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Participatory Approach for Improvements in Spate Irrigation Systems

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Mekelle University

Supervisors

Prof. Fabio Castelli

(School of Engineering)

Prof. Elena Bresci

(School of Agriculture)

Abraham Mehari Haile, PhD.

(UNESCO-IHE – Delft)

Candidate

Giulio Castelli, BSc

“Marco Polo describes a bridge, stone by stone.
-But which is the stone that supports the bridge? - Kublai Khan asks.
-The bridge is not supported by one stone or another,- Marco answers, -but by the line of the arch that they form.
Kublai Khan remains silent, reflecting. Then he adds: -Why do you speak to me of the stones? It is only the arch that matters to me.
Polo answers: -Without stones there is no arch.”

“Marco Polo descrive un ponte, pietra per pietra.
- Ma qual è la pietra che sostiene il ponte? - chiede Kublai Kan.
- Il ponte non è sostenuto da questa o da quella pietra, - risponde Marco, - ma dalla linea dell'arco che esse formano.
Kublai Kan rimase silenzioso, riflettendo. Poi soggiunse: - Perché mi parli delle pietre? è solo dell'arco che mi importa.
Polo risponde: - Senza pietre non c'é arco.”

Italo Calvino, Le Città Invisibili.

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Abstract

Spate irrigation is a complex and unique form of water management. Water is diverted from seasonal rivers through the use of diversion structures made by stones, earth and brushwood, which are located within the river bed. Despite its widespread diffusion and its history, spate irrigation is one of the least studied techniques at academic level.

The development of modernized spate irrigation schemes realised in the last 15 years in Raya Valley (Ethiopia) resulted in disappointing performances, mainly due to a poor consideration of the very particular characteristics of wadi catchments. Local farmers, who showed a deep knowledge of the river system and of the irrigation techniques, and who represented the beneficiaries of the improvements, where involved only at the level of consultation after the failure of the main projects.

The purpose of this study has been to develop and test a participatory framework for selection and design of effective improvements in spate systems. A participatory approach based on Diagnostic Analysis was realised utilising Participatory Rural Appraisal (PRA) techniques and Participatory Design methodology. A participatory analysis of the problems of the scheme was realised, then problems were ranked and suitable solutions were proposed.

Farmers recognised the need of more resistant diversion structures and gabion walls for the stabilisation of the river bank. Together with the local community, the main features of the design were identified and used for a preliminary analysis of the structures. The involvement of farmers in the planning phase of the work also helped to highlight that not only irrigation-related problems, but also flood-related problems threaten agricultural production and rural livelihoods. Rather than an irrigation system approach, a river system approach is then suggested for framing future development strategies.

List of symbols and abbreviations

A	Catchment area
a	Width of the diversion bund
A_g	Area of a gabion section
AIP	Agribusiness Innovation Program
ASCE	American Society of Civil Engineers
B	Gabion length
C	Coefficient for v_{cr} calculation
c_g	Gabions apparent internal cohesion
D1	Diversion 1
D2	Diversion 2
D3	Diversion 3
D4	Diversion 4
DA	Diagnostic Analysis
DEM	Digital Elevation Model
d_{gab}	Mean diameter for filling stones
d_x	Sediment diameter relative to the x^{th} percentile
e	Eccentricity
ELEV	Mean catchment elevation
f	Full discharge factor
f1	Coefficient for taking into account velocity effect for local scour (Da Deppo and Datei)
f2	Coefficient for taking into account shape effect for local scour (Da Deppo and Datei)
f3	Coefficient for taking into account flow angle effect for local scour (Da Deppo and Datei)
FAO	Food and Agriculture Organization of the United Nations
FBFS(s)	Flood Based Farming System(s)
Fr	Froud number
G*	Apparent growth factor calculated with farmers hydrological information
GDP	Gross Domestic Product
G_t	Discharge growth factor for return period t
HCD	Human Centred Design
IFAD	International Fund for Agricultural Development
K_1	Coefficient for taking into account shape effect for local scour (Richardson and Richardson)
K_2	Coefficient for taking into account flow angle effect for local scour (Richardson and Richardson)
K_3	Coefficient for taking into account bed condition effect for local scour (Richardson and Richardson)
K_4	Coefficient for taking into account grain size effect for local scour (Richardson and Richardson)
K_4	Coefficient for the calculation of K_4 (Richardson and Richardson)
L	Length of the diversion bund

L1	Width of the northern canal of wadi distributary system
L2	Width of the southern canal of wadi distributary system
M	Momentum with respect to barycentre for a gabion section
m.a.s.l.	meters above sea level
MAF	Mean Annual Flood peak discharge
MAP	Mean Annual Precipitation
MSL	Mean Stream Length
n	Manning"s coefficient
N	Normal force
NGO(s)	Non-Governmental Organisation(s)
PD	Participatory Design
PRA	Participatory Rural Appraisal
PRDA	Participatory Rapid Diagnosis and Action planning
PSNP	Productive Safety Net Programme
P_u	Specific weight of metallic net for gabions
Q	Discharge
Q*	Discharge for the entire basin corrected with the full discharge factor
Q_h	Discharge from average level of a "high" level flood
Q_l	Discharge from average level of a "low" level flood
Q_m	Discharge from average level of a "medium" level flood
Q_{max}	Maximum flood within living memory
Q_t	Discharge for return period t
Q_y	Discharge from mean level of the yearly maximum flood within living memory
R	Hydraulic radius
S	Slope
s	Local scour
SRTM	Shuttle Radar Topography Mission
SSI(s)	Semi-Structured Interview(s)
T	Shear force
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-IHE	UNESCO Institute for Hydraulic Engineering
UTM	Universal Transverse of Mercator
v	Flow velocity
v_{cdx}	Critical flow velocity for grain size x
v_{icdx}	approach velocity corresponding to critical velocity for incipient scour in the accelerated flow region at the the pier/bund for diameter x
WGS84	World Geodetic System 1984
y	Flow depth
y_h	average level of a "high" level flood
y_l	average level of a "low" level flood
y_m	average level of a "medium" level flood
y_{max}	Maximum flood level within living memory
y_y	mean level of the yearly maximum flood within living memory

α	Angle of the intake bund with the flow
γ_g	Specific weight of gabions (including porosity)
γ_s	Specific weight of gabions filling material
γ_w	Specific weight of the water
θ_{gab}	Shields parameter for gabions filling material
σ_{adm}	Maximum admissible structural normal pressure by gabions
σ_{max}	Maximum normal pressure on a gabion section
τ	Shear stress acting on a gabion surface
τ_{adm}	Maximum admissible structural shear stress by gabions
τ_c	Critical shear stress for water drag for gabions
τ_{flow}	Shear stress of the flow
υ^*	Gabions apparent internal friction angle
χ_{def}	Correction coefficient for τ_c calculation
Ω	Flow area

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1 Introduction

1.1 Project Framework

The thesis is developed in the framework of the "Spate Irrigation Project" coordinated by UNESCO – IHE and Meta-Meta, and funded by IFAD for the period 2011 and 2014. In the framework of the project UNESCO – IHE is the organization responsible for administrative and financial management, working with other partners in a network of institutes and organizations.

Objectives of the project are:

- Train farmer communities. partners and support organizations (safety net programmes, NGOs, agricultural research systems, extension services, IFAD investment project staff, private sector) to implement effective spate irrigation improvement project – covering the entire range of activities from water management, agronomy, livestock keeping, storage and forestry.
- Develop pro-poor agricultural growth programmes in spate irrigation dependent areas – which are among the most marginal areas in their countries.
- Work on value added farming systems in the spate areas (commercial fodder, groundwater based horticulture, niche crops, strategic oil seed crops, industrial crops such as cluster bean) – moving from marginal agriculture to mainstream market farming.
- Implement scaling-up and -out of project results through enhanced knowledge exchange and strengthening of country networks.

The project involves 4 "beneficiary countries": Ethiopia, Pakistan, Yemen and Sudan. The network of partners in Ethiopia comprehends: Farmers associations, regional governments, large rural infrastructure investment programs (PSNP and AIP), large regional NGOs, extension services, Agricultural Research Organization, Haramaya University and Mekelle University.

1.2 Background

Spate irrigation is a form of water resource management which is based upon the diversion of floodwater from river beds. The flow is then conveyed in channels and used for crops irrigation, drinking water requirements, forest and grazing land development and groundwater recharge (van Steenbergen, Lawrence, Mehari, Salman, & Faurès, 2010).

Spate irrigation is typical of arid and semi-arid countries, where surface runoff is usually the main source of water. Here runoff is generated in mountain catchments during short and intense precipitations and flows in ephemeral rivers (wadis). Appreciable discharges are usually present for few hours, with a recession flow of few days. Whereas the water is diverted for irrigation purposes, floodwater is spread in adjacent fields, where subsistence crops are grown. Irrigation water can be applied before the planting period, in order to maximize the moisture content of the soil during the growing period, or used as additional irrigation, mainly when spate flows occur during the growing period or where there is a substantial rainfall input.

It is thought that this practice began in Yemen around five thousand years ago. Today it covers around 3 million hectares of irrigated land around the world in areas distributed in arid and semi-arid zone of Near East, Africa, South and Central Asia and Latin America. In these contexts usually spate irrigation is one of the main sources of livelihood for the poorest sector of society and it is often practised and managed outside from the formal irrigation sector (van Steenbergen et al., 2010).

Despite its tradition, its relevance for rural livelihoods and the potential as strategy for water management in arid climates, spate irrigation has been neglected in the technical literature. There is a claim of major understanding and development of spate irrigation systems and related design and management options taking into account their main characteristics, for instance the uncertainty related to the ephemeral regime of river systems, sediment transport and soil management, the heavy burden for operation and maintenance, and the complex and dynamic nature of water rights and rules (van Steenbergen et al., 2010).

Spate irrigation in Ethiopia has developed more recently than in other countries due to the increasing of food demand caused by population growth (van Steenbergen et al., 2010). Some spate systems have been used for generations and others have been developed during last years. The effort in developing spate systems is driven both by government"s investments and farmers" own initiative (van Steenbergen, Mehari, Alemehayu, Alamirew, & Geleta, 2011).

Despite the effort in developing spate irrigation, experience showed a limited number of successful interventions. This is reported to be linked with the poor consideration of farmers" preferences, knowledge, institutions and rules while developing new projects. On the contrary, most of the interventions were dominated by an engineering approach (Kidane, 2009). The analysis of two irrigation systems, receiving water respectively from a dam and a perennial river diversion, carried out by Teshome (2003) also shows a lack of consideration for farmers" knowledge and preferences and recommends "that more research will be addressed to the question of farmers" knowledge, to options for irrigation that recognise the life-worlds and environment of farmers, and to the technical optimisation of irrigation without the preoccupation of bureaucracy".

1.3 Problem Statement

Growing population and food vulnerability of Ethiopia require an improvement of irrigation practices in the country. The recent development efforts for spate irrigation systems partially failed to achieve the expected results due to a design strategy which was too centred on an engineering approach. The low number of successful interventions is linked with a lack of appropriate knowledge of the social, hydrogeological and geographical characteristics of the local situation. Farmers" knowledge of the context, which has been highly valuable in other countries, has not been taken sufficiently into account. In addition to this, neither farmers" own preferences in development and planning nor their system of institutional rules were sufficiently considered. New project approaches should be developed in order to match effective developments for food production, taking into account farmers" participation and cooperation in developing agriculture and, in particular, spate irrigation.

1.4 Research Questions

How can the participatory approach be developed for effective improvements in Spate Irrigation Systems?

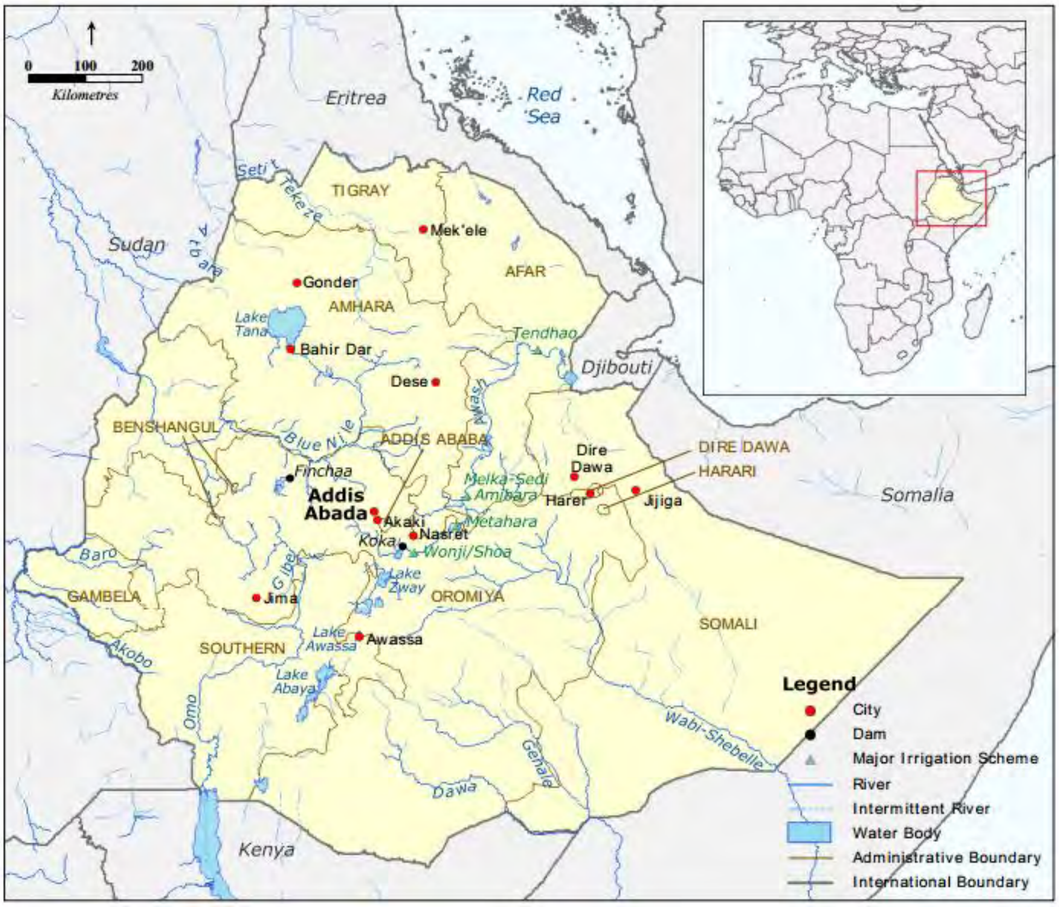
- How can problems be identified and ranked in a participatory manner and what solution can be selected for being effective?
- How the farmers‟ knowledge can be incorporated in the planning and design phases?

1.5 Area of Study

1.5.1 General overview of Ethiopia

Ethiopia (Figure 1.1) is located in the centre of the horn of Africa, extending between latitude 3°N and 15° N and longitude 33° E and 48° E (van den Ham, 2008).

Figure 1.1 - Map of Ethiopia



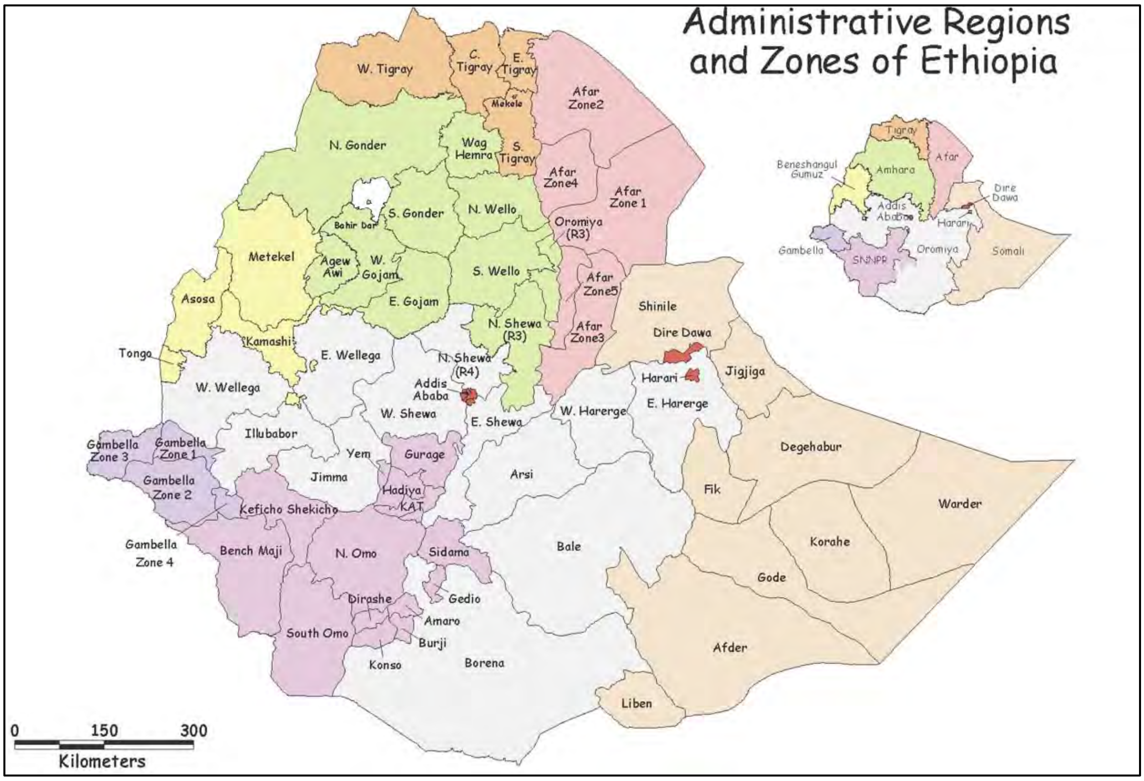
[*Source*: adopted from FAO (2014)]

The total area is 1,104,300 km^2 of which 104,300 are covered by water; the terrain is constituted by a high plateau with central mountains interrupted by the Rift valley, with the presence of the Danakil depression in the Northeast. The climate can be defined as tropical monsoon with wide topographic-induced variation. The country is bordered by

Eritrea at North, Sudan and South Sudan at West, Somalia at East and South and Kenya in the South (United States Central Intelligence Agency, 2000).

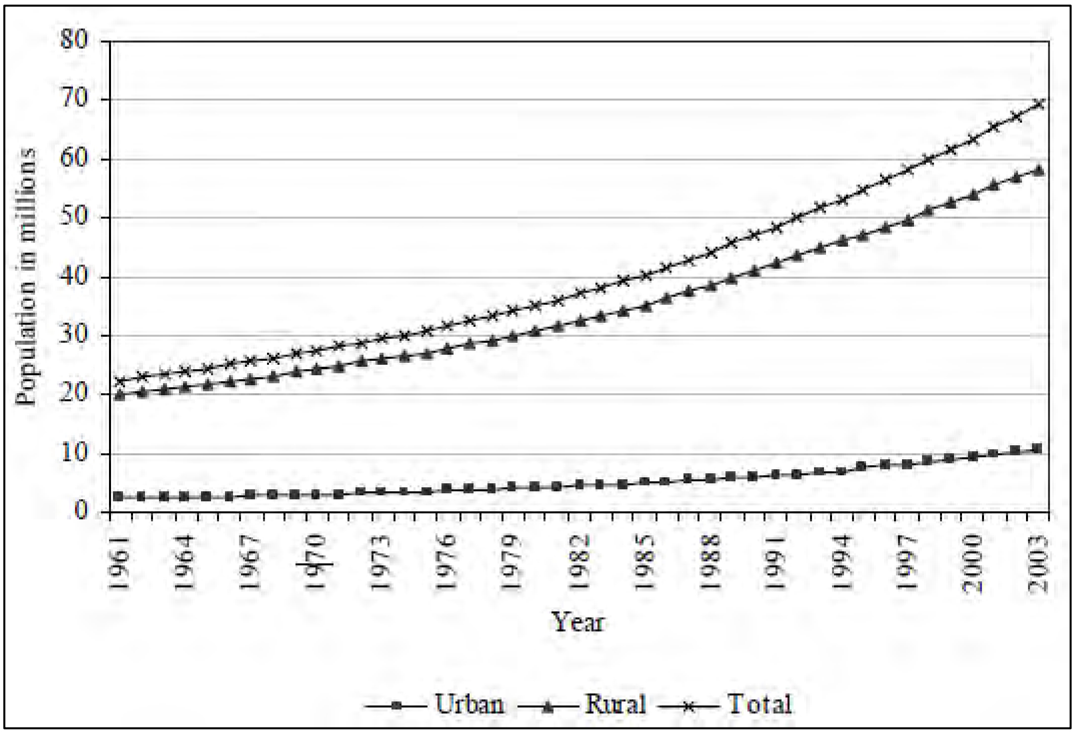
Ethiopia is a federal republic divided in 9 ethnically based states called „*kililoch*" (singular - *kilil*) and 2 self-governing administrations* called *astedaderoch* (singular - *astedader*) (Figure 1.2); Adis Abeba* (Addis Ababa), Afar, Amara (Amhara), Binshangul Gumuz, Dire Dawa*, Gambela Hizboch (Gambela Peoples), Hareri Hizb (Harari People), Oromiya (Oromia), Sumale (Somali), Tigray, Ye Debub Biheroch Bihereseboch na Hizboch (Southern Nations, Nationalities, and Peoples) (United States Central Intelligence Agency, 2000; van den Ham, 2008; Yazew, 2005).

Figure 1.2 - Administrative regions and zones of Ethiopia



The population estimated in 2014 is 96,633,458, with a growth rate of 2.89%; the population living in urban areas in 2011 was 17% (Figure 1.3).

Figure 1.3 - Population growth in Ethiopia



[*Source*: adopted from Yazew (2005)]

The highland complex of mountains and plateaux, situated above 1,500 m.a.s.l., represents the principal geomorphologic feature of the country, which is divided from Northeast to Southwest by the East African Rift Valley, which ranges from 40 to 60 km of width and it is occupied by a string of lakes. The lowest point are -125 m.a.s.l. in the Danakil depression and the highest mountain is Ras Dashen Mountain , 4620 m.a.s.l. (United States Central Intelligence Agency, 2000; Yazew, 2005).

In the highlands, averages temperatures range around 16 °C during the wet season and 21 °C in the dry season. In the lowlands they increase until to 27 °C in the wet season and 35 °C in the dry season. The Danakil lowlands and depressions experience extreme temperatures around 49 °C.

Annual rainfall varies from less than 100 mm in the east side of the country, at the border with Somalia and Djibouti to 2,400 mm in the highlands. The country average is 744 mm/year. A bi-modal rainfall pattern is present in the Southern and Eastern highlands, where smaller rains are present during the months of January and February (Belg), and major rainfall takes place from June to mid-September (Kiremit) (Yazew, 2005).

As shown in Table 1.1 Ethiopia faces famine and drought crisis with a cyclic occurrence. Famine is often linked with major drought crises, which have a chance of occurrence almost every two years.

Table 1.1 - Chronology of Ethiopian droughts and food shortages (EM-DAT Emergency Disaster Database, 2004)

Year	Total number of people affected in 10^6	Total number of deaths
1965	1.5	2,000
1973	3	100,000
1974	3	200,000
1977	0.3	-
1978	1.4	-
1983	7	-
1984	7.8	300,000
1987	7.3	-
1989	5.7	-
1990	6.5	-
1991	6.2	-
1992	0.5	-
1993	6.7	-
1994	3.9	-
1997	1	-
1998	0.8	-
1999	8.4	-
2000	10.5	-
2001	1	-
2002	16.3	-
2003	13.2	-
2004	7.2	

[*Source*: adopted from Yazew (2005)]

1.5.1.1 Water resources

Ethiopia annual renewable water resources amounts to 122 billion m^3 but withdrawals are only 4.6 billion m^3, with 6% use in the domestic sector, less than 1% in industry and around 94% allocated to agriculture (FAO, 2014). Detailed information is shown in Table 1.2.

Table 1.2 - Water in Ethiopia - sources and use

Water: sources and use

Renewable water resources			
Average precipitation		848	mm/yr
		936	10^9 m^3/yr
Internal renewable water resources		122	10^9 m^3/yr
Total actual renewable water resources		122	10^9 m^3/yr
Dependency ratio		0	%
Total actual renewable water resources per inhabitant	2004	1 685	m^3/yr
Total dam capacity	2002	3 458	10^6 m^3
Water withdrawal			
Total water withdrawal	2002	5 558	10^6 m^3/yr
- irrigation + livestock	2002	5 204	10^6 m^3/yr
- domestic	2002	333	10^6 m^3/yr
- industry	2002	21	10^6 m^3/yr
• per inhabitant	2002	81	m^3/yr
• as % of total actual renewable water resources	2002	4.6	%
Non-conventional sources of water			
Produced wastewater		-	10^6 m^3/yr
Treated wastewater	2002	0	10^6 m^3/yr
Reused treated wastewater	2002	0	10^6 m^3/yr
Desalinated water produced	2002	0	10^6 m^3/yr
Reused agricultural drainage water		-	10^6 m^3/yr

[*Source*: adopted from FAO (2014)]

The country can be divided in 12 river basins which form 4 major drainage systems:

1. The Nile basin (33% of total surface), which includes Abbay or Blue Nile, Baro-Akobo, Setit-Tekeze/Atbara and Mereb basins of the country and drains the northern and central parts of the country westwards;
2. The Rift Valley (28% of total surface), which includes Awash, Denakil, Omo-Gibe and Central Lakes basins
3. The Shebelli–Juba basin (33% of the total surface), which includes Wabi-Shebelle and Genale-Dawa basins and drains the south-eastern mountains eastwards
4. The North-East Coast (6% of the total surface), which includes the Ogaden and Gulf of Aden basins.

(FAO, 2014)

Table 1.3 shows the details of annual runoff by river basin.

Table 1.3 - Area and annual runoff by river basin

Area and annual runoff by river basin

Major drainage system	River basin	Area [1]	As % of total area	Annual runoff	As % of total runoff
		(ha)	(%)	(km^3/yr)	(%)
Nile Basin		**36 881 200**	**32.4**	**84.55**	**69.0**
	Abbay (Blue Nile)	19 981 200	17.6	52.60	42.9
	Baro-Akobo	7 410 000	6.5	23.60	19.3
	Setit-Tekeze/Atbara	8 900 000	7.8	7.63	6.2
	Mereb	590 000	0.5	0.72	0.6
Rift Valley		**31 764 000**	**27.9**	**29.02**	**23.7**
	Awash	11 270 000	9.9	4.60	3.7
	Denakil	7 400 000	6.5	0.86	0.7
	Omo-Gibe	7 820 000	6.9	17.96	14.7
	Central Lake	5 274 000	4.6	5.60	4.6
Shebelli-Juba		**37 126 400**	**32.7**	**8.95**	**7.3**
	Wabi-Shebelle	20 021 400	17.6	3.15	2.6
	Genale-Dawa	17 105 000	15.1	5.80	4.7
North East Coast		**7 930 000**	**7.0**	**0.00**	**0.0**
	Ogaden	7 710 000	6.8	0.00	0.0
	Gulf of Aden	220 000	0.2	0.00	0.0
Total		**113 701 600**	**100.0**	**122.52**	**100.0**

[1] The areas are estimates and the total area is slightly different from the total area of the country, which is 110 430 000 ha. This last figure should be considered as being the correct one nationally

[*Source*: adopted from FAO (2014)]

1.5.1.2 Agriculture and irrigation in Ethiopia

Agriculture represents the main source of income (50% of GDP) and occupation (90% of the population) for Ethiopia; main cultivation for the country are cereals (teff, maize, sorghum, barley, wheat and millet), coffee, sugarcane, oil seeds and pulse (Yazew, 2005).

The country is rich in potentially exploitable agricultural land and only 16% of 66 million ha suitable for rainfed and irrigated agriculture are cultivated. Most of the agricultural activities are located in the highlands, between 1000 m.a.s.l. and 3000 m.a.s.l.. Agricultural production is mainly developed by smallholder farmers, whose farmland is often split in different plots and it is mostly realized by low productivity rainfed farming (Yazew, 2005).

Irrigation practices in Ethiopia started some centuries ago, while the first modern irrigation schemes were built in 1950s. Various studies indicate that the maximum irrigable area in the country is 3.6 million ha, but lowers to 2.7 million considering also financial availability, current technologies, land and water resources. The total irrigated area in the country was indicated as 290 000 ha in 2001. The irrigated areas by region are shown in Table 1.4.

Table 1.4 - Irrigated area by region

Irrigated area by region

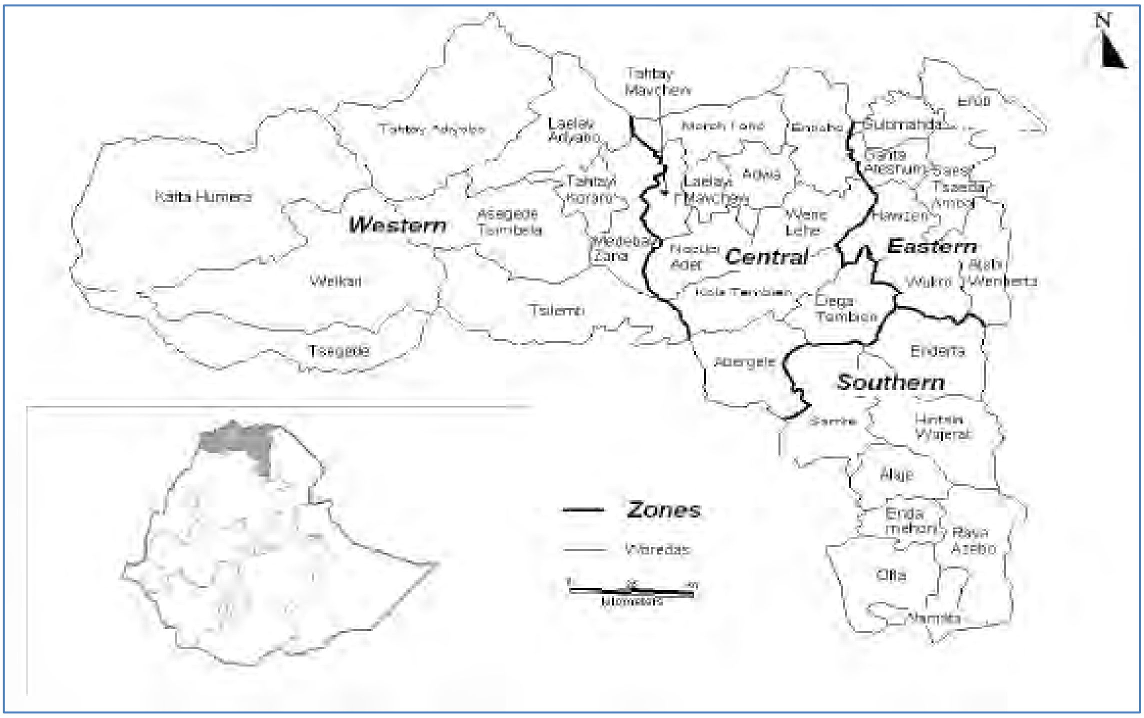
Region	Traditional small-scale irrigation	Number of farmers	Modern small-scale irrigation	Number of farmers	Private small-scale irrigation	Medium- & large-scale public irrigation	Total irrigation	As % of total irrigation
	(ha)	(No)	(ha)	(No)	(ha)	(ha)	(ha)	(%)
Addis Ababa	352	8 608	0	0	0	0	352	0.12
Afar	2 440	16 640	0	0	2 000	39 319	43 759	15.11
Amhara	64 035	384 210	5 752	17 166	0	0	69 787	24.11
Benshangul-Gum	400	2 000	200	170	0	0	600	0.21
Dire Dawa	640	1 536	860	2 696	0	0	1 500	0.52
Gambela	46	373	70	280	0	0	116	0.04
Hareri	812	558	125	71	0	0	937	0.32
Oromia	56 807	113 614	17 690	61 706	2 614	35 376	112 487	38.85
SNNPR	2 000	2 700	11 577	45 000	800	20 308	34 685	11.98
Somali	8 200	16 400	1 800	7 000	0	2 700	12 700	4.39
Tigray	2 607	25 692	10 000	40 000	0	0	12 607	4.35
Total	138 339	572 331	48 074	174 089	5 414	97 703	289 530	100.0

[*Source*: adopted from FAO (2014)]

1.5.2 Tigray Region

Tigray Region (Figure 1.4) is situated in the extreme north of Ethiopia, located between latitude 12º 15" N and 14º 50" N, and longitude 36º 27" E and 39º 59" E. Its total extension is approximately 8 million ha, covering the area from the Sudan border in the West to Eritrea in the North and the Ethiopian regions of Amhara and Afar border in the South and East. The population of the region is around 3.3 million with an annual population growth of 3.3%.

Figure 1.4 - Administratve boundaries of Tigray

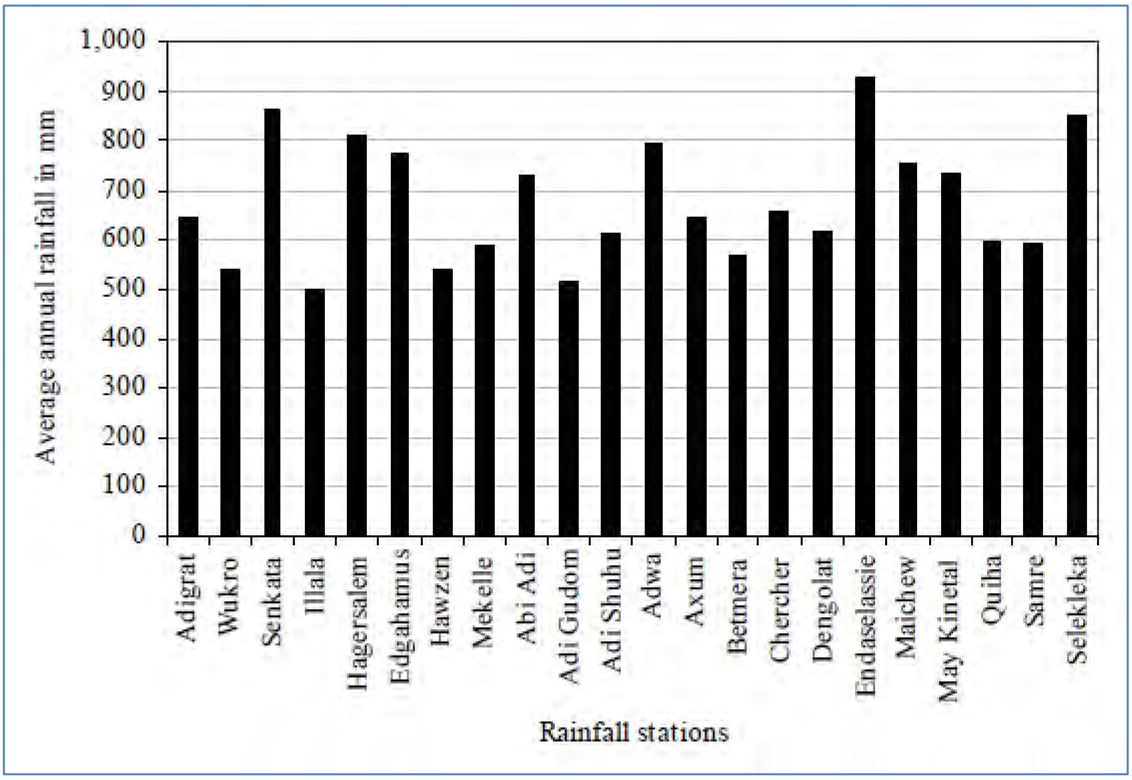


[*Source*: adopted from (FAO, 2003)]

Tigray is mainly characterised by an high mountain plateau, with a general altitude range of 2,000 to 3,000 m.a.s.l., and undulated terrain and plain lowlands in the Eastern and Western escarpments. The effect of erosion from main rivers, the Tekeze and Mereb rivers, and their tributaries, produced gorges and valleys that literally cut the main highland plateau (Yazew, 2005).

The climate of the region can be classified as semi-arid. The Kiremt season (summer rains) lasts from June until mid-September, when around the 80% of annual rain falls in the region. Some areas in the South-eastern highlands and Northeastern lowlands can get consistent rainfall during the Belg Season (January-February). Tigray is the driest region in Ethiopia; the annual rainfall ranges from 980 mm on the central highlands to 450 mm on the North-eastern areas (Figure 1.5). Annual average temperatures are around 22 °C in the highlands and 26 °C in the lowlands, while June has the average maximum temperature (28 °C) and December the lowest (9 °C) (Yazew, 2005).

Figure 1.5 - Average annual rainfall at different locations in Tigray



[*Source*: adopted from Yazew (2005)]

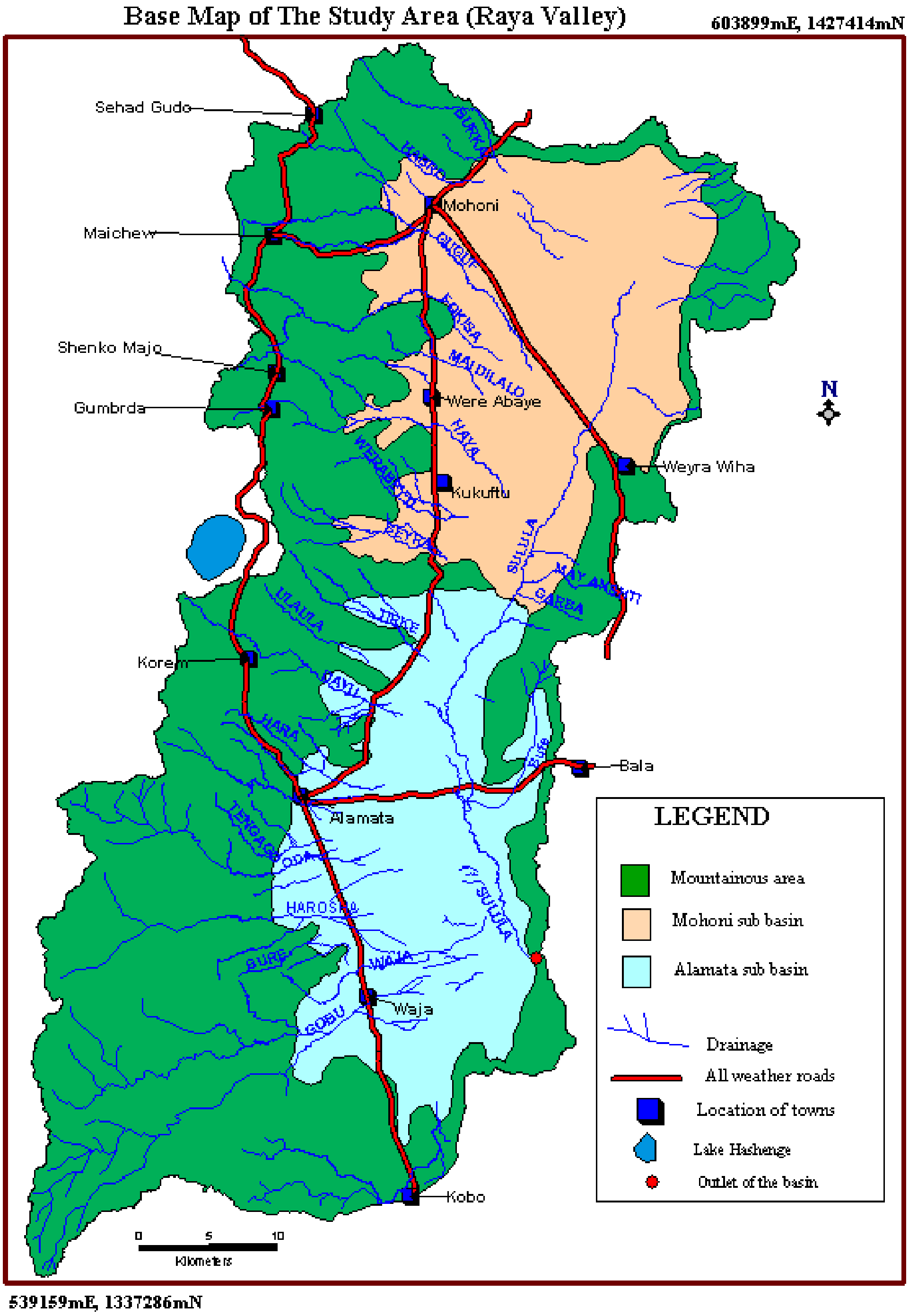
1.5.3 Harele and Raya Valley

The study has been carried out for the spate irrigation system of Harele tabia (municipality) which abstracts water from Harosha river, in the southern part of Raya Valley. The Municipality is located in Alamata woreda (department), in Tigray region, around 120 km south from the regional capital, Mekele.

Raya Valley is located between 39°22‟ to 39°25‟ north latitude and 12°17‟ to 12°15‟ east longitude, in the south-east of Tigray region. It comprehends the whole area of Alamata and Raya-Azebo woredas and the eastern highlands from Endamekoni and

Ofla Woredas. Figure 1.6 and Figure 1.7 show the location and the detailed map of Raya Valley.

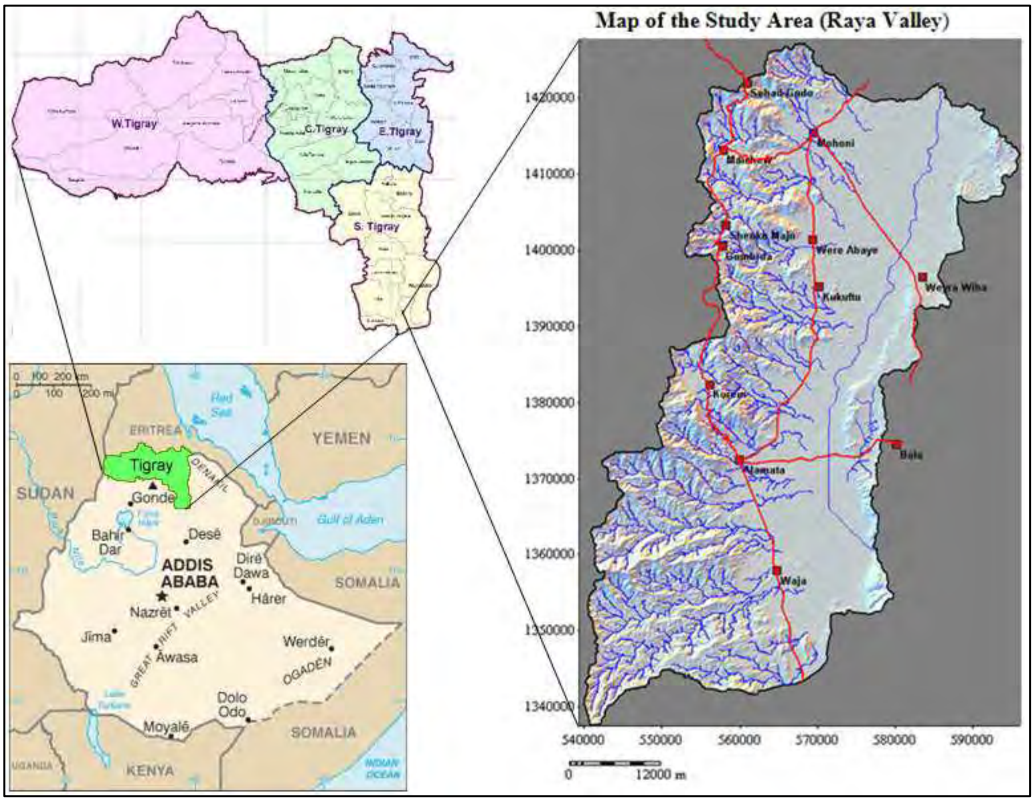
Figure 1.6 - Map of Raya Valley



[*Source*: adopted from Hagos (2010)]

The Spate Irrigation system of Harele has a command area of about 70-80 ha and is located in the northern part of Harele Tabia, part of the system lies also in the northern Tabia of Lemaat. Figure 1.8 shows the location of Harele tabia, while Figure 1.9 and Figure 1.10 represent satellite images of the command area.

Figure 1.7 - Location and map of Raya Valley



[*Source*: adopted from Hagos (2010)]

Figure 1.8 - Location of Harele Tabia - UTM WGS84 Coordinates

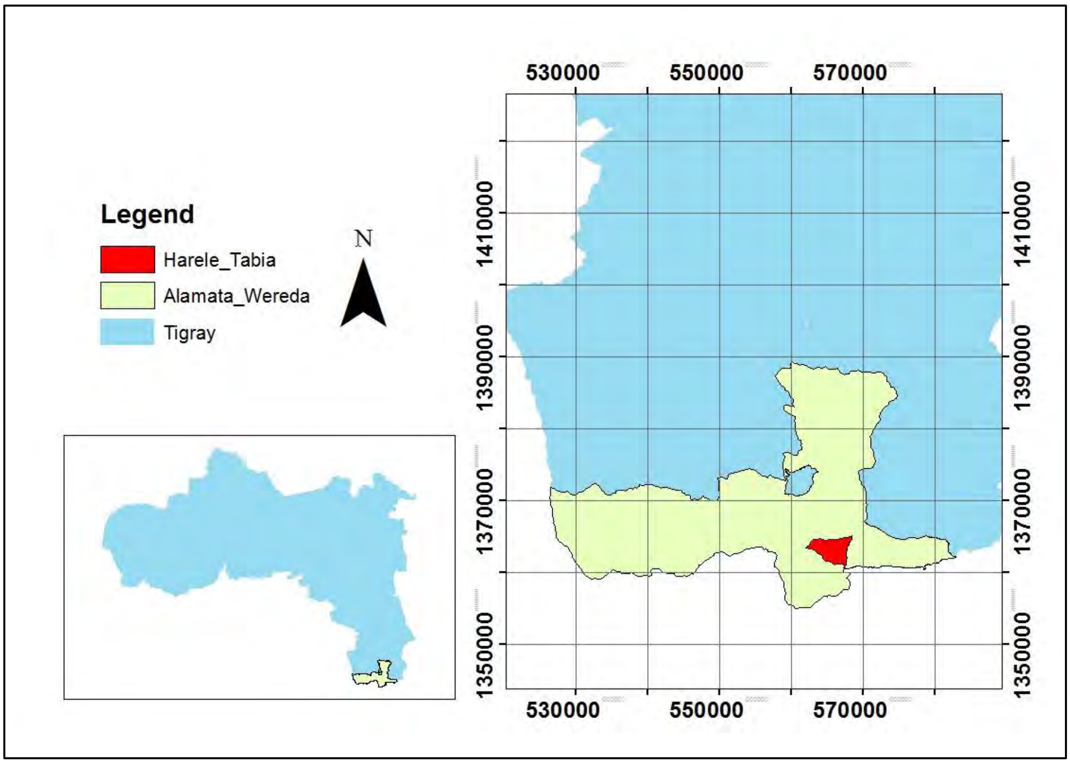


Figure 1.9 - Command Area (yellow) and Harele Tabia (red) - Google Earth

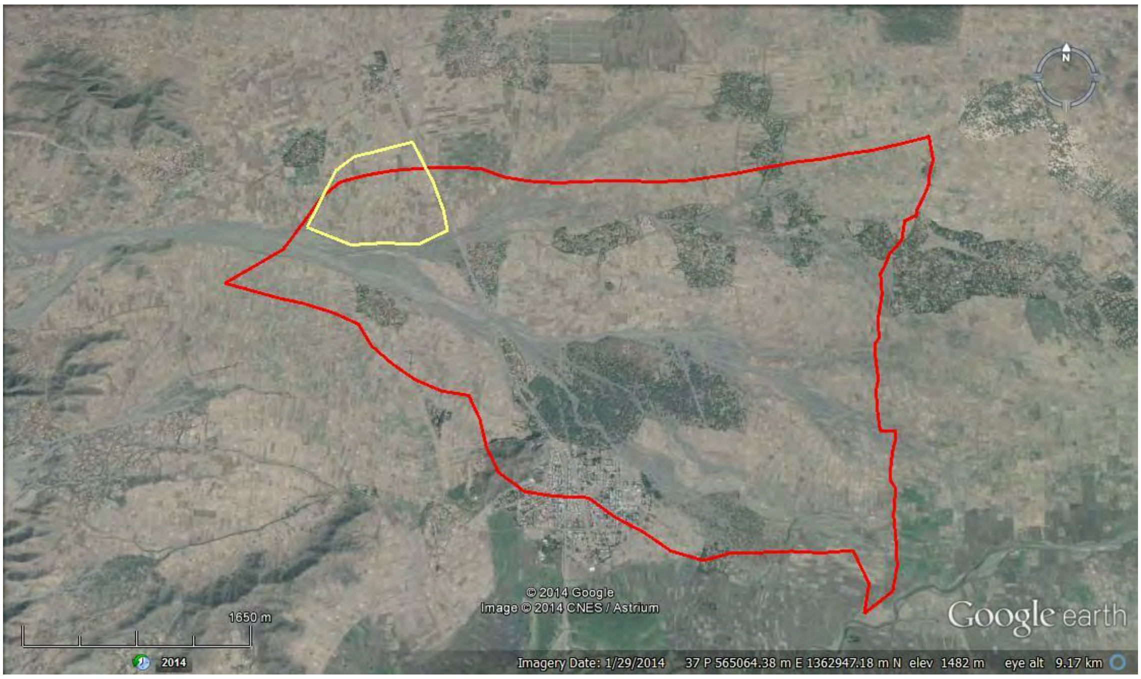


Figure 1.10 - Command Area (yellow) and Harele Tabia (red) - Google Earth (detail)

2 Literature Review

2.1 Flood based farming systems

Flood Based Farming Systems (FBFSs) are a family of farming techniques based on the use of unpredictable and potentially destructive floods as water supply for multiple uses, such as irrigation, rangeland and agro-forest management, domestic and livestock water supply, groundwater recharge (Embaye, 2013; Mehari, 2014).

FBFSs are a relevant option for water management and livelihood sustainability in arid and semi-arid region. Furthermore they represent an unique adaptation strategy to climate change, as they exploit water resources produced during floods rather than perennial flows (Mehari, Demissie, Embaye, & Getaneh, 2013).

FBFSs are different from both rainfed farming system and irrigated farming system, due to the exceptional nature of flood water supply. This is related to the level of uncertainty of flood events, the technical difficulty of abstracting and managing flood water, the higher sediment transport capacity of flows, the nature of water rights and the operation and maintenance standards which are very different from the traditional ones (Mehari et al., 2013).

The main techniques for Flood Based Farming are:

- **Flood recession farming:** Flood recession farming is practiced using soil moisture stored in subsurface soils after the inundation of wetlands, floodplains and lakeshores.
- **Flood-spreading weir:** This technique is based on the artificial inundation of floodplains through flood spreading weirs.
- **Spate irrigation:** Spate irrigation utilizes artificial bund or spurs for abstracting flood water from ephemeral rivers, deviating flood water to fields, water ponds or groundwater recharge areas.

2.2 Spate irrigation: review and definition

Spate irrigation is a form of water resource management which is based upon the diversion of floodwater from river beds. The flow is then conveyed in channels and used for crops irrigation, drinking water requirements, forest and grazing land development and groundwater recharge (van Steenbergen et al., 2010).

Spate irrigation is typical of arid and semi-arid countries, where surface runoff is usually the main source of water. Here runoff is generated in mountain catchments during short and intense precipitations and flows in ephemeral rivers (wadis). Appreciable discharges are usually present for few hours, with a recession flow of few days. Whereas the water is diverted for irrigation purposes, floodwater is spread in adjacent fields, where subsistence crops are grown. Irrigation water can be applied before the planting period, in order to maximize the moisture content of the soil during the growing period, or used as additional irrigation, mainly when spate flows occur during the growing period or where there is a substantial rainfall input.

Spate irrigation schemes are based on the diversion of floodwater through the use of artificial bunds built within the river bed. In traditional spate irrigation schemes, bunds and canals are made by local materials, such as stones, earth and brushwood. Modernisation of spate scheme is often realised with the use of concrete or gabions. An example of traditional intake is shown in Figure 2.1.

Figure 2.1 - Traditional spate irrigation intake - Ethiopia

[*Source*: adopted from (van Steenbergen et al., 2010)]

It is thought that this practice began in Yemen around five thousand years ago. Today it covers around 3 million hectares of irrigated land around the world in areas distributed in arid and semi-arid zone of Near East, Africa, South and Central Asia and Latin America. In these contexts usually Spate Irrigation is one of the main sources of livelihood for the poorest sector of society and it is often practised and managed outside from the formal irrigation sector (van Steenbergen et al., 2010). Estimations of spate irrigated areas for Africa and Asia are reported in Table 2.1.

Table 2.1 - Estimates of spate Irrigated areas in Africa and Asia

Country	**Area under Spate Irrigation (ha)**	
	FAO-AQUASTAT	*Expert meeting 2008*
Algeria	56 050	56 000
Eritrea	17 490	17 000
Ethiopia	-	140 000
Iran	-	419 500
Morocco	26 000	165 000
Pakistan	720 000	640 000
Tunisia	27 000	1 000
Yemen	218 000	117 000

[*Source*: adopted from (van Steenbergen et al., 2010)]

Despite its tradition, its relevance for rural livelihoods and the potential as strategy for water management in arid climates, spate irrigation has been neglected in the technical literature. There is a claim of major understanding and development of spate irrigation systems and related design and management options taking into account their main characteristics, for instance the uncertainty related to ephemeral regime of river systems, sediment transport and soil management, the heavy burden for operation and maintenance, and the complex and dynamic nature of water rights and rules (van Steenbergen et al., 2010).

According to FAO guidelines (van Steenbergen et al., 2010), typical characteristics of Spate systems are:

- **Indigenous diversion systems,** which are built using local materials and traditional techniques, capable of capturing small floods as well as to avoid large floods entering the irrigation scheme.
- **Sediment management,** as a prominent issue. As flood water in ephemeral rivers has a heavy sediment load, special sediment management techniques are in use or should be improved. Fluvial sediment also represents a natural fertilizer for spate systems.
- **Soil moisture conservation systems**, which are vital, especially when floods come before the sowing period.
- **Social organization and cohesion within the farmers,** which is needed to ensure the correct management of a complex system such as a spate irrigation system, given the fact that the burden for operation and maintenance is relevant, and floods can come with unknown intensity and frequency.

Spate systems can be classified according to their size, flow regimes (only spate flow, flow includes significant base flow and conjunctive use of spate and groundwater), the type of infrastructure (traditional intakes and canals, improved traditional systems, modernized and new systems) and operation and maintenance (farmers managed, farmers supported from agencies and agency managed).

A typical classification is based upon four main categories:

- ***Small schemes under farmer management using traditional diversion practices:***
  These schemes are present on smaller wadis, where farmers usually can manage floodwater by themselves using simple structures. The most suitable options for improvements can be related to the reduction of labor needed for building structures, operation and maintenance.
- ***Medium-scale/large-scale schemes under farmer management using traditional diversion practices:***
  Schemes usually found or larger wadis. They comprehend multiple intake points but they can be treated as a succession of single schemes. Typical options for system improvement are represented by modernization of structure using concrete and gabions.
- ***Large and technically complex schemes:***
  The construction of larger and technically complex systems requires the involvement of technical and managerial support systems (agency, private sector, local government). In these schemes, permanent diversion structures could be considered. These schemes could modify the hydrology of the wadi and require a study of their impact, sustainability and manageability.
- ***Schemes with access to sufficient shallow groundwater or base flows:***
  Such systems have direct access to groundwater. Incentives and projects for well-digging could be considered, together with a monitoring activity in order to prevent the disruption of the aquifer.

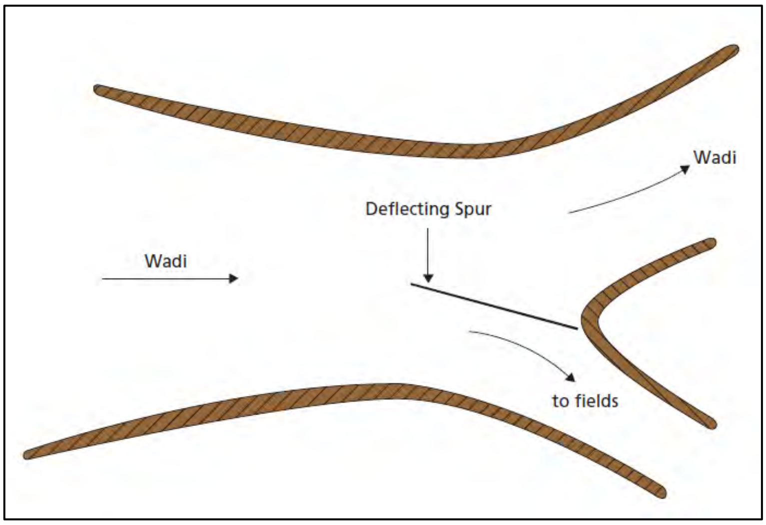
(van Steenbergen et al., 2010).

2.2.1 Elements of a traditional spate irrigation systems

Typical elements of a spate irrigation scheme are (Spate Irrigation Network, 2014; van Steenbergen et al., 2010):

- **Diversion structures:** diversion structures have to divert water flowing in the wadi bed. They have to work under different flow conditions, avoiding that large and uncontrolled flows enter in the system as well as excessive sediment. In traditional systems they are often made with local material, such as stones, brushwood and earth.
  In traditional spate systems, two types of diversion structures may be present:
  Spur-type deflector (Figure 2.2): usually found in upstream zones of the system, wadi catchment, which is constituted by a deflecting spur whose role is to deviate a part of the flow into the main irrigation canal, leaving the rest of the water flowing in downstream.

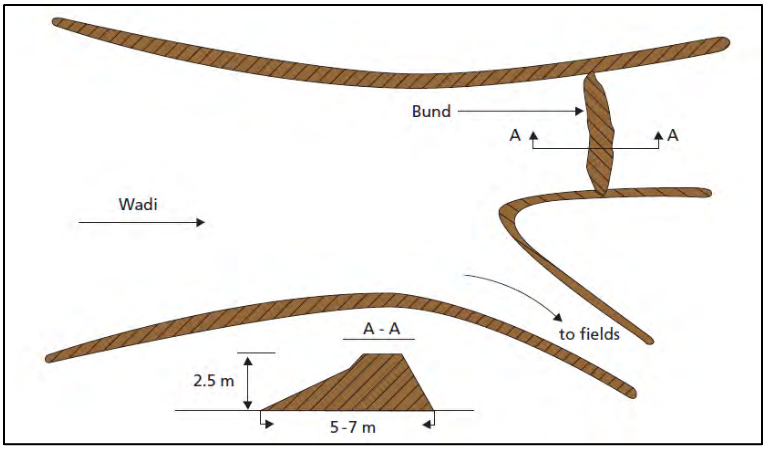
Figure 2.2 - Spur-type deflector



[*Source*: adopted from (van Steenbergen et al., 2010)]

Bund-type diversion (Figure 2.3): typical of the downstream part of a system/catchment, and in general of mild slopes. It is usually built with a bund which block the water flowing in the river, allowing the lateral abstraction.

Figure 2.3 - Bund-type diversion



[*Source*: adopted from (van Steenbergen et al., 2010)]

- **Main irrigation channels:** those channels deliver water from the intake to the command area. Usually their slope is the same as the river, in order to maintain the same sediment rate of the original flow, avoiding their deposition in the canals. They are usually designed for the maximum discharge, sometimes with zig-zag profile.
- **Delivery system:** the water delivery system is usually based on secondary canals. After secondary canal, two technical solution can be in place:
  Tertiary/field canal distribution: in this case, field distribution is realized with smaller canals to fields.

Field-to-field distribution: this kind of distribution is realized by breaking field bunds. The upstream farmer has right to flood his field. When his irrigation turn ends, he has to break a bund of his field for allowing water to go to the adjacent farmer"s downstream field.

2.2.2 Wadis hydrology and sediment transport

Hydrology of spate flows is characterized by a great variability in frequency and intensity of flood events. Spate events are generated by localized and intense precipitation and can have very high peak discharges. Rainfall data for wadis catchment are seldom available, but their analysis suggests a highly localized rainfall occurrence, with rainfall measurements poorly correlated even at a distance of 15 – 20 km. Wadi catchments have usually sparse vegetation and rocky soils, resulting in low infiltration rates and high erosion (van Steenbergen et al., 2010).

Sediment transport rates for wadis can be two or three order of magnitude higher than the ones observed in perennial rivers. Thus, sediment management represents a key factor for operation and management of spate schemes (van Steenbergen et al., 2010).

Conventional hydrological modelling has a limited effectiveness in the estimation of wadis runoff, due to the localized nature of precipitation and the limited number of data and studies available for seasonal rivers. Average runoff amount is often calculated with empirical formulas and requires wise hydrological judgement in assessing the most appropriate selection of methods and coefficients. In this environment, the use of local knowledge for the understanding of the characteristics and hydrology of a catchment is highly valuable and should be used for the estimation of design discharges (van Steenbergen et al., 2010).

2.3 Spate irrigation in Tigray Region

2.3.1 Development of spate irrigated agriculture

Spate irrigation in Ethiopia has developed more recently than in other countries. Some spate systems have been used from generations and others have been developed during last years. The effort in developing spate systems is driven both by government"s investments and farmers" own initiative (van Steenbergen et al., 2011). Anyway, water harvesting practices have been present since 560 BC (Alemehayu, 2008). In some zones of Ethiopia, however, irrigation is practiced from centuries (Teshome, 2003).

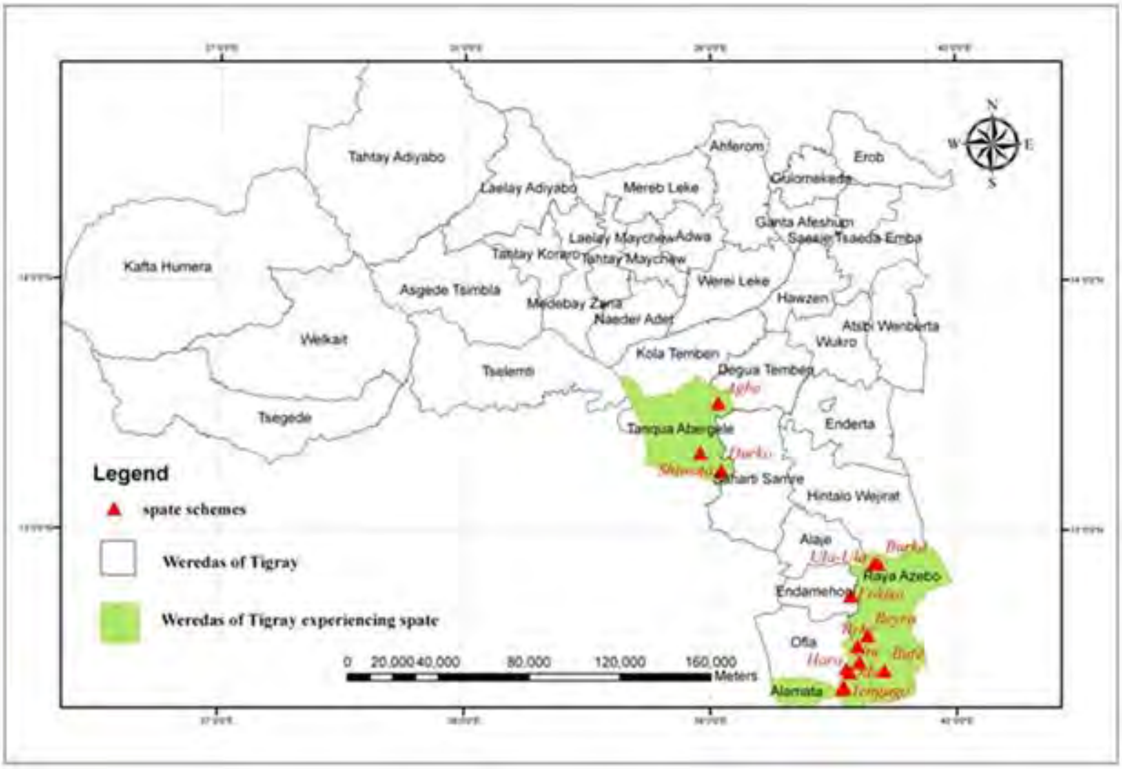
Spate irrigation has been practised for centuries in Tigray, especially in Raya valley (Raya Azebo and Alamata woredas) (Abate, 2013; Embaye, Mezgebu, & Yazew, 2013; Kidane, 2009; Spate Irrigation Network, 2014). The regional government has made strong efforts to improve the traditional spate irrigation systems in the last 10 years (Kidane, 2009; van Steenbergen et al., 2011).

In Raya valley Spate Irrigation is practised using the water flowing from Maichew and Ofla highlands, situated at east of Mekoni and at north of Alamata. (Kidane, 2009).

2.3.2 Spate irrigation schemes in Raya Valley

The modernization process of spate systems in Tigray began in late 90s (Abate, 2013; Embaye et al., 2013). The modernization was early conducted in Raya Azebo and Alamata woredas and, from 2010 – 2011, attempts were made in Tanqua Abergele woreda (Durko, Agbe and Shiwata schemes) (Embaye et al., 2013). A detailed map of the spate irrigation schemes present in Tigray is presented in Figure 2.4.

Figure 2.4 - Location of woredas and spate schemes in Tigray



[*Source*: adopted from (Embaye et al., 2013)]

The first system to be designed was Hara modernised system in 1998, followed by Tirke system in 2004. The design of both systems was based on the conventional approach for perennial rivers. Diversion structures were realised with diversion weirs, closed intakes and works in concrete masonry, while the canal system was provided of modern division structures, canal and pipe crossings (Abate, 2013; Embaye et al., 2013). These systems became completely unused after the first rainy season due to the complete siltation of the system, as designers didn"t take into account the exceptional sediment load of wadi. (Libsekal Gebremariam, 2014). Figure 2.5 shows the effects of siltation occurred in Hara spate irrigation system.

Figure 2.5 - Intake of Hara scheme

[*Source*: adopted from (Libsekal Gebremariam, 2014)]

After the failure of modernized structures, farmers in Hara began to divert water with traditional diversion structures located upstream (Kidane, 2009; Mehari et al., 2013) but in 2010 the scheme fully stopped functioning and nowadays agriculture in the area is only rainfed (Mehari et al., 2013).

Fokisa, Beryu and Burka spate irrigation schemes were built in 2005. For these new schemes, farmers were consulted about their knowledge and their preferences, but in the end their involvement in the design was limited to the choice of the diversion angle and the off-take. The main changes from the design of Hara and Tirke schemes were:

- Change of the off-take to open
- Change of the diversion angle from 90° to 120°
- Removal of crossing structures with pipes
- Enlargement of the canal size

This approach avoided the complete siltation of the diversion structures but some siltation problems still remained unsolved. In addition to this, crop water requirements were underestimated. This was due to two main errors in design:

- An irrigation time of 24 hours was considered, even if in seasonal rivers water is only present for 4-5 hours.
- In the calculation of crop water requirements the effect of rainfall was considered. Due to the extreme variability of rainfall, this led to a frequent underestimation of water requirements in dry years.

(Libsekal Gebremariam, 2014)

In Fokisa modernized system the planned irrigated area was 500 ha, but the system serves only 162 ha. After the modernization, the main operation and maintenance task for the farmers become removing of sediment from the structures of the system and the burden for maintenance was not reduced (Kidane, 2009). Kidane also revealed that at the time of his study concrete structures were becoming unmanageable and farmers were building another traditional diversion upstream from the previous one.

Ula-ula, Buffie, Tengago and Dayu spate schemes were constructed in 2006. In these schemes the following improvements were considered:

- The crop water requirements were calculated considering 4 hours irrigation time, neglecting the effect of rainfall by safe side.
- The design was limited to the main canal.

Again, the main problems (siltation, reduction of the discharge delivered by main canal) were not solved, but the main lesson was that the area irrigated by modernized schemes should not exceed 200 ha. In 2011 the design of the new schemes of Durko, Agbe and Shiwata schemes was undertaken assessing flood duration and frequency by interviewing the farmers and command areas were calculated for a single flood (Embaye et al., 2013).

Guguf spate scheme has been improved with flexible diversion structures made with gabions and this solution provided good performance in spreading flood water (Mehari et al., 2013). At the time of the study of Embaye et al. (2013), also Oda scheme was in construction with some innovations such as the one introduced in Guguf, but there is no information about its performance.

A resume of the modernisation efforts developed in Tigray region is shown in Table 2.2.

Table 2.2 - Modernization efforts in Tigray region

Scheme	Year	Main improvements from previous design	Outcome
Hara and Tirke	2000 - 2004		Complete failure
Fokisa, Beryu and Burka	2005	- Change of the off-take to open - Change of the diversion angle from 90° to 120° - Removal of crossing structures with pipes - Enlargement of canal size	Partial failure
Ula-ula, Buffie, Tengago and Dayu	2006	- Crop water requirements calculated considering 4 hours irrigation time, neglecting the effect of rainfall - The design was limited to the main canal	Partial failure, but better assessment of the area served
Durko, Agbe and Shiwata	2011	- Assessing flood duration and frequency by interviewing the farmers	-
Oda, Guguf	2011	- Use of gabions for diversion structures	Good performances in Guguf scheme

[*Source*: adopted from Embaye et al. (2013)]

2.3.3 Performance assessment of traditional and modernized spate systems in Raya Valley

According to Spate Irrigation Network (2014), traditional spate irrigation systems in Raya Valley are performing better than modernized ones. Farmers have gained a considerable knowledge about the use of floodwater for productive activities during centuries of practice. Unlike the traditional ones, modernized systems are performing poorly.

Under a technical point of view, the main causes of a better performance of traditional systems can be related to the skill acquired by the farmers (Spate Irrigation Network, 2014):

- Ability of farmers to select proper position and orientation of diversion structures
- Farmers usually build the inlet of traditional structures at a higher level than the river bed at the beginning of the rainy season. In this way only a small part of the first flood is diverted, minimizing the damage to the structures. First floods excavate the inlet and allow the diversion during the recession phase
- Traditional canals are built with a zigzag manner with a proper slope. With straight canals, when flow exceeds the capacity of the canal, it usually retreats causing breaches
- Farmers place boulders and woods upstream of the diversion in order to slow down the floods, minimizing the risk of a failure of diversion structures
- During floods not all farmers irrigate simultaneously, some attend the inlet, dredging the silt which flows into the system

In addition to this, the scarce consideration of farmers during the implementation of the modernization projects results in a low sense of ownership. On the other hand, farmers in traditional systems have developed strong rules and regulations, this contributes to create a perception of fair distribution of irrigation water, resulting in a high level of cooperation and sense of ownership (Embaye et al., 2013).

2.3.4 Rationale for the use of a participatory framework

According to Embaye et al. (2013), Kidane (2009) and Abate (2013), the main problem of the modernization strategy has probably been the lack of involvement of beneficiary farmers. Their knowledge, capabilities and preferences have never been taken into account. The above mentioned examples demonstrate that some improvements were suggested from farmers. Kidane also emphasizes that in traditional non-modernized schemes, like Boboteya, farmers are capable of carrying out system management, dealing with the typical issues.

Strong institutional agreements are in place in traditional spate irrigation systems (Embaye et al., 2013) and farmers have also developed effective technical strategies for operation and maintenance of spate systems (Spate Irrigation Network, 2014). The participation of farmers in the modernization of spate irrigation systems has been limited to consultation and gathering information about design features of concrete off-takes (Embaye et al., 2013). Therefore there is a need of a real participation of the farmers in the development project, considering their active involvement in planning and designing interventions, not only as a resource for technical information, but as actual project partners.

3 Research Methodology

3.1 General perspective: Diagnostic Analysis

The research approach is developed in the perspective of Diagnostic Analysis (DA), defined as an "appraisal and analysis of existing irrigation systems with the objective to identify problems and to define the causes or constraints, underlying these problems" (Falciai, 1996).

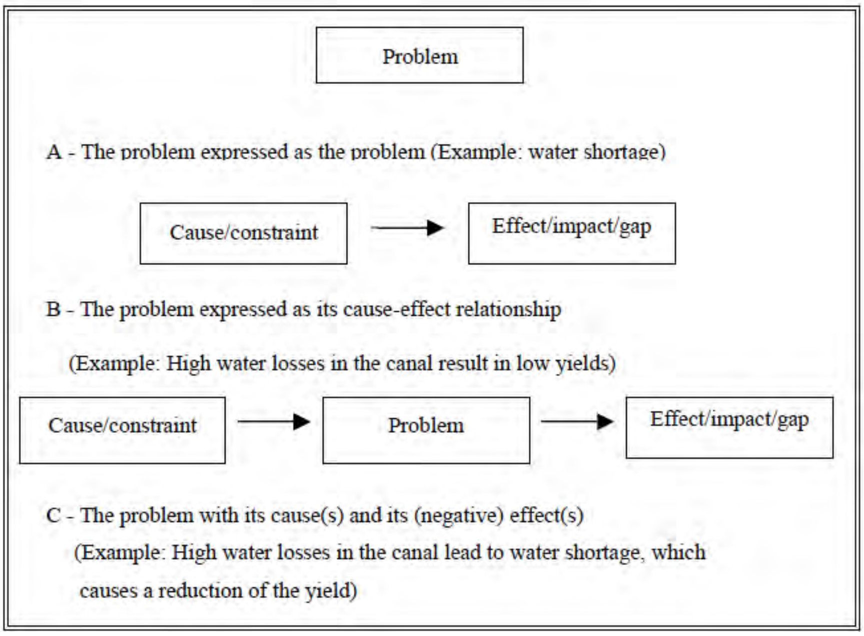
DA is an approach for the development of a general system, in particular an irrigation system, based on the analysis and identification of existing problems in order to identify the causes underlying these problems. Generally it is seen a base point for the selection of solutions aiming to reduce or eliminate problems, namely the problem solving process.

Basic concepts for DA are (Falciai, 1996: 8 - 11):

- ***Problem:*** A problem is the gap or deficiency between the existing situation and one"s expectation regarding this situation, i.e. the desired situation.
- ***Cause:*** A cause is something that prevents the attainment of the desired situation (i.e. one"s expectation regarding the actual situation).
- ***Solution:*** A solution is that activity or measure which alleviates (removes) the cause or causes of a problem.

In general, a problem may be perceived from its effects, namely its impacts on the existent situation. Different representations of the cause-problem-effect chain are given in Figure 3.1.

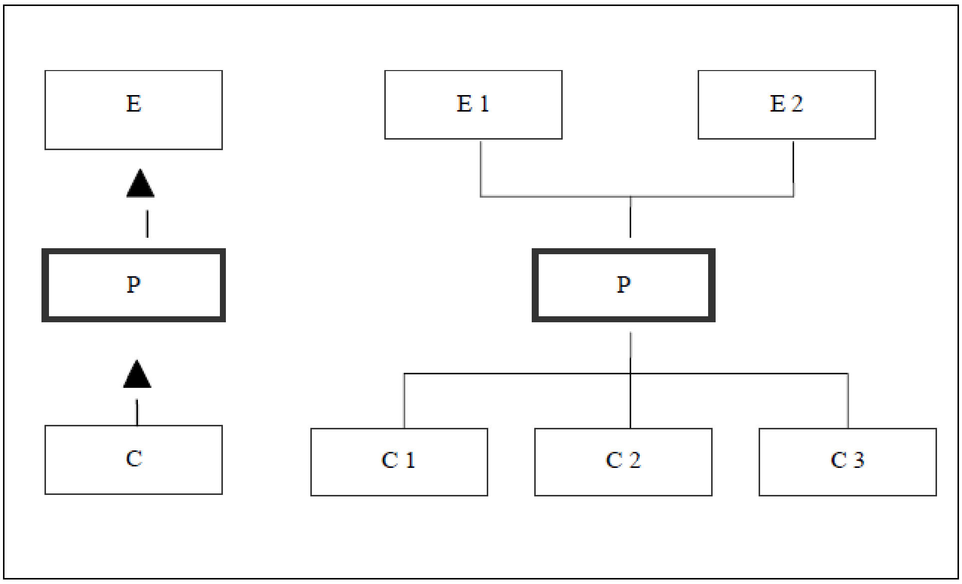
Figure 3.1 - Diagnostic Analysis - cause-problem-effect chain



[*Source*: adopted from Falciai (1996)]

As represented in the graphics of Figure 3.2, the causal chain may be more complicated: multiple causes may underlie a single problem, causes themselves may be seen as sub-problems with other causes and a problem may have multiple effects.

Figure 3.2 - Single and multiple cause and effect problems



[*Source*: adopted from Falciai (1996)]

3.1.1 Social implications of Diagnostic analysis

Diagnostic analysis of problems and constraints, within an irrigation system, involves social dynamics and cooperation between different kinds of knowledge (e.g. engineers, local leaders and farmers).

Firstly, the identification of problems is influenced by the parties involved in the process. This does not mean that only the farmers should be involved in the diagnosis and the selection of the problems to be solved/the causes to be removed.

Discussing the nature of problems and solutions, Falciai (1996) also stresses the difference between "hard" and "soft" objectives. Hard objectives are identified when the ideal situation identified by the problem statement is absolute and it must be achieved. Soft objectives are identified when the situation is open to change, and the desired situation can be discussed and reshaped by users and groups involved. The definition of hard or soft objectives and the redefinition of soft objectives are also part of the social dimension of diagnostic analysis.

The need of a solution for a certain problem is not only depending on the negative effects related to it, but also on the capacity of the farmers to solve the problem and on the priority given to the problem itself. The solution must also be socially acceptable and therefore the analysis should not encompass only technical issues.

General characteristics of the solution are (Falciai, 1996: 13):

- it must be "technically" possible, e.g. the increase of the water supply requires sufficient water availability from the existing source or the mobilization of new water resources,

- it must remove the negative effect. In case of serious water losses in the canal two solutions may be technically possible: (a) increase of the discharge, and (b) lining of the canal,
- it must offer clear advantages i.e. result in a net benefit, not only in financial terms, but probably also in socio-political terms. For instance, an increase in water availability in the tail-end of a scheme through a reduction in water use in the top-end will cause a slight reduction in yields in the upstream reaches but will result in a net increase in the overall production. However, the upstream situated farmers may refuse such a solution,
- it must be within the capacity of the farmers, e.g. the cost must not surpass their financial capacity or labour requirements must be within the limits of labour availability,
- it must not cause additional problems, e.g. a new water resource may lead to an increase in agricultural production but may also cause salinization of the scheme area with all negative effects of this.

3.1.2 Diagnostic analysis and problem solving as a research perspective

In the research framework, the perspective of DA has been used as a support for a participatory identification of the existing problems of the scheme and constitutes the basis for an analysis of the possible solutions.

The successive step has been the identification and the study/design of appropriate solutions for the selected scheme, namely the "problem-solving" phase.

The analysis of the irrigation system has been carried out using a participatory methodology, Participatory Rural Appraisal (PRA). The selection of most relevant problems and the design and implementation of possible solutions have been developed using a framework for participatory design. The following sections will present a general literature review of the participatory approaches used and the definition of the research methodology for the present study.

3.2 Literature Review

3.2.1 Participatory Rural Appraisal (PRA)

Participatory Rural Appraisal has been defined as a "family of approaches and methods to enable local (rural or urban) people to express, enhance, share and analyse their knowledge of life and conditions, to plan and to act" (Chambers, 1994: 1253).

The key concept in PRA is that local people are creative, capable of carrying their own analysis, identifying problems and constraints, planning and eventually taking actions. Researchers and field workers should act as facilitators and help local people to carry on their own system analysis. PRA involves a series of methods which can be used and adapted for each case of study, ranging from simple spatial representations of the study area (participatory mapping) to matrix ranking of different options (Cavestro, 2003).

PRA has been developed starting from the methodology of Rapid Rural Appraisal (RRA) (Cavestro, 2003; Chambers, 1994; De Campos Guimaraes, 2009). RRA is a research approach developed in late 70s, the main characteristic of the method is to quickly collect, analyse and evaluate information about a rural context („quick and dirty" approach) without losing time in expensive, time consuming and often misleading questionnaires („long and dirty" approach) (Cavestro, 2003). The main concern about RRA is related to the objective of a participative collection of information. RRA is mainly identified as a process of data gathering, functional to the delivery of a certain objective. Information is not shared with local people and the project goals are not to be discussed. PRA is rather part of a process of empowerment as it allows people to participate in the data gathering as active researchers.

"PRA has much in common with RRA but differs basically in the ownership of information, and the nature of the process: in RRA information is more elicited and extracted by outsiders as part of a process of data gathering; in PRA it is more generated, analysed, owned and shared by local people as part of a process of their empowerment." (Chambers, 1994: 1253).

Chambers also identifies 6 key principles at the basis of both PRA and RRA, and 4 principles characteristics of PRA:

Principles of RRA and PRA (Chambers, 1994: 1254):

1. *A reversal of learning*, to learn from local people, directly, on the site, and face-to-face, gaining insight from their local physical. technical and social knowledge
2. *Learning rapidly and progressively*, with conscious exploration, flexible use of methods, opportunism, improvisation, iteration and crosschecking, not following a blueprint program but being adaptable in a learning process.
3. *Offsetting biases*, especially those of rural development tourism, by being relaxed and not rushing, listening not lecturing, probing instead of passing on to the next topic, being unimposing instead of o important, and seeking out the poorer people and women and learning their concerns and priorities.
4. *Optimising trade-offs*, relating the costs of learning to the usefulness of information, with trade-offs between quantity, relevance, accuracy and timeliness. This includes the principles of optimal ignorance - knowing what it is not worth knowing, and then not trying to find it out, and of appropriate imprecision - not measuring what need not be measured, or more accurately than needed, following the dictum attributed to Keynes that it is better to be approximately right than precisely wrong.
5. *Triangulating,* meaning crosschecking and progressive learning and approximation through plural investigation. This variously involves assessing and comparing findings from several, often three:
    - methods
    - types of item or sets of conditions
    - points in a range or distribution
    - individuals or groups of analysts
    - places
    - times
    - disciplines
    - investigators or inquirers and combinations of these.
6. *Seeking diversity*, meaning looking for and learning from exceptions, oddities, dissenters, and outliers in any distribution. This has been expressed in terms of seeking variability rather than averages, and has been described in Australia as the principle of maximum diversity, or "maximising the

diversity and richness of information". This can involve purposive sampling in a non-statistical sense. It goes beyond triangulation; for it deliberately looks for, notices and investigates contradictions, anomalies, and differences, and includes negative case analysis.

Principles of PRA (Chambers, 1994: 1254 - 1255):

1. *They do* it: facilitating investigation, analysis, presentation and learning by local people themselves, so that they generate and own the outcomes, and also learn. This has been expressed as "handing over the stick" (or pen or chalk). It requires confidence that "they can do it." Often the facilitator initiates a process of participatory analysis and then sits back or walks away, taking care not to interview or interrupt.
2. *Self-critical awareness:* meaning that facilitators continuously and critically examine their own behaviour. This includes embracing error – welcoming error as an opportunity to learn; facing failure positively - "failing forwards"; and correcting dominant behaviour.
3. *Personal responsibility:* PRA practitioners tend to take personal responsibility for what is done rather than relying on the authority of manuals or of a rigid set of rules. This is in the spirit of the words of the one-sentence manual "Use your own best judgement at all times".
4. *Sharing:* of information and ideas between local people, between them and outsider facilitators, and between different practitioners (encouraging photocopying and non-attribution), and sharing field camps, training and experiences between different organizations, regions and countries.

In his article Chambers (1994) emphasizes the significance of several methodological "discoveries" of PRA experiences. First of all local people have strong knowledge about the context and well-developed capabilities in terms of analysis and planning. The role of researchers is to work as a facilitator and/or a collaborator; to do that it is necessary to build a genuine and open rapport with local people, presenting themselves honestly and clearly about their work, participating to the local task showing humility and willingness to learn from local population. Past experiences showed also the importance of visual methodologies as Venn diagrams, matrices and mapping. This and other tools are better performing if linked in sequences, building proper research strategies together with local people.

PRA also involves a series of reversals in perspective and approach. There is a shift in the kind of knowledge "from etic to emic": there is no more a fixed methodological perspective imposed by the researcher but rather a more open structure. Under the methodological point of view, the emphasis is no longer on extracting the information from an individual, but on developing knowledge in a group. Visual methods replace verbal ones and there is more emphasis in comparing quantities rather than measuring exact values. As discussed before there is emphasis on the rapport with people and relations shifts from the classical dichotomy „researcher – rural people" to a more participative and dynamic interaction. The last reversal is about power issues, while other methods emphasize the „extraction" of information from rural people, PRA rather empowers them, giving priority to enable the people to carry out their own analysis and implement and evaluate their own planning options.

3.2.1.1 Criticism on PRA methodologies

Participatory Rural Appraisal has been used for years in development cooperation and a number of criticisms, shortcomings and pitfalls have been analysed and experienced.

De Campos Guimaraes (2009) presents a list of problems related to PRA which are mainly related to the danger of an improper representation of power dynamics inside the communities, to the claim of PRA as a stand-alone methodology and to the tendency of a bureaucratization of participation.

Knowledge claims of PRA: Although it may seem, PRA does not represent a standalone methodology and it needs to be integrated with secondary data and more classical or technical analysis. Local knowledge should not be opposed to traditional one, rather there is a need of co-existence. Also insider-outsider dynamics could lead to an incorrect representation of reality, and especially social realities: if not acknowledged, power inequalities within the community may allow influent people to „take possession" of PRA session, influencing the analysis.

Myth of the community: Often PRA, and in general participatory methods, is applied assuming unrealistic simplification about local people. The term „community" is referred to an ideal group while, within a social reality, different groups (with competitive interests) can be present. Also communities" capabilities are often overestimated, assuming that the „ideal group" is capable of everything if effectively empowered. Other criticisms are related to an improper and simplified vision of the model of individual behaviour within a group, which is usually complex and specific for each social situation.

Bureaucratization of participation: A radical concept of empowering participation such as the one embodied in PRA can represent a critical issue when it is applied in a context in which outcomes have been previously identified or driven by donors.

Kapoor (2002) analyses more deeply the power issues within Chamber"s work. He asserts that the main pitfall of PRA approach is to partially neglect the management of power inequalities especially during the phase of discussion and consensus building, without a consistent ground for mediation and formal institution for balancing power inequalities. The nature of the process, free rather than coercive and public rather than private, can enhance the power imbalance

3.2.1.2 PRA in the context of spate irrigation and improvement in irrigation systems

Participatory Rural Appraisal has been used in several cases study in the framework of irrigated agriculture development and spate irrigation.

Tesfai and de Graaff (2000) utilised PRA for a spate scheme in Eritrea with good results and obtaining a detailed representation of management strategies in the area to be utilised for the preparation of community action plans. Their methodology comprehended techniques focusing on spatial aspects (village resource mapping in combination with transects), techniques focusing on development trends (historical profiles, trend lines and seasonal calendar) and techniques focusing on social aspects (Semi Structured Interviews, livelihood mapping and ranking of problems).

In the framework of Participatory Rapid Diagnosis and Action Planning (PRDA), van den Ham (2008) carried out an analysis of the Dodota Spate Irrigation Scheme in Oromia (Ethiopia). His approach comprehended PRA techniques for system diagnostic:

Semi Structured Interviews, transects, timelines, seasonality diagramming and matrix ranking.

An interesting approach has been experimented by Saeed, Ashraf, and Bruen (2002) in their analysis of skimming wells in Pakistan. They applied PRA techniques in order to identify problems and constraints related with the use of shallow wells as water source for irrigation, allowing farmers to gain a handle on the technology and develop effective improvements. Their approach also comprehended technical methodologies as simple pumping tests. Table 3.1 shows their approach to PRA analysis:

Table 3.1 – Example list of PRA techniques used for the analysis of skimming wells

	PRA Technique	Purpose
1	Semi structured interview	To obtain insights into farmers‟ perception, their constraints and possible improvements in skimming wells.
2	Trend line	To identify the months with high water table, peak water demand for crops and high skimming well operational hours.
3	Pie Chart	To observe the change in cropping pattern after installation of skimming well and percentage contribution of well water.
4	Field walk	To gain more insight into the problems mentioned by farmers and to help identify and locate additional problems with the skimming wells.
5	Flow chart	To visualize cause-effect relationship and identify solution to solve the problems with farmers skimming wells.
6	Mapping	To understand the design of skimming wells, spatial distances between strainers and length of strainers and blind pipe.
7	Preference ranking	To identify and prioritize skimming well problems.

[*Source*: adopted from Saeed et al. (2002)]

3.2.2 Participatory Design

Participatory Design (PD) is a methodology which allows designers and people destined to use a certain technology or system, namely „users‟, to cooperate and engage in a process of mutual learning with the aim to develop the design of appropriate solutions (Cole, Pinfold, Ho, & Anda, 2013; Spinuzzi, 2005; Steen, 2011).

PD can be defined as a Human Centred Design (HCD) approach. HCD approaches aim to enable designers to cooperate with „users‟ in order to develop a project outcome which matches users‟ practices, needs and preferences (Steen, 2011). Steen also summarizes the main principles of HCD approaches: "the active involvement of users for a clear understanding of their behaviour and experiences; the search for an appropriate allocation of functions between people and technology; the organisation of iterations, within a project, of conducting research and generating and evaluating solutions; and the organisation of multidisciplinary teamwork."

PD approach has its roots in 70s in Scandinavia; the methodology has mainly been applied to computer science and information technology (Spinuzzi, 2005; Steen, 2011) but in recent years it has been developed for designing civil infrastructures in rural contexts (Cole et al., 2013).

According to Spinuzzi (2005), PD should be defined as a „research methodology", even if it is a loose one, and not a design approach. The object of the methodology is the practical or „tacit" knowledge, namely an implicit form of knowledge used and developed in the everyday practice which is not usually systematic and bounded. The various formal and informal practices and institutions related to irrigation and farm management can be an example of tacit knowledge in the framework of agrarian development. The emphasis on users" practical knowledge has both a political and ethical meaning, giving the right place in the design process to users" knowledge, needs and preferences.

The methodology of PD is derived from participatory action research. The focus is on building a common ground between designers and users, which become co-designers, in order to provide appropriate solutions. The research process is represented by the design process itself: during its phases there is a focus on mutual understanding which allows stepping forward to next design phases (Spinuzzi, 2005).

The main stages of Participatory Design methodology are (Cole et al., 2013; Spinuzzi, 2005):

1. **Initial exploration of work:** in this phase researchers/designers familiarise with users/co-designers and with the way in which they work together. This stage involves the exploration of technologies, practices, procedures and work routines. The main objective is to build a „common language" between designers and users. Research methods for phase 1 are developed from ethnography and can range from interviews to examination of artefacts.
2. **Discovery process:** in this phase designers and users should agree on the priorities and on the work organization. The main objective of this stage is to clarify the desired project outcome in line with users" values and goals. Methods to be used in the second phase are represented by role plays, organisational games, workflow models and interpretation sessions.
3. **Prototyping:** in this phase users and designers engage an iterative design process with the aim of shaping new artefacts. Various methods for cooperative and collaborative design can be used in this stage.

Spinuzzi (2005) identifies three main criterion for the evaluation of PD:

- **Quality of the life for workers:** PD should aim to users" empowerment, meaning to allow user to take control over the design process and consequently on the project outcome. Reflexivity and agreement from both designers and users should be reached, as well as a real codetermination of project outcome.
- **Collaborative development:** collaborative development is a key factor in determining the success of PD. An essential requirement for achieving cooperation is to perform a data collection together with users. Proving effective mechanism of inclusion/representation and consensus building is vital.

- **Iterative process:** PD should be based on a subsistent iterative process in order to develop strong mutual understanding and sound collaboration between the parts involved. Continual participation, various revisiting stages and an analysis phase which goes beyond the performances of the project artefact should be present.

Cole et al. (2013), who applied the methodology for creating new sanitation technologies, also recommend:

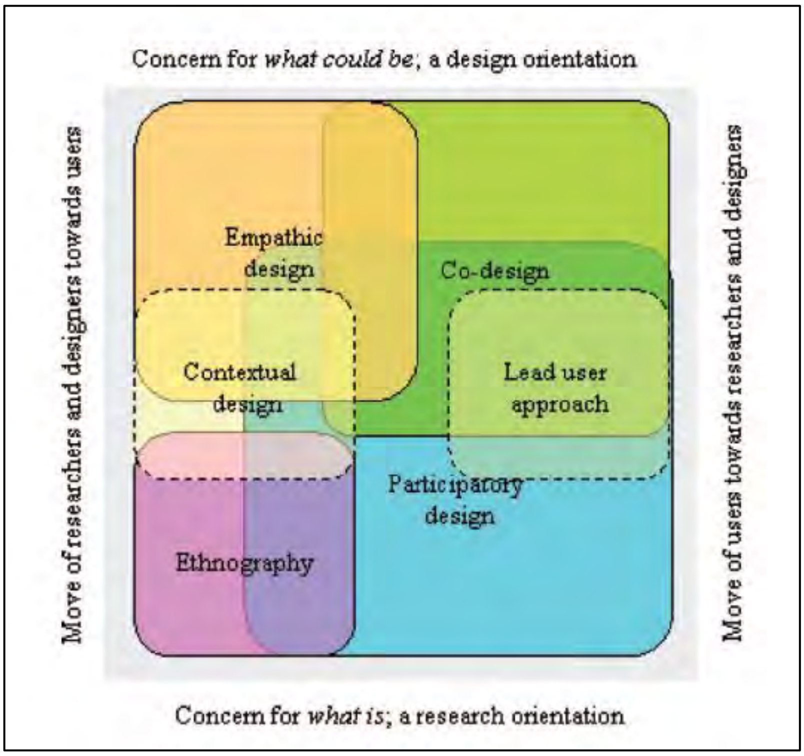
- the development of specific and common design criteria which should be clear and supported by users and
- a final technical refinement of the design created during the participatory process.

3.2.2.1 Issues and limitations of Participatory Design

Spinuzzi (2005) discusses the main limitations of the methodology. He firstly identifies the risk that designers focus too much on the artefact, rather than on the work process. In addition to this, he discusses the problems related to an improper and superficial use of ethnographic methodologies for the study of local knowledge, practices and preferences. This tendency can be in a certain sense reduced by iterating the PD methodology, reflecting and re-analysing with the users the design process. On the other hand, another practical limitation is represented by need of time for applying the participatory process properly.

According to Steen (2011), two tensions are always present in HCD methodologies, and practitioners have to recognize cope with them. The first tension is between designers" and users" knowledge, and it "originates from the differences between the world of researchers and designers and the world of users, and the gap between these worlds". The second tension is between the focus on past and present practices and the possibility of innovations, and it "occurs because HCD aims both to understand the present and to design for the future". Steen asserts that researcher have to find a balance for each tension and must be aware that each HCD methodology has its own natural imbalances. He describes PD has a wide family of methods which is slightly more concerned with past and present technologies, being characterised by a research perspective, and with the designers" knowledge. A graphical representation of the concept of „tension" for various HCD approaches is showed in Figure 3.3.

Figure 3.3 - Different human-centred design approaches, with different starting points and emphases



[*Source*: adopted from Steen (2011)]

3.3 Practical methodology

The methodology proposed for the study is based upon the approach of the Diagnostic Analysis and it is divided in five phases:

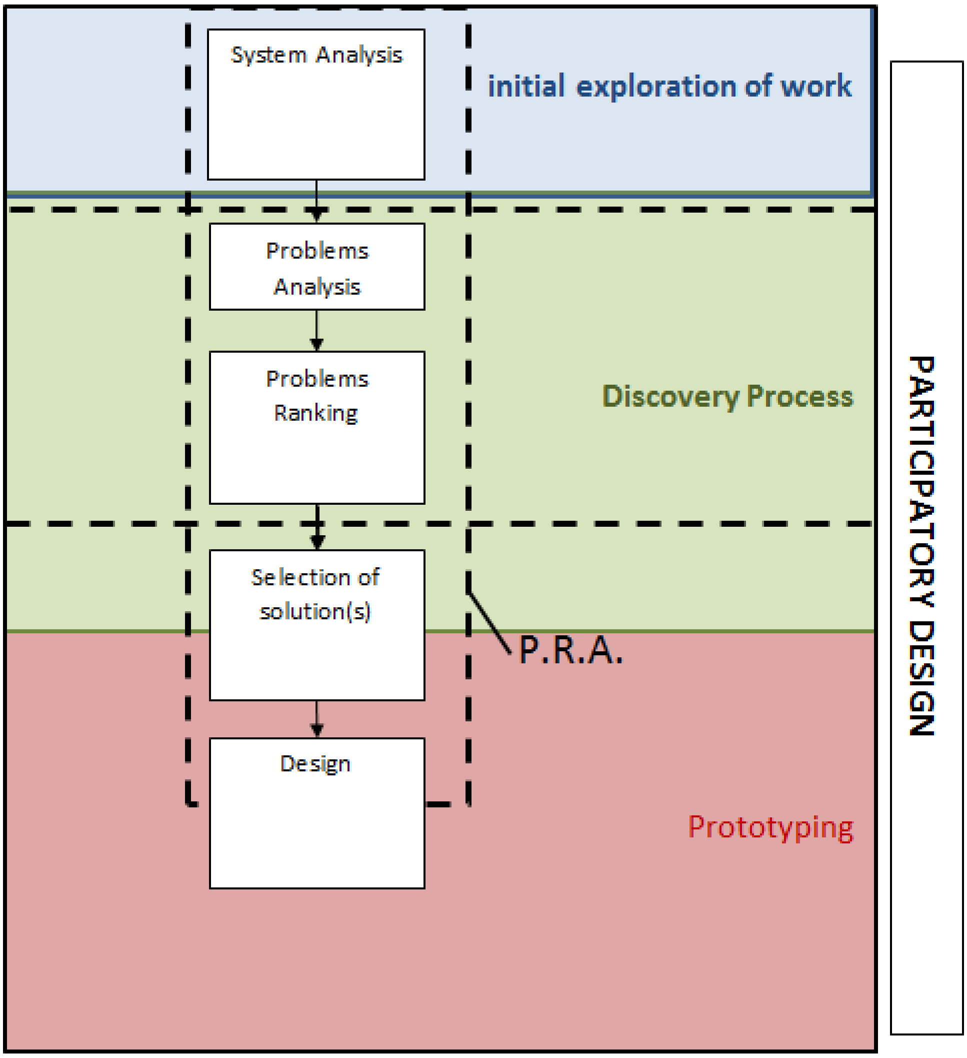
1. **System analysis**: analysis of the spate irrigation system
2. **Problems analysis**: identification of problems and constraints for the system
3. **Problems ranking**: selection of most relevant problems and constraints
4. **Selection of solutions**: selection of effective solutions for removing or attenuating problems and constraints of the system
5. **Design**: design of proposed solutions

The analysis of the system has been carried out using PRA methodology jointly with secondary data analysis and technical considerations. In the second and third stage, PRA tools and meetings have been used for the selection of the most relevant problems and constraints. The design of the solution has been developed using the PD methodology as defined by Spinuzzi (2005) and Cole et al. (2013).

PRA and PD are not used in sequence, but in combination: the "initial exploration of work" and the "discovery process" phases of PD have been carried out during the phases 1, 2 and 3. In other words the "initial exploration of work" consists in a participatory analysis of the system and the "discovery process" comprehends a participatory identification of problems and selection of most important ones. Indeed, the second phase of PD methodology is more complex of a simple selection of problems and comprehends also the selection of suitable design criteria and work organisation.

Part of the design activity (mainly the first outline) was carried out together with the local community, then a technical refinement followed. The framework used for the analysis is represented in Figure 3.4.

Figure 3.4 - Methodology



As PRA should be developed with a maximum flexibility, the selection of most appropriate tools was realized on the field and changed during the PRA itself.

3.3.1 Field activity organisation

The field activity took place from the 25th of April 2014 to the 13th of June 2014. Initially some formal meetings were held with the representatives of Alamata Woreda (Water resources bureau, Administrative bureau, Agricultural bureau) and with the representatives in Harele Tabia for general information and formal authorizations. The PRA activity was undertaken during the following period until a formal meeting, to which most of the farmers have been invited, which was organized for sharing and discussing the results of the analysis of the system, ranking emerged problems and setting the ground for a design process.

3.3.2 Selection of the study area

The irrigated areas around Harosha river extend over the flat area portion of the river basin. According to the first visits and interview, the irrigated area under the control of the farmers of Harele Tabia is represented by the command area of four big diversions upstream the bridge of the road from Alamata to Addiss Abeba, situated on the left bank, and of 9 small diversions downstream the bridge, 6 on the left side and 3 on the right side.

For the methodology proposed, the command area of the 4 big upstream diversions was chosen. The selection allowed the interaction with a good cluster of farmers working on the same area, representing a sub-area of Harele irrigated areas representative of the dynamics, constraints and opportunities of the whole. The reduction of the study area was also decided for having a better and more focused analysis in line with the time availability and the size of the research team, formed by two people (the author and an interpreter who also worked as co-researcher and facilitator).

3.3.3 PRA Techniques

This section will discuss in details PRA techniques used during the field activity. For each technique, a description, its practical application and its objective will be presented.

The techniques are organised according with the classification presented by Tesfai and de Graaff (2000): techniques focusing on spatial aspects of spate irrigation system, techniques focusing on temporal aspects of spate irrigation system and techniques focusing on socio-economical aspects of spate irrigation system. Another category has been added in order to capture the characteristics of the last technique used: “techniques focusing on spatio-temporal aspects”.

3.3.3.1 Techniques focusing on spatial aspects

- *Participatory Map:* The map of the system was developed with a group of 4 farmers, from the highest point from which the spate irrigation system was visible, namely the bridge downstream the system. Farmers were asked to draw a map together with the researcher, focusing on the position of the diversions, protection structures, villages and civil infrastructures (bridges, streets). After drawing, the map was used for associating each diversion with the command area and the number of farmers served. The map was then used for planning part of the field activity and as a reference for other techniques. The map was often checked and modified during other activities, but no substantial changes were made.
- *Field walks:* The objective of field walks was to gain information about the system while walking and moving in different parts of it. Some field walks were performed during the PRA activity, mainly focusing on the canal system and the agrarian system. Field walks were organized together with farmers, sometimes planning them the day or two days before and other times starting walking and continuing with the farmers present on the field side. The two objectives of field walks were: (a) to gain more detailed spatial information about the system, (b) to organize and develop discussions about traditional techniques and structures for water management and irrigation water distribution. The activity involved different groups of farmers varying the number of components. (Figure 3.5)

Figure 3.5 - Field walk for the analysis of irrigation structures and water distribution realised on 1/5/2014

- *Transects*: The exercise of *Transects* was performed during one field walk: the objective was to follow a predetermined path analysing the spatial differences along it. The path followed was inside a dry canal, from the abstraction point until the delivery structures, in order to gain knowledge about the distribution channel network. The activity was carried out in groups of 3 farmers.
- *Structures analysis:* The activity was structured as an interview/questionnaire about the characteristics of a sample structure in the irrigation system. The interview was taken during a field visit together with a group of three farmers, including two irrigation representatives.
- *Design discussion:* At the end of the field activity, in order to define with the community some useful design criteria and to set the ground for the design phase, a structured discussion about some technical issues on the diversion was undertaken. In a plenary meeting with the community some technical issues emerged during the PRA activity were presented and discussed. Big blank papers and markers were used to share ideas and possible design schemes. It was noticed that mainly expert farmers spoke during the meeting. The issues discussed will be presented in the findings section.

3.3.3.2 Techniques focusing on temporal aspects

- *Trend lines:* To understand the temporal variability of the hydrologic events and their effects, including, crop production, farmers were asked to indicate: (1) the intensity of rainfall, (2) the number of days of flood, (3) water availability in the river, (4) water availability for the farmers, (5) damage to diversions, (6) erosion. Except (2), the other characteristics were evaluated on a scale ranging from 1 to 5, in order to have a simple way of understanding. The exercise was carried out for the command area of each diversion structure (group of 3 – 4 farmers). Farmers were asked to recollect the information for a period comprised between last 5 and 10 years, according to how long they could remind the information above.

- *Seasonal calendar:* The objective of the activity was to identify the time in the year in which farmers perform a certain activity/duty. In a meeting with 3 farmers it was asked which the main activities were for each month, and the results were sketched and discussed on a paper block.
- *Semi Structured Interviews SSIs about hydrology:* (SSIs) are a technique for investigation developed in Social Sciences. They differ from a regular interview as they have an open approach: the interview is not structured in a series of questions, but it is more similar to an open discussion in which only a few points should be taken. The key point of an SSI is the freedom to approach each selected theme from the interviewee‟s perspective without constraints and to move to, start or end with different topics from the ones selected. This freedom aims to gain new and sometimes unexpected insights. The objective to direct SSIs on hydrological information was to have a preliminary set of information about the hydrological phenomena in the wadi and to assess the level of knowledge of the farmers in order to calibrate a really effective participative hydrological analysis. The points selected were:
    - What is the flow regime in the rainy season? (water every day, which portion of the river, flow channels etc.)
    - Could you remind how many floods have been last year/two years ago?
    - Which was the water level of the major flood in the last five years?
    - When there is a crop failure, is the situation the same for every farmer?
    - Which is the main reason for a crop failure? (water scarcity, diversion break, flooding)
- *Hydrological information collection:* This activity had the purpose of evaluating water levels in the river bed, in order to perform a hydraulic calculation of river discharges with the slope-area method and to have information about the flow hydrographs. A group of three farmers, selected from the most experienced in the irrigation management, was gathered and the incoming activities were explained. The gauging site was selected according to the farmers‟ preference (the most suitable for their analysis). The following levels were identified:
    - Maximum flood within living memory
    - Mean level of the yearly maximum flood within living memory

  After that, farmers were asked to provide their own classification of the floods which can occur in the year, by defining the level of “high”, ”medium” or “low” level flood according to their knowledge of the river system. After that, farmers defined the number of occurrences of each of the above mentioned flood levels for a dry, normal and wet year. At last, for each of these categories, the total hydrograph time and the time to peak level for the flood event were identified.

3.3.3.3 Techniques focusing on socio-economical aspects

- *Interviews:* Regular structured interviews were realized for specific purposes and involving main representatives for the irrigation system. The list of interviews carried out during the field work is reported in Table 3.2.

Table 3.2 - Structured interviews during field activity

Date	Name	Purpose	Questions/Topics
30/4	Adane (vice mayor of Harele Tabia)	Introduction and presentation	1. How Harele and Harosha SIS are linked 2. How many farmers of Harele are involved in irrigation 3. Who is responsible for irrigation management 4. How and when it is possible to meet and work with farmers
4/6	Frehiwot (officer for Natural Resources Management) and Abrehet (responsible for diversions building from the agricultural bureau)	Institutional agreements with the community and with the local government	1. Intervention for building flood protection structures on the right bank of the river and involvement of farmers 2. Modernization of the system and institutional agreements for construction of improved diversion structures and involvement of farmers 3. Election of Abo Mais – irrigation representatives 4. Data about the command area of each diversion for the study area
11/6	Abo Mais (irrigation representatives) for diversion 1, 3, 3	Irrigation management, cross checking and integration of information gathered with other PRA activities	1. How the water delivery system is organised and which are the main rules 2. How a farmer is entitled to water right 3. How the size of the structure is decided (if relative only to the farmer having water right or to all) 4. Physical characteristics of the system

- *Semi Structured Interviews (SSIs):* A series of SSIs was carried out with the following checklist:
  - History of the system
  - Problems in the system
  - Management structures (WUAs, representatives, rules and regulation)
  - Off-farm activities (what, when, how much, income)

  The activity was carried out with single farmers and in group (2-3 people) as shown in Figure 3.6.

Figure 3.6 - Group session for Semi-Structured Interview realised on 8/5/2014

- *Resource availability diagram:* The goal of the activity was to understand which resources are available for the farmers in the spate irrigation scheme. A list of amenities was presented to a group of 4 farmers and each of them was classified as "available", "partially available" or "not available".
- *Ranking of problems:* The objective of the ranking activity was to identify the most prominent problems. The analysis of the system allowed making a list of all the problems identified together with the farmers. In a general meeting with the community the problems were presented and it was asked if there were other issues to discuss (Figure 3.7). As farmers agreed with the proposed list, a free discussion was undertaken in order to rank the problems. For each one a sheet with a drawing and the description of the problem was made (Figure 3.8) and, using sheets as a visual support the classification was organized on the ground (Figure 3.9). Drawings where inserted to work with both literate and illiterate farmers. The complete list of drawings is shown in Annex I. A pair wise ranking had been considered in case the farmers wouldn‟t have reached an agreement in the discussion, but they managed to present a univocal ranking.

Figure 3.7 - Picture of participatory meeting held on 5/6/2014 in the centre of Harele Tabia

Figure 3.8 – Problem sheets for representing the problems of the size of diversion structures

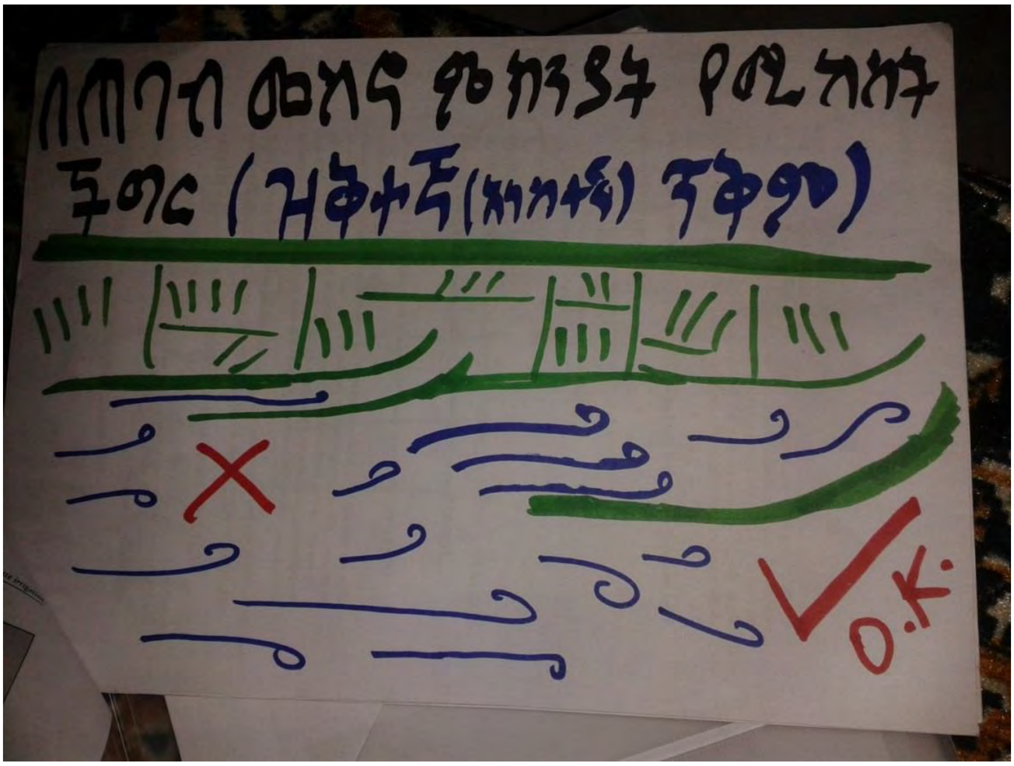


Figure 3.9 - Ranking of problems using problem sheets during the participatory meeting of 5/6/2014

3.3.3.4 Techniques focusing on spatio-temporal aspects

- *Crop production analysis:* The objective of the technique was to assess the inter-annual trend of crop production identifying the main reasons for low and high production, in relation with the position of the farmland analysed. During the ploughing period, some field walks were undertaken in the command area. Farmers working on the field were interviewed asking information about crop production, size of the field and the crop grown for a period ranging from 5 to 10 years until present. The exercise was done for the field in which the farmer was ploughing at the moment of the analysis, as each farmer can have more than one field in different places of the command area. For each interview a GPS point was taken in order to associate each trend to a zone of the command area. To each farmer, it was also asked about issues and possible development of the system. The activity was also very useful to gain more spatial information about the extension of the system and the presence of farmers from other Tabias around Harele.

3.3.3.5 Resume table

Table 3.3 shows the detailed list of PRA techniques used during field activity.

Table 3.3 - List of PRA activities undertaken during the fieldwork

Focus	Name	Purpose
Spatial Aspects	*Participatory map*	To define position of the diversions, protection structures, villages and civil infrastructures (bridges, streets); to have information about command areas and farmers served.
	Field walks	To obtain spatial information about the system. To organize and develop discussion about traditional techniques and structures.
	Transects	Along a canal, to collect information about the distribution network.
	Structures analysis	To analyse the characteristics of a sample structure in the irrigation system
	Design discussion	To define with the community some useful design criteria and to set the ground for the design phase
Temporal Aspects	*Trend lines*	To understand the temporal variability of the hydrologic events and their effects, including, crop production.
	Seasonal calendar	To identify the time in the year in which farmers perform a certain activity/duty.
	SSIs about hydrology	To have a preliminary set of information about the hydrological phenomena in the wadi and to assess the level of knowledge of the farmers in order to calibrate a really effective participative hydrological analysis.
	Hydrological information collection	To evaluate water levels in the river bed, and to have information about the flow hydrograph
Socio-economical Aspects	*Interviews*	Table 3.2 - Structured interviews during field activity (Table 3.2)
	SSIs	To have more information about: history of the system, problems in the system, management structure, off-farm activities
	Resource availability diagram	To understand which resources are available for the farmers in the spate irrigation scheme
	Ranking of problems	To identify the most prominent problems in the spate irrigation system
Spatio-temporal Aspects	*Crop production analysis*	To assess the inter annual trend of crop production identifying the main reasons for low and high production related to the position of the farmland analysed

4 Main findings and results discussion

4.1 System analysis

4.1.1 Secondary data analysis

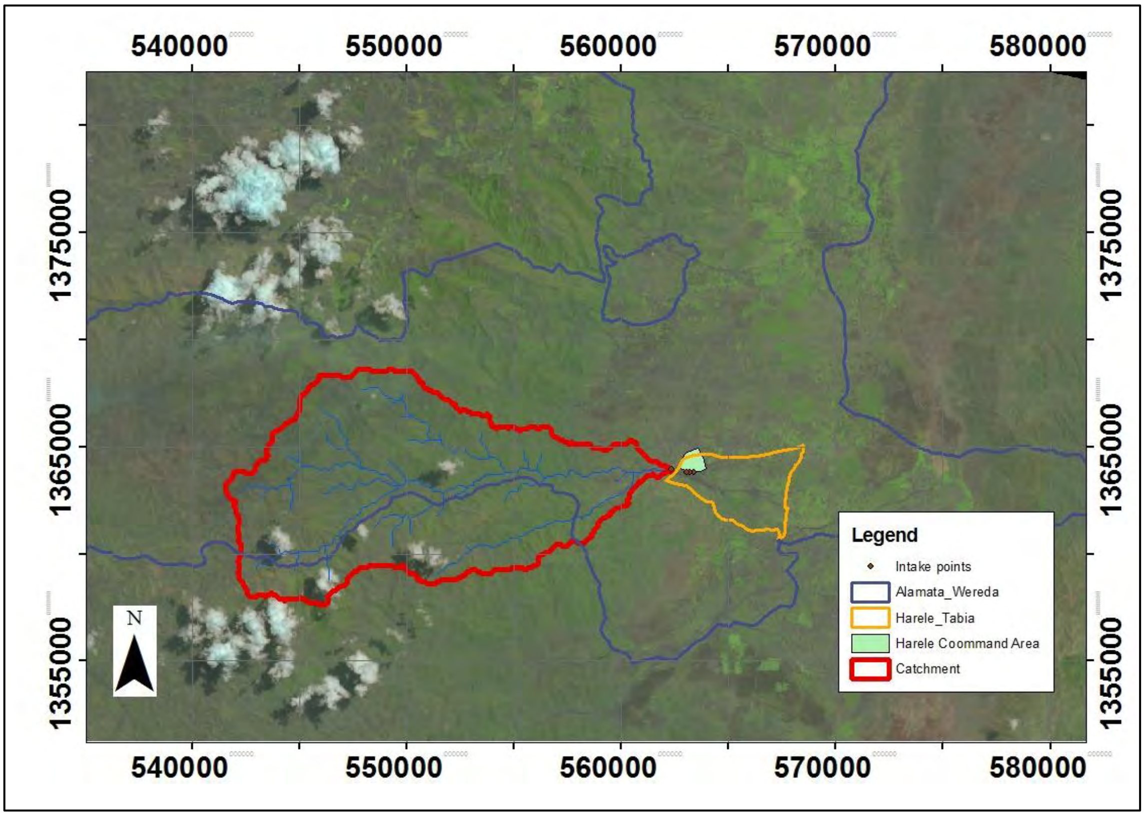
In this section, an analysis of available secondary data is carried out. The analysis will concentrate on Harosha river basin and its geographical features, in order to elaborate hydraulic and hydrological information for a comparison and integration with primary data.

4.1.1.1 Geographical features

Geographical analysis has been carried out starting from SRTM (Shuttle Radar Topography Mission) Digital Elevation Model (DEM). The terrain model has been elaborated using HEC GeoHMS spatial analysis tools. The DEM was resampled on a 90 m resolution grid.

Harosha river basin has an overall extension of 135.4 km^2. The northern part of the basin lies in the Alamata woreda, while the southern part is comprehended in Amhara Region, across the southern border of Tigray. The catchment area is located between coordinate 540000 m and 560000 m E, and 1355000 m and 1370000 m N in UTM WGS84 Projected coordinates system. Figure 4.1 shows the extension of the catchment delineated using HEC GeoHMS software.

Figure 4.1 - Harosha river catchment



Like other wadis in Raya valley, Harosha river ends in its distributary system: when the water arrives in the flat part of the basin, it splits in various channels and it flows until it infiltrates in the soil. The first intake of the spate irrigation scheme is located before the beginning of the distributary system, namely the first division of the wadi bed.

The closure section of the basin was selected before the beginning of the distributary system, as shown in Figure 4.2.

Figure 4.2 - Position of the catchment closure section (white), with the position of intakes (red) and command area (yellow) - Google Earth

The altitude of the basin ranges from a minimum of 1523 m.a.s.l. to 3051 m.a.s.l.. The mean altitude is 2120 m.a.s.l.. The drainage network is obtained from flow accumulation grid selecting the cells relative to an upstream catchment of 129 cells, equal to 1.05 km^2. This threshold has been selected from a comparison with Google Earth imagery, checking the initial points of the effective drainage network. Figure 4.3 shows the altimetry of the basin; the detailed information about stream length is represented in Figure 4.4.

The main soil unit is composed by leptosols (FAO World Reference Base for Soil Resources). The soil map of the basin is shown in Figure 4.5.

Figure 4.3 - Harosha river basin - Elevation and drainage network

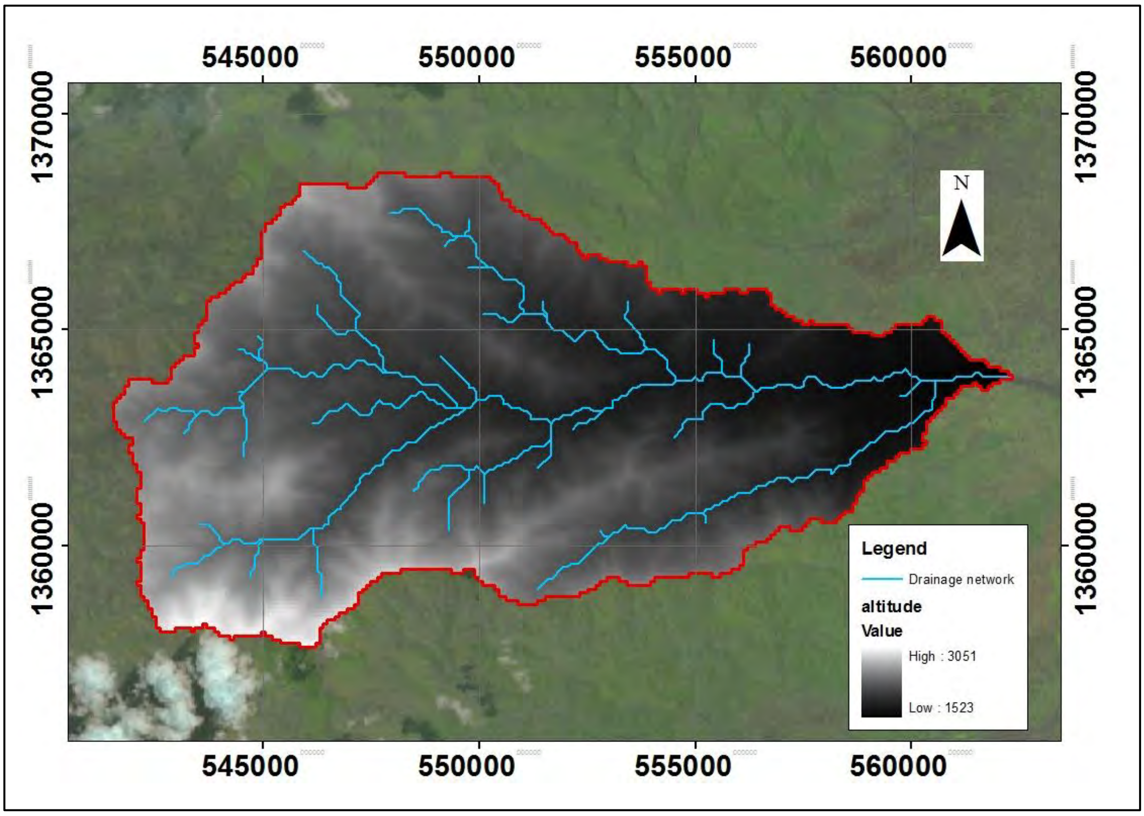


Figure 4.4 - RIver network statistics calculated with ARCGIS - Stream Length (m)

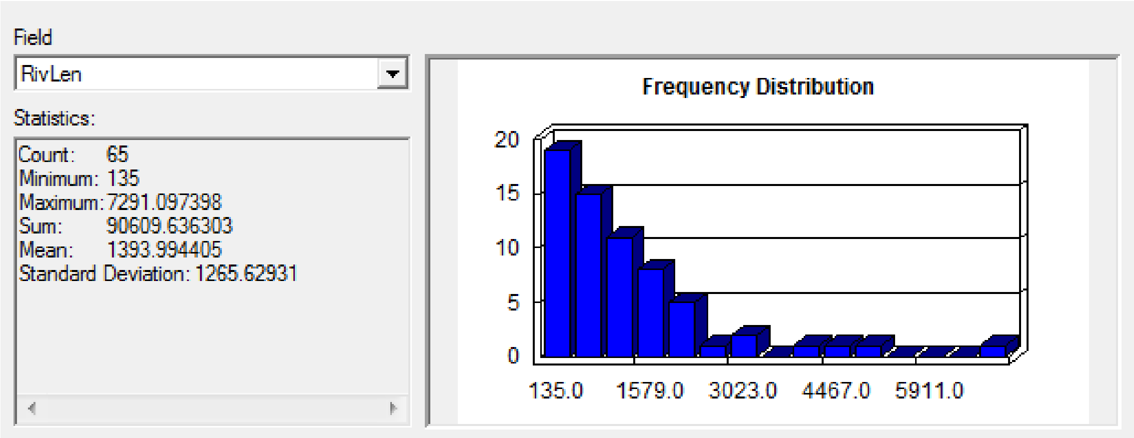
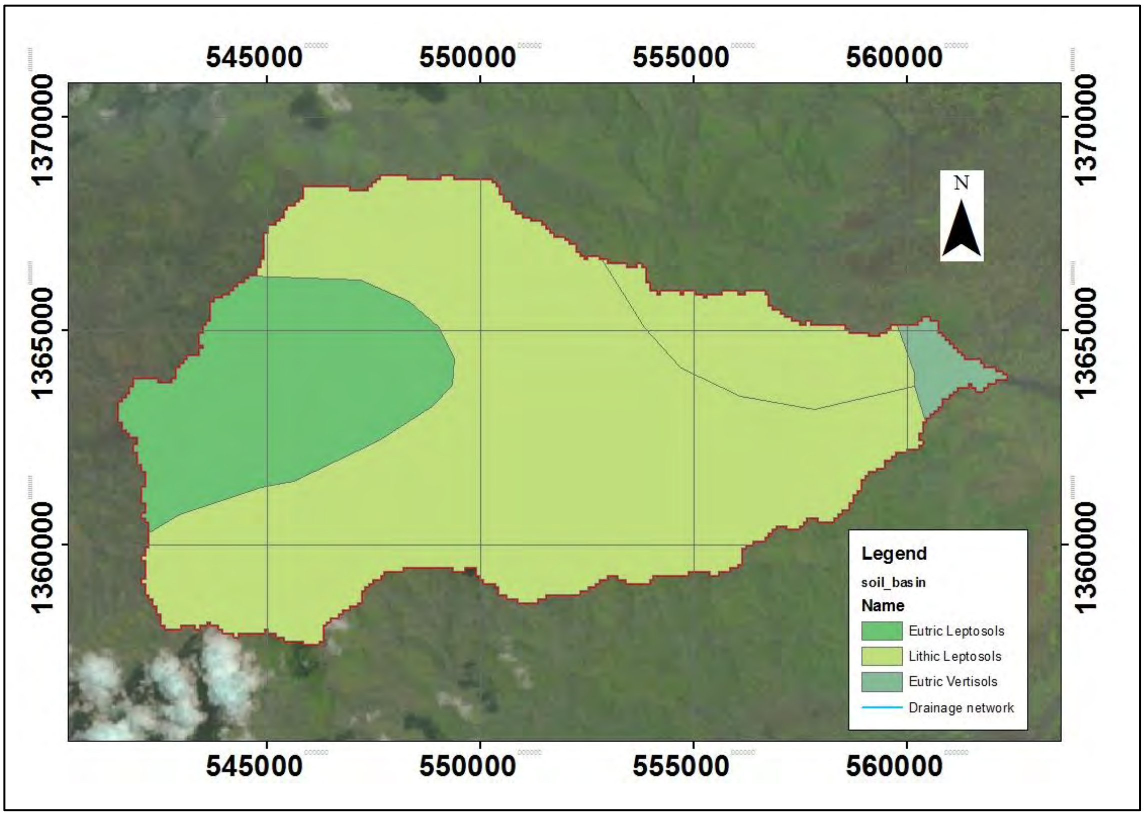


Figure 4.5 - Harosha river basin - Soil map



[*Source*: Mekele University Data]

4.1.1.2 Climatic data

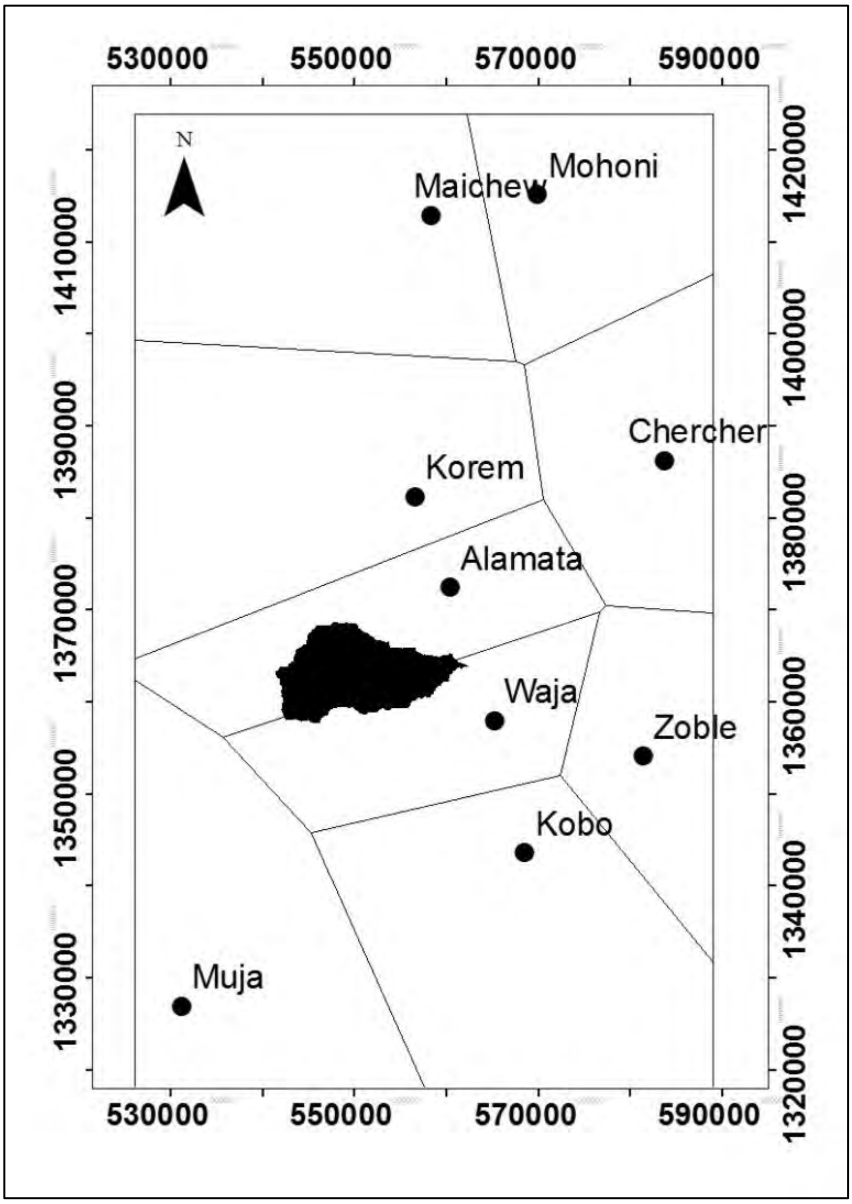
Climatic data are obtained from the raingauges network around the study area. Those data are available at the Tigray Meteorological Office, in Mekelle.

The analysis of Thiessen polygon (Figure 4.6) shows how the basin climatology can be analysed using Waja and Alamata Rainfall stations. Table 4.1 shows the characteristics of meteorological stations used for the analysis.

Table 4.1 – Meteorological stations data

Station Name	**Northing UTM-WGS84 (m)**	**Easting UTM-WGS84 (m)**	**Altitude (m)**	**Catchment overlapping area (m^2)**	**Fraction of catchment area (%)**
Alamata	560502	1372456	1547	96282085	0.71
Waja	565315	1357995	1446	39166115	0.29

Figure 4.6 – Meteorological stations network and Thiessen polygons



Rainfall and temperatures for Alamata station are shown in Table 4.2 and Table 4.4. The data relative to Waja station are reported in Table 4.3 and Table 4.5.

Table 4.2 - Rainfall data (mm) for the period 1996 -2012 - Alamata station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1996	133	0	69	123	115	25	77	250	36	8	58	0	895
1997	46	0	125	27	29	22	87	54	72	192	139	0	792
1998	179	23	26	35	20	0	348	272	64	18	0	0	984
1999	44	0	21	9	7	1	211	432	67	55	0	0	847
2000	0	0	10	44	74	0	246	450	68	15	83	73	1063
2001	0	0	158	13	30	17	225	244	25	10	10	3	733
2002	98	0	18	112	8	4	73	214	46	14	0	90	675
2003	76	70	42	94	25	13	112	234	23	0	0	67	754
2004	33	16	40	168	14	50	117	243	41	8	21	20	770
2005	21	1	110	132	66	24	142	167	33	6	0	0	702
2006	0	0	216	176	5	0	123	192	54	2	0	24	791
2007	12	46	8	109	10	10	165	215	51	0	8	0	633
2008	22	3	0	7	21	11	84	212	61	53	55	0	528
2009	0	0	11	89	0	0	93	68	0	0	0	38	299
2010	0	41	170	29	57	29	230	321	18	26	0	0	920
2011	17	0	73	36	49	0	138	127	0	0	98	0	537
2012	0	0	52	191	0	0	174	236	12	12	0	0	675
AVERAGE	40	12	68	82	31	12	156	231	39	25	28	19	741
STD.DEV	51	20	63	60	31	14	73	101	23	45	42	29	178

Table 4.3 - Rainfall data (mm) for the period 1996 - 2012 - Waja station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1996	20	0	83	121	166	26	94	195	54	15	48	5	827
1997	10	0	90	20	27	4	60	55	7	230	79	0	581
1998	76	31	47	27	38	0	311	345	92	8	0	0	975
1999	41	0	71	36	4	40	92	324	47	0	1	43	699
2000	74	0	0	56	19	7	154	259	7	37	30	8	651
2001	0	0	60	20	26	23	150	197	37	10	0	0	523
2002	63	0	22	64	0	7	65	158	55	0	0	82	516
2003	0	61	42	93	0	8	113	329	51	0	1	43	741
2004	32	44	31	88	6	22	50	113	25	4	43	8	465
2005	0	8	17	134	88	7	148	169	21	1	0	0	593
2006	0	0	74	131	28	23	73	182	74	32	8	9	634
2007	21	18	27	96	0	8	223	277	56	7	4	0	736
2008	13	0	0	4	35	7	125	164	100	7	59	0	513
2009	23	13	30	57	4	0	143	79	25	35	22	32	460
2010	0	10	25	132	66	0	255	386	55	4	11	7	951
2011	3	0	73	39	111	4	207	163	32	11	26	0	670
2012	0	0	35	141	39	48	235	276	21	17	0	19	831
AVERAGE	22	11	43	74	39	14	147	216	45	25	19	15	669
STD.DEV	26	18	27	45	44	14	74	93	26	53	24	22	154

Table 4.4 - Monthly mean maximum and minimum temperature for the period 1996-2005 – Alamata station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax (°C)	27.1	29.4	30.3	31.5	33.5	34.3	32.1	30.3	30.5	30	28.9	27.6
Tmin (°C)	11	11.8	13.8	15.5	16.9	17.6	17	15.4	14.4	13	11.6	10.6

[*Source*: adopted from Hagos (2010)]

Table 4.5 - Monthly mean maximum and minimum temperature for the period 1996-2005 – Waja station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax (°C)	27.3	29	29.3	30.5	32.3	34.3	32.2	30.4	31.3	29.8	28.7	28.4
Tmin (°C)	12.8	11.2	13.8	14.8	15.3	17	17.8	17.3	15.7	13.1	12.2	9

[*Source*: adopted from Hagos (2010)]

Other relevant climatic data were retrieved from Kobo station, located at 568641 m N, 1343604 m E, at an altitude of 1524 m.a.s.l. (Table 4.6).

Table 4.6 - Monthly mean values for some climatic data for the period 1996 - 2005 – Kobo station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Relative Humidity at 6:00 (%)	86.8	77.5	76.2	74.7	70.4	53.9	70.6	83.5	87.5	80.3	75	80.6
Relative Humidity at 12:00 (%)	53.9	43	37.7	42.3	39.1	29.2	39.9	48.2	45.5	35.8	35.7	44.6
Relative Humidity at 18:00 (%)	57.6	42.5	40.6	42.5	39.1	30	45.8	53.6	52.6	41.8	38.1	46.2
Sunshine hours (h)	7.8	7.4	8.4	8.2	8.6	6.6	5.3	6	6.7	8.5	9.3	8.5
Wind speed at 2m (m/s)	1.8	1.9	2	1.9	1.7	2	1.9	1.6	1	1	1.1	1.2
Reference evapotranspiration calculated with Penman-Monteith ET0 (mm/d)	2.9	3.7	3.8	4.3	4.6	5	4.1	3.8	3.8	3.5	3.2	2.9

[*Source*: adopted from Hagos (2010)]

4.1.1.3 Hydrological characteristics

Mean annual flood peak discharge

Mean annual flood peak discharge (MAF) is estimated with the methodologies proposed by (van Steenbergen et al., 2010). The empirical formulas used for the calculation are in Table 4.7. Results are shown in Table 4.8.

Table 4.7 - Method for Mean annual flood peak discharge estimation

Method	Empirical equation for MAF (m^3/s)	Note
Binnie	$MAF = 3.27 \cdot A^{1.163} \cdot MSL^{-0.935}$	Regional flood formula developed for wadis in Southern Yemen
Nouh	$MAF = 0.322 \cdot A^{0.56} \cdot ELEV^{0.44}$	Developed from regressions on data from 26 gauging stations
Farquharson et al.	$MAF = 0.172 \cdot A^{0.57} \cdot MAP^{0.42}$	Developed from 3 637 station years of data collected from arid zones worldwide.
Bullock	$MAF = 0.114 \cdot A^{0.52} \cdot MAP^{0.537}$	Developed using data from 43 semi-arid catchments in Botswana, Zimbabwe, South Africa and Namibia

[*Source*: adopted from (van Steenbergen et al., 2010)]

With:

- MAF = mean annual flood peak discharge [m^3/s]
- A = catchment area [km^2]
- ELEV= mean catchment elevation [m]
- MSL = main stream length [km]
- MAP = mean annual precipitation [mm]

Table 4.8 - MAF calculation results - m^3/s

Method			MAF (m^3/s)
Binnie	A	135.4	722.63
	MSL	1.394	
Nouh	A	135.4	146.29
	ELEV	2119.64	
Farquharson et al.	A	135.4	44.75
	MAP*	720	
Bullock	A	135.4	50.10
	MAP*	720	

* Thiessen polygons method

In relation with the empirical nature of the equations used for MAF calculation, it was noticed that:

- MAF obtained with Farquharson et al. and Bullock formulas can be underestimated as a result of an underestimation of MAP. This effect derives from the low elevation of the two gauging stations of Alamata and Waja in comparison with the catchment elevation, while most of the runoff of an ephemeral catchment in arid areas is produced in the upstream part of the basin (van Steenbergen et al., 2010).
- Binnie formula can overestimate MAF. This effect is related to the geomorphology of the catchment, which presents well defined streams even in the most upstream zones. Due to this effect, MSL results very short and leads to an increase of MAF. In addition to this, the formula is derived only for wadi catchments in a particular country (Yemen).
- Nouh formula could avoid the problems described as it does not depend of a possibly underestimated MAP value and due to the fact that it depends on the elevation of the basin, which represents a particular feature for Ethiopian basin located on the highland plateau.

According to the consideration presented above, Nouh formula is used for the following analysis.

Flow return periods

Peak discharges for different return periods are evaluated according to FAO guidelines (van Steenbergen et al., 2010). For each return period t the discharge (Q_t) is calculated as:

$$Q_t = MAF \cdot G_t$$ where G_t is a growth factor correspondent to t.

The analysis is calculated starting from Nouh‟s MAF, results are presented in Table 4.9.

Table 4.9 - Discharge for return period

Flood return period (y)	**Growth factor**	**Q_t (m^3/s)**	**Flood return period (y)**	**Growth factor**	**Q_t (m^3/s)**
5	1.3	190.2	30	3.7	541.3
6	1.5	219.4	32	3.8	555.9
7	1.7	248.7	34	3.9	570.5
8	1.8	263.3	36	4	585.1
9	1.9	277.9	38	4.1	599.8
10	2.1	307.2	40	4.2	614.4
12	2.3	336.5	42	4.3	629.0
14	2.5	365.7	44	4.4	643.7
16	2.7	395.0	46	4.5	658.3
18	2.8	409.6	48	4.6	672.9
20	3	438.9	50	4.7	687.5
22	3.1	453.5	100	6.5	950.9
24	3.3	482.7	150	7.8	1141.0
26	3.4	497.4	200	8.9	1301.9
28	3.5	512.0			

4.1.2 Spatial aspects

4.1.2.1 Overview and description of the system

The participatory maps realized with the community identified the main structures in the system, with a focus on the wadi area, and allowed to know an approximated size of the command areas for each diversion considered, including the number of single parcels present. The sketch realised with the farmers are shown in Figure 4.7 and Figure 4.8.

Figure 4.7 - Participatory map 1 sketched on field notes, realized on 30/4/2014

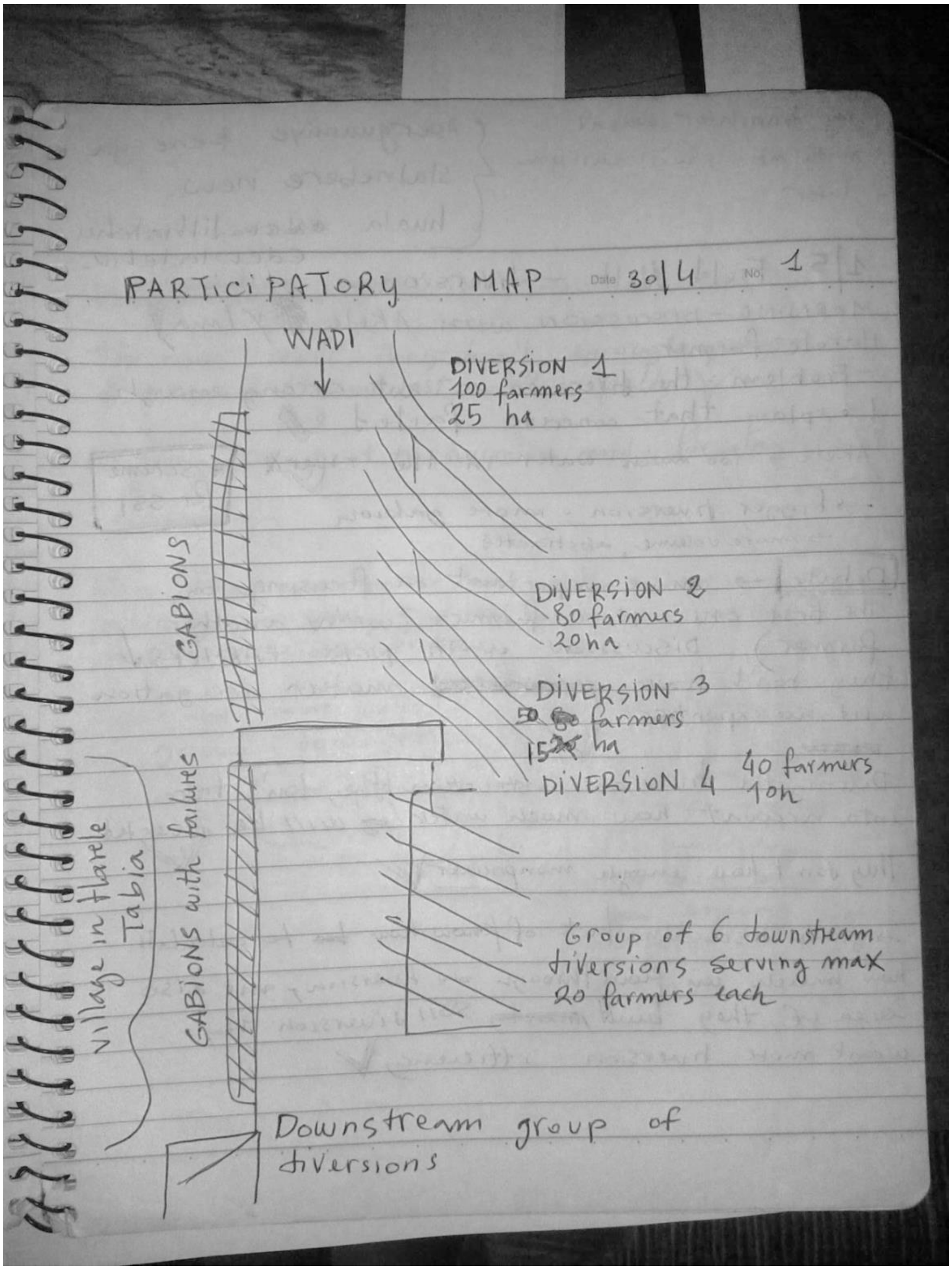
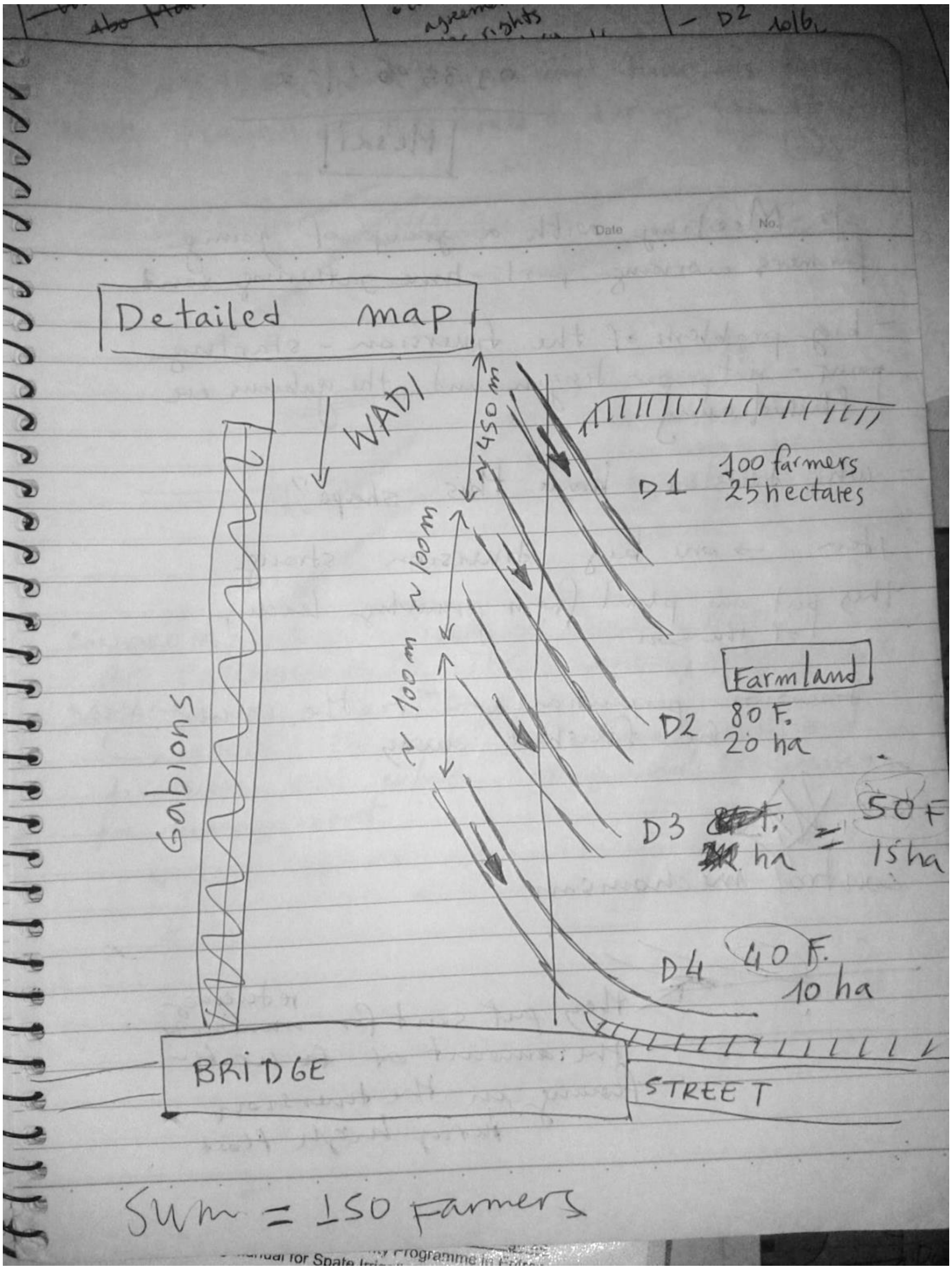


Figure 4.8 - Participatory map 2 (detail) sketched on field notes, realized on 30/4/2014



Diversions were named from 1 (most upstream) to 4 (most downstream, immediately upstream of the bridge).

Protection structures have been built on the right side of the river, upstream and downstream of the bridge, which divides the scheme in two parts. The villages of Harele Tabia are situated in the right side of the river.

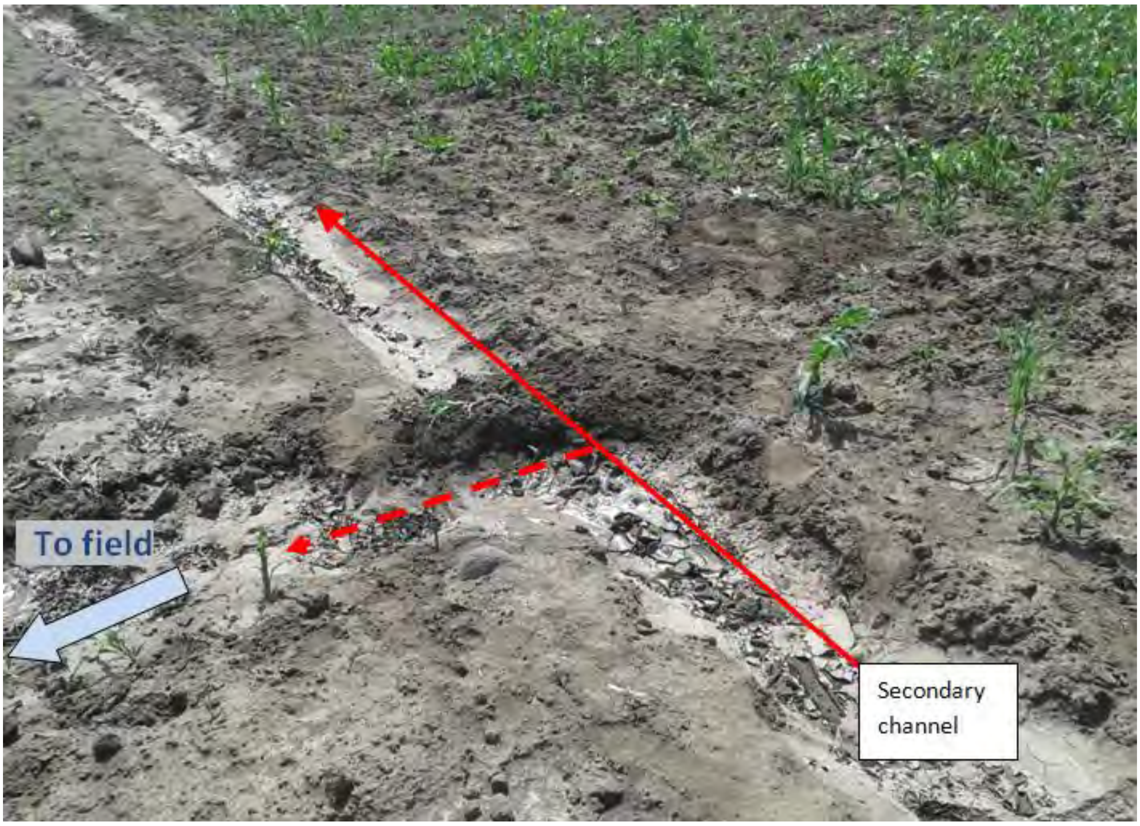
According to the information given by farmers a total area of 70 ha is under control of the selected diversions.

Each farmer owns more than one parcel and those may be in different command areas. The total number of farmers working, namely households owning land, in the selected study area was reported to be around 150.

During field walks and visits for the crop failure analysis farmers helped to clarify that also people from the northern Lemaat Tabia are cropping in the command area, since it extends also in other Tabias.

The structure of the canal system was analysed through transect walks, field walks and interviews with Abo Mais. The irrigation scheme comprehends diversion, primary, secondary and field canals. The water distribution is managed with micro-bunds in the canals, diverting water in each secondary or field canal. Figure 4.9 shows a micro diversion used in the distribution network.

Figure 4.9 - Micro-diversion for field water distribution



Interviews also highlighted other characteristics of the system like the number of secondary canals. Table 4.10 shows the characteristics of command area obtained with the interviews.

Table 4.10 - Main characteristics of the command area

Diversion	Number of parcels	Command area (ha)	Number of secondary canals
1	100	25	20
2	80	20	15
3	50	15	10
4	40	10	10

Each secondary canal pours into other field canals, ranging from 1 to 10 according to the cases, with an average of 2 – 3. The average field size is around 50 m x 75 m.

During the activities it also emerged that farmers are working for expanding the system, in particular extending the main canal of diversion 2. Some farmers, far from the river bed, are cropping with no water input from the diversions.

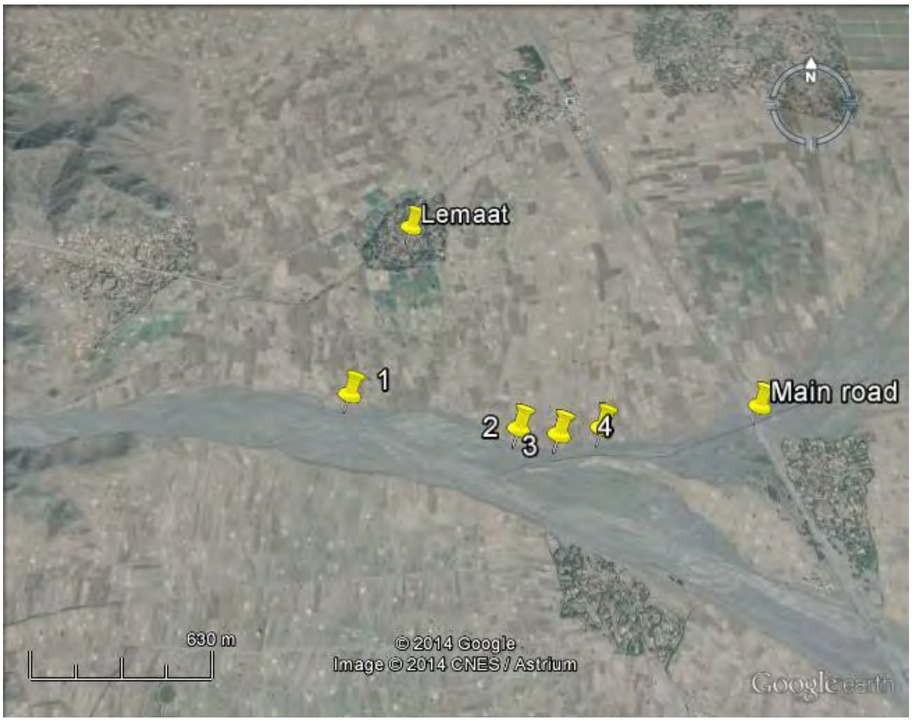
4.1.2.2 Hydraulic structures and water management

Hydraulic structures in the system were object of more detailed analysis.

Field visit and group discussions helped to identify the shape of diversions and how they work, highlighting particular design choices and features, and related problems.

Four diversions were analysed for the selected study area, from upstream to downstream Diversion 1, 2, 3 and 4 (D1, D2, D3 and D4). The position of diversion structures has been localised on Google Earth based on GPS surveying (Figure 4.10)

Figure 4.10 - Position of diversion - Google Earth



Diversion works can be identified as "spur-type deflector" as they are realized with a diversion channel which is built on a side of the river bed: a lateral bund, parallel to the river channel, works as discharge separator. The channel is built by excavating the lateral bank of the river and using landfill for the lateral bund, which is reinforced with stones, brushwood and, when allowed by resource availability, gabions. A diversion bund built with sand and brushwood is shown in Figure 4.11.

A typical problem reported for diversions is that they usually break down during high floods and they need daily maintenance activity during rainy season, due to the fact that construction materials are not strong enough to face violent floods flowing in the wadi.

Figure 4.11 - Particular of diversion bund – Diversion 2

During the field visit it emerged that the diversion canal has upward slope. Farmers, interviewed during the last group meeting explained that this is used for having a major sedimentation in the first part of the canal, which is cleaned by farmers during and after high floods. This feature reduces diversion efficiency and farmer explained that, due to the fact that it works well for managing sedimentation, a better design for balancing these two effects should be considered.

Field measurements were taken for D4, where the slope of the canal ranges from 0.9% in the upstream part and 0.15% in the downstream part. The width of diversion canal is around 2.7 m.

The upward slope ends when the level of the canal arrives at the level of the field distribution system, situated around 2.50 m over the river bed.

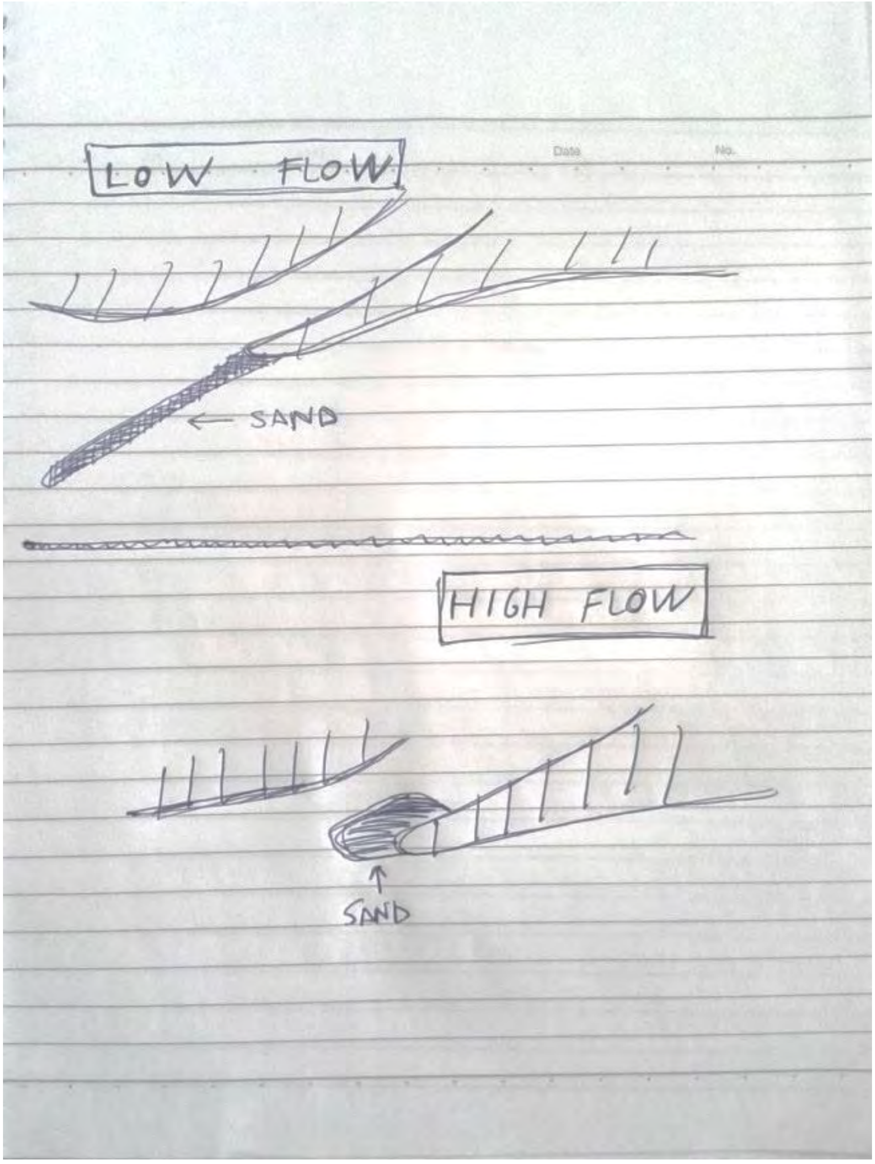
The use of gabions has been sponsored by the government after a big flood in 2010. At the time of the visit gabions were installed only in D3 and D4. Farmers reported the structure reinforced with gabions to be more resistant than the others, even if only few gabions are installed. Moreover, gabions on the outer bund of D3 works as reinforcement also for D4 being actually a reinforcement for the inner bund of D4. Gabions installed on D4 are shown in Figure 4.12.

Figure 4.12 - Installation of gabions

During the discussions in group meetings some traditional techniques for water management at the intake level were discussed and sketched (Figure 4.13):

- During low flow periods farmers build an additional bund using terrain which starts from the permanent bund, extending in diagonal upstream direction, intercepting the low flow channels.
- During high flow periods farmers use to gather pile of sand and clay at the beginning of the channel, partially blocking the intake, allowing only a smaller part of the violent flood to access the irrigation system.
- Farmers also build small bunds parallel to the flow inside the river bed in order to divide the discharge and direct only a small part to the diversion. This seems to be used in the period of high flow to prevent damages to the diversions, but it has been reported only by few farmers.

Figure 4.13 - Sketch realized with farmers - sand bunds for flood water management



In addition to the PRA field analysis, a questionnaire-type activity was carried out in order to share farmers‟ knowledge and opinion about the structure. It has been carried out for D3. The outcome of the activity is reported.

1) WHEN WAS THE STRUCTURE BUILT? In January 2004, without gabions, which were installed after 2010.
2) WHAT WERE THE CRITERIA FOR THE CONSTRUCTION? The structure was built according to the suggestion of an expert of the Water Bureau and it is 2 m wide. Some farmers agreed to build it according to the measurements of the expert, some other would rather have used traditional methods without any sort of calculation. Usually structures are built using sand, leaves and when available gabions, using shovels and diggers. The sand and clay used for the building were dig from the channel of the diversion.
3) IS THE STRUCUTRE GOOD? Apart from the problem of the breakings, farmers believe that the structure is performing well
4) WHAT KIND OF MAINTENANCE DOES IT NEED? Usually the structure needs to be rebuilt with clay, plants and stones. The structure also needs everyday maintenance during floods (rainy season), including removing sediments deposited in the canal
5) HOW OFTEN DOES IT NEED MAINTENANCE? Apart from the day by day maintenance during rainy season, there are 3 main maintenances in January, February and June. Additional maintenance may be in March and July.
6) WHERE AND HOW DOES IT USUALLY BREAK DOWN? The first 100 meters (not including additional bunds for low flow) are in danger of breaking down. The main reason is related with the power of floods, due to the steep slopes and the volume of water.
7) WHEN THE STRUCTURE WORKS CORRECTLY DOES IT DIVERT ENOUGH WATER? Yes
8) IS THE DIVERSION OFTEN SILTED UP? Sedimentation is another big problem. When there is too much sediments, water may flow outside the deflection bund. Farmers cope with this effect doing day by day digging and removing sediments during floods
9) WHAT OTHER SMALL STRUCTURES ARE USED IN COMBINATION WITH THE DIVERSION? Additional bunds are used. At field level, water distribution is managed though micro diversions in canals. Farmers also practise holes in the fields for retaining more water.
10) HOW MUCH TIME IS NEEDED FOR BUILDING SUCH A DIVERSION? It takes 15 days for building the diversion, and 4 hours for the smaller additional structures.
11) HOW MUCH TIME IS NEEDED FOR THE MAINTENANCE OF SUCH A DIVERSION? If all the farmers participate, around 5 days.
12) WHAT IS THE AVERAGE WATER DEPTH IN THE DIVERSION? 515 mm +- 5mm
13) WHAT IS THE MAXIMUM WATER DEPTH IN THE DIVERSION? 810 mm +- 5mm
14) WHAT WATER LEVEL IN THE WADI DOES CORRESPOND TO STRUCTURE BREAK? Not known
15) HOW MANY FIELDS/PARCELS ARE SERVED BY THE DIVERSION? 80*
16) HOW MANY OWNERS OF FIELDS/PARCELS DO USUALLY ATTEND THE MAINTENANCE WORKS? Around 60*
17) WHERE WAS LOCATED AND HOW WAS THE PREVIUOS DIVERSION STRUCTURE? The previous diversion was downstream and was built without proper measurements, but with the same shape. The diversion was washed away by a violent flood. The new one is in a better place.

Questions marked with * are in contrast with the information, double-checked, given for the mapping activity. This is probably due to the fact that the farmers participating in the Structure analysis activity were not well informed about the size of the command area of D3. It could be assumed that around 75% of farmers participate in the maintenance activity.

From the questionnaire and from the interviews realized for understanding institutional agreements in place it emerged that the structure is built in cooperation with the water resources bureau. The diversion point is chosen according to the experience of farmers which usually chose the point where the bank is more stable, having a good knowledge of the erosive evolution of it.

4.1.2.3 Problems linked to the collapse of river bank

Structure analysis, field walks and crop production analysis produced information about the erosive tendency of the wadi bank.

During structure analysis farmers reported that in 2009 the government built a flood protection structure on the right bank of the wadi for protecting villages from being flooded (see Participatory Map). According to the farmer, the structure doesn"t allow the river to flood in the right bank and thus there is a higher volume of water flowing in the wadi and flooding the left bank, causing lateral erosion on the side of the fields and soil loss. The soil loss is reported to be 13 ha in 3 years. When the flood protection structure was built, farmers suggested moving it a little bit away from the river bed.

Farmers observed that the left bank is stable where there are gabions and they suggested providing gabions for reinforcing the bank in order to mitigate soil loss.

This information was confirmed by interviews taken during the Crop production analysis. According to the interviewed farmers, the size of their fields was reduced by erosion, mainly in the last 3 years.

4.1.3 Temporal aspects

4.1.3.1 Recent history of the system

The analysis of the history of the system mainly focused on the event related to the evolution of the structures related to the river system and the recent events. Information was collected comparing and integrating interviews and SSIs.

According to the community, spate irrigation has ever been practiced in Raya Valley and there is great experience about the technique. The construction of a protection wall for the right bank of the river was completed around 2009. Farmers reported an extreme flow event happened during the rainy season of 2010. In the occasion, all the existent diversion structures were washed away by the flow and the bridge of the main street was seriously damaged. At the peak of the flood the water completely submerged the bridge which was about to collapse. Starting from 2011, the local government implemented a program for improving the resistance of diversion structures, and the first gabions structures were built together with the experts of the bureau.

It was also reported that 2013 was the driest year of the last 10 years and this led to poor crop production for almost the total of the farmers.

4.1.3.2 Seasonal calendar of farming activities

The seasonal calendar (Figure 4.14) highlighted the main activity during the year. By the interviews carried out during the field activity it emerged that farmers carry out also off-farm activities, like growing cattle or working in the city centre, during the whole year. A typical operation is also buying and growing oxen for the ploughing and seeding period, then selling them afterwards.

Figure 4.14 - Seasonal calendar

Activity	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DIVERSION BUILDING	■					■						
PLOUGHING		■	■									
SEEDING (maize, sorghum)				■	■							
SEEDING (teff)						■						
MAINTENANCE WORKS ON DIVERSION							■	■	■			
REMOVING PARASITE PLANTS									■			
HARVESTING (teff, sorghum)										■		
HARVESTING (maize)											■	
YIELDING												■

4.1.3.3 Trend lines

Trend lines were realized with selected group of farmers for each diversion. The results are divided for each feature analysed, in order to have a better comparison of these ones. Results are shown from Figure 4.15 to Figure 4.19 and from Table 4.11 to Table 4.15.

Figure 4.15 - Trend lines - Water availability in the river

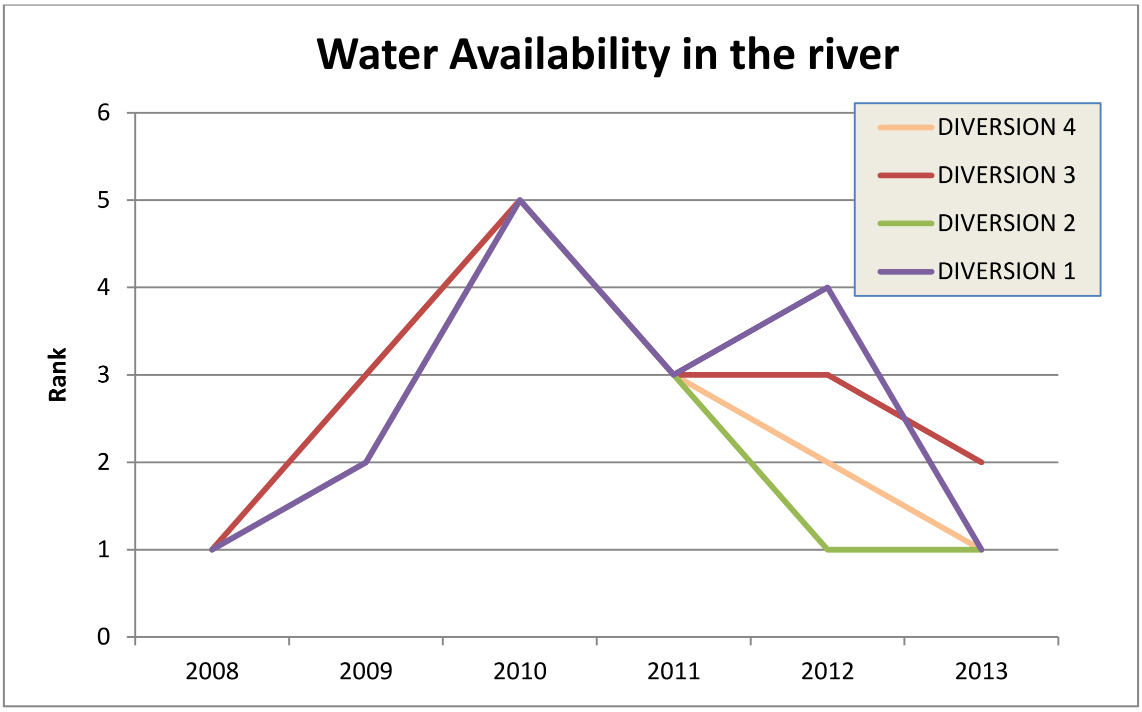


Table 4.11 - Trend lines - Water availability in the river

Water availability in the river (1-5)				
diversion	***4***	***3***	***2***	***1***
2008		1	1	1
2009	3	3	2	2
2010	5	5	5	5
2011	3	3	3	3
2012	2	3	1	4
2013	1	2	1	1

Figure 4.16 - Trend lines - Water availability for the farmers

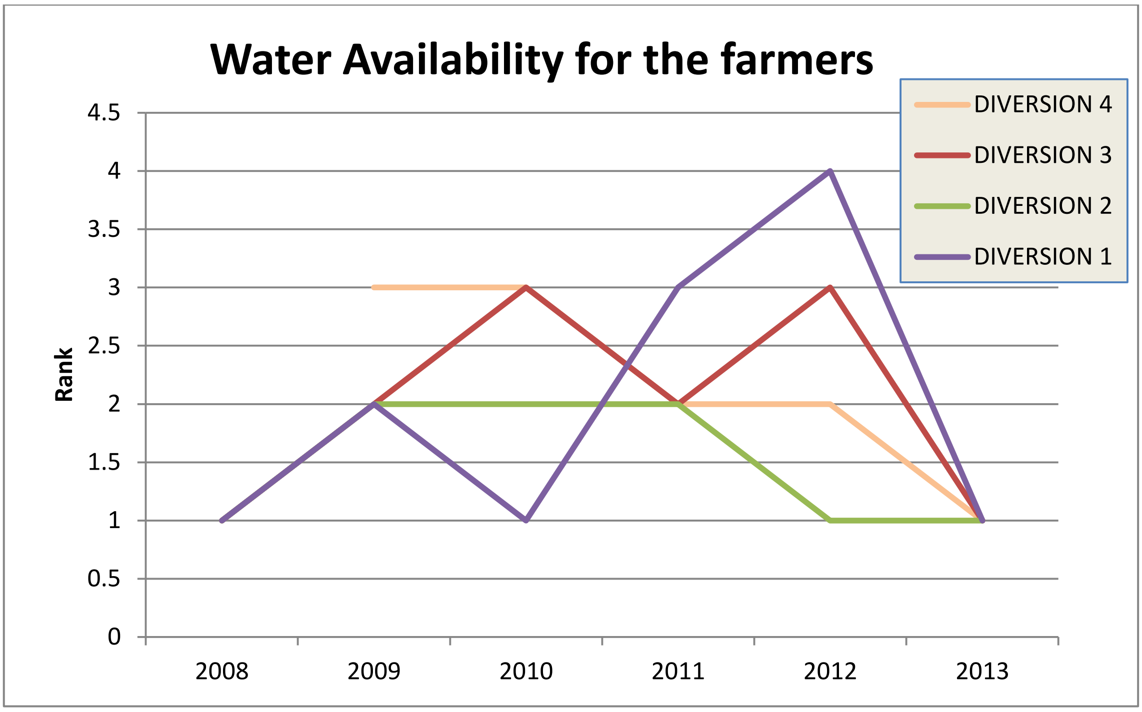


Table 4.12 - Trend lines - Water availability for the farmers

Water availability for the farmers (1-5)				
Diversion	***4***	***3***	***2***	***1***
2008		1	1	1
2009	3	2	2	2
2010	3	3	2	1
2011	2	2	2	3
2012	2	3	1	4
2013	1	1	1	1

Figure 4.17 - Trend lines - Damage to diversions

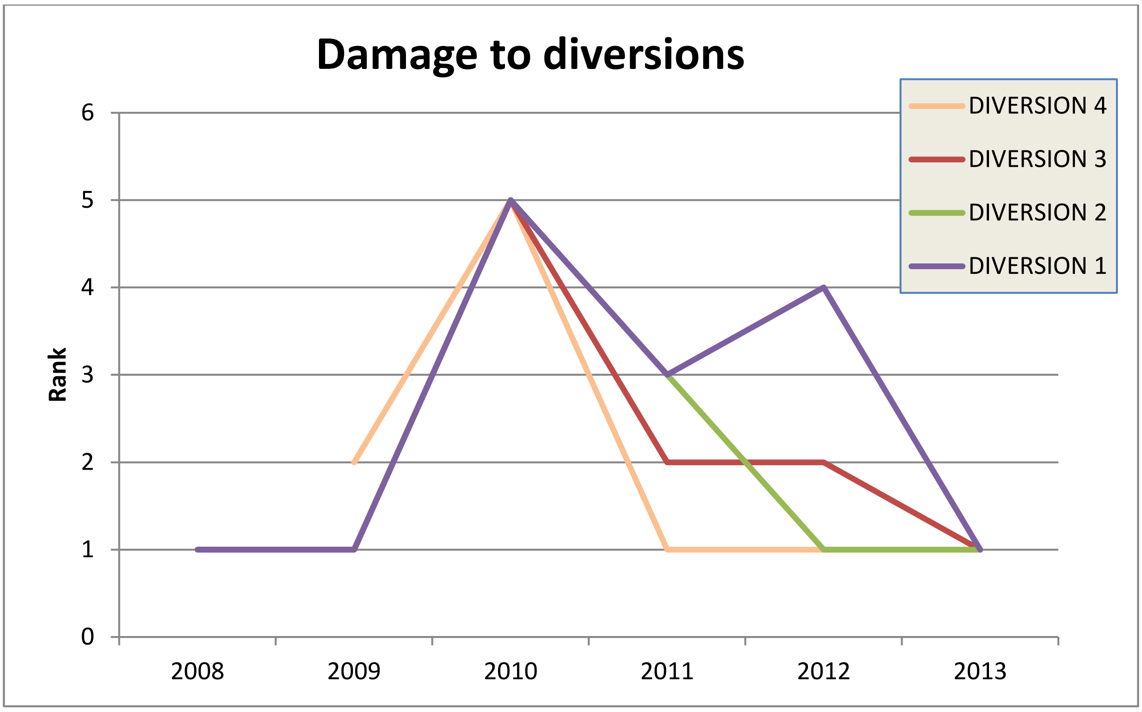


Table 4.13 - Trend lines - Damage to diversions

Damage to diversion (1-5)				
Diversion	***4***	***3***	***2***	***1***
2008		1	1	1
2009	2	1	1	1
2010	5	5	5	5
2011	1	2	3	3
2012	1	2	1	4
2013	1	1	1	1

Figure 4.18 - Trend lines - Bank erosion

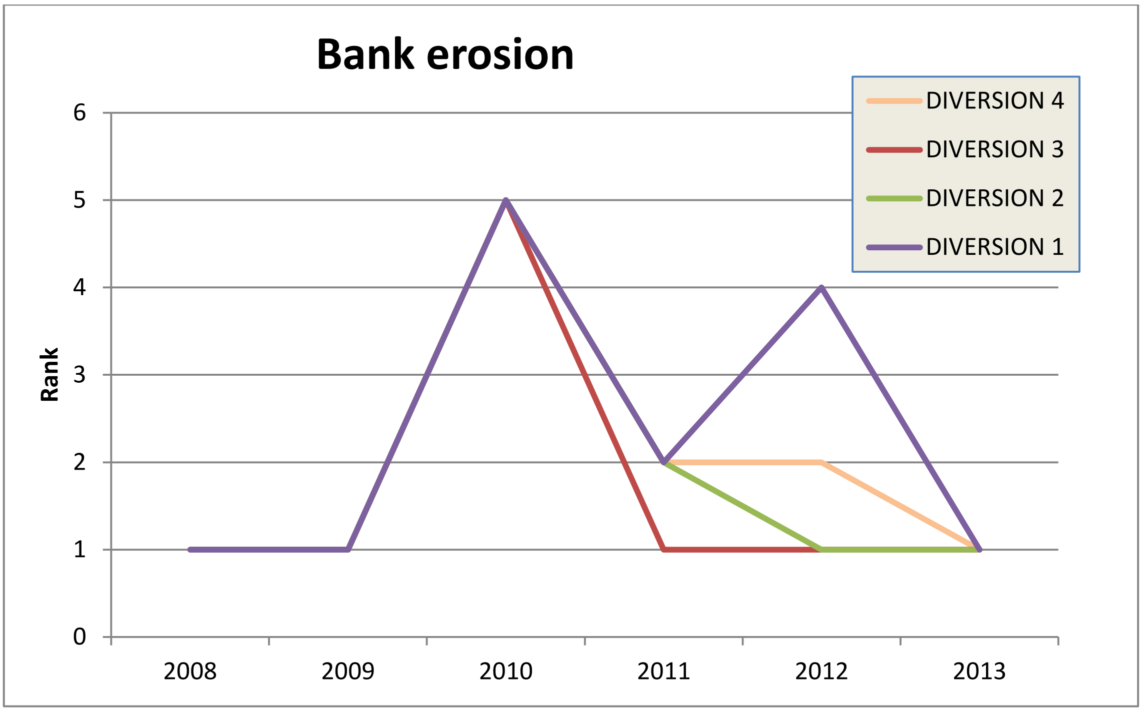


Table 4.14 - Trend lines - Bank erosion

Bank erosion (1-5)				
Diversion	4	3	2	1
2008		1	1	1
2009	1	1	1	1
2010	5	5	5	5
2011	2	1	2	2
2012	2	1	1	4
2013	1	1	1	1

The trend analysis showed that, in general, more water in always available for the farmers of D1, which is situated more upstream than the others, and, in particular, upstream a big separation of the river bed in two channels, namely the beginning of the distributive system of the ephemeral river. This led to a more intense water flow at the intake and to higher erosion of the lateral bank. It can also be noticed that damage to diversion seems to be reduced after the installation of gabions, even if year 2010 presented extreme flow intensity, especially for D4 (which is also protected by the inner gabion wall constructed for D3). Due to the higher resistance of the structures, more water was available for D4 and D3 in average flow years.

Figure 4.19 - Trend lines - Crop production

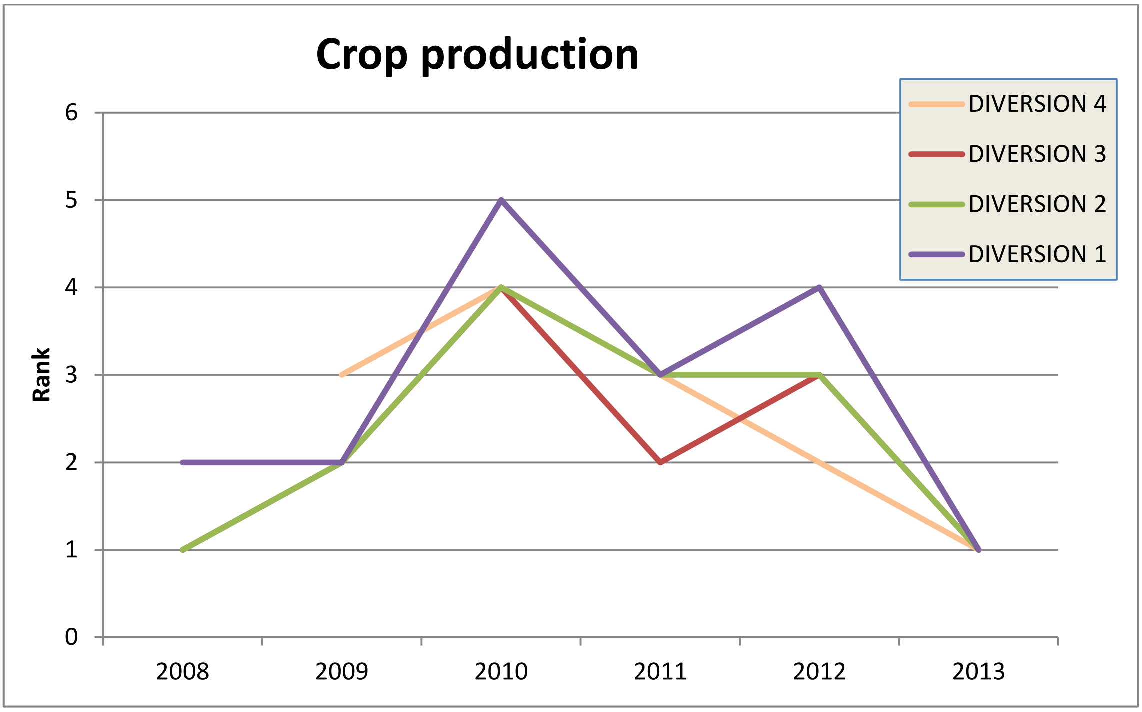


Table 4.15 - Trend lines - Crop production

Crop production (1-5)				
Diversion	4	3	2	1
2008		1	1	2
2009	3	2	2	2
2010	4	4	4	5
2011	3	2	3	3
2012	2	3	3	4
2013	1	1	1	1

The analysis of crop production showed also a generally better crop production for D1, due to higher water availability in a favourable position, and a good production in 2010, related to the high rain input, tendency confirmed by all interviews taken during PRA activity.

4.1.3.4 Hydrological information collection

The hydrological investigation was carried out with SSIs and more detailed questionnaires and activities directed to a good understanding of the local hydrology. SSIs didn"t produced remarkable and self-consistent data, but allowed to understand that the knowledge of the farmers of the hydrological and hydraulic characteristics of the river can be effectively used for design. With reference to the method described in paragraph 3.3.3.2, the analysis has been carried out for the gauging section shown in Figure 4.20. Water levels are reported in Table 4.16.

Figure 4.20 - Gauging site position - Google Earth

Table 4.16 - Water levels for different flow conditions

Type of flood	**Level**	**Duration**		**Number of occurrences**		
		to peak	**to end**	**dry year**	**average**	**wet year**
	cm	*hr*	*hr*			
High	180	2	8	1	2	6
Medium	100	1	5	2	3	8
Low	50	0.5	2	3	4	12

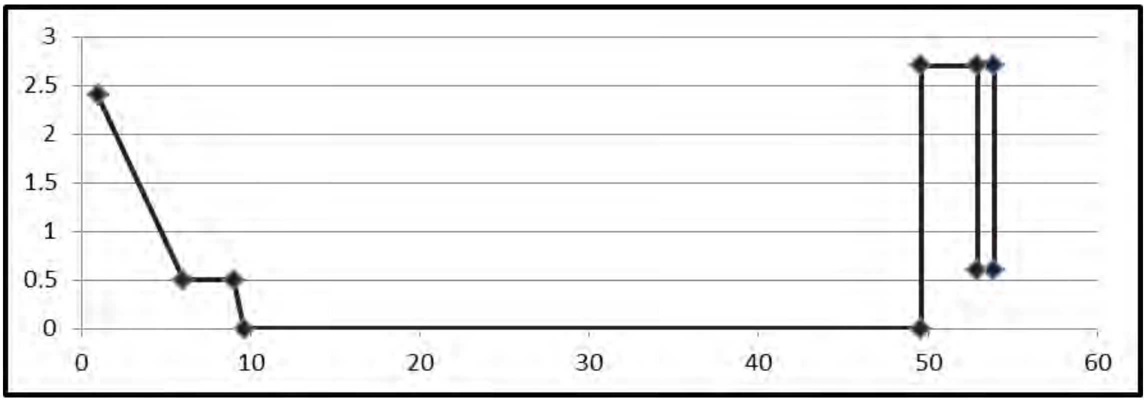
The water level of the maximum flood within living memory was 4 meters, while the mean level of the yearly maximum flood within living memory was reported to be around 2.20 meters.

The geometry of selected cross section (gauging site) is reported in Table 4.17 and Figure 4.21.

Table 4.17 - Points of gauging cross section

point	Horizontal distance from left bank (m)	elevation (m)
1	1	2.4
2	6	0.5
3	9	0.5
4	9.6	0
5	49.6	0
6	49.6	2.7
7	52.9	2.7
8	52.9	0.6
9	53.9	0.6
10	53.9	2.7

Figure 4.21 - Gauging cross section (m)



Slope Area calculation

An analysis of the discharge correspondent to the water levels identified by farmers was carried on using the methodology suggested by van Steenbergen et al. (2010).

Manning‟s formula was applied, considering a Manning‟s n coefficient of 0.035 for dry wadi beds (Landell Mills Development Consultants, 2011; van Steenbergen et al., 2010). Figure 4.22 shows a detail of river bed material at the gauging section.

$$Q = \frac{1}{n} \cdot \Omega \cdot R^{0.67} \cdot S^{0.5}$$

Where:

- Q is the discharge [m^3/s]
- n is Manning‟s coefficient [$s/m^{1/3}$]
- Ω is the flow area [m^2]
- R is the hydraulic radius [m]
- S is the slope.

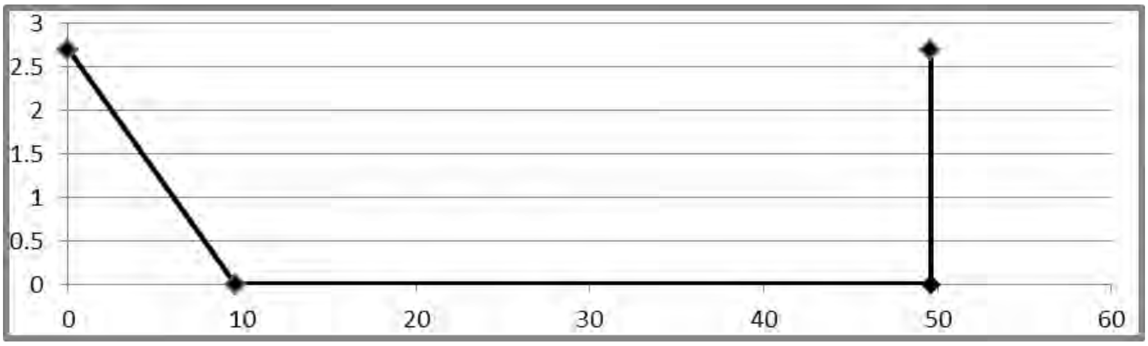
Figure 4.22 - Gauging site - bed material

For the calculation a simplified trapezoidal shape is considered (Table 4.18 - Figure 4.23):

Table 4.18 - Points of simplified gauging cross section

point	Horizontal distance from left bank (m)	elevation (m)
1	0	2.7
2	9.6	0
3	49.6	0
4	49.6	2.7

Figure 4.23 - Simplified gauging cross section (m)



The slope value for the selected cross section was calculated from the DEM considering the average slope of the river reach correspondent to the gauging section point. The slope obtained is equal to 0.0015 m/m.

Table 4.19 reports the result of the analysis.

Table 4.19 - Slope area analysis - calculations

level	y	Ω	R	Name	Q	Definition
	m	m^2	*m*		m^3/s	
y_{max}	4	188.4	3.206	Q_{max}	455	Maximum flood within living memory
y_y	2.2	96.6	1.920	Q_y	165	Discharge from mean level of the yearly maximum flood within living memory
y_h	1.8	77.8	1.605	Q_h	118	Discharge from average level of a "high" level flood
y_m	1	41.8	0.935	Q_m	44	Discharge from average level of a "medium" level flood
y_l	0.5	20.4	0.483	Q_l	14	Discharge from average level of a "low" level flood

The cross section is located in the wadi distributary system, after the first division of the river bed, in the northern branch. In order to estimate the discharge values for the whole catchment a rough and simple criterion is adopted. It is assumed that the flow splits proportionally to the width of each distributary channel. Each discharge is obtained as:

$$Q_i^* = f \cdot Q_i$$

where

- Q_i^* is the full catchment discharge for the level i
- Q_i is the discharge for level i
- f is the full discharge factor, calculated as:

$$f = \frac{L1 + L2}{L1}$$

In which L1 and L2 are the length of northern and southern branch respectively. The shape of distributary system is shown in Figure 4.24; Table 4.20 shows the details of f calculation.

Results for Q* are shown in Table 4.21.

Table 4.20 - full discharge factor calculation

L1	171	m
L2	111	m
Full discharge factor	1.649	

Figure 4.24 - Northern and southern branches of the distributary system at Harele intakes

Table 4.21 - Values of discharge for the complete catchment

Name	**Q**
	m^3/s
Qmax*	750
Qy*	272
Qh*	194
Qm*	72
Ql*	22

The value of Q_y* provides an estimation of the Mean Annual Flood Peak Discharge (MAF) provided by farmers. The return period of Q_{max}* is evaluated with the approach presented in paragraph 4.1.1.3. A Growth factor value G* is calculated as:

$$G^* = \frac{\text{Qmax}*}{\text{Qy}*} = 2.75$$

which is correspondent to a return period variable from 16 to 18 years (Table 4.9 - Discharge for return period).

Farmers have been farming the area for more than the return period analysed. Comparing the return period analysed with the hydrological analysis of paragraph 4.1.1.3, it is believed that farmers could have overestimated the level relative to Q_y.

From the described analysis it is possible to say that Nouh formula provides the appropriate estimation of MAF (Paragraph 4.1.1.3).

4.1.4 Socio-economical aspects

4.1.4.1 Local rules and regulations

Information about local rules was obtained with SSIs and structured interviews.

The management of irrigation activities is coordinated and directed by farmers‟ representatives, called Abo-Mais (fathers of the river). For each diversion, one or two Abo-Mais are elected by farmers, according to their attitude and impartiality. They stay in charge until their behaviour and decisions are considered loyal and impartial. If this happens, the charge can last for life. Their role is to control that each farmer has the possibility to have irrigation water for his field and they have the duty of organising the activities.

Water delivery regulation

The irrigation sequence is determined by the time of a farmer‟s contribution to the maintenance works. The more one farmer works, the earlier turn he receives in the sequence. The list of hours of contributions is made by Abo Mais.

For each diversion, the water is delivered to all secondary canals at the same time: a separated list of the hours of contribution is made for each secondary canal and this determines the irrigation sequence. If there is not enough water, the water is delivered according to the global list, regardless of the position of the farmer in the scheme, so a secondary canal can be open and close more times.

Access to water rights

The right to have water is acquired by working in the maintenance works. Female farmers (alone), old famers and sick people are entitled of Water Rights even without working. If a female farmer joins the works, she will get water first, regardless of the number of hours.

Penalties

If a farmer tries to cheat or is not respectful of the rules, a penalty ranging from 50 to 100 Birrs is applied. Penalties are collected by Abo-Mais and used for buying construction materials. If the farmer cannot or doesn‟t want to pay, the case is forwarded to the woreda court. Water users associations have no legal status.

4.1.4.2 Institutional arrangements

The interview with local government officers highlighted the institutional agreement for the building and reparation of diversion structures.

During the big flood of 2010 existent diversions, which were built with sand, were completely washed away. From 2011 a governmental program is assisting farmers in building new diversions.

Every year a local officer visits the irrigation system, checking the most seriously damaged diversions. After this selection, gabions are delivered to the farmers for rebuilding it. If a diversion has to be fully rebuilt, farmers are usually the ones who should select the diversion point, while local officers establish the width of the intake and the height of the bunds.

4.1.5 Spatio-temporal aspects

Spatio-temporal aspects were analysed through the application of the "crop production analysis".

General trends in crop production evaluated with trend lines (Paragraph 4.1.3.3) were cross-analysed with particular trends localised in different zone of the command area.

It was noticed that:

- In 2010 big rain led to the complete destruction of the diversion structures, but, overall crop production has a maximum (rank 5) even without the irrigation water input.
- In 2011 and 2012 crop production was sufficient (ranked between 2 and 4). Irrigation water input partially fulfilled water demand. Anyway high efforts were required for operation and maintenance during the year.
- In 2013, low rains generally led to poor harvest.

Table 4.22 shows a resume of the information gathered.

Table 4.22 - Crop production analysis

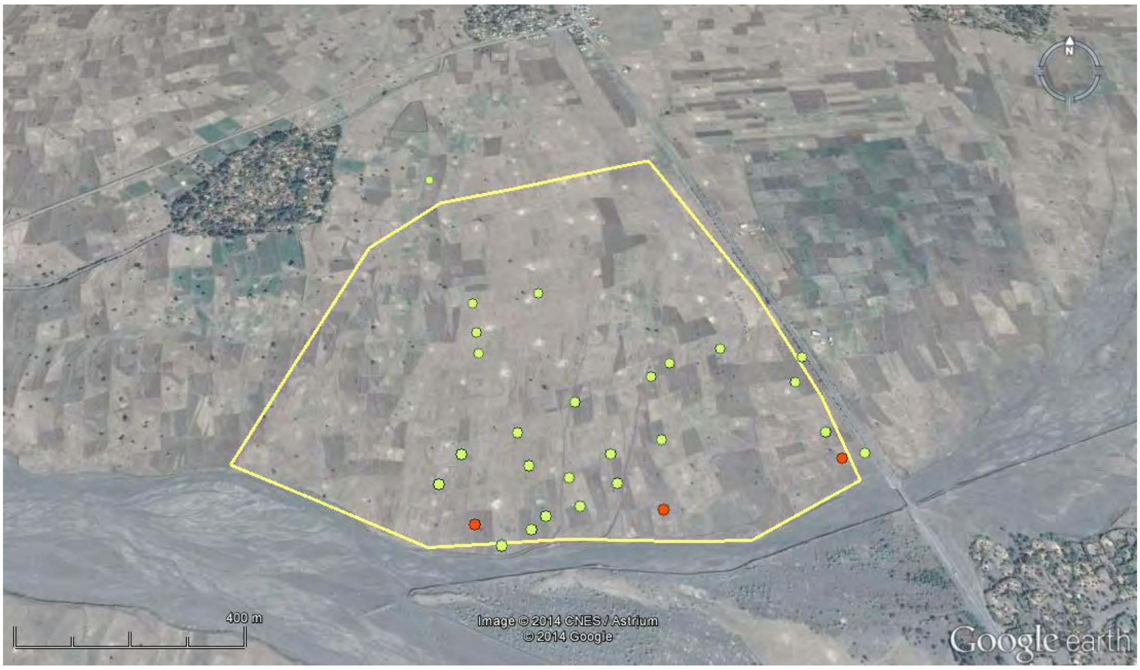
Year	Rainfall	Diversion structures		Crop production rank
2010	high	destroyed	High soil water content	5
2011 and 2012	medium	needed maintenance	Sufficient irrigation water and effect of rainfall	2÷4
2013	low	no damage	no water diverted, low soil moisture content	1

The main localized tendencies were:

- Farmers who own land at the head of diversion canals, and in particular near to the intake point, manage to abstract water even during 2013 summer and got satisfying level of crop production (rank 4-5). The water amount was too little to be delivered downstream in the canal.
- Farmers owning land in the tail of the system experienced very low harvest even in 2011-2012 (rank 1)

- During 2010 flooding season, despite the high crop production, some fields located next to the river were eroded due to left bank collapse. In addition to this, almost all farmers who own land near to the river referred to be menaced by erosion and expressed the need for bank protection systems. The GPS position of interviews that revealed erosion is shown in Figure 4.25.

Figure 4.25 - Position of analysed (green) and eroded (red) fields – Google Earth



4.2 Problems analysis

During the various phases of the field activity, the most relevant problems of the irrigation system were analysed and discussed with farmers, representatives and officers. Main problems analysed were:

1. **Present diversion structures are too small, with low diversion efficiency** – some farmers reported that the water diverted by irrigation structures is too few, The main reason reported is the presence of design errors, in particular because the width of the intake is too small.
2. **Diversion structures are too weak -** problem reported by all farmers interviewed. Diversion structure, built with earth, few gabions, stones and brushwood, are too weak. This lead to a heavy burden for the daily maintenance during the flooding season and to the collapse of diversion structures during violent floods.
3. **Lateral erosion** – during large floods, portions of the left bank collapse under the effect of river erosion, leading to loss of cultivable land for farmers.
4. **Lack of manpower** – Despite the high need of maintenance, it was reported that not all farmers participate to the maintenance works, leading to a lack of manpower. Most of the farmers interviewed reported that people who don‟t participate are often discouraged from the poor performances of diversion structures.
5. **Lack of materials -** Materials, in particular proper building materials such as gabions and concrete, are lacking.

6. **Flood risk for villages –** When the river floods, villages, which are generally built close to the wadi bed, are menaced despite protection structures which have been built before 2010. In some parts, gabions built collapsed. An example of structural failure of a gabion wall is shown in Figure 4.26.

Figure 4.26 - Collapse of protection works, right bank, downstream of Highway bridge

7. **Flood risk for fields –** Like the area of villages, located on the right bank of the wadi, also farmland have often been flooded. This led to crop failures and water logging problems, especially for farmers who have grown Teff, which is very sensitive to water ponding on the field.
8. **Presence of parasite plants and pests –** In some interviews problems related to the presence of parasite plants and pests were reported. Usually parasite plants grow during spring (April – May) and are removed by farmers while ploughing. Their presence increase with the intensity of early rains.
9. **Sedimentation –** Farmers having their fields next to the wadi reported that the deposition of sediment from floodwater represents a problem for the crops. This usually happens when the water level in the river exceeds the banks level.

4.3 Problems ranking

Problems were ranked with the rules described in paragraph 3.3.3.3. They were also ranked by the researcher before the activity in order to make a comparison between farmers‟ decision and engineer‟s perspective (Table 4.23).

Table 4.23 - Ranking of problems

PROBLEM	RANK RESEARCHER	RANK FARMERS
Size of the present diversion structures (too small) and low diversion efficiency	3	5
Weakness of the diversion structures	1	1
Lateral erosion	2	2
Lack of manpower	7	7
Lack of materials	8	8
Flood risk for villages	4	3
Flood risk for fields	5	4
Presence of parasite plants and pests	9	9
Sedimentation	6	6

4.4 Selection of solutions

Technical solutions for the outlined problems have been analysed. In particular, the discussion of suitable solution focused on the two main problems identified for the scheme by farmers: lateral erosion and the weakness of diversion structures.

Solutions were selected with regard with the whole PRA activity and with focus discussions during the final participatory meeting.

4.4.1 Weakness of the diversion structures

The major problem identified by farmers consists in the weakness of the existing diversion structures. During the field activity it emerged that:

- Frequent damages to diversion structures force farmers to work in operation and maintenance during and after floods. When damages are particularly severe, farmers may not have the possibility of abstracting water during the whole rainy season.
- Diversions improved with gabions are more stable. In addition to this, farmers identified gabions as a suitable solution for improvements, as they asserted to be capable of installing and maintaining them.
- Structure analysis revealed that the most sensitive part of a diversion is represented by the first part which directly faces the flood. This part is often washed away by the flow.
- Farmers prefer to maintain a scheme based upon multiple diversion structures with the present shape.
- Farmers assert that the current sediment management strategy (using uphill diversion channel as sediment trap) is working. As a matter of fact, sedimentation is not considered as a prominent issue (rank 6 out of 9).
- The apparently low diversion efficiency of the intake structures is not perceived as relevant as their weakness.

Due to the considerations here listed it was decided to work on the first part of the diversion, improving the stability of the "nose", using gabions as construction material. Particular focus will be on the effect of erosion under the structure. The management of sediment and the canal design appear to have sufficiently good performances.

4.4.2 Structure against lateral erosion

Lateral erosion is considered as the second most relevant problem in the scheme.

- The erosion rate in the study area is reported as 13 ha of cultivable area in 3 years (around 16% of the present extension).
- Some farmers in the scheme lost relevant part of their fields (around 30% - 40% of the area)
- The problem is perceived as relevant not only by the farmers who are directly involved, but also other farmers perceive the danger of the soil loss.
- Flood protection structures located on the right bank of the river collapsed in various points, probably due to design errors and inadequate foundations.

Due to the factors mentioned above and to technical considerations analysed for the use of gabions for diversion structures it is proposed to design river bank protection structures with gabions on the left bank of the river, with attention also to their effect as flood protection structures.

4.5 Design

4.5.1 Diversion structures

The design process for improving the diversion structures has been developed considering the farmers‟ suggestions.

A preliminary design for the initial part of the diversion bund (intake nose) has been carried out. As the farmers suggested, the core of the intake spur will be realised in gabions, and it will be covered by stones and earth in order to reduce its permeability and to realise a better shape for water diversion. Here a schematic design of the core is analysed, while it is expected that farmers will contribute in the coverage.

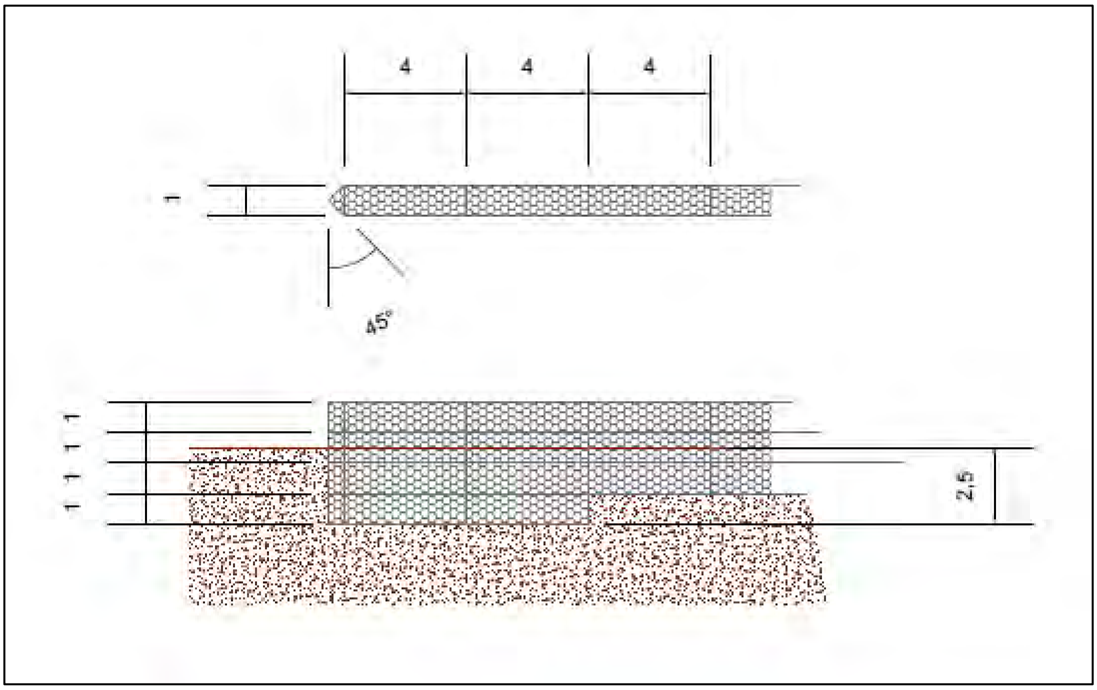
For the preliminary design, gabions and technical features from MACCAFERRI South Africa were selected.

The design scheme for the core of the diversion bund is characterized by a sharp nose, which has the role of deviating the flow incident to the structure, lowering the dynamic water pressure on it. Deep foundation should be realized in order to reduce the scour effect of the flow.

The sharp nose will be realised by simply cutting standard gabions, or by constructing a new shape with the metallic net.

The design scheme is showed in Figure 4.27.

Figure 4.27 - Diversion bund core design



4.5.1.1 Local scour calculation

Local scour calculation has been evaluated in order to prevent the core of being washed away by underflow which may occur after intense erosive phenomena. The nose of the structure can be considered as a bridge pier, and local scour is estimated with correspondent formulas.

Two approaches has been used for the local scour evaluation.

(a) Da Deppo and Datei (1999)

Local scour s is calculated as

$$\frac{s}{a} = f1\left(\frac{v}{v_{cd50}}\right) \cdot 2 \cdot \tanh\left(\frac{y}{a}\right) \cdot f2(shape) \cdot f3\left(\alpha, \frac{L}{a}\right)$$

where:

- s is the local scour [m]
- a is the width of the pier/bund [m]
- L is the length of the pier/bund [m]*
- α id the angle with the flow [°]
- y is the flow depth [m]
- v is the flow velocity [m/s]
- v_{cd50} is the flow velocity for bed material [m/s], which is calculate as $v_{cd50} = C \cdot \sqrt{d_{50}}$, with C ranging from 5 to 7 for standard sediment density
- $f1\left(\frac{v}{v_{cr}}\right)$ is a coefficient dependent on the velocity and the critical velocity as follows:

  0 for $v/v_{cd50} \leq 0.5$

  $2 \cdot (v/v_{cr} - 1)$ for $0.5 < v/v_{cd50} < 1$

1 for $v/v_{cd50} \geq 1$

- $f2(shape)$ is a coefficient equal to 1 for rounded piers, 0.75 for sharp-shaped piers and 1.3 for rectangular piers
- $f3\left(\alpha, \frac{L}{a}\right)$ is a coefficient equal to 1 being $\alpha = 0°$

* where necessary l will be considered → ∞, or at the best approximation for very long piers.

(b) Richardson and Richardson (2007)

Local scour s is calculated as

$$\frac{s}{y} = 2.0 \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4 (\frac{a}{y})^{0.65} \cdot Fr^{0.43}$$

where:

- K_1 is a correction coefficient which takes into account the shape of the pier/bund. (from Table 4.24)

Table 4.24 - K_1 values

Shape of pier nose	K_1
(a) Square nose	1.1
(b) Round nose	1.0
(c) Circular cylinder	1.0
(d) Sharp nose	0.9
(e) Group of cylinders	1.0

[*Source*: adopted from (Richardson & Richardson, 2007)]

- K_2 is a correction coefficient for the angle of attack of the flow assumed equal to one as $\alpha = 0°$
- K_3 is is a correction coefficient for evaluating bed conditions (from Table 4.25.)

Table 4.25 – K_3 values

Bed condition	Dune height, m	K_3
Clear-water scour	N/A	1.1
Plane bed and antidune flow	N/A	1.1
Small dunes	$3 > H < 0.6$	1.1
Medium dunes	$9 > H > 3$	1.1 to 1.2
Large dunes	$H > 9$	1.3

[*Source*: adopted from (Richardson & Richardson, 2007)]

- K_4 is a correction factor for the size of bed material, which is evaluated as follows:

  1 for $d_{50} < 2$ mm or $d_{95} < 20$ mm

  $0.4 \cdot (K_5)^{0.15}$ elsewhere

  where $K_5 = \frac{v - v_{icd50}}{v_{cd50} - v_{icd95}} > 0$

  - v_{icdx} is the approach velocity corresponding to critical velocity for incipient scour in the accelerated flow region at the the pier/bund for diameter x, calculated as $v_{icdx} = 0.645(\frac{d_x}{a})^{0.053} \cdot v_{cdx}$ [m/s]

- v_{cdx} is the critical velocity for the motion of grain size x [m/s]

The calculation of the localised scour at the intake bund is realised for the maximum flood within living memory. Results for method (a) are shown in Table 4.26; results for method (b) are reported in Table 4.27.

Table 4.26 - Scour depth calculation according to approach (a) (Da Deppo & Datei, 1999)

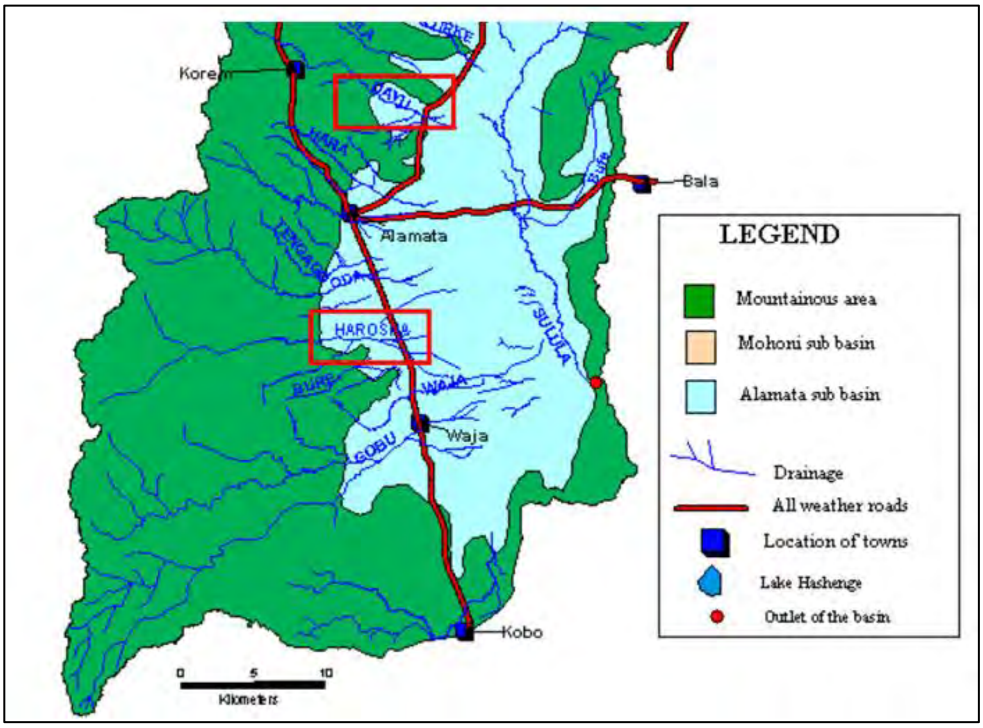
y	a	v	Q	d_{50}	v_{cd50}	f1	f2	f3	s
m	*m*	*m/s*	m^3/s	*mm*	*m/s*				*m*
4	1	2.42	455.2	1.06	0.20	1	0.75	1	1.50

Table 4.27 - Scour depth calculation according to according to approach (b) (Richardson & Richardson, 2007)

y	a	V	Q	Fr	d_{50}	K_1	K_2	K_3	K_4	s
m	*m*	*m/s*	*m3/s*		*mm*					*m*
4	1	0.68	455.2	0.39	1.06	0.9	1	1.1	1	2.14

For the analysis of the size distribution of bed material, the data analysed by Libsekal Gebremariam (2014) for Dayu basin have been used. The position of Dayu river with respect to Harosha river is shown in Figure 4.28.

Figure 4.28 - Location of Dayu river



[*Source*: adopted from Hagos (2010)]

The size distribution is reported in Table 4.28.

Table 4.28 - Bed material size distribution for Dayu river

Sieve size (mm)	fraction of total weight analysed
>250	98.54%
150	95.97%
80	91.92%
50	86.72%
25	79.64%
5	61.44%
4.75	61.24%
2.36	53.53%
2	50.94%
1	36.32%
0.5	20.45%
0.25	5.03%
0.106	0.90%
0.053	0.25%
pan	0.00%
1.064 mm	interpolated value of d_{50}

[*Source*: adopted from Libsekal Gebremariam (2014)]

From the results calculated, the depth of the foundation plan appears to be sufficient for the first two gabions. The 2.5 m depth has been considered only for the first two gabions, after the second one, a 1.5 m is selected, assuming a reduction of the scour effect.

4.5.1.2 Hydraulic shear stress check

Hydraulic shear stress check is performed in order to analyse if the gabions can resist to the flow drag.

The shear stress of the flow τ_{flow} is calculated as:

$$\tau_{flow} = \gamma_w \cdot S \cdot y$$

where:

- γ_w is water specific weight [N/m^3]
- S is the slope of the channel
- y is the water depth [m]

The critical shear stress for gabion wall is calculated according to Bongio (2012):

$$\tau_c = \theta_{gab} \cdot \chi_{def} \cdot (\gamma_s - \gamma_w) \cdot d_{gab}$$

where:

- θ_{gab} is the value of Shields parameter for filling stones within a gabion, equal to 0.12

- χ_{def} is a corrective coefficient >1 for taking into account that gabions are flexible and can resist to shear force even after deformation, but it is safely assumed equal to 1
- γ_s is stones specific weigh, assumed as 20 N/m^3
- γ_w is water specific weight [N/m^3]
- d_{gab} is the mean diameter for filling stones, assumed equal to 0.15 m

Results are reported in Table 4.29.

Table 4.29 – Diversion structures - Hydraulic shear stress check - results

Q	y	τ_{flow}	τ_{cr}
m^3/s	*m*	*N/m^2*	*N/m^2*
455.18	4	58.8	183.6

4.5.1.3 Further development and design refinement

For the refinement of the design of the diversion structure it will be necessary to give an estimation of the water pressure on the bund and to evaluate the effective sedimentation rate in the uphill diversion channel.

In order to perform the requested analysis it will be necessary to set up a 2D-3D model of the intake section. It is also suggested to develop some pilot installation for checking the effectiveness of the proposed solutions.

The monitoring activity of the pilot project will generate information and data for the model implementation, and a refined model will be useful for improved bunds and scaling up.

4.5.2 Gabion walls

The design of gabions reinforcements for the left bank of Harosha river has been carried out through the use of MACSTARS W software, developed by Officine Maccaferri s.p.a. (2009) The software allows the design of gabion walls in different conditions of terrain geometry and geology, soil properties, aquifer level and gabions filling material.

MACSTARS allows multiple stability check with different standards and for a control in a different one. From the original MACSTARS file, other standards can be used for technical verifications. In absence of a clear regulation for the design of gabions and retaining walls in the framework of Ethiopian building laws, two types of verifications have been used:

- Verifications according to Italian standard “norme tecniche per le costruzioni (NTC) – 2008”- multiplier combination A2-M2-R2 and EQU-M2-R1.
- Verifications according to European standard Eurocode 7 - multiplier combination A1-M1-R2.

The stability analysis has been carried out for no flow conditions and maximum flow condition, namely during the occurrence of Q_{max}. This case has been simulated by using an aquifer situated 4 m above the ground level.

For the chosen case study, the simplified bank geometry of the gauging section (Figure 4.23) was chosen. For a preliminary design, gabions from MACCAFERRI South Africa were selected. Five blocks of gabions were utilised (Table 4.30).

Table 4.30 - Blocks of the gabion wall

Block	Height (m)	Length (m)
1	0.5	3
2	1	3
3	1	2.5
4	1	2
5	1	1.5

The terrain below the structure should be excavated until 1 m depth in order to allow sufficient foundation depth. Figure 4.29 shows the excavation for the foundation, Figure 4.30 shows the section of the gabion wall and Figure 4.31 shows the dimensions of the gabions.

Figure 4.29 - Gabion wall - detail of the excavation for foundations

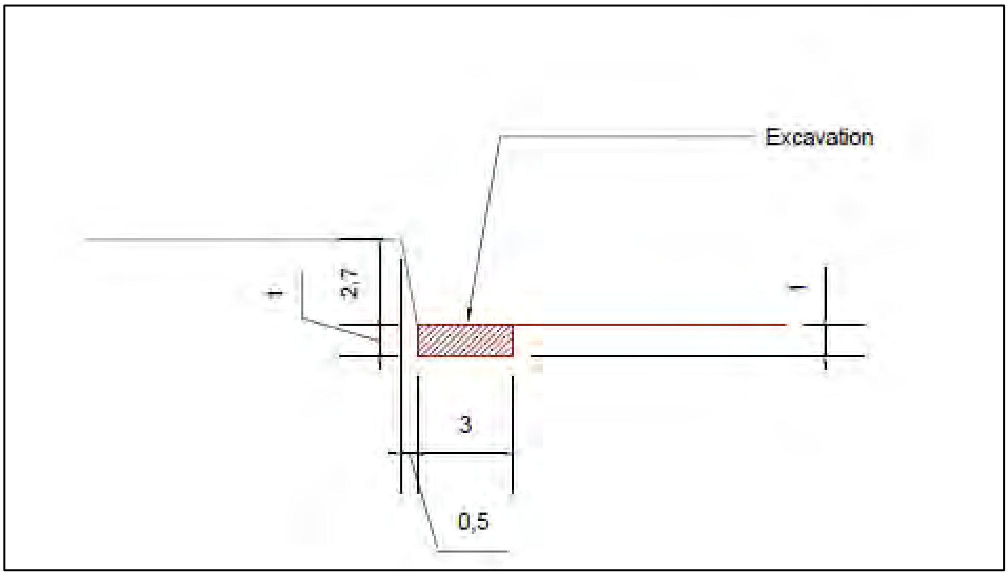


Figure 4.30 - Gabion wall

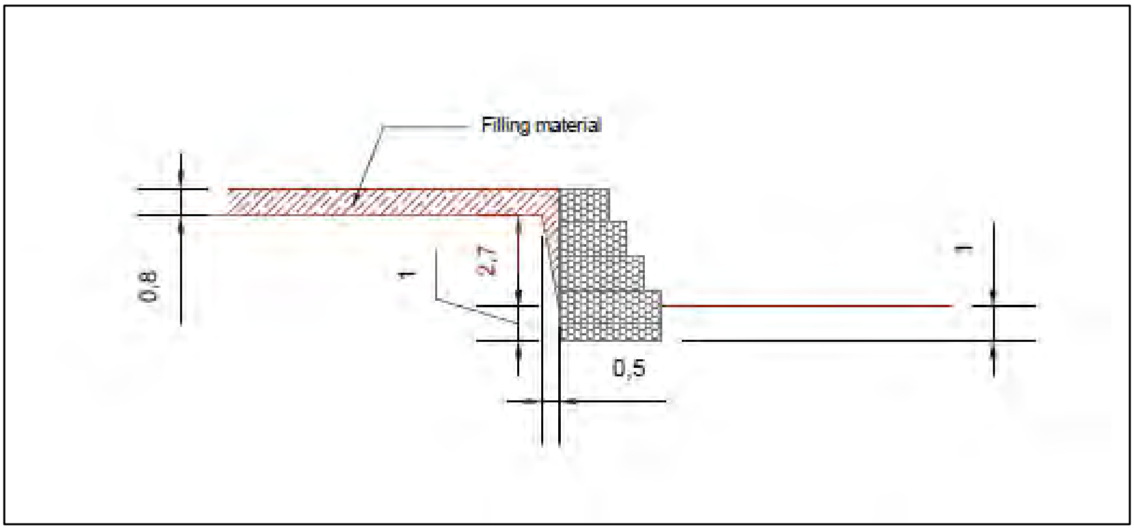
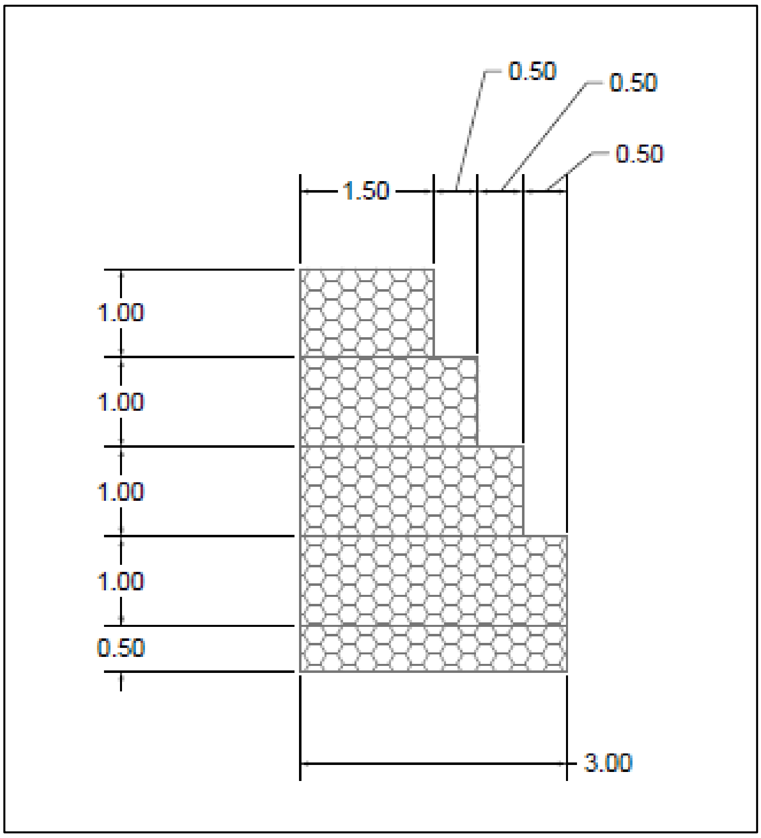


Figure 4.31 - Gabion wall - dimensions



The assumptions made for soil properties are reported in Table 4.31:

Table 4.31 - Gabion wall - soil assumptions

Soil type	Sandy clay	Gravels
Description	Terrain and backfill material	Gabion filling
Friction angle (°)	30	45
Saturated specific weight (kN/m^3)	19	18
Natural specific weight (kN/m^3)	17	15
Cohesion	0	0

4.5.2.1 Stability check

The checks made for the gabion structure and respective security factors are included in Table 4.32 and Table 4.33. MACSTARS report sheets are shown in Annex II: Macstars reports.

Table 4.32 - Gabion wall security factors for dry conditions

Verification	Security Factor – dry conditions	
	Italian standard	Eurocode 7
Global stability analysis – Bishop method	2.057	2.571
Bearing capacity	5.391	4.632
Sliding	1.564	2.246
Overturning	4.414	5.514

Table 4.33 - Gabion wall security factors for wet conditions

Verification	Security Factor – wet conditions	
	Italian standard	Eurocode 7
Global stability analysis – Bishop method	2.056	2.570
Bearing capacity	5.469	4.576
Sliding	1.604	2.264
Overturning	4.480	5.553

4.5.2.2 Internal pressures check

In addition to the stability checks presented before, the resistance of elements the gabion wall to internal pressures has been checked.

For each interface between two blocks of the gabion walls, shear stresses and normal pressures have been compared to the maximum values for the gabion walls. The method presented by (Orlando, 2003).

The maximum admissible values have been calculated as follows:

1. Maximum admissible normal pressure $\sigma_{adm} = 5 \cdot \gamma_g - 3 \left[\frac{kg}{cm^3}\right]$

   where γ_g is the specific weight of gabions [t/m^3]
2. Maximum admissible shear stress $\tau_{adm} = N \cdot \tan\varphi^* / B + c_g$[kN/m^2]
   where:
   - $\varphi^* = 25° \cdot \gamma_g - 10°$ (with $\cdot \gamma_g$ in t/m^3) [°]
   - $c_g = 0.03 \cdot P_u - 0.05 \left[\frac{kg}{cm^3}\right]$ where P_u is the specific weight of metallic net for each volume unit of gabion in kg/m^3, equal to 0.15 for d=2.7 mm wire, characteristic of selected gabion set.
   - N is the force normal to the surface as a result of the elements over the surface (soil and gabions) [N]

For each surface between gabions, maximum normal pressure σ_{max} and shear stress τ are calculated as follows:

1. $\sigma_{max} = \mathrm{N}/(\mathrm{B} - 2\mathrm{e})$

   where:

   - N is the force normal to the surface as a result of the elements over the surface (soil and gabions) [N]
   - e = M/N is the value of eccentricity of the normal force, with M equivalent to the momentum of the components of N with respect to the barycentre of the section [m]
   - B is the length of the section [m]
2. $\tau = T/A_g$
   where:
   - T is the shear force applied to the section [N]
   - A_g is the area of the section [m^2]

The calculation results are reported in Table 4.34; details are shown in Annex III: Gabion wall - Internal pressure check calculations.

Table 4.34 - Gabion wall - internal pressures check

interface	τ	τ_adm	σ_max	σ_amm
	kN/m^2	kN/m^2	kN/m^3	kN/m^3
1 - 2	1.46	23.23	15.65	450
2 - 3	4.38	29.96	26.54	450
3 - 4	7.88	36.09	36.70	450
4 - 5	11.67	41.91	46.74	450

5 Conclusions

This work analysed the possibility of developing a participatory approach for improvements in spate irrigation systems. For the selected case study of Harosha spate system, main problems and potential solution were found together with the participation of local population. Farmers were also involved in planning and designing of the potential solutions.

5.1 Research questions

The main research question for the thesis work was:

How can the participatory approach be developed for effective improvements in Spate Irrigation Systems?

The participatory approach was realised in the perspective of Diagnostic Analysis. An analysis of the scheme was undertaken, with the objective of identifying its main problems. A study of the potential solutions to these problems was then realized for improving the performance of the system by removing main constraints.

The research question was divided in two sub questions, the first one relative to the analytic phase of the work and the second one about the planning and designing phases.

1. How can problems be identified and ranked in a participatory manner and what solution can be selected for being effective?

The identification of problems was realised together with the local community of farmers using the Participatory Rural Appraisal method. Firstly an analysis of the characteristics of the system was undertaken, with the aim of identifying the main problems. Spatial, temporal, socio-economical and spatio-temporal features of the system were analysed through the PRA techniques, integrated with an analysis of available secondary data. A list of the problems in the scheme with relative discussion was then realised together with the farmers.

Everyday activity and discussion on the field allowed a daily confrontation with local population about the main problems of the scheme that were definitively ranked in a group meeting. The meeting was carried out without the help of any particular technique, as the 2 months work already set the ground for effective discussions. The mutual learning realised with PRA activities also helped to understand properly people‟s choices and opinion.

Problems were ranked as follows:

1. weakness of the diversion structures
2. lateral erosion
3. flood risk for villages
4. flood risk for fields
5. size of the present diversion structures (too small) and low diversion efficiency
6. sedimentation
7. lack of manpower
8. lack of materials

9. presence of parasite plants and pests

During the meeting it was chosen to work for solving the first two problems.

According to the farmers, the main problem of diversion structures is their weakness. Participatory approach helped to understand that the weakest zone is represented by the first part of the diversion, which is usually washed away during floods. The design of improved intake structures with the use of gabions was selected as a suitable solution.

Lateral erosion is recognized as the second most prominent problem for the scheme, as farmers who have their farmland adjacent to the river lost a relevant portion of cultivable land due to the collapse of the left bank. The problem is perceived also from the rest of the farmers who want to be protected from the progress of soil loss phenomena. The information obtained from the farmers also helped to identify an estimation of the farmland loss rate (13 ha in 3 years). A retaining gabion wall was designed for reducing the problem.

2. How the farmers' knowledge can be incorporated in the planning and design phases?

The knowledge and ideas of farmers were incorporated in the design phase by using a participatory design approach, based on the definition of a common framework for the description and analysis of the situation of the system. In practical terms, the shared knowledge accumulated during the PRA analysis phase allowed to understand farmers‟ needs and observations and converge to a defined design strategy.

For resolving the problem of structural weakness of the diversion structures a preliminary design of the initial part of the intake bund was realised, analysing in particular the scour effect of the flow and its pressure on the structure. The farmers‟ consultation was fundamental for understanding that there is no need of changing the intake shape, as the community prefers by far a system with multiple intakes, effective except for structural problems. In addition to this farmers selected gabions as a suitable construction material and have a fundamental role in identifying design discharges. The discharges identified through farmers‟ involvement were used as design discharge and for selecting the most appropriate MAF estimation method. The results were also coherent with other studies in the area (Libsekal Gebremariam, 2014).

For solving the problem of lateral erosion a gabion wall was chosen. Again farmers‟ involvement was crucial in order to understand the discharge used for the hydraulic analysis of the structure and the water pressure on the wall, and for having a confirmation on the most suitable materials.

5.2 Additional considerations

5.2.1 Sediment management strategy and canal system operation

During the PRA activity it emerged how the farmers manage effectively the sediment load during spate flows. An intake channel characterised by upward slope is used for reducing flow velocity, forcing the sedimentation in the first part of the channel, reducing the amount and the size of sediment entering the canal system. According to farmers, the solution is performing fairly well, and sedimentation problems are not perceived as heavy constraints for the system.

Canal system operation has been performed by farmers even after state intervention in 2010. Farmers assert to do not want modification to the canal system, which allows performing operation in line to local regulation. Modification to the system may alter the current management strategy and make the canal operation more difficult.

In conclusion, several parts of the irrigation scheme are effectively managed by local community and development approach should not interfere with the current fashion without considering farmers‟ own capacity and strategies. Brand new technical solutions should not be considered where alternative local technologies are performing quite effectively. As a matter of fact, farmers didn‟t ask for heavy changes to the scheme, but proposed only improvements to the existing original structures

5.2.2 Ex post analysis of criticism on PRA and social implications of Diagnostic Analysis

The work aimed at evaluating and testing a participatory planning and design approach taking into account potential criticisms and limitations. Regards to paragraphs 3.1.1 and 3.2.1.1 the following considerations were made:

Social implications of DA

The proposed solutions aim to remove the negative effects which are seen as problems by the local community. According to the analysis of the system, the proposed design is within farmers‟ capability (simple design schemes, use of local materials) and it is in line with local rules and regulations (multiple intakes, no interventions and impact on canal network and water distribution).

Knowledge claims of PRA

The information obtained with PRA techniques was cross checked with secondary data. In addition to this, the same topics were covered with different techniques, in order to highlight potential contradictions and misunderstandings.

Myth of the community and *Power inequalities*

Spate irrigation requires high level of coordination within the farmers‟ community. Thus, the farmers‟ group is very cohesive as people have to effectively cooperate in order to secure proper water management. This feature was confirmed by the field activity and problems related to non-homogeneity of the community had little relevance. In this sense spate irrigation schemes appear to be an enabling environment for participatory approach.

Bureaucratization of participation

In the framework of the participatory process, a relevant place was given to the identification of the scheme problems. This has been done for not focusing only on the improvements regarding the intake part and the distribution system. Thanks to this approach, also other issues were raised, like the flood vulnerability of the scheme.

6 Recommendations

- In the implementation of new strategies for spate irrigation development, farmers should participate also in the planning phase of the intervention, rather than at the level of consultation during the design phase.
- Farmers" own technical solutions should be carefully monitored and evaluated through scientific and on-field research. The thesis work showed as they have reached a satisfactory sediment management system by using upward slopes in the intake canal. This kind of design should be evaluated and carefully described even using 1D and 2D modelling as previously done for modernized intakes (Libsekal Gebremariam, 2014) and settling basins (Embaye, Beevers, & Mehari Haile, 2012).
- The attempts of improving spate irrigation systems in the last 10-15 years were characterized by a trial-error process. Several schemes were modernized with heavy investment costs for concrete structures and their performance was evaluated during their working life. This approach provides disappointing results for some cases, due to the fact that high costs resulted in immediate failures. The technique still remains valuable for the spate irrigation environment, as there is little knowledge about how to build really appropriate structures. The approach should be implemented for simpler and less expensive structures like the ones that could be designed following farmers" suggestions. As an example, monitoring the performances of upward slope intake canals would result in useful information for further modelling and design.
- In the framework of spate irrigation, a major obstacle to the design is represented by the scarcity of data. There is a need of deeper understanding of hydrological and hydraulic laws referred to ephemeral rivers, with the aim of developing standard procedures for estimation of discharge and sedimentation rates at the design level.
- Farmers from Harele emphasized the problems of "flooding of fields" and "flooding of villages", and, more in general, the management of flood water besides irrigation purposes. Rural livelihoods in spate systems rely on flood water, but at the same time they are threatened by the destructive potential of floods. A new approach is suggested: in order to obtain real development, spate systems should be considered within the framework of the river system management, rather than under the spotlight of irrigation system development.

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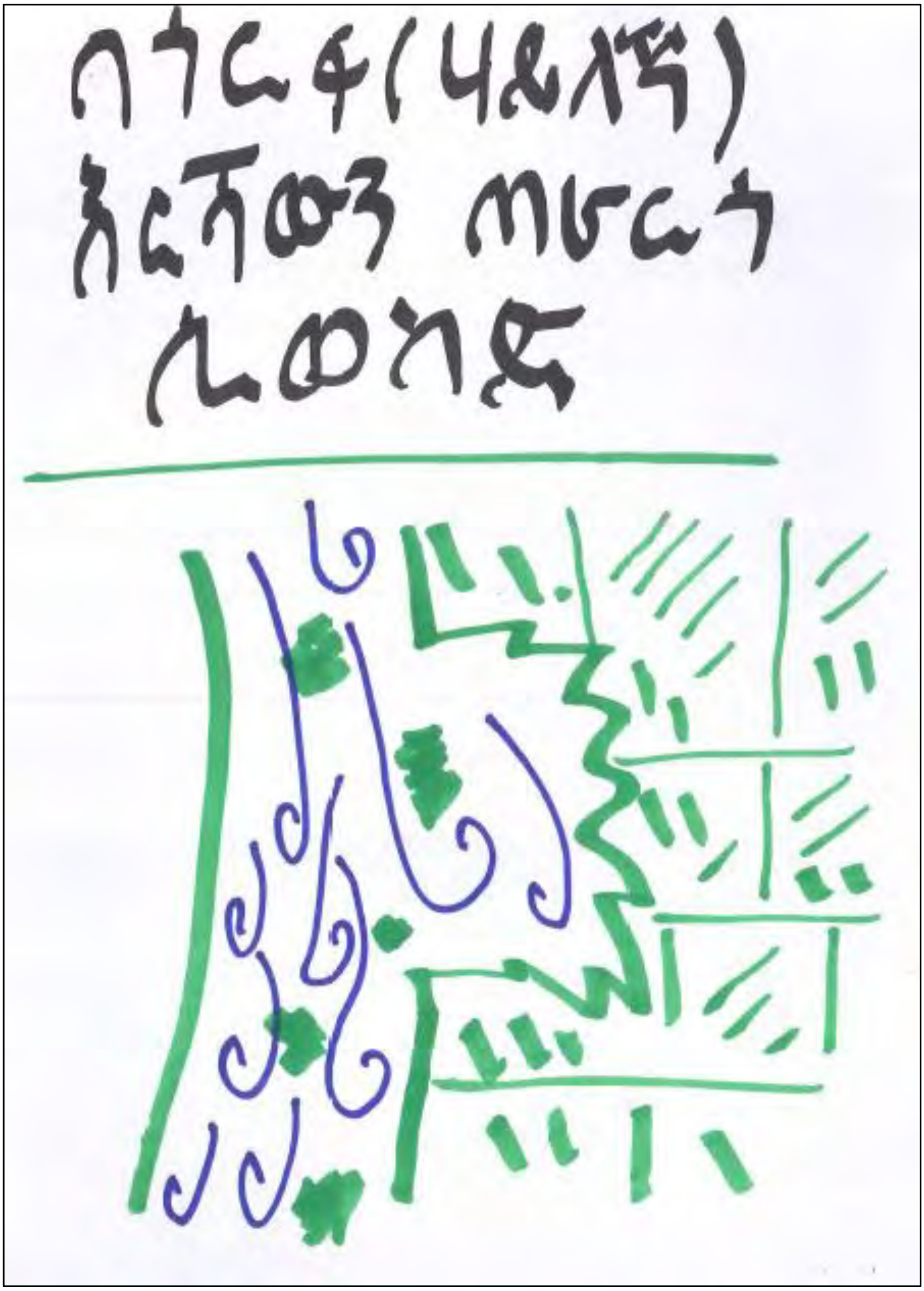
Annex I: Problem sheets

Weakness of the diversion structures

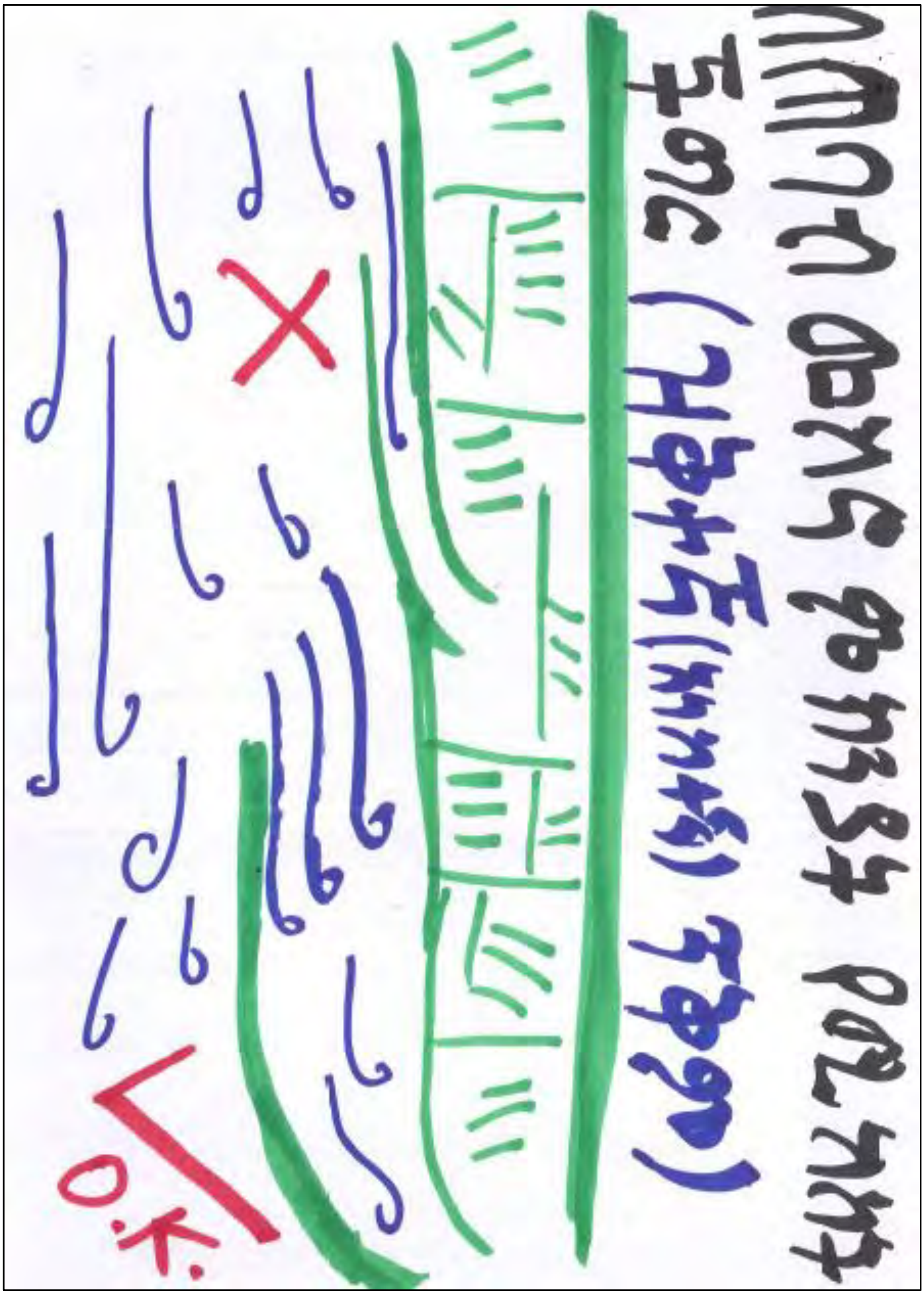
Lateral erosion



Flood risk for villages

Flood risk for fields

Size of the present diversion structures (too small) and low diversion efficiency



Sedimentation

Lack of manpower

Lack of materials

Presence of parasite plants and pests

Annex II: Macstars reports

Checks according to Italian standard "norme tecniche per le costruzioni (NTC) – 2008"

MacStARS W – Rel. 3.0

Maccaferri Stability Analysis of Reinforced Slopes and Walls
Officine Maccaferri S.p.A. - Via Kennedy 10 - 40069 Zola Predosa (Bologna)
Tel. 051.6436000 - Fax 051.236507

giulio

Project Title: Harosha river retention wall

Cross Section: general

Site: left bank

Folder:

File: gabion_Harosha_def

Date: 09/06/2014

Checks according to: Norme tecniche per le costruzioni D.M. 14/01/2008
Verifiche nei confronti dello SLU

TABLE OF CONTENTS

SOIL PROPERTIES

Soil: GRAVELS Description: gravels

Cohesion Class: Coeff. Parziale - Coesione efficace
Cohesion [kN/m²]: 0.00
Friction Angle Class: Coeff. Parziale - tangente dell'angolo di resistenza a taglio
Friction Angle [°]: 45.00
Ru value: 0.00
Weight Class: Coeff. Parziale - Peso dell'unità di volume - favorevole
Bulk unit weight - above GWT [kN/m³]: 15.00
Bulk unit weight - below GWT [kN/m³]: 18.00

Elastic Modulus [kN/m²]: 0.00
Poisson's ratio: 0.30

Soil: SANDY CLAY Description: Sandy Clay

Cohesion Class: Coeff. Parziale - Coesione efficace
Cohesion [kN/m²]: 0.00
Friction Angle Class: Coeff. Parziale - tangente dell'angolo di resistenza a taglio
Friction Angle [°]: 30.00
Ru value: 0.00
Weight Class: Coeff. Parziale - Peso dell'unità di volume - favorevole
Bulk unit weight - above GWT [kN/m³]: 17.00
Bulk unit weight - below GWT [kN/m³]: 19.00

Elastic Modulus [kN/m²]: 0.00
Poisson's ratio: 0.30

STRATA PROFILES

Stratum: BASE Description:

Soil : SANDY CLAY

X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]
0.00	5.70	10.00	5.70	10.50	3.00	35.00	3.00

WALL

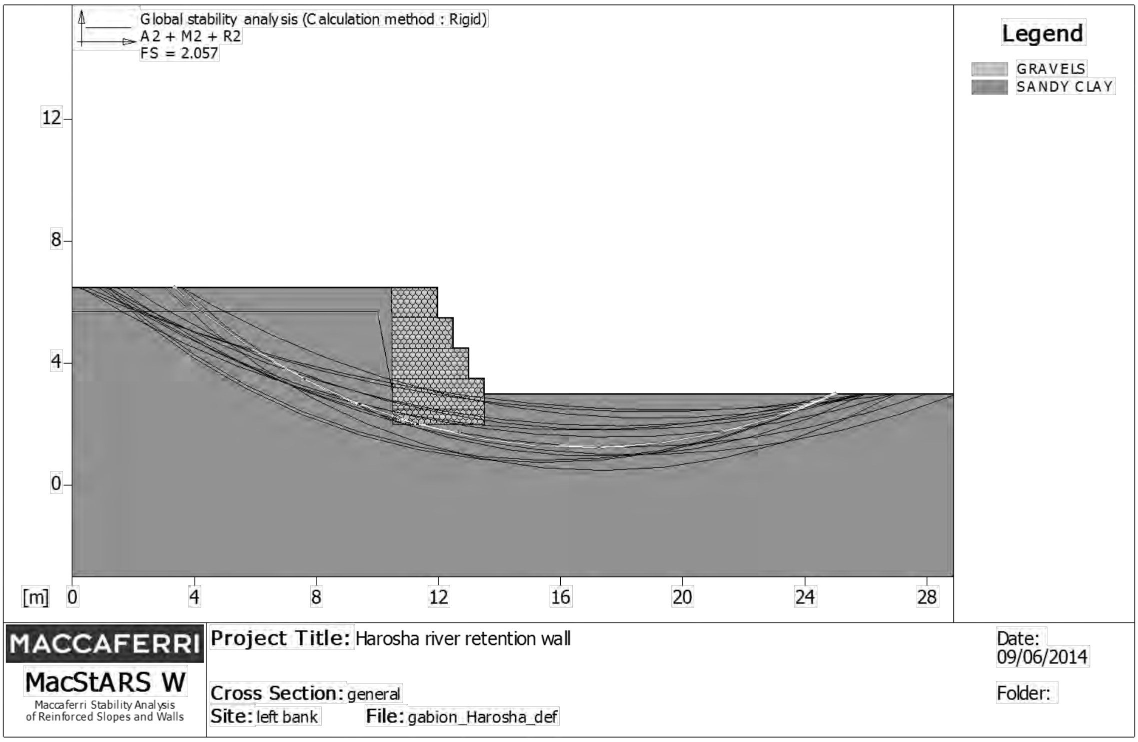
Wall : GAB1

Wall origin [m]: Abscissa = 13.50 Ordinate = 2.00
Wall batter [°] = 0.00

Gabion filling soil: GRAVELS
Backfill soil: SANDY CLAY
Gabion covering soil: SANDY CLAY
Gabion foundation soil: GRAVELS

Layer	Length [m]	Height [m]	Offset [m]
1	3.00	0.50	0.00
2	3.00	1.00	0.00
3	2.50	1.00	0.50
4	2.00	1.00	1.00
5	1.50	1.00	1.50

CHECKS RESULTS



Global Stability Check :

Multiplier combination : A2 + M2 + R2
Reinforcements active Forces according to Rigid Method
Stability analysis with circular surfaces according to Bishop's Method
Evaluated Safety Factor ....: 2.057

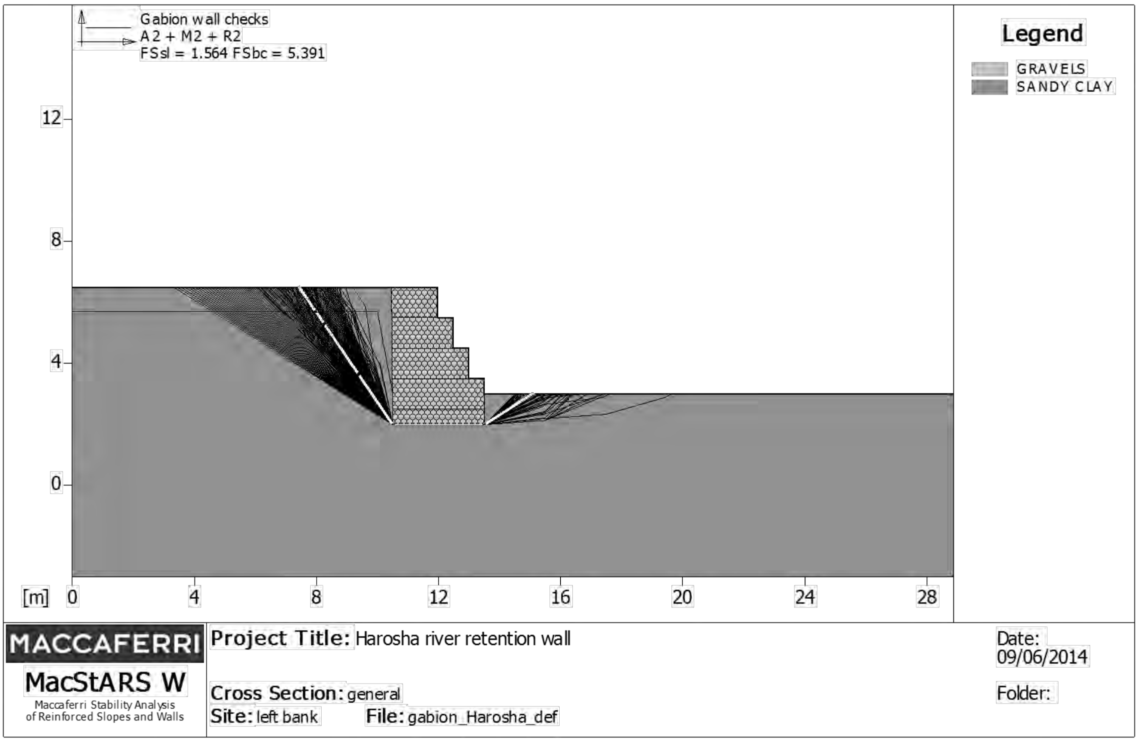
Surfaces searching range

Starting range, abscises [m]		Arrival range, abscises [m]	
First point	Second point	First point	Second point
0.00	4.00	25.00	33.00

Number of starting point on the starting segment ....: 9
Total number of trial surfaces ....: 108
Minimum base length of slices ....[m]......: 2.00
Superior limit search angle ....[°]......: 0.00
Inferior limit search angle ....[°]......: 0.00

Multiplier	Class
1.25	Coeff. Parziale - tangente dell'angolo di resistenza a taglio
1.25	Coeff. Parziale - Coesione efficace
1.40	Coeff. Parziale - Resistenza non drenata
1.00	Coeff. Parziale - Peso dell'unità di volume - favorevole
1.00	Fs Rottura Rinforzi
1.00	Fs Sfilamento Rinforzi
1.10	Coeff. Parziale R - Stabilità

CHECKS RESULTS



Wall Checks :

Multiplier combination : A2 + M2 + R2

Considered block : GAB1

Resistance force [kN/m] : 87.47

Active force [kN/m] : 55.94

Sliding class : Coeff. parziale R - Scorrimento

Sliding safety factor : 1.564

Ultimate bearing pressure [kN/m²] : 341.18

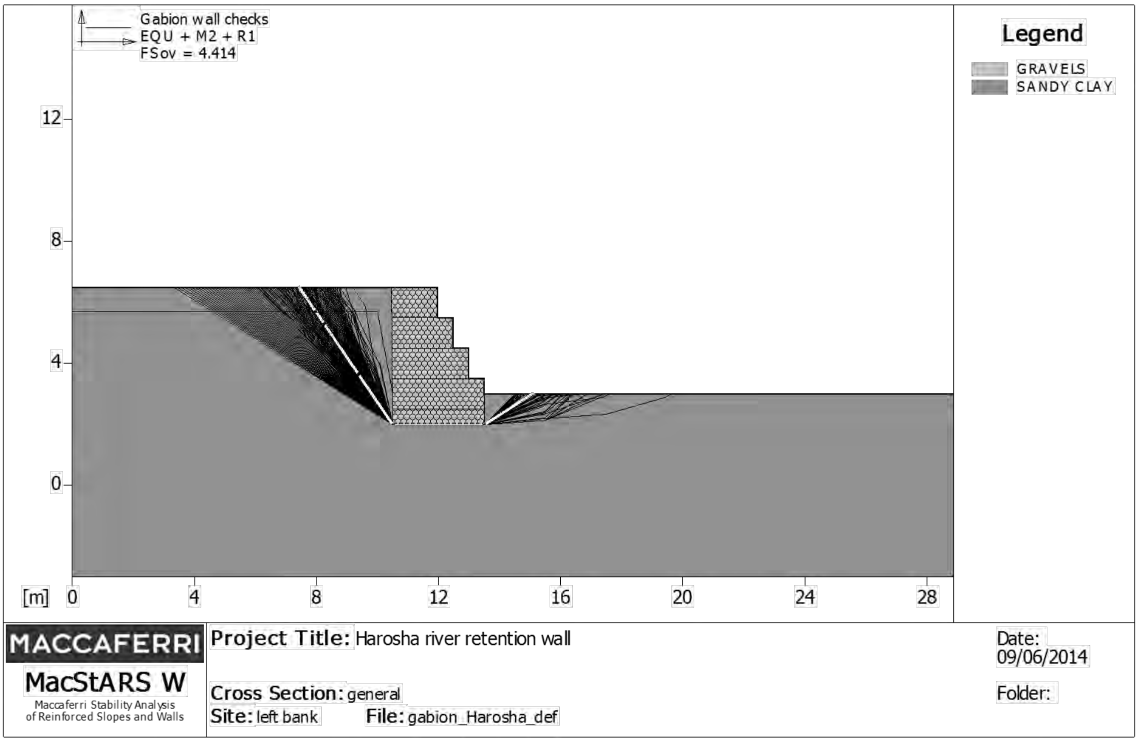
Active pressure [kN/m²] : 63.29

Pressure class : Coeff. parziale R - Capacità portante

Bearing capacity safety factor : 5.391

Multiplier	Class
1.25	Coeff. Parziale - tangente dell'angolo di resistenza a taglio
1.25	Coeff. Parziale - Coesione efficace
1.40	Coeff. Parziale - Resistenza non drenata
1.00	Coeff. Parziale - Peso dell'unità di volume - favorevole
1.00	Coeff. parziale R - Scorrimento
1.00	Coeff. parziale R - Capacità portante

CHECKS RESULTS



Wall Checks :

Multiplier combination : EQU + M2 + R1
Considered block : GAB1
Moment resistance [kN*m/m] : 339.78
Overturning moment [kN*m/m] : 76.97
Overturning class : Coeff. parziale R - Ribaltamento
Overturning safety factor : 4.414

Multiplier	Class
1.25	Coeff. Parziale - tangente dell'angolo di resistenza a taglio
1.25	Coeff. Parziale - Coesione efficace
1.40	Coeff. Parziale - Resistenza non drenata
0.90	Coeff. Parziale - Peso dell'unità di volume - favorevole
1.00	Coeff. parziale R - Ribaltamento

MacStARS W – Rel. 3.0

Maccaferri Stability Analysis of Reinforced Slopes and Walls
Officine Maccaferri S.p.A. - Via Kennedy 10 - 40069 Zola Predosa (Bologna)
Tel. 051.6436000 - Fax 051.236507

giulio

Project Title: Harosha river retention wall

Cross Section: general

Site: left bank

Folder:

File: gabion_Harosha_def_water

Date: 09/06/2014

Checks according to: Norme tecniche per le costruzioni D.M. 14/01/2008
Verifiche nei confronti dello SLU

TABLE OF CONTENTS

SOIL PROPERTIES

Soil: SCL Description: Sandy Clay

Cohesion Class: Coeff. Parziale - Coesione efficace
Cohesion [kN/m²]: 0.00
Friction Angle Class: Coeff. Parziale - tangente dell'angolo di resistenza a taglio
Friction Angle [°]: 30.00
Ru value: 0.00
Weight Class: Coeff. Parziale - Peso dell'unità di volume - favorevole
Bulk unit weight - above GWT [kN/m³]: 17.00
Bulk unit weight - below GWT [kN/m³]: 19.00

Elastic Modulus [kN/m²]: 0.00
Poisson's ratio: 0.30

Soil: STON Description: stones

Cohesion Class: Coeff. Parziale - Coesione efficace
Cohesion [kN/m²]: 0.00
Friction Angle Class: Coeff. Parziale - tangente dell'angolo di resistenza a taglio
Friction Angle [°]: 45.00
Ru value: 0.00
Weight Class: Coeff. Parziale - Peso dell'unità di volume - favorevole
Bulk unit weight - above GWT [kN/m³]: 15.00
Bulk unit weight - below GWT [kN/m³]: 18.00

Elastic Modulus [kN/m²]: 0.00
Poisson's ratio: 0.30

STRATA PROFILES

Stratum: BASE Description:

Soil : SCL

X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]
0.00	5.70	10.00	5.70	10.50	3.00	35.00	3.00

WATER TABLE PROFILES

Water table: FLOOD Description:

X [m]	Y [m]	Y [m]	P [kN/m²]	X [m]	Y [m]	Y [m]	P [kN/m²]
0.00	7.00			35.00	7.00		

WALL

Wall : GAB1

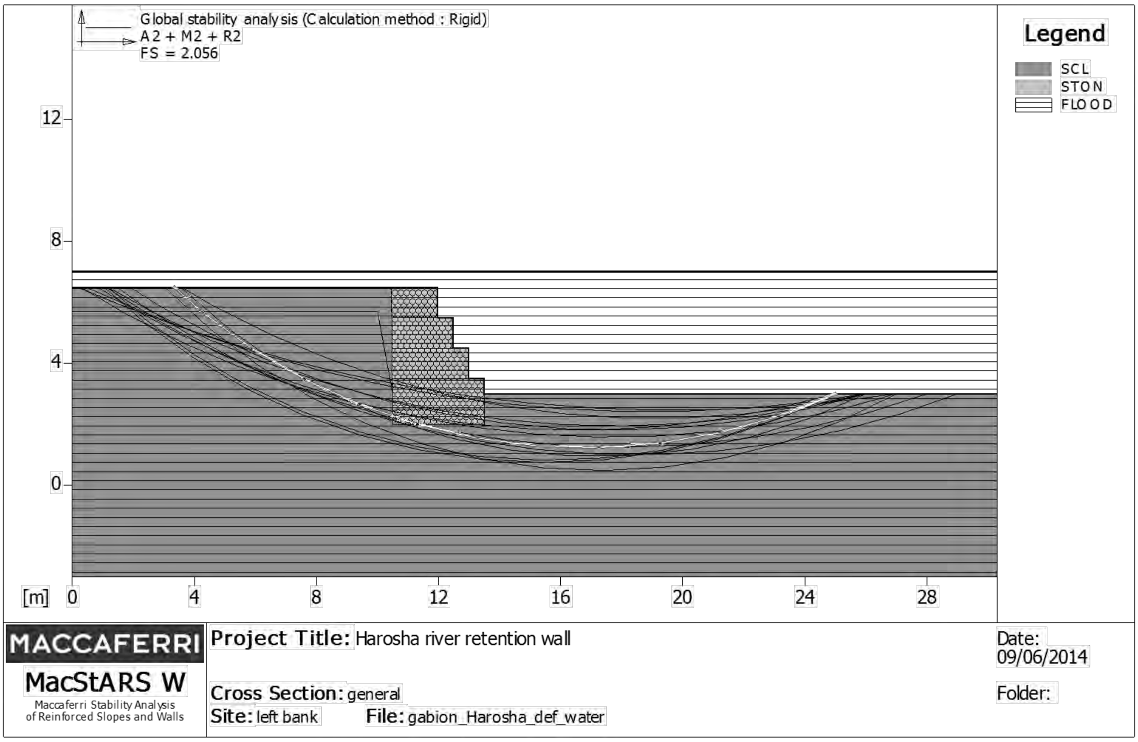
Wall origin [m]: Abscissa = 13.50 Ordinate = 2.00
Wall batter [°] = 0.00

Gabion filling soil: STON
Backfill soil: SCL
Gabion covering soil: SCL
Gabion foundation soil: STON

Layer	Length [m]	Height [m]	Offset [m]

1	3.00	0.50	0.00
2	3.00	1.00	0.00
3	2.50	1.00	0.50
4	2.00	1.00	1.00
5	1.50	1.00	1.50

CHECKS RESULTS



Global Stability Check :

Multiplier combination : A2 + M2 + R2
Reinforcements active Forces according to Rigid Method
Stability analysis with circular surfaces according to Bishop's Method
Evaluated Safety Factor......: 2.056

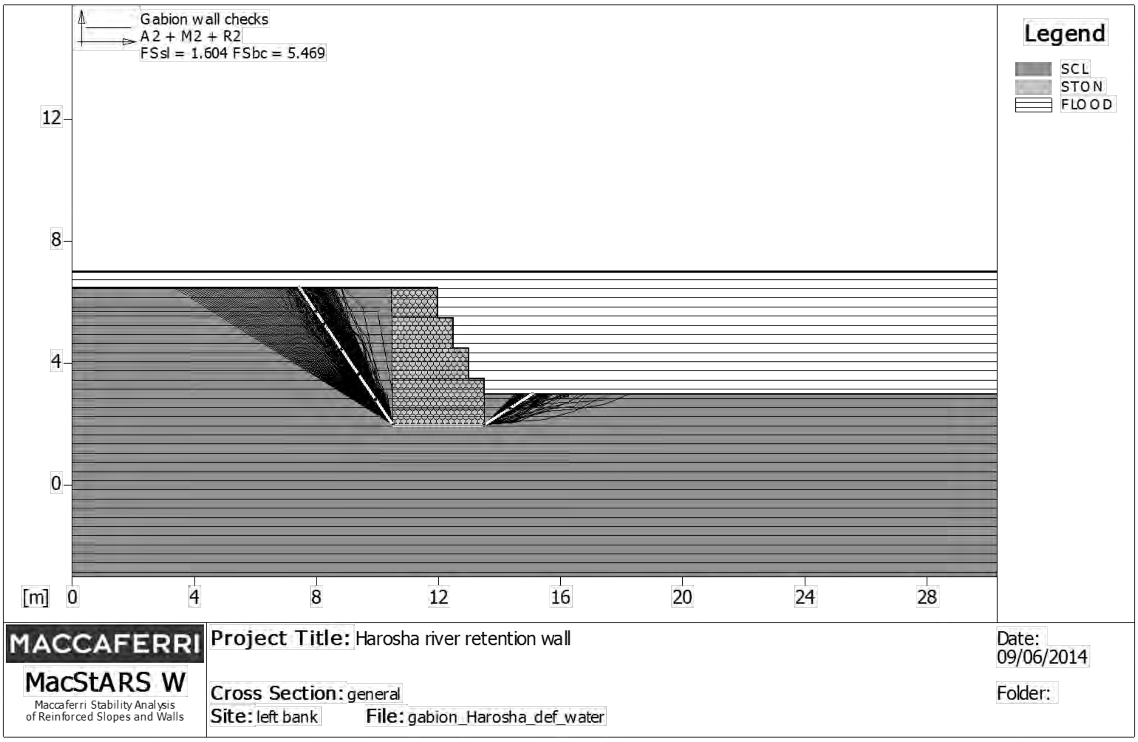
Surfaces searching range

Starting range, abscises [m]		Arrival range, abscises [m]	
First point	Second point	First point	Second point
0.00	4.00	25.00	33.00

Number of starting point on the starting segment......: 9
Total number of trial surfaces......: 108
Minimum base length of slices......[m]......: 2.00
Superior limit search angle......[°]......: 0.00
Inferior limit search angle......[°]......: 0.00

Multiplier	Class
1.25	Coeff. Parziale - tangente dell'angolo di resistenza a taglio
1.25	Coeff. Parziale - Coesione efficace
1.40	Coeff. Parziale - Resistenza non drenata
1.00	Coeff. Parziale - Peso dell'unità di volume - favorevole
1.00	Fs Rottura Rinforzi
1.00	Fs Sfilamento Rinforzi
1.10	Coeff. Parziale R - Stabilità

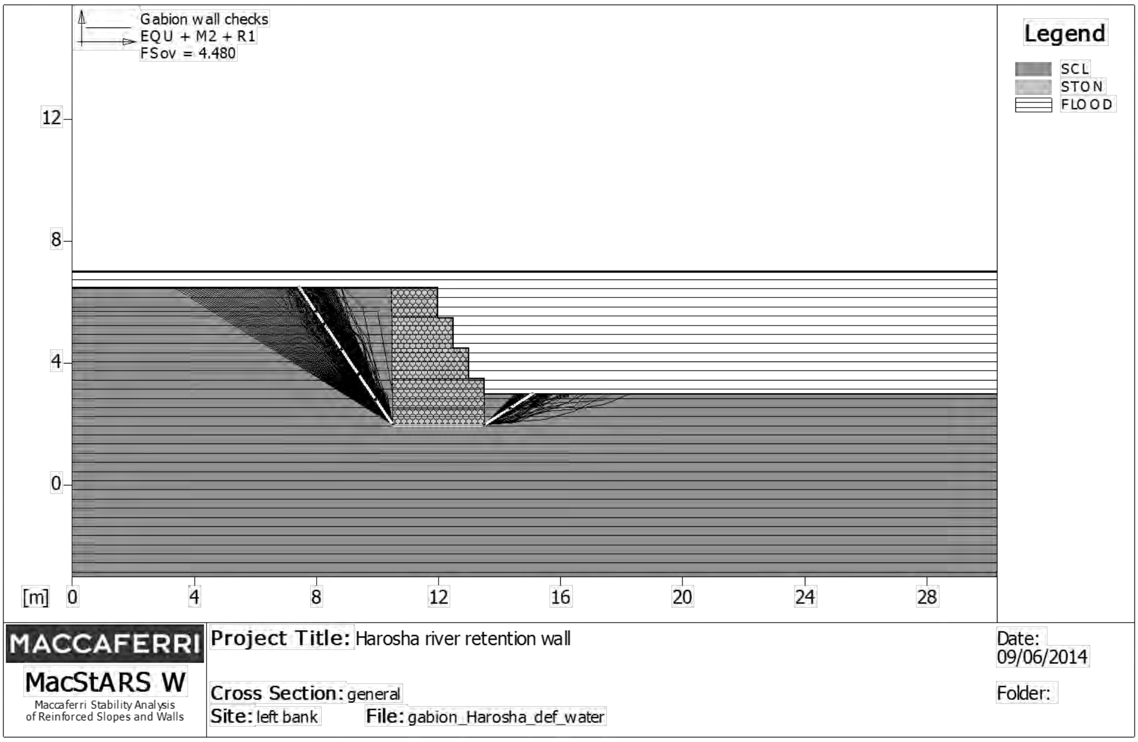
CHECKS RESULTS



Wall Checks :

Multiplier combination : A2 + M2 + R2
Considered block : GAB1
Resistance force [kN/m] : 47.56
Active force [kN/m] : 29.66
Sliding class : Coeff. parziale R - Scorrimento
Sliding safety factor : 1.604
Ultimate bearing pressure [kN/m²] : 187.82
Active pressure [kN/m²] : 34.35
Pressure class : Coeff. parziale R - Capacità portante
Bearing capacity safety factor : 5.469

Multiplier	Class
1.25	Coeff. Parziale - tangente dell'angolo di resistenza a taglio
1.25	Coeff. Parziale - Coesione efficace
1.40	Coeff. Parziale - Resistenza non drenata
1.00	Coeff. Parziale - Peso dell'unità di volume - favorevole
1.00	Coeff. parziale R - Scorrimento
1.00	Coeff. parziale R - Capacità portante



Wall Checks :

Multiplier combination : EQU + M2 + R1
Considered block : GAB1
Moment resistance [kN*m/m] : 163.21
Overturning moment [kN*m/m] : 36.43
Overturning class : Coeff. parziale R - Ribaltamento
Overturning safety factor : 4.480

Multiplier	Class
1.25	Coeff. Parziale - tangente dell'angolo di resistenza a taglio
1.25	Coeff. Parziale - Coesione efficace
1.40	Coeff. Parziale - Resistenza non drenata
0.90	Coeff. Parziale - Peso dell'unità di volume - favorevole
1.00	Coeff. parziale R - Ribaltamento

Checks according to Eurocode 7

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Maccaferri Stability Analysis of Reinforced Slopes and Walls
Officine Maccaferri S.p.A. - Via Kennedy 10 - 40069 Zola Predosa (Bologna)
Tel. 051.6436000 - Fax 051.236507

giulio

Project Title..........: Harosha river retention wall

Cross Section........: general

Site.........: left bank

Folder.....:

File.........: gabion_Harosha_def

Date........: 09/06/2014

Checks according to: Eurocode 7 EN 1997-1
Eurocode 7 EN 1997-1

TABLE OF CONTENTS

SOIL PROPERTIES

Soil: GRAVELS Description: gravels

Cohesion Class: Effective cohesion
Cohesion [kN/m²]: 0.00
Friction Angle Class: Angle of shearing resistance (Tan phi)
Friction Angle [°]: 45.00
Ru value: 0.00
Weight Class: Weight density
Bulk unit weight - above GWT [kN/m³]: 15.00
Bulk unit weight - below GWT [kN/m³]: 18.00

Elastic Modulus [kN/m²]: 0.00
Poisson's ratio: 0.30

Soil: SANDY CLAY Description: Sandy Clay

Cohesion Class: Effective cohesion
Cohesion [kN/m²]: 0.00
Friction Angle Class: Angle of shearing resistance (Tan phi)
Friction Angle [°]: 30.00
Ru value: 0.00
Weight Class: Weight density
Bulk unit weight - above GWT [kN/m³]: 17.00
Bulk unit weight - below GWT [kN/m³]: 19.00

Elastic Modulus [kN/m²]: 0.00
Poisson's ratio: 0.30

STRATA PROFILES

Stratum: BASE Description:

Soil : SANDY CLAY

X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]
0.00	5.70	10.00	5.70	10.50	3.00	35.00	3.00

WALL

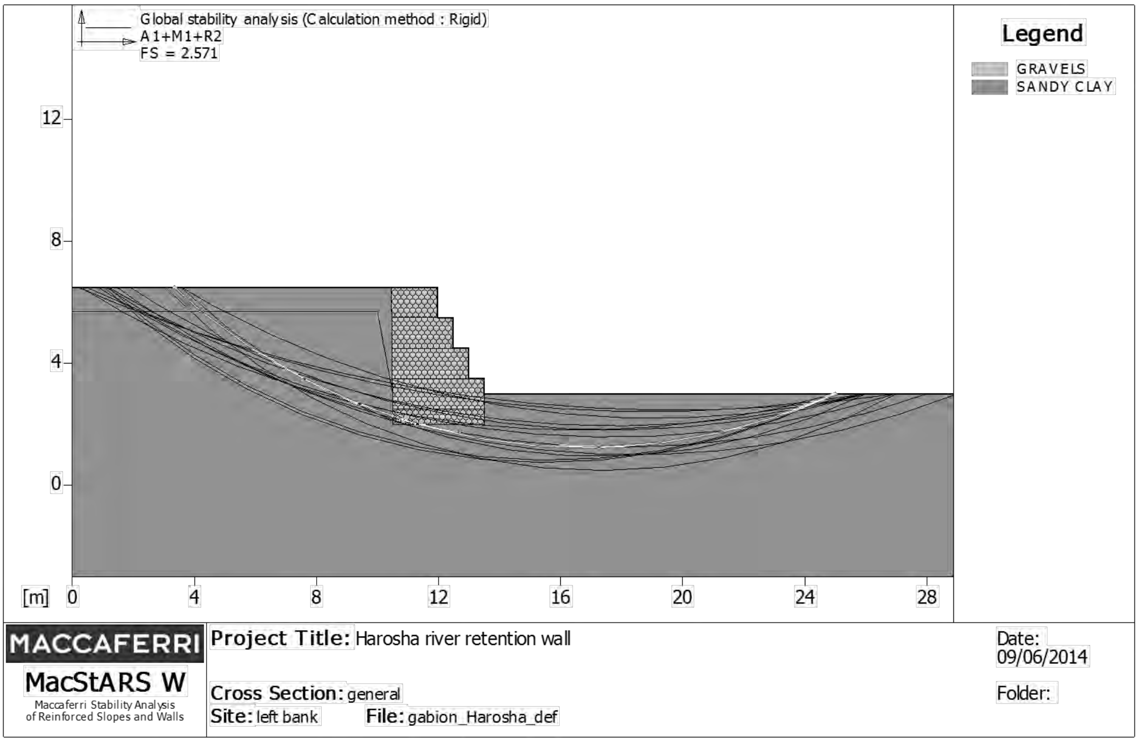
Wall : GAB1

Wall origin [m]: Abscissa = 13.50 Ordinate = 2.00
Wall batter [°] = 0.00

Gabion filling soil: GRAVELS
Backfill soil: SANDY CLAY
Gabion covering soil: SANDY CLAY
Gabion foundation soil: GRAVELS

Layer	Length [m]	Height [m]	Offset [m]
1	3.00	0.50	0.00
2	3.00	1.00	0.00
3	2.50	1.00	0.50
4	2.00	1.00	1.00
5	1.50	1.00	1.50

CHECKS RESULTS



Global Stability Check :
Multiplier combination : A1+M1+R2
Reinforcements active Forces according to Rigid Method
Stability analysis with circular surfaces according to Bishop's Method
Evaluated Safety Factor: 2.571

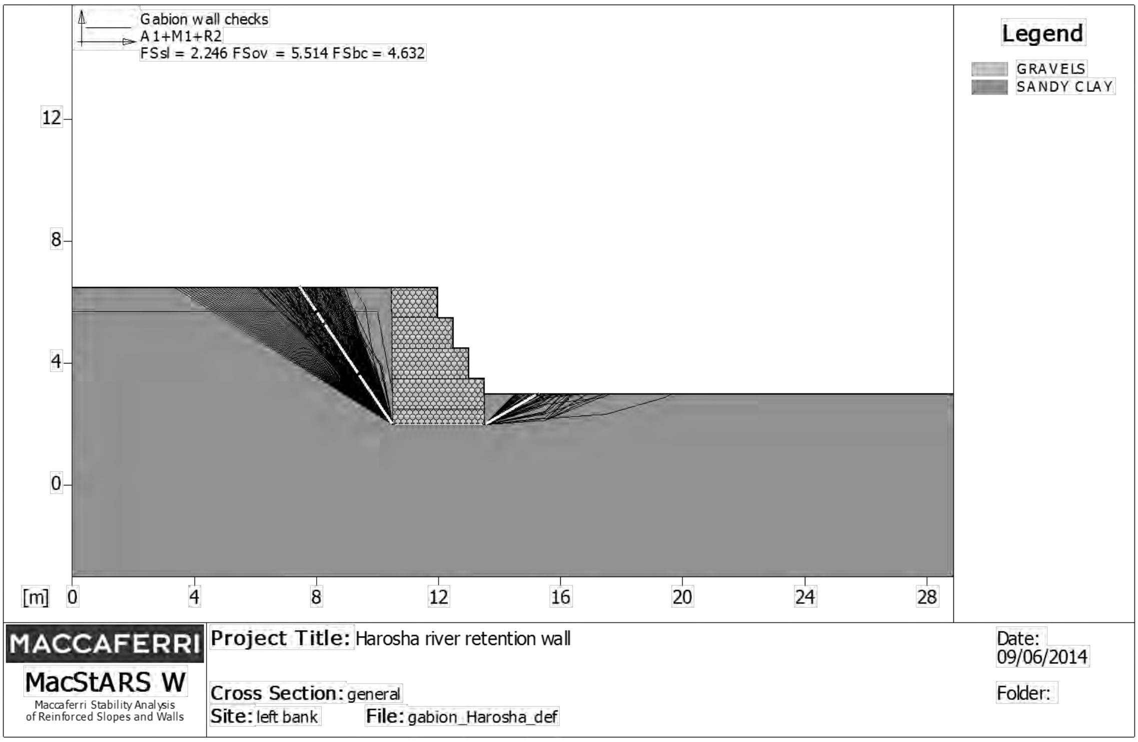
Surfaces searching range

Starting range, abscises [m]		Arrival range, abscises [m]	
First point	Second point	First point	Second point
0.00	4.00	25.00	33.00

Number of starting point on the starting segment: 9
Total number of trial surfaces: 108
Minimum base length of slices [m]: 2.00
Superior limit search angle [°]: 0.00
Inferior limit search angle [°]: 0.00

Multiplier	Class
1.00	Angle of shearing resistance (Tan phi)
1.00	Effective cohesion
1.00	Undrained shear strength
1.00	Weight density
1.00	Tensile strength of reinforcement
1.00	Pullout resistance of reinforcement
1.10	Ground resistance for overall stability

CHECKS RESULTS



Wall Checks :

Multiplier combination : A1+M1+R2
Considered block : GAB1

Resistance force	[kN/m] :	108.50
Active force	[kN/m] :	43.92
Sliding class : Sliding resistance		
Sliding safety factor	:	2.246
Moment resistance	[kN*m/m] :	374.49
Overturning moment	[kN*m/m] :	67.92
Overturning class : Overturning		
Overturning safety factor	:	5.514
Ultimate bearing pressure	[kN/m²] :	402.83
Active pressure	[kN/m²] :	62.12
Pressure class : Bearing capacity		
Bearing capacity safety factor	:	4.632

Multiplier	Class
1.00	Angle of shearing resistance (Tan phi)
1.00	Effective cohesion
1.00	Undrained shear strength
1.00	Weight density
1.10	Sliding resistance
1.40	Bearing capacity
1.00	Overturning

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Maccaferri Stability Analysis of Reinforced Slopes and Walls
Officine Maccaferri S.p.A. - Via Kennedy 10 - 40069 Zola Predosa (Bologna)
Tel. 051.6436000 - Fax 051.236507

giulio

Project Title..........: Harosha river retention wall

Cross Section........: general

Site........: left bank

Folder.....:

File.........: gabion_Harosha_def_water

Date.......: 09/06/2014

Checks according to: Eurocode 7 EN 1997-1
Eurocode 7 EN 1997-1

TABLE OF CONTENTS

SOIL PROPERTIES

Soil: SCL Description: Sandy Clay

Cohesion Class	: Effective cohesion	
Cohesion	[kN/m²] :	0.00
Friction Angle Class	: Angle of shearing resistance (Tan phi)	
Friction Angle	[°] :	30.00
Ru value	:	0.00
Weight Class	: Weight density	
Bulk unit weight - above GWT	[kN/m³] :	17.00
Bulk unit weight - below GWT	[kN/m³] :	19.00
Elastic Modulus	[kN/m²] :	0.00
Poisson's ratio	:	0.30

Soil: STON Description: stones

Cohesion Class	: Effective cohesion	
Cohesion	[kN/m²] :	0.00
Friction Angle Class	: Angle of shearing resistance (Tan phi)	
Friction Angle	[°] :	45.00
Ru value	:	0.00
Weight Class	: Weight density	
Bulk unit weight - above GWT	[kN/m³] :	15.00
Bulk unit weight - below GWT	[kN/m³] :	18.00
Elastic Modulus	[kN/m²] :	0.00
Poisson's ratio	:	0.30

STRATA PROFILES

Stratum: BASE Description:

Soil : SCL

X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]
0.00	5.70	10.00	5.70	10.50	3.00	35.00	3.00

WATER TABLE PROFILES

Water table: FLOOD Description:

X [m]	Y [m]	Y [m]	P [kN/m²]	X [m]	Y [m]	Y [m]	P [kN/m²]
0.00	7.00			35.00	7.00		

WALL

Wall : GAB1

Wall origin [m] : Abscissa = 13.50 Ordinate = 2.00

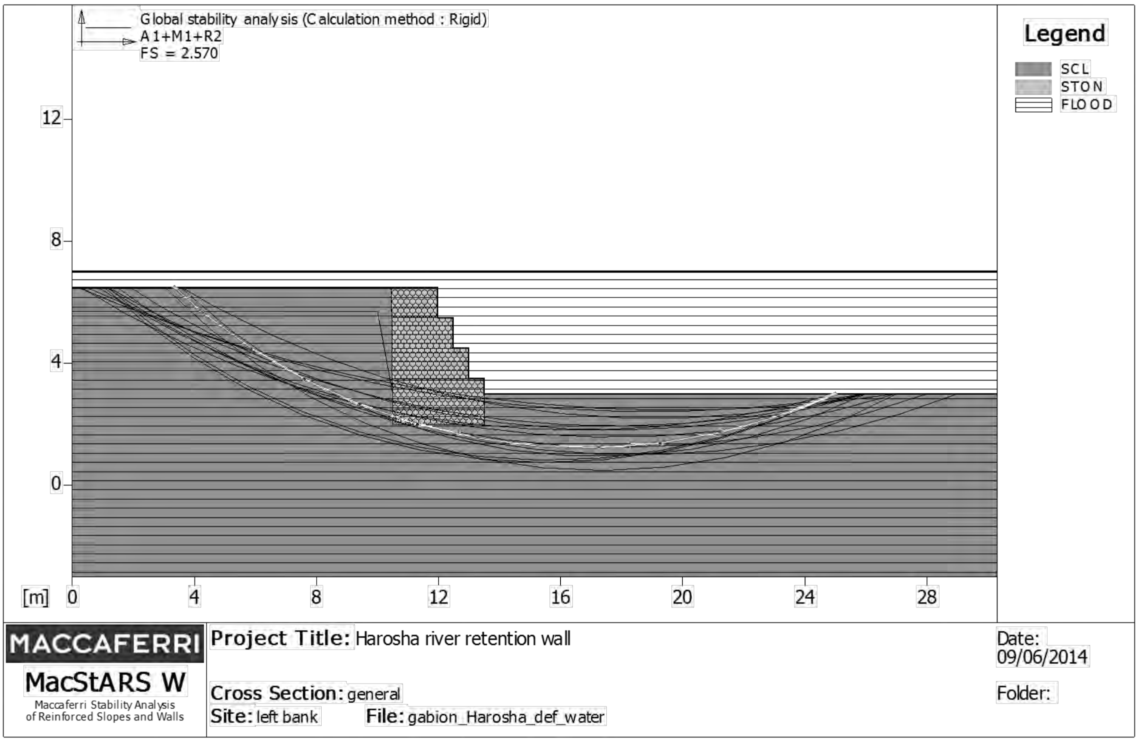
Wall batter [°] = 0.00

Gabion filling soil	: STON
Backfill soil	: SCL
Gabion covering soil	: SCL
Gabion foundation soil	: STON

Layer	Length [m]	Height [m]	Offset [m]

1	3.00	0.50	0.00
2	3.00	1.00	0.00
3	2.50	1.00	0.50
4	2.00	1.00	1.00
5	1.50	1.00	1.50

CHECKS RESULTS



Global Stability Check :
Multiplier combination : A1+M1+R2
Reinforcements active Forces according to Rigid Method
Stability analysis with circular surfaces according to Bishop's Method
Evaluated Safety Factor: 2.570

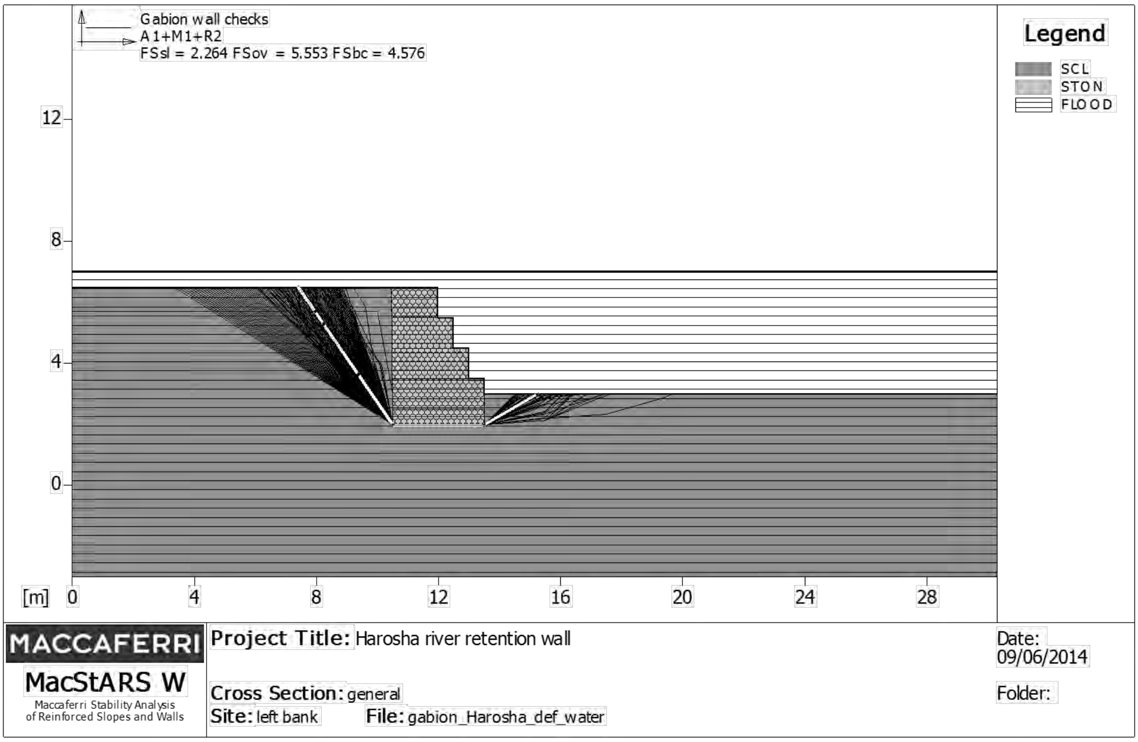
Surfaces searching range

Starting range, abscises [m]		Arrival range, abscises [m]	
First point	Second point	First point	Second point
0.00	4.00	25.00	33.00

Number of starting point on the starting segment: 9
Total number of trial surfaces: 108
Minimum base length of slices [m]: 2.00
Superior limit search angle [°]: 0.00
Inferior limit search angle [°]: 0.00

Multiplier	Class
1.00	Angle of shearing resistance (Tan phi)
1.00	Effective cohesion
1.00	Undrained shear strength
1.00	Weight density
1.00	Tensile strength of reinforcement
1.00	Pullout resistance of reinforcement
1.10	Ground resistance for overall stability

CHECKS RESULTS



Wall Checks :

Multiplier combination : A1+M1+R2
Considered block : GAB1
Resistance force [kN/m] : 59.14
Active force [kN/m] : 23.75
Sliding class : Sliding resistance
Sliding safety factor : 2.264
Moment resistance [kN*m/m] : 203.94
Overturning moment [kN*m/m] : 36.72
Overturning class : Overturning
Overturning safety factor : 5.553
Ultimate bearing pressure [kN/m²] : 216.91
Active pressure [kN/m²] : 33.86
Pressure class : Bearing capacity
Bearing capacity safety factor : 4.576

Multiplier	Class
1.00	Angle of shearing resistance (Tan phi)
1.00	Effective cohesion
1.00	Undrained shear strength
1.00	Weight density
1.10	Sliding resistance
1.40	Bearing capacity
1.00	Overturning

Annex III: Gabion wall - Internal pressure check calculations

ϒ_fill	specific weight gabions fill
d_wire	diameter of gabion wire
ϒ_soil	specific weight soil
ϕ	soil friction angle
c	soil cohesion
q	overweight over soil surface per unit length
β	angle from the vertical of hillside surface
i	wall angle
δ	soil-gabion friction angle (assumed = soil friction angle)
Ka	soil pressure coefficient
B	interface length
h	height of the block immediately over the interface
h_cum	height of the blocks over the interface
S1	overweight over soil surface
S2	soil pressure
S	total soil pressure
Sh	horizontal component of total soil pressure
Sv	vertical component of total soil pressure
W	gabion weight for single block
W_cum	total gabion weight over the selected interface
N	force normal to the surface
T	shear force applied to the section
ϕ*	gabion internal friction angle
Pu	metallic net density
cg	gabions internal apparent cohesion
τ	shear stress acting on a gabion surface
τ_adm	maximum admissible structural shear stress by gabions
σ_max	maximum normal pressure on a gabion section
σ_amm	maximum admissible structural normal pressure by gabions
S1h	horizontal component of the overweight over soil surface
S2h	horizontal component of the soil pressure
b1h	distance from barycentre for S1h
b2h	distance from barycentre for S2h
MSh	momentum of horizontal components
bv	distance from barycentre for Sv
MSv	momentum of vertical components
W_over	weight over a surface
MW	momentum of wall internal weight
M	total momentum
e	eccentricity

gabions

d_wire	2.7	mm
ϒ_fill	15	kN/m3

foundation

ϒ_soil	17	kN/m3		
ϕ	30	°	0.523599	rad
c	0	kN/m3		
q	0	kN/m3		

β	90	°	1.570796	rad
i	0	°	0	rad
δ	30	°	0.523599	rad

Ka	0.297

interface	B	h	h_cum	S1	S2	S	Sh
	m	m	m	kN/m	kN/m	kN/m	kN/m
1 - 2	1.5	1	1	0.00	2.53	2.53	2.19
2 - 3	2	1	2	0.00	10.10	10.10	8.75
3 - 4	2.5	1	3	0.00	22.73	22.73	19.69
4 - 5	3	1	4	0.00	40.42	40.42	35.00

interface	Ag	W	W_cum	N	T
	m2	kN/m	kN/m	kN/m	kN/m
1 - 2	1.5	22.5	22.5	23.76	2.19
2 - 3	2	30	52.5	57.55	8.75
3 - 4	2.5	37.5	90	101.37	19.69
4 - 5	3	45	135	155.21	35.00

ϕ*	27.5	°	0.479966	rad
Pu	6.66	kg/m3		
cg	0.1498	kg/cm2	14.98	kN/m2

interface	τ	τ_adm	σ_max	σ_amm
	kN/m2	kN/m2	kN/m3	kN/m3
1 - 2	1.46	23.23	15.65051	450
2 - 3	4.38	29.96	26.54223	450
3 - 4	7.88	36.09	36.70275	450
4 - 5	11.67	41.91	46.73834	450

interface	b1h	b2h	S1h	S2h	MSh	bv	MSv
	m	m	kN/m	kN/m	kNm/m	m	kNm/m
1 - 2	0.5	0.33	0.00	2.19	0.73	0.75	0.95
2 - 3	1	0.67	0.00	8.75	5.83	1	5.05
3 - 4	1.5	1.00	0.00	19.69	19.69	1.25	14.21
4 - 5	2	1.33	0.00	35.00	46.67	1.5	30.31

interface	W_over	MW
	kN/m	kNm/m
1 - 2	0.00	
2 - 3	22.50	5.625
3 - 4	30.00	18.75
4 - 5	37.50	41.25

M	e	σmax
kNm/m	m	kN/m3
0.22	-0.00918	15.65051
4.84	-0.08416	26.54223
13.27	-0.13092	36.70275
24.89	-0.16039	46.73834

σamm
kN/m3
450