Performance assessment of Mush Irrigation Scheme in Ethiopia for opportunities for best water management practices

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Contents

Summary

An assessment of the Mush Irrigation Scheme (MIS) in Debre Birhan, Amhara, Ethiopia was conducted during the spring[1] (Tseday) season of 2015. The study aimed to evaluate the operation and efficiency of the irrigation scheme and assess potential cropping and water management alternatives for potato, fodder and other cultivated crops. The evaluation made use of group discussions, farmer surveys and field measurements. This assessment underlies the approach of the Africa RISING Project to facilitate sustainable intensification of agricultural production using a systems (in this case scheme) approach. It evaluated the option of irrigating alternative crops and its potential effect on both crop and water productivity as well as potential irrigation expansion.

The operation of the system is constrained by water resource availability and capacity to utilize the limited water resources efficiently. Springs supply the scheme with a discharge of 0.16 m^3/s. As the nursery uses roughly 40 % of the available flow during weekdays only 0.09 m^3/s is available at the head of the canal for irrigation. As such, the scheme management faces challenges to provide water access to the members of the three groups in an equitable manner. Members currently irrigate an average of 0.34 ha per farmer. Due to the dilapidated state of the canal and leakages from poorly maintained outtakes, transmission losses between 0.25 and 0.67m^3/hr/m occur. The system, though operating at acceptable system efficiency, has highly variable application efficiencies between different farmers and crops, ranging between 21 and 80%, which partly explained the large variability in land and water productivity observed in the scheme. In spring season (Tseday) land and water productivity were found lowest for lentil (527 kg/ha and 0.51 kg/m^3, respectively) while higher values were obtained for potato (6800 kg/ha and 6.54 kg/m^3, respectively). While the water productivity is higher, for potato the crop has a higher water demand throughout the season stressing the scheme further. Through efficient management of flood irrigation (70%), the current irrigated acreage of 27 ha could be increased to 45 ha (of potatoes) or 63 ha of irrigated lentil. Improved irrigation methods and/or on-farm water management may lead to even larger increases in irrigable land.

Mush Irrigation Scheme in its current state (i.e. including system losses) is presently operating at full capacity, which leaves very little room for temporary storage during the spring season. The potential for storages during the other seasons is feasible given the availability of unirrigated fields and high elevation variability for gravity fed irrigation. This will require further assessments to document flows during these times to design appropriately sized storage structures which, given the land limitation, will need to be considered carefully. The scheme contains several springs. However, their contribution to the scheme throughout the season is not clear. Identification of recharge zones in combination with geomorphology will assist in understanding the contribution of the existing springs to the overall water availability in the scheme. Furthermore, a better understanding of groundwater level fluctuations throughout the year would allow for the investigation into whether over-irrigation or inefficient usage leads to increased groundwater levels in the dry season. This could lead to improved scheme planning and operation.

[1] There are four seasons: Kremt/Meher - summer; Belg – autumn; Bega – winter and Tseday – spring. Source: http://www.ethiopiantreasures.co.uk/pages/climate.htm

Background and justification

To intensify rural agricultural systems, water availability and access are key factors. The development and performance of smallholder irrigation is highly dependent upon the users' ability to manage such systems efficiently. As such, the managerial capacity of scheme managers and farmers as well as the maintenance of functional irrigation infrastructure is equally important in achieving sustainable irrigation systems (Bembridge, 2000). This is often achieved if a certain level of ownership and responsibility within the smallholder irrigation system is obtained (Garces-Restrepo, Vermillion, & Munoz, 2007). As such, the aim of the project is to: i) evaluate the availability of water resources for irrigation and agricultural productivity within the scheme; ii) assess the management structure and responsibility of the members within the scheme and iii) evaluate whether the scheme could be improved.

The study was carried out in a period of one week and thus represents only a snapshot of the state of the system. Furthermore, the quasi-quantitative survey carried out to assess key elements of the research focused primarily on those members of the Mush Irrigation Scheme who are participants in the Africa RISING interventions hence may not highlight the perceptions and actions of all members within the scheme. That said, the responses as indicated below suggest a fair representation of the households as they are generally similar across different participants.

Objectives

The main objective of this study was to assess the performance of the Mush Irrigation Scheme, thereby evaluating the opportunities for best water management operation and practices of the system through a holistic evaluation of the scheme's human and environmental components. During the study, the following objectives were addressed:

- Understand the management structure and operation within the scheme with regards to water distribution
- Evaluate the current level of water and land productivity through surveys of water use, irrigated acreage and production
- Assess irrigation system flows and flow distributions within the scheme in terms of equitable water access
- Evaluate changes in water and land productivity that could be achieved through changes in scheduling durations and cropping patterns

Description of study area

Mush Irrigation Scheme (MIS) is situated within Gudo Beret Kebele, Basona Worena Woreda, North Shewa Zone of Amhara Region. The region is located within the Ethiopian highlands. The altitude ranges between 2650 and 3350 m a.s.l. Gudo Beret is located approximately 130 km North East of Addis Ababa and 32 km North of Debre Birhan. Mush Irrigation Scheme has a command area of approximately 80 ha. The irrigators in the scheme are organized in three irrigation groups. The division of irrigators in groups are based on both plot size and number of farmers in each group. Three members who are elected and work on volunteer basis represent each group at the MIS management committee. The MIS management committee has the overall authority to administer the scheme through construction planning and coordination as well as its management and operation. The management committee also administers the community's financial cooperative that operates a nursery and supplies potato and tree seedlings to farmers. The financial operations of the committee also offer credit and savings facilities to community members.

Rainfall occurs during both Belg/autumn (February – April) and Meher/Kremt/summer (June – September) seasons. The average annual rainfall received varies from 950 to 1200mm and mean annual temperature varies between 6^0C and 20^0C (Table 1). The black clayey-loam soils, classified as Vertisols and Cambisols, characterize the area. A livelihood profile of Amhara for 2005 (Central Statistical Authority) indicated that Gudo Beret had a population of 6471 comprised of 1502 households. About 30% of the households in the larger Amhara Region were female-headed (Central Statistical Agency, 2007).

Table 1: Average weather data at Debre Birhan for 2000-2014 (source: Agricultural Research Center, Debre Birhan; 9.60650 N; 39.50280E and 2765m a.s.l.)

	Jan.	***Feb.***	***Mar.***	***Apr.***	***May.***	***Jun.***	***Jul.***	***Aug.***	***Sep.***	***Oct.***	***Nov.***	***Dec.***
Max. Temp. (^{0}C)[a]	19.8	20.7	21.2	20.7	21.4	21.7	18.4	18.3	19.0	19.1	19.1	19.0
Min. Temp. (^{0}C)[a]	5.8	6.5	7.4	8.3	8.1	7.9	8.9	8.8	7.2	4.4	3.7	3.7
Rainfall (mm)	13.6	15.9	27.2	44.7	58.1	51.4	254.9	331.7	188.2	22.6	11.1	6.4
Rel. Humidity (%)[a]	55.9	53.8	51.9	57.9	56.1	56.9	78.3	78.2	69.4	55.9	56.2	56.0
Wind speed (m/s)	2.55	2.72	2.61	2.27	2.12	2.04	1.51	1.40	1.47	1.69	2.08	2.20
Sunshine (hours)	8.9	8.3	7.6	7.0	8.7	7.0	5.3	5.8	6.4	9.0	10.1	9.7

[a] Max. Temp, Min. Temp. and Rel. Humidity referring to maximum temperature, minimum temperature and relative humidity, respectively.

The major crops grown in the scheme are wheat, faba bean, teff, barley, lentil and field pea. The main economy is based on crop production, supplemented by livestock production. The mainstay of agriculture is the *Kremt/*long rains (June – September) which support the *meher* harvest. Areas with irrigation complement the rain-fed cropping with irrigated *Tsedy* season. Irrigation is practiced in *Tsedy* during the months of January to May.

Methodology

1.1 Focus group discussion and household surveys

Group discussions were facilitated with the management committee members and irrigation group leaders to obtain a better insight into water access throughout the irrigation scheme, management structure and operations (see figure 1 in Annex). The group discussion of the MIS management committee was complimented by small group discussions with the leaders of the three individual MIS groups. A discussion with the chairman of the MIS was also held separately as a follow-up on the issues noted from the other discussions. Semi-structured surveys were carried out at different levels of the scheme with stakeholders as well as farmers. The semi-structured surveys were designed to gain a better understanding of the overall scheme management structure, the management within each of the irrigation groups and on-farm water management and agricultural practices.

One semi-structured questionnaire was implemented at the Mush Irrigation Scheme committee level to gain insight into the overall scheme management structure and perceived scheme performance. Seven members (6 men and 1 woman) participated in the survey. Each of the interviewees owns fields within the scheme and is involved in irrigation activities aside from their committee responsibilities. This discussion aimed at getting a scheme overview, the committee's vision on the future of the MIS and to fill in missing information arising from the various stakeholder discussions. A second semi-structured survey was implemented with individual group leaders to evaluate the implementation of water allocation within their group as well as their perceptions on the operation efficiency of the system within and among their groups. Additionally, constraints and opportunities at group level were assessed. A third level of surveys were implemented with fourteen farmers from the three groups. The majority of the selected interviewees were farmers participating in the Africa RISING's irrigated fodder protocol located in Group 1. Hence, additional farmers were selected from Group 2 and Group 3 to provide a scheme-wide assessment. From a total of 14 farmers (3 female and 11 male farmers), 6, 3 and 5 farmers belonged to Group 1, Group 2 and Group 3, respectively (Table 2).

Table 2: Overview of the interviewed farmers within a group and their crop within the Africa RISING project.

ID	*Group*	*Crop*	*Gender*
1	1	Fodder	Female
2	1	Fodder	Male
3	1	Potato	Male
4	1	Fodder	Male
5	1	Potato	Male
6	1	Potato	Male
7	2	---	Male
8	2	---	Male
9	2	Fodder	Male
10	3	Fodder	Female
11	3	---	Female
12	3	---	Male
13	3	---	Male
14	3	---	Male

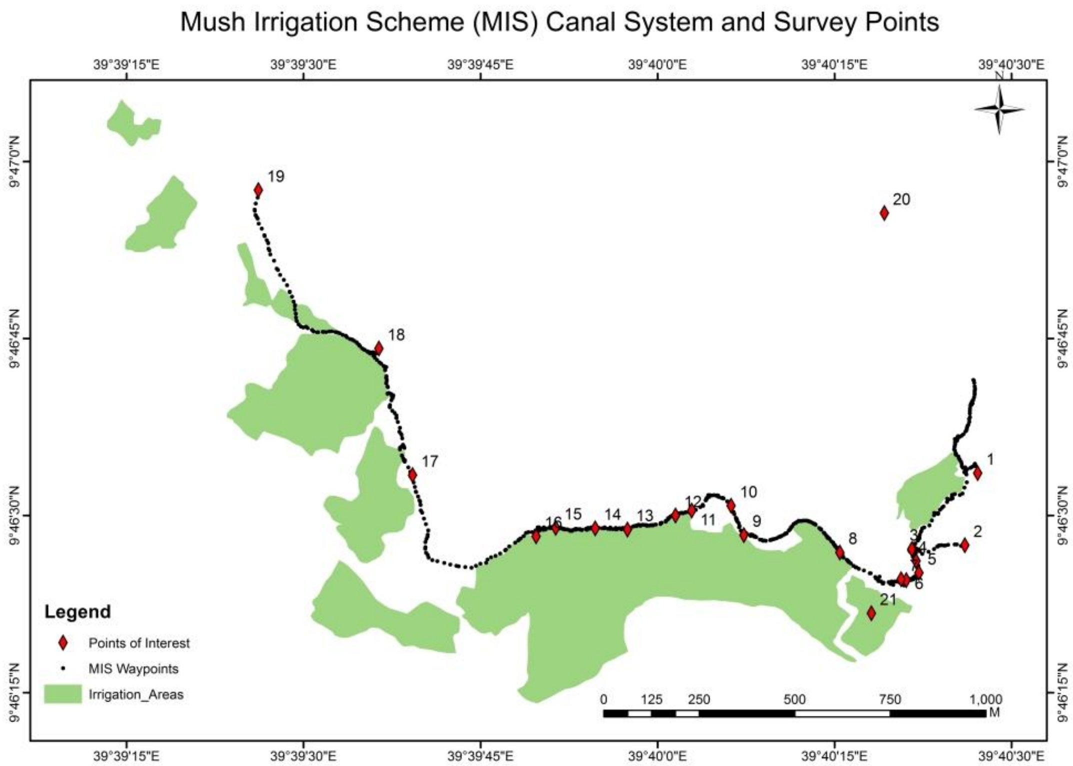
1.2 Mapping of irrigation scheme and discharge measurements

The scheme layout from the spring until the end of the canal was mapped using a GPS (Figure 1 and in Annex Figures 2, 3 and 14). GPS point locations were recorded along the canal to identify the start and end point of each group along the canal as well as scheme operation and management points of interest (e.g. weed infestation, canal leakage/seepage areas, spring sources). Google Earth was used as a base map for the study area. The flow measurements were carried out during the day. Velocity measurements and canal dimension were recorded at selected points to assess potential changes in hydrological regimes within the system as well as to determine water losses and/or gains along the canals. A simple area (average) velocity method was used to compute the discharges along the canals:

$$\mathbf{V} * \mathbf{A} = \mathbf{Q} \qquad \textbf{Equation 1}$$

where V is the flow velocity (m/s) at a point along the canal, A is the cross-sectional area (m^2) of the canal at the flow measurement point and Q is the computed discharge (m^3/s).

The canal dimensions were measured using meter-rule with accuracy of +/-1 cm. The flow velocities were measured at representative points along the canal using a Valeport 002 flow meter (Valeport Ltd., 1996). Low flow depths and lack of canal uniformity along the canal made the selection of measurement points limited. Measurements only covered Group 1 and sections of Group 2 due to limited water availability. At the time of the field measurements water only reached 45 % of the total canal length (i.e. approximately 1,233 m from the beginning of the scheme). A catchment evaluation was carried out as it became obvious that factors beyond the command area of MIS may play a role in the sustainability of the irrigation system.



ID	Description		ID	Description
1	Spring 1 source at tank		12	Lined gate section
2	Spring 2 source		13	End of Group 1 Canal reach
3	Main canal gate		14	Upstream3
4	Flow point A		15	Downstream3 (100m)
5	Upstream1		16	Flow point C
6	Downstream1 (41m)		17	End of Group 2 Canal reach
7	Canal road crossing		18	Spring source supplement to Group 3
8	Flow point B		19	End of Group 3 Canal reach
9	Upstream Lined Canal2		20	MIS Office
10	Downstream lined canal2 (100m)		21	MIS Nursery
11	End of concrete lining			

Figure 1: GPS waypoints marking the canal reach and flow measurement points

1.3 Evaluating current and future productivity of the Mush scheme

1.3.1 On-farm water management

Discharge at canal diversions, on farm irrigation method, duration of irrigation, number of irrigation events and general irrigation practices were monitored. Water availability for irrigation was estimated based on discharges measured at specific locations along the canal (Figures 1 and 2). Simple calculations using the lowest recorded discharge within a specific canal section resulted in conservative estimates of available irrigation water at plot level. The estimation of water delivered to a particular field was based on the total irrigation time and the assumption that fields received the full discharge determined at a particular canal diversion (Figures 4 and 5 in Annex).

To evaluate the benefit of the irrigation season, land and water productivity was calculated for both the kremt and tsedy season (Equations 2-3). Yields were obtained from the farmer surveys. Estimations on irrigated volume were based on duration and discharges associated to flood irrigation as it is the main practice within the scheme. The calculation of total water productivity when supplementary irrigation is performed is highly variable from year to year as it depends on rainfall occurrence and duration. In this particular case the total average rainfall in both the kremt and tsedy season was calculated based on the available time series (i.e. 2000-2014). As land and water productivity are affected by the characteristics of the marketable product (moisture content at marketing point) computations were based on non-processed farm weights (farm-gate yield measures):

$$\textbf{Total Water Productivity}\ (\mathbf{kg\ m^{-3}}) = \frac{\textbf{Harvestable Yield}\ (\mathbf{kg})}{\textbf{Total Water Consumption}^{2}\ (\mathbf{m^3})}$$

Equation 2

$$\textbf{Land Productivity}\ (\mathbf{kg\ ha^{-1}}) = \frac{\textbf{Harvestable Yield}\ (\mathbf{kg})}{\textbf{Cropped Area}\ (\mathbf{ha})}$$

Equation 3

To estimate the irrigation depth for potato and fodder, changes in soil moisture storage was measured using the gravimetric method. Water content of soil samples from the irrigated plots taken before irrigation were compared with those taken 24 hours after irrigation (Black, 1995 as summarized by DeAngelis, 2016).

1.3.2 Sustainability of the Mush Irrigation Scheme:

AquaCrop (Raes, Steduto, Hsiao, & Fereres, 2012) was used to estimated crop water requirement and productivity for both traditional and newly promoted crops. The irrigation system was noted to operate between the months of January until May. This covers the period of the belg/short rains season. Results were used to determine whether the scheme could be optimized supplying water to a larger command area through either improving on-farm water management or choosing different crops. A comparison of the current irrigated acreage versus potential irrigable acreage under different crops offered insights into possible levels of sustainable agricultural production with optimal water management. To assess the potential irrigable area during the irrigation season irrigation demands for barley, lentil, potato, oats and faba beans were evaluated against the canal flows over the irrigation period. The limitations of detailed on-farm management characteristics constrained the models calibration. Therefore, standard optimal operating standards and guidelines were used. AquaCrop was setup for local climatic conditions and ran based on growing degree days with default parameters for potato and barley as per AquaCrop version 4.0 (Raes, Steduto, Hsiao, & Fereres, 2012). For lentil, faba beans and oats growth parameters were set up employing the FAO-suggested single crop coefficients (Allen, Pereira, Raes, & Smith, 1998).

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[2] Total water consumption is the summation of applied irrigation and the effective rainfall (Dastane, 1978) over the crop growth period

Results

1.4 Characterization and operation of Mush irrigation scheme

1.4.1 Scheme characterization

Mush Irrigaton Scheme only operates within the *tsedy* season (January to May) with the other seasons being rain-fed. The scheme is fed by two main spring sources (Figure 1) with additional springs supplying water within the scheme. The main canal has a total length of 2740 m from which the upper 885 m is lined and the remaining 1850 m is unlined. The irrigation scheme has a planned command area of only 40 ha due to limited water supply from the springs. According to the survey the actual irrigated area is at best 60% as to accommodate all farmers during each irrigation cycle in all 3 groups.

The scheme has 230 members with a land ownership between 0.25 and 1.5 ha from which 0.06 to 1 ha is irrigated (Table 3). Members generally own both irrigated and rainfed fields. The average irrigated plot size per farmer is 0.34 ha. The membership distribution across the 3 irrigation groups are 75, 67 and 88 in Group 1, Group 2 and Group 3 respectively. Based on the farmer surveys, the average irrigation capacity under the current management only covers the land holdings for approximately 27% of the farmers.

Table 3. Average irrigated and rain-fed proportions of farmer land ownership within MIS

	Area (ha)	*Number of parcels*
Owned irrigated land	0.34	1.25
Owned rain-fed land	0.92	0.92

Each group receives irrigation water on a rotational basis for a fixed duration of 10 days per month. The timing for each of farmer within the same group is based on their field location relative to the main irrigation canal. Farmers at the head and near the canal receive water first as it is diverted downstream. In the event that not all farmers receive water within a monthly cycle they obtain priority in the following cycle. All available water in the canal is fully utilized with irrigations carried out both during the day and at night, inclusive of holidays. This thus nullified the proposed objective of incorporating temporary storages of irrigation flows. Women farmers whose irrigation schedule falls during the night either swap with their male neighbors or have male neighbors irrigate for them. Farmers preferred nighttime irrigation as it is cooler, with larger discharge from the canal (no withdrawals by the community nursery). The nursery was noted to withdraw up to 50% of the total available discharge at the onset of the canal during its working times of 8am – 4pm limiting water availability for irrigation in the scheme.

The farmers expressed the increasing water scarcity and its effect on dry season agricultural production as one of their major concerns. The difference between the potential irrigable area and the area quantified from the surveys point towards potential over-irrigation of fields reducing water availability for the remaining land in the command area. Especially farmers in Group 3, whose access is much more limited due to transmission losses in the system, identified on-farm water management as a way to curb the water shortages.

1.4.2 Scheme membership, management and fees

The scheme, a farmer-managed irrigation system, is governed by a committee comprised of 10 volunteering members (3 members from each group and a chairman). The scheme management oversees the operation and maintenance of the irrigation canal as well as the operation of an income-generating nursery that supplies both tree and potato seedlings to the farmers as well as the general market.

The scheme membership for life fee is US$2/ha of irrigable area. New membership is required upon change in land ownership (e.g. from parents to children). All children have a responsibility to apply for their personal membership upon land inheritance and/or other acquisition of land within the scheme's command area. It is noted that the membership comprises from as short as 5 years to as long as 70 years depending on the age of the farmer and the gender (Table 4). The average membership duration among the interviewed scheme members was determined as 27 years. The majority of scheme members have a high school degree (Table 5).

Table 4: Gender composition of Mush Irrigation Scheme households

Household characteristics	***%***
Male members > 60 years of age	6
Female members >60 years of age	6
Male members 15-60 years of age	28
Female members 15-60 years of age	35
Male child <15 years of age	13
Female child <15 years of age	12

Table 5: Mush Irrigation Scheme members classified by literacy levels

Literacy levels	***%***
Illiterate family members [can't read or write]	24
Members up to high school education	70
Members with college level education	6

Access to irrigation water is open to all community members with fields in the command area. Irrigation access is based on a payment of US$2/ha per season. The contribution is used for canal management and inputs needed for the nursery activities. For registered MIS members, the nursery profits are shared annually with scheme members following a shareholding system. This offers a secondary source of income to households. The MIS committee limits the number of shares available for purchase (US$0.50 per share) per member to between 1 and 100 shares each year. It was noted that potato growers are availed more water shares (up to US$200 worth of water shares) while lentil growers receive the least shares (maximum US$5 worth of water shares) to reflect their higher water consumption. This provides the potato farmers with water access at a schedule of every 15 days rather than after 20 days for all other crops. There are no potato growers in Group 3 because implementing the 15-day cycle of irrigation in Group 3 was found to be technically impossible. The average share ownership in 2015 season was estimated at 14.6 shares/member.

Farmers are obligated to support the committee in operational and management tasks related to the scheme such as participation in meetings to discuss scheme issues, payments of water rates, labor and monetary support for canal improvement and maintenance, and responsibility in the care of the canal system by informing the management of any concerns regarding matters that may impact the operation of the canal. In case of non-participation in committee mandated canal improvement activities the committee levies a penalty of US$2.50 to the concerned individual.

Aside from the additional income from nursery shares household income is mainly based on subsistence agriculture. The labor contribution to paid agricultural activities for male and female members is 1.79 and 2.36 persons/household, respectively. Within the scheme farmers mainly cultivate their own land with very few cases of hiring labor or other payment arrangements. For those community members who engage in paid agricultural labor within the community the payment in terms of produce is on average 216 kg/person per season whereas the labor compensation wage is US$6.8/person per season. Community members working in the nursery are compensated using standard farm labor wages.

Aside from water access, the scheme provides support to the farmers with regards to local potato seed and tree seedlings, credit services, dividends from nursery profits, local money saving services, crop marketing of their produce, and linkage to external partners such as NGOs for trainings. The management committee coordinates farmers' access to hybrid seeds of crops that are not easily available within the community and resolves disputes and conflicts within the scheme. The interviewed farmers acknowledged the benefits of being a member in the scheme and supported the scheme management.

1.4.3 Water availability and delivery along the Mush Scheme

The flow at the main canal gate was 0.16m^3/s and dropped to 0.09m^3/s at Check A point (Table 6 and Figure 2). The 50% reduction is due to the withdrawal of irrigation water for the nursery and corresponds with the estimated redraw mentioned by the MIS management committee during the focus group discussions. Due to the unlined, irregular canal into the nursery no reliable flow readings were obtained.

Table 6: Flow velocities and discharges at different locations along the main canal

Group	*Description*	*Length (m)*	*Latitude*	*Longitude*	*V (m/s)*	*Q, (m³/s)*
1	Main canal gate	0	9.774	39.673	6.57	0.161
1	Flow measuring point A	40	9.774	39.673	3.06	0.091
1	Upstream1	74	9.774	39.673	4.28	0.090
1	Downstream1 (41m)	115	9.773	39.673	2.74	0.082
1	Flow measuring point B	318	9.774	39.671	4.39	0.066
1	Upstream Lined Canal2	623	9.775	39.669	4.23	0.076
1	Downstream lined canal2 (100m)	705	9.775	39.668	4.99	0.075
1	Lined gate section	885	9.775	39.667	2.81	0.067
2	Group 2 Start	1018	9.775	39.666	1.89	0.067
2	Upstream3	1100	9.775	39.665	2.18	0.062
2	Downstream3 (100m)	1206	9.775	39.664	2.68	0.115
2	Flow measuring point C	1265	9.775	39.664	5.95	0.120

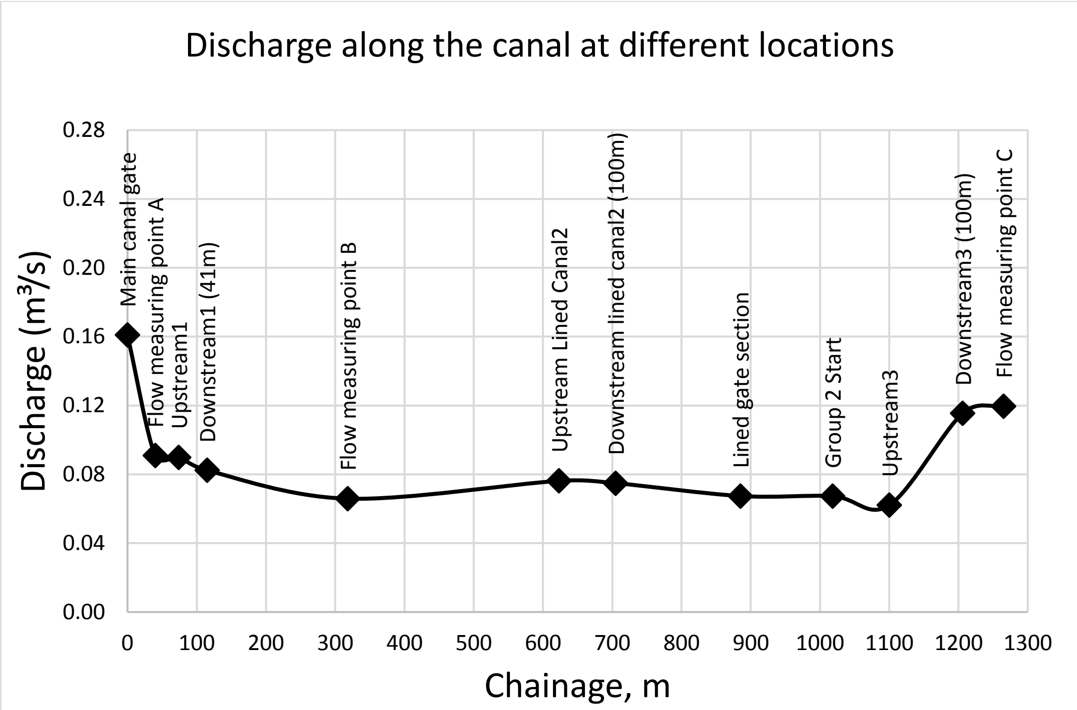

Figure 2. Plot of flow discharges along the Mush Irrigation Scheme's main canal

Although no discharge measurements could be carried out beyond Flow measuring point C as the canal was dry, spring sources were noted in some stretches of the canal especially in Group 3 which supplemented some of the farmer's irrigation needs. The increase in discharge at Flow Measuring Point C from 0.06 m^3/s to 0.12m^3/s occurred during the close of the nursery withdrawal (Figure 2). This further supports the proportional use of water between the nursery and the farmers' fields. The sharp drop in flow between the Group 2 Start waypoint and the Upstream 3 waypoint was due to leakage from the canal (Figure 6, in Annex).

Based on the discharge measurements (Table 5) and the irrigation management within the scheme (i.e. cyclic scheduling of water between groups as well as to individual plots within the group) fields tend to be irrigated with similar discharges as those measured in the canal. Hence, each plot received the full discharge from the main canal at that specific location for the period required before flow was diverted to the next field on the schedule. This confirms the perception of the scheme members that distribution is equitable as they do contribute to planning. As such, when water constraints are observed within the scheme, scheme members accept restrictions to water access or changes in the irrigation schedule.

Transmission losses of 0.67 $m^3/hr/m$ at the distance of 74 to 115 m along the canal as well as flow gains up to 0.25 $m^3/hr/m$ at a distance of 1206 to 1265 m were observed. The variability in transmission losses are likely to be overestimated due to irregular canal dimensions resulting in a lower accuracy of the determined flow characteristics. However, visual observation of the irrigation canal indicated numerous wet patches around canal stretches in a generally dry landscape outside the irrigated fields does confirm a combination of canal leakages as well as the occurrence of high groundwater tables and springs. Further detailed documentation is needed to quantify the number of leakages along the canal. Especially in the unlined sections where higher losses are expected and contributing towards increased sub-lateral flow downstream. Minor service works and better controls of diversion gates will be instrumental in controlling these leakages.

1.4.4 Cropping patterns and irrigation frequency at scheme level

Rain-fed crops are faba beans, barley, wheat, beans, field pea and potatoes; whereas during the irrigation season lentil, faba beans, wheat, barley, beans, potato and fodder are cultivated.

For both the irrigated and rainfed crops the agricultural practices are characterized as labor intensive using low technology inputs. The farmers mainly rely on manual and/or animal labor for field ploughing and manual labor for weed control (Table 7). No usage of pesticide or insecticide was reported among the farmers. Fertilizer has been limited to Diammonium Phosphate (DAP) and UREA fertilizers with application rates frequently below the recommended rates.

Table 7. Intensity of main cultural activities supporting the irrigated fields

Crop	***Number of Ploughing***	***Number of Weeding***
Wheat	3	2
Barley	3	1
Faba beans	2	1
Rain-fed lentil	2	0
Potato	5	0
Field pea	1	0
Irrigated lentil	3	0

The farmers within the MIS mainly rely on the *kremt*/long rain season for unirrigated cultivation and the *tsedy*/short rains with irrigation supplement for the irrigated cultivation. Depending on the weather some minimal cultivation is carried out in the other seasons. A range of crops are grown based on weather and predicted irrigation water availability with individual farmers making choices on which crops to grow. The scheme community members noted changes in their cropping patterns for the irrigation season. Wheat and barley are being replaced during the spring season by faba beans, potatoes and lentil due to increased water shortages as well as pressure from pests and diseases. Furthermore barley has a relatively low economic return compared to crops like potato even if irrigation rates are decreased due to water shortages. Other crops like faba beans are preferred as they are lower nutrient demanding crops and hence could cope with the noted reduction in soil fertility by some of the interviewees. In general, farmers selected lentil for its tolerance to low water, potatoes for the greater returns even for reduced land size under irrigation, faba beans for better yields under low fertility and field peas for pest-related challenges.

Reduction in water availability from the MIS canal was highlighted as a major reason for changes to the farming system. The reductions in water availability were attributed to changes in weather, increased domestic withdrawal at the spring source, increased withdrawal by the nursery and the impact of the eucalyptus plantation upstream of the main spring sources within the watershed.

The cultivation intensity and irrigation frequency was evaluated for the *tsedy* season based on the surveys conducted at farm and scheme level (Table 9). Water availability was generally limited to scarce for all crops. Lentil, barley and beans were generally assessed to receive limited water compared to the other crops.

1.5 Irrigation practices and on-farm water management

A majority of the farmers practiced flood instead of furrow irrigation by leading the water to the lower end of the field and then irrigating backwards towards the head. This resulted in higher irrigation depths applied to the lower areas of the field compared to the upper part of the field. Given that farmers are not very familiar with furrow irrigation those who do implement furrow still start their irrigation at the lower end of the field. The farmers employing furrow irrigation generally irrigated 3 furrows at a time with furrow lengths of 8 – 12 m. The farmers filled the three consecutive furrows at a time before moving to the next set upstream of the inflow. An assessment of the furrow irrigation farmers showed an average irrigation rate of 1.8 m/min furrow flow rate and a filling duration of 0.7 min/m. The recession time recorded was 25-30 min. The method of starting irrigation at the lower end together with the poor leveling of the fields and the furrow slopes being inhomogeneous leads to higher excess flows compared to the flood irrigated fields (Table 8). This leads to significant application losses (over 50%) at plot level, which feed neighbouring “non-irrigated” rain-fed plots.

Table 8. Irrigation application rates measured on March 27, 2015

Farmer	*Irrigation Method*	*Crop*	*Plot Area (m^2)*	*Flow rate (m^3/s)*	*Irrigation duration (mins)*	*Irrigation application (m^3)*
Farm #1	Furrow	Potato	125	0.04	30	0.57
Farm #2	Flooding	Fodder	115	0.04	25	0.52
Farm #3	Furrow	Fodder	103	0.04	20	0.47
Farm #4	Furrow	Fodder	67	0.04	25	0.90

Table 9: Cultivation intensity by members of MIS in Tsedy (irrigation) season. Values show the average landholding size for a specific crop during the irrigation season and the corresponding frequency of irrigation.

				Lentil			*Potato*			*Field Pea*			*Faba Beans*			*Fodder*			*Barley*			*Beans*		
Group	***No. of members***	***Tsedy irrigated area***	***Rain-fed area***	***Area***	***Frequency[1]***	***Availability[2]***	***Area***	***Frequency***	***Availability***	***Area***	***Frequency***	***Availability***	***Area***	***Frequency***	***Availability***	***Area***	***Frequency****	***Availability***	***Area***	***Frequency***	***Availability***	***Area***	***Frequency***	***Availability***
1	75	0.4	0.9	0.2	1.5	1.0	0.1	4.5	3.0	0.3	3.0	3.0	0.6	-	2.0	0.1	5.0	3.0	0.3	2.0	2.0	0.3	1.0	2.0
2	67	0.5	0.9	0.2	1.0	1.7	0.1	3.0	3.0	0.1	2.0	3.0	0.3	2.5	2.5	-	-	-	-	-	-	-	-	-
3	88	0.3	1.0	0.3	1.4	2.2	-	-	-	-	-	-	0.3	-	2.0	0.0	2.0	3.0	0.3	-	2.0	0.2	-	2.0
Mean		0.4	0.9	0.2	1.3	1.8	0.1	4.0	3.0	0.2	2.5	3.0	0.3	2.5	2.2	0.1	3.5	3.0	0.3	2.0	2.0	0.2	1.0	2.0

Note: [1]Number of irrigations received by a crop during the cropping season; [2]Level of farmer-perceived irrigation water availability (1=abundant, 3=scarce).

*The fodder estimation is based on the intervention through Africa RISING where wetting front detectors are used to schedule irrigation. Hence, the frequency and availability noted does not represent general practices in the scheme.

A comparison of water contents for fodder and potato fields under furrow irrigation further demonstrates that potato fields gained an average of 8% moisture storage from irrigation while fodder fields only gained 4% storage and never achieved field capacity. Based on the changes in soil moisture larger irrigation amounts were applied to potato fields.

Table 10: Soil moisture content (g/g; water: soil) before (PRE) and after (POST) irrigation measured at three locations (REPS) across the fields

ID	*Irrigation*	*Crop*	*Sample*	*Average soil moisture ± SD**	*Change in soil moisture (g/g)**
1	Furrow	Fodder	PRE	0.29 ± 0.01	0.05 ± NA
		Fodder	POST	0.33 ± NA	
2	Furrow	Fodder	PRE	0.30 ± 0.00	0.06 ± NA
		Fodder	POST	0.36 ± NA	
3	Furrow	Potatoes	PRE	0.32 ± 0.02	0.11 ± 0.02
		Potatoes	POST	0.42 ± 0.00	
4	Furrow	Fodder	PRE	0.42 ± 0.01	0.01 ± 0.06
		Fodder	POST	0.43 ± 0.05	
5	Furrow	Potatoes	PRE	0.30 ± 0.02	0.04 ± 0.01
		Potatoes	POST	0.34 ± 0.03	

* Average soil moisture change with standard deviation

A detailed assessment of the water contribution from irrigation was made for four furrow irrigated fields to compute the water application efficiencies of farmer irrigation. Computations are based on changes in soil storage moisture (
Table 10), assuming 40% water losses by surface flow and/or deep percolation of the irrigation application (Table 11). The soil moisture variability is quite high between fields, both before and after irrigation, indicating the subjective farmer determination of appropriate levels of irrigation. Table 11 shows that the application efficiency, derived from soil storage (application depth) compared to the application flows into the fields, are highly variable: from a low of 26% to a high of 80% (Table 11). This has the implication that much of the applied irrigation water was not stored in the soil but was lost as runoff.

Table 11: Application efficiencies of four sample fields

Farmer	***Plot 2***	***Plot 3***	***Plot 5***	***Plot 6***
Crop	Potatoes	Potatoes	Fodder	Fodder
Irrigation depth, %	3.94	10.76	4.02	6.39
Irrigation depth, mm/30cm	11.82	32.27	12.06	19.16
Application depth, mm	46	40	23	45
Application efficiency, %	26	80	52	43

1.6 Current land and water productivity in Mush irrigation scheme

To assess water productivity, the estimated application rate of 0.52m^3/ha for the monitored flood irrigated field (Farm #2, Table 8) was assumed to be representative for flood based irrigation within the scheme. The average seasonal rainfall estimates for both the *kremt* and the *tsedy* season, used for the total water productivity calculations, were derived from the 2000-2014 database. The total water productivities, reflecting the crops' performance relative to all available

water resources are representative of the yield potentials under the existing scenarios of cultivation (
Table 12).

Table 12: Land and total water productivity for the main crops during Kremt and Tseday seasons

	Area (ha)		***Yield (kg)***		***LP (kg/ha)***		***TWP (kg/m³)***	
	Kremt	*Tseday*	*Kremt*	*Tseday*	*Kremt*	*Tseday*	*Kremt*	*Tseday*
Faba Beans	0.29	0.29	336	233	1139	800	0.14	0.77
Barley	0.24	0.13	392	250	1635	2000	0.20	1.93
Beans	0.19	0.19	183	100	978	533	0.12	0.51
Field pea	0.28	0.19	225	175	800	933	0.10	0.90
Wheat	0.34	-	377	-	1104	-	0.14	-
Lentil	-	0.23	-	120	-	527	-	0.51
Potato	-	0.08	-	567	-	6800	-	6.54
Fodder (Oats)	-	0.05	-	240	-	4800	-	4.62

Key: LP – land productivity; TWP – total water productivity

The results show higher land and water productivity levels for potatoes followed by fodder, in the tsedy season than those found in Derib et al. (2011). The higher water productivity might be positively affected by the higher irrigation availability (4.0 and 3.5 times irrigation frequency) as well as the harvest product having a high moisture content compared to cereal crops. Nevertheless, the total water productivities are considerably higher in Tsedy than in Kremt even though the yields are lower, reflecting the higher utilization efficiency of water in the dry season compared to the rainy season. Tsedy season water productivities are shown to range between 4 to 9 times the levels in kremt season. These results confirm the potential production increases possible with well managed irrigation systems in Mush Irrigation Scheme. The land productivity on the other hand shows variations between seasons and crops. Despite the effect of climate variability, water availability and crop management partially explain the difference in land productivity between the two seasons. However, it is clear that the crop grown has a stronger influence.

1.7 Potential for increasing land and water productivity

The surveys and field assessments indicate that Mush Irrigation Scheme is a water-limited irrigation area. This implies that the extent and intensity of irrigated area and production is constrained by water resources rather than land resources. The optimization of the production system thus calls for a program to capitalize on the returns gained from water rather than land. Assuming that farmers maintain current levels of farm inputs the alternative optimization for increased land productivity can only be achieved through increases in water use efficiency. Increases in water use efficiency would require an understanding of the cropping patterns and thus water requirements during the irrigated season, thereby facilitating optimal application of irrigation water as well as reducing off-field losses and over-irrigations. This would offer possible benefits such as increased availability of water to bring more acreage under irrigation and enabling higher returns on the water available for application.

Assuming optimal cultural farm practices, with recommended fertilization, pest and weed controls, as well as sufficient irrigation, the model results indicate significant land productivity (yield) increases during the tsedy season relative to the current management level (Table 13). It is significant to note that except for lentil, a reduced total water productivity was obtained for all crops.

Table 13: Modelled actual evapotranspiration, water input (irrigation and effective rainfall) and crop yield using AquaCrop

	Barley			***Lentil***			***Potato***			***Oats***			***Faba Beans***		
	ET_c	Rain	Irri	ET_c	Rain	Irri	ET_c	Rain	Irri	ET_c	Rain	Irri	ET_c	Rain	Irri
January	54	5	55	54	5	20	54	5	19	54	5	59	54	5	66
February	132	16	165	132	16	174	132	16	180	132	16	160	135	16	183
March	154	28	207	153	28	166	154	28	218	153	28	172	159	28	141
April	129	45	74	131	45	85	130	45	121	131	45	85	42	12	29
May	46	29	11	114	59	54	20	10	9	138	59	79	-	-	-
June	-	-	-	29	12	3	-	-	-	50	19	29	-	-	-
Total (mm)	**514**	**123**	**512**	**612**	**165**	**502**	**489**	**104**	**546**	**658**	**172**	**584**	**389**	**61**	**419**
Biomass (kg/ha)		9146			8772			11413			20160			2495	
Yield (kg/ha)		3018			3948			8943			10080			606	
TWP kg/m³		0.48			0.59			1.38			1.33			0.13	
IWP, kg/m³		2.45			2.40			8.62			5.86			0.99	

Key: ETx - total crop evapotranspiration (mm); Rain - precipitation component to crop water requirement (mm); Irri - irrigation demand (mm); Biomass – total biomass production (kg/ha); Yield – harvestable crop yield (kg/ha); TWP – total water productivity (kg /m^3); and IWP – irrigation water productivity (kg /m^3).

This is due to the increased irrigation supplied by the model leading to higher yields compared to the current amount of water applied in the fields. As stated before, the implementation of AquaCrop model makes three major assumptions for enhanced irrigated crop production: i) applied irrigation is effectively timed and efficiently utilized by the crops in yield production, ii) all needed agronomic practices are implemented efficiently, and iii) no uncontrollable human and/or natural hazards occur to constrain yield. These are ideal situations that never happen (Oweis & Hachum, 2012) in real life hence the results presented herein are nothing but potential targets.

The weekly flow availability (0.062 m^3/s) averaged over a week based on the operation plans of the scheme and nursery withdrawal was estimated at 33034m^3. This flow was taken as the present irrigation potential for the canal for planning a new irrigation model. The computation of potential irrigable area is presumed on the ideal system devoid of socio-economic and cultural factors that could not be assessed within the scope of this study. Based on the FAO indicative field application efficiency for flood irrigation and the estimated irrigation application depths and ET_c results (Table 13) (Brouwer, Prins, & Heibloem, 1989) the potential irrigable area was estimated (Table 14). Results suggested the available discharge at the canal (excluding the portion used by the nursery) would be sufficient to increase the current area cultivated in the irrigation scheme. Given that the amount of irrigation frequencies is far below the modelled irrigation depths the areal coverage is on the conservative side. On the other hand, channel losses need to be quantified to ensure the estimated potential.

Table 14: Computed potential irrigable area for major crops grown in Mush Irrigation Scheme

Crop	*Growing days*	*Irrigation Days*	*Irrigation weeks*	*ET_c (mm)*	*Rain, (mm)*	*Irri (mm)*	*TID (m^3/m^2)*	*PIA (ha)*
Barley	116	113	16	514	123	512	0.5115	52
Lentil	145	135	19	612	165	502	0.5017	63
Potato	106	105	15	489	104	546	0.5461	45
Oats	150	150	21	658	172	584	0.5838	61
Faba Beans	100	80	11	389	61	419	0.4193	45

Key: ETx – maximum evapotranspiration, Rain – rainfall, Irri – water applied by irrigation, TID – total irrigation demand for crop, PIA – potential irrigable area

1.8 Watershed Management

During the walkthrough of the irrigation system the study team observed areas of land slippage into the head gully source of the spring outlets (Figures 7-13 in Annex). Further, significant areas of erosion upstream of the irrigation scheme and cultivation close to the spring sources were noted. Of major concern was the established eucalyptus forest above the irrigation scheme. The forest is characterized by trees approximately 8-12 years old on heavily eroded land. There is almost no undergrowth within this forest area resulting in low erosion production of the topsoil.

The upper watershed above the scheme's main spring sources is covered with eucalyptus forests. This may have potential negative effects on the watershed's ability to recharge the groundwater and hence could influence the long-term sustainability of the scheme. The farmers' concerns regarding the state of the watershed and especially the spring recharge in the presence of the eucalyptus forest is noted. Several studies document the concerns regarding the long term impact of eucalyptus plantations on shallow groundwater and soil recharge capacities (Palanisami & Joshi, 2011) (Holland & Benyon, 2010) (Benyon, Doody, Theiveyanathan, & Koul, 2009) (Thorburn & Walker, 1993) (Engel, Jobbagy, Stieglitz, Williams, & Jackson, 2005) (Sargent, 1998) (Sunder, 1993). A study of the hydrogeology of this catchment is suggested to address these worries by the community and to formulate options for improving the health of the watershed.

Discussion and Recommendations

The scheme is one of the many small-scale irrigation schemes in Ethiopia that work on a rotational basis. Currently in several of those irrigation schemes the question is raised whether the right crops are grown (high water productivity & market value) and if water productivity and overall irrigation can be improved. Particularly in this scheme a combination of individual water allocations and association nurseries are competing for the same water source. Farmers are still relatively new to irrigation and the concept of optimal water management. Hence, farmers irrigate as much as possible the moment they have water access especially if the rotation to water access is very long. This study gathered the baseline information to evaluate potential gaps for capacity building as well as future research/assessments needed to improve scheme functionality.

1.9 On-farm Management

The scheme generally does not have significant surface drainage losses out of the command area but in-field losses are extremely high. This status if not managed portends a major threat to the sustainability and reliable operation of the irrigation scheme. The poor in-field water management is a risk factor as it limits access to water by other farmers. Preliminary results show that this leads to low water productivity of the current cultivated crops and a low cultivated area. Half of the scheme's discharge is used for the nursery, leaving the irrigators with an average of about 4500 m^3/day. Based on the farmer interviews the majority of the area is attributed to less water productive crops due to challenges of water shortage, soil fertility, pest and disease resistance. However, based on the modeling results water and land productivity could be further increased for cereals, fodder as well as potato without reducing areal size. One of the first steps to accomplish this will be through improved on-field water management (e.g. furrow irrigation instead of flood) and better irrigation scheduling where possible.

Capacity building can help to improve the application and water use efficiency in the field. Trainings on on-farm management shall include, but are not limited to, better furrow design and maintenance, field bunding to reduce off-field water discharges, flow stream regulation into fields to provide enough opportunity time for effective infiltration, proper design of contoured plots to effectively manage on-field water flows and reduced soil erosion without constraining high *Kremt* season surface runoffs. A modification of the traditional methods of irrigation (flooding and furrow) with improved techniques of land levelling, optimum furrow forming and basin forming to control out-of-plot losses can lead to considerable savings in irrigation water. Capacity building on on-farm water management might be further achieved when farmers have access to irrigation scheduling tools that provide insight concerning how much water to apply. The question on when to apply is a bit more challenging given the rotational scheduling throughout the scheme. However, given the Aquacrop results area could be extended from the current 27 ha effectively irrigated to 45 ha for potatoes. According to the simulations even greater irrigable areas can be achieved with less water intensive crops. Africa Rising is currently testing whether the wetting front detector, one of the available irrigation scheduling tools are suitable to train farmers in on-field water saving for potato and fodder, two highly demanded crops. Water productivity as a measure of the returns to limited water access is thus a valuable tool to guide the scheme in selection of suitable crops but it should be implemented in conjunction with economic and cultural considerations based on farmer interest for specific production, consumption and market needs.

1.10 Scheme management

At scheme level, the current operational system is sufficiently managed to ensure maximum use of the available resources. Unfortunately, this does not translate to optimal use with large areas of the command area left fallow due to water shortages. It is noted that due to the round-the-clock irrigation schedule no excess flows are available hence there is not potential to remedy temporary storages. To optimize water efficiency it is suggested that the scheme implements a strategy to consolidate areas in the scheme with similar crops and distribute water accordingly. This can be implemented by extending the current system that enables group one farmers marginally greater access to water as they grow more water demanding crops and group 3 less water by requiring production of less water demanding crops. A hybrid system would be to group farmers growing different crops together and supplying water as per crop needs.

Aside from the management of the scheme, a high level of maintenance is required. At numerous locations water losses were identified throughout the scheme. Better operation and maintenance to minimize distribution losses coupled with long-term investment in canal lining shall make distribution more amenable to the suggested changes in distribution scheduling. Sections of the spring source gorge are also experiencing soil slumps. Two stone gabions have been constructed across the gorge and a short length of stone retaining wall has been constructed to protect the sides.

1.11 Groundwater and springs

Mush Irrigation Scheme solely depends on spring sources. A number of low discharge springs and high water table areas were noted within the scheme. The hydrology of these potential groundwater sources is not well understood. Given the increasing demand and the decreasing water availability, a proper inventory of all springs recharging the command area would help to further optimize water requirements and allocation. Groundwater recharge assessments as to determine the potential for targeted recharge ponds in the watershed could supplement the current springs. Tracer studies can be performed to map the age, source and recharge areas of groundwater and help to understand the nature and behavior of these springs. This would also clarify whether some of the wetted areas are created by seepage losses from the canal, fields and lateral flows throughout the command area. The identified recharge zones and low groundwater tables may be utilized as localized sources for irrigation water. These can be tapped as surface flows and/or shallow open dug wells that can be pumped to reduce the pressure from the main canal supply. This report thus suggests a plan to understand the sustainability of these spring sources and formulation of steps to develop protection and conservation initiatives, preferably led by the community’s input as a basis of capacity building on their water resources.

1.12 Watershed Management

Community mobilization for watershed management such as constructing stone terraces within the eucalyptus forests to encourage water infiltration and reduce erosion would further benefit the sustainability of the scheme. With the abundant availability of stones in the watershed more work on building stone gabions and retaining walls is needed to both protect the spring sources as well as the neighboring fields from erosion and soil slumps. The community could benefit from trainings on integrated watershed management whilst enhancing awareness on how to sustainably manage spring sources as well as prevent erosion and landslides. Sensitization to the interrelationships between the natural environment, resource access and use should be prioritized, especially in the context of the existing social/economic structure around the Mush Irrigation Scheme. For example, farmer training centers could be used to facilitate trainings on watershed management concepts in the context of existing challenges of agricultural development.

Conclusions

The management of Mush Irrigation Scheme is functionally effective in managing the irrigation system with most of the farmers confident in the equity and fairness of the system. This does not negate the great concern by the farmers on the insufficiency of the water supply that has limited their farming activities to one *Kremt* season crop and one *belg*/irrigated crop with several months of fallow fields. The cultural field practices, compounded with the tough terrain in the cultivable area has made both farming and the associated irrigation methods unadaptable to the limited water supplies; especially with the highlighted reductions in spring supplies over the past years.

Need for capacity development of the farmers on on-farm management is extremely crucial to maintain and/or increase the irrigable acreage of the scheme. The study notes the high potential for productivity increases even under the limited water availability, with opportunities for increasing the irrigated areas as well as improving the yield levels through better on-farm water management. According to the model simulations efficient management of flood irrigation could increase the current irrigated acreage of 27 ha to 45 ha of potatoes or 63 ha of irrigated lentil. Improved irrigation methods and/or on-farm water management may lead to even larger increases in irrigable land.

The mobilization of the community to adopt watershed management practices both within the kebele and in private and public forests from which the scheme's water arise should be encouraged. The long-term health of the scheme will greatly depend on the sustainability of the spring sources, which is threatened by both the changes in weather patterns and the human activities within the watershed. Steps towards better agroforestry activities, erosion control and soil cover approaches should be considered. The on-going work by Africa RISING is therefore of significant relevance and pushing forward with these activities and recommendations to ensure sustainable intensification of irrigated agricultural production in Mush Irrigation Scheme will only improve the livelihoods of the community.

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Annex 1: Illustrations

Photo 1: A farmer interview by a research staff

Photo 2: Canal system walk to assess physical state and GPS-plot the main canal system

Photo 3: Taking flow velocity readings along Group 1 Main Canal reach

Photo 4: Monitoring of farmer furrow irrigation practice – excess flows out of field into neighboring field and open pasture area

Photo 5: Monitoring of farmer furrow irrigation practice – excess flow into neighboring field

Photo 6: Leakages through diversions missing appropriate gates on the lined canal section

Photo 7: Eucalyptus-covered upstream of Mush Irrigation Scheme's watershed

Photo 8: Soil slump and erosion of the upstream canals between the spring source and top of the Mush Irrigation Scheme canal

Photo 9: Eucalyptus forest upstream of Mush Irrigation Scheme – heavily eroded with no undergrowth

Photo 10: Soil slump and gully erosion along spring source in Group 3

Photo 11: Contact spring source showing possible relationship between geological formations and spring points

Photo 12: Gabion constructed to arrest the rate of erosion around the main spring source

Photo 13: Cultivation too close to the spring source and canal system with possible consequences of increased soil erosion

Photo 14: Spring source used as a secondary water source by a farmer in Group 3