Internacional Irrigation Mangement Institute (IIMI)
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ACTUAL VERSUS POTENTIAL WATER USE
In Cabuyal Watershed - Colombia

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Summary

The International Irrigation Management Institute (IIMI) together with the International Centre for Tropical Agriculture (CIAT) conducted a study about prevailing and potential water use practices in the sub-watershed of the Cabuyal River in the mid hills in south-west Colombia The need for this study arouses during meetings in which farmers expressed their desire for irrigation facilities

The overall objective of the study was to identify ways to improve the effective and sustainable use of the water resources To diagnose the potential for increased water use, a comparison was made between the total amount of available water and the quantity that is actually used for domestic, agricultural and industrial purposes On the basis of this comparison, recommendations about a future increase in water use (for example for irrigation) were drawn, taking into account existing and potential water conflicts within as well as between different water users' groups

To estimate the total water availability in the sub-watershed (3,200 ha) hydrologic and climate data for the main watershed (65,000 ha) were interpolated to the sub-watershed where these kind of data were not available The rain-runoff relation of the main river (Ovejas River) was established by analysing the hydrograph and rainfall patterns This relation was used to estimate river flows in the tributary river (Cabuyal River) This method proved to be very suitable in the case of the Cabuyal sub-watershed, as physical conditions determining the rain-runoff relation (precipitation pattern, slopes, soils and vegetation) are similar for both the main river and its tributary

The minimum quantity of water available during the dry months in the sub-watershed amounts to 260 l/s, or 22,464 m^3 per day The quantity of water actually used by inhabitants living in the area totals 2 156 m^3 per day (i e 10 % of the total) of which some 16 % is for domestic purposes 79 % for irrigation and only 5 % for industrial uses In spite this abundance of water, downstream users of the main drinking water system are suffering from water shortage because upstream inhabitants use the drinking water for irrigation The limited capacity of the drinking water systems does not allow for domestic and agricultural use at the same time To solve these water conflicts it is recommended to give priority to domestic purposes and to discourage or banner the use of drinking water for agricultural purposes

To meet agricultural water needs some local farmers developed their own individual irrigation methods These initiatives in which farmers use motor pumps to draw water from springs, can be used as examples in further irrigation development in the sub-watershed

In terms of water availability there is scope to construct communal irrigation schemes However, the organisational and economic feasibility is questionable, as irrigation is only needed for 2 months per year

No conflict about water between the different drinking water systems has been reported However, in order to avoid future water right problems, water users' groups should register their claims on water with the Watershed Authority as stated in the Colombian Water Law

Off side impacts of increased water use by sub-watershed inhabitants for a big hydropower plant downstream will be negligible in terms of water quantity This hydropower plant gets its water from the main river (Ovejas River) which has a minimum flow of 10 m^3/s The studied tributary (Cabuyal River) only carries 0 26 m^3/s in the dry season This means that during the dry months only 2 5 % of the water quantity in the main river originates in the sub-watershed Changes in water use in the sub-watershed will therefore have limited effect on the water quantities in the main river

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Chapter 1 INTRODUCTION

1 1 Background

In 1992 CIAT started the Hillside Program with the objective to ' improve the welfare of the hillside farming community by developing sustainable and commercially viable agricultural production systems"[1] In Colombia the program is mainly working in the Cabuyal River watershed, situated in the mid hills of south-west Colombia

In a planning by objective session held in 1993 the inhabitants of the watershed indicated the shortage of water during the dry season as one of their main problems Within the Cabuyal River watershed conflicting interests relating to water exist, especially during the dry months (July and August) For example, during the dry months water supplied by the main drinking water system in the area is insufficient for all beneficiaries, forcing the inhabitants of the lower parts to use alternative sources (wells, springs or small streams) for their domestic water supply The farmers in the lower zone accuse the farmers in middle reach of using the water from the drinking water system for irrigating their vegetable plots, causing water shortage in the lower zone However, the farmers in the middle reach claim that the amount of water in the system has decreased as a result of deforestation caused by farmers in the higher parts of the watershed near the intake[2]

Therefore farmers asked the Hillside Program to investigate the possibilities of increased water use (for example irrigation) using the available water resources in the area, like small streams and rivers At the same time INAT[3] was interested in the irrigation potential of the watershed as they plan to implement a number of small-scale irrigation systems in hill areas

A big hydropower plant in the Cauca River providing electricity for Cali is located about 15 km downstream of the watershed At this moment the water leaving the watershed is not benefiting this hydropower plant as the Ovejas River (of which Cabuyal River is a tributary) joins the Cauca River just downstream of the dam However plans were developed by CVC to divert the Ovejas River as additional supply in the dry season[4] It is obvious that an increased water use will have its impact on the water quantities leaving the watershed

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[1] Annual Report Hillside Program, 1995
[2] H Ravnborg & J Ashby 1996
[3] INAT Instituto Nacional de Adecuacion de Tierra colombian government institute responsible for irrigation development
[4] E B Knapp et al 1995

CIAT and IIMI in a joint effort decided to execute an investigation about the actual and potential water use taking into account the conflicting interests within and outside the watershed as described above The research was supported by INAT and started in April 1996 The results are presented in this report

The first chapter deals with the research questions, the methodology and a brief description of the study area In the second chapter a description of the hydrology and the available water resources will be given In chapter 3 the actual water use per sector (domestic, agricultural and industrial) and the existing water conflicts among different water users' groups are elaborated In chapter 4 an assessment of the potential water use in the watershed is made, taking into account the existing conflicting interests for water Various possible scenarios and its impacts on downstream water availability are investigated and discussed In chapter 5 some conclusions about the methodology and actual versus potential water use are drawn

1 2 Objective and research questions

The overall objective of the study is to identify ways to improve the effective and sustainable use of water resources in the Cabuyal watershed To diagnose the potential for increased water uses (for example by irrigation) a comparison between the actual and potential water use is accomplished In view of the conflicting interests within and outside the watershed an attempt to assess possible impacts of increased water use on water quantities downstream will be made Although some attention will be paid to off-site conflicting interests, the emphasis will be on impacts within the watershed It is expected that the information generated by this study, can be used by farmers within the watershed as input in future discussions about water use

The following research questions were formulated

What water sources exist in the watershed?
What is the total water quantity available in the watershed?
How is the water actually used?
Which water sources are used and which are not used?
What conflicting interests about water exist?
What is the potential for increased water use, for example, by irrigation?
What are the possible impacts on water quantities downstream of increased water use?

1 3 Brief description of the study area

The sub-watershed of the Cabuyal River is situated in Southwest Colombia in the Department Cauca The terrain is mountainous, characterised by deep gullies and steep slopes (up to 75%) Elevations ranges from 1150 to 2200 m a s l

The climate is humid and the high rain intensities combined with the steep slope form a serious risk for soil erosion The soils are from volcanic origin (Oxic Dystropept and

Typic Dystrandept) and are considered to be of low fertility due to low effective cation exchange and base saturation About 15 % of the area is covered by forest

Administrative boundaries of watersheds rarely coincide with hydrological boundaries, as administrative boundaries tend to follow rivers while the hydrological limites are determined by crests In the case of Cabuyal watershed the actual hydrological watershed comprises an area of 3300 hectares while the watershed defined by administrative boundaries includes about 7400ha divided in 22 'veredas'

The Pan-American Highway which crosses the area, provides good access throughout the year to the middle zone, while the dirt roads in the higher and lower zones prohibit good access during the wet months

Some 5500 inhabitants belonging to different ethnic groups (mestizos and indigenous groups like Paez and Guambianos) are living in the administrative watershed, mainly small subsistent farmers with an average of 2 hectares of cultivated land The main crops cultivated are coffee, beans, tomatoes and banana

1 4 Methodology

1 4 1 Existing data

Since CIAT's Hillside Program already has been working in the area for several years a lot of information about the area is available This information includes climate data, topographical maps, maps on soils & land use, hydrologic information and socio-economic data Most topographical material is digitised (in ArcInfo format) The first step in the methodology was to collect, analyse and systematise the information available in CIAT, INAT, CVC[5] and other institutions

1 4 2 Structured interviews

To complement existing information 3 questionnaires were developed

1 Diagnosis of water resources & water users' groups
2 Inventory of existing irrigation techniques
3 Management of drinking water systems

The first survey sampled the vereda[6] level (one per vereda, 21 total) by interviewing key persons about available water resources and prevailing water use practices in their vereda Information deducted from this questionnaire was analysed to estimate the number of water sources, the way these sources are actually used by different water users' groups

[5] CVC (Cooperativa Valle de Cauca) is the regional watershed management authority
[6] Vereda is an official administrative unit of between 183 and 665 ha for the study area

and the quantity of water used for the different purposes. It also served to assess the existing and potential conflicts about water.

From this inventory it became clear that, although there is no irrigation scheme in the watershed, some people use motor pumps or take water from the drinking water systems to irrigate their individual plots during the dry months (July/August).[7] The second questionnaire dealt with these existing irrigation techniques. Some 50 persons were interviewed about the applied irrigation methods including the costs and benefits involved.

The existing drinking water systems appeared to be an important water source, not only for water for domestic purposes but also for agricultural uses. Therefore, it was decided to execute a third survey consisting of structured interviews with members of the organising committees responsible for the management of the systems. In total 9 surveys were taken, one for each drinking water system.

1.4.3 Spatial data collection

In order to update and correct existing topographical maps, air photos (scale 1:35000) were magnified to 1:5000 to be used. In combination with the questionnaire about water resources and water use practices farmers were asked to indicate on the photos where water resources existed and whether they were used for domestic, agricultural or industrial purposes. Whenever necessary the sites were visited together with the informants to verify the information in the field. The information yielded from this participatory mapping exercise was later digitised in ArcInfo format compatible with existing GIS-coverage's (maps).

Unfortunately photos covered only 60 % of the watershed. For the remaining area topographic maps were used. Although farmers had more difficulties orienting themselves with maps than with air photos, this method gave satisfactory results as well.

1.4.4 Estimating Gross Water Availability

To assess the total quantity of water available in the watershed hydrologic and climate data were studied. For the river in the sub-watershed (Cabuyal River) no long-term series of flow data exist. CVC and CIPASLA[8] carried out 7 flow measurements over a time span of 2 years (1994 and 1995). Although very valuable, these measurements are not sufficient to predict river flows in the sub-watershed because of the irregular precipitation pattern (and hence river flow pattern) within as well as over the years.

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[7] INAT constructed a small irrigation scheme benefiting 19 families, but this scheme is used as drinking water system.

[8] Cipasla: Consorcio Interinstitucional para una Agricultura Sostenible en Laderas. Consortium formed by organisations working in the development of the watershed.

However, daily river flow data for a bigger river (Ovejas River) of which Cabuyal is a tributary, are available for a 15 year period These data were used to estimate the parameters relating precipitation and runoff Parameters for the bigger river were interpolated to its tributary, the Cabuyal River Using the available precipitation data for the studied watershed, an estimate of river flows in the Cabuyal River was made To determine the precipitation - runoff relation the AWBM Catchment Water Balance Model was chosen This computer program is a semi-lumped model that relies on comparing observed and simulated catchment outflows for calibration of internal model parameters It makes use of daily precipitation, daily runoff and monthly evapotranspiration data

Flow data for the main river (Ovejas River) were used to calibrate the model Once calibrated the model was applied to its tributary, the Cabuyal River The results were compared with the 7 existing flow measurements

Chapter 2 WATER AVAILABILITY

2 1 Introduction

CIAT started collecting climatic and hydrologic data in the Cabuyal sub-watershed in November 1993 Unfortunately, none of the climatic stations established and managed by HIMAT (at that time the responsible government agency for hydrology) fall within the study area So no long term climate and hydrological data series exist for the sub-watershed

Consequently it was decided to analyse the climatic and hydrological conditions of the bigger watershed of Ovejas River for which long-term data series do exist The Cabuyal river is a tributary of the Ovejas river and the physical characteristics of the Ovejas watershed (geology, topography, soils, climate and vegetation cover) show strong similarities with the study area For this study, it is assumed that hydrologic parameters determining the river flow in both the mayors as well in the sub-watershed are similar The rainfall-runoff relation for the main river was determined using the AWBM Catchment Water Balance Program Daily flow data for the mayor river (Ovejas) were used to calibrate the model Once calibrated the model was applied for its tributary, the Cabuyal River The simulated flows were compared with actual the river flow data measured by CIPASLA In this way a satisfactory estimate of the water availability in the Cabuyal Watershed could be made

In the next paragraph a description will be given of the climatic and hydrological conditions for both the main and the sub-watershed Followed by a description of the computer model used to analyse and simulate river flows The results of the flow simulations are compared with the actual available flow data Finally, conclusions about the applicability of the model to estimate water availability in the Cabuyal watershed are drawn

2 2 Climate and hydrology in the main watershed

2 2 1 Climate

The main watershed of Ovejas River comprises an area of 100,000 ha, situated in south-west Colombia in the foothills of the Andes with altitudes ranging from 1150 to 2300 m a s l (map, figure 2 1)

Six-climate stations representative for the Ovejas watershed were selected and daily precipitation and monthly temperature data were analysed The mean annual rainfall for the period studied[9] amounts to 2065 mm with a pronounced dry period in July and August (70 and 80 mm respectively) The mean monthly temperature varies little during

[9] i e 1974 - 1988, years selected on basis of data availability

the year, but differs considerately from place to place, depending on the altitude The mean monthly temperatures reported vary from 13°C (2650 m a s l) to 21°C (1200 m a s l)

Potential evapotranspiration was calculated using CROPWAT[10] Total potential evapotranspiration (ET_0) varies from 1106 mm to 1306 mm per year, depending on altitude, and is relatively evenly distributed throughout the year

Must needs for irrigation occur during the period from mid June to the beginning of September (2-3 months) when the potential evapotranspiration exceeds the 80 % probable precipitation (i e the rainfall statistically occurring 4 out of 5 years) Refer tables 2 1 & 2 2 and figure 2 2

2 2 2 Hydrology

CVC registered river flow for Ovejas River at a location 200 meters downstream from where the Cabuyal River joins the Ovejas River (figure 2 1) At this point the catchment of the Ovejas River comprises an area of 61,500 ha Daily river flow data for 1974 to 1988 were analysed For these years the average river flow was 19m³/s with mean minimum flows in August and September (8 5m³/s) and an absolute minimum of 3 5m³/s Although river flow varies greatly over years during wet months, minimum flows during August and September are fairly regular (refer to figure 2 3) Expressed in millimetres average annual water yield for the catchment amounts to 990mm (for more details see table 2 3)

Figure 2 4 gives the flow duration curve for Ovejas River for 1974 - 1988 A curve with a steep slope results from stream flow that varies markedly and is largely fed by direct runoff, whereas a curve with a flat slope results from stream flow that is well sustained by surface releases or groundwater discharges The slope of the lower end of the duration curve (i e low flow characteristics) shows the behaviour of the perennial storage in the catchment area, a flat slope at the lower end indicates a large amount of storage and a steep slope indicates a negligible amount[11] The curve for Ovejas River shows a fairly steep slope, which is explained by the mountainous character of its catchment area and near surface geological stratification Instantaneous high floods, caused by direct surface runoff and near surface through-flow, occur after intensive rainfall These high floods contribute considerably to the total river flow

This observation is affirmed by an analysis of the hydrograph As calculated from a graphical baseflow separation[12] the base flow index is approximately 0 77, or in other words 77 % of the river flow is determined by baseflow (i e subsurface flow) and 23 % is contributed by direct surface runoff, causing occasional high floods of over 100 m³/s

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[10] Computer program developed by FAO to determine crop water needs version 5 7 1991 The program uses the modified Penman Monteith formula

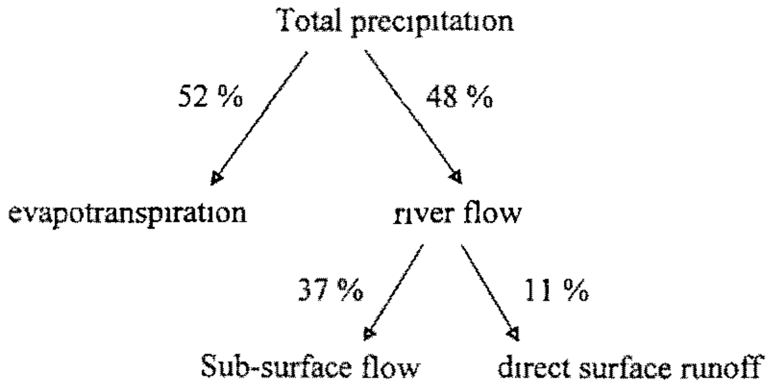
[11] See Peters 1994, Shaw and Harvey 1993

[12] For methods of baseflow separation see Peters 1994, Bates 1989 and paragraph 2 3

Moldan (1994)[13] suggests that for longer-term studies (i e several years) of catchment areas with negligible flow to deep groundwater, the most accurate method to estimate actual evapotranspiration is to deduct runoff from precipitation Using this method for Ovejas River catchment the mean actual evapotranspiration totals 1076mm (that is 2066 - 990mm) per year The potential evapotranspiration according to Penman was calculated at 1106 to 1306mm Taking in account that actual evapotranspiration is less than potential due to deficits in the dry period (130mm in a average year), this seems a reasonable estimation In view of the mountainous characteristics, steep slopes and geology of the area, it seems reasonable to assume that losses to deep groundwater will be limited (figure 2 5)

The water balance for the Ovejas watershed looks as follows from the 2066 mm of precipitation occurring in an average year 1076 mm (52 %) is lost to evapotranspiration while 990 mm (48 %) is transferred to river flow The river flow consists of 762mm baseflow and 228 mm direct surface runoff

Directed Graph



A schematic representation of the water balance in Ovejas Watershed is given in figure 2 6

2 3 Available water sources in the sub-watershed

The study area is rich in natural water resources The Cabuyal river, the principal river originating in the sub-watershed, is about 20 kilometres long and carries water throughout the year The CVC in collaboration with CIPASLA executed several flow measurements in 1994 and 1995 (table 2 5) The measurements at 3 different sites in the river show that 25 % of the total river flow at the lowest point in the watershed originates in the upper zone, 25 % in the middle zone and 50 % in the lower zone Zone as defined by Hillsides programs (Annual report)

[13] Moldan (1994) pp 215 - 217

In the watershed according to hydrological boundaries (3200 ha) there are about 135 springs carrying water all year around, although their flow reduces considerably during the dry months July and August to only a few litres per minute These little spring form streams that feed the Cabuyal River

Before the drinking water systems were constructed, groundwater was an important source of water Nearly every household had its own well for domestic purposes Now the majority of inhabitants have access to piped water, the importance of groundwater an on-farm source of water has decreased dramatically about 65 wells, varying from 15 to 25 meter deep, remain in the watershed The majority of the wells are used for drinking water only in case the public drinking water system runs dry For details on hydrologic features see table 2 6

2 4 Description of the computer model AWBM

The AWBM Catchment Water Balance Program was developed by the Co-operative Research Centre (CRC) for Catchment Hydrology, Monash University Australia The latest version available on Internet was used (version 2 0, Jan 1996)[14] The program relates runoff to rainfall using daily rainfall, daily runoff and monthly evaporation data The model uses 3 surface stores to simulate partial areas of runoff[15] The water balance of each surface store is calculated independently of the others The model calculates the moisture balance of each partial area at daily time steps At each time step, rainfall is added to each of the 3 surface moisture stores and evaporation is subtracted from each store The water balance equation is

$$store_{(t+1)} = store_t + rain - evaporation \quad (with\ t = 1\ to\ 3)$$

If the value of moisture in the store becomes negative, it is reset to zero If the value of moisture in the store exceeds the capacity of the store, the moisture in excess becomes runoff and the store is reset to the capacity

When runoff occurs from any store, part of the runoff becomes recharge of the baseflow The fraction of the runoff used to recharge the baseflow store equals runoff multiplied by the base flow index (BFI), i e the ratio of baseflow to total flow in the stream flow

The remainder of the runoff is surface runoff The baseflow store is depleted at the rate of (1 - K) * BS where BS is the current moisture in the baseflow store and K is the baseflow recession constant

The baseflow index and the baseflow recession constant are graphically determined by the program (figures 2 7 & 2 8) The partial areas and the corresponding storage

[14] http //civil-www eng monash edu au/crcch/awbm/awbm htm

[15] Boughton 1987 & 1990

capacities are estimated by the program and further refined by a process of trial and error The best results for Ovejas watershed are presented in the table 2 7
Figure 2 9 shows the comparison between the simulated and the actual flows in the Ovejas River The overall R-square is 0 75 The program tends to over estimate low flows and under estimate peaks during wet years (1974 and 1975), while during the driest year (1980) the program over estimated peak flows Although the program is less accurate in predicting peak flows, generally the program minimum flows are simulated in a satisfactory way For the purpose of this study (i e to assess irrigation potential) minimum flows are far more important than peak flows

2 5 Simulated flows in the Cabuyal River

The parameter values calculated for the greater watersheds (i e baseflow index, baseflow recession constant, partial areas and their corresponding storage capacities) were applied to the Cabuyal River sub-watershed

In November 1993 some local inhabitants of the watershed started registering daily climate data with technical support of CIAT's Hillside program Table 2 5 gives a summary of data registered in 2 local climate stations These daily data were used to simulate river flow in Cabuyal River (for results see table 2 8) Figure 2 10 shows the comparison between the simulated and actual river flow The simulated flow coincides well with the measured values

The mean monthly simulated flow in those two years was about 760 l/s, with a minimum of 260 l/s occurring in September The maximum simulated flow amounts 1420 l/s However, as the program tends to under-estimate peak flows, in reality the peak flow might be higher

2 6 Conclusions

2 6 1 Applicability of the computer model used

The AWBM model analyses an hydrograph of total river flow data and calculates a baseflow separation to distinguish between two mechanisms contributing to river flow i e subsurface flow and direct surface runoff It uses existing data to calibrate the model to the actu l circumstances The parameters derived in this way can be used for watersheds with si lar characteristics The program can be considered as a semi-blackbox model, as it does not explicit address interactions between vegetation, soil characteristics, soil water contents and subsurface flow

The principles used by the AWBM program, i e hydrograph analysis and baseflow separation, gave very promising results In Colombia daily flow data for most mayor rivers are registered by government agencies like CVC and IDEAM[16] and therefore, long term flow data series exist Furthermore IDEAM developed a map indicating the boundaries of the principal watersheds in Colombia (refer figure 2 11) For many sites within each of these watersheds daily precipitation data over a longer time period are available In terms of data availability the method using the hydrograph of the main river to estimate water quantities in its tributaries is feasible for most parts of Colombia Considering the positive results obtained in the case of Cabuyal watershed it would be worthwhile trying this methodology in other hillside watersheds[17] in Colombia

2 6 2 Water availability in the sub-watershed

The AWBM program estimates a minimum flow of 260 l/s occurring in September Unfortunately, for the Cabuyal watershed daily precipitation data are only available for a 3 year period Therefore a flow simulation for a longer and more representative time period could not be executed

Knapp et al (1995) simulated the impact of irrigation development in the Cabuyal watershed on river flow using the program AEGIS+ Their conclusion was that for every 100 ha of irrigated land there would be a reduction of 10 % in river flow Unfortunately, neither the river flow nor the irrigation needs were quantified Taking a minimum monthly flow of 260 l/s (at the lowest point where Cabuyal joins Ovejas) as simulated by the AWBM program, the irrigation demand would be 0 26 l/s/ha This value coincides well with the peak demand of 0 28 l/s for tomatoes, calculated with CROPWAT (see chapter 3 and table 3 3)

Combining the results of the present study and Knapp's study it can be concluded that a minimum flow of 260 l/s in the Cabuyal River during the dry months (August - September) seems a realistic estimate

In the following chapter an estimation will be elaborated of which part of this available water is actually used and for which purposes, followed by an assessment of the potential of increased water use

[16] IDEAM Instituto De Hidrologia Meteorologia y Estudios Ambientales
[17] The program does not count for deep percolation losses so it might be less suitable for flat areas where deep ground water plays a mayor role in the water balance

Chapter 3 ACTUAL WATER USE

3 1 Introduction

In this chapter a description of different water users' groups in the watershed will be given per type of water use (i e domestic, agricultural and industrial use) For each type an estimation of water quantities actually utilised is made The chapter concludes with an assessment of existing water conflicts occurring within and between water users' groups The information used to write this chapter was derived from 3 questionnaires held among the inhabitants in the watershed The information was complemented by a participatory mapping exercise in which community leaders of each vereda were asked to indicate water sources and their use on air photos with a scale of 1 35000

3 2 Water for domestic purposes

In the landscape defined by administrative boundaries, 9 rural drinking water systems supply water for domestic purposes to some 4500 beneficiaries Over 84 % of all inhabitants have access to piped drinking water Persons without access to the drinking water systems, mainly in the lower veredas, have their own pipes drawing water from springs, hand collect water from little streams or use private wells

The biggest system provides water to 45 % of the families living in 11 of the 22 veredas It has a design capacity of 15 l/s but due to technical problems it only draws 10 l/s from its source, the Cabuyal River It was constructed with support of a private organisation for coffee cultivators (Comite de Cafeteros)

Other systems are smaller with estimated capacities varying from 1 to 5 l/s The majority were constructed by the beneficiaries themselves The sources tapped by the systems are small streams In none of the systems is the water treated Although this might pose potential health risks, there was no evidence that domestic water quality has negatively impacted community health

Each system has its organising committee (*Junta de acueducto*) composed of 4-6 representatives of the beneficiary group This committee is responsible for management of the system i e maintenance minor repair and the collection of water fees The water fees vary from US$ 1 50 to US$ 0 40 per month The money collected is sufficient for minor repairs but in case of mayor damage, beneficiaries are obliged to seek outside assistance, as water fees are too low for maintaining a capital fund Most organising committees have rules and regulations, for example stating that drinking water should not be used for agricultural purposes However, reglementary fines in case of 'misuse' of water are rarely imposed, even though many farmers are using the systems to irrigate their plots

Problems reported by the organising committees concern the lack of maintenance resulting in leaking pipes, bad quality and small diameters of pipes and water shortage during the dry season This water shortage is mainly caused by the fact that farmers are using the water for irrigation (see paragraph 3 4) Refer to tables 3 1 and 3 2 for more details on the drinking water systems

3 3 Water for agricultural purposes

Farmers in the watershed pointed out that without irrigation they would not cultivate annual crops during the dry month of July, August and September as they consider the risk of drought too high

In 1961, INAT constructed a small-scale irrigation scheme benefiting 18 families in the vereda of Cidral in the upper part of the watershed At this moment this scheme is exclusively used for domestic purposes, as the beneficiary families do not have access to a drinking water system Furthermore, the flow in the source (a small stream originating in the vereda) is reduced considerably during the dry season to only 3 l/s This amount is insufficient to provide water for both domestic and agricultural purposes INAT plans to rehabilitate the system and to provide training on irrigation management to the beneficiaries However, in view of the limited water availability in the source it is doubtful whether the system should ever be used for irrigation

Farmers in the watershed have developed their own individual systems to meet irrigation needs An estimated 320 farmers (20 % of all families) practice some kind of irrigation Of these 280 uses drinking water systems as source while the remaining 40 farms draw water from little streams Generally irrigation is used for tomatoes although at a smaller scale, bean, pea, onion, papaya, potato and blackberry are irrigated

Three methods of irrigation can be distinguished utilising drinking water systems, using motor pumps and drawing water from little streams by gravity A description of each method is given below

3 3 1 Utilising drinking water systems

In most cases water is taken directly from the tap with hose pipes and crops are irrigated manually In a few cases farmers have constructed small storage tanks (5 m^3) from which water is taken manually or feeds sprinklers Four persons reported that they take water from the tap with buckets

The area irrigated per person is small, on the average 3000 m^2 The investment costs per 'system' are low the mean length of pipe needed is 170 meters (US$ 17) If a storage tank was built, the investment costs rise to US$ 247 None of the irrigating farmers an extra fees above the standard for drinking water although they use far more water than they would use for domestic purposes exclusively

As already mentioned, according to the rules and regulations for the drinking water systems, use for irrigation is not permitted A sketch of a typical system is given in figure 3 1

3 3 2 Utilising motor pumps

A growing number of farmers are purchasing motor pumps to extract water from one of the numerous small springs/streams in the watershed A few farmers rent their pump to others who need irrigation but cannot afford to buy a pump themselves Most irrigators apply water directly with sprinklers or manually Others constructed storage tanks (10 m^3) from which water is conducted by gravity to the irrigated fields Depending on the minimum flow in the source, a simple structure to raise the water level and/or store the water may be needed These little check dams are constructed in wood or stone

The average area irrigated this way is 4500 m^2 per person, the maximum area reported was 2 ha The high cost of the motor pump makes this type of irrigation relatively expensive The motor pump cost around US$ 1500 depending on the capacity Additional costs, like pipes and storage tanks, bring the total investment to US$ 2100 per system Operational costs are estimated at US$ 180 per irrigation season excluding depreciation Those who are renting pumps pay US$ 20 per irrigation, or approximately US$ 200 per season

For many farmers high investment costs are a serious obstacle in adopting this method A sketch of a typical system is given in figure 3 2

3 3 3 By gravity

Seven persons surveyed take advantage of the topographical position of their plot *vis a vis* the water source (small streams) allowing water to be conducted by gravity Generally a storage tank (5 m^3) at field level is needed from which water is taken manually, by surface irrigation or sprinkler On average an area of 1400 m^2 per person is irrigated in this manner

Farmers use a mean length of 700 meters of pipe which corresponds to on investment of US$ 70 Additional costs (storage tank and construction costs) raises the average investment to US$ 370 per system

The position of most water sources is too low compared with potentially irrigable plots to allow for gravity flow, and in most cases either very long pipelines or motor pumps will be needed Obviously, where possible this method is cheaper and more convenient (less maintenance) than using motor pumps A sketch of a typical system is given in figure 3 3

3 4 Industrial use

The importance of industrial activities in the watershed is limited as the major source of income is agriculture Small industrial activities which are mainly found in the middle zone, include cassava processing plants (4), milk and cheese processing plants (2), a bakery and a petrol station Furthermore, at 17 places a total of 5900 chickens are processed bi-monthly Most enterprises take water from the main drinking water system except for the cassava processing plants, which take water from nearby streams None of the enterprises pay fees above base rates for drinking water regardless of the extra amount of water used for their industrial activity

Although current industrial water use is negligible, impact on water quality may not be This issue however, is beyond the scope of this study[18]

3 5 Quantification of water use

3 5 1 Domestic use

At the time of this study (1996) some 5360 inhabitants are living within the administrative boundaries encompassing the watershed It is estimated that a person in a rural area consumes 120 litres of water per day for domestic purposes[19] Using this estimate results in a consumption of 643 m^3 per day for the watershed For domestic animals, a further estimates 17 m^3 is needed bringing the total to 660 m^3 per day for domestic uses

Unfortunately, it is not known how many persons are living in the watershed defined by its hydrological boundaries However, the sources used by 3 out of 9 drinking water systems fall within the hydrologic boundaries (table 3 1) The number of beneficiaries of these systems amount 2773 Together they consume an estimated 350 m^3 of water per day

3 5 2 Agricultural use

The farmers interviewed about their irrigation systems, generally had little idea about the quantity of water they used for their crops Most irrigators claim that they apply irrigation after a period of 8 days without rain Others start irrigating when crops start suffering drought symptoms None measure the quantity of water actually used for irrigation Therefore CROPWAT was used to estimate the irrigation requirement for the principal crop (i e tomato) The net irrigation requirements for July - September amounts 1 17 mm

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[18] A study about water quality in the Cabuyal watershed is currently be executed by graduate student C Mathuriau in collaboration with Universidad del Valle in Cali Colombia Some preliminary results are presented in paragraph 3 7

[19] R M Ramirez 1992

per day, with an assumed efficiency of 70 % it will be 1 67 mm per day (for details refer table 3 3)

The area irrigated with the different drinking water systems is 84 ha Intakes of these systems all fall within the hydrological watershed The irrigation need for this area amounts to1403 m^3 per day during the dry months

The area irrigated with water from small streams is 18 ha, requiring 301 m^3 water per day So, total water use for agricultural purposes is estimated at 1704 m^3 per day during the dry months

3 5 3 Industrial use

In terms of water quantities consumed, industry does not play an important role in the study area an estimated 102 m^3 of water is daily consumed by small scale industrial activities

3 5 4 Total Consumption

The minimum flow in the Cabuyal River is estimated at 260 l/s, or 22,464 m^3 per day The total amount of water used in the watershed is 2156 m^3 per day

So, 9 6 % of the total available water in the watershed is actually used, of which 79 % for agriculture, 16 % for domestic purposes and 5 % for industrial activities (see figure 3 4 & 3 5)

3 6 Conflicts about water within beneficiary groups using the same system

Although engineers generally consider irrigation and drinking water facilities as separate units with different design parameters in terms of quantity and quality, inhabitants in the watershed do not seem to make such a distinctions water from the only irrigation system is exclusively used for domestic purposes, while water from drinking water systems is widely used for irrigation This practice cause water conflicts in the drinking water systems as these were not designed for agricultural purposes[20]

Downstream beneficiaries of the biggest drinking water system, which benefits 45 % of the watershed s total population, are suffering from water shortage during the dry months and accuse middle zone inhabitants of excessive use of water for irrigating their tomato plots To resolve these problems, a number of solutions have been suggested by farmers and people working together in a watershed based organisation called CIPASLA

[20] For irrigating 1 ha of land an estimated amount of 16 700 liters per day is needed while for domestic uses 150 liters per day is sufficient

3 6 1 Water meters

Among the beneficiaries a discussion is going on to introduce water meters In this way the persons using a large amount of water (i e those who use the water for irrigation[21]) are going to be charged for the amount of water they use However, it is questionable whether this will solve the problem of water shortage downstream According to the current rules and regulations using drinking water for agricultural purposes is not permitted By charging per unit of water consumed, use of water for agricultural purposes is 'legalised', so they may take as much as they are willing to pay for[22] People who now refrain from irrigating their plot because it is prohibited, will have the opportunity to do so Until the tariff per m^3 water for water is raised substantially, irrigating farmers claim they would be willing to pay as cultivating tomato is a profitable activity All of this could adversely affect the poorest consumers

Furthermore, measuring, billing and administrating water quantities is an elaborative and complex task, and collecting payment even more so At this time the organising committee of the system is not prepared for these tasks Experiences from other countries shows water meters in a rural setting are easily manipulated or avoided In view of the above it is anticipated that water meters will not solve the problems of water shortage

3 6 2 Reforestation upstream

Middle zone farmers claim that water shortage problems are caused by deforestation upstream Consequently, CIPASLA began to mobilise support for reforestation and establishment of buffer zones along water courses[23]

There is no evidence however that the deforestation argument is true The influence of deforestation upstream on water quantities in water courses downstream is still far from clear A review of 94 catchment experiments to determine the effect of vegetation on water yields, revealed that water yields tend to increase rather than to decrease with deforestation[24] Others argue that grass vegetation is more effective than forest in augmenting baseflow and hence, minimum flows in the dry season[25] Hamilton (1987)[26] warns against high expectations that reforestation of watersheds will significantly to increase water availability In the dry season reforestation may even reduce water in sources due to increased evapotranspiration Few will argue the beneficial effects of reforestation and protecting water sources, but it is misleading to assume that these activities will increase the amount of water

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[21] Industrial use is negligible

[22] Water meters as instrument to detect 'misuse' of water is little effective as it is already widely known in the watershed who is using drinking water for agricultural purposes

[23] Ravnborg & Ashby, 1996

[24] Bosch & Hewlett, 1982

[25] Ponce & Lindquist and chapter 5 (recommendations)

[26] Hamilton & Pearce (1987) and Hamilton (1985)

The determining factor in water availability seems to be the system's limited capacity in combination with over-utilisation Even during dry months a minimum flow of 25 l/s is available in the source where as the system can only draw 15 l/s

A solution for the water shortage problems should therefore be sought in convincing middle zone farmers to reduce their over-utilisation of water or in improvements in the system itself (refer to paragraph 4 2)

3 7 Water conflicts between the different drinking water systems

Although several systems are sharing the same source and operate independently of each other, no water conflicts between drinking water systems are apparent

It remains unclear how water rights issues or concessions are arranged, the prevailing practice is that a person who wants to use water from a source just takes it Only one out of the 9 systems registered their claim for water with the Watershed Authority (CRC) although the Colombian water law states that each entity tapping water needs to seek permission and register its claim It is possible drinking water committees are not aware of the usefulness of registration or simply are not willing to pay the concession fee Lack of registration of water use by drinking water systems poses a serious risk of future water conflicts as pressure on natural water resources is likely to increase

3 8 Water quality [27]

Samples for determining water quality were taken at 5 different sites in the Cabuyal River during the rainy season (table 3 4) Results of the chemical analyses of the samples are presented in table 3 4 and figure 3 6, 3 7 and 3 8 The water quality study is still ongoing at this time and therefore, no firm conclusions can be drawn Nevertheless, based on these samples a few preliminary remarks will be made

The water in the upper part of Cabuyal River is of good quality and suitable for human consumption It should be noted however, that the intake of the drinking water system is not protected and that no water treatment is applied The lack of protection and treatment posses a risk of water contamination as people and livestock can enter freely upstream of intakes

Sampling did not detect negative impact on water quality caused by cassava processing plants These samples however, were taken during the rainy season (November) while there were maximum flow and dilution effects The impact in the dry season when the river is low and the contamination is less diluted, might be different This will be known in a later stage of the research

[27] This paragraph is based on some preliminary results of an on going study on water quality executed by C Mathurіau in collaboration with Universidad del Valle in Cali

The amounts of soil residues in suspension gradually increase moving downstream These preliminary results are insufficient to conclude anything about the role of soil erosion from different sources

3 9 Conclusions

Only an estimated 10 % of the total water available is actually consumed for domestic, agricultural and to a lesser extent for industrial activities Although it should be emphasised that it is desirable to exploit all water available, there is still ample scope for increased efficient use of water

Water use for agricultural purposes is increasing as farmers grasp opportunities for economic benefit Motor pumps and gravity are used to draw water from the numerous small springs or streams in the area

Existing conflicts over water occur mainly within the different water users' groups using the same drinking water system Downstream users face water-shortages during the dry months and because farmers accuse upstream of using drinking water for irrigation The systems' capacities were not designed for the demands of agriculture, which are many times that needed for domestic use

At present no water conflicts were reported between the different drinking water systems However, the lack of registration of water claims by the drinking water systems pose risks for future water conflicts

Chapter 4 ACTUAL VERSUS POTENTIAL WATER USE

4 1 Introduction

Hypothetically, water available during the dry months (July to September) in the whole watershed is estimated at 260 l/s (22,464 m^3 per day) of which 2156 m^3 per day is actually used for domestic, agricultural and industrial purposes Only 10 % of available water in the watershed is currently consumed As a result in theory 235 l/s is available during the dry season for socio-economic development This figure however, should be looked at critically Not all water captured by the watershed can be used Water from springs originating in the lower parts is at little use for higher parts Flow measurements by CVC at 3 points in the Cabuyal River show that 25 % of the water is originating in the higher, 25 % in the middle and 50 % in the lower reach So 50 % of the available water is of little or no use for the inhabitants of the middle and higher zone

Furthermore, from an environmental point of view it is undesirable to extract all water from the river, even if this were possible

Despite these reservations the study makes clear that there is still ample scope for rural development opportunities through rational exploitation of water by the agricultural sector

In this chapter possibility of increased water use and improved access to water, its problems and proposed solutions will be elaborated per sector (i e drinking water, irrigation) As industrial activities are playing a minor role in terms of water use and it is not expected that this will change in the near future, industry is not taken into consideration in this analysis

4 2 Drinking water

4 2 1 Expected changes in water use

The main increase in water use for domestic purposes will be caused by population growth In Colombia the annual population growth is 1 7 % (1994) Assuming this growth for the coming 10 years the population in the watershed defined by its administrative boundaries will increase from 5400 to approximate 6400 inhabitants As a result the water consumed for domestic purposes could increase from 660 to 785 m^3 per day for the inhabitants living into the administrative boundaries, this quantity is not just taken from hydrological watershed

The population taking water from sources within the hydrological watershed could grow from 2773 to 3285 persons The amount of water used per person is not expected to grow dramatically in a rural setting like the Cabuyal watershed Conservatively, an increase from 120 to 150 litres per person per day might be assumed As a result the projected from 120 to 150 litres per person per day might be assumed As a result the projected water use for domestic purposes will rise from 350 to 500 m^3 per day, considering only the inhabitants living in the watershed according to its hydrologic boundaries

4 2 2 Improved access to drinking water

At present some 84 % of the inhabitants receive water for domestic uses from 9 drinking water systems Persons without access to these systems, mainly in the lower veredas, have their own pipes drawing water from springs, access water from small streams or use private wells Currently a new drinking water system is under construction, benefiting inhabitants in the 2 lower veredas[28] The system will improve the access to piped water in a zone where this access is relatively low

Local drinking water systems mainly in the higher zone are suffering water shortages to leaking pipes, poorly maintained intakes and limited capacity of main pipes and reservoirs Small investments in these systems will improve their performance dramatically assuring reliable water supply to beneficiaries belonging to the poorest part of the population Furthermore, improving performance of local systems may allow for increases in the number of beneficiaries per system Members of the organising committees of 5 out of the 6 local systems propose increasing water tariffs to pay for technical improvements However, some technical and financial support from outside may be needed

The main problems in the 3 larger drinking water systems concern water scarcity for downstream users during the dry season This water shortage is caused by upstream water users who use drinking water for agricultural purposes (paragraph 3 6) In the largest system, which serves nearly half the watershed's population, water diverted by the system is sufficient to meet all beneficiaries' domestic water needs Even if population growth for the next 10 years (from 2400 to 2840 persons) is taken into account water in the system will be enough to meet domestic water needs of its beneficiaries Nevertheless, because an estimated 64 ha is currently irrigated from the system during the dry months, water reaches only half of the beneficiaries

There is scope to improve the system's performance the design capacity is 15 l/s while only 10 l/s was measured Lack of adequate maintenance cause leakage in pipes and some stretches need to be replacement Furthermore, improving the design of the intake and regular cleaning will increase the amount of water entering the system Another possibility would be to increase its design capacity to allow for all water available in the source during the dry months to enter the system i e 25 l/s

The table below summarises the potential of water use in the Laguna-Pescador system for the above mentioned options

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[28] Personal communication Comite de Cafeteros 1996

Table 4 1 Potentıal of Pescador-Laguna drınkıng water system durıng the crıtıcal dry months

optıon	performance	flow (l/s)	m^3 per day	Domestıc use* & Number of benef	agrıcultural use** & ha under ırrıgatıon
actual	Actual sıtuatıon wıth 64 ha ırrıgated	10	864	154 m^3 1025 beneficıarıes	710 m^3 64 hectares
optıon 1	Actual performance, prıorıty to domestıc use, wıth populatıon growth	10	864	426 m^3 2840 beneficıarıes	438 m^3 25 hectares
optıon 2	Idem wıth ımproved performance to allow for full desıgn capacıty	15	1296	426 m^3 2840 beneficıarıes	870 m^3 50 hectares
optıon 3	ıdem wıth ıncreased capacıty to use all water avaılable ın source	25	2160	426 m^3 2840 beneficıarıes	1734 m^3 100 hectares

* 150 lıtre per person per day
** 16 7 m3 per hectare per day (CROPWAT, 70 % efficıency)

The table makes clear that currently the drınkıng water system's performance ıs ınsufficıent to provıde water for both domestıc and agrıcultural purposes Even wıth ımproved performance the water wıll not be suffıcıent for the projected domestıc water needs plus ırrıgatıon at current levels, ıe 64 ha Only ıf actual capacıty ıs ıncreased to extract all water avaılable at the source, can the system be used for domestıc purposes and agrıculture wıthout causıng water shortage downstream Thıs requıres a mayor ınvestment ın larger capacıty pıpes and storage tanks It ıs questıonable whether the extra hectares under ırrıgatıon wıll justıfy thıs ınvestment

Therefore to solve water shortage problems ın the larger drınkıng water systems, serıous efforts should be undertaken to dıscourage water use for agrıcultural purposes to ensure a relıable domestıc water supply for downstream users

4 2 3 Expected water conflıcts

Although several drınkıng water systems are sharıng the same source and operate ındependently of one other, no water conflıcts between drınkıng water systems are apparent Hence, no future water conflıcts between drınkıng water systems are expected In any case ıt ıs hıghly recommendable that the organısıng commıttees of the local systems regıster theır claım on water wıth the authorısed government ınstıtutıon as stated by the Colombıan water law to avoıd future problems

4 3 Agricultural use

4 3 1 Irrigation potential

Need for irrigation occurs 2 to 3 months during the year During the remaining months precipitation is generally sufficient for crops cultivated in the area with local technologies

In terms of water availability there seems to be ample scope for irrigation development Giving priority to domestic purposes (projected at 500 m^3 per day for the watershed population in 2007), and taking into account the amount of water actually used for irrigation and industrial purposes (1806 m^3 /day) Hypothetically an estimated 20,158 m^3 per day (or 230 l/s) is available for further expansion of irrigation, remembering that about 58 l/s (25 %) originates in the middle and 115 l/s (50 %) in the lower zone

CIAT[29] generated a map indicating land in the watershed, which can potentially be irrigated Plots bigger than 1 hectare and with slopes less than 7% were considered to be suited for irrigation (see map in figure 4 1) About 785 hectares in the watershed match with these criteria, of which 380 ha fall in the lower zone and 205 ha in the middle zone

Giving these estimates of land suited for irrigation and water availability it can be concluded that water availability rather than suitable land will be the limiting factor in potential irrigation scheme development In the higher zone only 10 l/s is available (the drinking water system takes 15 of 25 l/s), allowing for 35 hectares[30] of irrigation If farmers in the higher zone decide to use this water, 48 l/s remain for the middle zone farmers, sufficient to irrigate 170 ha of land The remaining 66 l/s permit 235 hectares for irrigation in the lower zone

It should be noted that real irrigation potential will be lower since it is impossible and undesirable to extract all water from the river

4 3 2 Irrigation methods

There are well over 100 small springs/streams scattered over the hydrologic watershed of which the majorities are yet exploited However, flows during the dry season are considerably reduced the order of a few litres per second For some sources flows are too small to provide water for an irrigation scheme of several hectares, without major storage facilities This was clearly shown in the case of The Cidral Irrigation project where the beneficiaries are utilising the water exclusively for domestic purposes, because flow during the dry period (3 l/s) is so low

Some sources however, can be exploited for irrigation on a small scale as demonstrated by the initiatives taken by individual farmers A growing number have invested in motor

[29] Knapp & Rubiano, CIAT 1995

[30] peak requirements amounts to 0 28 l/s/ha (CROPWAT)

pumps, pipes and reservoirs to irrigate their plots An estimated 40 motor pumps are actually in use for irrigation of which some are rented to a number of farmers These local initiatives described in chapter 3, provide examples that can be followed for further irrigation development in the watershed Advantages of these small individual 'schemes' are their flexibility and suitability for the dispersed locations of irrigatable plots For many small farmers however, the high investment costs of a motor pump will be a serious obstacle The economic and social feasibility of sharing motor pumps between several users should be investigated Development organisations working in the area might be interested in providing support in the form of loans or subsidies to groups of irrigators that share common pumps

In a few cases the location of the water source allows for gravity flow

The Cabuyal River can be tapped for a communal irrigation scheme However a few points should be taken into account Firstly, although farmers stated that they would be interested, they do not have experience in operating and managing communal irrigation schemes Experiences with larger drinking water systems shared by several veredas show that presently farmers are not prepared for these tasks Training in irrigation operation and management would be needed Secondly, due to hilly topography irrigatable plots would be scattered requiring extensive piping to reach each individual plot Thirdly, the river is low with respect to the area to be irrigated, which will demand a long conducting pipe from intake to the highest plot For example, if the river is tapped in the middle reach in order to irrigate land in the lower zone, 5 km of pipe will be required from intake to the highest plot These are high initial investment costs for a system that only will be used for supplementary irrigation during 2 or 3 months per year A detailed study should be executed to assess the organisational and economic feasibility of a communal irrigation scheme

4 3 3 Future water conflicts

Water availability is the limiting factor in irrigation development in the watershed An increase in irrigated area might lead to conflicts if farmers do not arrange their water claims The prevailing practice is that any person who wants to use water from a source takes it This practice poses the potential for future water conflicts

At this time no conflicts of interest for the use of springs/streams were reported but this is likely to change if more farmers decide to exploit these sources for irrigation Or, as one farmer interviewed expressed "If 3 motor pumps extract the water at the same time this stream will run dry" Colombian Water Law states that one is owner of a source if it originates and ends within one's property This is no relevant in the Cabuyal watershed as none of the sources fall under this definition

Water management should be taken up for discussion at the watershed level by a community organisation, for example CIPASLA, before irrigation is further developed In any case, care should be taken that priority is given to water for domestic purposes and that no water is extracted upstream of existing drinking water intakes without an impact assessment

4 4 Off site impacts of increased water use

CVC was asked to develop plans to divert water from the Ovejas River to the Salvajina Reservoir to supply a hydropower plant As Cabuyal River is a tributary of Ovejas River, increased water use in the study area will directly influence the amount of water that could be diverted

If approximately every additional 100 hectares of irrigated land results in an estimated 28 l/s reduction in river flow, development of 600 hectares under irrigation will consume more than half the water available in the Cabuyal River during the critical months

However, an analysis of the mean monthly river flow for the Ovejas River, 10 km downstream of Cabuyal River[31], makes clear that the mean flow for the critical months (July and August) amounts 10 8 m^3/s Therefor, even in the unlikely case that the inhabitants of Cabuyal watershed manage to use all water of the Cabuyal River its effect on the amount of water to be diverted for the hydropower will be a negligible 2 5 %

4 5 Conclusions

The capacity of the largest drinking water systems is insufficient to meet both domestic and irrigation needs Increasing the capacity will require a mayor investment It is questionable whether the expected benefits i e extra water for agricultural purposes will justify such an investment Therefore, to solve water shortage for downstream users the use of drinking water for agricultural purposes should be strongly discouraged

The local drinking water systems are suffering from technical problems Small investments in these systems are likely to improve their performance, assuring reliable water supply to beneficiaries belonging to the poorest of the population

There is however, ample scope for increased water use for agricultural purposes Although no official irrigation scheme exist, farmers are developing their own individual irrigation methods These initiatives can be used as examples for further irrigation development In view of water availablity a communal irrigation drawing water from the Cabuyal River seems feasible However, a detailed study should be executed to assess the economic feasibility As farmers do not have experience in managing irrigation schemes, training on management would be essential

At present no water conflicts between the users of different water sources were reported Increased water use might cause conflicts as none of the water user groups have

[31] station Los Cambulos data available for 1981-1995 CVC

registered their claim on water with the watershed authority, as stated by the Colombian water law

Increased water use within the watershed will have a negligible impact on the water quantities in the main Ovejas River

Chapter 5 RECOMMENDATIONS

The needs for this study arouse during meetings when in which farmers expressed their desire for irrigation facilities This study in which the actual water use was compared with the total quantity available in the sub-watershed, makes clear that in terms of water availability there is scope for rational exploitation of water resources, without negative impacts on downstream water users

To improve the effective and sustainable use of water resources in the Cabuyal sub-watershed the following recommendations are made

- **Give priority to water use for domestic purposes**

  Downstream beneficiaries in the main drinking water systems are suffering from water shortage during the dry months This is caused by the systems limited capacity in combination with unauthorised water use for irrigation in the middle reach Increasing delivery capacity requires a major investment, which is hardly justified by the expected extra benefits Therefore, the use of drinking water system for agriculture should be prohibited as stated in the rules and regulations of the systems

- **Strengthen the organising committees of the drinking water systems**

  Water shortage problems for downstream users can be solved in large part if organising committees are strong enough to force on their own rule that use of drinking water for agriculture is prohibited

  Most systems are suffering from leakage caused by lack of maintenance Minor repairs can be paid for with the collected water fees The issue of rising the water fees to allow for major improvements in the systems should also be discussed with the beneficiaries

- **Improve the local drinking water systems**

  Small investments in the local drinking water systems, like replacing pipes and the construction of storage tanks, will improve their performance dramatically This will improve access to piped water, especially in the higher parts of the sub-watershed, where flow rates are relatively low Some financial support from outside may be needed

- **Register claims on water with the watershed authority**

  Only one of the nine drinking water systems registered their claim on water with the watershed authority Although until now, no water conflicts between individual water users and the drinking water systems were reported, this situation might change as pressure on water sources increase Organising committees may be reluctant to register their claim because the watershed authorities collect a fee for water concessions However, the lack of registration poses a risk for future water conflicts This issue should be taken up with the organising committees CIPASLA could take the lead in this

- **Build upon farmers' experiences in irrigation development**

  Farmers in the area are developing their own individual methods for irrigating their plots Some 40 farmers are using motor pumps to draw water from numerous small streams in the sub-watershed These methods are relatively cheap, flexible and well adapted to the scattered position of irrigatable plots Furthermore, farmers already have experience with these local techniques of irrigation For the individual small farmer the investment of a motor pump might be an obstacle Therefore the possibility of collectively obtaining credit and shared use of motor pumps among a small group of beneficiaries should be investigated in more detail

  In view of water availability a communal irrigation system drawing water from the Cabuyal River is feasible However, farmers do not have experience in managing communal systems Water management training would be essential Furthermore, it remains to be seen if the scheme will be economically feasible[32] as irrigation in the watershed is only needed for 2 or 3 months per year

- **Protect water sources**

  CIPASLA took the initiative to mobilise inhabitants to protect water resources by fencing and planting trees in the area around springs and streams These efforts should be supported, as a large number of the springs are still unprotected Special attention should be given to the sources used by drinking water systems Unprotected sources pose a risk for contamination as cattle can freely enter upstream of the intakes of drinking water systems

[32] At present in Colombia the mean investment costs amount to US$ 7000 per hectare for new schemes

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ACRONYMS

BID	Banco Interamericano de Desarrollo
CIAT	Centro Internacional de Agricultura Tropical, international research institute for tropical agriculture
CIPASLA	Consorcio Interinstitucional para una Agricultura Sostenible en Laderas, Consortium formed by development organisations working in Cabuyal watershed
CVC	Corporacion Autonoma Regional del Valle de Cauca, Colombian regional watershed management authority
CRC	Corporacion Autonoma Regional del Cauca Colombian regional watershed management authority
HIMAT	Instituto Colombiano de Hidrologia, Meteorologia y Adecuacion de Tierras, at present called INAT
IDEAM	Instituto de Hidrologia y Estudios Ambientales, Colombian government institute responsible for hydrological and environmental studies
IGAC	Instituto Geografico Agustin Codazzi, Colombian geographic institute
IIMI	Instituto Internacional del Manejo de la Irrigacion, International research institute for irrigation management
INAT	Instituto Nacional de Adecuacion de Tierras, Colombian government institution responsible for irrigation development

TABLES

Table 2 1 MONTHLY PRECIPITATION* (in mm)
OVEJAS WATERSHED

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1974	272	348	360	231	176	115	115	37	196	282	348	146	2625
1975	102	338	165	177	267	116	199	136	122	231	363	376	2592
1976	114	204	188	187	128	43	10	47	80	264	182	158	1607
1977	90	76	165	249	136	82	41	44	125	225	224	184	1640
1978	143	56	232	228	156	63	70	33	110	158	197	336	1780
1979	182	111	285	275	224	80	42	222	146	256	247	108	2176
1980	183	278	75	149	110	71	24	65	78	219	119	172	1541
1981	78	221	240	274	294	126	88	88	42	231	351	173	2206
1982	306	221	328	319	208	47	49	5	141	303	274	225	2425
1983	162	134	264	334	208	42	35	39	34	264	185	261	1961
1984	327	264	230	224	299	118	109	125	207	367	262	162	2695
1985	314	76	182	189	160	62	62	160	123	207	236	158	1928
1986	232	277	184	203	145	82	10	50	148	368	191	91	1981
1987	135	115	171	174	230	48	83	48	91	391	209	84	1781
1988	96	118	101	246	191	129	96	83	132	252	372	231	2046
Average	182	189	211	230	196	81	69	79	118	268	250	191	2066
80 %	114	115	171	189	156	62	41	44	91	231	197	158	1569
median	162	204	188	228	191	80	62	50	123	256	236	172	1950

based on 6 selected climate stations Silvia Morales Mondomo La Aguada El Amparo and Piendamo
interpolation according to climate zones used by CVC

Table 2 2 Monthly potential evapotranspiration in mm, Ovejas watershed according to Penman - Monteith, ET_0

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Salvajin	105	106	118	105	102	105	124	124	114	105	99	99	1306
Cajibio	90	84	96	87	90	90	102	105	93	90	87	90	1106

altitude 1150 m a s l
* altitude 1800 m a s l

Table 2 3 MEAN MONTHLY RIVER FLOW , OVEJAS ABAJO
in m3/s

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
1974	37 9	54 1	56 7	30 6	27 5	16 2	11 5	8 5	9 0	18 1	36 0	27 6	28 4
1975	23 3	36 8	34 3	22 7	25 5	15 9	20 2	12 2	10 9	19 7	42 5	60 0	27 0
1976	32 8	33 5	26 6	29 8	24 3	14 9	8 8	6 2	4 4	13 6	17 8	17 3	19 2
1977	11 0	8 9	8 7	14 8	21 1	13 5	9 5	7 1	6 8	11 7	18 1	11 7	11 9
1978	20 7	10 9	9 7	16 8	18 4	12 3	9 7	8 6	7 2	7 5	10 1	18 9	12 6
1979	16 2	12 7	24 5	20 5	27 1	27 3	11 4	10 9	15 8	21 3	30 4	19 3	19 8
1980	17 0	31 5	23 2	15 0	14 6	11 2	8 3	6 9	7 0	9 9	9 3	13 2	13 9
1981	12 8	14 1	15 8	20 8	31 8	21 8	14 9	9 9	7 8	8 8	19 2	20 2	16 6
1982	35 7	29 6	38 1	36 1	34 6	21 4	12 0	8 4	7 9	12 6	16 8	21 7	22 9
1983	17 9	22 0	22 4	39 5	26 8	17 2	7 7	6 3	7 0	9 6	16 6	17 0	17 0
1984	26 2	26 5	22 1	26 4	42 0	26 0	15 8	10 7	12 0	21 7	36 0	28 1	24 5
1985	36 0	23 6	16 4	20 9	25 4	18 3	10 9	9 0	8 3	14 0	27 4	21 3	19 3
1986	26 8	32 8	37 0	23 4	19 8	15 2	10 2	7 7	7 2	17 4	22 6	17 4	19 8
1987	13 3	9 9	9 6	10 7	17 6	10 4	8 0	6 5	6 7	21 4	25 2	25 5	13 7
1988	12 3	9 1	8 9	11 8	14 9	16 9	17 7	11 4	9 5	15 2	41 1	45 1	17 8
Average	22 7	23 7	23 6	22 7	24 8	17 2	11 8	8 7	8 5	14 8	24 6	24 3	19 0
Median	20 7	23 6	22 4	20 9	25 4	16 2	10 9	8 5	7 8	14 0	22 6	20 2	19 2
ST DEV	9 4	13 0	13 5	8 5	7 5	5 0	3 7	2 0	2 7	4 9	10 6	12 7	5 0

Table 2 4 Climate data for 2 stations in Cabuyal Watershed

year	month	precipitation		max temp		min temp	
		Campina 1550 m a s l	Ventanas 1650 m a s l	Campina 1550 m a s l	Ventanas 1650 m a s l	Campina 1550 m a s l	Ventanas 1650 m a s l
1993	nov	209 8	222 1	23 8	23 3	16 4	14 3
1993	dec	259 9	238 0	23 7	23 6	17 2	14 5
1994	jan	295 3	328 0	24 1	23 3	17 5	14 1
1994	feb	105 6	71 0	24 6	23 5	16 8	13 8
1994	mar	176 0	280 5	24 2	23 4	17 0	14 1
1994	apr	258 6	206 2	24 8	22 8	17 0	14 5
1994	may	172 0	185 0	25 0	25 5	17 0	14 5
1994	jun	60 8	72 5	25 8	24 4	16 4	13 4
1994	jul	42 7	49 0	27 0	25 0	15 6	13 6
1994	aug	10 2	13 0	27 5	25 9	16 0	12 9
1994	sep	59 0	70 5	27 6	26 6	15 1	13 5
1994	oct	185 8	186 5	24 8	23 9	16 0	14 5
1994	nov	272 0	243 0	23 6	23 2	16 2	14 4
1994	dec	108 0	182 5	24 8	23 7	15 5	14 4
		1746 0	**1887 7**				
1995	jan	88 6	125 6	25 5	24 4	15 6	14 0
1995	feb	50 2	46 0	26 5	24 9	15 2	13 4
1995	mar	217 9	159 0	26 3	24 4	16 1	14 6
1995	apr	310 6	354 0	24 7	23 3	15 9	14 5
1995	may	202 0	122 1	24 7	23 3	16 4	14 3
1995	jun	103 2	129 6	25 7	23 1	16 4	14 0
1995	jul	156 0	135 5	25 2	23 1	16 4	13 6
1995	aug	92 2	64 0	25 9	23 8	15 8	13 4
1995	sep	76 4	58 0	26 8	25 3	16 1	14 1
1995	oct	233 4	224 5	25 3	23 2	15 5	13 6
1995	nov	189 2	155 5	24 3	22 9	16 1	14 2
1995	dec	138 0	186 0	23 5	22 8	16 2	14 0
		1857 7	**1759 8**				
1996	jan	237 2	213 5	24 1	22 7	16 2	13 9
1996	feb	146 9	138 0	23 9	22 9	16 2	13 9
1996	mar	303 8	278 5	24 4	23 3	16 3	14 3
1996	apr	171 6	181 5	24 5	23 6	16 5	14 1
1996	may	263 4	158 5	24 0	23 1	16 3	14 1
1996	jun	105 6	60 5	24 4	23 8	16 2	13 9
1996	jul	48 8	64 5	24 6	23 4	15 4	13 2
1996	aug	48 2	43 0	25 0	25 0	15 6	12 7
1996	sep	44 4	62 5	26 1	25 4	16 0	13 3

Table 2 5 CABUYAL RIVER FLOW

measured in m^3/s

	29-Apr-94	13-Sep-94	3-Oct-95	30-Mar-95	9-Aug-95	19-Oct-95	23-Sep-96	25-Oct-96
Lower part	1 36	0 29	0 54	1 21	0 52	0 56	0 27	0 39
Middle part	0 752	0 13	0 30	0 51	0 24	0 28		
Upper part	0 31	0 07	0 15	0 28	0 12	0 16		

distribution of water over the watershed

	29-Apr-94	13-Sep-94	3-Oct-95	30-Mar-95	9-Aug-95	19-Oct-95	mean	per zone
Lower part	100%	100%	100%	100%	100%	100%	100%	50%
Middle part	55%	46%	56%	42%	46%	49%	49%	25%
Upper part	23%	24%	28%	23%	22%	28%	25%	25%

Table 2 6 hydrological information
Cabuyal Watershed

Zone		VEREDA	Rivers	Springs within watershed	total springs	Little streams	Deep wells	depth	natural lakes
high	1	El Oriente	2	19	21	21	1	18	0
(1700	2	Buenavista	3	13	20	22	3	18	0
2200	3	El Cidral	2	7	7	7	0		0
m a s l)	4	Los Quingos	2	4	10	12	0		1
		subtotal		43	58		4		1
middle	5	La Laguna	2	6	21	22	0		1
	6	Santa Barbara	3	2	5	2	0		0
(1500	7	El Porvenir	2	3	6	8	1	?	0
1700	8	Ventanas	2	9	22	22	18	12-18	0
m a s l)	9	Crucero Pescador	1	2	7	7	0		0
	10	Panamericana	3	12	18	18	1	15	0
	11	La Campiña	2	6	14	15	0		0
	12	Potrerillo	2	11	11	12	3	15-28	0
		subtotal		51	104		23		1
low	13	Palermo	1	9	21	21	3	18-20	0
	14	Cabuyal	2	7	15	15	14	12-25	2
(1500	15	La Llanada	2	11	11	11	8	18-27	0
1175	16	El Socorro	2	12	23	24	5	18-23	0
m a s l)	17	La Isla	2	2	5	8	1	15-18	0
		subtotal		41	75		31		2
outside	18	Caimito		0	26	27	3	18	0
hydrological	19	La Esperanza	1	0	9	10	1		0
watershed	20	Primavera		0	15	15	2	18-24	0
	21	El Rosario	1	0	10	10	0		0
		subtotal		0	60	62	6		0
		total		135	297	62	64		4

* total springs in watershed according to administrative boundaries (7400 ha)

Table 2 7 AWBM flow sımulatıon model actual and estımated flow

for Ovejas Rıver ın mm per month

	1974		1975		1976		1977		1978		1979	
	esti mated	actual	esti mated	actual	esti mated	actual	esti mated	actual	estı mated	actual	esti mated	actual
Jan	26	166	100	102	137	144	38	48	85	91	104	71
Feb	124	215	151	146	129	133	25	35	46	43	74	51
Mar	165	249	123	151	128	117	39	38	60	43	143	108
Apr	142	130	122	97	120	127	87	63	96	71	145	87
May	136	121	150	112	111	107	92	93	94	81	142	119
Jun	102	69	105	68	71	63	65	57	67	52	112	116
Jul	87	51	128	89	54	39	46	42	48	43	80	50
Aug	62	37	86	54	40	27	33	31	35	38	70	48
Sep	59	38	77	46	28	19	24	29	25	31	83	67
Oct	111	80	98	86	27	60	37	51	20	33	106	94
Nov	168	153	159	181	59	76	83	77	50	43	129	129
Dec	122	121	201	263	64	76	62	51	134	83	88	85
Total	1302	1430	1500	1395	969	988	631	615	760	652	1276	1025
R-sqr	0 81		0 84		0 89		0 83		0 81		0 66	

	1980		1981		1982		1984		1985		1987	
	estı mated	actual	esti mated	actual	esti mated	actual	esti mated	actual	esti mated	actual	esti mated	actual
Jan	87	75	26	56	158	157	172	115	181	158	80	58
Feb	111	125	74	56	135	117	164	105	105	94	63	39
Mar	85	102	102	69	186	167	160	97	119	72	82	42
Apr	74	64	116	89	198	153	150	112	112	89	78	46
May	84	64	160	140	176	152	190	184	114	111	106	77
Jun	49	48	109	93	117	91	135	110	81	78	63	44
Jul	37	37	100	65	89	53	119	69	58	48	48	35
Aug	27	30	66	44	65	37	89	47	43	40	35	28
Sep	20	30	47	33	48	33	95	51	31	35	25	28
Oct	18	43	48	39	86	55	162	95	54	62	82	94
Nov	38	39	123	82	121	72	157	153	90	116	90	107
Dec	39	58	106	89	128	95	136	123	74	94	81	112
Total	669	715	1076	855	1508	1182	1728	1261	1060	997	834	710
R-sqr	0 81		0 79		0 93		0 68		0 77		0 50	

R sqr tot 0 75

Partıal areas	A1	40 mm	0 047
	A2	220 mm	0 897
	A3	600 mm	0 056
Baseflow Index	0 77		
Recessıon constant	0 99		

Table 2 8 AWBM flow sımulatıon model sımulated flow Cabuyal Rıver

		Ventanas*		measured	
		mm/month	l/s	date	l/s
1994	Jan	115	1420		
1994	Feb	57	704		
1994	Mar	102	1259		
1994	Apr	109	1346	29 Apr	1361
1994	May	96	1185		
1994	Jun	66	815		
1994	Jul	50	617		
1994	Aug	37	457		
1994	Sep	24	296	13-Sep	285
1994	Oct	21	259		
1994	Nov	43	531		
1994	Dec	62	765		
	total	**782**			
1995	Jan	64	790		
1995	Feb	37	457		
1995	Mar	35	432	3-Mar	531
1995	Apr	104	1284	30-Mar	1210
1995	May	77	951		
1995	Jun	63	778		
1995	Jul	55	679		
1995	Aug	40	494	9-Aug	524
1995	Sep	29	358		
1995	Oct	37	457	19-Oct	558
1995	Nov	55	679		
1995	Dec	67	827		
	total	**663**			
1996	Jan	75	926		
1996	Feb	74	914		
1996	Mar	116	1432		
1996	Apr	91	1123		
1996	May	89	1099		
1996	Jun	60	741		
1996	Jul	45	556		
1996	Aug	33	407		
1996	Sep	23	284	23-Sep	272

* statıon Jose Domıngo 1650 m a s l

Table 3 1 General information about drinking water systems in Cabuyal watershed

No	Name	Benefitting veredas	No of benefiary families	No beneficiaries	Tariff ($/month)	Source	Capacity (lt/seg)
1	Laguna Pescador*	Caimito	612	2341	1500	Rio Cabuyal	15
		Crucero/Pescador			1000		
		El Porvenir			1500		
		El Socorro			1500		
		La Campiña			1500		
		La Laguna			1000		
		La Llanada			1500		
		Los Quingos			1500		
		Palermo			1500		
		Pescador			1500		
		Potrerillo			1500		
2	Carrizales (Usenda)	Buenavista	196	748	400	Rio Carrizal	5
		Cabuyal			500		
		La Isla			500		
		Panamericana			500		
3	Santa Barbara Ventanas	Santa Barbara	127	516	500	Rio Guaycoche	2
		Ventanas			500		
4	El Cidral	El Cidral	70	351	200	Quebrada La Colorada	2
5	El Oriente	El Oriente	14	32	0	Varios zanjones	1
6	El Rosario	El Rosario	90	305	200		2
7	La Esperanza	La Esperanza	30	124	0		1
8	Primavera	Primavera	25	92	0		1
9	Santa Barbara*	Santa Barbara	22	81	200	Quebrada La Colorada	1

* the sources of these drinking water systems fall within the watershed defined by its hydrological boundaries

Table 3 2 Number of beneficiaries per drinking water system

Zone	Name of the Veredas	Total population	Number of Beneficiaries	Benefitting population (%)
	El Oriente	48	32	67
High	Buenavista	210	201	96
(1700 2200 msnm)	El Cidral	351	351	100
	Los Quingos	435	335	77
	La Esperanza	158	124	78
	Primavera	92	92	100
	El Rosario	400	305	76
Subtotal		1694	1440	85
	La Laguna	412	288	70
	Santa Barbara	325	302	93
Middle	El Porvenir	223	223	100
(1500 1700 msnm)	Ventanas	295	295	100
	Crucero/Pescador	258	236	91
	Panamericana	199	195	98
	La Campiña	174	163	94
	Potrerillo	268	230	86
	Pescador	225	225	100
Subtotal		2379	2157	91
	Palermo	191	58	30
	Cabuyal	248	248	100
Low	La LLanada	186	62	33
(1175 1500 msnm)	El Socorro	369	369	100
	La Isla	104	104	100
	Caimito	186	120	65
Subtotal		1284	961	75
TOTAL		5357	4558	85

table 3 3 crop water requirements (CROPWAT) for tomato in Cabuyal watershed

Month	decade	coeff K_c	ETcrop mm/day	Eff Rain mm/day *	IRReq (mm/day
May	2	0 70	2 01	2 70	0 00
May	3	0 70	2 05	4 29	0 00
Jun	1	0 70	2 09	2 98	0 00
Jun	2	0 76	2 30	1 77	0 54
Jun	3	0 87	2 72	1 63	1 09
Jul	1	0 99	3 15	1 50	1 65
Jul	2	1 07	3 51	1 37	2 15
Jul	3	1 10	3 66	1 40	2 26
Aug	1	1 10	3 70	1 37	2 34
Aug	2	1 10	3 75	1 37	2 38
Aug	3	1 05	3 48	1 92	1 56
Sep	1	0 90	2 90	2 21	0 68
Sep	2	0 70	2 18	2 63	0 00
TOTAL			**365 0**	**271 3**	**146 4**

* 80 % probable rainfall

per season (125 days)	146 4 mm
per day	1 17 mm
with 70 % efficiency	1 67 mm

peak demand 2 38 mm/day	0 28 l/s/ha
with 70 % efficieny	0 39 l/s/ha

Table 3 4 location of water quality sampling

	name of station	altitude in meters above sea level
1	drinking water intake	1880
2	first bridge	1660
3	la selva	1550
4	panamerican highway	1500
5	sugar mill	1290

Table 3 5 Chemical analysis of water quality samples

	station 1	station 2	station 3	station 4	station 5
Temperature (°C)	16 3	19 2	18 7	19	20 5
Turbidness (UTN)	5	16	22	23	66 9
pH (units)	6 61	6 96	6 9	6 94	7 05
Residuum total (mg/l)	33	60	63	75	120
Residuum not filterable (mg/l)	4	16	11	12	42
Residuum filterable (mg/l)	29	44	52	63	78
Alkalinity (mg $CaCO_3$/l)	11 9	16 6	17 6	19 4	20 5
Total hardness (mg $CaCO_3$/l)	12	16	13	18	16
DBO5-20°C (mg O_2/l)	0 62	1 4	1 5	0 7	0 75
Conductivity (μmhos/cm)	21 2	28 7	28 6	23	28 2
Cianydes (mg CN /l)	<0 004	<0 004	<0 004	<0,004	<0 004
Phosphatos (mg P-PO_4^{3-}/l)	0 022	0 022	0 051	0 022	0 073
Nitrates (mg N-NO_3 /l)	0 0714	0 052	0 106	0 111	0 166
Nitrites (mg N-NO_2 /l)	0 0016	0 0027	0 0063	0 0088	0 016
Ammonia (mg N-NH_3/l)	0	0 2	0 25	0 3	0 7
Disolved oxygen (mg O_2/l)	9 7	9 6	9 1	9 7	9 6
Saturation in O_2 (%)	94	97	94	100	103
Total coliforms (per 100 ml water)	330	3500	1100	8000	8000
Faecal coliforms (per 100 ml water)	<2	<2	<2	<2	<2

FIGURES

FIG. 2.1. Ovejas Watershed: Climate and Flow measurement stations

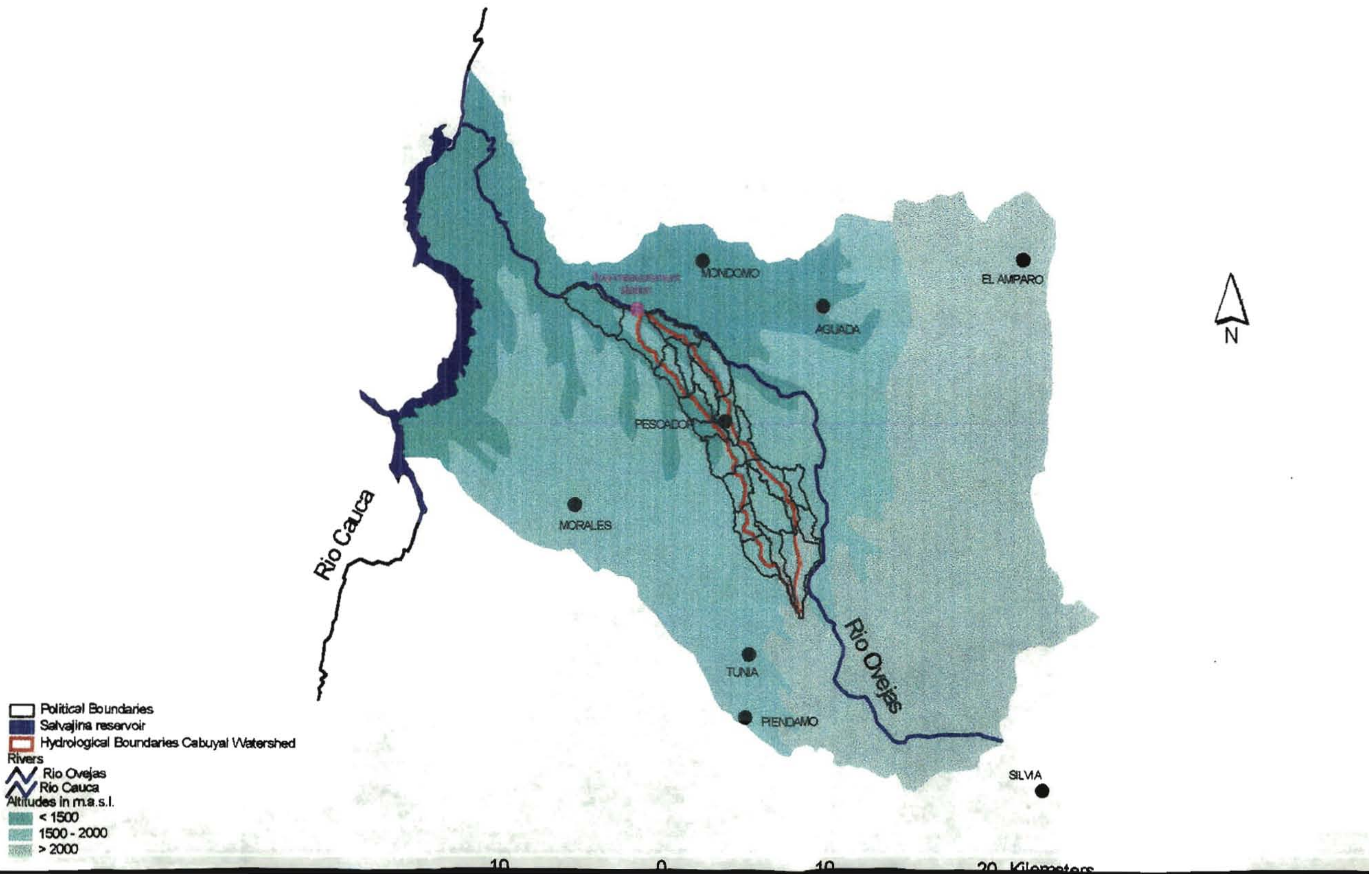


Figure 2.2: Water balance: precipitation - evapotranspiration in mm
Ovejas watershed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation	182	189	211	230	196	81	69	79	118	268	250	191	2066
80 % precipitation	114	115	171	189	156	62	41	44	91	231	197	158	1659
Evapotranspiration	105	106	118	105	102	105	124	124	114	105	99	99	1306
Deficit / Surplus*	9	9	53	84	54	-43	-83	-80	-23	126	98	59	
Deficit / Surplus **	77	83	93	125	94	-24	-55	-45	4	163	151	92	

* 80 % precipitation - evapotranspiration — total deficit = 206 mm per year

** precipitation - evapotranspiration — total deficit = 124 mm per year

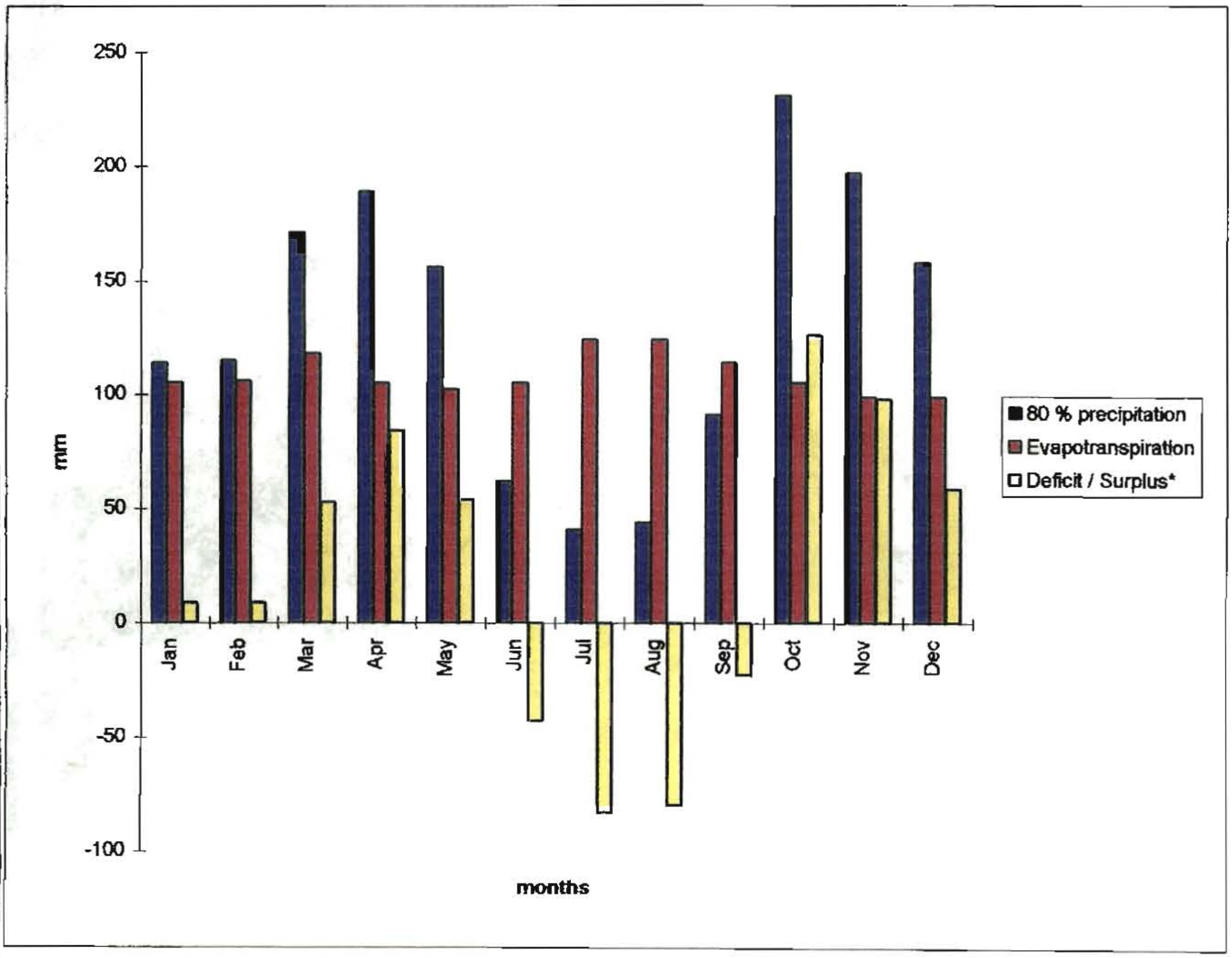
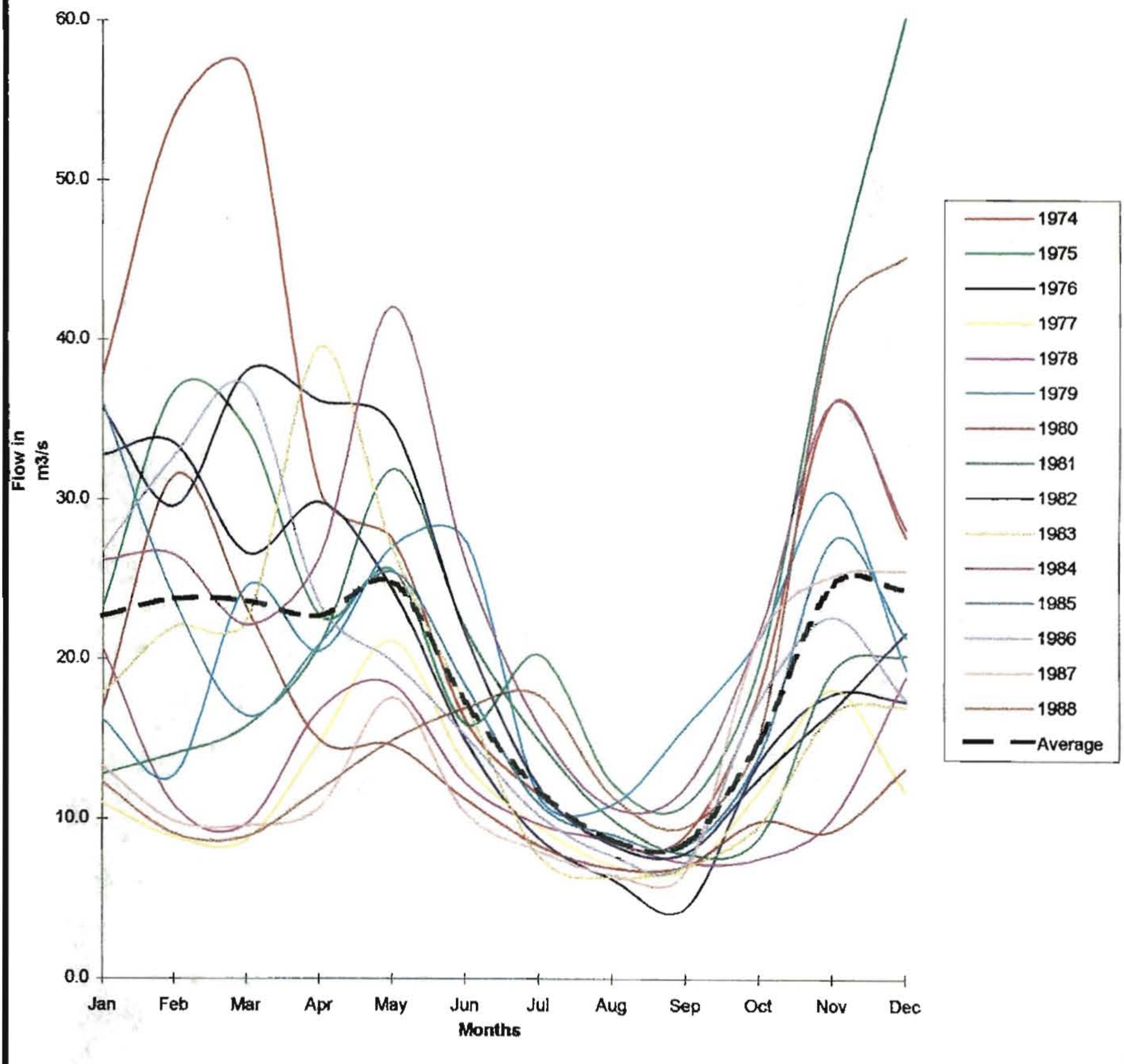


Figure 2.3: Ovejas River Flows in m3/s for 1974 - 1988



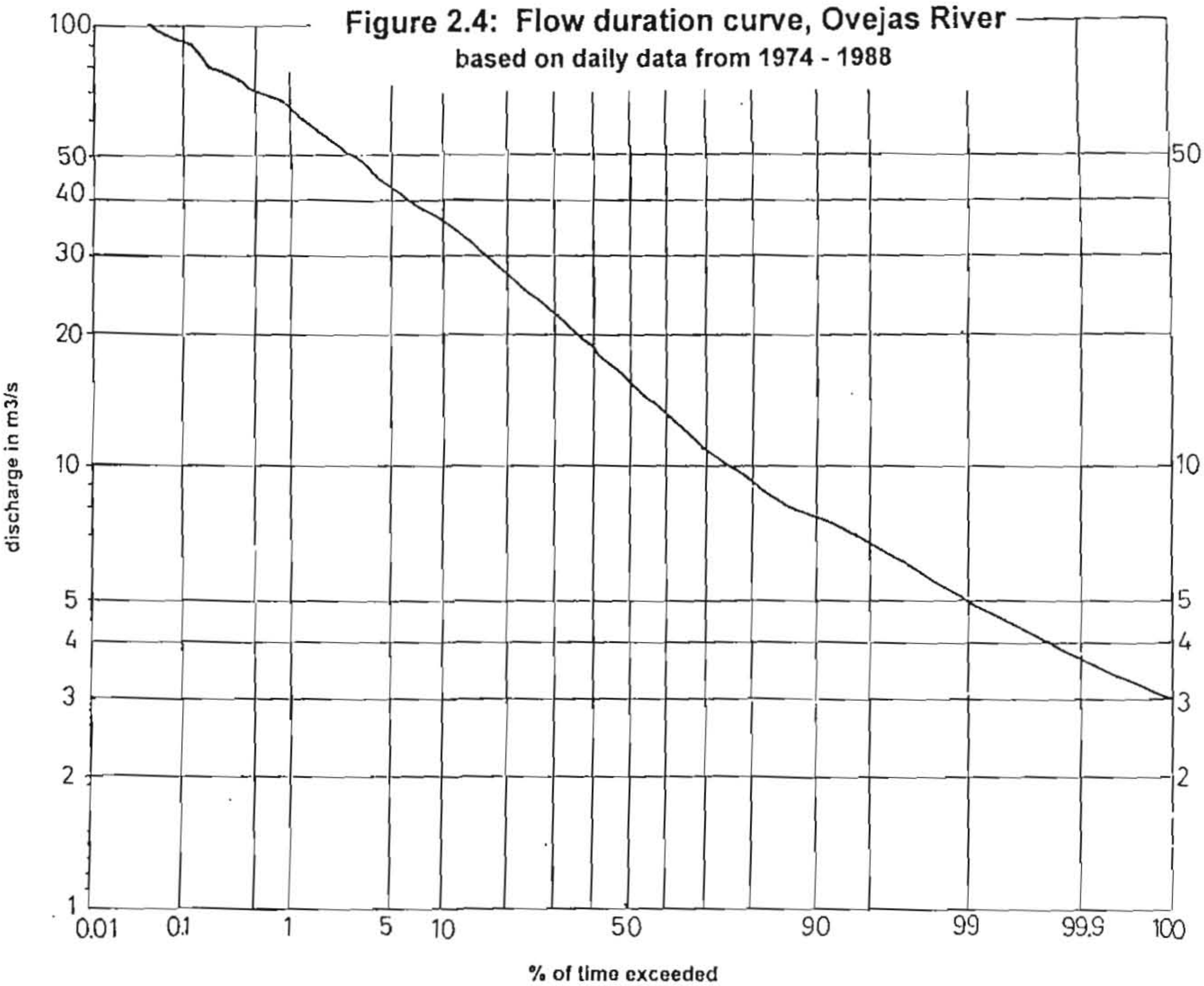


Figure 2.4: Flow duration curve, Ovejas River
based on daily data from 1974 - 1988
discharge in m3/s
100
50
40
30
20
10
5
4
3
2
1
0.01
0.1
1
5
10
50
90
99
99.9
100
% of time exceeded

Figure 2.5: Waterbalance Ovejas watershed

precipitation, riverflow and evapotranspiration in mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
precipitation	182	189	211	230	196	81	69	79	118	268	250	191	2066
river flow	99	103	103	99	108	75	51	38	37	65	107	106	990
evapotrans. (Penman)	105	106	118	105	102	105	124	124	114	105	99	99	1306

precipitation - riverflow	1076

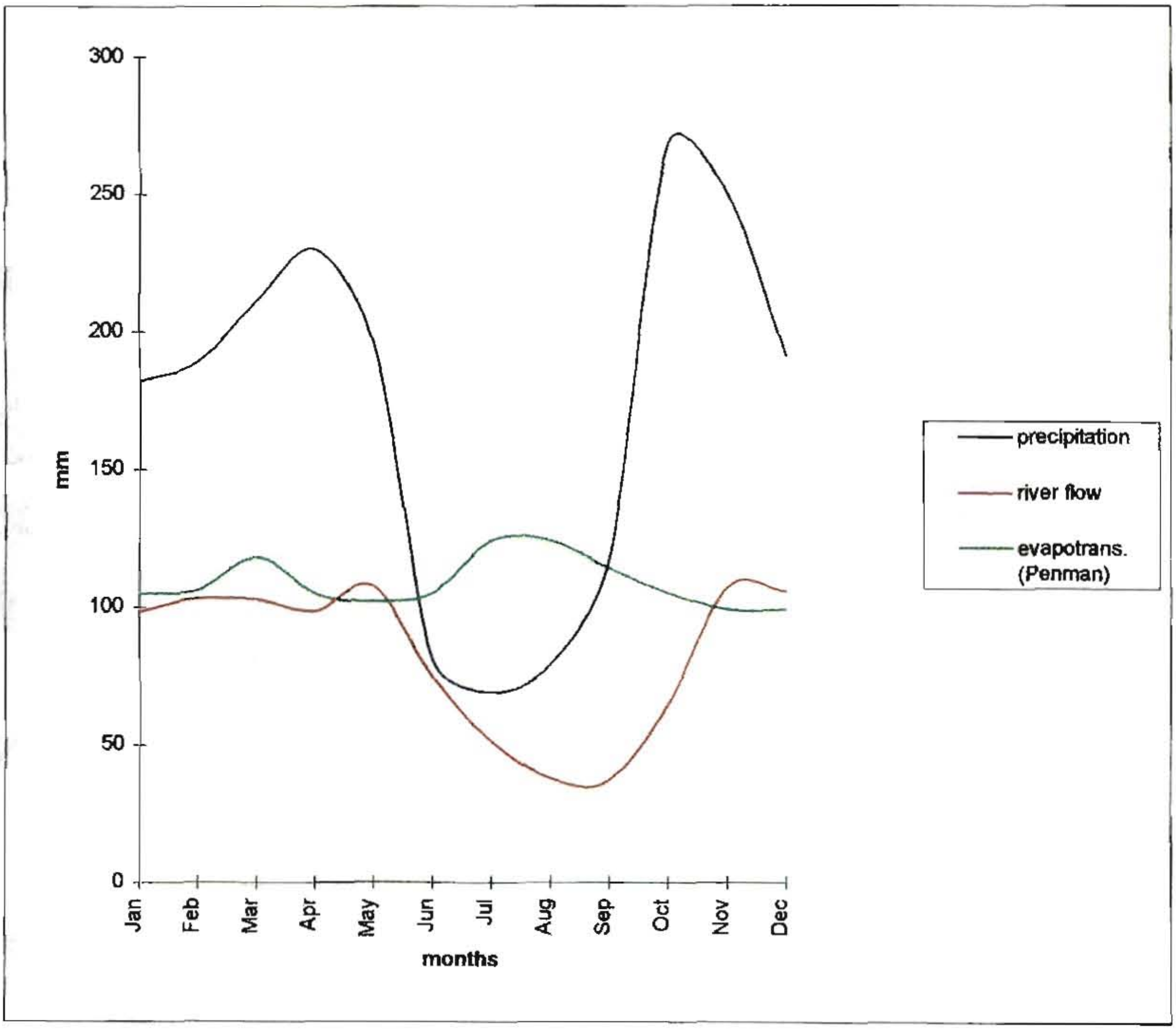


Figure 2.6: Schematic representation of the hydrologic cycle in Ovejas watershed

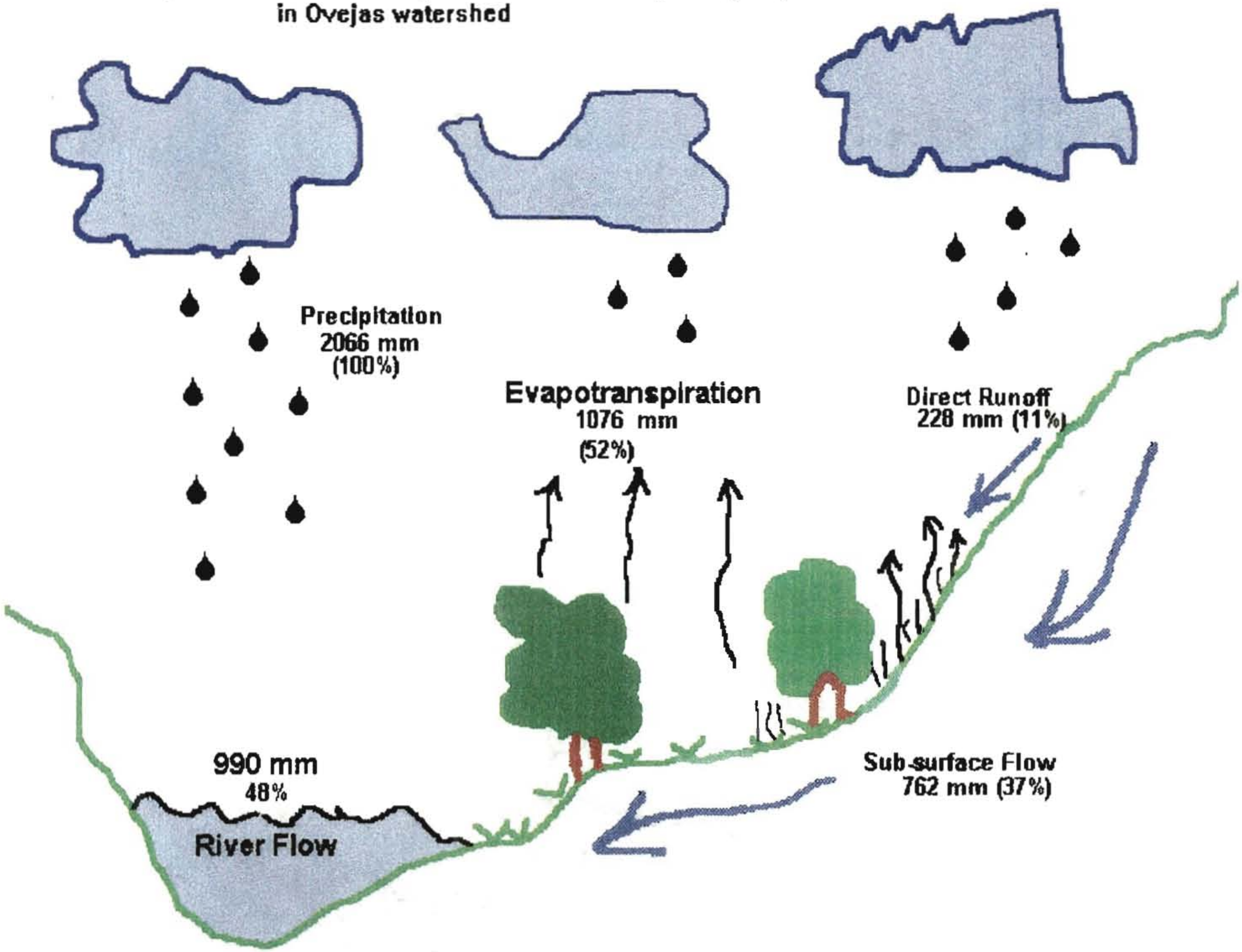


Figure 2.7:
AWBM Catchment Water Balance Programme
graphical determination on BFI (baseflow index)

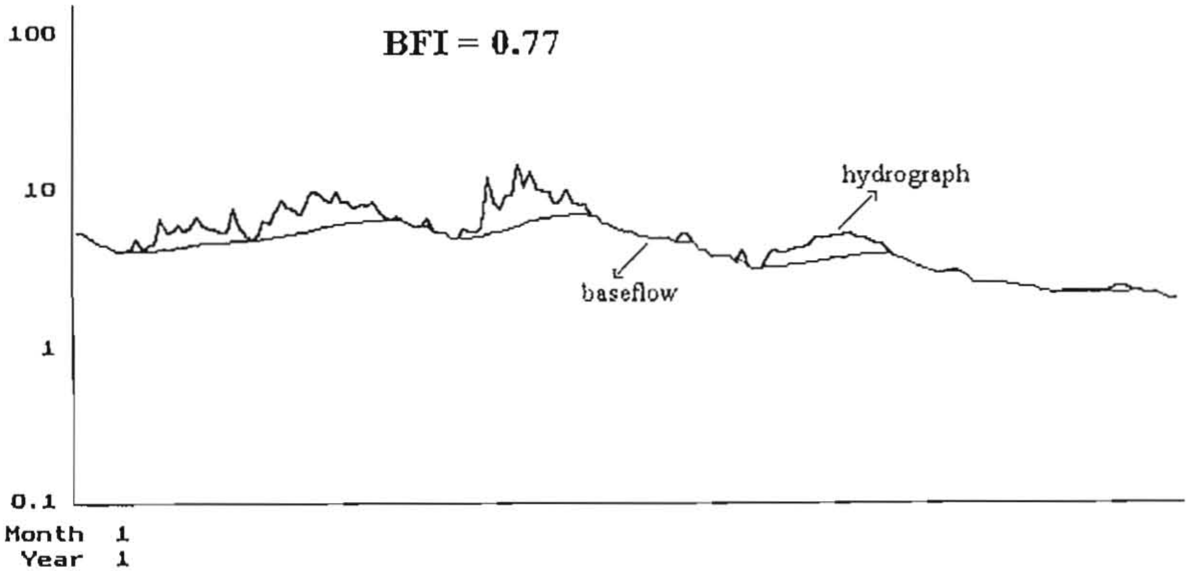
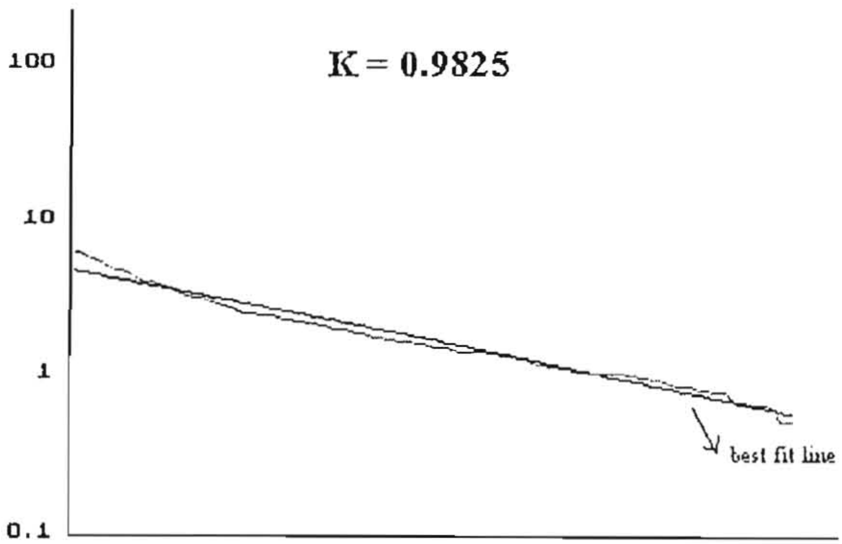


Figure 2.8:
AWBM Catchment Water Balance Programme
graphical determination of baseflow recession constant, K



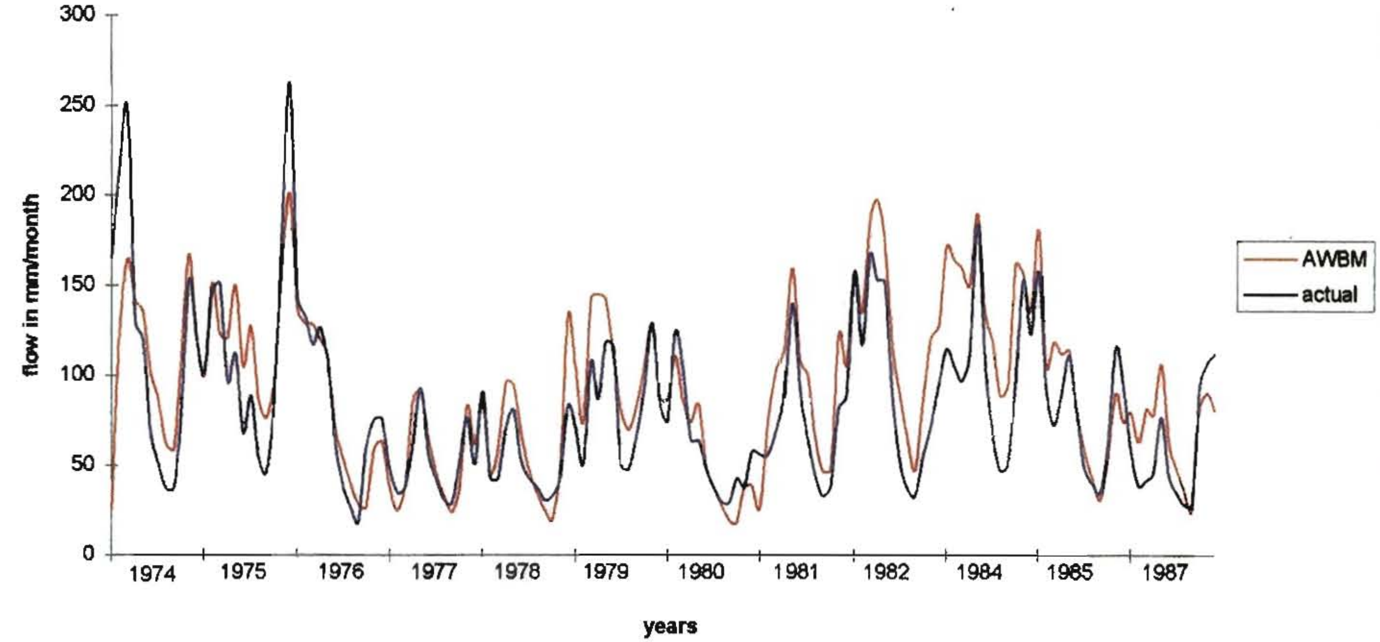


Figure 2.9: comparison simulated and actual flow for Ovejas River, AWBM model

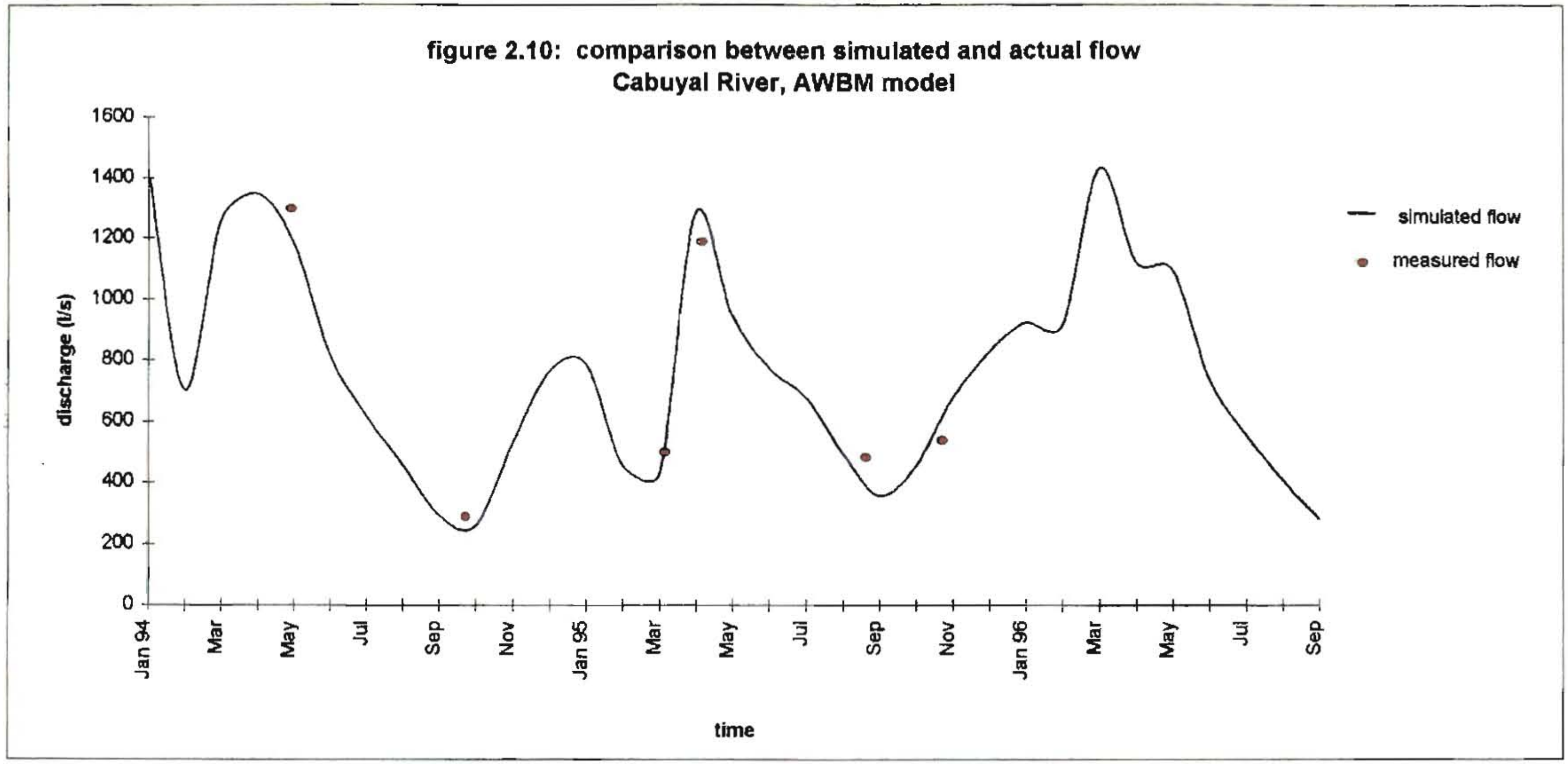
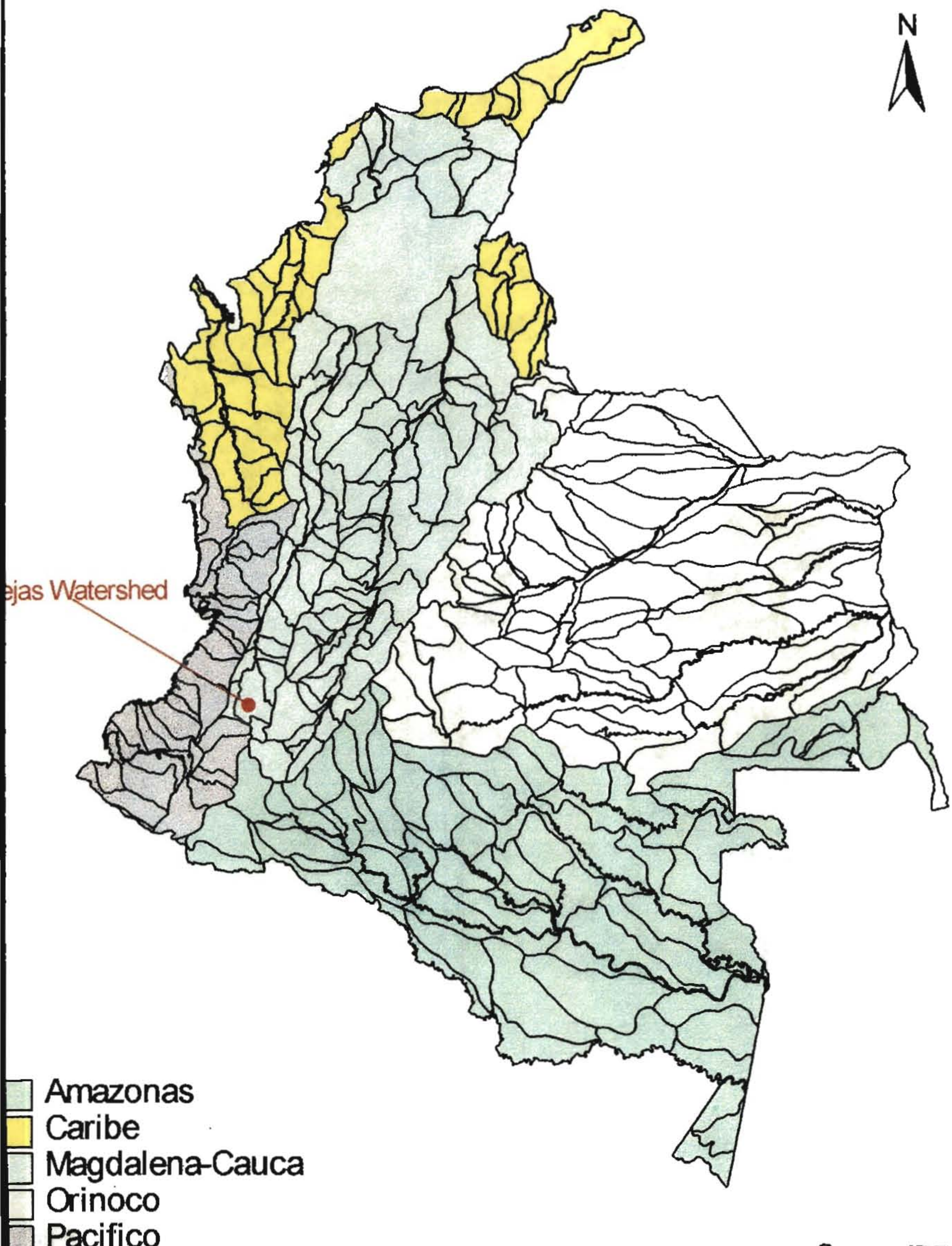


figure 2.10: comparison between simulated and actual flow
Cabuyal River, AWBM model
1600
1400
1200
1000
800
600
400
200
0
discharge (l/s)
Jan 94
Mar
May
Jul
Sep
Nov
Jan 95
Mar
May
Jul
Sep
Nov
Jan 96
Mar
May
Jul
Sep
time
simulated flow
measured flow

FIG. 2.11 Main Watersheds in Colombia



Source: IDEAM

Figure 3.1: local irrigation method using drinking water system

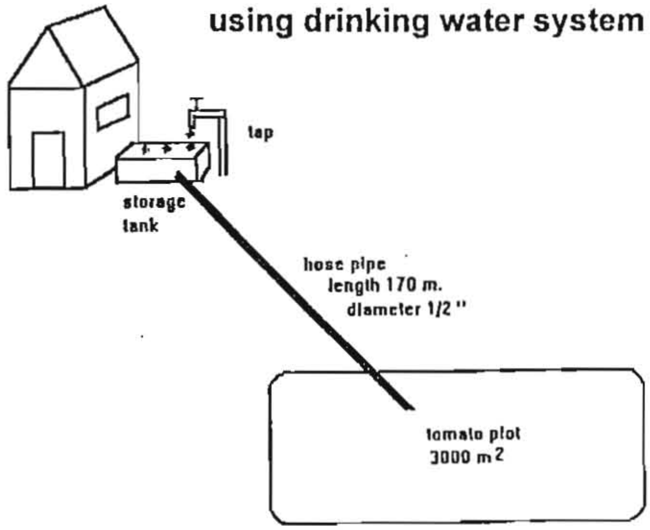


figure 3.2 : local irrigation method using motor pump

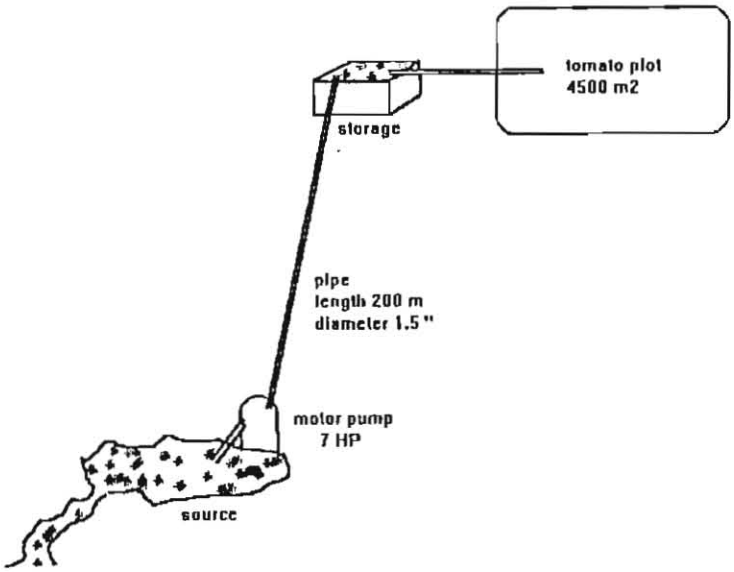


figure 3.3: local irrigation method by gravity

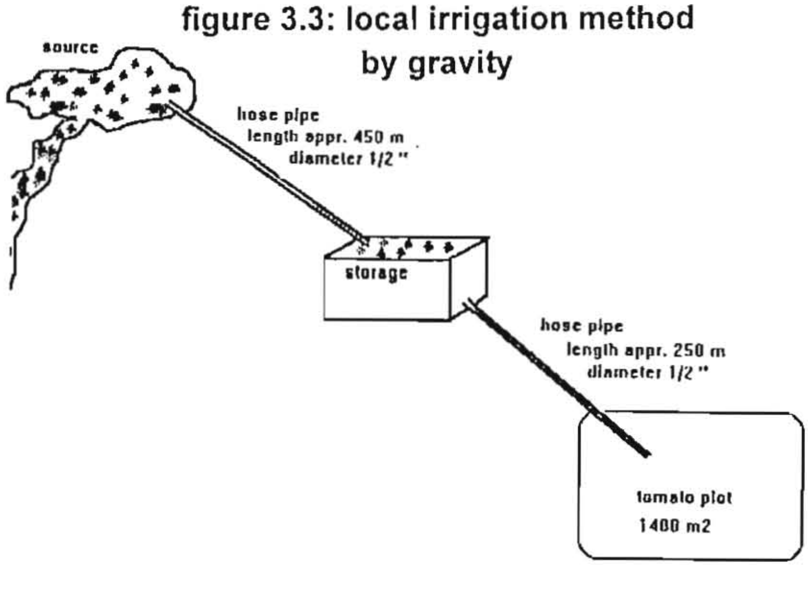


Figure 3.4: Total water use

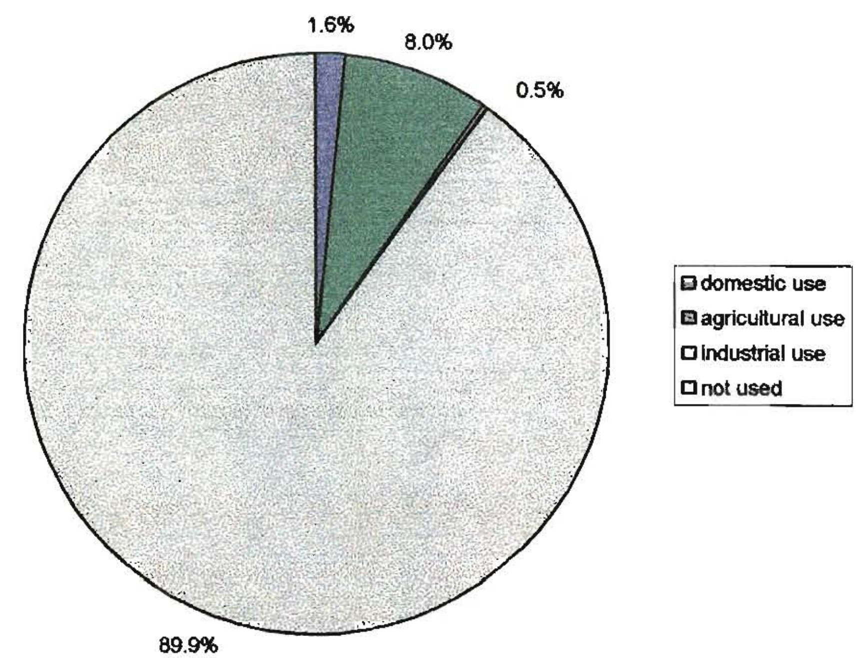


Figure 3.5: Water use per sector

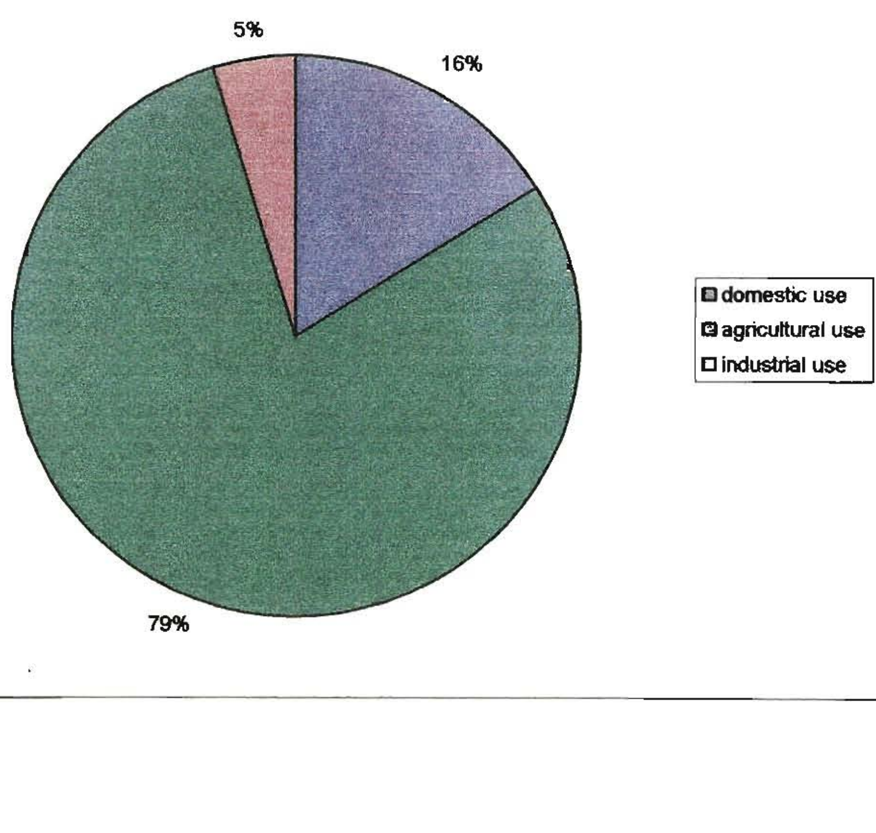


figure 3.6: distribution of ammonia, nitrates, nitrites and phosphates over the stations

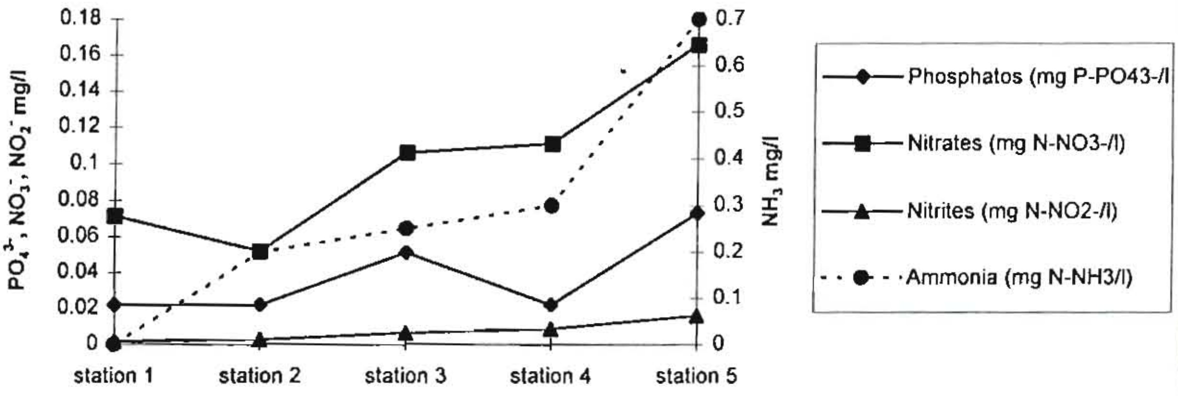


figure 3.7: distribution of temperature and disolved oxygen over the stations

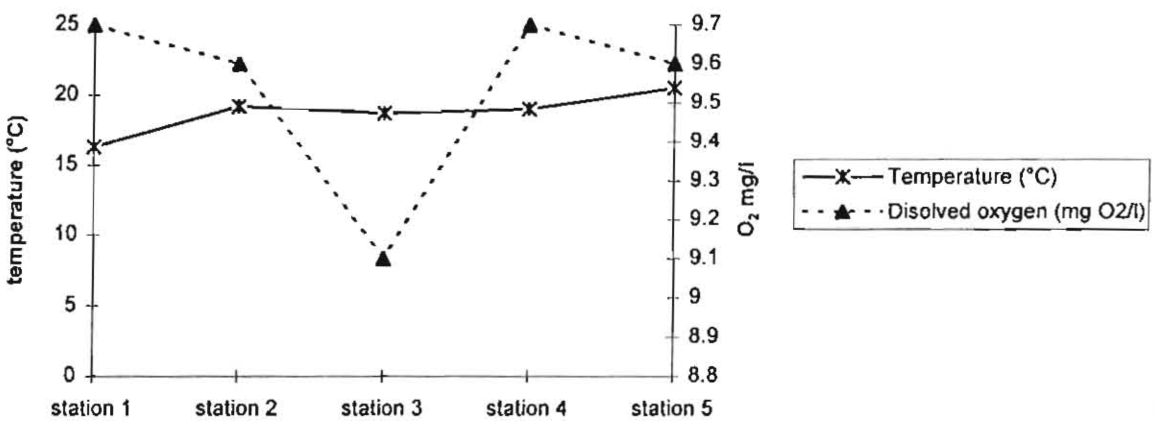


figure 3.8: distribution of residuum and turbidness over the stations

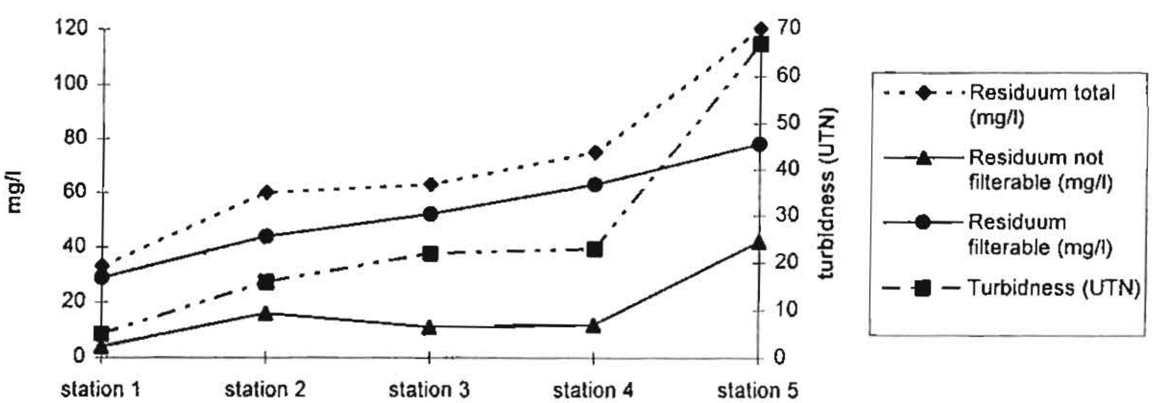


Fig. 4.1 Irrigation Potential in Cabuyal Watershed