UPTEC W04 009
Examensarbete 20 p
Februari 2004

Water Supply for Irrigation of Balda Lupaxi Bajo, Chimborazo, Ecuador

Vattentillgång för bevattning av Balda Lupaxi Bajo, Chimborazo, Ecuador

---

Sonja Halmstad

ABSTRACT

This report is a part of a prefeasiblity study to investigate the possibilities to introduce an irrigation system in a rural part of the Andes in Ecuador. The report concentrates on the water supply for the prefeasability study called *Estudio de Prefacitbilidad de un Proyecto de Riego en los Andes – el Caso de Balda Lupaxi Bajo, Chimborazo, Ecuador*. The field study was carried out in March to May 2003 in the indigenous village of Balda Lupaxi Bajo situated in the province of Chimborazo. In this area the precipitation is inferior throughout the year. Consequently the harvest is poor and it is not possible to cultivate during parts of the year. The project was initiated by UNASAC, an indigenous organization for farmers. UNASAC would use this report for finding finances to complete further studies and finally implement an irrigation system.

The main aims of this report are to identify a suitable site for water supply and to determine the size of the area possible to irrigate. Further, a distribution design of the water supply has been investigated. This was carried out by field studies, water analyses, interviews and processing of hydrological and meteorological data.

Four alternatives of water supply were studied, both river and ground water. The most appropriate water supply according to the study is the Llinllin River. The other investigated alternatives were rejected due to lack of water, insufficient water quality and high costs. The Llinllin River alternative consists of a direct abstraction, open channels and a siphon. This alternative can support 250 hectares under the constraints taken in this study.

In order to continue this project the farmers need to solve the social problems within and between the villages. An improvement of the communication with the nearby villages is necessary. There are many stakeholders involved in the usage of the Llinllin River and therefore it is of great importance to find a sustainable solution for the water abstraction.

Keywords: prefeasability study, irrigation, water supply, MFS, Andes, Columbe

SAMMANFATTNING

Denna rapport är en del av en förstudie som syftar att undersöka möjligheterna för ett bevattningsprojekt i de ecuadorianska Anderna. Rapport koncentrerar sig på vatten-tillgången för förstudien *Estudio de Prefacitbilidad de un Proyecto de Riego en los Andes – el Caso de Balda Lupaxi Bajo, Chimborazo, Ecuador*. Fältundersökningarna gjordes under mars till och med maj 2003 i Balda Lupaxi Bajo, en indian-by i provinsen Chimobrazo. I detta område är nederbörden bristfällig och följaktligen är skörden dålig och det är inte möjligt att bruka jorden under delar av året. Idén till projektet initierades av en bonde-förening som kallas UNASAC. UNASAC kommer att använda rapporten i sitt sökande efter finansiellt stöd för fördjupande studier och slutligen ett genomförande av projektet.

Målet med denna delrapport är att identifiera en lämplig plats för vattenuttag och att bestämma hur många hektar som kan bevattnas. Vidare presenteras ett förslag till utformning av vattenavledningen. Studien har gjorts genom fältstudier, vattenanalyser, intervjuer och bearbetning av hydrologiska och meteorologiska data.

Fyra vattenuttagsalternativ undersöktes, både flod- och grundvatten. Det mest lämpliga alternativet enligt denna studie är floden Llinllin. De andra undersökta alternativen förkastades på grund av brist på vatten, otillräcklig vattenkvalitet och höga kostnader. Llinllin-alternativet består av en direkt avledning, en öppen kanal och en sifon. Alternativet kan försörja 250 hektar av bevattnad odlingsmark under de antaganden som är gjorda i rapporten.

För att fortsätta med detta projekt måste bönderna lösa de sociala problem som finns i och mellan byarna. Kommunicationen med de närliggande byarna är nödvändig. Det finns många intressenter av Llinllin floden och det är nödvändigt att finna en hållbar lösning för vattenuttaget.

Nyckelord: förstudie, bevattning, vattentillgång, MFS, Anderna, Columbe

PREFACE

This study is a part of the report “Prefeasability Study of an Irrigation Project in the Andes – Case study of Balda Lupaxi Bajo, Chimborazo, Ecuador” by Halmstad and Lindell (2004) and is a Master’s Thesis report at the Aquatic and Environmental program at Uppsala University in Sweden. The field study was carried out together with Lina Lindell in Ecuador in the spring of 2003 and the writing of the report during the fall of 2003. The study is financed by the Swedish International Development Cooperation Agency (Sida) as a Minor Field Study (MFS) and Göransson and Sandvikens travel scholarship. The MFS was received through the Committee of Tropical Ecology at the Uppsala University.

The Swedish supervisor was Allan Rodhe, professor in Hydrology at Uppsala University, who also was the examiner. The supervisor in Ecuador was Oswaldo Pérez, mechanical engineer at the University in Riobamba, ESPOCH.

To get a more comprehensive view it is recommended to read the whole prefeasablility study that also include social aspects and the determination of the water demand.

This report would not have been possible without the help and support of the people I have met during my work both in Ecuador and Sweden. There are some I would like to give a special thank you to…

… the employees at the hydrology department of INAMHI in Quito, especially Javier Roura.
… Susana Nuñez and coworkers at MAG in Quito.
… Luis Pilatsig at the Ministry of Energy and Mines for his help with the geology.
… Marybell Montenegro G. at CNRH for her enthusiasm.
… Marco Vivar, Angel Baño and David Flores at DCF for the fieldtrips.
… Sonia Rosera, José Franklin Arcos Torres and Jorge Segovia at ESPOCH.
… the Coro’s family and the people of Balda that assisted the fieldwork.
… Anders Gustafsson and Lennart Strömquist at SWECO with their families for their support and inspiration.

… PO Hårdén and Andreas Gyllenhammar at Uppsala University for their help with the GIS.
… Chong-Yu Xu at Uppsala University for his help with processing the meteorology and hydrology data.
… my supervisor Allan Rodhe at Uppsala University.
… my supervisor Oswaldo Pérez at ESPOCH with family for their support and understanding.
… Lina Lindell for good companionship.
…my mother and father for their help with the revision of the language.

Uppsala, the 20th of January 2004

UPTEC W 04 009, ISSN 1401-5765
Department of Earth Sciences, Air and Water Science, Uppsala University.
Printed at the Department of Earth Sciences, Uppsala University, Uppsala, Sweden 2004

ACRONYMS

	English	Spanish
CLIMAN	Climatic Monthly Analysis	
CNRH	National Council of Hydrologic Resources , Ecuador	*Consejo Nacional de Recursos Hídricos*
CODERECH	Regional Corporation of Development in Chimborazo, Ecuador	*Corporación de Desarrollo Regional de Chimborazo,*
DFC	Agricultural Forestry Development	*Desarrollo Forestal Campesino*
ESPOCH	The University in Riobamba, Ecuador	*Escuela Superior Politécnica del Chimborazo*
FAO	Food and Agriculture Organization of the United Nations	
GIS	Geographical Information System	
GPS	Global Positioning System	
IGM	The Military Institute of Geography, Ecuador	*Instituto Geográfico Militar*
INAMHI	The National Institute of Meteorology and Hydrology, Ecuador	*Instituto Nacional de Meteorología e Hidrología*
INDA	National Agrarian Institute, Ecuador	*Instituto National de Desarrollo Agrario*
INERHI	The National Institute of Hydraulic Resources, Ecuador	*Instituto Ecuatoriano de Recursos Hidráulicos*
MAG	The Ministry of Agriculture, Ecuador	*Miniterio de Agricultura y Granadería*
MFS	Minor Field Study	
ORSTROM	French Institute for Scientific Research for Development	
Sida	Swedish International Development Cooperation Agency	
UNASAC	Agricultural Organization in Columbe	*Unión de Asociaciones de Trabajadores Agrícolas de Columbe*

TABLE OF CONTENTS

1 INTRODUCTION

This project was initiated by UNASAC, *Unión de Asociaciones de Trabajadores Agrícolas de Columbe,* an organization for some indigenous communities located in the Andes of Ecuador. UNASAC is active in the rural parish of Columbe, a part of the province of Chimborazo, situated in the central part of the country. Columbe is located about 3 100 meter above the sea level (m a.s.l.) in a very dry part of the Andes. The area is often affected by frosts, hail and winds. The inhabitants of the parish are farmers and are mostly indigenous. The cultivated land is situated on 3 100 to 3 300 m a.s.l. and a number of different crops are cultivated today such as wheat, corn, peas and potatoes. The agricultural land is mainly dry, sandy and short of organic material. This means that the water holding capacity is low. Consequently the harvest is very poor and according to some locals it is impossible to cultivate between July and January. The pastureland has become less productive than before and for that reason the amount of cattle has decreased. The situation for the farmers in the area is insecure as the chance of achieving a good harvest depends on when the frost occurs and when the unreliable rain falls. To secure the food production in the area UNASAC wishes to implement an irrigation system. Today there is no irrigation in the Columbe area. An irrigation system would be very helpful for the communities, as it would increase the value and the productivity of the land. Today the farmers harvest once a year but with irrigation they could harvest twice.

Throughout the Andean history irrigation has been a fundamental natural resource. There are technical evidences of irrigation activities from the time before the Hispanics and the Incas. During the prehispanic and preinca ages the irrigation technologies were based on the social structure of the community (Noordholland de Jong et. al., 1999). The most common way of irrigation was gravity fed systems. Another way of dealing with the water shortage was to bring the field to the source of water. Some of these methods were fields watered by the humidity of low clouds and fields dug close to the water table (Boelens et. al., 1998). During the Inca age (12th to 15th century) the amount of arable land increased by intensive terracing of mountain slopes to improve irrigation and decrease erosion. The Incas also built irrigation systems in warm and dry valleys where framing previously had been difficult. During the Spanish colonization the social structure changed and therefore also the way of irrigation. The Hispanics brought along their water laws and regulations from Spain. The Spanish water regulations ignored the traditional rights and customs (Noordholland de Jong et. al., 1999).

Today it is still common with irrigation in the Andes. Two irrigation projects were visit during the fieldwork in Ecuador: San Juan and Licto, both in the province of Chimborazo . San Juan is a small project that started as a soil conservation project. The project includes irrigation with minisprinklers, terraces, composting, greenhouse cultivation and a guinea pig farm. The site is about 0.5 ha and is located at 3 450 m a.s.l.. The irrigation water is collected from rivers at higher elevation and transported to a small tank close to the field. The Licto project involves irrigation of 1 100 ha in 17 villages. Most irrigation is done by furrows. The water intake in this project is also from rivers at a higher elevation and transported by open channels and siphons to the fields.

UNASAC is an umbrella organization for the agricultural workers in Columbe. The organization includes 16 communities and works for improving the situation of the farmers. At present time UNASAC is less active than earlier and there are only a few members involved in the organization. There is hope that an irrigation project could bring the organization to life again.

The aim of this project is to make a part of a prefeasibility study to find out if it is possible to implement an irrigation system in Balda Lupaxi Bajo, Chimborazo, Ecuador. UNASAC will use the prefeasablility study to apply for financial aid from national organizations or the government. Therefore this document is aimed at local water ministries and organizations and is intended to support the development of agriculture in the region.
The specific goals of this study are:

- to investigate water supply and distribution alternatives
- to determine possible acreage to irrigate

This is accomplished by analyzing data and information gathered in Ecuador during April and May 2003. Fieldwork such as interviewing and hydrological investigations including water sampling was also carried out during this period. The university of Riobamba analyzed the samples regarding both physical and chemical parameters.

2 THE STUDY AREA

Columbe is a parish 30 km south of Riobamba in the Chimborazo province (Figure 2.1 and 2.2). The capital, also called Columbe, is situated a couple of kilometers off the Pan American Highway. The parish holds 16 169 inhabitants in 80 different villages (Ministerio del Ambiente, 2000). The climate is affected by the high altitude. The average temperature in Columbe, at a height between 3 100 - 4 200 m a.s.l., is 13ºC and the average yearly precipitation is less than 400 mm. The precipitation is uneven and has tended to gradually decrease (Comité National sobre el Clima, 2001).

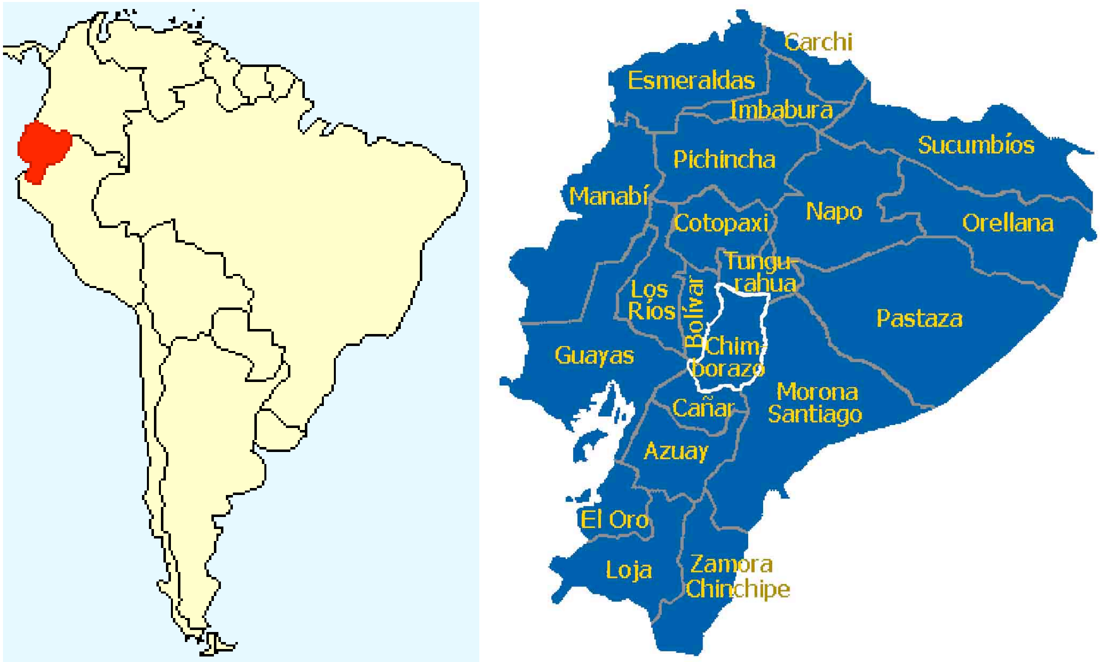


Figure 2.1 Ecuador and its provinces

Balda Lupaxi Bajo is an indigenous community in the parish of Columbe. 150 families live in the village and totally the village has about 1 000 inhabitants. The main occupation is agriculture. There is no other source of income in the village. There are piped water and electricity in the village even though these domestic services are not reliable. There is no sanitary service. A dirt road runs though the village that becomes damaged during the rainy seasons. Most of the cultivation is carried out on the hillsides and the cattle are kept on a pasturage land. The land of Balda Lupaxi Bajo with surroundings belonged to a hacienda until the land reforms in the 1970s. The hacienda in Balda Lupaxi Bajo had a water tank for irrigation of their pasturage. A national law in the 1970s made the hacienda owners move out and sell their land quite peacefully. The farmers could now buy the land from the National Agrarian Institute, INDA, which was responsible for legalization and expropriation of land in Ecuador. Two groups were formed in the village. One group thought that a communal form of farming was to be preferred and the other wanted each farmer to have his own land. In reality the latter occurred. Each farmer got plots in different parts of the Columbe parish, not only within the village of Balda Lupaxi Bajo. Today these plots have been divided into even smaller parts when parents share the land among their children.

Henceforward the abbreviation Balda will represent Balda Lupaxi Bajo if nothing else is mentioned. There is a village called Balda Alto about 4 kilometers east of Balda Lupaxi Bajo that should not be mistaken for Balda Lupaxi Bajo.

Figure 2.2 Chimborazo province

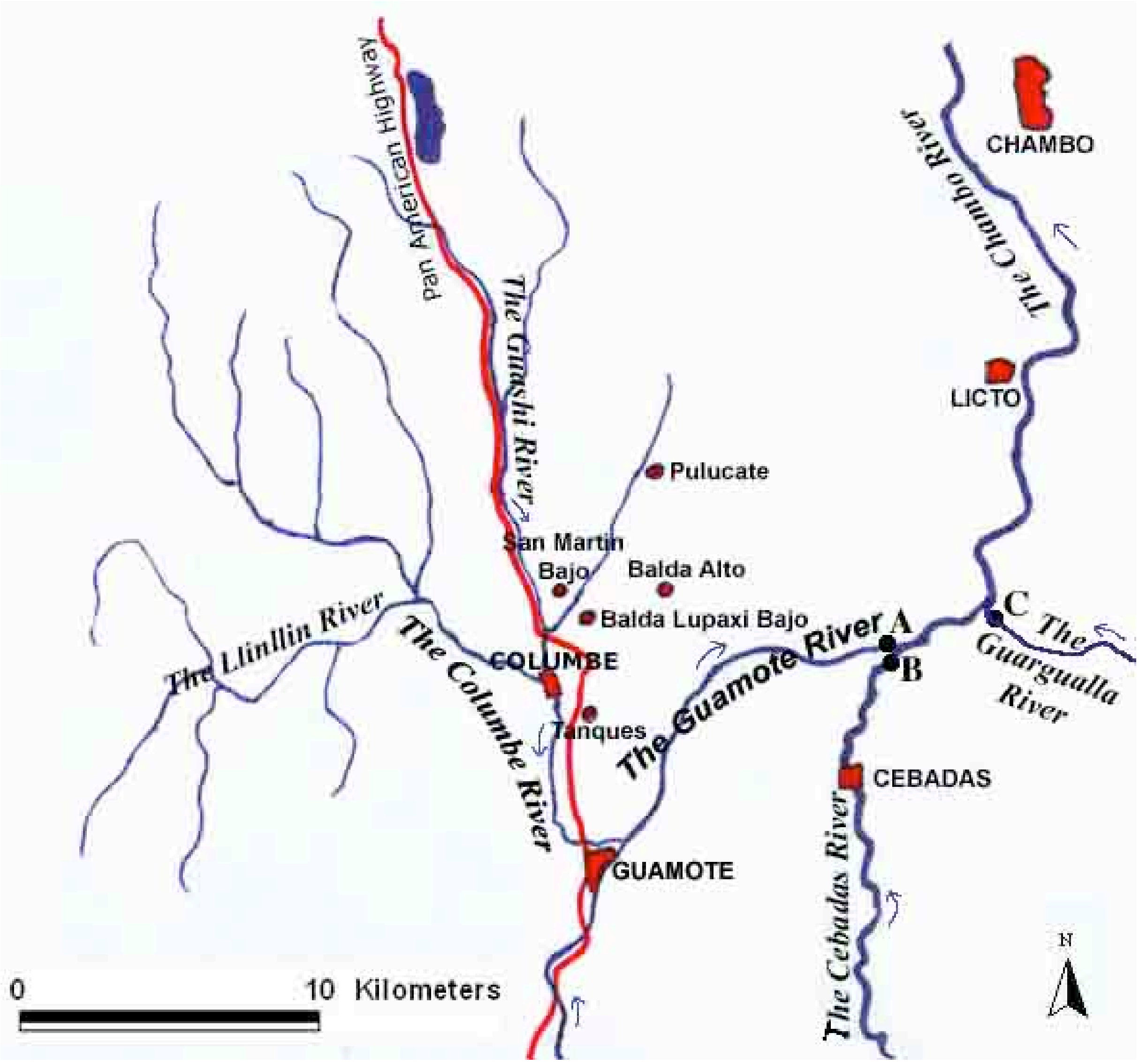


Figure 2.3 Columbe with surroundings. A, B and C are discharge stations.

3 WATER DEMAND AND PRESENTATION OF THE WATER SUPPLY ALTERNATIVES

In this part of the report the water demand and choices of water supply and distribution will be presented. The choices of alternatives were based on the study of suitable zones for irrigation, discussions with the locals, observations in the area, studies of the topographic maps and the economical constraints. Investigations of the soil, crop use, climate and socio-economics were done to find the water demand and suitable zones to irrigate. The water demand and suitable zones to irrigate is represented in the *Estudio de Prefactibilidad de un Proyecto de Riego en los Andes – el Caso de Balda Lupaxi Bajo, Chimborazo, Ecuador* (Halmstad & Lindell, 2004). The areas that were studied are the parts of Columbe parish that belong to the people of Balda. As mentioned before, the property of the people of Balda spreads out in different parts in the Columbe parish, not necessary physically connected to the village of Balda. The areas that were investigated, Loma Gaushi, Gampala and the Pasturage, are shown in Figure 3.1.

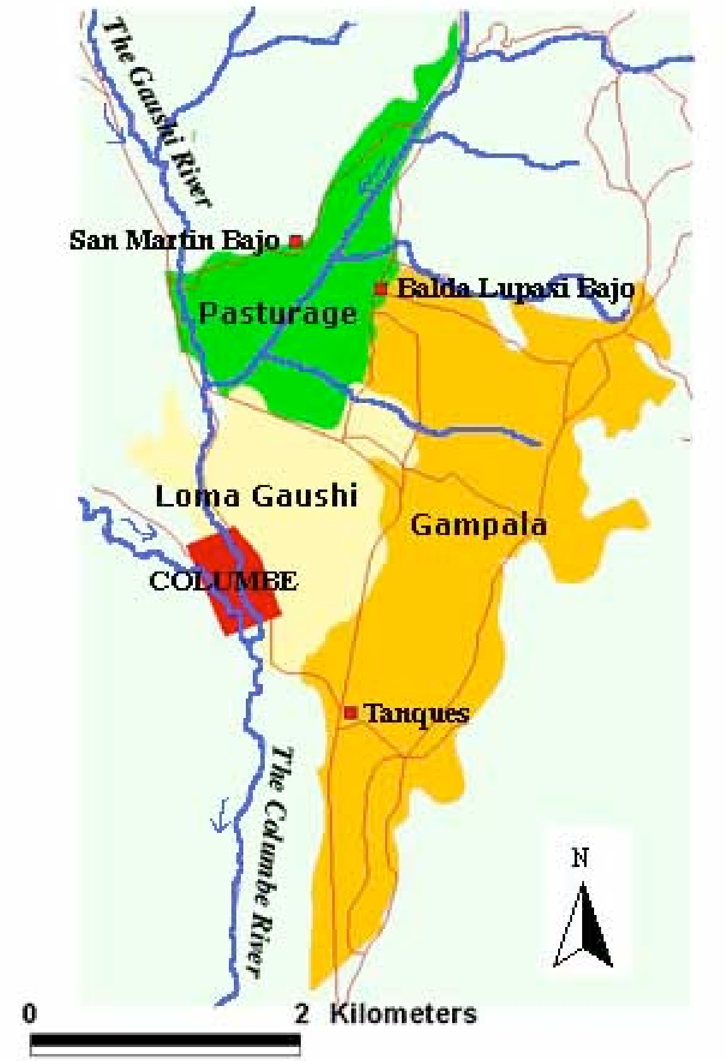


Figure 3.1 The zones of investigation

3.1 Suitable zones to irrigate

The conclusions made by Halmstad & Lindell (2004) were that the most suitable area to irrigate are the slopes of Gampala. The pasturage between Balda and San Martin Bajo is saturated with water during parts of the year. It would be difficult and expensive to drain the zone to achieve land suitable to cultivate. The pH is high in this part and that could limit the choice of crops. Loma Gaushi has the problem of severe erosion. The soil has poor water holding capacity due to its shallowness and texture. Because the erosion is advanced it is necessary to take actions to regain the soil. Planting eucalyptus trees that have the capacity to percolate the hard ground could be one option. The last alternative is Gampala. Even this part has problems with erosion but not as severe as Loma Gaushi. In order to create optimal cultivation at Gampala improvements of the soil texture and nutrition level together with constructing terraces are needed. The erosion of the slopes is a problem that could worsened by irrigation if proper soil conserving techniques are not used. (Halmstad & Lindell, 2003)

3.2 Water demand

According to the local farmers they would grow vegetables and alphalpha if they had irrigation. The water demand for potatoes, carrots and alphalpha were calculated in order to represent the variety of possible crops. The average water demand is presented in Table 3.1. Monthly calculated water demand for the years of 1964-1967 and 1971-1978 is shown in Appendix 1. The average maximum water demand during the calculated years was 0.25 l/(s ha). (Halmstad & Lindell, 2004)

Table 3.1 Calculated water demand in millimeters for potatoes, carrots and alphalpha. Source: Halmstad & Lindell, 2004.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Potatoes	68	46	44	27	-	-	-	-	-	-	24	39
Carrots	-	5	19	34	65	48	-	27	33	41	64	52
Alphalpha	57	32	31	32	55	47	59	68	48	39	50	54

3.3 Water supply and distribution alternatives

The farmers of Balda have some irrigation alternatives that they wish to have investigated. One of those is pumping water from the Columbe River to a large tank on Loma Gaushi. From there the water could be led in pipes to fields at Gampala and in open channels by gravitation to the pasturage. According to the locals the Columbe River never dries out. Another alternative of interest is to pump ground water from the pasturage to the fields on Loma Gaushi and Gampala. Previously the hacienda used a water hole called La Victoria for irrigation purposes and pumped water to a tank. The water was used for pasturage plants. The people of Balda now wish to investigate the possibility of using the ground water as a source for irrigation water. Both the Columbe River and the pasturage options would involve pumping.

The zone chosen to irrigate in this study was Gampala according to the soil investigations. The fields at Gampala vary in elevation between 3 200 and 3 400 m a.s.l.. The type of irrigation design chosen for the water supply calculations was furrow irrigation. Furrow irrigation is widely used in the Andes and the method is easily used and maintained by the farmers. The alternatives of sprinkler and drip irrigation are still under introduction in the area. With time and increased experiences sprinklers may be a future option of irrigation design. The application efficiency of furrow irrigation design is assumed to be 60% (FAO, 2000). In this project the farmers would have their own small water reservoir next to their field to store water according to a schedule made by the users. Dividing the water at the field will not be discussed further in this report.

The Columbe River and shallow ground water at the pasturage were chosen as alternatives for water supply to meet the wish of the locals. The idea of building a reservoir at the top of the Loma Gaushi was rejected as a reservoir would increase the cost considerably. Consequently the Columbe River alternative would involve a direct abstraction by pumping water from the river to the fields at Gampala. The ground water alternative would also involve pumping from the shallow ground water at the pasturage to the fields at Gampala. Other water supplies in the area were investigated by studying the topographic map of the nearby area (Map: IGM, 1971, Map: IGM, 1991, a, b, c, Map: IGM, 1992). Two river alternatives for water supply were found from the topographic information; the Llinllin River and the Pulucate Creek. Both alternatives would involve river diversion with open channel distribution using gravity as the transportation force. The Llinllin River alternative would include direct abstraction from the river and a siphon. The Pulucate Creek alternative would include a storage reservoir to collect water during rainy seasons. The discussion above results in the four alternatives that will be examined in this report. The four alternatives are shown in Figure 3.2.

Alternative 1.	Direct abstraction by pumping from the Columbe River at 3 146 m a.s.l. to fields at Gampala
Alternative 2.	Direct abstraction by pumping ground water from the pasturage at 3 160 m a.s.l. to fields at Gampala.
Alternative 3.	Direct abstraction by gravity from the Llinllin River at 3 400 m a.s.l. to fields at Gampala
Alternative 4.	Abstration by gravity from the Pulucate Creek at 3 320 m a.s.l. to a reservoir at Gampala

The alternatives will be the basis for the studies in the next two chapters and presented in more detail in chapter 5.

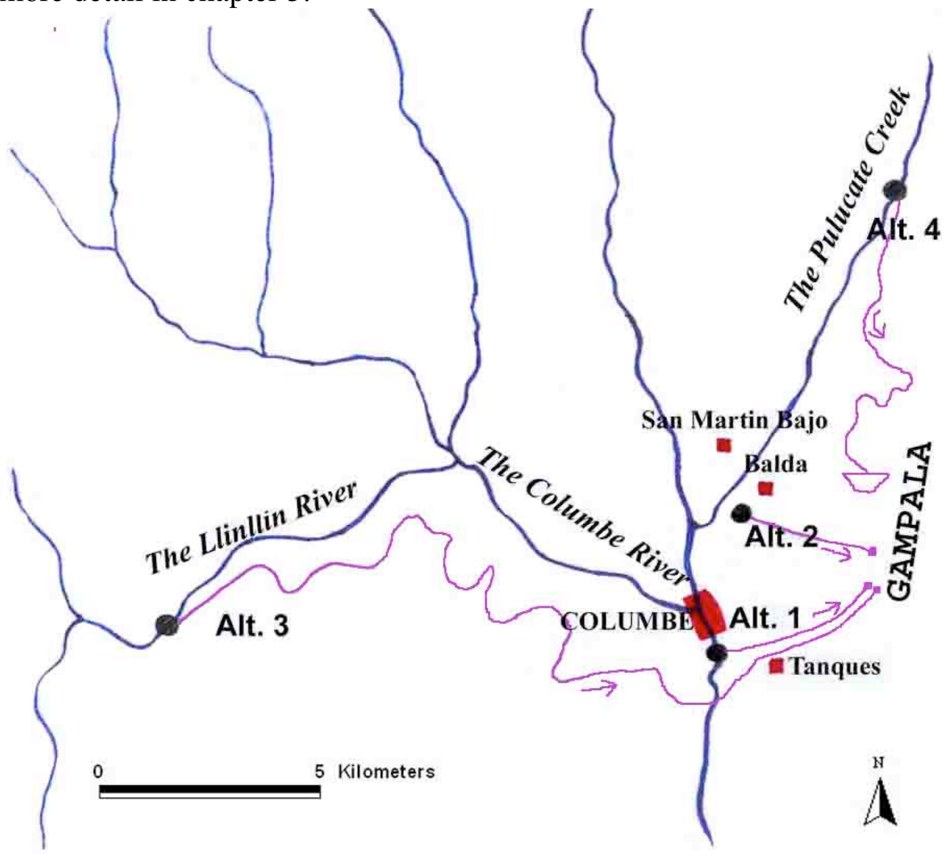


Figure 3.2 The four alternatives of water supply

4 HYDROLOGY

4.1 Surface water

Three of the alternatives presented in previous chapter involve river water as a water supply for irrigation. No water discharge measurements or quality samples have been previously done in Columbe River, Llinllin River or the Pulucate Creek. A river with known discharge data was needed as a reference river. Water samples had to be taken to give some guidance about the water quality. Discharge data was gathered at the National Institute of Meteorology and Hydrology (INAMHI) in Quito. Other information such as the catchment areas was obtained by processing GIS information from MAG. The precipitation data was needed to estimate the variation of rainfall in the area. The variation was used for calculating the discharge of the rivers. The precipitation information was gathered at INAMHI and in digital form at MAG.

The closest river found that could be used as a reference river was the Guamote River at a discharge station at the junction with the Cebadas River. Other close rivers were also investigated. The plots of the specific discharge for the Guargualla River and the Cebadas River showed different hydrologic regimes for the rivers (plot in Figure 4.1 and locations in Figure 2.3). When the Guamote River has its dry period in the late summer the others have their peak discharge. There are two factors that mainly influence the climate in the Andes. The air mass from the east carries rain that falls in July to September. The influences from the west are affected by the mountain range with rainy period in December to March. The Columbe parish is close to the border between these regimes, but the meteorology in the catchment of the Guamote River follows the occidental regime. There are great variations in precipitation within the area because of conditions such as altitude, slope orientation among other things (MAG, 1976).

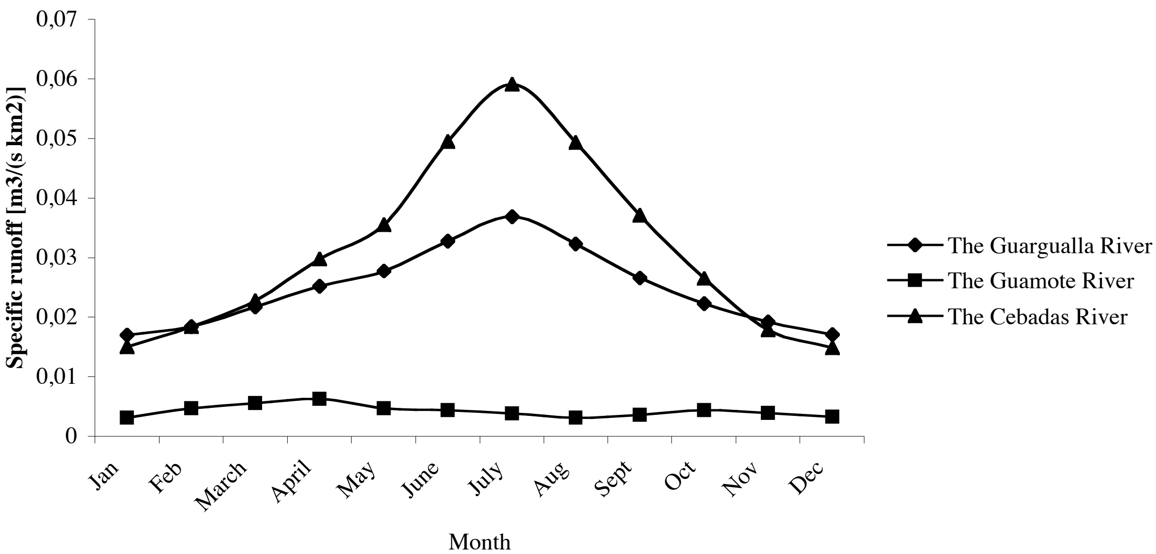


Figure 4.1 Comparison of the specific runoff for the Cebadas River, the Guargualla River and the Guamote River.

The Guamote River was chosen as a reference river because the Columbe River, Llinllin River and Quebrada Pulucate all belonged to the catchment system of the Guamote River.

According to the locals in Columbe all the rivers also have their high peaks in the spring like the Guamote River.

4.1.1 The Guamote River

The catchment area of the Guamote River at the confluence with the Cebadas River is 604 km^2 and is situated in the valley between Riobamba and Palmira. It is a part of the Chambo River system. INAMHI has daily recorded the discharge of the Guamote River from 1965 to 1978. The measuring point was upstream the Cebadas River at the coordinates 01 52 38 S, 78 38 06 W. The station has the INAMHI cod H786. During the 14 years there is one month lacking data (June 1969). The monthly and yearly averages are shown in Figures 4.2 and 4.3.

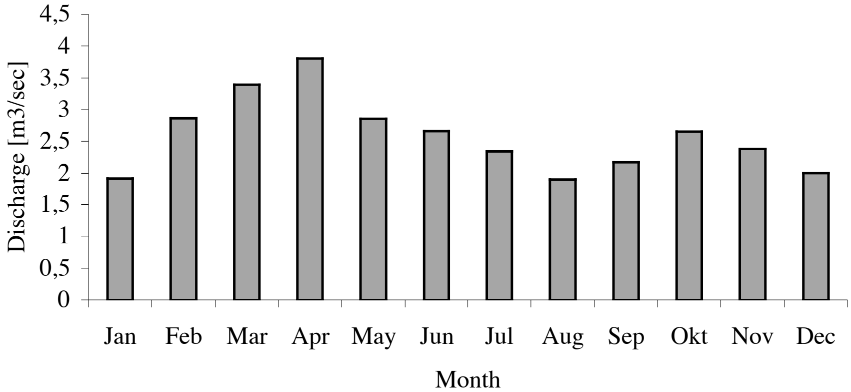
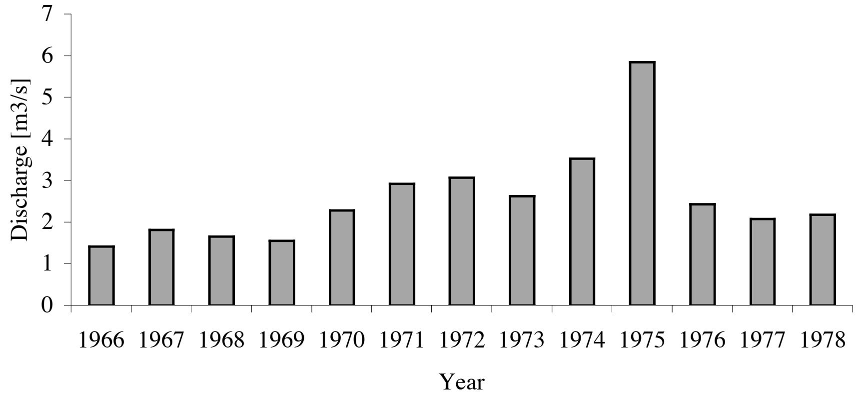


Figure 4.2 Monthly average discharges for the Guamote River, 1966-1978.

Figure 4.3 Annual average discharges for the Guamote River 1966-1978.



4.1.2 Precipitation

The variations in precipitations in the river catchments were needed to transform the Guamote River's catchment to the rivers of interest. INAMHI has several precipitation stations around the Columbe parish and the ones used are listed in Table 4.1. INAMHI has together with ORSTROM developed a statistic model called CLIMAN that homogenizes and criticizes precipitation data and defines homogenous regions of annual precipitation (Erazo, 1999).
The homogenous zones that CLIMAN has defined could not be use due to that the discharge areas included several zones and there were lack of information for some of these zones. Another way of finding the precipitation variation was needed. INAMHI has several precipitation stations around the Columbe parish and the ones used are listed in Table 4.1.

The CLIMAN report presents periods of good quality data, which are used in this section. The Juan de Velasco station was not treated in the CLIMAN report and consequently all data was used. The INAMHI data was represented as monthly values of precipitation.

Table 4.1 The INAMHI station

	Guamote	**Cebadas**	**Juan de Velasco**	**Cajabamba**	**Guaslan**	**Palmira**
INAMHI code	M134	M395	M409	M394	M133	M398
Location	01°56'00''S 78°43'00''W	01°54'28''S 78°38'27''W	01°49'30''S 78°52'53''W	01°41'05''S 78°45'47''W	01°43'15''S 78°39'40''W	02°03'26''S 78°44'20''W
Altitude [m a.s.l.]	3020	2930	3109	3160	2850	3180
Average yearly precipitation [mm]	450	442	1300	830	618	545
Period	1964-94	1964-96	1970-78, 1980-93	1963-96	1964-98	1935-92
Period of good quality data	1964-67, 1971-73, 1976-94	1968-88, 1993-96	No info	1963-70, 1972, 1977-81, 1984, 1987-96	1964-98	1935-68, 1971-73, 1976-80, 1987-92

The years that all stations had good quality data were 1977-78, 1980 and 1987-88. Even during these years there were months lacking information. These years of good quality were used to find any relation between elevation and precipitation. The result is shown in Figure 4.4 and no relationship could be found.

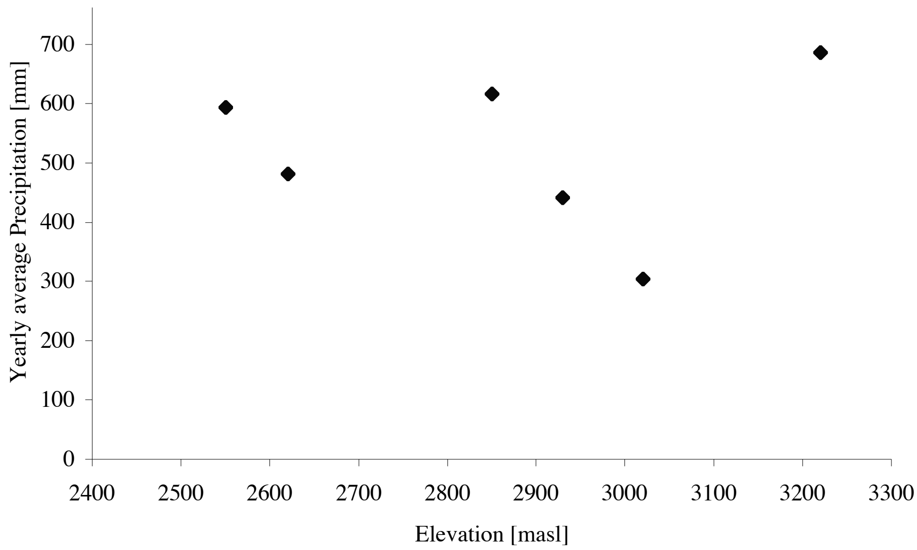


Figure 4.4 Relation between yearly average precipitation and elevation.

Since no relationship between precipitation and elevation was found the method of Thiessen polygons was used. The polygons and stations were presented in the GIS data received from MAG and can be viewed in Figure 4.5.

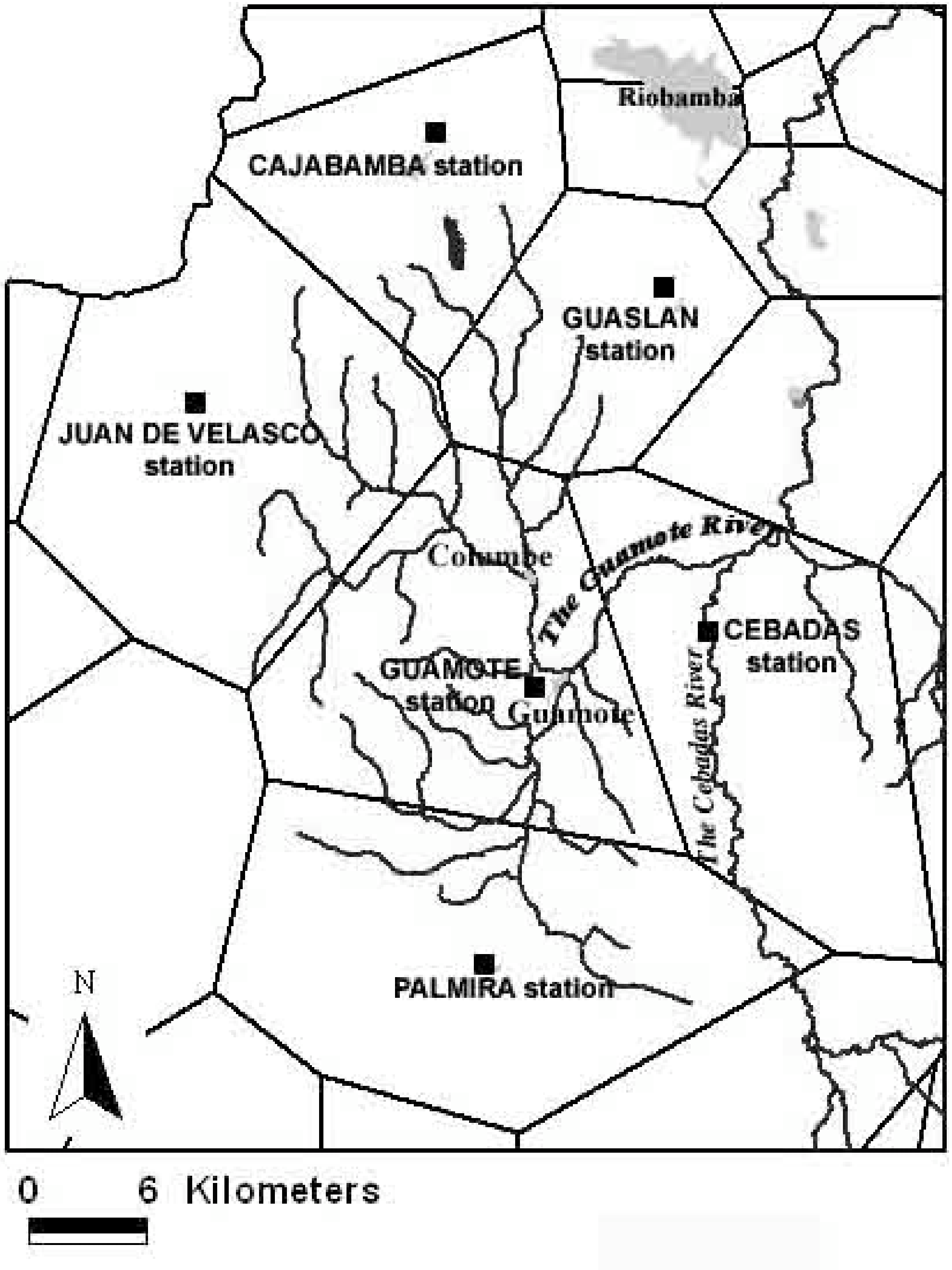


Figure 4.5. Map of the precipitation station and Thiessen polygons Source: MAG

A Thiessen network is constructed by locating the stations at a map and drawing perpendicular bisectors to the lines connecting the stations. In this way each point of the area is ascribed to the nearest precipitation station. The polygons formed around the stations are the boundaries of the areas assumed to be controlled by the station in each polygon. The weighted average of the precipitation, P, over an area, A, is determined according to Eq 4.1 where $A_1 \ldots A_n$ is the areas of the polygons and $P_1 \ldots P_n$ the precipitation of the stations representing the polygons. (Linsley et al, 1949):

$$P = \frac{A_1}{A} P_1 + \frac{A_2}{A} P_2 + ... + \frac{A_n}{A} P_n \qquad \text{(Eq. 4.1)}$$

The monthly average precipitation for each station ($P_1 \ldots P_n$) was calculated for the six stations with the goal to find averages from years when all stations had data. This was somewhat troublesome because of lacking information and because some monthly averages consist only of one year. The results of the station monthly averages are presented in Appendix 2. The catchment areas of the rivers and elevation of abstraction are presented in Table 4.2 and Figure 4.6. The area proportion of the total catchment areas inside the different polygons are presented in Table 4.3. The catchment areas were defined by using GIS (Other: MAG). The Pulucate Creek alternative was not investigated since there was no water flow and the salinity was high (see section 4.2.4).

Table 4.2. Catchment areas estimated at the point of elevation

	The Columbe River	**The Llinllin River**	**The Guamote River**
Elevation [m a.s.l.]	3 146	4 300	2 840
Catchment area, A_{River} [km^2]	305	58	604

Table 4.3 The area proportions of the catchment areas inside the following Thiessen polygons.

Thiessen Polygon	**Area proportion of the Guamote River catchment area** $\frac{A_{Polygon}}{A_{Guamote River}}$	**Area proportion of the Columbe River catchment area** $\frac{A_{Polygon}}{A_{Columbe River}}$	**Area proportion of the Llinllin River catchment area** $\frac{A_{Polygon}}{A_{Llinllin River}}$
Guamote	0.44	0.32	0.46
Palmira	0.17	-	-
Juan de Velasco	0.19	0.38	0.54
Guaslan	0.10	0.21	-
Cajabamba	0.05	0.09	-
Cebadas	0.06	0.01	-

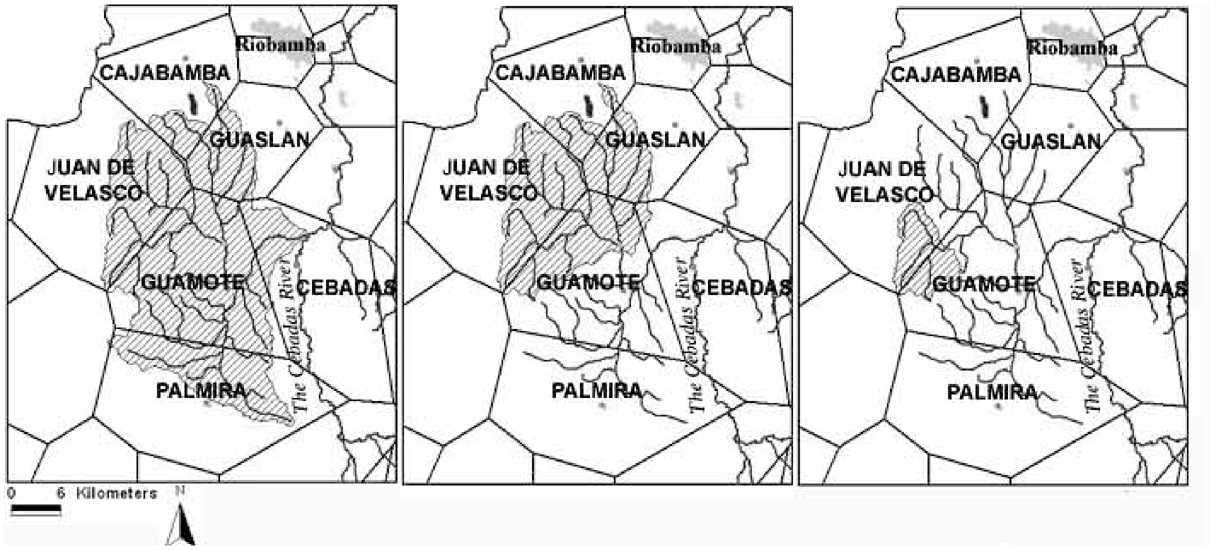


Figure 4.6. Catchment areas from left: The Guamote River,The Columbe River and The Llinllin River. For more map details see Figure 4.5

4.1.3 Field observations and river water quality

The planned water abstraction locations at the Columbe River, the Llinllin River and the Pulucate Creek were visited and some discharge measurements were done. The time for the fieldwork was during the rainier season. The discharge was measured by a simple stick test and water samples were taken. For some of the alternatives it was not possible to carry out the measurement at the planned location of abstraction. In the Llinllin River the measurements could not be done because of communication problems with and between the locals and in the Pulucate alternative it was not possible because no water was found. According to the locals there are only water in the Pulucate Creek after heavy rainfalls at the chosen point of abstraction. The measurements in those cases were done at a lower elevation. The water samples were analyzed by the University of Riobamba and tested for salinity (measured in deciSiemens per meter), pH, chlorides, carbonates and solid residue. The results are presented in Table 4.4. For some guidelines for irrigation water quality by FAO see Appendix 5.

Table 4.4 River water quality and measured discharge

	Columbe River		**Llinllin River**	**Pulucate Creek**
Date	April 21st 2003	May 5th 2003	May 5th 2003	May 11th 2003
Planned elevation for abstraction [m a.s.l.]	3 146		3 400	3 320
Elevation for discharge test and sampling [m a.s.l.]	3 145		3 286	Approx 3 200
Discharge [m^3/s]	3.9	4.6	3.1	0.0038
Conductivity [dS/m]	0.28	0.18	0.12	6.40
Chlorides [mg/l]	17.0	21.3	9.9	18.5
Solid residue [ml/l]	< 0.50	< 0.1	< 0.1	< 0.1
Carbonates [mg/l]	648	160	200	560
pH	7.4	6.6	6.4	6.8

4.1.4 Conclusion on surface water

An important conclusion made was that there is no water in the Pulucate Creek at the point of planned abstraction most of the year. The water in the creek also had a very high conductivity. This was probably due to human activities. At this point the Pulucate Creek alternative was rejected and no more investigations were done.

The 14 years discharge data from the Guamote River should be sufficient to make discharge calculations of the rivers of interest. The problem of too few years used when calculating the monthly precipitation means of the stations representing the Thiessen polygons should not affect the final calculations of the river discharge. For those calculations only the relationship between the areas is important and not the absolute number.

4.2 Ground water

The second alternative of water supply presented in section 2.4 involves pumping shallow ground water from the pasturage between Balda and San Martin Bajo to the fields at Gampala. In this part of the report the hydrogeology of the pasturage will be studied. The geology was studied and a slug test was carried out to give information about the hydraulic characteristics. Quality data of the ground water was obtained by water samples and data from INAMHI. Interviewing the locals and measurements of the water level in existing wells gave information on the current ground water use and water level variations.

4.2.1 Hydraulic characteristics of the aquifer

The geology of the pasturage is a deposit terrace formation overlaying the two locally known rocks “cangagua” or “sicalpa”. The cangagua is a vulcanic deposit rock and the sicalpa consists of tuffs or agglomerates of volcanic origin. Both the cangagua and sicalpa are impermeable except at fracture zones. The superficial deposit terrace consists of conglomerized alluvial material such as sand, lime and clay. The deposits originate from the erosion of the mountains. This alluvial terrace could be expected to be a source of water if zones of coarser material with high hydraulic conductivity would be found. (Map: Ministerio de Recursos Naturales y Energéticos, 1982 and Map: Ministerio de Recursos Naturales y Energéticos, 1978)

<u>Slugtest - Hvorslev method</u>

The purpose of a slug test is to estimate the hydraulic conductivity of a confined aquifer *in situ*. The slug test consists of creating a very brief pressure pulse at one point in the aquifer and observing the transient response at the same point. The pressure pulse can be generated by instantaneously injecting or withdrawing a slug of known volumes into/from a well and then measuring the rate at which the water level returns to its initial level. Possible slugs are solid slugs, a bailer or a slug of water. The disadvantage of a slug test is that it only gives measurements for the zone close to the well. It is difficult to generalize the characteristics of a larger area only from measurements in one well. (Sanders, 1998)

Cherry and Freeze (1979) describe the Hvorslev method that is used to find the hydraulic conductivity in a confined aquifer. In the method a point piezometer was used (Figure 4.7).

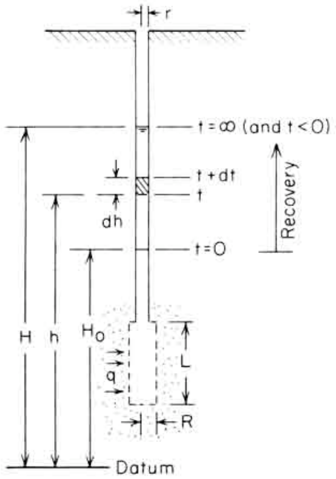


Figure 4.7 Slug test. Source Freeze and Cherry 1979

The recovering flow, q, at the piezometer tip at any time is proportional to the hydraulic conductivity, K, the soil and to the unrecovered head difference, H – h:

$$q(t) = \pi r^2 \frac{dh}{dt} = FK(H - h) \qquad \text{(Eq 4.2)}$$

where F is a factor that depend on the shape and dimension of the intake and r is the radius of the well. The basic time lag, T_0, is defined as:

$$T_0 = \frac{\pi r^2}{FK} \qquad \text{(Eq 4.3)}$$

T_0 can be defined as the time that would be required for the complete equalization of the head difference if the original rate of inflow were maintained. Using the initial conditions of h = H_0 at t = 0 the solution of the differential equation formed by substituting Eq 4.3 in Eq. 4.2 is:

$$\frac{H - h}{H - H_0} = e^{-t/T_0} \qquad \text{(Eq 4.4)}$$

If the recovery is normalized to H – H_0 and plotted on a logarithmic scale, a straight-line plot results. When t = T_0 (H-h)/(H-H_0) is 0.37 and ln((H-h)/(H-H_0)) is -1. This is used to find T_0 graphically in a plot of head difference and time. The hydraulic conductivity can then be determined from Eq 4.2. The shape factor has been evaluated by Hvorslev for a piezometer intake of length L and radius R and L/R > 8. The final equation for the conductivity is:

$$K = \frac{r^2 \ln(L/R)}{2LT_0} \qquad \text{(Eq 4.5)}$$

Results of the slug test

The slug test was carried out at the pasturage in an already existing well (location in Figure 4.9b). The well was mainly used for watering the animals and as water supply for laundry. The chosen slug for this study was a slug of water that was poured into the well. The advantage with this method is that it is costless but may be a source of error because the slug was not added instantaneously. In the field test in Balda the slug consisted of a large bucket of water that was poured into a hand dug well with a rectangular, constant cross-section. The Hvorslev method assumes a well with a cylindrical shape. To deal with the difference in cross-section shape a hypothetic cylindrical shaped well was defined with that has the same contact area between water and wall as the parallelpiedic shaped well that was used in the field measurements. The contact area at the bottom of the well has been assumed to be small relatively the rest of the contact area and therefore not considered.

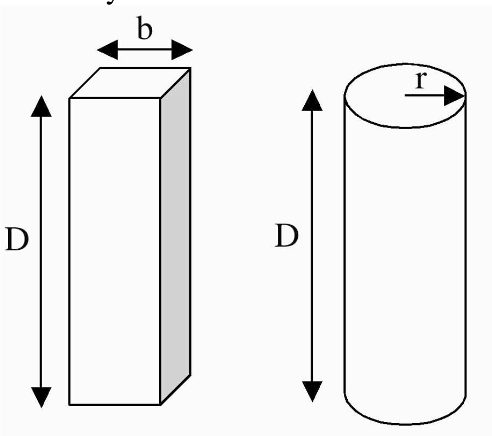


Figure 9.8 A parallelpiedical shaped well and cylindrical shaped well.

$A_{cylinder} = 2 r \pi D$ (Eq 9.6)

$A_{parallelpied} = 4 b D$ (Eq 9.7)

where r is the radius of the circular cross-sectional, b the length of the side of the square cross-section and D the water depth (Figure 4.8). The found relation between the radius and the side length were $r = 2b/\pi$. Further the Hvorslev method is based on test with a point piezometer with an intake length of L and radius R. In the Balda case the well had no piezometer and the radius was constant. The radius was therefore assumed to be equal to r in Eq 4.5. This meant that water could seep into the well all along surface where the water was in contact with wall of the well. The intake length, L, also varied during the test because the water level changed. This was taken into consideration by calculating the conductivity, K, for both maximum and minimum L. By adding water to the well the water would also be seeping into the wall of the well above the ground water table level. But the proportion of water above the water table level compared to the total depth was relatively small. Under the assumptions and simplifications done the following results were calculated (results of measurements and plot can be found in Appendix 3):

$T_0 = 7\ 860$ s
$K(L = 4 \text{ m}) = 7{,}28 \cdot 10^{-6}$ m/s
$K(L = 4.2 \text{ m}) = 7.09 \cdot 10^{-6}$ m/s

From the slug test calculations the hydraulic conductivity was $7{\cdot}10^{-6}$ m/s. This can be compared with the range of conductivities for sediments/rocks in Table 4.5.

Tabell 4.5 Hydraulic conductivity Source: Sanders 1998.

Sediment/Rock		**Hydraulic Conductivity [m/s]**
Clay		10^{-11} to 10^{-8}
Silt		10^{-9} to 10^{-5}
Sand		10^{-7} to 10^{-3}
Sandstone	Tightly cemented	10^{-10} to 10^{-7}
	Loosely cemented	10^{-8} to 10^{-5}
Basalt	Unfractured	10^{-11} to 10^{-8}
	Fractured	10^{-6} to 10^{1}
Fractured igneous and metamorphic rocks		10^{-10} to 10^{-6}

4.2.2 Current use and variation of ground water

At the time of the fieldwork there were some electric pumps that withdrew ground water from the pasturage. Most of the water is used for domestic purposes in the villages around the pasturage. Not all the public wells were investigated due to communication problems between the villages. Most likely is that the other villages around the pasturage also pump ground water for domestic use. If the ground water alternative becomes realistic this has to be better investigated. Approximately yearly withdrawal for the public wells investigated were estimated by the power used for pumping to 260 000 m^3 in Balda (well PW 1) and 70 000 m^3 in La Providencia (well PW 2). The locations of the wells are presented in Figure 4.9b.

To receive information about the variation of the ground water at the pasturage interviews and measurement of the water level in some existing wells were done. The locations of the investigated wells are shown in Figure 4.9b as Well 4-7 and the results of the measurements in Appendix 4. The wells are all hand dug, unlined and at the date of observation used for watering animals. According to the owners cangagua was found while digging some of the wells. Few of the wells has yellowish water. The color is probably due to iron contents in the soil. The observations of the five wells were carried out in April to May. This period receives the greatest precipitations during the year with an average about 50 mm/month. During the time of observation the water level in the wells varied a up to 60 cm. According to the locals the ground water level can vary up to about one meter during a year.

4.2.3 Ground water quality

INAMHI provided data on water quality tests done in 1977 in wells close to Balda. All wells are public and used for domestic purposes and are presented in Figure 4.9a as Well 1-3. Two of the tested wells are located three kilometer west of Guamote and one three kilometers north of the village Columbe. The results are presented in Table 4.6.

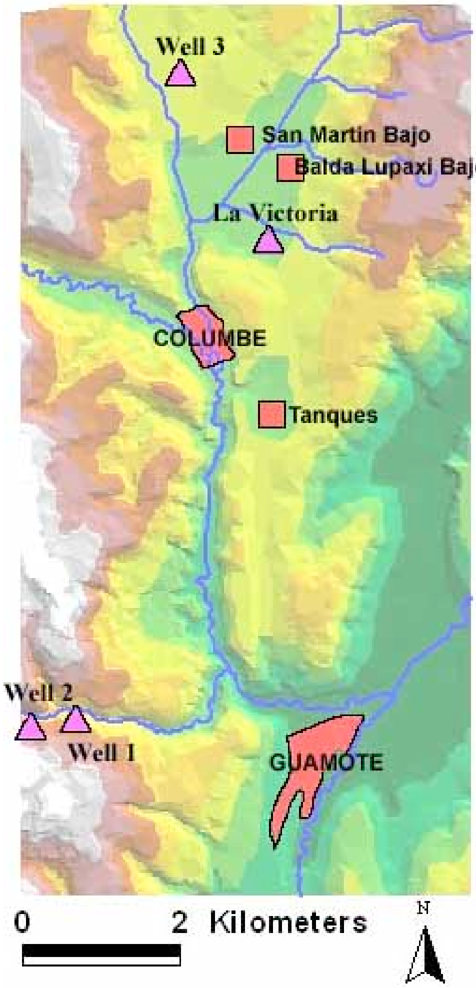


Figure 4.9a Water quality wells, Well 1-3 and La Victoria.

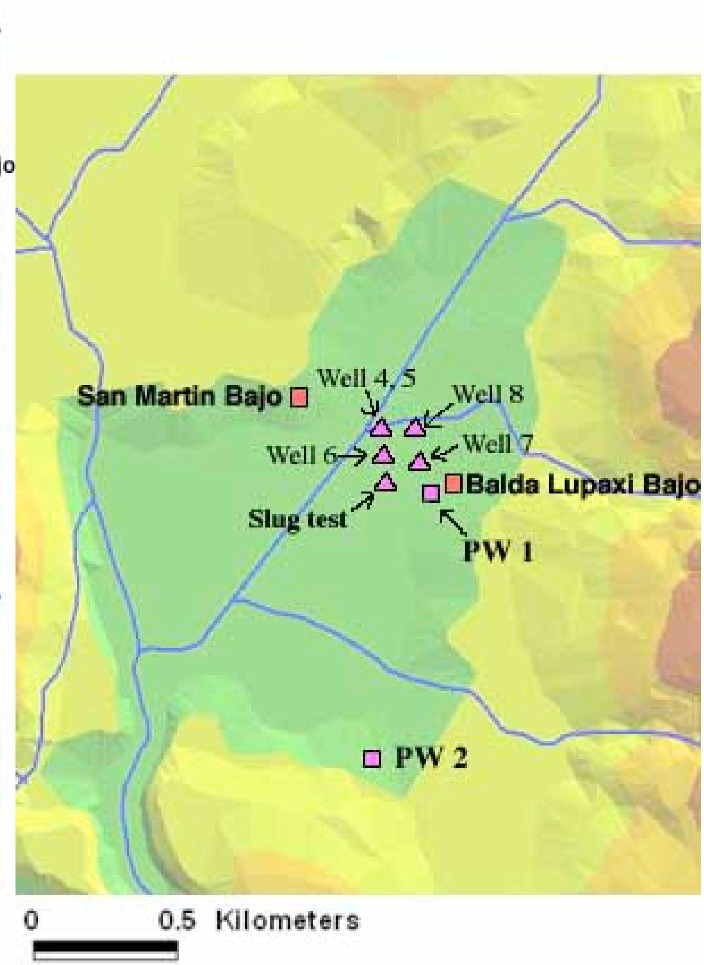


Figure 4.9b Public wells PW 1-2 and investigated wells 4-8.

Two samples of the ground water from the pasturage in Balda were taken to find the quality. The samples were taken in the water hole called La Victoria at two occasions. The location is shown in Figure 4.9a and results in Table 4.6.

Table 4.6 Ground water quality

	Well No 1	**Well No 2**	**Well No 3**	**La Victoria**	
Date	1977	1977	1977	April 21st 2003	May 7th 2003
Conductivity [dS/m]	1.2	1.2	0.9	0.19	1.10
Chlorides (Cl) [mg/l]	-	-	-	46.9	41.2
Solid residue [ml/l]	-	-	-	1.0	< 0.1
Carbonates (CO_3^{2-}) [mg/l]	-	-	-	306.2	608.0
pH	5.0	5.0	5.0	5.9	6.7

4.2.4 Conclusions on ground water

There are physically good conditions for finding ground water at the pasturage if a sediment layer of sand or gravel is found. To obtain more information about the physical conditions further drilling and sampling has to be done. Because the slug test was simplified and the aquifer probably not is confined the result should be considered as indicative and not as a definite number of the hydraulic conductivity. More detailed well tests with more than one well involved can tell more about the characteristics than the single slug test. The results of ground water quality show that the pH is less than the normal for irrigation according to FAO except for one occasion at La Victoria. The large variation in the results is somewhat strange when there is not much time difference between the two samples. This could maybe be the result of human activity around and in the water hole. If the ground water alternative becomes reality, further samples have to be taken.

5 THE WATER SUPPLY ALTERNATIVES

In this chapter the alternatives of water supply and distribution will be investigated more closely based on the conclusions made in chapter 4. The possible amount of water abstraction and engineering design will be presented for the alternatives that have not been rejected. The possible water abstraction will be compared with the water demand to estimate how many hectares of irrigation the alternative can support. The alternative of the Pulucate Creek was rejected due to lack of water and poor water quality as discussed in section 4.1.4. Three alternatives are left; the Columbe River, the Llinllin River and ground water at the pasturage. All alternatives transport the water to the fields at Gampala.

5.1 Water rights

The National Council of Hydrologic Resources (CNRH) is the agency responsible for permitting development of water supply system in Ecuador. The CNRH regulates and coordinates requests for the development of project of domestic, agricultural and industrial water supply. The agency is relatively new and took over after the National Institute of Hydraulic Resources (INERHI) that was previously responsible for the development of water projects. According to the Water Law, article 84, an application to require water-use rights has to consist of the following (INERHI, 1985):

- Name of the river or other source where the water will be taken, parish, canton and province.
- The necessary discharge of abstraction and where the abstraction would be located
- The names and addresses of known users
- Objective for which water is going to be used
- Structures and installations required for the water usage
- Time frame to implement the works
- Studies and technical plans to justify and explain the request of the water

In Riobamba the Regional Corporation of Development (CODERECH) deals with water rights. CODERECH handles the hydrological resources, irrigation systems and drainage and flood control. The corporation applies the politics and norms that CNRH formulates. According to CODERECH the process of receiving water-use rights takes about three months and cost about 80 USD except lawyer costs (N. Rodriguez, com.pers.). The process consists of an application, a publication and a technical study. According to a lawyer firm in Riobamba (E. Rojas, com.pers.) the lawyer cost is about 300 USD.

5.2 River water

To find the most suitable water supply and maximum area to irrigate a simple water balance model was constructed. The possible discharge to abstract was calculated from discharge data of the Guamote River. The water supply was balanced with the monthly water demand presented in section 3.2.

5.2.1 Water Balance Model

The water balance model was constructed in Microsoft's Excel. Monthly discharge and demand data from the years 1965-67 and 1971-78 were used to study the monthly water balance. During these years there are both data of river discharge and meteorology. Monthly averages were used to eliminate daily fluctuations in storage. The water supply was balanced against the demand (see Appendix 1) including the losses in the irrigation system (schematic construction in Figure 5.1). The losses from the irrigation system depend on the systems efficiency, in this case for furrows. A certain percent of the river water was left to protect the envirnoment and leave water to other water abstraction systems downstream.

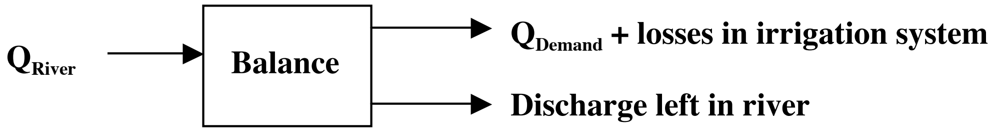


Figure 5.1 The water balance model.

The equation for the balance that includes the constants and variables presented in Table 5.1 was:

$$\text{Water balance} = Q_{\text{River}}(1-\theta) - Q_{\text{Demand}} \frac{A_{\text{Irrigated}}}{\eta_{\text{Irrigation}}} \qquad \text{(Eq 5.1)}$$

Table 5.1 Variables and constants in the water balance model.

Constants
Area irrigated $A_{\text{Irrigated}}$
Catchment area $A_{\text{Discharege}}$
Fraction of discharge left in the river θ
Efficiency of irrigation system $\eta_{\text{irrigation}}$

Variables
River discharge Q_{River}
Water demand per hectare Q_{Demand}
Precipitation P_{Station}

By changing the irrigated area the model presents the water deficit in percentage deficit out of the months when irrigation was needed. The water deficit was defined as when the water demand, including the losses, exceeds the water supply minus the discharge left in the river (the water balance less than zero).

The available discharge in the rivers, Q_{River}, was calculated with the Guamote River as a reference river, Eq 5.2. As both the Columbe River and the Llinllin River are parts of the Guamote River system the discharges of the rivers were calculated by a transposition of the Guamote River's discharge data. The monthly average discharge data of the Guamote River, ($Q_{\text{Guamote River}}$) was multiplied by the portion that each river's catchment area (A_{River}) makes of the Guamote River's catchment area ($A_{\text{Guamote River}}$) and the portion that the average precipitation (P_{River}) of the catchment area of the Columbe River makes of precipitation ($P_{\text{Guamote River}}$) of Guamote River.

$$Q_{\text{River}} = Q_{\text{GuamoteRiver}} \frac{A_{\text{River}}}{A_{\text{GuamoteRiver}}} \frac{P_{\text{River}}}{P_{\text{GuamoteRiver}}} \qquad \text{(Eq 5.2)}$$

The calculations assume that the runoff coefficient, $Q/(A \cdot P)$, is constant over the cachment of the Guamote River. This is probably not the reality but due to lack of further information the assumption was made. The precipitation in the catchments was calculated according to section 4.1.2.

5.2.2 The Columbe River

The Columbe River is a part of the Guamote River's catchment (Figure 2.3). The Columbe River belongs to the same water system as the Llinllin River. The planned water abstraction is downstream the junction with the Gaushi River downstream the village Columbe (Figure 3.2). At the elevation of 3 146 m a.s.l. the river has a catchment area of 305 km^2. The Columbe River alternative would consist of a water abstraction and pumping directly up to the fields at Gampala. The design would involve pumping about 3 000 m horizontal and 134 m vertical.

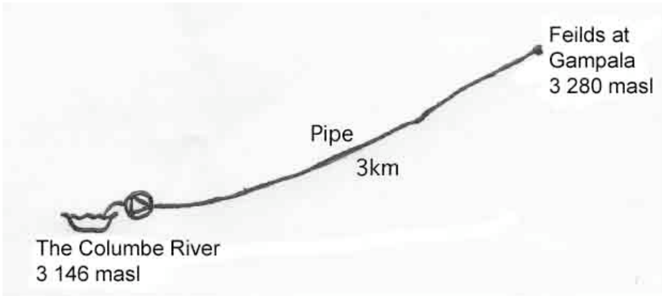


Figure 5.2 The location of planned abstraction, the Columbe River and a schematic design of the distribution. Photo: S. Halmstad, 2003.

Water balance

The results from the water balance model are presented in Table 5.2. The catchment areas that were used are the ones presented in Table 4.2 and 4.3. The percent discharge left in the river was chosen to be 50%. At the time of the fieldwork there was a great uncertainty how much water was used downstream. This must be further examined to secure the water supply of other water projects. The efficiency was set to 60% as discussed in section 3.3.

Table 5.2 Results of runs of the water balance model, the Columbe River alternative.

	Run No 1	Run No 2	Run No 3
Irrigated area, $A_{Irrigated}$ [ha]	1 200	1 300	1 400
Percent of discharge left in the river, θ [%]	50	50	50
Efficiency of irrigation system $\eta_{irrigation}$ [%]	60	60	60
Water deficit potatoes [%]	3.2	4.8	4.8
Water deficit alphalpha [%]	4.1	4.1	4.9
Water deficit carrots [%]	4.9	4.9	6.9

If the acceptable percent time of water deficit is chosen to be 6% about 1 300 ha could be irrigated according to the water balance model. A 6% water deficit can be accepted when annual crops are used. From an economically point of view perennial crops are more vulnerable to water deficit.

Engineering

To check the possibility to construct an irrigation system supplying water for 1 300 ha a rough estimate was done to decide the need of power and suitable pump. At this stage only the hydraulic power, defined as the power needed to lift the water, was calculated. The hydraulic power (P_{hyd}) only includes lifting water with a certain discharge (Q) the vertical height (H) of (Eq 5.3). This estimation ignores horizontal transportation, losses and pump efficiencies and thus gives a lower limit for the total power needed.

$$P_{hyd} = \rho g H Q \qquad \text{(Eq 5.3)}$$

where g is the acceleration of gravity and ρ the density of water. If 1 300 ha was to be irrigated, if the pump would run 24 hours per day and if the elevation difference is 134 m the average hydraulic power needed would be:

- Potatoes: 413 kW or 554 hp
- Alphalpha: 514 kW or 689 hp
- Carrots: 559 kW or 750 hp

One of the most powerful pumps at the Ecuadorian market[1] has 50 hp and an efficiency of 48%. A pump of this kind costs about 4 000 USD. With this information in mind it becomes somewhat unrealistic to irrigate 1 300 ha that needs at least 25 pumps of the one described. If the irrigated area is decreased to 50 ha, one pump would be sufficient to cover the hydraulic power with the pump efficiency included. But as few hectare as 50 ha is most likely not economically defendable to irrigate with a pump that needs 50 hp and involves large electricity costs. The electricity costs[2] for pumping for irrigation of 50 ha would exceed 35 000 to 75 000 USD (depending on what crop is considered).

Conclusions on the Columbe River

Pumping irrigation water is most likely not economically feasible in the Balda case. If only vegetables such as carrots and potatoes and pasturage plants are to be cultivated there will be problems covering the costs of the irrigation system. A pump system also requires electricity supply that in Ecuador is relatively costly and not always reliable. Power shortage during longer periods could be devastating if it happens during the driest part of the year.

5.2.3 The Llinllin River

The Llinllin River is located in the western part of the Columbe parish and is a part of the Guamote River's catchment area (Figure 2.3). The Llinllin River alternative would consist of a water intake at 3 400 m a.s.l., a concrete lined open channel, divided by a siphon into two parts (Figure 5.3). A water intake at 3400 m a.s.l. would give a catchment area of 58 km^2.

[1] According to TUBYMAC, a pipe merchandise workshop at the corner of Veloz Street and Brazil Street in Riobamba, Ecuador.

[2] Electricity cost, 4.62 centavos per kWh, according to the newspaper El Comercio the 21st of May 2003

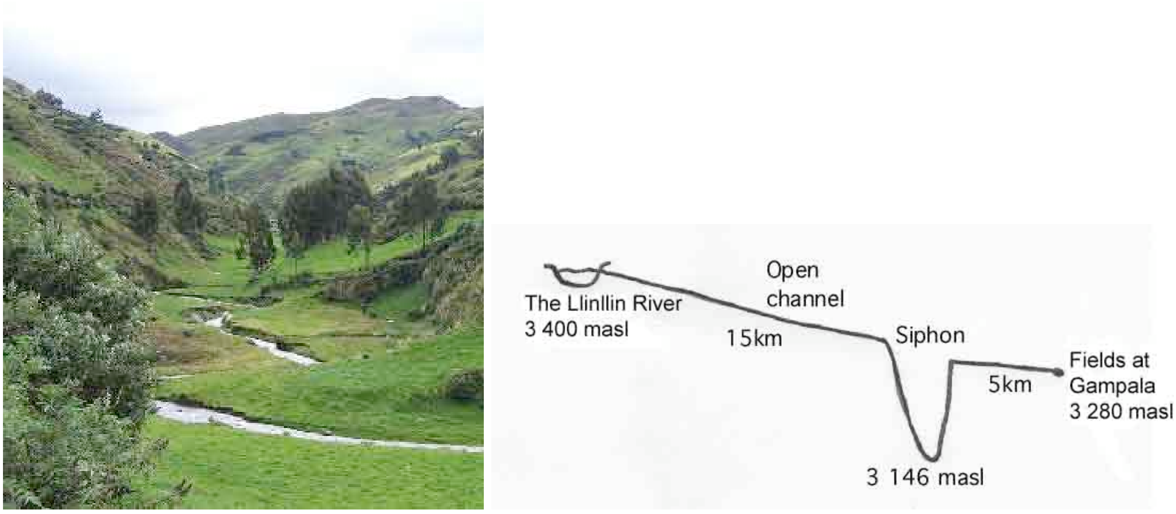


Figure 5.3 The Llinllin River and a schematic design of the distribution. Photo: S. Halmstad, 2003.

Water balance

The water balance was calculated in the same way as for the Columbe River alternative in section 5.2.2. All the constants were chosen to be the same as for the Columbe River alternative and discharge left in the river set to 50% and irrigation efficiency to 60%. The results are presented in Table 5.3.

Table 5.3 Results of runs of the water balance model, the Llinllin River alternative.

	Run No 1	Run No 2	Run No 3
Irrigated area, $A_{Irrigated}$ [ha]	200	250	300
Percent of discharge left in the river, θ [%]	50	50	50
Efficiency of irrigation system $\eta_{irrigation}$ [%]	60	60	60
Water deficit potatoes [%]	0	1.6	3.2
Water deficit alphalpha [%]	3.3	4.1	7.4
Water deficit carrots [%]	2.9	5.9	10.8

With acceptable water deficit of 6% about 250 ha could be irrigated according to the water balance model. The maximum discharge abstracted during this time was 0.14 m^3/s. This will be used as channel design discharge in next section.

To find the sensitivity of the model two of the constants were changed to study their effects on the results. Because of the great uncertainty of users downstream and the type of irrigation system both the discharge left in the river, θ, and the efficiency, η, could be changed. To show the sensitivity of the model, the Run No 2 in Table 5.3 was modified by changing θ and η by 15 percentage units (Table 5.4).

Table 5.4 Sensitivity analysis of Run No 2 in Table 5.3.

	θ [%]								
	35			**50**			65		
	η [%]			η [%]			η [%]		
	45	60	75	45	**60**	75	45	60	75
Water deficit potatoes [%]	1.6	0	0	3.2	**1.6**	0	11.3	3.2	3.2
Water deficit alphalpha [%]	4.1	3.3	0.8	10.7	**4.1**	3.3	22.1	12.3	5.7
Water deficit carrots [%]	6.9	2.9	2.0	15.7	**5.9**	3.0	24.5	16.7	8.8

The results of the sensitivity analysis show that the estimated times for water deficit for both alphalpha and carrots are more affected by changes in the parameters than the potatoes. The furrow irrigation has one of the lowest efficiencies of the irrigation systems used today. If the system is changed the efficiency will most likely change to a higher value than 60%. The sprinkler efficiency is, for example, around 75%.

<u>Engineering</u>

The open channel system of the Llinllin River alternative consists of 15 km open channel from the water intake at 3400 m a.s.l., a siphon and 5 more km open channel to the last user (Figure 3.2 and 5.3). The chosen material for the lining of the channel was concrete and the slope 4 ‰. Lining a channel is costly compared to earthen channels but the advantage is that the smoother surface and consequently a higher permissible water velocity will allow a smaller cross-section for a certain discharge. The loss through seepage is also greatly reduced. The factors that have to be considered in the design of the channel are: the kind of material lining the channel bottom, which determines the roughness, the freeboard and the most efficient section.

Selection of channel cross-section and freeboard

For a certain given flow and slope, channels with the least contact between water and bottom surface (wetted perimeter) will minimize the resistance and maximize the discharge. The optimum channel, from a hydraulic viewpoint, is the semicircular cross-section. It has the least wetted perimeter among all sections with the same area and is the most hydraulic efficient section. But the semicircular section is difficult and expensive to construct and maintain. A close alternative is the trapezoidal cross-section that is more widely used. (Chow, 1959)

The best hydraulic dimension of the channel was determined by using Manning's equation for uniform flow in open channels (Chow, 1959):

$Q = \frac{A R_h^{2/3} S_0^{1/2}}{n}$ (Eq 5.4) $R_h = \frac{A}{P}$ (Eq 5.5) $v = \frac{Q}{A}$ (Eq 5.6)

Q - discharge
v - velocity
A - area of the cross-section of the waterway
R_h - hydraulic radius
P - wetted perimeter
S_0 - longitudinal surface slope
n - Manning's coefficient of resistance.

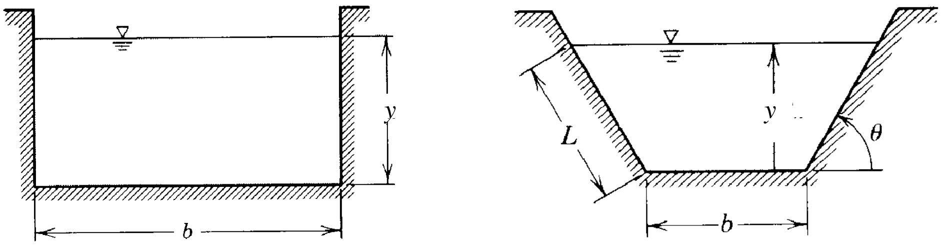


Figure 5.4 The rectangular (left) and trapezoidal (right) cross-section of an open channel. Source: Freeze, 1979.

The two alternatives of cross-sections studied in this report will be a trapezoidal section and a rectangular section (Figure 5.4). The rectangular is considered because it is simple to construct. To optimize the hydraulic efficiency the trapezoidal cross-section should have a side and a bottom of equal length and a side slope of 60%. The rectangular section should have a width that is the double its height (Table 5.5). The water depth in the channel is shown in Figure 5.4 as y, which is sometimes also called the normal depth.

Tabel 5.5 Optimal hydraulic dimensions

Cross-Section	Bottom b	Side length L	Side slope θ
Trapezoidal	$\frac{2}{\sqrt{3}}y$	$\frac{2}{\sqrt{3}}y$	60 %
Rectangular	2y	-	-

For the study following values were given:
$Q = 0.14\ m^3/s$
$n = 0.015$ for concrete
$S_0 = 0.004$

The freeboard (t) is the vertical distance from top of the channel construction to the water surface. This is to secure the channel for unexpected high peaks in discharge. The U.S. Bureau recommends heights of about 5-30% of the flow depth, y (Chow, 1959). In Ecuador a practical criterion is one third of the normal depth in the channel (Olazával et al 1999). The chosen height of the freeboard was set to be one third of the depth:

$t = \frac{y}{3}$ (Eq 5.7)

With the above constraints the following dimensions of the channel were chosen:

Table 5.6 Channel dimensions, discharge and velocity.

	Q [m^3/s]	y [m]	b [m]	t [m]	S_o	v [m/s]
Trapezoid	0.14	0.27	0.31	0.09	0.004	1.1
Rectangular	0.14	0.26	0.51	0.09	0.004	1.0

Siphon
A siphon is needed to transport the water through a valley. At the bottom of the valley the Pan American Highway must also be passed. The siphon has a length of 1 300 meters and transports water through the 175 meters deep valley, see Appendix 6 for dimensions.

Hazen Williams equation was used to estimate the friction loss in the siphon pipe. It is an empirical exponential formula based on turbulent flow and fixed exponents. The only variable is the Hazen Williams coefficient that reflects the roughness of the interior surface of a pipe. The Hazen Williams coefficient of new PVC is 140 m$^{0.37}$/s, old PVC 130 m$^{0.37}$/s, new cast-iron 130 m$^{0.37}$/s and old cast-iron 100 m$^{0.37}$/s.

Hazen Williams equation (Addison, 1945):

$$Q = 0.278\, C\, D^{2.36}\, S^{0.54} \quad \text{(Eq 5.8)} \qquad S = \frac{H}{L} \quad \text{(Eq 5.9)}$$

Q – discharge
C – Hazen Williams coefficient of friction
D – diameter of pipe
S – slope of the energy gradient
L – length of pipe
H – friction loss per unit length of pipe

Four alternatives with different combinations of D and C were studied to decide the head loss and pipe diameter. The results are presented in Table 5.7.

Table 5.7 Hazen Williams calculations of head loss in the siphon.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
D [m]	0.315	0.315	0.25	0.25
Q [m^3/s]	0.14	0.14	0.14	0.14
C [m$^{0.37}$/s]	130	100	130	100
L [m]	1 330	1 330	1 330	1 330
H [m]	**7.1**	**11.5**	**19.4**	**31.6**

If a head loss less than 30 m can be accepted a pipe diameter of 0.25 m will be chosen. It is important that the siphon will function even when the pipes age. If the pipes would erode so that the coefficient of friction falls below 100 the discharge would decrease. To take this into consideration the discharge for lower values of C was calculated by using Eq. 5.8 and Eq 5.9 with the results in Table 5.8.

Table 5.8 Discharge variation with pipe ageing (decreasing C).

D [m]	**H** [m]	**L** [m]	**C** [$m^{0.37}/s$]	**Q** [m^3/s]
0.25	30	3 300	100	0.14
"	"	"	90	0.12
"	"	"	80	0.11
"	"	"	70	0.10

The maximum pressure of the pipe is of interest when deciding pipe material. To estimate the maximum pressure at the bottom of the pipe the hydraulic pressure, p_{hyd}, due to the hydraulic height, h, was calculated, Eq 5.10. The hydraulic height gives the maximum pressure that could possible occur. In case of a temporary shut down, the pipes have to manage a pressure of the total hydraulic height when the siphon is filled with water. In reality, during usage, the friction and velocity difference lowers the pressure. Relatively the hydraulic height the negative influence of the friction and velocity on the pressure is small.

$$p_{hyd} = \rho g h \qquad \text{(Eq 5.10)}$$

The maximum hydraulic pressure in the pipe will be 1.7 MPa at the bottom of the siphon. Because of the heavy pressure for the lower part of the siphon an iron pipe is most suitable for this part. To minimize the costs, the pipe can then gradually be changed to PVC that can hold less pressure. The change in material affects the calculation of the head loss in the siphon because of larger friction in the iron pipe. The maximum head loss of 31.6 m, Alternative 4 in Table 5.7, is calculated for a siphon completely constructed of iron. The real head loss if PVC pipes also are used will be less than this maximum value.

<u>Rough cost calculations</u>

A rough cost calculation was done on the Llinllin River alternative. The cost calculations of the intake, channel, culverts and brim outlets were based on price information from a previous study in the province of Charchi, Ecuador (Bergman and Gustafson, 1996). Brim outlets and culverts were included in the cost calculation. Brim outlets are needed to prevent over flow and are constructed every 500 meters and culverts to pass roads and creak ravines. The above costs include labor, equipment and transports and are based on 1997 year’s price level. The cost calculation for the siphon was done using information from a pipe merchandise workshop[3] in Riobamba in May 2003. The cost of the siphon does not include labor or transports.

[3] TUBYMAC, corner of the Veloz Street and Brazil Street in Riobamba, Ecuador

Table 5.9 Costs, the Llinllin River alternative.

		Amount	Unit	Price per unit [USD per unit]	Cost [USD]
Intake					10 000
Channel		20 000	meter	40	800 000
Culverts		20	pieces	500	10 000
Brim outlets		40	pieces	200	8 000
Siphon	Iron 2 MPa	200	meter	60	
	PVC 1.6 MPa	515	meter	51	
	PVC 1.25 MPa	265	meter	44	57 525
	PVC 0.8 MPa	80	meter	26	
	PVC 0.63 MPa	240	meter	23	
Total cost					**885 525**

The cost calculation is exclusive studies and unexpected expenses. Neither the costs of the secondary system (furrows and the small private reservoirs) nor the costs for maintenance of the system are considered in this cost estimate. To improve and complement the existing road system a fixed cost should be added. This is not done here because of lack of information about existing roads.

Conclusion on the Llinllin River

The Llinllin River alternative involving an open channel and a siphon is technically feasible. The alternative could supply 250 hectare of irrigation, under the constraints done, and includes an 20 km open channel from an elevation of 3 400 m a.s.l. to the fields of Gampala at 3 280 m a.s.l.. The choice of channel cross-section will depend on a more detailed cost calculation, either trapezoidal or rectangular. The diameter of the siphon will be 0.25 m that involves a maximum head loss of 30 m. In order to say anything about the economic feasibility of the alternative a more detailed cost calculations has to be done. The total cost has to be compared with the total benefits that an irrigation project would give.

5.3 Ground water

The ground water alternative would involve transporting water from the pasturage at approximately 3160 m a.s.l. to the fields at Gampala at maximum elevation at about 3 280 m a.s.l. thus pumping 120 m (Figure 3.2). As discussed in the conclusions on the Columbe River alternative it is hard to find an economically defendable pump system to support the irrigation at Gampala because of the large elevation difference. The pumping alternatives involve expensive equipment that requires electricity that adds to the running costs. It is not economically sustainable to pump water for irrigation if there are large height difference between the water source and the fields. If the soil at the pasturage had been more suitable for cultivation (section 3.1) irrigation of the pasturage could have been an alternative. The hydraulic power needed would then be drastically decreased.

At this point the alternative of ground water at the pasturage was rejected.

6 DISCUSSION AND RECOMMENDATIONS

The most suitable alternative of water supply and distribution according to this study is the Llinllin River. The other alternatives failed because of lack of water, defective water quality and high construction and maintenance costs. The Llinllin River alternative, consisting of an open channel and a siphon, can supply about 250 ha of irrigated land. Most water supplies for irrigation systems in the Andes consist of river diversion and gravity fed distribution. There are collected knowledge and experience from other similar projects in the area. The irrigation project in Licto has been successful and could function as a prototype project for the Balda project.

The Llinllin River alternative is technically feasible but it is difficult at this stage to say anything about the economical feasibility. In order to do this a detailed cost-benefit calculation has to be done. The benefits must include the raise in harvest but also the social benefit an irrigation system would bring.

During the fieldwork communication problems made it difficult to carry out interviews, tests and samplings. At this stage the project must build on participitation of all members in Balda to anchor the intention of the project. If the project is about to proceed it must be an improvment of such participitation. An important step now is to apply for the water rights for the Llinllin River. This can be time consuming and should therefore be considered at this stage. Balda has to start a disscision how to solve how the water should be divided at the fields at Gampala. As the Llinllin River involves a channel passing through other villages a dialogue has to begin between the villages in the area to facilitate the work and to reach a better understanding of the water problem as a village boarder-crossing problem. Cooperation between villages is important in a project like this where there are many stakeholders and the water is scarce.

REFERENCES

Litterature

Addison H., 1945, *A Treatise on Applied Hydraulics,* Third edition, Chapman & Hall LTD. London.

Appolin F., Boelens R., Dávila G., Narváez E., Torres P.,1996. *El Riego en la Comunidad Andina: una Construccion Social* CICDA, CESA, SNV, CAMAREN, Quito Ecaudor.

Bergman M., Gustafson M., 1996 *Förstudie för bevattningskanal, Charchi, Ecuador*, Master's thesis no 380, Devision of Hydraulic Engineering at the Department of Civil and Environmental Engineering, Royal Institute of Technology, Stockholm, Sweden

Boelens R., Dávila G. (ed.), 1998. *Searching for Equity. Concepts of justice and equity in peasant irrigation.* Van Gorcum, Assen, The Netherlands

Chow, V. T., 1959, *Open-Channel Hydraulics,* McGraw-Hill Book Company, Inc. New York.

Comité Nacional sobre el Clima, 2001. *Comunicación Nacional República del Ecuador. Convencion Marco de las Naciones Unidas. Cambio Climático.* Ministerio del Ambiente, Quito, Ecuador. [www.unfccc.int/resource/docs/natc/ecunc1.pdf] 3d Jan 2003

Erazo A., Hoorelbeke R., 1999. *Parámetros meteorológicos "Cuenca del Río Pastaza".* IFEA-I.R.D., INAMHI, Quito, Ecuador

FAO, 2000 , *Guidelines for Water Management and Irrigation Development*, Land and Water Digital Media Series 12, FAO Irrigation Guidelines CD-ROM

Freeze, R. A., and Cherry, J. A. 1979, *Groundwater,* Prentice-Hall, Inc, Englewood Cliffs, NJ, USA

Halmstad, S., Lindell, L., 2004, *Estudio de Prefactibilidad de un Proyecto de Riego en los Andes – el Caso de Balda Lupaxi Bajo, Chimborazo, Ecuador* Minor Field Study Report, Commitee of Tropical Ecology, Uppsala University, Manuscript : January 2004, Uppsala, Sweden

INERHI, 1985 *Ley de Creacion del INERHI, Ley de Aguas, Reglamento de Aguas Reformas a la Fecha (1985),* INERHI, Quito

Linsley, R., Kohler, M., Paulhus, J., 1949. *Applied Hydrology*, McGraw-Hill Book Company, Inc, New York, USA

MAG, 1976, *Estudio Hidro-Meteorologico e Hidrogeologico Preliminar de Las Cuencas de los Rios Pastaza Chimbo y Chanchan*, Ministerio de Agricultura, Quito, Ecuador

Ministerio del Ambiente, 2000. *Informe del Ecuador Sobre la Convención de Lucha Contra la Desertificación.* Ministerio del Ambiente, Quito. [www.unccd.int/cop/reports/lac/national/2000/ecuador-spa.pdf] 1st of Feb 2003

Noordholland de Jong J., Boelens R., Heredia L., Gerbrandij G., Núñez P., 1999. *Hacia una vision integral del riego andino*, CAMAREN, Quito Ecuador

Olazával H, Nordholland de Jong J, A. J., 1999, *Riego Andino, Infrastructura de Riego: Elementos Técnicos Y Sociales,* CAMAREN Quito Ecuador

Sanders, L., 1998, *A manual of Field Hydrogeology,* Prentice-Hall, Inc, Upper Saddle River, NJ, USA

Sävborg E., Hagman U. (ed.), 2000. *Länder i fickformat nr 709 Ecuador*, Utrikespolitiska institutet, Stockholm, Sweden

US Army Corps of Engineers, 1998, *Water assessment of Ecuador,* US Army Corps of Engineers Mobil District and Topographic Engineering Center.

Personal communication

Inés Chapi, Licto Ecuador, May 2003

Montolvo, Lucy. Responsable for cumminucation of the irrigation project and development in Guange Licto (Responsable de capacitacion y comunicacion proyecto de riego y desarrollo Guangue Licto), CESA Riobamba Ecuador, April 2003

Rodriguez, Nelson, 2003, CODERECH, Riobamba, Ecuador. April 2003

Rojas Inca, Edgar, 2003, Lawer, Riobamba, Ecuador. April 2003

Maps

IGM, 1971, *Riobamba* nr 3888 Scale 1:100 000

IGM, 1991, a, *Pallatanga* nr 3888-III Scale 1:50 000

IGM, 1991, b, *Riobamba* nr 3888-I Scale 1:50 000

IGM, 1991, c, *Palmira* nr 3887-I, Scale 1:50 000

IGM, 1992, *Guamote* nr 3888-II Scale 1:50 000

Ministerio de Recursos Naturales y Energéticos, 1982 *Mapa Geológico Nacional de la República del Ecuador*, Ministerio de Recursos Naturales y Energéticos, Ecuador. Scale 1:1 000 000

Ministerio de Recursos Naturales y Energéticos, 1978 *Mapa Geológico del Ecuador, Riobamba, hoja 70*, Ministerio de Recursos Naturales y Energéticos, Ecuador. Scale 1:100 000

Other

INAMHI, Division of Hydrology: Daily discharge data from Río Guamote AJ Cebadas, H786, Río Cebadas AJ Guamote, H790, Río Guargualla AJ Cebadas, H789 during 1965-1978. Ministry of Energy and Mines, Quito, Ecuador.

INAMHI, Division of Meteorology. Montly precipitation data from Guamote, M134, Palmira, M398, Guaslan, M133, Cebadas, M395, Juan de Velasco, M409, Licto, M407, Cajabamba, M394 during 1977-1988. Ministry of Energy and Mines, Quito, Ecuador.

MAG, unknown year. GIS information. MAG, Ecuador

APPENDIX 1

Water demand

Potatoes

Table A1.1 The water demand of potatoes in the cropping area, calculated with an effective precipitation of 80%. Source: Halmstad and Lindell (2004).

	1964	1965	1966	1967	1971	1972	1973	1974	1975	1976	1977	1978	Average		
													[mm]	[m³/ha]	[l/s ha]
Jan	84	59	67	50	60	53	70	72	78	52	56	51	63	628	0.23
Feb	68	73	59	44	52	48	39	18	0	26	71	60	46	464	0.19
Mar	72	79	56	71	0	0	26	61	40	14	70	37	44	439	0.16
Apr	34	0	32	45	18	0	55	27	54	11	34	16	27	272	0.11
May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jun	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sep	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oct	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nov	23	0	23	31	25	0	30	31	0	26	19	12	18	183	0.07
Dec	15	22	25	63	47	39	26	43	49	14	36	0	32	316	0.12
Total	297	232	262	305	202	140	246	251	221	144	286	175	230	2302	

Carrots

Table A1.2 The water demand of carrots in the cropping area, calculated with an effective precipitation of 80%. Source: Halmstad and Lindell, 2004.

	1964	1965	1966	1967	1971	1972	1973	1974	1975	1976	1977	1978	Average		
													[mm]	[m^3/ha]	[l/s ha]
Jan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Feb	30	34	18	1	11	7	0	0	0	0	36	26	14	136	0.06
Mar	62	68	45	60	0	0	16	51	31	8	60	26	35	355	0.13
Apr	44	0	42	56	29	6	64	37	63	17	43	24	35	353	0.14
May	77	54	66	83	88	66	69	58	76	27	84	32	65	650	0.24
Jun	40	70	63	27	48	39	64	52	33	46	53	53	49	489	0.19
Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug	37	54	54	65	50	47	41	48	52	35	33	43	46	464	0.17
Sep	52	76	78	86	57	78	34	10	55	45	25	22	52	515	0.20
Oct	64	19	63	11	11	71	66	49	0	40	48	55	41	413	0.15
Nov	75	0	71	78	73	33	82	86	47	84	75	68	64	642	0.25
Dec	38	46	50	89	72	63	49	64	69	34	58	7	53	532	0.21
Total	518	419	548	556	438	411	484	453	426	337	514	357	455	4551	-

Alphalpha

Table A1.3 The water demand of alfalfa in the cropping area, calculated with an effective precipitation of 80%. Source: Halmstad and Lindell, 2004.

	1964	1965	1966	1967	1971	1972	1973	1974	1975	1976	1977	1978	Average		
													[mm]	[m^3/ha]	[l/s ha]
Jan	78	53	61	44	54	47	64	67	73	47	51	46	57	571	0.21
Feb	52	57	42	26	36	31	23	3	0	12	57	46	32	322	0.13
Mar	56	62	39	53	0	0	10	45	25	5	55	21	31	309	0.12
Apr	40	0	38	51	24	2	60	33	59	15	40	21	32	320	0.12
May	66	43	54	71	76	55	59	48	66	21	74	23	55	547	0.20
Jun	38	67	60	25	46	36	61	50	31	45	50	51	47	466	0.18
Jul	65	76	68	54	79	66	56	60	13	45	69	61	59	594	0.22
Aug	59	77	78	90	74	69	63	68	73	49	52	65	68	680	0.25
Sep	49	72	74	83	53	75	31	7	52	43	22	19	48	483	0.19
Oct	61	15	60	8	8	68	63	46	0	37	45	53	39	386	0.14
Nov	60	0	65	73	66	17	68	65	26	57	52	46	50	495	0.19
Dec	39	46	51	89	72	63	49	64	70	34	58	7	54	536	0.21
Total	664	570	690	668	587	531	607	556	487	409	625	458	571	571	0.21

APPENDIX 2

Average precipitation of stations used in the Thiessen polygon method

Table A2.1 Mean precipitation from stations used in the Thiessen method for determining average rainfall

	Years used to calculate mean	Guamote [mm]	Palmira [mm]	Juan de Velasco [mm]	Guaslan [mm]
Jan	77, 78, 88	22	31	70	30
Feb	77, 78, 88	93	39	94	66
March	77, 78	48	42	118	80
April	77, 78	47	80	127	89
May	77, 78	28	18	54	34
June	77	22	25	80	37
July	77, 87	3	17	48	18
Aug	77, 87	12	12	37	32
Sept	77	59	31	38	66
Oct	77, 87	43	38	100	71
Nov	87	7	46	66	64
Dec	80	28	34	57	46

APPENDIX 3

Field measurements and results of slug test

Well location: Pasturage in Balda, GPS-location: 17M 0754372 9793708 3170±8 m a.s.l.
Date: 030528
Well data: area; 72x72 cm
Total depth of well; 450 cm
Depth of water before test, H; 400 cm
Type of slug: Water poured into well (119.5 liters)
Depth of water instantaneously after slug added, H_0; 420.5 cm

Table A5.1 Water level response after slug injection.

Time [min]	$H-h$ [cm]	$\frac{H-h}{H-H_0}$	Time [min]	$H-h$ [cm]	$\frac{H-h}{H-H_0}$
0	-20.5	1.00	61	-12	0.59
0.25	-20.5	1.00	65	-11.5	0.56
0.75	-20	0.98	71	-11	0.54
1	-20	0.98	76	-10.75	0.52
1.5	-19.5	0.95	81	-10.5	0.51
2	-19.5	0.95	86	-10	0.49
2.5	-19.5	0.95	91	-9.75	0.48
3	-19	0.93	96	-9.5	0.46
3.5	-19	0.93	101	-9	0.44
4	-18.75	0.91	106	-8.75	0.43
4.5	-18.5	0.90	111	-8.5	0.41
5	-18.5	0.90	116	-8.25	0.40
5.5	-18.5	0.90	121	-7.75	0.38
6.5	-18.25	0.89	126	-7.5	0.37
7.5	-18	0.88	131	-7.25	0.35
8.5	-17.5	0.85	136	-7.25	0.35
9.5	-17.5	0.85	141	-7	0.34
10.5	-17.25	0.84	146	-6.75	0.33
11.5	-17.25	0.84	151	-6.5	0.32
12.5	-17	0.83	156	-6.5	0.32
13.5	-16.75	0.82	161	-6.25	0.30
14.5	-16.75	0.82	166	-6	0.29
15.5	-16.5	0.80	171	-5.75	0.28
16	-16.5	0.80	176	-5.5	0.27
21	-16	0.78	181	-5.5	0.27
26	-15.5	0.76	186	-5.25	0.26
31	-14.75	0.72	191	-5.25	0.26
36	-14.25	0.70	196	-5	0.24
41	-13.75	0.67	201	-4.75	0.23
46	-13.25	0.65	206	-4.5	0.22
51	-13	0.63			
56	-12.5	0.61			

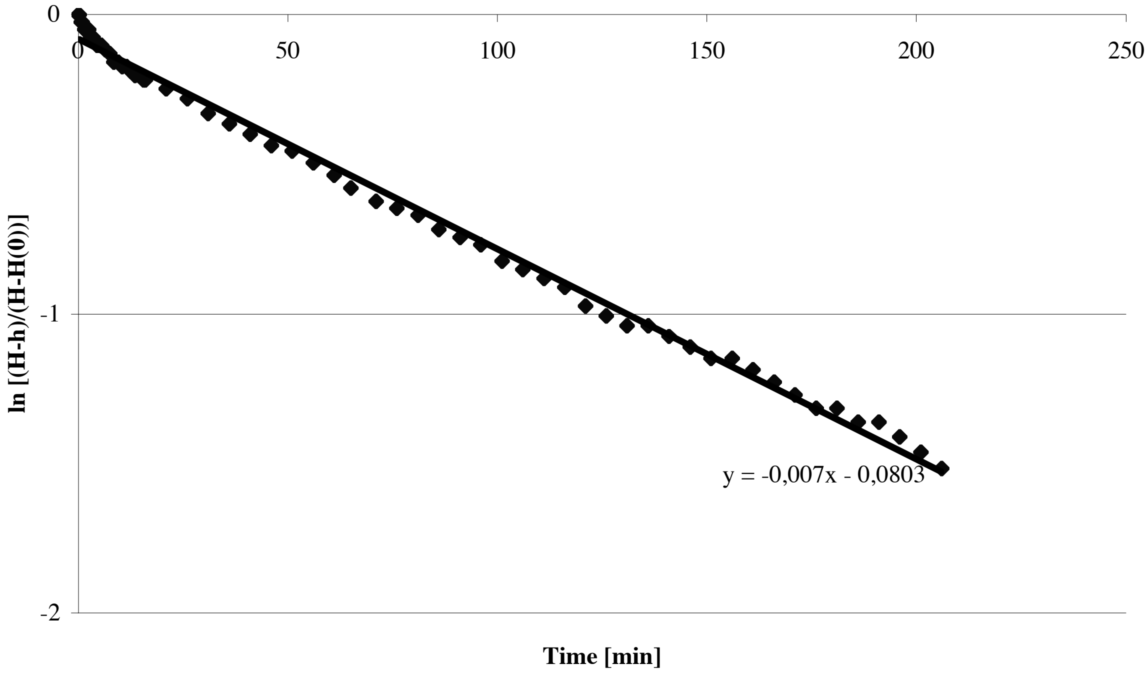


Figure A3.1 The recovery of the water level plotted on logarithmic scale.

APPENDIX 4

Ground water variations at the pasturage

The water level observations on the pasturage were done during April and May 2003. All the observed wells were hand dug and mainly used for watering animals. Some had yellowish water probably due to iron contents in the soil. The wells were located with a GPS and coordinates, elevation and owners are shown in Table A4.1 and the results in Table A4.2:

Tabell A4.1 Well information

Well No	GPS coordinate	GPS elevation	Owner	Well depth [m]
4	17M 0754353 9793934	3176 ± 8 m a.s.l.	No info	2.05
5	17M 0754350 9793930	3174 ± 10 m a.s.l.	No info	1.75
6	No info	No info	Transito Atupaña	3.75
7	17M 0754505 9793786	3180 ± 11 m a.s.l.	Domingo Chimbolema	3.30
8	17M 0754487 9793924	3178 ± 10 m a.s.l.	Salvador Tenenaula	1.80

Tabell A4.2 Ground water level below ground surface, 2003

Date	No 4 [m]	No 5 [m]	No 6 [m]	No 7 [m]	No 8 [m]
14/4	1.65	1.35	1.30	-	-
20/4	1.30	1.25	1.20	-	-
25/4	1.16	1.12	1.15	0.30	-
4/5	1.10	1.15	1.03	0.45	1.30
6/5	1.08	1.15	1.00	0.40	-
8/5	1.02	1.20	1.08	0.40	1.45
14/5	1.10	1.20	1.25	0.50	1.45
27/5	1.50	1.35	1.20	0.70	1.55

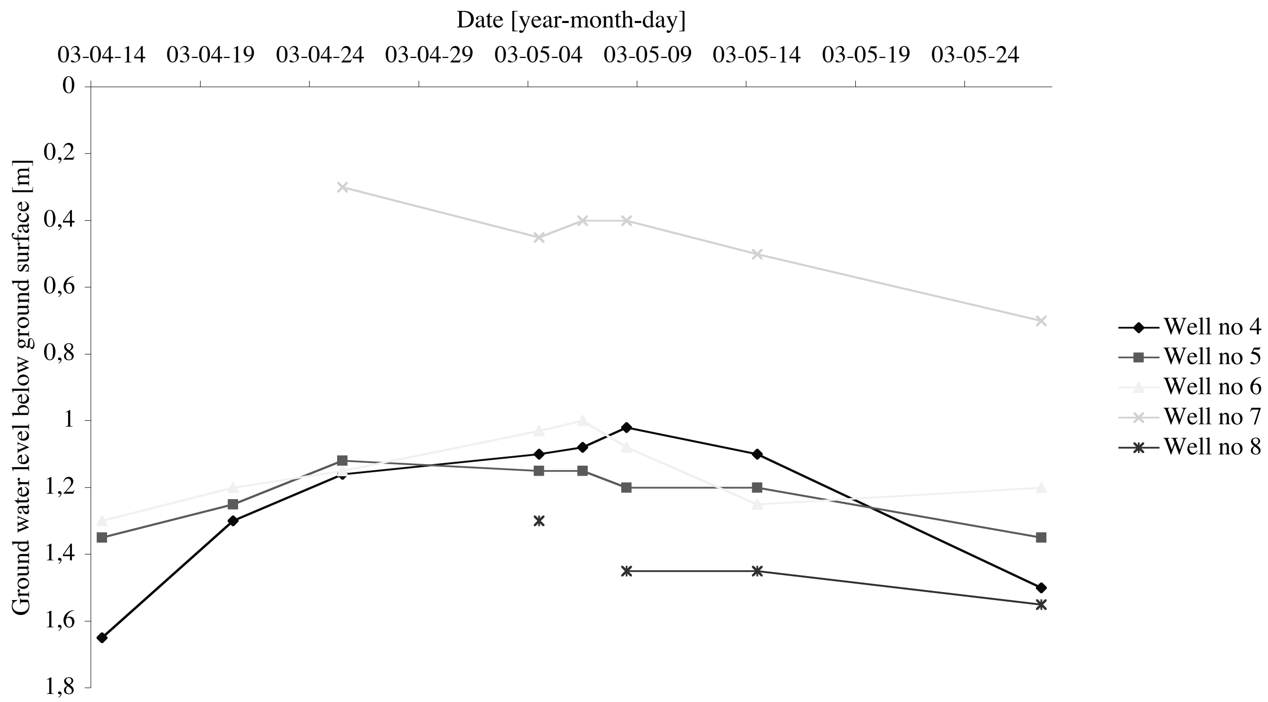


Figure A4.1 Ground water variations at the pasturage during April and May 2003

APPENDIX 5

Irrigation water quality guidelines

Food and Agriculture Organization of the United Nations, FAO, has presented guidelines for evaluation of water quality for irrigation (some presented in Table A5.1). The guidelines emphasize on long-term influence of water quality on crop production, soil conditions and farm management. Water used for irrigation can vary greatly in quality depending upon quantity of dissolved salts, measured in deciSiemens per meter. The salts originate from dissolution of weathering of the rock and soil but also from human activity. The salts are carried to the soil with the irrigation water where they remain behind as the water evaporates or is used by the plants. The salt reduce the water availability to the crop to such extent that yield is affected. Another problem is that certain ions such as sodium, chloride, or boron from soil or water can accumulate in sensible crops. The damage this causes also affects the crop yield. The deterioration of equipment due to water-induced corrosion or encrustation is also a problem that farmers practicing irrigation faces. Sediment content and pH are parameters that can cause these problems. (Ayers and Westcot, 1985)

Table A5.1 FAO guidelines for irrigation water quality. Source: Ayers and Westcot, 1985

Potential Irrigation Problem	**Unit**	**Degree of Restriction on Use**		
		None	**Slight to moderate**	**Severe**
Salinity	dS/m	< 0.7	0.7 – 3.0	> 3.0
Chloride (Cl) (surface irrigation)	mg/l	< 141	141 - 354	> 354
pH			Normal Range 6.5 – 8.4	

Reference:

Ayers, R. S. and Westcot, D. W., 1985, *Water Quality for Agriculture*, FAO Irrigation and Drainage Paper 29 Rev. 1, Rome, Italy

APPENDIX 6

Schematic sketch of the siphon in the Llinllin River alternative