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ECOMANAGE – INTEGRATED ECOLOGICAL COASTAL ZONE MANAGEMENT SYSTEM

Deliverables 2.6 & 2.8 - Argentina: D2.6 - SIG mapping of hydrogeologic parameters, including groundwater recharge assessment and vulnerability to pollution, D2.8 - Groundwater flow and transport components of the global estuary model

(2nd Part: Bahía Blanca estuary)

Study developed for the European Commission DG Research INCO-CT Programme under contract number INCO-CT-2004-003715. Study developed within the framework of LNEC Research Plan for 2005-2008, referring to the study "Optimised management of coastal aquifers and interaction between ground and surface waters"

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I&D HIDRÁULICA E AMBIENTE

RELATÓRIO 434/**2008 – NAS**

DELIVERABLES 2.6 & 2.8 - ARGENTINA

D2.6 - SIG MAPPING OF HYDROGEOLOGIC PARAMETERS, INCLUDING GROUNDWATER RECHARGE ASSESSMENT AND VULNERABILITY TO POLLUTION

D2.8 - GROUNDWATER FLOW AND TRANSPORT COMPONENTS OF THE GLOBAL ESTUARY MODEL

ABSTRACT

Bahía Blanca case study area comprises three watersheds that discharge in the estuary, near Bahía Blanca city, from west to east: Sauce Chico, Saladillo and Napostá Grande. The total area is 3,915 km^2.

The study area is included in the Colorado basin that is characterized by faulted bedrock which affects the Paleozoic substratum. Since tertiary age no significant faults occur and the overlying sediments were deposited with a gentle slope towards the centre of the basin in a syneclise structure.

The pedologic description is based on the Soil Map of the Buenos Aires Province of the Argentine Republic. From the pedologic description of the soils and their properties, the information required to run the sequential daily water balance models and to characterize the S parameter of the DRASTIC index of groundwater vulnerability to pollution was derived.

Land use is of major importance to characterize the depth of the soil subject to the evapotranspiration and to define the ability of a determined area to produce direct runoff. Both these informations are also needed for the sequential daily water balance models. These models allow the computation of the direct runoff, real evapotranspiration and deep percolation processes. Deep percolation is an estimator of groundwater recharge.

A detailed description of these sequential daily water balance models is presented. Two methods were applied, (A) one, included in the BALSEQ_MOD program, that computes direct runoff using the soil properties and the real evapotranspiration using the dual crop coefficient approach, and (B) another, included in the BALSEQ program, which computes direct runoff using the land use/soil properties and the real evapotranspiration assuming a constant crop coefficient. Both methods require the computation of the potential evapotranspiration. The potential evapotranspiration is computed using the reference evapotranspiration and the crop coefficients. Daily climate data recorded in Bahía Blanca Aerodrome is used. This data was processed and missing data were filled. Also the precipitation from this climate station was used. For each land cover unit the crop coefficients were determined and presented.

Another method used to estimate groundwater recharge is the separation of the surface flow hydrograph. This method, included in the DECHIDR_VB program, is described and is applied to the Cerro del Águila stream flow gauge station, in the upper Napostá Grande watershed.

From the applied methodologies, the BALSEQ method provided the best results: average precipitation = 723 mm.year^{-1}, real evapotranspiration = 631 mm.year^{-1}, average direct runoff = 27 mm.year^{-1}, average recharge = 61 mm.year^{-1}.

Finally, groundwater discharge to the estuary, as determined in Heffner (2003), is only 2,000 m^3.d^{-1}, a value that represents less than 1 mm.year^{-1} if the total watershed area is considered.

DELIVERABLES 2.6 & 2.8 - ARGENTINA

D2.6 - MAPEAMENTO SIG DE PARÂMETROS HIDROGEOLÓGICOS, INCLUINDO A CARACTERIZAÇÃO DA RECARGA DAS ÁGUAS SUBTERRÂNEAS E DA VULNERABILIDADE À POLUIÇÃO

D2.8 - AS COMPONENTES DE FLUXO E DE TRANSPORTE DE ÁGUAS SUBTERRÂNEAS DO MODELO GLOBAL DO ESTUÁRIO

RESUMO

A área do caso de estudo de Bahía Blanca é composta por três bacias hidrográficas que escoam para o estuário, perto da cidade de Bahía Blanca. De oeste para leste essas bacias são: Sauce Chico, Saladillo e Napostá Grande. A área total é de 3 915 km^2.

A área de estudo insere-se na bacia do Colorado que se caracteriza pela ocorrência de rocha-mãe fracturada que afecta o substrato paleozóico. Desde o Terciário que não ocorrem falhas significativas e os sedimentos foram depositados suavemente em direcção ao centro da bacia.

A descrição pedológica baseia-se no Mapa de Solos da Província de Buenos Aires da República Argentina. A partir da descrição pedológica dos solos e das suas propriedades determinou-se a informação necessária para correr os modelos de balanço hídrico sequencial diário e para caracterizar o parâmetro S do índice DRASTIC de vulnerabilidade à poluição das águas subterrâneas.

A ocupação do solo é de grande importância para caracterizar a profundidade do solo sujeita a evapotranspiração e para definir a capacidade de uma determinada área para produzir escoamento directo. Esta informação é também necessária para os modelos de balanço hídrico sequencial diário. Estes modelos permitem o cálculo dos processos de escoamento directo, de evapotranspiração real e de infiltração profunda. A infiltração profunda é um estimador da recarga de águas subterrâneas.

Apresenta-se uma descrição detalhada destes modelos de balanço hídrico sequencial diário. Aplicaram-se dois métodos, (A) um, incluído no programa BALSEQ_MOD, que calcula o escoamento directo utilizando as propriedades do solo e a evapotranspiração real utilizando a abordagem do coeficiente cultural dual, e (B) outro, incluído no programa BALSEQ, que calcula o escoamento directo a partir da ocupação do solo e das propriedades do solo e a evapotranspiração real assumindo um coeficiente cultural constante. Os dois métodos requerem o cálculo da evapotranspiração potencial. Esta é calculada a partir da evapotranspiração de referência e dos coeficientes culturais. Utilizaram-se os dados meteorológicos diários (incluindo precipitação) registados na estação do Aeroporto de Bahía Blanca. Processaram-se estes dados e preencheram-se as lacunas. Para cada unidade da ocupação do solo cartografada determinaram-se e apresentaram-se os coeficientes culturais.

Utiliza-se também o método da separação do escoamento superficial para estimar a recarga das águas subterrâneas. Descreve-se o método, incluído no programa DECHIDR_VB, e faz-se a sua aplicação à estação hidrométrica de Cerro del Águila, na parte superior da bacia hidrográfica do Napostá Grande.

Das metodologias aplicadas, o método do BALSEQ produziu os melhores resultados: precipitação média = 723 $mm.ano^{-1}$, evapotranspiração real = 631 $mm.ano^{-1}$, escoamento directo = 27 $mm.ano^{-1}$, recarga = 61 $mm.ano^{-1}$.

Finalmente, a descarga de águas subterrâneas para o estuário, tal como determinada por Heffner (2003), é de apenas 2000 $m^3.d^{-1}$, um valor que representa menos de 1 $mm.ano^{-1}$ se se considerar a área total da bacia hidrográfica.

DELIVERABLES 2.6 & 2.8 - ARGENTINA

D2.6 - MAPEO SIG DE PARÁMETROS HIDROGEOLÓGICOS, INCLUYENDO LA EVALUACIÓN DE RECARGA DE AGUAS SUBTERRÁNEAS Y LA VULNERABILIDAD A LA CONTAMINACIÓN

D2.8 – COMPONENTES DE FLUJO Y TRANSPORTE DE AGUAS SUBTERRÁNEAS DEL MODELO ESTUARINO GLOBAL

RESUMEN

El área del caso de estudio de Bahía Blanca comprende tres cuencas hidrográficas que descargan en el estuario, cerca de la ciudad de Bahía Blanca, de oeste a este: Sauce Chico, Saladillo y Napostá Grande. El área total es de 3915 km^2.

El área de estudio se inserta en la cuenca del Colorado la cual se caracteriza por un basamento fallado en bloques que ha afectado la cobertura sedimentaria paleozoica. Desde el Terciario la región se distingue por la falta de fallamiento e inclinación suave de las capas hacia el centro de la cuenca, lo cual constituye una de las condiciones de las sineclisas.

La descripción pedológica está basada en el Mapa de Suelos de la Provincia de Buenos Aires de la República Argentina. A partir de la descripción pedológica de los suelos y sus propiedades se obtuvo la información requerida para aplicar modelos de balance diario de agua en el suelo y para caracterizar el parámetro S del índice DRASTIC de vulnerabilidad a la contaminación del agua subterránea.

El uso del suelo es de gran importancia para caracterizar la profundidad del mismo que se encuentra sujeta a la evapotranspiración y para definir la capacidad de un área para producir escurrimiento directo. Ambas informaciones son también necesarias para implementar los modelos de balance diario de agua en el suelo. Esos modelos permiten el cálculo del escurrimiento directo, la evapotranspiración real y los procesos de percolación profunda. La percolación profunda es un estimador de la recarga de agua subterránea.

Se presenta una descripción detallada de los modelos de balance diario de agua en el suelo. Dos métodos fueron aplicados, (A) uno, incluido en el programa BALSEQ_MOD, que calcula el escurrimiento directo usando las propiedades del suelo y la evapotranspiración real utilizando una aproximación dual de coeficientes de cultivo y (B) otro, incluido en el programa BALSEQ, que calcula el escurrimiento directo aplicando la relación uso de suelo/ propiedades del suelo y la evapotranspiración asumiendo un coeficiente de cultivo constante. Ambos métodos requieren el cálculo de la evapotranspiración potencial, la cual se calcula usando la evapotranspiración de referencia y los coeficientes de cultivo. Se utilizan datos climáticos diarios registrados en el Aeródromo de Bahía Blanca. Estos datos fueron procesados y los datos faltantes fueron estimados. También fueron

utilizados datos de precipitación de esta estación meterológica. Para cada unidad de cobertura de suelo fueron determinados y son presentados sus coeficientes de cultivo.

Otro método utilizado para estimar la recarga de agua subterránea es la separación del escurrimiento directo mediante un hidrograma. Este método, incluido en el programa DECHIDR_VB, es descripto y aplicado a los datos de la estación de aforo del arroyo Cerro del Águila en la cuenca superior del río Napostá Grande.

De las metodologías aplicadas, el método BALSEQ proporcionó los mejores resultados: precipitación media = 723 mm.año^{-1}, evapotranspiración real media = 631 mm.año^{-1}, escurrimiento directo medio = 27 mm.año^{-1}, recarga media = 61 mm.año^{-1}.

Finalmente, la descarga de agua subterránea al estuario, como ha sido evaluada en Heffner (2003), es solamente de 2000 m^3.d^{-1}, un valor que representa menos de 1 mm.año^{-1} si es considerada el área total de las cuencas.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLES

DELIVERABLES 2.6 & 2.8 - ARGENTINA

D2.6 - SIG MAPPING OF HYDROGEOLOGIC PARAMETERS, INCLUDING GROUNDWATER RECHARGE ASSESSMENT AND VULNERABILITY TO POLLUTION

D2.8 - GROUNDWATER FLOW AND TRANSPORT COMPONENTS OF THE GLOBAL ESTUARY MODEL

1 General Description

1.1 Introduction

Bahía Blanca case study area (Fig. 1) comprises three watersheds that discharge in the estuary, near Bahía Blanca, from west to east: Sauce Chico, Saladillo and Napostá Grande. The case study area is located between latitudes 37º51'S and 38º47'S and between longitudes 61º57'W and 62º43'W, or in UTM, zone 20S coordinates, between parallels 5811000 m S and 5705000 m S, and between meridians 525000 m W and 592000 m W.

The area under study is the area of each watershed more the area that extends from the western part of the Sauce Chico watershed until the estuary and the area that extends from the eastern part of the Napostá Grande to the estuary. The limit of these areas is given by the topography. The total area is 3,915 km^2. Topography was provided by partner IST (see Deliverable 2.12, Leitão *et al.*, 2006). Minimum altitude is near the coastline, at sea level, and maximum altitude is at Sierra de la Ventana ridge system with 1,243 m.

This report, in conjunction with Deliverable 2.7 (Leitão *et al.*, 2007), constitutes the hydrogeological characterisation of the Bahía Blanca site.

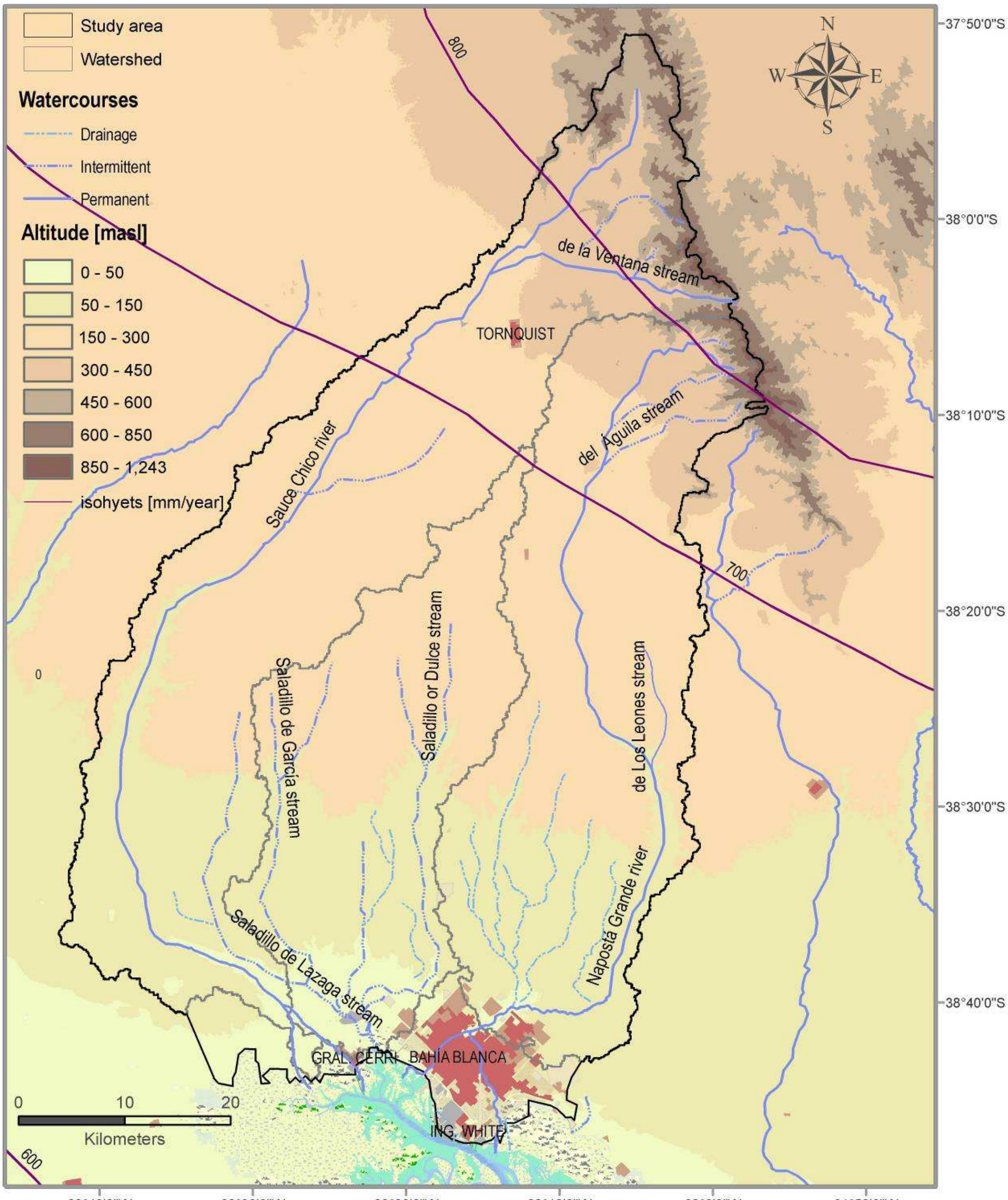
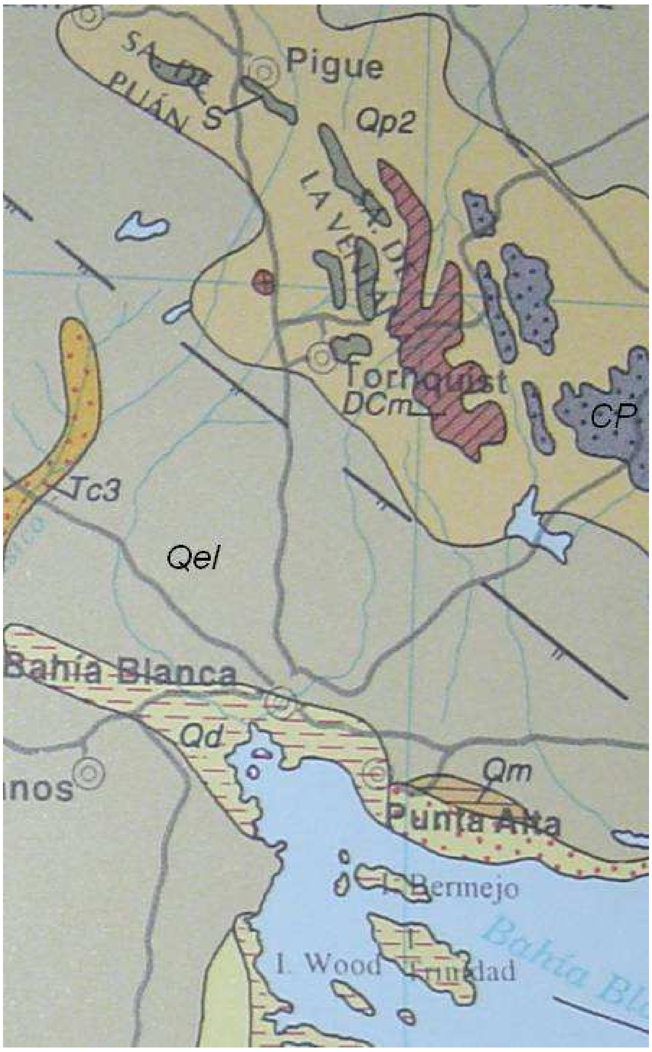


Fig. 1 – The Bahía Blanca case study area

1.2 Geology

The geological and geophysical characterization of the study area has been subject to various previous global studies that concern the main morphostructural regions of Sierras Australes of the Buenos Aires province and of Colorado basin (Bonorino, 1988; Albouy 1994, Carrica, 1998).

In a very simple way, the study area is included in the Colorado basin that is characterized by faulted bedrock which affects the Palaeozoic substratum. Since tertiary age no significant faults occur and the overlying sediments were deposited with a gentle slope towards the centre of the basin in a syneclise structure. Fig. 2 shows the geology of the area (SEGEMAR, 1997). Table 1 presents a summary of the geological formations occurring in the area and makes the correspondence between these formations and the general hydrogeological features of the study area. The hydrogeology is later described in section 2. Fig. 4 and Fig. 3 show two geological cross-sections in perpendicular directions that allow understanding the relations between the different geological formations.



S: Silurian, Ventana group
DCm: Devonian-Carboniferous marine, part of the Ventana group
CP Carboniferous-Permian, Pillahuincó group
Tc3: Miocene, Chasicó formation
Qp2: Pleistocene
Qel: Loess, Holocene
Qm: Quaternary marine ("Querandinense", 6,000 years)
Qd: Quaternary, deltaic

Source: SEGEMAR (1997)

Fig. 2 – Geology of Bahía Blanca case study area

Table 1 – Hydro-stratigraphy of the Bahía Blanca case study area

Hydrogeological Sections (Dymas, 1974)		Geological formations		Lithology	Age	Hydraulic properties	Known outcrops
Epiparian		Bahia Blanca		Sandy silts	Holocene		MC-LC
		La Viticola		Aeolic sandy silts			MC-LC
		Las Escobas		Beach sands			LC
		Saavedra		Sandy silts			UC
		Agua Blanca / Lujan		Fluvial sands and silts	Upper Pleistocene		UC-MC-LC (valleys)
		Del Aguila		Colluvial sands and silts			UC
		Maldonado		Marine clayey silts		Aquifer - Aquiclude	LC
		Las Malvinas		Gravels and sands	Medium-lower Pleistocene	Aquifer	UC
		Conglomerates		Conglomerate			UC
		La Norma / Pampean sediments		Sandy silts. "Tosca"	Upper Pliocene Upper Miocene	Aquifer - Aquitard	UC – MC - LC
		Chasicó		Sands, silts and clays	Miocene-Pliocene	Aquitard - Aquifer	no
		Red conglomerate		Conglomerate	Upper Miocene		UC
Paranian		Barranca Final		Claystone - Cinerites	Miocene	Aquiclude	no
Hipopa-ranian	Upper	Ombucta		Sands, silts and clays	Eocene-Oligocene	Aquifer - Aquiclude	no
		Pedro Luro		Clayey silts	Paleocene-Upper Cretaceous	Aquiclude	no
	Lower	Colorado		Sandstones, Gravels and conglomerates	Upper Cretaceous	Aquifer	no
		Fortin		Sandstones		Aquifuge	no
Hydrogeologic basement		Ventana group	Providencia Naposta	Quartzites and quartzitic sandstones	Lower Devonian Upper Silurian	Aquifuge. Aquifer due to fracturation	UC
		Curamalal group	Trocadero Mascota				UC-MC
		Crystalline basement		Granitic and metamorphic rocks	Precambrian	Aquifuge	no

MC = medium catchment; UC = upper catchment; LC = lower catchment

Source: Carrica (1998, adapted from Bonorino, 1988)

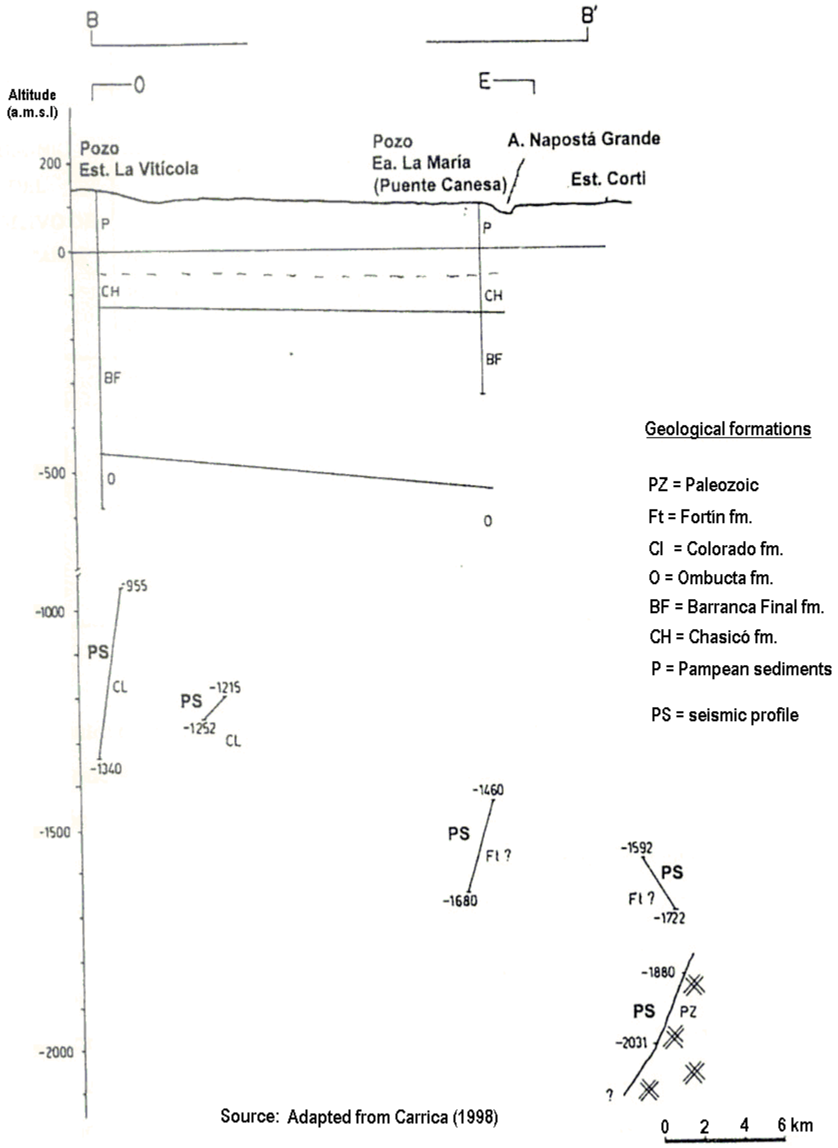


Fig. 3 – Geological cross-section N of Bahía Blanca (approximately W-E)

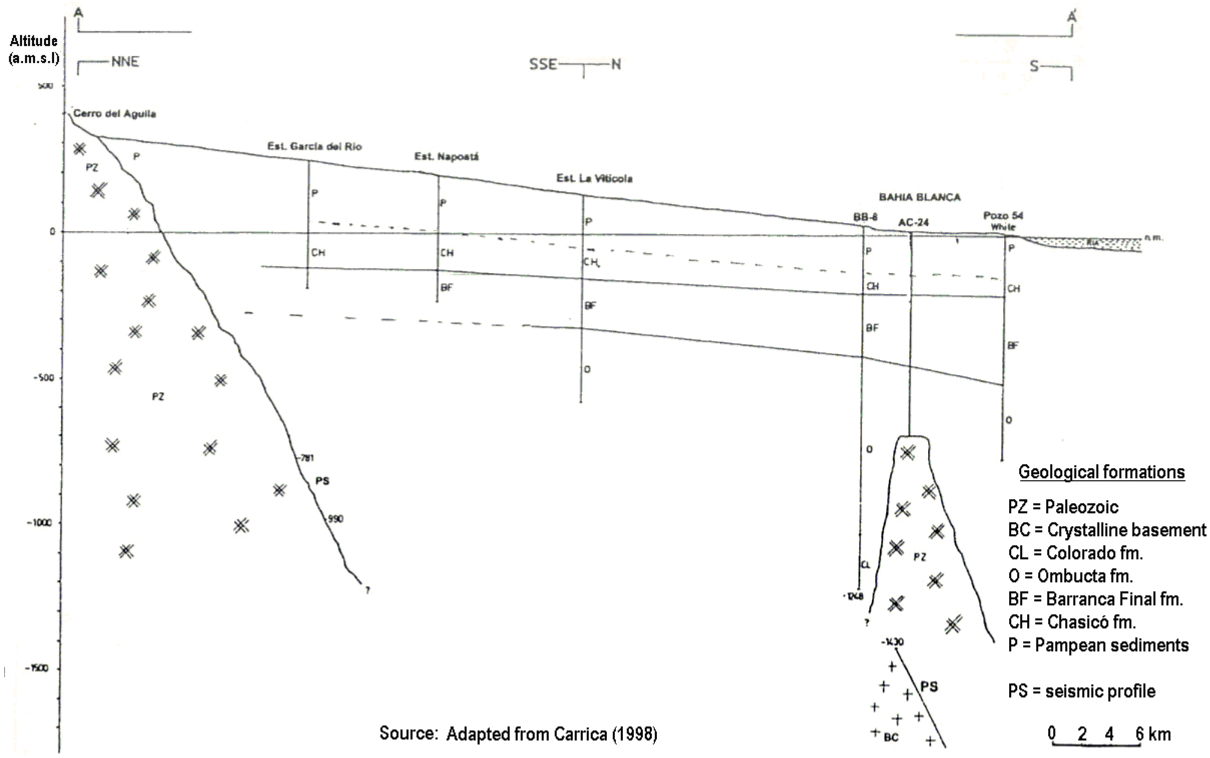


Fig. 4 – Geological cross-section Cerro del Águila-Bahía Blanca (approximately N-S)

1.3 Pedology

The pedologic description is based on the Soil Map of the Buenos Aires Province of the Argentine Republic (INTA-CIRN, 1989).

The map displays the entire inventory of the soils of the Buenos Aires province, delimiting the geomorphologic units and subunits and showing the geographic distribution of the cartographic units and edaphic domains. These edaphic domains are defined as regions where certain subgroups of soils are dominant (generally two and rarely three). The edaphic domains coincide in some cases with the geomorphic subunits and in other cases they represent subdivisions within these subunits. The cartographic units are subdivisions of the edaphic domains and they are integrated by one or more soil groups geographically linked within a certain landscape. They make up associations, consociations, or complexes of subgroups and their phases.

The soil map presents for each edaphic domain a description of the cartographic units, indicating the soils that compose them and the principal land-use limitations (such as poor drainage, susceptibility to eolic and hydric erosion, alkalinity, depth, and rockiness). The map also indicates the morphological characteristics of the taxonomic units with representative profiles of all the subgroups recognized within each domain. The description of the profiles is accompanied by chemical and physical data.

As mentioned above, each cartographic unit can be composed of up to three soils; the order in which these soils appear in the documentation accompanying the soil map indicates their relative areal importance. If only one soil is listed, then it is referred to as a consociation and is understood to make up at least 85 % of the surface area of the cartographic unit. If two soils are named, then the first corresponds to 60 % of the cartographic unit, while the second corresponds to 40 %. In the case of three soils, the first is understood to cover 50 % of the cartographic unit, the second 30 % and the third 20 %.

In general, the dominant soil types in the region are Haplustols, Argiustols and Argiudols. The map of the cartographic units of the soils is presented in Fig. 5. A general description of these soils is found in Table 2.

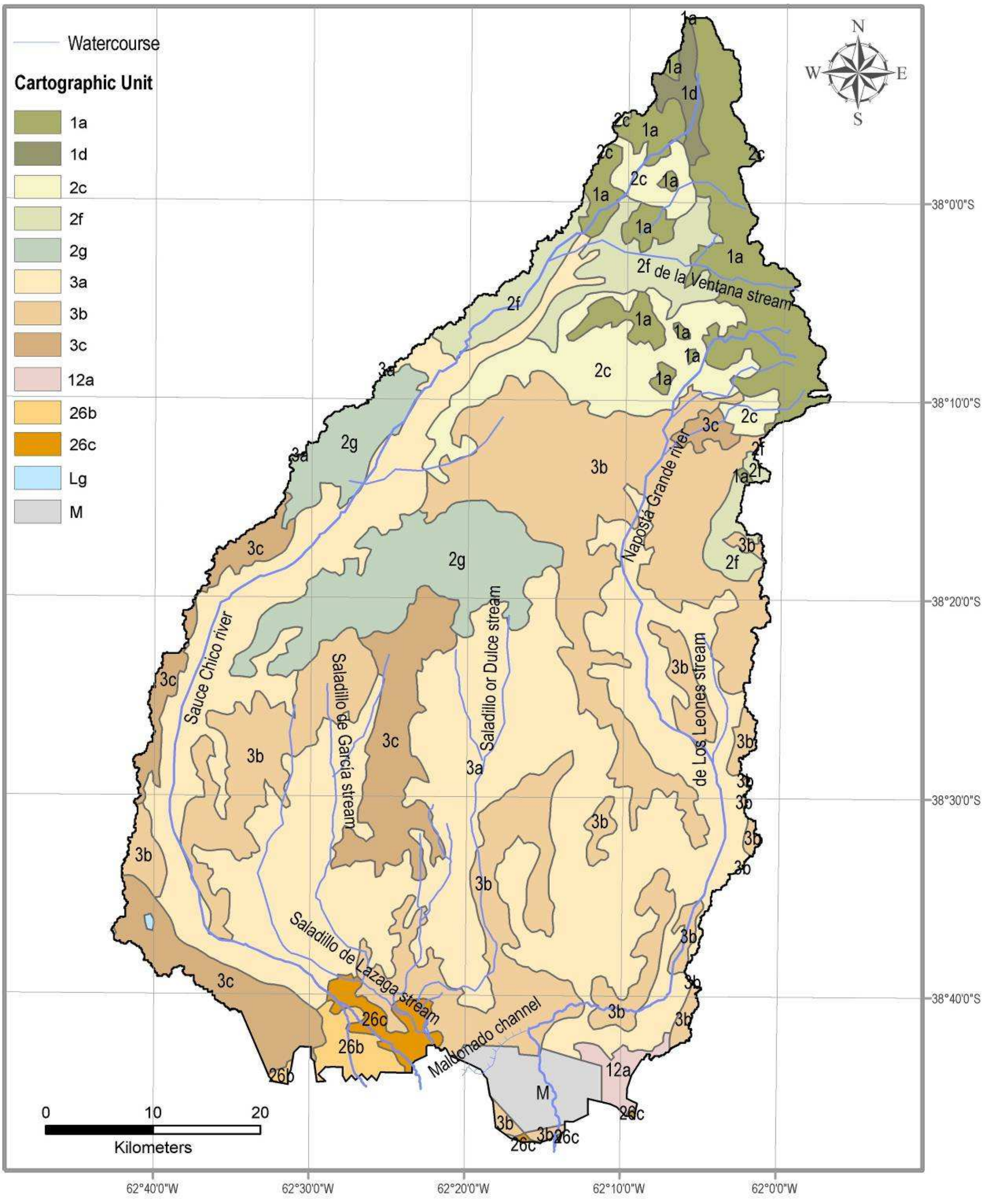


Fig. 5 – Soil map of the Bahía Blanca case study area

Table 2 – Soil Cartographic Units of the Bahía Blanca case study area

EDAPHIC DOMAIN	CARTOGRAPHIC UNIT	TAXONOMIC UNIT	%	ORDER GROUP / SUBGROUP	TEXTURAL FAMILY	PHASE	LAND-USE LIMITATIONS
1	1a	Rock	60				Depth Rockiness
		M_{18}li3	40	Lithic Hapludol	fine loam		
	1d	M_{17}tc3i	50	TypicArgiudol	fine loam	sloping	Susceptibility to hydric erosion
		M_{18}tc4i	50	Typic Hapludol	coarse loam	sloping	
2	2c	M_{17}tc3i	50	Typic Argiudol	fine loam	sloping	Depth Susceptibility to hydric erosion
		M_{17}tcsi	30	Typic Argiudol		thin sloping	
		M_{18}pa	20	Petrocalcic Hapludol			
	2f	M_{17}tc3	50	Typic Argiudol	fine loam		Depth Pedregosity
		M_{17}tc	30	Typic Argiudol			
		M_{18}pa	20	Petrocalcic Hapludol			
	2g	M_{17}tc3	50	Typic Argiudol	fine loam		Depth
		M_{17}tcs	30	Typic Argiudol		thin	
		M_{17}tcs'	20	Typic Argiudol		very thin	
	2p	M_{17}tc3s'	60	Typic Argiudol	fine loam	very thin	Depth Hydric erosion
		E_{25}tc	40	Typic Udipsament			
3	3a	M_{24}tc2	50	Typic Haplustol	fine		Depth Hydric erosion
		M_{24}eni	30	Entic Haplustol		sloping	
		M_{24}li	20	Lithic Haplustol			
	3b	M_{24}tc2s'	50	Typic Haplustol	fine	very thin	Depth
		M_{21}tcs'	30	Typic Argiustol		very thin	
		M_{24}tc	20	Typic Haplustol			
	3c	M_{21}tc3s	60	Typic Argiustol	fine loam	thin	Depth
		M_{24}li	40	Lithic Haplustol			
4	4a	M_{24}en4	50	Entic Haplustol	coarse loam		Susceptibility to hydric erosion Depth
		M_{24}ens	30	Entic Haplustol		thin	
		E_{23}us	20	Ustic Torripsament			
	4b	M_{24}en4	50	Entic Haplustol	coarse loam		Depth Low moisture retention capability Susceptibility to hydric erosion
		E_{26}tcs	30	Typic Ustipsament		thin	
		E_{26}tc	20	Typic Ustipsament			
	4c	E_{26}tc	50	Typic Ustipsament			Low moisture retention capability Susceptibility to hydric erosion
		E_{23}us	30	Ustic Torripsament			
		E_{22}tc	20	Typic Cuarzipsament			
12	12a	M_{21}tc2	50	Typic Argiustol	fine		Depth Poor drainage
		M_{21}tcs	30	Typic Argiustol		thin	
		F_{28}tc	20	Typic Natrustalf			
26	26a	E_{13}ac3	>85%	Aquic Ustifluvent	fine loam		Poor drainage - Salinity
	26b	E_{13}ac3	60	Aquic Ustifluvent	fine loam		Salinity - Sodic alk. at deep > 50 cm - Poor drainage
		F_{28}tc	40	Typic Natrustalf			
	26c	A_{11}ah4	60	Aquolic Salortid	coarse loam		Sodic alk. at deep < 50 cm Poor drainage
		M_{25}tc	40	Typic Natrustol			
27	27a	E_{25}tc	50	Typic Udipsament			Low moisture retention capability Aeolian erosion
		E_{22}tc	30	Typic Cuarzipsament			
		M_{18}en	20	Entic Hapludol			
	27c	M_{24}en4	60	Entic Haplustol	coarse loam		Low moisture retention capability Aeolian erosion
		E_{26}tc	40	Typic Ustipsament			
M	Miscelaneous						

1.4 Land use

Land use was taken using the Landsat satellite image from April, 18, 2004. The image processing and results obtained are presented in Deliverable 2.12 (Leitão *et al.*, 2006). This image covers 3,380 km^2, which represents 86 % of the study area. The western and the northern parts are not characterised. The classification of the satellite image, validated with the training sites, is represented in Table 3. The land use is represented in Fig. 6.

In addition, land use conditions also play a significant role in aquifer vulnerability; in agricultural landscapes, ploughing and fertilizer application impact on the soil porosity, texture and organic matter content. In the Bahía Blanca region, the land is used for livestock production and agriculture. Grains – namely wheat, corn, oats, sorghum and barley – are the dominant agricultural crops.

Table 3 – Classification of land use in Bahía Blanca case study area

Class	Area (km^2)
crops - small (fallow land, wheat)	1,203
Pastures (for cattle)	1,034
Bare soil (sowed land and/or urban area)	880
Tidal flats	118
Crops (sunflowers, soy)	94
Saltmarshes (spartina alt-dens, sarcocornia per)	24
Crops (sorghum, maize)	18
Water	7
Transitional vegetation (shrubs)	2
Sand plains, sand banks, beaches	0.16
water (water + sediments)	0.04

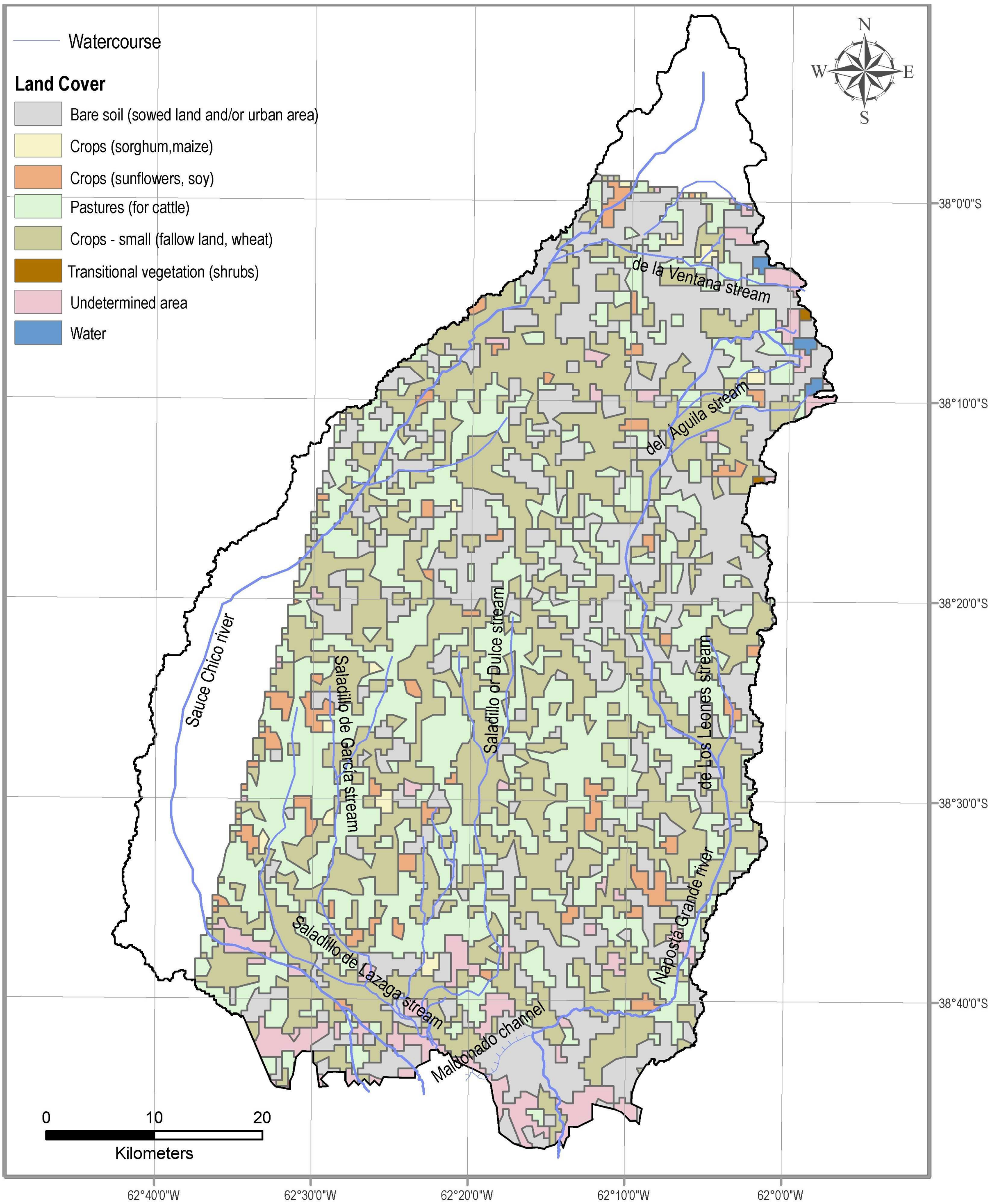


Fig. 6 – The Land use in Bahía Blanca case study area [Source: Deliverable 2.12 (Leitão *et al.*, 2006)]

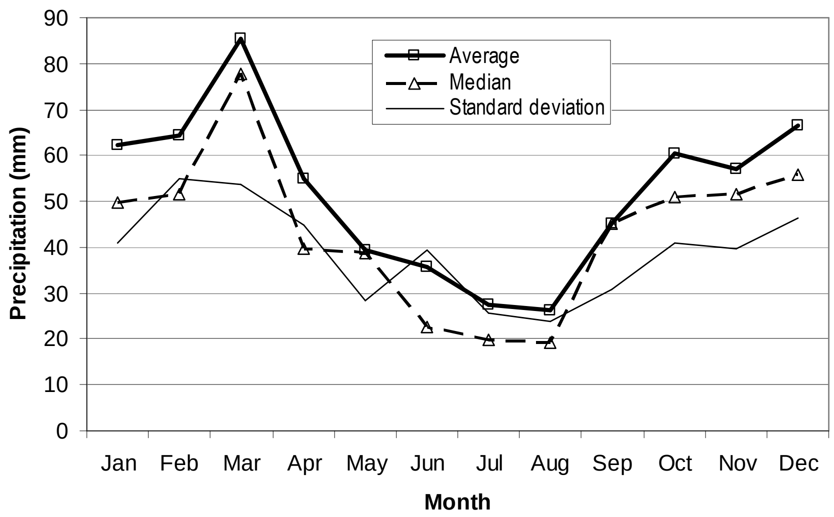
1.5 Climate

The climate characterisation presented in this section is based on CADAUNS (2006a). Climate is temperate, with annual average temperatures between 14 ºC and 20 ºC, and thermal stations well differentiated. Rains provide a sub-humid or transition character. Winds are predominant from NW, with annual average speed of 24 $km.h^{-1}$.

The average annual precipitation recorded in Bahía Blanca for the period 1951-2000 is 625 $mm.year^{-1}$. For the same period, Fig. 7 shows the average, the median and the standard deviation of the monthly precipitations.

According to the Thornthwaite climate classification system, weather in Bahía Blanca is described in the group dry subhumid, with null or low water surplus. According to the Köpen climate classification weather belongs to the BS climatic type, semi-arid.

The Thornthwaite-Mather water climatic balance, using the averages of the 40 year-series from 1959 to 1998 of monthly reference evapotranspiration and monthly precipitation, and considering the maximum amount of water available for evapotranspiration of 100 mm, showed that there is water surplus from March to September, and a water deficit from October to February CADAUNS (2006b).



Data source: CADAUNS (2006a)

Fig. 7 – Average, median and standard deviation of the monthly precipitations

2 Hydrogeology

2.1 Introduction

The conceptual hydrogeological model hereinafter synthesized is based on the lithoestratigraphic scheme proposed by Dymas (1974), modified by Bonorino (1988). It also reproduces the description of Leitão *et al*. (2007). The presentation is a simplified version of this complex system, aiming to understand the basic structure in which the groundwater study carried out in this project occurs. This hydrogeology section is based in the geological description provided in section 1.2. Geological cross-sections and a hydro-stratigraphy table may be found there.

2.2 Crystalline bedrock

The hydrogeological basement in the area is composed by the crystalline bedrock and by the Palaeozoic sediments that form the nucleus of the Sierras Australes of the Buenos Aires province (S, DCm, CP). The outcrops of these formations appear only in the high and median basin and are represented only by the Palaeozoic quartzite and quartzitic sandstones. Their deepness and thickness strongly varies from place to place, and they extend all over the study area. Around Bahia Blanca they were detected at 722 m depth and 6 km to the north they were found at 1,700 m depth.

This formation is generally classified as an aquifuge. It is considered that these rocks have no primary porosity and therefore no storage or transmissivity of water. Nevertheless, in some areas the folds and fracturation systems can produce a significant secondary porosity that plays an important role in water circulation creating springs, locally denominated "ojos de agua", and feeding the rivers up gradient all year long.

2.3 Hipoparanian Sector

This section includes the geologic formation from upper Cretaceous to Oligocene. Its presence can be registered only in depth in the lower and medium meridian parts the watersheds (Fig. 4). It comprises different sets of formations, of marine and continental origin, that can act as confined aquifer, aquitard and aquifuge.

The deep hydrothermal system of Bahía Blanca corresponds to the upper part of this hydrogeological sector, inserted in the formations known as Colorado and Ombucta. This important aquifer, due to its complexity and magnitude, has been studied by several authors, among which are the works of Wichmann (1918), García and García (1964) and Bonorino (1988).

The recharge area of this system was identified to be located in the piedmont of the SW hill side of Sierras Australes. Nevertheless, a hydraulic connection between the phreatic aquifer and the deep regional flux is also supposed to exist, being responsible for the entrance of the surplus of water generated in the upper part of the basin to supply the regional deeper flow.

2.4 Paranian Sector

It is represented by a sedimentary miocenic formation of marine origin that results from a transgression period, known as Barranca Final Formation. It overlaps the previous sector in disconformity. This sector is classified as an aquiclude with some intercalations of aquifer formations with high content of salt. Close to Bahía Blanca this formation appears between 250 and 350 m below the surface.

2.5 Epiparanian Sector – phreatic aquifer

At the present state of knowledge this sector is, from a hydrogeologic point of view, the most interesting system in terms of continuity in water transmission, constituting the phreatic aquifer of this region (Carrica *et al*., 2003). It is composed of one or two main formations that outcrop in the area, depending on the region, and is composed by a set of sediments that extend from the Mio-Pliocene to the present days.

The main hydrogeological formation is "La Norma", known as "Sedimentos Pampeanos" (Fidalgo *et al.*, 1975), which belongs to the Upper Miocene-Lower Pleistocene (De Francesco, 1992). It forms the lower limit of the system in the study area and outcrops in several parts of the basin. Its lithology is mainly silty with fine sand and clays and includes calcium carbonate cement as well as calcareous levels. The mineralogical composition of these sediments is quartz and alkaline feldspaths and volcanic glass, being the smaller fraction composed by calcite, illite, and montmorillonite (Bonorino *et al*., 2001). This is a multi-layer system with aquifer-aquitard levels that is regionally considered with a homogeneous transmissivity.

In some parts of the coastal area, from 5 m above the sea level until the bottom of the Bahía Blanca estuary, the pampean sediments are covered by sandy, silty and clay (bottom to top) formations of marine environment, denominated "Maldonado Formation" (Fidalgo, 1983), an Upper Pleistocene formation also known as post-pampean. Its thickness can reach 15-20 m close to the main channels and decreases towards the continent until it disappears some 4 to 5 km from the coast. This formation has very low hydraulic gradient and a hydrodynamic where vertical movements dominate.

Accordingly to the information available, the maximum thickness of the overall aquifer formation is less than 200 m, decreasing towards the hill side of Sierras Australes (Bonorino *et al.*, 2001). Regionally the base of this aquifer is difficult to define as well as the continuity of different sedimentary layers that might occur. This aquifer is considered in close hydraulic connection with the surface water of the valley above due to the rapid changes in the piezometric levels after rain events as well as to the low salinity of its waters.

The piezometry maps presented in Carrica (1998) for the Napostá Grande watershed correspond to data obtained in 1980-1990. Close to the hills the predominant flow direction is NE-SW, almost perpendicular to Sierra de la Ventana ridge, an important area of groundwater recharge. Here the surface water acts as influent towards the phreatic aquifer. In the medium part of the watersheds the groundwater flow is mainly N-S. In the plain area, the situation is reversed and the groundwater feeds the rivers in most parts of its extension. The groundwater flow in the low part of the watershed is divided in 3 sectors (Bonorino, 1988) with different directions due to fault systems and several other vicissitudes, like the various subterraneous works at Bahía Blanca city. The morphology of the phreatic surface is radial and divergent with the concavity towards the upper part of the terrain. The hydraulic gradients are very different from the upper and lower watershed: the higher values are closer to the hills around 13 per thousand, lowering to the medium area of the watershed to values of the order of 2 to 6 per thousand, and in the south values in some parts to less than 1 per thousand.

Also in the upper watershed of Sauce Chico hydraulic gradients of 13 per thousand were calculated (Albouy, 1994). Unpublished data collected by Albouy indicate that hydraulic gradients in the middle watershed are around 4 per thousand and for the lower basin they are of the order of 4 per thousand or lesser.

The lithologic and geometric changes of the aquifer and the insufficient and disperse information does not allow to confer representative values of the hydraulic characteristics. Here are presented some of the existing values for the cases where information was collected. The permeability of this system is attributed to a secondary porosity from macropores and microfissures.

Torrente *et al.* (1989) have determined permeability values of 0.08 and 2 $m.d^{-1}$ and an effective porosity of 12.5 %, based on laboratory results of granulometric and volumetric analysis in samples with loess with predominant lime content (60 – 70 %) from the adjacent region of the hills. Bonorino *et al.* (2000) based on 6 pumping tests carried out in Cabildo sector have determined transmissivity values between 50 and 200 $m^2.d^{-1}$, K between 0.5 and 2 $m.d^{-1}$, and average specific yield of 0.1 with delayed yield (Albouy *et al.*, 2005). It is possible that the permeability in the hilly environments is larger due to the higher sand content of the loess (Rossi, 1996). In the coastal zone pumping tests carried out in the Maldonado formation have given transmissivities between 51 and 62 $m^2.d^{-1}$ (Bonorino and Sala, 1983). Carrica (1998) has determined, for a sector of Napostá Grande river between Cerro del Águila and García del Río, values of transmissivity of 93 $m^2.d^{-1}$ and hydraulic conductivity of about 1.2 $m.d^{-1}$, considering a local aquifer thickness of 75 m. Albouy (1994) indicates for the top 50 m of aquifer in the Sauce Chico upper basin permeability values between 1 and 3 $m.d^{-1}$.

Using a methodology that considers the isopiezometry lines, Carrica (1988) found transmissivities for the Pampean sediments that discharge into the Napostá Grande river between 100 $m^2.d^{-1}$ and 330 $m^2.d^{-1}$, and hydraulic conductivities between 0.3 $m.d^{-1}$ and 5 $m.d^{-1}$.

The base of the Epiparanian sector, in the low and medium watershed, is composed by sand and clay that becomes more sandy southwards. This level is an aquifer resurgent or semi-resurgent with water of stable quality (2 a 5 $g.L^{-1}$ of total dissolved solids) also with recharge in the piedmont of the SW hill side of Sierras Australes. Some wells have natural thermal springs with 30 $m^3.h^{-1}$ (water between 25 and 34°C). Transmissivity values are about 50 $m^2.d^{-1}$, with permeability of about 2.5 $m.d^{-1}$.

2.6 Hydraulic functioning of the aquifer systems

The two main watersheds, Sauce Chico and Napostá Grande, may be divided in three sectors, upper, middle and lower watersheds. The upper watersheds are related to expressions of the Ventana mountain ridge, and their altitudes range from approximately 215 m up to 1,243 m (in Tres Picos hill). They comprise the mountain and hilly areas where the crystalline bedrock outcrops, and the piedmont deposits and the upper altitudes of the sedimentary plains, that occur adjacent to the piedmont and in between the more elevated areas.

In the upper watershed areas, infiltration in the crystalline bedrock is very low. In the piedmont areas, the water courses loose their definition due to the infiltration of water in the modern colluviums and alluviums. The low density of the drainage network in the sedimentary plains shows that these areas present good conditions to infiltrate water. The sedimentary plains are partially drained by the water courses, but a considerable amount of water flows out of the upper watershed by groundwater flow. It is assumed that there is also some bank storage in the alluvial aquifer from water that may infiltrate into the alluviums during the surface water storms.

The middle watersheds develop down gradient the upper watersheds and present minimum altitudes of approximately 80 m. They are formed mainly by the sedimentary plains that behave as an infiltration area. The water courses transmit the water generated in the upper watersheds plus the groundwater that discharges into it. In the rainy periods some flooded areas of small dimension may be formed, that are hydraulically separated from the aquifer system, due to the silty clay nature of their bottom. The presence of these flooded areas indicates that the superficial loessic sediments as well as calcrete levels have low permeability, which difficult the infiltration and percolation of water into the aquifer system.

The lower watersheds develop from the limits of the middle watersheds until the Bahía Blanca estuary. In this part the water courses act mainly as a conductor of externally generated streamflow as it does not receive additional water from inside the watershed. Most of the time, evaporation and evapotranspiration are the only hydrological processes that consume almost all the precipitation water. Discharge is expected to be small and the groundwater medium discharges mainly to the estuary.

3 Groundwater vulnerability to pollution

According to Lobo Ferreira and Cabral (1991) it is believed that the most useful definition of vulnerability is one that refers to the intrinsic characteristics of the aquifer, which are relatively static and mostly beyond human control. It is proposed therefore that the groundwater vulnerability to pollution be defined, in agreement with the conclusions and recommendations of the international conference on "Vulnerability of Soil and Groundwater to Pollutants", held in 1987 in The Netherlands, as (Duijvenbooden et al., 1987):

"**the sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer**".

The aquifer vulnerability may be characterised as a function of the physical system properties in terms of more or less favourable conditions in the system for a pollutant load to contaminate the aquifer. This approach may be considered a parametric one, in which different variables are characterised and put together to produce an index, as is the case of the DRASTIC index for a pollutant load occurring in the ground surface (cf. Aller et al., 1987)

In Deliverable 2.6 prepared for Santos estuary coastal zone (Oliveira et al., 2005) the DRASTIC vulnerability index has been described and applied to that area. For the Bahía Blanca case study area this index has not been applied in the framework of the EcoManage Project, despite some work has been carried out to compute this index. In Annex 1 it is presented the characterisation of the soil parameter based on the information available from the Soil Map of the Buenos Aires Province.

The Bahía Blanca estuary case study area has already been subject to some vulnerability assessments, namely by Lexow et al. (1994), that estimated the vulnerability to the pollution of the phreatic aquifer of the upper Napostá Grande watershed, using DRASTIC and GOD methods, and by Albouy and Bonorino (1998) that studied the upper Sauce Chico watershed using DRASTIC methodology.

From these assessments, the upper Napostá Grande watershed presented DRASTIC index values between less than 75 and more than 155 (for a possible scale from 23 to 226), which represent low to moderate vulnerability values. The GOD method gave results between 0.18 and 0.45 (for a possible range between 0.00 and 1.00) which also represents low to moderate vulnerability index. The same kind of values were obtained for the upper Sauce Chico watershed that presented DRASTIC indexes between 79 and 131, which represent low to moderate vulnerability values.

4 Methods for groundwater recharge assessment

4.1 Introduction

The choice of a model or method to compute recharge derives from the conceptualization of the recharge process of a study area. This conceptualization is based on the physical system, its geometry, all the inputs and outputs of water and its locations. The computation of recharge is based on mass balances between water coming in, going out or being stored in the water system. These mass balances are generally water-mass balances but can also be any substance-mass balance diluted in water. Models to compute recharge may be grouped into mass balances above saturated zone and mass balances in the saturated zone. Only the water mass balances are considered.

The **water mass balances above the saturated zone** are predictive models as they quantify recharge by computing the processes prior to recharge occurrence (precipitation, infiltration, water stored in the surface and in the vadose zone). The **soil daily sequential water balance** is an appropriate method to estimate deep percolation and hence recharge. This method requires knowledge of the climatic data to characterize precipitation and reference ET, and knowledge of medium characteristic parameters, that depend on the complexity of the selected model. These models allow for estimation of distributed recharge in a region, produce results by recharge episode and may be applied to any geological medium (intergranular, fissured, karstic or more than one type). However, the more general application is for intergranular, as the soil storage is more easily quantified, and preferential pathways are less important.

The **water mass balances in the saturated zone** are response models as they represent the reaction of the groundwater medium to the recharge process. Several methods are available depending on the hydrogeological setting, for instance: (1) surface flow hydrograph separation, (2) spring discharge quantification, (3) flow quantification in aquifer sections, (4) saturated zone storage change (water level change), (5) combination of these methods, also including human water abstractions. These methods are integrative for a region and may compute recharge by episode.

In the **surface flow hydrograph separation method** base flow and direct runoff are separated. Base flow is an estimate of recharge that occurs in the area defined by a watershed when all groundwater flow inside the watershed discharges to the surface water streams inside that watershed (*i.e.* there is a coincidence between the watershed and the hydrogeological basin). The hydrogeological settings more favourable to observe this requisite are local systems of metamorphic and igneous rocks, with intergranular or fissured porosity. In some cases of sedimentary rocks with intergranular porosity, even if stratified, this requisite may still be found. The surface flow hydrograph separation method is probably the easiest recharge calculation method to use, as it does not require medium characteristic parameters, and only requires knowledge of daily precipitation and flow series.

The **spring discharge method** provides a direct measurement of the amount of water that recharged the system. It requires the knowledge of the area drained by the spring, which is not an easy value to obtain. Due to the structure of the groundwater flow paths and its significant water volumes this method is mainly applicable for karstic hydrogeological settings. For the other hydrogeological media, despite the possible occurrence of large flow springs, it is likely that it exists diffuse discharge in important amounts which difficult the quantification of discharge.

The **flow quantification in aquifer sections** is applicable to any hydrogeological medium requiring the knowledge of the recharge area upgradient the measuring section, the constant monitoring of the piezometric level in both sides of the section and the aquifer transmissivity along the measuring section. These requirements turn the application of the method more difficult.

The **water level change** is a direct consequence of recharge. Time step for the application of this method is very short. For the application of this method it is required that in a study volume, the difference between groundwater flow entering and leaving the system is negligible in relation to the water level rise. This method also requires the characterization of effective porosity in the depth of water level oscillation.

Among the referred to methods, two of them are applied to the Bahía Blanca case study area: the **soil daily sequential water balance** and the **surface flow hydrograph separation method**. These are described in more detail in the next sections.

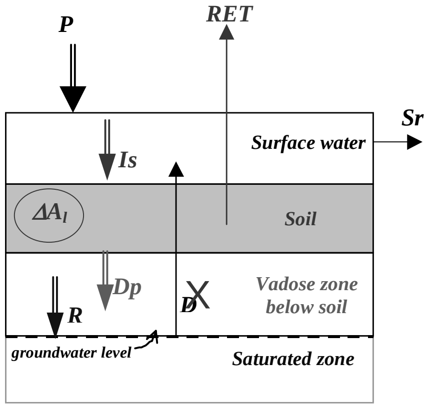
4.2 Soil daily sequential water balance

4.2.1 Introduction

For the conceptual case of an area where there is no artificial recharge, no surface flow entering the area, and the groundwater level is always below the soil zone, the water balance equation for the soil of that area can be expressed by (Fig. 8):

$$P - RET - \Delta A_l - Sr - Dp = \varepsilon \qquad \textbf{Eq. 1}$$

where P is the precipitation, RET is the effective evapotranspiration, ΔA_l is the variation (*final - initial*) of the water stored in the soil, Sr is surface runoff, Dp is deep percolation and ε is the calculation error of the balance.



P = precipitation
Sr = surface runoff
Is = surface infiltration
ΔA_l = difference of water stored in the soil in the end of the day and in the beginning of that day
RET = effective evapotranspiration
Dp = deep percolation
R = recharge
D = groundwater discharge

Fig. 8 – Soil water balance of an area with no discharge of groundwater and no surface flow entering in the system.

The sequential mass balance approach intends to measure or estimate and compute P, RET, Sr and ΔAl parameters, computing Dp by solving Eq. 1 considering $\varepsilon = 0$. The sequential water balance is carried out in a determined time step, for instance the daily time step.

Recharge (R) is then assumed to be equal to Dp:

$$R = Dp = P - RET - \Delta A_l - Sr \qquad \textbf{Eq. 2}$$

The soil daily sequential water balance method is a good method to forecast differences on total recharge in response to changing daily precipitation pattern. Moreover as a general characteristic of the method it allows for the determination of seasonal recharge. However it must be taken into account that the presented method provides a value of the water available for deep percolation, and that this deep percolation will take some time to reach the aquifer.

4.2.2 The BALSEQ numerical model

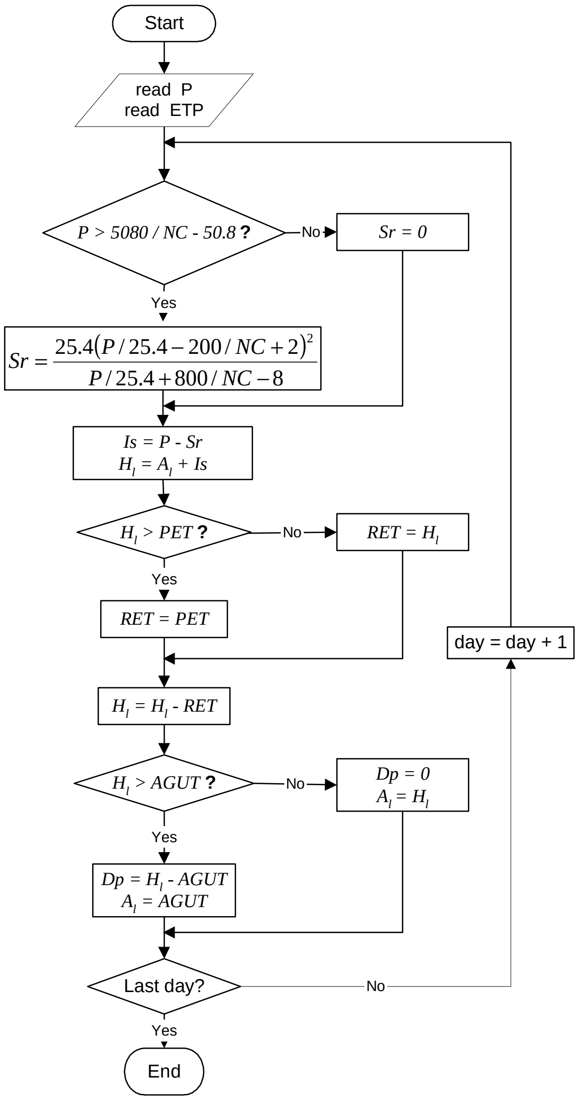
A soil daily sequential water balance methodology was implemented in BALSEQ numerical model (Lobo Ferreira, 1981; Lobo Ferreira & Delgado Rodrigues, 1988). Fig. 9 shows the flowchart of the BALSEQ model. In this model the runoff curve number (NC) that depends on soil permeability and on land use, is used in the process of estimating surface runoff. NC values vary between 0 (corresponds to the area with very high permeability, where all water infiltrates into the soil), and 100 (corresponds to a completely impermeable zone).

The effective evapotranspiration is calculated using the potential evapotranspiration (the evapotranspiration that would occur if the water available in the soil was not a limiting factor) and the amount of water available in the soil. This water available in the soil is calculated by a sequential water balance that daily updates the water stored in the soil.

The computation of deep percolation depends on the maximum amount of water available in the soil for evapotranspiration ($AGUT$):

$$AGUT = (\,sr - wp\,)\,.\,rd \qquad \textbf{Eq. 3}$$

in which sr is the specific retention (or field capacity), wp is the wilting point and rd is the depth of the plant roots. If after the process of evapotranspiration the water stored in the soil is above the $AGUT$ value, the water in excess to $AGUT$ becomes deep percolation.



P = precipitation
PET = potential evapotranspiration
NC = runoff curve number
Sr = surface runoff
Is = surface infiltration
Al = water stored in the soil in the end of the day
Hl = water stored in the soil along the day
RET = evapotranspiration
$AGUT$ = maximum amount of water available for evapotranspiration
Dp = deep percolation

Fig. 9 – Chart flow of BALSEQ model for daily sequential water balance in the soil

4.2.3 The BALSEQ_MOD numerical model

BALSEQ numerical model has been subject to changes and new methods have been implemented to calculate surface infiltration, effective evapotranspiration and deep percolation. These methods, developed in Oliveira (2004) have all been included in the BALSEQ_MOD numerical model and are presented in the next sections.

4.2.4 Computation of surface infiltration

This procedure was developed and presented in Oliveira (2004, 2007), using the results of the application of the Philip surface infiltration model, to a set of situations that could be representative of the different infiltration conditions (namely soil texture, daily precipitation, precipitation distribution and initial soil moisture).

The procedure computes surface infiltration (Is) using the following formula:

$$Is = \begin{cases} P & \text{if } P \leq P_{lim} \\ a.P + b & \text{if } P > P_{lim} \end{cases} \qquad \textbf{Eq. 4}$$

where P is precipitation; $Plim$ is precipitation limit or threshold computed by the intersection of two straight lines of equations $Is = P$ and $Is = a.P + b$, that is $P_{lim} = b / (1-a)$; a and b are the parameters of the straight line and are presented on Table 4 as a function of the textural soil class (check Fig. 10 for the definition of the textural class) and of the initial soil moisture (θ_i). If θ_i is not the one presented on Table 4 then the parameters of the straight line are calculated assuming a linear variation between a and b parameters of the nearest (above and below) straight line parameters:

$$\begin{cases} a = a_1 + \dfrac{(a_2 - a_1)}{(\theta_{i2} - \theta_{i1})}.(\theta_i - \theta_{i1}) \\ b = b_1 + \dfrac{(b_2 - b_1)}{(\theta_{i2} - \theta_{i1})}.(\theta_i - \theta_{i1}) \end{cases} \qquad \textbf{Eq. 5}$$

where θ_{i1} is the known initial soil moisture below θ_i, a_1 and b_1 are the corresponding known straight line parameters, and θ_{i2} is the known initial soil moisture above θ_i, and a_2 and b_2 are the corresponding known straight line parameters.

As an example, surface infiltration on a silty clay soil (assuming sr = 0.387 and n = 0.479), with θ_i = 0.35sr + 0.65n = 44.7 % is given by:

$$Is = \begin{cases} P & \text{if } P \leq 1.00 \\ 0.203\, P + 0.797 & \text{if } P > 1.00 \end{cases} \qquad \textbf{Eq. 6}$$

This equation was calculated using the straight line equations (Table 4) for $\theta_{i2} = 0.25sr+0.75n$ = 45.6% ($Is = 0.182P + 0.775$; $a_2 = 0.182$ and $b_2 = 0.775$) and for $\theta_{i1} = 0.5sr+0.5n$ = 43.3% ($Is = 0.236P + 0.832$; $a_1 = 0.236$ and $b_1 = 0.832$) and Eq. 5 and Eq. 4 with $P_{lim} = b / (1 - a)$.

Table 4 – Relation between Is and P for the cases in which $P > P_{lim}$, as a function of soil texture and initial soil moisture

Texture	P_{lim} (cm/d) [$=b/(1-a)$]	b in $Is = aP+b$	a in $Is = aP+b$	θ_i	P_{lim} (cm/d) [$=b/(1-a)$]	b in $Is = a P + b$	a in $Is = a P + b$	Texture
Loamy sand wp = 5.5% sr = 12.5% n =43.7%	5.72	0.924	0.838	$\theta_i = wp$	1.54	1.000	0.351	Sandy clay loam wp = 14.8% sr = 25.5% n = 39.8%
	5.64	0.967	0.828	$\theta_i = 0.5wp+0.5sr$	1.46	0.977	0.332	
	5.55	1.005	0.819	$\theta_i = sr$	1.36	0.938	0.312	
	4.75	0.918	0.807	$\theta_i = 0.5sr+0.5n$	1.17	0.835	0.284	
	4.40	0.987	0.776	$\theta_i = 0.25sr+0.75n$	1.00	0.734	0.269	
	4.03	0.999	0.752	$\theta_i = 0.1sr+0.9n$	0.85	0.630	0.257	
	3.34	1.064	0.682	$\theta_i = n$	0.50	0.376	0.250	
Sandy clay wp = 23.9% sr = 33.9% n = 43.0%	1.08	0.803	0.255	$\theta_i = wp$	2.17	1.460	0.327	Silty clay loam wp = 20.8% sr = 36.6% n = 47.1%
	1.01	0.770	0.235	$\theta_i = 0.5wp+0.5sr$	1.59	1.018	0.359	
	0.92	0.729	0.208	$\theta_i = sr$	1.37	0.942	0.310	
	0.81	0.677	0.169	$\theta_i = 0.5sr+0.5n$	1.12	0.809	0.275	
	0.74	0.637	0.139	$\theta_i = 0.25sr+0.75n$	0.94	0.713	0.241	
	0.67	0.598	0.109	$\theta_i = 0.1sr+0.9n$	0.78	0.629	0.199	
	0.52	0.489	0.059	$\theta_i = n$	0.54	0.491	0.093	
Silty clay wp = 25.0% sr = 38.7% n = 47.9%	1.64	1.028	0.375	$\theta_i = wp$	1.63	1.022	0.374	Clay loam wp = 19.7% sr = 31.8% n = 46.4%
	1.50	0.995	0.336	$\theta_i = 0.5wp+0.5sr$	1.54	1.004	0.347	
	1.28	0.907	0.292	$\theta_i = sr$	1.41	0.959	0.319	
	1.09	0.832	0.236	$\theta_i = 0.5sr+0.5n$	1.16	0.835	0.283	
	0.95	0.775	0.182	$\theta_i = 0.25sr+0.75n$	0.96	0.706	0.264	
	0.81	0.708	0.126	$\theta_i = 0.1sr+0.9n$	0.74	0.556	0.251	
	0.47	0.459	0.029	$\theta_i = n$	0.44	0.357	0.191	
Clay wp = 27.2% sr = 39.6% n = 47.5%	1.44	0.973	0.323	$\theta_i = wp$	3.85	1.007	0.738	Silt loam wp = 13.3% sr = 33.0% n = 50.1%
	1.31	0.928	0.289	$\theta_i = 0.5wp+0.5sr$	3.67	1.191	0.676	
	1.15	0.883	0.231	$\theta_i = sr$	2.90	0.998	0.655	
	1.00	0.834	0.166	$\theta_i = 0.5sr+0.5n$	2.67	1.254	0.531	
	0.87	0.772	0.115	$\theta_i = 0.25sr+0.75n$	2.45	1.377	0.437	
	0.73	0.682	0.070	$\theta_i = 0.1sr+0.9n$	1.73	0.985	0.432	
	0.38	0.373	0.007	$\theta_i = n$	1.24	0.867	0.301	
Loam wp = 11.7% sr = 27.0% n = 46.3%	2.65	1.362	0.487	$\theta_i = wp$	2.17	1.461	0.327	Silt wp = 7.2% sr = 29.7 % n = 44.3%
	2.54	1.420	0.442	$\theta_i = 0.5wp+0.5sr$	1.59	1.017	0.358	
	2.40	1.465	0.390	$\theta_i = sr$	1.36	0.939	0.309	
	1.67	1.010	0.394	$\theta_i = 0.5sr+0.5n$	1.11	0.810	0.271	
	1.48	0.978	0.340	$\theta_i = 0.25sr+0.75n$	0.94	0.721	0.234	
	1.27	0.894	0.298	$\theta_i = 0.1sr+0.9n$	0.79	0.644	0.189	
	0.76	0.568	0.255	$\theta_i = n$	0.53	0.491	0.081	
Sandy loam wp = 9.5% sr = 20.7% n = 45.3%	3.79	0.999	0.737	$\theta_i = wp$	For sand soil $Is = P$ (hence a = 1, b = 0)			Sand wp = 3.3% sr = 9.1% n =43.7%
	3.72	1.077	0.710	$\theta_i = 0.5wp+0.5sr$				
	3.63	1.158	0.681	$\theta_i = sr$				
	3.32	1.312	0.604	$\theta_i = 0.5sr+0.5n$				
	2.67	1.068	0.600	$\theta_i = 0.25sr+0.75n$				
	2.49	1.155	0.537	$\theta_i = 0.1sr+0.9n$				
	2.14	1.268	0.407	$\theta_i = n$				

Is = surface infiltration; P = precipitation; $Plim$ = precipitation threshold; sr = specific retention (or field capacity); n = porosity; wp = wilting point; θ_i = initial soil moisture. The wp, sr and n values are average values taken or calculated (in the case of the silt texture) from Rawls and Brakensiek (1989).

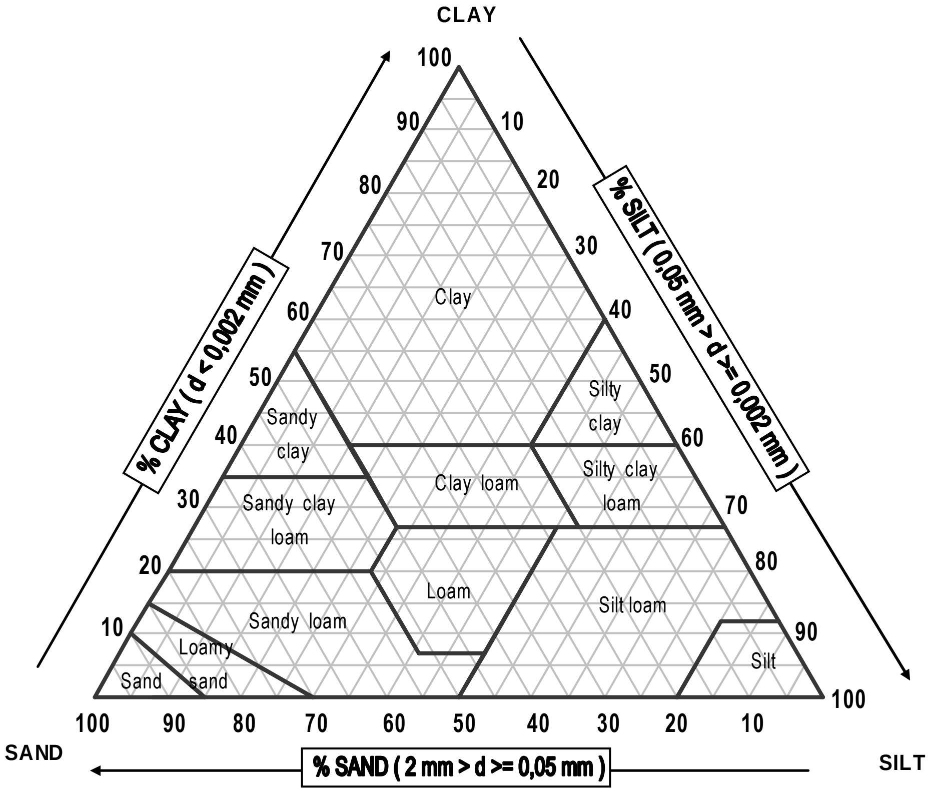


Fig. 10 – Soil textural triangle adopted by the United States Department of Agriculture

In the BALSEQ_MOD numerical model, surface infiltration can be calculated either by the methodology already implemented in the BALSEQ numerical model (Lobo Ferreira, 1981) by using the runoff curve number (see section 4.2.1), or it can be computed, assuming that there is no surface medium water storage (and hence no evaporation from the surface water medium), by the difference between precipitation and surface infiltration:

$$Sr = P - Is \qquad \textbf{Eq. 7}$$

4.2.5 Computation of evapotranspiration

4.2.5.1 Introduction

The effective evapotranspiration (RET) is estimated by (Allen *et al.*, 1998):

$$RET = (K_a \,.\, K_{cb} + K_e) \,.\, ET_o \qquad \textbf{Eq. 8}$$

where ET_o is the reference evapotranspiration, K_{cb} is the basal crop coefficient, K_e is the soil water evaporation coefficient and K_a is the water stress coefficient.

The ET_o refers to the evaporation from a hypothetical reference crop.

The K_{cb} and K_e terms of the equation integrate the physical and physiological differences between the specific field crop and the reference crop; hence their values vary along the time (depending on the vegetative stage). The use of the two different coefficients, K_{cb} and K_e, constitutes the dual crop coefficient approach.

The K_a term is related to the stress conditions in which the crop develops and is mainly dependent on the water available in the soil during the crop growth.

The determination of the effective evapotranspiration is not straightforward. Hence, methods based on climatic information, vegetation type and water availability in the soil, are used.

4.2.5.2 Estimation of the reference evapotranspiration

The reference evapotranspiration (ET_o), refers to the evapotranspiration of a surface that Allen *et al.* (1998) define as **a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s.m^{-1} and an albedo of 0.23**. In ET_o estimation, the water available in the soil is not limiting the transpiration. To its estimation Allen *et al.* (1998) selected the FAO Penman-Monteith method, and presented a description of the method and of the process to quantify its parameters.

The FAO Penman-Monteith method was derived from the original method of Penman-Monteith that uses an aerodynamic resistance and a crop resistance defined for the grass reference surface. The FAO Penman-Monteith method is described by (Allen *et al.,* 1998):

$$ET_o = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \frac{900}{T + 273} \times u_2 \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34 \times u_2)} \qquad \textbf{Eq. 9}$$

where:

ET_o reference evapotranspiration (mm.d^{-1});
R_n net radiation at the crop surface (MJ.m^{-2}.d^{-1});
G soil heat flux density (MJ.m^{-2}.d^{-1});
T mean daily air temperature at 2 m height (ºC);
u_2 wind speed at 2 m height (m.s^{-1});
e_s saturation vapour pressure (kPa);
e_a actual vapour pressure (kPa);
$e_s - e_a$ saturation vapour pressure deficit (kPa);
Δ slope vapour pressure curve (kPa.(ºC)$^{-1}$);
γ psychrometric constant (kPa.(ºC)$^{-1}$).

The equations to compute the several variables of Eq. 9 are presented accordingly to Allen *et al*. (1998). To understand how these formulas were derived Allen *et al*. (1998) work may be consulted.

- Δ - slope vapour pressure curve (kPa/ºC)

$$\Delta = \frac{4098 \times e^o(T)}{(T + 237.3)^2} \qquad \textbf{Eq. 10}$$

where T is mean air temperature (ºC); $e^o(T)$ is the saturation vapour pressure at temperature T (kPa);

- T – mean air temperature (ºC)

$$T = \frac{T_{max} + T_{min}}{2} \quad \textbf{Eq. 11}$$

where T_{max} is the maximum air temperature (ºC); T_{min} is the minimum air temperature (ºC);

- $e^o(T)$ – saturation vapour pressure at temperature T (kPa)

$$e^o(T) = 0.6108 \times \exp\left(\frac{17.27 \times T}{T + 237.3}\right) \quad \textbf{Eq. 12}$$

- e_s – mean saturation vapour pressure (kPa)

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \quad \textbf{Eq. 13}$$

- e_a – actual vapour pressure (kPa)

$$e_a = \frac{e^o(T_{min}) \times \frac{RH_{max}}{100} + e^o(T_{max}) \times \frac{RH_{min}}{100}}{2} \quad \textbf{Eq. 14}$$

where T_{min} stands for minimum temperature (ºC); RH_{max} stands for maximum relative humidity (%).

- γ – psychrometric constant (kPa/ºC)

$$\gamma = 0.000665 \times P \quad \textbf{Eq. 15}$$

where P is atmospheric pressure (kPa).

- u_2 – wind speed at 2 m height (m.s^{-1})

$$u_2 = u_z \times \frac{4.87}{\ln(67.8 \times z - 5.42)} \quad \textbf{Eq. 16}$$

where u_z is the measured wind speed at z m above ground surface (m/s).

- R_n – net radiation at the crop surface (MJ.m^{-2}.d^{-1})

$$R_n = R_{ns} - R_{nl} \quad \textbf{Eq. 17}$$

where R_{ns} is net solar radiation (MJ/m^2/d); R_{nl} net long wave radiation (MJ/m^2/d).

- R_{nl} – net long wave radiation (MJ.m^{-2}.d^{-1})

$$R_{nl} = \sigma \times \left[\frac{(T_{max} + 273.16)^4 + (T_{min} + 273.16)^4}{2}\right] \times \left(0.34 - 0.14 \times \sqrt{e_a}\right) \times \left(1.35 \times \frac{R_s}{R_{so}} - 0.35\right) \quad \textbf{Eq. 18}$$

where σ is the Stefan-Boltzmann constant = 4.903 × 10^{-9} MJ.$^{K-4}$.m^{-2}.d^{-1}; R_s solar radiation (MJ.m^{-2}.d^{-1}); R_{so} solar radiation that would occur if there was clear-sky conditions (MJ.m^{-2}.d^{-1}).

- R_s – solar radiation (MJ.m^{-2}.d^{-1})

$$R_s = \left(a_s + b_s . \frac{n}{N}\right) . R_a \quad \textbf{Eq. 19}$$

where n is the actual duration of sunshine (hour); N is the maximum possible duration of sunshine or daylight hours (hour); R_a is the extra-terrestrial radiation (MJ.m^{-2}.d^{-1}); a_s e b_s are two parameters (dimensionless), that should be calibrated for local conditions. If this calibration has not been carried out the values of a_s = 0.25 and b_s = 0.50 are recommended. If there is no data available on n, the relation n/N may be approximated using the cloudiness observations as represented in Table 5 for oktas and in Table 6 for tenths.

Table 5 –Relation between cloudiness expressed as oktas and n/N

Oktas	0	1	2	3	4	5	6	7	8
n/N	0.95	0.85	0.75	0.65	0.55	0.45	0.35	0.15	-

Source: Doorenbos and Pruitt (1977)

Table 6 –Relation between cloudiness expressed as tenths and n/N

Tenths	0	1	2	3	4	5	6	7	8	9	10
n/N	0.95	0.85	0.8	0.75	0.65	0.55	0.5	0.4	0.3	0.15	-

Source: Doorenbos and Pruitt (1977)

- R_{so} – solar radiation that would occur if there was clear-sky conditions (MJ.m^{-2}.d^{-1})

$$R_{so} = (0.75 + 2 \times 10^{-5} \times a) \times R_a \qquad \textbf{Eq. 20}$$

where a is altitude above sea level (m); R_a extraterrestrial radiation (MJ.m^{-2}.d^{-1}).

- R_a – extraterrestrial radiation (MJ.m^{-2}.d^{-1})

$$R_a = \frac{1440}{\pi} \times G_{sc} \times d_r \times [\omega_s \times \sin(\varphi) \times \sin(\delta) + \cos(\varphi) \times \cos(\delta) \times \sin(\omega_s)] \qquad \textbf{Eq. 21}$$

where G_{sc} is the solar constant = 0.0820 MJ.m^{-2}.min^{-1}; d_r is the inverse relative distance Earth-Sun (rad); ω_s is the sunset hour angle (rad), φ is latitude (rad); δ is solar declination (rad).

- d_r – inverse relative distance Earth-Sun (rad)

$$d_r = 1 + 0.033 \times \cos(2 \times \pi / 365 \times J) \qquad \textbf{Eq. 22}$$

where J is the number of the day in the year, starting at 1 January.

- ω_s – sunset hour angle (rad)

$$\omega_s = arccos(-tan(\varphi).\ Tan(\delta)\ ) \qquad \textbf{Eq. 23}$$

- δ – solar declination (rad)

$$\delta = 0.409 \times \sin(2 \times \pi / 365 \times J - 1.39) \qquad \textbf{Eq. 24}$$

- R_{ns} – net solar radiation (MJ.m^{-2}.d^{-1})

$$R_{ns} = 0.77 \times R_s \qquad \textbf{Eq. 25}$$

- G – soil heat flux density (MJ.m^{-2}.d^{-1})

For the case of daily or 10-day reference evapotranspiration computations, the value of G is low when compared with R_n. For this reason Allen *et al.* (1998) suggest that for these time periods G may be ignored.

For the computation of monthly reference evapotranspiration, using monthly mean values of the parameters, G may be approximated by the following equation:

$$G = 0.14\ (T_{month} - T_{month\ before}) \qquad \textbf{Eq. 26}$$

where T_{month} is mean air temperature at the current month (ºC) and $T_{month\ before}$ is mean air temperature of the previous month (ºC).

4.2.5.3 Determination of the basal crop coefficient (Kcb)

Four distinct vegetative stages may be identified during the crop growth: (1) initial (up to 10 % ground cover), (2) crop development (until total ground cover), (3) mid-season (until the start of maturity); and (4) late-season (until harvest or full senescence).

The definition of a crop coefficient curve as a function of the vegetative growth is made by defining the crop coefficient values for initial (Kcb ini), middle (Kcb mid) and late (Kcb end) seasons, and the length of each crop growth stage (Fig. 11).

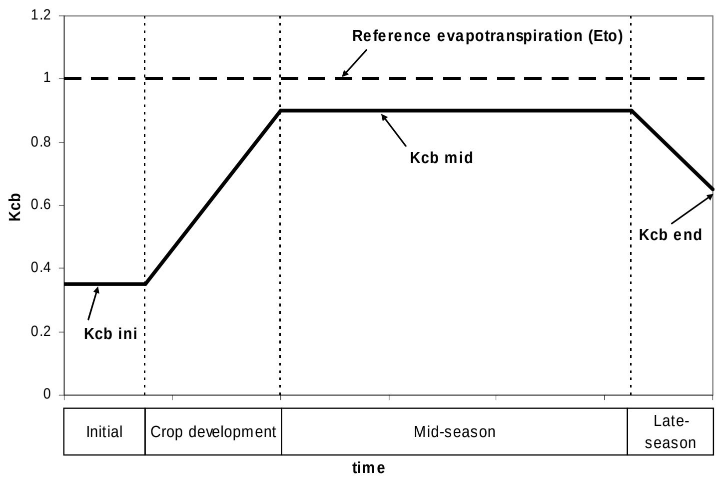


Fig. 11 – Crop coefficient curve defined using the values of $K_{cb\ ini}$, $K_{cb\ mid}$ and $K_{cb\ end}$

Indicative values for K_{cb} are indicated in Table 17 of Allen *et al.* (1998) – Annex 2. In the case of minimum relative humidity conditions and wind speed different from the "standard" ones (45 % and 2 m.s^{-1}, respectively), the $K_{cb\ mid}$ and $K_{cb\ end}$ values should be adjusted using the formula:

$$K_{cbi} = K_{cbi(\text{table})} + [0.04.(u_2 - 2) - 0.004.(HR_m - 45)].(a_i / 3)^{0.3} \qquad \textbf{Eq. 27}$$

Where $K_{cbi(\text{table})}$ is the K_{cb} value determined for "standard" conditions for the stage i (i = mid or i = end), a (m) is the average crop height, u_2 (m.s^{-1}) is average wind speed during stage i, determined or corrected at a 2 m distance above the ground and HR_m (%) is the average, for the stage i, of the minimum daily relative humidity.

Fig. 12 shows an example of the basal crop coefficients distribution for two vegetation types that co-exist in a cartographic unit (non-irrigated wheat and orchard), along four hydrological years that start in October, the 1st, 1995. For the non-irrigated wheat Kcb_ini = 0.15, Kcb_mid = 1.10, Kcb_end = 0.15. For the orchard Kcb_ini = 0.35, Kcb_mid = 0.9, Kcb_end = 0.65. For the non-irrigated wheat the vegetation cycle periods are the following: 1st day of the crop after the 1st of October (*day_ini*) = day 32, initial stage length (*L_ini*) = 30 day, crop development length (*L_dev*) = 140 day, mid-season length (*L_mid*) = 40 day, late-season length (*L_end*) = 30 day. For the orchard, *day_ini* = day 152, *L_ini* = 30 day, *L_dev* = 50 day, *L_mid* = 130 day, and *L_end* = 30 day.

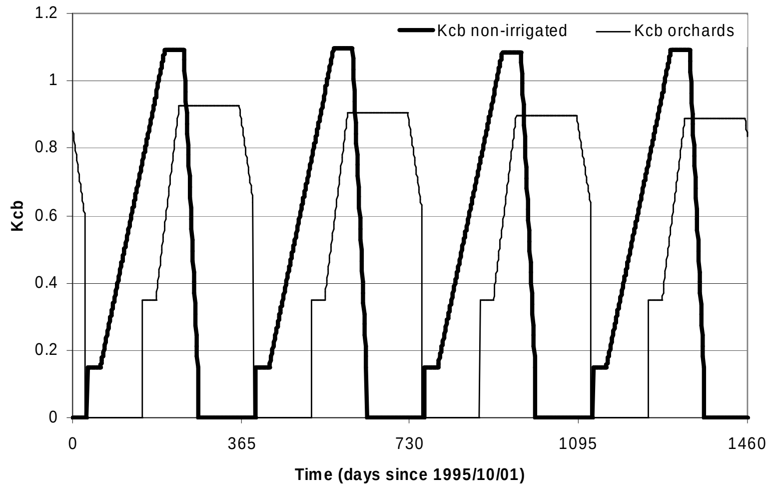


Fig. 12 – Basal crop coefficient (K_{cb}) for each vegetation cover, not considering the interdependency between the crop coefficients

For the K_{cb} values that are not tabulated, Allen *et al.* (1998) propose the use of the following formulas:

- Natural vegetation and crops not listed in Table 17 of Allen *et al*. (1998) and in Annex 2: For areas above a few hectares $K_{cb\,full}$ may be approximated by:

$$K_{cb\,full} = \min(1.20;\ 1.0+0.1.a) + [0.04.(u-2) - 0.004.(HR_m - 45)].(a/3)^{0,3} \qquad \textbf{Eq. 28}$$

- Sparse vegetation:

$$K_{cb\,mid\,adj} = K_{c\min} + \left(K_{cb\,full} - K_{c\min}\right).\min\left[1;\ 2.f_c;\ \left(f_{c\,eff}\right)^{\left(\frac{1}{1+a}\right)}\right] \qquad \textbf{Eq. 29}$$

where $K_{cb\,mid\,adj}$ is the estimated K_{cb} during the mid-season period when plant density and/or leaf area are lower than full cover conditions; $K_{cb\,full}$ is the estimated K_{cb} during the mid-season for vegetation having full ground cover or leaf area index > 3; $K_{c\,min}$ is the minimum K_c for bare soil (approx. 0.15-0.20); f_c is the fraction of soil surface that is covered by vegetation as observed from top (0.01 – 1); $f_{c\,eff}$ is the effective fraction of soil surface covered or shaded by vegetation (0.01 – 1) – in BALSEQ_MOD it is assumed equal to f_c; a is the plant height (m). $K_{cb\,full}$ is given by $K_{cb\,mid}$ for the conditions of full-cover crop given in table 17 of Allen *et al*. (1998), corrected for climate conditions (Eq. 27). Fig. 13 shows the sparse basal crop coefficients distribution for the previous example.

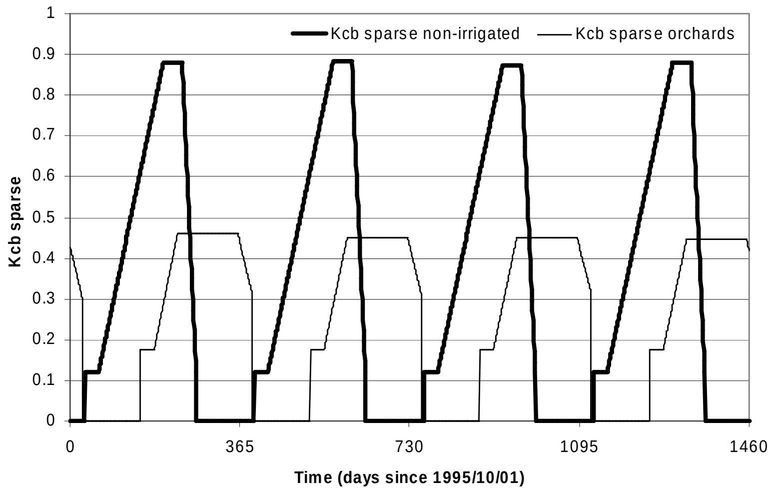


Fig. 13 – Sparse basal crop coefficient (K_{cb}) for each vegetation cover, not considering the interdependency between the crop coefficients

For the late-season period $K_{cb\ end\ adj}$ may also be computed using Eq. 29 with $K_{cb\ end}$ instead of $K_{cb\ mid}$.

In the case of the presence of two vegetation-types in the same area, Allen *et al*. (1998) suggest some procedures that take into account the existence of an energy upper limit for the evapotranspiration, given by $K_{c\ max}$, with a given by the tallest vegetation and K_{cb} by the largest value:

$$K_{c\ max} = \max\left(\{1.2 + [0.04.(u_2 - 2) - 0.004.(HR_m - 45)].(a/3)^{0.3}\}; \{K_{cb} + 0.05\}\right) \quad \textbf{Eq. 30}$$

$K_{c\ max}$ presents values between 1.05 and 1.30.

In the BALSEQ_MOD model (Oliveira, 2004), for the cases where two crops exist, the following procedure was used:

$$K_{cb\ adj\ (\text{crop 1},\ corrected)} = K_{cb\ adj\ (\text{crop 1})} \,.\, K_{c\ max} / (K_{cb\ adj\ (\text{crop 1})} + K_{cb\ adj\ (\text{crop 2})})$$

$$K_{cb\ adj\ (\text{crop 2},\ corrected)} = K_{cb\ adj\ (\text{crop 2})} \,.\, K_{c\ max} / (K_{cb\ adj\ (\text{crop 1})} + K_{cb\ adj\ (\text{crop 2})}) \quad \textbf{Eq. 31}$$

where $K_{cb\ adj\ (\text{crop 1})}$ refers to the $K_{cb\ adj}$ of crop 1, estimated by Eq. 27 as if this crop existed alone. The same applies for crop 2. Fig. 14 shows the adjusted sparse basal crop coefficients for the considered example.

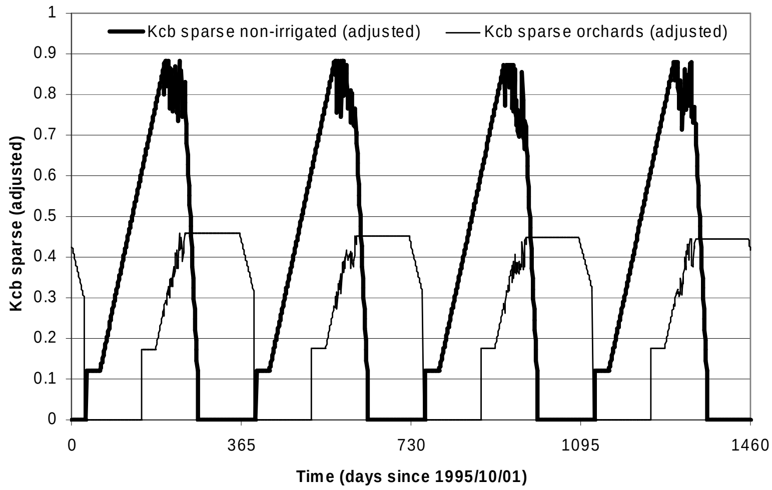


Fig. 14 – Sparse basal crop coefficient (K_{cb}) for each vegetation cover, not considering the interdependency between the crop coefficients

4.2.5.4 Determination of the soil water evaporation coefficient (Ke)

In terms of the evaporation component of RET (related to K_e), when the soil is wet, evaporation from the soil occurs at the maximum rate. However the sum $K_e + K_{cb}$ can not exceed a limit value ($K_{c\,max}$ - Eq. 30), which is determined by the energy available in the soil for evapotranspiration ($K_e \leq K_{c\,max} - K_{cb}$). On another hand K_e may not exceed the available energy in the wet exposed fraction of the soil (f_{ew}): ($K_e \leq f_{ew} \,.\, K_{c\,max}$). K_e is given by:

$$K_e = \min(K_r \,.(K_{c\,max} - K_{cb})\ ;\ f_{ew} \,.\, K_{c\,max}) \qquad \textbf{Eq. 32}$$

where K_r is a evaporation reduction coefficient that depends on the amount of water stored in the upper part of the soil subject to evaporation (topsoil).

Quantification of K_r requires a topsoil daily water balance. Its value varies between 1 for a soil with water content equal to field capacity (sr) and 0 for a soil at the wilting point (wp). While the water content is above a threshold given by (1 - p) * available water, K_r = 1. Available water is given by the difference between field capacity and wilting point. Below this threshold K_r is given by:

$$K_r = (\theta - wp).\ [\ (1-p)\ .\ (sr - wp)\ ]^{-1} \qquad \textbf{Eq. 33}$$

where θ is the water content.

As an average, and looking at the values published in Allen *et al.* (1998) for different soil types, the value of p may be assumed as 42 % of the available water.

In the case of a bare soil, while the water content is above the threshold value (1 - p) * available water, a value of K_e = 1.15 may be assumed.

4.2.5.5 Determination of the water stress coefficient (K_a)

K_a is a parameter similar to K_r. But, in this case, it depends also on the type of crop. Its value varies between 1 for a soil with water content equal to sr and 0 for a soil at wp. While the water content is above a threshold given by (1 - p) * available water, K_a = 1. Below this threshold K_a is given by:

$$K_a = (\theta - wp). [(1 - p) . (sr - wp)]^{-1} \qquad \textbf{Eq. 34}$$

where θ is the water content.

The values for p are published on Table 22 of Allen *et al.* (1998) and Annex 2. These values apply for $Etc = (K_{cb} + K_e) . ET_o$ = 5 mm.day^{-1}. It can be adjusted for different ETc using:

$$p = p_{(\mathrm{ETc=5mm/d})} + 0{,}04 . (5 - ET_c) \qquad \textbf{Eq. 35}$$

The adjusted p is limited to $0.1 \le p \le 0.8$.

A value of 0.50 is commonly used for many crops. The value of p may also be corrected as a function of the soil type. For fine textured soils (clay) $p_{(\mathrm{ETc=5mm/d})}$ should be reduced by 5 % to 10 %. For more coarse textured soils (sand) it should be increased by the same amount (Allen *et al.,* 1998).

4.2.5.6 Determination of the fraction of the soil surface covered by vegetation as observed from the top (f_c) and of the wet exposed fraction of the soil (f_{ew})

It is assumed that the influence zone of the roots is horizontally given by the area occupied by the vegetation. So it is assumed equal to the fraction of soil surface that is covered by vegetation as observed from top (fc). fc varies along the time, depending on the development stage of the vegetation. Up to two vegetation types may be considered. The sum of the fc of each vegetation type can not be larger than 1. The following parameters must be characterised for each vegetation type: maximum area (fc_max), minimum area (fc_min, equal to 10 % or in the case of perennial crops equal to fc_max) and rest time area (fc_0, equal to 0 in the case of dormancy or plant inexistence, or equal to fc_max in the case of evergreen forests). During a year-cycle fc assumes the following values:

- before initial stage, or after the end of the late-season stage: $fc = fc\_0$;
- in the initial stage: $fc = fc\_min$;
- in the crop development stage: fc varies linearly between fc_min in the first day and fc_max in the last day;
- in the mid-season and late-season: $fc = fc\_max$.

The wet exposed fraction of the soil (few) is given by $few = 1 - (fc_1 + fc_2)$, where fc_1 and fc_2 stand for the fractions occupied by vegetation 1 and vegetation 2.

Fig. 15 shows an example of the area fractions occupied by two crops (non-irrigated wheat and orchard) and by the bare soil, along a hydrological year that starts in the 1st of October. For the non-irrigated wheat fc_min = 10 %, fc_max = 60 %, fc_0 = 0 %. For the orchard fc_min = 20 %, fc_max = 80 %, fc_0 = 0 %.

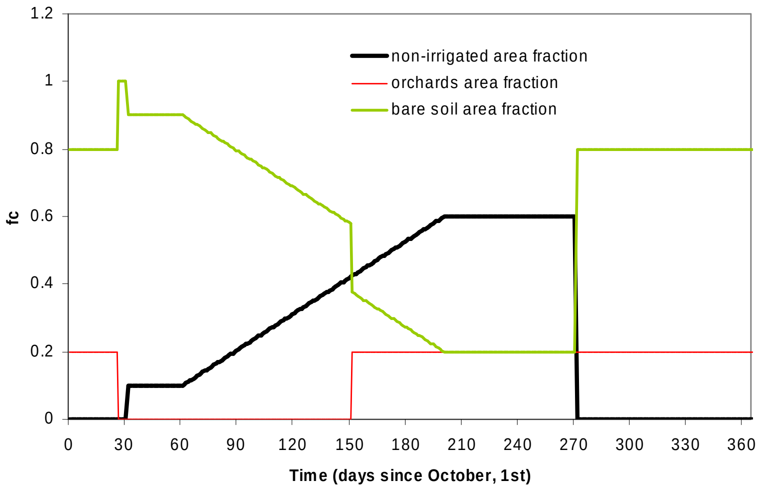


Fig. 15 – Yearly distribution of the land fraction occupied by each vegetation cover and by the bare soil

4.2.5.7 Determination of the soil moisture

The computation of the Ka parameter requires the quantification of the soil water content (expressed in % volume of water / volume of soil) above the wilting point (θ_i - wp). The water content above the wilting point reflects the water that may be mobilised by the plants for the evapotranspiration process. As the plants can withdraw water along the depth of their roots, instead of the soil water content, a different variable, A_l, is used that refers to the amount of water stored in the root depth (rd) that may be mobilised by the plants, which is given by:

$$A_l = (\theta_i - wp)\ .\ rd \qquad \textbf{Eq. 36}$$

In the BALSEQ_MOD model the daily amount of water available for evapotranspiration, $A_{l\ ETR\ (\text{day, cover } i)}$, is given by:

$$A_{l\ ETR\ (day,\ \text{cover } i)} = A_{l\ ini(day,\ \text{cover } i)} + Is_{(day,\ \text{cover } i)} + A_{l\ inc(day,\ \text{cover } i)} \qquad \textbf{Eq. 37}$$

where cover i refers to the vegetation or crop type 1 or 2 or to the bare soil, $A_{l\ ini}$ is the amount of water that exists in the soil in the end of the previous day of the sequential water balance, Is is the surface infiltration computed for the current day, and $A_{l\ inc}$ represents, for the case of the vegetation cover, the increase, from the previous to the current day, of the amount of water in the soil due to the increase of the area covered by the vegetation or due to the increase of the root depth.

For the case of the bare soil, $A_{l\ inc}$ is null, except for the day in which one vegetation cover becomes inactive. In that day, the amount of water in the bare soil is increased by the amount of water that existed in the vegetation cover area in the previous day, and $A_{l\ inc}$ of the bare soil is:

$$A_{l\ inc(\text{day, bare soil})} = [A_{l\ ini(\text{day, cover})} / rd\_1_{(\text{cover})} \, . \, thick_{(\text{day})}] \, . \, fc_{(\text{day-1,cover})} / fc_{(\text{day, bare soil})}$$ **Eq. 38**

where $thick$ represents the bare soil thickness subject to evapotranspiration, rd_1 is the root depth of the cover in the last day that it existed, fc is the fraction of the area occupied by the cover, day the current day and day-1 the previous day.

For each vegetation cover, the following terms are related to the increase of the amount of water in the soil, expressed in terms of water column in the area occupied by the vegetation crop (Fig. 16):

a) Term related to the increase of the root depth (A_{l1}), considering the soil water content that exists in the growth zone of the plant roots:

$$A_{l1} = [rd_{(\text{day,cover})} - rd_{(\text{day-1})}] * (sr - wp - \theta_{l\ def1}) * fc_{(\text{day-1,cover})} / fc_{(\text{day,cover})}$$ **Eq. 39**

where $\theta_{l\ def1}$ is given by:

$$\theta_{l\ def1} = A_{l\ def(\text{day-1,cover,1})} / [rd\_1_{(\text{cover})} - rd_{(\text{day-1,cover})}]$$ **Eq. 40**

$A_{l\ def\,(\text{day-1,cover,1})}$ represents the deficit of water in the soil thickness between the root depth in the previous day [$rd_{(\text{day-1})}$] and the maximum root depth of the plants (rd_1), the soil water content reaches the field capacity (sr).

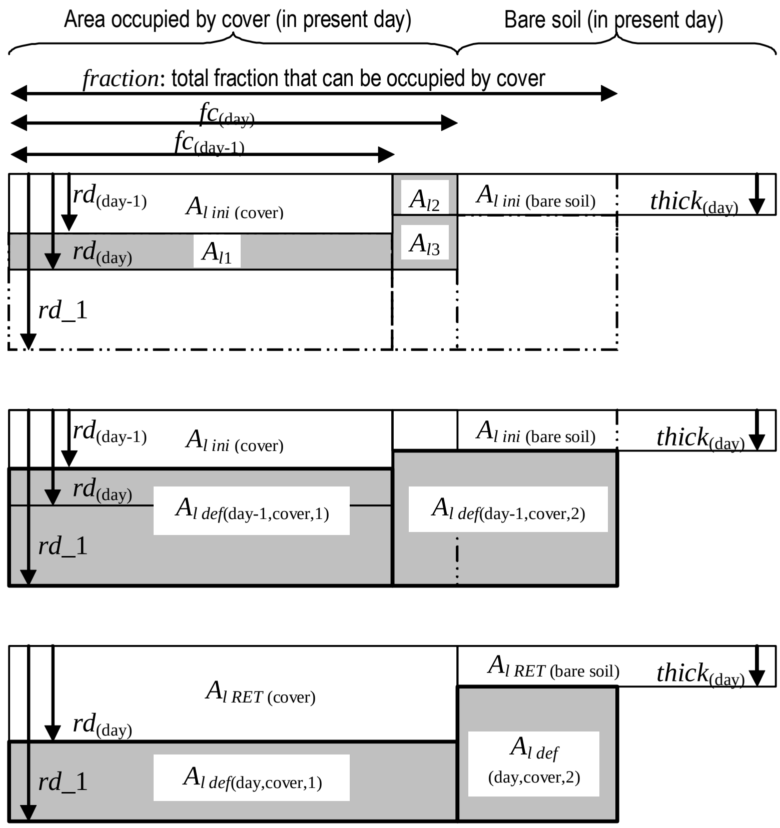


Fig. 16 – Situations considered during the water balance for the case of the increase or the reduction of the fraction occupied by a specific vegetation cover or of the soil thickness subject to evapotranspiration.

Due to the increase of the plant root depth, the term $A_{l\ def}$ (day,cover,**1a**) is updated for the new depth that still has to be fulfilled by the plant roots [between rd_1 and $rd_{(day)}$]:

$$A_{l\ def(day,cover,\mathbf{1a})} = A_{l\ def(day-1,cover,1)} / [rd\_1_{(cover)} - rd_{(day-1,cover)}] \;.\; [rd\_1_{(cover)} - rd_{(day,cover)}] \;.\; fc_{(day-1,cover)} / fc_{(day,cover)} \qquad \textbf{Eq. 41}$$

b) Term related to the increase of the area in the zone of the bare soil (A_{l2}), considering the soil water content that exists in this zone:

$$A_{l2} = [fc_{(day,cover)} - fc_{(day-1,cover)}] * A_{l\ ini\ (day,\ bare\ soil)} / fc_{(day,cover)} \qquad \textbf{Eq. 42}$$

c) Term related to the increase of the area below the depth subject to evaporation of the bare soil (A_{l3}, applicable if $rd_{(day)}$ > thickness of the evaporating zone [$thick_{(day)}$], considering the water content that exists in the soil in the zone of increase of the plant's root depth:

$$A_{l3} = [rd_{(day,cover)} - thick_{(day)}] \;.(sr - wp - \theta_{l\ def2}).\; [fc_{(day,cover)} - fc_{(day-1,cover)}] / fc_{(day,cover)} \qquad \textbf{Eq. 43}$$

where $\theta_{l\ def2}$ is given by:

$$\theta_{l\ def2} = A_{l\ def(day-1,cover,2)} / [rd\_1_{(cover)} - thick_{(day-1)}] \qquad \textbf{Eq. 44}$$

$A_{l\ def\ (day-1,cover,2)}$ represents the deficit of water in the soil thickness between the bare soil bottom in the previous day [$thick_{(day-1)}$] and the maximum root depth of the plants (rd_1), required to increase the soil water content to the field capacity (sr).

In the area previously below the bare soil and that currently is also occupied by the vegetation cover, there is a change in the amount of the water deficit. As this area is now part of the fraction occupied by the vegetation cover, the following applies:

$$A_{l\ def\ (day,cover,\mathbf{1b})} = A_{l\ def\ (day-1,cover,\ 2)} / [rd\_1_{(cover)} - thick_{(day-1)}] \;.\; [rd\_1_{(cover)} - rd_{(day,cover)}] \;.\; [fc_{(day,cover)} - fc_{(day-1,cover)}] / fc_{(day,cover)} \qquad \textbf{Eq. 45}$$

The water increase that results from increasing both the thickness and the area of the vegetative cover, expressed in height of the water column in the vegetation area fraction, is:

$$A_{l\ inc\ (day,\ cover)} = A_{l1} + A_{l2} + A_{l3} \qquad \textbf{Eq. 46}$$

and the water required to fulfil the field capacity between the plant root depth and its maximum depth is:

$$A_{l\ def\ (day,cover,1)} = A_{l\ def\ (day,cover,\mathbf{1a})} + A_{l\ def\ (day,cover,\ \mathbf{1b})} \qquad \textbf{Eq. 47}$$

If the day in which the vegetation cover becomes inactive, the amount of water related to the cover becomes null:

$$A_{l\ RET(day,cover)} = 0 \qquad \textbf{Eq. 48}$$

and the terms related to $A_{l\ def}$ become:

$$A_{l\ def(day,cover,\mathbf{1})} = 0 \qquad \textbf{Eq. 49}$$

because the vegetation cover does not exist any more. In the area below the new bare soil, that in the next plant cycle will be occupied by the plant roots again, $A_{l\ def}$ is:

$$A_{l\ def(\text{day,cover,}\mathbf{2})} = [rd\_1_{(\text{cover})} - thick_{(\text{day-1})}] * [\ sr - (\ wp + A_{l\ ini(\text{day,cover})} \ / \ rd_{(\text{day-1,cover})}\ )\ ] \qquad \textbf{Eq. 50}$$

4.2.5.8 Determination of the root depth

The root depth (rd) is important to define the amount of water available for evapotranspiration: It depends on the development stage of the vegetation. Up to two vegetation types may be considered. For each one, the following parameters must be characterised: minimum root depth (rd_0), maximum root depth (rd_1). During a year cycle rd assumes the following values:

- before initial stage, or after the end of the late-season stage: rd = 0;
- in the initial stage: rd = rd_0;
- in the crop development stage: rd varies linearly between rd_0 in the first day and rd_1 in the last day;
- in the mid-season and late-season: rd = rd_1.

For the bare soil fraction a constant value is assumed along the year – only rd_1 (or $thick$) – is defined. According to Allen *et al.* (1998), the depth of the upper part of the soil that is subject to drying by evaporation is 10-15 cm.

Fig. 17 shows an example of the soil thickness subject to evapotranspiration for two vegetation covers (non-irrigated wheat and orchard) and for the bare soil, along a hydrological year that starts in the 1st of October. For the non-irrigated wheat rd_0 = 150 mm, rd_1 = 1,200 mm. For the orchard rd_0 = rd_1 = 1,500 mm. For the bare soil $thick$ = rd_1 = 150 mm.

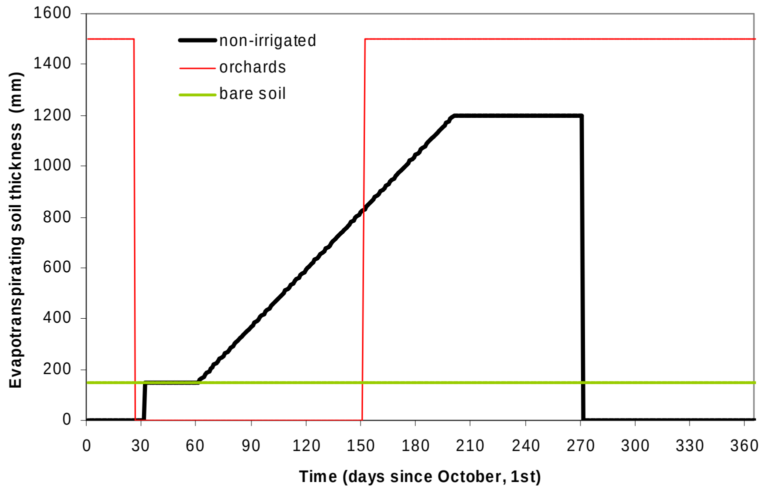


Fig. 17 – Yearly distribution of the soil thickness subject to evapotranspiration for each vegetation cover and for the bare soil.

4.2.5.9 Computation of effective evapotranspiration (*RET*)

Using the above described methodology the effective evapotranspiration is computed for each one of the up to 2 land covers and for the bare soil. Fig. 18 shows the *RET* values for the presented example of the non-irrigated wheat, the orchard and the bare soil, all of them expressed in terms of the water height in relation to the fraction of the soil surface covered by each vegetation type or by the bare soil.

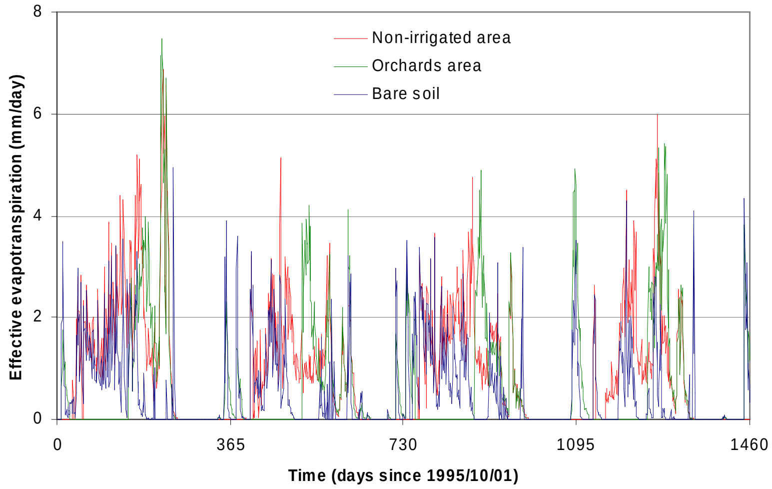


Fig. 18 – Effective evapotranspiration of each vegetation cover or bare soil (values referred to the soil surface occupied by them).

For the complete area, the effective evapotranspiration (*RET*) – Fig. 19 – is obtained by:

$$RET = RET_{cover\ 1} .\ fc_{cover\ 1} + RET_{cover\ 2} .\ fc_{cover\ 2} + RET_{bare\ soil} .\ fc_{bare\ soil} \qquad \textbf{Eq. 51}$$

where fc is the fraction of soil surface occupied by each cover or by the bare soil [Note that the sum of the fc is equal to 1].

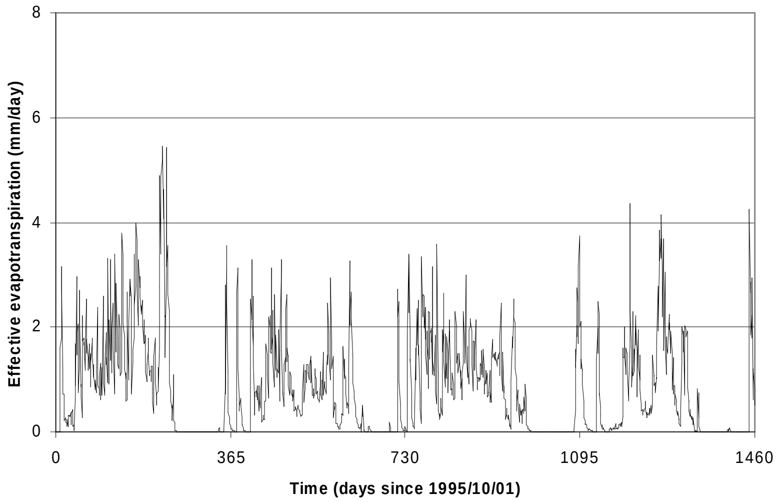


Fig. 19 – Effective evapotranspiration of the complete area.

4.2.5.10 Summary of the information required to estimate RET in the BALSEQ_MOD model

The following information is required to run the BALSEQ_MOD model, in order to compute the effective evapotranspiration:

- daily surface infiltration (Is);
- daily reference evapotranspiration (ET_o);
- the fraction of the area occupied by each land cover (f_c) or by the bare soil (f_{ew}); in the case of vegetation cover it is necessary to know the area fraction occupied by vegetation during mid-season and late-season stages (fc_max), and the area fraction occupied by vegetation during the initial stage of the development (fc_min); for static land covers the same fractions are required but fc_max = fc_min;
- the soil depth subject to evapotranspiration. For the vegetation cover, two soil depths are defined accordingly to the development stage of the vegetation: the initial stage (rd_0), and the mid-season and late season crop development stage (rd_1). For bare soil a depth of 15 cm subject to evaporation is assumed;
- the basal crop coefficients. Applied only for the vegetation covers, three values are required for each vegetation cover for initial ($Kcb\ ini$), middle ($Kcb\ mid$) and late ($Kcb\ end$) seasons. These depend on the vegetation height, the air relative humidity, the wind speed, the fraction of land surface covered by the vegetation;
- the first day of the initial stage (*day_ini*), and the length of each crop growth stage: initial stage length (L_ini), crop development length (L_dev), mid-season length (L_mid) and late-season length (L_end);
- threshold values for the minimum amount of water stored in the soil that allow the effective evapotranspiration to occur at the maximum rate (p), both for the vegetation cover and for the bare soil.

4.2.6 Computation of deep percolation

The soil moisture storage variation (ΔA_l) and the deep percolation (Dp) are computed by sequential water balance:

$$\Delta A_{l\,(day,\,\mathrm{cover}\,i)} + Dp_{(day,\,\mathrm{cover}\,i)} = Is_{\,(day,\,\mathrm{cover}\,i)} + A_{l\,inc(day,\,\mathrm{cover}\,i)} - RET_{(day,\,\mathrm{cover}\,i)} \qquad \textbf{Eq. 52}$$

As $\Delta A_{l(day,\,\mathrm{cover}\,i)} = A_{l\,end(day,\,\mathrm{cover}\,i)} - A_{l\,ini(day,\,\mathrm{cover}\,i)}$ and from the sequential water balance $A_{l\,ini(day,\,\mathrm{cover}\,i)}$, $Is_{(day,\,\mathrm{cover}\,i)}$ and $RET_{(day,\,\mathrm{cover}\,i)}$ are already computed, it is needed to decompose $A_{l\,end(day,\,\mathrm{cover}\,i)} + Dp_{(day,\,\mathrm{cover}\,i)}$ from the following equation:

$$A_{l\,end(day,\,\mathrm{cover}\,i)} + Dp_{(day,\,\mathrm{cover}\,i)} = A_{l\,ini(day,\,\mathrm{cover}\,i)} + Is_{\,(day,\,\mathrm{cover}\,i)} + A_{l\,inc(day,\,\mathrm{cover}\,i)} - RET_{(day,\,\mathrm{cover}\,i)} \qquad \textbf{Eq. 53}$$

The most straightforward process to compute deep percolation is used in the BALSEQ model (Lobo Ferreira, 1981), which assumes that all the water that drains freely under the action of gravity will become deep percolation. In this case the amount of water stored in the *soil* is upper limited by $AG_{sr(day,\ \mathrm{cover}\ i)} = rd_{(day,\ \mathrm{cover}\ i)}.sr$, where rd is root depth and sr is specific retention (or field capacity). When this amount is larger than $AG_{sr(day,\ \mathrm{cover}\ i)}$ the water flows in depth, becoming deep percolation:

$$Dp_{(day,\ \mathrm{cover}\ i)} = \max(A_{l\ ini(day,\ \mathrm{cover}\ i)} + Is_{(day,\ \mathrm{cover}\ i)} + A_{l\ inc(day,\ \mathrm{cover}\ i)} - RET_{(day,\ \mathrm{cover}\ i)} - AG_{sr(day,\ \mathrm{cover}\ i)}\ ;\ 0) \quad \textbf{Eq. 54}$$

Knowing Dp and substituting in Eq. 53, $A_{l\ end}$, is computed:

$$A_{l\ end(day,\mathrm{cover}\ i)} = \min(A_{l\ ini(day,\mathrm{cover}\ i)} + Is_{(day,\mathrm{cover}\ i)} + A_{l\ inc(day,\mathrm{cover}\ i)} - RET_{(day,\mathrm{cover}\ i)};\ AG_{sr(day,\mathrm{cover}\ i)}) \quad \textbf{Eq. 55}$$

These equations are valid when the phreatic level is below the *soil* bottom. The use of these equations in the daily sequential water balance model imply that in the end of the day all the water present in the *soil* exceeding the storage corresponding to the field capacity value has been able to drain through all the soil thickness. In many cases that may not happen, as drainage depends on the hydraulic conductivity, the hydraulic head and on the soil thickness. If the water remains in the *soil*, this will have an amount of stored water larger than AG_{sr} and this water may be used in the evapotranspiration process in the next day.

For the BALSEQ_MOD program the procedure referred to by Samper *et al.* (1999) was adopted, where deep percolation is given by the water in the soil exceeding AG_{sr} however limited by the maximum amount of water that the *soil* may transmit in the considered time interval ($K_s.\ \Delta t$), where K_s is the saturated vertical hydraulic conductivity of the soil and Δt is the time step (1 day):

$$Dp_{(day,\mathrm{cover}\ i)} = \min\{\max[A_{l\ ini(day,\mathrm{cover}\ i)} + Is_{(day,\mathrm{cover}\ i)} + A_{l\ inc(day,\mathrm{cover}\ i)} - RET_{(day,\mathrm{cover}\ i)} - AG_{sr(day,\mathrm{cover}\ i)};\ 0];\ (K_s.\Delta t)\} \quad \textbf{Eq. 56}$$

Replacing $Dp_{(day,\ \mathrm{cover}\ i)}$ in Eq. 55 $Al_{end(day,\ \mathrm{cover}\ i)}$ is obtained. However with the application of this equation the amount of water in the *soil* may exceed the maximum amount of water that the *soil* may contain ($AG_{l(day,\ \mathrm{cover}\ i)} = rp_{(day,\ \mathrm{cover}\ i)}.n$ where n is porosity). In this case it is assumed that if $Al_{end(day,\ \mathrm{cover}\ i)}$ given by Eq. 55 exceeds $AG_{l(day,\ \mathrm{cover}\ i)}$, the difference will be added to the direct runoff or to the water stored in the surface medium (ponding) (that in BALSEQ_MOD is considered null):

$$Sr_{(day,\mathrm{cover}\ i)} = Sr_{previously\ computed(day,\mathrm{cover}\ i)} + (A_{l\ end(day,\mathrm{cover}\ i)} - AG_{l\ (day,\mathrm{cover}\ i)}) \quad \textbf{Eq. 57}$$

The amount of water stored in the *soil* becomes:

$$A_{l\ end\ (day,\mathrm{cover}\ i)} = AG_{l\ (day,\mathrm{cover}\ i)} \quad \textbf{Eq. 58}$$

Deep percolation thus calculated may still not translate the deep percolation of a day. This is due to the fact that while plant roots are developing and growing in depth, the volume of soil existing between the root depth in that day [$rp_{(day)}$] and the maximum depth that will be achieved by the plants (rp_1) may present a moisture content below the field capacity.

The deep percolation calculated by Eq. 54 or Eq. 56, now on designated as Dp_{soil}, is not draining downward by gravity forces, but will fulfil the soil voids until its moisture content attains the field capacity.

Consider the three zones represented on Fig. 20:

1 – below the land area occupied by vegetal cover 1 [$fc_{(\text{day, cover 1})}$];

2 – below the land area occupied by vegetal cover 2 [$fc_{(\text{day, cover 2})}$] – if it exists;

3 – below the bare soil, that can also be decomposed in three sub-zones:

3.1 – the area that during the vegetal cover 1 development will be occupied, that is, the area below [$fraction_1 - fc_{(\text{day, cover 1})}$];

3.2 – the area that during the vegetal cover 2 development (if it exists) will be occupied, that is, the area below [$fraction_2 - fc_{(\text{day, cover 2})}$];

3.3 – the area below the bare soil that will never be occupied by the vegetal cover ($1 - [fraction_1 + fraction_2]$).

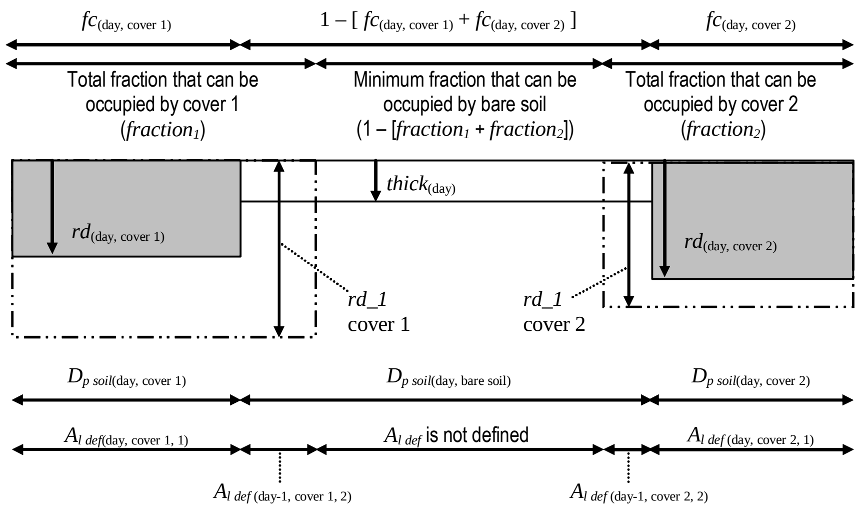


Fig. 20 – Terms used for the computation of deep percolation when the dual crop coefficient is used for the computation of evapotranspiration

In the case of the first two zones the water amount required to fill the soil voids until its moisture content attains the field capacity is represented by $A_{l\,def(day,\text{ cover }1,1)}$ and $A_{l\,def(day,\text{ cover }2,1)}$ as calculated in Eq. 47. Dp_{soil} is the calculated for the vegetal covers {$Dp_{soil[day,\text{ cover }1]}$ and $Dp_{soil[day,\text{ cover }2]}$}. Deep percolation and the new values of $A_{l\,def}$ are given by:

$$Dp_{[day,\text{ cover }i]} = \max(Dp_{soil\,[day,\text{ cover }i]} - A_{l\,def\,Eq.\,47\,(day,\text{ cover }i,1)};\ 0) \quad \textbf{Eq. 59}$$

$$A_{l\,def(day,\text{ cover }i,1)} = \max(A_{l\,def\,Eq.\,47\,(day,\text{ cover }i,1)} - Dp_{soil\,[day,\text{ cover }i]};\ 0) \quad \textbf{Eq. 60}$$

where i assumes the values 1 or 2. In the case that cover 2 does not exist, i only assumes value 1.

To determine deep percolation of the third zone the three sub-zones must be considered. In the case of sub-zones 3.1 and 3.2, the water amount required to fill the soil voids until its moisture content attains the field capacity is given by $A_{l\ def\ (day\text{-}1,\text{cover }1,2)}$ and $A_{l\ def(day\text{-}1,\text{cover }2,2)}$. The terms $A_{l\ def}$ refer to the calculated values of the previous day, as they have not been updated to the present day of the balance. Dp and $A_{l\ def}$ are given by:

$$Dp_{3.i\ (day)} = \max(\ Dp_{soil\ (day,\ \text{bare soil})} - A_{l\ def(day\text{-}1,\text{cover }i,2)};\ 0\ ) \qquad \textbf{Eq. 61}$$

$$A_{l\ def(day,\text{cover }i,2)} = \max(A_{l\ def(day\text{-}1,\text{cover }i,2)} - Dp_{soil\ (day,\ \text{bare soil})};\ 0) \qquad \textbf{Eq. 62}$$

where i assumes values 1 or 2. In the case that cover 2 does not exist, i only assumes value 1.

In the case of sub-zone 3.3, water contents below field capacity are not occurring. In this case $A_{l\ def}$ is not defined and deep percolation is given directly by $Dp_{soil\ (\text{day, bare soil})}$:

$$Dp_{3.3\ (day)} = Dp_{soil\ (day,\ \text{bare soil})} \qquad \textbf{Eq. 63}$$

For the whole area of the bare soil, $Dp_{(\text{day, bare soil})}$ is given by:

$$Dp_{(day,\ \text{bare soil})} = \{Dp_{3.1\ (day)} \cdot [fraction_1 - fc_{(day,\ \text{cover }1)}] + Dp_{3.2\ (day)} \cdot [fraction_2 - fc_{(day,\ \text{cover }2)}] + Dp_{3.3\ (day)} \cdot (1 - [fraction_1 + fraction_2]\ )\} \,/\, \{1 - [fc_{(day,\ \text{cover }1)} + fc_{(day,\ \text{cover }2)}]\} \qquad \textbf{Eq. 64}$$

Fig. 21 shows the distribution of deep percolation for three different land covers, expressed in water column height in relation to the land fraction they occupy. Fig. 22 shows the global value of Dp for the study area, computed with:

$$Dp = Dp_{non\text{-}irrigated} \cdot fc_{non\text{-}irrigated} + Dp_{orchards} \cdot fc_{orchards} + Dp_{bare\ soil} \cdot fc_{bare\ soil} \qquad \textbf{Eq. 65}$$

being fc_i the fraction of the area occupied by each one of the cultures or by the bare soil. [Note: sum of fc_i = 1].

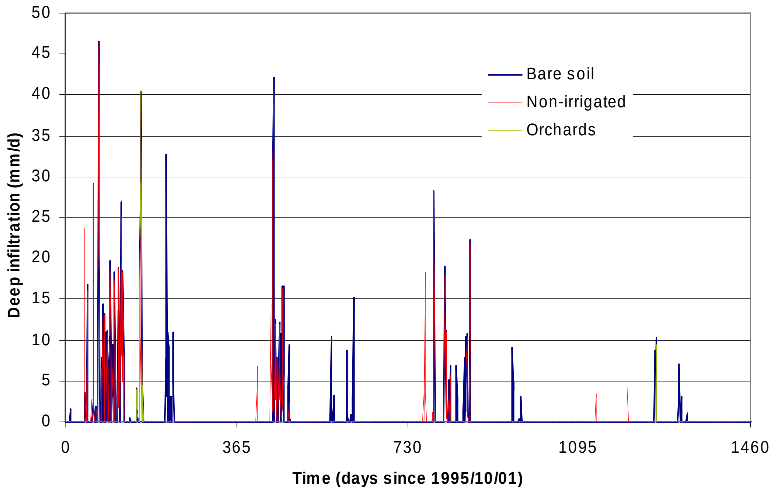


Fig. 21 – Deep percolation by vegetal cover or bare soil (values referred to the area occupied by each cover or bare soil).

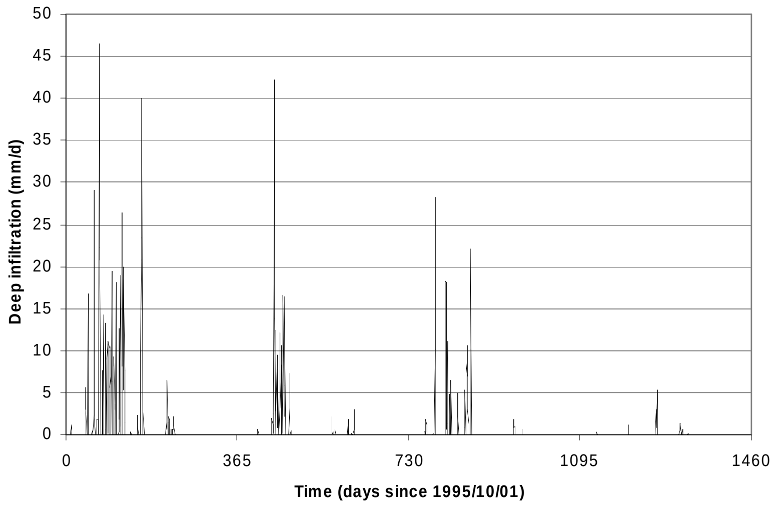


Fig. 22 – Deep percolation for the whole area.

As mentioned in section 4.2.1, the deep percolation is assumed to be equal to the recharge of groundwater.

4.3 Surface flow hydrograph separation method

Surface or total flow (F) of a water stream is mainly composed of (1) direct runoff or overland flow (Fd), produced in the watershed above the place where it is measured, resulting from precipitation that does not infiltrate into the soil surface and that is not retained (for example in the plants canopy, buildings, dams, etc.), and (2) base flow (Fb), resulting from water that infiltrates into the soil, goes through the subsurface and eventually comes to the surface, being the discharge of groundwater to the watershed:

$$F = Fd + Fb$$ **Eq. 66**

The hydrograph represents surface flow against time (Fig. 23). The two large flow components of total flow (Fd and Fb) may be separated in the hydrograph. Several methods exist (*c.f. e.g*. Linsley *et al*., 1975). One of these, which is the basis of the methodology used in this study, consists in connecting total flow that exists in the beginning of the rising limb to the total flow that exists in the end of direct runoff. Linsley *et al.* (1975) present the following equation to estimate time from the hydrograph peak until a point located in the end of the recession curve that reflects the end of direct runoff (A is watershed area above the measuring station in km^2 and *n* is number of days):

$$n = 0{,}8 \, . \, A^{0,2}$$ **Eq. 67**

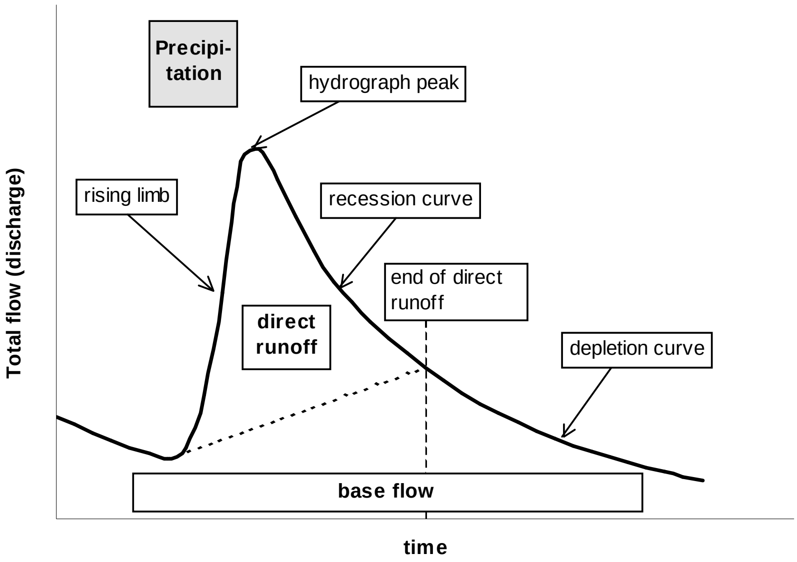


Fig. 23 – Method to separate total flow in direct runoff and base flow

The procedures developed for hydrograph separation (HS) use a daily time step and were programmed in DECHIDR_VB using Visual Basic 6.0. The general technique for the separation follows the method represented in Fig. 24, though in this case the total flow in the beginning of the rising limb is always zero. The method consists in plotting a straight line linking the hydrograph origin of the precipitation/flow (P/F) episode under analysis with total flow calculated in the beginning of day n + 1. Day n [computed with Eq. 67] refers to the number of days with direct runoff after the hydrograph peak [Fig. 24A] or the end of the precipitation if this exceeds the hydrograph peak [Fig. 24B]. The area above the line represents direct runoff of the episode under analysis while the area below the line represents its base flow.

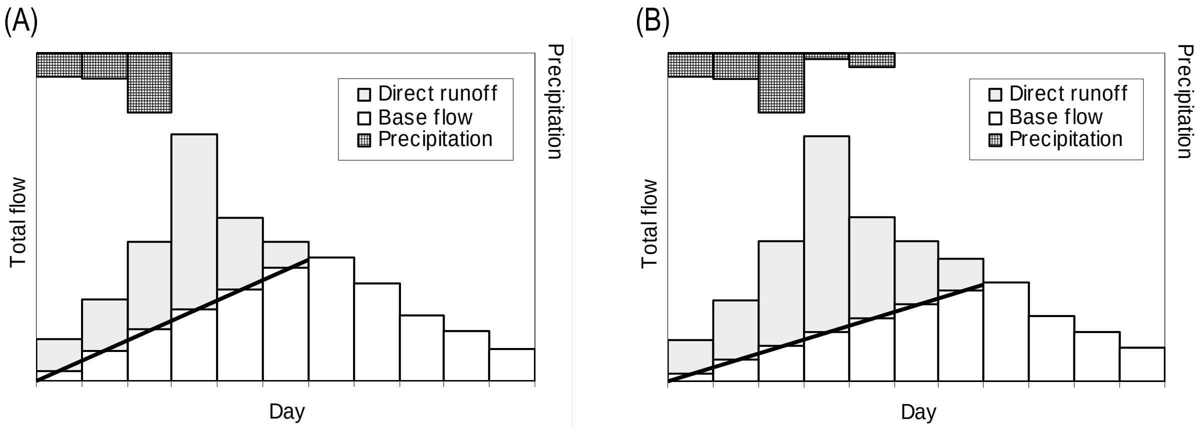


Fig. 24 – Example of the process of hydrograph separation, for n = 2 day, using as criterion (A) the day of the hydrograph peak, (B) the last precipitation day

The HS turns to be a more complex process due to the occurrence of different superimposed episodes, which cause that, in the same day, the recession of several P/F episodes may be occurring.

To deal with this situation a set of procedures is developed in order to isolate distinct P/F episodes. The separation is carried out sequentially considering the input data series: date, total flow and precipitation.

The first step consists in determining the first day of a new P/F episode (episode B). Considering total flow existing since the beginning of the episode under analysis (episode A), it is considered that a new episode (episode B) starts when: (1) total flow is larger or equal to total flow in the previous day and total flow in the previous day is lower than total flow calculated two days before; (2) total flow is larger than total flow in the day before and this is equal to total flow calculated two days before. Depending on the selected option, the beginning of that episode is considered valid (1) in the day in which the previous conditions were met, independently of the occurrence of precipitation, (2) only in the first day of the rising limb after the day in which the previous conditions were met and the precipitation is larger than a precipitation threshold, defined as the minimum daily precipitation that must occur before direct runoff is generated.

Being established the first day of the episode B, the second step consists in determining the recession of episode A. To do this, a recession coefficient (α) of episode A is found by fitting a negative exponential curve of the type:

$$F = F_0 \,.\, \mathrm{EXP}(-\alpha \,.\, t) \qquad \textbf{Eq. 68}$$

to the flows of the recession or depletion period in the days before the beginning of episode B, being F total flow in the end of time t of the decreasing period and F_0 total flow when t = 0. The days used to compute α are selected starting in the day before the first day of episode B and moving backwards while the flow in the actual day is lower than the flow in the previous day. If there is a day with precipitation and at least two values exist for the computation of the exponential fitting, then this day and the previous days are not taken into account. If there is no precipitation then the days used for the computation of α are those indicated in Table 7.

Table 7 – Days used to compute the recession coefficient (α) for the case where there is no precipitation

Number of days of total flow decreasing before the first day of a new episode, if there is no precipitation	2	3	4	5	6 or more
Days used	1st and 2nd	2nd and 3rd	2nd, 3rd and 4th	3rd, 4th and 5th	4th and following

The rejection, when possible, of the first days of the recession curve for the computation of α is due to the fact that these values of total flow are affected by direct runoff, which would lead to a value of α higher than the real one.

With the computed α, the water mass balance between the amount of precipitation that contributes to the episode and the corresponding total flow may be controlled. In this case, to accept α

it is required that total flow is not larger than precipitation. If it is larger, a new α is searched that meets the equality between total flow and precipitation, using the process described hereinafter.

Consider the existence of a P/F episode – episode A – starting on day i = 1 for which the recession curve is to be determined, and another episode – episode B – starting on day i = m + 1, whose total flows are added to total flows of episode A (Fig. 25).

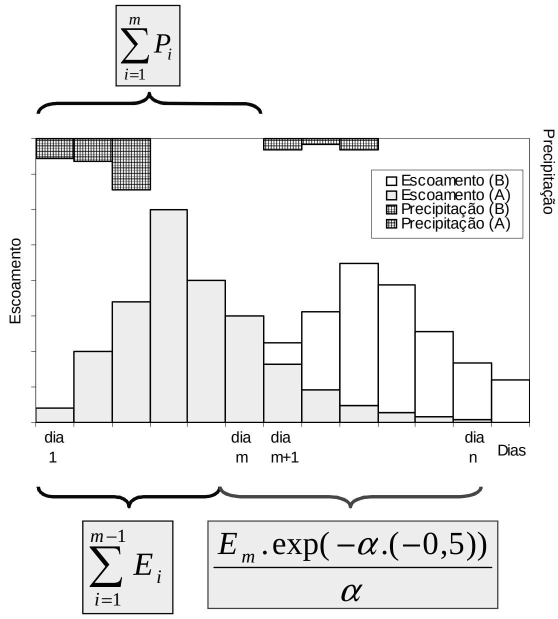


Fig. 25 – Components considered in the mass balance verification between precipitation and total flow corresponding to one episode of precipitation/flow.

The objective is to determine the α that satisfies the condition:

$$\sum_{i=1}^{m} P_i = \sum_{i=1}^{n} E_i \qquad \textbf{Eq. 69}$$

where P_i is precipitation on day i, E_i is total flow of day i, and n is the last day of episode A.

The member $\sum_{i=1}^{n} E_i$ may be separated in the following terms:

$$\sum_{i=1}^{n} E_i = \sum_{i=1}^{m-1} E_i + \frac{E_m.\exp(-\alpha.(-0,5))}{\alpha} \qquad \textbf{Eq. 70}$$

where $E_m.\exp(-\alpha.(-0,5))$ represents total flow in the beginning of day m and $\frac{E_m.\exp(-\alpha.(-0,5))}{\alpha}$ represents total flow since the beginning of day m until the depletion of episode A.

That is, replacing Eq. 70 on Eq. 69:

$$\alpha - \frac{\exp(0,5.\alpha)}{\sum_{i=1}^{m} P_i - \sum_{i=1}^{m-1} E_i}.E_m = 0 \qquad \textbf{Eq. 71}$$

In Dechidr_VB program, the resolution of this equation is made by the bisection method, using as minimum α the initially calculated (the one that made total flow to be larger than total precipitation) and as maximum α, 100 d^{-1}. The equation may present more than one solution for α. In this case the α closer to the initially calculated is chosen.

If total flow of episode A until the day before the starting of episode B is larger than precipitation of episode A, it is not possible to find a solution, and in this case an α = 100 d^{-1} is assumed, not being observed the mass balance criterion.

The consideration of the mass balance strengthens the flow hydrograph separation method, but makes it more dependent of the accurate computation of the precipitation that falls inside the watershed. If the precipitation inside the watershed is underestimated, this criterion will highly condition the computation of α and the total flow separation, penalizing base flow. For this reason, it is given in the program the possibility of not verifying the mass balance.

The third step consists in calculating flow of episode A in the days that follow the starting of episode B, using Eq. 68, with F_0 given by total flow in the day before the starting of episode B.

The advantages of the HS method in estimating recharge are: (1) it is easy to apply with precipitation and flow data usually available; (2) only requires the definition of two parameters (1- number of days in which there is direct runoff, and 2- precipitation threshold – if this parameter is considered); (3) it is not constrained to fixed parameters of the watershed because each P/R episode is considered separately; (4) it is able to control and maintain the mass balance between precipitation and the produced total flow; (5) it integrates all the processes of the hydrological cycle that take place in the watershed, measuring the response of the system to those processes; (6) it is applicable to the whole watershed, not requiring the definition of recharge and discharge areas of the groundwater medium.

The following limitations are referred to: (1) it is vulnerable to errors in the determination of total flow; (2) it is dependent on the as good as possible estimation of precipitation in the watershed, mainly if the balance between precipitation and total flow is used; (3) it considers that water streams are only receiving bodies (does not consider bank storage) and that all groundwater discharges to those streams inside the watershed; (4) it may not be used directly if there are dams that inhibit natural flow.

Base flow (or the discharge of groundwater) of a watershed is a measure of the groundwater recharge that has occurred in the watershed if: (1) there was no lateral groundwater flow entering the watershed, (2) groundwater flowed towards the surface streams inside the watershed, (3) there was no evaporation from shallow groundwater, (4) there was no human groundwater abstraction or its value was small enough and could be neglected.

5 Groundwater recharge assessment in Bahía Blanca

5.1 Previous studies

The Bahía Blanca case study area has been the focus of several recharge assessment studies. These studies were carried out for several parts of the study area and comprised different techniques for recharge estimation.

Carrica (1993) presented the daily sequential soil water balance model Balshort and applied it to the south western Pampean region to estimate the soil water excess.

Albouy (1994) in his PhD studied the recharge processes of the upper Río Sauce Chico basin.

Albouy and Bonorino (1997) estimated the average recharge of the Río Sauce Chico upper watershed as 123 mm.year^{-1} using precipitation (= 760 mm.year^{-1}) and temperature data for the period 1956-1985, and precipitation and surface runoff data for the period 1940-1945. From the recharge value of 123 mm.year^{-1}, 53 mm.year^{-1} is estimated as base flow and the remaining is recharge that flows outside the Río Sauce Chico upper watershed as groundwater flow. Base flow was estimated as 42 % of surface runoff using the methods of average monthly values of surface flow measured during the dry period and the graphical hydrograph separation technique.

Carrica and Lexow (2002, 2004) presented the estimation of the natural recharge of the upper Arroyo Napostá Grande basin (area = 195 km^2), using several techniques: sequential daily water balance at the basin scale (Visual Balan program – Samper *et al*. 1999) and at the soil scale (Balshort program – modified from Carrica, 1993); chloride balance and surface flow recession curve analysis. The surface flow recession curve analysis allowed to estimate an average base flow of 32 mm.year^{-1} and an average direct runoff of 35 mm.year^{-1}. This value of baseflow corresponds to 48 % of the surface flow and only 5.3 % of precipitation. The general conclusions presented by Carrica and Lexow (2004) are that the phreatic aquifer in this area receives direct rain recharge through the unsaturated zone, recharge located in the piedmont area and indirect recharge from bank storage during the streamflow peaks in smaller quantity. The main mechanism of groundwater recharge occurred in the piedmont area. The total groundwater recharge was estimated to be between 7 % and 9 % of the annual precipitation average (= 727 mm.year^{-1} for the period 1888-1998), that is recharge ≈ 51 mm.year^{-1} – 65 mm.year^{-1}.

During the development of a preliminary groundwater flow model in the coastal industrial area of Bahía Blanca, Albouy *et al*. (2005) used an average groundwater recharge of 150 mm.year^{-1}, with lower values of 100 mm.year^{-1} in natural occurring soils and values of 250 mm.year^{-1} in the areas occupied by the factories, that took also into account water originated from irrigation, pluvial discharges, pipe water losses, etc.

5.2 Surface flow information

According to Heffner (2003) the total surface flow to the estuary is 263,000 $m^3.d^{-1}$. This value is mainly achieved by the contributions of the (1) Naposta Grande river, with an average flowrate of 1.0 $m^3.s^{-1}$ or 86,400 $m^3.d^{-1}$, representing 26 $mm.year^{-1}$ (watershed = 1,237 km^2), and 4.4 % of the precipitation (considered as 585 $mm.year^{-1}$) and (2) Sauce Chico river with an average flowrate of 1.9 $m^3.s^{-1}$ or 164,000 $m^3.d^{-1}$, representing 37 $mm.year^{-1}$ (watershed = 1,600 km^2), and 6.3 % of the precipitation. The remaining 5 % of the surface flow comes from other smaller watersheds that comprise the Maldonado channel (from a natural drainage), Saladillo de García and Dulce, where the last two constitute the Maldonado river.

The average values presented by Heffner (2003) are in the same order of magnitude of the measurements carried out during the EcoManage Project: from 2006-03-24 until 2008-03-18 the average flowrate of Napostá Grande was determined to be 91,105 $m^3.d^{-1}$ (27 $mm.year^{-1}$) and from 2006-03-31 until 2008-03-18 the average flowrate of the Sauce Chico was determined to be 118,065 $m^3.d^{-1}$ (27 $mm.year^{-1}$).

The weighted average of the values calculated for Sauce Chico and Napostá Grande represent 5.5 % of the precipitation (= 585 $mm.year^{-1}$). Assuming that this value is representative of the average surface flow to the estuary, this is estimated to be 32 $mm.year^{-1}$. As surface flow to the estuary has been estimated by Heffner (2003) to be 263,000 $m^3.d^{-1}$, the estimated value corresponds to a contribution area of 3,000 km^2. The knowledge of this value of surface flow equal to 32 $mm.year^{-1}$ is important because it allows to validate the groundwater recharge assessment results obtained using the sequential daily water balance models.

5.3 Climate information

In the beginning of this study several climate stations were searched to provide the required data. The identified stations are presented in Table 8. The stations Puerto Rosales, Altos de Palihue, Aerodrome and Puerto Cuatreros are located close to the city of Bahía Blanca. Tres Picos is located more to the north, south of the city of Tornquist. The data available at each station is represented in Table 9.

Table 8 – Location of the meteorological stations and data source

Meteorological station	Latitude	Longitude	Altitude (masl)	Data source
Puerto Rosales	38º 55' 20" S	62º 04' 20" W		Instituto Argentino de Oceanografía
Tres Picos	38º 17' 26" S	62º 10' 17" W	210	Laboratory of Hydrology of Universidad Nacional del Sur
Altos de Palihue	38º 44' S	62º 10' W	41	Universidad Nacional del Sur
Puerto Cuatreros	38º 45' S	62º 23' W		Instituto Argentino de Oceanografía
Cerro Manitoba	38º 06' S	62º 06' W		Universidad Nacional del Sur
Bahía Blanca Aerodrome	38° 44' S	62° 10' W	83	http://meteo.infospace.ru/wcarch/html/e_day_stn.sht?stn=4911 http://www.tutiempo.net/clima/Bahia_Blanca_Aerodrome/877500.htm

Table 9 – Meteorological stations and summary of the available data

Meteorological station	Available data							
	Precipitation	Temperature	Pressure	RH	Wind	Solar radiation	Daily cloudiness	Dates with data
Puerto Rosales	Incomplete daily data	Incomplete hourly data for min. and max. Incomplete daily data for average Temperature	Incomplete daily data	Incomplete hourly data for min. and max. Incomplete daily data for average RH	Incomplete daily data			Jan, 1st 1999 – Dec, 31st 2005
Tres Picos	Incomplete?? ?? hourly data							August, 5th 2004 – May, 10th 2008
Altos de Palihue	Incomplete daily data	Incomplete daily data		Incomplete daily data	Incomplete daily data			Jan, 1st 1998 – Dec, 31st 2000
Bahia Blanca Aerodrome	Almost complete daily data	Almost complete daily data	Almost complete daily data	Almost complete daily data	Almost complete daily data		Almost complete daily data	Mar, 9th 2000 – Mar, 5th 2008
Puerto Cuatreros						Incomplete daily data		Dec, 1st 1999 – Dec, 31st 2005
Cerro Manitoba	Daily data							Jan, 1st 1935 – Dec, 31st 1945

Data is available for the period January, 1998 – March, 2008. For the period March, 2000 – March, 2008 it is possible to generate time-series for the entire climate data, coming from the meteorological station of Bahia Blanca Aerodrome published in the site http://meteo.infospace.ru/wcarch/html/e_day_stn.sht?stn=4911. Data on precipitation from this site is almost always null.

However, the site http://www.tutiempo.net/clima/Bahia_Blanca_Aerodrome/877500.htm provides precipitation data for the same location. Table 10 identifies the missing data. For a common data period, a cross correlation was tried between this data and precipitation data recorded on Altos de Palihue (Fig. 26). The squared regression coefficient (R^2) is extremely low, and there seems to be no relation between these two variables. For this reason missing data in Bahia Blanca Aerodrome records were assumed to be zero.

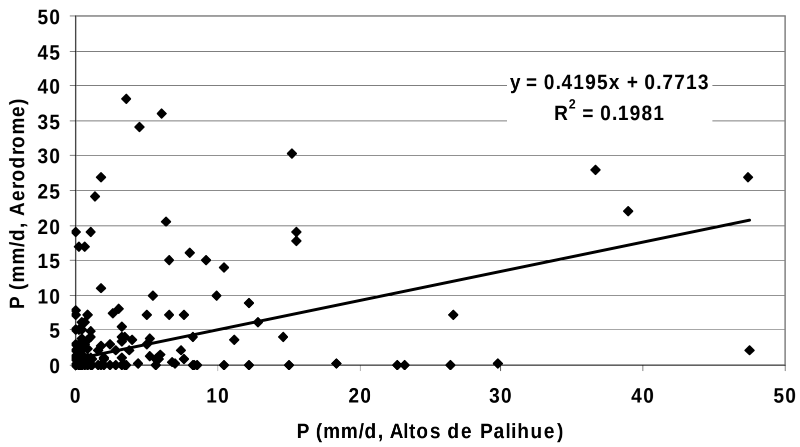


Fig. 26 – Cross-relation between daily precipitation recorded in Bahía Blanca Aerodrome and Altos de Palihue stations

Table 10 – Missing daily precipitation data on Bahía Blanca Aerodrome station

2000-01-31; 2000-02-07; 2000-02-23; 2000-03-19; 2000-04-15; 2000-05-06; 2000-05-17; 2000-06-24; 2000-07-09; 2000-07-14; 2000-07-18; 2000-07-20; 2000-07-22; 2000-09-14; 2000-09-22; 2000-10-02; 2000-10-15; 2000-10-20; 2000-11-04; 2000-11-30; 2000-12-15; 2001-01-16; 2001-02-09; 2001-02-17; 2001-02-24; 2001-02-27; 2001-04-13; 2001-04-30; 2001-05-12; 2001-05-15 and 2001-05-16; 2001-06-15; 2001-07-24; 2001-09-28; 2001-10-06; 2001-11-19; 2001-12-16; 2002-01-03; 2002-01-09; 2002-01-18; 2002-01-30; 2002-02-03; 2002-03-26; 2002-04-06; 2002-04-22; 2002-05-13; 2002-05-16; 2002-06-03; 2002-06-18 until 2002-06-21; 2002-06-28; 2002-07-20; 2002-08-26; 2002-09-07; 2003-01-13; 2003-03-01; 2003-09-23; 2005-08-07; 2005-08-13; 2005-08-23; 2005-09-03; 2005-10-21; 2005-11-17; 2005-12-22; 2006-01-23; 2006-02-21; 2006-02-26; 2006-04-12; 2006-05-05; 2006-06-08; 2006-10-13; 2006-11-30; 2006-12-13; 2007-03-06 and 2007-03-07; 2007-04-01; 2007-06-12; 2007-07-05; 2007-08-28; 2007-12-20; 2008-02-10; 2008-02-12; 2008-02-15; 2008-02-18; 2008-03-22

Table 11 – Monthly precipitation registered on Bahía Blanca Aerodrome station

Year	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000			48.5	9.9	84.1	18.0	12.4	24.6	45.5	43.7	44.5	3.8	
2001	58.4	60.2	53.6	169.9	65.5	21.8	16.5	101.6	68.3	126.5	52.1	13.7	808.1
2002	83.6	7.1	77.5	84.8	49.3	7.1	29.0	129.0	13.5	214.6	123.4	54.9	873.7
2003	27.9	71.9	21.8	19.6	60.5	17.3	0.0	13.5	39.9	163.8	54.4	91.7	582.2
2004	68.1	98.1	63.8	153.7	0.5	30.2	109.0	27.2	45.0	95.5	63.0	212.9	966.8
2005	18.3	156.7	37.1	121.4	153.2	28.0	71.4	21.1	95.3	14.0	67.3	46.0	829.5
2006	57.9	95.0	12.2	34.0	0.5	72.6	65.0	8.1	14.7	127.8	15.0	72.9	575.8
2007	72.1	115.8	80.3	154.9	10.7	0.0	8.4	26.9	98.6	73.4	38.4	17.3	696.7
2008	30.2	88.6											
Average	52.1	86.7	49.3	93.5	53.0	24.4	39.0	44.0	52.6	107.4	57.2	64.1	761.8

Note: The dates with missing data reported in Table 10 were assigned precipitation = 0. In the corresponding months monthly precipitation may be underestimated

Table 12 lists the climate data availability needed to compute daily reference evapotranspiratiom for the daily sequential water balance model, identifying the existing gaps.

Table 12 – Climate data used to estimate reference evapotranspiration and missing data for the period 2000-03-01 to 2008-02-29

Variable	Daily temperature		Daily relative humidity		Daily atmospheric pressure	Daily wind speed	Daily cloudiness
	maximum	minimum	maximum	minimum			
Units	ºC	ºC	%	%	KPa	m/s	%

The following dates have missing data for all the variables and were filled with the value registered in the last previous day with data:

2000-03-17; 2000-03-20; 2000-04-09; 2000-04-17; 2000-06-05; 2000-08-01; 2000-08-22; 2000-11-15;

2000-12-30 until 2001-01-01; 2001-01-30 until 2001-01-31; 2001-05-25 until 2001-05-26; 2001-07-31;

2001-09-07 until 2001-09-08; 2001-09-10 until 2001-09-11; 2001-11-23 until 2001-11-24; 2002-01-05 until 2002-01-06;

2002-02-16; 2002-04-06; 2002-04-15; 2002-06-10; 2002-08-21; 2002-10-19 until 2002-10-20; 2002-12-14;

2002-12-27 until 2002-12-29; 2003-03-01; 2003-04-04 until 2003-04-09; 2003-04-13; 2003-04-27; 2003-06-15; 2003-07-04; 2003-09-29.

The following dates have missing data for all the variables and were filled with the value registered in the day 2000-03-09: 2000-03-01 until 2000-03-08.

The following dates have missing data for daily atmospheric pressure and daily wind speed and were filled with the value registered in the previous day:
2001-09-28; 2003-03-19; 2003-08-06.

The following date has missing data for daily maximum relative humidity and was filled with the value registered in the previous day:
2006-03-25.

The following date has missing data for daily maximum relative humidity and was filled with the value registered in the following day:
2007-03-12.

Until 2004-06-15 there is information concerning daily minimum and maximum temperature. From 2004-06-16 this information is not available, but as six-hour data on temperature is available, at 0:00, 6:00, 12:00 and 18:00 (UTC - Universal Time Coordinated), the minimum and the maximum values of these records were attributed to the minimum and maximum daily temperature values.

For the relative humidity only the six-hour data was available for the whole period. For this reason the minimum and maximum recorded values were used as minimum and maximum relative humidity of the corresponding days.

The values presented for atmospheric pressure and wind velocity are daily averages of the six-hour data.

Finally, cloudiness, originally expressed in terms of tenths of sky covered by clouds, was calculated using the daily average of the six-hour data and then, despite existing Table 6 that could transform it into the relation n/N, a numerical approximation was applied, with the formula:

$$n/N = (10 - cloudiness) / 10 * 100\ \% \qquad \textbf{Eq. 72}$$

Table 13 shows the average monthly climate values obtained for the data registered on Bahía Blanca Aerodrome station.

Table 13 – Average monthly values of the climate variables registered on Bahía Blanca Aerodrome station

Date	Maximum daily temperature	Minimum daily temperature	Maximum daily relative humidity	Minimum daily relative humidity	Daily atmospheric pressure	Daily wind speed	Daily cloudiness
	(ºC)	(ºC)	(%)	(%)	(KPa)	(m/s)	(%)
2000-03	23.3	14.2	77.5	50.2	100.34	7.28	56.26
2000-04	19.9	9.7	88.0	54.5	100.65	6.48	60.56
2000-05	14.7	7.0	91.6	67.5	100.85	6.59	42.98
2000-06	13.0	4.9	90.6	68.7	100.44	6.63	40.19
2000-07	10.6	2.4	87.3	64.2	100.79	7.53	41.42
2000-08	12.9	3.1	84.6	55.5	100.72	7.75	47.50
2000-09	14.8	5.3	85.7	54.9	100.75	7.97	46.67
2000-10	17.5	8.6	84.6	56.7	100.69	7.39	46.13
2000-11	22.3	10.6	75.3	40.1	100.23	7.95	57.42
2000-12	27.4	14.9	60.6	23.1	99.92	8.85	67.42
2001-01	29.4	16.9	68.8	29.9	100.00	9.09	49.19
2001-02	29.3	17.6	72.0	35.7	99.97	8.26	68.39
2001-03	24.5	15.0	82.9	50.3	100.47	6.91	59.03
2001-04	18.6	9.4	87.2	57.0	100.58	6.28	57.17
2001-05	14.4	7.3	90.3	70.3	100.73	5.74	38.39
2001-06	12.9	4.6	90.1	64.5	100.88	7.04	50.42
2001-07	10.9	3.0	85.8	62.8	100.65	7.51	35.56
2001-08	14.7	6.9	86.0	62.9	100.76	6.15	46.69
2001-09	15.2	6.2	85.1	59.2	101.03	6.97	47.08
2001-10	19.3	11.1	92.4	69.0	100.65	7.14	34.11
2001-11	22.9	11.8	82.5	43.8	100.28	7.05	64.42
2001-12	26.6	14.7	72.2	40.5	100.25	8.59	61.69
2002-01	27.5	15.9	81.2	41.7	100.22	8.45	45.48
2002-02	26.7	14.8	77.0	40.2	100.35	7.36	67.14
2002-03	23.1	12.8	80.0	44.9	100.29	6.07	51.45
2002-04	18.3	9.3	84.3	56.8	100.47	6.85	61.92
2002-05	15.6	7.3	88.6	67.0	100.45	6.70	44.35
2002-06	11.2	1.5	83.4	59.8	100.85	6.75	57.17
2002-07	11.8	2.8	86.3	63.1	100.88	6.10	46.21
2002-08	13.0	6.0	84.9	61.7	100.46	6.91	29.35
2002-09	16.1	6.5	85.4	57.1	100.65	5.64	45.92
2002-10	20.8	10.8	83.6	52.4	100.16	6.93	50.40
2002-11	22.9	12.5	82.3	48.0	100.09	7.01	52.39
2002-12	26.8	15.3	78.5	44.7	100.20	8.20	50.86
2003-01	29.6	17.0	72.5	34.5	99.89	7.95	65.16
2003-02	26.8	15.7	75.6	40.3	99.97	7.86	69.20
2003-03	26.3	14.3	76.8	44.4	100.44	7.37	60.40
2003-04	17.9	8.9	86.4	59.2	100.83	4.91	42.50
2003-05	16.5	7.1	86.0	56.4	100.64	6.44	52.66
2003-06	13.7	5.3	83.0	56.6	100.55	6.92	41.67
2003-07	12.5	2.3	80.7	53.8	100.80	5.91	56.69
2003-08	13.3	3.3	80.8	53.4	101.11	5.61	57.66
2003-09	17.3	6.9	76.1	46.3	100.77	6.03	43.17
2003-10	21.0	10.7	79.9	50.3	100.36	6.43	52.74
2003-11	23.8	13.3	72.9	39.6	100.10	6.15	63.75
2003-12	26.1	14.4	63.0	27.0	99.92	6.59	62.74
2004-01	29.6	17.5	66.7	32.3	100.22	6.48	52.82
2004-02	25.5	14.8	77.3	43.2	100.57	5.52	44.31

Table 13 – Average monthly values of the climate variables registered on Bahía Blanca Aerodrome station (cont.)

Date	Maximum daily temperature	Minimum daily temperature	Maximum daily relative humidity	Minimum daily relative humidity	Daily atmospheric pressure	Daily wind speed	Daily cloudiness
	(ºC)	(ºC)	(%)	(%)	(KPa)	(m/s)	(%)
2004-03	26.5	16.5	74.3	42.6	100.37	5.90	33.23
2004-04	19.3	11.2	82.7	57.8	100.40	5.20	35.83
2004-05	13.8	4.5	84.6	48.4	101.36	4.43	48.85
2004-06	14.0	6.0	84.3	46.6	100.49	6.13	55.57
2004-07	13.0	5.2	82.5	55.1	100.72	5.73	56.37
2004-08	14.0	5.7	87.4	57.2	100.97	4.78	59.06
2004-09	18.6	7.9	74.0	34.4	100.67	5.75	68.78
2004-10	19.6	9.6	84.1	45.9	100.36	6.23	60.31
2004-11	23.3	13.2	83.0	43.1	100.45	5.20	59.23
2004-12	27.2	17.1	78.4	37.8	100.13	6.08	68.53
2005-01	28.5	18.2	66.5	28.4	100.04	6.56	80.40
2005-02	27.9	18.3	80.8	43.8	100.44	4.60	65.30
2005-03	25.6	15.0	75.9	33.5	100.36	4.99	80.00
2005-04	20.8	9.3	77.3	32.2	100.63	5.07	80.75
2005-05	17.1	7.5	75.4	39.7	100.24	5.26	65.16
2005-06	12.5	5.6	86.1	58.0	100.69	4.91	50.06
2005-07	12.8	4.3	87.9	58.1	100.95	4.92	54.09
2005-08	13.7	6.1	85.2	48.2	100.79	5.70	49.44
2005-09	17.4	6.9	84.3	39.4	101.10	4.79	68.00
2005-10	20.7	9.8	71.9	29.8	100.64	5.17	68.12
2005-11	25.5	14.8	66.2	27.8	100.15	5.53	72.25
2005-12	25.5	15.0	73.0	28.1	99.58	5.31	68.20
2006-01	28.4	18.0	66.9	27.1	100.16	5.65	79.14
2006-02	27.9	18.4	77.7	38.0	100.23	5.96	70.95
2006-03	24.7	14.0	76.4	35.2	100.31	6.20	77.77
2006-04	22.2	12.5	79.0	37.3	100.48	6.12	73.19
2006-05	16.0	6.2	82.0	44.7	101.13	5.39	60.30
2006-06	13.1	4.9	85.3	51.9	100.69	5.50	52.19
2006-07	14.2	6.2	81.0	48.2	100.50	6.22	58.23
2006-08	15.3	4.9	78.6	38.8	100.66	5.08	66.10
2006-09	18.8	7.5	69.0	29.4	100.65	5.28	71.19
2006-10	20.8	11.3	80.2	40.0	100.38	6.22	68.28
2006-11	24.8	13.7	62.1	25.9	100.34	6.74	79.86
2006-12	28.8	18.6	65.6	26.6	99.95	7.46	75.11
2007-01	29.2	18.8	71.3	32.1	100.10	8.03	76.24
2007-02	27.4	16.4	82.2	43.4	100.13	7.29	67.47
2007-03	24.1	14.9	86.1	50.3	100.36	7.81	69.62
2007-04	21.8	11.3	84.8	48.1	100.47	6.12	81.25
2007-05	14.0	5.1	86.8	50.6	100.90	6.60	67.88
2007-06	14.0	2.0	80.7	40.5	100.50	5.95	78.64
2007-07	11.6	1.0	77.5	42.0	100.65	5.60	78.28
2007-08	13.3	2.8	83.4	46.5	101.13	5.92	64.76
2007-09	18.0	9.4	84.1	50.8	100.82	7.41	63.31
2007-10	21.6	12.0	82.3	46.7	100.33	6.55	67.53
2007-11	23.1	12.0	74.6	39.1	100.15	7.30	76.14
2007-12	28.9	16.5	68.7	33.1	100.07	6.91	81.18
2008-01	29.6	19.5	72.7	41.6	100.19	7.15	70.30
2008-02	28.8	18.8	80.5	45.8	100.26	6.67	70.63

5.4 Calculation of reference evapotranspiration

The reference evapotranspiration was calculated using the methodology described in section 4.2.5.2. Data came from the meteorological station of Bahia Blanca Aerodrome (Table 8).

The results obtained are shown graphically in Fig. 27.

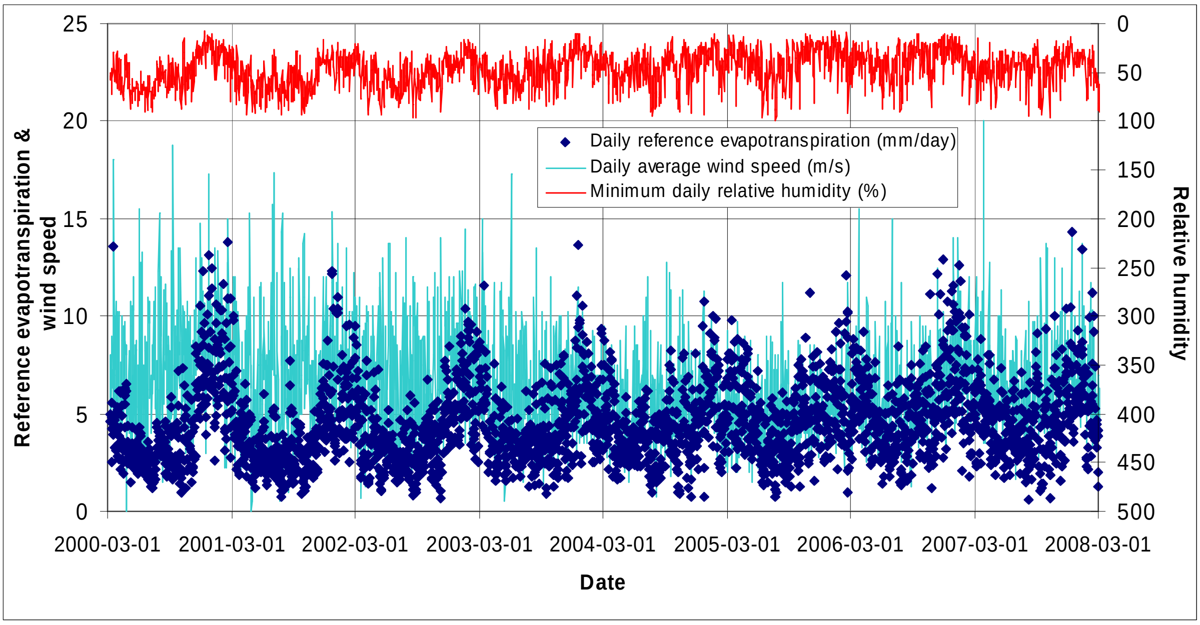


Fig. 27 – Daily reference evapotranspiration calculated for the Bahía Blanca aerodrome

The monthly values are represented on Fig. 28 and on Table 14. The higher values occur in December and January while the lower values usually occur in June and July.

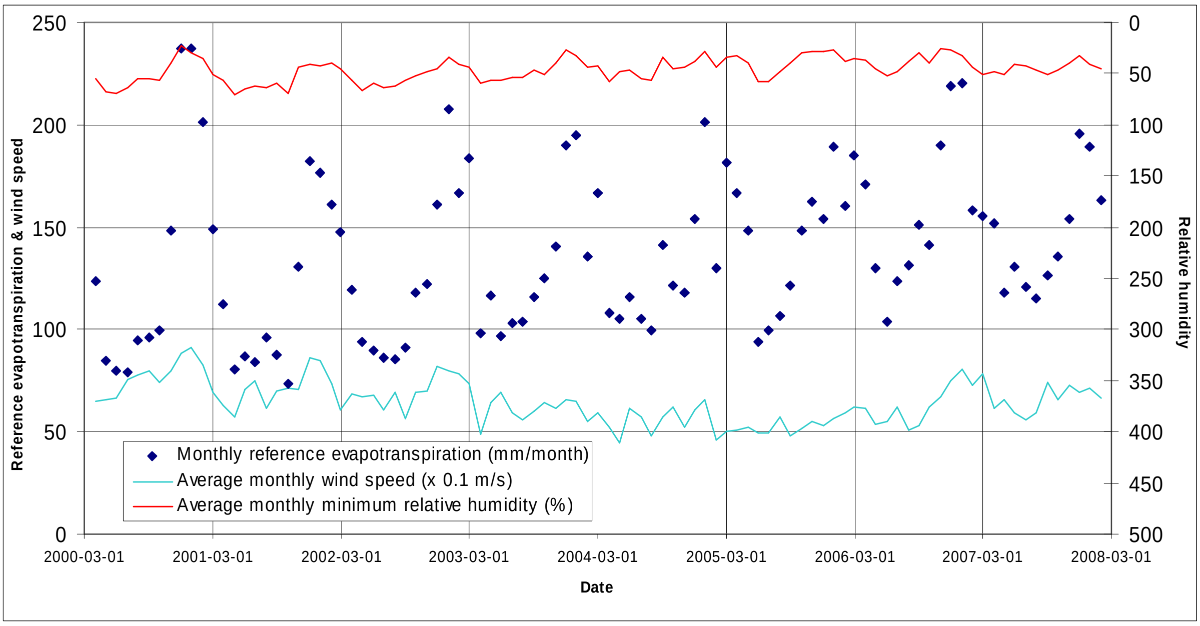


Fig. 28 – Monthly reference evapotranspiration calculated for the Bahía Blanca aerodrome

Table 14 – Monthly reference evapotranspiration computed using climate date registered on Bahía Blanca Aerodrome station

Year	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000			155.8	123.8	85.1	80.0	79.1	94.5	96.1	99.7	148.1	237.3	
2001	237.3	201.5	149.3	112.4	80.2	87.1	83.9	95.7	87.3	73.6	130.4	181.9	1520.6
2002	176.9	161.2	147.8	119.2	94.2	89.9	86.2	85.7	91.2	117.7	122.0	161.2	1453.3
2003	207.9	166.7	183.8	98.3	116.8	96.6	103.1	103.7	116.1	125.1	140.3	190.2	1648.5
2004	194.9	135.4	166.8	108.0	105.5	116.1	105.1	99.4	141.2	121.2	118.2	154.2	1566.1
2005	201.5	130.2	181.4	167.0	148.6	94.3	99.3	106.5	121.6	148.4	162.7	153.9	1715.4
2006	189.1	160.2	185.0	171.1	130.1	104.0	123.3	131.0	150.8	140.9	190.2	219.0	1894.9
2007	220.0	158.1	155.5	151.8	117.8	130.6	120.4	115.2	126.3	135.9	153.6	195.9	1781.3
2008	189.2	163.5											
Average	202.1	159.6	165.7	131.5	109.8	99.8	100.1	104.0	116.3	120.3	145.7	186.7	1654.3

5.5 Soil data

Soil has an important role in the water balance. It constitutes a buffer zone that conditions the water that can infiltrate into the soil, from where plants take water for evapotranspiration, and from where the excess water in the soil percolates to constitute deep percolation. Water that is deep infiltrated will no longer be available for evapotranspiration and is available to groundwater recharge. The amount of water that infiltrates into the soil, the water that the soil can store and the velocity by which water flows in the soil depends on the hydraulic properties of the soil. Some of these properties may be derived from laboratory tests. But in several cases these tests are not carried out. So, one possible source of information is the pedotransfer functions that relate soil hydraulic properties with soil textural analysis.

The Soil Map of the Buenos Aires Province of the Argentine Republic (INTA-CIRN, 1989) and the explanatory note provide information on the textural analysis of the soils. The soils have been presented in section 1.3. The following formulations were used to transfer textural information into estimations of porosity, field capacity, wilting point, all expressed in volume/volume units, and the hydraulic conductivity (length/time unit).

The soil porosity (ϕ) can be estimated by means of the equation

$$\phi = \sum_{1}^{h} \left(\phi_i . esp_i\right) \Big/ \sum_{1}^{h} esp_i \qquad \textbf{Eq. 73}$$

where h: number of soil horizons, esp_i: thickness of horizon i, ϕ_i: porosity of horizon i.

The porosity of each horizon can be determined in laboratory or can be estimated from equations which relate the porosity with other easier to obtain soil parameters. According to Rawls and Brakensiek (1989):

$$\phi_i = (2.65 - \rho_d) / 2.65 \qquad \textbf{Eq. 74}$$

where ρ_d: apparent density of soil.

If there is no determination of ρ_d, it can be estimated through:

$$\rho_d = 1.51 + 0.0025 . S - 0.0013 . S . MO - 0.0006 . C . MO - 0.0048 . CECc \qquad \textbf{Eq. 75}$$

where S: % of weight of sand, C: % of weight of clay, MO: % of organic matter, CEC_c: cationic exchange capacity of clay. Sand represent soil particles with dimensions in the range 2 mm to 0.05 mm, silt the soil particles in the range 0.05 mm to 0.002 mm, and clay the soil particles whose size is below 0.002 mm. In these formulas $C + S$ + % of weight of silt represent 100 %.

CEC_c can be estimated starting from Alberts *et al*., 1995:

$$CECc = CECsoil - MO \,.\, (1.42 + 1.70 \,.\, esp)$$ **Eq. 76**

For the characterisation of the hydraulic conductivity (K_s) the main source of information is pumping test analysis. So far this data is not available for the EcoManage Project. However, this parameter can be estimated as a function of the soil properties (Rawls and Brakensiek, 1989):

$$\ln K_s = 19.52348.\phi - 8.96847 - 0.028212.C + 0.00018107.S^2 - 0.0094125.C^2 \\ -8.395215.\,\phi^2 + 0.077718.S.\,\phi - 0.00298.S^2.\,\phi^2 - 0.019492.C^2.\,\phi^2 + 0.0000173.S^2.C \\ + 0.02733.C^2.\,\phi + 0.001434.S^2.\,\phi - 0.0000035.C^2.S$$ **Eq. 77**

where K_s (cm/h), S: % of weight of sand, C: % of weight of clay, ϕ: porosity of soil, and the formula is valid for 5% < C < 60% and 5% < S < 70%.

The field capacity of soil can be estimated by means of the equation:

$$cc = \Sigma\ [(pF\ 2 \text{ ou } pF\ 2.5)_i * esp_i] / \Sigma\, esp_i$$ **Eq. 78**

where the sum develops for all the horizons and esp_i is the thickness of horizon i. pF represents the logarithm of the pressure given by the height expressed in cm of a column of water. In this case, $pF\ 2$ represents a pressure of 0.1 atmosphere (or 103.3 cm of water column), and $pF\ 2.5$ represents a pressure of 0.33 atmosphere. These values are representative of the water suction that exists in a soil when its water content is at its field capacity.

When there is no determination of $pF\ 2$ or $pF\ 2.5$ in the laboratory, the following equation allows estimate $pF\ 2.5$ (Rawls and Brakensiek, 1989):

$$pF\ 2.5 = 0.2576 - 0.002\,.\,S + 0.0036\,.\,C + 0.0299\,.\,MO$$ **Eq. 79**

Using a similar procedure, the wilting point of soil, which is given by a suction of around 15 atmosphere or $pF\ 4.2$, is calculated through:

$$wp = \Sigma\,[(pF\ 4.2)_i * esp_i] / \Sigma\, esp_i$$ **Eq. 80**

If $pF\ 4.2$ is not determined in laboratory it can be estimated by means of the following pedotransfer equation (Rawls and Brakensiek, 1989):

$$pF\ 4.2 = 0.026 + 0.005\,.\,C + 0.0158\,.\,MO$$ **Eq. 81**

The values of porosity, field capacity, wilting point, hydraulic conductivity and the material of the upper horizon (excluding Ap) are presented in Table 15. Annex 3 presents the values obtained for the characterisation of these soil properties.

Table 15 – Soil hydraulic properties of the land Bahía Blanca estuary area

EDAPHIC DOMAIN	CARTOGRAPHIC UNIT (CU)	TAXONOMIC UNIT (TU)	%	Porosity [-]	Field capacity [-]	Wilting point [-]	Material of the upper horizon (Ap excluded)	Hydraulic conductivity [$mm.d^{-1}$]
1	1a	Rock [18]	60	0.003	0.0015	0.0007	5-clay	0.001
		M_{18}li3	40	0.56	0.41	0.24	10-clay loam	637
	1d	M_{17}tc3i (7)	50	0.48	0.33	0.18	6-loam	101
		M_{18}tc4i (8)	50	0.47	0.27	0.20	10-clay loam	42
2	2c	M_{17}tc3i [1]	50	0.48	0.33	0.18	6-loam	101
		M_{17}tcsi [1]	30	0.48	0.33	0.18	6-loam	101
		M_{18}pa [2]	20	0.61	0.55	0.31	10-clay loam	410
	2f	M_{17}tc3	50	0.48	0.33	0.18	6-loam	101
		M_{17}tc [1]	30	0.48	0.33	0.18	6-loam	101
		M18pa [2]	20	0.61	0.55	0.31	10-clay loam	410
	2g	M_{17}tc3	50	0.48	0.33	0.18	6-loam	101
		M_{17}tcs [1]	30	0.48	0.33	0.18	6-loam	101
		M_{17}tcs' [1]	20	0.48	0.33	0.18	6-loam	101
	2p	M_{17}tc3s' [1]	60	0.48	0.33	0.18	6-loam	101
		E_{25}tc	40	0.37	0.11	0.07	1-sand	3703
3	3a	M_{24}tc2	50	0.49	0.38	0.24	10-clay loam	38
		M_{24}eni [6]	30	0.44	0.29	0.16	8-sandy clay loam	92
		M_{24}li [9]	20	0.53	0.39	0.22	10-clay loam	385
	3b	M_{24}tc2s' [10]	50	0.49	0.38	0.24	10-clay loam	38
		M_{21}tcs' [11]	30	0.49	0.34	0.19	6-loam	151
		M_{24}tc [10]	20	0.49	0.38	0.24	10-clay loam	38
	3c	M_{21}tc3s	60	0.49	0.34	0.19	6-loam	151
		M_{24}li [9]	40	0.53	0.39	0.22	10-clay loam	385
4	4a	M_{24}en4	50	0.43	0.21	0.12	7-sandy loam	1244
		M_{24}ens [17]	30	0.43	0.21	0.12	7-sandy loam	1244
		E_{23}us	20	0.39	0.12	0.07	1-sand	5712
	4b	M_{24}en4	50	0.43	0.21	0.12	7-sandy loam	1244
		E_{26}tcs	30	0.41	0.17	0.10	7-sandy loam	2000
		E_{26}tc	20	0.39	0.13	0.06	7-sandy loam	2509
	4c	E_{26}tc	50	0.39	0.13	0.06	7-sandy loam	2509
		E_{23}us	30	0.39	0.12	0.07	1-sand	5712
		E_{22}tc	20	0.35	0.08	0.04	1-sand	3932
12	12a	M_{21}tc2	50	0.45	0.29	0.16	6-loam	167
		M_{21}tcs [12]	30	0.45	0.29	0.16	6-loam	167
		F_{28}tc [13]	20	0.41	0.21	0.13	7-sandy loam	442
26	26a	E_{13}ac3	> 85%	0.49	0.36	0.17	9- silty clay loam	30
	26b	E_{13}ac3	60	0.49	0.36	0.17	9- silty clay loam	30
		F_{28}tc [14]	40	0.48	0.34	0.17	11-silt loam	50
	26c	A_{11}ah4	60	0.45	0.26	0.15	7-sandy loam	226
		M_{25}tc [15]	40	0.46	0.33	0.18	6-loam	39
27	27a	E_{25}tc	50	0.37	0.12	0.06	2-loamy sand	2201
		E_{22}tc	30	0.44	0.08	0.03	1-sand	4267
		M_{18}en [16]	20	0.42	0.21	0.11	8-sandy clay loam	506
	27c	M_{24}en4	60	0.41	0.19	0.10	7-sandy loam	1112
		E_{26}tc	40	0.38	0.15	0.09	7-sandy loam	2454
M	Miscelaneous							

These taxonomic units (TU) don't have descriptions. The following TU were assumed:
[1] M_{17}tc3, [2] M_{18}pa3, [6] M_{24}en3i, [7] M_{17}tc3 of edaphic domain 3, [8] M_{18}tc4 of edaphic domain 3, [9] M_{24}li3, [10] M_{24}tc2, [11] M_{21}tc3s, [12] M_{21}tc2, [13] F_{28}tc3, [14] F_{28}tc3, [15] M_{25}tc4, [16] M_{18}en4, [17] M_{24}en4, [18] These are assumed values for the outcropping rock.

5.6 Land cover data

5.6.1 Introduction

Land cover information is important to define the crop coefficient curve and to define the maximum soil depth that may be subject to evapotranspiration.

The classes "Tidal flats", "Saltmarshes", "Water" and "Water and sediments" are not used to compute groundwater recharge.

For the other classes the parameters are presented in the next sections.

5.6.2 Crops – small (fallow land, wheat)

It is assumed that half the area classified in this class is occupied by wheat and the other half by the fallow land.

Wheat

According to the information provided by Eng. Agr. Jorge Lusto of the Department of Agronomy of the Universidad Nacional del Sur of Bahía Blanca (UNS), the wheat is sown between mid May-end June, and it is harvested between end December-mid January. Hence the day of June, 12th is assumed for the first day of the crop (day_ini), and all the vegetation periods are recalculated to this harvest time: initial stage length (L_ini) = 40 day, crop development length (L_dev) = 65 day, mid-season length (L_mid) = 65 day, late-season length (L_end) = 44 day. The basal crop coefficients are the following: Kcb_ini = 0.15, Kcb_mid = 1.10, Kcb_end = 0.15. The maximum height of the culture (H_cult) is 1 m, maximum root depth (Rp_1) is 1,500 mm and minimum root depth is (Rp_0) is 150 mm. The fraction of the area occupied during the mid-season and late-season stages (fc_max) is 100 % and the fraction of the area occupied during the initial stage of the development (fc_min) is 10 %. The threshold amount of water stored in the soil that allows the effective evapotranspiration to occur at the maximum rate (p) is 55 %.

Fallow land

Fallow land is assumed to be a bare soil. Thus, recharge computations in the fallow land are the same as carried out for the bare soil.

5.6.3 Pastures (for cattle)

In the case of pastures, it is assumed that the grass remains the whole year, and that the basal crop coefficient is constant = 0.90. The root depth is 500 mm. Plant height is 10 cm. The threshold amount of water stored in the soil that allows the effective evapotranspiration to occur at the maximum rate (p) is 40 %.

5.6.4 Bare soil (sowed land and/or urban area)

It is assumed that half the area classified in this class is occupied by the bare soil and the other half by the urban area.

The sowed land is treated as a bare soil (section 5.6.9).

The urban area is considered as impermeable, hence with no recharge, in 90 % of the area. The remaining 10 % of the area is also treated as a bare soil (section 5.6.9).

5.6.5 Crops (sunflowers, soy)

As for the other cases where two land uses are presented it is assumed that half the area classified in this class is occupied by sunflower and the other half by the soy cover.

<u>Sunflower</u>

According to the information provided by Eng. Agr. Jorge Lusto, sunflower is sown between mid October-November, and is harvested in March-April. *Day_ini* is thus assumed as November, 1st. The development periods and the basal crop coefficients are as described in Allen et al. (1998): *L_ini* = 25 day, *L_dev* = 35 day, *L_mid* = 45 day, *L_end* = 25 day, *Kcb_ini* = 0.15, *Kcb_mid* = 0.95, *Kcb_end* = 0.25. The maximum height of the culture (*H_cult*) is 1 m, maximum root depth (*Rp_1*) is 1,000 mm and minimum root depth is (*Rp_0*) is 150 mm. The fraction of the area occupied during the mid-season and late-season stages (*fc_max*) is 100 % and the fraction of the area occupied during the initial stage of the development (*fc_min*) is 10 %. The threshold amount of water stored in the soil that allows the effective evapotranspiration to occur at the maximum rate (*p*) is 45 %.

<u>Soy</u>

Soy is sown from end October until December. It is harvested between March and May. To run the BALSEQ_MOD model the following periods were assumed: *Day_ini* = December, 1st; *L_ini* = 20 day, *L_dev* = 25 day, *L_mid* = 75 day, *L_end* = 30 day, *Kcb_ini* = 0.15, *Kcb_mid* = 1.1, *Kcb_end* = 0.30. The maximum height of the culture (*H_cult*) is 0.8 m, maximum root depth (*Rp_1*) is 1,000 mm and minimum root depth is (*Rp_0*) is 150 mm. The fraction of the area occupied during the mid-season and late-season stages (*fc_max*) is 100 % and the fraction of the area occupied during the initial stage of the development (*fc_min*) is 10 %. The threshold amount of water stored in the soil that allows the effective evapotranspiration to occur at the maximum rate (*p*) is 50 %.

5.6.6 Crops (sorghum, maize)

It is assumed that half the area classified in this class is occupied by sorghum and the other half by maize.

Sorghum

Sorghum is sown in November-December, and is harvested in March-May. *Day_ini* is thus assumed as November, 1st. The development periods and the basal crop coefficients are as described in Allen et al. (1998): *L_ini* = 20 day, *L_dev* = 35 day, *L_mid* = 40 day, *L_end* = 30 day, *Kcb_ini* = 0.15, *Kcb_mid* = 1.0, *Kcb_end* = 0.35. The maximum height of the culture (*H_cult*) is 1.5 m, maximum root depth (*Rp_1*) is 1500 mm and minimum root depth is (*Rp_0*) is 150 mm. The fraction of the area occupied during the mid-season and late-season stages (*fc_max*) is 100 % and the fraction of the area occupied during the initial stage of the development (*fc_min*) is 10 %. The threshold amount of water stored in the soil that allows the effective evapotranspiration to occur at the maximum rate (*p*) is 55 %.

Maize

Maize is sown in mid-October until November. It is harvested between March-April up to May. The following parameters are used: *Day_ini* = November, 1st; *L_ini* = 25 day, *L_dev* = 40 day, *L_mid* = 45 day, *L_end* = 30 day, *Kcb_ini* = 0.15, *Kcb_mid* = 1.15, *Kcb_end* = 0.40. The maximum height of the culture (*H_cult*) is 2 m, maximum root depth (*Rp_1*) is 1,500 mm and minimum root depth is (*Rp_0*) is 150 mm. The fraction of the area occupied during the mid-season and late-season stages (*fc_max*) is 100 % and the fraction of the area occupied during the initial stage of the development (*fc_min*) is 10 %. The threshold amount of water stored in the soil that allows the effective evapotranspiration to occur at the maximum rate (*p*) is 55 %.

5.6.7 Transitional vegetation (shrubs)

It is assumed that the shrubs cover have constant parameters all over the year. The basal crop coefficient is constant = 0.80. The root depth is 1,000 mm. Plant height is 1 m. The threshold amount of water stored in the soil that allows the effective evapotranspiration to occur at the maximum rate (*p*) is 50 %.

5.6.8 Sand plains, sand banks, beaches

These areas are also assumed as bare soils.

5.6.9 Bare soil

Bare soils may occur all over the year or in periods when the fraction occupied by a specific vegetation type is not total. For the bare soil, the top 150 mm is subject to evaporation, and the threshold amount of water stored in the soil that allow the effective evaporation to occur at the maximum rate (p) is 42 %.

5.7 Application of the BALSEQ_MOD method

The Balseq_Mod method was applied for the period March, 1st, 2000 until February, 29th, 2008, using the daily precipitation and the daily reference evapotranspiration data presented or calculated in sections 5.3 and 5.4. The parameters required to run the model were determined in section 5.5 for the case of the soil dependent parameters and in section 5.6 for the land cover dependent parameters. The general results are presented in Table 16. Fig. 29 shows the areal distribution of the results by area. As the area of the land cover map does not cover the total watershed under study (3,915 km^2), the area where the BALSEQ_MOD was applied is the area where the land cover map fits inside the watersheds' area. This corresponds to a total area of 3,380 km^2. From this area, in 194 km^2 the methodology could not be applied either because of the inexistence of parameter data either because of the occurrence of water bodies.

Table 16 – Average results obtained using the BALSEQ_MOD method for the period 2000-03-02 until 2008-02-29

Process	Value
Precipitation (Bahía Blanca aerodrome)	723 mm.year^{-1}
Average reference evapotranspiration	1,642 mm.year^{-1}
Average real evapotranspiration	302 mm.year^{-1}
Average direct runoff	410 mm.year^{-1}
Average recharge	10 mm.year^{-1}

A) B) C)

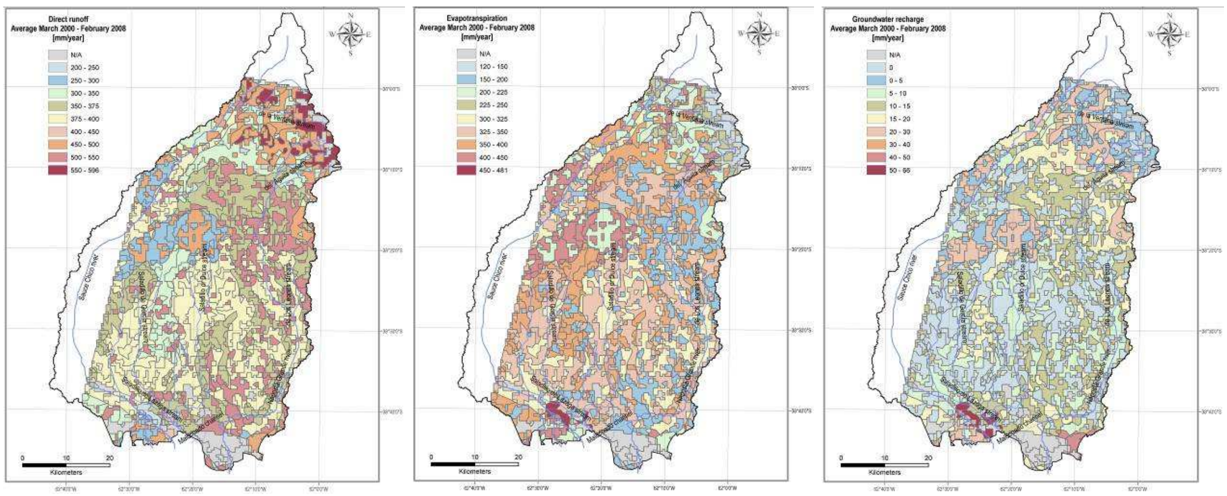


Fig. 29 – Distribution of the average results of the BALSEQ_MOD method for the period 2000-03-02 until 2008-02-29: A) Direct runoff; B) Real evapotranspiration; C) Groundwater recharge.

The analysis of these results shows that the applied methodology did not respond to what should be expected, because, as shown in section 5.2, surface runoff is expected to be much lower. As a matter of fact the results now obtained can be easily justified if one takes into account the evapotranspiration potential of the study area and its topography, mostly very flat. This means that the water estimated as direct runoff may remain in the top of the soil and be latter evapotranspirated. At the same time if this water remains in the soil more than one day it can infiltrate in the next day, and eventually constitute recharge. These possibilities are not taken into account in the BALSEQ_MOD method. On the contrary the classical BALSEQ model may take these possibilities into account, as it considers only two parameters, one of them, the characteristic number (NC) that may be adjusted to take into account the possibility of generating more or less direct runoff.

5.8 Application of the BALSEQ method

The BALSEQ method was also applied for the period March, 1st, 2000 until February, 29th, 2008, using the daily precipitation and the daily reference evapotranspiration data presented or calculated in sections 5.3 and 5.4. The application of the BALSEQ method requires the definition of the NC and the AGUT parameters (section 4.2.2). NC is chosen as a function of the land use. AGUT is chosen as a function of the soil properties (field capacity and wilting point) and the average root depths. Several runs with different combinations of NC and AGUT were carried out. Finally, five categories, each one with a different combination of AGUT and NC, were selected:

- **Rock outcrops**, in an area of 82 km^2, corresponding the soil taxonomic unit “Rock” which constitutes 60 % of the area of the cartographic unit '1a' (Table 15); AGUT was assigned a low value of AGUT = 10, due to the low field capacity and wilting point of the rock formations and a NC value of 95, which corresponds to a situation that generates large direct runoff and low soil infiltration;

- **Crops**, covering an area of 716 km^2, corresponding to the following land cover classes and areas: 50 % area 'crops - small (fallow land, wheat)' + 100 % area 'Crops (sunflowers, soy)' + 100 % area 'Crops (sorghum, maize)' + 100 % area 'Transitional vegetation (shrubs)'; AGUT was assigned a typical average value of 100, and NC equal to 60, due to the flat topography of the area and the type of soil;

- **Pastures**, covering an area of 1,034 km^2, corresponding to the area classified as 'Pasture' in the land cover map; AGUT was assigned a typical average value of 75, due to the lower root depths of the grass in relation to crops, and NC equal to 75;

- **Bare soil**, covering an area of 1,365 km^2, corresponding to the following land cover areas: 50% area 'crops - small (fallow land, wheat)' + 100 % area 'Bare soil (sowed land and/or urban area)' – 35 km^2 area classified as 'urban area' + 100 % area 'Sand plains, sand banks, beaches' – 82 km^2 area classified as 'Rock outcrops'; AGUT was assigned a low value of 50, due to the soil properties and the soil depth subject to evaporation, and NC equal to 60, due to the flat topography of the area and the type of soil;

- **Urban area**, covering an area of 35 km^2, corresponding to the area of the land cover class 'bare soil' that is classified in the soil map in the edaphic domain 'M' (miscellaneous area); in this area it is not considered to occur natural recharge, and hence the available precipitation water will constitute direct runoff or will be evapotranspirated.

Fig. 30 shows the spatial distribution of the results obtained with the BALSEQ method. Table 17 presents the results obtained for each one of the five categories. Excluding the urban area, that only covers 35 km^2, and considering the total area covered by the satellite image (3,380 km^2) which is not occupied by water bodies, the average precipitation is 723 mm.year^{-1}, real evapotranspiration is 631 mm.year^{-1}, average direct runoff is 27 mm.year^{-1}, average recharge is 61 mm.year^{-1}. The obtained values of direct runoff and recharge are in accordance with the values referred to in section 5.2 and in accordance with the values published in previous studies as presented in section 5.1.

A) B) C)

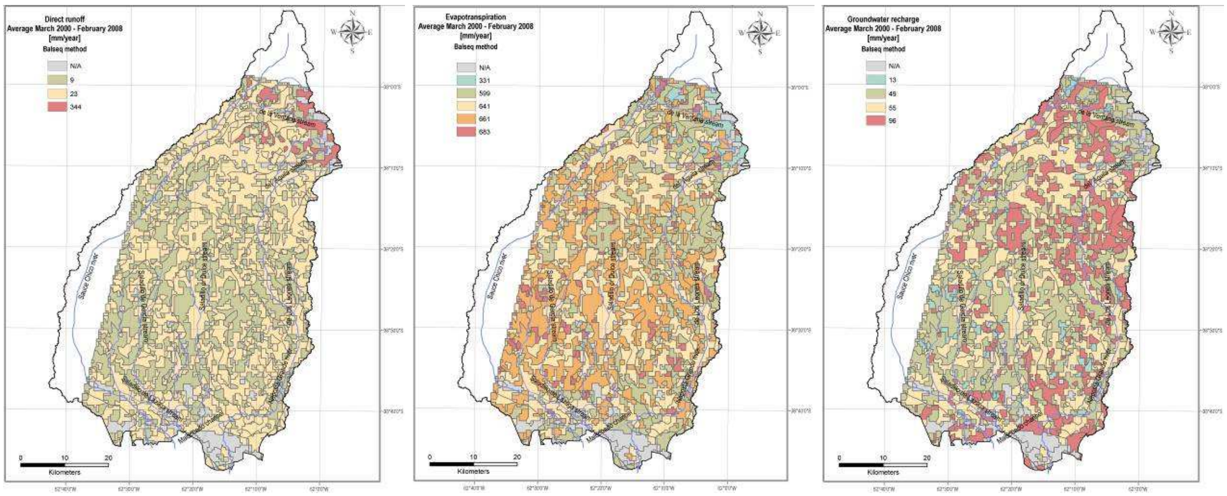


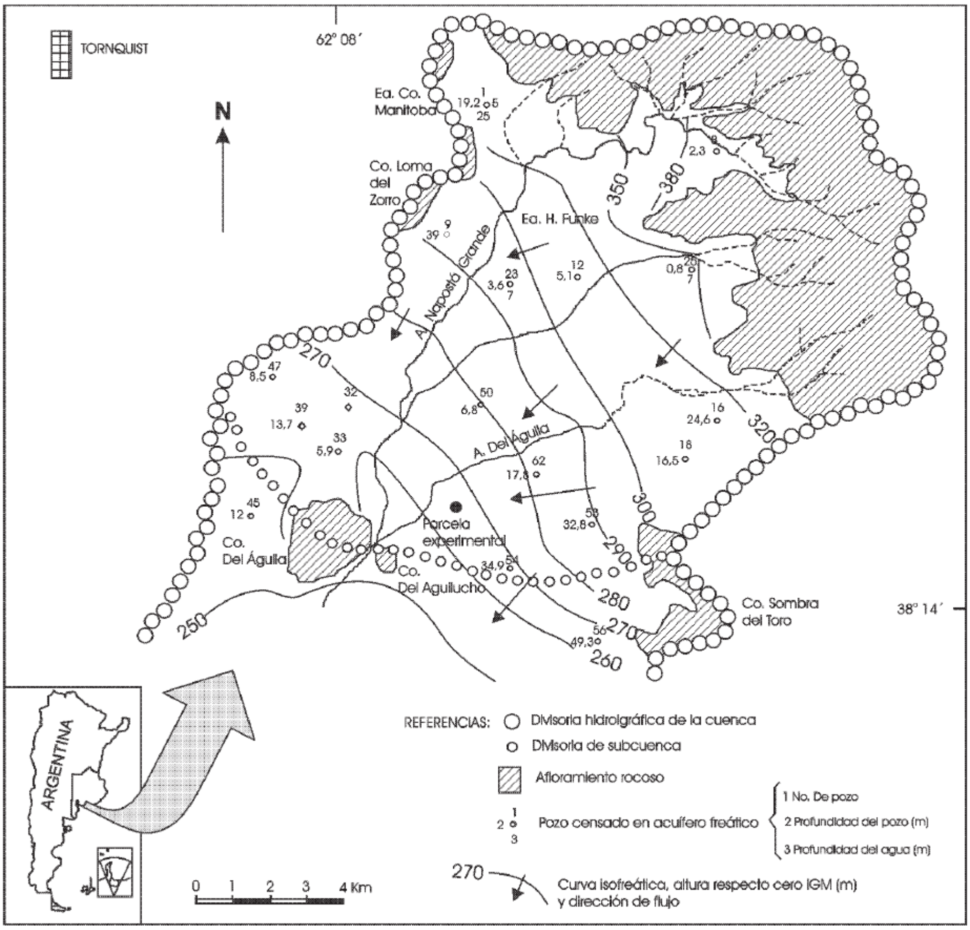
Fig. 30 - Distribution of the average results of the BALSEQ method for the period 2000-03-02 until 2008-02-29: A) Direct runoff; B) Real evapotranspiration; C) Groundwater recharge.

Table 17 – Average results obtained with the BALSEQ model for the period 2000-03-02 until 2008-02-29

Class	Area (km^2)	Aquifer recharge (mm.year^{-1})	Direct runoff (mm.year^{-1})	Real evapotranspiration (mm.year^{-1})
Rock outcrops	82	49	344	331
Crops	716	13	23	683
Pastures	1,034	49	9	661
Bare soil	1,365	96	23	599
Urban area	35	0	723	
Total (excluding urban area)	3,197	61	27	631
Total (including urban area)	3,232	60	658	

5.9 Application of the DECHIDR method

The stream flow series measured in Cerro del Águila stream flow gauge station, from 1/10/1935 until 30/09/1944, was analysed (Fig. 31). Precipitation for this period was measured in the rainfall gauge station of Cerro Manitoba. The DECHIDR_VB program was run with number of days after the peak of the hydrograph (n) = 2 days [n (Eq. 67) = 2.373 d], with the options 1) do not control the balance between precipitation and stream flow and 2) there is no need to occur precipitation in order to start a new episode of direct runoff. The second option was chosen because as it can be seen in the data sometimes there was an increase in stream flow without precipitation being detected.



Source: Carrica and Lexow (2004)

Fig. 31 – Upper Napostá Grande watershed

The obtained annual results are presented in Table 18. The annual average base flow was estimated to be 6.1 % of the precipitation and 57 % of stream flow.

Table 18 – Results of stream flow separation into base flow and direct runoff

Year*	P	F	Fd	Fb	F/P	Fd/P	Fb/P	Fb/F
1935/1936	590	30.5	8.5	22.0	5.2%	1.4%	3.7%	72.2%
1936/1937	515	35.6	12.7	22.8	6.9%	2.5%	4.4%	64.2%
1937/1938	368	27.5	8.8	18.7	7.5%	2.4%	5.1%	68.0%
1938/1939	652	56.2	23.1	33.1	8.6%	3.5%	5.1%	58.8%
1939/1940	709	116.7	51.8	64.8	16.5%	7.3%	9.1%	55.6%
1940/1941	830	113.3	51.2	62.1	13.6%	6.2%	7.5%	54.8%
1941/1942	555	31.8	6.9	25.0	5.7%	1.2%	4.5%	78.5%
1942/1943	574	68.0	26.7	41.3	11.9%	4.7%	7.2%	60.7%
1943/1944	670	105.4	61.8	43.5	15.7%	9.2%	6.5%	41.3%
Annual average	607	65.0	27.9	37.1	10.7%	4.6%	6.1%	57.0%

* The year starts at 1 of October and ends at 30 of September
P = precipitation, F = Stream flow, Fd = Direct runoff, Fb = Base flow

These values are different from the ones obtained by Carrica (1988, in Carrica and Lexow, 2004) that hand separated the hydrograph, where average base flow for approximately the same time series (there is a 3 month difference) was estimated as 32 mm.year^{-1} and direct runoff was estimated as 35 mm.year^{-1}. By using the new DECHIDR_VB method, the values obtained are slightly different: 37 mm.year^{-1} for base flow and 28 mm.year^{-1} for direct runoff. The differences in the results are due to the fact that the model used by Carrica (1988, in Carrica and Lexow, 2004) assumed that in the hydrograph the base flow was temporally interrupted after the beginning of the rising limb until the beginning of the depletion period. The DECHIDR_VB model always assumes that there is base flow.

Fig. 32 presents the average monthly values for the nine years series. Fig. 33 shows the probability distribution function of base flow in an yearly basis. It can be seen that the median baseflow is 0.05 mm.day^{-1}.

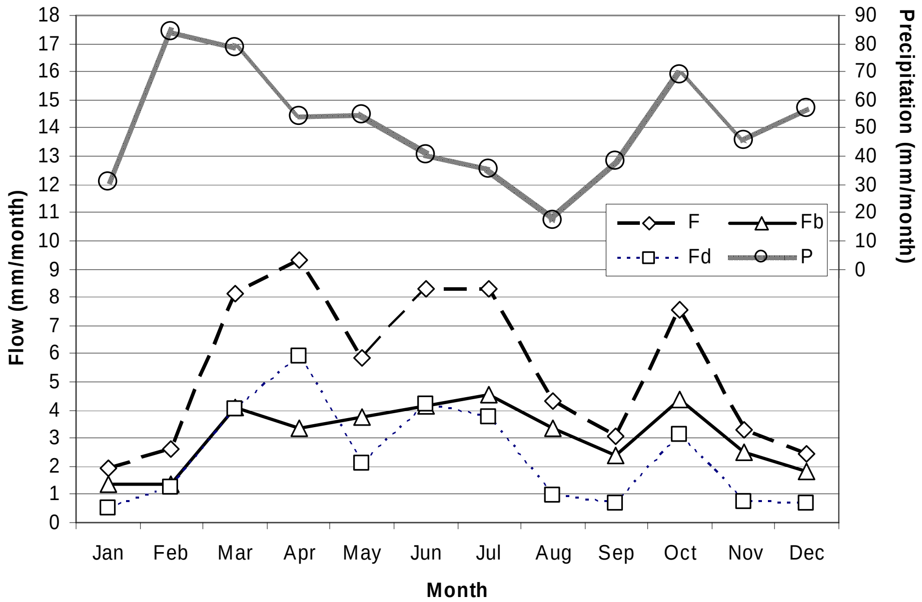


Fig. 32 – Average monthly values of flow, direct flow, base flow and precipitation for the series from 1 Oct 1935 until 30 September 1944

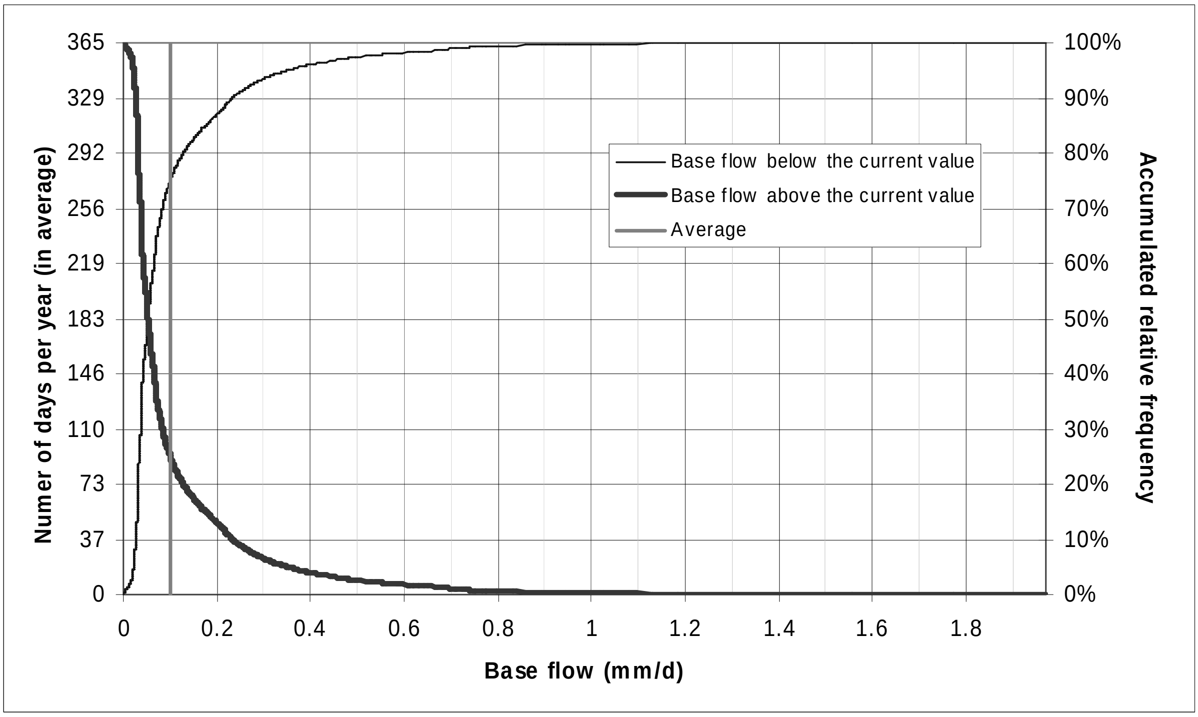


Fig. 33 - Probability distribution function of base flow in upper Napostá Grande watershed

6 Groundwater flow contribution to the estuary

Heffner (2003) presented a study concerning the contributions of the several water sources to the estuary. These contributions became totally from the north bank of the estuary. The following outputs of water to the estuary were identified:

- Surface flow;

- Groundwater discharge;

- Sewage discharge;

- Industrial discharge.

Considering an average precipitation of 585 mm.year-1, the following contribution volumes were estimated (Heffner, 2003):

Total surface flow to the estuary = 263,000 $m^3.d^{-1}$ (as Sauce Chico more Naposta Grande are 95 % of surface flow to the estuary, this amount was calculated using data presented on section 5.2 and the expression (Flow Sauce Chico + Flow Napostá Grande) / 0.95). This discharge represents 72.9 % of water discharged to the estuary, which represents 32 $mm.year^{-1}$, assuming the weighted average of the values calculated for Sauce Chico and Naposta Grande (5.5 % prec.) and precipitation= 585 $mm.year^{-1}$. This implies a watershed area of 3,000 km^2 [Area = 263,000 ($m^3.d^{-1}$) / 32 ($mm.year^{-1}$)].

Groundwater discharge to the estuary = 2,000 $m^3.d^{-1}$ calculated using Darcy's law = 0.6 % of water discharged to the estuary = 0.26 $mm.year^{-1}$, calculated using the expression (total surface water discharged to the estuary is 32 ($mm.year^{-1}$) / 72.9 % * 0.6 %).

Sewage discharge to the estuary = 84,000 $m^3.d^{-1}$ = 23.3 % of water discharged to the estuary = 10.3 $mm.year^{-1}$ (= 32 / 72.9 % * 23.3 %).

Industrial discharge to the estuary = 11,665 $m^3.d^{-1}$ = 3.2 % of water discharged to the estuary = 1.4 $mm.year^{-1}$ (= 32 / 72.9 % * 3.2 %).

7 Conclusions

Bahía Blanca case study area comprises three watersheds that discharge into the estuary, near Bahía Blanca city, from west to east: Sauce Chico, Saladillo and Napostá Grande. The area was extended from the western part of the Sauce Chico watershed until the estuary and from the eastern part of the Napostá Grande watershed to the estuary using the higher altitude topography as limits.

Geology and Hydrogeology base information was taken from the studies previously carried out by the Hydrogeology team of the Universidad Nacional del Sur, which in some cases were unpublished studies. The pedologic description is based on the Soil Map of the Buenos Aires Province of the Argentine Republic. The land use was produced in the framework of this EcoManage project by the University of Trieste team. Also climate data, including precipitation, was taken from internet for the Bahía Blanca Aerodrome. All this information is relevant to establish the conceptual hydrogeological model of the area.

Concerning the characterization of the aquifer vulnerability to pollution, the DRASTIC method was to be applied. The groundwater vulnerability to pollution using the DRASTIC method has been carried out previously for the Sauce Chico and Napostá Grande upper watersheds (*cf*. Lexow et al., 1994, and Albouy and Bonorino, 1998). For the totality of the area the soil parameter of the DRASTIC method has been determined. In the near future it is foreseen to apply the DRASTIC index to the whole area under study in Bahía Blanca. Meanwhile, the description of the DRASTIC index and the vulnerability assessment using the DRASTIC index has been made for the Santos, Brazil EcoManage case study area (*cf*. Oliveira et al., 2005).

Three methods were used to estimate recharge. Two different daily sequential water balance methods were applied, (A) one, included in the BALSEQ_MOD program, that computes direct runoff using the soil properties and the real evapotranspiration using the dual crop coefficient approach, and (B) another, included in the BALSEQ program, that computes direct runoff using the land use/soil properties and the real evapotranspiration assuming a constant crop coefficient. The third method is the separation of the surface flow hydrograph.

The analysis of the results provided by these methodologies showed that the BALSEQ_MOD method did not respond to what should be expected from observation data on surface runoff. The obtained values of direct runoff were too high because the flat topography of the terrain was not taken into account and the method did not considered the possibility of ponding. Using the BALSEQ method this situation may be taken into account in the quantification of the direct runoff process. The results obtained with the BALSEQ method were: average precipitation = 723 mm.year^{-1}, real evapotranspiration = 631 mm.year^{-1}, average direct runoff = 27 mm.year^{-1}, average recharge = 61 mm.year^{-1}.

The results provided by the hydrograph separation technique pointed for an average recharge value of 37 $mm.yr^{-1}$ in the upper Napostá Grande watershed. This value represents 57 % of the stream flow and 6.1 % of the average precipitation that, for the analysed period, was estimated as 607 $mm.yr^{-1}$.

Further developments of the recharge methodology are foreseen in order to take into account the possibility of ponding in the watershed. If ponding occurs there will be water available for infiltration in the next day or, as the evapotranspiration ability of the Bahía Blanca area is high, this water may also be evapotranspirated.

Following the results provided by Heffner (2003), groundwater discharge to the estuary is estimated as only 2,000 $m^3.d^{-1}$, a value that represents less than 1 $mm.year^{-1}$ if the total watershed area is considered.

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Annex 1 – Soil media characterisation for the DRASTIC index

The soil characterization is based on information available from the Soil Map of the Buenos Aires Province. Twelve soil types have been identified in the study area; however the dominant soil types in the region are Haplustols, Argiustols and Argiudols (section 1.3).

For each soil present in the study area, a soil type index based on grain size was assigned to each horizon according to the classification scheme of Aller *et al*. (Table 19).

Table 19 - Ranges and ratings for S - Soil media

Range	Rating
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated Clay (montmorillonite or smectite clays)	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay (Kaolinitic or illitic clays)	1

(Aller *et al.*, 1987)

The DRASTIC soil media ratings were calculated based on the horizons of taxonomic soil unit, according to the following criteria (Theves and Oliveira, 1996):

1. an average 25 cm minimum thickness must be present for a layer to be considered in the analysis,
2. when several soil layers are present, the index of the soil layer with the smallest index number is used,
3. a layer whose thickness is inferior to 25 cm can be added to a layer presenting an equal or smaller index,
4. if a layer is described by two textural classes, the class with the highest index number is chosen,
5. if the layer is described by three textural classes, an average texture is chosen for rating, and
6. if the texture of a layer is not included in the DRASTIC classification, then the index refers to the closest known DRASTIC classification, and the soil index is eventually determined by averaging with the other textural classes.

The characterization of the soil index for each taxonomic index is presented in Table 20. The final DRASTIC soil media ratings for the cartographic soil units were obtained by summing the products of the percentage of each soil type in a cartographic unit and their corresponding index (Table 21). The ratings vary from 3 for marshy soils to 9 for sands in the coastal zone. The majority of the area has a rating of 3 to 5 (Fig. 34) and most of these soils are under agricultural and urban land use.

Table 20 – Parameter S rating assignment of each taxonomic unit of the soil

EDAPHIC DOMAIN	TAXONOMIC UNIT	HORIZON (Soil profile)	HORIZON THICKNESS [cm]	% CLAY (< 2 µ)	% SILT (2-50 µ)	% SAND (50 µ-2mm)	TEXTURAL FAMILY	TEXTURE RATING	ATTENUATION THICKNESS [cm]	TOTAL THICKNESS [cm]	RATING
1	M_{18}li3	A1	27	29.00	29.20	40.90	CLAY LOAM	3	27	27	3
2	M_{18}pa3	A1	22	32.40	39.20	28.40	CLAY LOAM	3	0	22	10
	M_{17}tc3	Ap	13	24.60	39.20	36.20	LOAM	5	34	140	3
		A12	18	25.50	38.70	35.80	LOAM	5			
		B1	8	28.40	40.70	30.90	CLAY LOAM	3			
		B2t	26	31.50	32.90	35.60	CLAY LOAM	3			
		B3	38	24.30	36.40	39.30	LOAM	5			
		C	37	18.70	37.70	43.60	LOAM	5			
	M_{17}tc3s'	A1	20	25.50	38.70	35.80	LOAM	5			5
		B2t	17.5	31.50	32.90	35.60	CLAY LOAM	3			
	M_{24}en4	A1	20	11.02	21.30	67.68	SANDY LOAM	6	80	100	6
		AC	23	10.81	16.96	72.23	SANDY LOAM	6			
		C1	37	9.84	15.07	75.09	SANDY LOAM	6			
		C2	20	8.12	13.66	78.22	LOAMY SAND/ SANDY LOAM	6 or 8			
	E_{25}tc	A1	15	2.80	5.70	91.20	SAND	9	52	70	9
		AC	20	1.50	3.80	94.10	SAND	9			
		C1	17	1.23	5.34	93.43	SAND	9			
		C2	18	19.73	2.83	77.44	SANDY LOAM	6			
	M_{25}tc4	A1	14	26.00	39.50	34.50	LOAM	5		83	5
		B2t	20	57.10	25.10	17.60	CLAY	7			
		B3ca	24								
		B32ca	25	25.75	40.60	33.64	LOAM	5			
	M_{18}tc4	A1	38	32.90	43.40	23.70	CLAY LOAM	3	110	110	3
		B2	27	33.30	43.30	23.40	CLAY LOAM	3			
		IIC1	22	27.50	41.20	31.30	CLAY LOAM	3			
		IIIC2	23	27.30	35.40	37.30	CLAY LOAM	3			
3	M_{24}tc2	Ap	18	35.10	38.40	26.50	CLAY LOAM	3	62 a 84	84	3
		B21	19	39.60	35.20	25.20	CLAY LOAM	3			
		B22	22	40.10	27.10	32.80	CLAY/CLAY LOAM	3 or 5			
		B3	25	33.00	35.00	32.00	CLAY LOAM	3			
	M_{24}li3	A1	18	28.13	30.21	41.67	CLAY LOAM		18	18	10
	M_{21}tc3s	A1	14	21.30	36.20	42.50	LOAM	5	38	58	5
		B1	9	24.40	35.40	40.50	LOAM	5			
		B21t	20	29.90	37.80	33.20	CLAY LOAM	3			
		B22t	15	26.30	31.50	42.70	LOAM	5			
	M_{24}en3i	A1	40	25.00	27.40	47.60	SANDY CLAY LOAM	5	120	120	5
		AC	35	23.30	31.50	45.20	LOAM	5			
		C	45	23.54	32.13	44.33	LOAM	5			
	M_{21}tc2s'	A1	23	29.30	24.60	46.10	SANDY CLAY LOAM	5	20	43	5
		B2t	20	44.29	24.91	30.80	CLAY	3			
	M_{17}tc3	Ap	12	24.60	39.20	36.20	LOAM	5	34	140	3
		A12	19	25.50	38.70	36.10	LOAM	5			
		B1	8	28.40	40.70	30.90	CLAY LOAM	3			
		B2t	26	31.50	32.90	35.60	CLAY LOAM	3			
		B3	38	24.30	36.40	39.30	LOAM	5			
		C	37	18.70	37.70	43.60	LOAM	5			

Table 20 – Parameter S rating assignment of each taxonomic unit of the soil (Cont.)

EDAPHIC DOMAIN	TAXONOMIC UNIT	HORIZON (Soil profile)	HORIZON THICKNESS [cm]	% CLAY (< 2 µ)	% SILT (2-50 µ)	% SAND (50 µ-2mm)	TEXTURAL FAMILY	TEXTURE RATING	ATTENUATION THICKNESS [cm]	TOTAL THICKNESS [cm]	RATING
4	M24en4	A1	25	16.4	16.4	67.2	SANDY LOAM	6	135	135	6
		AC	44	17.1	16.3	66.6	SANDY LOAM	6			
		C	66	12.9	18.8	68.4	SANDY LOAM	6			
	E23us	A1	40	6.4	2.5	91.1	SAND	9	120	120	9
		AC	30	6.7	1.3	92	SAND	9			
		C	50	5.4	1	93.6	SAND	9			
	E26tcs	Ap	15	13.1	11.3	75.6	SANDY LOAM	6	80	80	6
		A12	13	10.7	13.5	75.8	SANDY LOAM	6			
		AC	34	10.2	14.2	75.6	SANDY LOAM	6			
		C	18	13.5	12.5	71.7	SANDY LOAM	6			
	E26tc	A1	16	6.4	12.0	81.6	LOAMY SAND	8	100	100	8
		AC	24	6.4	10.8	82.9	LOAMY SAND	8			
		Cca	> 60	5.1	11.2	83.7	LOAMY SAND	8			
	E22tc	AC	14	2.5	0.8	96.7	SAND	9	60	60	9
		C	46	2.3	0.5	97.2	SAND	9			
12	M_{21}tc2	A1	27.00	26.00	30.10	43.90	LOAM	5	107	107	3
		B2t	26.00	31.20	23.80	45.00	CLAY LOAM	3			
		B3	25.00	21.10	29.50	49.40	LOAM	5			
		C	29.00	15.97	39.67	44.35	LOAM	5			
	F_{28}tc3	A11	16.00	16.90	11.80	71.30	SANDY LOAM	6	85	125	5
		A12	24.00	14.60	7.60	77.80	SANDY LOAM	6			
		B2t	23.00	25.20	17.70	57.00	SANDY CLAY LOAM	5			
		B3	37.00	23.00	17.00	60.00	SANDY CLAY LOAM	5			
		C	25.00	20.50	16.20	63.03	SANDY CLAY LOAM	5			
26	E_{13}ac3	I	31	27.50	58.10	13.80	SILTY CLAY LOAM	5	31	140	4
		II	25	23.90	59.10	16.80	SILT LOAM	4			
		III	56	26.86	63.02	10.12	SILT LOAM	4			
	F_{28}tc3	A1	15	21.20	52.30	26.50	SILT LOAM	5	83	100	5
		B2t	17	32.00	53.00	15.00	SILTY CLAY LOAM	4			
		B3x	68	23.00	53.10	23.90	SILT LOAM	5			
	A_{11}ah4	I	26	15.20	28.70	56.10	SANDY LOAM	6	54	80	5
		II	21	21.20	23.30	55.20	SANDY CLAY LOAM	5			
		III	33	25.97	24.24	49.78	SANDY CLAY LOAM	5			
	M_{25}tc4	A1	19	19.10	46.00	34.90	LOAM	5	56	75	3
		B21t	17	27.50	38.40	34.00	CLAY LOAM	3			
		B22t	20	39.00	32.10	28.90	CLAY LOAM	3			
		B3ca	19	27.30	45.60	27.00	CLAY LOAM	3			

Table 20 – Parameter S rating assignment of each taxonomic unit of the soil (Cont.)

EDAPHIC DOMAIN	TAXONOMIC UNIT	HORIZON (Soil profile)	HORIZON THICKNESS [cm]	% CLAY (< 2 μ)	% SILT (2-50 μ)	% SAND (50 μ-2mm)	TEXTURAL FAMILY	TEXTURE RATING	ATTENUATION THICKNESS [cm]	TOTAL THICKNESS [cm]	RATING
27	E_{25}tc	Ap	30	7.90	6.80	85.30	LOAMY SAND	8	154	154	8
		AC	44	8.20	12.00	79.80	LOAMY SAND	8			
		C	80	4.90	7.70	87.40	LOAMY SAND	8			
	E_{22}tc	C1-C2	100	0.78	1.00	98.22	SAND	9	100	100	9
	M_{18}en4	A1	24	22.70	25.10	52.20	SANDY CLAY LOAM	5	91	115	6
		AC	22	18.80	24.30	56.90	SANDY LOAM	6			
		C1-C2	49	12.30	23.70	64.00	SANDY LOAM	6			
		C2ca	20	10.73	22.43	66.85	SANDY LOAM	6			
	M_{24}en4	A1	34	17.50	0.00	82.50	SANDY LOAM	6	58	116	6
		AC	24	15.66	0.00	84.34	SANDY LOAM	6			
		C	58	14.21	0.00	85.79	SANDY LOAM	6			
	E_{26}tc	A	50	13.60	8.00	77.90	SANDY LOAM	6	50	122	6
		C	72	11.10	6.00	82.90	LOAMY SAND	8			

Table 21 – Soil index ratings for each cartographic unit

EDAPHIC DOMAIN	CARTOGRAPHIC UNIT (CU)	TAXONOMIC UNIT (TU)	%	RATING (TU)	RATING (CU)
1	1a	Rock	60	10	7
		M_{18}li3	40	3	
	1d	M_{17}tc3i	50	3	3
		M_{18}tc4i	50	3	
2	2c	M_{17}tc3i	50	3	4
		M_{17}tcsi (1)	30	3	
		M_{18}pa (2)	20	10	
	2f	M_{17}tc3	50	3	4
		M_{17}tc (3)	30	3	
		M18pa (2)	20	10	
	2g	M_{17}tc3	50	3	3
		M_{17}tcs (4)	30	3	
		M_{17}tcs' (5)	20	5	
	2p	M_{17}tc3s' (5)	60	5	7
		E_{25}tc	40	9	
3	3a	M_{24}tc2	50	3	5
		M_{24}eni (6)	30	5	
		M_{24}li	20	10	
	3b	M_{24}tc2s'	50	3	4
		M_{21}tcs'	30	5	
		M_{24}tc	20	3	
	3c	M_{21}tc3s	60	5	7
		M_{24}li	40	10	
4	4a	M_{24}en4	50	6	7
		M_{24}ens	30	6	
		E_{23}us	20	9	
	4b	M_{24}en4	50	6	6
		E_{26}tcs	30	6	
		E_{26}tc	20	8	
	4c	E_{26}tc	50	8	9
		E_{23}us	30	9	
		E_{22}tc	20	9	
12	12a	M_{21}tc2	50	3	3
		M_{21}tcs	30	3	
		F_{28}tc	20	5	
26	26a	E_{13}ac3	> 85%	4	3
	26b	E_{13}ac3	60	4	4
		F_{28}tc	40	5	
	26c	A_{11}ah4	60	5	4
		M_{25}tc	40	3	
27	27a	E_{25}tc	50	8	8
		E_{22}tc	30	9	
		M_{18}en	20	6	
	27c	M_{24}en4	60	6	6
		E_{26}tc	40	6	
M	Miscelaneous				

These taxonomic units (TU) don't have descriptions. The following TU were assumed: (1) M_{17}tc3 thin sloping, (2) M_{18}pa3, (3) M_{17}tc3, (4) computed according to text thin, (5) computed according to text very thin, sum of horizons A1 and B2t, (6) M_{24}en3i

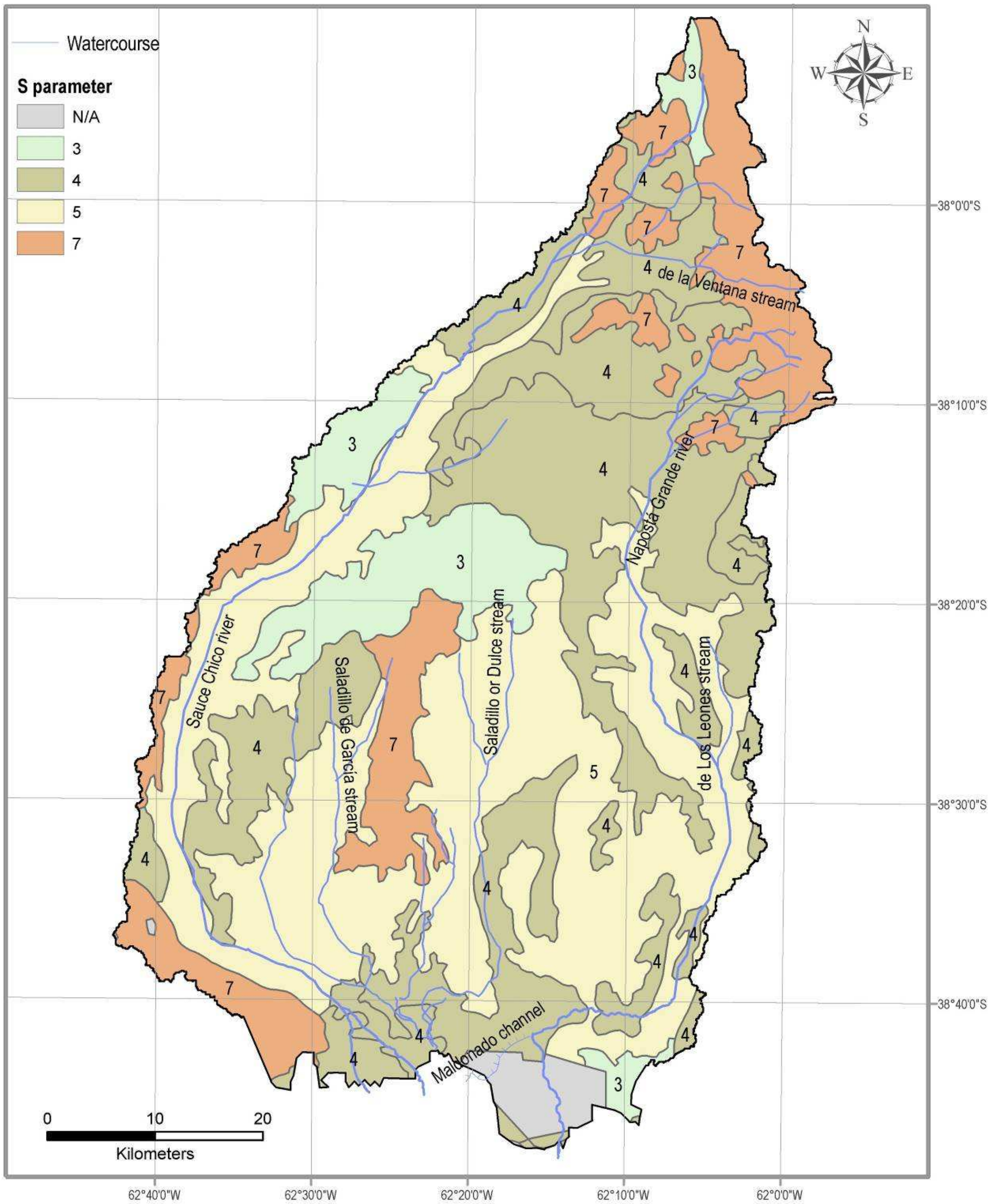

Fig. 34 – Characterisation of the Soil media (S)

Annex 2 – Parameters to be used for the calculation of real evapotranspiration in accordance to FAO's Penman-Monteith method, as a function of land cover

This annex was taken from Oliveira (2004). The presented table results from the junction of the following tables published in Allen *et al*. (1998):

- Table 11 – Lengths of crop development stages for various planting periods and climatic regions (days).
- Table 12 – Single (time-averaged) crop coefficients, Kc, and mean maximum plant heights for non stressed, well managed crops in subhumid climates (RHmin aprox. 45%, u2 aprox. 2 m/s) for use with FAO Penman-Monteith ETo.
- Table 17 – Basal crop coefficients, Kcb, for non stressed, well managed crops in subhumid climates (RHmin aprox. 45%, u2 aprox. 2 m/s) for use with FAO Penman-Monteith ETo.
- Tabela 22 – Ranges of maximum effective rooting depth (rp), and soil water depletion fraction for no stress (p), for common crops.

Tabela e título em Allen *et al.* (1998) ->		Tabela 11 (*) - Duração dos estádios de desenvolvimento* para vários períodos de plantação e regiões climáticas (dia)							Tabela 12 - Coeficientes culturais simples (ponderados pelo tempo), Kc, e média das alturas máximas das plantas, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO				Tabela 17 - Coeficientes culturais basais, Kcb, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO			Tabela 22 - Intervalos de profundidade máxima efectiva das raízes das plantas (rp),e fracção de depleção de água do solo para culturas comuns sem stress (p)	
Nome (em português)	Nome referido em Allen *et al*. (1998)	Inicial (L_{ini})	Desenvolvimento (L_{dev})	Médio (L_{mid})	Final (L_{late})	Total	Plantação	Região	Kc inicial (6)	Kc médio	Kc final	Altura máxima da cultura	Kcb inicial (31)	Kcb médio (31)	Kcb final (31)	Profundidade máxima das raízes (m) (56)	p: Fracção de depleção (57) (para ET ≈ 5 mm/day)
a. Pequenos vegetais	**a. Small Vegetables**								**0.7**	**1.05**	**0.95**		**0.15**	**0.95**	**0.85**		
brócolo	Broccoli	35	45	40	15	135	Set	Calif. Desert, EUA		1.05	0.95	0.3		0.95	0.85	0.4-0.6	0.45
couve de bruxelas	Brussel Sprouts									1.05	0.95	0.4		0.95	0.85	0.4-0.6	0.45
couve	Cabbage	40	60	50	15	165	Set	Calif. Desert, EUA		1.05	0.95	0.4		0.95	0.85	0.5-0.8	0.45
cenoura	Carrots	20	30	50/30	20	100	Out/Jan	Clima árido		1.05	0.95	0.3		0.95	0.85	0.5-1.0	0.35
		30	40	60	20	150	Fev/Mar	Mediterrâneo									
		30	50	90	30	200	Out	Calif. Desert, EUA									
couve-flor	Cauliflower	35	50	40	15	140	Set	Calif. Desert, EUA		1.05	0.95	0.4		0.95	0.85	0.4-0.7	0.45
aipo	Celery	25	40	95	20	180	Out	(Semi) Árido		1.05	1	0.6		0.95	0.9	0.3-0.5	0.2
		25	40	45	15	125	Abr	Mediterrâneo									
		30	55	105	20	210	Jan	(Semi) Árido									
crucíferas (1)	Crucifers (1)	20	30	20	10	80	Abr	Mediterrâneo									
		25	35	25	10	95	Fev	Mediterrâneo									
		30	35	90	40	195	Out/Nov	Mediterrâneo									
alho	Garlic									1	0.7	0.3		0.9	0.6	0.3-0.5	0.3
alface	Lettuce	20	30	15	10	75	Abr	Mediterrâneo		1	0.95	0.3		0.9	0.9	0.3-0.5	0.3
		30	40	25	10	105	Nov/Jan	Mediterrâneo									
		25	35	30	10	100	Out/Nov	Região Árida									
		35	50	45	10	140	Fev	Mediterrâneo									
cebola (seca)	Onion (dry)	15	25	70	40	150	Abr	Mediterrâneo		1.05	0.75	0.4		0.95	0.65	0.3-0.6	0.3
		20	35	110	45	210	Out; Jan	Região Árida; Calif.									
cebola (verde)	Onion (green)	25	30	10	5	70	Abr/Mai	Mediterrâneo		1	1	0.3		0.9	0.9	0.3-0.6	0.3
		20	45	20	10	95	Out	Região Árida									
		30	55	55	40	180	Mar	Calif., EUA									
cebola (semente)	Onion (seed)	20	45	165	45	275	Set	Calif. Desert, EUA		1.05	0.8	0.5		1.05	0.7	0.3-0.6	0.35
espinafre	Spinach	20	20	15/25	5	60/70	Abr; Set/Out	Mediterrâneo		1	0.95	0.3		0.9	0.85	0.3-0.5	0.2
		20	30	40	10	100	Nov	Região Árida									
rabanete	Radish	5	10	15	5	35	Mar/Abr	Medit.; Europa		0.9	0.85	0.3		0.85	0.75	0.3-0.5	0.3
		10	10	15	5	40	Inverno	Região Árida									
b. Vegetais (*Solanaceae*)	**b. Vegetables - Solanum Family (*Solanaceae*)**								**0.6**	**1.15**	**0.8**		**0.15**	**1.1**	**0.7**		
beringela	Egg plant	30	40	40	20	130	Out	Região Árida		1.05	0.9	0.8		1	0.8	0.7-1.2	0.45
		30	45	40	25	40	Mai/Jun	Mediterrâneo									
pimento	Sweet peppers (bell)	25/30	35	40	20	125	Abr/Jun	Europa e Medit.		1.05 (7)	0.9	0.7		1.00 (32)	0.8	0.5-1.0	0.3
		30	40	110	30	210	Out	Região Árida									
tomate	Tomato	30	40	40	25	135	Jan	Região Árida		1.15 (7)	0.70-0.90	0.6		1.10 (32)	0.60-0.80	0.7-1.5	0.4
		35	40	50	30	155	Abr/Mai	Calif., EUA									
		25	40	60	30	155	Jan	Calif. Desert, EUA									
		35	45	70	30	180	Out/Nov	Região Árida									
		30	40	45	30	145	Abr/Mai	Mediterrâneo									
c. Vegetais (*Cucurbitaceae*)	**c. Vegetables - Cucumber Family (*Cucurbitaceae*)**								**0.5**	**1**	**0.8**		**0.15**	**0.95**	**0.7**		
meloa	Cantaloupe	30	45	35	10	120	Jan	Calif., EUA	0.5	0.85	0.6	0.3		0.75	0.5	0.9-1.5	0.45
		10	60	25	25	120	Ago	Calif., EUA									
pepino	Cucumber	20	30	40	15	105	Jun/Ago	Região Árida									
		25	35	50	20	130	Nov; Fev	Região Árida									
pepino - mercado fresco	Cucumber - Fresh Market								0.6	1.00 (7)	0.75	0.3		0.95 (32)	0.7	0.7-1.2	0.5
pepino - colheita mecânica	Cucumber - Machine harvest								0.5	1	0.9	0.3		0.95	0.8	0.7-1.2	0.5
abóbora de Inverno	Pumpkin, Winter squash	20	30	30	20	100	Mar, Ago	Mediterrâneo		1	0.8	0.4		0.95	0.7	1.0-1.5	0.35
		25	35	35	25	120	Jun	Europa									
abóbora	Squash, Zucchini	25	35	25	15	100	Abr; Dez	Medit.; Reg. Árida		0.95	0.75	0.3		0.9	0.7	0.6-1.0	0.5
		20	30	25	15	90	Mai/Jun	Medit.; Europa									
melão	Sweet melons	25	35	40	20	120	Mai	Mediterrâneo		1.05	0.75	0.4		1	0.7	0.8-1.5	0.4
		30	30	50	30	140	Mar	Calif., EUA									
		15	40	65	15	135	Ago	Calif. Desert, EUA									
		30	45	65	20	160	Dez/Jan	Região Árida									
melancia	Water melons	20	30	30	30	110	Abr	Itália	0.4	1	0.75	0.4		0.95	0.7	0.8-1.5	0.4
		10	20	20	30	80	Mat/Ago	Próximo Oriente (deserto)									

Tabela e título em Allen *et al.* (1998) ->		Tabela 11 (*) - Duração dos estádios de desenvolvimento* para vários períodos de plantação e regiões climáticas (dia)							Tabela 12 - Coeficientes culturais simples (ponderados pelo tempo), Kc, e média das alturas máximas das plantas, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO				Tabela 17 - Coeficientes culturais basais, Kcb, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO			Tabela 22 - Intervalos de profundidade máxima efectiva das raízes das plantas (rp),e fracção de depleção de água do solo para culturas comuns sem stress (p)	
Nome (em português)	Nome referido em Allen *et al*. (1998)	Inicial (L_{ini})	Desenvolvimento (L_{dev})	Médio (L_{mid})	Final (L_{late})	Total	Plantação	Região	Kc inicial (6)	Kc médio	Kc final	Altura máxima da cultura	Kcb inicial (31)	Kcb médio (31)	Kcb final (31)	Profundidade máxima das raízes (m) (56)	p: Fracção de depleção (57) (para ET ≈ 5 mm/day)
d. Tubérculos	**d. Roots and Tubers**								**0.5**	**1.1**	**0.95**		**0.15**	**1**	**0.85**		
beterraba	Beets, table	15	25	20	10	70	Abr/Mai	Mediterrâneo		1.05	0.95	0.4		0.95	0.85	0.6-1.0	0.5
		25	30	25	10	90	Fev/Mar	Mediterrâneo & Árida									
mandioca: ano 1	Cassava: year 1	20	40	90	60	210	Estação da chuva	Regiões Tropicais	0.3	0.80 (8)	0.3	1		0.70 (33)	0.2	0.5-0.8	0.35
ano 2	year 2	150	40	110	60	360			0.3	1.1	0.5	1.5		1	0.45	0.7-1.0	0.4
cherovia	Parsnip								0.5	1.05	0.95	0.4		0.95	0.85	0.5-1.0	0.4
batata	Potato	25	30	30/45	30	115/130	Jan/Nov	Clima (Semi) Árido		1.15	0.75 (9)	0.6		1.1	0.65 (34)	0.4-0.6	0.35
		25	30	45	30	130	Mai	Clima Continental									
		30	35	50	30	145	Abr	Europa									
		45	30	70	20	165	Abr/Mai	Idaho, EUA									
		30	35	50	25	140	Dez	Calif. Desert, EUA									
batata doce	Sweet potato	20	30	60	40	150	Abr	Mediterrâneo		1.15	0.65	0.4		1.1	0.55	1.0-1.5	0.65
		15	30	50	30	125	Est. chuva	Regiões Tropicais									
	Turnip (and Rutabaga)									1.1	0.95	0.6		1	0.85	0.5-1.0	0.5
beterraba de açucar	Sugarbeet	30	45	90	15	180	Mar	Calif., EUA	0.35	1.2	0.70 (10)	0.5		1.15	0.50 (35)	0.7-1.2	0.55 (58)
		25	30	90	10	155	Jun	Calif., EUA									
		25	65	100	65	255	Set	Calif. Desert, EUA									
		50	40	50	40	180	Abr	Idaho, EUA									
		25	35	50	50	160	Mai	Mediterrâneo									
		45	75	80	30	230	Nov	Mediterrâneo									
		35	60	70	40	205	Nov	Região Árida									
e. Legumes (*Leguminosae*)	**e. Legumes (*Leguminosae*)**								**0.4**	**1.15**	**0.55**		**0.15**	**1.1**	**0.5**		
feijão (verde)	Beans (green)	20	30	30	10	90	Fev/Mar	Calif., Mediterranean	0.5	1.05 (7)	0.9	0.4		1.00 (32)	0.8	0.5-0.7	0.45
		15	25	25	10	75	Ago/Set	Calif., Egipto, Líbano									
feijão (seco)	Beans (dry)	20	30	40	20	110	Mai/Jun	Climas Continentais	0.4	1.15 (7)	0.35	0.4		1.10 (32)	0.25	0.6-0.9	0.45
		15	25	35	20	95	Jun	Paquistão, Calif.									
		25	25	30	20	100	Jun	Idaho, EUA									
feijão, lima	Beans, lima, large vines															0.8-1.2	0.45
grão de bico	Chick pea									1	0.35	0.4		0.95	0.25	0.6-1.0	0.5
faveira	Faba bean, broad bean	15	25	35	15	90	Mai	Europa									
		20	30	35	15	100	Mai/Abr	Mediterrâneo									
faveira, seca	- dry	90	45	40	60	235	Nov	Europa	0.5	1.15 (7)	0.3	0.8		1.10 (32)	0.2	0.5-0.7	0.45
faveira, verde	- green	90	45	40	0	175	Nov	Europa									
faveira, fresca	- fresh								0.5	1.15 (7)	1.1	0.8		1.10 (32)	1.05	0.5-0.7	0.45
grabanzo (??)	Grabanzo								0.4	1.15	0.35	0.8		1.05	0.25	0.6-1.0	0.45
grão de bico, feijão frade	Green gram, cowpeas	20	30	30	20	110	Mar	Mediterrâneo		1.05	0.60-0.35 (11)	0.4		1	0.55-0.25 (36)	0.6-1.0	0.45
amendoim	Groundnut (peanut)	25	35	45	25	130	Estação seca	África Ocidental		1.15	0.6	0.4		1.1	0.5	0.5-1.0	0.5
		35	35	35	35	140		Latitudes altas									
		35	45	35	25	140	Mai Mai/Jun	Mediterrâneo									
lentilha	Lentil	20	30	60	40	150	Abr	Europa		1.1	0.3	0.5		1.05	0.2	0.6-0.8	0.5
		25	35	70	40	170	Out/Nov	Região Árida									
ervilha	Peas	15	25	35	15	90	Mai	Europa									
		20	30	35	15	100	Mar/Abr	Mediterrâneo									
		35	25	30	20	110	Abr	Idaho, EUA									
ervilha - fresca	Peas -fresh								0.5	1.15 (7)	1.1	0.5		1.10 (32)	1.05	0.6-1.0	0.35
ervilha - seca/semente	Peas - dry/seed									1.15	0.3	0.5		1.1	0.2	0.6-1.0	0.4
soja	Soybeans	15	15	40	15	85	Dez	Trópicos		1.15	0.5	0.5-1.0		1.1	0.3	0.6-1.3	0.5
		20	30/35	60	25	140	Mai	EUA Central									
		20	25	75	30	150	Jun	Japão									
f. Vegetais perenes (com dormência no inverno e solo inicialmente nu ou com mulch)	**f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)**								**0.5**	**1**	**0.8**						
alcachofra	Artichoke	40	40	250	30	360	Abr (1º ano)	California	0.5	1	0.95	0.7	0.15	0.95	0.9	0.6-0.9	0.45
		20	25	250	30	325	Mai (2º ano)	(corte em Maio)									
espargos	Asparagus	50	30	100	50	230	Fev	Inverno quente	0.5	0.95 (12)	0.3	0.2-0.8	0.15	0.90 (37)	0.2	1.2-1.8	0.45
		90	30	200	45	365	Fev	Mediterrâneo									
hortelã	Mint								0.6	1.15	1.1	0.6-0.8	0.4	1.1	1.05	0.4-0.8	0.4
morangos	Strawberries								0.4	0.85	0.75	0.2	0.3	0.8	0.7	0.2-0.3	0.2

Tabela e título em Allen *et al.* (1998) ->		Tabela 11 (*) - Duração dos estádios de desenvolvimento* para vários períodos de plantação e regiões climáticas (dia)							Tabela 12 - Coeficientes culturais simples (ponderados pelo tempo), Kc, e média das alturas máximas das plantas, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO				Tabela 17 - Coeficientes culturais basais, Kcb, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO			Tabela 22 - Intervalos de profundidade máxima efectiva das raízes das plantas (rp),e fracção de depleção de água do solo para culturas comuns sem stress (p)	
Nome (em português)	Nome referido em Allen *et al*. (1998)	Inicial (L_{ini})	Desenvolvimento (L_{dev})	Médio (L_{mid})	Final (L_{late})	Total	Plantação	Região	Kc inicial (6)	Kc médio	Kc final	Altura máxima da cultura	Kcb inicial (31)	Kcb médio (31)	Kcb final (31)	Profundidade máxima das raízes (m) (56)	p: Fracção de depleção (57) (para ET ≈ 5 mm/day)
g. Culturas de fibras	**g. Fibre Crops**								**0.35**				**0.15**				
algodão	Cotton	30	50	60	55	195	Mar-Mai	Egipto; Paquistão;Calif.		1.15-1.20	0.70-0.50	1.2-1.5		1.10-1.15	0.50-0.40	1.0-1.7	0.65
		45	90	45	45	225	Mar	Calif. Desert, EUA									
		30	50	60	55	195	Set	Iémen									
		30	50	55	45	180	Abr	Texas									
linho	Flax	25	35	50	40	150	Abr	Europa		1.1	0.25	1.2		1.05	0.2	1.0-1.5	0.5
		30	40	100	50	220	Out	Arizona									
sisal (13, 38)	Sisal (13, 38)									0.4-0.7	0.4-0.7	1.5		0.4-0.7	0.4-0.7	0.5-1.0	0.8
h. Culturas oleaginosas	**h. Oil Crops**								**0.35**	**1.15**	**0.35**		**0.15**	**1.1**	**0.25**		
ricino	Castor beans	25	40	65	50	180	Mar	Climas (Semi) Áridos		1.15	0.55	0.3		1.1	0.45	1.0-2.0	0.5
		20	40	50	25	135	Nov	Indonésia									
nabo	Rapeseed, Canola									1.0-1.15 (14)	0.35	0.6		0.95-1.10 (39)	0.25	1.0-1.5	0.6
açafroa	Safflower	20	35	45	25	125	Abr	California, EUA		1.0-1.15 (14)	0.25	0.8		0.95-1.10 (39)	0.2	1.0-2.0	0.6
		25	35	55	30	145	Mar	Latitudes altas									
		35	55	60	40	190	Out/Nov	Região Árida									
sésamo	Sesame	20	30	40	20	100	Jun	China		1.1	0.25	1		1.05	0.2	1.0-1.5	0.6
girassol	Sunflower	25	35	45	25	130	Abr/Mai	Medit.; California		1.0-1.15 (14)	0.35	2		0.95-1.10 (39)	0.25	0.8-1.5	0.45
i. Cereais	**i. Cereals**								**0.3**	**1.15**	**0.4**		**0.15**	**1.1**	**0.25**		
cevada/aveia/trigo	Barley/Oats/Wheat	15	25	50	30	120	Nov	Índia Central		1.15	0.25	1		1.1	0.15	1.0-1.5	0.55
		20	25	60	30	135	Mar/Abr	35-45 ºL									
		15	30	65	40	150	Jul	África Oriental									
		40	30	40	20	130	Abr										
		40	60	60	40	200	Nov										
		20	50	60	30	160	Dez	Calif. Desert, EUA									
trigo de primavera	Spring Wheat									1.15	0.25-0.4 (15)	1		1.1	0.15-0.3 (40)	1.0-1.5	0.55
trigo de inverno	Winter Wheat	20 (2)	60 (2)	70	30	180	Dez	Calif., EUA									
		30	140	40	30	240	Nov	Mediterrâneo									
		160	75	75	25	335	Out	Idaho, EUA									
- com solos gelados	- with frozen soils								0.4	1.15	0.25-0.4 (15)	1	0.15-0.5 (41)	1.1	0.15-0.3 (40)	1.5-1.8	0.55
- sem solos gelados	- with non-frozen soils								0.7								
cereais (pequeno)	Grains (small)	20	30	60	40	150	Abr	Mediterrâneo									
		25	35	65	40	165	Out/Nov	Paquistão; Reg.Áridas									
milho	Maize (grain)	30	50	60	40	180	Abr	Africa Oriental (alt.)		1.2	0.60-0.35 (16)	2	0.15	1.15	0.50;0.15 (42)	1.0-1.7	0.55
		25	40	45	30	140	Dez/Jan	Climas Áridos									
		20	35	40	30	125	Jun	Nigéria (húmido)									
		20	35	40	30	125	Out	Índia (seco, frio)									
		30	40	50	30	150	Abr	Espanha (promavera, verão); Calif.									
		30	40	50	50	170	Abr	Idaho, EUA									
milho (doce)	Maize (sweet)	20	20	30	10	80	Mar	Filipinas		1.15	1.05 (17)	1.5		1.1	1.00 (43)	0.8-1.2	0.5
		20	25	25	10	80	Mai/Jun	Mediterrâneo									
		20	30	50/30	10	90	Out/Dez	Climas Áridos									
		30	30	30	10 (3)	110	Abr	Idaho, EUA									
		20	40	70	10	140	Jan	Calif. Desert, EUA									
milho-miúdo	Millet	15	25	40	25	105	Jun	Paquistão		1	0.3	1.5		0.95	0.2	1.0-2.0	0.55
		20	30	55	35	140	Abr	EUA Central									
sorgo	Sorghum	20	35	40	30	130	Mai/Jun	EUA, Paquis., Med.									
		20	35	45	30	140	Mar/Abrl	Região Árida									
- grão	- grain									1.00-1.10	0.55	1-2		0.95-1.05	0.35	1.0-2.0	0.55
- doce	- sweet									1.2	1.05	2-4		1.15	1	1.0-2.0	0.5
arroz	Rice	30	30	60	30	150	Dez; Mai	Trópicos; Mediterrâneo	1.05	1.2	0.90-0.60	1	1	1.15	0.70-0.45	0.5-1.0	0.20 (59)
		30	30	80	40	180	Mai	Trópicos									

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Nome (em português)	Nome referido em Allen *et al*. (1998)	Inicial (L_{ini})	Desenvolvimento (L_{dev})	Médio (L_{mid})	Final (L_{late})	Total	Plantação	Região	Kc inicial (6)	Kc médio	Kc final	Altura máxima da cultura	Kcb inicial (31)	Kcb médio (31)	Kcb final (31)	Profundidade máxima das raízes (m) (56)	p: Fracção de depleção (57) (para ET ≈ 5 mm/day)
j. Forragens	**j. Forages**																
alfalfa, temporada total (4)	Alfalfa, total season (4)	10	30	var.	var.	var.		último-4℃ na prim.até primeiro -4℃ no out.									
-efeitos de corte médios	- averaged cutting effects								0.4	0.95 (18)	0.9	0.7					
-períodos de corte individuais	- individual cutting periods								0.40 (19)	1.20 (19)	1.15 (19)	0.7	0.30 (44)	1.15 (44)	1.10 (44)	1.0-2.0	0.55
-para sementes	- for seed								0.4	0.5	0.5	0.7	0.3	0.45	0.45	1.0-3.0	0.6
alfalfa (4), 1º ciclo	Alfalfa (4) 1st cutting cycle	10	20	20	10	60	Jan Abr (último-4℃)	Calif., EUA.									
		10	30	25	10	75		Idaho, EUA.									
alfalfa (4), outros ciclos	Alfalfa (4), other cutting cycles	5	10	10	5	30	Mar	Calif., EUA.									
		5	20	10	10	45	Jun	Idaho, EUA.									
erva das Bermudas para semente	Bermuda for seed	10	25	35	35	105	Mar	Calif. Desert, EUA	0.35	0.9	0.65	0.4	0.15	0.85	0.6	1.0-1.5	0.6
a das Bermudas para feno (vários cor	Bermuda for hay (several cuttings)	10	15	75	35	135	---	Calif. Desert, EUA	0.55	1.00 (18)	0.85	0.35	0.5	0.95 (45)	0.8	1.0-1.5	0.55
trevo da Alexandria, Bersim	Clover hay, Berseem															0.6-0.9	0.5
- efeitos de corte médios	- averaged cutting effects								0.4	0.90 (18)	0.85	0.6					
- períodos de corte individuais	- individual cutting periods								0.40 (19)	1.15 (19)	1.10 (19)	0.6	0.30 (44)	1.10 (44)	1.05 (44)		
azevém - efeitos de corte médios	Rye Grass hay - averaged cutting effects								0.95	1.05	1	0.3	0.85	1.00 (45)	0.95	0.6-1.0	0.6
Pasto de relva	Grass Pasture (4)	10	20	--	--	--											
Sudan, 1º ciclo	Sudan, 1st cutting cycle	25	25	15	10	75	Abr	Calif. Desert, EUA									
Sudan, outros ciclos	Sudan, other cutting cycles	3	15	12	7	37	Jun	Calif. Desert, EUA									
feno de relva Sudan (anual)	Sudan Grass hay (annual)															1.0-1.5	0.55
- efeitos de corte médios	- averaged cutting effects								0.5	0.90 (19)	0.85	1.2					
- períodos de corte individuais	- individual cutting periods								0.50 (19)	1.15 (19)	1.10 (19)	1.2	0.30 (44)	1.10 (44)	1.05 (44)		
trevo da Alexandria, Bersim	Grazing pasture																
- em rotação	- Rotated Grazing								0.4	0.85-1.05	0.85	0.15-0.30	0.3	0.80-1.00	0.8	0.5-1.5	0.6
- extensa	- Extensive Grazing								0.3	0.75	0.75	0.1	0.3	0.7	0.7	0.5-1.5	0.6
relva	Turf grass																
- época fria (20, 36, 60)	- cool season (20, 36, 60)								0.9	0.95	0.95	0.1	0.85	0.9	0.9	0.5-1.0	0.4
- época quente (20, 36, 60)	- warm season (20, 36, 60)								0.8	0.85	0.85	0.1	0.75	0.8	0.8	0.5-1.0	0.5
k. Cana do açucar	**k. Sugar Cane**								**0.4**	**1.25**	**0.75**	**3**	**0.15**	**1.2**	**0.7**	1.2-2.0	0.65
cana do açucar, virgem	Sugarcane, virgin	35	60	190	120	405		Latitudes baixas									
		50	70	220	140	480		Trópicos									
		75	105	330	210	720		Hawaii, EUA									
cana do açucar (rebentos, depois de cortada)	Sugarcane, ratoon	25	70	135	50	280		Latitudes baixas									
		30	50	180	60	320		Trópicos									
		35	105	210	70	420		Hawaii, EUA									
l. Frutos tropicais e árvores	**l. Tropical Fruits and Trees**																
banana, 1º ano	Banana, 1st yr	120	90	120	60	390	Mar	Mediterrâneo	0.5	1.1	1	3	0.15	1.05	0.9	0.5-0.9	0.35
banana, 2º ano	Banana, 2nd yr	120	60	180	5	365	Fev	Mediterrâneo	1	1.2	1.1	4	0.6	1.1	1.05	0.5-0.9	0.35
ananás (21, 47)	Pineapple (21, 47)	60	120	600	10	790		Hawaii, EUA									
- solo nu	- bare soil								0.5	0.3	0.3	0.6-1.2	0.15	0.25	0.25	0.3-0.6	0.5
- com cobertura de relva	- with grass cover								0.5	0.5	0.5	0.6-1.2	0.3	0.45	0.45		
cacau	Cacao								1	1.05	1.05	3	0.9	1	1	0.7-1.0	0.3
café	Coffee																
- sem cobertura	- bare ground cover								0.9	0.95	0.95	2-3	0.8	0.9	0.9	0.9-1.5	0.4
- com ervas daninhas	- with weeds								1.05	1.1	1.1	2-3	1	1.05	1.05		
tamareiras	Date Palms								0.9	0.95	0.95	8	0.8	0.85	0.85	1.5-2.5	0.5
palmeiras	Palm Trees								0.95	1	1	8	0.85	0.9	0.9	0.7-1.1	0.65
árvore da borracha	Rubber Trees								0.95	1	1	10	0.85	0.9	0.9	1.0-1.5	0.4
chá	Tea																
- sem sombra	- non-shaded								0.95	1	1	1.5	0.9	0.95	0.9	0.9-1.5	0.4
- com sombra (22, 48)	- shaded (22, 48)								1.1	1.15	1.15	2	1	1.1	1.05	0.9-1.5	0.45

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m. Uvas e bagas	**m. Grapes and Berries**																
bagas (arbustos)	Berries (bushes)								0.3	1.05	0.5	1.5	0.2	1	0.4	0.6-1.2	0.5
uvas	Grapes	20	40	120	60	240	Abr	Latitudes baixas									
		20	50	75	60	205	Mar	Calif., EUA									
		20	50	90	20	180	Mai	Latitudes altas									
		30	60	40	80	210	Abr	Latitudes intermédias (vinho)									
- uvas ou passas	- Table or Raisin								0.3	0.85	0.45	2	0.15	0.8	0.4	1.0-2.0	0.35
- vinho	- Wine								0.3	0.7	0.45	1.5-2	0.15	0.65	0.4	1.0-2.0	0.45
lúpulo	Hops	25	40	80	10	155	Abr	Idaho, EUA	0.3	1.05	0.85	5	0.15	1	0.8	1.0-1.2	0.5
n. Árvores de fruto	**n. Fruit Trees**																
amendoeiras, sem cobertura do terreno	Almonds, no ground cover								0.4	0.9	0.65 (23)	5	0.2	0.85	0.60 (49)	1.0-2.0	0.4
macieira, cerejeira, pereira (24, 50)	Apples, Cherries, Pears (24, 50)															1.0-2.0	0.5
- sem cobertura do terreno, geada	- no ground cover, killing frost								0.45	0.95	0.70 (23)	4	0.35	0.9	0.65 (49)		
- sem cobertura do terreno	- no ground cover, no frosts								0.6	0.95	0.75 (23)	4	0.5	0.9	0.70 (49)		
- com cobertura do terreno activa, geada	- active ground cover, killing frost								0.5	1.2	0.95 (23)	4	0.45	1.15	0.90 (49)		
- com cobertura do terreno activa	- active ground cover, no frosts								0.8	1.2	0.85 (23)	4	0.75	1.15	0.80 (49)		
damasqueiro, pessegueiro, ameixieira (24, 25, 50, 51)	Apricots, Peaches, Stone Fruit (24, 25, 50, 51)															1.0-2.0	0.5
- sem cobertura do terreno, geada	- no ground cover, killing frost								0.45	0.9	0.65 (23)	3	0.35	0.85	0.60 (49)		
- sem cobertura do terreno	- no ground cover, no frosts								0.55	0.9	0.65 (23)	3	0.45	0.85	0.60 (49)		
- com cobertura do terreno activa, geada	- active ground cover, killing frost								0.5	1.15	0.90 (23)	3	0.45	1.1	0.85 (49)		
- com cobertura do terreno activa	- active ground cover, no frosts								0.8	1.15	0.85 (23)	3	0.75	1.1	0.80 (49)		
pêra abacate, sem cobertura do terreno	Avocado, no ground cover								0.6	0.85	0.75	3	0.5	0.8	0.7	0.5-1.0	0.7
citrinos, sem cobertura do terreno (26, 52)	Citrus, no ground cover (26, 52)	60	90	120	95	365	Jan	Mediterrâneo									
- 70% copa	- 70% canopy								0.7	0.65	0.7	4	0.65	0.6	0.65	1.2-1.5	0.5
- 50% copa	- 50% canopy								0.65	0.6	0.65	3	0.6	0.55	0.6	1.1-1.5	0.5
- 20% copa	- 20% canopy								0.5	0.45	0.55	2	0.45	0.4	0.5	0.8-1.1	0.5
citrinos, com cobertura do terreno activa ou ervas daninhas (27, 53)	Citrus, with active ground cover or weeds(27, 53)																
- 70% copa	- 70% canopy								0.75	0.7	0.75	4	0.75	0.7	0,75	1.2-1.5	0.5
- 50% copa	- 50% canopy								0.8	0.8	0.8	3	0.75	0.75	0.75	1.1-1.5	0.5
- 20% copa	- 20% canopy								0.85	0.85	0.85	2	0.8	0.8	0.85	0.8-1.1	0.5
coníferas (28, 54)	Conifer Trees (28, 54)								1	1	1	10	0.95	0.95	0.95	1.0-1.5	0.7
quivi	Kiwi								0.4	1.05	1.05	3	0.2	1	1	0.7-1.3	0.35
pomares (folha caduca)	Deciduous Orchard	20	70	90	30	210	Mar	Latitudes altas									
		20	70	120	60	270	Mar	Latitudes baixas									
		30	50	130	30	240	Mar	Calif., EUA									
oliveiras (40 a 60% do terreno coberto pelas copas) (29, 55)	Olives (40 to 60% ground coverage by canopy) (29, 55)	30	90	60	90	270 (5)	Mar	Mediterrâneo	0.65	0.7	0.7	3-5	0.55	0.65	0.65	1.2-1.7	0.65
pistácio, sem cobertura do terreno	Pistachios, no ground cover	20	60	30	40	150	Fev	Mediterrâneo	0.4	1.1	0.45	3-5	0.2	1.05	0.4	1.0-1.5	0.4
nogueira (24, 50)	Walnuts (24, 50)	20	10	130	30	190	Abr	Utah, EUA	0.5	1.1	0.65 (23)	4-5	0.4	1.05	0.60 (49)	1.7-2.4	0.5
o. Zonas húmidas - clima temperado	**o. Wetlands - Temperate Climate**																
zonas húmidas (tabua, junco)	Wetlands (Cattails, Bulrush)	10	30	80	20	140	Mai	Utah, EUA; geada									
		180	60	90	35	365	Nov	Florida, EUA									
tabua, junco, com geada	Cattails, Bulrushes, killing frost								0.3	1.2	0.3	2					
tabua, junco, sem geada	Cattails, Bulrushes, no frost								0.6	1.2	0.6	2					
vegetação pequena, sem geada	Short Veg., no frost								1.05	1.1	1.1	0.3					
pântano-canavial, águas paradas	Reed Swamp, standing water								1	1.2	1	1-3					
pântano-canavial, solo húmido	Reed Swamp, moist soil								0.9	1.2	0.7	1-3					
zonas húmidas (vegetação pequena)	Wetlands (short veg.)	180	60	90	35	365	Nov	Clima sem geadas									

Tabela e título em Allen *et al.* (1998) ->		Tabela 11 (*) - Duração dos estádios de desenvolvimento* para vários períodos de plantação e regiões climáticas (dia)							Tabela 12 - Coeficientes culturais simples (ponderados pelo tempo), Kc, e média das alturas máximas das plantas, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO				Tabela 17 - Coeficientes culturais basais, Kcb, para culturas sem stress e bem geridas, em climas sub-húmidos (RHmin aprox. 45%, u2 aprox. 2 m/s) para utilizar na ETo calculada pelo método de Penman-Monteith da FAO			Tabela 22 - Intervalos de profundidade máxima efectiva das raízes das plantas (rp),e fracção de depleção de água do solo para culturas comuns sem stress (p)	
Nome (em português)	Nome referido em Allen *et al*. (1998)	Inicial (L_{ini})	Desenvolvimento (L_{dev})	Médio (L_{mid})	Final (L_{late})	Total	Plantação	Região	Kc inicial (6)	Kc médio	Kc final	Altura máxima da cultura	Kcb inicial (31)	Kcb médio (31)	Kcb final (31)	Profundidade máxima das raízes (m) (56)	p: Fracção de depleção (57) (para ET ≈ 5 mm/day)
p. Especial	**p. Special**																
água, < 2m de profundidade ou em climas subhumidos ou trópicos	Open Water, < 2 m depth or in subhumid climates or tropics									1.05	1.05						
água, > 5m de profundidade, sem turbidez, clima temperado	Open Water, > 5 m depth, clear of turbidity, temperate climate									0.65 (30)	1.25 (30)						
	Principais fontes de dados, como referidas em Allen *et al*. (1998) ->	FAO Irrigation and Drainage Paper 24 (Tabela 22 de Doorenbos and Pruitt, 1977)							Kc ini: Doorenbos and Kassam (1979). Kc mid and Kc end: Doorenbos and Pruitt (1977); Pruitt (1986); Wright (1981, 1982). Snyder et al., (1989)				$K_{cb\ ini}$: Doorenbos and Kassam (1979); $K_{cb\ mid}$ and $K_{cb\ end}$: Doorenbos and Pruitt (1977); Pruitt (1986); Wright (1981, 1982), Snyder *et al.* (1989)				

Attention: Notes are in Portuguese.

(*) A duração dos estádios de desenvolvimento desta tabelas são apenas indicativos de condições gerais, mas podem variar substancialmente de região para região, com as condições de clima e de colheita, e com a variedade da cultura. O utilizador é fortemente aconselhado a obter informação local apropriada.

(1) Crucíferas incluem couve, couve-flor, brócolos e couves de Bruxelas. O largo intervalo nos comprimentos das estações é devido a diferenças na variedade e nas espécies.

(2) Estes períodos podem alargar-se em climas gelados de acordo com os dias com potencial de crescimento nulo e dormência do trigo. Sob condições gerais, e na ausência de dados locais, pode-se presumir que no Outono, a plantação em climas temperados do norte ocorre quando a média móvel de 10 dias da temperatura média diária do ar desce aos 17ºC ou o mais tardar 1 de Dezembro. A plantação do trigo da Primavera pode-se presumir que ocorre quando a média móvel de 10 dias da temperatura média diária do ar sobe até aos 5ºC. A plantação da Primavera do milho pode-se presumir que ocorre quando a média móvel de 10 dias da temperatura média diária do ar sobe até aos 13ºC.

(3) O final de estação para o milho doce será de cerca de 35 dias se for permitido o amadurecimento e secagem do cereal.

(4) Em climas com geadas mortíferas, as estações de crescimento podem ser calculadas, para a alfalfa e a relva, como: alfalfa: último -4°C na primavera até o primeiro -4°C no outono (Everson et al.,1978 , in Allen et al., 1998); relva: 7 dias antes do último -4°C na primavera e 7 dias após o último -4°C no outono (Kruse e Haise , 1974, in Allen et al., 1998).

(5) As oliveiras têm folhas novas em Março. Ver nota nº 29 para informação adicional, onde o Kc continua fora do "período de crescimento".

(6) Estes valores de Kc ini são genéricos e para uma situação típica de gestão da irrigação e de humedecimento do solo. Para humedecimmentos frequentes, tais como irrigação sprinkle de elevada frequência ou precipitação diária, estes valores podem aumentar substancialmente até 1 a 1,2. Kc ini é função do intervalo de humedecimento e da taxa de evaporação potencial durante os períodos inicial e de desenvolvimento e pode ser estimada mais adequadamente utilizando as figuras 29 e 30 em Allen et al. (1998), ou a equação 7-3 em Allen et al. (1998), ou utilizando o coeficiente cultural duplo Kcb ini + Ke.

(7)+(32) Feijões, ervilhas, legumes, tomates, pimentos e pepinos são por vezes criados em varas atingindo 1,5 a 2 m de altura. Nesses casos, devem-se utilizar valores superiores de K_c e de K_{cb}. Para feijões verdes, pimentos e pepinos, pode-se utilizar K_c = 1,15 e K_{cb} = 1,10; para tomates, feijões secos e ervilhas, K_c = 1,20 e K_{cb} = 1,15. Nestas condições h também deve ser aumentado.

(8)+(33) Os valores de meia estação para mandioca assumem condições de não-stress durante ou após a estação da chuva. Os valores de $K_{c\ final}$ e de $K_{cb\ final}$ consideram a dormência durante a estação seca.

(9)+(34) O valor de $K_{c\ final}$ para as batatas é de cerca de 0,40 com *vine kill.* O valor de $K_{cb\ final}$ é de 0,35.

(10)+(35) Estes valores de $K_{c\ final}$ e de $K_{cb\ final}$ são para inexistência de irrigação durante o último mês da estação de crescimento. O valor de $K_{c\ final}$ para beterraba de açúcar é superior, até 1,0, quando ocorre irrigação ou chuva significativa durante o último mês. Nas mesmas condições o valor de $K_{cb\ final}$ também é mais elevado, até 0,9.

(11)+(36) Os primeiros valores de $K_{c\ final}$ e de $K_{cb\ final}$ são para a colheita fresca. Os segundos valores são para colheita seca.

(12)+(37) O K_c para espargos normalmente permanece em $K_{c\ inicial}$ durante a colheita das plantas jovens, devido à cobertura do terreno ser esparsa. O $K_{c\ médio}$ é para o recrescimento seguinte da vegetação após o final da colheita das plantas jovens. A mesma situação acontece para K_{cb}.

(13)+(38) O K_c e o K_{cb} para o sisal depende da densidade da plantação e da gestão da água (p.e. stress de humidade intencional)

(14)+(39) Os valores mais baixos são para culturas regadas pela água da chuva tendo populações de plantas menos densas.

(15)+(40) Os valores mais altos são para colheitas manuais.

(16)+(42) O primeiro $K_{c\ final}$ é para colheita com humidade do cereal elevada. O segundo $K_{c\ final}$ é para colheita após secagem completa do terreno do cereal (até cerca de 18 % de humidade, base de massa de humidade). As mesmas situações aplicam-se para o $K_{cb\ final}$.

(17)+(43) Se for colhido fresco, para consumo humano. Utilizar o $K_{c\ final}$ ou o $K_{cb\ final}$ para milho do campo se o milho doce for deixado amadurecer e secar no campo.

(18)+(45) Este $K_{c\ médio}$ para culturas de feno é uma média global dos coeficientes de $K_{c\ médio}$ que utiliza os K_c antes e após o corte. É aplicado ao período que se segue ao primeiro período de desenvolvimento até ao princípio do período da última estação tardia da estação de crescimento. A mesma situação se aplica ao $K_{cb\ médio}$.

(19)+(44) Estes K_c para culturas de feno representam imediatamente após o corte; quando em cobertura total, e imediatamente antes do corte, respectivamente. Idem para K_{cb}. A estação de crescimento é descrita como uma série

de períodos de corte individuais.
(20)+(46)+(60) Variedades de relva da estação fresca incluem culturas densas de erva-de-febra (em inglês: bluegrass), azevém e festuca. As variedades da estação quente incluem erva das Bermudas e erva St. Augustine. Os valores de K_c = 0,95 e de K_{cb} = 0,90 para a estação fria representam uma altura de ceifa de 0,06 a 0,08 m sob condições gerais de turfa. No caso de haver uma gestão da água cuidadosa e não ser necessário um crescimento rápido, os K_c e K_{cb} para a turfa podem ser reduzidos de 0,10. As variedades de relva têm profundidades de raízes diferentes. Algumas atingem 1,2 m, enquanto outras apresentam profundidades baixas. As profundidades mais compridas representam condições em que há uma gestão de água cuidadosa, com maior depleção entre irrigações que favorecem o aprofundamento das raízes na procura da água.
(21)+(47) Cultura multianual. A planta do ananás tem uma transpiração muito baixa porque fecha os seus estomas durante o dia e abre-os durante a noite. Assim, a maioria da ET_c do ananás é evaporação a partir do solo. $K_{c\ médio}$ < $K_{c\ inicial}$ porque o $K_{c\ médio}$ ocorre quando a cobertura do terreno é completa, pelo que a evaporação do solo é menor. Os valores atribuídos assumem que 50% da superfície do terreno é coberta de mulch de plástico preto e que a irrigação é por aspersão. Para irrigação gota a gota por baixo do mulch de plástico, os K_c podem ser reduzidos de 0,10.
(22)+(48) Inclui as necessidades de água das árvores com sombra.
(23) Estes $K_{c\ final}$ representam K_c antes da queda das folhas. Após a queda, $K_{c\ final} \approx$ 0,20 para solos nus e secos ou para cobertura do terreno morta; e $K_{c\ final} \approx$ 0,50 a 0,80 para cobertura do terreno activamente em crescimento.
(24) Consultar as **Eq. 94, 97 or 98** e notas 26 e 27 para estimar K_c para culturas imaturas, e notas 27 e 28 para estimar K_{cb} para culturas imaturas.
(25)+(51) A categoria de frutas de caroço aplica-se a pêssegos, alperces, peras, ameixas e pecans.
(26) Estes valores de K_c podem ser calculados a partir da **Eq. 98** para $\mathbf{K_{c\ min}}$ **=** 0,15 e $\mathbf{K_{c\ full}}$ = 0,75, 0,70 e 0,75 para os períodos de estação inicial, media e final, e $\mathbf{f_{c\ eff} = f_c}$ em que f_c = fracção de terreno coberta pela copa das árvores (p.e., presume-se que o sol se encontra directamente acima). Os valores listados correspondem aos apresentados em Doorenbos and Pruitt (1977) e a medições mais recentes. O valor da meia estação é mais baixo que o inicial e o final devido aos efeitos do fecho dos estomas durante períodos de pico de ET. Para climas húmidos e sub-húmidos onde há um controlo estomático menor pelos citrinos, os valores de $K_{c\ inicial}$, $K_{c\ médio}$, e $K_{c\ final}$ podem ser aumentados de 0,1 – 0,2, de acordo com Rogers *et al*. (1983).
(27) Estes valores de K_c podem ser calculados como $\mathbf{K_c = f_c\ K_{c\ ngc} + (1 - f_c)\ K_{c\ cover}}$ onde $K_{c\ ngc}$ é o K_c dos citrinos sem cobertura de terreno activa (calculado como na nota 26), $K_{c\ cover}$ é o K_c, para a cobertura do terreno activa (0,95), e f_c define-se na nota 26. Os valores listados correspondem aos de Doorenbos and Pruitt (1977) e com medições mais recentes. Alternativamente, o K_c para os citrinos com cobertura de terreno activa pode ser estimado directamente a partir da **Eq. 98** fazendo $\mathbf{K_{c\ min} = K_{c\ cover}}$. Para climas húmidos e sub-húmidos onde há um controlo estomático menor pelos citrinos, os valores de $K_{c\ inicial}$, $K_{c\ médio}$, e $K_{c\ final}$ podem ser aumentados de 0,1 – 0,2, de acordo com Rogers *et al*. (1983). Para uma cobertura do terreno não activa ou apenas moderadamente activa (activa indica uma cobertura do terreno verde e em crescimento com um índice de area foliar (LAI) > cerca de 2 a 3), K_c deve ser ponderado entre K_c para inexistência de cobertura de terreno e K_c para cobertura de terreno activa, sendo a ponderação baseada no grau de verde e área foliar aproximada da cobertura de terreno.
(28)+(54) As coníferas apresentam controlo estomático substancial devido à reduzida resistência aerodinâmica. Os K_c e K_{cb} podem facilmente ir abaixo dos valores apresentados, que representam condições com boa disponibilidade de água em grandes florestas.
(29) Estes coeficientes representam cerca de 40 a 60% da cobertura do terreno. Utilize-se a **Eq. 98** e as notas 26 e 27 para estimar K_c para culturas imaturas. Em Espanha, Pastor e Orgaz (1994) encontraram os seguintes valores mensais de K_c para olivais com 60% de cobertura do terreno: 0,50; 0,50; 0,65; 0,60; 0,55; 0,50; 0,45; 0,45; 0,55; 0,60; 0,65; 0,50 (Janeiro a Dezembro). Estes coeficientes podem ser invocados utilizando $K_{c\ inicial}$ = 0,65, $K_{c\ médio}$ = 0,45, e $K_{c\ final}$ = 0,65, com comprimentos de estádios de 30, 90, 60 e 90 dias, respectivamente para os períodos inicial, de desenvolvimento, meia estação e final de estação, e utilizando K_c = 0,50 durante o Inverno ("fora de estação"), de Dezembro a Fevereiro.
(30) Estes K_c são para águas profundas em latitudes temperadas onde durante o ano ocorrem mudanças de temperatura grandes no corpo hídrico e a evaporação inicial e do período de pico é baixa uma vez que a energia da radiação é absorvida para dentro do corpo hídrico profundo. Durante os períodos de Outono e de Inverno
($K_{c\ final}$), o calor é libertado do corpo hídrico o que faz aumentar a evaporação acima da da relva. Assim, $K_{c\ médio}$ corresponde ao período em que o corpo hídrico ganha energia térmica e $K_{c\ final}$ ao período em que liberta energia térmica. Estes valores de K_c devem ser utilizados com precaução.
(31) Estes são os valores para K_{cb} que representam condições contendo um solo com a superfície seca. Este valores devem ser utilizados somente para a aproximação do coeficiente cultural duplo ($K_{cb\ ini}$ + K_e).
(32) Ver nota 7.
(33) Ver nota 8.
(34) Ver nota 9.
(35) Ver nota 10.
(36) Ver nota 11.
(37) Ver nota 12.
(38) Ver nota 13.
(39) Ver nota 14.
(40) Ver nota 15.
(41) Os dois valores de $K_{cb\ inicial}$ para o trigo de Inverno são para os casos de cobertura do terreno inferior a 10% ou para o período de dormência, de Inverno, se a vegetação cobre completamente o terreno mas as condições não são de gelo no solo.
(42) Ver nota 16.
(43) Ver nota 17.
(44) Ver nota 19.
(45) Ver nota 18.
(46) Ver nota 20.
(47) Ver nota 21.
(48) Ver nota 22.

(49) Estes $K_{cb\ final}$ representam K_{cb} antes da queda das folhas. Após a queda, $K_{cb\ final} \approx 0{,}15$ para solos nus e secos ou para cobertura do terreno morta; e $K_{cb\ final} \approx 0{,}45$ a 0,75 para cobertura do terreno activamente em crescimento.
(50) Ver nota 24.
(51) = (25)
(52) Estes valores de K_{cb} podem ser calculados a partir da **Eq. 98** para $\mathbf{K_{c\ min}}$ = 0,15 e $\mathbf{K_{cb\ full}}$ = 0,70, 0,65 e 0,70 para os períodos de estação inicial, média final, e $f_{c\ eff} = f_c$ em que f_c = fracção de terreno coberta pela copa das árvores (p.e., presume-se que o sol se encontra directamente acima). O valor da estação média é mais baixo que os valores dos estádios inicial e final devido aos efeitos do fecho dos estomas durante os períodos de evapotranspiração de pico. Para climas húmidos e sub-húmidos, em que há menor controlo estomático pelos citrinos, os valores de $K_{cb\ inicial}$, $K_{cb\ médio}$ e $K_{cb\ final}$ podem ser aumentados de 0,1 - 0,2, de acordo com Rogers *et al*. (1983).
(53) Estes valores de K_{cb} podem ser calculados por $K_{cb} = f_c K_{cb\ ngc} + (1 - f_c) K_{cb\ cover}$ em que $K_{cb\ ngc}$ é o K_{cb} dos citrinos sem cobertura de terreno activa (calculada como na nota 27), $K_{cb\ cover}$ é o K_{cb} para a cobertura de terreno activa (0,90), e f_c é definido na nota 27. Alternativamente, K_{cb} para os citrinos com cobertura de terreno activa pode ser estimado directamente pela **Eq. 98** fazendo $K_{c\ min} = K_{cb\ cover}$. Para climas húmidos e sub-húmidos, em que há o controlo estomático pelos citrinos é menor, os valores de $K_{cb\ inicial}$, $K_{cb\ médio}$, e $K_{cb\ final}$ podem ser aumentados de 0,1 - 0,2, de acordo com Rogers *et al*. (1983). Para coberturas de terreno não activas ou apenas moderadamente activas (activa indica cobertura de terreno verde e em crescimento com LAI > cerca de 2 a 3), K_{cb} deve ser ponderado entre K_{cb} para ausência de cobertura de terreno e K_{cb} para cobertura de terreno activa, com a ponderação baseada no grau de verde e na área foliar aproximada da cobertura de terreno.
(54) Ver nota 28.
(55) Estes coeficientes representam 40 a 60% da cobertura do terreno. Utilize-se a **Eq. 98**, e as notas 27 e 28 para estimar K_{cb} em culturas imaturas.
(56) Os valores mais elevados de Z_r são para solos sem estratificação significativa ou outras características que possam restringir a profundidade das raízes. Os valores mais baixos de Z_r podem ser utilizados para calendarização da irrigação e os valores mais elevados para modelar o stress hídrico do solo ou para condições de irrigação pela água da chuva.
(57) Os valores de p aplicam-se para ETc aproximadamente igual a 5 mm/day. O valor de p pode ser ajustado para diferentes ETc de acordo com: **p = p tabela 22 + 0.04 (5 - ETc)**, em que p se expressa como uma fracção e ETc como mm/d.
(58) A beterraba de açucar experimenta frequentemente emurchecimento no final da tarde em climas áridos mesmo para p < 0.55, com um impacto normalmente baixo no rendimento de açúcar.
(59) O valor de p para o arroz é de 0,20 da saturação.
(60) Ver nota 20.

Annex 3 – Derivation of the hydraulic properties of the soils present in the Land Bahía Blanca Estuary area

Edaphic Domain	Taxonomic unit	Horizon (Soil profile)	Horizon thickness [cm]	% Clay (< 2 µ)	% Sand (50 µ-2mm)	Organic matter (*)	Porosity [cm3/cm3]	Field capacity [cm3/cm3]	Wilting point [cm3/cm3]	Hydraulic conductivity [mm.d-1]	Material of the upper horizon (Ap excluded)
1	M18li3	**A1**	**27**	**29**	**40.9**	**4.36**	**0.56**	**0.41**	**0.24**	**637**	**clay loam**
2	M18pa3	**A1**	**22**	**32.4**	**28.4**	**7.74**	**0.61**	**0.55**	**0.31**	**410**	**clay loam**
	M17tc3	Ap	13	24.6	36.2	7.79	0.60	0.51	0.27	788	
		A12	18	25.5	35.8	6.38	0.58	0.47	0.25	544	loam
		B1	8	28.4	30.9	2.12	0.49	0.36	0.20	78	
		B2t	26	31.5	35.6	1.22	0.47	0.34	0.20	66	
		B3	38	24.3	39.3	0.43	0.44	0.28	0.15	73	
		C	37	18.7	43.6	0.19	0.42	0.24	0.12	113	
		TOTAL					**0.48**	**0.33**	**0.18**	**101**	**6-loam**
	M24en4	A1	20	11.02	67.68	2.98	0.49	0.25	0.13	2544	sandy loam
		AC	23	10.81	72.23	1.45	0.43	0.20	0.10	2016	
		C1	37	9.84	75.09	0.44	0.39	0.16	0.08	1462	
		C2	20	8.12	78.22	0.14	0.38	0.13	0.07	1589	
		TOTAL					**0.42**	**0.18**	**0.09**	**1749**	**7-sandy loam**
	E25tc	A1	15	2.8	91.2	0.91	0.39	0.11	0.05	4143	sand
		AC	20	1.5	94.1	0.72	0.38	0.10	0.04	4010	
		C1	17	1.2	91	0.25	0.36	0.09	0.04	2297	
		C2	18	23	90.3	0.00	0.36	0.16	0.14	6216	
		TOTAL					**0.37**	**0.11**	**0.07**	**3703**	**1-sand**
	M25tc4	A1	14	26	34.5	1.81	0.46	0.34	0.18	76	loam
		B2t	20	57.1	17.6	1.31	0.48	0.47	0.33	1	
		B3ca	24	0	0	0.43		0.27	0.03	0	
		B32ca	25	24.8	32.4	0.00	0.44	0.28	0.15	46	
		TOTAL					**0.33**	**0.33**	**0.17**	**6**	**6-loam**
	M18tc4	A1	38	32.9	23.7	0.81	0.50	0.35	0.20	48	clay loam
		B2	27	33.3	23.4	2.09	0.49	0.39	0.23	35	
		IIC1	22	27.5	31.3	0.95	0.45	0.32	0.18	45	
		IIIC2	23	27.3	37.3	1.36	0.42	-0.05	0.18	39	
		TOTAL					**0.47**	**0.27**	**0.20**	**42**	**10-clay loam**
3	M24tc2	Ap	18	35.1	26.5	4.78	0.55	0.47	0.28	132	
		B21	19	39.6	25.2	2.48	0.51	0.42	0.26	37	clay loam
		B22	22	40.1	32.8	0.76	0.48	0.36	0.24	33	
		B3	25	33	32	0.00	0.45	0.31	0.19	29	
		TOTAL					**0.49**	**0.38**	**0.24**	**38**	**10-clay loam**
	M24li3	**A1**	**18**	**27**	**40**	**3.69**	**0.53**	**0.39**	**0.22**	**385**	**10-clay loam**
	M21tc3s	A1	14	21.3	42.5	3.51696	0.51	0.35	0.19	366	loam
		B1	9	24.4	40.5	3.49972	0.51	0.37	0.20	324	
		B21t	20	29.9	33.2	2.25844	0.49	0.37	0.21	98	
		B22t	15	26.3	42.7	0.81028	0.46	0.29	0.17	131	
		TOTAL					**0.49**	**0.34**	**0.19**	**151**	**6-loam**
	M24en3i	A1	40	25	47.6	2.12	0.48	0.32	0.18	356	sandy clay loam
		AC	35	23.3	45.2	1.59	0.47	0.30	0.17	242	
		C	45	22.2	41.8	0.00	0.39	0.25	0.14	43	
		TOTAL					**0.44**	**0.29**	**0.16**	**92**	**8-sandy clay loam**
	M21tc2s'	A1	23	29.3	46.1	3.02	0.51	0.36	0.22	428	sandy clay loam
		B2t	20	36.1	25.1	1.34	0.49	0.38	0.23	30	
		TOTAL					**0.50**	**0.37**	**0.22**	**60**	**8-sandy clay loam**
	M17tc3	Ap	12	24.6	36.2	7.79	0.60	0.51	0.27	790	
		A12	19	25.5	36.1	6.38	0.58	0.47	0.25	559	loam
		B1	8	28.4	30.9	2.12	0.49	0.36	0.20	78	
		B2t	26	31.5	35.6	1.22	0.47	0.34	0.20	66	
		B3	38	24.3	39.3	0.43	0.44	0.28	0.15	73	
		C	37	18.7	43.6	0.19	0.42	0.24	0.12	113	
		TOTAL					**0.48**	**0.33**	**0.18**	**101**	**6-loam**

Annex 3 – Derivation of the hydraulic properties of the soils present in the Land Bahía Blanca Estuary area (cont)

Edaphic Domain	Taxonomic unit	Horizon (Soil profile)	Horizon thickness [cm]	% Clay (< 2 μ)	% Sand (50 μ-2mm)	Organic matter (*)	Porosity [cm3/cm3]	Field capacity [cm3/cm3]	Wilting point [cm3/cm3]	Hydraulic conductivity [mm.d-1]	Material of the upper horizon (Ap excluded)
4	M24en4	A1	25	16.4	67.2	1.22	0.44	0.22	0.13	1502	sandy loam
		AC	44	17.1	66.6	0.83	0.42	0.21	0.12	1061	
		C	66	12.9	68.4	1.00	0.43	0.20	0.11	1309	
		TOTAL					**0.43**	**0.21**	**0.12**	**1244**	**7-sandy loam**
	E23us	A1	40	6.4	91.1	0.34	0.36	0.11	0.06	3983	sand
		AC	30	6.7	92.0	1.00	0.40	0.13	0.08	7332	
		C	50	5.4	93.6	1.00	0.40	0.12	0.07	7273	
		TOTAL					**0.39**	**0.12**	**0.07**	**5712**	**1-sand**
	E26tcs	Ap	15	13.1	75.6	1.14	0.42	0.19	0.11	2650	
		A12	13	10.7	75.8	0.64	0.41	0.16	0.09	2047	sandy loam
		AC	34	10.2	75.6	0.41	0.40	0.16	0.08	1803	
		C	18	13.5	71.7	1.00	0.42	0.19	0.11	1973	
		TOTAL					**0.41**	**0.17**	**0.10**	**2000**	**7-sandy loam**
	E26tc	A1	16	6.4	81.6	0.62	0.40	0.14	0.07	2501	loamy sand
		AC	24	6.4	82.9	0.53	0.39	0.13	0.07	2651	
		Cca	> 60	5.1	83.7	0.43	0.39	0.12	0.06	2458	
		TOTAL					**0.39**	**0.13**	**0.06**	**2509**	**7-sandy loam**
	E22tc	AC	14	2.5	96.7	0.78	0.38	0.10	0.05	5742	sand
		C	46	2.3	97.2	0.05	0.35	0.07	0.04	3588	
		TOTAL					**0.35**	**0.08**	**0.04**	**3932**	**1-sand**
12	M21tc2	A1	27.00	26	43.9	3.69	0.51	0.37	0.21	381	loam
		B2t	26.00	31.2	45	1.24	0.46	0.32	0.20	131	
		B3	25.00	21.1	49.4	0.43	0.43	0.25	0.14	183	
		C	29.00	15.7	43.6	0.00	0.42	0.23	0.10	124	
		TOTAL					**0.45**	**0.29**	**0.16**	**167**	**6-loam**
	F28tc3	A11	16.00	16.9	71.3	1.21	0.43	0.21	0.13	2044	sandy loam
		A12	24.00	14.6	77.8	0.69	0.41	0.18	0.11	2629	
		B2t	23.00	25.2	57	0.55	0.43	0.25	0.16	329	
		B3	37.00	23	60	0.00	0.41	0.22	0.14	382	
		C	25.00	20.5	63.03	0.00	0.37	0.21	0.13	252	
		TOTAL					**0.41**	**0.21**	**0.13**	**442**	**7-sandy loam**
26	E13ac3	I	31	27.5	13.8	3.60	0.47	0.44	0.22	20	silty clay loam
		II	25	23.9	16.8	0.53	0.50	0.33	0.15	52	
		III	56	26	9.8	0.00	0.50	0.33	0.16	32	
		TOTAL					**0.49**	**0.36**	**0.17**	**30**	**9- silty clay loam**
	F28tc3	A1	15	21.2	26.5	1.59	0.47	0.33	0.16	60	silt loam
		B2t	17	32	15	1.00	0.52	0.37	0.20	38	
		B3x	68	23	23.9	1.45	0.47	0.34	0.16	52	
		TOTAL					**0.48**	**0.34**	**0.17**	**50**	**11-silt loam**
	A11ah4	I	26	15.2	56.1	2.33	0.48	0.27	0.14	859	sandy loam
		II	21	21.2	55.2	0.52	0.43	0.24	0.14	339	
		III	33	24	46	0.50	0.43	0.27	0.15	126	
		TOTAL					**0.45**	**0.26**	**0.15**	**226**	**7-sandy loam**
	M25tc4	A1	19	19.1	34.9	2.28	0.47	0.32	0.16	124	loam
		B21t	17	27.5	34	1.02	0.46	0.32	0.18	58	
		B22t	20	39	28.9	0.71	0.47	0.36	0.23	20	
		B3ca	19	27.3	27	0.00	0.46	0.30	0.16	41	
		TOTAL					**0.46**	**0.33**	**0.18**	**39**	**6-loam**

Annex 3 – Derivation of the hydraulic properties of the soils present in the Land Bahía Blanca Estuary area (cont)

Edaphic Domain	Taxonomic unit	Horizon (Soil profile)	Horizon thickness [cm]	% Clay (< 2 μ)	% Sand (50 μ-2mm)	Organic matter (*)	Porosity [cm3/cm3]	Field capacity [cm3/cm3]	Wilting point [cm3/cm3]	Hydraulic conductivity [mm.d-1]	Material of the upper horizon (Ap excluded)
27	E25tc	Ap	30	7.9	85.3	1.02	0.40	0.15	0.08	3955	
		AC	44	8.2	79.8	0.62	0.39	0.15	0.08	1927	loamy sand
		C	80	4.9	87.4	0.00	0.35	0.10	0.05	2023	
		TOTAL					**0.37**	**0.12**	**0.06**	**2201**	**2-loamy sand**
	E22tc	**C1-C2**	**100**	**0.7**	**88.1**	**0.03**	**0.44**	**0.08**	**0.03**	**4267**	**1-sand**
	M18en4	A1	24	22.7	52.2	2.22	0.47	0.30	0.17	508	sandy clay loam
		AC	22	18.8	56.9	0.67	0.43	0.23	0.13	405	
		C1-C2	49	12.3	64	0.29	0.40	0.18	0.09	620	
		C2ca	20	9.9	61.7	0.07	0.39	0.17	0.08	427	
		TOTAL					**0.42**	**0.21**	**0.11**	**506**	**8-sandy clay loam**
	M24en4	A1	34	14.2	66.95	1.63	0.45	0.22	0.12	1502	sandy loam
		AC	24	12.36	66.55	0.84	0.42	0.19	0.10	952	
		C	58	11.75	70.91	0.38	0.39	0.17	0.09	1027	
		TOTAL					**0.41**	**0.19**	**0.10**	**1112**	**7-sandy loam**
	E26tc	A	50	13.6	77.9	0.74	0.41	0.17	0.11	2665	sandy loam
		C	72	11.1	82.9	0.00	0.37	0.13	0.08	2327	
		TOTAL					**0.38**	**0.15**	**0.09**	**2454**	**7-sandy loam**

(*) Organic matter = Organic carbon * 1.724