criddle Et estimates could be correlated to provide a correction factor to apply to field Blaney Criddle estimates. Farmers could be provided with tables to convert Maximum and Minimum temperatures into Blaney Criddle evaporation estimates.

3.3.2.2 Evaporation pan

Evaporation pan measurements recorded by farmers are also possible but this would only provide potential Et estimates and not actual Et estimates. Pans could be monitored by farmers but would need a ready supply of water from a well or spring and protection from animals. (Ward and Trimble (2004) p92). These difficulties may make this method impractical.

3.3.2.3 Soil moisture balance

Actual Et can be obtained by researchers measuring soil moisture gravimetrically (Ward and Trimble (2004) p93, Doorenbos and Pruit (1993)). The recognized method is to take several field samples at several depths, seal them and take the samples to a soil lab for analysis. Gravimetric measurements could be taken in the field by trained farmers or DAs using very large samples (>1kg) and a set of kitchen scales. Soil samples could be air dried in the sun over a period of a week. Soils are very variable and a variety of soils and would have to be tested with several replicates.

Alternatively soil analysis to derive soil water and suction measurements could be used with tensiometers or gypsum block resistivity measurements (Ward and Trimble (2004) p75, 78).

Field capacity and wilting point for the different soils can be judged by touch in the field using a technique described by Hudson (1975) (Appendix 17). Farmers could be trained and provide information for catchment modelling. The results of this should be tested against soil moisture studies.

3.3.2.4 Lysimeters

Lysimeters are a small area of soil where runoff and subsurface flows in and out can be isolated. Lysimeters have limited application as they are very site specific and require a lot of monitoring, although they are useful to calibrate soil moisture models. The soil moisture content can be monitored either by weighing or by collecting the water draining out of the soil profile. Plots within fields surrounded by cutoff drains to prevent runoff could be used, however subsurface drainage can not be monitored and soil moisture would have to be measured using the methods outlined above.

A lysimeter could be built based on the design of water harvesting ponds in the area. Water falling below the rooting evapotranspirational depth could be collected in a sump accessed by a pipe (Ward and Trimble (2004) p94) and monitored by farmers.

3.3.2.5 Computer modelling.

Soil water and suction measurements could be used with measurements of infiltration rates (Ward and Trimble (2004) p78), saturated and unsaturated hydraulic conductivity (Ward and Trimble (2004) p79), and soil particle analyses (Ward and Trimble (2004) p74) to model soil water movement and evaporation using a computer program such as

Water Mod (www.greenhat.com.au/watermod) or FAO's CROPWAT which researchers are already familiar with. Both of these programs are on CD2 accompanying this report.

3.3.3 Stream flow (Q)

3.3.3.1 Location

The priority for calculating a water balance is to measure stream flow at the point that water leaves the catchment, while this reduces the recording by farmers and analysis by researchers, unless a water harvesting structure is planned at the exit point then measurements recorded by farmers will only provide a general estimate of the overall catchment characteristics and will not negate the need to monitor flows where water harvesting and soil conservation structures are planned. Flows from major tributaries and existing water harvesting structures should be recorded; this will allow the runoff characteristics of the sub-catchments to be estimated.

3.3.3.2 Measurement

There are three main approaches to measuring stream flow: direct measurement, estimates based on rainfall, and synthetic hydrographs (plots of the variation of discharge with time)

3.3.3.2.1 Direct measurement

A more detailed description of the methods in this section can be found in Appendix 9: Stream flow Measurement. The discharge at a point in time can be estimated using the continuity equation:

Discharge = (Cross Sectional Area) x (Flow Rate).

3.3.3.2.2 Cross sectional Area

Cross-sectional area varies with the height of water in the channel, as does the flow rate. Cross-sectional area of gauging points has to be measured accurately by researchers. Farmers could be provided with a pole and a tape measure to measure the height of water in the channel. Where possible farmers should be provided with conversion tables or measuring sticks calibrated in flow rates so that farmers can interpret the measurements for themselves.

The cross-sectional area is easier to determine if a regular, straight and smooth section of the stream channel is used. Such sections exist in the main gullies in Begasheka and Debre Kidan, but the bed is irregular. Gullies in Umbulo are more suitable. Building an artificial structure such as a spillway or a check dam would provide an easily calibrated gauging point.

3.3.3.2.3 Flow rate

This can be estimated using direct measurement of flow, or inferred from flood height since height and flow rate are correlated. Manning's equation or equations designed for weirs also use measurements of flood height.

The simplest direct measurement of flow would require farmers to observe the time taken for a float to travel a pre set distance (5-10m), three times and take the average reading and multiply this by 0.6. After a few measurements flow rate could be plotted against flood height which farmers could use in the field to convert flood heights into flow rates.

This calibration would need to be checked periodically. This method of comparison could also be used to check the validity of the chosen Manning's roughness coefficient.

Manning's equation (Ward and Trimble (2004) p. 207) uses flood height, channel dimensions, slope and a roughness coefficient to estimate discharge. Three measurements of water levels in the channel could be recorded by farmers and the average value taken.

Measurements of flood height could be improved by installing a measuring structure such as a v-notch weir or the construction of a spillway (Ward and Trimble (2004) p. 229) and the flow rate calculated using the appropriate equations. Measurements of the height of water flowing over the weir or spillway could be measured by farmers; only one measurement would be required to calculate flow at that point in time.

3.3.3.2.4 Hydrographs

Direct measurement methods allow unit hydrographs to be constructed by researchers that truly reflect the catchment characteristics, and also allow the discharge and peak flows to be calculated for any rainfall event after a few surface flow events have been recorded ((Appendix 10)(Ward and Trimble (2004) p397)). This requires that farmers observe several flow events recording flood heights and flow rates (which are then converted to discharge rates) and time of observation at regular intervals. This is time consuming and requires training on a flowing river and remuneration of sorts.

Daily measurements of stream flow can be used to construct recession hydrographs of flood events. These could be used to estimate groundwater recharge (3.3.4.3).

3.3.3.3 Estimates based on rainfall measurements.

These include the Rational and the SCS or NRSC method. Both can be used by researchers to estimate surface flows (Appendix 11 and Appendix 12).

3.3.3.3.1 The Rational Method

The Rational Method (Ward and Trimble (2004) p.140) (Appendix 11) calculates the peak flow rate based on rainfall intensity measurements. These can only be obtained from a recording raingauge or observations of the start and finish times of rainfall. This method assumes a constant proportion of the rainfall becomes surface runoff. This proportion is termed the catchment coefficient, which if not estimated directly from the relationship between stream flow and rainfall measurements, can be estimated from slope, soil type, soil condition, vegetation type /land use management values and read from tables. Cook's method (Hudson, 1993) (Appendix 11) is one such method reliant on tables. Further refinements to Cook's method can be made using time of concentration and area tables.

Actual runoff rates can be measured using runoff plots which can also be used to measure soil erosion. Combined with the rainfall data, runoff coefficients can be calculated at a range of scales from a whole catchment down to a few meters of hillslope. Ready made runoff plots are available in Debre Kidan and Begasheka, where water harvesting structures have been built. By measuring the volume of water collecting in these, a runoff coefficient can be calculated. In Begasheka the large stone lined water harvesting ponds are a trapezoid shape and the volume of water within them can easily be related to height.

The ponds also have constructed spillways, and flow over these is easy to relate to depth using Manning's equation (Appendix 9).

The rational method can be modified to calculate total runoff by replacing the rainfall intensity term with total rainfall for a particular storm. This method is likely to overestimate stream discharge if rainfall events occur in small showers (<5mm), for this reason small storms (<5mm) are ignored in computing stream discharge especially if rain has not occurred for more than 10 days.

Farmer observations of whether stream flow occurs at all could be used with the rainfall records to determine the size of rainfall event needed to generate runoff. Farmer Gebremedhin Hailu (R2) Begasheka, Embartom (R5) Umbulo, and Abraha Weldat (R3) have all agreed to do this.

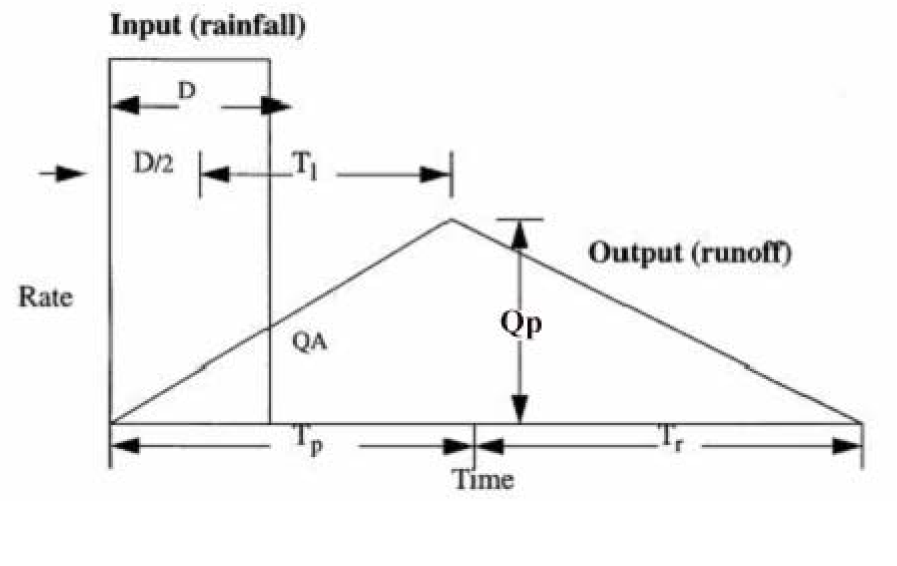
3.3.3.3.2 The Synder, SCS or NRSC method

The Synder, SCS or NRSC method uses Curve Numbers (CN) ((Appendix 11 and 12) (Ward and Trimble (2004) p.132))). Curve numbers are based on infiltration rates and surface storage properties of the catchment. The curves are curvilinear, and assume that the runoff coefficient for a catchment will initially be low but will increase with increasing rainfall. Curve numbers can be adapted to account for different soils, land use practices, antecedent conditions and rainfall distributions.

Further refinement is possible with this method and combined with rainfall durations, synthetic unit hydrographs can be developed.

3.3.3.3.3 Synthetic hydrograph methods

The simplest of these methods approximates the unit hydrograph with a triangular shape and equations have been developed to estimate Time to Peak (Tp), Recession Time (Tr), Peak Discharge (Qp) and Effective Rainfall (D), based on the SCS curve method. The parameters required are slope, catchment area, hydraulic length, rainfall, and SCS curve number ((Ward and Trimble (2004) p.132)(Appendix 12)).



The problem is that this method has primarily been developed for the USA and research or a review of literature is required to identify appropriate curve numbers and equations describing the hydrograph for the project areas.

Instead of relying on equations, actual measurements of peak flow, the time of peak flow, the start and finish times of rainfall and flows in the channel, could be measured by farmers and used to construct triangular hydrographs.

For measurements of peak flows farmers should record the height of debris or trash lines on the sides of the river channel (Benson and Dalrymple, 1967, p.16), this requires farmer training. Flow can be calculated by any of the methods mentioned above including Manning's equation. Farmer Abraha Weldat (R3) has agreed to do this in Debre Kidan at the exit point of the catchment on the May Gundi. He needs to be provided with modified rainfall recording sheets which contain a column for peak flow recording.

3.3.3.4 Computer modelling.

Surface water discharges can be modelled using GIS software like Arcview, TNT (www.microimages.com) and WMS (http://www.emrl.byu.edu). REST already have enough hydrological and GIS information to carry out some preliminary modelling at Begasheka (REST, unpubl.(b)) and Debra Kidan. A copy of the files in TNT format and the TNT trial software accompanies this report on a CD 2. The topography of the Umbulo and Beresa catchments has been digitized and the Arcview files are also on CD 1.

3.3.4 Groundwater (S)

It is likely that there are several aquifer types in the catchment areas. Sediment aquifers will be easier to identify and estimate groundwater storage for. Fractured hard rock aquifers are more difficult to determine (Ward and Trimble (2004) p336). Hard rock aquifers are likely on the high ground of the study areas.

In the water balance equation the groundwater term is represented by ΔS, a change in storage over the time interval. Storage can be estimated by either knowing how much water is in the ground at two different time intervals or by measuring how much water went into the ground (recharge) and how much came out (baseflow) over a certain period. Hence there are two aspects, groundwater storage and groundwater flow.

The simplest method to calculate ΔS is the *water budget method*. This assumes that the residual rainfall after accounting for stream flow and evaporation is groundwater. This works well if these terms can be measured accurately, but estimates of stream flow are likely to be inaccurate using the methods proposed above. Fetter (1994) found that when using the water budget method, errors in the measurement of the catchment water balance ended up being lumped in with ground water mainly because of the difficulty in its measurement. This is the case in the project area. The only alternatives are to measure groundwater storage and groundwater outflow.

It is possible however to ignore groundwater storage, in the following cases:

- By assuming that the groundwater storage returns to its minimum level at the end of the dry season every year. This is applicable where there are no groundwater abstractions, which is not the case in the project areas in Debre Kidan and Begasheka.

- o The water table measured in all wells across the catchment returns to the same level.

3.3.4.1 Groundwater outflow

There are two components of groundwater outflow, abstractions and natural drainage out of the catchment. Natural drainage can be measured by researchers using the hydraulic gradient method (Todd, 1980 p. 81). Water level measurements across the catchment are used to calculate the hydraulic gradient (i) and then used with estimates of hydraulic conductivity (K), and the cross sectional area (A) of the aquifer at the gauging point to calculate groundwater flow using

$$V = AKi$$

The hydraulic gradient (i) can be based on observations of water table heights in wells, requiring farmer measurements of the water level relative to the ground surface. Farmers should be provided with a tape and a marked measurement spot for this purpose. The height of the ground surface needs to be known with some accuracy. Maps could be used for this but the topological maps available are not of sufficient detail. A levelling survey is the recognised method of determining relative heights but is an expensive and difficult operation. Alternatives are to use GPS height measurements which are notoriously inaccurate, unless a differential GPS system is used, or a barometric survey, which is also inaccurate (+-1m) and subject to changes in air pressure. However repeated barometric surveys could be statistically analysed to improve accuracy.

The hydraulic conductivity can be estimated using the auger hole method, which measures the rate of rise or fall in water level in a hole dug into the water table. This could be done in the base of dry wells (Ward and Trimble, 2004 p.80). Water should be removed several times to remove any fine particles blocking soil pores first. The hydraulic conductivity is then 0.8 x the rate of rise. (Hudson, 1993). This method is not recommended if the water does not return to its original level within 10 mins. Farmers or DAs could conduct these tests themselves with training and if provided with tables to read off the results.

The cross sectional area (A) of the aquifer would have to be estimated from maps and ground GPS surveys conducted by researchers, trained farmers or DAs, although depth of the aquifer cannot be determined without geophysics or coring.

Difficulties in determining the depth of the aquifer and the need for a topographic survey make the hydraulic gradient method almost impractical, although water levels could be measured in the field by farmers.

3.3.4.2 Abstractions

Abstractions are a component of groundwater outflow. Pumps are being increasingly used for irrigation, cattle and domestic water use. Estimates of domestic water use can be made by surveys at hand pumps. Cattle water consumption can be estimated from the numbers of animals and their drinking requirements. Irrigation water abstractions would have to be assessed by asking farmers how long they irrigated for and determining the output of their pumps. These surveys could be conducted by researchers or trained DAs or the information gleaned form other operational research projects.

3.3.4.3 Ground water recharge

Researchers can use this method on two or more stream flow hydrographs (Appendix 14; Fetter, 1994. p 64) to work out the groundwater recharge (V_t in m^3) from semi-logarithmic plots of the flood recession curves. Taking the maximum stream flow rate (Q_o in m/s) and the time (t_l in s) taken for the stream flow rate to reach 10% of the maximum, $V_t = Q_o t_l/2.3$. If V_t is calculated for t_l on two consecutive flood recession curves the recharge rate of the aquifer is the difference in V_t.

This approach for assessing recharge has great scope for inaccuracies as it assumes that all the groundwater leaves as surface water at the catchment outlet and that there are no abstractions. In Debre Kidan and Begasheka there are some abstractions and also some flow within the sediments of the gulley bed.

Daily stream flow measurements after the main rains recorded by farmers could be analyzed, even though baseflow is likely to be short lived. Baseflow should be assumed to be stream flow occurring 24 hours after rainfall.

3.3.4.4 Groundwater storage

Groundwater storage can be determined by monitoring groundwater levels and knowing the storativity of the aquifer. Storativity is a measure of how much a depth of water added or removed changes the water level height. Storativity tends to decrease with aquifer depth. The amount of water draining or recharging from an aquifer may be found from the formula: $Vw = S\ A\ \Delta h$,

where **Vw** is the volume of water drained or added from an aquifer,

A is the surface area of the aquifer. This is relatively easy to estimate as it is often assumed to be the same as the catchment area (however this may be a gross simplification). A ground survey is required to identify the extent of different aquifers in the project areas.

Δh is the change in water level in the aquifer. Δh can be measured using farmer observations of water levels as discussed above in section 3.3.4.1.

S is storativity, the volume of water that an aquifer unit will absorb or expel from storage per unit surface area per unit change in head; S is difficult to measure and can be determined by the Slug test (Appendix 15) (Fetter, 1994 p 243; Ward and Trimble (2004) p330)

Slug tests rely on a rapid change in the water levels in a well, which is difficult to achieve in wide radius hand dug wells. However modified slug tests could be attempted in soil auger holes in the bottom of dry wells using the method outlined in section 3.3.4.1 Farmers or DAs could conduct these tests themselves with training and if provided with tables to read off the results.

Another method of estimating storativity is to observe the changes in water levels after rainfall, when there has been no surface runoff or the surface runoff is known. This can be done using rainfall records and farmer observations of water levels.

Without knowing storativity, groundwater levels will only give an indication of the size of the groundwater reservoir and whether the groundwater is being recharged or drained.

If the groundwater table returns to a previous level across the aquifer then the water balance can be calculated for that period by ignoring the ground water term.

3.3.4.5 Computer Modelling of ground water

With both of the above approaches, for estimating groundwater storage, researchers can obtain better estimates by modelling the aquifer properties (Fetter, 1994. p 593) using computer programs like the Groundwater Modelling System (GMS) (http:www.emrl.byu.edu and on CD 2 with this report) or Groundwater Vistas (http://www.groundwatermodels.com/software/SoftwareDesc.asp?software_desc_id=19 &software_id=6) both of which use Modflow, the USGS groundwater modelling algorithm. These programs allow modellers to match changes groundwater levels with aquifer properties. These programs need water level records along with other data. Surveying water levels should begin as soon as possible so that there is sufficient record to conduct computer groundwater modelling.

3.4 Recording of hydrological parameters

The current state of the rainfall recording is described in section 3.7. This section deals with the recording of new parameters which need to be recorded by farmers and used with additional research carried out by researchers. The main areas are outlined in Table 1 below.

The procedure for the monitoring and collation will be very similar to that of rainfall recording described in section 3.7. DAs should be approached and with researchers suitable observers should be recruited. New farm recorders need to be found to record temperatures, well levels, abstractions and peak flow measurements described in the earlier sections. These can be adapted versions of the rainfall recording forms. Appendix 16 contains some suggested versions of these forms.

DAs will be asked to collate this information, however for all measurements this will consist of transcriptions of the observers' forms. Evaporation measurements will need totalling and averaging to calculate the Blaney Criddle Et.

Researchers should make their own copies of the DAs' records and check against the observers' records before using the records in hydrological research.

Table 1: Further measurements required for water balance research

Water balance parameter	Farmer	Researchers	
	Recording	Measurements	Processing of farmer data into
Rainfall	Daily rainfall Start and finish times of rainfall Time of greatest intensity	Recording raingauge data logger	Areal rainfall Dekad total rainfall Monthly total rainfall Rainfall intensity duration curves
Evaporation	Daily temperature Soil moisture determination by hand.	Determine soil moisture holding properties	Evapotranspiration rates Prediction of crop stress and irrigation need Comparison of Penman equation with Blaney Criddle based on nearest Met station data to project sites
Stream Discharge	Presence of flow Daily flow measurements Peak flow heights Start time and finish times of floods Time of peak flow Float measurements rates over fixed length Water levels in water harvesting ponds	Channel cross sections Channel slope Channel roughness	Peak flow volumes Time to peak calculations Determine channel stage discharge relationship Total stream flow
Groundwater	Daily groundwater levels in pools and wells	Well surveys Specific yield and hydraulic conductivity tests GPS mapping Geological mapping Topographical levelling, especially of wells and surface ponds Well water sampling (Conductivity and pH)	Groundwater storage volume Groundwater recharge rates Groundwater outflow rates Effectiveness of land management Sustainable groundwater yield
Abstractions	Water records kept by local population	Observation and survey of abstractions from all water sources, springs, wells, hand pumps, surface ponds, river beds.	Total volume of water abstracted

3.5 Return of the results to farmers

Results of the catchment water balance study are to be presented by researchers to farmers and DAs at annual meetings. Farmers should be given paper copies of graphical representations of the results.

Farmers should be informed of:

- The state of the water balance and comparisons with previous years.
- The results from the other raingauges in their project areas presented as rainfall maps so that farmers can see which parts of the project areas are wetter than others.
- The soil moisture balance based on rainfall, evaporation data and soil moisture studies.
- The amount of water flowing in gullies, the minimum rainfall required to produce flow and the amount of water available for storage.
- In areas where there is groundwater, maps of the groundwater levels and changes compared to previous years should be produced. The effects of abstractions and recharge structures should be made clear to the farmers so that they can assess the sustainable level of groundwater abstractions.

3.6 Expected outputs

Farmers and DAs trained in hydrological techniques and informed of the hydrological conditions of their watershed.

Farmers, researchers and DAs provided with information enabling them to:

- chose appropriate crop varieties
- decide the amounts of irrigation water to provide
- design water harvesting and soil conservation structures
- determine the safe level of sustainable groundwater abstraction
- assess the effectiveness of soil and water conservation structures
- undertake simple hydrological measurements
- calculate a water balance
- simulate the effects of rainstorms and droughts

This information can also be used in combination with other research to determine:

- soil erosion rates
- the effects of afforestation
- the suitability, and design of suitable modifications for the project areas of the following methods
    - NRCS
    - Rational
    - Cook’s
    - Blaney Criddle
    - Groundwater recharge by flood recession

In addition researchers will produce papers to present to the international scientific community.

3.7 Current hydrological monitoring

In Beresa, Debre Kidan and Begasheka, three collecting raingauges were installed on farmers' homesteads, whilst in Umbulo five collecting raingauges were installed. One recording raingauge was installed at the DAs' office in each of the project areas (Hollingham, 2004a). These have a 1mm tipping bucket raingauge, a counter for the DAs to record daily rainfall and a datalogger which can be downloaded to a PC. A full description of the collecting and recording raingauges; the instructions for installation and for reading the raingauges and recording the rainfall are given appendices 2, 3, and 4. Slightly modified instructions for the export of datalogger files are included in Appendix 6.

Details of the locations of raingauges, names of recorders, and rainfall records from each of the project catchments, are presented in detail under the relevant project area in this report.

In all areas the farmers and DAs were trained to read the raingauges and given the tasks of: collating the farmer records and calculating monthly and dekad totals (Appendix 5) on record sheets similar to those in Appendix 1; and producing graphs to display the results in their offices.

State of recording

New rainfall recording forms have been given to the farmers in Umbulo and Begasheka but new rainfall recording sheets are required for Begasheka and Debre Kidan. The Mekelle researchers should translate these into Tigrinya. For the farmers and DAs, booklets of sheets should be made up out of the 13 daily sheets, a dekad sheet, and a monthly total sheet from Appendix1.

Farmers are recording the time that rainfall measurements were taken using the Ethiopian system. At present farmers are asked to record rainfall first thing in the morning ideally, and also note the time the recording was made. This information should be used by researchers when examining daily rainfall patterns at some future date. So far the TA has not compiled this information, or the weather information which could be used for evaporation estimation.

Records and the state of recording for each of the project areas are discussed in detail in the relevant sections of this report. So far the farmers have kept records of rainfall during the main rains; most are fairly committed and keep good records. The collation of the data by the DAs was more sporadic. Records for Begasheka were not available; records for Debre Kidan covered only the early part of the rains; records for Beresa were available for the main rains, but dekad and monthly totals were calculated incorrectly; in Umbulo the Awassa records were not available; and in Boricha records were complete and some monthly totals had been calculated.

There were various errors in the copying of the farmers' records to the DA record sheets in all project areas. DAs' collation needs to be improved through training. Preliminary training was given to the DAs when the raingauges were installed, however this has not been enough. Reasons for this are:

- poor numeracy;
- some DAs have changed (Umbulo (Awassa and Boricha));
- new record sheets and calculators (Awassa) have not been delivered.

Researchers need to:

- Train the DAs in how to collate farmer records on paper or computer, researchers should observe DAs filling in record sheets and set examples to work through.
- Ensure that farmers and DAs have booklets of the new record sheets. Mekelle researchers should translate the record sheets in Appendix 1 into Tigrinya. Sheets should also be labelled for them.

Researchers from both consortiums had not processed the rainfall data from the DAs or farmers. Some visits had been made by researchers (though these were not logged), but no rainfall data from any of the catchments was presented to the TA. This does not bode well for other farmer measurements like peak flows and groundwater levels. The reasons for this failure include:

- *Lack of continuity in Ethiopian hydrology researcher*. In both consortia the Ethiopian counterpart accompanying the TA in installing the raingauges and initiating rainfall recording has changed on every visit. In Mekelle it was unfortunate that Desta Gebremichael was away during the time of the visit. Desta seems still very much involved in the project and may have collected the farmers' records. Fasil Ejigu, Desta's replacement on this visit has worked with Desta in REST and has also carried out hydrological studies of Begasheka.

  In Debub, the previous counterpart, Tazebe Kiros had left to study a soil conservation MSc in Holland. His predecessor, Awdenegest Moges will be returning in May 2005 and will be using the rainfall data in his PhD. Feto Esino the counterpart on this visit, is in a similar position that Tazebe was in, and has other university duties which may prevent him from carrying out the analysis of the rainfall records and instigating other hydrological recording.

  The project coordinators should take overall responsibility to ensure that farmers and DAs receive new record books and their old record sheets are collated.
- *Lack of supervision by the TA*. Communication with Ethiopia is difficult. Both universities suffered from poor internet access and email communication has been minimal. Faxes and phone calls have proved better.
- *Lack of research utilizing rainfall data*. Project proposals have been developed by both consortia, however none have as yet been implemented; this situation might change. In Umbulo, Awdenegest Moges will shortly be using the rainfall data.

3.7.1 Mekelle Consortium

Desta Gebremichael of REST had worked with the TA on the previous visit and had helped install the raingauges in both project areas and been given technical advice on rainfall recording and additional hydrological measurements. Unfortunately he was absent at the time of the visit, returning just before the TA left for Mekelle. There was no opportunity to discuss in detail the rainfall recording with him.

The rainfall records had not been collated since the TA's last visit. Following the installation of the raingauges and up to two months afterwards, Dr. Mebrahtom, Ermias Aynekulu (MUC staff) and Desta Gebremichael had visited the site and checked recording procedures; but there were no reports of visits since then.

Farmer collecting raingauges are in good order, although all but one farmer in Begasheka had taken his raingauge inside the house to prevent vandalism. About half the farmers were present at the time of the visit, but all farmer rainfall record sheets were available for inspection. These were in good order and legible. Farmers were close to running out of rainfall recording forms and need to be provided with Tigrinya versions of the sheets in Appendix 1. These new sheets have additional columns to note the start and finish times of rains.

The DAs in both Debre Kidan and Begasheka were in Mekelle for computer training associated with the operational research program and so it was not possible to inspect their full records in the field.

There were some discrepancies between the farmer monthly totals, the totals transcribed by the DAs and totals calculated by the TA.

The dataloggers from both catchments contained no record, this appears to be because of mistakes made when downloading the data to the computer and preparation of the logger afterwards. Desta had been trained by the TA during the installation of the raingauges and instructions had been developed with him, however Fasil who had not had access to the instructions in the TA's 3rd report, had also tried to download the datalogger.

3.7.1.1 Debre Kidan

This catchment is 10km south of Hawzien, 100 km north of Mekelle. Some background material was available for the area from a REST (unpubl. (a)) document, written in part by Fasil Ejigu. DCI has been working with the BoA to construct wells and groundwater recharge structures in the area. The site was visited on 9th March 2005. Rainfall recording began on the 19th June 2004 and finished on 11th November 2004.

3.7.1.1.1 Climate

There is a meteorological station at Hawzien that has been in operation for 5 years. Rainfall is unimodal and erratic, averaging 479 mm/yr for the period 1998-2002. The average temperature is 21°C. (REST (unpubl.(a)).

3.7.1.1.2 Hydrological features

The area of the watershed is 901 ha. There is evidence of river channels and gulleying which in places has been checked. It is not until just before the exit of the catchment that permanent surface water is found. The surface water features here form the May Gundi, a tributary of the Ruba Kalaydibhara (Figure 3).

The discharge point on the May Gundi was inspected with Abraha, the rainfall recorder at R3. There were pools of water in the May Gundi from which cattle were drinking. Children were also collecting water for stall fed cattle, from a spring in the river bed (Figure 2). At the time of visit there were pools of water in the May Gundi from which cattle were drinking. Children were also collecting water, for stall fed cattle, from a spring in the river bed.

There are low stone terraces on the steeper slopes and infiltration pits on the flatter areas. There are also many hand dug wells, some open, some covered and fitted with Indian Mark 2 hand pumps. There are about 47 water wells in all, of which 12 have water for the whole year, and another 35 have water for five months of the year. Some are under construction or improvement, which generally consists of lining with stone.

A treadle pump was being used for irrigation from a hand dug well outside the catchment, there were also signs of diesel pumps pumping water from wells for irrigation in the project area. A REST and ‘A Glimmer of Hope’ hand pump had been installed on a hand dug well nearby to R2 for which 25 birr a month was collected from each family using it.

There are several groundwater recharge structures approximately 30m wide and 1m deep which have been constructed by the BoA in the in 2003. Water was observed in one of these.

The water table was about 0-3 m deep and there were signs (green grass, water in streambeds) indicating that the water table was close to the surface in some places. As at the time of visit it was close to the beginning of the hydrological year the water table is probably at its annual minimum.

__Figure 2: Water structures in Debre Kidan__

The outlet of the catchment on the May Gundi. (This section is ideal for flow measurements)

Treadle pump being used for irrigation just outside Debre Kidan

REST hand pump near R3

3.7.1.1.3 Physical condition of raingauges

The three collecting raingauges were placed in the catchment, the recording raingauge is located just to the north outside the catchment at the Debre Kidan Tabia DAs' office. The locations and distribution of the raingauges are not ideal. R1 would be better placed in the centre of the catchment, however the distribution of elevations is good. The locations of the raingauges and the people that monitor them are shown in Figure 3 and Table 2.

All collecting raingauge posts and fences were present and in good condition on the farms, however farmers had taken the raingauges off the mounting posts after November and had not replaced them.

The DA raingauge was still in position, but the cable to the counter in the DAs office had been cut, and when asked the DAs in Mekelle claimed that they knew nothing about it, implying that it must have happened recently.

Figure 3: Map of Debre Kidan catchment project area.

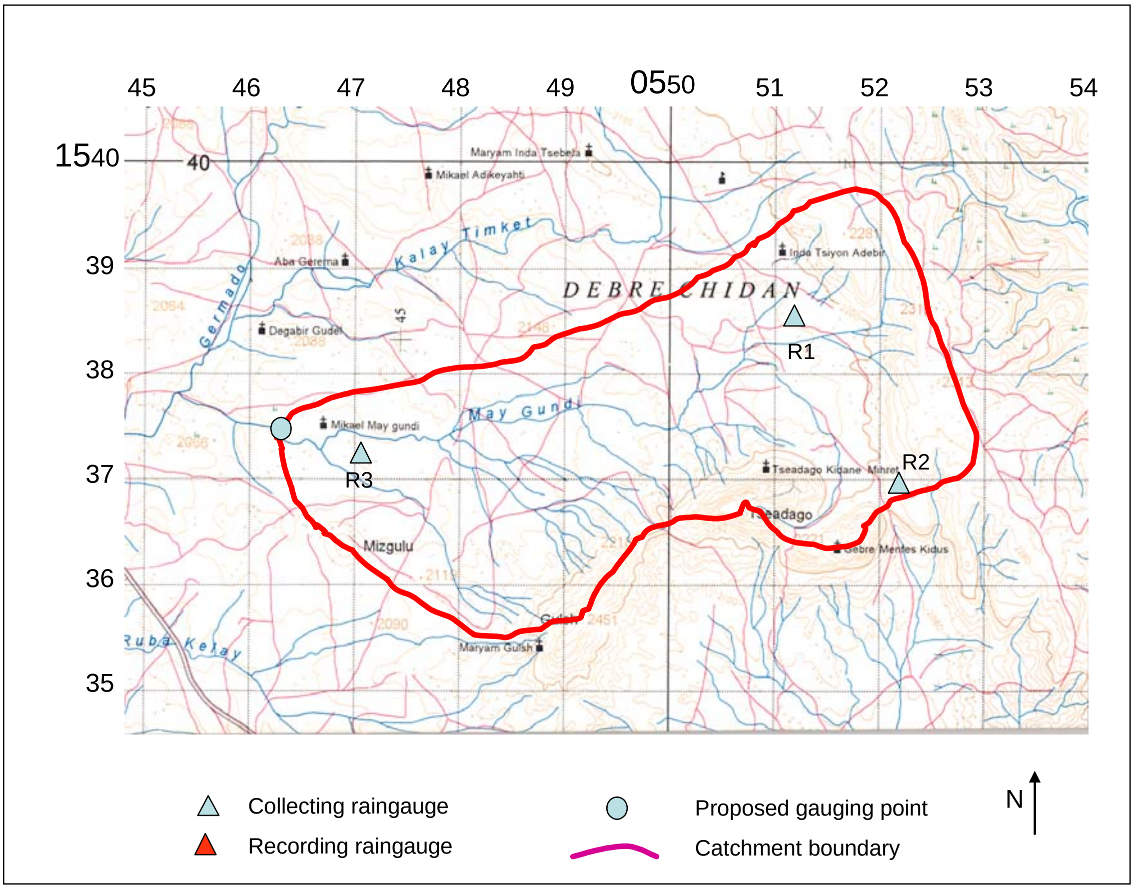


Table 2: Details of Debre Kidan raingauges

	R1	R2	R3	R4
Person	Haftu Abera (PA Chairman)	Gebre-medhine Hailu (Farmer)	Abraha Weldat (Farmer)	Tsehaye Gebremeskel (DA) Makonnen Gtselawe (DA) Zelealem Tsegay (DA) Kidist (HA) (recording raingauge).
Location	Adiwono		May Gundi	
Date installed	20/6/04	23/6/04	24/6/04	20/6/04
Elevation	2190m	2242m	2085m	2176m
Grid Ref	0551188 1538564	0552264 1536925	0546956 1537195	0550302 1539691
Situation	Exposed, 20 m from farmstead	Exposed, 20 m from farmstead	Exposed, 20 m from farmstead	within the DA compound surrounded by trees.
Position	Bottom of eastern ridge slope	a top a high col on the lower southern end of the eastern ridge, and the western end of the Tseadago ridge	on a low hill between the final confluence of the May Gundi before leaving the catchment	Just before the start of the eastern ridge slope,

3.7.1.1.4 Raingauge recording

3.7.1.1.4.1 Farmer Raingauges

The farmers reported that no rain had occurred since early November. In general the records were in good order and legible, and ran from 22nd June to 10th December 2004. Farmers need to be provided with Tigrinya versions of modified recording sheets (Appendix 1) with columns for the start time and finish times of rainfall, from which rainfall intensity can be estimated.

R1

The farmer and PA chairman Haftu Abera was at market. The raingauge was not fitted to the post to prevent vandalism. His records finished in September 2004. Rainfall totals were 1mm out from those transcribed for 10th June 10/96 and 12/96 August.

R2

The farmer Gebre Medhine Hailu was at his farmstead. The raingauge was not fitted to the post to prevent vandalism. His records finished in September. Gebre reported that rainfall was not as good as in previous years, however crop yields were better than expected. Estimates of crop yields per ha were obtained for wheat (800kg), barley (1200kg) and vetch (600kg). Rainfall totals were 0.3 mm out from those transcribed for July.

R3

The farmer Abraha Weldat was found working near to R2 and the raingauge was in the house for safe keeping. His records finished in September 2004. Rainfall totals were 1mm out for July from those transcribed. Rainfall was reportedly not as good as previous years. When told that the rainfall in R2 was greater, we were told that it was well known that the ridge caused rain and that he could see it raining higher up in the catchment and not on his farm. Crop yields per ha were obtained for Tef (500Kg) and barley (2600Kg).

R4 (DA raingauge)

The datalogger contained a record for 3 minutes on the 27th August 2004, but no rainfall had been recorded during this period. This indicates that the datalogger had not been launched after reading. Desta had reportedly tried to download the data from the datalogger without success. This may explain why there was no record.

3.7.1.1.4.2 DA collation of farmer rainfall records

It was not possible to view the DAs' transcriptions of the farmers' rainfall records as they were in Mekelle undergoing computer training. The Debre Kidan DAs should be visited and checks made on their collation procedures. They should also be provided with the new rainfall recording booklets with the new sheets with the extra columns for the start and finish times of rain from Appendix 1. These should be translated into their local languages.

The DAs in Mekelle confirmed that they were collating farmers' records, this was backed up by the by the farmers who reported that DAs had made copies of their sheets.

Dr Mebrahtom visited the DAs' office on Saturday 12th March 2005 and transcribed a copy of the DAs' records which covered the period 22nd June to 5th September 2004. This showed that the DAs had been collating the farmer rainfall records however their monthly totals were not always correct.

3.7.1.1.5 Analysis of rainfall records

Monthly rainfall totals are presented below in Table 3 and Table 4. Rainfall was highly variable with altitude across the catchment ranging from 233.5mm at R4 (mid altitude and to the north of the catchment), and 420mm at R2 (on the SW ridge). The DA raingauge (R4) recorded considerably less rain than the farmer raingauges, recording 56% of the rainfall at R2. This could be because R4 is a tipping bucket raingauge. R1 and R3 recorded 87% and 69% of the rainfall at R2. The temporal pattern of rainfall was similar for all gauges. The relationship between rainfall and altitude was plotted and regressed (Figure 4). The regression equation is

Rainfall (mm) = (0.7812 x Altitude (m)) - 1369.9 with an $R^2 = 0.3849$.

This low R^2 value is insignificant and is due to the low rainfall recorded at R4. Figure 4 implies that rain recorded at R4 should be multiplied by 1.5 to bring the rainfall nearer to the 350mm predicted from the rainfall altitude relationship.

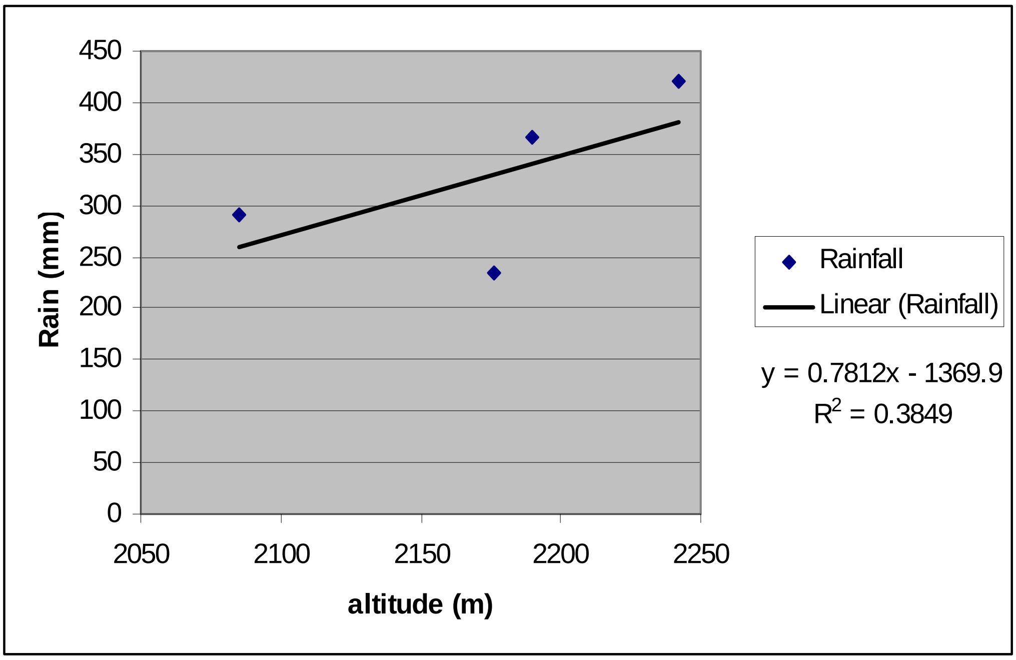
Table 3: International Monthly Rainfall totals for the farmer collecting raingauges for June 2004-March 2005.

Month	**R1**	**R2**	**R3**	**R4**	**Average**
March	0	0	0	0	0
April	0	0	0	0	0
May	0	0	0	0	0
June	25	37	37.8	24	31.0
July	143.5	169.0	111.0	103.0	131.6
August	178	202	140	106.5	156.6
September	19.0	12.0	2.0	0.0	8.3
October	1.5	0.0	0.0	0.0	0.4
November	0	0	0	0	0
December	0.0	0.0	0.0	0.0	0
January	0.0	0.0	0.0	0.0	0
February	0.0	0.0	0.0	0.0	0
Total	367	420	290.8	233.5	**327.8**
Ratio to R2	0.87	1.00	0.69	0.56	

Table 4: Ethiopian Monthly Rainfall totals for the farmer collecting raingauges for June 2004-June 2005

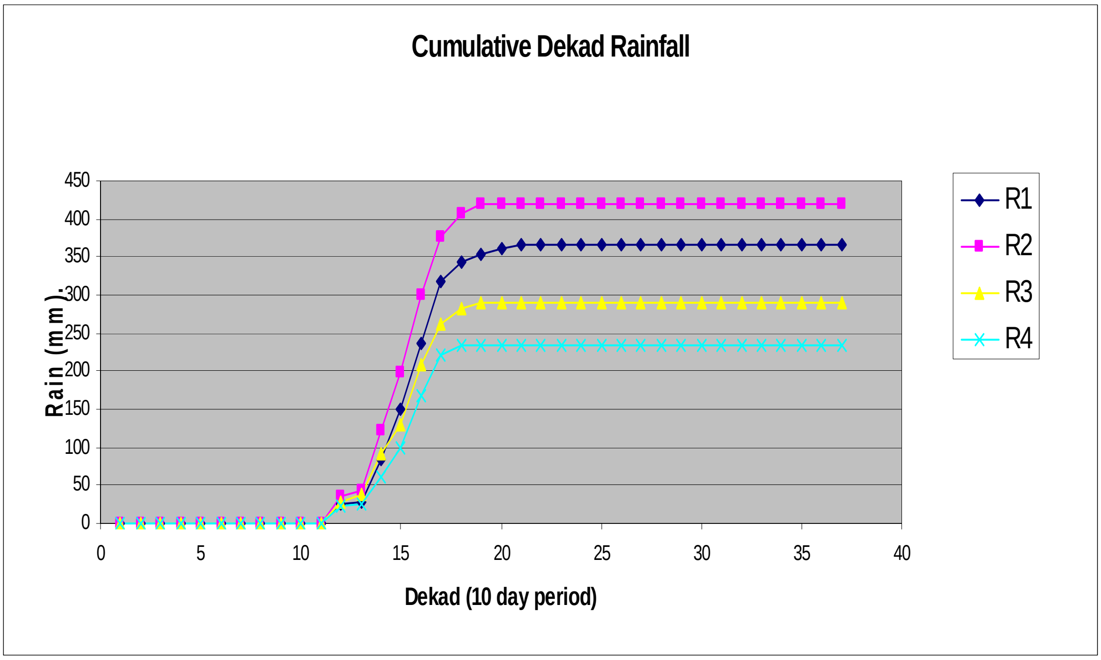
Month	R1	R2	R3	R4	R5	Average
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0.0
10	28	40	39	25	0	44.1
11	191	225	152	129	0	232.3
12	134.5	155	99.5	79.5	0	156.2
13	0	0	0	0	0	0.0
1	12	0	0	0	0	4.0
2	1.5	0	0	0	0	0.5
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
Total	367	420	290.8	233.5	0	**327.8**

Figure 4: Rainfall altitude relationship for Debre Kidan (2004)



A graph showing the rainfall distribution in dekads is presented in Figure 5. This shows that after a faltering start in dekad 13 (12th to 21st July 2004) the average rate of rainfall per dekad (56 mm) was constant until dekad 17 (8th to 17th August 2004). Rainfall had ceased by dekad 20 (7th to 16th September 2004). The main rains lasted 2 months.

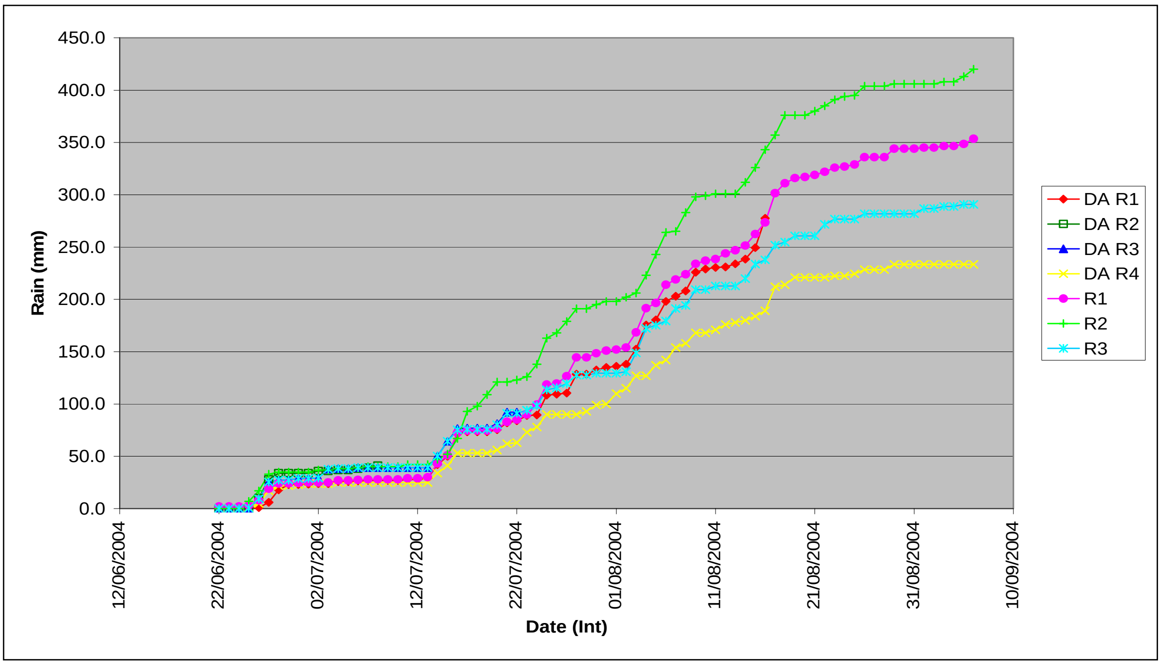
Figure 5: Dekad rainfall for the farmer raingauges in Debre Kidan



Comparison of DA and TA transcriptions of farmer records

DA records only covered the period June to August 2004 for R1 and R3 and June 2004 for R2. There were some discrepancies. R1 was generally under recorded by the DAs by as much as 28mm by the end of August 2004. Generally R2 and R3 were recorded correctly with 2mm less being reported by the DAs by the end of August 2004 (Figure 6).

Figure 6: Comparison of farmer and DA transcriptions of farmer rainfall records at Debre Kidan



3.7.1.1.6 Comparison with rainfall at Hawzien Meteorological station

There is a meteorological station at Hawzien that has been in operation for 5 years. Rainfall at Hawzien is unimodal and erratic, averaging 479 mm/yr from the last 5 years rainfall data. The DAs assess drought occurrence happening once every 2 years although the rainfall record for the past 5 years for Hawzien does not support this. (REST, unpubl. (a)) Table 5.

Table 5: Rainfall at Hawzien meteorological station 1999- 2003

Year (International)	Year (Ethiopian)	Annual Rainfall (mm)
1999	1991	508
2000	1992	502.6
2001	1993	528.6
2002	1994	358.8
2003	1995	502
6 - 10/2004	1996	327.8

The average rainfall for Debre Kidan for the period 24th June 2004 to 10th March 2005 was 327.8mm, however actual rainfall for 2004 is likely to be greater, as rainfall recording did not commence until June 2004. This is 91% of the annual rainfall recorded at Hawzien in 2002 (358.8mm), which was a drought year. The average rainfall for Debre Kidan in 2004-2005 was 68% of the average rainfall for Hawzien (480mm) for the period 1999-2003. This confirms farmers' observations that this year's rains were below average.

3.7.1.1.7 Other hydrological monitoring

The Debre Kidan catchment has the most parameters to record as it has a large number of wells and water recharge structures. This catchment has not been modelled or digitized

In Debre Kidan the TA discussed with Fasil recording:

- The water levels in the water harvesting ponds on a daily basis providing the farmers with tape measures and record sheets.
- Daily minimum and maximum temperatures for Blaney Criddle evapotranspiration calculations, providing the farmers with thermometers and record sheets.
- Flow at the outlet of the catchment. Providing observers with tape measures and recording sheets to record peak flow, time of peak flow, start and finish times of flow.
    - The outlet of the catchment was examined and the need to measure the channel dimensions accurately was discussed. Fasil suggested that REST could build a gabion spillway at the outlet to simplify flow measurements.
    - The discharge point on the May Gundi (Figure 2) was examined with Abraha the farmer recording rainfall at R3. We discussed with Abraha the possibility of recording stream flow. He was keen to record peak flood

level, telling us that debris lines were often left in the channel marking the peak flood level. We gave him a tape measure and asked him to record the peak flow level with a pole and to record this in the comments column of the rainfall record sheet.

- Groundwater levels on a daily basis, providing the observers with tape measures and record sheets.
- Topological surveys to determine the relative water table height from well observations.
- Surveys of gullies, vegetation and soils.
- Measurements of soil moisture and hydraulic properties.

Additional measurements applicable to Debre Kidan are:

- Surveys and observations of water abstractions.
- Surveys of farmers indigenous knowledge of climate and agriculture

3.7.1.1.8 Computers

The solar powered computer at the DAs office could not be inspected, however the panels were visible on the DA office roof.

3.7.1.2 Begasheka

The Begasheka catchment is some 90 km west of Mekelle, 10km west of Adi Abi. The total area of the watershed is 1035 ha. It is an area where REST have conducted many activities, including building large water harvesting dams for irrigation with which Fasil Ejigu was involved. Some background information is available (REST, unpubl. (a)) and part of a REST report detailing the design of water harvesting structures to which Fasil was an author. This report contains many estimates of catchment parameters (REST, unpubl. (b)).

Rainfall recording began on 19th June 2004 and records up to the 10th March 2005 were collected from farmers. There is an additional collecting raingauge in the nursery (R5) that has been recording rainfall daily since 1998. The project area was visited with Fasil Ejigu on the 10th March 2005.

3.7.1.2.1 Climate

The mean annual rainfall of the watershed is 741 mm, according to the 5 years rainfall data measured at the nursery site in the watershed. Similarly, the mean annual temperature and the mean annual potential evapotranspiration are 22.9^{0}C and 1837mm respectively (REST, (unpubl. (a)).

3.7.1.2.2 Hydrological features

The area appeared very dry. There are many surface water features, dry gullies cut through the lowlands and at the exit of the catchment there is permanent surface water which is used by the local population for drinking and washing. Numerous check dams have been constructed as well as water harvesting ponds in the largest tributaries. Groundwater is present in the valleys, and is collected from hand dug wells, and sealed wells with India Mark 2 handpumps donated by UNICEF. Hand pumps in the area were still providing water. Groundwater was reportedly high in minerals reflecting the basaltic rocks in the catchment. Pictures of the various hydrological features described are shown in Figure 7.

A hand dug well next to the water harvesting ponds on the way to R3 was dry and showed signs of collapse as it was not lined. The depth to the slumping marking the highest water mark was 3m deep and the well was a further 1.5m deep.

All the REST water harvesting structures were completed in May 2004 and were now dry, showing evidence of sedimentation. The nearest pair of ponds to R3 contained moist sediments and goats attempted to drink there, indicating that this had only just run dry. In these ponds the rip rap had been dislodged in places. The upstream pond was the most damaged and water had leaked out of this pond shortly after the rains. These ponds had gabion spillways covered in clay and rip rap and had been designed by Fasil.

Fasil reported that the water had been pumped from these ponds in a wasteful manner for crop irrigation. The pump might have been oversized as water had been pumped reportedly straight up into the air.

The water harvesting ponds near R2 had been damaged severely by the first flood flows caused by 34.5mm on the 1st July 2004. The spillway had been washed away completely. These water harvesting ponds had a soil bund covered in cemented stone as a spillway, and had been designed by another relatively new REST engineer. An excavated channel 3m wide and 0.75m extended at least 0.5km up the catchment over an old gulley upstream to deliver the runoff directly into the ponds.

Figure 7: Hydrological features in the Begasheka Catchment

REST water harvesting pond with gabion weir	Damaged REST water harvesting pond with cemented soil weir
	
Proposed gauging site at catchment exit	Nursery Raingauage
	

3.7.1.2.3 Physical condition of the raingauges

Three collecting raingauges are installed in the Begasheka catchment, R1 was placed in a farmers' field and fenced using iron posts, R2 and R3 were installed on the roofs of the farmers' houses. The recording raingauge is also mounted above the roof of the DAs' office. The location of the raingauges are shown in Figure 8, the details are in Table 6.

The siting of the raingauges is not ideal, although evenly distributed around the catchment there is very little difference in elevation and while they are all within the catchment, none are on the higher ridges surrounding the catchment.

All collecting raingauge posts and fences were present and in good condition. However on all farms except R3 the raingauges had been removed for safekeeping from November.

The DA raingauge was still in position but the datalogger was not functioning as the battery had gone flat. A new battery was purchased in Mekelle and the datalogger left with Dr Mebrahtom to reinstall. The counter in the DAs' office was still functioning. The gauge required cleaning.

Figure 8: Map of Begasheka catchment (gridlines approximate)

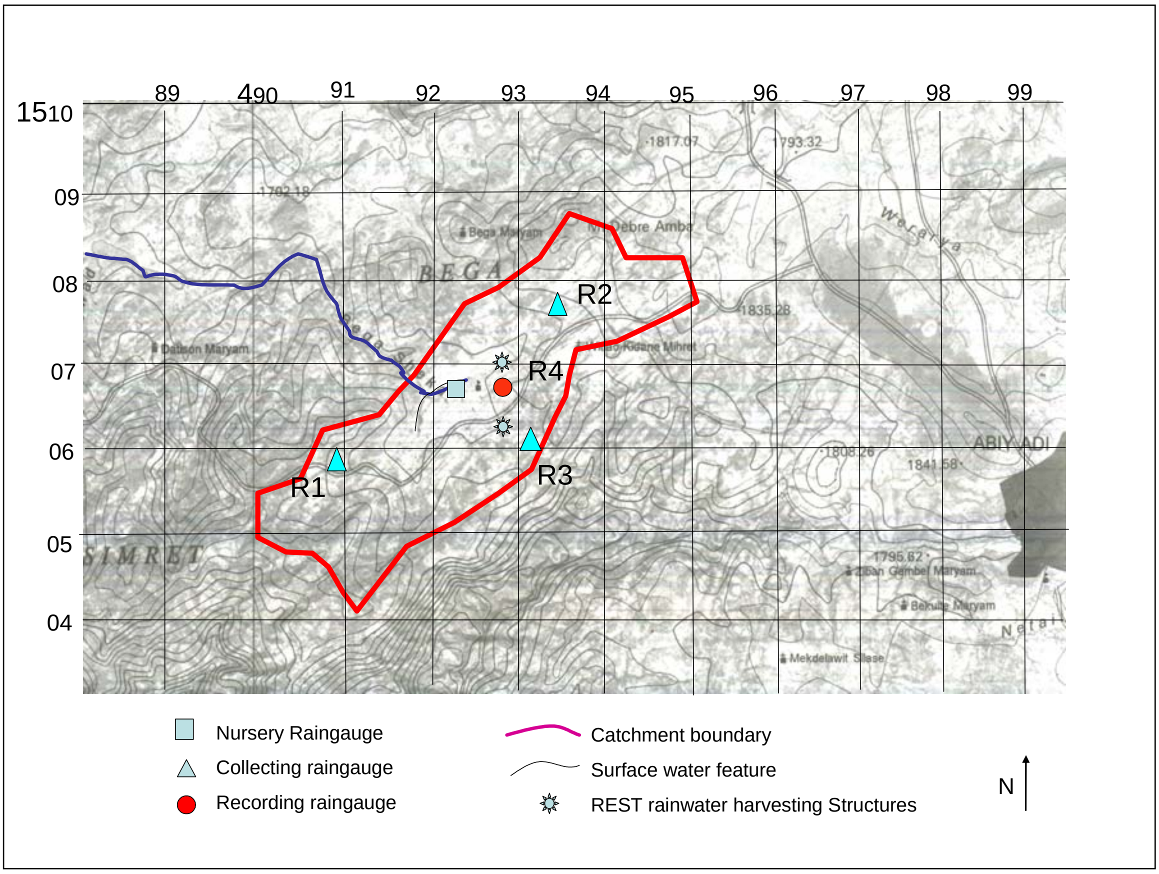


Table 6:Details of Raingauges in Begasheka

	R1	R2	R3	R4	R5
Person recording	Gebreziner Tewldu (priest)	Gebremedhin Hailu (Farmer)	Yeibyo Meresa (Farmer)	Legesse Ambaye (DA) (recording raingauge)	Nursery Manager
Location	SW	NE	SE	Central	N central
Date installed	27/6/04	27/6/04	27/6/04	27/6/04	1998?
Elevation	1780 m	1749m	1761m	1756m	1730m (approx.)
Grid Ref	0490920 1505806	0493437 1506770	0493274 1506164	0492745 1506772	0492250 1508700
Situation	Fenced and at groundlevel. Reasonably exposed, buildings and trees nearby (5m)	Mounted 1 m above roof, exposed	Mounted 1 m above roof, exposed	Exposed, mounted 1m above roof height	Sheltered Mounted on a 1m post above seedlings
Position	On low spur, surrounded by hills of the SW catchment boundary	On a low ridge just before the NE boundary of the catchment	On top of a low ridge towards the W edge of the catchment boundary	On the N slope of a small hill in the center of the catchment	In middle of sheltered Nursery enclosure

3.7.1.2.4 Raingauge recording

3.7.1.2.4.1 Farmer Raingauges

R1

The farmer, Gebreziner was not available and the raingauge was not fitted to the post to prevent vandalism. The rainfall records were available, records stopped in November. There were discrepancies in the monthly totals calculated by the Gebreziner and the DAs.

R2

The gauge was in the homestead for safe keeping, records had been kept till November. There were discrepancies in the monthly totals calculated by the TA and by the Gebremedin. Rainfall this year was reported as being good. Crop yields were slightly better than normal. Crop yields per ha were reported as Maize 300 Kg, finger millet 400 Kg, Tef 400 Kg.

Gebremedin reported no problems with the recording. We asked about specific rainfall events and if these had caused flood flow in the adjacent gulley which drained in to the REST water harvesting ponds. The first large rainfall event of 34.5mm on 1st July 2004 had caused the breaching of the REST water harvesting spillway. Subsequent rainfall over 20mm caused flood flow in the gulley close to his house. Gebremedin agreed to record the presence of flow in the gulley on the rainfall sheet.

R3

The raingauge was in place but the farmer, Yiebyo was not available. Records had been kept up right to date until our visit. There were discrepancies in the monthly totals calculated by the Yiebyo and the DA. This farmer was a former nursery worker and had previously logged rainfall there.

R4 (DA Raingauge)

The only data for this raingauge was taken from a poster in the DAs office (Figure 9). The datalogger contained no record.

R5 (The Nursery raingauge)

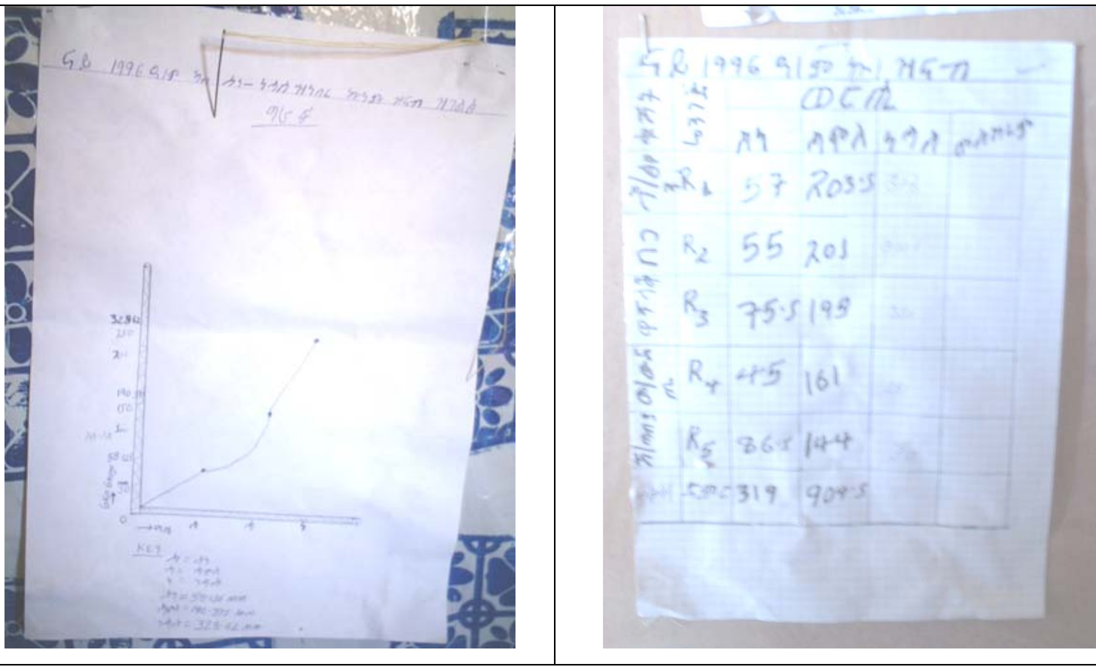
The nursery raingauge is of a different type and cracked. A spare raingauge was offered to replace it and left with Dr Mebrahtom. The manager was not available and so the daily records could not be inspected, and monthly totals for 2004 were obtained from a poster in the DAs' office. Rainfall records for 1998-2002 have been obtained from part of a REST report detailing the design of water harvesting structures (REST, unpubl. (b)).

3.7.1.2.4.2 DA collation of farmer rainfall records

It was not possible to view the DAs' transcriptions of the farmers' rainfall records as they were in Mekelle undergoing computer training. The Begasheka DAs should be visited and checks made on their collation procedures. They should also be provided with the new rainfall recording booklets with the new sheets with the extra columns for the start and finish times of rain from Appendix 1.

The DA rainfall records were not available at the time of the visit, but there were two A4 posters (Figure 9), one a table of the rainfall totals for all the raingauges on the site including the nursery, and a graph of the monthly average totals for the DA raingauge. The graph is plotted on plain paper and rainfall plotted on the y axis is not to scale. The farmer total monthly rainfall records on the table transcribed by the DAs' differs from those transcribed by the TA (Table 8). Rainfall was under recorded in June by 32mm for R3; July by 16mm for R2, and 12mm for R3. Raingauges R2 and R3 are thus under reported, R2 by 8 % and R3 by 14 %.

Figure 9: Graph and table of rainfall data collected by the DAs in Begasheka



3.7.1.2.5 Analysis of rainfall records

Taking the rainfall for the period 19th June 2004 to 10th March 2005, rainfall was very similar for all 3 farmer collecting raingauges. The range was 675.5- 699.5mm for the farmers' raingauges (Table 7). R1 in the west of the catchment appears to collecting slightly more rainfall. R2 and R3 were recording 96% of the rainfall at R1. The rainfall temporal distribution is similar for all farmer raingauges (Figure 10). R3 initially had more rainfall but this advantage disappeared by the end of August.

Analysis of the rainfall recorded at the nursery and the DAs for June and July (Table 8) shows that the nursery raingauge appears to be under recording (73% of R3), probably because it is of a different type and damaged. The DA raingauge appears to be under recording (66% of R3) and needs to be multiplied by a factor of 1.25 to give a similar result as R2. However both the nursery and the DA raingauges are close to one another and within a central basin of the catchment and this area might be receiving less rainfall. Next years' rainfall records recorded by the replacement nursery raingauge will help determine if this is so.

The DAs' transcriptions of the farmers' rainfall data differ from those of the TAs' (Table 8). R2 and R3 were significantly under recorded.

Table 7: Monthly rainfall totals (mm) transcribed from Farmers record sheets (24/6/04-10/3/05)

Month (Ethiopian)	R1	R2	R3		Month (International)	R1	R2	R3	Average (Int)
7	0	0	0		March	0	0	0	0
8	0	0	0		April	0	0	0	0
9	0	0	0		May	0	0	0	0
10	57	59	108		June	53	54.5	102.5	70
11	203	217	206		July	176	186.5	172.5	178.3
12	358.5	313	314		August	369.5	328	330.5	342.7
13	13	4	6		September	86	68.5	52.5	69
1	53	58.5	25.5		October	15	38	14	22.3
2	15	24	20		November	0	0	7	2.3
3	0	0	0		December	0	0	0	0
4	0	0	0		January	0	0	0	0
5	0	0	0		February	0	0	0	0
6	0	0	0						
Total	699.5	675.5	679		**Total**	699.5	675.5	679	**684.7**
Average			**684.7**						
Ratio to R1	1	0.966	0.971						

Figure 10: Dekad distribution of rainfall for the farmer collecting raingauges

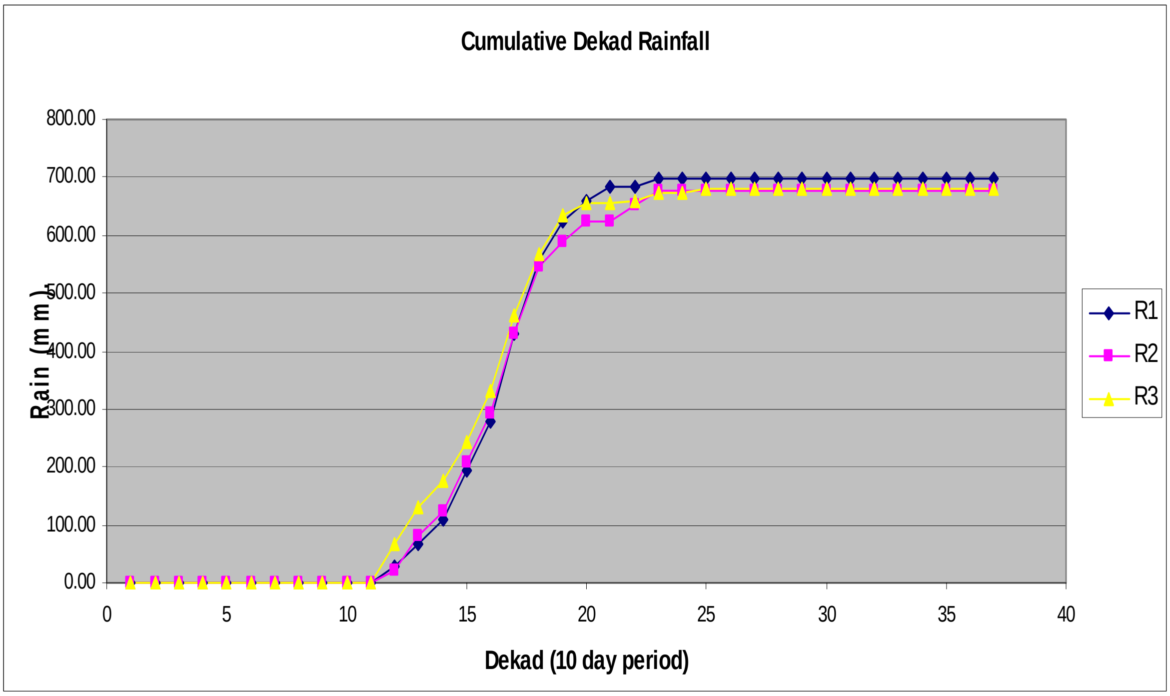


Table 8: Monthly totals transcribed from farmers records

	Transcribed by TA					Transcribed by DAs				
Month (Ethiopian)	**R1**	**R2**	**R3**	**R4**	**R5**	**R1**	**R2**	**R3**	**R4**	**R5**
(June) 10	57	59	108	45	87	57	55	75.5	45	87
(July) 11	203.3	217	206	161	144	203.3	201	198	161	144
Total	260.3	276	314	206	230.5	260.3	256	273.5	206	230.5
Average					**257.4**					**245.3**
Ratio to R3	0.83	0.88	1	0.66	0.73					

3.7.1.2.6 Comparison with nursery raingauge

The rainfall for 2004 was below average (687mm) compared to the rainfall record at the nursery for 1997-2002 (755mm) (Table 9 and Figure 11). However the situation may be worse than this, as the nursery gauge is under recording, as it is cracked. The rainfall for 2004 is likely to be greater than this as rainfall recording did not start until June and it is probable that at least 100mm of rainfall occurred between March-May 2004.

Rainfall was better than average in April, May and June 2004, but very much below average in July and August 2004.

Farmer Gebremedin at R2 reported that last years rains were good and that yields were good, which indicates that rainfall was about average or better. Rainfall for 2004 was considerably better than 2002 which was a drought year and similar to 2000 (Figure 11).

Figure 11: Rainfall at Begasheka nursery.

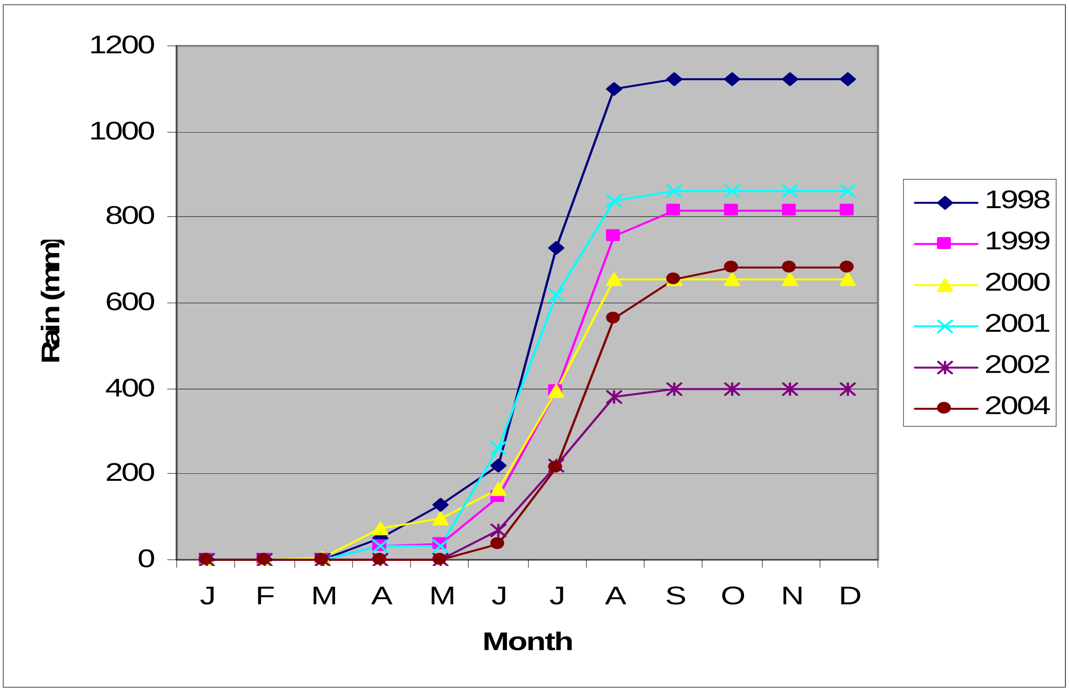


Table 9: Comparison of Begasheka nursery monthly rainfall records with average rainfall for 19/6/04-10/3/05 (rainfall in mm).

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
1998	0	0	0	50	80	90	510	370	20	0	0	0	1120
1999	0	0	0	30	5	110	250	360	60	0	0	0	815
2000	0	0	5	70	20	70	230	260	0	0	0	0	655
2001	0	0	0	30	0	230	360	220	20	0	0	0	860
2002	0	0	0	0	0	70	150	160	20	0	0	0	400
2004	0	0	0	70.0	178	342.7	69.0	22.3	2.3	0	0	0	684.6
Average (1998-2002)	0	0	1.0	36	21	114.0	300.0	274.0	24.0	0	0	0	770
Max	0	0	5.0	70	80	230.0	510.0	370.0	60.0	0	0	0	1120
Min	0	0	0	0	0	70.0	150.0	160.0	0	0	0	0	0
2004-average (98-02)	0	0	-1.0	34	157	229	-231	-252	-22	0	0	0	-85
% 2004/ Average (98-02)	0	0	0	194	849	300	23	8	10	0	0	0	89

3.7.1.2.7 Other hydrological monitoring

Fortunately this catchment has been surveyed by REST and enough GIS thematic layers are available to conduct some hydrological modelling. This information has been modelled already and has been used to design the REST water harvesting structures (REST, unpubl. (b)) and produce estimates of peak flows, hydraulic conductivity and runoff coefficients. However this needs refinement as flood flows are at present under estimated, as evidenced by the destruction of one set of water harvesting ponds.

The TA discussed with Fasil recording:

- The water levels in the water harvesting ponds on a daily basis providing recorders with tape measures and record sheets.
- Daily minimum and maximum temperatures for Blaney Criddle evapotranspiration calculations, providing farmers with thermometers and record sheets.
- Flow at the outlet of the catchment. Providing observers with tape measures and recording sheets to record peak flow, time of peak flow, start and finish times of flow.
    - The outlet of the catchment was examined and the need to measure the channel dimensions accurately. Fasil suggested that REST could build a gabion spillway at the outlet to simplify flow measurements.
    - Gebremedin the farmer recording rainfall at R2, was asked to record on the rainfall sheet whether there was flow in the gulley adjacent to his farm draining into the damaged water harvesting ponds.
- Groundwater levels on a daily basis, providing the observers with tape measures and record sheets.
- Topological surveys to determine the relative water table height from well observations.
- Surveys of gullies, vegetation and soils.

- Measurements of soil moisture and hydraulic properties.

Additional measurements applicable to Begasheka are:

- Surveys and observations of water abstractions.
- Surveys of farmers indigenous knowledge of climate and agriculture

3.7.1.2.8 Computers

The solar powered computer is installed in a separate DA office 700m from the recording raingauge and could not be inspected. A replacement circuit breaker was given to Dr Mebrahtom with instructions that it should be placed in the stores of the Begasheka DA office.

3.7.2 Debub Consortium

There are two catchments, Umbulo Wacho and Beresa selected by the Debub Consortium. There are six collecting raingauges in Umbulo Wacho and three in Beresa. Both project areas also have a recording raingauge.

Tezebe Kiros, who the TA had worked with on his last visit had gone to the Netherlands to study for an MSc. The TA was introduced to Shemalis Gebriye and Feto Esino. Shemalis had submitted a proposal previously. Feto had been given overall responsibility for the collation of rainfall records. Both had tried to download the data from the Korangoge recording raingauge without success. The rainfall records of the farmers had not been inspected since the TA's last visit. Farmers and DAs had not been supplied with fresh record sheets. Records of visits by the Debub consortium to the project areas were not available. Copies of the TAs reports, references and computer software brought or sent from previous visits were not available to Feto.

All the raingauges in both catchments were inspected and in good order, although some had not been read. Some farmers had stopped recording rainfall at the end of the rainy season but others had continued recording making their own copies of the rainfall recording sheets.

Farmers and DAs were provided with new record sheet booklets, watches and pencils. In addition farmers were asked to record the start and finish times of rainfall in additional columns to the daily record sheets (Appendix 1). DAs' recording books also contained sheets to record monthly and dekad totals. All daily sheets were marked with the Ethiopian month, and for the DAs the date ranges for the first few dekads were also labelled.

In both catchments the farmers asked about payment for recording rainfall. It was explained that the raingauge was a gift from DCI to help them make appropriate agronomic decisions, which was why the records were not taken from them. The data collected would be used by Debub researchers and the BoA and the results would be returned to them and would also help plan appropriate soil water conservation strategies and select appropriate crop varieties for their area. It was pointed out that the TA was not using this data for his own research.

Solar powered computers were present in the DA offices in the catchment. There were some problems with the computers in Boricha Woreda. All computers need Adobe Acrobat reader to enable project reports read.

3.7.2.1 Beresa

The Beresa area is 2 km from Butijura, 200 km to the north of Awassa and consists of several subcatchments. Road access is reasonable to most parts, however raingauges R1 and R3 are accessible only by foot.

Rainfall recording began on the 4th July 2004 and continued until the end of October 2004. Only Abela at R1 and Habtamua (DA) at R4 had restarted recording in March 2005. The datalogger contained a complete record for the period 4th July 2004 to 19th March 2005.

The catchment was visited on the 19th and 20th March 2005 with Tewodros Tefera and Shemalis Gebriye. The team visited the Butijura BoA office and met Mohammed Mosel, head of Natural Resources and Agriculture, who had replaced Ato Gemil, who had been present at the initial installation of the raingauges. The computer was in place, it was functioning properly and the farm recording software and a copy of the rainfall recording spreadsheet was installed.

The TA, Tewodros and Shemalis went to Beresa with Lema Seifi and Shemenus (DAs), and visited the Beresa DA office at the Progynist centre (0434178 0895814, 1915m). The farm recording spreadsheet and the rainfall recording spreadsheet were installed on the DA field office computer. Habtamua the DA responsible for the collation of the farmers' rainfall records at Beresa had not been given computer training, but Tewodros said that she would also have the opportunity. The datalogger attached to the recording raingauge contained a complete record.

3.7.2.1.1 Hydrological features

The project area is bordered to the north by the Dobena river, by the Dobo and Dobena (2000 m) ridges to the south and east, and the hills of Beresa and Getema (3000m) to the west. The lowest point is 1945m. This project area is problematic as the Dobena river is one of the catchment boundaries; there are no other surface water features; and consists of several subcatchments. Two subcatchments are readily identified separated by a low ridge which is not shown on the topological map. There are several depressions in the catchment which appear to have no exit.

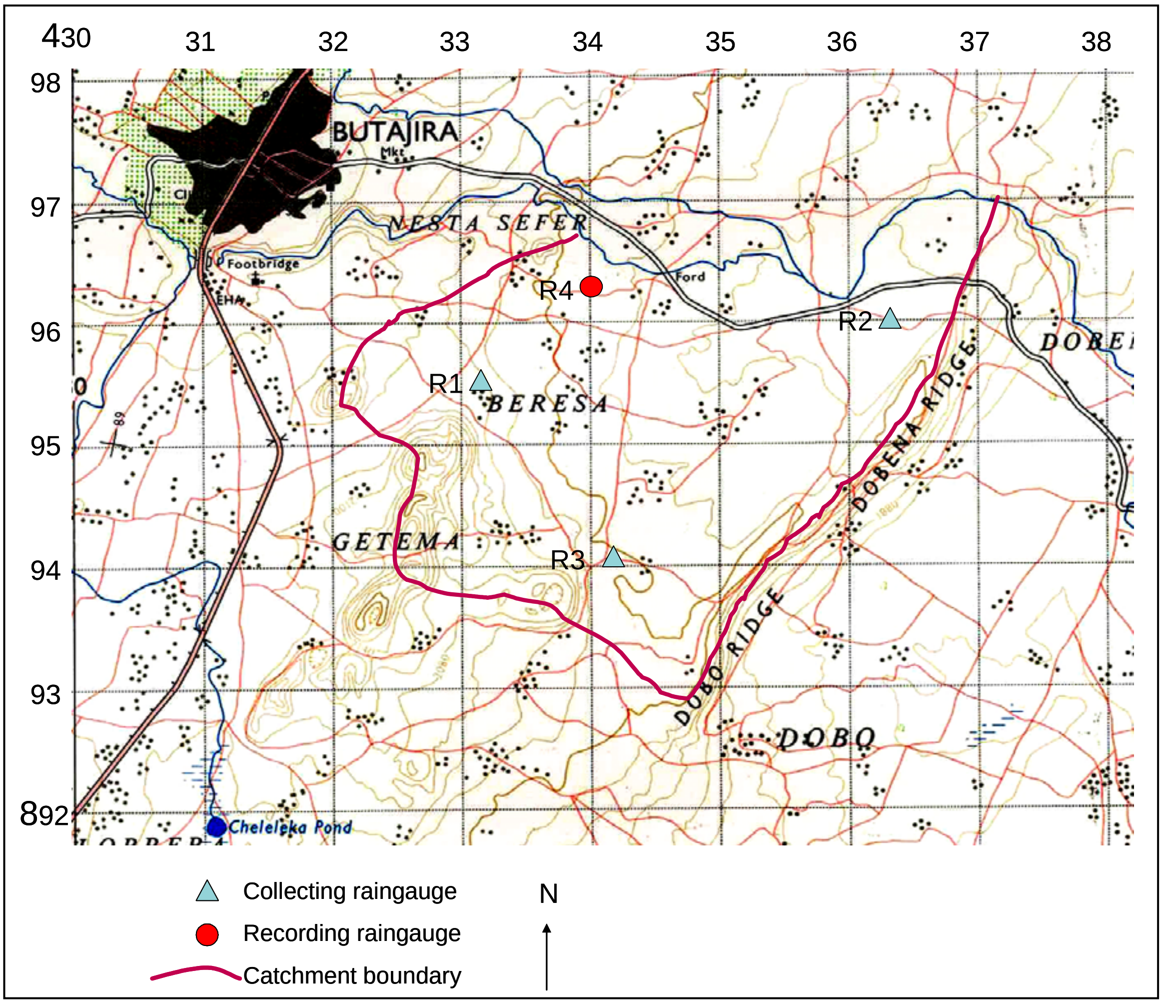
There are no wells either; however, wells do exist on the other side of the Dobena river. A piped water supply pumped from a well outside the catchment was being laid to R1. Groundwater is likely to exist, however wells dug in these loose soils might easily collapse and reportedly there is a hard rock layer at depth which is impenetrable. The underlying geology is volcanic lava flows, which outcrop in some areas. The lava has weathered to leave a sandy black soil which freely drains.

There are 21 water harvesting ponds to be constructed in the Kebele, A water harvesting pond that was under construction on the same farm as R3 during the TA's last visit was still unlined. This water harvesting pond had filled to 1.5m and had taken 3 days to drain completely.

3.7.2.1.2 The physical condition of raingauges

Three collecting and one recording raingauge were installed in the Beresa catchment in July 2004. They are well distributed and spaced, and represent a range of different elevations. All were in good order although the farmer collecting raingauges had not been read that day. The datalogger from the recording raingauge contained a complete record from the time of installation. The locations of the raingauges are detailed in Figure 12 and Table 10.

Figure 12: Location of raingauges in the Beresa catchment



Note: the road through the catchment area is the old road to Ziway, the new road is not on the map and runs along the opposite side of the Dobena River.

Table 10: Raingauges in Beresa catchment

	R1	R2	R3	R4
Person	Abela Naszr (Son of farmer)	Bratu Teme (farmer)	Musefa Mohamed and Nuria Musefa (Farmer and daughter)	Habtamua Ambawu (DA) Shemsu Hussen (DA) (recording raingauge)
Location	Beresa	Dobena Ridge	Dobo Ridge	Nesta Sefer
Date Installed	1/7/04	2/7/04	2/7/04	2/7/04
Elevation	2063m	1955m	2012m	1997m
Grid Ref	433165 895518	436317 896040	434224 894031	436317 89604
Situation	Exposed on hill top	Moderately Exposed	Some shelter from eucalyptus fence to the N	Sheltered by large tree to the SW
Position	Village compound on top of hill	Lowland village compound	Low col next to Dobo ridge	Low ridge near to Dobena river

3.7.2.1.3 Rainfall recording

Some raingauges had not been read and some farmers had stopped recording rainfall at the end of October 2004 at the end of the rainy season. Some farmers and the DAs had made their own copies of the rainfall recording sheets and had continued recording themselves.

On this visit photographs of record sheets were taken of R1, R3 and R4 (except October for R4), and photocopies made of the DAs' transcriptions. The recorders and the DA were given fresh record sheets in a bound booklet sufficient for 1 year.

3.7.2.1.3.1 Farmer recording

R1

The raingauge had not been read by Abela the recorder and contained 8mm of rainfall. Abela was not there, but he had started recording in March 2005. We explained the new record sheets to his brother and a nearby farmer. The brother was given the booklet of fresh record sheets, pencils and a watch to record time. Shemalis commented on the exposed position of the raingauge.

R2

This had also not been read for a few days, but contained 17mm. The recorder, Bratu, was not present and the record book, pencils and watch were given to his brother. Bratu had not recommenced rainfall recording in March 2005.

R3

The gauge had also not been read that day by Nuria the recorder, and contained 1mm. Rainfall records had been kept from June until October 2004 and she had recommenced reading the raingauge in March 2005 at the start of rains. She had made her own record sheets, but sometimes she was unable to read the gauge because she was away and so some records contained two or three days rainfall. She was asked to train somebody else to take the readings.

R4 (DA raingauge)

The recording raingauge had been installed at Habtamua Ambawu's house, 500 m from the DA office, and she had been given the task of collating all the rainfall data from all the raingauges and given a booklet of sheets sufficient for one year. The raingauge was in good order and the datalogger contained a full record.

Habtamau's records were only inspected briefly, as she had just received news that a relative had died at the time of the visit. Habtamua's own records of the R4 rainfall did not match those of the datalogger, although they are similar to those of the TA's transcription of R1 records (Figure 13). The datalogger recorded more rainfall in general, however there are periods in November 2004 to January 2005 that Habtamua recorded rainfall and none was recorded by the datalogger.

It is difficult to know why Habtamua's records did not match the datalogger, as both are connected to the same contact in the raingauge. It is possible that she is under recording deliberately, missing daily readings (although the counter would have to be reset) or the connection to the datalogger to the raingauge is intermittent and affected by wind.

An Excel spreadsheet was installed at the DAs' office to record rainfall and Habtamua was shown how to use it. This should enable her to calculate monthly and dekad totals more easily.

3.7.2.1.3.2 DA collation of farmer rainfall records

Farmer rainfall records are being collated by Habtamua, who had transcribed them and calculated monthly and dekad totals. Copies had been made by Shemalis and were given to the TA after the visit to Beresa. Unfortunately the daily sheets had not been labelled with the month, and monthly and dekad totals were not summed correctly, hence it was impossible to determine which sheets belonged to which month and to compare the DA records with the TA's own transcriptions of the farmers' records.

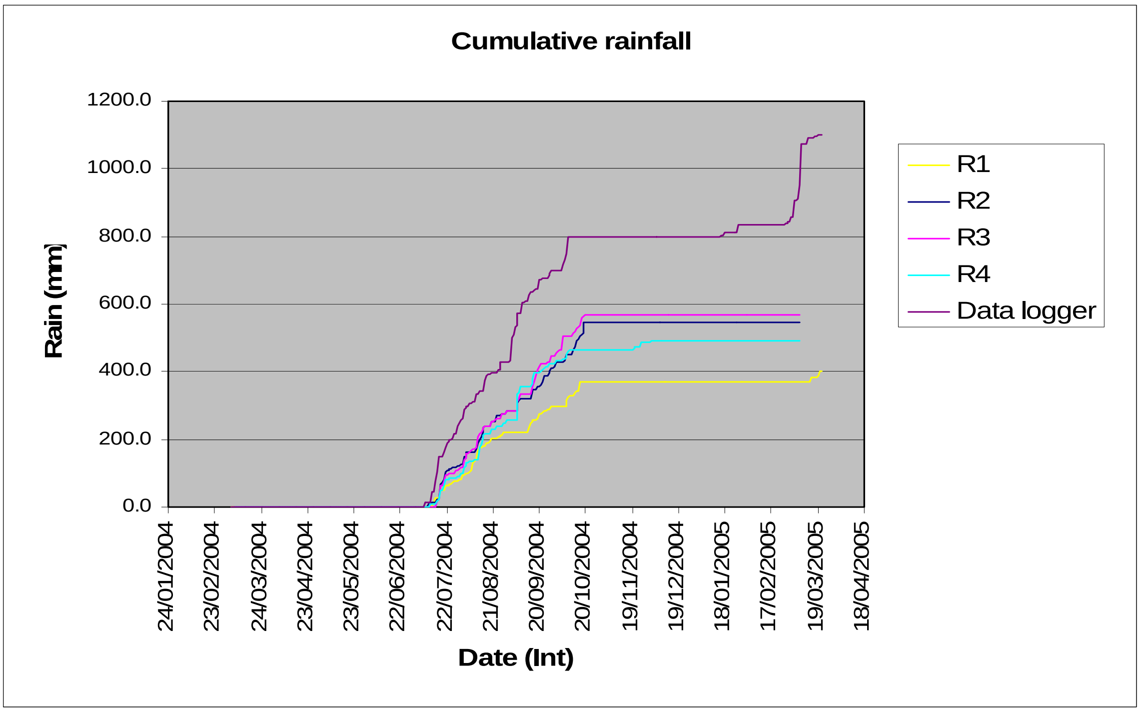
Habtamua was supplied with a fresh rainfall recording book, complete with sheets for transcribing farmers' records into monthly and dekad totals. The daily sheets were labelled and so were the first few dekads.

3.7.2.1.4   Analysis of rainfall records

The average rainfall for the Beresa catchment based on farmer and DA recorded totals was 554 mm for the period July – November 2004 (Table 11). Farmers had not started recording in January 2005, although there was evidence from the datalogger that some rainfall (3mm) had occurred and so true averages cannot be computed beyond November 2004.

It is apparent from Figure 13 that the datalogger is recording more rainfall than the other gauges in the catchment. This may indicate under recording by farmers, incorrect calibration, or faulty connection with the datalogger. It is difficult to know which is the case, and whether the datalogger records should be included in the calculation of averages in this report, without further investigation.

Figure 13: Cumulative dekad rainfall for the raingauges in Beresa



Rainfall for R2 and R3 are very similar, in both rainfall amount (547 mm and 568 mm respectively) and temporal pattern; both have approximately 50 mm per dekad from dekad 14 (9^{th} -19^{th} July 2004) to dekad 23 (16^{th} – 26^{th} October 2004) (Figure 13, Table 11 and Table 12). The rainfall recorded at R1 is very low, either due to its exposed position, the rain shadow of the surrounding hills, or poor recording.

Table 11:International Monthly totals for Beresa July 2004-March 2005

Month	**R1**	**R2**	**R3**	**R4**	**Data logger**	**Average R1-R4**
June	93.5	150.8	143.7	120	263	127
August	125.3	133.2	141.1	137	171	134.1
September	78.2	146.3	178.5	174	264	144.2
October	71	116.9	104.7	32	101	81.1
November	0	0	0	28	0	7
December	0	0	0	0	0	0
January	0	0	0	0	35	0
February	0	0	0	0	9	0
March	32.6	0	0	0	257	8.1
Total	400.6	547.2	568	491	1100	501.7
Average					621.4	
Total (J-N)	368	547.2	568	491	799	486.5
Average (J-N)					554.6	

Table 12: Ethiopian Monthly totals for Beresa June 1996-March 1997

Month	R1	R2	R3	R4	Data logger	Average R1-R4
10	0	11	0	8	12	4.7
11	132.7	159	177.3	134	299	150.7
12	86.1	151.8	156.5	213	263	151.8
13	0	0	0	2	35	0.5
1	112.2	168.3	192.8	106	189	144.8
2	37	57.6	41.4	0	1	34
3	0	0	0	28	0	7
4	0	0	0	0	0	0
5	0	0	0	0	35	0
6	0	0	0	0	241	0
7						
Total	368	547.2	568	491	1075	493.5
Ratio to R3	0.65	0.96	1	0.86	1.89	0.62

The data from the datalogger needs further analysis to determine rainfall duration/ intensity relationships and rainfall frequency analysis. This can be done using Excel pivot tables to extract the duration and the amount of rainfall of individual rain events. Feto was instructed how to do this.

3.7.2.1.5 Other hydrological monitoring

Beresa is the simplest of the catchments to monitor as it has no surface flow features or wells. The only features meriting measurement are water harvesting ponds.

This catchment has been digitized by researchers at CAZS, a copy of the Arcview files are on the CD accompanying this report.

The TA discussed with Shemalis and Tewodros about recording:

- Water levels in the water harvesting and surface ponds on a daily basis providing the farmers with tape measures and record sheets.
- Daily minimum and maximum temperatures for Blaney Criddle evapotranspiration calculations, providing the farmers with thermometers and record sheets.
- Surveys of vegetation and soils
- Measurements of soil moisture and hydraulic properties
- Surveys of farmers indigenous knowledge of climate and agriculture

3.7.2.1.6 Computers

The computers in both the Butijura BoA office and the Beresa DA office were working properly, although neither had Acrobat reader installed, so the DAs could not read the TAs previous reports. Habtamua had not been trained to use the computer, but she was offered the opportunity in the future by Tewodros.

3.7.2.2 Umbulo Wacho

The study area is located 15 km west of Awassa and is approximately 5 km x 10 km. with a total area of 3000 ha. It is the largest of the operational research areas. The study area forms part of the Awassa caldera which is within the African rift valley, itself tectonically active and widening. Moving west to east the topography consists of a plateau elevated at 2000 m, a scarp marking the edge of the caldera, falling to a lower basin area at 1750 m, followed by a low ridge at about 1780 m (fig. 3). A fuller description of the study area can be found in the TA's reports 1 and 2 (Hollingham, 2003 and 2004a).

The raingauge network installed in March 2004 in Umbulo Wacho and the farmer rainfall records were inspected on 30th June 2004. Analysis of the rainfall records from Umbulo Wacho at that time showed some discrepancies both in farmer and in researcher recording (Hydrologist TA's 3rd report (Hollingham, 2004b).

The Umbulo Wacho catchment was visited on the 17th, 20th and 21st March 2005. The raingauges and the rainfall record sheets were examined, and the DAs visited to check how data collection was going. The rainfall recording sheet was installed on the computer in the Korangoge DAs' office.

The recording raingauge contained a 15 minute record for the 3rd November 2004, when Feto had tried to read the datalogger and had no success.

Farmers and DAs were supplied with fresh record sheets in a bound booklet, watches and pencils. DA record books also contained sheets for calculating monthly and dekad totals (Appendix 1).

It was reported by Tewodros that the Debub Consortium decided to confine operational research activities to the Boricha side of the Umbulo project area as the Awassa BoA DAs had proved to be uncooperative.

3.7.2.2.1 Climate

In the Awassa basin average mean temperatures are 15-20°C, relative humidity between October-June is 67 % and between July-September 78 % and evaporation between Oct-January is 300 mm, February – May 300 mm, June- September 550 mm (Ethiopian Mapping Agency, 1988). Average rainfall at Awassa Meteorological station 1993-2003 is 985mm.

Fanage Wantage (Awassa HA) reported that it was wetter in Kejema than in Tenkaka, which were both wetter than Boricha. Rain tended to move from Kejema across the catchment to Boricha. Last year's rains (2004) were not good. The previous year's rains (2003) had been good but this had caused much flow in the gullies and also much erosion, although land closure has reduced these. Crop yields were generally good but maize gave poor yields because of lack of rain.

3.7.2.2.2 Hydrogeological features

Runoff in the catchment drains down several gullies onto a flood plain and into a temporary lake called Derba pond in the lower basin. Water leaves the pond by 3 holes in a fissure which was formed by an earthquake on 1st January 2001. The physical appearance of the fissure shares some similarities with gullies in the area.

The gullies appear to be controlled by the local geology, all trend NE –SW following the main faulting pattern or following transform faults. The process of gulleying appears to be a result of tunnelling erosion initiated by runoff from the flat plateau areas, which infiltrates down into the soft tuff until reaching a relatively impermeable layer of welded ignimbrite. The majority of gullies are 5-6 m wide tending to be deepest (15 m) in mid slope. Most gullies disappear when they reach the basin area, the exception being that through the Derba pond area. This gulley starts halfway down the slope towards Umbulo Wacho and extends past Tenkaka Umbulo (Denkaka Umbulo). At the time of the visit there were signs of debris carried by sheet flow across the basin trapped by small bushes, indicating that not all runoff entered the drainage points via the earthquake fracture gulley.

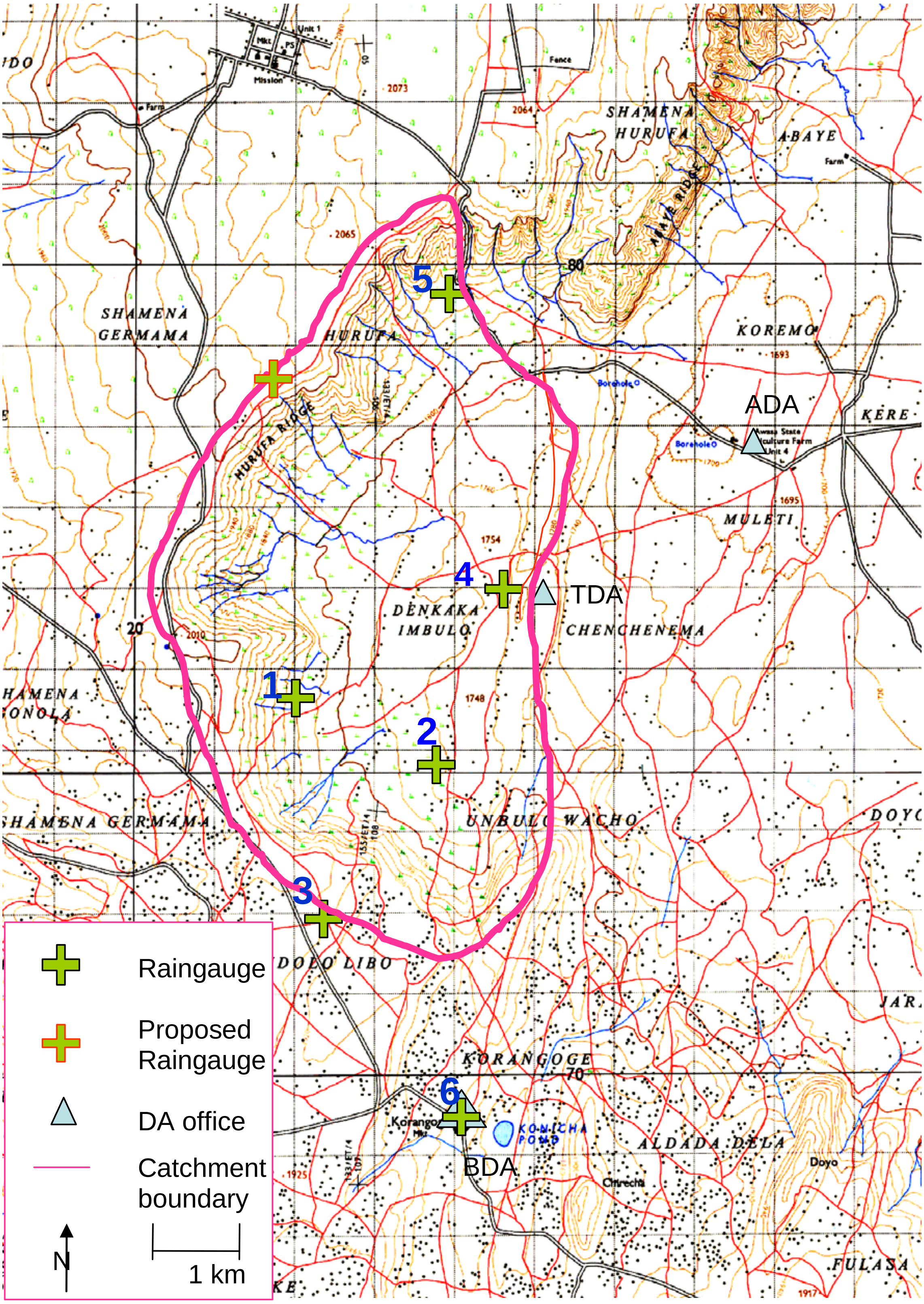
3.7.2.2.3 Physical condition of the raingauges

The location and the details of the Umbulo Wacho raingauges are given in the Table 13 and Figure 14 below.

Table 13: Raingauge locations and recorders

	R1	R2	R3	R4	R5	R6
Person	Eyasu Hameso: (Umbulo Wacho PA chairman)	Endrias Denbaro: (Farmer)	Yoseph Yunca (Farmer)	Gudeta Guracha (Farmer)	Embakom Firdamo (Farmer)	Danna and Sintayehu Nigusie (DAs)
Location	Kurnela	Wolema	Umbulo Wacho	Gogo	Gechemo	Korangoge
PA	Umbulo Wacho	Umbulo Wacho	Umbulo Wacho	Tenkaka Umbulo	Kejema Umbulo	Umbulo Wacho
Date installed (E.C)	20/3/04	20/3/04	13/4/04	26/3/04	28/3/04	21/3/04
Grid Ref	0422046 0774235	0423921 0773767	0422661 0772093	0424690 0776377	0423975 0779499	0424208 0769464
Situation	Sheltered	Sheltered	Slightly exposed	sheltered	exposed	exposed
Position	Inside of compound on midslope	Inside compound in valley bottom	Inside compound on top of ridge	Inside compound near to Derba Pond	In field next to gulley	On top of roof of building on plateau

Figure 14: Map of Raingauge locations in Umbulo Wacho



BDA , Borecha DA office; ADA, Awassa DA office; TDA, Tenkaka DA office.

3.7.2.2.4 Raingauge recording

3.7.2.2.4.1 Farmer recording

R1

Eyasu was not at home and his records were not available for inspection. The Raingauge had been read that day. A concrete water harvesting pond with a sediment trap had been constructed adjacent to the pond. The pond was half full and the runoff area was a field of enset.

R2

Endrias was not at home but the raingauge had been read and the rainfall records were up to date and in good order. His wife was asked questions about last year's rains but she felt unable to give an opinion because she was a woman.

R3

Yosef Yunca's records were in good order and up to date. He reported that this year's rains (2005) were better than the last which were better than previous years' and that yields had varied widely across the project area. Yields were good in his locality up on the plateau even for maize. Maize could last 14-15 days between rains during the seedling stage and to 20 days when flowering.

R4

Gudeta's raingauge was in good order, but had not been read as 27mm had been collected by the raingauge. The records were legible and up to date, but not in chronological order. He was supplied with 13 monthly record sheets in a booklet, a watch and some more pencils. When asked about last years rains he reported that there were poor rains until July 24th 2004. There was good rain in August 2004. This year's rains starting in March 2005 were good, last year's were bad.

Crop yields were low, maize produced no yield. Enset that was planted last year died. Maize could withstand 20 days between rains during the seedling stage and 30 days when flowering.

R5

Embartom's raingauge was in place with 80mm unread in the gauge. Reportedly it had overflowed several times, but there is no indication of this in the rainfall record. Records had been kept for nine months, up till January 2005. Embartom had not been supplied with record booklets by researchers back in July. He was supplied with a new record sheets booklet, a watch and some more pencils. He was asked to record whether there was flow in the adjacent gulley in the comments column of the rainfall recording form.

R6 (DA raingauge)

The counter in the DAs' office was functioning, and the DAs had a continuous record, despite changes in personnel. The recording raingauge contained no data and the date of the record was the 24th November 2004, when Feto had tried to read the datalogger and had no success.

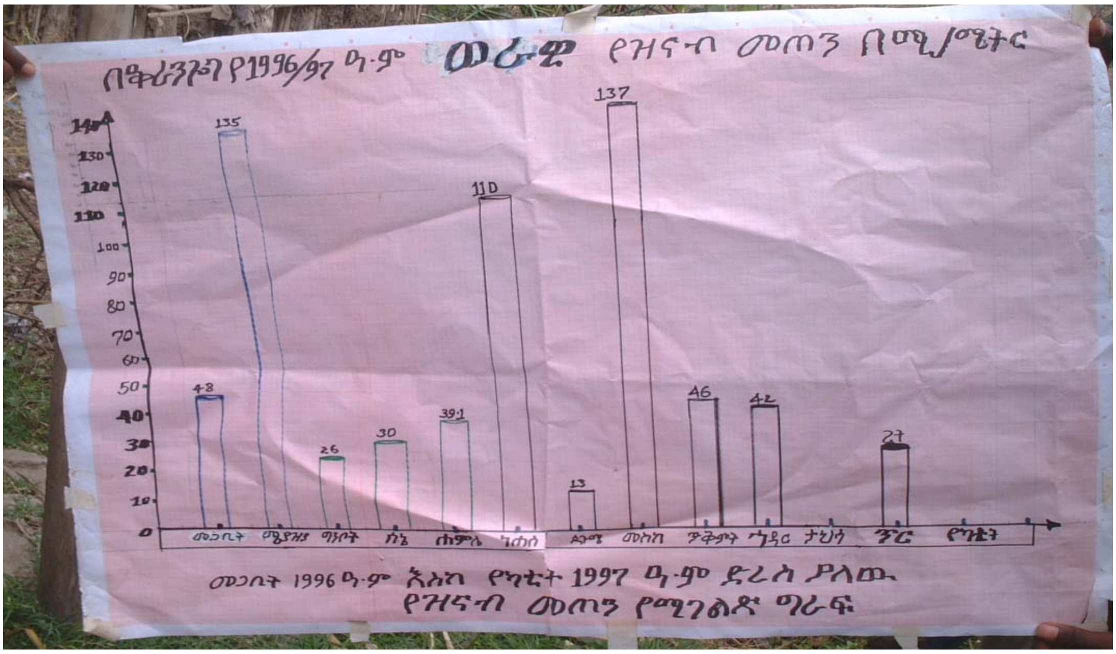
The logger was launched on the 17th March 2005, but 4 days later on the 21st March 2005 when the DA office was visited again, the datalogger had fallen from its mounting and was hanging by its cable. The electronics had become wet inside the casing and it no longer worked. The source of water ingress was an olive which was not screwed tight where the cable entered the casing. The datalogger was taken back to the UK to see if it could be repaired.

3.7.2.2.4.2 DA collation of farmer rainfall records

Farmer rainfall records are being collated by the Awassa and Boricha BoA DAs. The Debub University have found the Awassa BoA uncooperative and as a result are not as closely linked as the Boricha DAs. There is no solar powered computer in the Awassa DAs' office. The Boricha DAs were visited on the 17th and 21st of March 2005 and the Awassa DAs on the 20th March 2005.

The Boricha DAs at the Korangoge office had changed. The new DAs, Dessalean and Sintayehu, had collected some of the farmer rainfall records up until Dec 04. They had made a bar graph of monthly rainfall on the graph paper (Figure 15) which is correctly plotted.

Figure 15: Graph of R6 rainfall made by DAs



DAs had not been supplied with the new rainfall recording sheet booklets with the monthly and dekad rainfall total forms as recommended by the TA on his last visit. They were given new a record book with additional columns for recording start and finish times of rainfall. The rainfall recording spreadsheet was installed on their computer and a demonstration of how to enter data given.

The Awassa HA, Fanage Watan was visited at the DA office in Muleti on Sunday 20th March 2005. She reported that the Awassa DAs had not been supplied with record books, pencils pens and a calculator as promised. These had been purchased by the TA on his last visit and given to Tazebe to give to the farmers. She was supplied with 2 new DA record books, one for this year and one for last year. The Awassa DAs had started collecting farmers' rainfall records and had been advised by their supervisors to record the start and finish times of rain as the TA was now recommending.

3.7.2.2.5 Analysis of rainfall records

Cumulative dekad rainfall is presented in Figure 16 and Ethiopian and International monthly rainfall in Table 14 and Table 15. Average rainfall was 875 mm for the period March 2004-March 2005. Rainfall records for R1 and R5 are incomplete and the weighted average rainfall totals for the year (Table 14) have been calculated from their ratio to R2.

Table 14: Ethiopian monthly rainfall for 96-97 for Umbulo Wacho

Month	R1	R2	R3	R4	R5	R6	Average
7	66	68	0	48	41	43	44.3
8	173.1	193.5	104.2	136.5	153.5	116.5	146.2
9	32	42.5	18	12	25	26	25.9
10	70	66	44	46	66	30	53.4
11		85.5	51.5	92	60.5	35	54.1
12		198	110.8	199.5	155.5	112	129.3
13		11.5	7	7	3.5	15	7.3
1		123.5	101.8	76.5	25	131	76.3
2		41	36.6	19	32.5	46	29.2
3		64	36.2	46	38.5	43	38.0
4		82.5	37.9	30	153	0	50.6
5		111.5	82	63	0	27	47.3
6		82.5	65.5	64		36	41.3
Total	340.6	1170	694.9	839.5	753.5	660.5	743.2
Weighted Average Rainfall	1077.0	1170	694.9	839.5	810.7	660.5	**875.4**
Ratio	*0.92	1	0.59	0.72	+0.69	0.56	

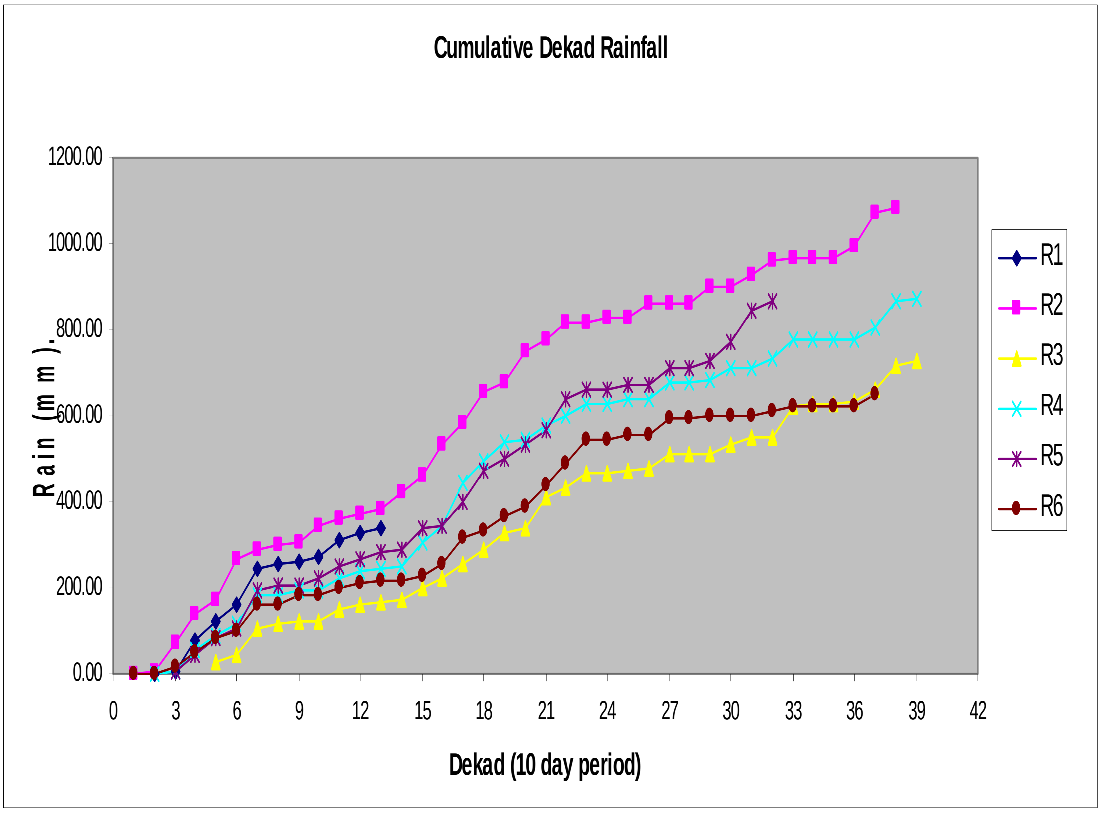
*Ratio of R5 to R2 for the period July-October 96 (E.C): +Ratio of R5 to R2 for the period July 96–April 97.

Table 15: International monthly rainfall for 2004-2005 for Umbulo Wacho

Month	R1	R2	R3	R4	R5	R6	Average
March	6	4	0	6	3.5	14	5.6
April	153.1	166.5	44.81	112	100.5	93	111.7
May	105	127.5	74.77	74.5	103.5	78.5	94.0
June	67.5	63	45.2	36	57.5	24	48.9
July	9	60.5	34.3	63.5	76.5	21	44.1
August	0	176	93.6	193.5	133	107	140.6
September	0	159.5	120	85.5	123	123	122.2
October	0	62	55.7	43	64	84	61.7
November	0	41	41	49.5	50.5	51	46.6
December	0	41	38.1	35	62.5	2	35.7
January	0	64	82	63	90.5	27	65.3
February	0	6	15	6	0	11	9.5
March	0.00	111.5	83.2	93.5	0	53	85.3
Total	340.6	1082.5	727.7	861.0	865.0	688.5	**871.2**
Ratio	*0.92	1.00	0.67	0.80	+0.90	0.64	

*Ratio of R5 to R2 for the period March-June 2005: +Ratio of R5 to R2 for the period March 2004-January 2005

Figure 16: Cumulative dekad rainfall for Umbulo



All raingauges followed a similar pattern. May to July averaged 20mm/dekad, August and September 39mm/dekad, and October to March 16mm/dekad. R1 and R2 are very similar R1 being 92% of R2. R4 and R5 are similar (80 and 90% of R2) as are R3 and R6 (64-67% of R2) (Table 15).

Contrary to Gudeta and Fanage Watan's opinions, both Gudeta and Emartom have similar rainfall and are neither the wettest nor the driest parts of the project area. The southern part of the basin (R2) is wettest, with the top of the Umbulo southern ridge being the driest.

3.7.2.2.6 Comparison with Awassa meteorological station

Table 16 shows the monthly rainfall for Awassa meteorological station compared to the weighted average Umbulo 2004 rainfall. February, March, May, June, July and October of 2004 were all drier than the average for Awassa (1993-2002), while January, September, November and December were wetter. Only April and August were about average. This confirms farmer reports that rainfall was bad in 2004, and Yosef's (R3) view that rainfall was better after July 2004. June and July 2004 had exceptionally poor rain (June's rainfall would be expected to occur once every 7 years and July's rainfall would be expected to occur once every 33 years).

Table 16: Monthly rainfall for Awassa Meteorological station compared to average Umbulo 2004 rainfall.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
1993	101.6	109.1	22.3	104.9	165.3	46.7	32.8	130.8	47.8	130.8	9.6	3.9	905.6
1994	0	3.7	56.8	108.7	81.5	146.2	295.7	118.9	68.9	58.8	19.1	2.9	961.2
1995	0	21.4	61.8	171.1	53.6	118.7	151.6	134.7	126.8	22.3	18.3	84.2	964.5
1996	78.4	36.9	89.6	113.9	161.5	243.3	121	180.7	145	70.6	19.7	1.4	1262
1997	23.4	1.7	75.1	125	73	111.2	98.8	113.9	119.1	157.5	132.2	24	1054.9
1998	92	140	90.8	86.6	88.9	52	172.9	108.3	110.1	193.3	104	0	1238.9
1999	19.8	0.4	105.5	27.1	64.7	99.8	135.1	83.6	125.4	120.4	20.1	16.2	818.1
2000	1.1	0	10.5	132	144.5	36.8	80	179.3	86.5	110.7	29	11.3	821.7
2001	1.8	39.9	122.7	67.2	233.7	137.8	93.4	131.7	89.7	80.2	2.6	21.3	1022
2002	52.5	2.4	28.8	119.6	85.2	91.9	76.6	190.4	83.2	34.3	0	41.5	806.4
Average	37.1	35.6	66.4	105.6	115.2	108.4	125.8	137.2	100.3	97.9	35.5	20.7	985.53
st dev	40.7	49.8	37.3	38.9	58.1	60.6	72.1	35.2	30.0	54.5	44.9	25.8	163.7
Max	101.6	140.0	122.7	171.1	233.7	243.3	295.7	190.4	145.0	193.3	132.2	84.2	1262
Min	0.0	0.0	10.5	27.1	53.6	36.8	32.8	83.6	47.8	22.3	0.0	0.0	806.4
Umbulo 2004	65.3	9.5	5.6	111.7	94.0	48.9	44.1	140.6	122.2	61.7	46.6	35.7	785.9
(2004 UMBULO)/-(1993 - 2002 average)	28.24	-26.0	-60.8	6.0	-21.2	-59.6	-81.7	3.4	21.9	-36.12	11.1	15.0	- 200
%(2004 UMBULO)/-(1993 - 2002 average)	176.2	26.7	8.4	105.7	81.6	45.1	35.1	102.5	121.9	63.1	131.4	172.8	79.7
% rank of exceedence of 2004 rainfall	72.1	48	100	50.7	56.5	15.6	2.8	68.1	72.1	24.9	80.3	85.2	100

3.7.2.2.7 Other hydrological monitoring

Umbulo is a complex catchment to monitor as there is no single observable outlet, and it is drained by three holes in a gulley through the floodplain. Water is delivered to the floodplain by gullies all over the catchment. For a water balance calculation all the gullies need to be monitored. Observations of flow across the floodplain and drainage into the gulley and holes would be useful.

This catchment has been digitized by researchers at CAZS, a copy of the Arcview files are on the CD accompanying this report.

Planned research in the project area includes an assessment of irrigation systems using the water harvesting ponds being built by the BoA and Awdenegest Moges' PhD studies. These proposals should provide some of the above information required for catchment modelling and the calculation of a water balance.

The TA discussed with Feto recording:

- The water levels in the water harvesting and surface ponds on a daily basis providing the farmers with tape measures and record sheets.
- Daily minimum and maximum temperatures for Blaney Criddle evapotranspiration calculations, providing the farmers with thermometers and record sheets.
- Flow measurement in gullies draining on to the floodplain. Providing observers with tape measures and recording sheets to record peak flow, time of peak flow, start and finish times of flow. Farmer Embartom recording rainfall at R5 was asked to record whether there was flow in the gulley adjacent to the raingauge.
- Surveys of gullies, vegetation and soils
- Measurements of soil moisture and hydraulic properties
- Surveys and observations of water abstractions
- Surveys of farmers indigenous knowledge of climate and agriculture

3.7.2.2.8 Computers

The computer in the DAs' Korangoge office had not had its MS office software activated and so had reduced functionality, the printer was also not working. This was remedied on a subsequent visit by Teferi Abay a computer engineering lecturer from DU. Adobe Acrobat reader should be installed on this machine so that copies of TA reports can be left on the computer for the DAs to read.

The computer in the Yirba office was not working, its hard drive had failed and it was taken back to Debub University for repair.

4 References

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* Electronic copies given to researchers

\+ Hard copies given to researchers

Appendices

Appendix 1: Record books for rainfall recording for Farmers and DAs

There are 3 sections to this appendix: title sheets, sheets for Farmers and sheets DAs.

Title sheets

There are 4 of these one for each project area. There is no difference in the title sheet for farmers or DAs. The wording on the sheets should be translated into local languages. Both English and local language wording should be on the title pages.

DCI Operational Research

Debub University
Centre for Arid Zone Studies
Boricha/ Awassa Woreda Agricultural Bureau

Hydrological Studies of Umbulo Watershed
Rainfall Record Book

Place ____________________ Woreda ____________________

Recorder ____________________

DCI Operational Research

Debub University

Centre for Arid Zone Studies

Gurage Woreda Agricultural Bureau

Hydrological Studies of Beresa Watershed

Rainfall Record Book

Place ____________________ Woreda ____________________

Recorder ____________________

DCI Operational Research

REST

Mekelle University

Centre for Arid Zone Studies

Hawzien Woreda Agricultural Bureau

Hydrological Studies of Debre Kidan Watershed

Rainfall Record Book

Place ____________________ Woreda ____________________

Recorder ____________________

DCI Operational Research

REST

Mekelle University

Centre for Arid Zone Studies

Tambien Woreda Agricultural Bureau

Hydrological Studies of Begasheka Watershed

Rainfall Record Book

Place ____________________ Woreda ____________________

Recorder ____________________

Record books for rainfall recording for Farmers

The following pages can be printed off to make record books for the Farmers. There are 3 types of recording sheet: a Daily recording sheet; Dekad recording sheet and a Monthly recording sheet. The correct title sheet, 13 daily sheets, 1 dekad sheet and 1 monthly sheet should be bound and presented to the farmers once a year.

Only Ethiopian and English versions of the sheets are presented here. Mekelle researchers should translate the sheets into Tigrinya.

Farmers should enter information into the sheets in the following ways:

Daily sheets the rainfall for each day should be entered into the appropriate column, and record the weather.

Dekad sheets add up the previous 10 days rainfall for each raingauge and enter it into the table. Then for each dekad calculate the average rainfall.

Monthly sheets calculate the monthly total for complete months only. There is a row at the bottom of the daily sheet for calculating the monthly total. Transcribe these totals into the monthly sheet. When the year is complete calculate the yearly totals for all the raingauges and the average annual rainfall.

Daily recording sheet, English version

Operational Research
Daily Rainfall Record Sheet

Place_______________________ Woreda_______________________

Month______________________ Recorder______________________

Date	Time	Rainfall (mm)	Start time	Finish time	Weather	Remark
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
Total						

Weather Conditions

Windy = (W) Cloudy = (C)

Cold = (F) Warm/sunny = (S)

ተግባራዊ (OPERATIONAL) ምርምር የቦርቻ/ሰዋማ ወረዳ ግብርና ቢሮ HYDROLOGICAL STUDIES ሱሞቡሱ ተፋሰስ
የዕለት የዝናብ መጠን መመዝገቢያ ቅፅ

ቦታ ____________________ ወረዳ ____________________

ወር ____________________ የመዘገበው ሰው ____________________

ቀን	የተመዘገበበት ሰዓት	የዝናብ መጠን (mm)	የአየሩ ሁኔታ	ዝናብ የጀመረበት ሰዓት	ዝናብ ያቆመበት ሰዓት	ማስታወሻ
1						
2						
3						
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የአየሩ ሁኔታ

ነፋሻ = (ነ) ደመናማ = (ደ)

ቀዝቃዛ = (ቀ) ሞቃት/ፀሃያማ = (ሞ)

Operational Research: Dekad (10 day) Rainfall Sheet

Place______________________ Woreda______________________

Month_____________________ Recorder_____________________

Dekad	Dates	Weather /remarks	Total Rainfall (mm) for Dekad
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
Total			

Operational Research
Monthly Rainfall Sheet

Place______________________ Woreda______________________

Year_____________________ Recorder_____________________

Month	Remarks	Total Monthly Rainfall (mm)
Total		

Record books for rainfall recording for DAs

The following pages can be printed off to make record books for the DAs. There are 4 header pages and 4 types of recording sheet: a Daily recording sheet for a single raingauge; a Daily record sheet, a Dekad recording sheet and a Monthly recording sheet. (all of the last 3 sheets have columns for all raingauges in the project area).

The correct title sheet, 13 daily sheets for a single raingauge, 13 daily sheets for all rain gauges. 1 dekad sheet or all rain gauges and 1 monthly sheet or all rain gauges should be bound and presented to the DAs once a year.

The record sheets presented here are designed for 4 raingauges, as have been installed in Debre Kidan and Beresa. Extra columns will have to be provided for Begasheka as there are 5 raingauges there. 4 raingauge sheets should be adequate in Umbulo, although 6 raingauges have been installed, 4 are in Boricha and 2 in Awassa Woredas.

Only Ethiopian and English versions of the sheets are presented here. Mekelle researchers should translate the sheets into Tigrinya.

DAs should enter information into the sheets in the following ways:

Daily sheets for a single raingauge, the rainfall for each day recorded by the counter in the DAs office should be entered as well as the weather.

Daily sheets for all project raingauges, Farmer and DA daily records should be entered into the appropriate columns**.**

Dekad sheets, using the Daily sheets for all project raingauges, add up the previous 10 days rainfall for each raingauge and enter it into the appropriate column. Then for each dekad sum up all the rainfall figures and divide by the number of raingauges to calculate the dekad average rainfall.

Monthly sheets, calculate the monthly totals for each raingauge for complete months only. There is a row at the bottom of the daily sheet for all project raingauges for calculating the monthly total. Transcribe these totals into the monthly sheet and then work out the sum of monthly rainfall for all of the raingauges and divide by the number of raingauges to calculate the monthly total rainfall. When the year is complete, calculate the yearly totals for all the raingauges and the average annual rainfall.

Operational Research
Daily Rainfall Recording Sheet

Place______________________ Woreda______________________

Month_____________________ Recorder_____________________

Date	Time	Rainfall (mm)	Start time	Finish time	Weather	Remark
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
Total						

Weather Conditions

Windy = (W) Cloudy = (C)

Cold = (F) Warm/sunny = (S)

ተግባራዊ (OPERATIONAL) ምርምር የቦርቻ/ሰዋሣ ወረዳ ግብርና ቢሮ
HYDROLOGICAL STUDIES ሰሞቡሱ ተፋሰስ
የዕለት የዝናብ መጠን መመዝገቢያ ቅፅ

ቦታ ____________________ ወረዳ ____________________
ወር ____________________ የመዘገበው ሰው ____________________

ቀን	የተመዘገበበት ሰዓት	የዝናብ መጠን (mm)	የአየሩ ሁኔታ	ዝናብ የጀመረበት ሰዓት	ዝናብ ያቆመበት ሰዓት	ማስታወሻ
1						
2						
3						
4						
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ድምር						

<u>የአየሩ ሁኔታ</u>

ነፋሻ =(ነ) ደመናማ =(ደ)
ቀዝቃዛ =(ቀ) ሞቃት/ፀሃያማ =(ሞ)

Operational Research DA
Daily Rainfall Record Sheet

Place_______________________ Woreda_______________________

Month______________________ Recorder______________________

Date	Weather /remark)	Rainfall (mm))			
		R1	R2	R3	R4
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
Total					

Operational Research : DA Dekad Rainfall Record Sheet

Place______________________ Woreda______________________

Start date_____________________ Recorder_____________________

Dekad (10 day period)	**Dates**	**Weather /remarks**	**Rainfall (mm)**					
			R1	R2	R3	R4	Sum	**Average**
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								
36								
37								
Total								

Operational Research
DA Monthly Record Sheet

Woreda______________________

Year_____________________ Recorder_____________________

Month	**Remarks**	**Rainfall (mm)**					
		R1	R2	R3	R4	Sum	**Average**
Total							

Appendix 2: Collecting raingauge installation procedure

The following design of the raingauge installations in Umbulo Wacho was designed with the help of Eyasu the Umbulo Wacho PA and the farmer Endrias Denbaro. They decided that the gauge should be mounted at 1.30m high to prevent damage from cattle and that there should be a fence around the raingauge to 1.2m

Materials

4 fence posts, 2m long, termite proof, 7 birr each

4 crossbars, provided by farmer

4 nails, 3 inch long

40 m of single strand barbed wire, 50 birr

1 post for raingauge, termite proof, planed flat at top on 1 side for 35cm, 7 birr each

3 screws, 1 inch, come with raingauge

50 staples, 1 inch

5 buckets of rock and gravel (obtained locally)

Tools

Measuring tape

Screw driver – Flat head

2 hammers

Saw

Wire cutters

Digging implements, obtained locally

Level

Gloves

First aid kit

Method.

Mark out the position of the posts on a 1.2 x 1.2m square with the tape measure.

Dig 4 holes for the posts using the digging implement 50 -80cm deep.

Dig a hole, 50 -70cm deep, for the raingauge mounting post in the centre of the square.

Place the fence posts in the post holes and mark the tops of the posts so that they are level at 1.2m.

Cut the fence posts to height.

Place the raingauge post in its hole and measure 10 cm above the fence, mark it and cut it to size.

Attach the mounting bracket for the raingauge to the post using the 3, 1 inch screws, so that in projects above the post. Use a nail to make pilot holes first.

Place all poles in the ground and back fill the holes with rocks, gravel and soil, making sure they are straight. For the raingauge post, attach the raingauge and use the level to check that the raingauge while backfilling.

Nail the cross bars to the top of the posts using the 3 inch nails, wedge the other end of the cross bar to the bottom of the adjacent post.

Mark on the fence posts, 10, 20, 30, 40, 65, 90, 105 and 120cm from ground level

Using gloves unwind the barbed wire. Starting at the 10cm mark, nail one end of the wire to the post using 2 staples.

Wind the wire around the other 3 posts and back to the first post using staples to attach the wire and a hammer to tension the wire.

At the starting post and using the second hammer, tack the wire at the 20 cm mark and continue tacking the wire at this level to the other posts.

Continue the above, raising the wire on the starting post to the mark above. When completed cut the wire and finish with 2 staples.

The raingauge installation is now complete. Farmers are now presented with a folder with recording sheets in Amharic, a pencil case containing 12 pencils, a rubber and a pencil sharpener, and instructions for taking rainfall measurements.

Appendix 3: Recording for the collecting raingauge

Description and maintenance of the raingauge

The raingauge is made up of 4 parts.

The clear plastic main body,

a green plastic funnel,

a clear plastic measuring tube graduated in inches, cm, and mm,

and a green plastic mount, to be attached to the post.

The main body of the raingauge slots on to the green plastic mount. The measuring tube slots on to the bottom of the funnel, and the funnel sits on top of the main plastic body. There is a circular slot at the bottom of the main body into which the measuring cylinder should sit, other wise the top of the raingauge will not be level.

The raingauge needs to be kept clean, please ensure that the hole in the funnel is not blocked other wise water may be lost especially during heavy rainfall.

Apart from the responsible person it is important to train other members of the household how to record rainfall for you in case you are absent or otherwise unable to record rainfall in the morning.

Measurement procedure.

Readings should be taken at the start of the day. Time of reading should also be recorded. It is important that rainfall is recorded at this time as this is when other raingauges in the area will also be read, it will be difficult to compare the reading with the other raingauges if readings are taken at a different time.

Remove the whole raingauge from the mount. Remove funnel with the attached measurement tube. Hold the measurement tube immediately.

Read the mm scale on the tube by holding level (not tilted) and raising the tube so that the top of the water in the tube is the same height as the eye.

If water has overflowed into the main body of the raingauge and the measuring tube is full,

> remove the funnel and pour the water from the tube back into the raingauge main body. If the funnel is kept on top of the tube when pouring the water back, water will be spilt.
>
> Place the funnel back on top of the measuring tube and pour the water in the main body in to the measuring cylinder to the 25mm mark.
>
> Make a note that 25mm has been collected.
>
> Discard the water from the tube making sure no water remains in the measuring tube.
>
> Repeat the procedure from (b), adding 25mm to the total each time, until the last of the water is poured into the measuring cylinder, make a note of this final reading and add it to the total.

For example the measuring cylinder is filled to 25mm twice, and the last reading is 15mm the total rainfall would be 65mm (25 +25 + 15 mm).

Make sure that the measuring cylinder is empty, reattach the funnel to the cylinder and place the funnel and measuring cylinder on the main body of the raingauge. Make sure that the cylinder slots in to the circular slot in the bottom of the raingauge body.

Recording Procedure

Record your daily reading, and the time and date the measurement was taken and the weather for the previous day on the record sheet provided. For example if there was a rainfall reading of 10mm at 1.03 on the 20th March, the reading and description of the weather would be entered on the record sheet for the row for the 19th March as illustrated below.

Day	Time	Reading (mm)	Weather	Remarks
18	0.45	2	C + W	
19	1.03	10	C	
20				

The weather should be described using the following 4 terms. Sunny/warm, Cloudy, Windy and Cold. Use the symbols representing these weather conditions to record the weather on the record sheet

If water is spilt and lost then use the greater than symbol (>) to indicate that the rainfall was greater than the recorded reading because some water has been lost.

Day	Time	Reading (mm)	Weather	Remarks
2	0.55	23	C + W	
3	1.13	>100	C	
4				

Use the greater than symbol (>) as well in the unlikely event that the main body of the raingauge is full and water has overflowed from the raingauge.

Some days there may be only a droplet of water in the bottom of the raingauge, record this as 0.5mm.

If the raingauge was not read on any day, mark the record sheet with a dash (-) to indicate that a reading was not recorded on that day. The reading taken the next day includes the missing day(s).

Day	Time	Reading (mm)	Weather	Remarks
9		-	C + W	
10	2.00	55	C	
11				

What will happen to the rainfall data?

The Tabia/Kebele DA will collect the data every week. He should make his own copy of the rainfall record sheet, and sign and date the record sheet in the remarks column. These copies of the farmers rainfall records will be kept and plotted in the Tabia/ Kebele DAs office. Daily rainfall will also be collected by another two farmers in the project area.

Data collected by the DA will be used by researchers to produce rainfall maps. Later they will estimate rates of soil erosion, the amount of water available to crops. Later measurements will be taken of the amount of water flowing out of the project area and waterlevels in the wells and groundwater recharge dams. Copies of the rainfall maps that they produce will be passed to the Tabia/Kebele DAs and will be available for inspection by the farmers. Results may also be communicated to all stakeholders (farmers and BoA) in a field day that may be organized in the Tabia/ Kebele.

What to do if the raingauge mount is broken

Make a mounting piece out of wood or of thin tin metal (from a tin can for instance) or tie the raingauge to the pole.

What to do if the raingauge is stolen

Please inform the Tabia/ Kebele DAs

Please also inform the other raingauge recorders in the study (list below) so they are aware of the problem.

There are no replacement raingauges available as these have to be imported from the UK.

Appendix 4: Rainfall recording procedure for the recording raingauge

Raingauge description and maintenance

The raingauge consists of 3 main parts

a white plastic square raingauge containing a tipping bucket shaped like a spoon.

a white digital counter with a reset button which uses a AAA battery

a black datalogger

The raingauge needs to be kept clean, please ensure that the hole in the funnel is not blocked other wise water may be lost especially during heavy rainfall.

The counter uses a AAA battery. If the counter is blank then the battery will need replacing or the connections in the counter will need cleaning.

Apart from the responsible person it is important to train other members of the household how to record rainfall for you in case you are absent or otherwise unable to record rainfall in the morning.

Rainfall measurement.

The digital counter records the amount of rainfall in mm directly and this can be copied directly to the record sheet.

Rainfall recording procedure

Readings should be taken at the start of the day. Time of reading should also be recorded. It is important that rainfall is recorded at this time as this is when other raingauges in the area will also be read, it will be difficult to compare the reading with the other raingauges if readings are taken at a different time. After recording a reading press the reset button on the digital counter so that it says zero, ready for the next day's readings.

Record your daily reading, the time and the weather for the previous day on the record sheet provided. For example if a rainfall reading of 10 mm is observed at 1.03 on the 20th March, you would enter the reading and description of the weather on the record sheet for the row for the 19th March as illustrated below.

Day	Time	Reading (mm)	Weather	Remarks
18	0.45	2	C + W	
19	1.03	10	C	
20				

The weather should be described using the following 4 terms. Sunny/warm (s), Cloudy (c), Windy (w) and Cold (F). Use the symbols representing these weather conditions to record the weather on the record sheet.

Some days it may have rained but there may be no rainfall recorded, in this case record the rainfall as less than 1 mm (<) and mark this as 0.5 mm when plotting the graph.

If a measurement is missed, use a dash (-) to indicate that a reading was not recorded on that day.

Day	Time	Reading (mm)	Weather	Remarks
9		-	C + W	
10	1.15	55	C	
11				

The Datalogger

Occasionally a researcher will come and download data from the datalogger. The datalogger records when the rainfall occurred and from this the rainfall intensity can be calculated. This information can be used to estimate the amount of runoff and rainfall erositivity in the project area.

What to do if the raingauge or counter is broken or stolen.

If the raingauge counter is blank please check the battery, the contacts may need cleaning.

If the raingauge body becomes detached from the base, secure it by taping it to the base. Do not tape over the top of the raingauge as this will reduce the amount of rainfall recorded.

If no rainfall is recorded by the counter after significant rainfall, check the wire leading from the raingauge to the counter for damage or the funnel of the raingauge for blockages.

If the raingauge is stolen or broken please inform the Tabia/ Kebele DA. Replacement gauges are not available locally and have to be imported.

Appendix 5: Collecting the rainfall data *(Instructions for Tabia/ Kebele DAs)*

Collecting Rainfall Data from farmers

Once a week rainfall data should be collected from the farmers, the DA should make his own copy of the farmers' rainfall record sheet, and sign and date their record sheet in the remarks column.

Using the rainfall data collected, rainfall totals for 10 day periods should be calculated for each for each raingauge, in the note book provided. This is so the rainfall measurements can be used for crop water requirement calculations. Monthly and Annual totals should also be calculated. This information will be collected by researchers from Mekelle periodically.

If a farmers' raingauge is broken at the mount it may be possible to make a mount out of wood or a piece of bendable metal. If a farmers' raingauge is stolen, then please inform Woldegebreal Ghawaria, head of Soil and water conservation, BOANR, Mekelle, and the other farmers. Replacement gauges are not available and will have to be imported.

Plotting the rainfall data

Plot the rainfall at each raingauge on the large graph paper sheets provided using a 1mm square for each mm of rainfall and 2 mm per day. Draw a line linking each consecutive day's rainfall. Where farmers have used the greater than symbol (>) draw an up arrow (↑) above that data point on the graph. Expect the farmers and researchers to inspect the rainfall graphs.

Missing readings

Where farmers have not recorded one or more consecutive daily readings, use the weighted average method. The reading taken after the missing days will contain the cumulative rainfall for those missing days.

Take the records from raingauges which have no data missing for those days,

Calculate the total rainfall for those gauges for each day, and for the day that the raingauge with the missing records was read.

Record these daily combined totals and add these rainfall totals for all days together.

Divide the combined rainfall for each day by the combined total for both days. This will give you a ratio of that day's rainfall to the total.

Using the ratio for the appropriate day multiply the reading following the missing readings from the raingauge with the missing data.

For instance suppose raingauge 3 had a missing reading on the 19/3 but recorded 19 mm on the 20/3, but raingauge 1 recorded 12 mm on the 19/3 and 5 mm on the 20/3, while raingauge 2 recorded 14 mm on the 19/3 and 7 mm on 20/3.

The total rainfall for gauges 1 and 2 on 19/3 is 26mm, and on the 20/3 it is 12 mm.

The total rainfall for gauges 1 and 2 for both days is 38 mm.

The ratio of rain on the 19/3 to the total for both days is 26÷38 =0.68,

And the ratio for the 20/3 is   12÷38 =0.32.

So for the 19/3 the rainfall would be 19 x 0.68 = 13 mm

and for the 20/3,   19 x 0.32 =   6 mm

Where the farmer has emptied the raingauge but not recorded a reading, use the relative ratio method.

For the period prior to the missing data calculate the total rainfall for he raingauge with the missing data.

Calculate the ratio of each raingauge against that of the recording raingauge.

Use this ratio too calculate the missing rain fall.

For instance suppose the recording raingauge recorded 13 mm, but the reading for R1 was missing. Prior to this R1 had recorded a total of 349 mm, prior to the missing reading and the recording raingauge 329 mm.

The ratio of rainfall recorded by R1 to that recorded by the recording raingauge is

349÷329 = 1.06

The missing reading for R1 is then 13 x 1.06 = 13.8 mm

What will happen to the rainfall data?

The data collected will be used by researchers to produce rainfall maps. Later they will estimate rates of soil erosion, the amount of water available to crops. Later measurements will be taken of the amount of water flowing down the gullies draining out of the project area and water levels within the wells and groundwater recharge dams. Copies of the rainfall maps that they produce will be passed to the BoA Woreda office and should be made available to the Tabia/ Kebele DAs and farmers. Results may also be communicated to all stakeholders (farmers and BoA) in a field day that may be organized in the Tabia/ Kebele.

Three daily raingauges in total will be set up in the project area. Details of all the raingauges are listed in the table below and the locations are also given in the map below.

Appendix 6: Instructions for downloading the datalogger

Overview

The datalogger needs to be prepared (launching) by the Boxcar software so it can start to log rainfall events. The datalogger also needs to be launched after data has been collected from the datalogger. **If the datalogger is already logging, then launching it will destroy the data already collected**. If the logger is already launched then start with the section labelled *Downloading data from the logger*.

The datalogger which is attached to the raingauge, records the time at which a total of 1mm of rainfall fell. The logger can record 8000 mm of rainfall, however frequent downloading will minimise the chances of missing data should the datalogger malfunction because of a poor battery or bad connection. The data can be viewed in the Boxcar software but better analysis and comparison with the other raingauges can be done if the data is imported into Excel.

Requirements

Datalogger

Datalogger cable (provided with logger)

Laptop with serial RS 232 port

Software: Boxcar (provided with logger)

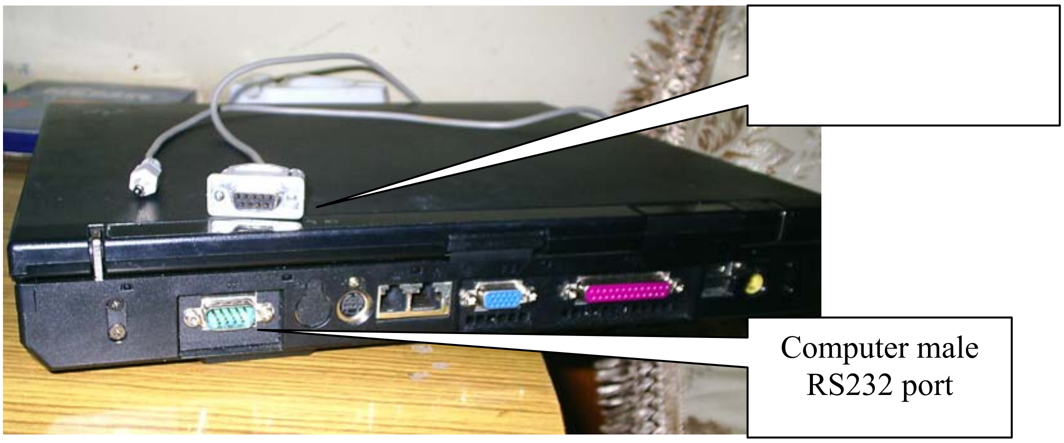
Microsoft Excel

Method

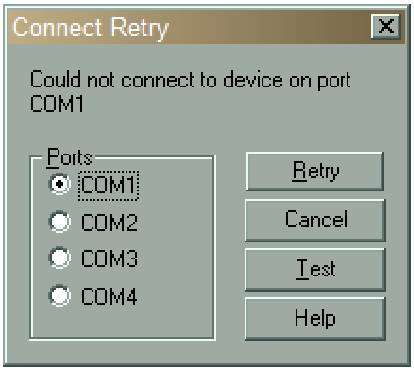
Launching the logger

If the datalogger is already logging, then launching it will destroy the data already collected. If the logger is already launched then start with the section labelled *Downloading data from the logger.*

Connect the logger to the computer via the cable. There is a socket on the logger for this purpose and the cable fits to the computers RS 232 port (some modern laptops do not have this port, old style serial mice use this port) which is male and has 2 rows and 9 pins in all.

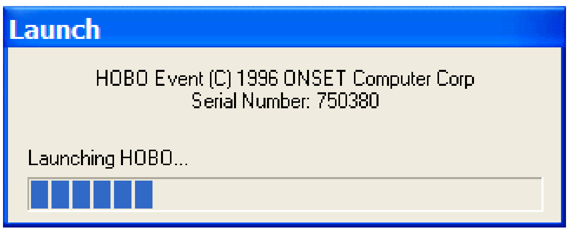


Start the Boxcar software, select Com 1 if necessary.



Select LAUNCH from the Logger menu. This brings up the launch dialog. (If it doesn't, check the cable connectors) Chose an appropriate name for the data and press the START button.

Watch the launch progress bar until the launch is complete. The logger is now recording data.

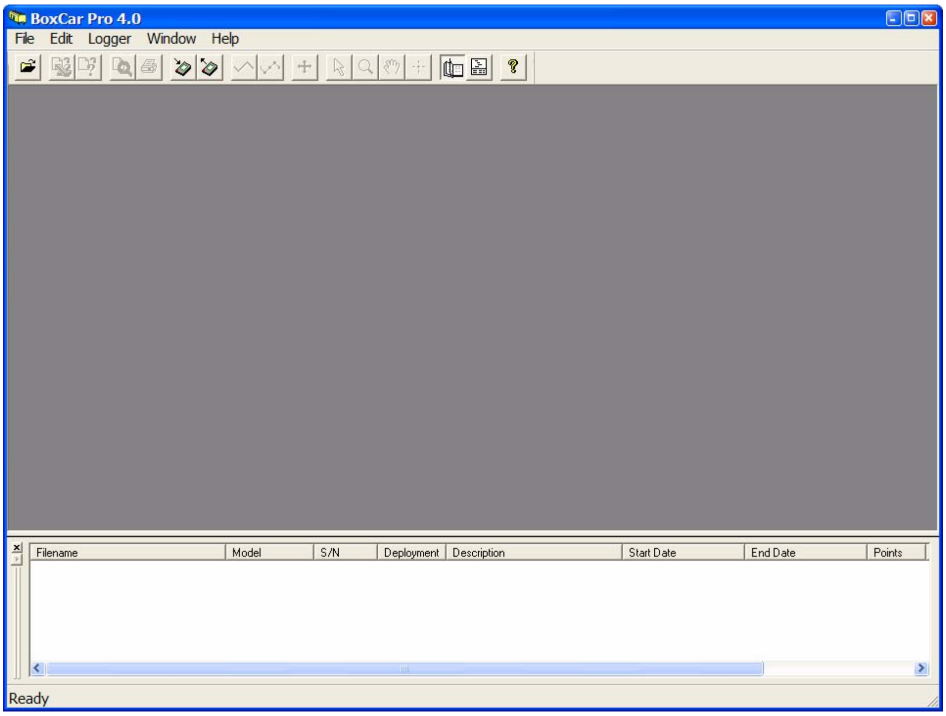


Disconnect the logger from the computer.

Downloading data from the logger

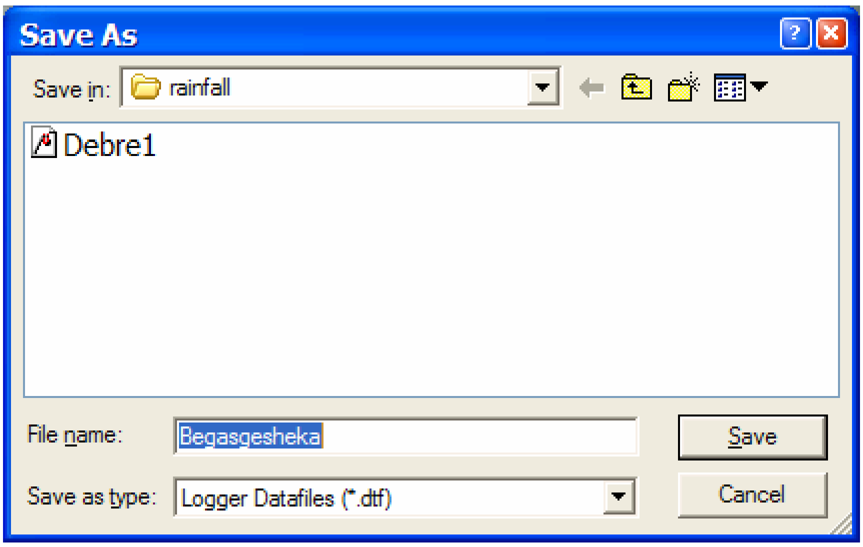
Connect the logger to the computer via the cable.

Start the Boxcar software.

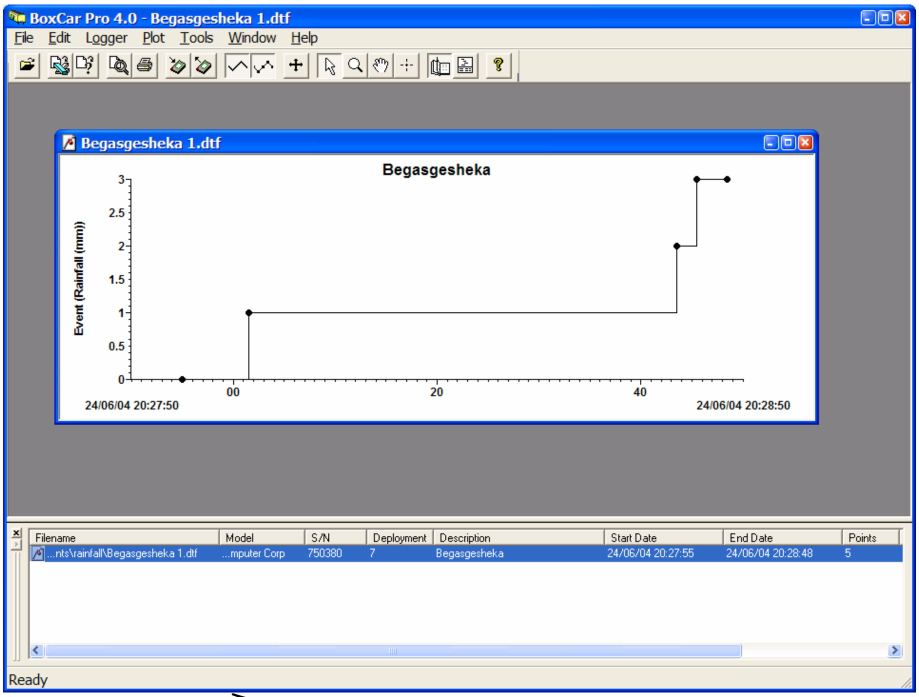


Select READOUT from the Logger menu and watch the progress bar until it is done.

Using the SAVE AS dialog box, name the off-loaded data file and choose where to store it.



If successful you should be presented with a graph showing the rainfall



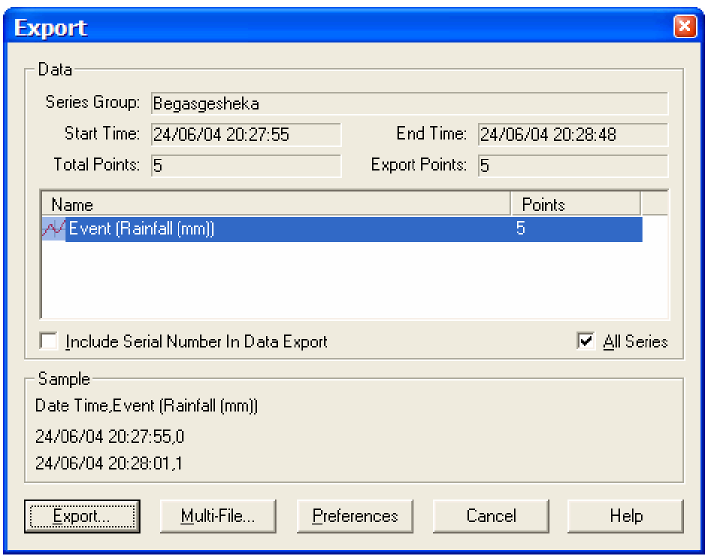
Exporting the data into Excel

Excel can read comma delimited files, but the time an[illegible] need to be in the same column so you can create graphs in Excel.

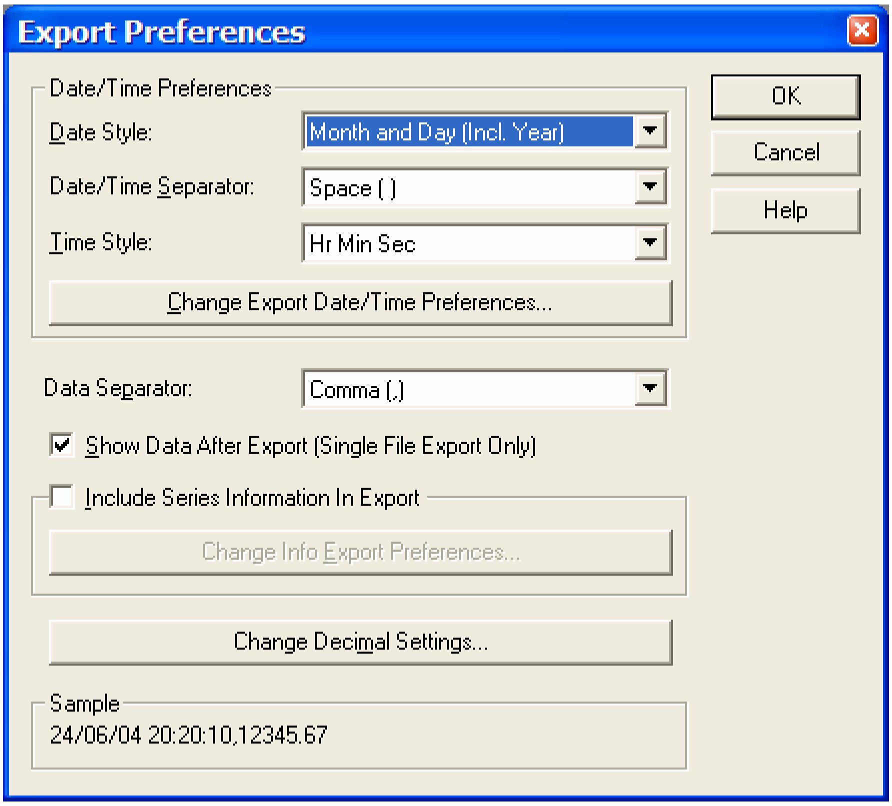
Select the file you have just downloaded from the logge[illegible] of the Boxcar program window)

Select FILE / EXPORT/ CUSTOM. This takes you to the export window (do not use the Excel export option in Boxcar as this will create files with the wrong date and time format).

Downloaded file name (this is the file to prepare for export into excel)



Click the PREFERENCES button, which takes you to the export preferences window.



Change the DATE STYLE to *month and day (incl. year)*.

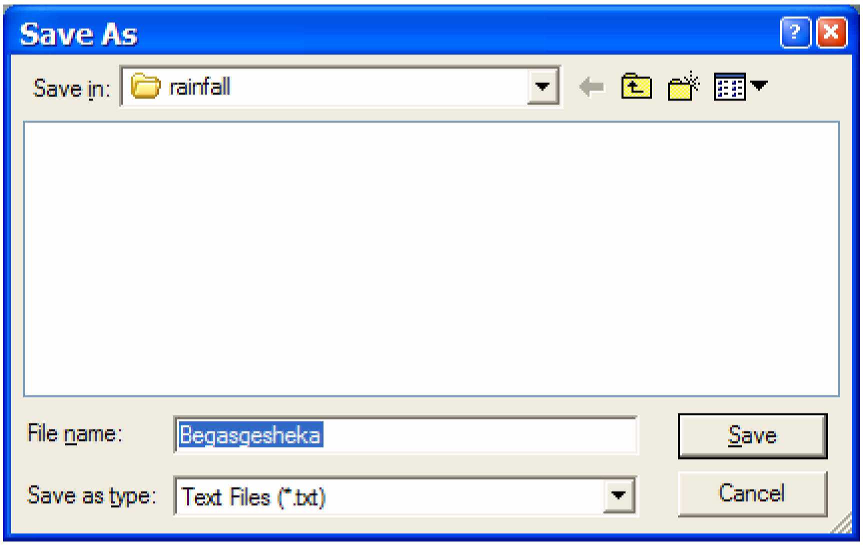
Change the TIME/DATE SEPERATOR to *space*.

Change the TIME STYLE to *Hr Min Sec*.

Change the DATA SEPARATOR to *comma*.

Click OK and return to the file export window.

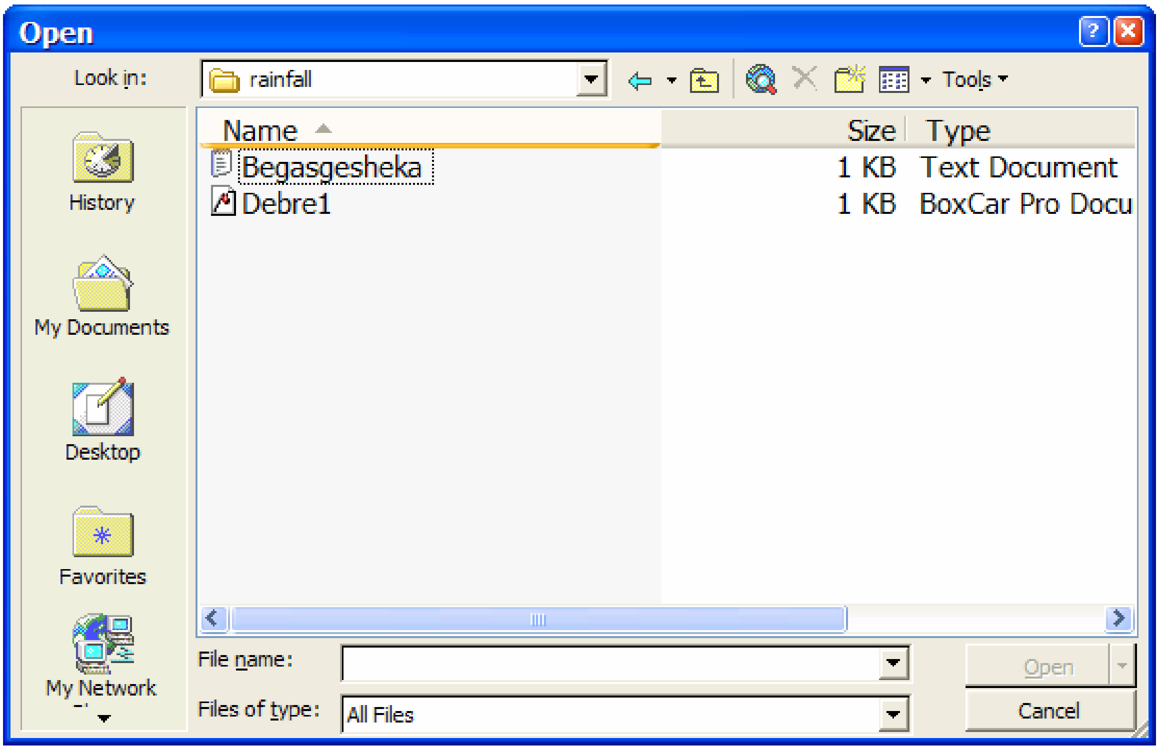
Click on the EXPORT button, and save the file as a text file in a convenient location.



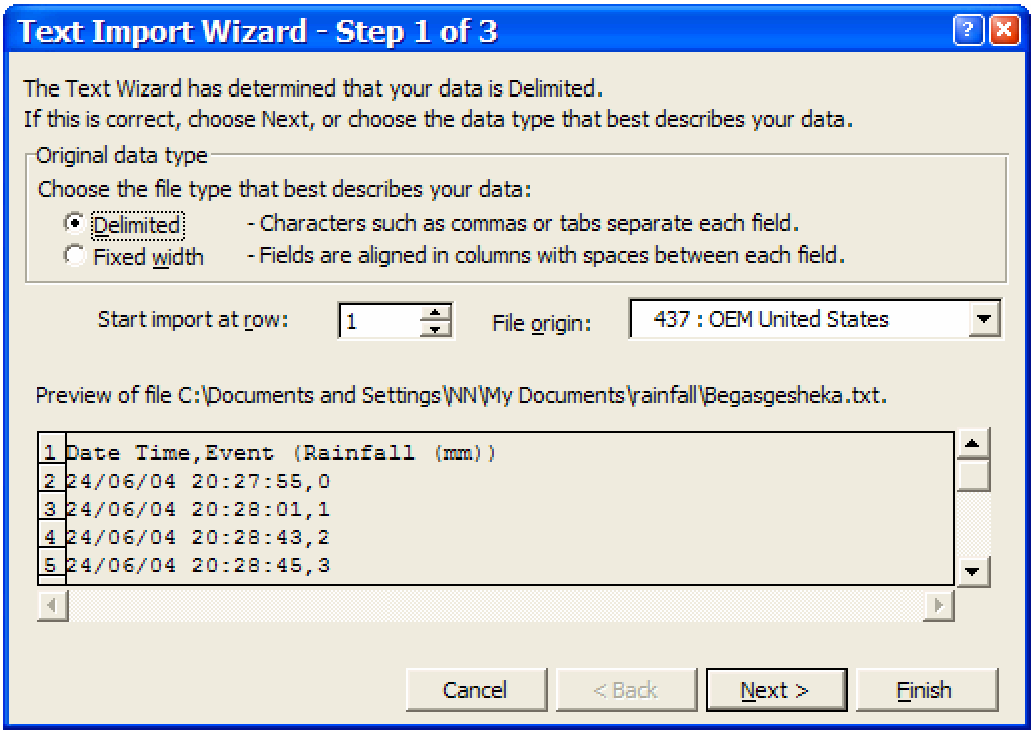
Now import the file into Excel

Start Excel.

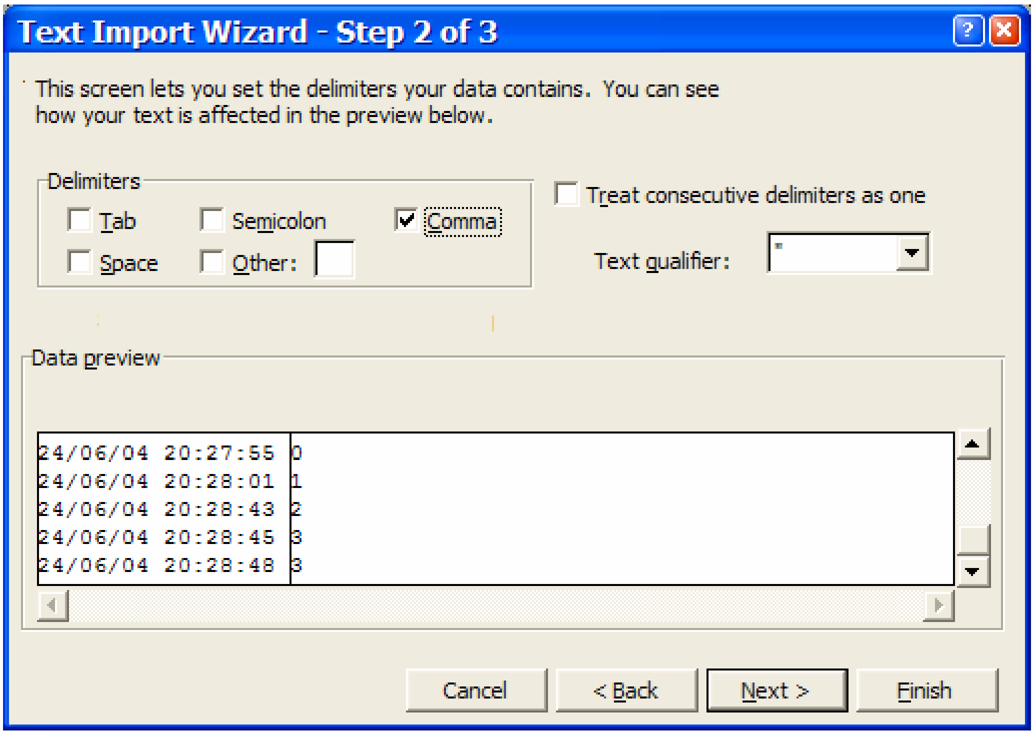
Open the text file you have just created. Excel will recognise this and start its import wizard.



Select the correct row to import from, this will be the row the data starts, ignore the column labels.

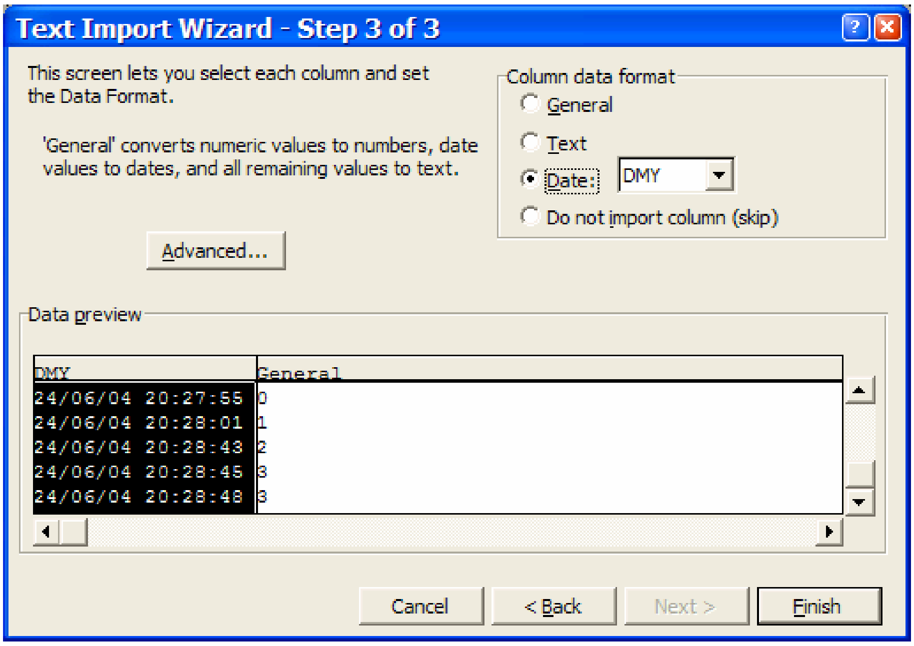


Select DELIMITED FILE OPTION and click NEXT this takes you to the delimiter window.

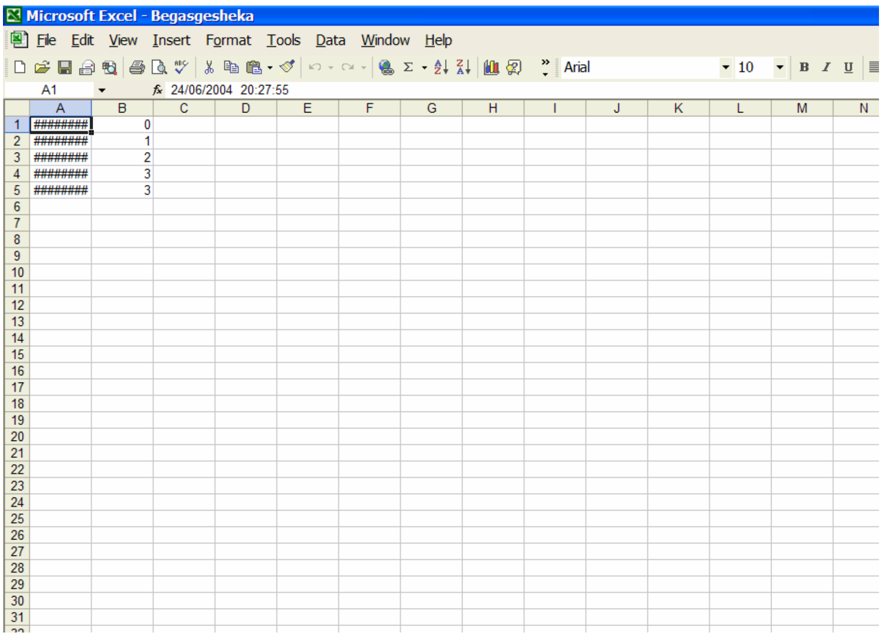


Select COMMA as a delimiter. The data should be separated by a line, which Excel uses to mark the position of the columns. Click NEXT, this takes you to the data format window.

Select DATE for the first column and GENERAL for the second column and click FINISH. Also ensure that the date settings on the computer are set correctly as Day, Month and Year.



You should now have two columns, one with the time date and the other with the rainfall. Widen the first column if necessary to make the date and time visible.



Save the file.

Appendix 7: Research proposals

RESEARCH PROPOSAL

TITLE: WATER RESOURCES INVESTIGATION:

A CASE STUDY IN BEGASHEKA WATERSHED

By:

Gebreegziabher Lemma

(M.Sc. STUDENT, FACULTY OF DRYLAND AGRICULTURE,

MEKELLE UNIVERSITY)

ADVISOR: **Dr. NATA TADESSE, ASSISTANT PROFESSOR OF HYDROGEOLOGY**

WATER RESOURCES INVESTIGATION: A CASE STUDY IN BEGASHEKAWATERSHED

Introduction

"We need a blue revolution (not a green revolution), which focuses on increasing agriculture production per unit water" Kophi Anana World Water Day, 2000. This in short can be quoted as "more crop per drop".

Cognizant, it is difficult to increase the amount of rainfall in the watershed so as to boost agricultural production, but it is possible to create a green heaven within the existing amount of rainfall and weather condition if every drop of water is productively used. Now a day's watershed is becoming a unit for community based rural development intervention through integrated watershed development approach.

Integrated watershed development approach is a process of formulation and carrying out courses of action involving the manipulation of resources in a watershed to provide goods and services without adversely affecting the soil, vegetation and water bases. In other words, a watershed is a hydrological unit that has been described and used as physical-biological unit and also on many occasions as a socioeconomic potential unit for planning and management of natural resources.

In watershed development activity water is a core resource. The amount of fauna and flora living in particular watershed is highly determined by the available water in the watershed. Knowing the available amount of water resources (both surface waters and groundwater) in a certain watershed will help a lot for a sustainable utilization of this precious natural resource for different purposes. This also enables to design any watershed development intervention that needs water as a basic principal element.

2. Backgrounds

This research will be conducted by taking Begasheka watershed as a case study area. The Begasheka watershed is located at about 10 Km north of Abi Adi town, Kolla Tambien Woreda, Central Zone of Tigray National Regional State. Geographically, it is positioned between longitude 38° 00" 55' E to 39° 00" 00' E and latitude 13° 00" 45' N to 13° 00" 40' N. It has an aerial extent of about 1034 ha.

The watershed includes three Kushet and about four villages of Begasheka tabia with a total population of 2571. The household number is 565: 418 male headed and 147 female headed. There is one rural road that crosses the watershed (Abide to Guya, Gurroro).

The area has a monomodal rainfall pattern, and the main rainy season is during summer from June to August. The remaining months are dry. It has the mean annual rainfall of 764 mm. Generally the area is categorized in Dry Weina Dega Agro climatic zone.

The altitude of the catchment varies from 1750 m to 1891 m above sea level. Maximum elevation differences between the peak mountain and the outlet of the watershed is about 141 m. The elevation difference is more in the remotest part (upstream side) of the watershed whereas the difference is very low in the middle and downstream parts of the watershed. Therefore, during high rainfall the runoff flows with a speedy velocity in the upstream side of the watershed and then it slows down in the middle and downstream parts of the watershed. As a result of this serious gulley erosion is observed at the base of the hills.

The watershed has only one perennial stream that begins near the outlet. In the dry season, the discharge of the stream is 67 lit/sec (the discharge is measured by flout method during the survey). The stream has a large command area out of the area under investigation. According to the information gathered from RWS department of REST, the area has also good groundwater potential. REST constructed four boreholes for supplying potable water for each village.

Generally, the watershed is covered by metamorphic rocks and unconsolidated materials ranging in age from Precambrian to recent. Slate and phyllites are found dominantly covering mountainous and hilly areas in different proportions. The hillside of the catchment area has shallow soil depth with silt loam textured; on the other hand the middle and down stream part of the watershed has deep profiled clay textured soil with significantly firm hardness, and the dominant soil colour is dull brown. The soil characteristics are the base for determining the infiltration rate of the land.

The natural vegetation cover of the study area is heavily affected by deforestation and overgrazing activities. As a result the vegetation of the area is largely composed of scattered naturally grown trees and shrubs (dominantly Ephorbia candilebrem species). Moreover, the exposed hillsides are not favourable for safe growth of trees and shrubs. However, limited sites has been terraced and planted by reforestation program.

The hilly part of the watershed is highly degraded. It has been used as pastureland for several years without any regulation. Moreover the surrounding people without any conservation practices have been cultivating the steep sloped hills. So this is believed to increase erosion and decrease infiltration rate.

Conservation practice is important to increase infiltration rate, reduce the velocity of runoff and minimize erosion. Due to this fact conservation practice initiates soil formation and vegetation growth.

Enatsion sub watershed has been intensively treated with SWC structures. Those constructed SWC structures are hillside terrace, stone-faced trench and check dams. The remaining other three sub watersheds also have old terraces on limited hilly areas.

Furthermore, newly introduce household based pond and large communal ponds have being undertaken in the watershed. Up to now about 50-house hold ponds that have a capacity of 182 m^3 each and about 7 large communal ponds having a total capacity of 3000 m^3 have been constructed.

3. Core Problems of BegashekaWatershed

• Recurrent drought caused by the land degradation, erratic rainfall nature, un proper land and water utilization.

• Generally the watershed has significant problem in distribution of rainfall through out the rainy season. According to the rainfall data record only 3% of the rain takes place in September; however, this month is the ripening period for dominant crops. This is considered to be the main cause for the recurrent crop failure facing the area.

Besides the rain distribution through out the month is not even. There is an average 5-10 day difference has been observed between each rainstorm in some critical time. This uneven distribution of rain also has negative impact on the normal growth of crops. On the other hand, based on rainfall records, the total amount of rainfall is enough to annual crops. So this study will have a considerable input in the investigation of rainfall-runoff and rainfall and water utilization relations, which enables to estimate the amount of water resource (both surface waters and groundwater), which is actually available within the watershed.

4. Objectives

Generally, the major objective of this research work is to conduct a systematic water resources investigation (both surface and groundwater) in the Begashekawatershed. Specifically, the objectives of this research work are the following:

To determine the amount of mean annual precipitation and evapotranspiration:

To determine the amount of mean annual surplus water, which is readily available for both surface runoff and infiltration:

To determine the amount of surface runoff from the watershed:

To determine the total amount of water which is actually available to recharge the groundwater circulation within the watershed:

To verify the occurrence of important groundwater reservoirs within different type of aquifers;

To determine the amount of groundwater currently used for different purposes.

To determine the water balance of the watershed (which takes into account both surface water and groundwater):

To determine the water (i.e., surface water and groundwater) quality and examine the suitability of the water for different purposes (domestic, irrigation and livestock).

To recommend potential sites for the development of groundwater using various techniques:

To suggest environmentally sound plans for conjunctive use of surface water and groundwater: and

To recommend actions for water (both surface water and groundwater) savings in the watershed.

5. Expected Output

The expected output of this research work includes:

Determination of the times of moisture deficit, soil moisture recharge and moisture surplus in the watershed:

Determination of the amount of surplus water, which is readily available for both runoff and infiltration:

Determination of the amount of surface runoff that can be collected and used for different purposes:

Determination of the amount of water, which is actually available to recharge the groundwater circulation within the watershed:

Water balance of the area which takes into account both surface water and groundwater:

Identification of better potential sites for the development of groundwater:

Suitability (i.e., quality point of view) of the water for different purposes:

Suitable methods for conjunctive use of surface water and groundwater for sustainable utilization, development and management these resources: and

Appropriate methods for water savings.

Methods

The proposed research project comprises the following activities:

Analysis and interpretation of topographical, hydrological, meteorological, soil, geological, and hydrogeological data and maps, and all the available materials relevant with respect to the objectives of the research:

Collect and analyze climatic data and definition of climatic indexes: Evapotranspiration measurements & Rainfall records:

Hydrologic study of the area: Stream flow measurement, measuring soil moisture potential, measuring the infiltration rate of the soil, determining the land use/cover of different land units by using GIS and field verification, assessing the physical features of the watershed (slope, past erosion, surface stoniness etc.) and estimating the peak runoff and annual runoff yield and calibration of unit hydrograph:

Soil and geological field investigations:

Collection of rock and soil samples:

Identification of crops that are available in the area:

Collection of plant root depths:

Inventory of hand dug wells, boreholes and springs:

Collection of water samples:

Collect and analyze borehole yields, spring yields, and depth of water table:

Collection and analysis of pumping test data: and

Analysis of collected rock, soil and water samples.

All the above listed activities will be applied at a different extent and detail in relation to the scale of investigation.

7. Work Plan

This project is expected to last 18 months from the date of approval, and the following is the detailed work plan of the project (please sea also the attached Work Plan).

- 1st March to 31st May: Literature review and secondary hydrometerological data collection:
- 1st June to 31st August: Primary hydrometerological data collection and analysis, reconnaissance field investigation, first phase water sample collection and analysis:
- 1st September to 30th November 2004: Detailed field investigation:
- 1st to 31st December 2004: Compiling and integrating the collected and acquired data:
- 1st January to 28th February 2005: Laboratory analysis:
- 1st March to 31st May 2005: Computer-aided analyses and interpretation:
- 1st to 31st May 2005: Second phase water sample collection and analysis: and
- 1st June to 31st August: Project report write up and submission.

8. Application of Results

The result will be helpful for sustainable utilization, development and management of water resources in the catchment. The prime beneficiaries of this research will be the peoples who are living in the area. The result from this research could also be helpful to those who may be interested to undertake further research works in the area. The results from this research could also be used as a model for conducting similar investigation in the others parts of the region.

9. Cost of the Project

Personnel

- Two round trip air tickets 2, 000 Birr Mekelle – Addis - Mekelle
- Per diem for a researcher (MSc Student) for 120 days field work

  (120 Birr/day x 120 day) 14, 400.000 Birr
- Per diem for a researcher (Advisor) for 90 days field work

  (240 Birr/day x 90 day) 21, 600.000 Birr
- Driver per diem for 120 days

  70 Birr/day x 120 day 8, 400.000 Birr
- Labourers per diem for 6 persons

  6 (35 Birr/day x 60 day) 12, 600.000 Birr

2. Materials

- 1 Lab top 15, 000.00 Birr
- 1 GPS 3, 500.00 Birr
- Aerial photographs 200.00 Birr
- Topo Maps 100.00 Birr
- Software's 6, 000.00 Birr
- Automatic rain gauge 2, 500.00 Birr
- Pan evaporation measurement 1, 500.00 Birr
- Stop watch 100.00 Birr
- Field Equipments 1, 000.00 Birr

3. Transport Cost

- Rental of Vehicles 10, 000.00 Birr
- Fuel 10, 000.00 Birr
- Motor oil 500.00 Birr
- Maintenance 500.00 Birr

4. Water Samples Analysis **27, 584.00 Birr**

1. Registration 10 Birr
2. Analysis cost for complete chemical water analysis 246.55 Birr
3. Analysis cost of traces, trace elements and some constituents to be determined

   for environmental pollution 381.05 Birr

4. Bacteriological Analysis 52.00 Birr

Cost per sample = 689.60 Birr

Number of water samples = 20.00

Total Cost for Complete Chemical and Biological Analysis of Water

2(689.90 Birr/Sample X 20 Sample) = 27, 584.00 Birr

5. Contingency 13, 748.40 Birr

GRAND TOTAL = 151, 232.40 Birr

10. Project Budget Summary

ITEMS	AMOUNT IN BIRR
1. PERSONNEL	**59, 000.00**
2. MATERIALS	**29, 900.00**
3. TRANSPORT COST	**21, 000.00**
4. WATER SAMPLES ANALYSIS COST	**27, 584.00**
5. CONTINGENCY	**13, 748.40**
TOTAL AMOUNT	**151, 232.40**

11. References

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Garg, S. K., 1987. Irrigation Engineering and Hydraulic Structures, Khanna Publishers, India.

Hamill, L. and Bell, F. G., 1986. Groundwater Resource Development, Butterworths, London, p. 344.

Leopold, L. B. and Dunne, T., 1978. Water in Environmental Planning, W. H. Freeman and Company, San Francisco.

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Stephen A. Thompson, 1999. Hydrology for Water Management, A. A. Balkema, Rotterdam.

Thornthwaite, C. W. and Mather, J. R., 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance, Publication in Climatology, Centerton, New Jersey, v. X, No. 3, p. 185-311.

Appendix 8: Evaporation estimation using the Blaney Criddle method

Doorenbos J, and Pruit , W.O. (1993) Crop Water Requirements. FAO irrigation and drainage paper 24. Rome

E_{tp} = P(0.46 T+8)   (mm/day)

P = mean daily % max possible annual daylight hours. (see table 12)

T = mean monthly temp

Table 12. Mean daily % of annual daylight hours for different latitudes(N*12/(Sum of Np for all months *12*365)

	Latitude																			
S	N	0	5	10	15	20	25	30	35	40	42	44	46	48	50	52	54	56	58	60
Jul	Jan	0.27	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.22	0.21	0.21	0.2	0.2	0.19	0.19	0.18	0.17	0.16	0.15
Aug	Feb	0.27	0.27	0.27	0.26	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.21	0.21	0.2
Sep	Mar	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.26
Oct	Apr	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.3	0.3	0.3	0.3	0.31	0.31	0.31	0.31	0.32	0.32	0.32
Nov	May	0.27	0.28	0.28	0.29	0.29	0.31	0.31	0.31	0.32	0.33	0.33	0.34	0.34	0.34	0.35	0.36	0.36	0.37	0.38
Dec	Jun	0.27	0.28	0.29	0.29	0.3	0.32	0.32	0.32	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.4	0.41
Jan	Jul	0.27	0.28	0.29	0.29	0.3	0.31	0.31	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.37	0.38	0.39	0.4
Feb	Aug	0.27	0.28	0.28	0.28	0.29	0.3	0.3	0.3	0.31	0.31	0.31	0.32	0.32	0.32	0.33	0.33	0.33	0.34	0.34
Mar	Sep	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Apr	Oct	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.25	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.22
May	Nov	0.27	0.27	0.26	0.26	0.22	0.25	0.24	0.23	0.22	0.22	0.22	0.21	0.21	0.2	0.2	0.19	0.18	0.18	0.17
Jun	Dec	0.27	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.21	0.21	0.2	0.2	0.19	0.18	0.17	0.17	0.16	0.15	0.13

Modified Blaney Criddle method

E_{tp} (mm/day)= a P (0.46 T + 8) -b

where *a* and *b* are empirical factors to account for wind speed, sunshine and humidity. (see table 13)

Table 13 Correction factors for the modified Blaney Criddle formula

Relative Humdity correction factor	Low (<20%)		Medium (20-50%)		High (>50%)	
	a	B	a	b	a	b
Sunshine Ratio Low (<0.6)						
Wind Low (<2m/s)	1.15	2.00	1.05	2.00	0.80	1.45
Wind Medium (2-8m/s)	1.28	1.80	1.15	0.85	0.88	1.55
Wind High (>8m/s)	1.40	1.60	1.25	1.70	0.98	1.65
Sunshine Ratio Medium (0.6-0.8)						
Wind Low (<2m/s)	1.35	2.30	1.20	2.20	0.97	1.80
Wind Medium (2-8m/s)	1.55	2.60	1.37	2.40	1.147	2.15
Wind High (>8m/s)	1.73	1.80	1.52	2.10	1.16	1.70
Sunshine Ratio High (>0.8)						
Wind Low (<2m/s)	1.55	2.60	1.37	2.40	1.14	2.15
Wind Medium (2-8m/s)	1.82	2.30	1.61	2.50	1.22	1.95
Wind High (>8m/s)	2.06	2.00	1.82	2.55	1.31	1.70

Results should be reduced by 10% for every 1000m for both methods

Appendix 9: Stream flow Measurement

Adapted from: Chapter 4 of N. W. Hudson (1993), Field measurement of soil erosion and runoff, Silsoe Associates, Ampthill, Bedford, United Kingdom , Food and Agriculture Organization of the United Nations; Rome,

http://www.fao.org/docrep/T0848E/t0848e00.htm#TopOfPage

VOLUMETRIC METHODS

The simplest way to estimate small flows is by direct measurement of the time to fill a container of known volume. The flow is diverted into a channel or pipe which discharges into a suitable container, and the time to fill is measured by stopwatch. For flows up to about 4 l/s, a bucket of 10 l capacity is suitable and will fill in 2½ seconds. For larger flows, an oil drum of 200 l can handle flows up to about 50 l/s. The time to fill must be measured accurately, especially when it is only a few seconds. The variation between several measurements taken in succession will give an indication of the accuracy of results.

If the water flow can be diverted into a pipe so that it is discharged under pressure, the rate of flow can be estimated from measurements of the jet. If the pipe can be arranged to discharge vertically upwards, the height to which the jet rises above the end of the pipe can be measured and the rate of flow calculated from the appropriate formula as shown in Figure 19. Estimates of discharge can also be made from measurements of the trajectory from horizontal or sloping pipes, and from partly filled pipes, but these are less reliable (Scott and Houston 1959).

VELOCITY/AREA METHOD

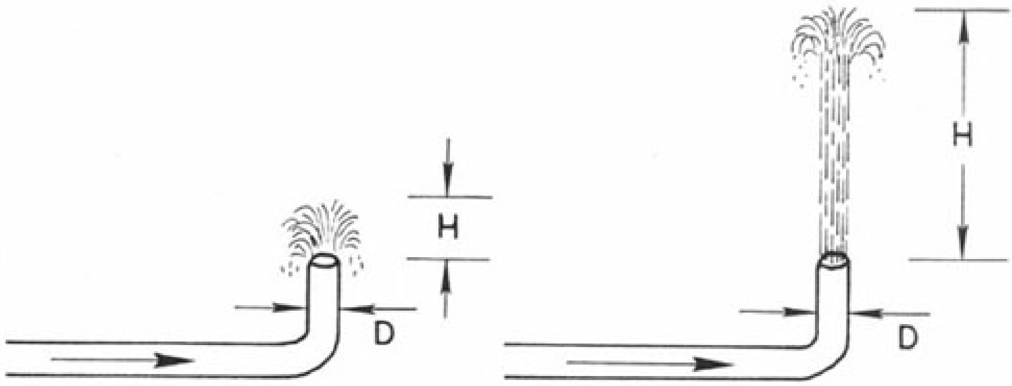
This depends on measuring the average velocity of flow and the cross-sectional area of the channel and calculating the flow from:

$Q(m^3/s) = A(m^2) \times V(m/s)$

The metric unit m^3/s is referred to as the **cumec**. Because m^3/s is a large unit, smaller flows are measured in litres per second (l/s).

A simple way to estimate the velocity is to measure the time taken for a floating object to travel a measured distance downstream. The velocity is not the same at all places in the stream, being slower at the sides and bottom, and faster on the surface, as shown in Figure 20. Taking 0.8 of the surface velocity as measured by the float gives an approximate value for the average velocity. Alternatively, the velocity can be measured below the surface by attaching a submerged weight to a float. The float and weight move down the stream together at the velocity of the stream at the depth where the weight is suspended. At about half the stream depth, the velocity is approximately the same as the average velocity for the whole stream. Float methods are only suitable for straight streams or canals where the flow is fairly even and regular.

FIGURE 19
Calculating the flow in pipes from the height of a vertical jet (Bos 1976)



(a) Low nappe (low discharge height)

$Q = 5.47D^{1.25} H^{1.35}$ (1)

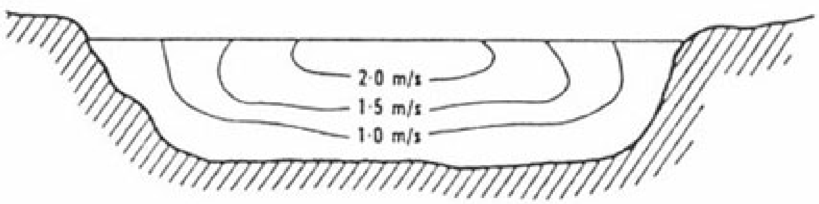
(b) Jet

$Q = 3.15D^{1.99} H^{0.53}$ (2)

Q in cubic metres per second; D and H in metres.

If $H < 0.4\,D$ use equation (1)
If $H > 1.4\,D$ use equation (2)
If $0.4D < H < 1.4D$ calculate both equations and take the average

FIGURE 20
Variation of velocity in a stream



Another method is to pour into the stream a quantity of strongly coloured dye, and to measure the time for this to flow a measured distance downstream. The dye should be added quickly with a sharp cutoff, so that it travels downstream in a cloud. The time is measured for the first and last of the dye to reach the downstream measuring point and an average of the two times is used to calculate the average velocity.

In turbulent streams the cloud of dye is dispersed quickly and cannot be observed and measured, but other tracers can be used, either chemical or radio-isotopes, in what is called the dilution method. A solution of the tracer of known strength is added to the stream at a constant measured rate and samples are taken at points downstream. The concentration of the sample taken downstream can be compared with the concentration of the added tracer and the dilution is a function of the rate of flow which can be calculated.

More accurate determination of velocity can be obtained by using a current meter. The two main types are illustrated in Figure 21. The conical cup type revolves about a vertical axis, and the propeller type about a horizontal axis. In each case the speed of revolution is proportional to the velocity, and the number of revolutions in a given time is counted, either on a digital counter or as clicks heard in earphones worn by an operator. In shallow streams small current meters will be mounted on rods and held by wading operators (Plate 23). When measurements of floodflows are to be measured on big rivers, the readings are taken either from a bridge, or an overhead cableway is installed well above maximum flood level, and the current meter is lowered on cables into the river with weights to hold it against the riverflow.

A current meter measures the velocity at a single point, and several measurements are required to calculate the total flow. The procedure is to measure and plot on graph paper the cross-section of the stream and to imagine that it is divided into strips of equal width as shown in Figure 22. The average velocity for each strip is estimated from the mean of the velocity measured at 0.2 and 0.8 of the depth in that strip. This velocity, times the area of the strip, gives the flow for the strip and the total flow is the sum of the strips. Table 2 shows how the calculations will be done for data shown in Figure 22. In practice, more strips would be used than the number shown in Figure 22 and Table 2. For shallow water a single reading is taken at 0.6 of the depth instead of averaging the readings at 0.2 and 0.8 of the depth.

Sometimes the information required on stream flow is the maximum flood flow, and a rough estimate can be made using the velocity/area method. The maximum depth of flow in a stream can sometimes be deduced from the height of leaves and trash caught in vegetation on the bankside, or from the highest signs of scour or sediment deposits on the bank. Alternatively some device can be installed which is designed to leave a record of the maximum level. To prevent false readings from turbulence in the stream, some kind of stilling well is used - usually a pipe with holes on the downstream side. The maximum depth of water can be recorded on a rod painted with a water soluble paint, or from traces left at the highest level from something floated on the water surface in the tube. Materials used have included ground cork, chalk dust and ground charcoal. Knowing the maximum depth of flow, the corresponding cross-section area of the channel can be measured, and the velocity estimated by one of the methods described, bearing in mind that the velocity at high flood will usually be faster than the normal flow.

FIGURE 21
Two types of current meter

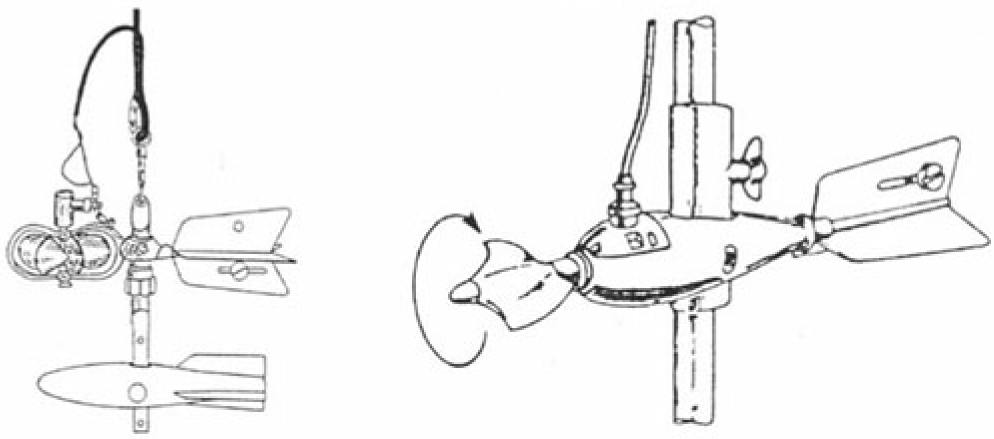


PLATE 23 Measuring streamflow with a current meter in Botswana
(FAO Photo Library)

FIGURE 22
Estimating the flow in a stream from measurement with a current meter. The calculations for this example are shown in Table 2.

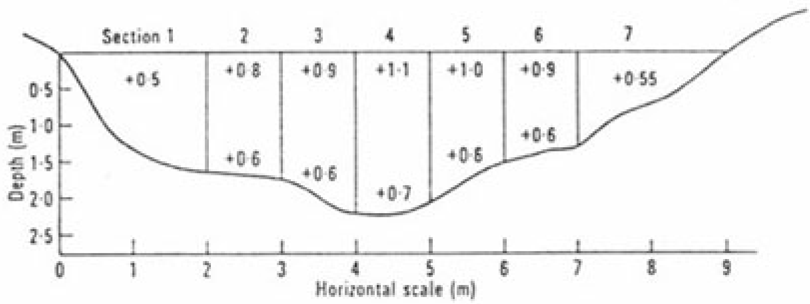


TABLE 2
Calculation of steamflow from current meter readings

1	2	3	4	5	6	7	8
Section	Flow velocity (m/s)			Depth (m)	Width (m)	Area (m^2) 5 x 6	Flow (m^3/s) 4 x 7
	0.2D	0.8D	Mean				
1	-	-	0.5	1.3	2.0	2.6	1.30
2	0.8	0.6	0.7	1.7	1.0	1.7	1.19
3	0.9	0.6	0.75	2.0	1.0	2.0	1.50
4	1.1	0.7	0.9	2.2	1.0	2.2	1.98
5	1.0	0.6	0.8	1.8	1.0	1.8	1.44
6	0.9	0.6	0.75	1.4	1.0	1.4	1.05
7	-	-	0.55	0.7	2.0	1.4	0.77
						TOTAL	9.23

D is the depth of the stream at the mid-point of each section.

RATING A GAUGING STATION

If a measurement of the flow is made by the current-meter method on different occasions when the river is flowing at different depths, these measurements can be used to draw a graph of amount of flow against depth of flow as shown in Figure 23. The depth of flow of a stream or river is called **stage**, and when a curve has been obtained for discharge against stage, the gauging station is described as being **rated**. Subsequent estimates of flow can be obtained by measuring the stage at a permanent gauging post, and reading off the flow from the rating curve. If the cross-section of the stream changes through erosion or deposition, a new rating curve has to be drawn up. To plot the rating curve, it is necessary to take measurements at many different stages of flow, including infrequently occurring flood flows. Clearly this can take a long time, particularly if access to the site is difficult, so it is preferable to use some type of weir or flume which does not need to be individually calibrated, and these are discussed in later sections.

FIGURE 23
An example of the rating curve for a stream or river

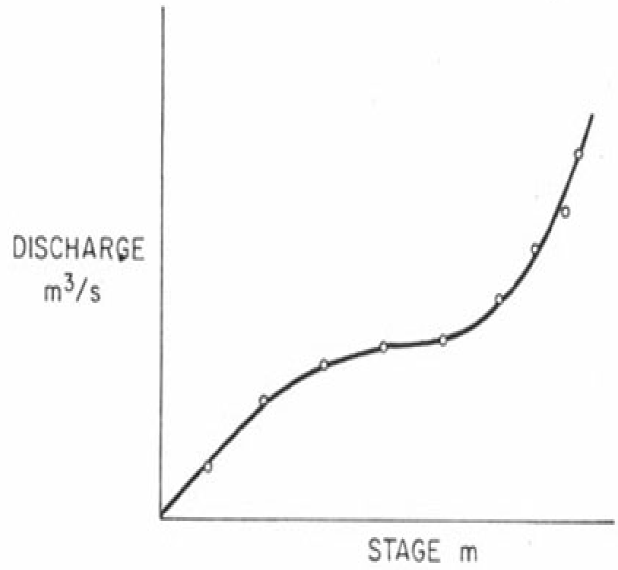
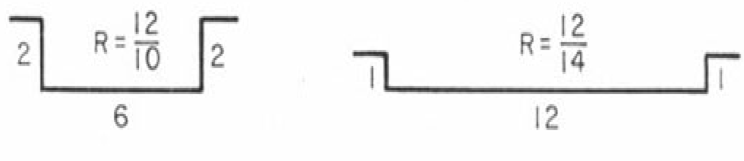


FIGURE 24
Channels with the same cross-sectional area can have a different hydraulic radius



EMPIRICAL FORMULAS FOR ESTIMATING VELOCITY

The velocity of water flowing in a stream or open channel is affected by a number of factors.

· *Gradient or slope*. All other factors being equal, velocity of flow increases when the gradient is steeper.

· *Roughness*. The contact between the water and the streambank causes a frictional resistance which depends on the smoothness or roughness of the channel. In natural streams the amount of vegetation affects the roughness, and also any unevenness which causes turbulence.

· *Shape*. Channels can have the same cross-sectional area, gradient and roughness, but still have different velocities of flow according to their shape. The reason is that water close to the sides and bottom of a stream channel is slowed by the friction effect, so a channel shape which provides least area of contact with the water will have least frictional resistance and so a greater velocity. The parameter used to measure this effect of shape is called the **hydraulic radius** of the channel. It is defined as the cross-sectional area divided by the wetted perimeter, which is the length of the bed and sides of the channel which are in contact with the water. Hydraulic radius thus has units of length, and it may be represented by either M or R. It is also sometimes called hydraulic mean radius or hydraulic mean depth. Figure 24 shows how channels can have the same cross-sectional area but a different hydraulic radius. If all other factors are constant, then the lower the value of R, the lower will be the velocity.

All these variables which affect velocity of flow have been brought together in a very useful empirical equation called the **Manning formula**, which is:

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

where:

V is the average velocity of flow in metres per second

R is the hydraulic radius in metres (the letter M is also used to denote hydraulic radius, standing for Mean Hydraulic Depth)

S is the average gradient of the channel in metres per metre (the letter i is also used to denote gradient)

n is a coefficient, known as **Manning's n**, or **Manning's roughness coefficient**. Some values for channel flow are listed in Table 3.

Strictly speaking, the gradient of the water surface should be used in the Manning formula and this may not be the same as the gradient of the streambed when the stream is rising or falling. However, it is not easy to measure the level of the surface accurately and so an average of the channel gradient is usually calculated from the difference in elevation between several sets of points each 100 metres apart.

Nomographs are available to assist solving the Manning formula, and an example is shown in Figure 25.

Another simple empirical formula for estimating velocity of flow is **Elliot's open-ditch formula** which is:

$$V = 0.3 \sqrt{mh}$$

where:

V is the average velocity of flow in metres per second

m is the hydraulic radius in metres

h is the channel gradient in metres per kilometre.

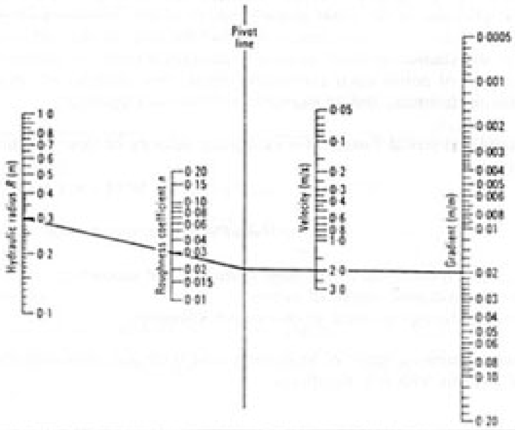
This formula assumes a value of Manning's n of 0.02 and so is only suitable for free-flowing natural streams with low roughness.

TABLE 3
Values of Manning's roughness coefficient n

(a) Channels free from vegetation	
Uniform cross-section, regular alignment free from pebbles and vegetation, in fine sedimentary soils	0.016
Uniform cross-section, regular alignment, free from pebbles and vegetation, in stiff clay soils or hardpan	0.018
Uniform cross-section, regular alignment, few pebbles, little vegetation, in clay loam	0.020
Small variations in cross-section, fairly regular alignment, few stones, thin grass at edges, in sandy and clay soils, also newly cleaned, ploughed, and harrowed channels	0.0225
Irregular alignment, ripples on bottom, in gravelly soil or shale, with jagged banks or vegetation	0.025
Irregular section and alignment, scattered rocks and loose gravel on bottom, or considerable weeds on sloping banks, or in gravelly material up to 150 mm diameter	0.030
Eroded irregular channels, channels blasted in rock	0.030
(b) Vegetated channels	
Short grass (50-150 mm)	0.030-0.060
Medium grass (150-250 mm)	0.030-0.085
Long grass (250-600 mm)	0.040-0.150
(c) Natural stream channels	
Clean and straight	0.025-0.030
Winding, with pools and shoals	0.033-0.040
Very weedy, winding, and overgrown	0.075-0.150

FIGURE 25
Nomograph for solving Manning's formula. If any 3 variables are known, the 4th can be found

Example: Given R = 0.3 m, n = 0.03, gradient = 2% or 0.02 m per m, find velocity V.
Solution: Join R = 0.3 and n = 0.03 and project to pivot line. Join the point on pivot line to gradient = 0.02. Intersection of the velocity scale gives V = 2.0 m/s.



GAUGING WEIRS

Gauging the flow in natural streams can never be precise because the channel is usually irregular and so is the relationship between stage and flow rate. Natural stream channels are also subject to change by erosion or deposition. More reliable estimates can be obtained when the flow is passed through a section where these problems have been reduced. This could be simply smoothing the bottom and sides of the channel, or perhaps lining it with masonry or concrete, or installing a purpose-built structure. There is a wide variety of such devices, mostly suitable for a particular application. A selection of those simple to install and operate are described here with reference to appropriate manuals for more expensive or complicated structures.

In general, structures across the stream which change the upstream level are called weirs, and channel-type structures are called flumes, but this distinction is not always followed. A more important distinction is between **standard** and **non-standard devices**. A standard weir or flume is one where if it is built and installed to a standard published specification, the flow can be directly obtained from the depth of flow by the use of charts or discharge tables, that is the flume is pre-calibrated. A non-standard weir or flume is one which needs to be individually calibrated after installation by using the velocity/area method as when rating a stream. There is such a wide range of standard devices available, that non-standard structures are best avoided except for one-off estimates of flood flows using the velocity/area method at a bridge, or ford, or culvert.

Most weirs are designed for free discharge over the critical section so that the rate of flow is proportional to the depth of flow over the weir, but some weirs can operate in the condition called **submerged** or **drowned**, where the level downstream interferes with the flow over the weir. Some types of weir can be corrected for partial submergence but this is an undesirable complication requiring additional measurements and more calculations so should be avoided where possible (Figure 26). Another variation best avoided is the **suppressed** weir, which is a weir set in channel of the same width as the critical section (Figure 27).

Sharp-crested weirs

The two most common types are the V-notch and the rectangular notch as shown in Figure 28. There must be a stilling pool or approach channel on the upstream side to smooth out any turbulence and ensure that the water approaches the notch slowly and smoothly. For accurate measurements the specification is that the width of the approach channel should be 8 times the width of the notch, and it must extend upstream for 15 times the depth of flow over the notch. The notch must have a sharp edge at the upstream side so that the flow is clear of the downside edge as shown in Figure 29. This is called the **end contractions**, which are required for the standard calibration to be applicable.

To read the depth of flow through the notch a measuring scale is set in the stilling pool in a position where it can be easily read. The zero of the scale is set level with the lowest point of the notch. The scale should be set well back from the notch so that it is not affected by the drawdown curve as the water approaches the notch.

FIGURE 26
Free flow and submerged flow over a sharp-crested weir

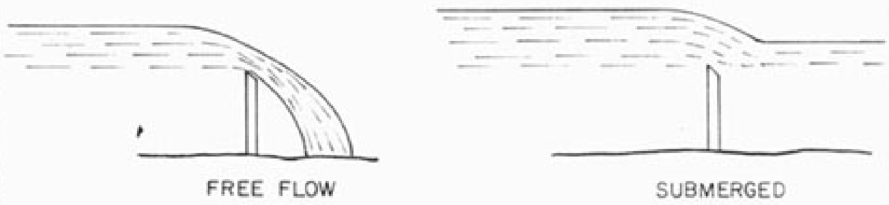
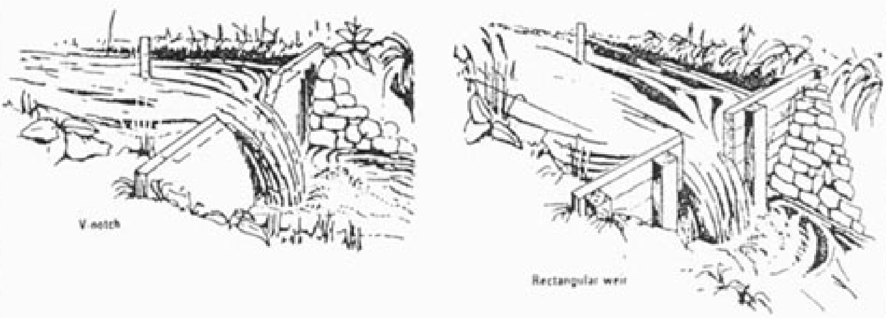


FIGURE 27
Unsupressed flow with end contractions and suppressed flow with the weir in a channel

FIGURE 28
Measuring streamflow with sharp-crested weirs

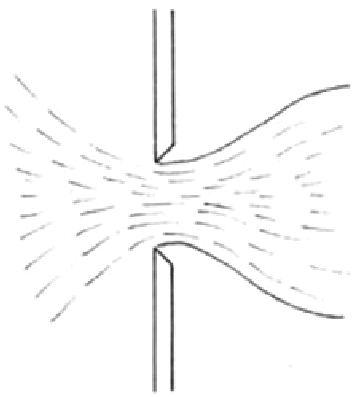
(a) 90° V-notch weir (b) rectangular notch weir



V-notch weirs are portable and simple to install in either temporary or permanent positions. The V shape means that they are more sensitive at low flows, but the width increases to accommodate larger flows. The angle of the notch is most commonly 90°, but calibration charts are available for other angles, 60°, 30° and 15°, if more sensitivity is required. Discharge values through small 90° V-notch weirs are given in Table 4.

For larger flows the rectangular weir is more suitable because the width can be chosen so that it can pass the expected flow at a suitable depth. Table 5 gives the discharge per metre of crest length and so can be applied to rectangular weirs of any size.

FIGURE 29
Sharp-crested weirs must have a sharp upstream edge



Other sharp-crested weirs

In some weirs the characteristics of the V-notch and the rectangular notch are combined. The Cipoletti weir has a horizontal crest like a rectangular notch and sloping sides like a V-notch, but for simple installations there is no advantage over the rectangular notch (Figure 30).

The compound weir is sometimes used when a sensitive measurement is required of low flows through the V-notch, and measurements are also required of large flood-flows through the rectangular notch. The more complicated design and calibration mean that this type is usually confined to serious hydrological studies (Figure 31).

Broad-crested weirs

On streams or rivers with gentle gradients it may be difficult to install sharp-crested weirs which require a free overfall on the downstream side. The alternative is weirs which can operate in the partly submerged condition. An example is the USDA-ARS triangular weir shown in Plates 24 and 25. This is nearly a standard weir in the sense that rating tables are available (USDA 1979), but the rating is influenced by the velocity of approach and the calibration should be checked by current meter measurements. Another example, which might be called either a flume or weir, is shown in Plate 26 and also requires rating by current meter.

MEASURING FLUMES

Several flumes have been developed in the USA for use in particular situations, and are widely used in spite of the awkwardness of the units of measurement. The design, construction and laboratory calibrations were all done in fps units, and until some laboratory undertakes the huge task of starting again in metric or SI units, the practical approach is to construct the flumes according to the original specifications in feet, and use the metric conversions of flow rates which have been computed by a consortium of hydraulic laboratories in The Netherlands (Bos 1976).

TABLE 4: Flow rates over a 90° V-notch weir (from USDI 1975)

Head (mm)	Flow (l/s)
40	0.441
50	0.731
60	1.21
70	1.79
80	2.49
90	3.34
100	4.36
110	5.54
120	6.91
130	8.41
140	10.2
150	12.0
160	14.1
170	16.4
180	18.9
190	21.7
200	24.7
210	27.9
220	31.3
230	35.1
240	38.9
250	43.1
260	47.6
270	52.3
280	57.3
290	62.5
300	68.0
350	100.0

TABLE 5: Flow rates over a rectangular weir with end contractions (from USDI 1975)

Head (mm)	Flow (l/s per metre of crest length)
30	9.5
40	14.6
50	20.4
60	26.7
70	33.6
80	40.9
90	48.9
100	57.0
110	65.6
120	74.7
130	84.0
140	93.7
150	103.8
160	114.0
170	124.5
180	136.0
190	146.0
200	158.5
210	169.5
220	181.5
230	193.5
240	205.5
250	218.5
260	231.0
270	244.0
280	257.5
290	271.0
300	284.0
310	298.0
320	311.5
330	326.0
340	340.0
350	354.0
360	368.5
370	383.5
380	398.0

FIGURE 30
A Cipolletti weir

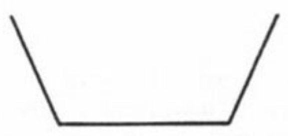


FIGURE 31
A compound weir

PLATE 24 A broad-crested V weir at IITA in Nigeria with downstream apron

PLATE 25 The approach to the weir and gantry for current meter measurements and sediment sampling

Appendix 10: Construction of hydrographs

Adapted from: Environmental systems research webpage

http://www.rpi.edu/dept/chem-eng/Biotech-Environ/Environmental/HYDROLOGY/hydrograph.html

Hydrographs

A hydrograph is a representation of flow for a particular stream and is used to evaluate the watershed runoff volumes and the peak flow rates from a single storm or set of storms. This information is then used in the design of flood control facilities.

Watershed runoff is a function of several things, including

- rainfall intensity
- storm duration
- type of vegetation in the watershed area
- size and shape of the watershed and many other factors

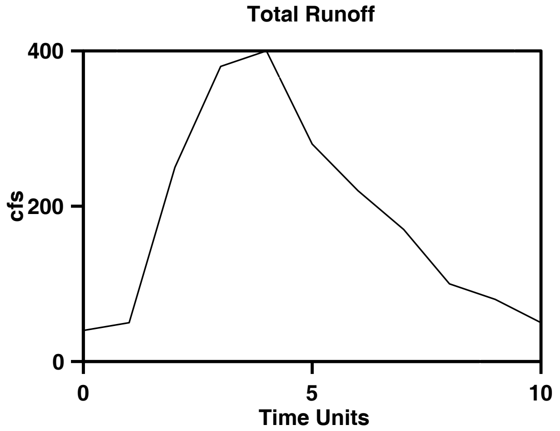
The synthetic hydrograph approach was initially developed in 1932 by L.K. Sherman and has been fine tuned by several others since then. The unit hydrograph serves to represent the run-off over a certain timespan from one inch of rainfall and is constructed as follows:

Provided information in the following table and an effective precipitation of 1.5 inches. (Effective rainfall is the total rainfall less infiltration, evaporation, transpiration, absorption and detention (the runoff volume divided by the catchment area).

:

Time Unit	Total Runoff (cfs)
0	40
1	50
2	250
3	380
4	400
5	280
6	220
7	170
8	100
9	80
10	50

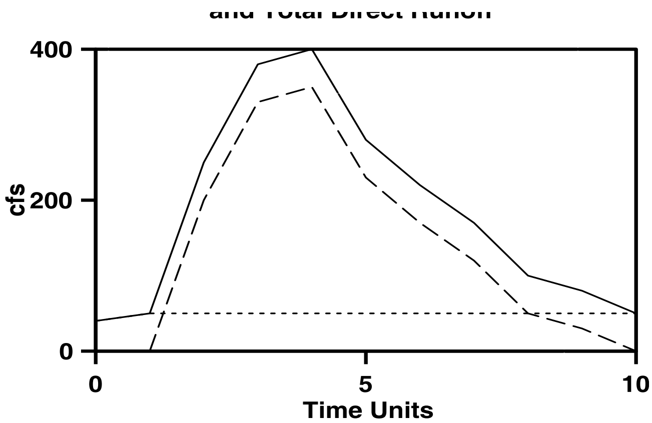
Graphed, the above table looks like



The next step is to subtract the base flow from the total runoff. Base flow is defined as the normal flow of the stream without the influence of storm-runoff. To determine the actual flow from runoff it is necessary to subtract the base flow from the total runoff. To find base flow, draw a line from the minimum beginning value of the hydrograph curve to the minimum ending value. The base flow for each time unit can then be read off the graph. In this example, the base flow is constant at 50 cfs.

Time Unit	Total Runoff (cfs)	Base-flow (cfs)	Direct Flow (cfs)
0	40	40	0
1	50	50	0
2	250	50	200
3	380	50	330
4	400	50	350
5	280	50	230
6	220	50	170
7	170	50	120
8	100	50	50
9	80	50	30
10	50	50	0

And this graph looks like

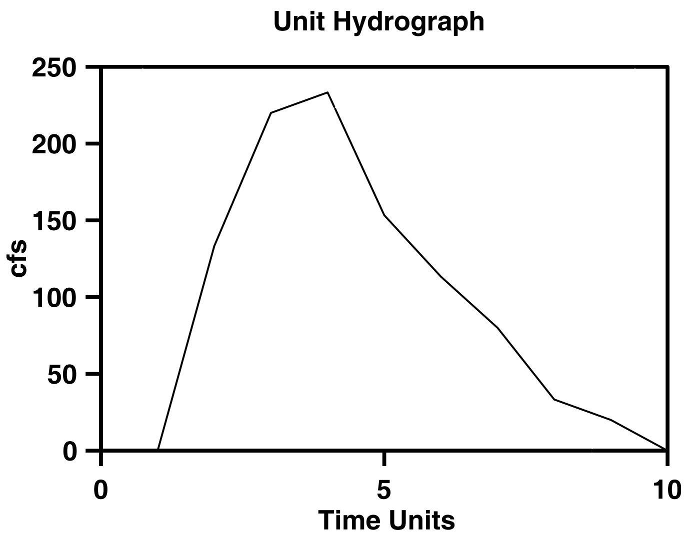


The dotted line is the base flow and the dashed line is the total direct flow from the storm.

The final step is to divide the direct flow by 1.5, the effective precipitation, to find the flow if just *one* inch of rain fell.

Time Unit	Total Runoff (cfs)	Base-flow (cfs)	Direct Flow (cfs)	Unit Hydrograph ordinate (cfs)
0	40	40	0	0
1	50	50	0	0
2	250	50	200	133.33
3	380	50	330	220
4	400	50	350	233.33
5	280	50	230	153.33
6	220	50	170	113.33
7	170	50	120	80
8	100	50	50	33.33
9	80	50	30	20
10	50	50	0	0

The graph for the unit hydrograph looks like



Appendix 11: Estimating Runoff

Adapted from: Chapter 7 of N. W. Hudson (1993), Field measurement of soil erosion and runoff, Silsoe Associates, Ampthill, Bedford, United Kingdom , Food and Agriculture Organization of the United Nations; Rome,

http://www.fao.org/docrep/T0848E/t0848e00.htm#TopOfPage

Maximum runoff rates

An estimate of the probable maximum rate of runoff may be required for the design of channels, drains or culverts, or to estimate maximum flood levels. Two simple empirical methods are described.

The Rational Formula

The rational formula is:

$$Q = \frac{CIA}{360}$$

where:

Q is the rate of runoff in cubic metres per second,
I is the intensity in millimetres per hour,
A is the catchment area in hectares,
C is a dimensionless runoff coefficient.

The formula was derived originally in English units and owes part of its popularity to the fact that, when using the most convenient English units, C becomes dimensionless because of a fortunate numerical coincidence:

For rain falling at 1 in/hour on 1 acre, 43560 (acre to ft^2)x 1/12 (inch/hour to ft/hour) x 1/3600 (hours to seconds) = 1.008 ft^3/s, which for all practical purposes can be taken as unity, so in English units the formula is:

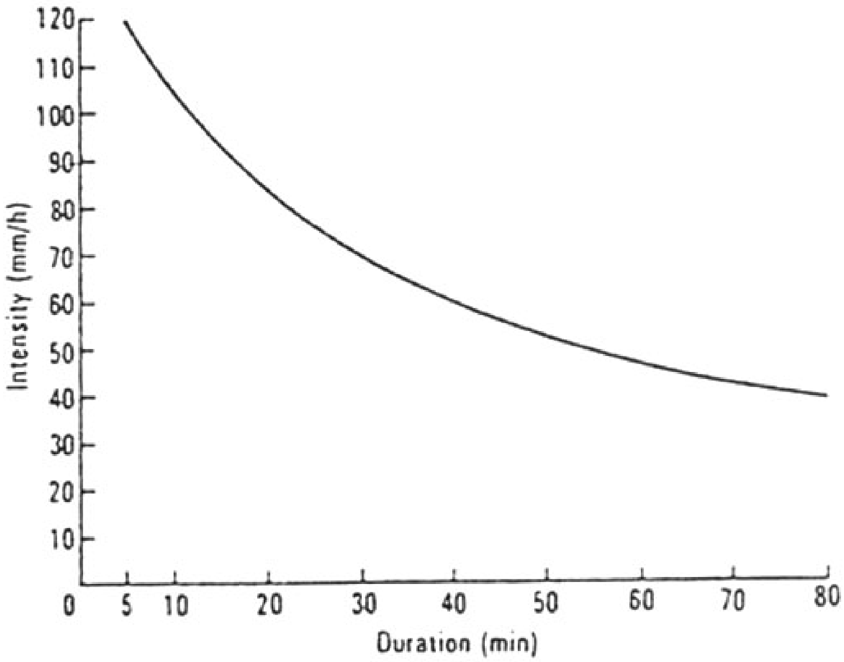
$$Q = CIA$$

where:

Q is the rate of runoff in cubic feet per second,
I is the intensity in inches per hour,
A is the area in acres,
C is the same dimensionless factor as in the metric formula.

To solve the equation each of the three factors on the right-hand side needs to be known. The area A is measured by surveying, or from maps or aerial photographs.

FIGURE 57
Relationship between intensity of rainfall and duration



To get the value of intensity I it is first necessary to estimate the gathering time of the catchment, that is, the longest time taken by surface runoff to get from any point in the catchment to the outlet. Table 11 gives values of gathering time for catchments of various size and slopes. Next information on the highest intensity of rain which is likely to last for the given gathering time is needed. Local rainfall records should be used to estimate this if possible. When local records are not available an estimate can be made from Figure 57 which is derived from rainfall records in Australia and Africa. Short duration storms of less than five minutes can have extremely high intensities and this method should not be used for gathering times of five minutes or less. This figure shows the heaviest rainfall likely to occur on average once in 10 years. To get corresponding figures for shorter or longer periods the conversion factors of Table 12 can be used.

TABLE 12 : Rainfall probability conversion factors for various return periods

2 years	0.75
5 years	0.85
10 years	1.00
25 years	1.25
50 years	1.50

The coefficient C is a measure of the proportion of the rain which becomes runoff. On a corrugated-iron roof almost all of the rain would run off, so C would be almost 1.0, while a well-drained sandy soil, where nine-tenths of the rain soaks in, would have a C value of 0.1. Table 13 gives some values of C. Where the catchment has several different kinds of topography, or land use, a weighted average is found by combining the different values in proportion to the area of each.

Cook's method

TABLE 13: Values of runoff coefficient C (from Schwab *et al.* 1981)

Topography and vegetation	**Soil texture**		
	Open sandy loam	**Clay and silt loam**	**Tight clay**
Woodland	**0.10**	**0.30**	**0.40**
Flat 0-5% slope	0.25	0.35	0.50
Rolling 5-10% slope	0.30	0.50	0.60
Hilly 10-30% slope			
Pasture	**0.10**	**0.30**	**0.40**
Flat	0.16	0.36	0.55
Rolling Hilly	0.22	0.42	0.60
Cultivated	**0.30**	**0.50**	**0.60**
Flat	0.40	0.60	0.70
Rolling Hilly	0.52	0.72	0.82
Urban areas	**30% of area impervious**	**50% of area impervious**	**70% of area impervious**
Flat			
Rolling	0.40	0.55	0.65
	0.50	0.65	0.80

This method was originally developed by an engineer of the US Soil Conservation Service, and requires an assessment of some of the main factors which affect runoff - the vegetative cover, the soil type and drainage, and the land slope. In Cook's original method there was a fourth factor of the extent of surface storage within the watershed, but trials have shown that the method can be simplified by ignoring this factor, without significant loss of its effectiveness.

For each of the three factors the catchment condition is compared with the conditions listed in Table 14. The description is found in the table which best fits the catchment, and the corresponding number is noted. Intermediate values can be used; for example, if half the catchment has heavy grass cover and the rest is not quite so dense, a value of 12 or 13 could be used. The arithmetic total of the number from each of the three columns is called the catchment characteristic (CC).

The area of the catchment is then measured, and using the area A and the catchment characteristic (CC), the maximum runoff can be read from Table 15. This gives the runoff for a 10-year probability, and the conversion factors given in Table 12 can be applied to get the corresponding figures for other time periods.

Another factor can be applied to take account of the shape of the catchment. Table 13 gives the runoff for a catchment which is roughly square or round. If the catchment is another shape the following conversion factors should be applied:

Square or round catchment	Long and narrow catchment	Broad and short catchment
1.0	0.8	1.25

TABLE 14: Values of Cook's watershed characteristics

Cover		**Soil type and drainage**		**Slope**	
Heavy grass	**10**	**Deep, well-drained soils**	**10**	**Very flat to gentle**	**5**
Scrub or medium grass	**15**	**Deep, moderately pervious soil**	**20**	**Moderate**	**10**
Cultivated lands	**20**	**Soils of fair permeability and depth**	**25**	**Rolling**	**15**
Bare or eroded	**25**	**Shallow soils with impeded drainage**	**30**	**Hilly or steep**	**20**
		Medium heavy clays or rocky surfaces	**40**	**Mountainous**	**25**
		Impervious surfacs and waterlogged soils	**50**		

Select the most appropriate factor from each of these three lists and add them together.

Example: Heavy grass (10) on shallow soils with impeded drainage (30) and moderate slope (10):

CC = 10 + 30 + 10 = 50.

TABLE 15: Estimating runoff by Cook's method

CC from Table 14, A in hectares, runoff in m^3/s

CC A	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**
5	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1
10	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.4	2.8	3.2	3.7
15	0.5	0.8	1.1	1.4	1.7	2.0	2.4	2.9	3.4	4.0	4.6	5.2
20	0.6	1.0	1.4	1.8	2.2	2.7	3.2	3.8	4.4	5.1	5.8	6.5
30	0.8	1.3	1.8	2.3	2.9	3.6	4.4	5.3	6.3	7.3	8.4	9.5
40	1.1	1.5	2.1	2.8	3.5	4.5	5.5	6.6	7.8	9.1	10.5	12.3
50	1.2	1.8	2.5	3.5	4.6	5.8	7.1	8.5	10.0	11.6	13.3	15.1
75	1.6	2.4	3.6	4.9	6.3	8.0	9.9	11.9	14.0	16.4	18.9	21.7
100	1.8	3.2	4.7	6.4	8.3	10.4	12.7	15.4	18.2	21.2	24.5	28.0
150	2.1	4.1	6.3	8.8	11.6	14.7	18.2	21.8	25.6	29.9	35.0	40.6
200	2.8	5.5	8.4	11.7	15.3	19.1	23.3	28.0	33.1	38.5	45.0	52.5
250	3.5	6.5	9.7	13.2	17.2	21.7	27.0	32.9	39.6	46.9	55.0	63.7
300	4.2	7.0	10.5	14.7	19.6	25.2	31.5	38.5	46.2	54.6	63.7	73.5
350	4.9	8.4	12.6	17.2	23.2	30.2	37.8	46.3	53.8	62.5	71.5	81.0
400	5.6	10.0	14.4	19.4	25.6	33.6	42.2	51.0	60.0	69.3	79.5	90.0
450	6.3	10.5	15.5	21.5	28.5	36.5	45.5	55.5	65.5	76.0	86.5	97.5
500	7.0	11.0	17.0	23.5	31.0	40.5	51.0	62.0	73.0	84.0	95.0	106.5

Runoff quantity or yield

In addition to knowing the probable **rates** of runoff, the total **quantity** which is likely to come from a watershed may be required. The total annual runoff is called the water yield, although one may be more interested in shorter periods, such as the monthly flow, or the amount from individudal storms. The usefulness of water for irrigation or domestic supplies not only depends upon the total amount, but also upon when it is available, and how reliable the supply will be. The average flow might be misleading if the likely variation on either side of the average, and the probable minimum flow are not known. The design of an irrigation scheme using a constant reliable flow would be very different from a scheme which requires storage to even out an unreliable and varying flow. Estimates of water availability therefore depend on having rainfall and stream flow records, and the longer and more reliable the records, the more accurate is the estimate based on them.

The methods of estimating water yield are quite different in arid climates and in humid climates. In humid climates the water table is fairly close to the surface most of the time, and higher than the bed of streams and rivers. There is therefore a steady seepage of groundwater into the streams, in addition to the direct runoff from storms. It is not possible to tell how much of the water in the stream has come from seepage flow and how much from storm flow, and so the total flow cannot be correlated with rainfall records; the only way to predict water yield is from past records of flow. In countries with sufficient data on stream flow, maps can be drawn showing isopleths, or lines of equal runoff. Naturally these resemble the rainfall maps, but the proportion of runoff is greater when the total rainfall is more, so the difference between low and high rainfall is magnified in runoff maps.

In arid regions there is no reservoir of groundwater, and so no seepage flow. The yield of runoff therefore consists entirely of storm runoff and this can be estimated from rainfall records.

The amount of runoff is the rainfall minus the losses, that is:

Q (runoff) = P (rainfall) - L (losses)

In semi-arid climates this method can be used to estimate annual runoff from annual rainfall by subtracting the estimated annual evapotranspiration. This is a function of land use and latitude, and can vary from 300 mm to 800 mm per year. If the cumulative runoff from a catchment is plotted against cumulative rainfall, the average losses can be determined from the slope of the graph as in Figure 58. Such a plot can be made using daily or weekly data or from individual storms.

In arid climates the loss is the infiltration and evaporation, and an estimate of yield can be obtained by applying the formula to each storm, assuming the same loss from each storm, with values from 10 mm to 20 mm per storm.

A more accurate method is to recognize that the losses are going to vary according to the amount of rainfall in the storm, and according to the amount of moisture which can be absorbed by the soil. This is the basis of the formula of the US Soil Conservation Service, which is:

$$Q = \frac{(I - 0.2S)^2}{I + 0.8S}$$

where: Q is the runoff in mm
I is the storm rainfall in mm
S is the amount of rainfall in mm which can soak into the soil during the storm.

FIGURE 58
Average runoff in arid or semi-arid climates can be found by plotting cumulative totals of measured rainall against measured runoff

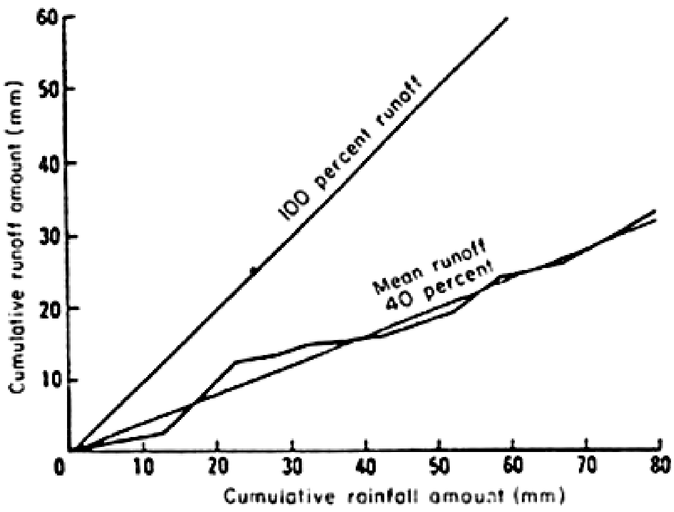


FIGURE 59
Relationship between runoff Q and rainfall I for various values of S using the US Soil Conservation equation

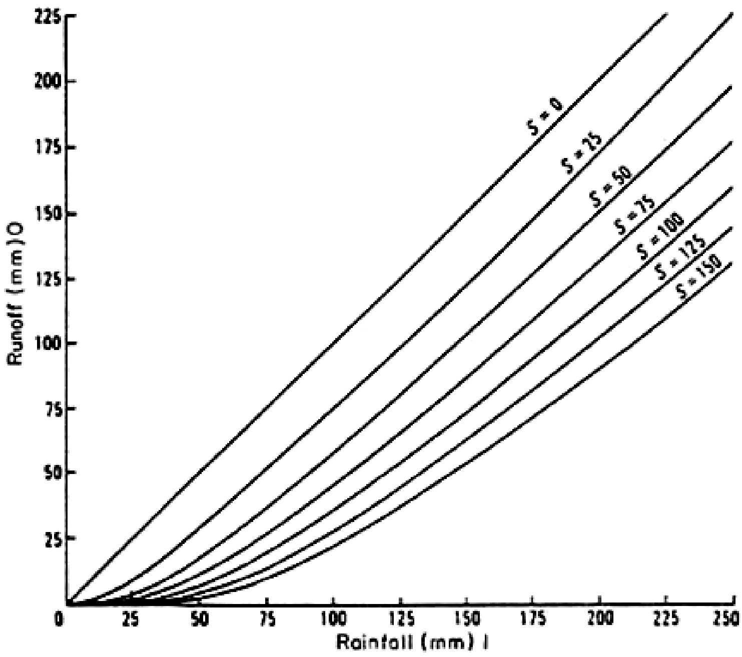


TABLE 16: Values of S (mm) for water yield formula. Intermediate values may be used (from USDA-SCS 1964)

Soil type	**Number of days since last storm which caused runoff**		
	More than 5	**2-5**	**Less than 2**
Good permeability, for example, deep sands	**150**	**75**	**50**
Medium permeability, for example, sandy clay loams and clay loams	**100**	**50**	**25**
Low permeability, for example, clays	**50**	**25**	**25**

One possibility is to assume a constant value of S for a given catchment. More accurate estimates can be made by assuming that if storms occur in quick succession the soil will not have time to dry out in between. Table 16 shows some values of S which make allowance for this and for the different storage capacity of different soils. Figure 59 shows the above equation plotted for various values of S.

An alternative method of estimating the effect of conditions in the watershed, using some different variables, is known as the Soil Conservation Service Method of Runoff Curves. Four variables are considered and in each case a selection has to be made from a list of alternatives. Ten categories of land use or cover are offered, as shown in the first column of Table 17, with a choice of two or three appropriate soil conservation practices such as contouring (i.e. planting on the contour) and terracing (i.e. use of graded channel terraces). The hydrological condition of the catchment is graded good, fair or poor, and subjective assessments are called for in this category. For arable land, the hydrologic condition reflects whether the rotation will encourage infiltration and promote a good tilth. For grassland, it is assessed on the density of the vegetative cover, and more than 75% cover is 'good', while less than 50% is 'poor'. For forest lands, the criteria are the depth of litter and humus, and the compactness of the humus. Finally the soil is designated as one of four hydrologic soil groups described in Table 18.

A disadvantage of this method is that it relies on subjective (i.e. non-measurable) assessments as well as factual criteria. The variables are combined as in Table 17 to give the curve number which can range from 25 to 100. A weighted average can be calculated when conditions vary within the watershed. The procedure would be to first decide the area according to soil group, then according to land use, then obtain the curve number for each treatment and condition.

Figure 60 shows the runoff for curve numbers and rainfall amounts, and is clearly very similar in form to Figure 59, which is not surprising because the runoff curve number and S value are merely alternative estimators of the conditions in the watershed which will affect yield.

TABLE 17

Estimation of runoff curve numbers (from USDA-SCS 1964)

Land use or cover	Treatment or practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Terraced	Poor	61	72	79	82
	Terraced	Good	59	70	78	81
Close seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Controued	Good	55	69	78	83
	Terraced	Poor	63	73	80	83
	Teraced	Good	51	67	76	80
Pasture or range	Contoured	Poor	68	79	86	89
	Contoured	Fair	49	69	79	84
	Contoured	Good	39	61	74	80
		Poor	47	67	81	88
		Fair	25	59	75	83
		Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods (farm wood-lots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		-	59	74	82	86
Roads		-	74	84	90	92

TABLE 18

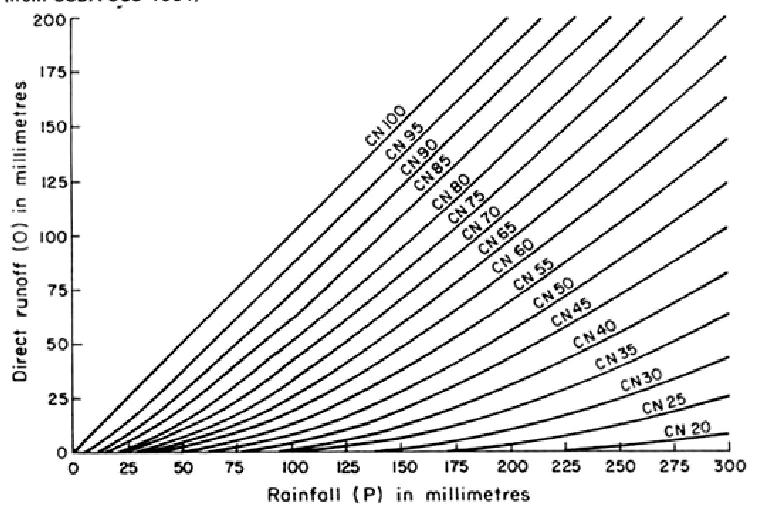
Hydrologic soil groups **(from USDA-SCS 1964)**

Hydrologic soil group	**Runoff potential**	**Infiltration when wet**	**Typical soils**
A	**Low**	**High**	**Excessively drained sands and gravels**
B	**Moderate**	**Moderate**	**Medium textures**
C	**Medium**	**Slow**	**Fine texture or soils with a layer impeding downward drainage**
D	**High**	**Very slow**	**Swelling clays, claypan soils or shallow soils over impervious layers**

The runoff curve method may be applied to estimate runoff from an individual storm, or weekly, monthly, or annual rainfall. It is also possible to use it to derive estimates of maximum rates of runoff, and an example of this is reported in FAO (1976b) but the authors stress that this is an example of where extrapolation is only permissible to an area of similar climatic conditions where exact comparisons have been made, and should otherwise be treated with extreme caution.

FIGURE 60

Relationship between rainfall and runoff using runoff curves derived from Table 17 (from USDA-SCS 1964)



Appendix 12: NRCS/SCS/Synder Curve number method for calculating stream flows

Adapted from: Purdue University, soil and water resources engineering website http://pasture.ecn.purdue.edu/~abe325/week.6/hydrograph.html and A.DWard and S.W.Trimble (2004) Environmental Hydrology, Lewis Publishers, New York

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Terms:

hydrograph = graph of water flow rate vs time

volume runoff = amount of runoff usually given in inches over a watershed area

initial abstraction = interception losses, surface storage, and water which infiltrates into the soil prior to runoff

antecedent moisture = soil water content prior to a rainfall event.

Introduction: Two characteristics of a runoff hydrograph are important, the peak or maximum runoff and the volume runoff (area under the curve). Only estimates of peak runoff rates are needed in the design of facilities where retention of runoff is minimal, e.g., erosion-control structures. Methods for estimating peak runoff are the Rational Method out lined in appendix and the Natural Resources Soil Conservation Service (NRCS) or SCS method. The (NRCS) will now be described (Ward and Trimble (2004) p132).

Volume runoff. According to NRCS, the volume runoff (Q) per unit area can be described as

$$Q = \frac{(I - 0.2S)^2}{I + 0.8S}$$

where: I = storm rainfall in inches

S = maximum potential difference between rainfall and runoff

S is therefore fixed for a given storm and can be evaluated from the effects of soil types, land treatment and antecedent moisture.

For convenience, S is defined as

$$S = \frac{1000}{CN} - 10$$

Be careful which CN curves you are using as imperial curves have to be multiplied by 25.4 for S in mm.

Imperial (inch) CN curves can be selected from page 133 of Ward and Trimble (2004) based on soil conditions and antecedent moisture.

Appropriate curves are

Land use	Soil group			
	A	**B**	**C**	**D**
Fallow poor condition	77	86	91	94
Cultivated with tillage	72	81	88	91
Cultivated with conservation tillage	62	71	78	81
Pasture /range poor condition	68	79	86	89
Pasture /range good condition	39	61	74	80
Meadow	30	58	71	78

Soil groups are based on infiltration rates (Ward and Trimble(2004) p132)

Group A (low runoff potential). Soils with high infiltration rates even when wetted, mainly deep well drained sands and gravels. Final infiltration rate > 7.6mm/hr.

Group B (poor runoff potential). Soils with moderate infiltration rates even when wetted, moderately deep, moderately drained with fine to moderate coarse textures. Final infiltration rate 3.8- 7.6mm/hr.

Group C (moderate runoff potential). Soils with slow infiltration rates even when wetted, soils with a layer that impedes drainage with moderately fine to fine textures. Final infiltration rate 1.3- 3.8mm/hr.

Group D (high runoff potential). Soils with very slow infiltration rates even when wetted, soils with a clay layer that impedes drainage, texture chiefly clay. Final infiltration rate <1.3mm/hr.

Adjustments for Antecedent Soil Moisture Condition (AMC) can be made by applying correction factors the appropriate AMC no can be selected from the table below (Ward and Trimble (2004) p133).

	AMC I	**AMC II**	**AMC III**
Dormant season (% soil water)	<4	4- 9	>9
Growing season (% soil water)	<12	12-17	>17
No of Days since rainfall that last caused runoff	>5	2-5	<2

The standard curve numbers presented above apply to AMC II which assumes that the soils are wet. Curve numbers can be adjusted using the factors in the table below (Ward and Trimble (2004) p133).

	Factors to convert CN to AMC I or AMC III	
Curve no AMCII	**AMC I**	**AMC III**
20	0.45	1.85
30	0.5	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07

Unit Hydrograph development.

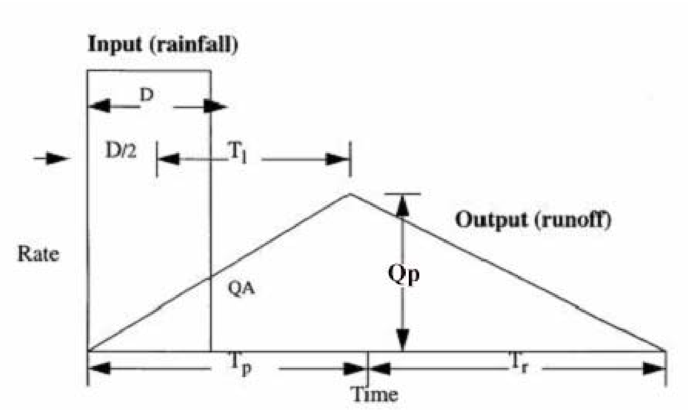
Unit Hydrographs can be used to simulate the Q at a specified time interval for any rainfall of any duration. Unit Hydrographs are usually constructed from observations of discharge as described in this appendix earlier, however many basins are ungauged and synthetic hydrographs have to be developed. The simplest synthetic hydrograph approximates the skewed bell shaped curve of natural hydrographs. These can be combined into composite hydrographs (see Ward and Trimble, 2004, p.149) but is complex and computer models like the USGS TR55 can do this.

The Triangular hydrograph method uses the Q or (QA) calculated using the S curve method above to calculate the peak discharge (Q_p). QA is the area under the line of the graph. This method usually underestimates $Q_{p.}$

The time taken for the discharge to reach from 0 to the Q_p is known as T_p the time to peak. The time taken for the flow to recede back to zero is known as the recession time (T_r). Another term T_l the lag time is the time between the average time that the main rain fell to T_p. The time of concentration T_c is the time taken for water particles from the furthest reaches of the catchment to reach the catchment exit. D is the duration of excess rainfall, sometimes this may be known from rainfall records otherwise it has to be estimated. Excess rainfall P_e is the part of the rainfall that is not infiltrated and can be estimated by

$$P_e = I - Q$$

The diagram below shows graphically many of the parameters described.



It is assumed that $T_L = 0.6\ T_c$ and $T_r = 1.67\ T_p$, so then:

$$QA = 1/2\,(2.67\ T_p)\ q_p$$

Solving for the peak runoff rate gives:

$$Q_p = \frac{0.75\,QA}{T_p}$$

where: Q_p = peak runoff rate (cfs) (multiply by 0.0028317 to get m^3/s)

Q = runoff (in) (divide by 25.4 if in mm) calculated using the runoff curve method

A = watershed area (acres) (divide by 0.4047 if in ha)

$$T_l = \frac{L^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}$$ (Ward and Trimble (2004) p137)

Where T_l = time lag in hours

L = the hydraulic length in feet (multiply meters by 0.3048) (the max. length of the flow path taken by water particles

S = defined by the curve no

Y = mean slope in %

T_c is the time of concentration (mins) and can be estimated from T_l (Ward and Trimble, 2004. p138) (T_c is not used in this method of calculating triangular hydrographs).

$$T_c = \frac{T_l}{0.6}$$

T_p = (time to peak (hrs)) can be estimated from farmer measurement of stream flows or by

$$T_p = 0.5D + 0.6T_l \qquad \text{(Ward and Trimble (2004) p147)}$$

Where *D* is the excess rainfall duration (hrs)

Suggested effective rain fall durations (D) when D is not known for the use of this formula are:

0.5 hr when $T_c < 3$ hr 1 hr when $3 < T_c < 6$, 1/5 T_c when $T_c > 6$

However measured effective rainfall can be measured from the recording rainfall records or from farmer observations.

An excel spreadsheet has been developed and accompanies this text allowing the user to produce there own synthetic hydrographs and estimate Q_p, T_p, T_l and T_r. Necessary parameters for this model are: I, CN, S (Slope), L, D and A.

Appendix 13: Calculating groundwater flow rates using the hydraulic gradient method (Todd, 1980 p. 81)

From Darcy's law it follows that the rate of groundwater movement is governed by the hydraulic conductivity of an aquifer and the hydraulic gradient. To obtain an idea of the order of magnitude of natural velocities, assume a productive alluvial aquifer with K= 75 m/day and a hydraulic gradient i = 10 m/l000 m = 0.01. Then from Eq. 3.5

$$v = Ki = 75(0.01) = 0.75 \text{ m/day} \qquad (3.42)$$

This is approximately equivalent to 0.5 mm/min, which demonstrates the sluggish Nature of natural groundwater movement.

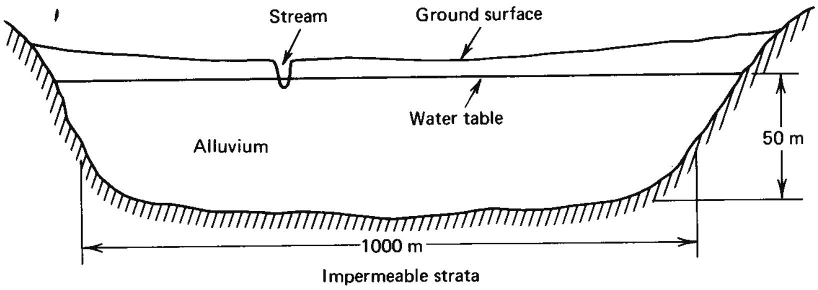


Fig. 3.8 Cross section of a typical alluvial floodplain containing an unconfined aquifer with groundwater flowing perpendicular to the section (not to scale).

If the above flow occurs within and perpendicular to the large alluvial cross section sketched in Fig. 3.8, then the total flow rate

$$Q = Av = (50)(1000)(0.75) = 37{,}500 \text{ m3/day} \quad (3.43)$$

which, when converted to usual stream flow units, amounts to only 0.43 m3/s. Thus, groundwater typically can be conceived of as a massive, slow-moving body of water.

Groundwater velocities vary widely depending on local hydrogeologic conditions; values from 2 m/year to 2 m/day are normal. Usually, velocities tend to decrease with depth as porosities and permeabilities also decrease. Velocities can range from negligible to those of turbulent streams in underground openings within basalt and limestone. Mechanisms such as wells and drains act to accelerate flows.

Appendix 14: Determining Ground Water Recharge from Baseflow

Adapted from Fetter (1994) p64

A plot of stream hydrograph with time on a arithmetic scale and discharge on a logarithmic scale yields a straight line. The total potential ground water discharge (V_t in m^3) is the volume of water discharge during a complete ground water recession

$V_{tp} = Q_o t_1 / 2.3$

Where (Q_o) = maximum stream flow rate (m/s) and t_1 is the time at which $Q = 0.1Q_o$

Amount of potential baseflow after some elapsed time (t), is

$V_t = V_{tp}/10^{(t/t1)}$

Recharge is the difference between the total potential ground water discharge and the potential baseflow remaining at the end of the last recession.

Appendix 15: Slug Tests and Bail down Tests

Fetter (1994), Chapter 7, pg. 243 - 261

Slug tests

The aquifer tests that we have discussed so far involve pumping and have some practical problems.

- they are expensive, requiring monitoring wells and many person-hours of labor to conduct.

- because water has to be removed and disposed of during the test, they pose disposal problems if the aquifer being tested is contaminated.

- tests in low permeability strata, such as might be considered for waste containment or that might already be contaminated, are not practical because of the difficulty of pumping water from low permeability material.

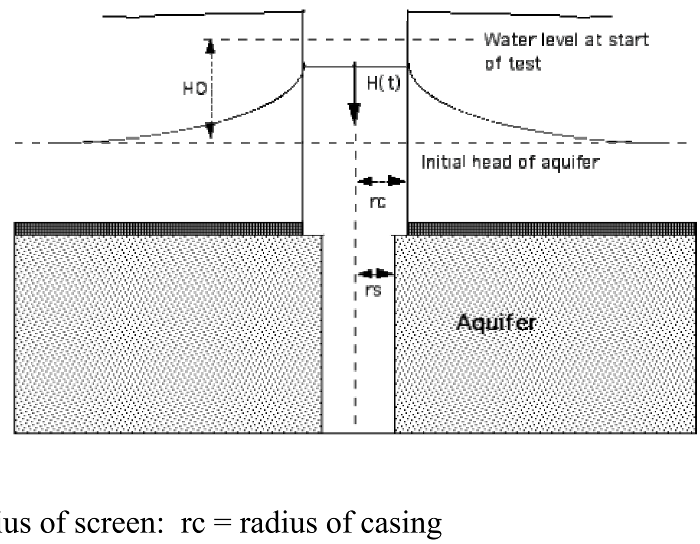
An alternative to a pump test is a **slug test** (also called a baildown test). In this test the water level in a small diameter well is quickly raised or lowered. The rate at which the water in the well falls (as it drains back into the aquifer) or rises (as it drains from the aquifer into the well) is measured and these data are analyzed.

Water can be poured into the well or bailed out of the well to raise or lower the water level. However, perhaps the easiest way to raise the water level in the well is to displace some of the water in the well by lowering into it a solid piece of pipe called a **slug**

Slug tests can be used to estimate transmissivity of the aquifer in the immediate vicinity of the well. Storativity can also be estimated, although storativity estimates are often difficult to make with any degree of accuracy.

Slug test for a fully screened, confined aquifer - the Cooper-Bredehoeft-Papadopulos Method

In this slug test, water level is raised in a well, and the level of the water in the well is measured over time as the water drains back into the aquifer and the level falls.



rs = radius of screen: rc = radius of casing

A plot is made on semi-log graph paper, with the ratio of the measured head to the head after injection (H / H0) plotted on the Y (linear) axis and time plotted on the X (logarithmic) axis.

The ratio of H/H0 is equal to a defined function:

$$H / H_0 = F(\eta, \mu)$$

Where...

$$\eta = Tt / r_c^2$$

and

$$\mu = r_s^2 S / r_c^2$$

Values of F have been tabulated for different μ (mu) and η (eta). To analyze the slug test data we need to match the data curve to one of a series of type curves.

Each type curve consists of H/H_0 values plotted against a range of η values for a particular value of μ.

In this case, we need to keep the Y axis of the two graphs the same, while sliding the overlay along until the data points are matched by one of the curves.

The matched curve gives us an approximate value for mu, while reading the time value from the data graph that is equivalent to eta = 1, gives us a t1 value. We can solve the following equations for T and S:

$$T = \frac{1.0 r_c^2}{t_1} \quad \text{and} \quad S = (r_c^2 \mu) / r_s^2$$

In our example on the overhead, the data were obtained on a pump test of a fully confined aquifer. The radius of the casing was 7.6 cm, the radius of the screen was 5.1 cm. The slug dropped (injected) into the well raised the water level .42 meter.

From the graph overlay, t1 = 12.5 seconds and mu = log $^{-3}$ = 10^{-3}.

$T = (7.6)^2 / 12.5 = 4.6\ cm^2/sec$

$S = 10^{-3} \times (7.6)^2 / (5.1)^2 = 2.2X10^{-3}$

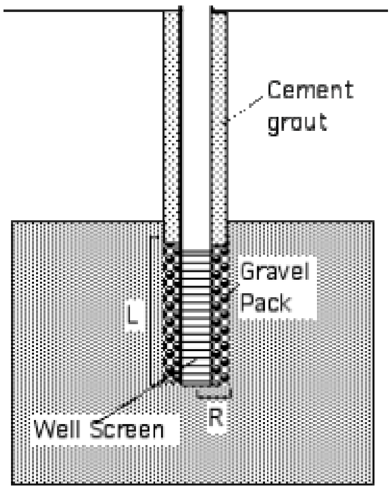
It must be noted that the T value obtained is that of the aquifer in the immediate vicinity of the well.

Also, it is often the case that the S value obtained is not very accurate due to the difficulty in exactly matching a particular type curve.

Hvorslev Slug Test Method

This is a method for analyzing slug test data from wells or auger holes that are not fully penetrating or fully screened.

For example, a piezometer well may be sunk to monitor the head and water quality of a specific level in an aquifer. This kind of monitoring well is easier and cheaper to install than a fully penetrating well.



This diagram shows the configuration for a piezometer sunk into a low permeability clay layer. The gravel pack is needed to keep the clay from entering the well.

If the length (L) of the piezometer intake is more than 8 times the radius (R) of the well screen (or gravel pack) then the following formula will apply for estimating hydraulic conductivity:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

r is the radius of the well casing (the well radius above the screen).

T_0 is the time it takes for the water level to rise or fall to 37 percent of the initial change. This can be found easily by plotting the head ratio H/H0 on a log Y axis against time on a linear X axis. The data points form a straight line, and the t value that corresponds to H/H0 = .37 can be read from the graph.

There are other methods for analyzing slug test data. Usually these methods yield an estimated value for hydraulic conductivity or transmissivity, but not a value for storativity. However, in many cases the rate of movement of water through an aquifer or aquiclude is of primary interest, particularly where the movement of contaminants is being tracked.

Long term monitoring of drawdown

A final word about pumping tests. Long term monitoring of the drawdown of an aquifer during pumping can yield valuable information as to the nature of the aquifer.

If drawdown is plotted against time on a logarithmic scale, it should form a straight line showing with no leveling off (the cone of depression will expand indefinitely).

If the curve bends upward it means that some source of recharge has been encountered by the cone of depression, either vertical leakage across a confining layer of the aquifer or horizontal recharge from a recharge boundary.

If the curve bends downward, it means that the cone of depression has encountered some kind of barrier to groundwater flow, such as the margin of the aquifer layer.

Appendix 16: Sample recording sheets for hydrological measurements

This appendix contains sample record sheets for daily temperature recording, daily flow measurements, peak flow measurements and daily well observations. These should be translated in to local languages

Daily Temperature Record Sheet

Peak Flow Record Sheet

Daily Flow Record Sheet

Daily Well Record Sheet

Operational Research
Daily Temperature Record Sheet

Place________________________ Woreda________________________

Month________________________ Recorder________________________

Date	Max Temp. (°c)	Min Temp. (°c)	Weather	Remark
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
Total				

Weather Conditions

Windy = (W) Cloudy = (C)

Cold = (F) Warm/sunny = (S)

Operational Research
Peak Flow Record Sheet

Place______________________ Woreda______________________

Month_____________________ Recorder____________________

Event	Date	Start time	Peak time	Finish time	Peak height (m)	Rain (mm)	Remark
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
Total							

Operational Research
Daily Flow Record Sheet

Place______________________ Woreda______________________

Month_____________________ Recorder____________________

Date	Time of observation	Water level (m)	Previous days rain (mm)	Remark
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
Total				

Operational Research
Daily Well Record Sheet

Well______________________ Woreda______________________

Month_____________________ Recorder____________________

Date	Well Depth (m)	Time	Weather	Remark
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
Total				

Weather Conditions

Windy = (W)　　Cloudy = (C)

Cold = (F)　　Warm/sunny = (S)

Appendix 17: Estimating soil moisture from the feel

from Hudson (1975) p.128.

Percent of available moisture	***Light soils*, loamy sands and sandy loams**	***Medium soils*, very fine sandy loam and silt loam**	***Heavy soils*, silty clay loams and clay loams**
0-25 (0% = wilting point)	Dry loose, flows through fingers.	Powdery, sometimes slightly crusted, but easily broken down into a powdery condition	Hard, cracked; difficult to break down into a crumbly condition
25-50	Appears dry, will not from a ball with pressure.	Some what crumbly, but holds together with pressure	Some what pliable balls under pressure.
50-75	Tends to ball under pressure, but seldom holds together when bounced in hand.	Forms a ball, somewhat plastic, sticks slightly with pressure	Forms a ball, ribbons out between thumb and forefinger
75-100	Forms a weak ball, breaks easily when bounced in hand	Forms a very pliable ball	Easily ribbons out between thumb and forefinger
100 (field capacity)	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand; soil sticks to thumb when rolled between thumb and forefinger.		
Saturated	Free water appears on soil when squeezed		

Appendix 18: Ethiopian Calendar and time systems

The differences in the Ethiopian and the international calendar and time systems can cause confusion. The farmers and DAs are using the Ethiopian systems and researchers the international. This difference in calendars and time systems can be confusing when compiling rainfall records and comparing with other records.

The International calendar is Gregorian while the Ethiopian calendar is a Julian type calendar with 12 months of 30 days with a 13th month of 5 or on a leap year 6 days. The 13th month falls in September, so although Ethiopians may use English month names these do not correspond to the numeral of the Ethiopian calendar. E.g. the first month in the Ethiopian calendar is Oct. The year starts on 11th September (Gregorian) and from then until 31st December the year number is seven less than the Gregorian year number. From 1st January to 10th September the difference is eight. The international year 2005 thus corresponds to the Amharic years 97-98. The difference in year numbering is due to the Ethiopian Orthodox Church disagreeing with the Roman Catholic Church about when the world was created.

The month names and their relationship to international months are as follows:-

Ethiopian month number	Ethiopian month Name	International (Gregorian) month number	International (Gegorian) month name
1	Meskerem	9-10	September/October
2	Tekemt	10-11	October/November
3	Hedar	11-12	November/December
4	Tahesas	12-1	December/January
5	Tir	1-2	January/February
6	Yekatit	2-3	February/March
7	Megabet	3-4	March/April
8	Meyazeya	4-5	April/May
9	Genbot	5-6	May/June
10	Senay	6-7	June/July
11	Hamlay	7-8	July/August
12	Nehasay	8-9	August/September
13	Paguemain	9	September (intercalary month)

In all of the project areas the main rains finish by Dec and the major rainy season starts in March. The 1st March (International) or 22/4 (Ethiopian) in Ethiopia, marks the start of the hydrological year. Graphs, tables and dekads presented in this report all start from this date.

Ethiopia also uses a different time system to the rest of the world. Each day starts with dawn which, because the country is so near the equator, is approximately 6 am all the year round. By the Ethiopian way of reckoning time 6.00am is 00:00 (or 12:00), midday is 6:00 and sunset is 12:00. A twelve hour clock is used so a minute after sunset is 00:01 and midnight is 6:00. The terms AM and PM are meaningless so the two twelve hour periods are simply known as 'Day' and 'Night'. Thus 9am would be described as ‘9 of the day’ and 9pm as ‘9 of the night’.