ICW Nota 1966
mei 1989

nota

instituut voor cultuurtechniek en waterhuishouding, wageningen

APPRAISAL OF THE IMPLEMENTATION OF WATER ALLOCATION POLICIES

Ir. T.N.M. Visser

Nota's (Notes) of the Institute are a means of internal communication and not a publication. As such their contents vary strongly, from a simple presentation of data to a discussion of preliminary research results with tentative conclusions. Some notes are confidential and not available to third parties if indicated as such

CONTENTS:

c) Each secondary and tertiary unit receives a volume of water proportional to its total irrigable area.
The performance of the current water supply is assessed by calculating the ratio of the intended volume -calculated as the share of the available irrigation water that should be allocated to a certain tertiary or secondary unit- to the actual volume e.g. the volume of water that is actually supplied to that unit in any period of time.

2. The water allocation policy is supposed to be directed at matching the crop water requirements in each tertiary unit. The performance of the current water supply is assessed by determining the ratio of the crop water requirements to the actual volume for each tertiary unit.

3. In the third case the "effectiveness" of the supplied irrigation water is considered. This is done by determining the ratio of the increase in actual evapotranspiration to the actual volume supplied in any period of time.

Table 1.1 shows the formulae of the three ratios applying to the different concepts listed above. It also contains the land use data needed and the models used. The complexity of the calculations increases from the first to the third ratio as shown by the increasing amount and complexity of ancillary data. Moreover some of the data required e.g. to calculate the third ratio, are rather difficult to obtain, like the hydraulic properties of unsaturated soil. This implies that the first ratio allows a finer spatial resolution in the appraisal of performance than the third ratio. Therefore, a trade-off has to be established in practice.

The Rio Tunuyan Irrigation Scheme is located just east of the Andes at an elevation of 650 m. It is an arid region with an average yearly rainfall of about 210 mm. The surface is almost flat with a slight inclination towards the east. The area irrigated by the Rio Tunuyan Irrigation Scheme is about 70.000 ha.

Figure 1.1 shows a map of the lay-out of the scheme. The Viejo Retamo runs from Junin just north of Rivadavia towards Philips. Figure 1.2 shows the lay-out of the command area of the Viejo Retamo

Table 1.1 Definition of different ratios quantifying irrigation performance; for each ratio the required land use data are indicated explicitly, with their source; the ancillary data necessary to calculate each ratio are also indicated

Ratios	Land use data. needed	Source	Model	Ancillary data
1. $R_i = \frac{V_i * (A_{ij} / A_i)}{V_{ij}}$	area with water rights; act. cult. area; total irrigable area;	satellite image; field survey;	-	discharges
2. $R_i = \frac{\sum_{k=1}^{n} ETp_k * A_{ik}}{V_i}$	crops or groups having a similar k_c	satellite image	CRIWAR	discharges meteorological data
3. $R_i = \frac{\sum_{k=1}^{n} (ETa_k - \hat{ETa}_k) * A_{ik}}{V_i}$	crops	satellite image	SWATRE	discharges meteorological data soil properties

V_i - Volume supplied to unit i (m3/month)
V_{ij} - Volume received at unit j, within higher order unit i (m3/month)
A_i - Irrigated area in unit i (m2)
A_{ik} - Area of crop k in unit i (m2)
ETp_k - Potential evapotranspiration of crop k (m/month)
ETa_k - actual evapotranspiration of crop k, irrigated (m/month)
$\hat{ETa}_k$ - idem, non-irrigated (m/month)
k_c - crop coefficient

In over 80 % of the area grapes are grown. Other crops are fruit trees (peaches, apricots, pears) and vegetables. Almost all the fields are irrigated by means of surface irrigation in borders. In addition to the surface water supplied by the irrigation system, groundwater is extracted all over the area and used to irrigate crops.

Chapter 2 deals with the calculation procedure used to determine the values of the different ratios. Chapter 3 describes the allocation of irrigation water and the evaluation of current water supply for all tertiary units of the study area based on the concept of an equitable distribution of the available irrigation water. Chapter 4 contains an evaluation of current water supply regarding the second concept e.g. matching crop water requirements. In chapter 5 a waterbalance study of the unsaturated zone under irrigated conditions is presented including the determination of the value of ratio 3 for two sub areas of the study area.

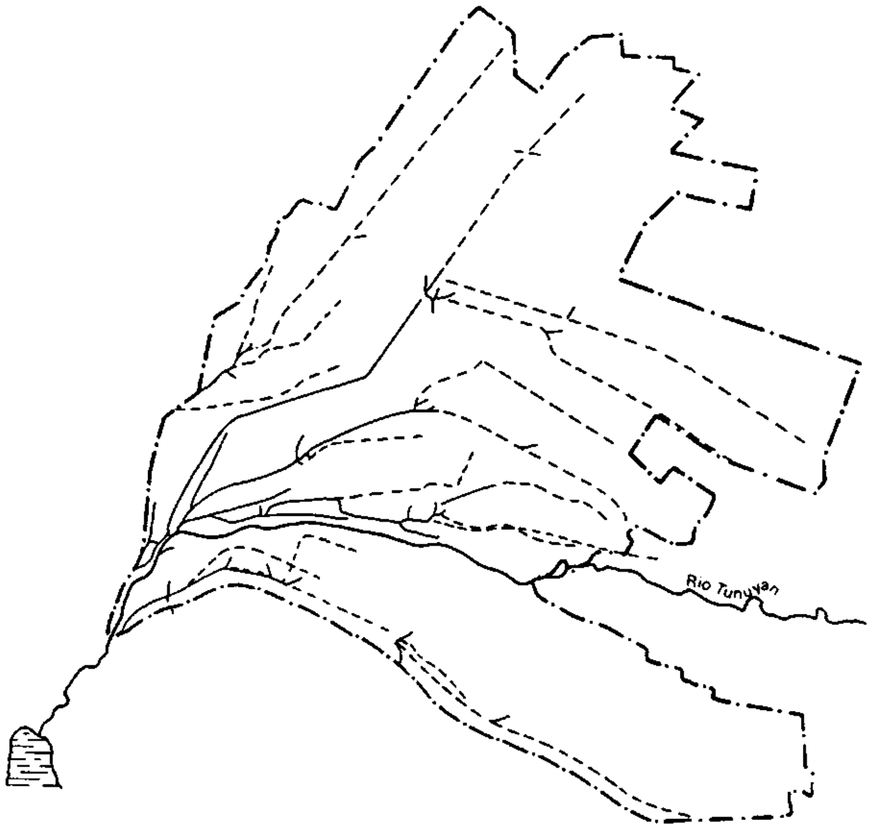


Fig 1.1 Lay out of Río Tunuyán Irrigation Scheme showing primary canals (——), secondary canals (----) and the boundary of the command area (—·—·—).

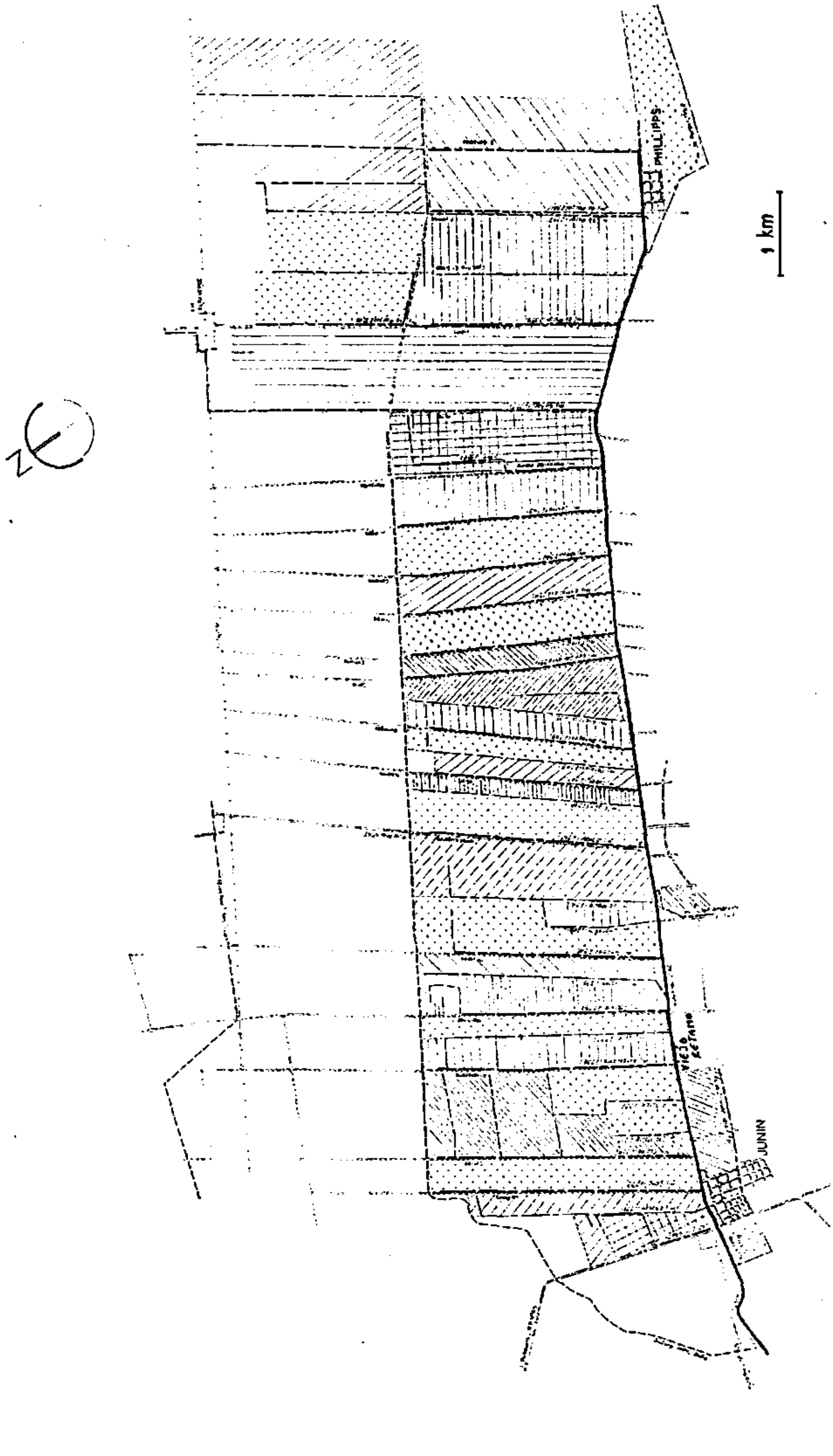


Fig 1.2 Lay-out of Viejo Retamo secondary unit.
command areas of tertiary units hatched to indicate boundaries.

CHAPTER 2. CALCULATION PROCEDURE

As described above the values of the three ratios (see Table 1.1) have to be determined for the different reference units, relevant to irrigation water management. These units are defined as the command areas of the primary, secondary and tertiary irrigation canals. All input point data, such as meteorological data and soil-physical properties must be referred to the same reference units. The processing of these input data results in the following information:
- amount of water needed in each tertiary unit per unit of time (10 days, month);
- amount of water applied in each tertiary unit per unit of time (idem);
- different ratios of these variables.

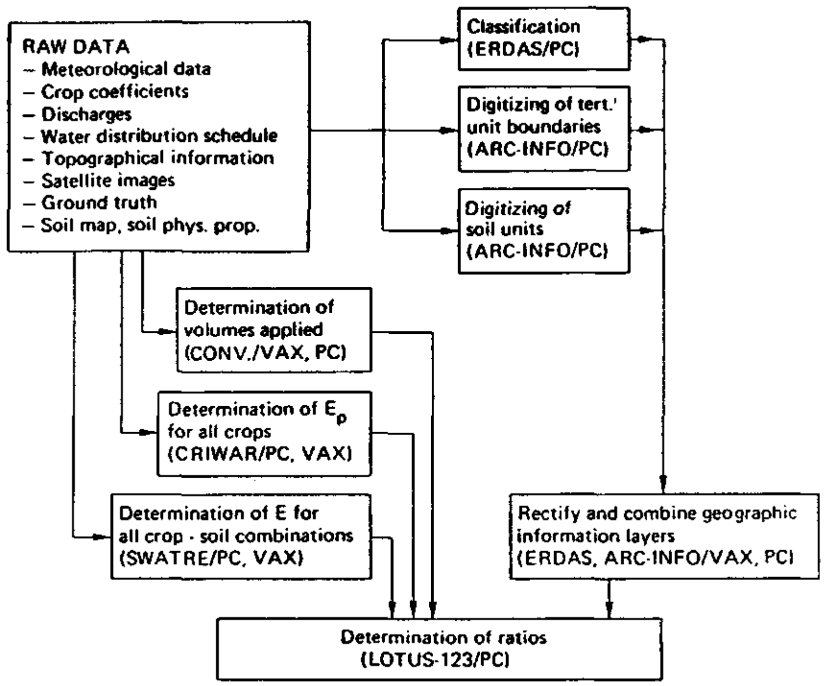


Fig. 2.1 Chart showing raw data and operations as required to calculate ratios

The different operations that have to be performed in order to determine the values of the three ratios are shown in Figure 2.1 It includes the software-hardware configurations used and the transfer of data between them. The raw data are listed in the upper left corner of the overview. The operations on the right can be characterized as Geographical Information System (GIS)-operations involving three information layers (classified image containing land use classes, map of irrigation infrastructure, soil map). They have to be rectified and combined in order to obtain the information needed: the distribution of land use classes and soil units in the different reference units. The activities on the left consist of the calculation of the volumes applied to each reference unit and the hydrological modeling. The use of the models results in the potential (CRIWAR) and the actual (SWATRE) evapotranspiration of all crops or crop-soil combinations. All information is combined in a LOTUS-123 worksheet to calculate the values of the different ratios.

The components of Figure 1.1 will be discussed briefly:

Raw data
A short list of the required input data is given to emphasize that satellites provide only part of the information, although accurate land use data are essential to improve irrigation management.

To calculate the value of the first ratio only 'basic' data on water flow, topography and the distribution of cultivated area (derived from satellite images) are needed. To calculate the value of the second ratio additional data concerning meteorology and crop factors have to be gathered. Also the information derived from the satellite data will have to be more specific, concerning different crops or crop types. Calculation of the third ratio can only be performed when data on the soil physical properties and distribution of the soil types occurring in the area are available. This implies that the first ratio can be mapped with a finer spatial resolution than the third ratio.

Determination of volumes of water supplied to each reference unit, per unit of time
In order to determine these volumes, discharge measurement structures should be installed - if not yet existing - at the inlet of all units concerned. Commonly the person in charge of the water distribution is also responsible for the registration of flow data. These data are mostly registered as the opening time of the structure, the closing time and the head over the weir crest at both moments. A computer program was developed to convert these data to volumes of water applied per turn and per period of 10 days. The figures on amounts applied per 10 days tend to fluctuate a lot. If a certain unit receives water on the 8th and 9th of the month and again on the 22nd the amount applied in the second decade will still be zero. Therefore in further processing the amounts are added up to amounts applied per month.

Determination of potential evapotranspiration, E_p, for all crops
To calculate the value of the second ratio (Table 1.1) the

potential evapotranspiration of all crops occurring in the area has to be known. The potential evapotranspiration of a crop depends on the meteorological circumstances, commonly expressed in the reference evapotranspiration E_0, and the crop properties, expressed in the crop factor k_c. The potential evapotranspiration of a crop can be determined by means of the program CRIWAR (Vos et al., 1988), given its k_c and some meteorological data. The program is based on FAO (1977).

Determination of actual evapotranspiration, E, for all crop-soil combinations with and without irrigation using SWATRE

SWATRE is a numerical model of water transport in the unsaturated zone. It needs a variety of input data amoung which the $h(\theta)$ and K(h)-relations of the different soil layers in the profile. Gathering reliable data on the soil hydraulic properties will not be easy in many cases. The program RETC (approach described by Van Genuchten, 1980) could be an adequate tool to derive these data from basic measurements of the water content at different pressure heads in a soil sample.

Once all necessary data are available SWATRE should be applied to the irrigated and not-irrigated situation in order to determine the increase in actual evapotranspiration due to the application of irrigation water.

Classification of land use

To map land use, classification of satellite images has to be performed by means of an image processing software package. To calculate the value of ratio 1 a classification discriminating cultivated and not-cultivated area is sufficient. Different methods to map cultivated areas using LANDSAT-TM satellite images can be applied.

Potential evapotranspiration is crop-dependent so in order to obtain the value of ratio 2 a classification discriminating crops or crop types is necessary. If the classification of individual crops turns out to be unfeasible, crop types can be discriminated, each crop type having a certain crop factor (k_c) assigned to it.

The map of the crop coefficient k_c is constructed by applying the following procedure:

- crops and crop varieties are mapped by means of a field survey for a number of reference plots;
- mean spectral reflectances are calculated with LANDSAT-TM data for each reference plot;
- reference plots are aggregated into clusters by means of unsupervised classification techniques;
- the resulting clusters are applied as training set with a supervised classification technique;
- crop coefficients k_c are assigned as a function of time to each mapped unit, which gives the required k_c-map.

<u>Digitizing of tertiary unit boundaries</u>
To be able to relate the land-use data to the reference units mentioned in the beginning of this section accurate information is needed on the location of the boundaries of the command areas of the different tertiary, secondary and primary canals. If no such information is available, it should be gathered by means of a field survey. Aerial photographs or possibly satellite images, could be used to facilitate this. The resulting map containing these boundaries should be digitized. This should be done in such a way that the data file containing the map is compatible to the classified images to combine them. Different GIS software packages offer the possibility to do this.

<u>Digitizing of soil units</u>
The difference in actual evapotranspiration in situations with and without irrigation depends heavily on the kind of soil. Therefore the spatial distribution of the different soil units within the different reference units has to be known. In order to obtain this information the boundaries of the soil units should be digitized, preferably in the same way as the map containing the reference unit boundaries.

<u>Rectify and combine geographic information layers</u>
In order to obtain the value of the ratios in Table 1.1 the cultivated area (ratio 1), the areas of the different crops or crop types (ratio 2) or the area of each crop-soil combination (ratio 3) within each reference unit should be determined. This is done by making an overlay of all three information layers (land use map, boundaries of reference units, boundaries of soil units). Before this, the three layers should be rectified e.g. transformed to the same coordinate system. Almost all GIS and Image Processing software packages offer the possibility to perform both rectification and overlay procedures.

<u>Determination of ratios</u>
All information obtained by performing the operations described above should be combined to determine the value of each performance indicator for all reference units. This is most easily done by transferring the results of both GIS-operations and model calculations to a spreadsheet program. The necessary calculations given by the formulas in Table 1.1 can be performed easily.

CHAPTER 3. ALLOCATION OF WATER AND EVALUATION OF CURRENT WATER SUPPLY REGARDING AN ALLOCATION POLICY DIRECTED AT AN EQUITABLE DISTRIBUTION OF THE AVAILABLE IRRIGATION WATER

As explained in part 1. the original objective of the waterdistribution in the Rio Tunuyan Irrigation Scheme was to supply surface water proportional to the area cultivated. Since an adequate registration of the cropped areas appeared to be impossible, it was decided to develop a system in which water rights could be acquired permanently by the farmers. It was assumed that the area with water rights would be representative for the actually cultivated area in a secondary or tertiary unit.

In this chapter the possibilty of improving the irrigation water management using remote sensing techniques to map actually cultivated areas is considered.

Three possible water allocation policies are considered:
1. Allocation of surface water proportional to the area with water rights
2. Allocation of surface water proportional to the actually cultivated area.
1. Allocation of surface water proportional to the total irrigable area.

The third policy does not apply to the actual situation in Mendoza but is relevant in many other areas.

In paragraph 3.1 the available data on total irrigable areas and areas with water rights of the tertiary units of the Viejo Retamo secondary canal are presented and commented. Paragraph 3.2 describes the mapping of actually cultivated areas in the command area of the Viejo Retamo. Paragraph 3.3 deals with the analysis of the distribution of cultivated area in the total area of the Rio Tunuyan Irrigation Scheme. Paragraph 3.4 and 3.5 describe the calculation of intended volumes -volumes that would be supplied if the distribution was performing ideally- and the evaluation of the current water supply.

3.1 Irrigable areas and areas with water rights of the tertiary units of the Viejo Retamo.

In the first column of table 3.1 the areas with water rights are shown that are used by the tomero (person in charge of the waterdistribution) while supplying water to the different tertiary units of the Viejo Retamo. The second column shows the areas with waterrights according to the administration of the Departamento General de Irrigacion (DGI). For some reason there is no exchange of information on water rights between the tomero and the DGI. The third column contains the total irrigable area of the tertiary units. They were determined during a survey that was performed as a part of the current project by M. Pieters and A. Drovandi (PIETERS, 1988). During this survey the exact location of the tertiary canals and the boundaries of their area of influence was determined. In 16 out of 33 cases the area with waterrights used in the water supply (column 1) exceeds the total irrigable area of a unit. In four cases also the current area with waterrights (column 2) exceeds the total irrigable area. Therefore the assumption that the area with waterrights is representative for the area that is actually cultivated does not seem correct.

3.2 Actually cultivated areas within the tertiary units of the Viejo Retamo.

An accurate registration of the actually cultivated area in the different tertiary units of the scheme during a certain growing season appeared impossible using "conventional" techniques. Satellite remote sensing could offer a possibilty to achieve this. Four different methods to classify cultivated and not cultivated area were applied in the area of the Viejo Retamo. In all four cases a Landsat Thematic Mapper (TM) image taken in january 1986 was used. TM images have a spatial resolution of 30 m x 30 m and contain information on the

Table 3.1 Comparison between data on total irrigable area of tertiary units, area with water rights as used in the water supply, area with water rights according to DGI and the actually cultivated area in ha.

Tertiary unit:	area with water rights used in water supp.	area with water rights DGI	total irrigable area	actually cultiv. area
Villa Junin	28	20.5	20.1	6.1
Salcedo	77	69.7	51.3	49.9
Chacon	87	72.7	91.1	89.0
Cano	153	122.6	132.3	121.2
Correa	212	198.3	213.2	188.4
1o Maure	40	38.3	38.8	34.1
Garcia	71	65.5	70.1	67.0
Arrascaeta	114	104.2	121.4	110.9
Lelio	79	72.5	75.3	70.1
2a Cabrera	138	125.3	131.1	116.7
Olivares	87	73.5	68.8	64.4
Gonzales	154	142.6	156.3	133.9
Ambrosini	40	44.3	40.9	18.7
2o Maure	189	180.9	192.5	166.0
Dell' Archipr.	30	16.1	19.5	11.7
Baldor	148	129.4	136.3	105.5
Olguin	61	48.1	53.0	46.9
Tobares	73	61.0	62.9	58.8
Parejas	75	64.7	67.2	56.8
Benegas	86	79.0	89.8	80.9
Alcaraz	127	126.8	125.6	89.2
Las Corias	81	62.1	72.7	65.1
Orrego	116	117.3	125.4	110.4
Estrella	104	102.1	112.9	103.6
Day	139	136.1	144.4	135.8
Castro	125	125.0	136.3	119.2
Marvilla Neira	180	165.3	181.2	158.7
Guinazu	396	392.3	448.6	423.8
1o Razgo	190	188.7	251.4	221.7
2o Razgo	315	312.5	356.1	352.7
3o Razgo	151	98.0	143.0	135.2
4o y 5o Razgo	824	812.4	872.9	739.7
TOTAL	4789	4434.9	4888.5	4253.5

amount of reflected radiation in six spectral bands: blue (TM(1)), green (TM(2)), red (TM(3)), near infrared (TM(4)), middle infrared (TM(5) and TM(7)) and the amount of emitted radiation in the thermal infrared part of the spectrum (TM(6)). In April 1988 a short field survey was performed in order to map the actual land-use in five tertiary units of the Viejo Retamo. The resulting maps were used partly as groundtruth for the classifications (200 ha) and partly to verify the results (1000 ha). As there was a time lag between the acquisition of the image and the survey this had to be done with care using only those areas whose land use had not changed between '86 and '88. The following crops were found in the mapped areas:

-Parral (Italian style wineyard with high soil cover)
-Vinedo (wineyard with plants in rows)
-Wineyards containing fruittrees
-Peaches
-Apricots
-Cherries
-Olives
-Pears

All image processing was performed on the ERDAS image processing system of the Staring Centre. ERDAS (Earth Resources Data Analysis System) offers all kinds of options to enhance and process remotely-sensed data. This includes displaying, classification, geometrical correction, and statistical analysis of images. ERDAS also contains a GIS module offering the possibilty to perform a selection of simple GIS activities such as making overlays and digitizing topographical features. A brief description of the four methods that were applied is given below.

1. An artificial image was created with pixel values calculated as:

$$\frac{DN\ 4}{DN\ 3} * \frac{DN\ 4}{DN\ 5} * \text{CONSTANT}$$

DN X stands for the Digital Number of band X representing the amount of reflected radiation in band X expressed in an arbitrary unit.

Vegetation tends to reflect a large part of the radiation in the near infrared part of the spectrum while it absorbs most of the radiation in the red part. Water (in leaves as well as in the soil) absorbs radiation in bands TM(5) and TM(7). Therefore the expression given above would have much higher values for cultivated surfaces (more biomass and water) than for not cultivated areas (much less biomass and water).

The values in this image were separated in two groups supposing the pixels having the lower values not to be cultivated and the ones having a higher value to be cultivated. The threshold value between the two classes was chosen in such a way that the area of about 200 ha with a known land use was classified optimally.

2. A principal component analysis was performed on bands 3,4,5 and 7. The value of the first PC appeared to be high for not cultivated areas and low for cultivated areas. An image was created containing this first PC and again all pixels were divided in two classes (cultivated and not cultivated) depending on their value. Like in the previous case a threshold value was chosen in such a way that the mapped area was classified optimally.

3. A supervised automatic classification was performed on cultivated and not cultivated area. To perform a supervised automatic classification, areas with a known land use (training sets) have to be indicated in the image, each representing a certain land use class. The classification program will compare the spectral signature of all picture elements (pixels) in the image to the spectral signature of the pixels in the trainingsets. Subsequently all pixels will be assigned to the class whose trainingset it matches best. Two trainingsets were used, one for the cultivated and one for the not cultivated area, both of about 100 ha.

4. A more detailed supervised automatic classification was performed discriminating different land use types including three not cultivated classes. The procedure for this classification will be explained further in chapter 4. Most pixels that were not classified because their spectral signature differed to much from those of the training sets appeared be part of built-up areas. Therefore these pixels were supposed to be not cultivated.

In order to make better use of the classified image in further calculations concerning the irrigation management, the cultivated area within a certain tertiary unit had to be obtained. This can be done by combining the classified image and a digitized map containing the boundaries of the command areas of the tertiary canals (VISSER, 1987).

The digitized map was created using the ARC-INFO package. ARC-INFO is an advanced geographic information system used to automate, manipulate, analyze and display geographical data in digital form. The resulting data-file was converted to raster format and transferred to the ERDAS workstation. The conversion was performed in such a way that the pixels within the area of a certain tertiary unit had a specific digital value assigned to them. Both map and classified image were geometrically corrected and transformed to the same coordinate system.

An overlay of both images was created yielding information on the areas that are cultivated within the different tertiary units. In other words, the digital value representing the land use class (cultivated / not cultivated) in the classified image and the digital value representing the unit in the map file had to be combined in such a way that the resulting value represented a specific land use class in a specific unit.

An example of such a combination is given in fig. 3.1 This is the procedure performed by the ERDAS module MATRIX.

Within ERDAS figures on the amounts of pixels that belong to a certain class etc. are stored in a trailer file that can be created with each image or GIS file (See ERDAS User Manual). This information was extracted from this file and written to an ASCII file by means of a small FORTRAN program. Now the information on cultivated and not cultivated area in all tertiary units was accesible for further calculations using the LOTUS-123 spreadsheet program.

Table 3.2 shows the cultivated area of 5 tertiary units resulting from the different classification methods and the results of the field survey. All methods except the detailed automatic classification tend to underestimate the cultivated area. The detailed automatic classification tends to overestimate the cultivated areas but gives the best results overall. Table 3.3 shows the difference between the results of the four methods and the results of the field survey.

Orig. value representing unit:

Orig. value representing land use class:	0	1	2	3	4	5	..	n
0	0	0	0	0	0	0	0	0
1	0	1	2	3	4	5	..	n
2	0	n+1	n+2	n+3	n+4	n+5	..	2n
3	0	2n+1	..	..	..	..	..	..
4	0	..	..	..	..	..	..	..
..	0	..	..	..	..	..	..	..
m	0	(m-1)n+1	..	..	..	..	..	mn

new values representing specific land use class in specific unit

Fig 3.1 Generation of new pixel values representing a specific land-use class in a specific unit as performed by the ERDAS module MATRIX.

The result of the detailed automatic classification is shown for all tertiary units in the last column of table 3.1 It shows that according to this classification about 87 % of the total area of the Viejo Retamo is cultivated. As stated above this may be considered to be slightly less in the actual situation.

Fig. 3.2 shows the fraction that is cultivated for all tertiary units. The position of the units on the x-axis of this figure corresponds with the their position on the secondary canal. The figure does not show any correlation between the irrigated area and the distance of the tertiary intake from the secondary intake.

Table 3.2 Cultivated areas according to different classification methods and field survey.

Tertiary unit:	Cultivated area according to: Ratios method	PC method	Autom class	Detail. Autom. class	Field survey
Gonzales	126.9	115.5	124.8	133.9	139.2
Alcaraz	86.6	97.6	73.8	89.2	79.9
Orrego	88.6	87.8	93.7	110.4	102.7
Day	112.1	109.3	113.8	135.8	125.4
2o Razgo	325.4	328.2	336.1	352.7	356.0

Table 3.3 Accuracy of classification methods given as:

$$\frac{|\text{cult. area (class)} - \text{cult. area (survey)}|}{\text{cult. area (survey)}}$$

Tertiary unit	Classification accuracy (%) Ratios method	PC method	Autom class.	Detail. autom class.
Gonzales	8.8	17.0	11.5	3.8
Alcaraz	8.4	22.2	7.6	11.6
Orrego	13.7	14.5	8.8	7.5
Day	10.6	12.8	9.3	8.3
2o Razgo	8.6	7.8	5.6	0.9
Mean	10.0	14.9	8.6	6.4

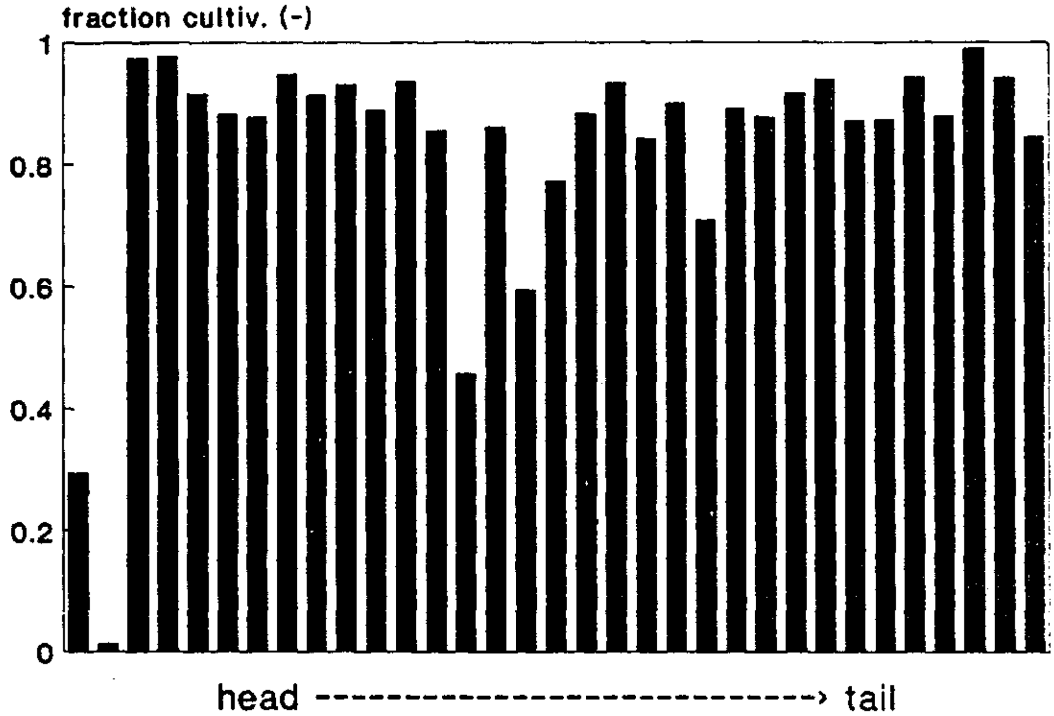


Fig 3.2 Fraction of total irrigable area that is actually cultivated for all tertiary units of the Viejo Retamo.

3.3 Cultivated areas in all secondary units of the Rio Tunuyan Irrigation Scheme.

In addition to the analysis of the cultivated areas and water ditribution in one secondary unit a classification of cultivated and not cultivated area was made of the whole area of the Rio Tunuyan Scheme. This in order to have an idea of the distribution of the cultivated areas in the total project area. In this case a Landsat MSS image was used. MSS images have a lower spatial resolution (80 m x 80 m). than TM images. They contain two bands in the visible part of the spectrum: green (MSS(4)), and red (MSS(5)), and two bands in the near infrared: (MSS(6) and MSS(7)). Using the lower resolution data, the size of the image files was reduced significantly.

In order to perform a cultivated vs not cultivated classification the amount of spectral information in the four bands was assumed to be sufficient.

First a Vegetation Index (VI) image was created consisting of:

$$VI = \frac{DN7}{DN5} * CONSTANT$$

Then the same thresholding procedure was performed as described in paragraph 3.2 separating cultivated and not cultivated area. The resulting image is shown in figure 3.3 The overlay shows the boundaries of the secondary units of the scheme.

Figure 3.4 shows the same secondary units with colors indicating the percentage of the area that is cultivated. In general the units on the outside of the scheme (e.g. at the tail ends of the main canals) tend to have a lower percentage of cultivated land than the ones closer to the beginning of the main canals.

This could be caused by the lack of sufficient surface water reaching the tail ends of the main canals. If such was the case it would be incorrect to base the future water distribution on the currently cultivated areas. An existing, not equitable situation would then be maintained. This once more illustrates the fact that before deciding wich water allocation policy has to be applied, it is very important to consider all technical and socio-economic factors involved.

In this case the decision whether to apply water according to the actually cultivated area or according to the total irrigable area is quite relevant. Given the fact that the difference between total irrigable area and actually cultivated area is much higher for the secondary units located at the end of the primary canals, intended volumes would be very much affected by the choice of the water allocation policy.

Fig 3.3 Classified image showing the cultivated and not cultivated area in the Río Tunuyán Irrigation Scheme; overlay shows the boundaries of the secondary units of the scheme.

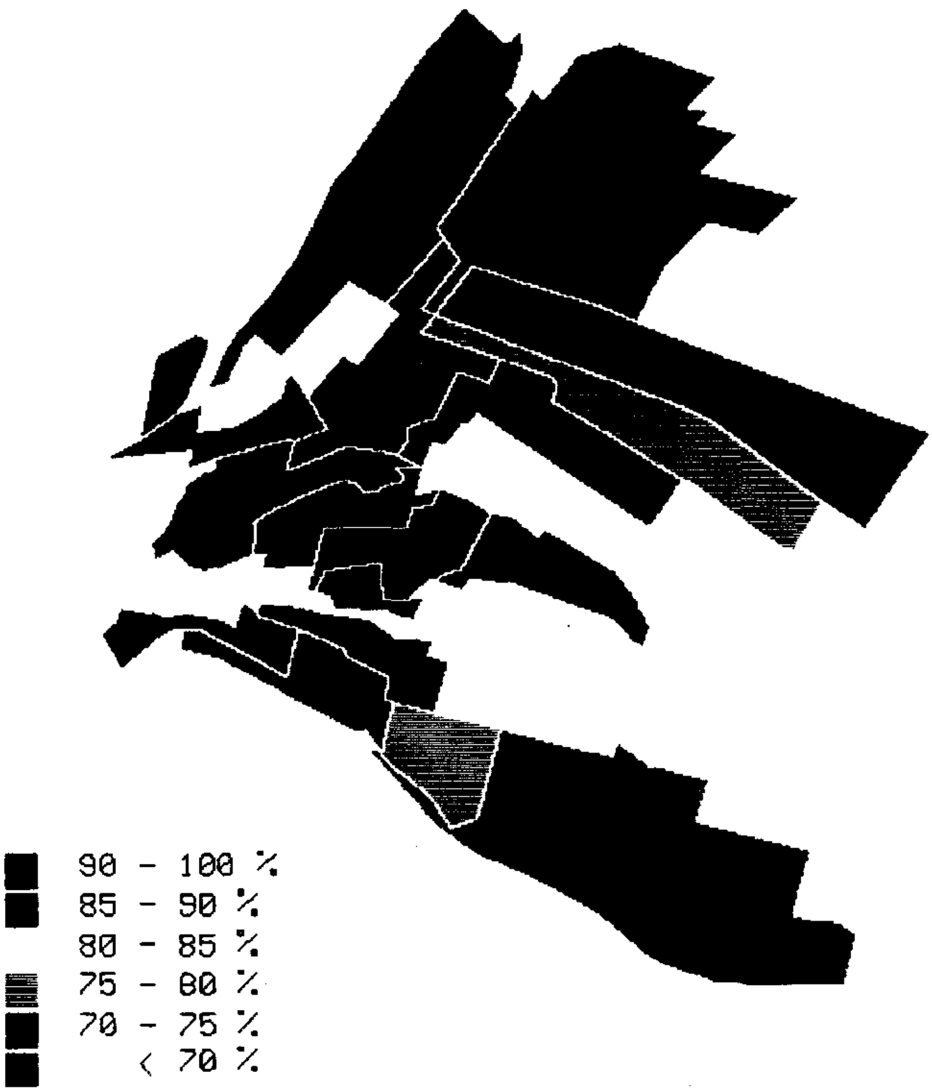


Fig 3.4 Image showing the percentage of the total irrigable area that is actually cultivated for all secondary units of the Río Tunuyán Irrigation Scheme.

3.4 Calculation of intended volumes according to areas with waterrights, actually cultivated areas and total irrigable areas for tertiary units of Viejo Retamo.

Based on the areas given in paragraph 3.1 and 3.2 the intended volumes for the different tertiary units can be determined, as necessary to implement the water allocation policies described in the beginning of this chapter. These are the volumes of surface water that would be applied to the different units if the distribution system was performing as envisaged by current regulations and practice.

The current allocation policies are based on a top-down concept, where water allocation to lower hierarchical levels in the network is established starting from the project intake. The volume of water flowing through the secondary inlet of the Viejo Retamo is therefore considered as a "boundary condition" which can not be changed. Suppose this value equals Vs(j) m3/month in month j. The waterdepth that should be applied to one hectare of land in the command area of the Viejo Retamo during month j (da(j)) is:

$$da(j) = \frac{Vs(j)}{As} \qquad \text{(m/month)}$$

where As is the area with water rights, the cultivated area or the total area of the command area of the Viejo Retamo in m2, depending on the objective that is chosen. The intended volume for a tertiary unit i of the Viejo Retamo during month j (Vint(i,j)) can now be determined as:

$$Vint(i,j) = A(i) * da(j) \qquad \text{(m3/month)}$$

where A(i) is the area with water rights, the cultivated area or the total area of the tertiary unit, again depending on the chosen objective.

Obviously this procedure could also be applied on a higher level determining the intended volumes for the secondary units given the necessary areas and the volume entering the primary canal. Starting with the volume of water available at the project in-take all intended volumes could thus be determined down to tertiary level.

In the growing season '87-'88 a fixed discharge measuring device was not yet constructed at the inlet of the Viejo Retamo secondary canal. Three current meter measurements were taken in November, December and March (see table 3.4).

In addition to the current meter measurements taken at the secondary inlet data on water flow were gathered at the tertiary off-takes.These data were obtained from the tomero of the Viejo Retamo. They consist of the opening times of the tertiary off-takes (the beginning of the turn), the head over the weir crest at the moment the gate is opened, the closing time of the tertiary off-takes (the end of the turn) and the head over weir crest at the moment the gate is closed. The rating curves of almost all measuring devices at the tertiary off-takes were obtained from BOS (1987).

Figure 3.5 shows a timetable containing the information on opening and closing times in October. The upper unit is the closest to the secondary intake the lowest unit is at the tail end of the secondary canal. Water is supplied to 3 up to 8 tertiary units at the same time.

All information was processed by means of a program named CONVERT yielding the volumes of water applied to all tertiary units in each turn and for all decades and months of the irrigation season. Table 3.4 contains the monthly totals for all months of the irrigation season (Vd(j)).

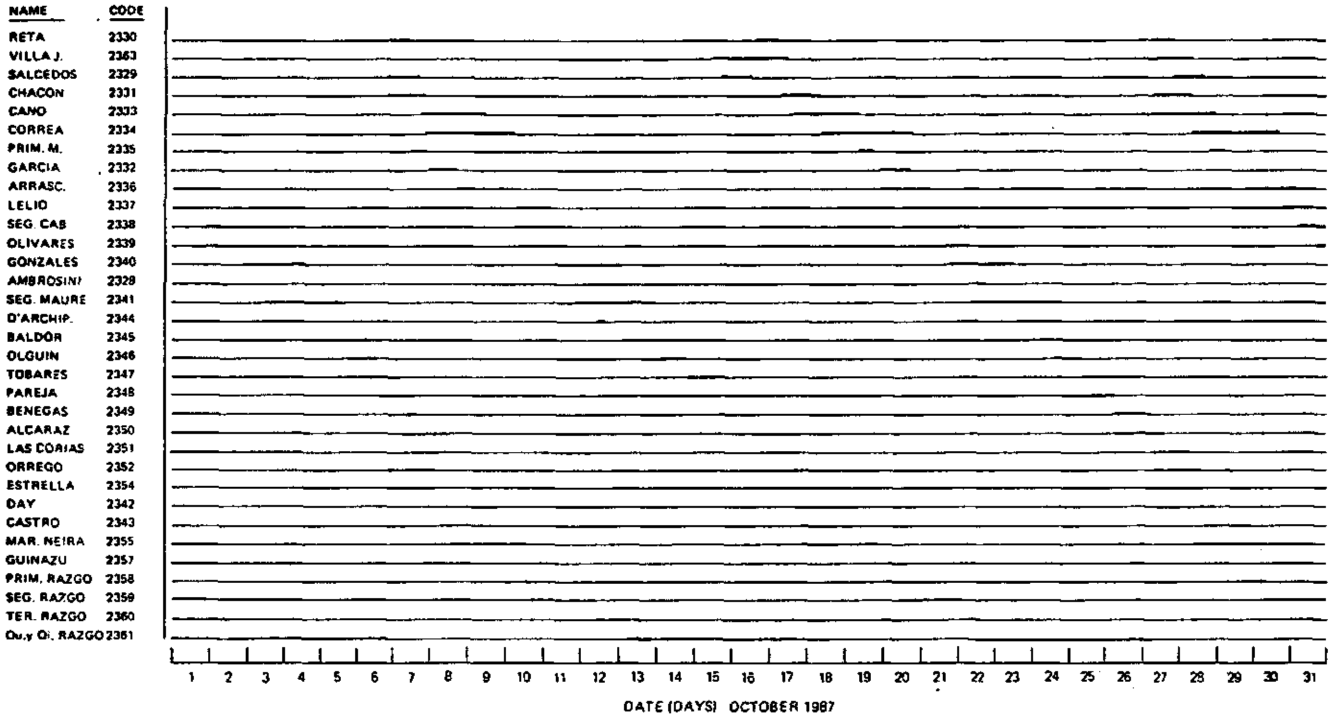


Fig 3.5 Time-table showing time and duration of surface water supply to the different tertiary units of the Viejo Retamo secondary unit.

The conveyance efficiency of the Viejo Retamo secondary canal in month j can be given as (Bos, 1982):

$$e = \frac{Vd(j)}{Vs(j)} \quad (-)$$

where

Vd(j) = total volume of water flowing through all the tertiary off-takes during month j (m3/month)

Vs(j) = volume of water flowing through the secondary inlet during month j (m3/month)

The values of these efficiencies are given in table 3.4 for those months in which the current meter measurements were taken. The average is about 0.70. The values of Vs for the remaining months were estimated by dividing the values of Vt by 0.70

The values of the intended volumes could now be calculated for all tertiary units of the Viejo Retamo and all months of the irrigation season 1987-1988 using the LOTUS-123 spreadsheet program.

3.5 Evaluation of the current situation for the tertiary units of the Viejo Retamo.

In order to evaluate the water delivery performance to the tertiary units the ratio of the intended volume to the actual volume -Ratio 1 in table 1.1- can be used. It is defined as:

$$\text{Ratio of the intended volume over the actual volume} = \frac{Vint(i,j)}{Vact(i,j)} \quad (-)$$

where

Vint(i,j) = intended volume for unit i in month j (m3/month)

Vact(i,j) = volume of surface water that is actually supplied to unit i in month j (m3/month)

The values of these ratios were calculated for all units and all months of the irrigation season using the LOTUS-123 spreadsheet program.

They are shown in figures 3.6 and 3.7 for the months September and January. The first two tertiary units contain a small town. Irrigation is applied to small parks and the trees that are planted along almost all roads. In those cases the total area of the unit does not equal the irrigable area. Also the result of the cultivated - not cultivated classification will be less reliable. Therefore the ratios of the intended volume over the actual volume concerning irrigable area and actually cultivated area do not have much meaning for these two units.

Table 3.4 Discharges at secondary inlet, volumes at secondary inlet, total volumes at tertiary off-takes and conveyance efficiencies for the different months of the irrigation season

Month:	Discharge at secon. inlet (m3/s)	Volume at secon. inlet (m3/month)	Tot. vol. at tertiary off-takes (m3/month)	conveyance efficiency (-)
August	-	-	1976331	-
September	-	-	3496223	-
October	-	-	4476257	-
November	2.55	6609600	4596619	0.70
December	2.15	5758500	4459477	0.77
January	-	-	4774120	-
Februari	-	-	4364756	-
March	3.08	8249472	5372238	0.65
April	-	-	4482429	-
May	-	-	4648663	-

For one unit no data on water supply were available in September nor January. For another unit no data were available in January. For those units all ratios were set to zero.

In the ideal case the values of the ratio of the intended volume to the actual volume would be equal for all tertiary units. Differences in the value of this ratio between the different tertiary units are caused by an inequitable water distribution.

The water supply regarding an equitable distribution according to the areas with waterrights (according to which the water is currently

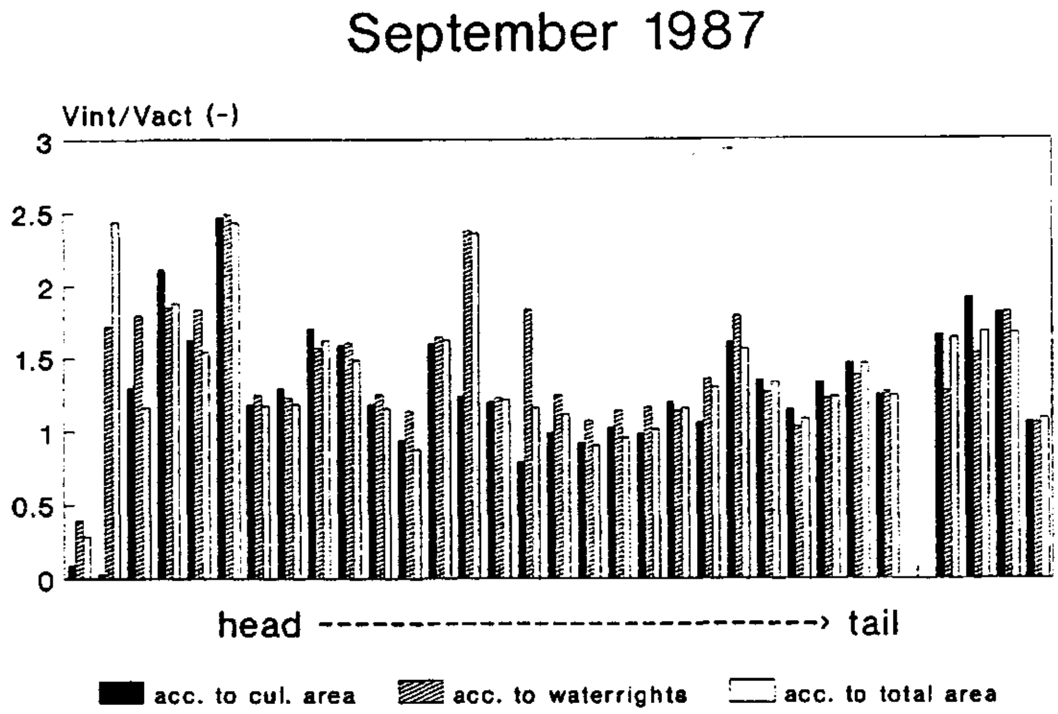


Fig 3.6 Ratio of the intended volume to the actual volume for all tertiary units of the Viejo Retamo in September regarding the allocation of surface water proportional to the area with waterrights, the total irrigable area, or the actually cultivated area.

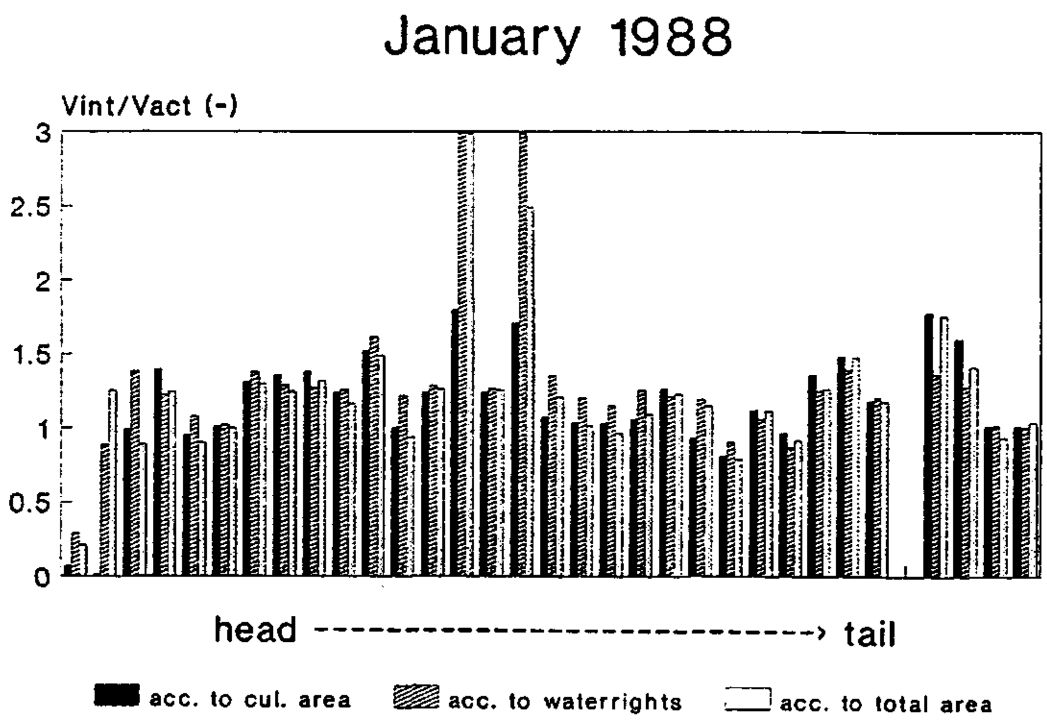


Fig 3.7 Ratio of the intended volume to the actual volume for all tertiary units of the Viejo Retamo in January regarding the allocation of surface water proportional to the area with waterrights, the total irrigable area, or the actually cultivated area.

supplied) does not seem to be structurally better than regarding the other two policies. In some units however, there are significant deviations which implies that intended volumes and irrigation performance differ substantially given different water allocation policies.

Fig. 3.8 shows the values of the ratios of the intended volume over the actual volume through the irrigation season for two units. Cano is located near the secondary inlet while Castro is near the tail end of the secondary canal. Except for september the ratio of the intended volume over the actual volume to the tertiary unit located near the inlet is always lower than for the one located near the tail end of the secondary canal.

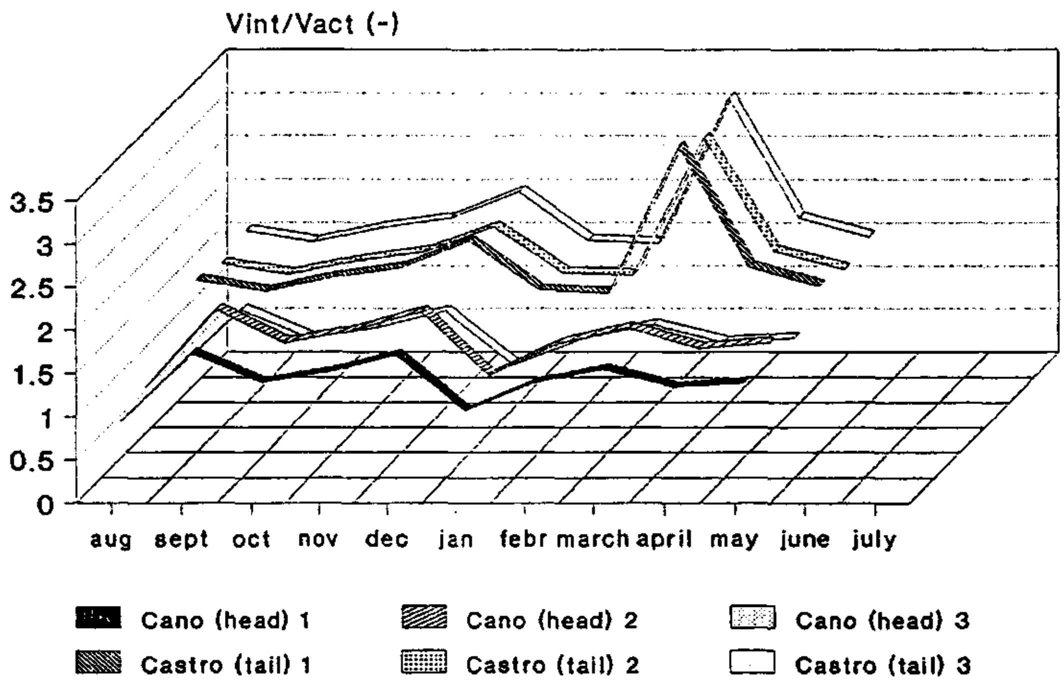


Fig 3.8 Ratio of the intended volume to the actual volume for two tertiary units of the Viejo Retamo during the period August '87 - July '88 regarding the allocation of surface water proportional to the area with waterrights (1) the total irrigable area, or the actually cultivated area (3).

CHAPTER 4. EVALUATION OF THE CURRENT WATER SUPPLY ACCORDING TO CROP WATER REQUIREMENTS

A different water allocation policy would be derived on the basis of a bottom-up concept, i.e. based on expected crop irrigation water requirements. The expected requirement equals the potential evapotranspiration of the crop minus the effective rainfall. The potential evapotranspiration is the amount of water that is lost to the atmosphere due to crop transpiration and soil evaporation when the crop is optimally supplied with water. In the area considered the amount of effective rainfall is so small that it can be neglected when calculating the expected crop irrigation water requirements.

The water supply to the tertiary unit i during month j can be evaluated on a monthly basis by calculating the tertiary unit efficiency $e_u(i,j)$ -Ratio 2 in table 1.1- (adapted from BOS, 1982):

$$e_u(i,j) = \frac{ETp(i,j)}{Vact(i,j)} \quad (-)$$

where

ETp(i,j) = Total potential evapotranspiration in unit i during month j (m3/month).

Vact(i,j) = Volume of water that is actually supplied to unit i during month j (m3/month).

In paragraph 4.1 the total potential evapotranspiration of the tertiary units of the Viejo Retamo secondary unit is calculated. In paragraph 4.2 the current surface water supply is evaluated not considering the volumes of water that are extracted from the groundwater. In the last paragraph an evaluation is performed taking into account both surface water and groundwater supply.

4.1 Calculation of total potential evapotranspiration of tertiary units of Viejo Retamo.

The potential evapotranspiration of a crop can be calculated as follows:

$$ETp = f * ETo \quad (mm / month)$$

where ETo is the reference crop evapotranspiration in millimeters per month and f a dimensionless crop factor.

The reference crop evapotranspiration depends on the meteorological conditions and can be calculated using the model CRIWAR (VOS, 1989) for a month or a ten day period. It can be considered to be constant within the project area. CRIWAR is based on the method described in FAO (1977). Within this method the reference crop evapotranspiration is calculated using the modified PENMAN formula. The values of ETo were calculated for every month of the year using CRIWAR. They are shown in table 4.1.

The crop factor (f) is crop dependent. The f-values for the different crops in Mendoza were determined by means of experimental trials. In order to obtain the total potential evapotranspiration of a certain tertiary unit i during month j (ETp(i,j)) the contributions of the different crops occurring in the unit have to be added together:

$$ETp(i,j) = \sum_{k=1}^{n} (A(i,k) * f(j,k) * 1000 * ETo(j)) \quad (m3/month)$$

where

A(i,k) = the area of crop k in unit i (m2)
f(j,k) = crop factor of crop k during month j (-)
ETo(j) = reference crop evapotranspiration during month j (mm/month)

The only data still missing consisted of the areas of the different crops in the different tertiary units.

This information was supposed to be obtained from the LANDSAT-TM satellite image. However a classification on individual crops appeared to be impossible due to the extreme variability in soil cover, crop age, undergrowth, etc. (MEEUWISSEN, 1989; VISSER, 1988).

Given this variability the possibility was considered to discriminate groups of crops having a similar f-value. This would only be possible if there was a relationship between the f-value and the spectral signature of a crop.

To find out if such a relationship existed, a cluster analysis was performed on the reflection data of 80 fields of which the vegetation was mapped in March 1988, using the statistical package SPSS. For every field the mean values of the digital numbers (DN) of the different TM-bands were calculated. In the cluster analysis these mean values were used. Regarding these values 8 land-use classes could be distinguished. Three classes contained mainly uncultivated fields. Each of the remaining five classes appeared to contain crops having similar f-values. In other words the relation between f-value and spectral signature mentioned above appeared to exist. Using this classes definition, training sets were created to be used in an automatic supervised classification (see par 3.2). This classification was performed on all pixels in the image. During such a classification, first the spectral signature of a pixel is compared to those of the pixels in the training sets. Then the pixel is assigned to the class whose spectral signature it matches best. The procedure of cluster analysis, class formation and classification is described in detail by MEEUWISSEN (1989).

The result is shown in fig. 4.1. Table 4.1 gives the f-values for the 5 crop classes in the different months of year. From May till August the plants of all crops in the different classes don't carry any leaves so the f-values of all classes equal zero during that period.

The same overlay procedure as described in paragraph 3.2 was used to obtain the areas of the different crop classes within the 33 tertiary units of the Viejo Retamo (A(i,k) in the equation above). Now the total potential evapotranspiration for the different months of the

Fig 4.1 Classified image of Viejo Retamo secondary unit showing areas with different crop classes (A, B, C, D and E) and the not cultivated area (NI).

year for all the tertiary units of the Viejo Retamo could be calculated.

Table 4.1 Values of reference crop evapotranspiration, ETo (mm/month) and f-values for different crop classes.

month:	ETo (mm/month)	f-values for crop classes: A	B	C	D	E
August	71	0.00	0.00	0.00	0.00	0.00
September	110	0.70	0.65	0.55	0.45	0.35
October	162	0.90	0.80	0.70	0.55	0.40
November	192	1.00	0.90	0.80	0.65	0.50
December	211	1.00	0.95	0.85	0.70	0.80
January	214	1.00	0.95	0.80	0.70	0.60
February	161	0.95	0.90	0.80	0.70	0.55
March	128	0.80	0.80	0.75	0.65	0.60
April	78	0.65	0.65	0.65	0.60	0.50
May	50	0.00	0.00	0.00	0.00	0.00
June	37	0.00	0.00	0.00	0.00	0.00
July	44	0.00	0.00	0.00	0.00	0.00

4.2 Evaluation of the current supply of surface water to the tertiary units of the Viejo Retamo.

Given the total potential evapotranspiration as calculated in the previous paragraph the current water supply to the tertiary units can be evaluated using the tertiary unit efficiency $e_u(i,j)$, defined in the beginning of this chapter. The values of these efficiencies are shown in fig. 4.2 and 4.3 for all tertiary units of the Viejo Retamo in September and January.

If the value of $e_u(i,j)$ is less than 1 for a certain unit in a certain month the amount of surface water supplied exceeds the potential evapotranspiration and the actual evapotranspiration might well be equal to the potential. If it exceeds 1, the amount of surface water supplied is less than the potential evapotranspiration and there is a condition of under-irrigation (with respect to surface water supply). In September most tertiary units obtain a volume of surface water that exceeds the total potential evapotranspiration. In January supply of surface water is less than the crop water requirements. Most units get a volume of surface water that is less than one third of the potential evapotranspiration.

Fig 4.4 shows the value of $e_u(i,j)$ through the year for two units respectively near the inlet (Cano) and at the tail end of the secondary canal (Castro). Except for September, the efficiency of the surface water supply to the unit at the tail end of the secondary canal exceeds the efficiency of the water supply to the unit close to the secondary inlet throughout the year.

4.3 Evaluation of conjunctive surface water and groundwater supply to the tertiary units of the Viejo Retamo

Taking into account the volumes that are extracted from the groundwater, the tertiary unit efficiency of unit i in month j should be defined as:

$$e_u(i,j) = \frac{ETp(i,j)}{Vact(i,j)} = \frac{ETp(i,j)}{Vsur(i,j) + Vgr(i,j)} \quad (-)$$

where Vsur(i,j) is the volume of surface water and Vgr(i,j) the amount of groundwater that was supplied to unit i, both in month j. The values of this efficiency are shown in fig. 4.5 and 4.6 again for

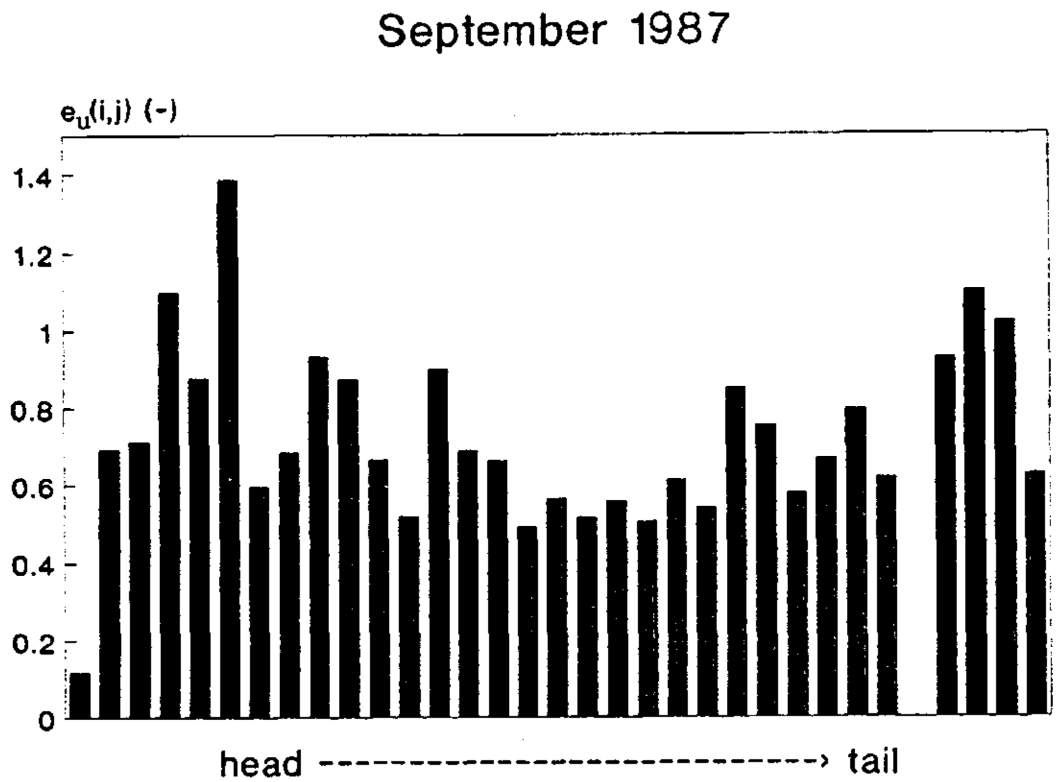


Fig 4.2 Tertiary unit efficiency ($e_u(i,j)$) for all tertiary units of the Viejo Retamo in September regarding the supply of surface water.

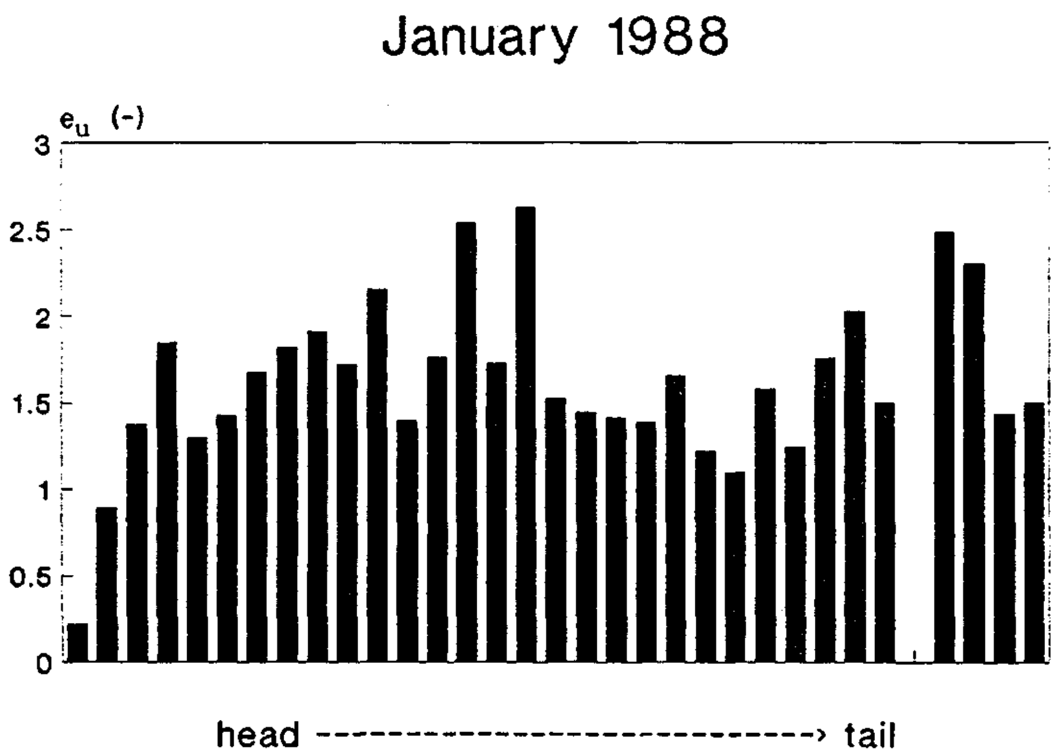


Fig 4.3 Tertiary unit efficiency ($e_u(i,j)$) for all tertiary units of the Viejo Retamo in January regarding the supply of surface water.

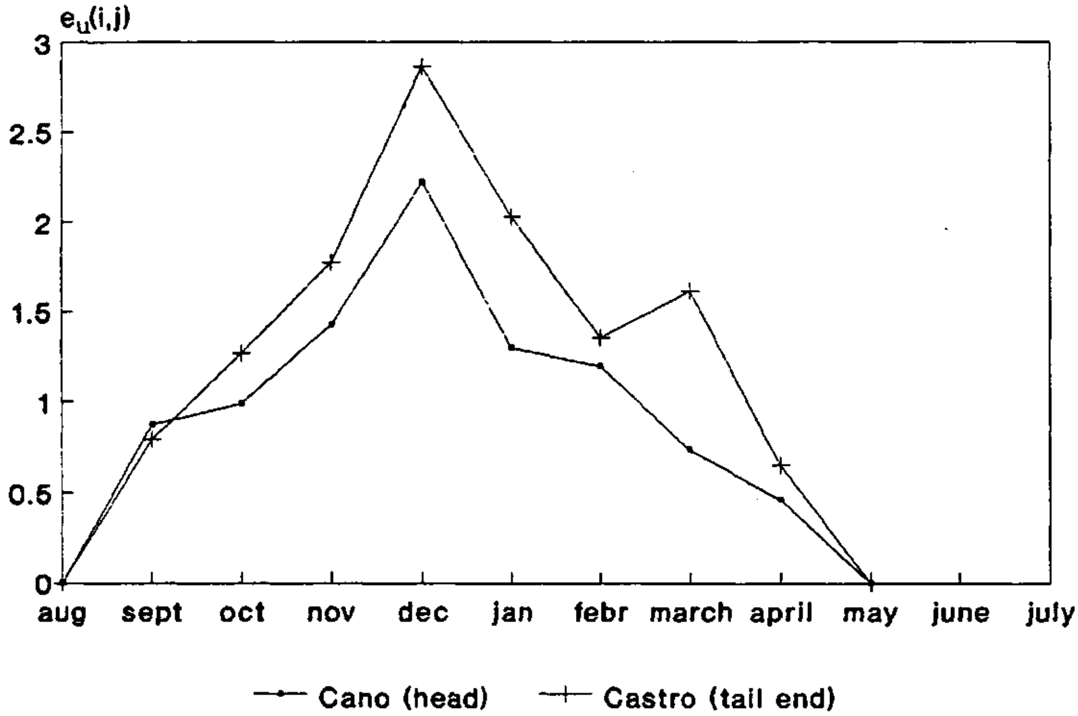


Fig 4.4 Tertiary unit efficiency ($e_u(i,j)$) for two tertiary units of the Viejo Retamo during the period August '87 - July '88 regarding the supply of surface water.

September and January. For four units no data on volumes of extracted groundwater were available. The concerning efficiencies were set to zero.

The variability of the efficiency of the water supply to the different units seems to be higher considering both surface water and groundwater supply instead of considering surface water supply only.

Table 4.2 shows the total volumes of evapotranspiration and applied surface water and groundwater in one year.

The volume of applied surface water equals the total volume delivered to all tertiary off-takes of the Viejo Retamo during one year. The volume of groundwater equals the total volume of water pumped from all the wells used for irrigation in the command area of the Viejo Retamo. These data were obtained from ing. Zuleta of DGI.

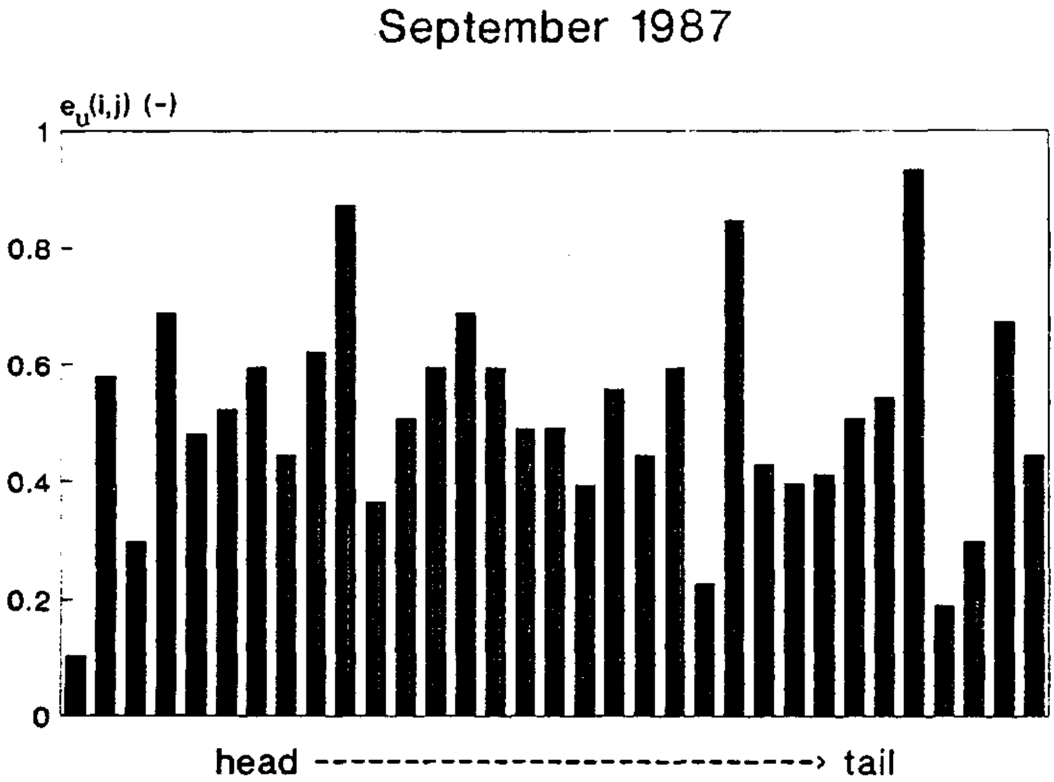


Fig 4.5 Tertiary unit efficiency ($e_u(i,j)$) for all tertiary units of the Viejo Retamo in September regarding the combined surface water and groundwater supply.

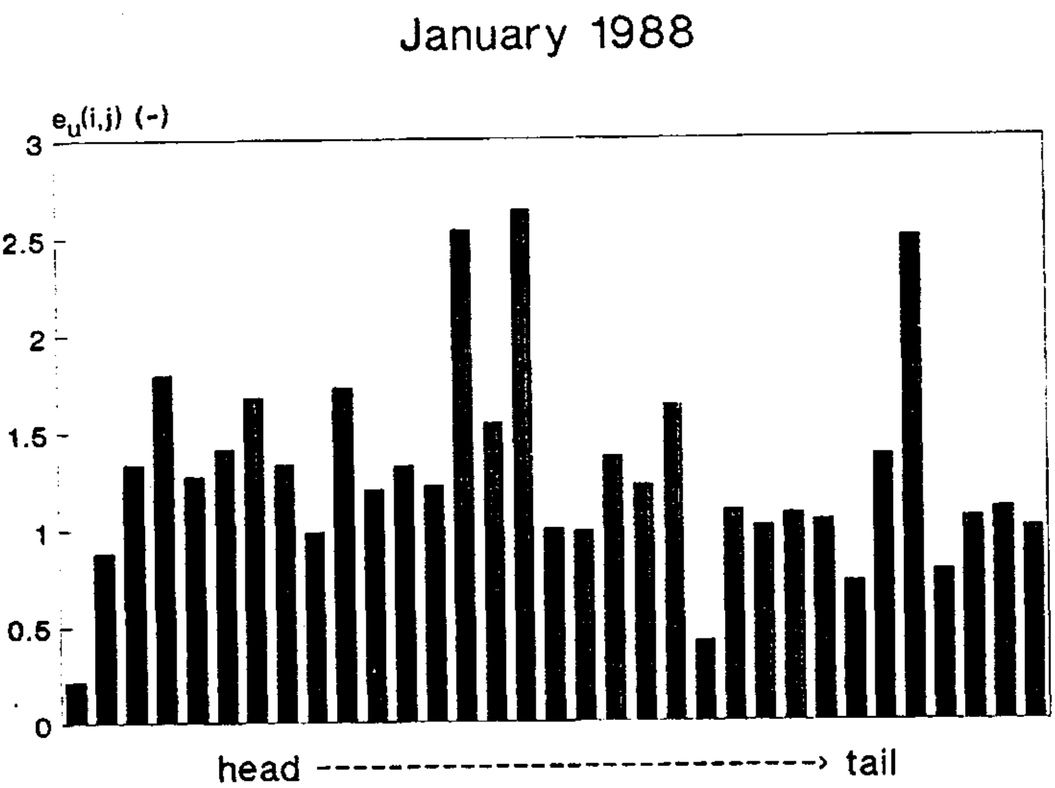


Fig 4.6 Tertiary unit efficiency ($e_u(i,j)$) for all tertiary units of the Viejo Retamo in January regarding the combined surface water and groundwater supply.

Table 4.2 Totals of average yearly potential evapotranspiration (ETp) and applied surface water and groundwater in '87 - '88 in the area of the Viejo Retamo.

ETp (m3/year)	Vol. of surface water applied (m3/year)	Vol. of ground-water applied (m3/year)	Ratio of ETp to total volume of water suppl. (-)
43628000	42647000	31542000	0.59

The total potential evapotranspiration exceeds the volume of surface water that was applied. One should realize however, that the actual evapotranspiration will not be equal to the potential level as calculated in paragraph 4.1.

Evapotranspiration consists of soil evaporation and crop transpiration. Soil evaporation will decrease when the upper layer of the top soil starts drying out. The effect of this reduction on total evapotranspiration will increase when soil cover by the crop is lower. Crop transpiration can still be potential in such a situation. Also crop transpiration might drop below potential level because of water shortage in the rootzone during a certain period or due to waterlogging. The total amount of water that is supplied (surface water plus groundwater) exceeds the total potential evapotranspiration. Given the fact that the actual evapotranspiration will be even less than the potential evapotranspiration a larger amount of irrigation water will percolate into deep groundwater than as indicated here by comparing total water supply with potential evapotranspiration.

CHAPTER 5. A WATERBALANCE STUDY OF THE UNSATURATED ZONE

To get to get better insight in the interrelation of evapotranspiration, groundwaterlevels, percolation, etc. the water transport in the unsaturated zone was simulated for three different soil types cropped with parral, the main crop in the area. This was done using the model SWATRE (FEDDES et. al., 1978; BELMANS et. al., 1983).

The leaves of the parral start to develop in September and the grapes are harvested in March - April. In April - May the plants lose their leaves again. The crop is irrigated from August untill May. Therefore a simulation period running from August till July was chosen.

SWATRE is a one dimensional finite-difference model for the unsaturated zone including water uptake by the roots. Boundary conditions are determined for each time step given certain input data. Subsequently water flow through the different soil compartments and water uptake by the roots is calculated.

5.1 SWATRE input.

Among others SWATRE needs three important types of input data:

1. Meteorological data

Within the model different formulas to calculate the upper boundary condition can be selected. Given the availability of data the penman equation (PENMAN, 1948) was chosen. This meant that the following data had to be gathered for every day of the simulation period:

- precipitation (including irrigation)
- short-wave radiation flux
- degree of cloudiness
- mean daily air temperature

- mean daily air humidity
- mean daily wind velocity (at 2 m height)

Historical data over a ten year period were obtained from a meteorological station in the project area. From these data the average meteorolgical circumstances were derived end entered for one year (August - July).

The applied amounts of surface water were calculated for every month of the irrigation season as follows: The program CONVERT (see paragraph 3.4) calculates among others the total volume of surface water that is delivered to all tertiary off-takes in the Viejo Retamo during a certain month. This value was divided by the area that is irrigated within the command area of the Viejo Retamo. The resulting value was multiplied by 0.7 in order to account for the losses that occur between the tertiary off-take and the field, yielding the mean layer of surface water that is applied to an irrigated parcel in the Viejo Retamo. This value is equal to the equivalent water depth as defined by Menenti et. al. (1989). They are shown in table 5.1.

Surface water is delivered to a tertiary unit about 30 times during the irrigation season and a certain parcel is irrigated once every three times water is delivered to the whole unit. Normally a turn will take about two to three days. Given the fact that surface water is supplied during ten months, the layers of surface water shown in table 5.1 were added to the natural precipitation on the 14th and 15th of each month concerned resulting in the simulation of 10 surface water applications during the irrigation season.

In addition to the surface water groundwater is applied between surface water applications. Amounts of extracted groundwater were obtained for all tertiary units of the Viejo Retamo. Again these values were divided by the cultivated area and multiplied by 0.7 in order to account for losses. The resulting layers (see table 5.1) of water were added to the natural precipitation at the end of each month.

Table 5.1 Average layers of surface water and groundwater (mm/month) applied to the cultivated area of the Viejo Retamo.

month:	aug	sep	oct	nov	dec	jan	feb	mar
surface water : (mm/month)	33	58	74	77	75	79	73	90
ground-water : (mm/month)	24	52	52	65	65	79	79	20

month:	apr	may	jun	jul	total
surface water : (mm/month)	75	78	-	-	712
ground-water : (mm/month)	27	20	-	-	483

2. Soil hydraulic data.

To be able to describe the water transport in the unsaturated zone the model needs the water content and the unsaturated conductivity as a function of the pressure head entered in tabular form for the different layers in the profile.

Water retention data were obtained from the results of a soil survey (CHAMBOULEYRON et. al., 1975) for two profiles (c16 and c17) occuring in the area of the Viejo Retamo. They consist of three (c16), respectively two (c17B) layers. These data existed of five measurements of pressure head and the corresponding water content. The program RETC (v. GENUCHTEN, 1986) was used to fit an analytical function to these measurements yielding an estimation of the different water retention curves. The measurements and the fitted curves are shown in fig. 5.1. The measurements and the curves seem to match fairly well.

RETC also offers the possibility of estimating the K(h) relation based on the water retention curve and an estimation of the saturated conductivity. The saturated conductivities were estimated using the soil types listed in WÖSTEN (1987) as a reference.

For profile c17 the saturated conductivities were estimated 20 and 15 cm/day (c17a) respectively 40 and 35 cm/day (c17b) for the two layers in the profile. This in order to know the effect on further calculations due to such a difference. The resulting K(h) curves are shown in figures 5.2, 5.3 and 5.4.

3. Crop data.

The following crop specific data are needed:
- rooting depth
- sink term (describing the water uptake by the roots at different pressure heads)
- soil cover
- soil cover - leaf area index (LAI) relationship
- crop factor

The average rooting depth of parral is 110 cm. This value was obtained from the literature available on the subject in Mendoza. The shape of the sink term was obtained from TAYLOR (1972).

Soil cover was one of the crop features that were mapped during a field survey by INCYTH/ICW in March 1988. The average value for parral was used obviously taking into account the loss of leaves in the

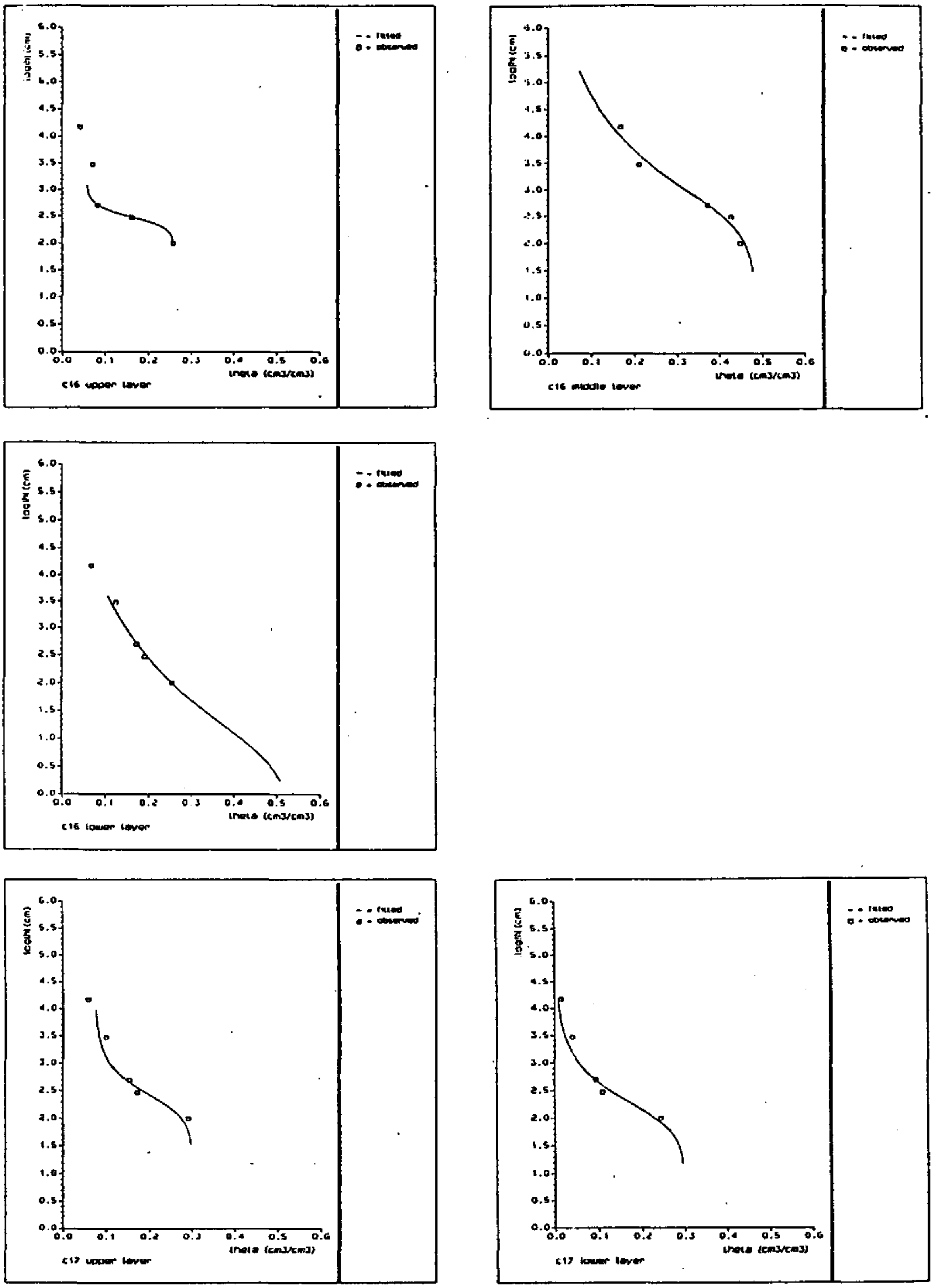


Fig 5.1 Measurements and curves fitted to these measurements of h - θ relation for different layers of profiles c16 and c17 resulting from ETC.

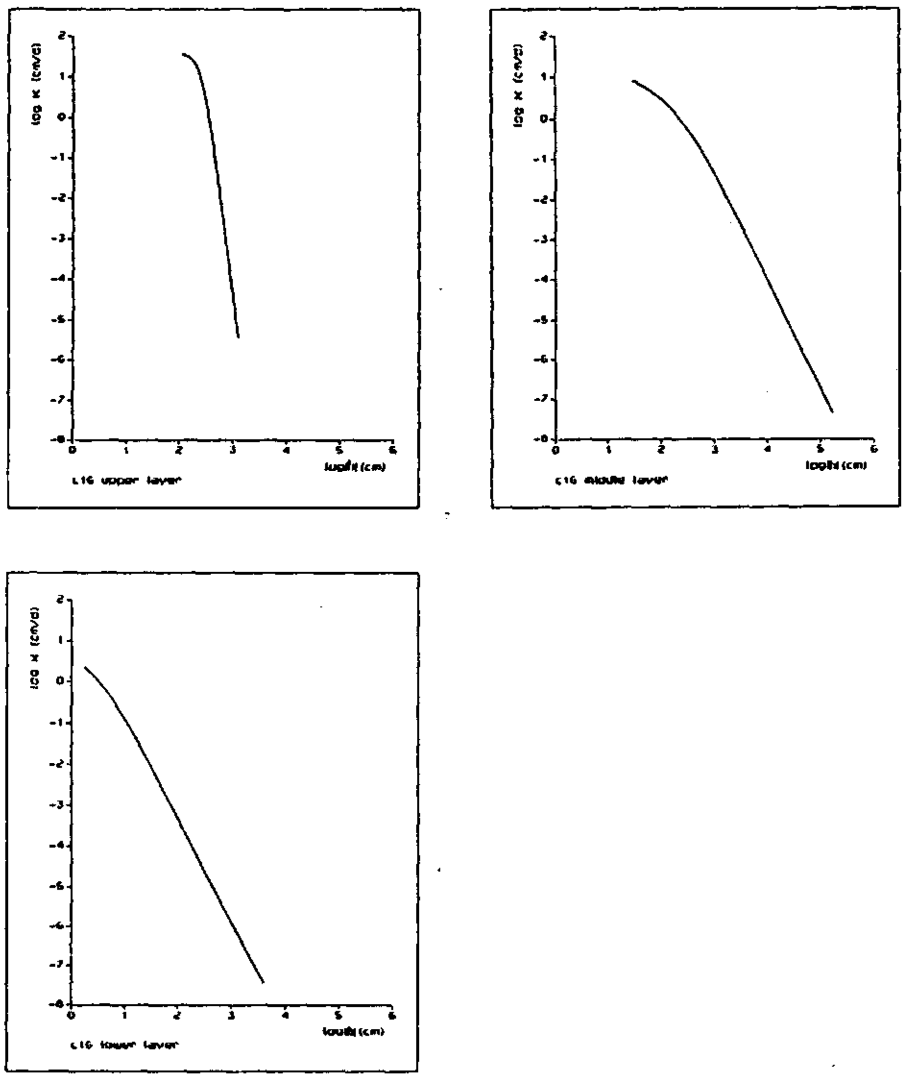


Fig 5.2 K(h) curves for different layers in profile c16 resulting from ETC.

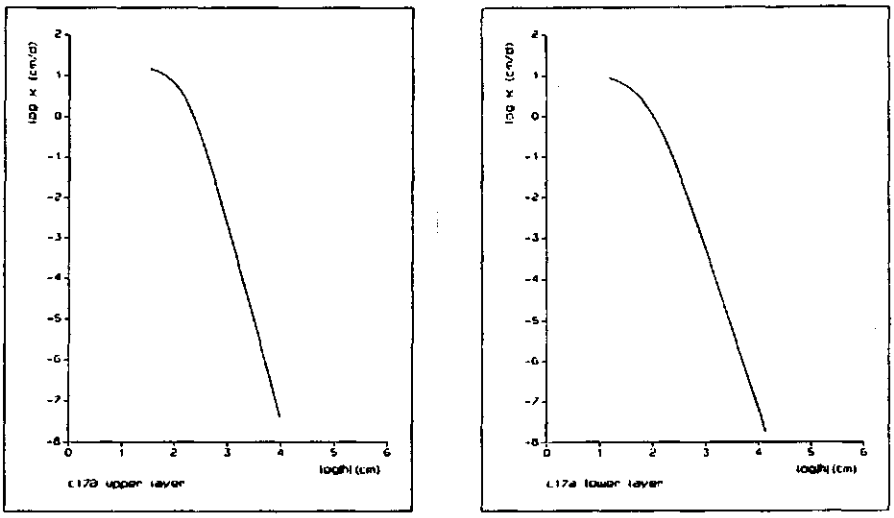


Fig 5.3 K(h) curves for different layers in profile c17a resulting from ETC.

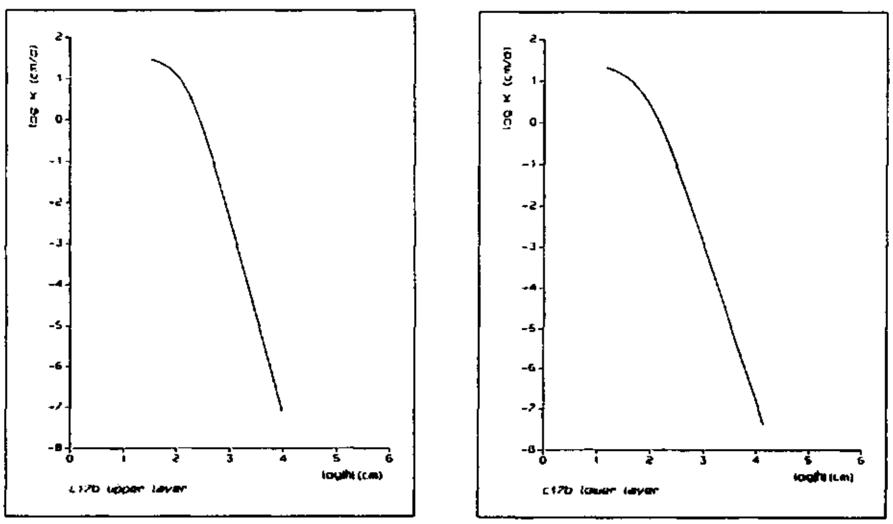


Fig 5.4 K(h) curves for different layers in profile c17b resulting from ETC.

period april-august and the occuring undergrowth. The function describing the relationship between soil cover and LAI was estimated from MARTINI (1977).

The crop factors that had to be entered here, were not the same as those used by the model CRIWAR. As mentioned in paragraph 4.1 CRIWAR is based on the modified PENMAN formula. This formula calculates the reference crop evapotranspiration ETo while the original PENMAN formula used in the SWATRE model calculates the open water evaporation Eo. Both values have to be multiplied by a crop factor in order to obtain the potential evapotranspiration of a crop given the current meteorological conditions. ETpot can be expresses in both ETo and Eo:

$$ETpot = f * ETo = g * Eo \quad (mm/day)$$

where f is the crop factor to be used with ETo and g the one to be used with Eo. Now the relation between f and g can easily be found:

$$g = (ETo/Eo) * f \quad (-)$$

The ratio (ETo (CRIWAR) / Eo (SWATRE)) appeared to be 0.80 for this area. The g-values could now be derived from the f-values given in the literature multiplying them by 0.8. Since the parral does not carry any leaves in the period May - August the f-values given in literature equal zero during that period. This means that soil evaporation and transpiration from weeds is not accounted for. When one is only interested in evapotranspiration related to crop production - like in chapter 4 - this does not pose any problem. However, when one is interested in the actual terms of the waterbalance using these values would mean introducing an error. Therefore the g-values were set to 0.2 during the period May - August. The average values of g for the different months are shown in table 5.2.

Table 5.2 g-values used with PENMAN formula in SWATRE.

month:	aug	sep	oct	nov	dec	jan	feb	mar
g :	0.20	0.40	0.60	0.60	0.70	0.70	0.70	0.60

month:	apr	may	jun	jul
g :	0.50	0.20	0.20	0.20

Apart from the data mentioned above SWATRE needs some more data on the initial conditions, the boundary condition at the bottom of the profile and the parameters controlling the calculation and the output of the results.

5.2 Model calibration.

One of the difficulties that were encountered during the model calculations was the determination of the boundary condition at the bottom of the profile. The first calculations showed that given the meteorological conditions the amount of water that infiltrated (precipitation + irrigation) exceeded the amount of water that was lost to the atmosphere due to crop transpiration and soil evaporation.

Regular measurements of the groundwaterlevels in the area indicate that there is no interannual trend. Therefore it was assumed that in a year with average meteorological circumstances the simulated groundwaterlevels should be the same in the beginning and at the end of the year.

The surplus mentioned above would have to be compensated for by a drainage flux at the bottom of the profile representing the amount of water drained into the surface water system. A constant flux of about 1.3 mm/day was assumed for the different profiles. Assuming a constant flux through the year obviously meant introducing a simplification. In the real situation this flux will depend on the groundwaterlevel and vary over time. However, this simplification was considered acceptible because a reasonable match was found between measured and simulated groundwaterlevels (see below).

For the groundwaterlevel at the beginning of the simulation period the average value of measurements taken in August in different years was taken.

Figure 5.5 shows the groundwaterlevels resulting from the simulations for the different profiles. At certain days observed levels are shown as well. These levels are the average value of the levels measured at 7 different sites in the command area of the Viejo Retamo during the season '86 - '87, a season with more or less average meteorological conditions. These sites are not necessarily located in an irrigated field. Therefore a comparision between measured and simulated levels has to be made with care.

However both measured and simulated levels do show the same fluctuation through the year. Higher groundwaterlevels from October till the middle of January (days 60 - 160). Lower levels in Februari and the beginning of March (days 160 - 200). High levels in April and May (days 230 - 310) and decreasing levels in June and July and August (days 310 - 365 and 1 - 40). The reasons for these fluctuations wil be discussed in the next paragraph.

5.3 SWATRE results.

In table 5.3 we see that the actual evapotranspiration is about 75 % of the potential evapotranspiration for all three profiles. This is largely due to a reduction of the actual soil evaporation compared to the potential soil evaporation. However, especially in profile c17a the actual crop transpiration is also significantly less than the

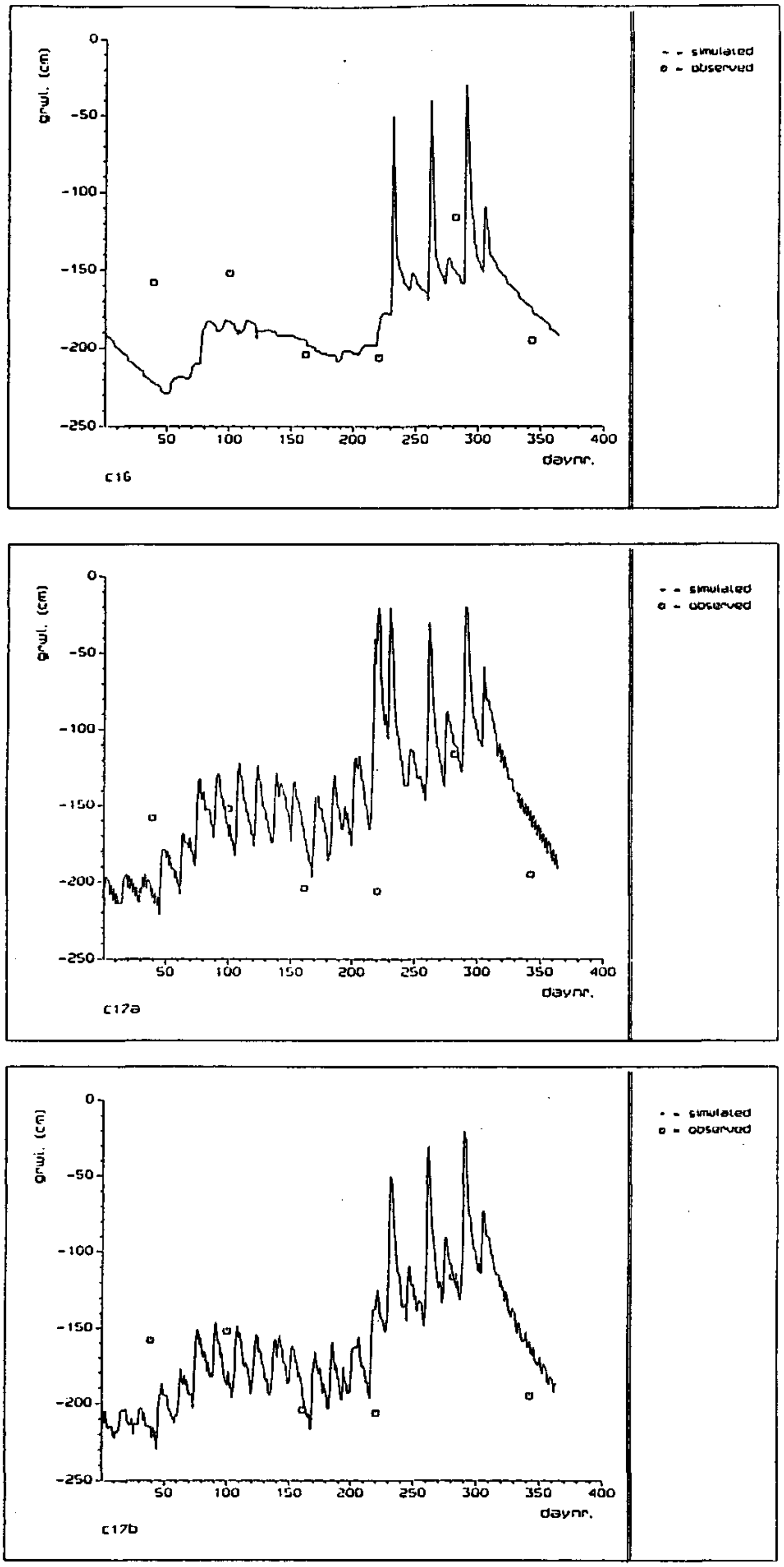


Fig 5.5 Observed and simulated groundwaterlevels for all three profiles.

potential crop transpiration. This is caused by the incidentally high groundwaterlevels shown in fig. 5.5. The lower part of the rootzone gets saturated with water and water uptake by the roots drops below the optimal level. Reduction in crop transpiration due to water shortage in the rootzone does not occur in the current situation according to the simulations.

Large differences in the year-totals of soil evaporation, crop transpiration and infiltration due to the different soil hydraulic properties of the three profiles do not occur.

Fig. 5.6 shows actual cumulative values of crop transpiration, soil evaporation, evapotranspiration and infiltration over the simulation period. The almost vertical sections in the cumulative infiltration curve are caused by the application of irrigation water. Because of the sharp increase of watercontent at the surface of the profile due to the irrigation, soil evaporation also increases. Occasionally the decrease of crop transpiration due to high groundwaterlevels can be noted.

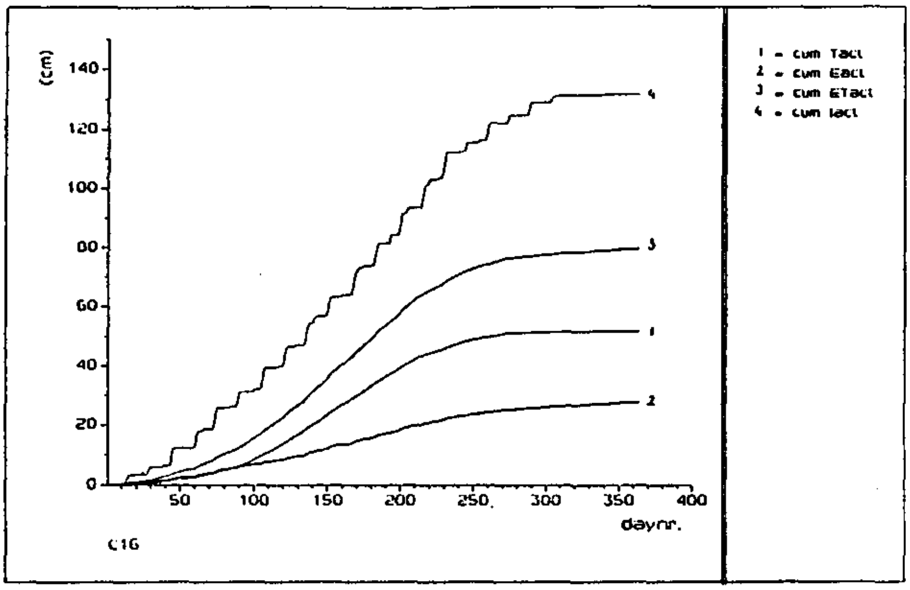
During the period September - October (days 40 - 90) groundwaterlevels rise because a surplus of irrigation water is applied that exceeds the drainage flux mentioned in paragraph 5.2. Cumulative infiltration increases much more sharply than the cumulative actual evapotranspiration in that period. From the beginning of November until the middle of January (days 100 - 170) an opposite situation exists. Evapotranspiration plus drainage flux exceed the amount of water infiltrating and groundwaterlevels drop slightly. Starting at the end of January (day 180) again the amount of water infiltrating exceeds the evapotranspiration by more than 1.3 mm/day (the drainage flux). This causes groundwaterlevels to rise substantially. During the period June - July no irrigation water is applied and natural precipitation is neglegible. Due to drainage and evapotranspiration the groundwaterlevel drops. In August (day 1 - 30) the irrigation season starts but the volumes applied are still small so groundwaterlevels keep falling.

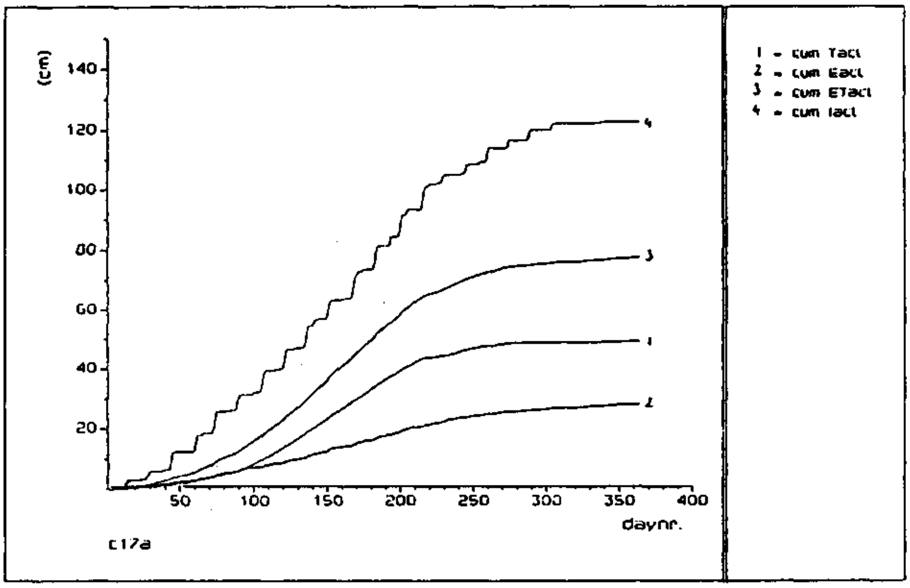
Table 5.3 Potential and actual values of evapotranspiration (ET), crop transpiration (T) and soil evaporation (E) and actual value of infiltration (I) in one year resulting from the simulations; soil profiles are indicated according to the codes assigned by CHAMBOULEYRON et. al. (1975).

profile	ETp (mm/yr)	ETa (mm/yr)	Tp (mm/yr)	Ta (mm/yr)	Ep (mm/yr)	Ea (mm/yr)	Ia (mm/yr)
c16	1054	798	525	519	530	279	1317
c17a	1054	779	525	494	530	285	1228
c17b	1054	794	525	509	530	285	1282

5.4 Determination of the effectiveness of the supply of irrigation water

To assess the effectiveness of the supply of irrigation water the value of the third ratio (see Table 1.1) as described in chapter 1. should be determined. Therefore two additional simulations were performed. One simulation was performed assuming no irrigation water applied and a groundwater depth equal to the depths found in the simulations described in the previous paragraph. One should realize that this is only realistic when just one tertiary unit at the time is considered. When larger areas are considered, large variations in groundwater recharge due to irrigation occur which would definitely





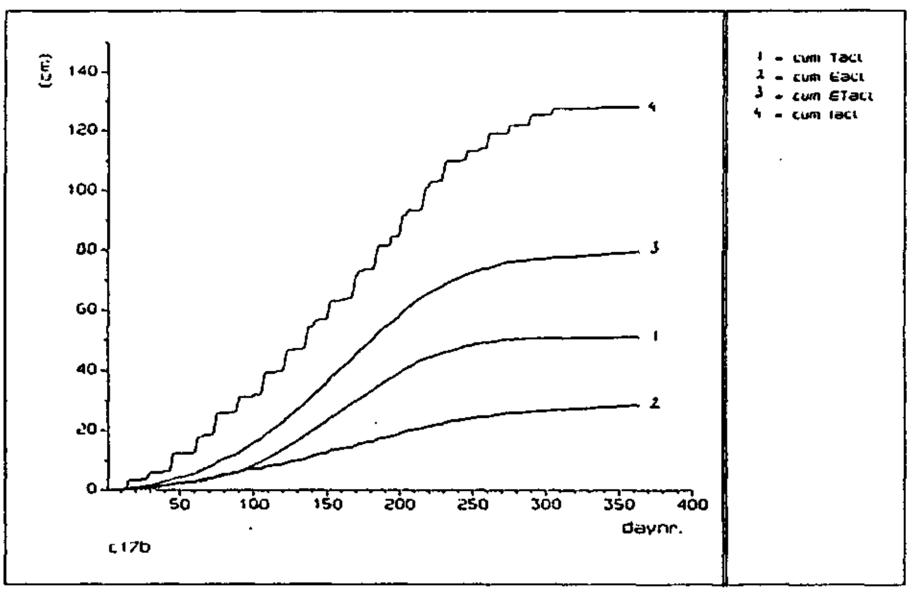


Fig 5.6 Cumulative values of actual crop transpiration (Tact), actual soil evaporation (Eact), actual evapotranspiration (ETact) and actual infiltration (Iact) for all three profiles.

affect the depth of the groundwater table. To illustrate how the constant water table assumption affects the results an additional simulation was performed taking a deep groundwater depth. The value of the third ratio was calculated regarding both shallow and deep groundwater table for the total area of tertiary units 1 through 20 (soil profile 16) and 21 through 33 (soil profile 17a). The values of actual crop transpiration, soil evaporation and evapotranspiration for the different cases and the values of the third ratio (see table 1.1) are shown in table 5.4.

As shown by the results in table 5.4 the contribution of capillary rise to meet crop water requirements is very significant in the situation with a shallow groundwater table. Crop transpiration is just slightly reduced by withholding surface water supply, i.e. R = 0.15, 0.22. In the case with the deep groundwater depth the difference in transpiration is obviously very large and the application of surface water is much more effective. It should be noted anyhow, that even in this case just about 50 % of the applied surface water does effectively contribute to crop water use, as shown by R = 0.56 and 0.42 for the coarser respectively finer soil profile.

5.5 Conclusions

The simulations show that in the current situation (surface and groundwater supply) crop transpiration is never significantly reduced due to water shortage in the rootzone. Ocassionally crop transpiration reduces because part of the rootzone gets saturated with water.

More than one third of the irrigation water that is applied throughout the year percolates into groundwater. Therefore it might be suggested to apply less irrigation water especially in the period February till May. However, given the current results it is hard to estimate the effect of such a decrease in applied irrigation water. If the amount of water infiltrating decreases the groundwaterlevel will drop. This will cause drainage and capillary rise to decrease as well. Groundwaterlevels will drop untill this decrease in drainage and capillary rise balances out the decrease in the amount of water infiltrating. To estimate the level at which this situation is reached a more extensive study of regional groundwater and surface water flow has been undertaken and will be reported later.

Table 5.4 Yearly values of actual crop transpiration (T), actual soil soil evaporation (E) and actual evapotranspiration (ET) as calculated by the simulation model SWATRE for the following situations: with actually applied irrigation water (irr.), without irrigation and current depth of shallow groundwater (not irr.), without irrigation and deep groundwater table (not irr. deep grw.); values of the actually applied surface water (measured at the tertiary in takes) (I) are used to calculate the values of the third ratio (See table 1.1) for the cases "not irr." (R (1)) and "not irr. deep grw." (R (2)). Results shown for the soil type present in tertiary units 1 through 20 and the soil type present in tertiary units 21 through 33 of secondary unit Viejo Retamo, Rio Tunuyan Irrigation District, Mendoza, Argentina.

	(mm)	Irr. (mm)			Not irr. (mm)			(-)	Not irr. deep grw. (mm)			(-)
	I	T	E	ET	T	E	ET	$e_i(1)$	T	E	ET	$e_i(2)$
Tertiary units 1-20	1067	519	279	789	478	90	568	0.22	107	95	202	0.56
Tertiary units 21-33	1067	495	284	779	495	128	623	0.15	222	106	328	0.42

CHAPTER 6. CONCLUSIONS

Given the project results achieved so far some general conclusions on the role of remote sensing in irrigation management can be drawn as well as some conclusions that apply specificly to the situation in the Rio Tunuyan Irrigation Scheme:

- Satellite remote sensing is an adequate tool to determine the actually cultivated area in the Rio Tunuyan Irrigation Scheme. Considering the fact that the specific circumstances in the project area do not seem to be especially favourable to the image processing procedures it can be assumed that this will be the case in most other areas.
- A promising method has been found to map crop irrigation water requirements. Further research will have to be performed to find out whether this method can be applied in general.
- Combined with other necessary data, remote sensing data are very useful in allocation of irrigation water and evaluation of current irrigation water supply given different water allocation policies.
- The areas with water rights currently used in the water distribution in the Viejo Retamo secondary unit differ substantially from the actually cultivated areas.
- The secondary units located at the tail ends of the primary canals of the Rio Tunuyan Irrigation Scheme tend to have a lower percentage of their area cultivated then the ones located at the heads of these canals. Further investigations should make clear if this is caused by the fact that not enough surface water reaches the ends of the primary canals.
- In the current situation (surface and groundwater supply) crop transpiration is never significantly reduced due to water shortage in the rootzone (in the average situation). Ocassionally crop transpiration reduces because part of the rootzone gets saturated with water.

ACKNOWLEDGEMENTS

I would like to thank Dr. M. Menenti (The Winand Staring Centre for Integrated Land, Soil and Water Research), Dr. M.G. Bos and Ir. W. Wolters (both Institute of Land Reclamation and Improvement) for their valuable comments on the concept version of this report.

REFERENCES

BELMANS, C., J.G. WESSELING and R.A. FEDDES, 1983. Simulation model of the waterbalance of a cropped soil: SWATRE. J. Hydrol., 63: 271-286.

BOS, M.G., 1987. Research on use of remote sensing in irrigation water management, Consultancy report. ILRI. 9 pp.

BOS, M.G. and J. NUGTEREN, 1982. On Irrigation Efficiencies, ILRI publication 19. 138 pp.

CHAMBOULEYRON, J.L., 1975. Evaluacion del aprovechamiento de los recursos hidricos en la region de Cuyo; Classificacion utilitaria con fines de riego de los suelos agricolas del area media del Rio Tunuyan. Convenio INCYTH, INTA, DGI, CRAS. Mendoza, Argentina. 51 pp.

FAO, 1977. Crop water requirements. FAO irrigation and drainage paper 24. (first edition 1977). 144 pp.

FEDDES, R.A., P.J. KOWALIK and H. ZARADNY, 1987. Simulation of field water use and crop yield. PUDOC, Wageningen, Simulation Monographs, 189 pp.

GENUCHTEN, M. Th. van, 1986. RETC.F77, program to analyse observed soil water retention and hydraulic conductivity data. (unpublished).

MARTINI, S. and M.R. SCIARETTA, 1977. Analisi del bilancio di radiazione (400 - 1350 nm) di un vigneto. Studi di Ecologia Agraria. 17 pp.

MENENTI, M., J. CHAMBOULEYRON, L. FORNERO, J. MORABITO and L. STEFANINI, 1982. Evaluacion y optimizacion del uso del agua en grandes redes de riego. Mendoza, Argentina. 176 pp.

MENENTI, M., J. CHAMBOULEYRON, L. STEFANINI, J. MORABITO AND L. FORNERO, 1985. Agricultural water use in large irrigation schemes. In: A. Perrier and C. Rion (Eds), Crop water requirements, Proceedings ICID Conference, (11-14 sept 1984): 597-610. UNESCO, Paris.

MEUWISSEN, I.J.M., 1989. Mapping of vegetation and evapotranspiration in the Rio Tunuyan Irrigation Scheme, Mendoza, Argentina, using a satellite image. Nota ICW, Wageningen, the Netherlands. (in press).

PENMAN, H.L., 1948. Natural evapotranspiration from open water, bare soil and grass. Proc. Roy. Soc. A. 193: 120-145

PIETERS, M., 1988. Studie naar de mogelijkheid van het gebruik van remote sensing bij het schatten van geirrigeerde oppervlakken. Stageverslag LUW. 19 pp.

TAYLOR, S.A. and G.M. ASHCROFT, 1972. Physical Edaphology. W.H. Freeman and Co. San Francisco: 434-435

VISSER, T.N.M., 1987. Use of satellite data in irrigation water management of Rio Tunuyan Irrigation Scheme. MSc thesis Agricultural University Wageningen, the Netherlands. 18 pp.

VISSER, T.N.M., 1988. Evaluation and Optimization of Irrigation Water Management by means of Satellite Remote Sensing and Hydrological Modeling. Progres Report 1. 20 pp.

VOS, J., P. KABAT, M.G. BOS, and R.A. FEDDES, 1989. CRIWAR: A Simulation program for calculating the crop irrigation water requirement of a cropped area. ILRI publication 46. 70 pp.

WOSTEN, J.H.M., M.H. BANNINK, and J. BEUVING, 1987. Waterretentie- en doorlatendheidskarakteristieken van boven- en ondergronden in Nederland: De Staringreeks. ICW report 18. 75 pp.