INTEGRATED WATER RESOURCES ASSESSMENT AND MANAGEMENT IN A DROUGHT-PRONE WATERSHED IN THE ETHIOPIAN HIGHLANDS

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Oloro Vahid McHugh

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INTEGRATED WATER RESOURCES ASSESSMENT AND MANAGEMENT IN A DROUGHT-PRONE WATERSHED IN THE ETHIOPIAN HIGHLANDS

Oloro Vahid McHugh, Ph.D.

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Food production shortfalls and accelerated land degradation are common in the semi-arid Ethiopian highlands. Both issues can be addressed to a significant extent by better water management. This dissertation presents four studies in eastern Amhara that examined effectiveness of a range of water management practices.

An on-farm study tested effectiveness of subsoiling, open and tied ridges, no till, and conventional maresha tillage to mitigate impact of dry spells on crops and to protect the soil. Tillage performance varied with seasonal rainfall distribution and intensity and land gradient. Ridges significantly increased soil moisture and grain yield and reduced soil loss. Subsoiling moderately increased grain yield and root growth, but led to higher soil loss than conventional tillage. No till minimized soil loss, but reduced yield during one season.

A second study measured plot and catchment hydrologic responses with and without conservation measures. Results show that severe erosion in the watershed occurred during few erratic storms rather than steadily across all seasons. Gently-sloped cropland generated over twice the seasonal runoff and sediment yield compared with steep rangeland. Plot runoff consistently exceeded catchment discharge demonstrating a scale effect. Catchment rehabilitation resulted in reduced peak discharge and longer duration streamflow compared to a catchment without these measures.

A third study examined hydrological and land cover changes in a wetland through remote sensing, hydrological measurements, rainfall records, and a residents' survey. All evidence indicated limited flooding and dense woody vegetation cover in the wetland 40 years ago and a trend towards current conditions of no living trees/bushes, extensive flooding, and heavy sedimentation. Results suggest changes are a consequence of increasing runoff from the catchment and higher population pressure that decreased potential of rainwater to infiltrate.

A fourth study surveyed households to assess what water resources they accessed and their water concerns. Each household relied on over 3 different water sources to assure daily supplies of 5-12 liters per person. Females assured most domestic water while male participation increased for livestock water and sources farther from home. Concerns included unhealthy water quality, unreliable year-round supply, and long up to 5 hours daily walking distances.

BIOGRAPHICAL SKETCH

The author was born in DR Congo where his parents served as U.S. Peace Corps Volunteers and Baha'i pioneers. He completed his primary and secondary education through home schooling in correspondence with Calvert Elementary School in Baltimore, Maryland and University of Nebraska Independent Study High School in Lincoln, Nebraska. In January 1996 he enrolled at Texas A&M University in College Station, Texas where he was awarded a four-year Presidential Achievement Award scholarship and completed a Bachelor of Science degree in Agricultural Engineering with Summa Cum Laude honors in December 1999. In January 2000 he enrolled at Cornell University where he conducted research on rice irrigation in Madagascar with support from a two-year New York State College of Agriculture & Life Sciences fellowship and completed a Master of Science degree in Agricultural and Biological Engineering in August 2002.

The author's Ph.D. studies in the Department of Biological and Environmental Engineering were supported by fellowship awards from Ford Foundation and the U.S. Environmental Protection Agency's Science To Achieve Results program. His major concentration was in Soil and Water Engineering with minors in Crop and Soil Sciences and Development Sociology. His Ph.D. work was supervised by Professors Tammo S. Steenhuis, Erick C.M. Fernandes, and Parfait M. Eloundou-Enyegue.

To my beloved family

Anita, Dermot, Gnilane, Amani, Mwangaza, Ousmane, Madelaine, and Mickey

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Finally, I thank all my family and friends who have always been very supportive. Special thanks to my wife, brother, parents, sister, brother-in-law, Aunt Madelaine, Uncle Mickey, and the Baha'is of Ithaca for constant interest and encouragement during the whole process.

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CHAPTER ONE

INTRODUCTION

Seasonal soil moisture deficits in rainfed crop production, extensive land degradation by water erosion, and lack of nearby clean reliable domestic and livestock water sources are priority concerns for numerous communities living in the semi-arid and subhumid Ethiopian highlands. Periods of infrequent highly intense rainfall followed by short intra-seasonal dry spells create a common problem of excess rainwater surface runoff eroding and flooding land one day and a couple weeks later in the same catchment rainfed crops showing signs of moisture stress due to soil dryness. In addition to the onsite effects of erosion reducing land productivity, high offsite sedimentation rates decrease storage capacity of micro-dams and reservoirs which hinder efforts to provide efficient long-term water resources.

This dissertation presents four studies undertaken in the Lenche Dima/Hara Swamp watershed in eastern Amhara State, Ethiopia. The studies examined a range of water management practices. Each of the following chapters presents one of the studies.

Chapter Two presents an investigation of land preparation practices that use rainwater more efficiently to mitigate impact of dry spells on rainfed crops and that protect the soil. On-farm experiments tested conservation tillage techniques implemented with oxen-drawn plows on a clay loam soil. Tested tillage techniques were subsoiling, open and tied ridges, no till, and conventional tillage with the maresha plow (the control). Effectiveness in improving root zone soil moisture, limiting soil loss, and improving sorghum and chickpea grain yield were determined.

Chapter Three presents a field study that measured hydrologic and sediment yield responses to natural rainfall on plots and catchments with and without conservation practices. The objectives were to investigate soil loss and surface runoff generation mechanisms and controlling factors, quantify hydrologic response to natural rainfall at multiple scales, and assess effectiveness of conservation measures implemented on different parts of the landscape.

Chapter Four presents a case study of hydrologic and land cover changes in Hara Swamp. Wetlands are important sources of water and plant production for humans and livestock in the Ethiopian highlands. Hydrological changes in these wetlands affect local populations and are indicators of change in the upstream catchments. An integrated approach using remote sensing images, limited hydrological measurements, climatic data, and a survey of residents was applied to gain complementary insights into what changes have occurred, when and why they occurred, and the local perceptions of these changes.

Chapter Five presents a survey study of households to assess what water resources the watershed communities accessed and their water concerns. Household labor to assure water needs, methods for water transportation, water uses from different source types, and communities' management of water resources were also examined.

CHAPTER TWO

PERFORMANCE OF IN-SITU RAINWATER CONSERVATION TILLAGE TECHNIQUES ON DRY SPELL MITIGATION AND EROSION CONTROL IN THE DROUGHT-PRONE NORTH WELLO ZONE OF THE ETHIOPIAN HIGHLANDS*

ABSTRACT

Grain production shortfalls in northern Ethiopia are commonly associated with occurrence of intra-seasonal dry spells or droughts and rapid land degradation which adversely impact crop yields. Suitable practices that use available rainwater more efficiently to mitigate impact of dry spells on crops and that protect the soil are needed to stabilize and improve grain yields in the predominately rainfed agriculture. During three cropping seasons on-farm experiments tested conservation tillage techniques implemented with oxen-drawn plows on a clay loam soil. Tested tillage techniques are subsoiling, open and tied ridges, no till, and conventional tillage with the maresha plow (the control). Effectiveness in improving root zone soil moisture, limiting soil erosion, and improving sorghum and chickpea grain yield were determined. Results demonstrate that performance of the tillage techniques varied with seasonal rainfall distribution and intensity and land slope gradient. Tied and open ridge significantly increased seasonal soil moisture in the root zone. Subsoiling slightly increased and no till slightly decreased soil moisture but were not statistically different from conventional tillage. Tied ridge and no till significantly reduced soil loss by more than half during seasons with moderate intensity storms, but during a season with high

* McHugh, O.V., T.S. Steenhuis, B. Abebe, E.C.M. Fernandes. Performance of in-situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone North Wello zone of the Ethiopian highlands. Submitted to Soil & Tillage Research

intensity storms tied ridge increased soil loss on 9 % slope. The increased soil disturbance of subsoiling led to higher soil loss rates than conventional tillage during all seasons. Grain yield decreased and runoff and erosion rates increased rapidly with increasing land slope gradient. During a season with moderate intensity rainfall tied and open ridge increased yield by 70% over the control while no till decreased yield. During a season in which high intensity rainfall events damaged the ridges, subsoiling had the best grain yield with a 42% increase over the control. Overall results of the study suggest that on slopes less than 8 % oxen-drawn ridge tillage and subsoiling, to a lesser degree, can effectively improve conditions that mitigate impact of short dry spells especially during seasons with less intense rainfall events.

INTRODUCTION

The situation

Annual food production shortages in many parts of Ethiopia are commonly linked to unreliable seasonal rainfall meaning dry spells or droughts and environmental degradation. In eastern Africa droughts occur about once to twice every decade often resulting in crop failure while intra-seasonal dry spells of over 2 weeks are an almost seasonal occurrence reducing yields 75 % when they occur during flowering or grain-filling crop development stages (Barron et al., 2003; Seleshi and Zanke, 2004). Widespread rapid cropland degradation in the Ethiopian highlands mostly caused by water erosion and soil nutrient mining practices reduce soil nutrient availability, water holding capacity, and infiltration rate which all exacerbate the effects of meteorological dry spells on crop yields (Haileslassie et al., 2005; Nyssen et al., 2004; Tekle, 1999; Sonneveld and Keyzer, 2003).

During non-drought years, there is sufficient rainfall in semiarid and dry sub-humid regions of sub-Saharan Africa including dry drought-prone parts of the Ethiopian highlands to obtain high crop yields even during seasons with short dry spells (Rockström et al., 2002). The main limitation in stabilizing and increasing grain yields in rainfed farming systems of dry spell-prone areas is crop water stress caused by inefficient use of total available seasonal rainwater. Inefficient use of rainwater is often a consequence of poor rainfall partitioning resulting in low root zone soil moisture and/or of poor plant uptake of available soil moisture (Rockström and Falkenmark, 2000). With over 98 % of Ethiopian agricultural area rainfed (FAO STAT, 2002) food production is particularly vulnerable to dry spells. Technologies that use rainwater more efficiently are needed. Conservation tillage and water harvesting technologies offer good prospects for infiltrating and storing more rainwater which is then available for plant uptake during dry periods (Rockström et al., 2002; Motsi et al., 2004; Wiyo et al., 2000). In addition erosion control and soil fertility improvements are needed (Rockström and Falkenmark, 2000; Rockström and de Rouw, 1997). In this study, on-farm experiments tested the effectiveness of open and tied ridges, subsoiling, and no till to increase soil moisture and decrease runoff and erosion during three cropping seasons in the chronically food-insecure drought-prone Lenche Dima watershed in eastern Amhara State, North Wello, Ethiopia.

Overview of rainwater conservation tillage techniques in Ethiopia

The in-situ rainwater conservation tillage techniques tested were open and tied ridging, subsoiling, and no till. Open and tied ridges have demonstrated mixed effectiveness at improving soil moisture in sub-humid and drier parts of sub-Saharan Africa depending on the site soil type, rainfall amount, and land slope (Motsi et al., 2004; Wiyo et al., 2000; Twomlow and Bruneau, 2000; Lal, 1995). The manual formation of ridges as is practiced in some other parts of Africa is not always feasible in the Ethiopian highlands where farmers are used to oxen-drawn tillage with a traditional single tined plow called maresha. This study tested an oxen-drawn ridger which consists of a relatively inexpensive ridging implement that simply attaches to the conventional maresha plow. Farmers have responded favorably to the ridger (Temesgen, 2000). However, knowledge is limited about the performance of the relatively small ridges, which are 10-15 cm high and less than 30 cm wide, made with the implement.

Subsoil cultivation is a technique that cuts soil deeper than achieved with conventional tillage. Subsoiling improves grain yield by enhancing root growth and infiltrating more rainfall deeper in the soil profile particularly in soils with compacted low permeability sub-layers (Salih et al., 1998; Abu-Hamdeh, 2003; Pikul and Aase, 2003; Xu and Mermoud, 2003; Pagliai et al., 2004; Birkas et al., 2004). Hardpans and soil compaction caused by repeated tillage to the same depth for generations and animal trampling has been reported in Ethiopia (Mwendera and Saleem, 1997), but little is known about their prevalence in croplands and the level of impact on agricultural yield. This study tested effectiveness of subsoiling implemented with an oxen-drawn subsoil cultivator recently developed by the Integrated Food Security Program (IFSP) in Debre Tabor, Ethiopia. The tested subsoiler cut the soil at 30-50 cm intervals an additional 6-12 cm below the 6-15 cm tillage depth of conventional tillage with maresha (Nyssen et al., 2000).

No till can improve infiltration, reduce erosion, and increase yield as a result of natural processes acting to improve soil quality (Lal, 1998; Dominy and Haynes, 2002; Wahl et al., 2004; Pala et al., 2000; Lal, 1995). No till is not commonly practiced in

Ethiopia, but farmers have expressed interest because of lower animal draft requirement and the possibility to plant crops earlier (seeds can be sown without waiting for a rain event to soften the soil before tillage) thus providing an early harvest during the annual period of household food shortage (Astatke et al., 2003). Although no till sometimes decreases grain yields during the first season of implementation, after several years of cropping with better adapted management techniques, yield increases have been observed (Astatke et al., 2003; Lal, 1998; Pala et al., 2000). Mulching can improve effectiveness of no till in enhancing soil moisture and reducing soil losses (Lal, 2000). The present study tested no till with 2.5 Mg ha^{-1} sorghum stalk mulching.

MATERIALS AND METHODS

Site and environmental conditions

Experiments were conducted during three cropping seasons (2003-04) on a farmer's field in the Lenche Dima watershed (N 11°50.415', E 39°43.871', 1540 m above sea level) located 16 km east of Weldiya town in North Wello, Amhara State, Ethiopia (see Figure 2.1). Mean annual precipitation in the period from 1975-1981 and 2003-2004 was 849 mm (Ethiopia National Meteorological Services Agency 1975-1981). The rainfall distribution is bimodal with a small rainy season (belg, mean 208 mm*)* during March - May and main rainy season (kremt, mean 483 mm) during July - October. Mean long-term daily maximum temperature is 33°C in June and the mean daily minimum is 12°C in November. As part of this study daily U.S. Class A pan evaporation, hourly ambient temperature, and 10-minute incremental rainfall (tipping bucket rain gauge) were monitored in the Lenche Dima watershed for 2003-2004.

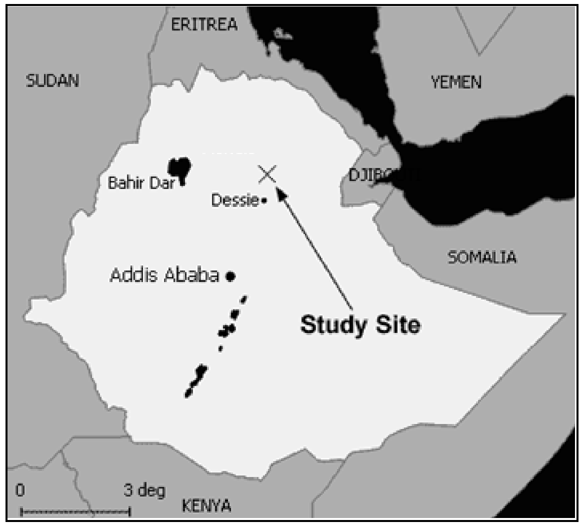


Figure 2.1. Location map of experiment site in North Wello, Amhara State, Ethiopia

Soil at the farm site is a clay loam with average bulk density of 1.56 Mg m^{-3} and is classified as vertic luvisol. According to the farm owner, no nutrients were applied, except for waste from roaming livestock, during continuous cultivation (teff, sorghum, chickpea) of the field for over 10 years prior to the experiments. The baseline soil properties determined at the Duke University Soil Laboratory (Durham, NC/USA) show increasing clay and silt content from 0-30 cm to 30-45 cm depth, low N and fair P nutrient contents, and neutral pH (Table 2.1).

Table 2.1. Soil characteristics at the experiment site

Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture Class	Bulk Density (g cm^{-3})	Total N (%)	Total P (%)	pH H_20 1:1	Organic Carbon (%)
0 – 30	48	25	27	Loam	1.57	0.10	0.14	7.4	1.1
30 - 45	41	29	30	Clay loam	1.56	0.10	0.15	7.4	1.1

Experimental design

The kremt 2003 and belg 2004 experiments were setup as randomized complete block design and the kremt 2004 experiment was split plot (see Table 2.2). Plots were 30 meters long and 5-6 meters wide and were hydrologically separated by compacted soil bunds 50 cm wide and 30 cm high. Treatments were replicated in three complete blocks. Blocks consisted of contour strips along a toposequence of decreasing slope downhill (concave) on one farmer's field (~ 0.75 ha). Plot slopes were 9-11 % for the top block 1, 4-8 % for the middle block, and 0-3 % for the bottom block. Unlike the top and bottom blocks which had similar mean slopes across plots within the same block, in the middle block the treatments were on plots with considerably different slopes (mean slope = M 4 %, SS 7 %, OR 6 %, TR 7 %, NT 6 %; treatments are described in the next paragraph). During kremt 2003 a local "early"-maturing (~140 days) red variety (locally called *Djigourti*) of sorghum (*Sorghum bicolor*) was planted while a local variety of desi-type chickpea (*Cicer arietinum*) was planted during belg 2004. An early maturing (~103 days) striga-resistant improved white variety of sorghum (P-9401 Gobye from Sirinka Agricultural Research Center, Amhara State, Ethiopia) was planted during kremt 2004.

Four land preparation techniques were tested during the first two rainy seasons (kremt 2003 and belg 2004) and a fifth treatment of no till was added during the third season (kremt 2004) of the study. The treatments were conventional tillage with maresha (M) which is the control, subsoiling with an animal-drawn subsoiler (SS), open (OR) and tied ridges (TR) created using an animal-drawn ridger, and no till (NT) with sorghum stalk surface mulching. No nutrients were applied to the plots during the first two seasons of experiments. During the third season (kremt 2004) nutrients were applied to five subplots within each main plot tillage treatment. Subplots were 5-6 meters wide

Table 2.2. Summary of experiments during each cropping season

Season	Crop	Experiment Design	Tillage Methods (main plots)	Fertilizer Applications[a] (subplots)
Kremt 2003	Sorghum	Randomized complete block	Maresha[b] Subsoiling Tied Ridges Open Ridges	None
Belg 2004	Chickpea	Randomized complete block	Maresha[b] Subsoiling Tied Ridges Open Ridges	None
Kremt 2004	Sorghum	Split plot	Maresha[b] Subsoiling Tied Ridges Open Ridges No till	N0 - None N1 - 20.5 kg N ha^{-1} N2 - 20.5 kg N ha^{-1} + 46 kg P ha^{-1} N2M1-20.5 kg N ha^{-1}+ 46 kg P ha^{-1} + 5 Mg ha^{-1} manure N3 - 41 kg N ha^{-1} + 46 kg P ha^{-1}

[a] N and P were applied as urea and diammonium phosphate (DAP) and manure was mainly from cattle; [b] Maresha tillage is the conventional method and the experimental control

(equivalent to main plot width) and 4 meters along slope (starting from the top of the plot) and were separated by 1.5 meter buffer zones. The nutrient treatments were no nutrient additions (N0); 20.5 kg N ha^{-1} as urea (N1); 20.5 kg N ha^{-1} + 46 kg P ha^{-1} as

DAP and urea (N2); 5 Mg ha^{-1} dry animal manure + 20.5 kg N ha^{-1} + 46 kg P ha $^{-1}$ as DAP and urea (N2M1); and 41 kg N ha^{-1} + 46 kg P ha $^{-1}$ as DAP and urea (N3). Nutrient treatments were randomly assigned to subplots within each main plot.

Experimental setup and crop management

All plots, except no till, were plowed twice during the off-seasons according to the conventional farm management practice using the conventional oxen-drawn single tine plow called maresha. The first tillage was along the slope contour 2-5 weeks after the previous crop harvest. The second tillage was along the slope after the first rain events of the upcoming cropping season softened the hard dry soil sufficiently for plowing. The final (third) tillage performed the day before sowing with the appropriate implement for each treatment was along the slope contour. Open and tied ridge plots were constructed with an oxen-drawn ridger implement which is easily attached to the traditional maresha plow (Temesgen 2000). The ridges were spaced 0.50 m apart. Plowing each row twice resulted in ridge heights of 10-15 cm and average width of 0.27 m. Cross ties of 8-12 cm height and at 1-2 m intervals were manually created with traditional hoes for the tied ridge treatment. The conventional tillage and subsoiling plots were plowed along the contour with a traditional maresha (described in Nyssen et al., 2000) and a subsoiler, respectively. The animal powered subsoiler named “Tenkara Kend” developed by the Integrated Food Security Program (IFSP) in Debre Tabor, Ethiopia has a flat blade extension that cuts the soil 6-12 cm below the normal plow depth (10-13 cm in this study) of conventional maresha tillage. In this study the subsoiler cut the soil at 0.3-0.5 m intervals along the slope contour. On the no till plots no tillage operation had been performed since land preparation with maresha plow for the previous season’s chickpea crop (5.5 months). Narrow lines about 3 cm deep were manually scraped/dug to sow seeds in the no till plots.

Regardless of treatment, all plots were manually sown in rows (on top of ridges for tied and open ridging) at 0.5 m spacing. A surface mulch of dry sorghum stalk 2.5 Mg ha^{-1} stored on another field from the previous kremt season was applied one day after sowing on the no till plots only. The stalks were aligned along the slope contour.

During the third season (kremt 2004) of the study nutrients were applied as single dose to subplots (at the rates discussed in the previous section) and incorporated (except for no till which remained surface applied) during the final tillage of land preparation. Locally purchased diammonium phosphate 18-46-0 (DAP) and urea 46-0-0 chemical fertilizers (N-P-K) and dry animal (mainly cattle) manure (1.7 % total N, 0.42 % total P) collected from local farmers' stalls were the sources/forms of applied nutrients.

The farmer who owned the land decided when all farm operations (tillage, weeding, harvest, etc.) were to be conducted. About a month after sowing sorghum plots were manually thinned to single plants with an average spacing of 0.25 m between plants and 0.5 m between rows. Weeding was carried out twice manually at 4-5 and 8-10 weeks, respectively, after sowing during each season. The no till plots required an additional weeding 3 weeks after sowing before the other treatment plots were weeded due to excessive weed infestation. No herbicides or pesticides were applied in any of the experiments.

Surface runoff measurement

A runoff collection system was setup at the bottom of main plots (5-6m x 30m) for conventional maresha tillage, subsoiling, and tied ridge treatments on all experimental blocks while no till plots (kremt 2004) only had runoff collection systems at the top (9-11 % slope) and bottom (0-3 %) blocks. Each collection system consisted of a sheet metal collector trough (6m long x 0.25m wide x 0.12m deep) which empties runoff into a series of three storage barrels (0.18 m^3 capacity each) interconnected by 10-slot flow divisors (see Figure 2.2). A plastic sheet was installed from about 10 cm buried below the soil at the bottom edge of the plot and extended over the trough lip into the trough. This effectively prevented runoff from seeping below the trough lip. Around 8 AM the following morning after every rainfall event the water level in all barrels was measured. The amount of water collected in the barrels was adjusted for direct and trough collected rainfall and for sediment volume. Daily rainfall amount measured at the farm location and rainfall interception area of trough and barrel collection system were used to adjust for direct rainfall during runoff calculations. The sediment volume measured at the bottom of each barrel and its water content were used to adjust runoff volume for sediment.

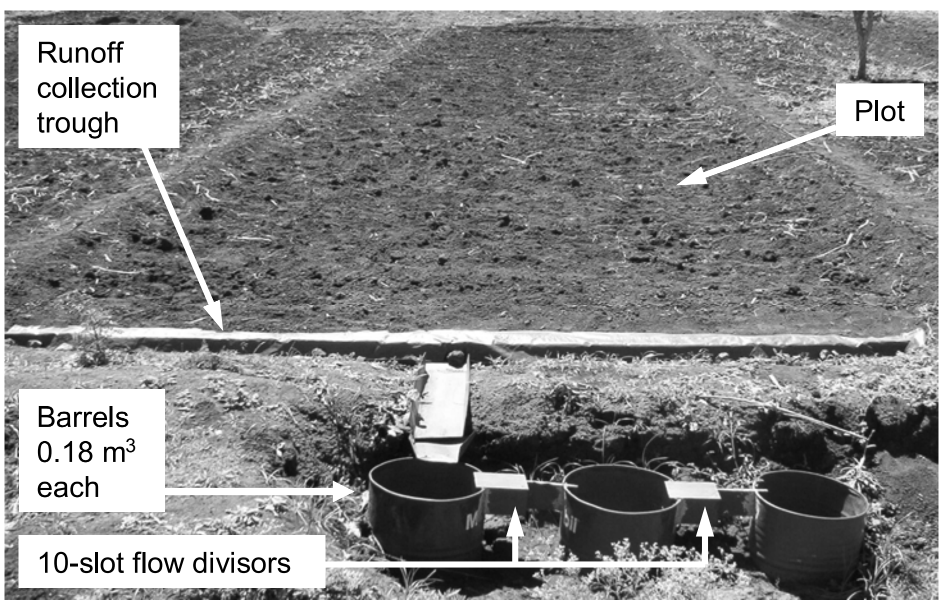


Figure 2.2. Plot runoff and sediment collection system (all components are metal except plastic apron on upper lip of collection trough)

Soil loss measurement

Water samples were taken from each barrel of the runoff collection system described above after vigorously stirring for about 30 seconds. The water samples were analyzed at Sirinka Agricultural Research Center (SARC) laboratory in Sirinka, Ethiopia for suspended sediment concentration using the filtration technique. This method involves filtering 100 ml of water sample to capture sediment particles larger than 1.2 µm and then oven drying this sediment at 105^{o}C for 24 hours before weighing. After emptying water from the barrels the volume of sediment left at the bottom was measured by counting the number of 1-liter cups, and fractions thereof, required to empty the barrel. A 400 ml sample of sediment was sun/air dried for 1-3 weeks (depending on the weather) and weighed to determine the dry weight. This same procedure of measuring the volume of sediment and drying a 400 ml sample was used to determine amount of sediment that deposited in the collector trough after each storm. All sediment is reported on a dry-weight basis. Total sediment is the sum of suspended, barrel, and trough deposited sediment.

Soil moisture measurements

Soil moisture was measured regularly (at 1-2 week intervals) with TDR soil moisture probes (Hydrosense 620, Campbell Scientific Inc.) and gravimetric field technique. Five to ten TDR measurements were taken with 12-cm long probes within three depth ranges (0-15, 15-30, and 30-45 cm) in random locations at the top half of each plot.

Measurements at 15-30 cm and 30-45 cm were taken by first digging small holes to 15 cm and 30 cm depths, respectively, before inserting the TDR probes. Readings from the probes were recalibrated for high clay soil type using results from gravimetric measurements taken concurrently at the same location. Linear regression was used to calibrate for each soil depth separately (0-15 cm, $r^2 = 0.70$, $P<0.001$; 15-30 cm, $r^2 = 0.50$, $P<0.001$; 30-45 cm, $r^2 = 0.41$, $P<0.001$) due to increasing interference of higher clay content with depth (see Table 2.1) on TDR measurements. Gravimetric measurements were taken regularly with 6.3 cm diameter x 5.7 cm height soil cores for each depth. Moist soil weight was measured immediately in the field. Samples were sun/air-dried for 1-3 weeks depending on climatic conditions before determining dry weight.

Grain yield and plant measurements

Grain yield was measured on two 2 x 2 meter quadrats for each kremt 2003 sorghum plot and two 3 x 3 meter quadrats for each belg 2004 chickpea plot. The kremt 2004 sorghum grain yield was measured on 2 x 2 meter quadrats in each subplot (total of $20m^2$ per main plot). All grain yields are for cleaned (ready for human consumption) grain adjusted to 12% moisture content.

For the kremt 2003 sorghum and belg 2004 chickpea experiments above-ground plant biomass and root mass were measured on six randomly selected plants distributed throughout each plot. During kremt 2004 above-ground biomass and root mass were measured for 3 randomly selected sorghum plants on each subplot giving a total of 15 plants per main plot. All plant and root samples were sun/air dried for at least 3 weeks before determining dry weight.

Statistical analysis

Analysis of Variance (ANOVA) to determine statistical significance of treatment effects was calculated using the General Linear Model (GLM) and F-test in MINITAB software (Minitab Inc., 2005). Treatment effects are considered to be statistically significant at P<0.05 and P<0.10 as indicated in the results. Significance of individual treatment differences is analyzed using Tukey's pair-wise comparison (at P<0.05 and P<0.10 as indicated in the results).

RESULTS AND DISCUSSION

Agro-climate

Rainfall amount and quality during the study period varied greatly between cropping seasons. Figure 2.3 shows on-site measured rainfall, mean temperature, and pan evaporation. Rainfall for each crop growth period from sowing to harvest totaled 422 mm for kremt 2003, 232 mm for belg 2004, and 418 mm for kremt 2004.

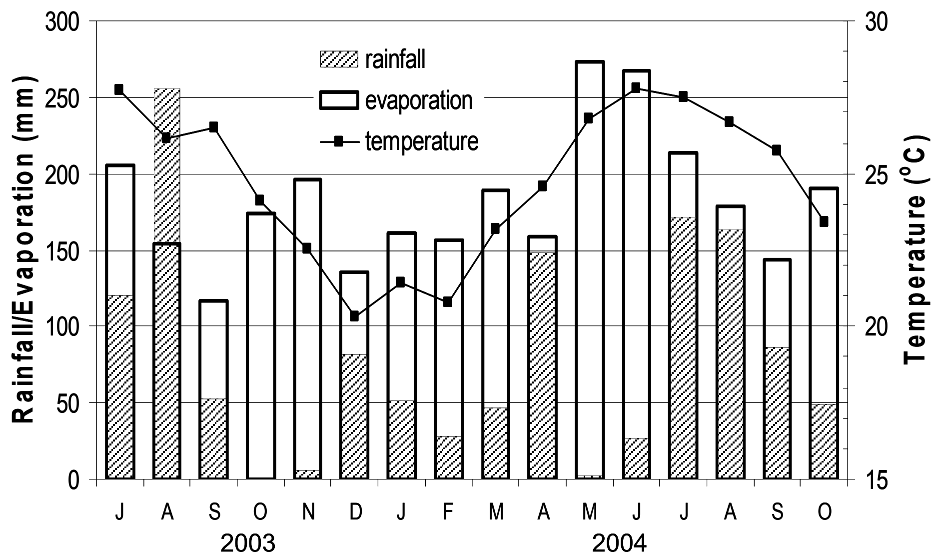


Figure 2.3. Monthly rainfall, pan evaporation, and mean temperature at experiment site during July 2003 to October 2004

Although the kremt 2003 and kremt 2004 seasons had similar rainfall totals their quality for crop production in terms of temporal distribution was remarkably different. During the kremt 2003 season 65 % (273 mm) of the total seasonal rainfall depth came during a 3 week period from the last day of July until the third week of August. The month of September 2003, which is a critical water requirement period for initiation of sorghum reproductive growth, only received 52 mm of rain and had an 11-day dry spell with no significant rainfall event (over 2 mm). The month of October 2003 during sorghum early grain-filling there was no rainfall while the period of November until sorghum harvest at the beginning of December received negligible rainfall. The poor temporal distribution of rainfall during kremt 2003 with periods of intense rainfall followed by lengthy dry spells contrasts with the kremt 2004 season which had similar total rainfall but no significant dry spell. As seen in Figure 2.3, during kremt 2004 the months of July, August, and September received better distributed proportions of the seasonal total rainfall compared with 2003 and in 2004 rainfall even extended into October (49 mm) providing critical water during the sorghum grain-filling stage. Rainfall events during kremt 2003 were generally stormy with short duration and high intensity while the kremt 2004 events were generally medium intensity long duration. Kremt 2003 had 8 events with I_{30} (30-minute maximum rainfall intensity) over 25 mm h^{-1} all occurring after sowing and with a maximum I_{30} of 93 mm h^{-1} compared with kremt 2004 which only had 3 events with I_{30} over 25 mm h^{-1} all occurring before sowing and with maximum I_{30} of 31 mm h^{-1}.

During belg 2004 rainfall was especially poorly distributed with essentially all precipitation coming during the period of mid-March until the end of April. There was a 37 day dry spell with no rain after sowing chickpea on February 11 and negligible (one event of 2 mm) rainfall during the 36 day period from the last week of April until the end of May which corresponded with the late grain-filling and maturity periods for the chickpea crop. Belg rainfall events were dominated by highly intense storms including 4 events with I_{30} (30-minute maximum rainfall intensity) over 25 mm h^{-1} all occurring over a month after sowing and with a maximum I_{30} of 75 mm h^{-1}.

Mean daily temperature varied between 20°C and 28°C during the 1.5-year period with maximum mean temperatures occurring during June and minimum mean during December (see Figure 2.3). Temperature and pan evaporation followed similar trends during the year. For all months, except August 2003, monthly pan evaporation exceeded precipitation. Pan evaporation rates are quite high with monthly means of 4 to 9 mm per day due to generally dry windy conditions, relatively hot temperatures, and many clear sunny days. The highest evaporation rates occurred during months/periods with no (or little) precipitation and dry land-surface conditions in the landscape surrounding the pan which probably resulted in pan evaporation greatly overestimating potential evaporation during those dry periods (Brutsaert and Parlange, 1998).

Surface runoff

Surface runoff from plots was significantly affected by tillage method, slope, and seasonal rainfall characteristics. Table 2.3 presents runoff during belg and kremt 2004 (the kremt 2003 runoff is not presented due to missing/poor quality data during several major storms early in the season which destabilized the collection system divisors). The block with the steepest slope of 9-11 % had significantly ($P < 0.05$) more runoff across tillage treatments with over 20 % of total seasonal rainfall lost (from field-scale perspective) to surface runoff compared with the 0-3 % and 4-8 % slope blocks generating less than 15 % rainfall runoff.

Table 2.3. Surface runoff during belg and kremt 2004[a] cropping seasons

Treatment	Surface Runoff (mm)				Seasonal Runoff Coefficient			
Slope	0-3%	4-8%[b]	9-11%	Mean**	0-3%	4-8%[b]	9-11%	Mean**
				Chickpea Belg 2004				
Maresha	35	32	55	41 A	0.15	0.14	0.24	0.18 A
Subsoiling	23	29	55	36 A	0.10	0.12	0.24	0.16 A
Tied ridge	6	33	36	25 A	0.02	0.14	0.16	0.11 A
Mean for slope class**	20 A	31 A	49 B	-	0.09 A	0.13 A	0.21 B	-
				Sorghum Kremt 2004				
Maresha	41	57	103	67 B	0.10	0.14	0.25	0.16 B
Subsoiling	25	63	99	62 B	0.06	0.15	0.24	0.15 B
Tied ridge	1	14	61	25 A	0.002	0.03	0.15	0.06 A
No till[c]	6	-	62	34 A	0.01	-	0.15	0.08 A
Mean for slope class**	18 A	45 B	81 C	-	0.04 A	0.11 B	0.20 C	-

[a] Kremt 2003 not presented because missing and poor quality data for several major storms that occurred early in the season; [b] Note conventional maresha tillage on 4 % slope while subsoiling and tied ridge are on 7 % slope gradient; [c] NT not measured during the season's first month (18-31 July 2004) which comprised about 5 % of total kremt 2004 runoff depth on the other treatment plots; Different letters are significantly different (Tukey's test) $^{*}P<0.10$, $^{**}P<0.05$

Among tillage treatments conventional tillage with maresha produced the most surface runoff volume followed by subsoiling, no till with stalk mulch, and tied ridge in that order. Subsoiling produced less (12 % less belg 2004 and 8 % less kremt 2004), but statistically similar runoff depth compared to conventional tillage with maresha. The effect of subsoiling on runoff was more significant on the 0-3 % slope during both seasons (see Table 2.3). At steeper slopes rainwater might not have enough residence time on the plot to take advantage of the deeper soil cutting which is the main feature of subsoil tillage.

During kremt 2004 tied ridge and no till with mulch produced less than half the runoff depth of conventional maresha tillage. Tied ridge and no till were particularly effective at capturing rainwater on the 0-3 % slope with over 98 % of seasonal rainwater captured in-field. In the case of the 4-8 % slope, tied ridge performed well (75 % less runoff than conventional tillage) during the less intense better temporally distributed rains of kremt 2004 season while during belg 2004 it performed similarly to conventional tillage due to numerous ridge breaks caused by intense rain storms and also because the tied ridge plot had a steeper slope (7 %) compared with the conventional tillage plot (4 %). During all seasons most ridges on the 9-11 % slope broke while on the 0-3 % slope there were no breaks for the tied ridges. All ridges wore down as the rainy season progressed resulting in progressively less efficient capture and storage of rainwater. During the 2003 kremt season final measured ridge height was on average 1.5 cm, belg 2004 season was 4 cm, and kremt 2004 season was 2.5 cm. The longer rainy period of the kremt rainy seasons (57 rainy days kremt 2003 and 48 rainy days kremt 2004 compared with 20 rainy days during belg 2004) with almost twice as much total seasonal rainfall and differences in the planted crops (kremt sorghum, belg chickpea) are possible reasons for greater ridge flattening during the kremt seasons.

Soil loss

Differences in seasonal rainfall characteristics greatly affected erosion rates (Table 2.4). The kremt 2003 season which had many high intensity storms at the beginning of August before crop establishment produced over twice the mean soil loss rate of any other season. The highly intense nature of belg 2004 rains resulted in similar seasonal soil loss as the kremt 2004 season which had less intense but almost twice as much total rainfall.

Slope gradient significantly influenced erosion rates and even more than it affected runoff rates. The 9-11 % slope class had a 17- to 89-fold increase in soil loss over the 0-3 % slope class but a less than 5-fold increase in surface runoff (Tables 2.3 and 2.4). During the rainy seasons we observed that on the 0-3 % slope no rills where apparent while at the steeper slopes and especially the 9-11 % slope all plots had at least one rill before the end of the cropping season. This suggests that the primary erosion mechanism at the 0-3 % slope was interill erosion while at the steeper slopes rill erosion combined with interill erosion to significantly increase soil loss rate. Also, the incidence of ridge failures was high on the steep slope class. After breaking, the concentrated flow of captured rainwater through the ridge gaps led to rill formation. Qualitative assessments of rills during the study period noted deep narrow rills on the open ridge plots, numerous microrills on the tied ridge plots, deep wide rills on conventional and subsoil plots, and shallow wide rills on the no till plots.

Tillage technique had a significant effect on soil loss rates but to a lesser degree than rainfall characteristics and slope gradient. No till produced the least sediment followed by tied ridge, conventional tillage, and subsoiling. The relatively small depth of

Table 2.4. Soil loss during each cropping season

Treatment	Total Sediment (Mg ha^{-1})				Suspended Sediment (Mg ha^{-1})			
Slope	0-3%	4-8%[a]	9-11%	Mean*	0-3%	4-8%[a]	9-11%	Mean*
				Sorghum Kremt 2003				
Maresha[b]	1.6	9.9	22.8	11.4 A	1.1	1.3	1.6	1.3 A
Subsoiling[b]	1.8	23.3	31.6	18.9 A	0.9	2.0	2.3	1.7 A
Tied ridge[b]	1.7	12.4	35.1	16.4 A	1.0	2.7	3.6	2.4 A
Mean for slope class**	1.7 A	15.2 B	29.8 C	-	1.0 A	2.0AB	2.5 B	-
				Chickpea Belg 2004				
Maresha	0.7	1.7	11.8	4.7 B	0.2	0.4	1.1	0.6 A
Subsoiling	0.7	6.2	13.3	6.7 B	0.2	0.3	1.4	0.6 A
Tied ridge	0.1	0.5	7.6	2.7 A	< 0.1	0.2	0.4	0.2 A
Mean for slope class**	0.5 A	2.8 B	10.9 B	-	0.1 A	0.3 B	1.0 B	-
				Sorghum Kremt 2004				
Maresha	0.2	0.6	13.3	4.7 A	0.1	0.2	1.4	0.6AB
Subsoiling	0.2	5.5	16.0	7.2 A	0.1	0.5	1.9	0.8 B
Tied ridge	< 0.1	<0.1	4.0	1.4 A	< 0.1	< 0.1	1.0	0.3 A
No till[c]	< 0.1	-	2.2	0.7 A	< 0.1	-	1.1	0.4AB
Mean for slope class**	0.1 A	2.1 B	8.9 B	-	0.05A	0.2 B	1.3 B	-

[a] Note conventional maresha tillage is on 4 % slope while subsoiling and tied ridge are on 7 % slope gradient; [b] Data missing for the season's first two major erosion events 7/31/03 and 8/1/03 which received 59 and 37 mm rainfall, respectively; [c] NT not measured during the season's first month (18–31 July 2004) which comprised about 7 % of total kremt 2004 soil loss on other treatment plots; Different letters significantly different (Tukey's test) *P<0.10, ** P<0.05

surface runoff, lack of significant disturbance to the soil surface, and increased weed cover effectively limited no till erosion rates. Tied ridges with its low runoff rates produced little soil loss during the season with less intense rainfall storms (kremt 2004), but drastically increased erosion (compared to conventional tillage) during the season with many high intensity storms (kremt 2003) particularly on the steeper slopes (Table 2.4). The high runoff rates combined with increased soil disturbance of conventional and subsoil tillage resulted in high seasonal soil loss rates (up to 32 Mg ha^{-1}) on the steeper slopes (> 9 %). On the gentle slope (0-3 %) both subsoiling and conventional tillage had similar low levels of soil loss (< 2 Mg ha^{-1}).

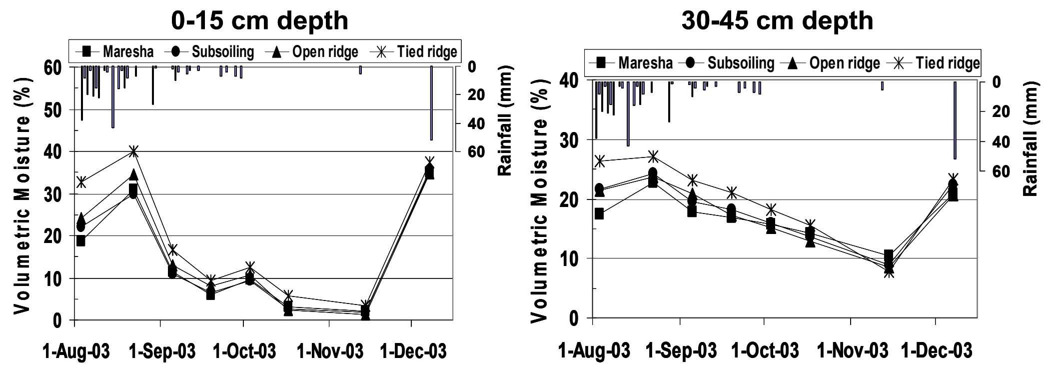
The sustainable maximum soil loss rate for the Ethiopian highlands ranges between 6 and 10 Mg ha^{-1}. The lower 6 Mg ha^{-1} is based on the annual soil formation rate for the climatic zone (semi-arid to dry subhumid or dry woina dega agroecological zone in Ethiopia) cited by Nyssen et al. (2004). The higher soil loss tolerance limit of 10 Mg ha^{-1} was applied by Mwendera and Saleem (1997) in their study of effect of cattle grazing pressure on soil loss. Given a sustainable maximum soil loss rate as 6-10 Mg ha^{-1} and the soil loss rates measured in this study, cropping on the steepest (9-11 %) slope class is not sustainable with any of the tested tillage methods (except possibly no till which was only tested for one season). Conversely, soil loss rates on 0-3 % slope were low (< 2 Mg ha^{-1}) for all tillage methods during all seasons. Taking into account that for the 4-8 % slope tied ridge was on a plot with 7 % slope like subsoiling but resulted in lower soil loss rates suggests that tied ridge could be sustainable up to a steeper slope limit than subsoiling on our soil type (Table 2.4).

Soil moisture for dry spell mitigation

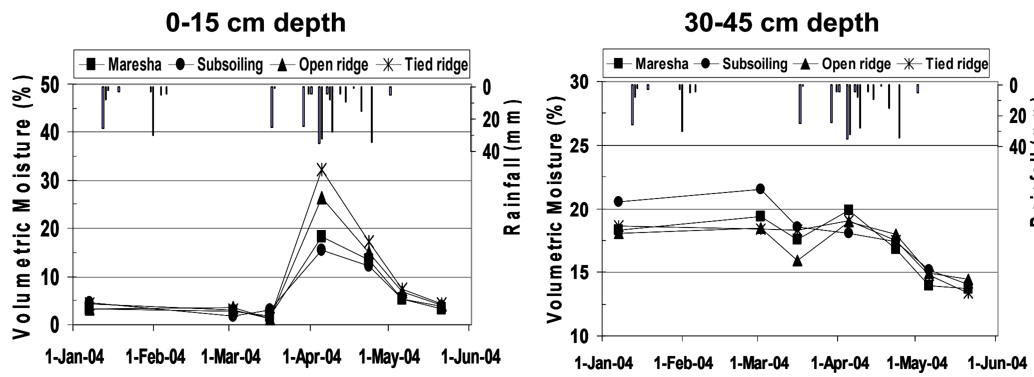
The amount of rainwater stored in the soil profile during the cropping season is important for plant growth (in rainfed agriculture) given the unreliable temporal distribution of rainfall observed at the study site. Effective tillage techniques capture rainwater and store sufficient moisture in the soil during rainy periods for continued plant uptake during dry periods. Figure 2.4 present soil moisture at 0-15 cm and 30-45 cm depths for each crop season. Overall trends show that the tied ridge plots had the best soil moisture within and across cropping seasons and at all depths. Tied ridge volumetric soil moisture was on average 24 % higher at 0-15 cm depth and 9 % higher at 30-45 cm depth compared to conventional tillage. However, effectiveness of ridges at capturing rainfall declined with steeper land slope and more intense seasonal rainfall events which broke many ridges reducing their efficiency to store rainwater.

Open ridges performed second best with higher seasonal soil moisture than subsoiling, no till, and conventional tillage. Open ridge soil water content averaged 15 % higher at 0-15 cm depth and 3 % higher at 30-45 cm depth than conventional tillage (Figure 2.4). An advantage of open ridge is that it required less labor to construct and was as effective as tied-ridge at capturing rainwater. As in the case of tied ridges, many open ridges broke on the plots with steeper slopes. However, ridge breaks for open ridges affected entire crop rows (in terms of rainwater storage) while breaks in tied ridges only affected the row interval between ties. Once breaks occurred in open ridges rainwater captured between ridges produced localized runoff through the break opening which then caused more ridge breaks downslope. Ridge breaks caused by intense storms is the reason for relatively less effectiveness of open ridge on soil moisture during kremt 2003 (Figure 2.4a) and belg 2004 (Figure 2.4b) compared with kremt 2004 (Figure 2.4c). An observed shortcoming of planting on ridges was their dryness at the beginning of the season which delayed seed germination and retarded

(a) Kremt 2003



(b) Belg 2004



(c) Kremt 2004

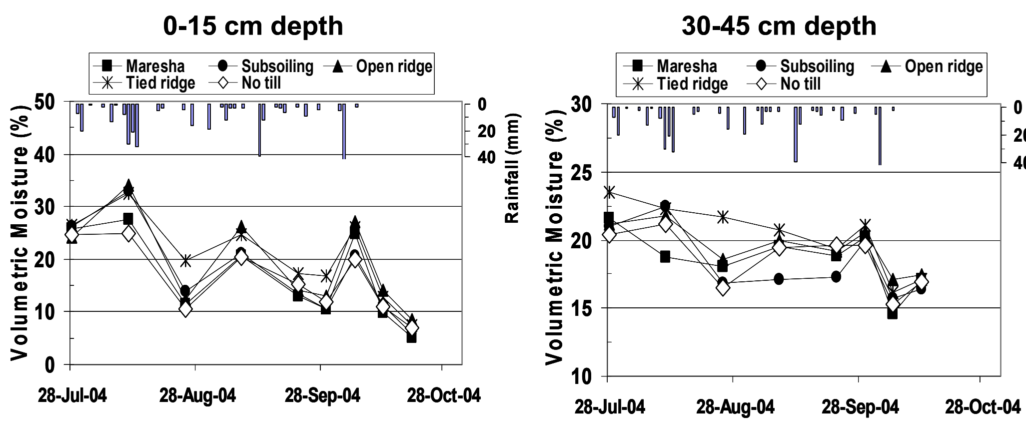


Figure 2.4. Soil moisture (lines) and daily rainfall (hanging bars) during (a) kremt 2003, b) belg 2004, and (c) kremt 2004

early plant growth (plant growth discussed in next section). Figure 2.5 shows how ridge moisture was significantly and consistently lower (51% less on average) than in the furrow/flat bed.

Subsoiling slightly increased (3 % overall) soil moisture compared with conventional tillage but not consistently for all seasons and soil depths. Any additional moisture during dry periods is important for plant growth especially during reproductive growth and grain-filling. During kremt 2003 and belg 2004 subsoiling and conventional maresha tillage had similar 0-15 cm surface soil moisture, but subsoiling had better soil moisture at 30-45 cm depth (Figure 2.4a,b) which is important for longer-term water storage. Rainfall distribution during kremt 2004 resulted in better (compared to kremt 2003 and belg 2004) soil moisture for all tillage methods (see Figure 2.4c).

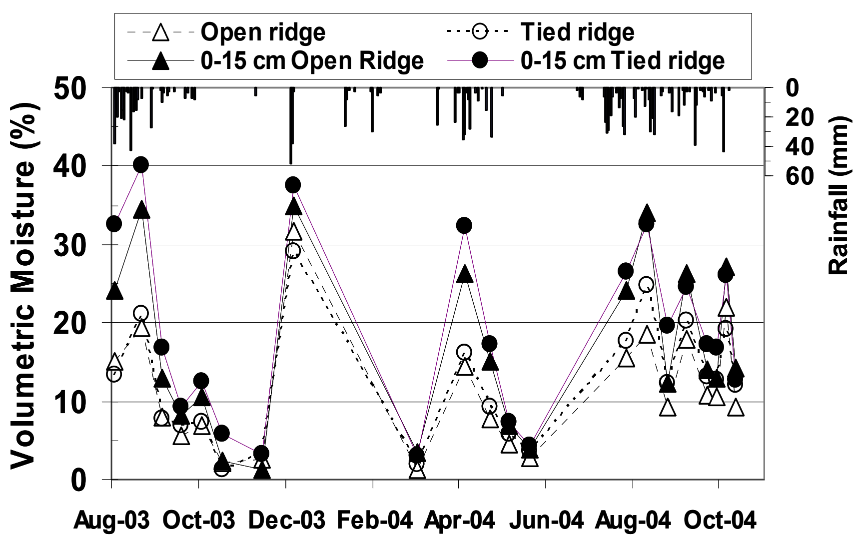


Figure 2.5. Soil moisture at 0-15 cm depth on top of ridges (open symbols) and in the adjacent furrows (closed symbols) and daily rainfall (hanging bars) during all cropping seasons (2003-2004)

No till with stalk mulching was only tested during the kremt 2004 cropping season. Figure 2.4c shows that surface moisture for no till was similar to that of conventional maresha tillage. Additional tests during cropping seasons with more intense rainfall and with longer no till periods (i.e. to permit natural processes of soil quality/structure improvement to occur) are needed to better determine effect of no till on soil moisture in the northern Ethiopian highlands dryland cropping systems.

Grain yield and plant growth

Sorghum grain yield responded significantly to land preparation tillage method during both 2003 and 2004 kremt seasons, but for the chickpea crop of belg 2004 tillage treatments did not produce statistically significant yield differences (Table 2.5). Among the tested land preparation methods subsoiling, tied ridges, and open ridges increased sorghum grain yield while no till reduced yield.

Table 2.5. Effect of tillage technique on grain yield and plant density

Treatment	Grain Yield (kg ha^{-1})			Plant Density (pl m^{-2})		
Season	Sorghum* Kremt'03	Chickpea Belg'04	Sorghum** Kremt'04	Sorghum Kremt'03	Chickpea Belg'04	Sorghum Kremt'04
Maresha	1430 A	200 A	730 A	7.8 A	17.2 A	7.0 A
Subsoiling	2030 B	320 A	970 B	8.4 A	16.8 A	6.2 A
Open Ridges	1470 A	240 A	1220 B	8.6 A	18.8 A	6.4 A
Tied Ridges	1530AB	280 A	1260 B	6.8 A	20.4 A	7.2 A
No Till	-	-	550 A	-	-	7.0 A

Different letters are significantly different (Tukey's test) * $P<0.10$, ** $P<0.05$

Subsoiling significantly increased grain yield by 42 % during kremt 2003 and 33 % during kremt 2004 compared to conventional tillage with maresha. In the cases of kremt 2003 and belg 2004, subsoiling produced the best grain yield among the tested tillage methods while tied and open ridge performed better during kremt 2004 (see Table 2.5). The improved grain yield of subsoiling is probably due to combined effects of slightly improved soil moisture and better root growth than conventional tillage. Table 2.6 presents plant root mass and total above-ground biomass. Root mass for subsoiling was higher than for conventional tillage during kremt 2003 and belg 2004 and lower during kremt 2004. Measurement of maximum principal roots depth during kremt 2004 found a mean depth of 27.3 (± 1.2 S.D.) cm for subsoiling, 22.1 (± 6.1) cm for conventional tillage with maresha, and 20.0 (± 1.0) cm for no till, (P = 0.15). This suggests that although root mass for kremt 2004 was lower in subsoiled plots the root depth was longer improving access to water and nutrients from a deeper soil volume which resulted in better yield and biomass than conventional tillage and no till.

Table 2.6. Root mass and above-ground biomass at harvest

Treatment	Root Mass (g m^{-2})			AG Biomass (g m^{-2})		
Season	Sorghum Kremt'03	Chickpea Belg'04	Sorghum** Kremt'04	Sorghum Kremt'03	Chickpea Belg'04	Sorghum** Kremt'04
Maresha	66.4 A	6.60 A	24.2 A	663 A	88 A	364 A
Subsoiling	86.5 A	7.15 A	22.2 A	758 A	110 A	380 A
Open Ridges	81.8 A	6.77 A	33.6 B	732 A	97 A	515 B
Tied Ridges	94.9 A	7.23 A	31.4 B	821 A	109 A	565 B
No Till	-	-	18.0 A	-	-	306 A

Different letters are significantly different (Tukey's test) * $P<0.10$, ** $P<0.05$

The potential benefit of ridging to improve grain yield (open ridges 67 % increase, tied ridge 73 % increase) was very apparent during the sorghum 2004 season. The seasonal difference in ridge performance (see Table 2.5) in the case of kremt 2003 and kremt 2004 is probably due to difference in rainfall intensity while poor performance during belg 2004 was associated with both the high intensity of storms and the long dry spell early in the growing season. Highly intense storms during kremt 2003 broke unprotected (i.e. little crop cover) unconsolidated ridges resulting in washing away of seeds, exposure/uncovering of young plant roots on ridges, and loss of plants at the ridge break gaps. The many sorghum plants that survived had retarded early growth due to lodging and difficulties with root and plant establishment. In terms of plants lost, tied ridge was more impacted due to numerous ridge breaks between ties compared with open ridge which generally had only one or two breaks in the entire row. As seen in Table 2.5, this resulted in 21 % less plant density for tied ridges compared with open ridges and 13 % less than on plots with conventional tillage (2003). Seed and young plant losses were partially compensated for by plant number adjustments made on all plots during plant thinning which is a common local practice. During kremt 2003 significantly lower soil moisture in ridges compared to flatbeds (see Figure 2.5) retarded early sorghum plant growth (27-days after sowing mean plant biomass was 3.9 g m^{-2} tied ridges, 4.9 g m^{-2} open ridges, 6.7 g m^{-2} conventional tillage, 7.1 g m^{-2} subsoiling; $P<0.05$), but as the season progressed and plant roots advanced deeper into the soil the ridge dryness effect became insignificant resulting in higher plant biomass at harvest on ridge tillage plots (Table 2.6).

During belg 2004 a major reason for poor performance of all and especially open and tied ridge treatments was the long dry spell early in the growing season. The increased working (displacement and turning over) of surface soil associated with ridging during land preparation resulted in increased evaporation losses of pre-tillage residual soil moisture. As seen in Figure 2.5, ridges (where chickpea seed was sown) were excessively dry during the first month after sowing which resulted in poor germination rates.

No till with stalk mulching produced the least grain of all tillage treatments (Table 2.5). The hard clay soil in no till plots resulted in poor root growth (Table 2.6) and plant establishment (i.e. lodging) which, in addition to the increased weed infestation, explain the poor grain and biomass production. It is of interest to mention that no till plots had the first and best germination rate (about 2 days earlier) of all treatments possibly due to the initially better surface moisture than the tilled plots which inverted dry surface soil and exposed subsoil to drying by the sun and wind.

Sorghum responded well to nitrogen additions. Table 2.7 presents grain yield for the nutrient subtreatments during the 2004 sorghum experiment. Addition of 20.5 kg ha^{-1} nitrogen as urea significantly increased grain yield by 62%. However, addition of 46 kg ha^{-1} phosphorous as DAP together with 20.5 kg ha^{-1} nitrogen resulting in less yield increase than only the urea (N) application and did not produce a statistically significant difference in yield compared with no nutrient addition. The addition of 5 Mg ha^{-1} animal manure in addition to 46 kg ha^{-1} phosphorous and 20.5 kg ha^{-1} nitrogen as chemical fertilizer resulted in a slight (7 %), but statistically significant ($P<0.05$), increase in yield compared with similar fertilizer application rate without manure (Table 2.7). The best grain yield increase of 109 % was obtained with 41 kg ha^{-1} nitrogen and 46 kg ha^{-1} phosphorous. This gain is likely more due to the high N application rather than the P component given the statistically insignificant yield increase (compared with no nutrient addition) obtained with the same P application but at lower N rate (20.5 kg ha^{-1}). Grain yield responses to nutrient additions overall suggest that N is the most limiting nutrient and that grain yield can easily double with application of the current local Sirinka Agricultural Research Center recommended dose of 41 kg ha^{-1} nitrogen and 46 kg ha^{-1} phosphorous for North Wello and the particular variety of improved sorghum used here. Further nutrient studies are needed to determine optimum doses of N and P fertilizer application and the longer term soil health benefits of manure application.

Table 2.7. Nutrient additions and sorghum grain yield (kg ha^{-1}) during kremt 2004

Treatment[a]	No Nutrient Additions	Urea ($N_{20.5}$)	DAP + Urea ($N_{20.5}$ P_{46})	DAP + Urea ($N_{20.5}$ P_{46}) + Manure (5 Mg ha^{-1})	DAP + Urea (N_{41} P_{46})
Maresha	430	670	520	670	920
Subsoiling	710	880	900	1000	1380
Open Ridges	570	1290	1280	960	1240
Tied Ridges	820	1310	1000	1210	1750
No Till	220	270	460	660	460
Overall Mean	550 A	890 B*	840 A	900 B**	1150 B**

[a] N and P additions are expressed in kg ha^{-1}; Different letters are significantly different (Tukey's test) * $P<0.10$, ** $P<0.05$

Although there was no statistically significant interaction between land preparation method and nutrient addition on grain yield the best mean yield of 1.75 Mg ha^{-1}, which is a four-fold increase over the 0.43 Mg ha^{-1} obtained from conventional maresha tillage with no nutrient addition, was produced by combining tied ridge and fertilizer application (Table 2.7). No till demonstrated the least response to the surface applied fertilizer nutrient additions compared to other treatments which incorporated the nutrient applications during tillage. Sorghum yield could have been higher during kremt 2004 for all treatments, but conditions of long duration light rains resulted in high yield losses by pests (especially stalk borer) and disease.

Slope gradient had a significant effect on grain yield across all tillage methods and for all seasons (Table 2.8). Grain yield decreased as plot slope increased for both sorghum seasons while chickpea yield increased with slope gradient. The decreased sorghum yield with steeper slopes is in part explained by less soil moisture associated with increased runoff and poorer performance of conservation tillage for steeper slopes and the high erosion rates (with consequent soil quality differences). The reason for low chickpea yield on the 0-3 % slope was fungus attack during the second half of the

Table 2.8. Slope gradient effect on grain yield (kg ha^{-1})

Treatment	Sorghum Kremt'03**			Chickpea Belg'04*			Sorghum Kremt'04**		
Slope	0-3%	4-8%	9-11%	0-3%	4-8%	9-11%	0-3%	4-8%	9-11%
Maresha	1410	1540	1350	140	210	310	830	830	430
Subsoiling	2400	1990	1700	290	310	380	1100	940	810
Open Ridges	1600	1830	0990	80	260	390	1900	890	680
Tied Ridges	1960	1470	1150	210	400	220	1510	1160	1020
No Till	-	-	-	-	-	-	860	460	140
Overall Mean	1840B	1710A	1300A	190A	300B	320B	1240C	880B	620A

Different letters are significantly different (Tukey's test) * P<0.10, ** P<0.05

growing season only affecting that block. This resulted in plant losses, pods with few and smaller seeds, and decreased plant density especially for the subsoiled plot (see Table 2.5). A possible reason for fungus attack on only the 0-3 % block could be that the generally better soil moisture status measured there created more favorable conditions for fungus growth. There were no statistically significant grain yield response interactions between slope and tillage method or between slope and nutrient additions.

LOCAL FARMER INSIGHTS

Comments and insights of 12 local farmers who tested the conservation tillage treatments and 28 others who visited the experiment site were sought and recorded to determine prospects and issues for wider-scale adoption and adaptation of conservation tillage methods. All the farmers were interested in testing the subsoiling while none were interested in testing the ridge tillage or no till. Discussions with farmers revealed their unwillingness to test ridge tillage was the much higher labor requirements of an additional tillage for ridge formation, manual planting along ridges, and, in the case of tied ridges, manual construction of cross-ties. Conventionally sorghum and chickpea seed are sown by broadcasting before final tillage with the maresha plow during land preparation. This requires little labor compared with manual planting along rows as for ridges. In the case of subsoiling (flatbed), the conventional practice of broadcast sowing can just as easily be applied. The farmers expressed concern for the weight of the subsoiler putting extra strain on the plow operator and the oxen (new lighter models are under development). Subsoiling is more demanding on oxen resulting in approximately 1/4 to 1/3 less area plowed per day (as observed in our experiments and by farmers) and the need of healthy strong oxen. For the case of no till, farmers strongly doubted that better grain yields can be obtained without tillage and were concerned about the manual labor for the more frequent weeding required without use of expensive/unavailable herbicide. The extra labor to bury seeds in shallow strips to prevent washing away was also of concern. The prospects for applying mulch is complex within the current farming system that has open field livestock foraging during the off-seasons and competing demands of crop residues for firewood, construction materials, and livestock feed.

Additional studies are required to compare the local farmer practice of “shilshalo” (local name) in which small furrows are created with the maresha plow during the second weeding operation to the tested ridging practice in which small ridges are constructed at the beginning of the season before sowing. An advantage of shilshalo will likely be less early season moisture stress and less plant loss and damage than were observed with the ridging/planting practice in the present study. We did not implement shilshalo because oxen could not plow after planting without disturbing adjacent plots.

CONCLUSION

Results of on-farm experiments during three cropping seasons demonstrate that conservation tillage can be beneficial for improving soil moisture, raising grain yields, and reducing runoff and soil loss in the northern Ethiopian highlands. However, performance varied greatly depending on seasonal rainfall intensity and temporal distribution and land slope gradient. Overall tied ridge tillage was the most effective at improving rainfall partitioning (i.e. less runoff loss from fields) and root zone soil moisture for dry spell mitigation and at reducing soil loss. However, the relatively small ridges created using the oxen-drawn ridger worked better for smaller than 8 % slopes limiting their applicability to mainly footslopes, valley bottoms, and plains. Open and tied ridge on steeper slopes resulted in significant soil loss, rill formation, plant damage with ridge breaks, and reduced rainwater capture and storage efficiency. Also, planting on the ridge resulted in decreased chickpea yield due to excessive ridge dryness during a belg 2004 early season dry spell.

Subsoiling was moderately effective for improving sorghum yield and soil moisture and for reducing runoff. However, our results suggest that increased soil disturbance associated with subsoiling can result in severe erosion rates on steep slopes. Subsoiling performed best slopes on less than 8 % under the soil conditions in this study and performed better in terms of grain yield than ridges when early season rainfall was very intense (ridge damaging). The potential benefits of subsoiling in other areas of Ethiopia might differ depending on the presence and extent of a plow pan.

No till with stalk mulching reduced soil loss, but also decreased grain yield substantially over one season.

Application of fertilizers, especially nitrogen, in combination with conservation tillage (tied and open ridges and subsoiling) resulted in an over three-fold increase in grain yield compared with conventional practice of maresha tillage and no nutrient addition. This finding underscores the importance of applying an integrated rainwater management and soil nutrient improvement program to address poor rainfed grain yields in northern Ethiopia.

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CHAPTER THREE

HYDROLOGIC AND EROSIONAL RESPONSE TO NATURAL RAINFALL AND EFFECTS OF CONSERVATION AND REHABILITATION MEASURES IN A DRY SUB-HUMID WATERSHED OF THE ETHIOPIAN HIGHLANDS*

ABSTRACT

A good understanding of runoff and erosion under actual field conditions at different scales is essential for effective land conservation and water resources planning in the Ethiopian highlands. Hydrologic and sediment yield response to natural rainfall was measured during three rainy seasons at plot (150-510m^2) and catchment (180-351ha) scales with and without conservation practices. Results show that runoff generation and erosion rates were significantly influenced by rainfall intensity, land cover, land slope gradient, scale of measurement, and the presence of conservation measures. Most runoff and erosion occurred during few large intense storms in particular seasons. A wide range in measured high infiltration rates indicated that runoff was generated on patches within plots. The potential of conservation measures to enhance water retention in the watershed was greater on valley cropland than hillside rangeland which generated under half the seasonal runoff and sediment yield despite situation on much steeper slopes. Effectiveness of cropland conservation ridging, subsoiling, and no till practices and rangeland conservation practice of tree regeneration and protection varied with intensity of storms during the season and land slope gradient. Plot measured storm runoff consistently exceeded catchment streamflow discharge demonstrating a scale effect. Land rehabilitation using gully checkdams, area closure

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* McHugh, OV, T.S. Steenhuis, B.M. Liu, Y. Abebe. Hydrologic and erosional response to natural rainfall and effects of conservation and rehabilitation measures in a dry sub-humid watershed of the Ethiopian highlands

from livestock, and terracing resulted in reduced catchment peak streamflow discharge and longer duration streamflow compared to a catchment in the same watershed without these measures.

INTRODUCTION

Extensive soil erosion by water and seasonal soil moisture deficit for crop production are priority concerns for numerous agricultural communities living in the semi-arid and sub-humid Ethiopian highlands. Periods of infrequent highly intense rainfall followed by short intra-seasonal dry spell create a common problem of excess rainwater surface runoff eroding and flooding land one day and a couple weeks later in the same catchment rainfed crops showing signs of moisture stress due to soil dryness. In addition to the onsite effects of erosion reducing land productivity (Haileslassie et al., 2005; Sonneveld and Keyzer, 2003; Tekle, 1999) offsite impacts of high sedimentation rates reducing storage capacity of micro-dams and reservoirs hinder efforts to provide efficient long-term water resources (Haregeweyn et al., 2005; McCornick et al., 2003). Appropriate land conservation measures can be effective to control soil erosion and improve soil moisture for crops and ecosystems. Improved understanding of hydrologic and erosional response to natural rainfall under different Ethiopian highland field conditions is essential for effective land conservation and water resources development and management planning.

Runoff and erosion in the Ethiopian highlands are highly variable depending on land use, topography, rainfall characteristics, land management, and soil properties (SCRP, 2000; Nyssen et al., 2004a). The influence of each of these factors at any given location is often hard to predict mainly due to data scarcity (Legesse et al., 2003).

Some commonly accepted mean estimated soil loss rates are 42 t ha^{-1} $year^{-1}$ for cropland, 5 t ha^{-1} $year^{-1}$ for grazing rangeland, and 5 t ha^{-1} $year^{-1}$ for wooded/bush rangeland (Nyssen et al., 2004a). The common catchment sediment yield used for water resources design in northern Ethiopia is 800 to 1200 t km^{-2} $year^{-1}$, but Haregeweyn et al. (2005) found a larger range of 487 to 1817 t km^{-2} $year^{-1}$ for catchments in Tigray region. That study also found that among nine variables (climate, soils, geology, land use, topography, etc.) that affect erosion, specific sediment yield for 400 reservoirs was most highly correlated ($r^2 = 0.65$) with channel (gully) erosion. These findings reveal that relative importance of erosion and runoff in different parts of the landscape varies with scale of interest and particular land and water use. Given the highly dissected landscape and the high rates of measured/estimated soil loss in many parts of the Ethiopian highlands, it is sometimes assumed that there are excessive runoff rates and therefore ample opportunities for rainwater harvesting with appropriate measures. The wide variation in observed runoff and soil loss in different studies indicates the need for measurement under as many different field conditions and scales as possible to provide detailed information for conservation and water resources planning (Hurni et al., 2005; Nyssen et al., 2004a; McCornick et al., 2003).

Sonneveld and Keyzer (2003) determined based on model predictions that soil erosion control through land conservation measures is an indispensable element of long-term regional development policy for Ethiopia to achieve national food security and raise rural income. Soil and water conservation measures have been widely implemented in the Ethiopian highlands (Nyssen et al., 2004a). Many of the common conservation measures such as soil and stone bunds, fanya juu, grass strips, double ditches, and controlled grazing have been found generally effective (but sometimes with negative side effects such as yield reduction per total land area) at reducing soil loss and surface runoff losses at the plot scale (SCRP, 2000; Herweg and Ludi, 1999; Mwendera and Mohamed Saleem, 1997). In addition to the community implemented conservation measures, farmer conservation tillage methods such as reduced or zero tillage, tied ridges, and subsoiling, which have been found effective at improving infiltration and grain yield and reducing runoff and soil loss under particular conditions (Motsi et al., 2004; Wiyo et al., 2000; Twomlow and Bruneau, 2000; Pagliai et al., 2004; Salih et al., 1998; Xu and Mermoud, 2003; Rockstrom et al., 2002), are currently being adapted and tested in the northern Ethiopian highlands with mixed (context dependent) results and overall generally low farmer adoption rates (Astatke et al., 2003; Brhane et al. 2006; Temesgen, 2000; BoA/GTZ IFSP, 2004).

While most past studies on impacts of conservation measures in the Ethiopian highlands have focused either on measurements at plot scale for single land use or at stream outlets for catchment scale, or on theoretical modeling approaches for basins, the current field study utilized an integrated watershed approach that examined soil infiltration rates, runoff generation, and soil loss for different land cover types and conservation practices at both plot and catchment scales all within the same watershed in North Wello, eastern Amhara State.

MATERIALS AND METHODS

Study area

Field measurements were collected during three rainy seasons (2003-04) at two experimental plot sites and two catchments within the Lenche Dima watershed (15.5 km^2) in eastern Amhara State, Ethiopia (Figure 3.1). Lenche Dima watershed is in a densely populated (218 persons per km^2) rural area located at N $11^o49.2'$-$11^o52.1'$ and

E 39°41.3'- 39°44.6' and is in the dry subhumid warm temperate highlands (1465-1900 m above sea level). The mean annual precipitation (1975-81 and 2003-04) is 849 mm. Rainfall distribution is bimodal with a small rainy season called belg (mean 208 mm*)* during March to May and main rainy season called kremt (mean 483 mm) during July to September. A mean 158 mm of rainfall comes during all other months.

(a) Ethiopia (b) Lenche Dima watershed

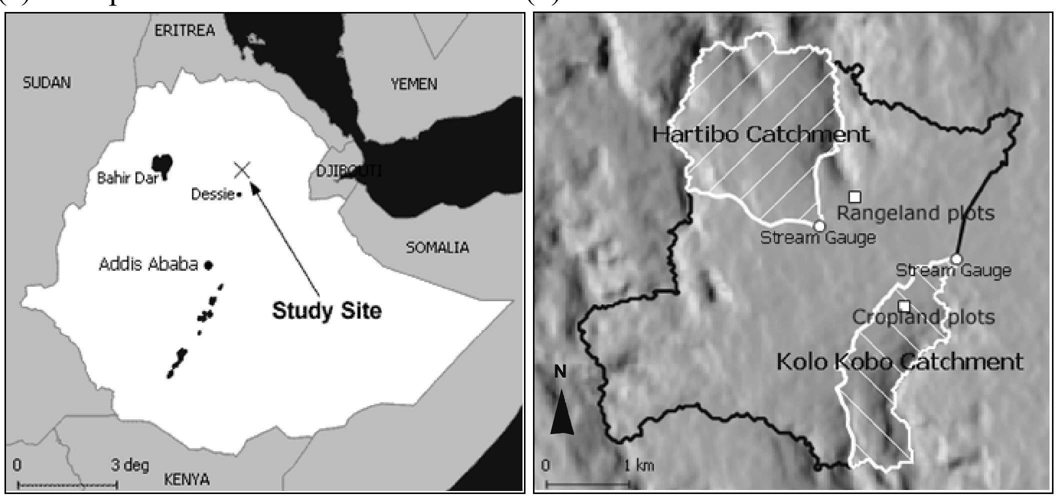

Figure 3.1. Location maps of (a) study site in Ethiopia and (b) runoff plots and gauged catchments in Lenche Dima watershed

Major soil types in the catchments of Lenche Dima watershed vary with topography. Distribution of soils is Regosols and Leptosols on the steep hills and mountains (33 % of total watershed area), Regosols on the upper footslopes (6 %), vertic Luvisols at the lower footslopes (18 %), Vertisols at the valley bottom cultivated areas (35 %), and Fluvisols in the plain areas that receive alluvial sediments (8 %) (Gizaw et al., 1999). The geology of the Lenche Dima watershed area, which is located in the marginal graben of the northeast Ethiopian plateau escarpment in the Afar depression, is comprised of varieties of trap series rocks from weathered basalt, graben fill quaternary sediments, and valley-floor later granite intrusions of probably tertiary age (Gizaw et al., 1999).

Land cover in the watershed includes over 58 % intensively cultivated cropland area located mainly in the central valley bottoms, 29 % grass and shrub rangeland and 5 % bush rangeland on the surrounding steep hillslopes, less than 1 % forest/woodland area scattered in small patches, and over 5 % settlement area (land cover based on 1986 aerial photo interpretation in Gizaw et al., 1999). Major crops are sorghum, teff, chickpea, and maize. Rangeland shrubs and trees are mostly *Acacia* spp., *Dodonia anguistifolia*, *Euclea schimperi*, and small patches of eucalypti plantations.

Experimental design and setup

Runoff was measured at the plot and catchment scales within Lenche Dima watershed. Runoff plots were setup on cropland and rangeland with and without conservation/rehabilitation measures. Soil type at the experimental plots was vertic Luvisol for the cropland and Regosol for the rangeland (see soil properties in Table 3.1). Paired catchments, one with many and the other few conservation measures, were selected for stream discharge measurements. Plot sites and catchments were selected to represent typical conditions of Lenche Dima watershed and the surrounding areas.

Cropland plots

Cropland runoff plots were constructed on a farmer's field in the southeastern quadrant of the Lenche Dima watershed (Figure 3.1). Runoff experiments were setup as randomized block design with three replications (except no till which only had two replications). Table 3.2 summarizes the plot setup and treatments. Plots were 30 m long and 5-6 m wide and were hydrologically separated by compacted soil bunds (0.5 m width, 0.3 m height) on the upper and side boundaries. Blocks consisted of contour strips along a toposequence of decreasing slope downhill (concave profile) on one farmer's field (~ 0.75 ha). Plot slopes were 9-11% for the top block 1, 3-8% for the middle block, and 0-3 % for the bottom block. Unlike the top and bottom blocks which had similar mean slopes across plots within the same block, in the middle block the treatments were on plots with considerably different slopes (mean slopes were conventional tillage 4 %, subsoiling 7 %, tied-ridge 8 %, no till 6 %; treatments are described in the next paragraph). During kremt 2003 and kremt 2004 sorghum (*Sorghum bicolor*) was planted while a desi-type chickpea (*Cicer arietinum*) was planted during belg 2004 (all crops were planted in 0.5 m-spaced contour rows).

Table 3.1. Soil characteristics at the plot sites in Lenche Dima watershed

Land cover	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density (Mg m^{-3})	Organic C[a] (%)
Cropland	0-30	48	25	27	Loam	1.57 ± 0.2	1.1
	30-45	41	29	30	Clay loam	1.56 ± 0.1	1.1
Shrub	0-30	68	9	23	Sandy loam	1.75 ± 0.2	1.0
rangeland	30-45	48	23	29	Loam	1.74 ± 0.2	1.3
Open Forest	0-30	47	23	30	Loam	1.59 ± 0.2	3.1
rangeland	30-45	39	27	34	Loam	1.72 ± 0.2	1.8

[a] Organic carbon

Table 3.2. Plot features and setup

Land unit	Treat-ment	Bl I[a] slope (%)	Bl II[a] slope (%)	Bl III[a] slope (%)	Width x length (m)	Land cover/management
Crop-land	M	2.2	3.9	9.5	6 x 30	Conventional maresha tillage
	SS	1.9	6.6	9.8	6 x 30	Subsoiling tillage
	TR	2.8	7.7	9.9	6 x 30	Tied ridge tillage
	NT[b]	2.2	-	9.8	5 x 30	No tillage
Range-land	SB	34.2	-	-	17 x 30	Shrubs, bushes (5% cover), grass, weeds, cactus and bare patches (footpaths)
	OF	34.8	-	-	17 x 30	Trees (62 % cover), grass, cactus and bare patches (footpaths)

[a] Mean plot slope within block (Bl); [b] NT only measured during kremt 2004 rainy season

Three land preparation techniques were tested during kremt 2003 and belg 2004 and a fourth treatment of no till was added during kremt 2004. The treatments were conventional maresha tillage (M) which is the control, subsoiling (SS), tied ridges (TR), and no till (NT) with 2.5 Mg ha^{-1} sorghum stalk mulching. The conventional tillage plots were plowed (to 10-13 cm depth in this study) with the Ethiopian traditional single-tined maresha plow (local name in Amharic; described in Nyssen et al., 2000). The subsoiling plots were plowed with the oxen-drawn subsoil cultivator named “Tenkara Kend” (means “strong arm” in Amharic) developed by GTZ in Debre

Tabor, Ethiopia. The subsoiler mixes the soil to the same depth as the maresha plow however the subsoiler has a flat blade extension that cut the soil an additional 6-8 cm below the maresha plow depth. In this study the subsoiler cut the soil at 0.3-0.5 m intervals (similar to conventional maresha tillage) along the slope contour. Tied ridges were constructed with an oxen-drawn ridger implement which is easily attached to the traditional maresha plow (described by Temesgen, 2000). The ridges were spaced 0.5 m apart. Plowing each row twice resulted in fairly small ridges with ridge height of 10-15 cm and average ridge width of 0.27 m. Cross ties of 8-12 cm height and at 1-2 m intervals were manually created with traditional hoes. On the no till plots no tillage operation had been performed since land preparation with maresha plow for the previous season's chickpea crop (5.5 months). Narrow lines about 3 cm deep were manually scraped/dug to sow seeds in the no till plots. A surface mulch of dry sorghum stalk 2.5 Mg ha^{-1} stored on another field from the previous kremt season was applied one day after sowing on the no till plots only. The stalks were aligned along the slope contour.

All plots (except no till) were plowed twice during the dry off-seasons (this is the conventional farm management practice in the area) using the conventional maresha plow. The first tillage was along the slope contour 2-5 weeks after the previous crop harvest. The second tillage was along the slope after the first rain events of the upcoming cropping season softened the hard dry soil sufficiently for plowing. The final (third) tillage performed the day before sowing with the appropriate implement (maresha, subsoiler, ridger) for each treatment was along the slope contour.

Rangeland plots

Two runoff plots were constructed about 100 m apart on the same hillside at the northern side of Lenche Dima watershed (Figure 3.1). Plots were 30 m long and 17 m wide (510 m^2). The plots were enclosed by stone-enforced compacted 0.5 m wide and 0.3 m high soil bunds on the upper and two side boundaries. A cutoff trench was constructed 5 m above each plot to intercept and redirect run-on water descending from the upper hillside. In addition 0.5 m wide and 0.1 deep trenches were constructed outside the upper and side bund boundaries to further assure no surface water flows entered the plots. Both plots were on 34-35 % average slope and had similar soil types but with higher surface sand content at the shrub rangeland (see Table 3.1).

One hillside plot was a conventional shrub (SB) and grass rangeland containing acacia shrubs, pear cactus, grass, weeds, and some bare soil/footpaths. The other plot was an open forest (OF) (61 % canopy cover) rangeland containing medium size acacia trees, grass, weeds, pear cactus, and some bare soil/footpaths. Both plots were open to similar daily moderate livestock grazing (cattle, goats, donkeys, and few camels) during the studies. The open forest rangeland used to be a shrub rangeland but after over 20 years of protection from tree and bush cutting by the adjacent Oromo village community natural regeneration has resulted in an open forest cover (according to elders in the adjacent Oromo village). It is one of the few natural forest patches in the watershed.

Catchments

Stream discharge was monitored during kremt 2004 for Hartibo and Kolo Kobo catchments within the Lenche Dima watershed. Both catchments contain land cover and topography typical of watersheds in the region with rangelands on the hillslopes, village settlements on the mid-slopes, and cropland on footslopes and the valley bottom. Table 3.3 presents characteristics of the catchments. A combination of field observations and computer terrain analyses were used to delineate catchment boundaries based on stream outflow monitoring points. Ground control points taken with a Garmin GPS72 were used to georeference ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite images acquired in 2003, from which a digital elevation map and false color image were derived. The Terraflow flow routing model (Arge et al., 2003) in GRASS GIS was used on the elevation map to find natural watershed boundaries, then modified by field observations taken with GPS. Analysis and classification of surface area, elevation, and slope gradient (presented in Table 3.3) were performed in Manifold GIS.

The ‘control’ Hartibo catchment is 351 ha and is located in the northwestern corner of the watershed (Figure 3.1). There were few conservation works in Hartibo (less than 5 % of the catchment area) during the study period. About 10 % of hillside areas had bench terraces installed and some tree seedlings planted (many during 2003 and up to kremt 2004). There are 4 earthen ponds (total capacity ~ 850 m^3) in Hartibo that collect and retain storm runoff from the hillsides and cropland.

The ‘conserved’ Kolo Kobo catchment is 180 hectares and is located at the southeastern corner of the watershed. Extensive conservation measures were established in Kolo Kobo during the 2003-2004 study period. By the start of kremt 2004 the Kolo Kobo catchment had significant fractions of the catchment closed off for one year from grazing for natural regeneration of vegetation (~ 15 % of hillside area), bench terraces constructed/ tree seedlings planted (~ 45 % of hillside area), and

Table 3.3. Paired catchments features and conservation measures

Feature		'Control' Hartibo	'Conserved' Kolo Kobo
Area (ha)		351	180
Elevation range (m)		1520 - 1730	1450 - 1770
Mean slope (%)		15.6	17.7
Maximum flow distance[a] (m)		3,020	3,700
Land cover (%)	Cropland	71.4	49.6
	Shrub/Grass/Bush	21.6	42.9
	Woodland/Forest	0.8	0.4
	Settlement	6.2	7.1
Slope class (% of total area)	< 3 %	5.9	1.9
	3-8 %	25.8	19.4
	8-15 %	27.7	28.5
	15-30 %	28.6	32.4
	> 30 %	12.1	17.8
Cropland conservation[b]		4 retention ponds, few soil bunds and vegetative barriers	2 retention ponds, few soil bunds and vegetative barriers
Rangeland conservation[b]		<5 % area bench terracing, few tree seedlings planted	>30 % area closed from livestock grazing, bench terracing, numerous tree seedlings planted
Gully conservation[b]		None	Sandbag/gabion checkdams and plantings in major channel bottom/sides

[a] Approximate water travel distance from furthest point in catchment to stream measurement point at outlet; [b] Note that conservation here refers to major introduced conservation measures and does not include common conventional conservation strategies longtime integrated into activities of the watershed population

sandbag and gabion checkdams (~30-50 m spacing) constructed and vegetation planted within the main drainage gullies (~ 1.3 km conserved gully length). The total area with conservation and rehabilitation works is about 30 % of the catchment. There are 2 earthen ponds (total capacity ~ 490 m^3) in Kolo Kobo which collect storm runoff.

Rainfall measurement

Rainfall during 10-15 minute increments was measured with automatic tipping-bucket rain gauges at the hillside shrub rangeland plot for the Hartibo catchment and at the top block of the cropland plots for the Kolo Kobo catchment. In addition, spatial distribution of rainfall in the Lenche Dima watershed was measured daily with 19 manual rain gauges distributed at least 500m between each rain gauge around the mid-perimeter between footslopes and mid-hillslopes of the watershed.

Runoff measurements

Plot runoff

A runoff collection system was setup at the lower boundary of each cropland and hillside rangeland plot. Each cropland collection system consisted of a sheet metal collector trough (6m long x 0.25m wide x 0.12m deep) which emptied runoff into a series of three storage barrels (180 liters capacity each) interconnected by 10-slot flow divisors (similar setup shown in Figure 3.2). A plastic sheet was installed from about 10 cm buried below the soil at the bottom edge of the plot and extended over the trough lip into the trough. This effectively prevented runoff from seeping below the trough lip. The hillside rangeland plots used similar setup with a series of three large storage tanks (850 liters capacity 1st and 3rd tank and 425 liters middle/2nd tank) interconnected by 10-slot flow divisors (Figure 3.2). For the hillside plots no metal trough collector was installed but rather a 0.1 m deep and 0.3 m wide excavated trench directed runoff into the first collector tank. The first collector tank in the series had a sheet metal extension that conveyed runoff from the trench into the tank (Figure 3.2). The collector trenches were very well compacted during setup and cleaned free of debris after each storm.

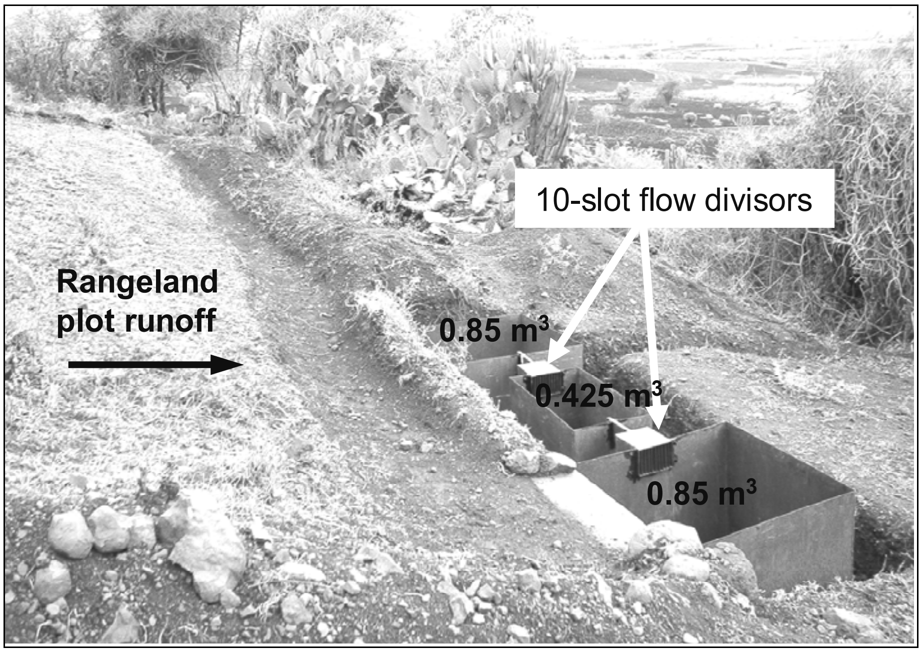

Figure 3.2. Plot runoff and sediment collection system at rangeland site

Early the following morning (8AM) after every rainfall event the water level in all barrels/tanks was measured. The amount of water collected in the barrels/tanks had to be adjusted for direct and trough collected rainfall and for sediment volume. Rainfall amount measured at the cropland and hillside plot sites and rainfall interception area of trough and barrel/tank collection system were used to adjust for direct rainfall during runoff calculations. The sediment volume measured at the bottom of each barrel and its determined water content were used to adjust runoff volume for displacement caused by accumulated sediment. Runoff fractions/percents/coefficients were calculated based on the fraction of runoff depth to rainfall depth.

Stream discharge

Streamflow stage was monitored during kremt 2004 using manual and automatic instruments at the Hartibo and Kolo Kobo catchment stream outlets. A pressure transducer and datalogger recorded at 2-5 minute intervals the streamflow water level at a stable cross-section along a natural straight stretch (~ 70 m) of the Hartibo stream outlet. The pressure transducer was inserted into a 38.1 mm diameter steel pipe which had two 5 mm diameter holes on opposite sides of the pipe facing the directions perpendicular to flow and spaced every 50 mm up the pipe. The pipe interior and exterior were cleaned of debris and sediments after every storm event. Streamflow height at the Kolo Kobo catchment rectangular culvert outlet (4-m wide) was measured manually with the aid of painted reference markings on the concrete culvert side wall. A trained individual recorded time, height, and width (for low flows) of flow every 5-10 minutes. Due to logistical difficulties during the nighttime storms, measurements were often halted before the long recession flows had ended. Times when flow completely stopped the next morning were recorded. An exponential decay function was fit to the normalized points from all the final recession curves then applied to the missing hydrograph segments. The amount of runoff that was estimated with fitted recession curves ranged from 0–15% of total storm discharge amounts.

Streamflow velocities for discharge volume calculations were estimated using Manning's equation for flow velocity in open channels and natural streams (Haan et al., 1994; Chow, 1959). Parameter values for Manning's equation were obtained from detailed measurements of the cross-section and channel bed slopes of the stream outlets (1.26 % slope for Hartibo and 2.05 % for Kolo Kobo) and detailed observations of the stream bed and side characteristics. Manning's n value for Hartibo (0.035) was computed using the procedure described in Chow (1959). At Kolo Kobo velocity measurements, taken by floating sticks over a 4 m length, were available for one storm, so the relationship was calibrated by fitting Manning's roughness coefficient to this storm. This resulted in a roughness value (n) of 0.053, which is high for normal tabulated concrete values (Haan et al., 1994), but the intermittent nature of the flows especially due to blockages caused by piles of sediment and trash at the entrance to the culvert, makes this a realistic estimate. The equation in Chow (1959) gives roughness (n) value of 0.045 so the applied fitted value is within reason.

Soil loss measurement

Soil loss was measured for the cropland and rangeland plots. Water samples were taken from each barrel/tank of the runoff collection system described above after vigorously stirring for about 30 seconds. The water samples were analyzed at Sirinka Agricultural Research Center laboratory in Sirinka, Ethiopia for suspended sediment concentration using the filtration technique. This method involves filtering 100 ml of water sample to capture sediment particles larger than 1.2 µm and then oven drying this sediment at 105^{o}C for 24 hours before weighing. After emptying water from the barrels/tanks the volume of sediment left at the bottom was measured by counting the number of 1-liter cups, and fractions thereof, required to empty the barrel/tank. A 400 ml sample of this tank sediment was sun/air dried for 1-3 weeks depending on the weather and weighed to determine the dry weight. This same procedure of measuring the volume of sediment and drying a 400 ml sample was used to determine amount of sediment that deposited in the metal collector trough after each storm for the cropland plots. All sediment is reported as dry weight.

Infiltration tests

Double ring infiltration rates were measured six times at each cropland and twice at each rangeland experimental plot (Bouwer, 1986). On the farm plots the inner ring was 20 cm and outer ring 30 cm diameter. On the rangeland plots the inner ring was 6.7 cm diameter and outer ring 13.5 cm. In addition to the measurements on the plots, 30-cm diameter single ring infiltration rates were measured at 36 other hillside and cropland sites, as indicated in the results, scattered around the Lenche Dima watershed. During all infiltration tests the rings were inserted to 10 cm soil depth and the water maintained at 5 cm ponding height. Measurements were taken during 5 minute increments for at least 150 minutes and until either steady state or when there was less than 5 % change in total infiltration volume between full hours which took up to 360 minutes.

Statistical analyses

Analysis of Variance (ANOVA) to determine statistical significance of plot treatment effects was calculated using the General Linear Model (GLM) in Minitab Inc. Release 14.1 statistical software. Significance of individual treatment differences is analyzed using Tukey's pair-wise comparison. Treatment effects are considered to be statistically significant at the $P<0.05$ and $P<0.10$ levels as indicated in the results. All correlation coefficients were calculated using the Pearson method.

RESULTS

Infiltration and land cover

Measured infiltration rates in the Lenche Dima watershed which are listed in Table 3.4 were lowest in cropland and highest in open forest/bush rangeland. Rates in cropland plots varied from slow at 0.6 mm h^{-1} to moderately fast at 53 mm h^{-1}. Rangeland plots had significantly faster rates due to their relatively undisturbed soil condition (i.e., no tillage), high organic matter content in the open forest soil (Table 3.1), and high sand content in the shrub rangeland soil. The open forest plot infiltration was 95-170 mm h^{-1} compared to 44-60 mm h^{-1} in the shrub rangeland plot. Infiltration on 36 other hillsides and farmers' fields sites dispersed throughout the watershed demonstrated similar significant ($P < 0.01$) differences with increasing rates for cropland, bare rangeland, shrub and grass rangeland, and bush rangeland, respectively (Table 3.4). Higher infiltration rates in rangeland were associated with larger vegetation. The slower conventional cropland and shrub rangeland infiltration rates measured on the plots compared to the other sites in the watershed were in part due to the use of a single ring infiltrometer for the other sites versus a double ring infiltrometer on the plots.

Rainfall, runoff, and sediment yield

Rainfall during kremt 2003, belg 2004, and kremt 2004 rainy seasons totaled 470, 232, and 553 mm, respectively. Most rainfall occurred during the months of April, July, and August. Figure 3.3 presents monthly rainfall, evaporation, and temperature. Evaporation exceeded rainfall during all months except August 2003. As seen in the figure, there were high intra-seasonal variations in rainfall distribution. Spatial variation of rainfall measured at 19 sites in the watershed was also significant with mean daily coefficients of variation of 41 % during kremt 2003, 69 % during belg 2004, and 80 % during kremt 2004. Such high temporal and spatial variations in rainfall are typical for the sub-humid and drier parts of northern Ethiopia (Segele and Lamb, 2005; Nyssen et al., 2005; Seleshi and Zanke, 2004).

Table 3.4. Ponded infiltration at plots and other sites in the Lenche Dima watershed

Location	Land use	Land cover/ tillage method	No. of sites	Final infiltration rate ($cm\ h^{-1}$) Median	Mean ± S.D	Cumulative 30-minute infiltration (cm)[a]
Plots[b]	Range-	Shrubland	2	5.2	5.2 ± 1.1	6.9 ± 1.6
	land	Open forest	2	13.2	13.2 ± 5.2	15.6 ± 4.0
	Crop-	Maresha	6	2.2	2.3 ± 2.0	3.1 ± 1.7
	land	Subsoiling	6	0.5	0.8 ± 0.9	2.2 ± 1.3
		No till	6	0.6	1.2 ± 1.5	2.2 ± 0.7
Other	Range-	Bareland	2	5.1	5.1 ± 1.0	7.1 ± 1.3
sites[c]	land	Grassland	6	9.6	11.6 ± 7.1	8.5 ± 3.2
		Shrubland	14	9.2	13.2 ± 8.4	9.6 ± 2.2
		Bushland	4	19.2	17.1 ± 6.3	12.9 ± 2.3
	Crop-	Maresha	10	4.3	4.5 ± 3.5	5.0 ± 3.3
	land					

[a] Mean ± standard deviation; [b] Measured with double ring infiltrometer; [c] Measured with single ring infiltrometer

During the kremt 2003, belg 2004, and kremt 2004 rainy seasons there were 49, 16, and 47 daily rainfall events over 0 mm depth of which 14, 5, and 18, respectively, generated surface runoff. Table 3.5 presents rainfall characteristics for all events that produced surface runoff. The storms (used in this paper to mean rainfall events that generated runoff on at least one cropland or rangeland plot) during belg were on average the largest with 33 mm per event. Kremt 2003 storms with a mean of 27 mm per event and 5 events over 30 mm were significantly larger than kremt 2004 storms which had mean event depth of 20 mm and no events over 30 mm. There was even greater disparity in seasonal rainfall intensities. Mean 30-minute maximum rainfall intensity (I_{30}) and 10-minute maximum rainfall intensity (I_{10}) of storms were highest during belg and much higher during kremt 2003 than kremt 2004 (Table 3.5). Kremt 2003 had 8 storms with I_{30} over 25 mm h^{-1} compared to 3 storms during kremt 2004.

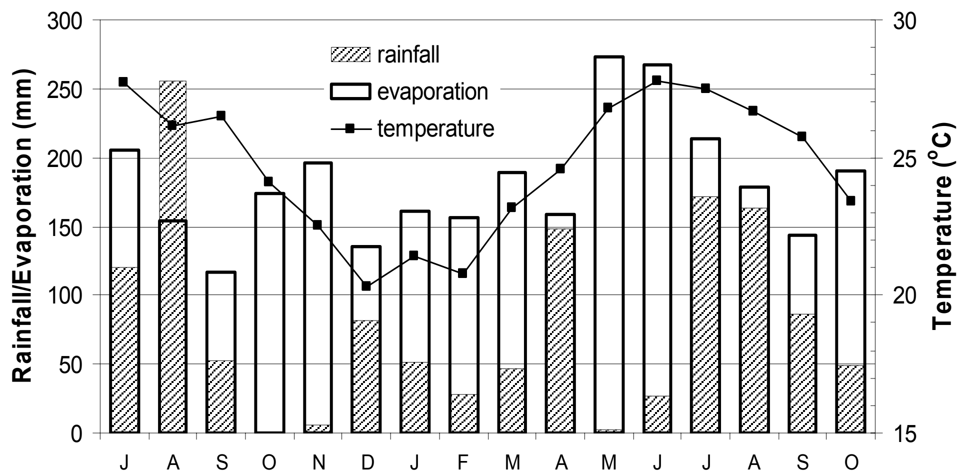

Figure 3.3. Monthly rainfall, pan evaporation, and mean temperature during July 2003 to October 2004

Rainfall generated significant surface runoff with as much as 66 % of storm depth leaving plots as overland flow. Table 3.6 lists runoff and sediment yield/soil loss for several storms and the mean for all storms. Runoff for the different land cover types was similar to what measured infiltration rates indicated. Cropland which had the lowest infiltration rates produced over twice as much runoff as rangeland with a mean runoff coefficient of 27 % (runoff depth as percentage of rainfall depth). The fast infiltration in the open forest rangeland resulted in a much lower runoff coefficient of

Table 3.5. Rainfall characteristics for storm events[a] during each rainy season and during the overall study period of 2003-2004

Rainy season		Kremt-03	Belg-04	Kremt-04	Overall
Number of events		14	5	18	37
Mean depth[b] (mm)		27 ± 15	33 ± 7	20 ± 9	24 ± 12
Max. depth (mm)		59	39	30	59
Mean I_{30}[b,c] (mm h^{-1})		33 ± 21	44 ± 23	17 ± 7	26 ± 18
Max. I_{30} (mm h^{-1})		93	75	31	93
Mean I_{10}[b,d] (mm h^{-1})		50 ± 27	78 ± 33	35 ± 13	46 ± 26
Max. I_{10} (mm h^{-1})		110	130	53	130
Mean duration[b] (h)		5 ± 4	5 ± 4	5 ± 3	5 ± 4
Depth	<10, mm	1	0	4	5
frequency	10-20	6	0	3	9
(events)	20-30	2	1	11	14
	30-40	2	4	0	6
	> 40	3	0	0	3
I_{30}[c]	<10, mm h^{-1}	1	0	3	4
intensity	10-20	3	1	10	14
frequency	20-30	4	1	4	9
(events)	30-40	4	1	1	6
	> 40	2	2	0	4
I_{10}[d]	<20, mm h^{-1}	1	0	2	3
intensity	20-40	2	0	9	11
frequency	40-60	8	2	7	17
(events)	60-80	0	1	0	1
	> 80	2	2	0	4

[a] Storm refers to a rainfall event that generated runoff on at least one cropland or rangeland plot in the watershed; [b] Mean event ± standard deviation; [c] I_{30}: 30-minute maximum rainfall intensity; [d] I_{10}: 10-minute maximum rainfall intensity

Table 3.6. Rainfall, runoff, and sediment yield for several major storms during each rainy season and the overall mean for 2003-2004. (OF: open forest; SB: shrub rangeland; M: conventional cropland; KK: Kolo Kobo 'conserved' catchment; HB: Hartibo 'control' catchment).

Date	Rainfall[a]			Runoff coefficient (%)[b]					Sediment yield (g m^{-2})		
	P[c]	I_{30}[d]	I_{10}[e]	OF[f]	SB[f]	M	KK	HB	OF	SB	M
Mean[g] '03-'04	24	26	46	3	13	27	5	5	7	23	77
7/31/03	59	93	110	2	12	-	-	-	16	114	323
8/12/03	22	26	41	13	52	36	-	-	78	300	21
8/16/03	54	51	99	14	17	66	-	-	43	78	368
8/19/03	16	-	-	12	40	58	-	-	30	65	158
3/29/04	39	58	89	0	1	3	-	-	0	0	1
4/4/04	38	75	130	2	27	38	-	-	0	36	246
4/5/04	32	27	50	1	9	32	-	-	0	2	97
7/13/04	30	26	52	2	13	47	-	2	0	2	35
8/14/04	21	23	40	5	34	46	10	15	2	2	61
8/15/04	27	16	35	4	26	39	3	12	1	6	71
9/13/04	25	18	41	3	15	50	7	3	0	0	77
10/3/04	30	23	43	4	17	60	-	-	4	4	89

[a] Rainfall measured at cropland plots; [b] Runoff depth as percentage of storm depth; [c] P: event rainfall depth (mm); [d] I_{30}: 30-minute maximum rainfall intensity (mm h^{-1}); [e] I_{10}: 10-minute maximum rainfall intensity (mm h^{-1}); [f] Calculated based on rainfall measured at rangeland plots; [g] Mean values for all measured storms during 2003-2004 rainy seasons except for KK and HB which were only measured during kremt 2004

3 % compared to 13 % in the shrub rangeland. During all storms conventional cropland and shrub rangeland plot runoff greatly exceeded stream discharge from the surrounding catchments which had over 90 % of areas covered with the same land cover types as in the plots. Stream discharge for both the Kolo Kobo and Hartibo catchments averaged 5 % of storm depths (Table 3.6).

Land cover differences resulted in greater disparity in soil loss than surface runoff (Table 3.6). Mean sediment yield per event on conventional cropland was 77 g m^{-2} which is over three-fold the 23 g m^{-2} on shrub rangeland and 7 g m^{-2} in the open forest rangeland despite situation of cropland on gentler slopes.

DISCUSSION

Runoff and sediment yield in the Lenche Dima watershed demonstrated extreme seasonal and location specific variability. Measured seasonal runoff varied from less than 2 mm or 1 % of rainfall depth to over 120 mm or 24 % of rainfall depth depending on seasonal rainfall characteristics, land cover, slope gradient, and land management practice. Similarly, seasonal sediment yield varied from less than 10 g m^{-2} to over 3,500 g m^{-2}. For effective watershed management planning it is necessary to understand what factors and which parts of the landscape produced particular runoff and sediment yield rates. This discussion will explore the influence of various factors on runoff production and soil loss in the Lenche Dima watershed and their implications for watershed management strategies.

Influence of rainfall characteristics on runoff generation and sediment yield

Correlation analysis indicates that rainfall intensity and depth were main determinants for amount of surface runoff and sediment yield produced in the study area. Table 3.7 presents correlation coefficients between rainfall characteristics and surface runoff. Runoff coefficient (runoff depth as percentage of rainfall depth) for plots and catchments was better correlated the maximum rainfall intensity (I_{30}) than with rainfall depth (P) and average rainfall intensity (I_{ave}) suggesting that Hortonian overland flow (i.e., rainfall intensity exceeding soil infiltration capacity) is a significant mechanism of runoff generation (Kange et al., 2001; Smith and Goodrich, 2005). However, the high range of infiltration rates measured in plots and catchments (Table 3.4) which were mostly above the storm intensities (Table 3.5) suggest that Hortonian overland flow is produced on small patches and not in all parts within each land unit. This is particularly evident in the case of the open forest rangeland which had infiltration rates of over 95 mm h^{-1} but produced runoff during storms with intensities less than half that value (Table 3.5). The little runoff produced in the open forest plot was probably generated on two small footpaths crossing the plot. This is in accordance with Ziegler et al. (2001) and Ziegler et al. (2004) who determined that footpaths can contribute highly disproportionately to overland flow generation in mountainous watersheds. The low values and significance of runoff correlation with 3-day and 7-day cumulative antecedent precipitation (CAP) suggests soils in the watershed are storing limited amounts of rainwater between storms which is also supported by the high infiltration rates.

Correlation with sediment yields indicates that rainfall intensity affected erosion rates most but rainfall depth was also very important (Table 3.8). The importance of rainfall intensity and depth is better understood by examination of differences in sediment

Table 3.7. Coefficients of correlation between storm characteristics and surface runoff. (SB: shrub rangeland; OF: open forest; M: conventional maresha tillage; SS: subsoiling; TR: tied ridges; NT: no till; HB: Hartibo 'control' catchment; KK: Kolo Kobo 'conserved' catchment)

Land unit		Rangeland		Cropland				Catchments	
Treatment		SB	OF	M	SS	TR	NT	HB	KK
Runoff coefficient	P^a	0.54*	0.51*	0.50*	0.52*	0.43*	ns	0.15	0.27
	$I_{ave}{}^b$	0.64*	0.60*	0.46*	0.44*	0.22	0.72*	0.58*	0.34
	$I_{30}{}^c$	0.85**	0.90**	0.50*	0.51*	0.53*	0.67*	0.59*	0.78*
	$I_{10}{}^d$	0.62*	0.64*	0.56*	0.56*	0.58*	0.73*	0.57*	0.57
	$CAP_3{}^e$	ns	ns	ns	ns	ns	0.70*	0.45*	ns
	CAP_7	ns	ns	ns	ns	ns	0.52*	0.68*	ns
Runoff volume	P^a	0.73**	0.70**	0.67**	0.65**	0.55*	0.68*	0.56*	0.59
	$I_{ave}{}^b$	0.70**	0.72**	0.42*	0.39	0.19	0.71*	0.71**	0.36
	$I_{30}{}^c$	0.81**	0.82**	0.58*	0.57*	0.59*	0.71*	0.73**	0.68
	$I_{10}{}^d$	0.52*	0.51*	0.55*	0.54*	0.56*	0.67*	0.52*	0.52
	$CAP_3{}^e$	0.44*	0.42*	ns	ns	ns	0.67*	0.51*	ns
	CAP_7	ns	ns	ns	ns	ns	0.54*	0.54*	ns
Peak discharge	P	-	-	-	-	-	-	0.37	0.65
	$I_{30}{}^c$	-	-	-	-	-	-	0.73**	0.16
	CAP_3	-	-	-	-	-	-	0.47*	ns

[a] P: total rainfall for each event; [b] I_{ave}: average rainfall intensity; [c] I_{30}: maximum 30-minute rainfall intensity; [d] I_{10}: maximum 10-minute rainfall intensity; [e] CAP_x: cumulative antecedent precipitation for x days prior to the event; * Significant at P<0.10 level; ** Significant at P<0.01; ns: Not significant

Table 3.8. Coefficients of correlation between rainfall/runoff characteristics and sediment yield. (OF: open forest; SB: shrub rangeland; M: conventional maresha tillage; SS: subsoiling; TR: tied ridges; NT: no till)

Land type		Rangeland		Cropland			
Treatment		SB	OF	M	SS	TR	NT
Total	P^a	0.49^{*}	0.46^{*}	0.70^{**}	0.72^{**}	0.70^{**}	0.64^{*}
sediment	$I_{ave}{}^{b}$	0.47^{*}	0.60^{*}	0.60^{**}	0.62^{**}	0.56^{**}	0.38
	$I_{30}{}^{c}$	0.62^{*}	0.67^{**}	0.71^{**}	0.73^{**}	0.72^{**}	0.87^{**}
	$I_{10}{}^{d}$	0.51^{*}	0.57^{*}	0.73^{**}	0.72^{**}	0.67^{**}	0.78^{**}
	$Q_{tot}{}^{e}$	0.78^{**}	0.85^{**}	0.66^{**}	0.61^{**}	0.70^{**}	0.72^{**}
Suspended	P^a	0.52^{*}	0.54^{*}	0.42^{*}	0.37^{*}	0.42^{*}	0.50^{*}
sediment	$I_{30}{}^{c}$	0.61	0.74^{**}	0.56^{**}	ns	0.36^{*}	0.84^{**}
	$I_{10}{}^{d}$	0.51^{*}	0.58^{*}	0.61^{**}	ns	0.33^{*}	0.69^{*}
	$Q_{tot}{}^{e}$	0.90^{**}	0.85^{**}	0.64^{**}	0.64^{**}	0.60^{**}	0.68^{*}

[a] P: total rainfall for each event; [b] I_{ave}: average rainfall intensity; [c] I_{30}: maximum 30-minute rainfall intensity; [d] I_{10}: maximum 10-minute rainfall intensity; [e] Q_{tot}: total event runoff; * Significant at P<0.10 level; ** Significant at P<0.01; ns: Not significant

yield across seasons and the contribution of individual storms to the total sediment yield. Figure 3.4 presents mean seasonal sediment yield for all plots. Although kremt 2003 and kremt 2004 had similar total seasonal rainfall, kremt 2003 produced over twice the sediment yield across all plots because it had more large-depth/high-intensity storms (Table 3.5). Most erosion loss occurred during few major storms. As seen in Table 3.6, the two storms on 7/31 and 8/16 eroded 6.9 Mg ha^{-1} of soil in the conventional cropland plot which is over 60 % of the total 11.4 Mg ha^{-1} sediment yield during the entire kremt 2003 season. During belg 2004 73 % of the mean 4.7 Mg ha^{-1} seasonal sediment yield occurred during two storms on 4/4 and 4/5. The three events on 8/15, 9/13, and 10/3 during kremt 2004 contributed over 50 % of the mean 4.7 Mg ha^{-1} total sediment yield. The important contribution of major events to long-term erosion in dry climates was also observed by Martinez-Mena et al. (2001).

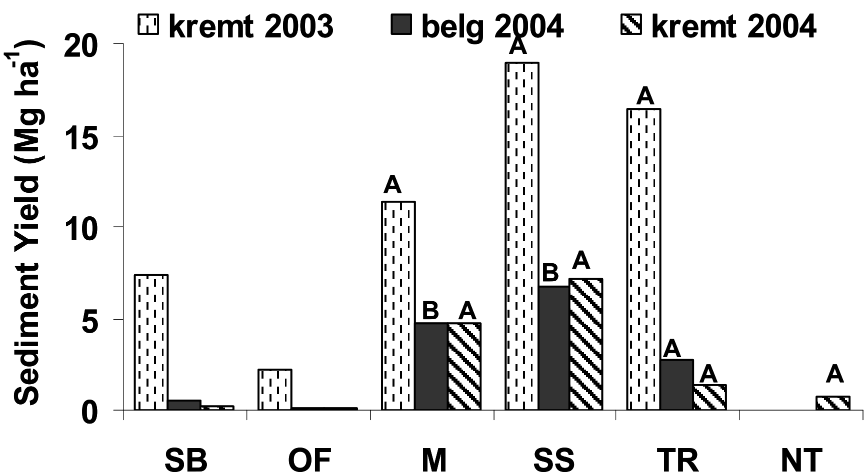

Figure 3.4. Mean seasonal sediment yield for rangeland and cropland plots (different letters during the same season indicate significant difference at P<0.10). Note NT only measured during kremt 2004. (SB: shrub rangeland; OF: open forest; M: conventional maresha tillage; SS: subsoiling; TR: tied ridges; NT: no till).

These results indicate that the number of high-intensity/ large-depth storms during the rainy season is a major predictor of the quantity of surface runoff and, even more so, erosion in the watershed. The observed differences between seasons suggest that the severe erosion which leads to the visibly degraded/dissected cropland and rangeland in many watersheds of this part of the Ethiopian highlands does not occur at a steady rapid rate across seasons but rather is very erratic and dependent on seasonal rainfall characteristics. These findings and the high spatial variability of rainfall observed in northern Ethiopia by Nyssen et al. (2005) underscore the importance to collect more detailed rainfall depth and intensity measurements in the Ethiopian highlands. Larson et al. (1997) demonstrated the need to plan land conservation practices based on protection from those severe storms which cause most of the erosion in the landscape rather than the common practice of designing measures with long-term precipitation data.

Land cover and landscape position

Cropland and rangeland, which are the two major land cover types in the watershed, produced very different runoff and sediment yield responses to similar rainfall. Placement in the landscape of cropland on the flatter footslopes and valley bottoms and rangelands on the steeper hillslopes is the norm for watersheds in the study area. Despite cropland placement on the gentler slopes of less than 11 % in this study, seasonal runoff and soil loss were several times higher than for the open forest and shrub rangeland on 34 % slope (see Figure 3.4 and Figure 3.5). This could be a result of many factors including soil disturbance during tillage of cropland and differences in soil type and quality (Morgan, 2005). These results suggest that from a watershed management perspective that although both are very important and integral to address there is greater opportunity on the lower cropland than the hillside rangeland to improve rainwater retention for soil moisture enhancement, groundwater recharge, and flood control.

Soil loss rates for the cropland and shrub rangeland were above the sustainable threshold during kremt 2003 but lower during kremt 2004 and belg 2004 (see Figure 3.4). The sustainable threshold used here is rates above the 6 Mg ha^{-1} annual soil formation rate for the dry sub-humid/woina dega zone of Ethiopia as cited by Nyssen et al. (2004a). During all seasons soil loss rates in the open forest were low at less than 2.5 Mg ha^{-1}. Low erosion rates in the open forest were likely because of limited runoff generation and the high soil organic matter content which could improve soil aggregate stability and soil structure (Morgan, 2005). The high soil organic matter content was a result of the community area closure that restricted livestock over 20 years ago enabling tree regeneration and because of the current practice of tree protection (moderate livestock grazing allowed but no tree and bush removal). Although not replicated, these results suggest that area closure and forestation practices which regenerate tree cover on hillslopes are effective for soil protection in the watershed.

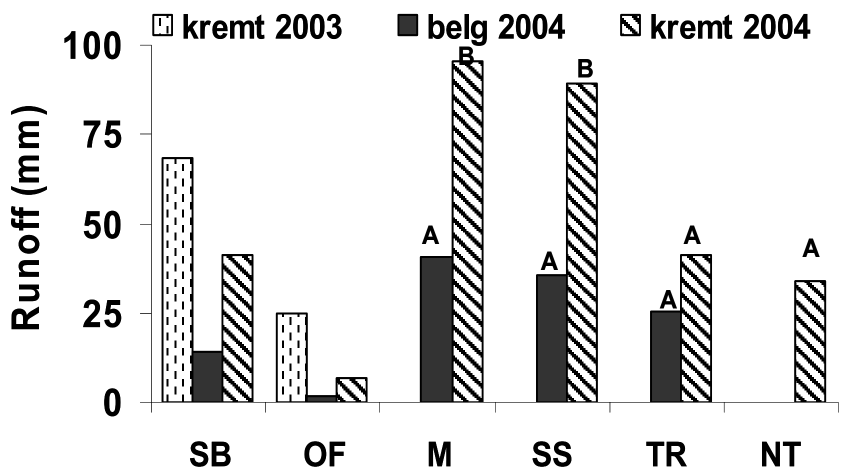

Figure 3.5. Mean seasonal runoff for rangeland and cropland plots (different letters during the same season indicate significant difference at $P<0.05$). M, SS, and TR are not presented during kremt 2003 because data missing and poor quality data for several major storms. Note NT only measured during kremt 2004. (SB: shrub rangeland; OF: open forest; M: conventional maresha tillage; SS: subsoiling; TR: tied ridges; NT: no till).

Land slope gradient

Cropland runoff and sediment yield increased significantly with land slope gradient (Figure 3.6 and Figure 3.7). Mean runoff depth on the 9-11% slope class was over twice as high as for plots on the 0-3 % slope class. The highly significant effect of slope gradient on overland flow could be due to less surface storage of rainwater and gravity causing greater runoff velocity on steeper slopes. Greater flow velocities on steep slopes also reduces residence time and hence probability of infiltration into the soil (van de Giesen et al., 2005).

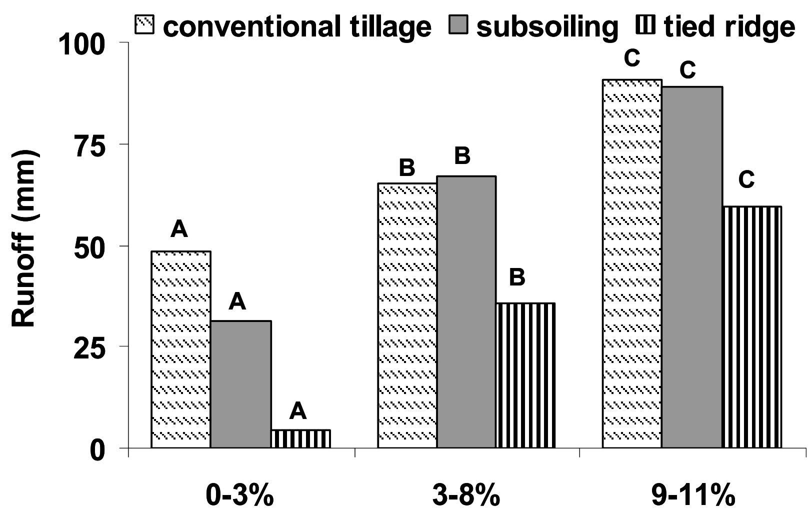

Figure 3.6. Slope effect on mean total runoff depth during seasons (different letters for the same treatment indicate significant difference at P<0.01).

Soil loss rate increased drastically, and faster than runoff, with increasing slope gradient (Figure 3.7). During all rainy seasons mean sediment yield increased more than four-fold from the 0–3 % to the 3-8 % slope classes and nearly-to-more than doubled from the 3-8 % to the 9-11 % slope classes. The strong slope effect on soil loss rate was due to the increased runoff volume and velocity and greater soil erodibility on steeper surfaces. Sediment yield on below 3 % slope for all plots was low at less than 2 Mg ha^{-1}. However, on the 9-11 % plots soil loss rates for all tillage methods exceeded twice the sustainable threshold of 6 Mg ha^{-1} (Figure 3.7). These results suggest that soil conservation planning needs to focus on appropriate watershed management practices that can effectively control cropland erosion on slopes greater than 8 %.

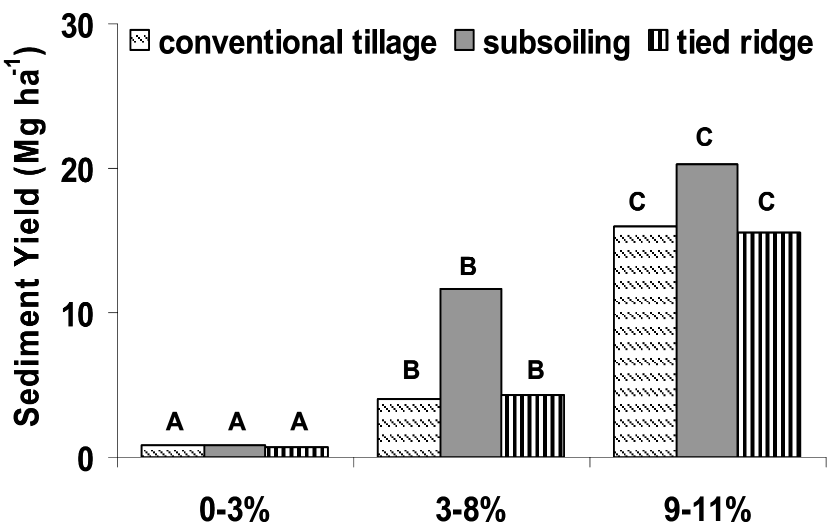

Figure 3.7. Slope effect on mean total sediment yield during seasons (different letters for the same treatment indicate significant difference at P<0.01).

From plot to catchment: scale effects

Hydrologic response to rainfall varied significantly from the plot (150–510 m^2) to the catchment (180–351 ha) scale (Table 3.6). Mean and event runoff for the catchments were at least 60 % lower than from shrub rangeland and cropland plots which was unexpected given that the catchment areas have over 90 % land area coverage under conventionally managed shrub rangeland and cropland (see Table 3.3). This result indicates that in the study zone scale of interest significantly affects the amount of surface runoff produced with an inverse relationship, but it is based on limited data. Scale effect was also observed by Stomph et al. (2002) and van de Giesen et al. (2005) in West Africa who found that surface runoff per unit slope length decreased for longer slopes mainly due to more opportunity time for infiltration on longer slopes. The scale effect is moderated in the current study by the steep topography and consequently shorter overland flow residence time.

Effectiveness of conservation and rehabilitation measures

The conservation and rehabilitation measures tested in plots and catchments were quite effective at reducing erosive runoff and sedimentation rates. Effectiveness varied between practices, seasons, and slope gradients. The following sections examine performance of the different measures.

Catchment integrated management

Paired catchment responses to rainfall suggest that the community implemented checkdams, area closure, and hillside terracing improved stream discharge characteristics in the 'conserved' Kolo Kobo (KK) catchment compared to the 'control' Hartibo (HB) catchment. A summary of streamflow characteristics are presented in Table 3.9 and stream discharge hydrographs for several representative storms are presented in Figure 3.8. The catchments had dry bed stream outlets with only spate flow followed by less than 15 h of recession flow. Both catchments yielded similar mean runoff discharge of 5 % despite differences in size, slope gradient, land cover, and percent conserved area (see Table 3.3). The Kolo Kobo catchment has 49 % smaller land area (180 ha KK, 352 ha HB), higher mean slope (18 % KK, 16 % HB), more shrub/grass/bush rangeland (43 % KK, 22 % HB), less cropland (50 % KK, 71 % HB), and a larger percentage of 'conserved' areas (over 30 % KK, less than 5 % HB) compared with the Hartibo catchment. According to inhabitants of the catchment

Table 3.9. Catchment streamflow response (summary of fourteen events in Hartibo and six events in Kolo Kobo)

Variable	Hartibo			Kolo Kobo		
	Mean[a]	Max.[b]	Min.[c]	Mean	Max.	Min.
Rainfall (mm)	21.6 ± 8.0	37.1	7.6	18.9 ± 8.9	26.5	7.4
Rainfall duration (h)	5.5 ± 2.9	11.5	0.8	3.4 ± 1.5	5.7	1.5
I_{30} (mm h^{-1})	16.4 ± 5.8	26.9	6.2	15.7 ± 4.6	22.8	9.6
Runoff (mm)	1.2 ± 1.5	4.4	0.1	1.1 ± 0.8	2.2	0.2
Runoff coefficient (%)	5.3 ± 5.6	17	1	4.9 ± 2.9	10	2
Runoff duration (h)	5.7 ± 2.3	9.8	1.5	7.3 ± 4.3	12.8	1.4
Qp[d] (mm h^{-1})	1.5 ± 1.7	4.4	0.2	0.6 ± 0.2	0.9	0.2
Pi[e] (mm)	8.1 ± 4.5	22.1	3.1	13.2 ± 7.4	24.1	6.2
Ti[f] (h)	1.3 ± 1.5	5.5	0.2	1.2 ± 1.3	3.4	0.1
Tp[g] (h)	0.9 ± 1.0	3.0	0.1	0.6 ± 0.5	1.3	0.2
Tr[h] (h)	3.2 ± 2.1	9.4	1.1	5.5 ± 3.1	10.4	1.2
Pp – Tp[i] (h)	0.7 ± 0.8	3.2	0.3	1.4 ± 1.2	3.5	1.1
Pf – Tf[j] (h)	1.5 ± 1.2	5.3	0.1	6.0 ± 3.2	9.7	1.1

[a] Mean ± standard deviation; [b] Maximum; [c] Minimum; [d] Peak stream flow discharge rate; [e] Cumulative rainfall before initiation of stream flow at outlet; [f] Time of initiation of stream flow; [g] Time to peak stream flow rate; [h] Time of recession; [i] Time lag from peak rainfall intensity to peak stream flow rate; [j] Time from end of rainfall to termination of streamflow

(a)

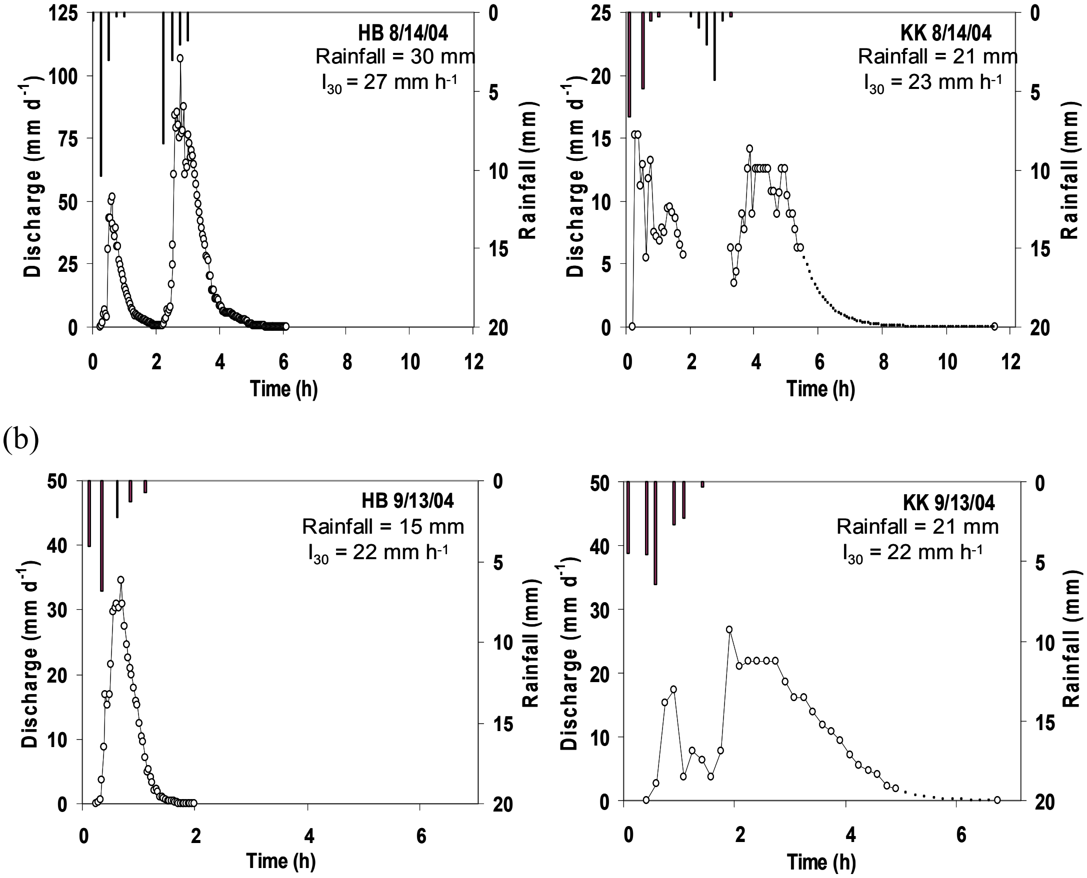

Figure 3.8. Stream discharge (measured: solid line with open circles; and recession fit: broken line) and 15-minute rainfall (bar graph) at Hartibo (HB) and Kolo Kobo (KK) catchments: (a) 14 August 2004 and (b) 13 September 2004

and those living beside the discharge measurement site, before implementation of conservation measures in 2003-04 the Kolo Kobo catchment produced significantly larger discharge volumes and had shorter duration of recession flows compared to stream discharge during kremt 2004. With the conservation measures Kolo Kobo mean event flow duration (7.3 h), recession flow duration (5.5 h), and duration of flow after termination of rainfall (6.0 h) all lasted significantly longer compared with the Hartibo catchment (5.7 h, 3.2 h, and 1.5 h, respectively) which did not have comparable conservation measures. Analysis of peaks shows significantly larger mean peak discharge (1.5 mm h^{-1} HB, 0.6 mm h^{-1} KK) and shorter mean time between peak rainfall intensity and peak discharge (0.7 h HB, 1.4 h KK) for the Hartibo catchment compared with Kolo Kobo. This moderated streamflow response to rainfall in Kolo Kobo is likely a result of the water storage and slow release function of sandbag and gabion checkdams in the main gullies. Kolo Kobo also had greater mean accumulated rainfall depth before initiation of streamflow (13.2 mm KK, 8.1 mm HB). This could in part be because of initial runoff capture behind checkdams.

As seen in Figure 3.9, reduction in peak discharge rates, closure of gullies from livestock grazing, and seeding of forage species in the gully bottom have resulted in stabilization and good growth of vegetation cover in the main gullies of Kolo Kobo during 2004 unlike the control Hartibo catchment which had bare and active main gullies during the entire rainy season. Before installation of checkdams Kolo Kobo gullies also remained bare year-round. Nyssen et al. (2004b) also observed that checkdams in combination with biological control measures to regenerate gully vegetation led to rapid gully stabilization in Tigray, northern Ethiopia.

Results suggest that appropriate conservation measures can be effective at rapidly reversing land degradation in the study area during the first season after implementation, but further studies replicated during several rainy seasons are required to assess longer-term performance. The gully checkdams filled rapidly with sediment during the first rainy season indicating the need for extensive annual maintenance in situations where the surrounding landscape continues to contribute high runoff and sediment flow. The integrated approach which also implemented bench terracing, area closure, tree plantings, etc. in the landscape is essential to assure the longer-term continued rehabilitation of gullies after the initial rapid stabilization assured by the checkdams and closure from livestock.

(a) July 2004 (b) October 2004

Figure 3.9. Gully rehabilitation in the Kolo Kobo catchment: (a) shortly after installation of checkdams and (b) the same location three months later with good vegetation cover and gully stabilization.

Conservation practices on cropland

Effectiveness of cropland conservation practices in dry environments depends on the amount of rainfall maintained on site (i.e., less runoff) to provide moisture for crop growth and the limiting of erosion in order to maintain on-site soil productivity. Cropland under conventional tillage with the traditional maresha (M) plow produced the largest mean runoff coefficient of 27 % (see Table 3.6 and Figure 3.5). Subsoil cultivation (SS) generated slightly less, but statistically similar runoff as conventional tillage. Tied ridges (TR) and no till (NT) practices significantly reduced plot runoff losses maintaining on average 10 % more storm rainwater onsite (see Figure 3.5). Tied ridges performed best on the 0-3 % slope and during the kremt 2004 season with less intense storms (see Figure 3.5 and Figure 3.6). Performance of tied ridge decreased on steeper slopes and during intense storms due to ridge breaks and instances of ridge overflow.

Results show high rates of soil loss on the steeper slopes of 9-11 % and during the kremt 2003 season for all tillage practices (see Figure 3.4 and Figure 3.7). During the kremt 2004 season with few intense storms tied ridge and no till significantly reduced soil loss rates but during the intense storms of kremt 2003 tied ridge increased soil loss rates compared with conventional tillage (see Figure 3.4). Soil loss during ridge breaks and the formation of rills by concentrated runoff flow through the breaks were observed as reasons for high soil loss rates on the steeper slopes and during intense storms. The problem of ridge breakage in the current study was exacerbated by the relatively small size of the ridges (10-15 cm ridge height) constructed with the animal-drawn ridging implement. Ridge performance on steeper slopes might improve with larger ridges. Subsoiling increased erosion rates on slopes over 3 % but was statistically similar to conventional tillage (see Figure 3.7). The increased soil disturbance of subsoil tillage on sloping surfaces facilitated soil detachment and displacement and formation of deeper rills. No till produced significantly less soil loss than all treatments but was only tested during kremt 2004 which was a season of less intense rainfall. Overall, the results suggest that the tested animal-drawn ridging practice was effective at conserving rainwater and soil onsite under the conditions in this study for slopes of 8 % or less and should not be used for steeper slopes especially during seasons with intense storms.

Relative importance of factors

Examination of the factors that influenced runoff generation and sediment yield at the various study sites indicates that seasonal rainfall, land cover type, land slope gradient (for cropland), land management practice, and scale of measurement were all significantly correlated to storm response (Table 3.10). Cropland runoff coefficient (r^2 = 0.43) and sediment yield (r^2 = 0.43) were best correlated with the slope gradient. However, comparison across all plot types indicated that land cover type was the factor most correlated with runoff (r^2 = 0.32) and sediment yield (r^2 = 0.36). The significant affect of land cover is expected given the large difference in infiltration rates observed between cropland and rangeland. The presence of conservation measures on plots was better correlated with storm runoff (r^2 = 0.25) than sediment yield (r^2 = 0.17) while the season during which the storm occurred was better correlated with sediment yield (r^2 = 0.34) than runoff (r^2 = 0.17). These are understandable given the severe erosion observed across all plots regardless of management practice for storms during kremt 2003 compared to the moderate soil loss during kremt 2004 (Figure 3.4). The conservation measures were generally more effective at reducing runoff than at limiting soil for the slope gradients studied.

Overall correlation results suggest that land slope gradient (cropland only) was the most important factor followed in importance by land cover type, seasonal rainfall, presence of conservation measures, and scale of measurement, respectively. This ranking of importance is indicative for the conditions in this study which had limited replications for the number of factors examined.

Table 3.10. Coefficients of correlation between storm response and the various factors

Factor	Runoff coefficient	Sediment yield
Season of rainfall[a]	0.17*	0.34*
Land cover type	0.32*	0.36*
Cropland slope gradient[a]	0.43*	0.48*
Scale of measurement	0.18*	-
Conservation measure or not[c]	0.25*	0.17*

[a] Kremt 2003 and kremt 2004 seasons only; [b] Conventional maresha tilled cropland only; [c] Open forest, tied ridges, and Kolo Kobo catchment were used as the conservation measures and shrub rangeland, conventional maresha tillage, and Hartibo catchment were the controls. * Significant at $P < 0.05$

CONCLUSION

Hydrologic and sediment yield responses to rainfall were measured during three rainy seasons at plot and one season at catchment scales within the same watershed in the northeastern Ethiopian highlands. Surface runoff and sediment yield rates were significantly affected by seasonal rainfall characteristics, land slope gradient, land cover, land management practice, and scale of measurement. Most runoff and sediment yield was produced during few large intense storms which occurred during particular seasons. A wide range of high infiltration rates measured for the different land covers indicated that runoff was likely generated on patches within plots rather than over the entire unit. Due to substantial differences in soil infiltration rates, cropland produced over double the runoff and sediment yield compared to rangeland despite placement of cropland on much gentler slopes. However, among the cropland plots slope gradient was very important causing drastically augmented runoff and soil loss as slope gradient increased from 2 % to 10 %. Scale of measurement also affected the amount of runoff with catchments producing consistently lower storm runoff depths than observed on the much smaller plots within the catchments.

Conservation practices were mostly effective at reducing erosive runoff and sediment yield. The community protected open forest rangeland which resulted from natural regeneration after area closure over 20 years ago generated much lower surface runoff and sediment yield rates compared with the adjacent shrub rangeland which is the most widespread land cover on hill slopes in the study area. The disparity was associated with faster infiltration rates and high soil organic matter content in the open forest. Cropland conservation tillage practices reduced runoff and soil loss on slopes below 8 % and performed better during seasons with fewer large intense storms. Ridging and no till performed best, but no till was only tested during one season. Subsoiling resulted in increased soil loss compared to conventional maresha tillage on slopes above 3 %.

Comparison of paired catchment hydrologic responses suggested that recent implementation of conservation measures, and in particular gully checkdams, was moderating peak stream discharge rates and lengthening duration of streamflow compared with a ‘control’ catchment in the same watershed which did not have these measures. Streamflow monitoring for several rainy seasons is required to assess longer-term impacts. An integrated management approach that reduces runoff and sediment from the surrounding landscape is essential for continued rehabilitation of gullies and degraded areas in the watershed.

The results of the study suggest that the severe erosion which leads to the visibly degraded/dissected cropland and rangeland in many watersheds of this part of the Ethiopian highlands does not occur at a steady rapid rate across seasons but rather is very erratic and dependent on seasonal rainfall characteristics, that from a watershed management perspective although both are very important and integral to address there is greater opportunity on cropland than rangeland to reduce soil loss and to improve rainwater retention for soil moisture enhancement and flood control, and that appropriate catchment conservation practices are capable of producing rapid visible rehabilitation of degraded areas.

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CHAPTER FOUR

INTEGRATED QUALITATIVE ASSESSMENT OF WETLAND HYDROLOGICAL AND LAND COVER CHANGES IN A DATA SCARCE DRY ETHIOPIAN HIGHLANDS WATERSHED*

ABSTRACT

Wetlands are important sources of water and plant production for humans and livestock in the dry drought-prone northern Ethiopian highlands. Hydrological changes in these wetlands affect local populations and are indicators of change in the upstream catchments. In this paper we present a case study of hydrological and land cover changes in Hara Swamp located southeast of Kobo in Amhara State. An integrated approach used remote sensing images, limited hydrological measurements, climatic data, and a survey of residents to gain complementary insights into what changes have occurred, when and why they occurred, and the local perceptions of these changes. Aerial photos and satellite images from 1964, 1973, 1986, 2000, and 2001 indicated limited flooding and dense woody vegetation cover in the wetland 40 years ago and a trend towards the current condition of no living trees/bushes, extensive flooding, and heavy sedimentation. Rainfall records revealed no significant trends which could sufficiently explain the observed changes in the wetland. A simple water budget analysis based on hydrological measurements indicated higher wetland flood levels were a result of increasing runoff and sediment inflow from the surrounding watershed over time. Reasons for increasing amounts of runoff were higher population pressure on the land and creation of more impermeable surfaces

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* McHugh, O.V., A.N. McHugh, T.S. Steenhuis, P.M. Eloundou-Enyegue. Integrated qualitative assessment of wetland hydrological and land cover changes in a data scarce dry Ethiopian highlands watershed.

including houses and road construction in the watershed. Local residents' perceptions of the wetland changes, which were collected first, validated the sparse biophysical data and provided supplementary details. An integrated watershed management strategy is required to reverse the recent trends and protect the wetland resources.

INTRODUCTION

Wetlands are important microenvironments within the landscape providing many ecological and socio-economic benefits in the Ethiopian highlands where water resources are unevenly distributed. Among the benefits from wetlands are water storage, sediment control, groundwater recharge, streamflow moderation, water filtration and purification, plant and fish products, biodiversity, and wildlife habitat (Wood, 2001; Dixon and Wood, 2003; Wondefrash, 2003). Ethiopia's wetlands make up an estimated 11,250 km^2, which is over 1% of the country's surface area, and comprise an estimated 3.7 % of the surface area of Amhara State where the current study was conducted (Kindie, 2001). Ethiopia's wetlands are threatened by increasing human population pressure, agricultural encroachment, intensive livestock grazing, deforestation, and construction (Abunie, 2003; Dixon, 2002; Edessa, 1993; Zeleke and Hurni, 2001, Desta, 2003). Sustainable wetland management must consider linkages between wetlands, the hydrology of the catchment, and local human needs and perceptions (Abbot and Hailu 2001; McCornick et al., 2003; Dixon, 2005). An integrated approach is appropriate to gather the information necessary for better management (Vogt, 2006; Haack, 1996).

In this paper we present a case study examining recent hydrological and land cover changes in a small wetland in eastern Amhara State. The rationale for the study is to demonstrate a simple integrated approach that uses remote sensing images, historic rainfall records, limited hydrological measurements, and local residents' perceptions to better understand land resources trends and their causes in a watershed that has limited recorded information. The results provide illustrations of issues which planners and local communities can use for better and more informed watershed development.

MATERIALS AND METHODS

Site description

Hara Swamp is a shallow seasonal lacustrine wetland situated in a subhumid drought-prone mountainous landscape. It is located 16 km east of Weldiya town in North Wello zone, Amhara State, Ethiopia (Figure 4.1). The wetland is within the town of Hara's watershed (11^o47-11^o54 N and 39^o43-39^o48 E; 1460-1730 m.a.s.l.). The area has a dry tropical climate (20-29^{o}C) with a bimodal rainfall pattern. Mean annual rainfall is 830 mm with a seasonal distribution of about 210 mm during the belg season (March-May), 490 mm during the kremt season (July-September), and 130 mm during the periods between rainy seasons.

Hara watershed is located in the marginal graben of the northeast Ethiopian plateau escarpment in the Afar depression. The geology of the area is composed of varieties of trap series rocks from weathered basalt, graben fill quaternary sediments, and valley-floor later granite intrusions of probably tertiary age (Gizaw et al., 1999). Major soil types in the catchment are Regosols and Leptosols on the hillsides, Luvisols and Vertisols in the cultivated low areas, and Fluvisols in flat parts that receive alluvial sediments.

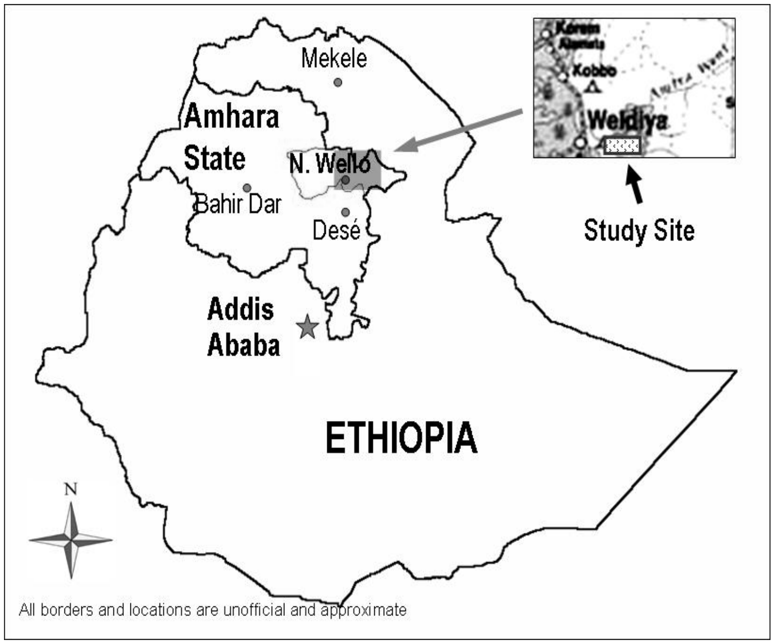


Figure 4.1. Location map of Hara watershed east of Weldiya, Ethiopia

Hara Swamp is situated at the lowest point in Hara watershed (47.9 km^2) and has no surface water outlets. Table 4.1 presents some characteristics. Given the relatively flat and shallow bathymetry of the wetland, seasonal flooded area varies greatly from dry conditions to over 210 hectares of flood. The chemical properties of the wetland (Table 4.1) are similar to those measured in Lake Tana in central Amhara State (Kebede et al., 2006).

Hara watershed has a population of approximately 7,500 people whose livelihoods depend mainly on mixed crop-livestock agriculture. Major crops are sorghum, teff, and chickpea and the most common livestock are cattle, donkeys, goats, and camel. The watershed is situated in a chronically food insecure zone and a majority of the population depends on external food assistance.

Table 4.1. Characteristics of Hara Swamp during 2004

Morphometric characteristics		Physiochemical characteristics	
Maximum depth (cm)	64	Daily temperature (^{o}C)	18-36
Max. flooded area (km^2)	2.1	Electrical conductivity (μS/cm)	254
Catchment area (km^2)	47.9		
Altitude (m.a.s.l.)	1462	pH	8.1
Latitude (^{o}N)	11^{o}50.6-11^{o}51.6	Major water use	Livestock consumption
Longitude (^{o}E)	39^{o}45.4-39^{o}46.7		

Survey data collection

A survey of 61 Hara watershed residents was conducted during September-October 2004. The primary objective of the survey was to understand the local population's perceptions of Hara Swamp and its changing conditions. Adult individuals over 30 years of age were selected at random from households in 18 villages surrounding Hara Swamp. Responses were recorded during formal interviews with a structured questionnaire composed of mostly open-ended questions. All formal interviews were conducted at or near the respondents' homes in the local language, Amharic, by Abdu Hussen, a native of Hara town who had a high school diploma-level of education. The interviewer was trained during pre-testing of the questionnaire. Group discussions and site visits were used to gather additional information and to explain findings of the structured survey.

Table 4.2 presents the survey respondents reported characteristics of themselves and their households. The respondents had lived on average 51 years in the Hara watershed. 83% were farmers and 97% owned livestock which indicate the respondents' intimate relationship with the land. The mean household size, land holdings, and livestock ownership are similar to those found in another study of the zone (Chapman and Desta, 1999).

Table 4.2. Characteristics of the survey respondents and their households

Respondent characteristics		Household characteristics	
No. of respondents	61	No. of households	61
Age[a]	52 ± 7	Household size[a,b]	5.4 ± 1.6
Gender	98 % male	Cultivated area (ha)[a]	1.4 ± 0.6
Education	17 % literate	Oxen owned[a]	1.8 ± 0.8
Occupation	83 % farmers	Large livestock[a,c]	3.8 ± 1.9
Years living in Hara[a]	51 ± 7	Medium livestock[a,d]	1.0 ± 1.6

[a] Mean ± standard deviation; [b] Number of people living in the home at time of interview; [c] Cattle, donkeys, and camels; [d] Goats and few sheep

Meteorological and hydrological measurements

Rainfall, evaporation, and ambient temperature were monitored in the Hara watershed during 2003-2004. Three recording rain gauges measured 15-minute rainfall on the western and eastern sides of Hara Swamp. Two temperature loggers recorded hourly ambient temperature. Daily evaporation was measured manually with a US Class A evaporation pan at Hara town. Historic rainfall data (1955-2003) were obtained from the Ethiopian National Meteorological Services Agency in Addis Ababa, Ethiopia.

A water height recorder (TruTrack WT-HR 2000) monitored the Hara Swamp surface water level at 15-minute intervals during the 2004 kremt rainy season (July –

September). Daily wetland water level was also recorded manually with a reference tree trunk on the western edge of the wetland. All water level data are adjusted to elevation at the deepest part of the wetland.

The surface water area-depth relationship was determined by tracking (walking) the boundary of the flooded area with a global positioning system unit (Garmin GPS 72) and recording water depth at the deepest part of the wetland. Figure 4.2 presents the GPS traced water boundaries and the water depth - surface area data. Regression analysis fit a logarithmic curve ($R^2 = 0.96$) to the water depth-surface water area relationship producing the equation

$$A_f = 0.59 \ln[D_{dp}] - 1.75 \qquad (1)$$

A_f is the area of flood water (million m^2) and D_{dp} is the depth of water (mm) at the deepest part of the wetland. The surface water volume-depth relationship was determined by integrating the area under the curve in equation (1) and adding the initial water volume stored in the wetland (the area under linear portion of the curve in Figure 4.2b) before July 14 (the first recorded depth-area data point) to obtain the equation

$$V_f = D_{dp}(0.59 \ln[D_{dp}] - 2.34) + 12.12 \qquad (2)$$

V_f is the volume of flood water in the wetland. The units are water depth (mm) and flood volume (thousand m^3). Equation (2) was used to calculate wetland surface water volume during the season.

Land cover assessment

Aerial photos and multispectral satellite images provide accurate snapshots of recent and past land cover conditions (Dwivedi, 2005). False color composites created by combining images captured at different wavelengths enable better visualization of vegetation, soil, wetland flooded area, and settlements in the landscape. Composite images were produced using Landsat MSS 1973, Landsat TM 1986, and Landsat ETM+ 2000 and 2001 images. The 1986, 2000, and 2001 false color composites were created using Band 4 in green, Band 5 in red, and Band 7 in blue. The Band 4 reflective infrared wavelength (0.76-0.90 μm) was selected because it is absorbed by water appearing dark and reflected by vegetation appearing bright. The mid-infrared Bands 5 (1.55-1.75 μm) and 7 (2.08-2.35 μm) contrast well revealing differences in types/condition of vegetation and soil. The 1973 composite was created using Band 4 in green, Band 2 in red, and Band 1 in blue because Landsat MSS does not record the mid-infrared bands used for the other years. The green (0.5-0.6 μm) and red (0.6-0.7 μm) wavelengths of Bands 1 and 2 are absorbed by vegetation showing differences in vegetation health.

(a) (b)

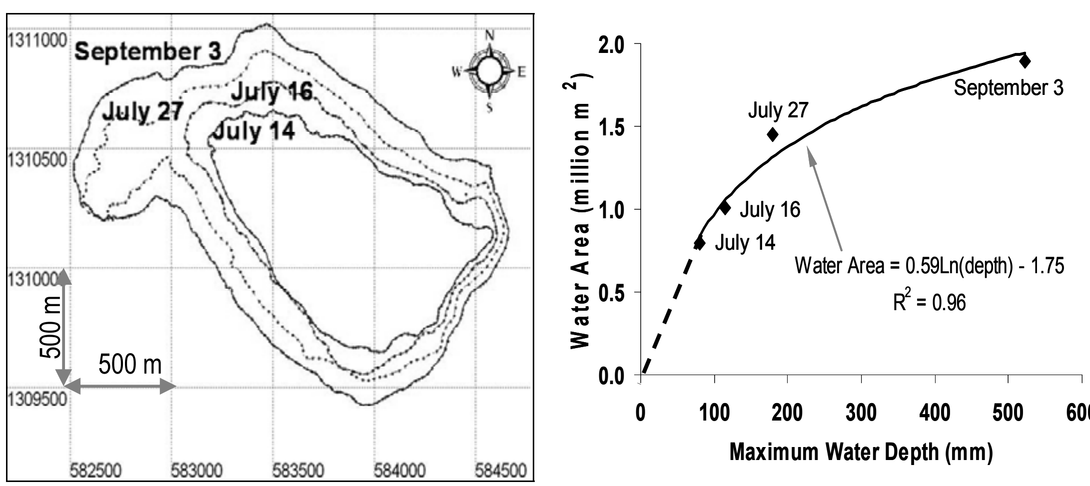


Figure 4.2. Hara wetland (a) GPS measured surface water boundary expansion during 2004 (coordinates in meters; UTM Zone 37) and (b) the water depth–surface area relation (equation and solid line – logarithmic regression fit; dashed line – linear fit)

Panchromatic aerial photos taken in November 1964 and 1986 were acquired from the Ethiopian Mapping Authority. The scanned aerial photos were georeferenced using ground control points taken with a Garmin GPS72 unit.

A combination of field observations and computer terrain analysis of a digital elevation model (DEM) were used to delineate catchment boundaries. All computer analyses of land cover and terrain were performed in Manifold GIS System Release 6.50. Locations, elevations, and the catchment boundary were crosschecked with the Ethiopian Mapping Authority's 1:50,000 scale topographic maps of Weldiya and Dana (produced in 1994 based on 1986 aerial photographs).

RESULTS AND DISCUSSION

Local perceptions of the wetland

Residents of Hara watershed currently derive many benefits from Hara Swamp which is located centrally in the watershed. Table 4.3 presents reasons respondents liked the presence of the wetland in their watershed and Table 4.4 presents their concerns. 92% of respondents liked having the wetland in the watershed. The primary reasons were the water and forage for livestock, the wood for cooking fuel, and the water for washing clothes that the wetland provides. Over a third of respondents said they would like to use the water the wetland stores to also irrigate crops.

The most commonly reported concern about the wetland was that it breeds mosquitoes (Table 4.4). Malaria is rampant in the area claiming lives yearly. A second common issue reported by three-fourths of respondents was the land it occupies could be used instead for crops or as livestock grazing grassland. The wetland including its

Table 4.3. Primary reasons that the respondents liked Hara wetland

Reasons	% respondents
Water for livestock	92
Water for crop irrigation[a]	41
Forage source for livestock	38
Fuel-wood source for home	31
Water for domestic use	11
Birds in/around the wetland	2
Don't like wetland	8

[a] Refers to potential use of water for irrigation; there is currently no crop irrigation

Table 4.4. Primary reasons that the respondents did not like presence of the wetland in the watershed

Reasons	% respondents
Too many mosquitoes	82
Livestock grazing area lost to flooding	72
Reduced cropland area in the watershed	72
Poor quality water source	33
Dangerous for humans	21
Dangerous for livestock	21
Public ownership of its resources	3

immediate surrounding area is publicly owned communal land with no restrictions on grazing, but cropping in the area is prohibited. Some respondents were concerned with the general danger to human health and of children or livestock getting stuck in the mud and drowning. Despite their many concerns only 8 % of respondents said they did not like the presence of the wetland in their watershed.

Remote sensing evidence and local perceptions of wetland changes

Satellite images and aerial photos from the past 40 years provide evidence of changing land cover and flood levels/area in Hara Swamp. Figure 4.3 presents aerial photos of the wetland in 1964 and 1986 and a panchromatic satellite image in 2000. It is quite apparent in these images which were all taken around the same time in the dry season that the wetland had dense woody vegetation cover in 1964 and 1986 but almost no vegetation in 2000. During the same time period the number of houses in Hara town greatly increased and a road was constructed (bottom left corner of Figure 4.3b,c). The wetland looked completely dry in 1964 (Figure 4.3a), very wet or possibly slightly flooded in 1986 (Figure 4.3b), and completely flooded in 2000 (Figure 4.3c).

Composite satellite images of the Hara watershed provide further evidence of recent hydrological and vegetation changes in the wetland. Figure 4.4 presents false color composites from 1973, 1986, 2000, and 2001 all taken less than two months apart during the dry season. In these images vegetation appears green, water dark color, and soil a combination of red and blue. Within the wetland area at the center of the watershed there appears a large area of dense vegetation in 1973. The 1986 image appears to have the least vegetation cover of all images. This could be because 1984 was a drought year and 1985 had below average rainfall (rainfall is presented in the

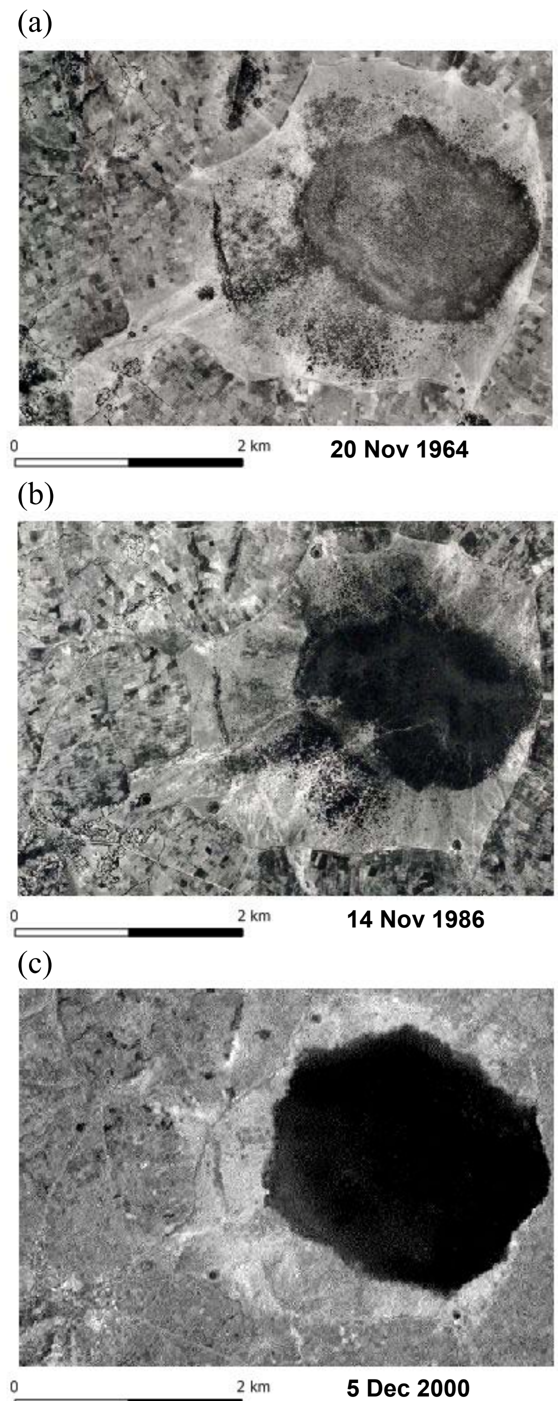


Figure 4.3. Aerial photos of Hara swamp (a) 20 November 1964 and (b) 14 November 1986, and panchromatic Landsat image (c) 5 December 2000.

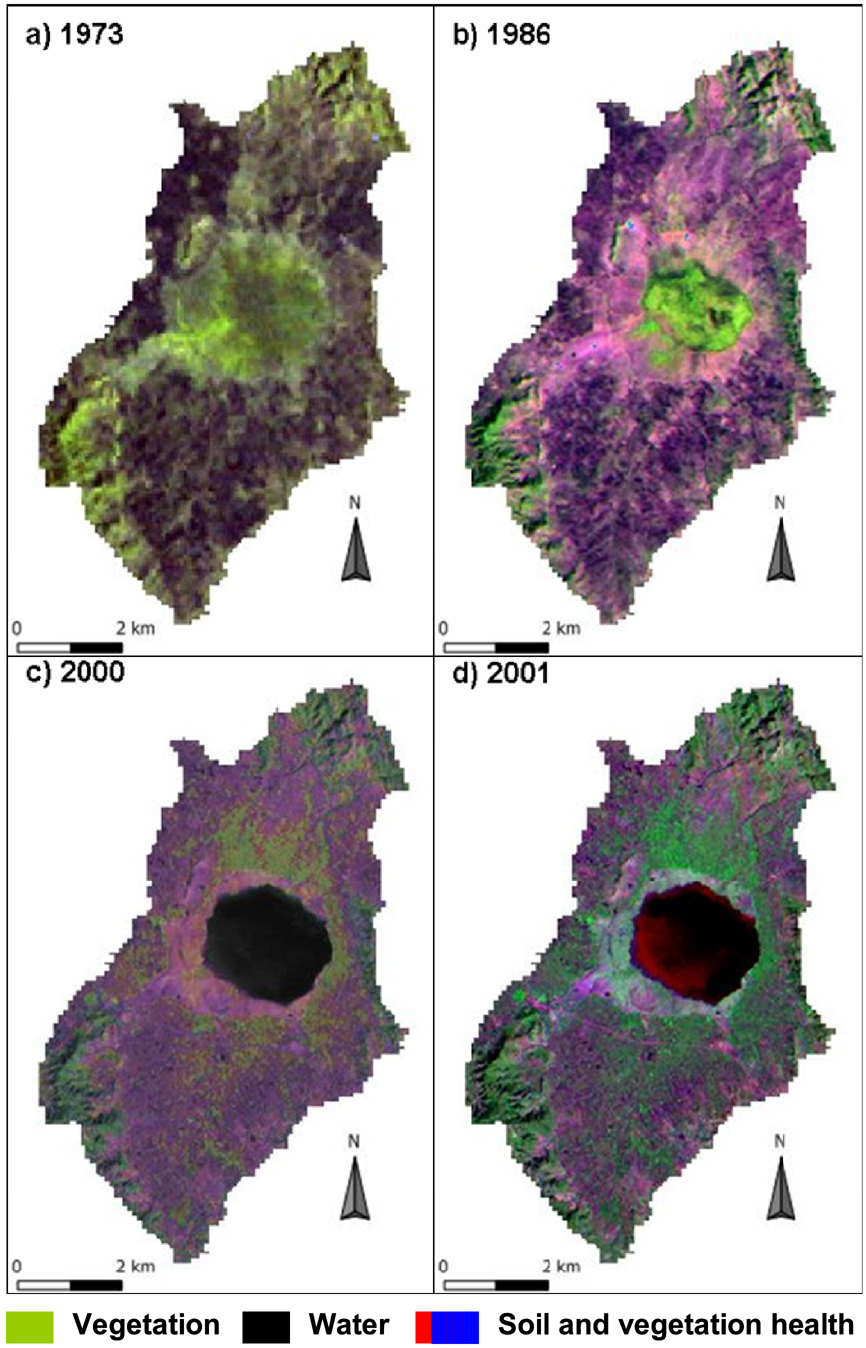


Figure 4.4. Landsat false color images (a) 31 January 1973, (b) 5 January 1986, (c) 5 December 2000, and (d) 5 December 2001

next section). In 2000 the wetland was completely flooded and there was little evidence of vegetation within it. The 2001 condition was similar to 2000 except for the reddish coloring to the west side of the wetland. This coloring suggests heavy sedimentation.

Local residents' perceptions of recent changes in Hara Swamp are in agreement with the information obtained from the remotely sensed images that were collected after the survey. Table 4.5 presents survey respondents perspectives of wetland changes. 84 % of the respondents said that over the past 30 years the annual maximum flood levels have greatly increased and all respondents said that in the past the wetland used to have almost no flooding. When asked how long ago the flooded conditions started the responses varied from 15 to 58 years ago with 81 % of respondents saying 20-30 years ago. All respondents said that sedimentation has also greatly increased in the wetland during the past 30 years.

Hara watershed residents also reported recent drastic changes in the wetland vegetation cover (Table 4.5). All respondents said there used to be dense trees, bushes, shrubs, and grass in and around the wetland 30 years ago. In 2004 when the survey was conducted there were no living trees or bushes within or near the wetland. Figure 4.5 shows the open water condition in 2004 as well as the numerous dead tree trunks which provide evidence of previous conditions. It is not known why all the trees are dead but a likely explanation are the longer and higher floods during recent years (Tiner, 1999). Although the wetland is officially classified on Ethiopian Mapping Authority maps as a swamp (i.e., wetland dominated by woody vegetation) based on past conditions it is more accurately described as a marsh (i.e., wetland dominated by grass and sedges) now. The northwestern part of the wetland had dense sedge (Cyperus latifolius) growth during kremt 2004.

Table 4.5. Perceptions of difference in current wetland condition compared to the past

	Now compared to:	No. of respon-dents	% respondents (now compared to the past)				
			Much less	Little less	Same	Little more	Much more
Maximum wetland flood area	Last year	56	4	12	84	-	-
	5 years ago	54	13	15	2	59	11
	30 years ago	54	9	7	-	-	84
Water quality now compared to 30 yrs ago		58	97	-	3	-	-
Sedimentation now compared to 30 yrs ago		52	-	-	-	-	100
Vegetation now compared to 30 yrs ago	Trees	58	100	-	-	-	-
	Bushes	58	100	-	-	-	-
	Shrubs	49	100	-	-	-	-
	Grass	43	100	-	-	-	-
Bird population now compared to 30 yrs ago		57	100	-	-	-	-

The information obtained through the survey of local residents confirmed and supplemented what the satellite images suggested. Given the snapshot nature of remote sensing historic evidence and the lack of hydrological records in this small watershed, and in Ethiopia in general, the complementarity of the local perceptions input was important to better validate our understanding of recent environmental trends.

Figure 4.5. Open water and numerous dead tree trunks are indicators of changing flood levels and vegetation cover at Hara Swamp (photo taken May 2004)

Rainfall records

There is the possibility that rainfall variation could explain the trend and some of the interannual differences in wetland flooding and vegetation cover observed in the satellite images. Figure 4.6 presents rainfall records for Hara town, Kobo (45 km northwest of Hara), and Weldiya (16 km west of Hara). Rainfall records for Hara only include 1977-81 and 2003-2004. During the years with gaps in the record Hara rainfall is predicted/estimated based on linear regression of Kobo and Weldiya rainfall records which together cover, except for a few gaps, the period of 1955-2003 (see Figure 4.6).

Weldiya has much higher rainfall than Hara and Kobo due to its 500 m higher altitude of about 1950 m.a.s.l.. Annual rainfall depth at all stations was very erratic, as is common in northern Ethiopia (Seleshi and Zanke, 2004), with coefficients of variation

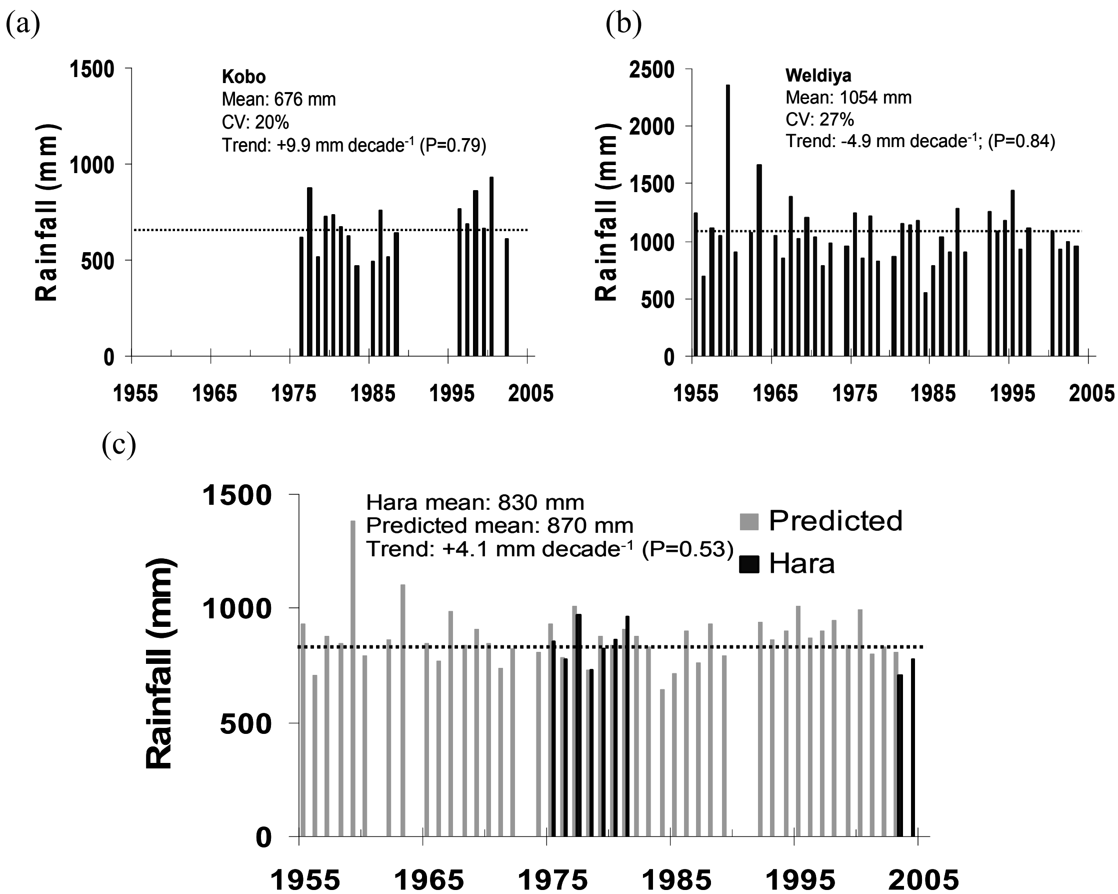


Figure 4.6. Annual rainfall records and trends: (a) Kobo 45 km northwest of Hara, (b) Weldiya 16 km west of Hara, and (c) Hara town actual and predicted based on linear regression of Kobo and Weldiya records (R^2 = 0.92, P = 0.02 for years with both Kobo and Weldiya records; R^2 = 0.52, P = 0.07 for Weldiya records only)

(CV) over 20%. There were no significant (P<0.05) trends in rainfall depth at any of the rainfall recording stations (Figure 4.6). In addition, the slight statistically insignificant positive rainfall trend at Hara was too small to explain the rapid wetland flood area increases observed during the last 40 years. Although only 6% of survey respondents reported climate as a reason for wetland changes, 100% of respondents said that rainfall in the area has significantly declined during the past 30 years. However, the rainfall records do not support this perception. Similarly, Meze-Hausken (2004) in an intensive study in the neighboring regions of Afar and Tigray found a widespread perception of decreasing rainfall during the past 20-30 years although the available rainfall measurements did not show any declining trend. The author determined some possible reasons for the local perceptions of a downward rainfall trend were environmental changes which have caused decreased moisture/water availability in the landscape, declining land productivity, and people's changing needs for rainfall (Meze-Hausken, 2004).

Rainfall distribution within the year could also affect the level of flood water. Figure 4.7 presents rainfall in Weldiya during the 12 months prior to when the satellite images in Figure 4.4 were captured. Total rainfall was not significantly different between the years except for 1985-86 which had the lowest rainfall. 1984 was a drought year with 48 % below normal depth in Weldiya. This can explain why in the January 1986 satellite image there is relatively little vegetation cover in the Hara watershed (see Figure 4.4b).

The seasonal distribution of rainfall was quite different between the years. A significant amount of rainfall in 1972 occurred during belg (April) while 2000 and 2001 had larger kremt seasons (Figure 4.7). The larger kremt season could possibly result in a higher flood level during the following dry season. Despite the difference in 2000 and 2001 rainfall depths the flooded areas were similar (Figure 4.4c, 4.4d).

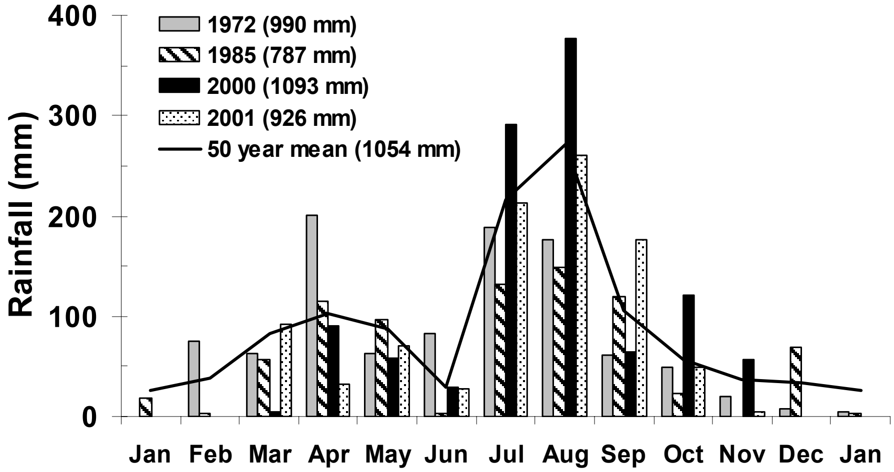


Figure 4.7. Monthly rainfall at Weldiya during the years prior to the satellite images

Overall, rainfall variation cannot sufficiently explain the trend of increasing annual flood water in the wetland. The long-term decline in wetland woody vegetation could be explained in part by the 1984/85 drought period but this is unlikely a sole reason because the area previously had similar droughts in 1956 and 1971 (see Figure 4.6b) which apparently did not decimate the extensive vegetation cover seen in 1973 (Figure 4.4a).

Hydrological assessment of wetland floods

An assessment of the wetland hydrology is important to understand possible reasons for the drastic increase in the flood level/area. Given that rainfall amounts have not changed significantly, the observed trend of greater flood levels suggests that there are either increased surface runoff amounts entering from the catchment or more rainwater infiltration in the catchment raising the groundwater level. We explore these hypotheses using measurements of wetland water budget components during kremt

2004 to determine the relative contribution of runoff and groundwater inflow to the wetland flood levels. These results are then compared to local perceptions.

A simple approximation of wetland water budget components was computed based on the monitored rainfall, pan evaporation, and wetland water level. The components of the water budget were related by the equation,

$$\Delta V_f = P_f + R_{in} - E_f - R_{out} + Q_{subsurface} \qquad (3)$$

where ΔV_f is change in wetland flood volume, P_f is rainfall directly over the wetland flood area, R_{in} is runoff inflow from the surrounding catchment, E_f is evaporation from the wetland flood area, R_{out} is surface outflow which was zero due to the topography of the surrounding catchment, and $Q_{subsurface}$ is net subsurface water flow through the wetland bed soil below the flood area.

Figure 4.8 presents monthly rainfall, evaporation, and temperature in the Hara watershed during 2003-04. Evaporation rates (E) were calculated from pan evaporation based on multiplication by the common lake coefficient factor of 0.70 (Haan et al., 1994). Mean evaporation rates exceeded rainfall during all months except August 2003 with a daily average of over 5 mm day^{-1}. Although most months during the year received some precipitation, 83 % of annual rainfall was concentrated during the two rainy seasons of belg (March – April) and kremt (July – September). Rainfall (P) during the study period of kremt 2004 (July – October) totaled 490 mm or 60 % of the annual rainfall.

Hara wetland water level responded rapidly after the commencement of the kremt 2004 rains. Figure 4.9 presents the mean daily wetland surface water level and rainfall. The wetland water level varied from almost dry at the beginning of the kremt season

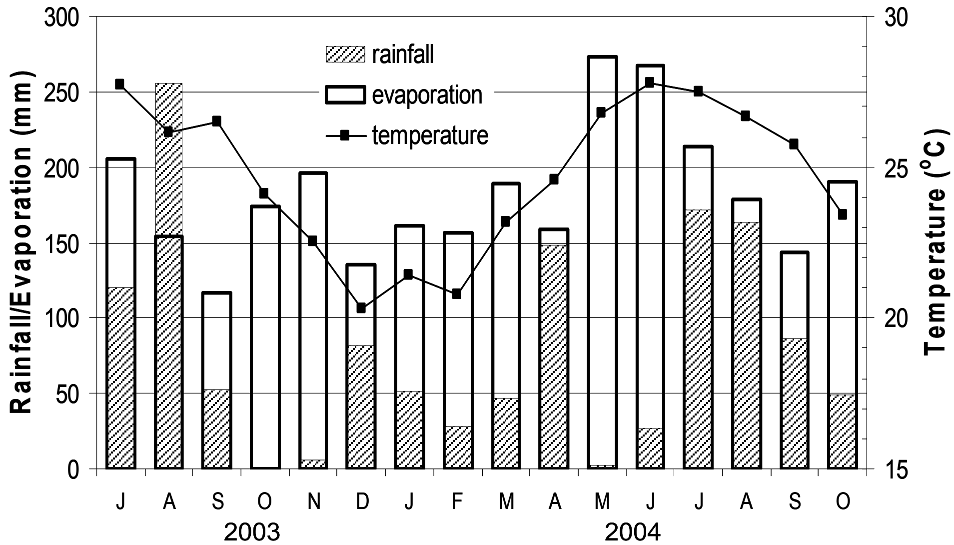


Figure 4.8. Monthly rainfall, evaporation, and ambient temperature in Hara watershed (2003-2004)

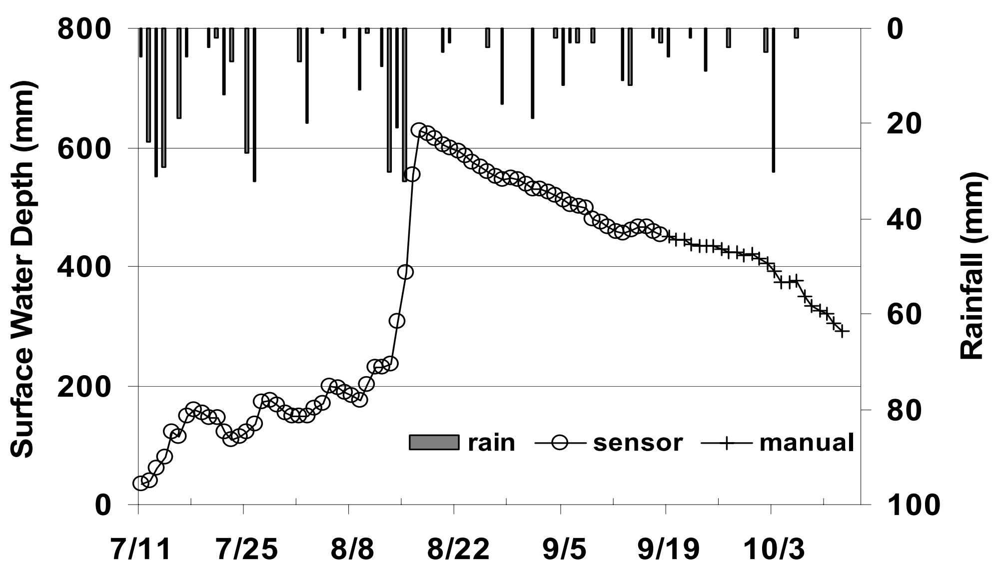


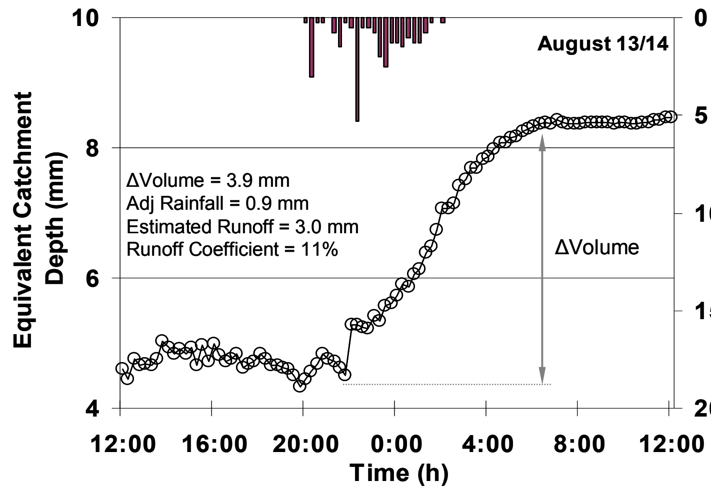
Figure 4.9. Mean daily maximum wetland surface water depth and rainfall during 2004

to 64 cm water depth covering over 200 hectares of land area during August. The surface water level responded rapidly to rainfall resulting in stepwise increases in water depth (rather than gradual increases) as the rainy season progressed. This type of rapid hydrologic response represents primarily surface runoff, and possibly limited rapid subsurface interflow (Brutsaert, 2005). During days without significant rainfall events the wetland water level declined rapidly suggesting relatively high evaporation losses and possibly downward percolation to the groundwater table (Figure 4.9).

The surface runoff (R_{in}) contribution to the wetland water volume can be estimated as the rapid change in wetland water volume during and for several hours immediately after storms. Figure 4.10 presents the stepwise depth increases observed for two storms and the method for estimating runoff volume for each storm. The surface water level started increasing shortly after the beginning of intense storms and often within 8 hours after rainfall terminated, the water level stopped increasing and began to decrease gradually (see Figure 4.10). Table 4.6 summarizes the seasonal runoff contribution from all major storms during kremt 2004. Runoff varied greatly across events with 73 % of the seasonal runoff occurring over a 3-day series of storms during August 13-15. The mean runoff coefficient (runoff depth as a percentage of the event rainfall depth) for all storms (listed in Table 4.6) was 5 %. This is an underestimate of actual seasonal runoff from the watershed because it does not take into account the rapid water losses into the soil and large cracks near the wetland during initial flooding of dry areas at the beginning of the rainy season.

Using the estimated runoff contribution, the measured evaporation and rainfall, and the recorded wetland storage depth, the groundwater contribution ($Q_{subsurface}$) during the kremt season was estimated based on the relationship in equation (3). Table 4.7

(a)



(b)

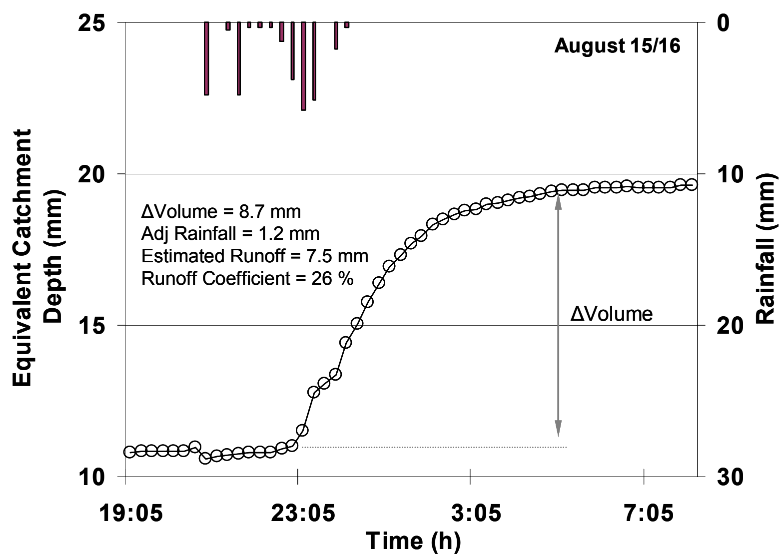


Figure 4.10. Storm runoff estimation based on wetland surface water volume increase during and for several hours after rainfall minus contribution from direct rainfall over the wetland flood area: (a) 13 August and (b) 15 August. Equivalent storage depth and rainfall are at 15-minute intervals. (Adj rainfall is the total rainwater volume falling directly over the wetland flood area expressed as an equivalent depth over the entire catchment).

Table 4.6. Runoff estimation (calculated as wetland surface water volume change during and for up to eight hours after major storms minus the contribution from direct rainfall over the wetland flood area).

Date	Δ Storage (mm)[a]	Rainfall[b] (mm)[a]	Runoff (mm)[a]	Coefficient of runoff (%)[c]
7/13/04	0.6	0.3	0.3	1
7/14/04	0.8	0.6	0.2	1
7/16/04	0.9	0.5	0.4	2
7/17/04	0.4	0.2	0.2	3
7/22/04	0.4	0.2	0.2	3
7/25/04	1.0	0.5	0.5	2
7/26/04	1.5	0.8	0.7	2
8/9/04	1.5	0.5	1.0	6
8/13/04	3.9	0.9	3.0	11
8/14/04	2.3	0.9	1.4	6
8/15/04	8.7	1.2	7.5	26
8/29/04	0.7	0.5	0.2	2
9/2/04	0.4	0.3	0.1	1
9/13/04	0.7	0.4	0.3	3
9/15/04	0.8	0.5	0.3	2

[a] Water volume expressed as an equivalent depth over Hara catchment area; [b] Volume of rainwater falling directly on wetland flooded area; [c] Runoff depth as percentage of rainfall depth over the entire catchment area.

presents the water budget for the Hara Swamp during the kremt 2004 period. All budget components are expressed as the depth equivalent of water volume distributed over the entire catchment area. Direct rainfall (P_f) and evaporation over the wetland flood area (E_f) were calculated as volumes based on the daily rainfall depth (P) and daily evaporation (E), respectively, and the corresponding mean daily wetland flood area (A_f) determined with equation (1). Runoff (R_{in}) contributed 49 % of total inflows. Given the shallow depth and large surface area of the wetland, it is not surprising to find that the remaining 51 % of inflow was from direct rainfall onto flooded areas (P_f).

Table 4.7. Hara wetland estimated surface water budget during kremt 2004 (7/11/04 – 10/1/04)

Estimated Parameter	Direct rainfall inflow	Runoff inflow	Evaporation loss	Δ Surface storage	Subsurface flow
Equivalent depth over catchment (mm)	17.1	16.3	17.5	15.4	-0.5
% of total inflow	51	49	52	46	2

The major loss (outflow) was evaporation (E_f) accounting for 52 %. There was an estimated minor net outflow to the groundwater ($Q_{subsurface}$) during the budget period (Table 4.7), but this is not very accurate as it includes all the errors in the other terms. Moreover, it is probably an underestimate because the runoff inflow calculation method does not account for initial water infiltration during wetting of the dry wetland bed. The wetland maintained 46 % of the total inflow as surface storage at the end of the rainy season in October.

The wetland hydrologic response to rainfall and the simple water budget analysis demonstrated that the variability in annual wetland high flood level was controlled by the amount of surface runoff entering from the catchment. Considering that surface runoff is the primary inflow the increase in wetland flood area during the past 40 years indicates that changes in the catchment have resulted in higher runoff amounts. Also, higher sedimentation rates, which often accompany increased runoff, might have contributed some to increasing flood areas by filling in the wetland bottom changing the water depth-surface area relationship. The creation of more impermeable surfaces in the watershed, such as the large increase in the number of houses (in Hara town especially) and the construction of the main road (apparent in the 1986 aerial photo but not in the 1964 aerial photo) to Afar region observed in the remote sensing images (Figure 4.3), can account for a large portion of the increased runoff and sedimentation over time. This is in accordance with Nyssen et al. (2002) who found that after construction of the Mekele-Adwa road in the adjacent region of Tigray increased runoff led to numerous severe gully formations offsite.

Local perceptions of reasons why the wetland has changed in recent years also confirmed the indications from the water budget analysis and remote sensing data (Table 4.8). The reasons given by the residents included increased erosion/gullying and runoff from the watershed and from the hillsides and Hara town in particular. Watershed land cover changes to fewer trees and increased cropland area were also given as reasons. 61 % of respondents said that the wetland changes are a consequence of human population increase. All respondents provided estimates of the watershed human population as more than doubling during the past 30 years. Except for the explanation of decreased rainfall (Table 4.8), the residents' perceived reasons for changes in the wetland (which were collected first) were plausible and well supported by the hydrological assessment data and the remote sensing images.

Table 4.8. Primary reasons for changes in Hara wetland during the past 30 years

Reasons	% respondents
Increased watershed erosion/gullying	79
Increased human population	61
Increased runoff from hillsides	46
Decreased number of trees in watershed	38
Increased runoff from Hara town	23
Increased cropland area	15
Increased livestock numbers	8
Decreased rainfall	6
Don't know	2

Implications of wetland changes for the local communities

The changing condition of the wetland and its contributing catchment has direct impacts on the benefits and concerns enumerated by the local population (Table 4.3 and Table 4.4). The expanding wetland flood area is reducing the critically needed grazing area for livestock. The water quality deterioration with increased sedimentation is reducing the ability to use the water for domestic purposes. The remaining woody vegetation which a third of respondents depend for cooking fuel has been killed possibly by the increased floods and will soon completely disappear. The increased runoff from the watershed means less water is available for the rainfed crops upon which this food insecure population depends. The high sedimentation entering the wetland is a result of erosion degrading land productivity in the watershed. These are some of the major implications of the recent trends found in Hara Swamp and Hara watershed. An integrated watershed management strategy is required to address these issues and to reverse the current trend.

CONCLUSION

Hara Swamp provides unique water and plant resources to the residents of Hara watershed who overall appreciate its presence in close proximity despite mosquito breeding and other concerns. Analysis of aerial photos and satellite image composites suggested that the current condition of the wetland is a drastic change from previous conditions of dense tree and bush cover and limited flooding 40 years ago. Rainfall records revealed no significant trends which could explain the changes observed in the wetland. Hydrological measurements and a simple wetland water budget suggested that increased surface runoff from the catchment produced the higher flood levels. Local residents' perceptions of the wetland in the past and reasons for changes to the present condition better validated and supplemented the information from the limited remote sensing and hydrological data. The integrated approach of understanding recent trends in the landscape through complementary methods provided better information for environmental planning in this data scarce area.

ACKNOWLEDGEMENTS

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CHAPTER FIVE

WATER RESOURCES FOR THE LENCHE DIMA WATERSHED COMMUNITIES, LIVESTOCK, AND CROPS: A BASELINE SURVEY*

EXECUTIVE SUMMARY

The USAID-funded (United States Agency for International Development) AMAREW (Amhara Micro-enterprise development, Agricultural Research, Extension and Watershed management) Project and Amhara State Regional institutions (Bureau of Agriculture, Amhara Regional Agricultural Research Institute, Environmental Protection Land Administration and Use Authority, etc.) are testing an integrated watershed management approach to development in two pilot watersheds in Gubalafto and Sekota woredas, Amhara State, northeastern Ethiopia. This chapter presents the results of a survey study of 87 households conducted in the Lenche Dima pilot watershed (Gubalafto woreda) at the beginning of the second year of project implementation to assess the watershed communities' currently accessed water resources and their water concerns, needs, and preferred development options. The survey results provided baseline water resources information for development planning and for evaluation of the integrated watershed management development efforts in the Lenche Dima pilot watershed.

The Lenche Dima watershed communities identified human, livestock, and crop water resource problems as among their primary constraints and their first priority for the

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* McHugh, O.V., B. Abebe, T.S. Steenhuis. Water resources for the Lenche Dima watershed communities, livestock, and crops: A baseline survey report. USAID-funded Amhara Micro-enterprise development, Agricultural Research, Extension, and Watershed management (AMAREW) Project, 22 May 2004, Bahir Dar, Ethiopia.

integrated development efforts in their watershed. During 2003 households in the watershed accessed, on average, more than 3 different water sources during the course of the year to assure their domestic and livestock water. The accessed domestic and livestock water resources include gully sand bed holes, community earthen ponds, and a dysfunctional generator-powered groundwater pump distribution system located within the watershed and a large shallow wetland, perennial rivers, open wells, natural springs, and a well maintained generator-powered groundwater pump system located outside the watershed. Current domestic water consumption is 5-12 liters per person per day which is well below the generally recommended minimum of 20 liters daily for personal hygiene, sanitation, and healthy living. Gender involvement in assuring water varies with source location and water use. Domestic and water from sources closer to home are predominately assured by female members of the household while there is higher male participation for livestock water and water sources farther from home.

There was no irrigated cropland located within the Lenche Dima watershed. However, some residents (14 % of all survey respondents), and especially those living in the Hartibo subcatchment (42 % of Hartibo respondents), cultivated irrigated plots in the Alewuha valley river irrigation scheme located outside the watershed. Average irrigated land area for these households is 0.9 timad (< 0.25 hectare). Although high-value non-cereal crops are cultivated in the Alewuha irrigation scheme, none of the survey respondents from the Lenche Dima communities grew crops different from their non-irrigated land during 2003.

Community identified problems with current domestic and livestock water resources varied with water source type. Bad water quality and health concerns were major problems for the community ponds, gully sand beds, wetland, and open well sources. Insufficient year-round water supply was a problem for all the accessed water sources except for the perennial rivers (outside the watershed). Many households complained about the far walking distance (2 to 5 hours walking roundtrip from home) for the perennial rivers, springs, and wetland sources. Other problems survey respondents listed mainly for the generator-powered pump system within the watershed were frequent system disrepair, slow maintenance, high labor for the recent replacement of the pump distribution system broken pipes, and the relatively high user price of pump water (especially too expensive to purchase for both livestock and domestic water needs).

The domestic and livestock water resource development options preferred by the survey respondents in the Lenche Dima communities were improved performance and reliability of their pump water system and further development of community ponds within their watershed.

The chapter concludes with some recommendations on water resources development for the Lenche Dima watershed communities. Recommended domestic and livestock water developments options included enabling sustainable community management of their current groundwater pump system; improving existing community ponds and limited construction of new ponds; and expansion and improvement of roof-water harvesting for all homes and buildings with suitable roofs. Irrigation development recommendations included promotion of high-value crops, better maintenance of the entire water system and equitable water sharing in the Alewuha irrigation scheme located outside the watershed. Development of various water resources for supplementary irrigation (such as on-farm or hillside reservoirs, water harvesting schemes, groundwater wells, etc.) should also be tested on a small scale within the watershed before widespread implementation.

INTRODUCTION

As part of a strategy to achieve food and water security while protecting the environment through sustainable land use development, an integrated watershed management (IWM) approach to development was tested in two pilot watersheds (Lenche Dima and Yeku) in Amhara National Regional State (ANRS), northeastern Ethiopia. The pilot sites were to serve as IWM models and examples that can be eventually extended throughout the ANRS. The major advantages of the IWM approach were involvement of those most affected by the decisions (i.e., the stakeholders) in all phases of the development of their watershed and holistic planning that addressed issues which extend across subject disciplines (biophysical, social, and economic sciences) and political boundaries (village, PA, woreda, zone, etc.).

The study reported in this chapter collected survey data in the Lenche Dima pilot watershed (Gubalafto woreda, North Wollo zone) about household water use, the domestic, livestock and crop water resources accessed by the communities living within the watershed, the concerns and problems with each water resource, and which water resources the watershed residents preferred to develop to solve or alleviate their water concerns. This study was conducted during the beginning phase of implementation of the IWM development approach in the Lenche Dima pilot watershed. The results of the study assisted in understanding current conditions and water development needs and constraints in the watershed. The results also provided baseline water resource survey data to which future survey data can be compared to objectively evaluate the results and impacts of the IWM development efforts in the Lenche Dima watershed.

METHODS

A survey of 87 households (consisting of 445 people) was conducted in the Lenche Dima watershed communities during the dry season from December 2003 to March 2004 (1996 E.C.). The 1550 hectare Lenche Dima watershed is located adjacent to the town of Hara in the Gubalafto woreda, North Wollo zone, Amhara Regional State in northeastern Ethiopia (N 11^{o}49.2'-11^{o}52.1', E 39^{o}41.3'- 39^{o}44.6'). The study site included the 12 largest of 15 villages within the watershed (Table 5.1). The watershed had four main village clusters or units (locally called Got) which were Lenche Dima, Kolo Kobo, Oromo, and Hartibo. These village clusters also happened to form separate subcatchments within the study watershed (see Figure 5.1 in the Results section). The survey was divided into the four village clusters since each of the subcatchments had different characteristics due to its location in the watershed and also because the governmental (BoA, ARARI, EPLAUA, etc.) and non-governmental agencies (USAID-funded AMAREW Project and SCF-UK/R2D Project) working in the watershed, in cooperation with the Lenche Dima communities, had established separate community management committees for each subcatchment (referred to as watershed management units; WMU) under the overall community watershed management organization (CWMO). This division of the study also enabled collection of location-specific information for better development planning.

A structured survey questionnaire was used to interview at least 20 heads of households (HHH) in each subcatchment (Table 5.1). All interviews were conducted in the local language (i.e., Amharic) by a university diploma-level natural resources management field specialist (Mr. Berihun Abebe). The interviewer was trained during pre-testing of the questionnaire.

Table 5.1. Survey sites and characteristics of respondents

Subcatchment	Lenche Dima	Kolo Kobo	Oromo	Hartibo	Overall
Unit Number	WMU #1	WMU #2	WMU #3	WMU #4	
Villages	Lenche Dima, Gerado, Kembelta	Kolo Kobo, Orani, Addis Kebele	Oromo, Tulu Bademi, Kile Gora	Abohla Gunda, Sefed Anba, Eroge	Entire Watershed
Households surveyed	20	23	20	24	87
Poor HH (0-1 ox)	6	10	7	4	27 (31%)
Medium HH (2 oxen)	9	11	12	13	45 (52%)
Rich HH (>2 oxen)	5	2	1	7	15 (17%)
Female head of HH	4	3	2	1	10 (11%)

HH: household

Households were selected to include the rich, medium, poor, and some women headed households. The wealth classification was based on a local definition of wealth which accounted for the number of oxen owned by the household with the poor having 1 or less, medium 2 oxen, and rich 3 oxen or more*. This classification was similar to that used by other studies in the area (Chapman and Desta, 1999).

Most of the respondents were selected at random, but in cases where the random process did not produce significant representation for a particular wealth group or women headed households the village officials and other randomly encountered residents in the village helped identify which households fit into the category. Other than efforts to assure some representation from the three wealth groups and women headed households, selection of the households was random with no preset quotas. Comparing the overall percent of interviewed households (i.e., the survey sample) in each wealth group with that reported by Chapman and Desta (1999) for the population in the North Wollo east plain food economy zone, the representation of wealth groups was quite similar except for a slight underrepresentation of poor and overrepresentation of medium in the current study. Considering that random selection of households in this survey produced a high percentage of medium households, and so poor households were sought and intentionally selected, suggested that the percent poor population in the Lenche Dima watershed communities might be less and percent medium population more than in the larger area (Gubalafto, Habru, and Kobo woredas) surveyed by Chapman and Desta (1999).

Group discussions, key informant interviews, and site visits were used to gather additional information and to explain findings of the structured household survey. Information obtained through group discussions and individual informants (i.e.,

* Oxen ownership is the simplest method of identifying wealth class. Not everyone in the community considers only oxen ownership for wealth class. Total livestock ownership, certain types of off-farm income, and a regular source of external monetary remittances are also commonly considered.

members of the local water committee, health workers at the Hara health post, and other residents from Lenche Dima) are noted accordingly in this report.

RESULTS

Population and environmental conditions

Environmental conditions

The Lenche Dima watershed is located at the lower limits (1,465-1,900 m.a.s.l.) of the highlands of northeastern Ethiopia (~545 km highway distance from Addis Ababa) about 16 km east of Weldiya town in North Wollo Zone. The watershed drains into Alewuha River and eventually into the Awash River basin. The climate is dry sub-humid with about 840 mm rainfall per year average and is characterized by intense erosive storms with high temporal and spatial variability. During normal non-drought years (the area has recurrent droughts) total rainfall is divided between two distinct rainy seasons which are belg (March and April; approx. 200-250 mm) and kremt (July, August, and September; approx. 450-550 mm). Annual temperatures are hot for the highlands with mean daily maximum of 33^{o}C during June and mean daily minimum of 12^{o}C during November (Gizaw et al., 1999).

The population

The Lenche Dima watershed communities had a total estimated population of 3,375 (Gizaw et al., 1999) living in 15 villages mainly located along the hillsides forming the periphery of the central cropland area of the watershed (see Figure 5.1). The watershed population was characterized as low-income rural agrarian with over 96 % of households earning income from crop production (McHugh et al., 2004a). Livestock production was the second most common source of income (excluding external aid/food relief). The livestock population was estimated at 1,458 TLU (Gizaw et al., 1999) consisting mainly of cattle, goats, donkeys, chicken, and, to a lesser extent, camels and sheep. There was very little reported involvement (3 %) in regular off-farm income activities during 2003. Most of the population (92 %) received external food aid to meet annual household food requirements (McHugh et al., 2004a).

Households in the watershed had on average over 5 members with fewer members for poor households and more for the richer ones (Table 5.2). 59 % of the population was younger than adult age (21 years) and 7 % were elders (60 years and over). The male population was 30 % higher than the female due to out-migration of females for work and marriage. The adult literacy and primary school completion rates were low at 13 % and 1 %, respectively. Household labor was divided into farm work for mainly male adolescents and adults, domestic activities for females and children, and daily livestock care mainly for children and adolescents both male and female (McHugh et al., 2004a).

Table 5.2. Population characteristics during 2003

Characteristic	Poor	Medium	Rich	Overall
Household size	4.3	5.1	6.7	5.1
Offspring/children living at home per HH	2.2	2.8	3.8	2.8
% population literacy	14	10	14	12
% offspring/children in school	12	9	16	10

HH: household

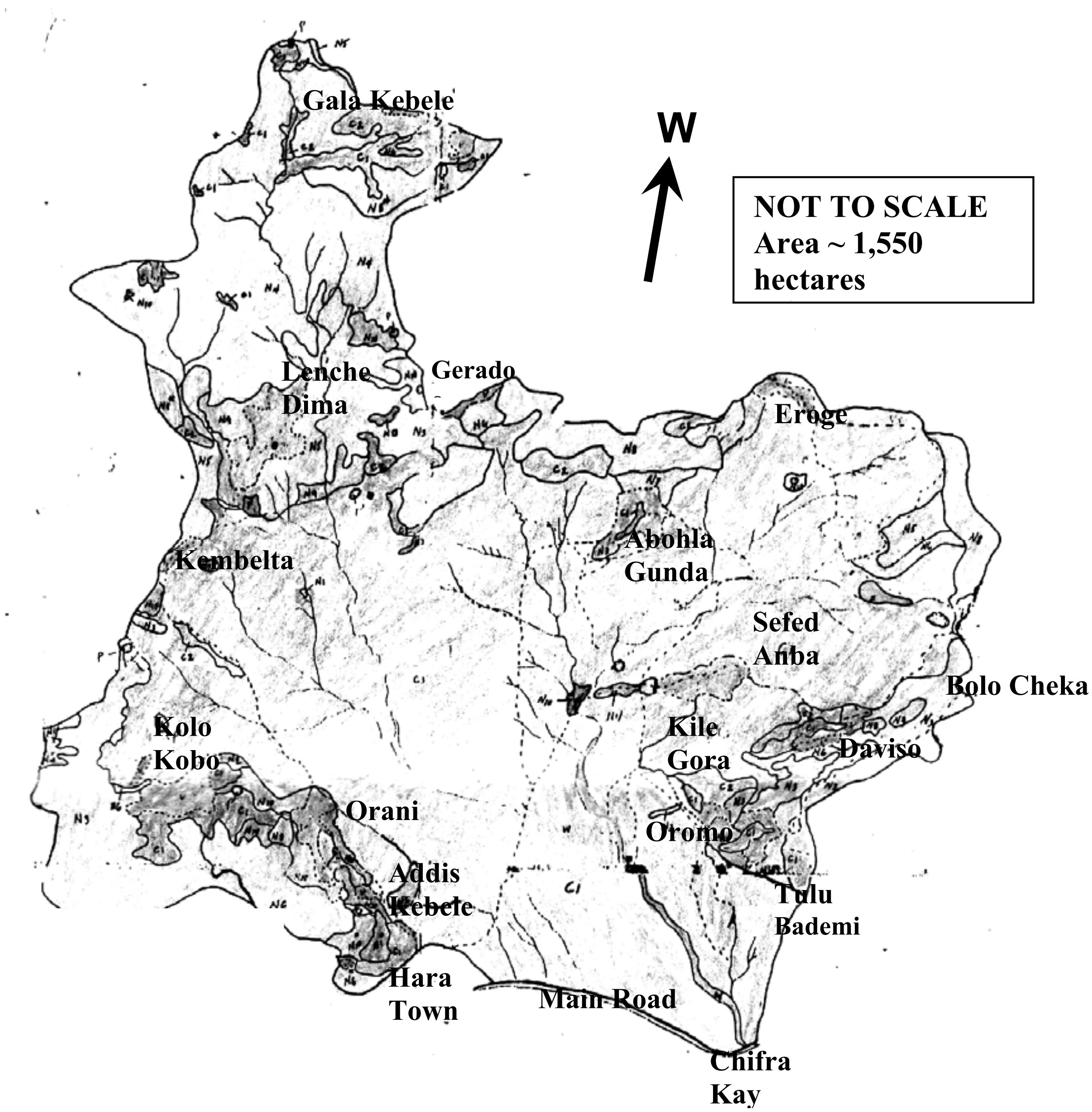

Figure 5.1. Map of Lenche Dima watershed communities (source: adapted from Belay 1999 Lenche Dima Land Use/Cover Map)

Domestic water

Water sources

Domestic water is the water used for human drinking, cooking, cleaning, and bathing. Table 5.3 presents the percent households in Lenche Dima watershed using various water sources at some time during the year. Most households (95 %) got their domestic water at some time during the year from water pumps. There was one generator-powered groundwater pump (called Oromo pump in this report because of its location near Oromo village) in the watershed which delivered to four water distribution points (see Figure 5.2) with one in each of the four subcatchments. In addition, in Hara town, which is adjacent to the Kolo Kobo subcatchment (see Figure 5.1), there was a water pump with several public distribution points close to each other around the center of town. When the Oromo water pump was broken or not fully functioning (during 1995 E.C. the pump operated for 2 discontinuous months total providing water to only the Oromo and Lenche Dima faucets), 71 % of the households interviewed (Lenche Dima = 65 %; Kolo Kobo = 100 %; Oromo = 90 %; Hartibo = 33 %) said they obtained water from the Hara pump. The difference between subcatchments using the Hara pump was probably because Kolo Kobo and Oromo were relatively closer to Hara town while Lenche Dima and Hartibo were quite far for transporting water (see Figure 5.1).

A majority (77 %) of households in all subcatchments, except Kolo Kobo (43 %), used community pond water for domestic purposes. Pond water was generally of less quality (see Figure 5.2) than pump water and half the area of Kolo Kobo subcatchment (i.e., Addis Kebele and Orani villages) was quite close to the Hara pump which provided reliable and clean water. These were the reasons for a lower percent of Kolo Kobo residents using pond water domestically. There were 9 functioning earthen community ponds distributed within the watershed (see Table 5.4). All these ponds were constructed more than 20 years ago according to the 2003 Lenche Dima/Laste Gerado Kebele chairperson Ato Sissay Mengsha. No private ponds were found in the watershed.

Table 5.3. Percent of households using source for drinking/domestic water (2003)

Source	L. Dima	Kolo K.	Oromo	Hartibo	Overall
Water pump	100	100	100	83	95
Community ponds	70	43	100	100	77
Rivers/perennial streams	75	0	45	79	49
Gully/storm flow	0	22	50	79	39
Open well	5	0	0	17	6
Hara wetland	0	0	0	0	0
Springs	25	0	0	0	6
Mean number of domestic water sources per HH during year	3.9	1.6	4.5	4.3	3.6

HH: household

A majority of households in Lenche Dima and Hartibo subcatchments, and almost half (49 %) of the households in the watershed, used river water for domestic purposes. There were no rivers or perennial streams within the watershed. The rivers accessed by the watershed population were quite far from all the villages inside the watershed. Because of the easily accessed Hara pump water, no one from Kolo Kobo made regular use of water from rivers for their home.

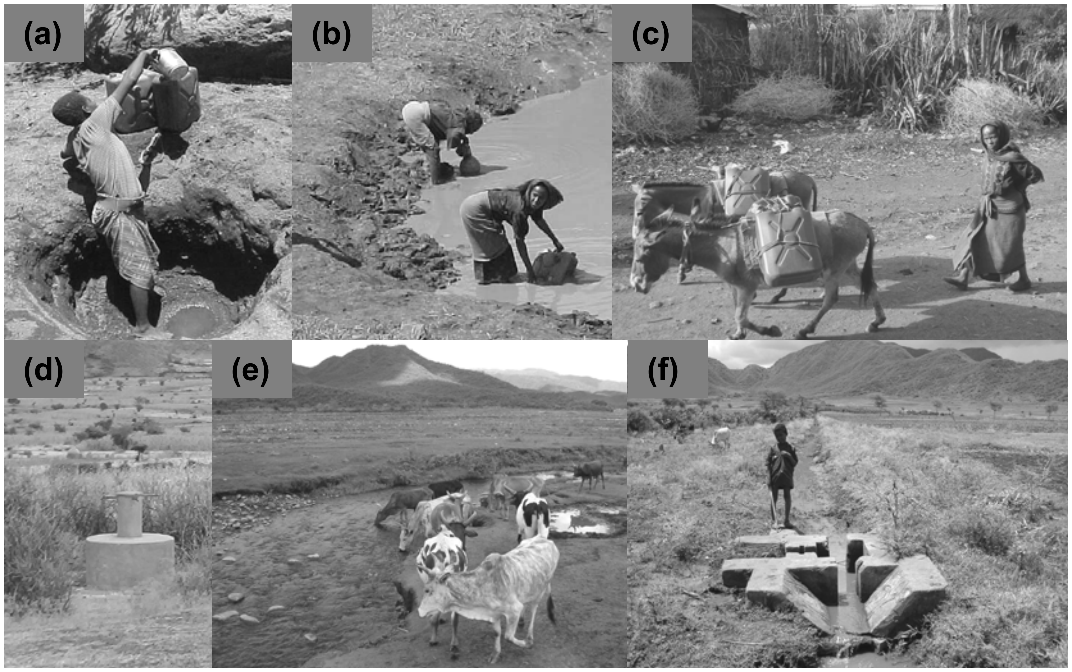

Figure 5.2. Water resources in the Lenche Dima watershed: (a) a gully-bed hole; (b) an earthen pond; (c) transport of Hara pump water; (d) a pump distribution point; (e) the Alewuaha river; and (f) an irrigation canal in Alewuaha irrigation scheme

Less than half (39 %) of households used storm flow and/or streambed water from gullies. Gully flow occurred only during and after medium to large storms and lasted for a maximum several hours after the rain stopped. After the flow stopped people also collected water from small scattered pools inside the gullies. The most common method to access water in gullies was by digging holes in the streambed sand and gradually filling the containers by dipping up water that seeped into the hole (see Figure 5.2). Streambed water can be collected for several days following a runoff-producing storm event.

A few households (see Table 5.3) in the Lenche Dima and Hartibo subcatchments got water from open wells and natural springs located a long walking distance outside the watershed. No one was found who uses Hara wetland, which was of large size, for domestic purposes because of the poor quality of the stagnant water. A few roof water harvesting structures were found in the watershed mainly at mosques which had corrugated metal roofs. This water was often used for ablutions so that everyone did not need to carry water from home when coming for prayers and devotions.

Table 5.4. Community ponds in the Lenche Dima watershed

ID	Location	Size	Primary Use	Condition
1	Gerado	Small	Livestock	Poor
2	Lenche Dima	Medium	Livestock	Very Poor
3	Lenche Dima	Medium	Livestock	Not Functioning
4	Kolo Kobo	Small	Livestock	Poor
5	Kolo Kobo	Large	Domestic	Good
6	Tulu Bademi	Very large	Domestic	Good
7	Kile Gora	Medium	Domestic	Good
8	Sefed Anba	Large	Domestic	Good
9	Sefed Anba	Very small	Livestock	Poor
10	Bolo Cheka	Large	Domestic	Poor

Most households (except in Kolo Kobo subcatchment which met most of its needs from the Hara pump) obtained domestic water from four or more different water sources during the course of the year (Table 5.3). Several interrelated factors (discussed in more detail below) including seasonal availability, water quality, water cost, source proximity, and regulations on use determined which water sources were accessed for domestic purposes by whom at any particular time of the year.

Method and labor of water transport

Most domestic water was transported from the source to home for use. Washing of clothes (about once per month) and other personal items and human bathing (about twice per month) often occur at or near the water source while drinking, cleaning, and cooking water was transported daily to the home. A combination of human and animal power was used to transport the water in jerricans, clay pots, rubber sacks, and other locally produced containers. On average households transported and consumed one to four, with most using two, 20 liter jerricans per day in their homes. The average domestic water use of 5-12 liters per person per day was considerably below the generally recommended 20 liters daily for personal hygiene, sanitation and healthy living (Kerr et al. 1989).

The use of animal versus human power and male versus female member of the household to transport water to the home varied with many factors including the water source type, source distance from the home, household wealth (i.e., access to donkeys or camel), and household composition (size, age and gender). Table 5.5 presents the transport methods. Generally as the source distance from home increased male and animal (almost exclusively donkeys; see Figure 5.2) participation increased. For the rivers and springs, which were the farthest away, animals were used either exclusively or in combination/rotation with human power by a majority (~ 80 %) of households. For the ponds and gullies which were the closest to homes over 60 % of households used only human power for transport. Of the accessed water sources on average 46 % of households used only human power, 24 % used only animal, and 30 % used a combination of animal and humans to transport the water to home. Richer households used animals for water transport more frequently (for 70 % of accessed sources) than the medium wealth (54 % of accessed sources) and the poor (43 % of accessed sources).

Table 5.5. Gender of labor and transport method for domestic water by source (% of households)

Water Transport	Pump	Pond	River	Gully	Well	Spring	Mean[a]
Only female	66	66	26	53	40	60	58
Only male	13	18	46	24	20	20	19
Both genders involved	21	16	28	23	40	20	23
Only humans	42	67	21	62	80	20	46
Only animals	23	12	42	0	20	80	24
Both humans and animals	35	21	37	38	0	0	30

[a] Mean across sources

The transport of domestic water was primarily performed by females. Of the accessed household water sources on average 58 % of households were by only females versus 19 % only males. For the most frequently accessed domestic water sources (i.e., pumps and ponds) female participation in assuring water was over 82 % of households and only females performed the task in 66 % of households. Male involvement in transporting water for home use was significant for distant sources such as rivers (males involved in 74 % of households, partly because collecting river water is combined with the task of watering the livestock) and, for closer water sources such as pumps, ponds, and gullies, often because there were no females or no capable female (i.e., good health or proper age) in the household to do the work. Collecting gully water sometimes involved a lot of digging in the streambed after each runoff event. Digging was done by both males and females, but in cases requiring a shovel and for deep excavations it was considered male's work.

Livestock water

Livestock water refers to the drinking and cleaning water provided to farm animals. With the large livestock population and the value of livestock as assets, as an income source, and for food production, the Lenche Dima communities placed high importance on reliable water access for livestock. Cattle (including oxen), goats, donkeys, and, to a lesser extent, sheep, camels, and chicken constituted the majority of livestock water demand in the watershed.

Table 5.6 presents the percent households accessing various water sources for their livestock. The main water sources were rivers, wetland, community ponds, and gullies. Rivers were the primary livestock water source with 90 % of households accessing them (see Figure 5.2). Over half of all surveyed households (56 %) took their livestock to Hara wetland, but with lower use by Lenche Dima (5 %) and Hartibo (42 %) subcatchments because of their relatively long distance from Hara (see Figure 5.1; the wetland was located about 45 minutes walk southeast of Hara town). Pond water was also accessed by 56 % of all households, but only 20 % of households in Oromo because the ponds near it (i.e., the Tulu Bademi and Kile Gora ponds) were primarily for domestic use (see Appendix). Half of the population obtained water for livestock from gullies after rain storms, but none of the survey respondents in the Lenche Dima subcatchment accessed gullies because they said that the rocky nature of the gullies in their subcatchment made water collection difficult.

A few households (≤ 8 %) used pump, spring, and open well water sources for livestock (Table 5.6). Although these sources were reliable and have good quality water their supply was limited, so households preferred to use them mainly for domestic purposes. Pump faucet water was purchased and households were generally not willing to buy (at the 2003 rates of 0.10 birr per animal) enough water for their entire domestic and livestock water demands. There was one cement trough next to the Oromo and Lenche Dima pump distribution faucets which animals could access with payment, but, according to a group discussion, due to the cost only oxen were watered there and often only during land preparation (i.e., peak tillage) times.

Table 5.6. Percent households using various water sources for livestock (2003)

Source	L. Dima	Kolo K.	Oromo	Hartibo	Overall
Water pumps	10	4	20	0	8
Community ponds	85	52	20	67	56
River/perennial stream	80	83	95	100	90
Gully/storm flow	0	65	50	79	50
Open well	5	0	0	12	4
Hara wetland	5	83	95	42	56
Springs	25	0	0	0	6
Mean number of livestock water sources per HH during year	2.6	3.2	3.5	3.0	3.1

HH: household

On average each household accessed more than three different water sources during the year to assure livestock water. As in the case of domestic water, there were several interrelated factors including seasonal availability, cost, source proximity, and regulations on use (discussed in more detail below) that determined who took which livestock to what source at any particular time of the year.

Labor

The labor required to assure livestock water generally involved taking the livestock to the water source (unlike domestic water which required carrying most, if not all, the water to home). The exceptions to that were for some livestock (such as poultry and unhealthy or young animals which were unable to travel to the source) and for some water sources (pumps, springs, open wells, and some of the community ponds which did not allow livestock to directly access the water, so humans had to transport (i.e., carry) the water outside the restricted area for the animals to drink).

Table 5.7 shows gender involvement in assuring livestock water by source. For the main livestock water sources (i.e., rivers and wetland) most households (> 87 %) involved males in the work largely because livestock watering was combined with the task of animal grazing in the extensive grassland areas surrounding the wetland and rivers. Female involvement was high (74 %) for ponds and gullies (70 %) due to their proximity to home and also because females went to these locations anyways to fetch water for domestic consumption (see Table 5.3), so they combined the two tasks. Female involvement was also high for the less used livestock water sources (pumps, springs, and wells) which were also accessed for domestic purposes.

Table 5.7. Gender of labor to assure livestock water by source (% of households)

Gender	Pump	Pond	River	Gully	Well	Wetland	Spring	Mean[a]
Only female	86	56	13	36	25	4	60	29
Only male	0	26	69	30	25	88	20	51
Both genders	14	18	18	34	50	8	20	20

[a] Mean across sources

Water for crops

Irrigation capacity

Irrigation provides crops with water during periods of inadequate rainfall. Given frequent rainfall shortage and unreliability in the plains of the North Wollo zone of Ethiopia, irrigation capacity is essential to maximize and stabilize year-to-year grain yields and for production of high-value crops such as vegetables, fruit, and spices.

Table 5.8 presents the land resources and irrigated area of the surveyed households in the Lenche Dima watershed. Only 14 % of households in the watershed cultivated land with developed irrigation capacity. No household was found in the study which irrigated cropland located inside the watershed. All irrigated land was located outside the watershed boundaries as presented in Figure 5.1.

The ownership/rental of irrigated land was not evenly distributed between subcatchments. 83 % of the interviewed households with irrigated land lived in the Hartibo subcatchment. Lenche Dima and Oromo subcatchments only had one household each (5 % of respondents in each subcatchment) with irrigated land while the Kolo Kobo subcatchment did not have anyone with irrigated land. All irrigated plots were in the Alewuha river plain irrigation scheme* (see Figure 5.2) which was located outside the Lenche Dima watershed to the north and northwest of the Hartibo subcatchment. The proximity of the Hartibo subcatchment to Alewuha was the reason for their greater ownership of irrigated land.

Table 5.8. Household land resources and irrigation (2003)

Description	L. Dima	Kolo K.	Oromo	Hartibo	Overall
Total cropland area per HH (timad)	8.5	7.9	8.5	12	9.3
% total cropland area rented	33	20	31	40	32
% total cropland area irrigated	0.3	0	0.3	3	1
% irrigated area rented	0	0	0	37	33
% HH with some irrigated land	5	0	5	42	14
Irrigated area per irrigating HH (timad)	0.5	0	0.5	1.0	0.9

HH: household

For the watershed as a whole only 1 % of the total cultivated area of households interviewed had irrigation capacity. About 1/3 of the irrigated area was rented with cash or harvest sharing arrangements (for more on land rental see McHugh et al., 2004a). On average, households who had access to irrigated land cultivate 0.9 timad (< 0.25 hectares) of irrigated area.

* The Alewuha irrigation scheme included both traditional irrigation methods and a more modern surface irrigation system built by the Amhara Region Co-SAERAR organization and was managed (2003) by the BoA and woreda offices in collaboration with the irrigation land owners and kebele water committees.

Irrigated crops

The crops cultivated by households from the Lenche Dima watershed on irrigated plots during 2003 were the same as found on non-irrigated plots, but with a particularly higher preference for maize than on non-irrigated plots. The crops cultivated on irrigated plots were 18 % teff (vs. > 50 % non-irrigated), 6 % sorghum (vs. > 40 % non-irrigated), 76 % maize (vs. 27 % spring/belg and 6 % summer/kremt non-irrigated), 0 % chickpeas (vs. > 1 % non-irrigated), and 0 % (vs. 1 % non-irrigated) other crops. All irrigated plots were planted during both rainy seasons (spring/belg and summer/kremt) and all repeated the same crop during the two seasons. A few farmers, but none of those interviewed, also planted crops on the Alewuha irrigated plots during the dry season (bega).

Other crops found on the southern side of the Alewuha irrigation scheme (i.e., near the Lenche Dima watershed), but not cultivated during 2003 by the households interviewed from the Lenche Dima watershed, included chickpeas, chili peppers (berberi), sugar cane, onion, potatoes, and cabbage. Discussions with Alewuha farmers revealed that crop selection for irrigated land depended, among other things, on plot location in the irrigation scheme (plots farther from the river source and from the distribution channels received less water), lack of knowledge/extension help about high-value crops, reliability and amount of seasonal/yearly rainfall, and regulation of water use by the local water committees and water users.

Income from irrigated crops

Most of the crops harvested from irrigated plots by the interviewed households during 2003 were not for sale but were for home consumption. All the harvest from 18 % of irrigated plots (vs. 9 % of non-irrigated plots) was consumed by the households, half or more of the harvest was consumed by households and the rest sold on 82 % of irrigated plots (vs. 90.5% of non-irrigated plots), and on none of irrigated plots (vs. 0.5 % of non-irrigated plots) was more than half of the harvest sold.

Irrigation increased production for the interviewed households by enabling two, and in other cases three, seasons of cultivation per year on all irrigated (vs. less than 1/4 of non-irrigated) plots and by increasing crop yields due to reduced crop water stress during periods of the season with rainfall shortage.

Gender of labor on irrigated plots

Farm work in the Lenche Dima communities was mainly performed by males (McHugh et al., 2004a). On the irrigated plots female involvement was even less. On 76 % irrigated plots (vs. 30 % non-irrigated plots) only males worked and 24 % irrigated (vs. 70 % non-irrigated plots) both males and females worked. In this case, the likely reason for the difference in gender participation was because the irrigated plots were in the Alewuha plain which was far from home (over 3 hours average roundtrip walking distance). Most females in the Lenche Dima watershed worked on their home plots and plots closer to their homes (McHugh et al., 2004b).

Domestic and livestock water resource problems

Source problems

The survey asked households to discuss any difficulties or complaints they had for each water source they used. Table 5.9 presents the results. Of all the water resources accessed for domestic and livestock water supply, households reported the fewest problems with the pump sources which had an average of 1.1 complaints per household and 84 % of households reporting at least one problem. The most complaints were for pond water which had an average of 2.6 complaints per household and all households reported at least one problem. The following sections discuss the various problems and complaints raised by the watershed residents for each water source.

Water quality and water-related health concerns

Poor water quality and harmful effects on human health were listed by most households for the pond, gully, and open well water (Table 5.9). Open wells were reported to have good quality water during the dry season, but during the rainy seasons storm runoff contaminated these sources. Due to the high runoff and erosion rates in the watershed, pond and gully water, which consisted of water from storm runoff, contained a lot of suspended sediment (highly turbid) and debris. The high clay content of soils in the watershed led to a lot of very slow settling colloids and sediment in the ponds. No, or very few, households had latrines or toilets and there was a high population of livestock in the watershed. Storm runoff washed and transported human and animal wastes which contained pathogens into ponds, gullies, and open wells. 59 % of survey respondents reported stomach health problems caused by their drinking water. Waterborne skin disease was also widely reported during individual discussions with residents. According to the Hara dispensary health workers the common problems for the area were amoeba and ascariasis, in addition to others which they were unable to diagnose due to lack of a medical laboratory.

For the other water sources (wetland, rivers, pumps, springs) fewer than 5 % of households reported water quality and health concern problems. None of the interviewed households used wetland water for domestic purposes because the wetland was stagnant and its water was totally unfit for human consumption. That was the reason why bad quality was not considered when listing problems with wetland water (i.e., respondents were likely not thinking in terms of problems for livestock consumption). The river water was clear and had relatively good quality water except after runoff-producing rainfall events when a lot of sediment and debris entered from land adjacent to the river and upstream. No water quality problems were reported for pumps and natural spring water.

Table 5.9. Percent households using water source reporting problems with the source

Problem	Pump	Pond	River	Gully	Well	Wetland	Spring
Poor water quality	0	97	4	87	60	4	0
Bad for human health	0	88	2	43	60	4	0
Malaria/mosquito breeding	0	64	16	37	40	42	0
Insufficient supply	46	87	9	85	80	64	100
Too far from home	25	1	92	0	20	96	100
High labor for maintenance	17	1	0	2	0	0	0
Expensive water	5	N/A	N/A	N/A	N/A	N/A	N/A
Disrepair/slow maintenance	25	0	N/A	N/A	0	N/A	N/A
% HH reporting at least one problem with source	84	100	100	100	100	100	100
Mean number of HH complaints for source[a]	1.1	2.6	1.2	2.1	2.0	2.1	1.9

[a] For this calculation poor water quality and unhealthy for humans were not treated as separate complaints; N/A: not applicable to the source
HH: households

Mosquito breeding and increased malaria were identified as problems by 64 % of households for ponds, but also many households listed them as problems for wetland (42 %), open well (40 %), gully (37 %), and river (16 %) water. There were some locations in and around gullies where water remained stagnant during the rainy season providing mosquito breeding areas. Although the wells, wetland, and rivers were located outside the watershed and were far distances from the respondents' homes, they were still listed as posing malaria problems. Frequent visits to these water source locations to access water and for livestock grazing increased exposure to mosquitoes and likelihood of acquiring malaria.

Availability of water supplies

For all sources, except rivers, many households reported insufficient supplies to meet water needs (see Table 5.9). Inadequacy in water supply for the sources was in some cases partly due to seasonal variability in supply (ponds, gullies, wetland) and in other cases due to the actual insufficient quantities of water available at the source to meet both the domestic and livestock needs of the communities (open wells, springs, ponds, gullies, pumps).

Table 5.10 presents the seasonal availability of water at sources and Table 5.11 presents when households reported accessing the different water sources. Pump, rivers, open wells, wetland, and natural spring water were available during all seasons of the year for non-drought years. For the generator-powered groundwater pump, water availability depended more on the maintenance, management, and operating conditions of the pump than on the season of the year. The 46 % of households (Table 5.9) reporting insufficiency in pump water supplies were referring to the frequent breakdown of the Oromo pump, the limited hours of operation, and also the fact that the pump did not provide most of the livestock water requirements of the communities.

Open wells, springs, wetland, and rivers had seasonal fluctuations in quantities of available water (i.e., more water available during the rainy seasons), but did provide some water to households at all times during the year. Discussions with the Lenche Dima watershed residents revealed that the high percentage (64 %) reporting insufficient supply of wetland water referred more to access and quality of the water than the actual amount of water in the wetland. As the wetland waters receded during prolonged periods with no rainfall the quality of the stagnant water became bad even for livestock to drink. Access to the receded wetland water also became difficult for the livestock due to the muddy and swampy conditions that had to be traversed to reach the water. When the rains arrived, the fresh water inflow improved the water quality and access to the wetland water was easier for livestock.

Table 5.10. Availability of supplies during years of normal rainfall

Season	Pump[a]	Pond	River	Gully	Well	Wetland	Spring
Spring/ Belg (March-May)	Often	Rarely	Always	Rarely	Often	Always	Always
Summer/ Kremt (June-September)	Often	Often	Always	Often	Always	Always	Always
Dry season/ Bega (October-February)	Often	None	Always	None	Often	Always	Always

[a] Availability depends more on maintenance and operating condition of pump than on season of the year

Pond and gully water were only available during the rainy seasons for years with normal rainfall patterns (Table 5.10). Pond water was more abundant and reliable during rainy seasons because of longer retention times (the water supply lasted for up to a month after major rainfall events) than gully water which was only available during storm runoff and for a few days following the rain storm in the sands of the streambed. In addition to the seasonal variation in availability of pond and gully water, when water was available it was still insufficient in quantities. Water in the sand beds of gullies was very limited in terms of accessible quantities. The current condition, distribution, sizes, number, and regulations on use of community ponds within the watershed did not assure enough water for all villages to meet their domestic and livestock water demands during the rainy season.

Households reported use of various water sources followed seasonal availability of the water source and of alternate sources (see Table 5.11). During the dry season pumps, rivers, springs, and open wells were accessed by most households for domestic water and rivers and the wetland for livestock water. During the two rainy seasons when the closer to home pond and gully water became available (i.e., during years of good rainfall), households preferred to use these water sources instead of the rivers, wetland, and natural springs which were a longer distance from home (discussed in the next section). During 2003 the belg rains were relatively good so many households accessed gully and pond water instead of the rivers and wetland water which were accessed during the belg for years of low rainfall.

Pump water use declined slightly after the dry season during the short rainy season (belg). Reported use of pump water declined even more (from 56 % to 29 % of households) during the main rainy season (kremt) because of the cheaper (cost free), and sometimes closer to home, pond and gully water.

Source location and distance from home

A major difficulty reported by households for the river, wetland, and spring water sources was the very long distance they needed to walk from home to access these sources (see Table 5.9). A quarter of households said that the pump water was too far. These households were referring to the Hara water pump and not the Oromo pump faucets located in their respective subcatchments which they normally used if it was operational (during 2003 it rarely supplied water).

Table 5.11. Reported seasonal use of water sources during 2003 (% of households)

Frequency	Pump	Pond	River	Gully	Well	Wetland	Spring
Dry season/ Bega (October-February)							
Often	44	0	79	0	100	94	80
Rarely	28	0	12	0	0	4	20
Negligible	28	100	9	100	0	2	0
Spring/ Belg (March-May)							
Often	25	4	0	11	80	4	20
Rarely	31	96	9	87	0	0	0
Negligible	44	0	91	2	20	96	80
Summer/ Kremt (June-September)							
Often	28	100	9	98	80	4	20
Rarely	1	0	0	0	0	0	0
Negligible	71	0	91	2	20	96	80

Table 5.12 presents the average reported walking time roundtrip from home to the water sources used by the Lenche Dima watershed communities. Community ponds and gullies were the closest to homes with an average of 24 minutes walking time roundtrip. The water pumps were the closest year-round water source. The reported distance to water pump faucets was higher than would exist if the Oromo water pump operated regularly because most households during 2003 used the Hara pump increasing their walking distance. In the Hartibo subcatchment the open wells were close, but for the Lenche Dima subcatchment the walking time was about 2 hours each way to the wells from home. The river, wetland, and spring sources were very far (2 to 5 hours walking distance roundtrip from home) demanding high amounts of daily time and energy (labor) to access.

Table 5.12. Mean walking distance/time in hours roundtrip from home to water sources

Source	L. Dima	Kolo K.	Oromo	Hartibo	Overall
Water pump	1.4	0.7	0.9	0.9	1.0
Community ponds	0.3	0.2	0.4	0.5	0.4
Rivers/perennial streams	5.0	4.4	2.8	3.4	3.8
Gully/storm flow	N/A	0.3	0.5	0.4	0.4
Open well	4.0	N/A	N/A	0.9	1.5
Hara wetland	4.0	2.3	2.4	2.9	2.5
Springs	3.3	N/A	N/A	N/A	3.3

N/A: not applicable

Table 5.13 lists the locations of the water sources used by the Lenche Dima watershed communities. Ten of the 24 water source locations (excluding numerous gully locations) accessed by the communities during 2003 were located outside the watershed. There were 5 pump water locations with one set of faucets in each of the four subcatchments and several sets of faucets within Hara town. There were nine functioning community water ponds all located inside the Lenche Dima watershed. The Hartibo subcatchment benefited from close access to four ponds. There were three perennial stream locations (Alewuha, Chereti, and Doro Giber), two open wells, and two springs accessed by the residents of the watershed. Seven major gully locations were named by the survey respondents although the total number of gully locations was numerous. The only wetland in the area was located in a wide shallow depression northeast of Hara town.

Labor for source maintenance

Few respondents identified maintenance labor demands as problems for any of the accessed water sources (Table 5.9). Rivers, springs, open wells, and the wetland did not require any significant amount of maintenance work by the communities. The community ponds required limited yearly maintenance to remove accumulated sediment and debris; repair pond embankments, spillway, and inflow channels; and to manage the pond enclosure and surrounding vegetation. All this labor was freely provided by the subcatchment communities and was organized by the kire, eder, or tertim (traditional non-governmental community associations) chairperson with technical support from the BoA (Gubalafto Bureau of Agriculture). The gullies required regular maintenance labor to re-dig the water access holes that were filled with sand after each major runoff event.

Table 5.13. Number of different locations accessed for each type of water source

Source	L. Dima	Kolo Kobo	Oromo	Hartibo	Overall[a]
Water pump distribution points	2 Hara, Begido	1 Hara, Kolo Kobo	3 Hara, Oromo, Ababanble	2 Hara, Oromo, Ababanble	5
Community ponds	3 Gerado, Lenche Dima, Kolo Kobo	2 Kolo Kobo (2)	2 Kile Gora, Tulu Bademe	4 Kile Gora, Sefed Anba (3)	9
Rivers/ perennial streams	3 Alewuaha, Chereti, Doro Giber	2 Alewuaha, Chereti	1 Alewuaha	1 Alewuaha	4
Gullies/storm flow	0	3 Kolo kobo, Mate bege, Menchu gora	3 Oromo, Sefed Anba, Wulawle	2 Ababanble, Sefed Anba	7
Open well	1 Chereti, Wodey Mada	0	0	1 Wodey mada	2
Wetland	1 Hara	1 Hara	1 Hara	1 Hara	1
Springs	2 Doro Giber, Woday	0	0	0	2 Sum = 31

[a] Total number of different locations used by the interviewed households in the watershed

Labor for maintenance of the water pump system was identified as a concern by 17 % of the survey respondents. During 2003 the Lenche Dima watershed communities were involved in vast repairs of the pump water distribution system mostly replacing broken plastic pipes with newly installed steel pipes. This was the reason for the respondents listing the pump water sources as requiring high labor for maintenance.

During normal years (i.e., no new major installations) the pump system required a minimal amount of labor for maintenance and repairs.

Source disrepair and consumer cost of water

All the water sources, except the water pumps, were accessed for free by all members of the communities without any monetary payment. Users of the water pump were required to pay per container of water they collected and per animal for livestock that drank from the pump-fed water troughs. The costs (water fees) were 0.10 Ethiopian birr per 20-25 liter jerrican, 0.05 birr per 10-liter container, and 0.10 birr per animal to access the water troughs. The water fee collected by the local pump management committee was used to pay for the pump-generator fuel and oil and for the salaries of the pump operator (80 birr per month) and the water fee collectors (40 birr each per month) at each water distribution point. The guards of the Oromo pump were not paid and the work was arranged on a rotation basis being provided by community members. According to the Oromo pump operator, the amount of money collected from the water fees just covered operation costs and was insufficient to pay for maintenance of the generator/pump and the water distribution system or for occasional repairs by outside technicians. Thus far, these costs have been mainly covered by outside sources such as the Gubalafto Woreda government and international aid agencies with the community providing labor help.

Only 5 % of households complained about the cost to buy water from the pump sources. During group discussions local residents of the watershed said the pump water prices were affordable for domestic purposes, but expensive to buy for all their livestock water needs.

Another complaint about the Oromo water pump was its frequent breakdown and extended periods of disrepair (Table 5.9). During 1995 E.C. (2003) the Oromo pump, according to the pump operator, provided water for a total of 2 months and only to the Oromo and Lenche Dima faucets with none to the Kolo Kobo and Hartibo faucets (the distribution pipes to these two locations were broken). The reason for the constant disrepair was frequent breakdown of the generator system and lack of money and local technical expertise to make fast repairs. The water pump committee and community waited until external assistance was provided to pay for repairs to the generator/pump system. This assistance was most recently provided during 2003 by the USAID-funded AMAREW Project in Bahir Dar, Ethiopia.

During discussions with residents of the watershed, a problem with the water pump that was raised was the limited hours of operation when the pump was working properly. Many residents would have liked longer hours of operation. The limited hours of operation resulted in long lines of people delayed while waiting to fill their containers at the water faucets. When the pumps were fully functional hours of water distribution were from 6h-10h and from 15h-18h (according to the Hara and Oromo pump operators).

Crop water resource problems

Residents of the watershed identified lack of rainfall and crop moisture stress as their greatest constraints to obtaining high and reliable crop yields inside the Lenche Dima watershed. Since there was not any irrigation in the watershed farmers applied agronomic methods to alleviate water stress. When asked, the only practices farmers say they used to alleviate crop water problems was timing of tillage, planting, weeding, and other activities. However, there were other practices used by farmers to control erosion which also assisted in conserving soil moisture (see McHugh et al., 2004b).

The absence of developed irrigation capacity inside the Lenche Dima watershed and the community's lack of knowledge about and development of water harvesting and crop water resources were the major crop water resource problems. Although several households owned irrigated land in the Alewuha River plain outside the watershed, these farmers cultivated land far from the water diversion source and hence had limited irrigation capacity on their land. In addition to the shortage of irrigation water, during discussions farmers in Alewuha said that lack of knowledge about high-value crops and their marketing were problems.

WATER RESOURCES DEVELOPMENT OPTIONS

Domestic and livestock water

There were many possibilities for improving water resources for domestic and livestock uses given the above water problems identified by the communities. During the survey all respondents preferred that future water development focus on water pumps for domestic water and community ponds for livestock water. The respondents said the water pumps were the best because they provided good quality water and were close to their homes. They liked community ponds because they provided a close source of adequate quality water for livestock. There were other options that could be considered for improving the Lenche Dima community water resources including roof and other rainwater harvesting systems (Nega and Kimeu, 2002; Alem, 1999), open groundwater wells, manual or renewable energy (i.e., solar, wind) powered groundwater pumps, or more elaborate water resource schemes (Kerr et al., 1989), but this discussion will focus on community ponds and generator-powered groundwater pump systems since the respondents of the study all expressed interest in developing these sources.

The main issues that needed to be addressed to improve the community's access to pumped water were related to sustainable management of the currently existing system and water pricing considerations to include use of the source to meet livestock water demands. When the Oromo pump system was functioning well the local residents had very few complaints about their domestic water supplies. Sustainable management of the Oromo pump water system required community self-reliance (no or very limited dependence on external aid), technically-trained and competent operators, and an effective community-organized pump management committee as well as environmentally sustainable management of the watershed lands to ensure adequate recharge of the pump well aquifer. To achieve these requirements outside help was needed to educate, train, and organize the community and operator/management staff accordingly (i.e., community and local capacity building) and to cover initial financial costs until the community rapidly assumed full responsibility. The issue of adjusting water prices to give access to livestock required a study of how much households were ready to pay for their combined domestic and livestock water, the self-sustainable operating costs of the pump system, and the well, pump, and distribution system capacities to deliver the increased water demand.

The main issues related to further developing community water ponds for livestock used in the Lenche Dima watershed were increased water storage capacity and duration and sustainable management of the watershed lands to reduce sedimentation problems. The existing ponds had insufficient capacity to meet all livestock requirements during most of the year. Increased storage capacity and duration could be achieved by constructing more ponds and improving the current ponds. Constructing new ponds required removing more of the already insufficient watershed land (see McHugh et al., 2004a,b) from crop production and grazing. Pond improvement possibilities included increasing the capacity of individual ponds, lining of earthen ponds to reduce seepage and percolation losses, implementation of techniques such as oil film and effective wind breaks that reduce evaporation losses, reducing loss of pond capacity to sedimentation, and good management practices that protect the ponds from misuse and damage.

Water resources for crops

The absence of developed water resources for crops in the Lenche Dima watershed meant that there were numerous crop water development needs and options. Some of the possible development options are listed below. The limited local financial resources for investments, lack of land, and the degree of environmental degradation in the watershed (McHugh et al., 2004b) made some of the options hardly feasible (Inocencio et al., 2003).

Some crop water resource development options that could be considered inside the Lenche Dima watershed included:

- In-situ rainwater harvesting practices such as tie-ridges, micro-catchments, etc.
- External catchment water harvesting (problem: can require a lot of land)
- On-farm, micro-dam, or hillside storage reservoirs for supplementary irrigation (problems: require a lot of land and labor)

- Irrigation from open or pumped groundwater wells (problems: high financial investments required and a groundwater recharge study must be conducted first)
- Irrigation from and/or around Hara wetland (problems: the wetland is located considerably far outside the Lenche Dima watershed and there were community restrictions on use of the wetland water and cultivation in its surrounding areas; a feasibility study was also required)
- Better hillside management and cropland agronomic practices to increase and conserve soil moisture and groundwater

Among the main issues for developing the irrigation land owned by Lenche Dima residents in the Alewuha irrigation scheme (outside the watershed) were increased access to irrigation water for plots far from the water diversion source and agricultural extension assistance on intensive production of high-value irrigated crops and their marketing.

CONCLUSION

Residents of the Lenche Dima watershed accessed a wide variety of water sources to meet their domestic and livestock water requirements because none of the existing water sources fully provided all their water needs. Each of the water sources had its problems which made it inadequate and/or undesirable for the communities to use as their sole or primary water source. The water resource improvement options that the community preferred were development of a pump water system for domestic water and community ponds for livestock water.

Rainfall unreliability and shortage created a need to develop from virtual non-existence crop irrigation water resources in the Lenche Dima watershed. Many residents, especially in the Hartibo subcatchment, had irrigated land in the Alewuha irrigation scheme outside the watershed, but due to shortage of irrigation water and lack of knowledge about and cultivation of high-value crops Lenche Dima residents only gained marginal benefits from their small irrigated land area. There were many crop water resource development options that could be tested for the communities to improve their agricultural production.

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APPENDICES

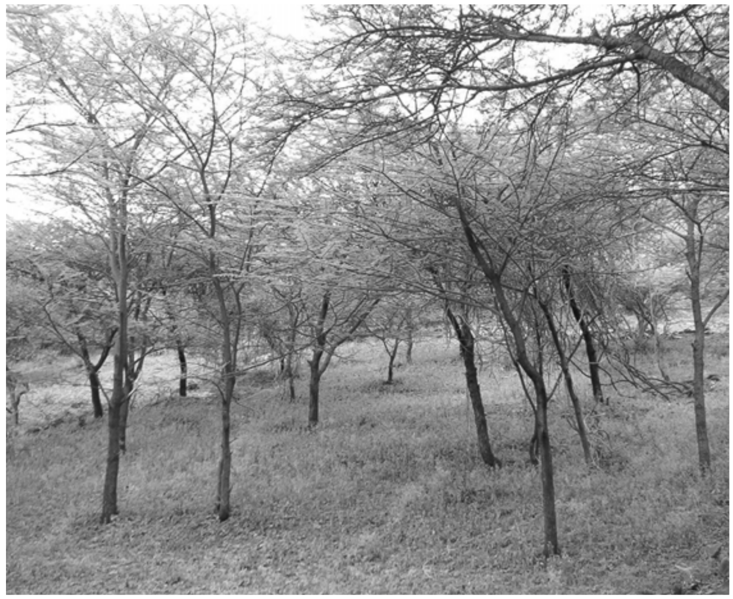
APPENDIX 1

PHOTOS OF RESEARCH SITES

Figure A1.1. Rangeland plot runoff and sediment collection system side-view

Figure A1.2. Cropland plot runoff and sediment collection system side-view

(a)



(b)

Figure A1.3. Rangelands plots (a) open forest and (b) shrub/grassland

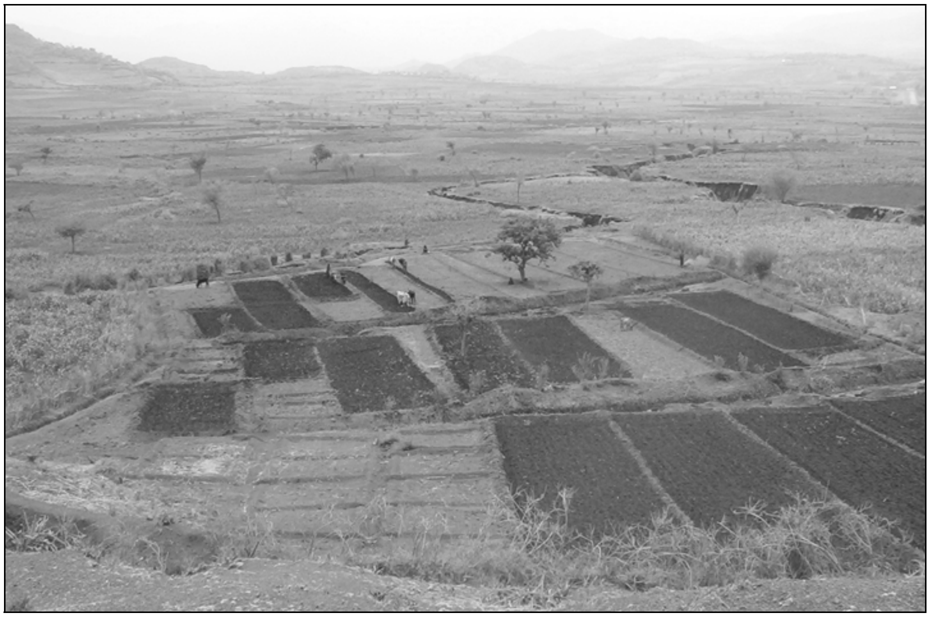


Figure A1.4. Cropland plots during land preparation

Figure A1.5. No till with sorghum stalk contour mulching

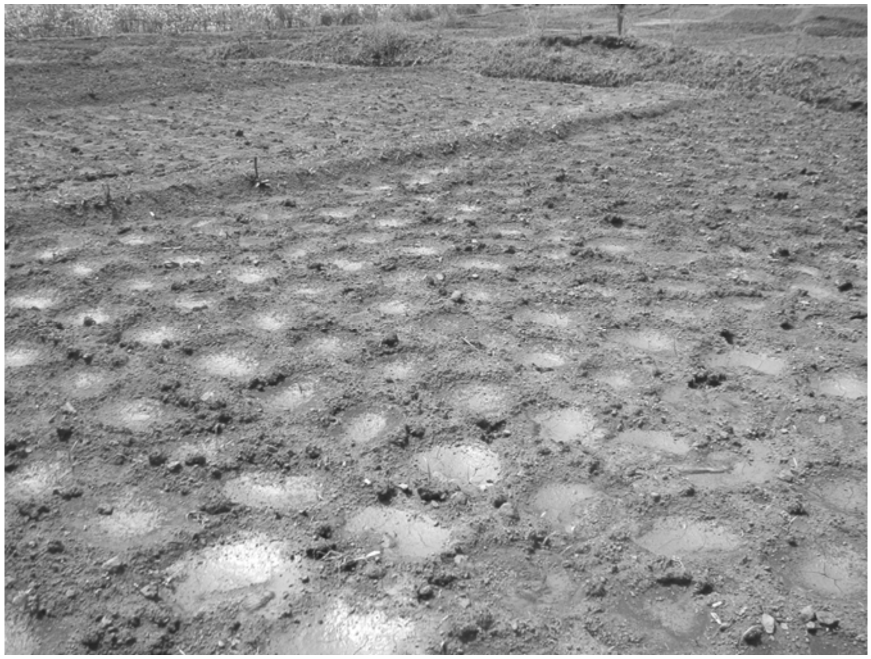


Figure A1.6. Tied ridges after a rainfall event

Figure A1.7. Ridge formation with an ox-drawn ridger

(a)

(b)

(c)

Figure A1.8. Tillage implements (a) maresha; (b) subsoiler; and (c) ridger

Figure A1.9. Evaporation pan and rain gauge installed at Hara Elementary School

Figure A1.10. Kolo Kobo hillside area closure (left side of hill)

Figure A1.11. Sandbag checkdam in Kolo Kobo catchment

Figure A1.12. Hartibo stream gauge site with automatic water height recorder

Figure A1.13. Side-view of stream gauge installation

APPENDIX 2

ADDITIONAL DATA

A. Daily rainfall

Manual rain gauge at Hara Elementary school

Date of measurement (day after rain event) and rainfall (mm)

3-Apr-03	0	1-May-03	0	1-Jun-03	0
4-Apr-03	0	2-May-03	0	2-Jun-03	0.6
5-Apr-03	0	3-May-03	0	3-Jun-03	0
6-Apr-03	0	4-May-03	0	4-Jun-03	0
7-Apr-03	0	5-May-03	0	5-Jun-03	0
8-Apr-03	0	6-May-03	0	6-Jun-03	0
9-Apr-03	0	7-May-03	0	7-Jun-03	0
10-Apr-03	0	8-May-03	0	8-Jun-03	0
11-Apr-03	0	9-May-03	0	9-Jun-03	0
12-Apr-03	0	10-May-03	0	10-Jun-03	0
13-Apr-03	0	11-May-03	0	11-Jun-03	0
14-Apr-03	0.4	12-May-03	0	12-Jun-03	0
15-Apr-03	14	13-May-03	0	13-Jun-03	0
16-Apr-03	1.8	14-May-03	0	14-Jun-03	0
17-Apr-03	33.8	15-May-03	0	15-Jun-03	0
18-Apr-03	39	16-May-03	0	16-Jun-03	0
19-Apr-03	0	17-May-03	1	17-Jun-03	0
20-Apr-03	7.3	18-May-03	0	18-Jun-03	0
21-Apr-03	0	19-May-03	0	19-Jun-03	0
22-Apr-03	79.4	20-May-03	0	20-Jun-03	0
23-Apr-03	0	21-May-03	0	21-Jun-03	0
24-Apr-03	0.2	22-May-03	0	22-Jun-03	0.8
25-Apr-03	0	23-May-03	0	23-Jun-03	4.2
26-Apr-03	0	24-May-03	0	24-Jun-03	0.6
27-Apr-03	0	25-May-03	0	25-Jun-03	0
28-Apr-03	0	26-May-03	0	26-Jun-03	0
29-Apr-03	0	27-May-03	0	27-Jun-03	0
30-Apr-03	0	28-May-03	0	28-Jun-03	0.2
		29-May-03	0	29-Jun-03	0
		30-May-03	0	30-Jun-03	6.6
		31-May-03	0		

1-Jul-03	0	1-Aug-03	50.4	1-Sep-03	1.8
2-Jul-03	0	2-Aug-03	25	2-Sep-03	0
3-Jul-03	0	3-Aug-03	0	3-Sep-03	0
4-Jul-03	1	4-Aug-03	0	4-Sep-03	0
5-Jul-03	8	5-Aug-03	0.8	5-Sep-03	0
6-Jul-03	0	6-Aug-03	28.8	6-Sep-03	0
7-Jul-03	0	7-Aug-03	7.4	7-Sep-03	2.4
8-Jul-03	0	8-Aug-03	12.4	8-Sep-03	8.4
9-Jul-03	6	9-Aug-03	5	9-Sep-03	6.4
10-Jul-03	0	10-Aug-03	16.8	10-Sep-03	0.8
11-Jul-03	0	11-Aug-03	13.4	11-Sep-03	0
12-Jul-03	20.8	12-Aug-03	24	12-Sep-03	5
13-Jul-03	0	13-Aug-03	0	13-Sep-03	1.2
14-Jul-03	0.2	14-Aug-03	4	14-Sep-03	0
15-Jul-03	0	15-Aug-03	5.4	15-Sep-03	0
16-Jul-03	3.6	16-Aug-03	0	16-Sep-03	2
17-Jul-03	0.6	17-Aug-03	43.8	17-Sep-03	0.6
18-Jul-03	0	18-Aug-03	0	18-Sep-03	0
19-Jul-03	0	19-Aug-03	14.8	19-Sep-03	0
20-Jul-03	1.8	20-Aug-03	2.2	20-Sep-03	0
21-Jul-03	0	21-Aug-03	13	21-Sep-03	0
22-Jul-03	0	22-Aug-03	6	22-Sep-03	0
23-Jul-03	1.6	23-Aug-03	0	23-Sep-03	0
24-Jul-03	1.4	24-Aug-03	0	24-Sep-03	13.4
25-Jul-03	1.6	25-Aug-03	7	25-Sep-03	0
26-Jul-03	1.6	26-Aug-03	1	26-Sep-03	2
27-Jul-03	6.8	27-Aug-03	0	27-Sep-03	0
28-Jul-03	0	28-Aug-03	0	28-Sep-03	0.5
29-Jul-03	5	29-Aug-03	0	29-Sep-03	0.5
30-Jul-03	9	30-Aug-03	0	30-Sep-03	0
31-Jul-03	1	31-Aug-03	23.6		

1-Oct-03	9.2	1-Nov-03	0	1-Dec-03	0
2-Oct-03	0	2-Nov-03	0	2-Dec-03	0
3-Oct-03	0	3-Nov-03	0	3-Dec-03	0
4-Oct-03	0	4-Nov-03	0	4-Dec-03	0
5-Oct-03	0	5-Nov-03	0	5-Dec-03	0
6-Oct-03	0	6-Nov-03	0	6-Dec-03	0
7-Oct-03	0	7-Nov-03	0	7-Dec-03	39
8-Oct-03	0	8-Nov-03	0	8-Dec-03	37
9-Oct-03	0	9-Nov-03	0	9-Dec-03	5.4
10-Oct-03	0	10-Nov-03	0	10-Dec-03	0
11-Oct-03	0	11-Nov-03	0	11-Dec-03	0
12-Oct-03	0	12-Nov-03	5.6	12-Dec-03	0
13-Oct-03	0	13-Nov-03	0	13-Dec-03	0
14-Oct-03	0	14-Nov-03	0	14-Dec-03	0
15-Oct-03	0	15-Nov-03	0	15-Dec-03	0
16-Oct-03	0	16-Nov-03	0	16-Dec-03	0
17-Oct-03	0	17-Nov-03	0	17-Dec-03	0
18-Oct-03	0	18-Nov-03	0	18-Dec-03	0
19-Oct-03	0	19-Nov-03	0	19-Dec-03	0
20-Oct-03	0	20-Nov-03	0	20-Dec-03	0
21-Oct-03	0	21-Nov-03	0	21-Dec-03	0
22-Oct-03	0	22-Nov-03	0	22-Dec-03	0
23-Oct-03	0	23-Nov-03	0	23-Dec-03	0
24-Oct-03	0	24-Nov-03	0	24-Dec-03	0
25-Oct-03	0	25-Nov-03	0	25-Dec-03	0
26-Oct-03	0	26-Nov-03	0	26-Dec-03	0
27-Oct-03	0	27-Nov-03	0	27-Dec-03	0
28-Oct-03	0	28-Nov-03	0	28-Dec-03	0
29-Oct-03	0	29-Nov-03	0	29-Dec-03	0
30-Oct-03	0	30-Nov-03	0	30-Dec-03	0
31-Oct-03	0			31-Dec-03	0

1-Jan-04	0	1-Feb-04	2	1-Mar-04	0
2-Jan-04	0	2-Feb-04	20	2-Mar-04	0
3-Jan-04	0	3-Feb-04	0.6	3-Mar-04	0
4-Jan-04	0	4-Feb-04	0	4-Mar-04	0
5-Jan-04	0	5-Feb-04	3	5-Mar-04	0
6-Jan-04	0	6-Feb-04	0	6-Mar-04	0
7-Jan-04	0	7-Feb-04	2.8	7-Mar-04	0
8-Jan-04	0	8-Feb-04	1.4	8-Mar-04	0
9-Jan-04	0	9-Feb-04	0	9-Mar-04	0
10-Jan-04	0	10-Feb-04	0	10-Mar-04	0
11-Jan-04	0	11-Feb-04	0	11-Mar-04	0
12-Jan-04	0	12-Feb-04	0	12-Mar-04	0
13-Jan-04	0	13-Feb-04	0	13-Mar-04	0
14-Jan-04	31.8	14-Feb-04	0	14-Mar-04	0
15-Jan-04	9	15-Feb-04	0	15-Mar-04	0
16-Jan-04	3.4	16-Feb-04	0	16-Mar-04	0
17-Jan-04	0	17-Feb-04	0	17-Mar-04	0
18-Jan-04	0	18-Feb-04	0	18-Mar-04	25.4
19-Jan-04	0	19-Feb-04	0	19-Mar-04	1.2
20-Jan-04	5.6	20-Feb-04	0	20-Mar-04	0
21-Jan-04	0	21-Feb-04	0	21-Mar-04	0
22-Jan-04	0	22-Feb-04	0	22-Mar-04	0
23-Jan-04	0	23-Feb-04	0	23-Mar-04	0
24-Jan-04	0	24-Feb-04	0	24-Mar-04	0
25-Jan-04	0	25-Feb-04	0	25-Mar-04	0
26-Jan-04	0	26-Feb-04	0	26-Mar-04	0
27-Jan-04	0	27-Feb-04	0	27-Mar-04	0
28-Jan-04	0	28-Feb-04	0	28-Mar-04	0
29-Jan-04	0	29-Feb-04	0	29-Mar-04	0
30-Jan-04	0			30-Mar-04	16.4
31-Jan-04	0			31-Mar-04	0

1-Apr-04	4	1-May-04	0	1-Jun-04	0
2-Apr-04	2.4	2-May-04	2.2	2-Jun-04	2
3-Apr-04	0	3-May-04	0	3-Jun-04	0
4-Apr-04	0	4-May-04	0	4-Jun-04	0.8
5-Apr-04	25.4	5-May-04	0	5-Jun-04	0
6-Apr-04	28.2	6-May-04	0	6-Jun-04	0
7-Apr-04	0	7-May-04	0	7-Jun-04	0
8-Apr-04	1	8-May-04	0	8-Jun-04	0
9-Apr-04	5.2	9-May-04	0	9-Jun-04	0
10-Apr-04	16.4	10-May-04	0	10-Jun-04	0
11-Apr-04	0	11-May-04	0	11-Jun-04	0
12-Apr-04	0	12-May-04	0	12-Jun-04	0
13-Apr-04	5.6	13-May-04	0	13-Jun-04	0
14-Apr-04	0	14-May-04	0	14-Jun-04	0
15-Apr-04	7.8	15-May-04	0	15-Jun-04	0
16-Apr-04	0	16-May-04	0	16-Jun-04	0
17-Apr-04	0	17-May-04	0	17-Jun-04	0
18-Apr-04	0	18-May-04	0	18-Jun-04	0
19-Apr-04	0	19-May-04	0	19-Jun-04	0
20-Apr-04	0	20-May-04	0	20-Jun-04	0
21-Apr-04	26.4	21-May-04	0	21-Jun-04	0
22-Apr-04	0	22-May-04	0	22-Jun-04	0
23-Apr-04	0	23-May-04	0	23-Jun-04	1.4
24-Apr-04	0	24-May-04	0	24-Jun-04	0
25-Apr-04	30	25-May-04	0	25-Jun-04	6
26-Apr-04	0	26-May-04	0	26-Jun-04	1.8
27-Apr-04	0	27-May-04	0	27-Jun-04	14.4
28-Apr-04	0	28-May-04	0	28-Jun-04	0
29-Apr-04	0	29-May-04	0	29-Jun-04	0
30-Apr-04	0	30-May-04	0	30-Jun-04	0
		31-May-04	0		

1-Jul-04	0	1-Aug-04	0	1-Sep-04	0
2-Jul-04	0	2-Aug-04	6.4	2-Sep-04	13.6
3-Jul-04	0	3-Aug-04	17.6	3-Sep-04	0.4
4-Jul-04	0	4-Aug-04	1	4-Sep-04	0
5-Jul-04	0	5-Aug-04	1.8	5-Sep-04	0
6-Jul-04	0	6-Aug-04	0	6-Sep-04	9
7-Jul-04	0	7-Aug-04	0	7-Sep-04	1.8
8-Jul-04	0	8-Aug-04	1	8-Sep-04	2.2
9-Jul-04	0	9-Aug-04	0	9-Sep-04	0
10-Jul-04	0	10-Aug-04	15.4	10-Sep-04	0
11-Jul-04	0	11-Aug-04	0	11-Sep-04	0
12-Jul-04	5	12-Aug-04	0	12-Sep-04	0
13-Jul-04	21	13-Aug-04	12	13-Sep-04	0
14-Jul-04	27	14-Aug-04	28	14-Sep-04	26
15-Jul-04	22	15-Aug-04	20	15-Sep-04	8.4
16-Jul-04	0	16-Aug-04	30	16-Sep-04	0
17-Jul-04	20	17-Aug-04	0	17-Sep-04	0
18-Jul-04	7	18-Aug-04	0	18-Sep-04	3
19-Jul-04	0	19-Aug-04	0	19-Sep-04	0
20-Jul-04	0	20-Aug-04	0	20-Sep-04	9
21-Jul-04	0	21-Aug-04	5	21-Sep-04	0
22-Jul-04	0	22-Aug-04	1.5	22-Sep-04	0
23-Jul-04	14	23-Aug-04	0	23-Sep-04	1
24-Jul-04	7	24-Aug-04	0	24-Sep-04	0
25-Jul-04	0	25-Aug-04	0	25-Sep-04	6
26-Jul-04	23.4	26-Aug-04	0	26-Sep-04	0
27-Jul-04	25	27-Aug-04	4.5	27-Sep-04	5
28-Jul-04	0	28-Aug-04	0	28-Sep-04	0
29-Jul-04	0	29-Aug-04	19	29-Sep-04	0
30-Jul-04	0	30-Aug-04	0	30-Sep-04	1
31-Jul-04	0	31-Aug-04	0		

1-Oct-04	0	1-Nov-04	0
2-Oct-04	0	2-Nov-04	0
3-Oct-04	5	3-Nov-04	0
4-Oct-04	36.6	4-Nov-04	0
5-Oct-04	0	5-Nov-04	0
6-Oct-04	0	6-Nov-04	0
7-Oct-04	2	7-Nov-04	0
8-Oct-04	0	8-Nov-04	0
9-Oct-04	2.4		
10-Oct-04	0		
11-Oct-04	0		
12-Oct-04	0		
13-Oct-04	2.8		
14-Oct-04	0		
15-Oct-04	0		
16-Oct-04	0		
17-Oct-04	0		
18-Oct-04	0		
19-Oct-04	0		
20-Oct-04	0		
21-Oct-04	0		
22-Oct-04	0		
23-Oct-04	0		
24-Oct-04	0		
25-Oct-04	0		
26-Oct-04	0		
27-Oct-04	0		
28-Oct-04	0		
29-Oct-04	0		
30-Oct-04	0		
31-Oct-04	0		

B. Daily pan evaporation

Raw data with no coefficients applied. Measured at Hara town.

Date	(mm)	Date	(mm)	Date	(mm)
1-Jul-03	2.5	1-Aug-03	4.7	1-Sep-03	7.6
2-Jul-03	5.1	2-Aug-03	-5.1	2-Sep-03	-7.6
3-Jul-03	6.1	3-Aug-03	5.1	3-Sep-03	38.1
4-Jul-03	5.5	4-Aug-03	3.3	4-Sep-03	-10.2
5-Jul-03	7.6	5-Aug-03	16.1	5-Sep-03	12.7
6-Jul-03	17.8	6-Aug-03	-0.2	6-Sep-03	-10.3
7-Jul-03	27.9	7-Aug-03	14.9	7-Sep-03	13.5
8-Jul-03	11.1	8-Aug-03	17.7	8-Sep-03	3.9
9-Jul-03	2.5	9-Aug-03	-3.5	9-Sep-03	26.2
10-Jul-03	5.1	10-Aug-03	18.5	10-Sep-03	-7.6
11-Jul-03	3.0	11-Aug-03	31.6	11-Sep-03	10.1
12-Jul-03	2.5	12-Aug-03	2.5	12-Sep-03	6.3
13-Jul-03	12.9	13-Aug-03	4.0	13-Sep-03	2.5
14-Jul-03	10.2	14-Aug-03	-4.8	14-Sep-03	5.1
15-Jul-03	8.7	15-Aug-03	-5.1	15-Sep-03	12.2
16-Jul-03	15.8	16-Aug-03	20.9	16-Sep-03	3.1
17-Jul-03	7.6	17-Aug-03	12.7	17-Sep-03	-7.6
18-Jul-03	12.7	18-Aug-03	4.6	18-Sep-03	7.6
19-Jul-03	6.9	19-Aug-03	20.0	19-Sep-03	15.2
20-Jul-03	10.2	20-Aug-03	-2.2	20-Sep-03	2.5
21-Jul-03	20.3	21-Aug-03	0.9	21-Sep-03	7.6
22-Jul-03	11.8	22-Aug-03	7.6	22-Sep-03	-5.1
23-Jul-03	9.0	23-Aug-03	12.7	23-Sep-03	8.3
24-Jul-03	11.8	24-Aug-03	1.9	24-Sep-03	10.2
25-Jul-03	9.2	25-Aug-03	-6.6	25-Sep-03	-0.5
26-Jul-03	11.9	26-Aug-03	-2.5	26-Sep-03	5.1
27-Jul-03	-5.1	27-Aug-03	27.9	27-Sep-03	13.2
28-Jul-03	7.5	28-Aug-03	-7.6	28-Sep-03	8.1
29-Jul-03	3.9	29-Aug-03	10.2	29-Sep-03	2.5
30-Jul-03	8.6	30-Aug-03	13.4	30-Sep-03	-6.0
31-Jul-03	22.5	31-Aug-03	6.9		

Date	(mm)	Date	(mm)	Date	(mm)
1-Oct-03	5.1	1-Nov-03	5.1	1-Dec-03	7.6
2-Oct-03	17.8	2-Nov-03	7.6	2-Dec-03	5.1
3-Oct-03	7.6	3-Nov-03	7.6	3-Dec-03	5.1
4-Oct-03	7.6	4-Nov-03	12.7	4-Dec-03	5.1
5-Oct-03	2.5	5-Nov-03	12.7	5-Dec-03	5.1
6-Oct-03	10.2	6-Nov-03	10.2	6-Dec-03	23.8
7-Oct-03	2.5	7-Nov-03	7.6	7-Dec-03	14.1
8-Oct-03	7.6	8-Nov-03	7.6	8-Dec-03	7.9
9-Oct-03	5.1	9-Nov-03	12.7	9-Dec-03	2.5
10-Oct-03	5.1	10-Nov-03	10.2	10-Dec-03	2.5
11-Oct-03	12.7	11-Nov-03	10.7	11-Dec-03	2.5
12-Oct-03	10.2	12-Nov-03	10.2	12-Dec-03	2.5
13-Oct-03	12.7	13-Nov-03	7.6	13-Dec-03	5.1
14-Oct-03	5.1	14-Nov-03	7.6	14-Dec-03	5.1
15-Oct-03	7.6	15-Nov-03	10.2	15-Dec-03	7.6
16-Oct-03	5.1	16-Nov-03	7.6	16-Dec-03	7.6
17-Oct-03	5.1	17-Nov-03	10.2	17-Dec-03	5.1
18-Oct-03	5.1	18-Nov-03	12.7	18-Dec-03	7.6
19-Oct-03	7.6	19-Nov-03	10.2	19-Dec-03	5.1
20-Oct-03	7.6	20-Nov-03	12.7	20-Dec-03	2.5
21-Oct-03	10.2	21-Nov-03	15.2	21-Dec-03	5.1
22-Oct-03	7.6	22-Nov-03	7.6	22-Dec-03	5.1
23-Oct-03	7.6	23-Nov-03	10.2	23-Dec-03	5.1
24-Oct-03	10.2	24-Nov-03	7.6	24-Dec-03	5.1
25-Oct-03	7.6	25-Nov-03	7.6	25-Dec-03	5.1
26-Oct-03	12.7	26-Nov-03	10.2	26-Dec-03	5.1
27-Oct-03	12.7	27-Nov-03	7.6	27-Dec-03	7.6
28-Oct-03	7.6	28-Nov-03	7.6	28-Dec-03	5.1
29-Oct-03	7.6	29-Nov-03	5.1	29-Dec-03	5.1
30-Oct-03	5.1	30-Nov-03	7.6	30-Dec-03	7.6
31-Oct-03	10.2			31-Dec-03	7.6

Date	(mm)	Date	(mm)	Date	(mm)
1-Jan-04	5.1	1-Feb-04	-5.4	1-Mar-04	10.2
2-Jan-04	7.6	2-Feb-04	3.1	2-Mar-04	15.2
3-Jan-04	7.6	3-Feb-04	2.5	3-Mar-04	10.2
4-Jan-04	5.1	4-Feb-04	-2.1	4-Mar-04	20.3
5-Jan-04	7.6	5-Feb-04	7.6	5-Mar-04	7.6
6-Jan-04	7.6	6-Feb-04	25.5	6-Mar-04	7.6
7-Jan-04	7.6	7-Feb-04	6.5	7-Mar-04	7.6
8-Jan-04	7.6	8-Feb-04	7.6	8-Mar-04	5.1
9-Jan-04	7.6	9-Feb-04	7.6	9-Mar-04	5.1
10-Jan-04	7.6	10-Feb-04	7.6	10-Mar-04	7.6
11-Jan-04	5.1	11-Feb-04	7.6	11-Mar-04	7.6
12-Jan-04	7.6	12-Feb-04	10.2	12-Mar-04	7.6
13-Jan-04	24.2	13-Feb-04	10.2	13-Mar-04	10.2
14-Jan-04	6.5	14-Feb-04	7.6	14-Mar-04	7.6
15-Jan-04	8.5	15-Feb-04	5.1	15-Mar-04	7.6
16-Jan-04	7.6	16-Feb-04	7.6	16-Mar-04	5.1
17-Jan-04	7.6	17-Feb-04	7.6	17-Mar-04	10.2
18-Jan-04	5.1	18-Feb-04	5.1	18-Mar-04	8.8
19-Jan-04	5.6	19-Feb-04	10.2	19-Mar-04	7.6
20-Jan-04	7.6	20-Feb-04	7.6	20-Mar-04	5.1
21-Jan-04	10.2	21-Feb-04	17.8	21-Mar-04	7.6
22-Jan-04	7.6	22-Feb-04	10.2	22-Mar-04	12.7
23-Jan-04	7.6	23-Feb-04	7.6	23-Mar-04	10.2
24-Jan-04	5.1	24-Feb-04	7.6	24-Mar-04	10.2
25-Jan-04	5.1	25-Feb-04	7.6	25-Mar-04	10.2
26-Jan-04	7.6	26-Feb-04	5.1	26-Mar-04	22.9
27-Jan-04	5.1	27-Feb-04	7.6	27-Mar-04	7.6
28-Jan-04	5.1	28-Feb-04	10.2	28-Mar-04	5.1
29-Jan-04	5.1	29-Feb-04	10.2	29-Mar-04	6.2
30-Jan-04	5.1			30-Mar-04	7.6
31-Jan-04	9.6			31-Mar-04	-3.6

Date	(mm)	Date	(mm)	Date	(mm)
1-Apr-04	-2.7	1-May-04	9.8	1-Jun-04	17.2
2-Apr-04	7.6	2-May-04	10.2	2-Jun-04	15.2
3-Apr-04	5.1	3-May-04	7.6	3-Jun-04	13.5
4-Apr-04	20.3	4-May-04	7.6	4-Jun-04	10.2
5-Apr-04	15.5	5-May-04	7.6	5-Jun-04	10.2
6-Apr-04	5.1	6-May-04	17.8	6-Jun-04	15.2
7-Apr-04	-1.5	7-May-04	7.6	7-Jun-04	15.2
8-Apr-04	-7.5	8-May-04	7.6	8-Jun-04	12.7
9-Apr-04	8.8	9-May-04	7.6	9-Jun-04	25.4
10-Apr-04	7.6	10-May-04	22.9	10-Jun-04	25.4
11-Apr-04	12.7	11-May-04	10.2	11-Jun-04	10.2
12-Apr-04	0.5	12-May-04	10.2	12-Jun-04	10.2
13-Apr-04	7.6	13-May-04	10.2	13-Jun-04	12.7
14-Apr-04	2.7	14-May-04	12.7	14-Jun-04	10.2
15-Apr-04	7.6	15-May-04	15.2	15-Jun-04	12.7
16-Apr-04	5.1	16-May-04	12.7	16-Jun-04	10.2
17-Apr-04	5.1	17-May-04	10.2	17-Jun-04	10.2
18-Apr-04	7.6	18-May-04	17.8	18-Jun-04	10.2
19-Apr-04	7.6	19-May-04	15.2	19-Jun-04	12.7
20-Apr-04	16.2	20-May-04	15.2	20-Jun-04	10.2
21-Apr-04	5.1	21-May-04	17.8	21-Jun-04	10.2
22-Apr-04	7.6	22-May-04	12.7	22-Jun-04	11.6
23-Apr-04	7.6	23-May-04	10.2	23-Jun-04	10.2
24-Apr-04	19.8	24-May-04	17.8	24-Jun-04	13.6
25-Apr-04	10.2	25-May-04	15.2	25-Jun-04	12.0
26-Apr-04	7.6	26-May-04	15.2	26-Jun-04	6.8
27-Apr-04	7.6	27-May-04	17.8	27-Jun-04	10.2
28-Apr-04	10.2	28-May-04	12.7	28-Jun-04	17.8
29-Apr-04	7.6	29-May-04	12.7	29-Jun-04	10.2
30-Apr-04	12.7	30-May-04	10.2	30-Jun-04	10.2
		31-May-04	12.7		

Date	(mm)	Date	(mm)	Date	(mm)
1-Jul-04	7.6	1-Aug-04	-1.2	1-Sep-04	8.5
2-Jul-04	10.2	2-Aug-04	7.4	2-Sep-04	13.1
3-Jul-04	7.6	3-Aug-04	8.6	3-Sep-04	10.2
4-Jul-04	7.6	4-Aug-04	4.3	4-Sep-04	7.6
5-Jul-04	15.2	5-Aug-04	7.6	5-Sep-04	-8.8
6-Jul-04	7.6	6-Aug-04	5.1	6-Sep-04	6.9
7-Jul-04	12.7	7-Aug-04	8.6	7-Sep-04	9.8
8-Jul-04	12.7	8-Aug-04	5.1	8-Sep-04	10.2
9-Jul-04	17.8	9-Aug-04	5.2	9-Sep-04	10.2
10-Jul-04	12.7	10-Aug-04	7.6	10-Sep-04	7.6
11-Jul-04	12.6	11-Aug-04	7.6	11-Sep-04	12.7
12-Jul-04	15.9	12-Aug-04	1.8	12-Sep-04	10.2
13-Jul-04	21.9	13-Aug-04	17.8	13-Sep-04	-1.9
14-Jul-04	9.3	14-Aug-04	14.9	14-Sep-04	-1.8
15-Jul-04	12.7	15-Aug-04	17.3	15-Sep-04	7.6
16-Jul-04	27.6	16-Aug-04	5.1	16-Sep-04	7.6
17-Jul-04	1.9	17-Aug-04	7.6	17-Sep-04	8.1
18-Jul-04	7.6	18-Aug-04	7.6	18-Sep-04	10.2
19-Jul-04	7.6	19-Aug-04	7.6	19-Sep-04	-6.2
20-Jul-04	10.2	20-Aug-04	-0.1	20-Sep-04	7.6
21-Jul-04	7.6	21-Aug-04	14.2	21-Sep-04	10.2
22-Jul-04	-8.9	22-Aug-04	12.7	22-Sep-04	8.6
23-Jul-04	-3.2	23-Aug-04	7.6	23-Sep-04	10.2
24-Jul-04	10.2	24-Aug-04	7.6	24-Sep-04	3.5
25-Jul-04	-2.0	25-Aug-04	7.6	25-Sep-04	12.7
26-Jul-04	17.4	26-Aug-04	2.0	26-Sep-04	-2.6
27-Jul-04	10.2	27-Aug-04	12.7	27-Sep-04	7.6
28-Jul-04	10.2	28-Aug-04	11.4	28-Sep-04	7.6
29-Jul-04	7.6	29-Aug-04	12.7	29-Sep-04	8.6
30-Jul-04	10.2	30-Aug-04	5.1	30-Sep-04	10.2
31-Jul-04	7.6	31-Aug-04	15.2		

Date	(mm)	Date	(mm)
1-Oct-04	10.2	1-Nov-04	12.7
2-Oct-04	12.6	2-Nov-04	12.7
3-Oct-04	-6.6	3-Nov-04	10.2
4-Oct-04	7.6	4-Nov-04	10.2
5-Oct-04	10.2	5-Nov-04	10.2
6-Oct-04	4.5	6-Nov-04	7.6
7-Oct-04	7.6	7-Nov-04	12.7
8-Oct-04	12.6		
9-Oct-04	7.6		
10-Oct-04	7.6		
11-Oct-04	10.2		
12-Oct-04	13.0		
13-Oct-04	10.2		
14-Oct-04	10.2		
15-Oct-04	7.6		
16-Oct-04	7.6		
17-Oct-04	10.2		
18-Oct-04	5.1		
19-Oct-04	10.2		
20-Oct-04	10.2		
21-Oct-04	10.2		
22-Oct-04	10.2		
23-Oct-04	10.2		
24-Oct-04	10.2		
25-Oct-04	5.1		
26-Oct-04	10.2		
27-Oct-04	10.2		
28-Oct-04	10.2		
29-Oct-04	10.2		
30-Oct-04	7.6		
31-Oct-04	10.2		

C. Monthly meteorological data

Measured at Hara town

Date	Rainfall (mm)	Number of rainy days	Minimum daily temperature (°C)	Maximum daily temperature (°C)	Mean daily temperature (°C)
Apr-03	175.9	8	18.7	31.0	24.9
May-03	1.0	1	18.6	35.7	27.2
Jun-03	13.0	6	19.9	36.8	28.4
Jul-03	120.4	17	20.1	35.4	27.8
Aug-03	256.2	20	18.8	33.5	26.2
Sep-03	52.4	13	18.3	34.7	26.5
Oct-03	0.0	0	14.9	33.3	24.1
Nov-03	5.6	1	14.0	31.1	22.6
Dec-03	81.4	3	12.5	28.1	20.3
Jan-04	51.8	5	15.7	27.1	21.4
Feb-04	27.8	5	14.6	26.9	20.8
Mar-04	47.0	4	15.7	30.6	23.2
Apr-04	148.4	10	18.3	30.9	24.6
May-04	2.2	1	18.0	35.6	26.8
Jun-04	26.4	6	19.9	35.7	27.8
Jul-04	171.4	10	19.9	35.1	27.5
Aug-04	163.2	14	19.0	34.4	26.7
Sep-04	86.4	13	17.9	33.6	25.8
Oct-04	48.8	5	15.1	31.7	23.4

D. Plant and yield data

Measured at on-farm research plots

Sorghum Kremt 2003

Plot	Treat-ment	Mean slope (%)	Grain yield (t ha^{-1})	A.G. biomass (t ha^{-1})	Root mass (g m^{-2})	Plant density (pl m^{-2})	1000 grain (g)
1	SS	9.8	1.70	5.12	47.3	8.0	38.8
2	TR	9.9	1.15	7.28	80.7	6.5	33.2
3	M	9.5	1.35	5.31	48.8	7.1	33.6
4	OR	11.1	0.99	4.91	54.4	6.9	32.7
5	M	3.9	1.54	7.28	66.5	9.4	37.3
6	OR	5.7	1.83	8.35	95.9	9.9	36.4
7	SS	6.6	1.99	6.79	70.3	9.9	34.3
8	TR	7.7	1.47	8.19	92.7	6.9	37.6
9	SS	1.9	2.40	10.84	142.0	7.4	39.1
10	M	2.2	1.41	7.29	83.9	7.0	34.8
11	OR	2.3	1.60	8.71	95.2	8.9	35.6
12	TR	2.8	1.96	9.16	111.2	7.1	36.6

Chickpea Belg 2004

Plot	Treat-ment	Mean slope (%)	Grain yield (t ha^{-1})	A.G. biomass (t ha^{-1})	Root mass (g m^{-2})	Plant density (pl m^{-2})	1000 grain (g)
1	SS	9.8	0.38	1.12	8.2	19.5	116.0
2	TR	9.9	0.22	0.89	6.9	15.3	113.9
3	M	9.5	0.31	0.79	5.4	19.4	115.6
4	OR	11.1	0.39	0.97	6.1	20.8	120.3
5	M	3.9	0.21	0.83	6.5	16.4	159.9
6	OR	5.7	0.26	0.95	5.2	12.5	115.6
7	SS	6.6	0.31	1.07	7.3	16.1	112.5
8	TR	7.7	0.40	0.95	5.5	17.9	117.3
9	SS	1.9	0.30	0.98	6.3	11.4	115.5
10	M	2.2	0.19	1.08	7.8	12.6	140.3
11	OR	2.3	0.08	1.00	9.0	23.2	165.4
12	TR	2.8	0.21	1.43	9.3	28.1	107.5
13	M extra	~2.8	0.10	0.80	6.7	20.3	138.5
14	SS extra	~2.8	0.28	1.21	6.8	20.3	115.5

Sorghum Kremt 2004

Plot	Treat-ment	Mean slope (%)	Sub-treat-ment	Grain yield (t ha^{-1})	A.G. biomass (t ha^{-1})	Root mass (g m^{-2})	Plant density (pl m^{-2})	1000 grain (g)
1	SS	9.8	N2M1	0.22	2.14	15.5	5.8	27.7
			N2	0.43	2.1	16.8	8	23.6
			N0	0.81	5.74	48.5	7.5	24.5
			N1	0.92	4.41	26.4	7	26.7
			N3	1.67	4.2	24.3	7.3	22.6
2	TR	9.9	N2M1	0.41	5.06	57.1	9.5	21.8
			N2	1.44	6.52	42.9	9	20.8
			N1	1.2	5.09	37.1	7.3	19.2
			N3	1.45	6.1	41.9	6.5	28.5
			N0	0.61	4.99	21.9	6.8	26.2
3	M	9.5	N2	0.21	3.8	38.1	7.5	26.2
			N0	0.37	2.03	25.6	7.8	20.2
			N1	0.51	3.53	24.5	7.5	21.8
			N3	0.53	3.5	30.9	6.8	22.5
			N2M1	0.52	3.08	21.1	6.8	25.9
4	OR	11.1	N2	1.17	5.01	44.3	7	23.4
			N0	0.31	3.06	18.4	7.3	22
			N3	0.99	6.24	39.2	7.5	25.1
			N1	0.36	4.05	36.3	6.3	22
			N2M1	0.55	6.25	44.8	5.8	20.8
5	M	3.9	N2M1	0.99	4.66	26.9	7	20.8
			N3	0.89	3.76	29.9	5.5	25.5
			N0	0.51	2.59	14.1	8.8	20.3
			N1	0.96	3.04	16.5	6	22.5
			N2	0.87	2.44	17.6	6.3	23.4
6	OR	5.7	N2M1	0.77	3.21	22.4	5	27.9
			N3	1.14	3.92	19.7	5.8	20.6
			N1	1.3	7.06	34.7	6.3	21.1
			N2	1.33	4.49	26.1	5.3	27.1
			N0	0.69	4.81	25.1	5.8	24.9
7	SS	6.6	N3	0.92	3.06	17.9	5	24.7
			N1	0.93	3.89	21.3	6.5	24.9
			N2M1	1.2	2.69	17.1	7	26.6
			N2	1.13	3.73	22.7	7.3	25.4
			N0	0.57	3.22	21.3	8	25.2
8	TR	7.7	N2	0.96	4.62	18.9	6	27.2
			N1	1.17	5.95	33.1	9	20.9
			N3	1.64	5.72	21.3	6.3	23.5
			N0	0.87	5.76	28.8	8.3	26.9
			N2M1	0.82	6.71	24.3	4	25.1
9	SS	1.9	N0	0.75	4.09	26.7	6	25.1
			N1	0.79	3.78	21.6	5	22.3
			N2	1.15	3.6	22.7	4.3	28.9

			N3	1.55	3.28	10.7	4	24.1
			N2M1	1.59	4.96	23.5	5	27.3
10	M	2.2	N2M1	0.49	2.36	15.7	6.8	26
			N0	0.4	2.08	12.3	7	23.2
			N1	0.55	2.67	17.9	10.5	25.1
			N2	0.47	3.55	23.2	5.8	24.1
			N3	1.35	4.3	26.4	4.3	26.8
11	OR	2.3	N0	0.71	2.54	14.4	7.8	27.9
			N2	1.35	3.63	21.6	7.3	26.1
			N3	1.6	5.46	34.4	8	21.7
			N2M1	1.57	3.57	18.1	6.8	24.6
			N1	2.22	9.18	51.7	4.8	28.4
12	TR	2.8	N1	1.56	4.25	23.5	8.8	24.2
			N0	0.98	3.66	25.1	9.3	23.1
			N3	2.15	5.16	35.7	7	25.7
			N2M1	2.4	6.19	30.1	6.8	27
			N2	0.62	6.02	23.5	3.5	29.1
Aa	NT	9.8	N3	0.01	0.99	11.7	8	4.5
			N0	0.05	1.1	10.9	5	24.7
			N2M1	0.37	1.79	13.9	8.5	26.6
			N1	0.11	1.27	5.9	8	22.5
			N2	0.18	1.45	8	8.3	24.7
Ab	NT	5.9	N1	0.19	2.13	10.7	9	24.2
			N2	0.64	3.72	19.2	7.5	24.8
			N2M1	0.61	3.87	18.1	7.3	25.3
			N0	0.31	2.3	10.4	6.3	25.1
			N3	0.54	2.73	17.3	6.3	25.1
Ag	NT	2.2	N2	0.57	1.99	14.9	5.8	20
			N0	0.3	3.75	24.3	4.5	22.4
			N3	0.83	3.19	25.6	6.5	21.5
			N1	0.5	3.52	22.7	7.3	22.9
			N2M1	1	5.84	31.5	7	23.4
Ac	OR	BII	N2M1	0.37	2.84	20.5	7.0	27.7
extra			N2	1.10	4.62	24.0	6.5	27.7
			N0	0.40	2.73	22.4	6.8	25.1
Ad	TR	BII	N2	0.96	2.39	10.1	8.5	25.8
extra			N0	1.02	4.68	11.7	7.5	24.7
			N2M1	1.80	9.14	41.6	7.8	28.1
Ae	M	BII	N0	0.33	3.84	21.3	6.8	22.8
extra			N2M1	1.37	7.98	44.3	6.3	21.0
			N2	0.70	4.94	24.0	8.0	24.1
Af	SS	BII	N2	0.92	4.42	20.5	5.5	22.7
extra			N0	0.58	4.39	25.9	6.5	26.9
			N2M1	1.25	5.12	16.0	6.0	26.9
Ah	NT	BI	N0	0.43	2.42	13.6	8.0	25.9
extra			N2	1.01	3.66	17.9	6.8	25.0
			N2M1	2.20	9.40	47.2	5.8	29.4
Ai	M	BI	N0	1.78	6.57	34.9	4.3	29.3

extra			N2	0.79	3.39	34.4	2.3	31.1
			N2M1	0.83	2.35	8.8	5.0	29.0
Aj	SS	BI	N0	0.82	2.31	15.7	7.3	26.3
extra			N2	0.63	2.77	16.5	8.5	28.6
			N2M1	1.53	5.84	33.9	11.0	27.3
Ak	OR	BI	N2M1	3.19	12.50	86.9	7.8	28.3
extra			N0	2.94	9.33	80.0	10.5	28.7
			N2	1.61	3.59	20.5	7.3	30.3
AL	TR	BI	N2M1	1.95	7.41	35.5	5.5	28.8
extra			N2	1.08	6.72	44.3	3.3	32.4
			N0	1.31	6.55	49.9	7.0	24.1

Symbols key

Treatments

M – conventional tillage with maresha plow

SS – subsoiling with Tenkara Kend plow

TR – tied ridge with ridger and manual ties

OR – open ridge with ridger

NT – no till

Sub-treatments

N0 – No nutrient addition

N1 - 20.5 kg N ha^{-1} as urea

N2 - 20.5 kg N ha^{-1} + 46 kg P ha^{-1} as DAP and urea

N2M1-20.5 kg N ha^{-1}+ 46 kg P ha^{-1} (DAP and urea) + 5 Mg ha^{-1} manure

N3 - 41 kg N ha^{-1} + 46 kg P ha^{-1} as DAP and urea

Extra – plots of smaller size (5m wide x 15m long) with similar treatments in the same farm (not included in statistical analysis due to unbalanced design)

Slope

BI – 0-3 % slope

BII – 3-8 % slope

BIII – 8-11% slope

E. Infiltration tests

Test number	Site	Land cover	Initial rate (mm h^{-1})	30-min cumulative (mm)	Final rate (mm h^{-1})
1	1	bareland	217	81	58
2	2	bareland	187	62	44
3	1	bushland	346	144	80
4	2	bushland	262	103	179
5	3	bushland	367	153	205
6	4	bushland	321	117	218
7	1	cropland	278	115	79
8	2	cropland	109	39	50
9	3	cropland	204	77	91
10	4	cropland	183	80	95
11	5	cropland	210	46	3
12	6	cropland	50	8	0.6
13	7	cropland	76	34	23
14	8	cropland	138	43	53
15	9	cropland	133	42	36
16	10	cropland	67	11	22
17	1	grassland	251	102	86
18	2	grassland	214	85	66
19	3	grassland	122	39	34
20	4	grassland	159	64	180
21	5	grassland	204	85	106
22	6	grassland	303	133	221
23	1	shrubland	244	96	57
24	2	shrubland	246	83	62
25	3	shrubland	442	98	43
26	4	shrubland	174	57	52
27	5	shrubland	280	116	64
28	6	shrubland	312	129	76
29	7	shrubland	221	108	232
30	8	shrubland	189	93	193
31	9	shrubland	217	91	200
32	10	shrubland	233	60	72
33	11	shrubland	270	121	292
34	12	shrubland	231	88	171
35	13	shrubland	266	119	225
36	14	shrubland	194	81	108

Conventional maresha plots (30 cm outer and 20 cm inner double ring)

Time (min)	8/16/2004 P3 top Volume (ml)	8/17/2004 P5 top Volume (ml)	8/10/2004 P10 top Volume (ml)	8/30/2004 P5 bottom Volume (ml)	9/9/2004 P10 bottom Volume (ml)	9/6/2004 P3 bottom Volume (ml)
5	550	130	200	360	348	175
10	210	50	115	205	265	65
15	160	25	217	215	224	20
20	175	0	158	240	172	35
25	173	19	175	150	157	33
30	173	18	200	175	158	28
35	190	0	200	150	140	40
40	200	0	150	200	134	48
45	180	15	180	180	126	65
50	172	0	168	130	138	70
55	158	10	130	155	130	130
60	165	0	220	130	128	64
65	140	12	150	157	105	75
70	128	0	180	125	95	70
75	132	10	190	130	128	73
80	125	0	195	150	115	50
85	120	0	185	180	105	48
90	126	5	210	140	108	68
95	115	0	245	160	104	70
100	90	7	145	152	95	60
105	82	0	120	180	110	72
110	87	0	217	115	100	50
115	81	5	160	110	100	48
120	75	0	205	150	108	46
125	78	0	220	173	115	50
130	70	5	200	100	100	80
135	70		208	130	105	85
140	65		225	138	100	70
145	67		175	200	98	50
150	60		165	111	107	64
155	63		175	100	100	60
160	57		185	124	100	55
165	52		180	170	88	80
170	50		208	150	80	75
175	50		156	145	95	50
180	45		200	135	110	65
185	47		127	120		85
190	40		150	135		90
195	40		154	170		50

200	40	128	135	65
205	33	135	100	65
210	25	180	122	50
215	24	225	140	50
220	21	165	125	58
225	20	170	150	61
230	15	185	135	55
235	15	140	155	62
240	12	150	130	59
245	10	160	125	
250	10	175	150	
255	8	145	140	
260	6	140		
265	8	128		
270	8	125		
275	7	120		
280	8	110		
285	6	115		
290	8	108		
295		110		
300		100		
305		85		
310		98		
315		60		
320		72		
325		77		
330		65		
335		60		
340		60		
345		58		
350		62		
355		55		
360		60		

Subsoiling plots (30 cm outer and 20 cm inner double ring)

Time (min)	8/19/2004 P7 top Volume (ml)	8/14/2004 P1 top Volume (ml)	8/9/2004 P9 top Volume (ml)	9/1/2004 P7 bottom Volume (ml)	9/2/2004 P1 bottom Volume (ml)	9/7/2004 P9 bottom Volume (ml)
5	142	300	348	230	165	410
10	123	150	200	50	80	225
15	0	100	60	30	30	215
20	61	50	30	45	35	200
25	50	70	50	44	20	210
30	50	100	15	50	25	230
35	43	100	23	50	20	195
40	0	80	35	27	23	184
45	28	87	29	26	38	165
50	0	105	38	30	27	210
55	18	98	20	31	22	190
60	0	91	17	40	28	145
65	0	86	18	30	30	143
70	20	70	20	25	29	180
75	0	68	20	23	20	150
80	18	72	27	21	28	190
85	0	75	32	24	26	172
90	15	65	29	22	33	130
95	0	70	30	21	25	175
100	0	70	38	20	26	105
105	19	64	30	23	20	90
110	0	61	35	20	19	98
115	0	60	27	21	21	100
120	12	60	30	22	32	90
125	0	55	31	24	25	95
130	0	58	24	22	23	93
135	10	52	25	24	22	105
140	0	55	27	20	15	115
145	0	57	29	20	25	85
150	7	51	16	20	23	93
155	0	50	25	24	24	90
160	8	50	19	20	30	88
165	0	50	10	21	19	94
170	0	45	20	20	18	110
175	7	48	20	18	15	98
180	0	52	25	19	20	87
185	0	46	20		17	89
190	5	45	0		19	75
195		45	0		16	80

200	45	0	20	83
205	40	23	15	73
210	42	10	16	65
215	46	23	14	73
220	40	9	13	78
225	40	15	15	83
230	35	0	13	92
235	37	12	17	75
240	33	9	14	84
245	29	20	14	90
250	36	40	13	85
255	20	95	15	60
260	26	50	16	77
265	26	25	12	70
270	26	50	14	67
275	25	27	11	61
280	23	18	18	72
285	27	9	15	70
290	25	15	12	68
295	25	14	13	65
300	21	10	17	63
305	18	12	12	
310	15	15	13	
315	12	10	11	
320	10	12	11	
325	10	9		
330	13	10		
335	14	10		
340	11	11		
345	12	12		
350	13	9		
355	10	10		
360	11	10		

No till plots (30 cm outer and 20 cm inner double ring)

Time (min)	8/12/2004 Ag top Volume (ml)	8/13/2004 Aa top Volume (ml)	8/18/2004 Ab top Volume (ml)	8/31/2004 Ab bottom Volume (ml)	9/3/2004 Aa bottom Volume (ml)	9/9/2004 Ag bottom Volume (ml)
5	237	250	262	255	400	450
10	65	120	133	87	150	100
15	27	50	62	58	135	70
20	26	42	65	78	138	65
25	30	75	58	60	133	61
30	37	50	50	50	127	68
35	40	48	45	67	160	54
40	32	52	49	55	138	50
45	28	50	41	62	105	57
50	35	44	37	54	82	45
55	30	48	32	60	148	40
60	29	55	30	50	112	44
65	26	49	28	38	114	39
70	32	46	28	42	137	31
75	24	40	21	45	126	35
80	20	42	20	47	136	30
85	26	40	22	40	100	38
90	24	40	17	50	135	33
95	22	38	13	46	118	30
100	20	35	14	45	88	30
105	20	37	13	40	120	36
110	25	31	15	42	158	29
115	28	33	13	40	121	32
120	22	30	14	38	125	28
125	20	28	10	36	142	30
130	24	32	10	32	95	33
135	22	30	12	30	105	27
140	18	27	10	30	100	29
145	15	29	10	29	130	32
150	20	32	11	26	110	31
155	16	35	9	28	135	26
160	19	30	9	28	143	29
165	16	26	10	26	110	34
170	12	23	9	24	73	25
175	10	20	8	27	125	29
180	15	20	5	29	130	24
185	17	21	4	25	122	
190	12	18	5	28	125	
195	14	15	6	30	130	

200	10	19	5	24	102
205	10	16		26	118
210	12	15		29	122
215	8	15		27	90
220	8	15		23	109
225	10	18		25	120
230	9	16		28	116
235	8	14		26	105
240	8	14		22	110
245		16			
250		19			
255		12			
260		12			
265		15			
270		17			
275		13			
280		14			
285		12			
290		10			
295		13			
300		10			
305		10			
310		8			
315		8			
320		5			
325		5			
330		6			
335		7			
340		5			
345		5			
350		5			
355		4			
360		6			

Shrub rangeland (SB) and open forest rangeland (OF) plots (13.5 cm outer and 6.7 cm inner double ring)

Time (min)	5/25/2004 SB top Volume (ml)	5/26/2004 SB bottom Volume (ml)	5/27/2004 OF top Volume (ml)	5/272004 OF bottom Volume (ml)
5	80	100	170	160
10	30	50	95	100
15	23	35	100	50
20	25	36	80	40
25	20	32	110	50
30	25	30	95	50
35	27	33	80	55
40	23	31	100	48
45	20	29	95	45
50	20	30	85	49
55	25	27	90	50
60	20	28	83	46
65	21	25	88	48
70	20	25	80	45
75	28	26	80	40
80	16	24	80	42
85	20	25	75	37
90	16	22	77	35
95	16	20	68	32
100	17	20	70	30
105	14	18	72	30
110	15	20	66	33
115	13	21	55	28
120	16	18	60	30
125	14	18	58	26
130	15	20	54	31
135	14	16	50	28
140	12	17	50	29
145	11	18	45	28
150	12	16	40	25

F. Storm rainfall

Auto – recorded by tipping bucket rain gauge with datalogger

Manual – recorded daily by technician or elementary school student

I_{ave} – average rainfall intensity during storm event

I_{30} – 30 minute maximum rainfall intensity

I_{10} – 10 minute maximum rainfall intensity

CAP_x – Cumulative antecedent precipitation for x days prior to the storm event

Kolo Kobo cropland plots site

Date	Auto Rainfall (mm)	Manual Rainfall (mm)	I_{ave} (mm h^{-1})	I_{30} (mm h^{-1})	I_{10} (mm h^{-1})	CAP_3 (mm)	CAP_5 (mm)	CAP_7 (mm)
7/31/03	58.5	50.0	35.1	92.6	109.8	18.7	24.0	27.0
8/1/03	37.3	34.0	7.2	36.6	42.6	73.3	78.1	83.4
8/6/03	41.4	38.0	11.3	34.6	42.6	0.3	37.6	103.9
8/7/03	24.2	20.0	3.2	34.2	40.8	49.4	49.4	87.6
8/10/03	19.3	21.0	3.0	15.4	16.8	33.1	81.0	81.3
8/10/03	17.7	15.0	1.6	26.6	53.4	28.8	100.3	100.6
8/12/03	22.2	22.0	13.3	25.6	41.4	43.2	68.9	118.0
8/16/03	53.5	43.0	3.3	51.4	99.0	1.8	25.7	63.0
8/19/03		16.0				53.8	55.6	79.5
8/20/03	17.3	15.0	8.7	21.4	44.4	0.0	53.8	55.6
8/21/03	17.4	8.0	7.5	23.6	51.6	17.3	34.8	71.1
8/30/03	33.9	27.0	7.0	31.8	53.4	0.0	1.4	7.6
9/7/03	13.1	10.0	1.9	8.8	19.8	3.6	3.6	4.9
9/28/03	10.2	7.0	20.4	20.4	30.6	0.9	5.6	12.6
3/29/04	38.6	24.0	6.7	57.9	89.4	0.8	0.8	0.8
4/4/04	37.9	35.0	15.2	74.6	129.6	3.1	4.9	45.2
4/5/04	32.4	32.0	2.9	27.0	50.4	37.9	42.8	82.6
4/9/04	22.1	28.0	26.5	40.2	70.2	12.5	41.5	82.8
4/25/04	32.8	34.0	6.2	19.8	50.4	0.0	0.0	1.9
7/12/04	22.8	24.0	3.7	16.8	50.4	4.5	4.5	4.5
7/13/04	29.5	31.0	5.4	25.8	51.6	27.6	27.6	27.6

7/14/04	29.0	29.0	3.3	31.0	51.6	56.8	57.1	57.1
7/16/04	27.2	19.0	6.0	28.4	53.4	51.6	86.6	98.3
7/17/04	6.2	6.0	2.7	7.6	18.0	68.4	97.9	125.5
7/22/04	12.1	14.0	3.6	13.8	21.6	10.2	10.2	43.9
7/25/04	24.9	26.0	2.8	14.6	34.8	21.1	31.3	31.3
7/26/04	27.4	32.0	5.5	16.2	33.6	31.4	48.1	56.5
8/9/04	13.5	13.0	1.0	12.6	22.8	1.9	1.9	21.8
8/13/04	25.9	30.0	4.6	9.6	22.8	6.9	19.1	22.3
8/14/04	20.6	21.0	6.9	22.8	39.6	32.8	32.8	48.2
8/15/04	26.5	32.0	8.0	16.2	34.8	53.4	53.4	66.9
9/2/04	14.0	19.0	6.0	13.2	22.8	0.6	6.2	25.1
9/5/04	7.7	12.0	1.3	14.2	33.6	2.1	16.1	16.7
9/13/04	25.0	39.0	5.6	18.4	41.4	1.3	3.3	7.1
9/15/04	8.2	12.0	5.5	13.2	34.8	25.6	26.9	29.2
9/24/04	5.5	9.0	1.3	5.6	9.0	2.0	2.0	15.3
10/3/04	30.1	44.0	4.3	23.4	42.6	11.2	11.2	17.7

Oromo rangeland plots site

Date	Auto Rainfall (mm)	Manual Rainfall (mm)	I_{ave} (mm h^{-1})	I_{30} (mm h^{-1})	I_{10} (mm h^{-1})	CAP_3 (mm)	CAP_5 (mm)	CAP_7 (mm)
7/31/03		30.0						
8/1/03		40.0						
8/6/03		40.0						
8/7/03		40.0						
8/10/03		20.0						
8/10/03		12.0						
8/12/03		40.0						
8/16/03		56.0						
8/19/03		22.0						
8/20/03		16.0						
8/21/03		12.0						
8/30/03		22.0						
9/7/03		12.0						
9/28/03		22.0						
3/29/04		16.0						
4/4/04		20.0						
4/5/04		24.0						
4/9/04		28.0						

4/25/04		42.0						
7/12/04	26	26.0	4.0	16.2	28.8	3.9	3.9	3.9
7/13/04	23	22.0	3.6	21.4	42.6	29.8	29.8	29.8
7/14/04	17	14.0	1.9	6.2	10.8	53.1	53.1	53.1
7/16/04	21	26.0	4.5	15.2	36.6	25.5	66.5	70.4
7/17/04	14	24.0	4.6	19.8	47.4	38.7	87.6	91.5
7/22/04	12	16.0	3.4	12.2	24.6	3.0	3.0	38.2
7/25/04	19	24.0	2.4	12.2	22.8	16.6	19.6	19.6
7/26/04	27	26.0	5.1	14.8	39.6	22.5	37.6	38.7
8/9/04	16	18.0	1.4	15.2	23.4	2.0	2.3	21.0
8/13/04	27	28.0	3.3	10.7	20.3	1.3	17.8	19.5
8/14/04	30	32.0	9.9	26.9	41.6	28.4	41.6	46.7
8/15/04	37	40.0	10.6	24.4	31.5	57.6	58.1	74.4
9/2/04	13	16.0	5.6	13.7	23.4	0.8	12.4	16.5
9/5/04	12	18.0	1.7	20.8	27.4	1.3	14.7	14.7
9/13/04	27	30.0	7.3	21.8	30.5	0.3	0.5	4.3
9/15/04	8	12.0	10.1	12.2	17.3	30.0	30.0	30.2
9/24/04	9	12.0	2.2	12.7	21.3	2.8	7.4	11.2
10/3/04		34.0						

G. Runoff and sediment yield

Cropland plots runoff (mm) (treatment subscripts indicate block number/slope class)

Date	M3	SS3	TR3	NT3	M2	SS2	TR2	M1	SS1	TR1	NT1
7/31/03	missing										
8/1/03	missing										
8/6/03	4.2	10.2	4.1		10.1	7.2	7.3	9.6	3.1	5.1	
8/7/03	4.4	9.9	6.4		7.2	10.4	6.6	3.2	0.7	8.2	
8/10/03	8.9	10.4	9.1		8.9	7.7	7.6	3.4	0.7	3.0	
8/10/03	7.9	10.6	9.6		9.5	9.7	8.2	2.9	1.8	4.9	
8/12/03	missing										
8/16/03	missing										
8/19/03	10.6	10.5	10.5		7.6	10.5	10.7	9.7	8.7	10.5	
8/20/03	9.5	10.5	9.9		9.2	10.6	9.9	3.4	3.6	7.3	
8/21/03	1.1	1.2	1.9		0.7	1.3	1.7	0.1	0.9	1.4	
8/30/03	8.8	5.3	7.1		4.1	9.0	4.7	5.4	4.9	6.1	
9/7/03	0.1	0.1	0.3		0.0	0.0	0.0	0.0	0.0	0.0	
9/28/03	missing										
3/29/04	2.7	2.4	0.1		0.2	1.4	0.0	0.0	0.0	0.0	
4/4/04	27.1	24.6	10.3		6.5	6.0	8.7	10.1	7.2	2.2	
4/5/04	10.4	10.4	10.5		10.4	10.3	10.3	10.4	6.2	0.5	
4/9/04	10.0	9.8	10.0		10.0	9.8	10.0	10.1	7.2	2.6	
4/25/04	4.6	7.7	5.3		5.2	1.5	4.3	4.1	2.2	0.5	
7/12/04	6.7	4.2	3.3		4.4	4.9	4.9	2.1	1.9	0.1	
7/13/04	6.9	10.3	7.8		26.4	26.3	8.2	8.9	6.9	0.5	
7/14/04	10.5	10.4	10.5		10.4	10.3	10.6	10.4	6.4	1.6	
7/16/04	0.0	0.1	0.0		0.2	0.0	0.0	0.1	0.0	0.0	
7/17/04	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	
7/25/04	4.3	2.6	0.1	1.0	0.5	0.2	0.0	0.3	0.1	0.0	0.0
7/26/04	4.0	10.2	0.2	8.3	5.8	5.5	0.0	2.9	0.1	0.0	0.0
8/9/04	0.8	0.8	0.0	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.1
8/13/04	5.3	4.9	0.5	3.2	8.0	5.6	0.0	1.6	0.0	0.0	0.1
8/14/04	10.1	9.5	4.0	10.2	10.6	10.0	0.1	8.3	5.4	0.2	0.1
8/15/04	10.3	10.3	9.7	11.9	10.5	10.4	0.5	10.3	5.2	0.2	4.3
9/2/04	1.4	1.9	1.2	1.0	0.1	0.4	0.0	0.0	0.0	0.0	0.1
9/5/04	2.1	1.3	1.3	1.8	0.3	1.3	0.0	0.2	0.0	0.0	0.0
9/13/04	24.1	17.0	16.5	8.9	6.6	16.2	6.2	6.5	4.8	0.1	0.6
9/15/04	4.4	3.9	3.0	3.6	4.2	3.6	1.6	2.7	1.8	0.0	0.0
9/24/04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10/3/04	35.9	35.9	24.8	12.0	10.2	10.2	5.6	7.7	7.2	0.1	0.5

Rangeland plots runoff (mm)

Date	Open forest	Shrub rangeland
7/31/03	0.7	3.6
8/1/03	0.8	1.6
8/6/03	0.8	2.8
8/7/03	2.1	3.0
8/10/03	0.2	0.9
8/10/03	0.7	2.6
8/12/03	5.2	21.0
8/16/03	7.7	9.7
8/19/03	2.7	8.8
8/20/03	1.6	5.4
8/21/03	0.4	2.6
8/30/03	0.4	2.3
9/7/03	0.0	0.1
9/28/03	1.6	4.0
3/29/04	0.0	0.2
4/4/04	0.5	5.4
4/5/04	0.3	2.2
4/9/04	0.1	0.5
4/25/04	1.0	6.1
7/12/04	0.1	0.9
7/13/04	0.4	3.0
7/14/04	0.0	0.1
7/16/04	0.0	0.3
7/17/04	0.4	2.3
7/22/04	0.1	0.8
7/25/04	missing	
7/26/04	missing	
8/9/04	0.1	1.3
8/13/04	0.0	0.4
8/14/04	1.6	10.0
8/15/04	1.5	9.7
9/2/04	0.0	0.2
9/5/04	0.2	1.0
9/13/04	0.8	4.2
9/15/04	0.1	0.5
9/24/04	0.1	0.5
10/3/04	1.3	5.9

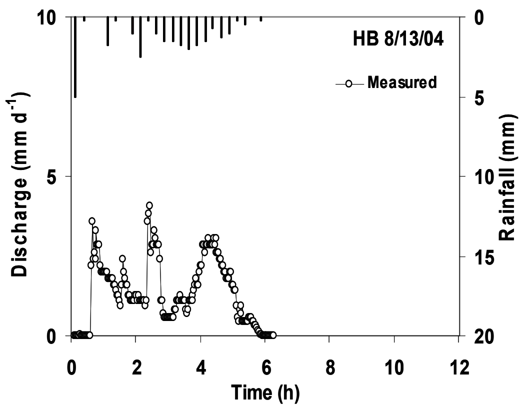
Cropland plots sediment (t ha^{-1}) (7/12/04 – 7/17/04 occurred before kremt-04 tillage)

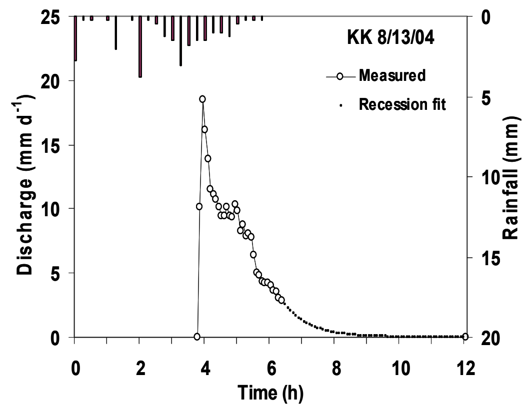
Date	M3	SS3	TR3	NT3	M2	SS2	TR2	M1	SS1	TR1	NT1
7/31/03	6.45	7.23	9.20		System failure						
8/1/03	missing										
8/6/03	0.83	2.50	1.61		1.06	1.80	0.48	0.45	0.60	0.39	
8/7/03	0.60	2.55	2.25		0.92	1.68	0.47	0.15	0.17	0.23	
8/10/03	0.64	0.73	0.66		0.45	0.64	0.15	0.03	0.01	0.05	
8/10/03	1.34	1.32	1.55		0.98	1.15	1.06	0.05	0.08	0.09	
8/12/03	0.40	1.57	1.55		1.14	2.11	0.61	0.01	0.06	0.18	
8/16/03	6.70	7.51	9.56		2.80	7.90	4.31	0.65	0.37	0.41	
8/19/03	2.96	4.31	4.13		1.09	4.16	2.61	0.19	0.32	0.14	
8/20/03	1.77	2.47	2.85		0.98	2.40	2.00	0.04	0.06	0.15	
8/21/03	0.01	0.01	0.04		0.02	0.03	0.02	0.00	0.01	0.01	
8/30/03	1.10	1.36	1.71		0.49	1.46	0.63	0.05	0.09	0.06	
9/7/03	0.00	0.00	0.02		0.00	0.00	0.00	0.00	0.00	0.00	
9/28/03	missing										
3/29/04	0.03	0.10	0.00		0.00	0.02	0.00	0.00	0.00	0.00	
4/4/04	4.44	5.09	2.60		1.08	2.25	0.25	0.49	0.46	0.02	
4/5/04	1.88	1.78	1.18		0.06	1.24	0.05	0.07	0.07	0.00	
4/9/04	4.74	5.20	3.22		0.51	2.41	0.19	0.09	0.14	0.08	
4/25/04	0.72	1.13	0.60		0.05	0.24	0.04	0.04	0.02	0.00	
7/12/04	0.26	0.70	0.13		0.01	0.02	0.03	0.01	0.03	0.00	
7/13/04	0.57	0.58	0.89		0.49	0.72	0.02	0.00	0.01	0.00	
7/14/04	1.90	2.53	1.65		0.30	0.87	0.02	0.58	0.38	0.01	
7/16/04	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	
7/17/04	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	
7/22/04	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	
7/25/04	0.28	0.47	0.04	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/26/04	2.24	3.32	0.00	0.35	0.01	0.27	0.00	0.01	0.00	0.00	0.00
8/9/04	0.00	0.07	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8/13/04	1.37	1.54	0.00	0.08	0.26	1.02	0.00	0.00	0.00	0.00	0.00
8/14/04	1.79	1.73	0.09	0.41	0.02	0.84	0.00	0.01	0.01	0.00	0.00
8/15/04	1.89	2.22	0.07	0.14	0.12	1.48	0.00	0.11	0.09	0.00	0.00
9/2/04	0.14	0.35	0.10	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9/5/04	0.38	0.79	0.43	0.13	0.00	0.07	0.00	0.00	0.00	0.00	0.00
9/13/04	2.27	2.72	1.92	0.37	0.02	0.46	0.01	0.01	0.03	0.00	0.00
9/15/04	0.49	0.45	0.39	0.07	0.03	0.47	0.02	0.01	0.01	0.00	0.00
9/24/04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/3/04	2.47	2.36	1.01	0.45	0.18	0.86	0.03	0.03	0.05	0.00	0.00

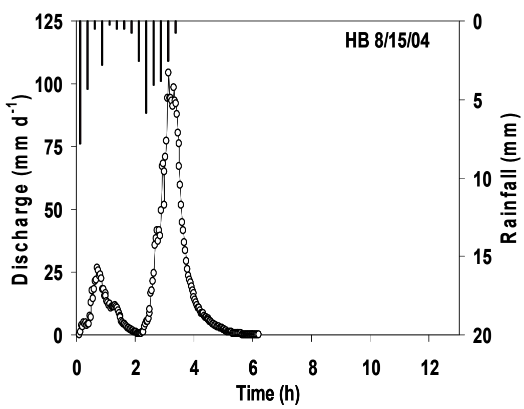
Rangeland plots sediment yield (kg ha^{-1})

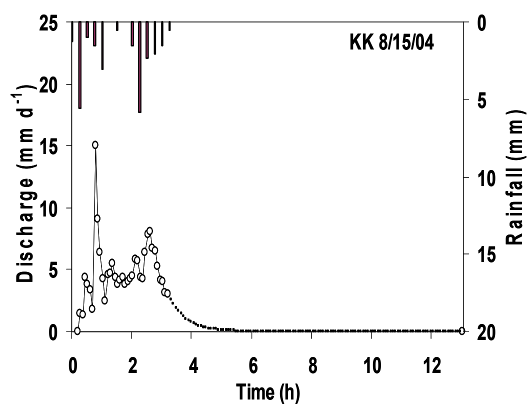
Date	Open forest	Shrub rangeland
7/31/03	155.0	1140.5
8/1/03	8.1	294.9
8/6/03	44.8	413.6
8/7/03	171.2	329.0
8/10/03	2.2	26.2
8/10/03	66.6	251.6
8/12/03	780.3	2995.7
8/16/03	434.4	777.6
8/19/03	303.0	654.0
8/20/03	85.5	178.9
8/21/03	3.9	51.9
8/30/03	4.2	23.3
9/7/03	0.0	2.2
9/28/03	139.4	224.0
3/29/04	0.2	1.5
4/4/04	2.1	358.3
4/5/04	1.6	19.2
4/9/04	0.5	4.7
4/25/04	2.9	75.7
7/12/04	0.4	4.6
7/13/04	1.4	18.3
7/14/04	0.0	1.0
7/16/04	0.1	4.2
7/17/04	9.3	33.3
7/22/04	0.5	8.2
7/25/04	missing	
7/26/04	missing	
8/9/04	0.5	9.4
8/13/04	0.0	0.4
8/14/04	21.0	18.9
8/15/04	13.3	64.3
9/2/04	0.0	1.0
9/5/04	1.3	7.7
9/13/04	2.5	3.6
9/15/04	0.6	1.3
9/24/04	0.4	3.7
10/3/04	41.1	41.9

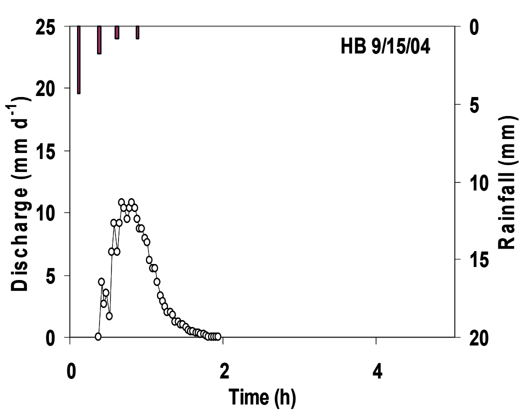
Catchments discharge

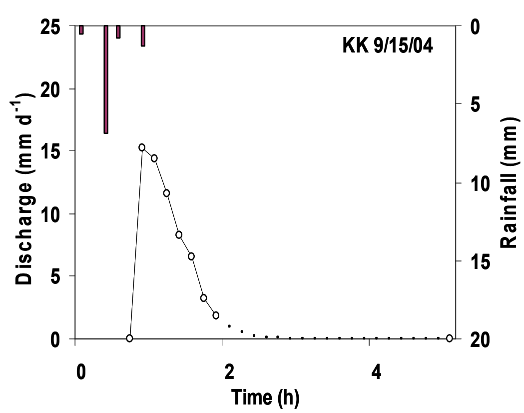




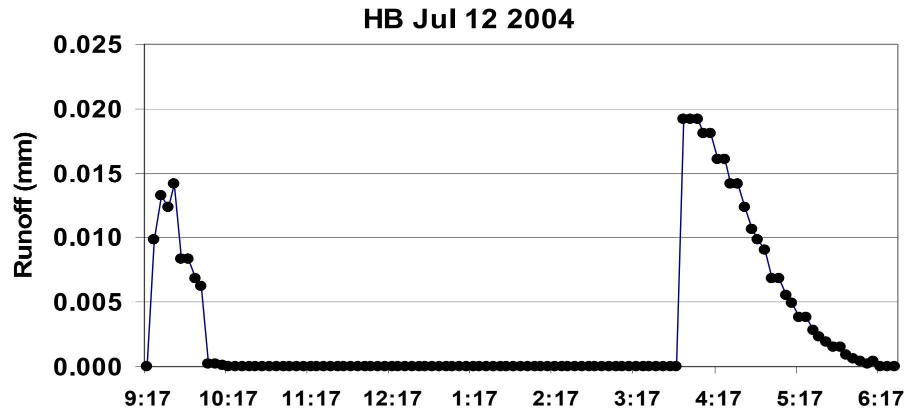


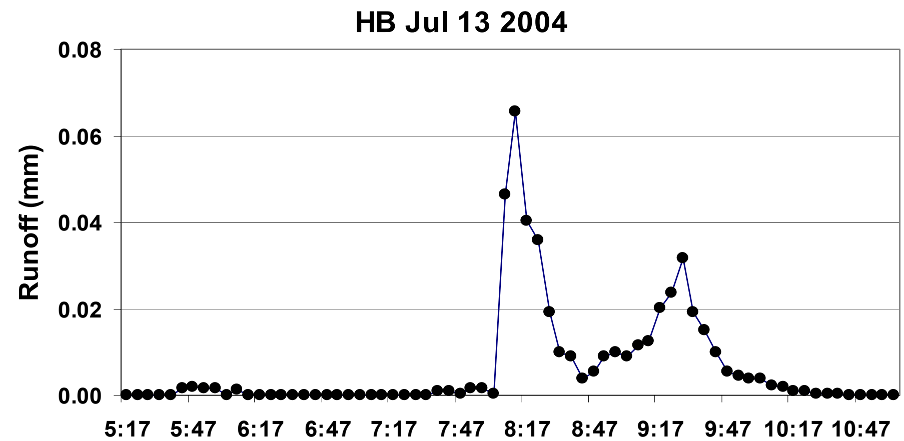


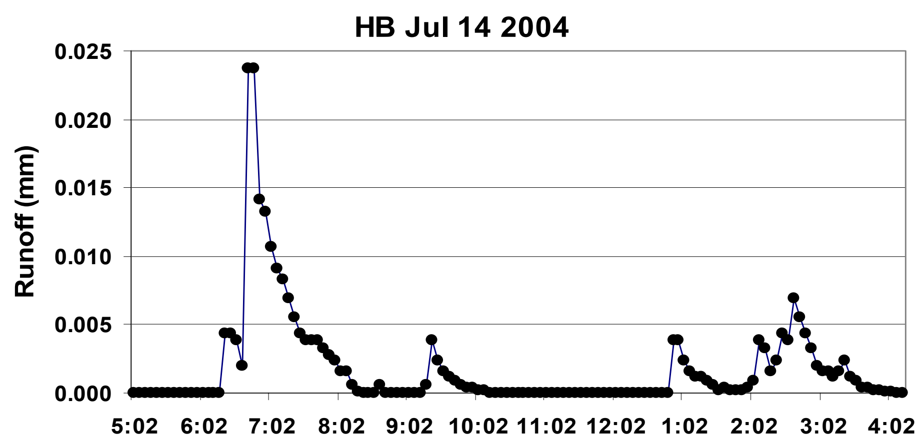


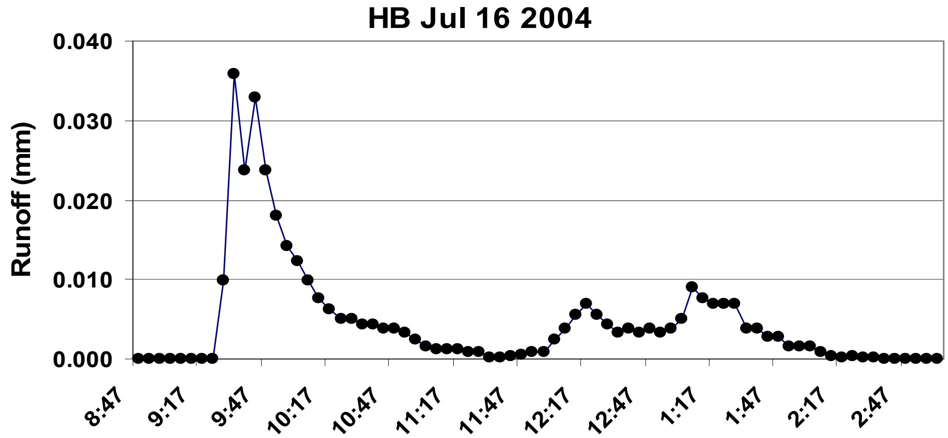


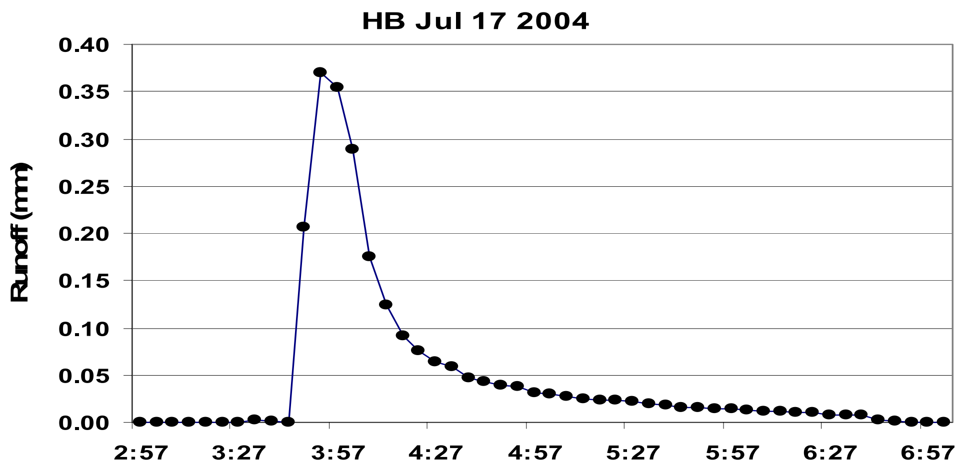
Hartibo hydrographs (mm flow volume during 5-minute intervals between data points)

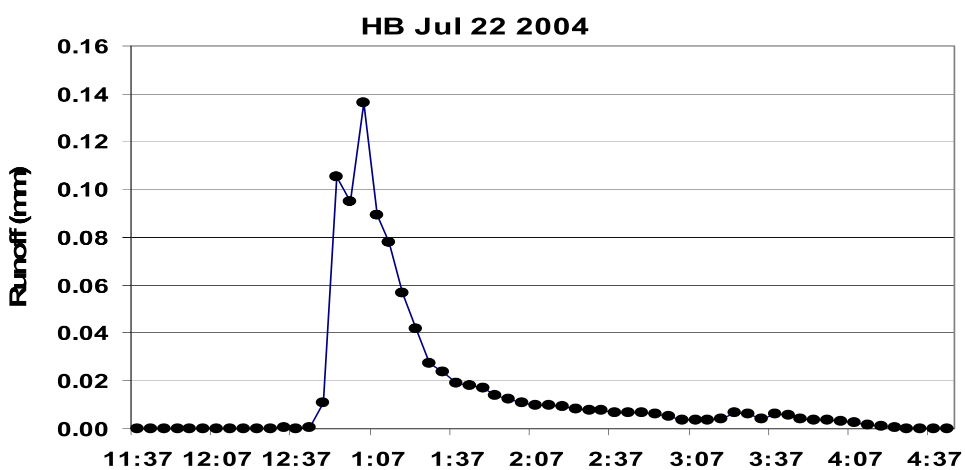


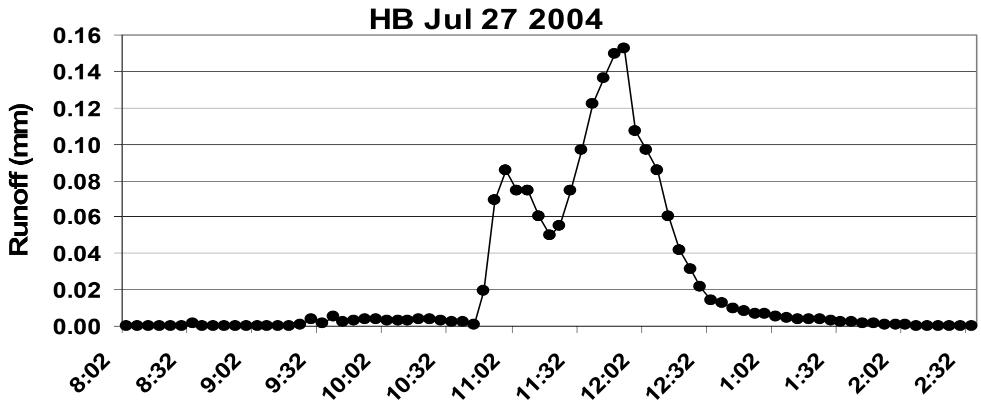




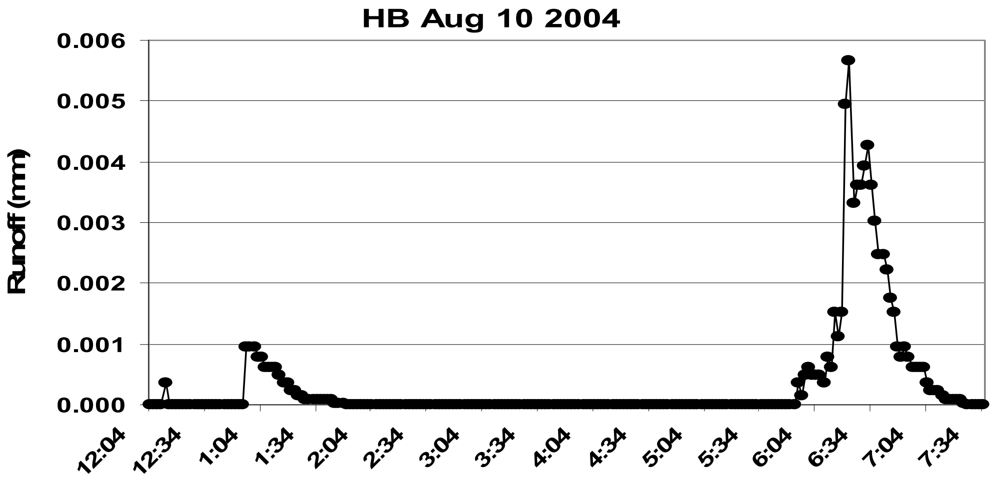

HB Jul 16 2004
Runoff (mm)
0.040
0.030
0.020
0.010
0.000
8:47
9:17
9:47
10:17
10:47
11:17
11:47
12:17
12:47
1:17
1:47
2:17
2:47


HB Jul 17 2004
Runoff (mm)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2:57
3:27
3:57
4:27
4:57
5:27
5:57
6:27
6:57

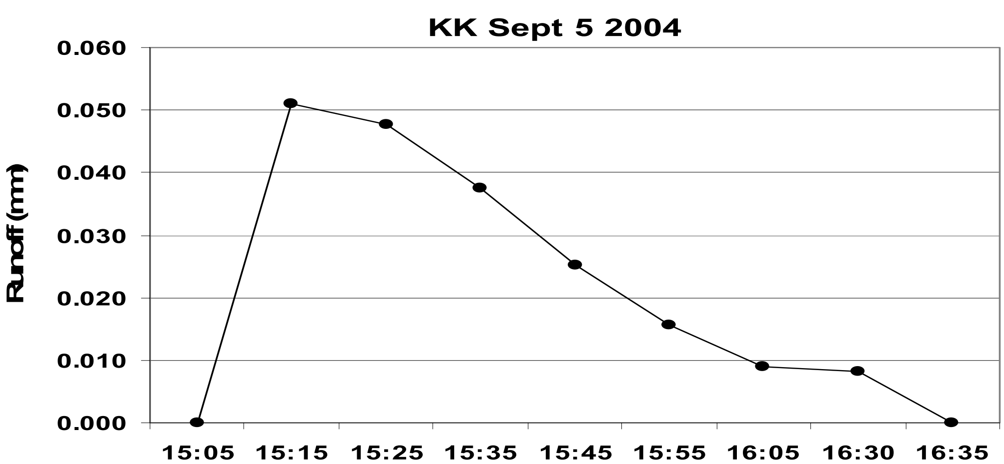

HB Jul 22 2004
Runoff (mm)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
11:37
12:07
12:37
1:07
1:37
2:07
2:37
3:07
3:37
4:07
4:37



Hartibo hydrographs (mm flow volume during 2-minute intervals between data points)



Kolo Kobo hydrographs (mm flow volume during intervals between data points)



H. GPS ground-truthing points

Land cover/ land use classes for ground-truthing

LC/LU Unit	Symbol	Description
Water course	W	Streams and other permanent large drainage channels
Pond	P	Constructed and natural water bodies
Settlement	V	Towns, villages, and other areas with buildings and habitations including the immediately surrounding homesteads
Agricultural (intensive)	A1	Cultivated land units with 80-100% of the land in the unit cultivated
Agricultural (moderate)	A2	Cultivated land units with 60-79% of the land in the unit cultivated
Bare land	N1	Areas that have little or no vegetation cover, mainly with highly degraded land (gullies, rills) and shallow/poor soil
Bare land/rocks	N2	Areas that have little or no vegetation cover, mainly rocks
Grassland	G	Areas with permanent grass cover, used for grazing
Shrub land	S	Areas covered with short shrubs and thorny bushes with little useful wood, usually stony with very rugged microrelief
Bush land	B	Areas covered with small trees, bushes, and shrubs. Scattered large trees can sometimes be found.
Woodland	F1	Areas with 60-70% trees mixed with short bushes and open areas (open forest)
Natural Forest	F2	Areas with trees forming closed or nearly closed canopy (70-100%) with herbs and shrubs beneath
Plantation Forest	F3	Areas with planted trees (planted prior to 2003). For areas where trees were planted during 2003 write the prior class cover followed by (/F3).

LENCHE DIMA WATERSHED (AUG-NOV 2003)

Point	Decimal minutes 11^{o} N	Decimal minutes 39^{o} E	Accuracy meters	Elevation meters	Classification LU/LC class
1	51.573	44.382	6.7	1466	N1
2	51.530	44.415	6.7	1477	N1/G
3	51.424	44.418	6.8	1473	N1/G
4	51.359	44.430	6.9	1478	W
5	51.192	44.390	6.5	1482	N1/G
6	51.129	44.327	6.9	1484	A1
7	50.375	44.044	7.6	1520	V
8	50.293	43.875	7.6	1558	N1
9	50.250	43.965	11.8	1566	F3
10	50.171	43.985	8.4	1608	G/S/F3
11	50.181	43.910	8.5	1585	B/F3
12	50.208	43.902	8.3	1584	F1/F3
13	49.985	43.794	9.0	1606	G
14	50.018	43.870	10.8	1643	N2
15	50.035	43.637	8.4	1594	V
16	50.095	43.683	7.8	1576	NI/F3
17	50.191	43.801	9.5	1574	A1
18	49.956	43.621	11.2	1644	S/G
19	49.861	43.622	10.8	1640	G/S
20	49.806	43.653	9.1	1640	N1/S/G
21	49.787	43.637	7.7	1603	A1
22	49.675	43.697	7.8	1669	S
23	49.695	43.781	7.8	1722	S/G
24	49.551	43.854	6.9	1750	S/G
25	49.426	43.829	7.8	1750	B/S
26	49.305	43.772	14.4	1761	S/B
27	49.330	43.671	11.7	1768	S
28	49.409	43.537	8.2	1760	S/G
29	49.556	43.511	8.3	1715	S
30	49.387	43.449	8.2	1727	S
31	49.333	43.334	11.6	1737	S/G
32	49.311	43.418	9.8	1763	S/B
33	49.375	43.253	9.1	1748	S/B/G
34	49.440	43.197	8.2	1746	B/S
35	49.450	43.200	12.0	1713	N2
36	49.482	43.162	8.9	1707	B/G/S
37	49.492	43.125	7.8	1714	V
38	49.552	43.089	9.4	1668	F1
39	49.566	42.992	14.7	1676	F1
40	49.625	43.003	9.4	1660	G/S
41	49.604	42.949	8.5	1649	A1
42	49.612	42.892	8.2	1665	B/S/G
43	49.655	42.777	7.7	1669	V

44	49.711	42.732	6.9	1670	G
45	49.710	42.654	6.9	1675	G
46	49.763	42.607	7.3	1664	S/G
47	49.748	42.560	7.6	1669	A1
48	49.722	42.518	8.4	1684	G/S
49	49.697	42.493	7.9	1694	A1
50	49.713	42.379	8.1	1700	A1
51	49.768	42.414	8.3	1679	F1
52	49.758	42.377	9.1	1688	S/G
53	49.680	42.309	8.3	1716	F3
54	49.667	42.252	8.5	1737	S/G/F3
55	49.626	42.167	8.8	1748	S
56	49.550	42.025	10.3	1788	S
57	49.504	41.930	11.1	1806	G
58	49.511	41.901	11.9	1828	S/G/F3
59	49.582	41.924	8.7	1813	V
60	49.562	41.930	8.8	1809	A1
61	49.642	41.901	8.9	1808	G/S
62	49.740	41.848	8.0	1849	S/G
63	49.804	41.890	9.5	1892	S
64	49.865	41.910	8.8	1849	B
65	49.920	42.009	8.0	1846	B
66	49.917	42.113	8.1	1829	B
67	49.956	42.215	9.0	1771	S
68	49.970	42.247	12.9	1741	F1
69	50.001	42.309	8.1	1723	V
70	49.809	42.425	8.5	1700	Gully
71	51.301	43.804	8.7	1537	B
72	51.451	43.744	8.6	1582	V
73	51.493	43.680	9.3	1598	N1
74	51.557	43.565	10.2	1602	S/G
75	51.655	43.545	8.7	1588	N1
76	51.776	43.509	8.4	1637	S
77	51.927	43.463	8.3	1681	S
78	51.976	43.334	8.4	1706	F1
79	52.023	43.281	7.3	1694	V
80	52.035	43.225	9.9	1673	S
81	52.038	43.179	8.5	1639	A1
82	52.023	43.091	7.9	1630	P
83	52.037	43.014	8.2	1626	N1
84	52.052	42.985	9.1	1640	B
85	52.039	42.878	9.6	1643	A1
86	52.115	42.833	8.8	1678	S
87	52.131	42.825	8.8	1710	B
88	51.978	42.812	9.0	1694	S
89	51.834	42.896	8.0	1684	N1/S
90	51.863	42.858	9.8	1688	S
91	52.022	42.732	10.2	1687	S
92	52.056	42.570	9.0	1676	B/S

93	52.012	42.553	8.1	1662	A1
94	51.838	42.556	8.5	1617	N1/gully
95	51.017	43.201	7.5	1538	P
96	51.564	42.634	7.5	1588	P
97	51.806	42.653	8.4	1617	A1
98	51.827	42.429	10.8	1696	B/S
99	51.774	42.410	9.7	1695	N2
100	51.682	42.404	10.5	1699	V
101	51.639	42.370	12.4	1672	B
102	51.428	42.345	12.7	1662	S
103	51.446	42.367	12.5	1628	A1
104	51.382	42.337	9.5	1690	V
105	51.339	42.418	13.9	1685	S/B
106	51.275	42.487	12.7	1695	S
107	51.131	42.551	9.9	1691	S/B
108	51.080	42.476	9.7	1722	S/B
109	51.022	42.431	8.7	1724	S/B
110	50.993	42.506	9.6	1646	G
111	50.789	42.514	8.1	1628	A1
112	50.727	42.498	8.4	1640	B/S
113	51.029	43.819	8.3	1502	Water pump/well
114	51.023	43.874	7.5	1498	A1
115	50.875	43.990	7.1	1502	A1
116	50.733	44.113	7.4	1495	A1
117	50.667	44.163	9.1	1503	V
118	50.884	44.067	6.7	1495	A1
119	51.008	44.067	7.8	1488	A1
120	51.078	44.046	7.8	1489	A1
121	51.185	44.184	8.7	1488	A1
122	51.222	44.179	7.5	1481	W/N1/stream
123	51.245	44.352	7.3	1486	A1
124	51.303	44.466	9.0	1484	V
125	51.336	44.517	7.3	1494	A1
126	51.443	44.515	7.9	1480	A1
127	51.574	44.455	8.6	1492	G
128	51.622	44.502	7.9	1500	A1
129	51.663	44.562	9.0	1511	A1
130	51.750	44.637	9.7	1521	V
131	51.633	44.624	7.5	1514	A1
132	51.520	44.651	8.4	1509	V
133	51.489	44.602	7.9	1503	A1
134	51.439	44.578	7.3	1481	N1
135	51.527	44.338	7.7	1482	A1
136	51.536	44.321	7.7	1479	N1gully
137	51.555	44.302	7.2	1483	A1
138	51.520	44.157	7.3	1500	A1
139	51.577	44.069	7.1	1508	A1
140	51.657	44.084	7.4	1513	V
141	51.673	44.009	7.5	1517	P

142	51.596	43.983	7.7	1510	A1
143	51.586	43.904	8.9	1520	A1
144	51.549	43.873	7.9	1522	A1
145	51.561	43.902	8.2	1522	N1/gully
146	51.479	44.044	8.3	1505	A1
147	51.433	44.137	8.5	1498	A1
148	51.372	44.282	8.7	1489	A1
149	51.424	44.348	7.9	1489	A1
150	51.444	44.311	9.0	1479	G/gully
151	51.086	43.906	8.0	1510	S
152	51.145	43.863	8.2	1514	A1
153	51.246	43.797	7.7	1515	A1
154	51.304	43.721	7.8	1520	N1
155	51.333	43.658	9.2	1544	V
156	51.399	43.748	7.6	1547	A1
157	51.629	43.362	7.5	1652	B/S
158	51.421	43.695	8.3	1581	N2
159	51.420	43.627	8.5	1594	S
160	51.469	43.538	7.5	1642	S
161	51.533	43.519	10.4	1640	S
162	51.485	43.438	8.4	1667	S
163	51.395	43.408	8.7	1677	S
164	51.328	43.433	9.7	1668	S
165	51.272	43.411	8.1	1660	S
166	51.257	43.452	7.3	1651	S
167	51.363	43.372	8.1	1694	S
168	51.419	43.341	8.4	1680	S
169	51.507	43.387	8.8	1692	S
170	51.519	43.327	7.7	1663	S
171	51.564	43.441	8.0	1670	S
172	51.578	43.467	8.0	1649	A1
173	51.366	43.397	8.1	1665	V
174	51.753	43.390	7.8	1651	S/B
175	51.775	43.400	8.1	1658	N2
176	51.835	43.407	9.5	1686	S
177	51.839	43.357	9.8	1668	S
178	51.963	43.308	8.0	1679	S
179	51.950	43.342	8.3	1629	A1
180	51.791	43.307	8.7	1621	A1
181	51.551	43.251	7.6	1600	A1
182	51.397	43.208	9.9	1605	B
183	51.336	43.210	10.2	1598	V
184	51.124	43.246	9.4	1568	V
185	51.074	43.754	9.2	1528	A1
186	51.121	43.644	7.2	1516	A1
187	51.166	43.642	7.5	1522	N1
188	51.211	43.639	7.7	1533	N1
189	51.311	43.605	7.5	1552	A1
190	51.331	43.548	10.0	1565	S/B

191	51.290	43.561	7.6	1554	A1
192	51.287	43.522	10.9	1569	S/N1
193	51.198	43.522	11.8	1565	B
194	51.186	43.541	8.5	1552	V
195	51.132	43.500	9.7	1567	S/B
196	51.128	43.461	8.1	1570	S
197	51.200	43.374	9.4	1581	S
198	51.266	43.298	8.7	1590	F1
199	51.203	43.323	8.6	1582	A1
200	51.111	43.298	7.9	1549	A1
201	51.084	43.376	8.4	1540	A1
202	51.085	43.444	9.3	1549	F2/B
203	51.115	43.540	8.5	1542	F2
204	51.003	43.537	8.0	1523	A1
205	51.004	43.450	9.4	1528	A1
206	51.026	43.300	7.4	1532	A1
207	50.943	43.287	7.2	1538	G/S
208	50.910	43.322	7.2	1529	A1
209	50.875	43.295	7.8	1527	N1
210	50.873	43.371	7.4	1530	A1
211	50.884	43.437	7.8	1512	A1
212	50.899	43.448	9.9	1504	N1
213	50.843	43.477	7.5	1524	N1/G
214	50.805	43.411	7.7	1532	A1
215	50.779	43.529	8.8	1527	A1
216	50.778	43.615	8.3	1525	A1
217	50.868	43.666	9.8	1521	A1
218	50.737	43.625	8.6	1526	A1
219	50.698	43.637	9.1	1521	W
220	50.716	43.762	8.9	1531	A1
221	50.797	43.828	9.5	1522	A1
222	50.726	43.909	9.2	1520	A1
223	50.629	43.968	9.3	1515	A1
224	50.638	44.082	8.5	1511	A1
225	50.539	43.987	6.7	1514	A1
226	50.599	43.955	7.1	1512	N1
227	50.624	43.849	7.2	1519	A1
228	50.661	43.689	6.7	1526	A1
229	50.721	43.506	6.6	1532	A1
230	50.761	43.363	7.2	1540	A1
231	50.829	43.285	6.9	1537	A1
232	50.924	43.219	8.6	1541	A1
233	50.988	43.193	6.9	1538	W/N1
234	50.994	43.226	7.0	1541	A1
235	51.070	43.179	7.9	1547	A1
236	51.178	43.165	8.4	1563	A1
237	51.154	43.097	7.3	1560	A1
238	51.271	43.098	7.3	1565	A1
239	51.309	43.005	9.6	1561	A1

240	51.422	42.993	6.9	1565	A1
241	51.425	43.053	8.7	1568	A1
242	51.598	43.000	10.9	1572	W/N1
243	51.639	43.048	7.6	1579	A1
244	51.770	43.062	7.3	1591	A1
245	51.881	43.027	7.7	1602	N1
246	51.955	42.992	8.1	1615	N1
247	51.905	42.947	8.3	1621	A1
248	51.800	42.921	8.3	1637	N2/G
249	51.787	42.962	10.6	1634	B
250	51.748	42.805	9.1	1611	V
251	51.738	42.784	9.7	1609	P
252	51.856	42.801	8.9	1650	G/N1
253	51.913	42.738	8.6	1649	G/N1
254	51.849	42.716	8.0	1642	A1
255	51.808	42.628	9.6	1635	A1
256	51.154	42.627	7.6	1611	A1
257	51.662	42.551	9.9	1613	A1
258	51.621	42.532	10.2	1613	S
259	51.488	42.552	7.7	1607	A1
260	51.373	42.563	7.9	1606	A1
261	51.310	42.606	7.7	1608	S
262	51.213	42.667	8.6	1603	A1
263	51.165	42.733	8.4	1608	V
264	51.202	42.782	7.7	1578	S/G
265	51.070	42.825	9.3	1578	S/F1
266	51.059	42.864	7.7	1534	A1
267	50.935	42.893	7.7	1565	A1
268	50.850	42.864	7.3	1564	A1
269	50.923	42.755	8.2	1577	A1
270	50.766	42.765	7.8	1579	A1
271	50.816	42.951	7.9	1560	A1
272	50.777	43.060	8.1	1551	A1
273	50.739	43.155	8.0	1546	N1/G
274	50.716	43.168	9.4	1557	A1
275	50.715	43.224	8.2	1549	A1
276	50.727	43.367	8.5	1540	A1
277	49.897	43.506	9.8	1616	N1
278	49.824	43.490	7.0	1615	P
279	49.831	43.525	7.2	1606	A1
280	49.766	43.456	7.7	1631	A1
281	49.688	43.524	9.4	1656	V
282	49.496	43.674	7.6	1657	G
283	49.533	43.662	9.0	1649	A1
284	49.561	43.592	8.2	1647	A1
285	49.527	43.598	9.3	1653	G/S
286	49.595	43.428	8.1	1653	A1
287	49.417	43.373	8.5	1670	A1
288	49.462	43.296	8.2	1668	V

289	49.521	43.254	8.2	1651	A1
290	49.608	43.121	8.7	1644	A1
291	49.604	43.024	8.5	1645	A1
292	49.661	42.928	8.4	1633	A1
293	49.725	42.825	8.1	1645	A1
294	49.799	42.817	7.6	1632	G
295	49.818	42.738	8.2	1643	A1
296	49.888	42.683	8.1	1630	N1/W
297	49.872	42.629	8.0	1641	B
298	50.024	42.664	7.2	1627	A1
299	50.035	42.767	9.4	1619	A1
300	50.089	42.893	7.3	1608	A1
301	50.011	42.979	9.3	1599	A1
302	50.051	43.101	7.3	1585	A1
303	50.030	43.162	10.9	1578	N1/G
304	49.988	43.218	7.7	1585	A1
305	50.103	43.297	8.9	1571	N1
306	50.096	43.288	7.9	1578	A1
307	50.111	43.431	10.3	1579	A1
308	50.115	43.545	8.6	1582	A1
309	50.689	42.542	7.8	1614	N1/gully
310	50.199	43.637	8.8	1562	N1
311	50.266	43.667	8.9	1561	A1
312	50.372	43.748	7.7	1543	A1
313	50.294	43.832	8.4	1562	A1
314	50.304	43.927	9.8	1553	N1
315	50.342	43.961	8.4	1556	A1
316	50.548	42.694	8.2	1597	A1
317	50.495	42.614	8.3	1648	S/B
318	50.600	42.518	8.0	1663	S
319	50.716	42.392	9.5	1633	A1
320	50.747	42.342	8.6	1670	S
321	50.599	42.386	8.2	1672	B/S
322	50.476	42.518	8.7	1681	S/G
323	50.450	42.476	7.5	1658	A1
324	50.376	42.436	8.3	1683	S
325	50.336	42.469	7.9	1644	G
326	50.232	42.436	8.7	1665	S/G
327	50.173	42.356	9.8	1665	S/N2
328	50.232	42.271	10.5	1671	S/G
329	50.216	42.215	10.6	1670	S/G
330	50.141	42.238	10.9	1651	S/N2
331	50.010	41.829	9.7	1743	S/G
332	50.075	41.560	8.4	1760	A1
333	50.085	41.503	8.8	1792	S/B
334	50.088	41.350	10.1	1803	S/B
335	50.110	42.203	10.5	1678	S
336	50.126	42.450	10.7	1642	F3
337	50.149	42.516	10.5	1626	N1/Large gully

338	50.179	42.550	10.6	1634	G
339	50.228	42.629	8.5	1624	water tank
340	50.208	42.631	7.2	1622	A1
341	51.613	44.312	7.2	1473	road culvert 8
342	50.577	44.181	9.4	1448	road culvert 1
343	50.662	44.187	7.3	1507	road culvert 2
344	50.762	44.204	7.4	1507	road culvert 3
345	51.364	44.491	7.4	1483	road culvert 4
346	51.397	44.52	7.9	1482	road culvert 5
347	51.498	44.497	7.1	1486	road culvert 6
348	51.531	44.465	7.5	1484	road culvert 7
349	50.349	44.523	7.7	1496	school rain gauge
350	50.443	42.269	6.7	1770	P
351	49.969	42.439	8.1	1770	P
352	50.215	42.617	7.2	1628	P
353	51.327	42.957	7.7	1551	Pump faucet
354	51.033	43.812	7.5	1497	Pump faucet
355	50.045	43.226	8.0	1528	Pump faucet
356	50.22	42.65	7.4	1625	Pump faucet
357	50.441	44.358	8.3	1499	Water outlet

HARA SWAMP WATERSHED (JUL-OCT 2004)

Point	Decimal minutes 11^o N	Decimal minutes 39^o E	Accuracy meters	Elevation meters	LU/LC Class 1st(primary)	2nd	3rd
1	50.213	43.892	16.2	1578	B	G	
2	50.150	43.868	17.9	1593	F2		
3	50.103	43.849	13.3	1604	G	F2	N1
4	50.032	43.791	9.7	1603	N1		
5	49.996	43.733	9.7	1603	N1		
6	49.965	43.669	15.3	1614	N1	N2	G
7	49.905	43.665	9.8	1620	G	N1	
8	49.811	43.635	15.4	1623	W	S	
9	49.752	43.670	9.1	1638	N1	B	
10	49.729	43.662	9.9	1634	W	N2	N1
11	49.745	43.763	10.8	1643	N1	N2	
12	49.755	43.709	20.4	1668	S	N2	
13	49.773	43.716	10.0	1683	S	N2	
14	49.760	43.744	9.7	1694	F2	F1	S
15	49.722	43.748	9.3	1608	G	S	B
16	49.691	43.792	8.4	1724	S	B	
17	49.655	43.848	17.3	1692	N1	G	
18	49.692	43.931	9.6	1650	A1	G	F2
19	49.747	43.992	12.1	1614	G	S	
20	49.808	43.930	23.4	1606	G	N1	
21	49.971	44.120	8.1	1585	G	S	B
22	50.028	44.307	7.9	1547	N2	N1	G
23	50.054	44.386	12.6	1524	W	A1	A2
24	50.048	44.415	9.7	1529	W	A1	A2
25	50.116	44.490	7.8	1518	V	A2	
26	50.195	44.473	8.2	1512	V		
27	50.264	44.545	8.5	1509	V		
28	50.390	44.565	8.4	1455	V		
29	50.108	44.485	17.4	1500	W	A1	
30	50.046	44.545	13.2	1515	F3	A2	
31	49.963	44.511	11.8	1524	A2	A1	
32	49.890	44.446	13.3	1542	G	S	
33	49.830	44.380	8.3	1555	G	N2	S
34	49.771	44.351	8.5	1552	F3	A2	
35	49.251	44.363	14.9	1546	W	N1	N2

36	49.695	44.360	10.7	1571	N1		
37	49.662	44.352	13.1	1602	N2	G	S
38	49.627	44.401	13.8	1593	A1	S	G
39	49.443	44.366	13.3	1578	V	F1	
40	49.356	44.464	10.8	1585	F2	G	B
41	49.319	44.521	10.4	1584	F2	S	
42	49.320	44.703	10.6	1557	S	G	
43	49.430	44.876	10.5	1525	A1		
44	49.461	44.951	8.2	1519	A1		
45	49.483	44.974	8.3	1524	W		
46	49.636	45.110	11.3	1500	W		
47	49.854	45.286	8.8	1488	W		
48	50.067	45.383	9.7	1478	W	A2	
49	49.635	45.179	12.9	1515	N1		
50	49.528	45.238	13.1	1506	A2	N1	
51	49.362	45.310	9.5	1502	A2	N1	
52	49.336	45.319	9.5	1500	N2	S	
53	49.321	45.334	8.8	1504	N2	S	
54	49.163	45.475	12.8	1517	N2		
55	49.133	45.598	8.6	1525	N2	N1	
56	49.204	45.674	8.6	1536	N1	G	
57	49.190	45.755	8.3	1536	N1	G	V
58	49.161	45.947	9.6	1551	V	N1	G
59	49.222	46.043	17.5	1566	V	N1	G
60	49.223	46.119	10.9	1564	V	N2	G
61	49.285	46.201	11.1	1579	V	N2	
62	49.538	46.393	10.1	1569	N2		
63	49.631	46.501	8.9	1545	N2		
64	49.790	46.512	10.4	1516	N2	V	
65	49.990	46.325	9.2	1499	F3	G	
66	50.109	46.341	17.2	1493	N1		
67	50.338	46.416	8.2	1469	A1		
68	50.391	46.509	9.2	1467	N1	G	
69	50.525	46.708	13.3	1475	N1		
70	50.717	46.892	8.0	1473	N1	V	
71	50.762	46.979	15.4	1489	F2		
72	50.872	47.025	9.0	1523	F2	N2	
73	50.901	47.038	15.6	1511	F2	N2	
74	50.933	47.021	18.0	1516	N2	F2	
75	50.994	47.017	9.2	1516	N2	F2	
76	51.106	46.997	8.2	1510	N2		
77	51.254	46.996	9.2	1516	N2	G	

78	51.290	46.871	8.1	1478	N1		
79	51.291	46.719	12.8	1465	N1		
80	51.303	46.940	14.3	1496	N1	G	
81	51.341	46.995	10.2	1517	N1	B	
82	51.422	47.002	10.1	1538	N1	B	
83	51.446	47.039	14.2	1532	F2	B	
84	51.494	47.065	10.3	1530	F2	B	
85	51.539	47.050	9.3	1522	N1	B	F3
86	51.580	46.996	8.0	1506	V	B	
87	51.667	46.921	9.5	1503	V		
88	51.724	46.924	10.2	1500	N1	A1	
89	51.718	47.024	9.9	1502	N1	A2	
90	51.792	47.032	9.4	1498	A1	G	
91	51.866	47.004	9.5	1486	N1		
92	51.999	46.995	8.2	1502	A1		
93	52.046	46.853	8.0	1502	A1	G	
94	52.186	46.663	8.6	1492	A2		
95	52.221	46.523	11.8	1488	V		
96	52.309	46.463	9.2	1485	N2		
97	52.438	46.091	8.1	1494	N2	P	
98	52.301	45.793	7.9	1478	N2		
99	51.906	45.572	14.1	1471	A2		
100	52.229	45.366	8.5	1484	N2	V	
101	51.972	45.294	7.6	1500	N1	G	
102	51.869	45.225	8.4	1511	G	N1	
103	51.689	45.182	9.1	1514	N1	G	
104	51.598	45.132	7.4	1527	N1	G	
105	51.550	44.944	6.9	1475	A2	G	
106	51.560	44.784	13.6	1486	V	G	
107	51.461	44.685	11.7	1492	F3	G	
108	51.429	44.563	7.2	1476	V	F3	
109	51.376	44.502	7.8	1474	V		
110	51.290	44.455	7.5	1479	V	G	
111	51.037	44.305	9.2	1489	A1		
112	50.707	44.191	7.5	1500	V		
113	51.491	44.624	13.3	1496	F3	G	
114	51.529	44.659	13.7	1498	V	G	
115	51.570	44.691	13.5	1497	A2	V	G
116	51.626	44.722	9.1	1496	V	G	
117	51.641	44.752	13.6	1489	A2	G	
118	51.586	44.800	13.4	1491	S	B	
119	51.584	44.872	8.4	1485	A1	B	

120	51.600	44.899	7.7	1483	G	A1
121	51.654	44.966	7.6	1481	G	A1
122	51.738	45.104	9.8	1502	F3	A1
123	51.750	45.158	9.1	1542	N2	
124	51.792	45.184	7.7	1566	S	G
125	49.278	44.462	13.8	1602	V	
126	49.164	44.454	11.8	1592	V	N2
127	49.082	44.441	9.3	1590	S	
128	49.059	44.466	10.9	1592	N1	
129	48.944	44.536	9.9	1581	N1	G
130	48.902	44.545	11.3	1587	V	
131	48.788	44.566	8.0	1593	A1	
132	48.759	44.601	8.4	1591	A1	
133	48.696	44.624	8.0	1599	F1	
134	48.583	44.617	10.4	1610	B	F1
135	48.510	44.572	12.3	1619	N1	
136	48.509	44.530	8.8	1633	A1	
137	48.512	44.486	12.0	1629	A1	
138	48.462	44.498	13.3	1647	N1	
139	48.415	44.512	9.3	1651	F1	
140	48.392	44.525	13.3	1661	V	
141	48.375	44.541	10.3	1656	S	
142	48.337	44.583	12.1	1655	N1	S
143	48.312	44.620	10	1650	F1	N1
144	48.318	44.711	8.5	1641	V	
145	48.338	44.714	10.1	1645	V	
146	48.236	44.749	9.7	1650	V	
147	48.177	44.777	9.6	1552	S	
148	48.132	44.804	8.1	1643	S	G
149	48.094	44.833	8.2	1648	F1	
150	48.087	44.863	8.8	1651	N1	N2
151	48.021	44.878	8.1	1649	V	
152	48.067	44.936	8.7	1620	F1	
153	48.067	45.007	9.1	1608	V	
154	48.031	45.015	12.5	1610	A2	
155	47.912	45.042	9.5	1611	P	
156	47.865	45.052	7.3	1620	G	
157	47.900	45.115	11.2	1614	V	
158	47.919	45.161	7.9	1613	S	
159	47.940	45.237	8	1612	A2	S
160	47.999	45.276	8.3	1607	S	
161	48.060	45.292	12.3	1603	V	

162	48.146	45.348	7.9	1610	V	
163	48.215	45.351	12.6	1592	V	
164	48.274	45.371	9.7	1590	V	
165	48.325	45.397	7.5	1588	V	
166	48.404	45.452	8.5	1570	P	
167	48.462	45.505	10.7	1588	V	
168	48.504	45.523	10.5	1583	F1	
169	48.522	45.547	10.0	1577	F1	S
170	48.594	45.613	7.4	1564	A2	
171	48.682	45.666	7.5	1549	A1	
172	48.782	45.775	8.3	1547	A1	
173	48.795	45.850	7.6	1556	S	
174	48.837	45.875	9.6	1560	F1	
175	48.872	45.859	8.2	1559	N1	
176	48.958	45.893	8.3	1564	A1	
177	49.066	45.908	8.0	1564	V	
178	49.048	45.962	7.6	1569	P	
179	49.025	45.955	9.1	1569	V	
180	49.023	46.062	9.4	1589	V	
181	49.028	46.132	8.4	1595	V	
182	49.014	46.203	11.9	1615	V	
183	49.093	46.142	9.3	1597	V	
184	49.196	46.094	8.8	1588	N1	
185	49.237	46.038	8.5	1571	F1	
186	49.324	45..977	13.0	1558	F1	G
187	49.397	45.921	8.7	1538	N1	
188	49.433	45.885	8.2	1525	N1	
189	49.519	45.802	7.4	1513	A1	N1
190	49.599	45.745	12.2	1497	N1	
191	49.747	45.694	7.6	1488	A1	
192	49.856	45.616	7.0	1482	N1	
193	49.936	45.581	7.2	1482	N1	G
194	50.069	45.513	8.8	1480	G	N1
195	51.698	44.616	10.7	1512	A2	
196	51.768	44.664	10.2	1524	V	
197	51.837	44.700	12.4	1527	V	
198	51.869	44.731	8.5	1521	A2	
199	51.892	44.800	11.4	1522	A2	
200	51.957	44.709	8.6	1521	A1	
201	52.008	44.710	8.1	1520	N1	
202	52.133	44.633	8.7	1525	V	
203	52.181	44.665	8.4	1529	S	V

204	52.245	44.700	12.3	1527	F1	
205	52.323	44.727	9.1	1529	V	
206	52.370	44.770	8.4	1529	F1	V
207	52.364	44.809	8.2	1528	A1	
208	52.356	44.847	7.6	1526	A1	G
209	52.400	44.913	7.8	1520	A1	
210	52.391	44.972	9.4	1514	A1	N1
211	52.326	45.039	8.6	1504	N1	A1
212	52.287	45.121	8.4	1500	A2	G
213	52.307	45.119	8	1499	N1	
214	52.333	45.143	8	1493	N1	
215	52.356	45.207	9.5	1497	V	
216	52.388	45.244	8.6	1496	V	
217	52.271	45.182	10.3	1489	N1	
218	52.206	45.225	7.1	1488	N1	
219	52.155	45.261	8.9	1488	P	
220	52.044	45.376	9.3	1481	A2	
221	51.979	45.431	10.3	1477	N1	
222	51.906	45.525	7.0	1472	A1	
223	51.789	45.530	8.2	1467	P	
224	51.709	45.469	7.6	1465	B	
225	51.684	46.156	8.8	1467	N1	
226	51.766	46.197	10.3	1471	N1	
227	51.842	46.244	26.6	1477	A1	
228	52.041	46.377	8.0	1478	A1	
229	52.236	46.426	8.4	1489	V	
230	52.205	46.526	7.0	1495	V	
231	52.098	46.547	9.7	1478	N1	W
232	52.037	46.545	6.9	1484	A1	
233	51.918	46.618	7.4	1485	A1	
234	51.869	46.656	7.9	1484	N1	
235	51.772	46.813	7.1	1482	N1	W
236	51.742	46.834	7.5	1489	N1	
237	51.686	46.878	13.0	1506	V	
238	51.632	46.891	9.4	1504	N1	
239	51.560	46.851	7.6	1492	A1	
240	51.515	46.695	7.6	1476	A1	
241	51.490	46.629	9.2	1472	A1	
242	51.421	46.506	7.0	1467	G	
243	51.382	46.433	8.3	1471	N1	
244	51.344	46.374	15.2	1470	G	

APPENDIX 3

LENCHE DIMA WATER RESOURCES SURVEY INSTRUMENT

WATER, AGRICULTURE, AND LAND RESOURCES MANAGEMENT SURVEY: Lenche Dima Watershed, Gubalafto Woreda

Date : ____/_____/2003/04	Interviewer : _________________
Village Name: _________________	Farmer N^{o} : __________
Subcatchment: ________________	PA/KA (Admin. Unit): _______
Woreda: ____________	Watershed Management Unit: _______

I. Household Information (35 minutes)

A.) HOUSEHOLD COMPOSITION AND LABOR RESOURCES

To begin, I would like you to list all the people who normally live in your household, starting with yourself and your spouse, then your children and finally other people. (List individual names first, and then ask the other questions afterwards). Circle appropriate answer.

ID	Name	Sex	Age	Relation to head of household	Place of birth	Ethnic origin
#		M= male F= female	Estimate years age	1= head 2=spouse 3=child 4=other relative 5=none	1=ancestors born in area 2=newcomer born in area 3=newcomer	1= Amhara 2=other; identify
1.		M F	………..	1 2 3 4 5	1 2 3	1 2
2		M F	………..	1 2 3 4 5	1 2 3	1 2
3 Etc.		M F	………..	1 2 3 4 5	1 2 3	1 2

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(Table continued from previous page)

A.) HOUSEHOLD COMPOSITION AND LABOR RESOURCES

Education	Health status in last season	Special position in community	Member of association	Works in household farms?	Works off farm for income?
1=no formal (illiterate) 2=no formal (literate) 3=some primary (illiterate) 4=some primary (literate) 5=primary completed 6=beyond primary	1=very good 2=good 3=medium 4=bad 5=very bad	1=none 2=village head 3=teacher 4=religious leader 5=other,explain	1=yes; write type of association 2. no	1=none 2=rarely 3=sometimes 4=often	1=none 2=rarely 3=sometimes 4=often
1 2 3 4 5 6	1 2 3 4 5	1 2 3 4 5	1 2 ……….	1 2 3 4	1 2 3 4
1 2 3 4 5 6	1 2 3 4 5	1 2 3 4 5	1 2 ……….	1 2 3 4	1 2 3 4
1 2 3 4 5 6	1 2 3 4 5	1 2 3 4 5	1 2 ……….	1 2 3 4	1 2 3 4

B.) Income and Labor Sources

1.) What are the sources of money for your household (1995E.C.)? *Enter amount for each category even if zero.* Rank: Most 1st: ____ 2nd: _____ 3rd: _____

a.) livestock sale; how much total? ____ birr; which animals: _______

b.) food grain crop sale (example teff); how much? _______ birr, what: ____

c.) non-grain crop sale (example oilseed); how much? _______ birr what:___

d.) off-farm work; how much? _______ birr, what activity: ___________

e.) work on other farms around your area; how much? _____ birr

f.) other activity; how much? ________ birr Activity: _____________

2.) Does your household also receive money from people who do not currently live here? ☐ *1. Yes* ☐ *2. No* If yes, estimate total amount last year(1995E.C.) ____ birr

3.) Did you receive labor help during 1995 E.C. from people who do not currently live here? ☐ *1. Yes; community labor sharing* ☐ 2. *Yes; family or relatives*

☐ 3. *Yes; paid labor* ☐ *4. No* If yes, estimate amount;

Number of people _____________ Total number of days ____________

C.) Food Sufficiency

1.) Period of household food shortage during last year (1995 E.C.) Circle the months.

None Jan Feb March April May June July Aug Sept Oct Nov Dec

2.) How much food did your household produce and what part of that was consumed by the household? Total production____ sacks; Part consumed by household___sacks

3.) How much average *food-for-work* did your household receive last year?

__________ kg grain per month

4.) How much *food relief* (no work) did your household receive last year?

__________ kg grain per month ____________ liters oil per month

D.) Oxen Ownership (circle the answer)

1.) How many oxen do your household have?

1. 0

2. 1

3. 2

4. > 2; How many? ___________

2.) How do you accomplish your plowing?

1. *only use own oxen*
2. *rent in exchange for part of harvest*
3. *rent in exchange for labor*
4. *borrow with no form of compensation*
5. *other means, explain:*_________________

II. WATER SURVEY (30 minutes)

A.) SOURCES OF WATER AND WATER ISSUES

Please list the various sites where your household accesses water. Begin with the closest, then 2nd closest, etc. from house. Explain other choices on back of page. Please circle the appropriate answers.

ID	Type of source	Water source	Distance to house	Uses (circle all that apply)	When do you use this source? (circle all that apply)
	1.Private pond 2.Community pond 3.Gully after rain 4.River 5.Water pump 6. Open well 7.Lake/wetland 8. Other; explain	Location Name *(If it is a water pump, write the pump location and the faucet location)*	Walking time Going only (one-way)	1. Drinking/ cooking 2.Bathing 3.Cleaning 4.Livestock 5.Irrigation	1.Rarely belg 2.Often belg 3.Rarely kremt 4.Often kremt 5.Rarely dry season 6.Often dry season
1.near	1 2 3 4 5 6 7 8	---------	……..	1 2 3 4 5	1 2 3 4 5 6
2.	1 2 3 4 5 6 7 8	---------	……..	1 2 3 4 5	1 2 3 4 5 6
3. etc	1 2 3 4 5 6 7 8	---------	……..	1 2 3 4 5	1 2 3 4 5 6
8.far	1 2 3 4 5 6 7 8	---------	……..	1 2 3 4 5	1 2 3 4 5 6

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(Table continued from previous page)

A.) SOURCES OF WATER AND WATER ISSUES

Who mostly goes there to get water?	How is the water transported?	How many people per day to assure water?	Any problem with this water source? Circle all that apply.
1. Males only 2. Females only 3. Mostly males 4. Mostly females 5. Both equal	1. Human only 2. Animal only 3. Mostly human 4. Mostly animal 5. Both equal	Number of people	1. None 2. Bad water quality; *explain* 3. Bad for human health; *explain* 4. Malaria/mosquito breeding 5. Insufficient water 6. Too far 7. High labor to maintain 8. Expensive to buy 9. Other; explain below
1 2 3 4 5	1 2 3 4 5	………..	1 2 3 4 5 6 7 8 9
1 2 3 4 5	1 2 3 4 5	………..	1 2 3 4 5 6 7 8 9
1 2 3 4 5	1 2 3 4 5	………..	1 2 3 4 5 6 7 8 9
1 2 3 4 5	1 2 3 4 5	………..	1 2 3 4 5 6 7 8 9

1.) If your community was to develop additional water sources which would you prefer to contribute money/labor to construct or improve?

Ranking: Best option 1^{st}: ☐ 2^{nd}: ☐

a.) pond; why and how? ___________________________________

b.) water harvesting system; what, why, and how? _______________________

c.) water pump; why and how? __________________

d.) open groundwater well; why and how? _________________

e.) other; explain? ________________________

III.) AGRICULTURE (40 minutes)

A.) FARM PLOTS AND CROP MANAGEMENT

Please list all the plots of your household during 1995 E.C. Start with plot closest to house, then 2nd closest, etc. Circle all the appropriate answers.

ID	Own, Rent, or Lend	Plot location	Plot size/ area	Distance to house	Proximity to watershed	Plant *belg* and k*remt*	Crops planted this year *(belg and kremt)*
P L O T	1. Own 2. Rent 3. Lend *(if rent or lend explain how below)*	Location name	Area in timad	Walking time Going only (one-way)	1. Inside watershed 2. < 1 km outside watershed 3. >1km outside watershed	1. yes; both 2. Only *belg* 3. Only *kremt*	1.Tef 2.Sorghum 3. Maize 4.Chickpea 5.Other; list 6. None *Belg square* *Kremt circle*
1near	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
2	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
3	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
4	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
5	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
6	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
7	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
8	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
9	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6
10 far	1 2 3	……..		…	1 2 3	1 2 3	1 2 3 4 5 6

(Right side of table continued on next page)

(Table continued from previous page)

A.) FARM PLOTS AND CROP MANAGEMENT

Crop use	Do you plant here every year?	Do you irrigate this crop?	Who works on the plot including all activities?	Soil problems on plot (circle all that apply)
1.All consumed 2.All sold for cash 3.Most consumed 4.Most sold for cash 5.Equal consumed/sold 6.Other; explain	1. Yes 2. No; skip one year 3. No; skip more than one year	1. Yes, all of season 2. Yes, most of season 3. Yes, rarely 4.No	1. Males only 2. Females only 3. Mostly male 4. Mostly female 5. Both equal	1. None 2. Low fertility 3. High rilling/gullying 4. High sheet erosion/general loss of soil 5.Low infiltration/high runoff generation 6. Low moisture retention/dries quickly 7.Water logging/ bad drainage 8. Other; explain
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8
1 2 3 4 5	1 2 3	1 2 3 4	1 2 3 4 5	worst: ☐ circle others: 1 2 3 4 5 6 7 8

Explain Others from Table:

B. FARMING PRACTICES (only for closest, one middle, and farthest plots). LIST ALL THAT APPLY FOR EACH QUESTION. Once you have identified how a farmer learned a specific technique you should not repeat the question or answer for the other plots.

(Left side of Table)

ID	Current soil improvement practices	How did you learn this technique?	Current soil loss/erosion control practices	How did you learn this technique?
P L O T	1.Crop rotations 2.Chemical fertilizer 3.Manure 4.Compost 5.Ashes 6.Recycling plant residues 7.House trash/garbage 8.Other 1; below	1.Self-experimentation 2.Other farmers in community 3.Ancestors/it is a traditional practice 3.BoA 4.NGO project 5.other; explain	1.Contour tillage 2.Soil bund 3.Stone bund 4.Hedge or special plants 5.Trash line 6.Grass strips 7.Maintain residue cover 8.Cutoff drains 9.Other 1; below	1.Self-experimentation 2.Other farmers in community 3.Ancestors/it is a traditional practice 3.BoA 4.NGO project 5.other; explain
near	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐
med	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐
far	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐

(Right side of Table)

Soil moisture management practices	How did you learn this technique?	Drainage practices	How did you learn this technique?
1.Mulching 2.Residue incorp. 3.Ridging 4.Deep tillage 5.Timing of planting 6.Timing of other farm activities 7. Weeding furrows 8. Other 1; below	1.Self-experimentation 2.Other farmers in community 3.Ancestors/it is a traditional practice 3.BoA 4.NGO project 5.other; explain	1.None 2.Cutoff drain 3.In-plot drainage channels 4.Outlet drainage channel 5.Land leveling 6.Other 1; below	1.Self-experimentation 2.Other farmers in community 3.Ancestors/it is a traditional practice 3.BoA 4.NGO project 5.other; explain
a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐
a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐
a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐	a.☐b.☐c.☐d.☐ e.☐f.☐g.☐h.☐

Soil Improvement	Soil Loss Control	Moisture Management	Drainage
8. Other 1:	9. Other 1:	8. Other 1:	6. Other 1:
9. Other 2:	10. Other 2:	9. Other 2:	7. Other 2:
10. Other 3:	11. Other 3:	10. Other 3:	8. Other 3:

C.) Soil and Water Management Constraints

1.) What are the major constraints (difficulties) in trying to successfully manage soil?

Ranking: Most problem 1st: ☐ 2nd: ☐

a.) No difficulties

b.) Lack of enough time/labor to do all the necessary work

c.) Lack of knowledge/techniques and access to knowledge/training programs

d.) Lack of materials; explain: ______________________

e.) Lack of money or credit; explain purpose for money:______________

f.) Bad location of plots; explain problem:______________

g.) Other; explain: _____________________________________

D.) Cash Crops (for sale)

1.) What cash crops (for sale) are the farmer most interested in growing/testing (even if it requires irrigation)? Best 1st: ☐ 2nd: ☐

a.) Vegetable; which _______________________________

b.) Oilseed; which ____

c.) Pulse(beans, chickpeas, etc) ; which _____________________

d.) Cereal (food grain); which _________________________________

e.) Fruit; which ____

f.) Other; explain:_________________________________

2.) What are the primary constraints (difficulties) to production of cash crops?

Ranking: Most problem 1st: ☐ 2nd: ☐

a.) Hard to find seeds for crop of interest

b.) Lack of knowledge/experience and access to good extension/training program

c.) Insufficient water/unreliable rainfall

d.) Lack of fertile land

e.) Lack of enough time/labor

f.) Lack of money/credit; for what, explain: ______________________

g.) Lack of market or means to sell the harvest

h.) Other; explain: _____________________________________

IV.) LAND RESOURCES MANAGEMENT (15 minutes)

A.) Hillsides 1a.) Do you like the idea of community hillside area closure?

☐ *1. Yes* ☐ *2. No*

1b.) Do you think that it can be successful in your watershed? ☐ *1. Yes* ☐ *2. No*

2.) What are the primary constraints (difficulties) for successfully putting more land under area closure? Ranking: Most problem 1st: ☐ 2nd: ☐

a.) Lack of knowledge on how to do it and no extension help

b.) Lack of enough time/labor for the community to successfully manage it

c.) Lack of enough land in the watershed to put aside for area closure

d.) Lack of real community ownership/control of the hillside lands

e.) Lack of individual ownership/control of the hillside lands

f.) Lack of community organization to accomplish the tasks

g.) No problems or difficulties for the community to do it successfully

h.) Other; explain:_________________________________

B.) Views on Erosion

1.) Do you consider erosion a serious problem for your crop production?

☐ *1. Yes* ☐ *2. No*

2.) What are the most serious consequences (worst effect) of erosion in your watershed? Ranking: Worst problem 1st: ☐ 2nd: ☐

a.) Loss of cropland to gullies

b.) Loss of seeds and harvestable area due to rills and on-farm erosion

c.) Reduction in crop yields due to loss of soil fertility

d.) Flooding of lands due to sedimentation of drainage channels

e.) Loss of productive hillside land for livestock grazing

f.) Too much sediment entering ponds each year

g.) Other; explain:________________________________

3.) What activity do you think is the primary reason for the currently high erosion in the watershed? Ranking: Main reason 1st: ☐ 2nd: ☐

a.) Creation of more roads/paths within the watershed; explain:__________

b.) Changes in land cover/land use on hillsides; explain: ___________

c.) Current cultivation practices on cropland; explain: ______________

d.) Changes in the rainfall compared to past; explain: ____________

e.) Careless land management because of no real ownership/responsibility for the land

f.) Other; explain:________________________________

APPENDIX 4

HARA WETLAND SURVEY INSTRUMENT

Hara Wetland Watershed Historic Survey 2004/1997 E.C.

Date : _____/______/2004	**Interviewer : ______________**
Farmer N^{o} : ______	**Village Name:_________________**
Kebele #: _________	**Woreda: ________**

I. Household Information (10 minutes)

A.) To be asked to only one older (> 35 years) member (male or female) of the household

1.) Name of Person Interviewed: ____________________________________

2.) Gender: ☐ a. Male ☐ b. Female 3.) Age: __________ years

4.) Living in the Hara wetland watershed since 19______ E.C. or for _______ years

5.) Educational level: ☐

a.) Illiterate d.) Elementary school grades 5-8

b.) No elementary school but able to read/write school

c.) Elementary school grades 1-4 e.) Beyond/above elementary

6.) Occupation: ☐

a.) Farmer d.) Government/kebele/woreda worker

b.) Teacher e.) Shopkeeper or shop owner

c.) Religious/Mosque/Church worker f.) Other: ______________

7.) How many people are living in your household now (include yourself):

______ adults ______ children (<15y)

8.) How many livestock does your household own:

a.)Oxen: ______ b.) Cows/Bulls/Calves: _____ c.) Sheep: ____ d.) Goats: ____

e.) Donkeys ____ f.) Horses ___ g.) Camel ____ h.) Poultry: _____

9.) How much cropland area does your household (specify land area in timad for all plots): Own (timad): 1.____; 2.____; 3._____; 4._____; 5._____; 6._____; 7._____; 8._____; 9.____; 10.____

Rent (timad): 1.____; 2.____; 3._____; 4._____; 5._____; 6._____; 7._____; 8._____; 9.____; 10.____

10.) Where are the most important places where your **livestock get water:**

Main ☐ , 2nd ☐, 3rd ☐

a.) Hara wetland
b.) Ponds
c.) Pump/faucet
d.) Gully
e.) River
f.) Other: ___________________

11.) Do you use **water** from the wetland for washing clothes, bathing, cooking, human drinking, or house construction? Select all that are true.

a.)None☐ b.)Washing clothes☐ c.)Bathing☐ d.) Cooking☐

e.)Human drinking☐ f.)Construction☐

12.) Where are the most important sources where your **livestock get feed/graze**:

Main☐, 2nd☐, 3rd☐

a.) Inside the wetland (define wetland)
b.)The grassland area around the wetland
c.) On the hillsides and hilltop
d.) Cropland residues
e.)Grass areas around Alewuha river
f.) Other: _________________

13.) What are the most important **fuel sources** for your household:

Main ☐ , 2nd ☐ , 3rd ☐, 4th ☐

a.) Wood and plants <u>inside</u> wetland area e.) Animal dung/manure

b.) Wood from <u>outside</u> the wetland area f.) Crop residues/sorghum stalk

c.) Charcoal g.) Brush/dry plant materials

d.) Kerosene h.) Other: ______________

II. Watershed and Wetland History (20 minutes)

A.) Hara Watershed History

1.) If there are now 15,000 people living inside the Hara watershed villages including Hara Town, how many people do you think lived in the watershed:

a.) **5** years ago (1992 EC): _______ b.) **10** years ago (1987 E.C.):_______

c.) **30** years ago (1967E.C.):______

2.) How does the land cover on the **hillsides and hilltops** in the Hara watershed now compare with **30** years ago

Now <u>Less</u> [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus/weeds f.)Crops g.)Bareland h.)Houses **]** than before;

Now <u>More</u> [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus/weeds f.)Crops g.)Bareland h.)Houses**]** than before

3.) How does land cover **below the hillsides** in the Hara watershed now compare with **30** years ago (circle):

Now <u>Less</u> [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus/weeds f.)Crops g.)Bareland h.)Houses **]** than before;

Now <u>More</u> [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus/weeds f.)Crops g.)Bareland h.)Houses**]** than before

4.) How does the **number of livestock** grazing in the Hara watershed now compare with **30** years ago ☐

a.) The same number of livestock now as before

b.) Now a little less livestock than before

c.) Now much less livestock than before

d.) Now a little more livestock than before

e.) Now much more livestock than before

5.) How does **rainfall** in the watershed this year compare to:

Last year ☐, **5** years ago☐, **30** years ago☐

a.) The rainfall now is the same as before

b.) Now a little less rainfall than before

c.) Now much less rainfall than before

d.) Now a little more rainfall than before

e.) Now much more rainfall than before

6.) How does **land productivity**/crop yields in the watershed now compare with **30** years ago?

a.) The land productivity/crop yield now is the same as before

b.) Now a little less land productivity than before

c.) Now much less land productivity than before

d.) Now a little more land productivity than before

e.) Now is much more land productivity than before

7.) How does the **soil and land condition** in the watershed now compare with **30** years ago (circle answers):

Now <u>Less</u> [a.)Gullies b.)Erosion c.)Soil fertility d.)Runoff/flooding e.)Soil moisture retention f.)Plant pests**]** than before;

Now <u>More</u> [a.)Gullies b.)Erosion c.)Soil fertility d.)Runoff/flooding e.)Soil moisture retention f.)Plant pests**]** than before

B.) Hara Wetland History

1a.) As long time ago as <u>you</u> can remember has there always been an area of standing water/flooding in the place that has a wetland this year?

a.)Yes, always flooded☐ b.)No☐, flooding started about ____ years ago;

* (If yes above skip) Explain what you think caused the flooding to start then:

1b.) Compared with how it looks now, describe how did the land area that has the **wetland** look different:

a.) <u>5 years ago (1992 E.C.):</u>

b.) <u>10 years ago (1987 E.C.):</u>

c.) <u>30 years ago (1967 E.C.):</u>

2.) How is the **maximum** wetland **flooding/water area during the year** now compared to: Last year ☐, **5** years ago☐, **30** years ago☐

a.) The <u>same</u> flooding/water area/size now as before

b.) Now a <u>little smaller</u> flooding/water area/size than before

c.) Now <u>much smaller</u> flooding/water area/size than before

d.) Now a <u>little bigger</u> flooding/water area/size than before

e.) Now <u>much bigger</u> flooding/water area/size than before

3.) How does the amount of water in the wetland during the **minimum/driest time during the year** this year compare to:

Last year ☐, **5** years ago ☐, **30** years ago ☐

a.) The same amount of water now as before

b.) Now a little less water than before

c.) Now much less water than before

d.) Now a little more water than before

e.) Now much more water than before

4.) How does the **total amount** of **plants inside the wetland** now compare to:

5 years ago☐, **30** years ago☐

a.) The same amount of vegetation now as before

b.) Now a little less amount of vegetation than before

c.) Now much less amount vegetation than before

d.) Now a little more vegetation than before

e.) Now much more vegetation than before

f.) I don't know

5.) How does the types of vegetation/**plants inside the wetland** this year compare with **30** years ago (circle):

Now Less [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus f.)Algae g.)Reeds/bamboo h.)Other ______**]** than before;

Now More [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus f.)Algae g.)Reeds/bamboo h.)Other ______**]** than before

6.) How does the types of **wild animals <u>inside</u> the wetland** area this year compare with **30** years ago (circle):

Now <u>Less</u> [a.)Birds b.)Leeches c.)Fish d.)Frogs e.)Snakes f.)Lizards g.)Other: _______**]** than before;

Now <u>More</u> [a.)Birds b.)Leeches c.)Fish d.)Frogs e.)Snakes f.)Lizards g.)Other: _______**]** than before

7.) How does **total** amount of **plants <u>around</u>** the **grazing area near the wetland** now compare with **30** years ago ☐

a.) The <u>same</u> amount of vegetation now as before

b.) Now a <u>little less</u> amount of vegetation than before

c.) Now <u>much less</u> amount of vegetation than before

d.) Now a <u>little more</u> vegetation than before

e.) Now <u>much more</u> vegetation than before

f.) I don't know

8.) How does the types of **plants <u>around</u>** the **grazing area near the wetland** now compare with **30** years ago:

Now <u>Less</u> [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus f.)Algae g.)Reed/bamboo h.)Weeds i.)Other ____**]** than before;

Now <u>More</u> [a.)Trees b.)Bushes c.)Shrubs d.)Grass e.)Cactus f.)Algae g.)Reed/bamboo h.)Weeds i.)Other____**]** than before

9.) How does the **wetland water quality/purity** now compare with **30** years ago ☐

a.) The wetland water quality now is the <u>same</u> as before

b.) Now the wetland water is **cleaner/purer** than before

c.) Now the wetland water is **<u>less</u> clean/pure** than before because (select all that apply) more soil/sediment☐, smells worse☐, more sickness after human drinking ☐,more salt☐,tastes worse☐, more plant residues☐

d.) I don't know

III. Perspectives of the Wetland and Environmental Change (10 minutes)

1.) Do you **like** the presence of the wetland in the watershed: a.) Yes ☐ b.)No ☐

*Explain why (write all the reasons):

2.) What are the reasons **you like** the wetland (list all):

Main Reason ☐, 2nd ☐ , 3rd ☐, 4th☐, 5th☐

a.) Water for livestock

b.) Water for domestic use

c.) Water for crop irrigation

d.) Livestock grazing grass/feed production <u>inside</u> the wetland

e.) Wild animals for hunting; which animals: ________________________

f.) Fuelwood for home

g.) It makes the area look beautiful; explain how or why: ____________________

h.) Other: ___________________________________

3.) What are the reasons **you do not like** the wetland:

Main reason ☐ , 2nd ☐, 3rd ☐, 4th ☐, 5th ☐

a.) Too many mosquitoes

b.) Too much cropland area lost to the wetland

c.) Too much grazing land area lost to the wetland flooding

d.) Bad water quality

e.) Dangerous for people/children

f.) Dangerous for livestock

g.) Other; Explain: ________________________________

4.) What are the primary reasons for **changes to the wetland** during the past 30 years: 1st ☐, 2nd ☐, 3rd ☐, 4th ☐

a.) Rainfall has decreased during the past 30 years

b.) Increase in the number of people living in the watershed

c.) Increase in the number of livestock grazing in the watershed

d.) Increase in the total land area with crop cultivation

e.) Decreased number of trees and forests in the watershed

f.) Increased soil erosion and gullying in the watershed

g.) Increased runoff from hillsides

h.) Increased runoff from Hara town

i.) Other 1; Please explain:________________________

j.) Other 2: Please explain: _____________________________

k.) I don’t know

5.) What are the primary reasons for the changes that have occurred in the **amount of trees/forests and bushes** of the watershed during the past 30 years:

Main reason ☐, 2nd ☐, 3rd ☐, 4th☐

a.) Rainfall has decreased during the past 30 years

b.) Increase in the number of people in the watershed

c.) Increase in the number of livestock in the watershed

d.) Increase in the land area cultivated for crops

e.) Less soil fertility

f.) Increased construction of houses

g.) Other; Please explain:___________________________________

h.) I don't know

6.) For the **future**, how do you think the watershed will change during the **next 10 years**? Circle the answers.

a.) In the future *More / Less / Same* number of **people** and houses than now

b.) In the future *More / Less / Same* number of **trees** and bushes than now

c.) In the future *More / Less / Same* number of **livestock** than now

d.) In the future *More / Less / Same* number and size of **gullies** than now

e.) In the future *Better / Worse / Same* **soil fertility** than now

f.) In the future *More / Less / Same* crop yield/ **land productivity** than now

g.) In the future *More/ Less /Same* size and amount of **water in the wetland** than now; ***Please explain** why the wetland size will change or not in the future:

h.) In the future *More / Less / Same* **difficulty** to get **domestic and livestock water** than now

i.) Additional comments or predictions: ______________________________

7.) What changes in the wetland would you like to see in the future? Please describe what and why.

8.) What changes in the Hara watershed would you like to see in the future? Please describe what and why.

9.) Are/were there any other similar natural wetlands/lakes near (< 20 km) Hara in the past or presently? a.) No ☐ b.)Yes ☐ If yes, where and when?