Towards sustainable watershed development and management: the case of participatory design and construction of a communal drain system*

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Introduction

In the past, improved watershed management was generally synonymous to achieving a particular, often single technical objective, e.g. improved forestry, better soil conservation, or the introduction of water harvesting. These projects were initiated and executed with little or no real involvement of farmers. The new approach addresses the much more fundamental issues of poverty alleviation and sustainable development of watersheds for the welfare of farmers and communities. Watershed development and management is thus seen in its entire complexity, where inter-related factors and their interactions are considered with the main objective of poverty alleviation and food security of watershed communities (Sharma and Krosschel, 1998). With the new emphasis on poverty alleviation and food security through appropriate natural resources management both people and natural resources become the primary focus of integrated watershed management (Pathak and Klaij, 2000).

Over the past six years, the Joint Vertisol Project (JVP), a consortium of research institutions, working with extension services and small holder farmers, developed technologies for raising the productivity of Vertisols of the Ethiopian highlands. Three elements particularly important for Ethiopian highland conditions were adapted from an improved Vertisol technology cropping system developed by ICRISAT for India (El-Swaify *et al.*, 1985). Central element to the success of this technology is an effective soil and water conservation and surface drainage system allowing the second element namely cropping of traditionally rainy season fallow systems. The system consists of an approximately 0.9 m wide bed and a 0.4 m wide shallow furrow. The broad bed and

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***** In: Paulos Dubale, Asgelil Dibabe, Asfaw Zeleke, Gezahegn Ayele and Abebe Kirub (Eds) (2001) *Advances in Vertsols Management in Ethiopian Highlands*. Ethiopian Agricultural Research Organisation, Addis Ababa, Ethiopia. Pp.219-226.

furrow system (BBF) is laid out at a grade of 0.4 to 0.8% for safe disposal of runoff (Kampen, 1982). In the Ethiopian highland context, improved drainage enabled early sowing of improved wheat varieties. In combination with chemical fertilizer input, farmer managed demonstration trials of "improved Vertisol wheat technology" packages have resulted in appreciably higher wheat yields; we have recorded up to four-fold yield increases over traditional yields which are typically about 0.6 to 0.8 t ha^{-1}.

During 1990-95, on-farm research was executed at three villages (Inewari, Ginchi and Hidi) with a particular focus on the adoption behaviour of the participants in on-farm research. In these experimental villages, adopting farmers used the technology on scattered individual plots. In many cases these plots bordered natural gullies to which the bed and furrow system were directed to allow free drainage. Where this was not the case drainage from their fields spilled into adjoining plots downstream thereby creating conflicts because it could hinder the downslope farmer, and the upslope farmer when the drained runoff could not effectively be expelled. Under these circumstances a watershed management approach towards improving drainage is required.

We address the case of the participatory design and construction of a main drain system in the Joint Vertisol Project agricultural micro-watershed in Ginchi. The watershed is typical of the region, its altitude is 2200 m asl, annual rainfall is 1139 mm, annual reference evapotranspiration is 1296 mm, and mean temperature is 16.3 °C. Through the combination of abundant main rainy season rainfall, cool temperatures and the intrinsically low hydraulic conductivity of Vertisols, severe surface waterlogging and runoff occur from July until the end of the rains by mid September. Poor field drainage is the norm in this critical period resulting in production loss and deterioration of the resource base by water erosion. Indeed, farmers of the watershed considered rainy season waterlogging a primary constraint to increased agricultural production. During watershed walks and discussions with farmers, Ministry of Agriculture, and other stakeholders farmers decided on the design and construction of a main drainage system and a cutoff drain.

This paper first describes the watershed characteristics; it then discusses technical aspects of the main drain design, followed by discussion of socioeconomic aspects of farmer participation in the design and construction of the communal drain system.

Main characteristics of the Ginchi watershed

A topographical survey provided data on terrain elevations, field boundaries and ownership, gullies and gully boundaries, pathways, trees, and settlements of the Ginchi micro-watershed. The data were geo-referenced. The 45 ha micro-watershed, forming lower part of a 300 ha large watershed, is cultivated by 64 farmers, of whom 6 women farmers, using 152 fields having an average size of 0.3 ha. The upper part of the oblong (1000 x 450 m) watershed is convex with slopes ranging from 2.3-3%, a steeper middle part with slopes up to 4%, and a concave lower part with slopes as low as 1.6%. The major drainage axis is 1100 m long, covering an elevation difference of 23.4 m. Pathways that are grassed had a total length of 4.6 km, covering 1.4 ha (Fig. 1).

About 2.1km of field gullies patterned an imperfect surface drain system in the 45 ha sub-watershed. Imperfect because many gullies were not stable, and were not or poorly connected. In addition, only 29 fields out of the total of 152, or in area 11 out of 45 ha, bordered hence directly drained into this badly connected gully system.

Ginchi is a typical teff growing area, between 1994 and 1998 farmers cultivated teff annually on over 50% of the watershed area. The Improved Vertisol wheat technology was adopted by farmers who cultivated improved wheat on 2-20% in the micro-watershed depending on the year. Important N-fixing legumes such as chickpea and roughpea were grown on 7 to 10% of the total area. Farmers using the improved Vertisol wheat technology recognized improper drainage being a constraint to crop production.

Agricultural gravity drainage systems

Around Ginchi, the mean main rainy season rainfall, from July through September, is 602 mm, the mean potential evapotranspiration is a low 263 mm, which accounts for a measured seasonal runoff during 1994 to 2000 ranging from 76 to 359 mm. The need for improved drainage, as already voiced by farmers is one of high-priority.

The objective of an agricultural drainage system is to facilitate water to flow from the land so that agriculture can benefit from reduced water levels. Two distinctions can be made; the system evacuates water underground, or over the soil surface. Both types of systems require an internal drainage system or field drainage system, which lowers water levels in the field, and an external or main drainage system, which conveys the water to the outlet.

Surface drainage systems are applied when waterlogging occurs on the soil surface, which is the case in the Ginchi, and other Vertisols areas in the Highlands. Surface drainage is defined as (ICID, 1982):

> *The diversion or orderly removal of excess water from the surface of the land by means of improved natural or constructed channels, supplemented when necessary by shaping and grading of the land surface to such channels*.

Surface drainage is primarily intended to reduce ponding and prevent prolonged saturation of the upper soil profile, by accelerating flow to an outlet without causing undue siltation or soil erosion. Therefore, on the one hand we are concerned with removing agricultural constraints (improve field conditions for crop growth), and on the other hand with conserving the resource base applying engineering principles to ensure non-erosive water flow through channels and waterways. These waterways tend to follow the maximum slope. Slopes are moderate in the Ginchi watershed; hence, grassed waterways are appropriate. The vegetation reduces the flow velocity while it allows a higher velocity than unlined waterways. For slopes less than 5%, allowable velocities for erosion resistant soil covered by dense grass is 2 m $s^{-1.}$ In our design of the waterway we adopted an allowable flow velocity of 1.7 m $s^{-1,}$ a roughness coefficient of the Manning formula of n=0.04, and a parabolic cross section shape.

Deciding on design runoff

To properly control excess surface flow of water throughout a sub-watershed we need to know what peak runoff rates we can expect, because this rate determines the required cross sections of the main drain and culverts. The magnitude of the peak runoff relates to the frequency of occurrence; very high rates occur less frequently. To accommodate a very high peak runoff rate can be expensive, as channel cross section have to be larger. The challenge is therefore to compromise between expensive designs that work most of the time, and much less expensive ones that will fail occasionally. For main drain designs, return periods of 5 to 25 years are usually considered (Boonstra, 1994). At the time of the waterway construction only one season of runoff measurements in the micro-watershed had passed. We therefore decided on a design runoff rate of 0.05 m^3 ha^{-1} s^{-1} somewhat lower than the 0.06 m^3 ha^{-1} s^{-1} based on Cooks model (Soil Conservation Service, 1972) when using a 10-year return period for rainfall. Presently we have eight years of runoff data available, and it seems that the then adopted design peak runoff rate is realistic for a 5 year return period (Fig. 2). The existing gully system was largely inadequate to accommodate the adopted design peak runoff rate, as was already apparent from severe gully head erosion in the watershed.

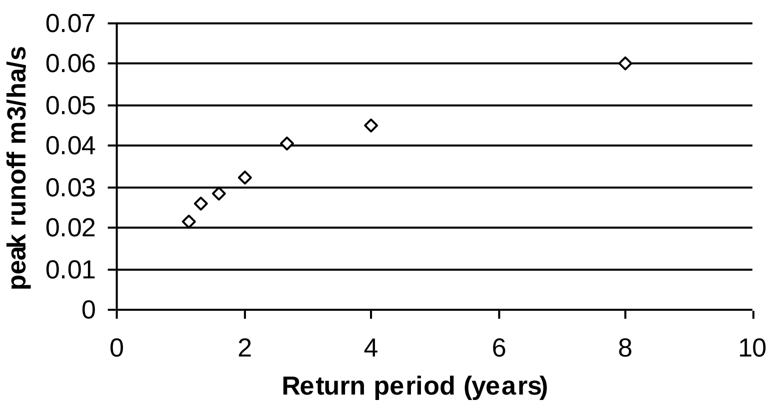

Fig. 1. Peak runoff rate- return period relation for a 45 ha Ginchi agricultural micro-watershed derived from runoff data from 1994 to 2000.

Farmer view of main drain design aspects

Farmers expressed their interest in improving external drainage in their watershed. However, they were unwilling to do the necessary reshaping and increasing the size of the existing gullies running through their fields because it would take out part of their individual productive land. In a series of meetings held in the spring of 1995 farmers, Ministry of Agriculture extension staff, and project staff discussed possible alternatives. Eventually, parties agreed to project a main drain (grassed waterway) on the 2 to 10 m wide communal grassed pathways that cross the watershed.

This was an excellent alternative because it allowed the projected waterway to largely follow the maximum slope of the natural gully system. A transect walk with farmers across the micro-watershed led to the development of a map showing principal waterways during heavy rains, and this map was about 90% accurate when a formal topo survey to determine slope gradients was conducted**.** Because the runoff contributing area steadily increases from the top of the watershed to its outlet, the runoff flow through the waterway correspondingly increases. We envisaged 6 successive waterway sections to cope with the expected runoff volumes. Waterway section parameters are given in Table 1. The projected waterway would greatly improve the overall drainage situation because not only would the new waterway add 0.85 km to the existing gully system, most of the runoff would bypass these gullies. Therefore the size of the gullies would be amply sufficient to serve as stable field drains. In addition, farmers agreed to construct a cutoff drain, upslope of the 45 ha sub-watershed with the aim to divert water from an upslope 15 ha into a large gully, thus stopping it from running through the sub-watershed. Farmers were however reluctant to accept the much wider and deeper drains than they were used to, necessary to expel runoff safely.

In the new situation a total of 89 fields would be bordering and draining directly into the man drain, while the 29 fields draining directly into the gullies that served as secondary drains. Farmers could add a few more secondary drains linking more fields to the main drain at a later stage. This allowed for a flexible modular approach enabling farmers to invest time and effort at their convenience to improve drainage of fields not yet properly connected. Implementation of the new main drain required considerable earth moving (Table 1.)

Table 1. Adopted parabolic section dimensions and characteristics of a main drain grassed waterway, based on a design discharge of 0.05 $m^3s^{-1}ha^{-1}$, a Manning roughness of n=0.04, and a maximum flow velocity of 1.7 m .s^{-1}.

Drain Section Number (Fig. 1)	Slope (m/m)	Section length (m)	Contributing area (ha)	Design discharge Q (m^3s^{-1})	Section Depth D (m)	Section Width T (m)	Cross section Area (m^2)	Earth moved (m^3)
1	0.023	375	6	0.3	0.4	1.0	0.27	100
2	0.016	75	12	0.6	0.5	1.5	0.50	38
3	0.016	120	18	0.9	0.55	2.0	0.73	88
4	0.016	60	20	1.0	0.5	2.5	0.83	50
5	0.016	210	30	1.5	0.55	3.3	1.21	254
6	0.023	60	30	1.5	0.55	3.3	1.21	73

Farmer planning for and construction work of the common drain

The project emphasised that sustainability and success of community action for such common work would depend a great deal on the capacity of the local people to organise themselves rather than depend on the external agencies. In some villages, local community organisation may be strong and cohesive, so with some assistance from the extension and development agencies, acting as a catalytic agent, they may organise themselves to do the job. In places where local community organisation is non-existent or weak, extension and development agencies may need to make extra effort to create capacity of the local community to organise themselves to do the job. That is why, short cut methods and use of force or compulsion, directly or indirectly, should be avoided even when a slightly longer time is required to organise people and make impact. So in order to ensure replicability of such effort, the project staff facilitiated discussion meetings and raised issues in addition to those raised by the farmers and encouraged them to take decisions on the points mentioned below. A number of meetings were required to agree on those procedural matters.

Work started in May 1995 just ahead of the main rains. Prior to the actual drain construction several meetings involving potential participants were convened to discuss and take decision on a whole range of issues, e.g.

- the work schedule, given that the construction period would coincide with land preparation activities and several regular and festival related holidays during which farmers, most of them being Orthodox Christians, were not supposed work,
- who would contribute to the earth work and how much,
- if a plot within the sub-watershed was rented, whether the tenant or the land owner would contribute labor.

Because the grassed pathways were dry, breaking the sod by hand was difficult hence time consuming. We therefore decided to use a tractor with a three-body one-way moldboard plow to break up the sod. Thus within seven hours 1.3 km of drain was broken and a considerable volume of soil was loosened, partially shaping the projected waterway which greatly facilitated final shaping using hand labor.

Forty-one farmers who had land in WS-1 worked together voluntarily to construct the drain. In total 33 out of 53 sampled households participated thereby moving an estimated 500 m^3 of earth requiring 173 person days. Obviously, participation was influenced by individual benefits farmers expected to gain from the communal waterway.

Determinants of participation

Data were collected from those who participated in the drain construction as well as a matching sample of non-participants. Participation was defined in two ways: time spent both in preparatory meetings and earth work, and time spent only in earth work. Then to explain both participation (yes vs no) and the extent of participation (time spent), Tobit regression was fitted with participation (PART) as a dependent variable and a number of independent variables. The best fit equation contained the following independent variables: *LAND*[1]*:* the number of *kerts* owned in the sub-watershed area; *PROX:* the proportion of land parcels owned in the sub-watershed that form a compact set with at

[1] The *kert* is the traditional unit of measurement in Ethiopia which is equivalent to one-fourth of a hectare.

least one parcel bordering on the drainage channel ; *CAPL:* the ratio of number of draught animals owned to adjusted size of the family workforce, where the adjustment is made by giving an unitary weight to all members aged between 15-59 years while children aged between 6-14 years receive a weight of only one-third; *LEAD*: a dummy variable representing leadership qualities (it is equal to 1 if the household head is a member of the executive committee of the local Peasant Association and to zero otherwise); *YALT* : a dummy variable representing access to non-agricultural incomes (it is equal to 1 if any member of the household earns incomes from a non-agricultural occupation, and zero otherwise); *LOUT*: the proportion of land owned by the household which is located outside the sub-watershed ; and *CROP* : the proportion of land allocated to wheat growing in the sub-watershed.

Tests have shown that either of the two definitions of participation was appropriate for explaining determining factors, so the broader definition was adopted (Gaspart et al., 1998). The best fit estimated Tobit equation is as follows:

$$\underset{}{PART} = \underset{(-1.060)}{5.8250} + \underset{(2.420)}{1.6144}LAND + \underset{(3.262)}{9.4763}PROX + \underset{(3.194)}{6.2326}\,CAPL + \underset{(5.814)}{22.5350}\,LEAD$$

$$- \underset{(-0.475)}{1.5591}\,\mathrm{YALT} - \underset{(-1.134)}{5.6335}\,\mathrm{LOUT} + \underset{(0.126)}{0.4382}\,CROP$$

Log-likelihood: - 126.53   Figures in the parentheses are t statistics

It is evident from the results that all the coefficients are of the expected sign. However, four variables are highly statistically significant: *LAND* (at 1.6% level of significance); *PROX* (at 0.11%); *CAPL* (at 0.14%); and LEAD (at close to 0.00%). In particular, the larger the land area of a farmer in the watershed where a drain was constructed, greater was the willingness to participate and contribute because of the possibility of deriving larger gains from the use of the new technology. Similarly land area as such in the watershed may not be adequate if most of the fields are not located near the drain to benefit from it. We found that nearer the plot to the proposed drain, greater was the probability and degree of participation . Farmers with a larger capital (in this case draught animal, the principal form of capital in the watershed) per family work force were more likely to participate and contribute more because of the potential for deriving benefits by using animals and the BBM. Farmers in any leadership position in the Peasant Association (member, chairman) were more inclined to participate and contribute more to the construction. It is noteworthy that members of the executive committee of the local Peasant Association have contributed an average of 22 hours, compared with 12 hours for all participating households and with 7.5 hours for all sample households (whether they have participated or not). The reason may be that members or chairman of a Peasant Association may want to maintain their leadership and role model status in the community by participation and demonstration. Although access to outside income was not a statistically significant factor, its negative sign indicates that families with access to non-farm income (because of higher education of children or because of business), particularly when such income is high in relation to farm income, may show less interest in participating and contributing to common drain construction. This seems logical as these farms, at least in the beginning may see secured non-farm income as more attractive than uncertain potential income from the drain and the BBM technology.

In addition to this general pattern, we also encountered evidence of the usual 'free rider' and 'prisoner's dilemma' problems in collective action. Some farmers having plot(s) close to the main drain or within the sub-watershed did not participate though they adopted the BBM technology during the ensuing crop season and derived benefit from improved drainage. Others in similar situations contributed knowing that non-participant would also benefit. On the other hand, some farmers not having any plot within the sub-watershed or having a plot but not planting improved wheat in the ensuing season contributed labor perhaps because they expected benefit in the future. The earth work was started from the bottom end of the sub-watershed and fewer farmers participated in the beginning but as the work progressed and it became evident that the drain would be constructed, more farmers joined in. By the time the work reached the end of the sub-watershed, more farmers started coming and requesting to expand the drain length to cover more land. This was, however, not possible in that year.

There may be other important factors in specific locations, which may positively or negatively influence participation. It is important to identify such factors in consultation with the community and take appropriate approach to motivate and induce maximum voluntary participation by the farmers who are likely to benefit from such enterprise.

Discussion and concluding remarks

Individual adoption of the Vertisols package is important but because adoption in a scattered field may lead to less effective overall drainage, community level decision and agreement is then required about construction and maintenance of field drains and the communal main drain to expel water from individual plots in a watershed context. Construction of such drains should be on a voluntary basis by beneficiary farmers. However, where necessary extension and development agencies may assist local communities to organise themselves. Drainage solutions are watershed-based. Engineering data including design and rainfall data are essential for drainage channel design. Obviously farming communities need the help of public service organizations for the design of main drains. Individual farmer's motivation to participate and make voluntary contribution depend largely on the potential personal gains that the farmer canxpect from a common drain system. It may be necessary to identify important motivating factors in each location and develop approach to participation accordingly

Farmers cultivating the sub-watershed appreciated the drainage improvement brought about by their communal drain. In 2000, farmers cultivating an area close to the micro-watershed solicited technical information before they started their own very limited in scope communal drain development. An important question is, can we expect resource poor farmers, whose land tenure is not secure to invest in watershed-based communal soil conservation? Benefits of this "structural" intervention accrue over years to individual farmers. It is important that the communal efforts go hand in hand with new crop production technologies that enhance the structural interventions by quickly increasing productivity on individual farmer basis. Research plays an important but limited role in achieving these goals as the Indian experience learns.

The MoA of India's 25-year plan on sustainable rainfed agriculture through Watershed Development proposes to cover 63 mi. ha. For the first 5 year period 10 mi. ha are to be developed at a total cost of about one billion USD, or about UD$ 100. - per ha. Long Indian experience learns that integrated watershed management projects show a number of constraints: peoples participation and beneficiary ownership need to be enhanced, greater flexibility in watershed development guidelines to account for local knowledge, research is needed in farming systems and watershed technology, public funds are needed along with larger contributions from "External Funding Agencies", a greater need for capacity building and human resources then earlier anticipated, cost sharing either in time or cash with beneficiaries, stronger linkages between improved land conservation and production systems, institutional arrangements that complement the strength of linkages between NGOs , local government bodies and the Government. It is believed that optimal use of public funds will be greatly enhanced through institutional arrangements that empower communities to plan implement, monitor and maintain their watersheds. Participatory development is believed to enhance a demand driven process through which will add far more resources to those made available by the Government

Clearly, in the Ethiopian context it means that sustainable agricultural development along the "Indian" way poses tremendous challenges.

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