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ORIGINAL ARTICLE

Climate and water budget change of a Mediterranean coastal watershed, Ravenna, Italy

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Abstract It is generally difficult to quantify exactly the freshwater going in or out of the coastal watersheds along the northern Adriatic Sea because, on one hand, excess water is drained and pumped into the sea to prevent flooding but, on the other hand, water is brought onto the land from far away for irrigation. Fragmentation of water authorities makes it difficult to collect all the necessary information. Climate change and increasing salinization of the coastal aquifers make it imperative, however, to better know the quantities of freshwater involved in these small basins. The water budget of a small coastal agricultural watershed along the Adriatic Sea in Italy (The Quinto Basin near Ravenna) is presented here considering different land uses. The evaporation of open water and the evapotranspiration of wetlands, pine forests, bare soil and irrigated agriculture are calculated based on the Penman–Monteith equation and the Cropwat program. The current water budget is based on average climate data from 1989 to 2008 and drainage and irrigation data. Predictions for future evapotranspiration, net irrigation and hydrologic deficit are calculated with climate data from IPCC (The Fourth Assessment Report (AR4) 200, Climate change 2007). From the study results, the soil type may determine whether or not a crop will need more or less irrigation in the future. Regulations on land use should therefore consider which crop type can be grown on a specific soil type. Water budget analysis in scenarios A1b and A2 both show an increase of water deficits in the summer and an increase of water surplus in the winter. This is explained by the fact that a larger percentage of the rain will fall in winter and not during the growth season. The open water evaporation will decrease under future climate scenarios as a result of increased relative humidity in winter and decreased wind velocity. This may have a positive effect on the water cycle. The current irrigation is very abundant, but has beneficial effects in contrasting soil salinization and saltwater intrusion into the coastal aquifer.

Keywords Mediterranean · Water budget · Soil · Climate change · Land use · Agriculture · Evaporation · Evapotranspiration

Introduction

Climate change will have a large influence on the water budget of Mediterranean countries (e.g., Giorgi and Lionello 2008). In general, summers are thought to become warmer and rainfall more sporadic with more frequent periods of drought. This will have a large influence and economic impact on agriculture (Oleson and Bindi 2002; Tubiello et al. 2000). This paper studies the current and future hydrologic budget of one particular small watershed along the Adriatic coast of Italy: the Quinto Basin in the Province of Ravenna. This basin is typical for many polder basins and watersheds along the northern Adriatic coast of Italy. We characterized the Quinto Basin on the basis of land use such as agriculture, wetlands, pine forests and more. For each of the six types of land uses, the yearly and seasonal evapotranspiration is calculated for the current and two future climate scenarios (A1B and A2) and compared to the annual and seasonal precipitation to understand whether there is a deficit or a surplus in the water

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balance. One of the main scopes of this study was to obtain an insight into the amount of freshwater recharging the aquifer that is below the Quinto Basin, and the deficit or surplus in the water balance is an indication for that. Therefore, we considered all land uses and all ins and out's including drainage data and irrigation of the Quinto Basin.

Other water budget studies usually consider a much larger territory such as the whole of Europe (Wriedt et al. 2008, 2009) or consider one particular land use, such as crops of maize (e.g., Tubiello et al. 2000). The advantage of calculating the water budget of a small basin as presented in this paper is that it is easier to recover important data such as irrigation and drainage data. This type of data usually is difficult to collect in Italy and some other Mediterranean countries due to the fragmentation and complex organization of public agencies in combination with private water supplies (Zucaro and Pontrandolfi 2005).

Water budget analysis is a sound basis for water management (Healy et al. 2007; Mencio et al. 2010) and is important in relation to the study of saltwater intrusion.

Generally, the Adriatic coast along the southern Po Plain is undergoing extensive saltwater intrusion caused by subsidence, dune destruction, encroachment along rivers, drainage, droughts, transpiration and more (Antonellini et al. 2008; Giambastiani et al. 2007, 2008; Mollema et al. 2010a). The remaining freshwater consists mostly of lenses floating on top of the salt water (Antonellini et al. 2008) that may change shape and size over short periods of time (Marconi et al. 2011). To better understand the behavior of these freshwater lenses, it is important to know how much freshwater infiltrates into the underlying aquifer. This may seem a trivial question but is a very difficult one to answer for an area where, on one hand, water is pumped out to sea to keep the land from flooding and, on the other hand, water is poured on top of the land to irrigate agriculture. Another complicating factor is that in the climate of the Adriatic coast, with dry hot summers and wet cold winters, the natural vegetation plays an important role in the hydrologic cycle: for example, the pine trees may absorb more than the incoming rain, contributing to the up-coning of salt water (Mollema et al. 2010a). To the best of our knowledge, this is the first attempt to publish a complete water budget of an irrigated and drained watershed on the Adriatic coast.

Given that we cannot assess the validity of the statistical methods used to downscale from the global climate models (GCMs) to the regional climate models (RCMs), we decided to extract directly the data for our region from the GCMs (IPCC 2007), averaging over many models. The resulting climate data show some interesting similarities and variations with climate data based on regional downscaling of GCMs.

Setting

The Quinto Basin has a surface area of 10,355 ha (roughly 10 km^2) and is confined between two rivers flowing from the northern Apennines to the Adriatic Sea: the Uniti River in the north and the Bevano Stream in the south (Fig. 1). The eastern border of the basin follows the coastline of the Adriatic Sea for 4 km and the basin tapers out toward the west with the western boundary partly along the Ronco River, one of the tributaries of the Uniti River. The basin is detached by the mountains as a consequence of subsidence and drainage of the low-lying fields. Subsidence has caused the fields to sink until 1.5 m below sea level and 13.4% (1,388 ha) of the Quinto Basin is actually below sea level.

Two main sandy units characterize the stratigraphy of the area: a relatively thick medium grained sand shallow unit (from 0 to −10 m m.s.l.), and a lower fine-grained sand unit of lesser thickness (from −21 m to −26 m m.s.l. (Figs. 2, 3). These two sand bodies are separated close to the coast by a clayey-silt and sandy-silt unit (from −10 to −21 m m.s.l.). The Pre-Flandrian continental silty-clay basement is at a depth of about −26 m in (Veggiani 1971) (Fig. 2).

The largest part of the basin is covered by farmland. Two pine forests, a beach and gravel quarries are some other important features of the basin. The irrigation water used in the summer for the crops comes from the Po River through the Canale Emiliano-Romagnolo (CER). Most of the drinking water comes from a retention basin in the Apennine Mountains (Ridracoli). Officially, there is no groundwater exploitation in the coastal aquifer, but some undeclared wells do exist.

Because of the irrigation and mechanical drainage of the basin, the water budget is complex to calculate. The incoming water fluxes consist of rainfall, irrigation water and inflowing water from the rivers. The outgoing fluxes consist of evaporation, transpiration, drainage toward the rivers, drainage through the channels and pumping station. Runoff is typically not considered in this area because of its flat topography. Also, underground outflow to sea is thought to be so small that it can be ignored.

Current and future climate

The climate of the Quinto Basin is Mediterranean with generally warm and dry summers and wet and mild winters (Giorgi and Lionello 2008). The climate data used in this study to calculate the current water balance have been collected at the Technical Agronomic Institute of Ravenna (ITAS 1989–2008) and at three other weather stations, Martorano, Volano and Camse (ARPA 2008). Monthly average values of temperature and precipitation were calculated and then averaged again over 20 years from 1989 to 2008 (Table 1) and over the four weather stations. The

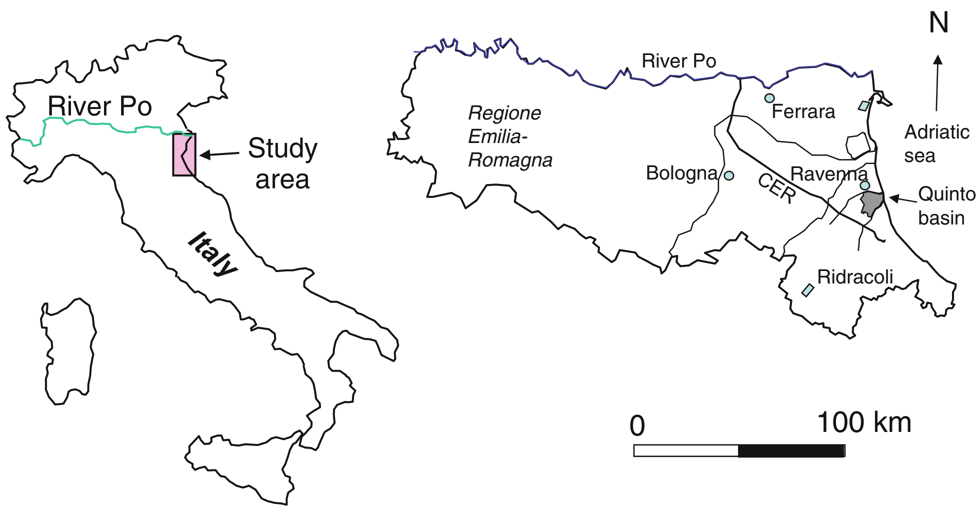
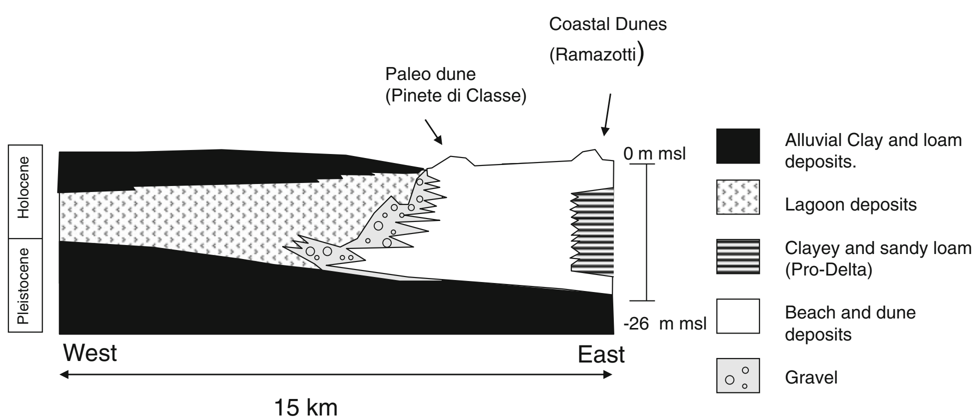


Fig. 1 Index map of study area in Italy and the regione Emilia-Romagna. Note the location of the pumping station and the channel (Canale Emilia-Romagna or CER) that brings irrigation water from the Po River to the basin

Fig. 2 Geologic cross section based on the geologic map by Preti (2002)



total average annual precipitation is 635 mm. The average maximum temperature is 19°C. The average minimum temperature is 8°C.

To be able to calculate the future water balance of the basin with the current land use, future climate data were extracted from the IPCC (2007). We have chosen an ensemble of models that contained the two scenarios and eight parameters needed in our calculations for the period 2080–2099 that was chosen for the Waterknow (Circle-Med) project (Table 2). The two scenarios considered are: (1) IPCC A1b, where a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology is foreseen, and (2) scenario A2 that considers a very heterogeneous world with high population growth and less concern for rapid economic development (IPCC 2007).

The climate data in the vector format were extracted from NetCDF files for the selected grid point. Then the temperature was converted from °K to °C, the humidity was converted from specific humidity to relative humidity, and the separate wind components were added to obtain the total wind velocity. See Tables 3 and 4 for the future climate data that we used.

In comparison with today, the minimum temperature is higher the whole year round. The maximum temperature is higher mostly in winter, but will not increase considerably in summer. The total annual precipitation is thought to decrease from 635 to 619 mm (scenario A1b) or 596 mm (scenario A2). Relatively more rain will fall in winter: 46% currently, 61% in the future under for A1b, and 64% under A2.

A comparison of historical data carried out by the Regione Emilia-Romagna (2010) of the period 1991–2008 compared with those of 1961–1990 indicates that the average and maximum temperature have already increased by 2° in the study area since the 1960s and the precipitation has decreased in winter, spring and summer, but has increased in the fall.

The only published future local climate data at the start of this study was on surface air temperature (Tomozeiu

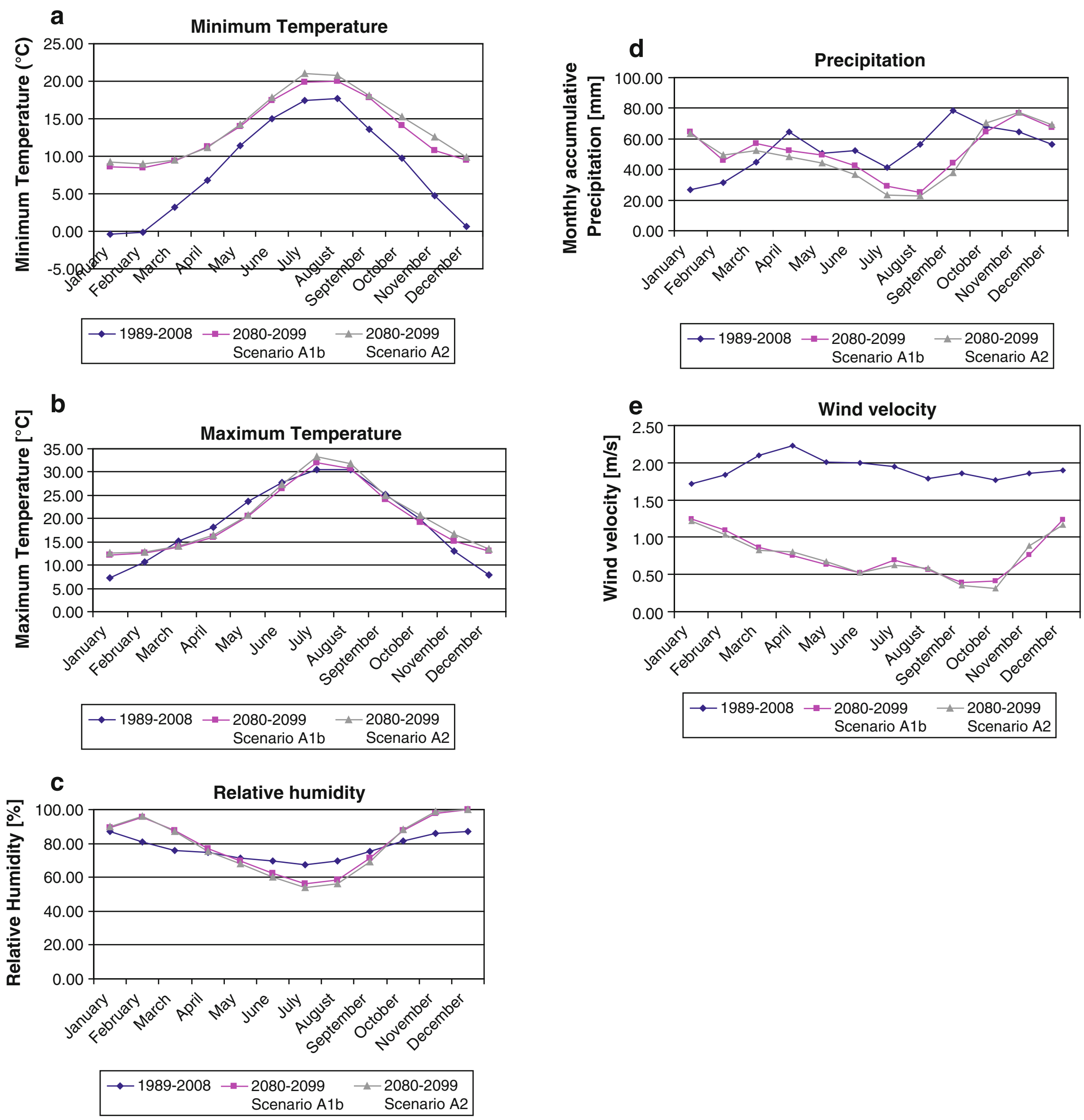


Fig. 3 Graphs of current average climate data and average climate 2088–2099. **a** Minimum temperature, **b** maximum temperature, **c** humidity, **d** precipitation, **e** wind velocity

et al. 2007). The future maximum temperature presented by us here is similar to that presented in Tomozeiu et al. (2007). The minimum temperature presented in this study is higher than the one presented in Tomozeiu et al. (2007), especially in winter. For the water budget calculations, this does not have a large impact, but for agricultural practices it may make a difference (see "Discussion" at the end of this paper).

Soil and land use

The Quinto Basin covers a total of 10,355 ha of which the largest part is used for irrigated agriculture (66%), 10% is covered by pine forests, 9% is urban area, and 9% is open surface water or wetlands (Table 5, Fig. 4). The basis for this division was the land use map by Corticelli (2003). The urban areas are not considered in the water balance calculations since the interest of this study was more in the other type of land uses.

Five soil types are distinguished in the Quinto Basin (Filippi 1994). Three of those are sandy soils (Cerba-type soils), whereas the other two are richer in clay and loam (Omobono and Risaia del Duca soils) with respect to the first three. In reality, many different crops types are grown on the five different soil types, but to reduce the number of calculations we averaged the three sandy soils into one that we called Cerba (Table 5): Cerba soils cover 39% of the surface of the watershed, Sant'Omobono soils 23%, and

Table 1 Average climate data over 20 years (1989–2008) used for evapotranspiration calculations and all other components of the water budget

Month	Average minimum temperature (°C) 1989–2008	Average maximum temperature (°C) 1989–2008	Relative humidity (%)	Precipitation (mm month^{-1})	Wind velocity (m s^{-1})
January	−0.36	7.28	87.3	26.9	1.7
February	−0.08	10.68	80.8	31.5	1.8
March	3.16	15.20	75.6	44.5	2.1
April	6.78	18.17	74.9	64.3	2.2
May	11.38	23.68	71.2	50.6	2.0
June	15.03	27.66	69.6	52.5	2.0
July	17.49	30.44	67.6	41.2	1.9
August	17.69	30.59	69.9	56.3	1.8
September	13.53	25.10	75.0	78.2	1.8
October	9.73	19.90	81.3	67.9	1.8
November	4.80	13.01	86.2	64.8	1.9
December	0.67	7.97	87.2	56.1	1.9
Annual average or total	8.32	19.14	77.2	52.9 (total 634.9)	1.9
Average winter (October–March)	2.99	12.34	71.4	57.2 (total 291.8 46%)	2.0
Average summer (April–September)	13.65	25.94	83.1	48.6 (total 343.1 54%)	1.9

Risaia del Duca soils 38%. By overlaying land use and soil maps, it is apparent that all pine forests are on sandy soil (Cerba). Most horticultural and orchards areas are on Sant'Omobono clay. The open surface waters are 42% on Sant'Omobono clay, 42% on Risaia del Duca loam and 16% on Cerba sand. Wetlands are mainly on Cerba soil. Irrigated agriculture is 19% on Cerba soil, 15% on Sant'Omobono and 31% on Risaia del Duca soil (Fig. 5).

Calculation methods of evaporation, crop evapotranspiration and soil moisture

An important component of the water budget of the Quinto Basin is the evaporation of the surface water and the evapotranspiration of areas covered with crops and natural vegetation. Evaporation from open surface water depends on many different climate variables: wind, humidity of the air, temperature of the air, vapor pressure deficit, etc. The open water evaporation is calculated with the recommended equation by Maidment (1992, p. 4.36), which is based on the Penman–Monteith equation that describes how the available energy from the sun is used for evapotranspiration of water, taking into account all types of resistances provided by vegetation in case of evapotranspiration. For open water, this resistance is zero. Although we do have the required data for 1989–2008 from the weather stations, the output of the climate models do not provide all variables needed for these calculations for the future climate scenarios. Therefore, we assumed for example that the solar radiation available for evaporation is assumed to be the same in 2070–2100 as at the present, even though a change in cloudiness could change this in the future.

The potential evaporation E_p of open surface water was calculated with equations of Penman (1948) given by Maidment (1992):

$$E_p = \frac{\Delta}{\Delta + \gamma}(R_n + A_h) + \frac{\gamma}{\Delta + \gamma}\frac{6.43(1 + 0.536U_2)D}{\lambda} \qquad (1)$$

where R_n = net radiation exchange for the free water surface (mm day^{-1}), A_h = energy advected to the water body (mm day^{-1}), U_2 = wind speed measured at 2 m (m s^{-1}), D = vapor pressure deficit $e_s - e$ (kPa), λ = the latent heat of vaporization depending on the surface temperature of the water, (MJ kg^{-1}), Δ = the gradient of the saturated vapor pressure with respect to temperature, (kPa C^{-1}), and γ = the psychometric constant depending on the specific heat of moist air, the atmospheric pressure and the ratio of the molecular weight of water vapor to that of dry air and λ (kPa C^{-1}).

We used Cropwat (Smith 1992) based on the equations by Allen et al. (1998) to calculate the crop evapotranspiration (Etc), soil moisture deficits and net irrigation need. From the original Penman–Monteith equation and the equations of the aerodynamic and surface resistance, the FAO Penman–Monteith method to estimate ET_o is summarized in:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (2)$$

where ET_o = reference evapotranspiration (mm day^{-1}), R_n = net radiation at the crop surface (MJ m^{-2} day^{-1}),

Table 2 List of the 15 GCMs models from which future climate data for the period 2070–2100 were extracted (IPCC 2007)

Models	Country	Resolution (° Lat × ° Lon)	Time series	Variables
BCCR:BCM2	Bjerknes Centre for Climate Research, Norway	2.8 × 2.8 T63L31	2080–2099	Temperature (daily mean), specific humidity, wind speed
CNRM:CM3	Centre National de Recherches Meteorologiques, France	2.8 × 2.8 T63L31	2080–2099	Temperature (daily mean), precipitations, barometric pressure, specific humidity, wind speed
CONS:ECHO-G	Meteorological Institute, University of Bonn, Germany	3.7 × 3.75 T30L19	2080–2099	Temperature (daily mean), precipitation, barometric pressure, wind speed
	Meteorological Research Institute of KMA, Korea			
	Model and Data Groupe at MPI-M, Germany			
CSIRO:MK3	Australia's Commonwealth Scientific and Industrial Research Organisation, Australia	1.875 × 1.875 T63L18	2080–2099	Precipitations
GFDL:CM2 GFDL:CM2_1	Geophysical Fluid Dynamics Laboratory, USA	2 × 2.5	2080–2099	Temperature (daily mean), precipitations, barometric pressure, wind speed
INM:CM3	Institute for Numerical Mathematics, Russia	4 × 5	2080–2099	Temperature (daily maximum and minimum)
IPSL:CM4	Institut Pierre Simon Laplace, France	2.5 × 3.75	2080–2099	Temperature (daily mean), precipitations, barometric pressure, specific humidity, wind speed
MPIM:ECHAM5	Max-Planck-Institut for Meteorology, Germany	1.875 × 1.875	2080–2099	Temperature (daily mean), precipitations, barometric pressure, wind speed
MRI:CGCM2_3_2	Meteorological Research Institute, Japan	2.8 × 2.8 T42	2080–2099	Temperature (daily mean), precipitations, barometric pressure, specific humidity, wind speed
NASA:GISS_ER	Goddard Institute for Space Studies, USA	4 × 5	2080–2099	Temperature (daily mean), barometric pressure, specific humidity, wind speed
NCAR:CCSM3	National Centre for Atmospheric Research, USA	1.4 × 1.4	2080–2099	Temperature (daily mean), precipitations, barometric pressure, specific humidity
NIES:MIROC3_2MED	National Institute for Environmental Studies, Japan	2.8 × 2.8 T42	2080–2099	Temperature (daily maximum and minimum)
UKMO:HADCM3	UK Met. Office, UK	2.75 × 3.75	2080–2099	Temperature (daily mean), precipitations, barometric pressure, wind speed
UKMO:HADGEM1		1.25 × 1.875	2080–2099	Precipitations

G = soil heat flux density (MJ m^{-2} day^{-1}), T = mean daily air temperature at 2-m height (°C), U_2 = wind speed at 2-m height (m s^{-1}), e_s = saturation vapor pressure (kPa), e_a = actual vapor pressure (kPa), $e_s - e_a$ = saturation vapor pressure deficit [kPa], Δ = slope vapor pressure curve (kPa °C^{-1}), and γ = psychrometric constant (kPa °C^{-1}).

The reference evapotranspiration, ET_o, provides a standard to which evapotranspiration at different periods of the year or in other regions can be compared and evapotranspiration of other crops can be related. The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. For many crops, the so-called crop factor has been determined that relates the reference evapotranspiration to the transpiration of that particular crop.

The program Cropwat calculates a monthly water budget using average climate values. We assume that the change in climate has the largest influence on the crop evapotranspiration and that the decrease in crop evapotranspiration due to increasing CO_2 can be neglected, as Tubiello et al. (2000) concluded. In this study, we also assumed that no adaptation to climate change occurred in agricultural practices. That is, we did not change planting dates or crop scheduling in response to climate change. Only one irrigation schedule is applied: when soil moisture deficit is 100%, irrigation is started. This is one of the more likely irrigation schedules, even if it may not be the most efficient (Wriedt et al. 2009). Table 6 shows the crop characteristics used in our study.

The soil moisture deficit and amount of water needed for irrigation depend not only on the climate but also on the

Table 3 Climate data average over 15 GCMs models extracted from IPCC data center (scenario A1b)

Month	Average minimum temperature 2080–2099		Average maximum temperature 2080–2099		Relative humidity		Precipitation		Wind speed	
	(°C)	Difference compared to 1989–2008 (°C)	(°C)	Difference compared to 1989–2008 (°C)	(%)	Difference compared to 1989–2008 (%)	(mm month^{-1})	Difference compared to 1989–2008 (%)	(m s^{-1})	Difference compared to 1989–2008 (m s^{-1})
January	8.55	+8.91	12.11	+4.83	89.2	+1.88	64.5	+139.59	1.2	−0.47
February	8.49	+8.57	12.49	+1.81	95.2	+14.43	45.8	+45.25	1.1	−0.74
March	9.38	+6.23	13.78	−1.42	87.7	+12.08	57.0	+27.89	0.9	−1.24
April	11.22	+4.44	15.99	−2.18	76.8	+1.86	52.1	−18.96	0.8	−1.48
May	14.00	+2.62	20.45	−3.23	69.5	−1.73	49.6	−2.06	0.6	−1.38
June	17.38	+2.35	26.49	−1.16	62.6	−7.03	42.4	−19.26	0.5	−1.47
July	19.87	+2.37	31.91	+1.47	56.4	−11.20	29.0	−29.44	0.7	−1.26
August	19.95	+2.26	30.67	+0.08	58.3	−11.63	25.0	−55.52	0.6	−1.22
September	17.80	+4.28	24.13	−0.97	71.3	−3.68	44.0	−43.79	0.4	−1.46
October	14.13	+4.40	19.22	−0.68	87.8	+6.51	64.8	−4.59	0.4	−1.36
November	10.83	+6.03	15.19	+2.18	97.9	+11.68	76.8	+18.62	0.8	−1.10
December	9.46	+8.79	13.07	+5.10	100.0	+12.80	67.6	+20.49	1.2	−0.66
Annual average or total	13.42		19.62		79.4		51.6 total 618.7		0.8	
Average winter (October–March)	10.14		14.31		93.0		62.8 total 376.5 61%		0.9	
Average summer (April–September)	16.70		24.94		65.8		40.4 total 242.2 39%		0.6	

type of soil. The available soil moisture needed for the water budget of the soil and irrigation needs is estimated using the soil water characteristics hydraulic properties calculator by Saxton (2003). Soil water characteristics is based on the statistical analysis of 1,722 samples where linear regression was used to establish relationships between soil composition (clay, sand and loam content) and soil properties, such as capacity of water storage and conductivity. Table 7 shows the soil characteristics of our study area.

Crop evapotranspiration

Crop evapotranspiration is a large component in the water budget of the *Quinto* Basin since most of the land is used for agriculture. In the Ravenna area, many different crops including cereals (wheat, corn), alfalfa, vegetables (peas and others), vines (grapes) and fruit (e.g., peaches, nectarines) are cultivated (Ravenna Province 2007). To limit the number of computations that are needed to calculate the total crop evapotranspiration, soil moisture deficit and irrigation needs, we have chosen only the most frequently occurring crops. For horticulture, those are vines (grapes) and peaches; for cereals, wheat and maize, and furthermore alfalfa.

The resulting Etc, soil moisture deficit and net irrigation needs for each crop on each type of soil under the three different climate scenarios (one for the present and two for the future) is shown in Table 8. During the months in which the land is not cultivated, we assume that there is only bare soil evaporation (see below) and add those values to the Etc.

The difference in irrigation for scenario A1b and A2 are presented in Figs. 6 and 7. There is not always a similar change of water needs for all crops with a changing climate. The annual Etc of all crops is less under both climate scenarios A1b and A2 than it is at present. This is because the maximum temperature is less in spring (growth season) compared to the current climate. The crops on the sandy Cerba soil need most irrigation in absolute terms, both at present and in the future. Sandy soils do not store a lot of water. The relative increase in irrigation for crops on Cerba soil is smaller than for the crops on other soil types, since crops on Cerba soils require a lot of irrigation water also nowadays. It is apparent that climate change has a stronger

Table 4 Climate data average over 15 GCMs models extracted from IPCC data center (scenario A2)

Month	Average minimum temperature (°C) 2080–2099		Average maximum temperature (°C) 2080–2099		Relative humidity (%)		Precipitation (mm month^{-1})		Wind velocity (m s^{-1})	
	(°C)	Difference compared to 1989–2008 (°C)	(°C)	Difference compared to 1989–2008 (°C)	(%)	Difference compared to 1989–2008 (%)	(mm month^{-1})	Difference compared to 1989–2008 (%)	(m s^{-1})	Difference compared to 1989–2008 (m s^{-1})
January	9.28	+9.64	12.58	+5.30	89.9	+2.64	63.2	+134.74	1.2	−0.51
February	8.99	+9.07	12.80	+2.12	95.8	+15.03	49.5	+56.91	1.0	−0.80
March	9.50	+6.34	13.99	−1.21	87.0	+11.36	52.1	+17.00	0.8	−1.28
April	11.11	+4.33	16.46	−1.71	75.5	+0.62	48.5	−24.62	0.8	−1.43
May	14.28	+2.90	20.74	−2.94	67.8	−3.38	44.5	−12.20	0.7	−1.34
June	17.78	+2.75	27.29	−0.37	60.1	−9.50	36.7	−30.15	0.5	−1.47
July	20.99	+3.50	33.24	+2.80	54.1	−13.53	23.5	−42.85	0.6	−1.33
August	20.71	+3.02	31.76	+1.17	56.3	−13.61	22.8	−59.53	0.6	−1.20
September	18.12	+4.60	25.01	−0.08	69.1	−5.96	38.1	−51.37	0.4	−1.50
October	15.27	+5.54	20.63	+0.73	88.2	+6.92	70.2	+3.49	0.3	−1.46
November	12.53	+7.73	16.71	+3.70	99.1	+12.88	77.1	+18.95	0.9	−0.98
December	9.90	+9.24	13.46	+5.49	100.0	+12.80	69.4	+23.59	1.2	−0.73
Annual average or total	14.04		20.39		78.6		49.6 total 595.5		0.7	
Average winter (October–March)	10.91		15.03		93.3		63.6 total 381.5 64%		0.9	
Average summer (April–September)	17.16		25.75		63.8		35.7 total 214 36%		0.6	

impact on the Risaia del Duca silty loam and the Sant'Omobono silty clay soils.

In the A1b climate scenario for years 2080–2099, the soil type has a large influence on whether irrigation needs will increase or decrease. For example (Fig. 6), alfalfa on the Risaia del Duca silty loam soil will need an increase of irrigation, whereas there is a decrease for the same crop, on the same climate on the Sant'Omobono silty clay soil.

In the more dramatic A2 climate scenario for years 2080–2099, alfalfa, vines and maize growing on all soil types will need more irrigation. Maize will need the largest increase in irrigation water of up to 116 mm and more. The crops grown on Risaia del Duca silty loam soil, in general, will need the highest increase in irrigation water and will be affected by the climate change the most.

The crops that show the least effect, in the climate change scenarios that we tested, are peaches and wheat that actually will need less water except under A2 growing on Risaia del Duca soil.

Wetlands

The evapotranspiration occurring in the *Quinto* Basin wetlands is calculated by applying Cropwat for swamp reed in water and swamp reed on moist soil. Based on Quickbird satellite images (2005), the wetlands consist of 30% reed in standing water and 70% reed in moist soil (see Table 6 for crop factors). Most wetlands are on the Cerba sandy soil. The annual Etc for both kinds of reeds decreases in our A1b and A2 climate scenarios.

Bare soil

Some agricultural land is not used in the summer or winter months and some natural areas, such as the beaches and also part of the gravel quarries, are covered with bare soil. Allen et al. (1998) indicate that bare soil evapotranspiration is similar to the evapotranspiration of any crop in its initial growth stage (Etc during non-growing periods). We use Cropwat with crop factors graphically deduced from Allen et al. (1998) for two different types of bare soil:

Table 5 Summary of land use and soil data in the *Quinto* Basin

ETc_Class	Area in hectares	Percentage of total area Quinto Basin	Subtotals categories on all soils together
Bare soil coarse	120.02	1.2	Bare soil 2.2%
Bare soil fine medium	108.24	1.0	
Forestry production on Cerba (fine sand)	1046.44	10.1	Forestry 10.1%
Horticultural and fruit on Cerba (fine sand)	56.00	0.5	Horticulture and fruit 4.3%
Horticultural and fruit Sant'Omobono (silty clay)	346.65	3.3	
Horticultural and fruit on Risaia del Duca (silty Loam)	45.58	0.4	
Irrigated agricultural on Cerba (fine sand)	2,027.97	19.6	Irrigated agriculture 65.8%
Irrigated agricultural area on Sant'Omobono (silty clay)	1,591.38	15.4	
Irrigated agriculture on Risaia del Duca (silty loam)	3,189.24	30.8	
Natural area on Sant'Omobono (silty clay)	5.31	0.1	Natural area 0.1%
Urban area on Cerba (fine sand)	322.03	3.1	Urban area 8.6%
Urban area on Sant'Omobono (silty clay)	293.60	2.8	
Urban area on Risaia del Duca (silty loam)	265.84	2.6	
Water areas Cerba (fine sand)	290.61	2.8	Water areas 6.6%
Water areas Sant'Omobono (silty clay)	108.69	1.0	
Water areas Risaia del Duca (silty loam)	285.07	2.8	
Wetlands Cerba	194.46	1.9	Wetlands 2.4%
Wetlands Sant'Omobono	1.39	0.0	
Wetlands Risaia del Duca	56.57	0.5	
Total	10,355.1	100	100

fine-medium textured and coarse textured soil. We assume it rains once a week (wetting period 7 days) and that the infiltration depth is 20 mm. The total annual evapotranspiration for the period 1989–2008 is 472 mm. For the period 2080–2099 in scenario A1b, it is 441 mm, and in the A2 scenario, it is 497 mm for the same period (Table 8).

To arrive at a yearly evapotranspiration value of agricultural land, we added the bare soil evapotranspiration to the annual and seasonal crop evapotranspiration for the months in which the areas are without vegetation.

Pine forests

There are two pine forests in the Quinto Basin: the Ramazzotti pine forest along the coast from the Uniti River in the north to the Bevano Stream in the south, and a second one 5 km from the coast called *Classe* pine forest; both forests cover 10% of the *Quinto* Basin. Even though many detailed quantitative studies have been done to determine how much water trees transpire (see Wullschleger et al. 1998 for an overview; Mollema et al. 2010a; Teobaldelli et al. 2004), it is difficult to extrapolate the estimates obtained in the present with those for future climate.

We used, therefore, the crop factors for conifers to represent the pine trees and get an estimate of evapotranspiration under both current and future climate scenarios.

The Etc for the period1989–2008 is 1,091 mm, whereas for the A1b scenario 951 mm and for A2 scenario 968 mm.

Evaporation from open surface waters

Open surface waters and wetlands together account for 6.6% of the *Quinto* watershed. Evaporation from these water surfaces is an important element in the water budget. Most open surface waters are relics from old quarries or part of active gravel quarries. The quarries have removed the upper sand layer up to 10–12 m and sometimes even deeper (Fig. 2). The average annual open water evaporation for 1989–2008 amounts to 1,529 mm, whereas in 2070–2100 it will be 1,466 mm (A1b) or 1,467 mm (A2). The decrease in annual evaporation can be explained by the fact that the maximum temperature from our climate model data did not increase, whereas the relative humidity increased in winter and the wind velocity decreased all year round.

Irrigation

Most of the farmland crops need irrigation in the *Quinto* Basin. The water is brought in from the CER (Emilia-Romagna Channel) or from the *Ronco* River, through a network of channels that cover the whole area (Fig. 8). It is

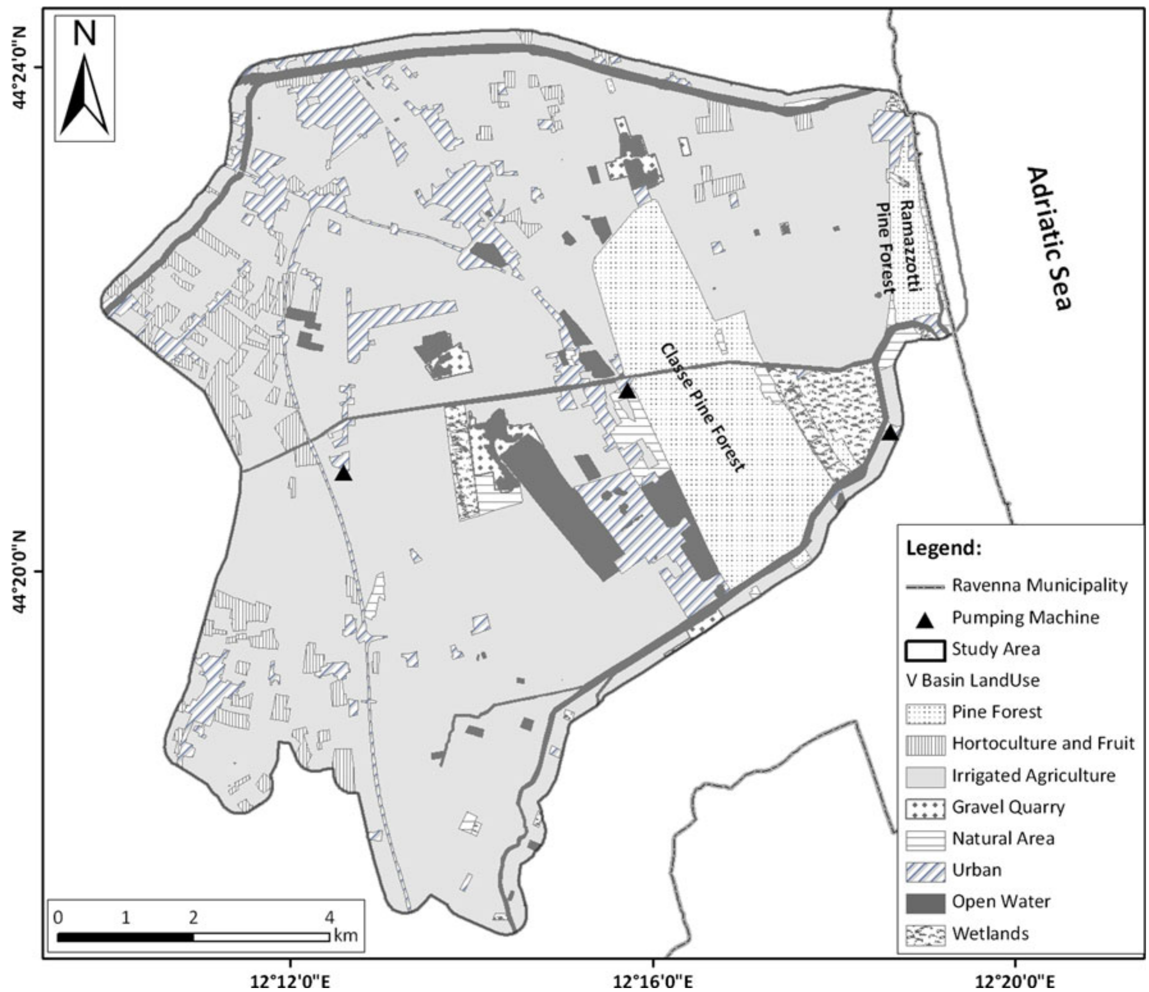


Fig. 4 Land use map

not easy to quantify how much water exactly is used for irrigation. The irrigation authority (Land reclamation Consortium for Central Romagna) has provided us with the data in Table 9 that show the amount of water that came in through the channels and how much surface area it served in 2008. By dividing the volume of water by the surface area served, we arrive at an average quantity of 711 mm for irrigation, which is more than the average annual rainfall of 635 mm and much more than the irrigation need of the various crops. Although there are reasons to believe that the numbers above do not completely represent reality (see “Discussion”), they are the only data we have and we need to use them in our budget calculations.

Drainage

A large land reclamation pumping station located along the Fosso Ghiaia channel (Fig. 8) drains excess water out of the *Quinto* Basin and discharges it to the sea. The location of the pumping station was decided in 1920 and its upgrading went on through the 1960s when land reclamation made the previously swampy areas suitable for agriculture. The drainage is managed by the same authority that controls the irrigation. The amount of water discharged to sea is not directly measured. Based on the electricity bill, one can infer the amount of hours the pumps worked and, knowing the capacity of the pumps, one can calculate the volumes of drained water. Table 9 gives the monthly average volumes drained for the period 1995–2008 in cubic meters as well as an average volume per surface area in cubic meters per hectare and in cubic millimeters per square millimeter. The average drained water height per month varies from 9 mm in July to 29 mm in December. The average drained water height for the summer is 67 mm and for the winter 127 mm.

The annual drained water height varied from 68 mm in 2000 to 424 mm in 1996.

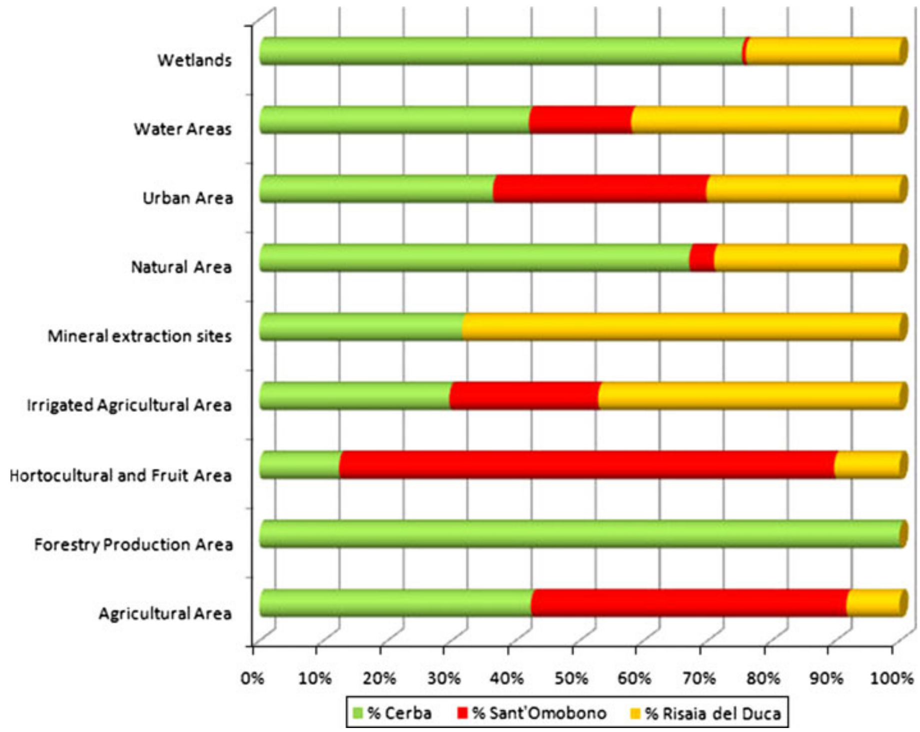


Fig. 5 Histogram showing how much of each land use category occurs on each soil type

Table 6 Crop characteristics used in the CROPWAT calculations

Crop	Planting date	Kc ini	Kc mid	Kc end	Root depth
Alfalfa	01 March	0.40	0.95	0.40	1.20
Maize	15 April	0.30	1.20	0.50	1.00
Wheat	15 October	0.30	1.15	0.25	1.40
Grapes	15 September	0.40	0.70	0.40	1.50
Peaches	20 October	0.45	0.90	0.65	1.40
Moist reed *Phragmites australis*	1 March	0.90	1.20	0.70	1.50
Water reed *Phragmites australis*	1 March	0.90	1.20	0.70	1.50
Pine tree (conifer)	November/March	1.00	1.00	1.00	1.50

Annual and seasonal water budget for the Quinto Basin

Annual and seasonal deficit: current, A1b and A2

To compare the effect of climate change on the different land uses, we defined a hydrological deficit or surplus as:

$$\text{Deficit/surplus} = P - \text{Etc}$$

where P is the precipitation and Etc is evapotranspiration: evaporation only in case of open water evaporation and evapotranspiration in case of crops or natural vegetation.

We calculated the annual deficit as well as the deficit for summer (April through September) and winter (October through March).

We calculated a weighted average crop evapotranspiration to compare the irrigated agriculture and horticulture to other land uses. The weighted and averaged ETc considers the relative presence of crop types (based on the Ravenna PRIP-SAU). For irrigated agriculture, it is 64.9% wheat, 23.4% maize and 11.7% alfalfa. Using these input data, the Etc for the current climate becomes (see Table 11)

$$\text{Etc} = 0.649 \times 577.7 + 0.234 \times 691.7 + 0.117 \times 892 = 641 \text{ mm}$$

Similarly, we calculated the ETc for the other climate scenarios and horticulture.

There is an annual hydrological surplus for horticulture and coarse textured bare soil for all climate scenarios (Fig. 9a, Table 11). There is an annual deficit for the wetlands, the fine to medium textured bare soil (except for A1b), pine forests and open water evaporation.

If we consider the winter and summer separately, the deficit becomes very well defined. All land uses except open water evaporation show a surplus in winter under all climate scenarios (current A1b and A2). All land uses

Table 7 Soil properties in the *Quinto* Basin

Soil type	Cerba	Risaia del Duca del Duca	Sant'Omobono
Percentage of total surface in *Quinto* Basin	39.2%	38.2%	22.7%
Texture	Fine sand	Silty loam	Silty clay
Composition %: sand, silt, clay	96, 3, 1	4, 36, 60	9, 63, 28
Total available soil moisture in %	30.0	116	174
Maximum rain infiltration rate in mm	40	40	40
Initial soil moisture depletion in mm	0	0	0
Initial available soil moisture in mm	30.0	116	174

under all climate conditions (except coarse bare soil under current climate) show a deficit in summer.

The surpluses in winter are larger in the future under A1b and A2 than at present, and the deficits in summer are larger in the future, except for the open water evaporation.

The calculations show similar results for the A1b and A2 scenarios for the winter season. The largest difference in winter surplus between the two scenarios is only 4 mm for irrigated agriculture. On the contrary, the difference between the two scenarios A1b and A2 in terms of summer deficit is much larger; irrigated agriculture has a deficit that is 36 mm larger under A2 than under A1b, the deficit for wetlands is 170 mm larger under A2 than under A1b and the deficit for the fine-medium bare soil evaporation Is 337 mm larger under A2 than under A1b.

In summary, the increase in summer deficits is felt more by bare soil, open water and wetlands and a little less by irrigated agriculture and horticulture (Fig. 10).

Simplified water balance

We use the following expression to calculate the deficit or surplus in the current freshwater budget, which includes also irrigation and drainage for the agricultural fields:

$$\Delta W = P - \mathrm{Etc} - D - \mathrm{Sout} + I - R - \mathrm{Ewt} \pm \Delta S \qquad (1)$$

where ΔW is the deficit/surplus, P is precipitation, Etc is the evapotranspiration, D is the drainage, Sout is the outflow of water to sea, I is irrigation water, R is surface runoff, Ewt is evaporation from the groundwater table, and $\pm\Delta S$ is change in soil moisture storage.

Many of the factors in Eq. 1 (e.g., Sout, R, Ewt, ΔS) may be assumed to be zero for simplification; this is justified by the fact that the land is flat and runoff is insignificant.

Then the simplified water balance equation becomes:

$$\Delta W = P - \mathrm{Etc} - D + I \qquad (2)$$

Using average values for precipitation, crop evapotranspiration, drainage and irrigation, the surplus or deficit for the current climate in summer (April through September) becomes (See Tables 9, 10, 11):

$$\Delta W \text{ summer} = 343 - 542 - 67 + 711 = 445\,\text{mm (surplus)}$$

The surplus divided equally over 183 days is 2.4 mm day^{-1}, which is the possible recharge of the unconfined aquifer.

On the other hand, the water budget for the current climate in winter (October through March) is:

$$\Delta W \text{ winter} = 292 - 108 - 127 + 0 = 57\,\text{mm (surplus)}$$

Divided over 182 days is 0.3 mm day^{-1} of surplus or recharge of the aquifer.

Discussion

Climate change and models

Predicting climate change in general and for the Po Plain in particular is a complicated business. The weather and the resulting hydrology in the Po-Plain, of which our study area is a small part, depend on the weather and climate in two mountain chains (Alps and Apennines) as well as in the plain itself. Some of the predictions resulting from the global climate models (GCMs) that we used for this study (see "Current and future climate"; IPCC 2007) agree with other model predictions (Giorgi and Lionello 2008; Tomozeiu et al. 2007) and also with trend analysis of historical data (Regione Emilia-Romagna 2010). For example, less rain in summer and relatively more rain in winter seem to be a common result from all these different sources. Other papers (Tubiello et al. 2000; Tomozeiu et al. 2007) have shown an increasing maximum temperature in summer for the future that does not result from the climate data that we retrieved ourselves, which actually show a slight decrease in maximum temperature in spring. The Regione Emilia-Romagna (2010), however, show that in the period 1989–2009 the maximum temperature has already gone up by 1°C compared to the 1960–1991 reference. The largest impact of future climate change assuming that our climate predictions are correct is caused by the fact that more rain is going to fall in winter during the non-growing season.

Table 8 Crop evapotranspiration values for each of the crops and soil moisture deficits and net irrigation for the different soils

	Climate 1989–2008			Climate scenario A1b			Climate scenario A2		
	Etc (mm year^{-1})	SMD (mm year^{-1})	Net irrigation (mm year^{-1})	Etc (mm year^{-1})	SMD (mm year^{-1})	Net irrigation (mm year^{-1})	Etc (mm year^{-1})	SMD (mm year^{-1})	Net irrigation (mm year^{-1})
Peach Sant'Omobono	581.6	2,752.6	176.1	516.8	2,724.2	119.4	525.5	2,950.7	119.5
Peach Cerba	581.6	1,018.5	179.5	516.8	812.1	148.0	525.5	822.0	159.1
Peach Risaia del Duca	581.6	3,908.3	94.6	516.8	2,724.2	94.9	525.5	2,127.5	95.6
Grapes Sant'Omobono	673.2	4,292.4	235.4	592.3	5,805.2	241.0	602.4	5,356.4	287.1
Grapes Cerba	673.2	1,496.1	292.6	592.3	1,362.2	298.1	602.4	1,336.5	337.8
Grapes Risaia del Duca	673.2	5,908.0	227.7	592.3	4,163.9	226.1	602.4	3,865.9	303.8
Wheat Sant'Omobono	577.7	3,194.3	146.0	515.0	5,646.9	71.7	522.5	3,591.5	70.5
Wheat Cerba	577.7	1,137.7	195.7	515.0	973.7	143.2	522.5	995.5	166.7
Wheat Risaia del Duca	577.7	4,641.5	112.9	515.0	5,646.9	0.0	522.5	3,568.2	128.6
Maize Sant'Omobono	729.2	3,246.9	372.5	669.0	6,162.1	370.3	680.6	4,802.0	434.6
Maize Cerba	729.2	1,209.6	434.0	669.0	1,206.1	435.2	680.6	1,283.8	462.8
Maize Risaia del Duca	729.2	6,032.2	282.3	669.0	3,302.5	282.4	680.6	3,495.0	398.5
Alfa Sant'Omobono	892.0	6,687.9	462.7	799.3	9,999.0	455.2	813.0	8,577.5	525.0
Alfa Cerba	892.0	2,140.7	535.4	799.3	1,989.9	520.6	813.0	2,193.8	547.3
Alfa Risaia del Duca	892.0	10,622.2	420.0	799.3	6,388.2	418.4	813.0	5,756.9	520.0
M Reed Cerba	1,020.0	2,609.5	532.5	885.6	2,528.0	500.3	902.4	2,330.9	546.6
W Reed Cerba	1,119.8	2,528.0	642.6	973.0	2,410.7	591.0	991.6	2,335.7	636.3
Pine Trees Cerba	1,089.6	2,329.2	633.9	951.6	2,238.9	585.4	968.7	2,340.7	620.5

Note that for the months that the soil is bare, the value for bare soil evapotranspiration is added

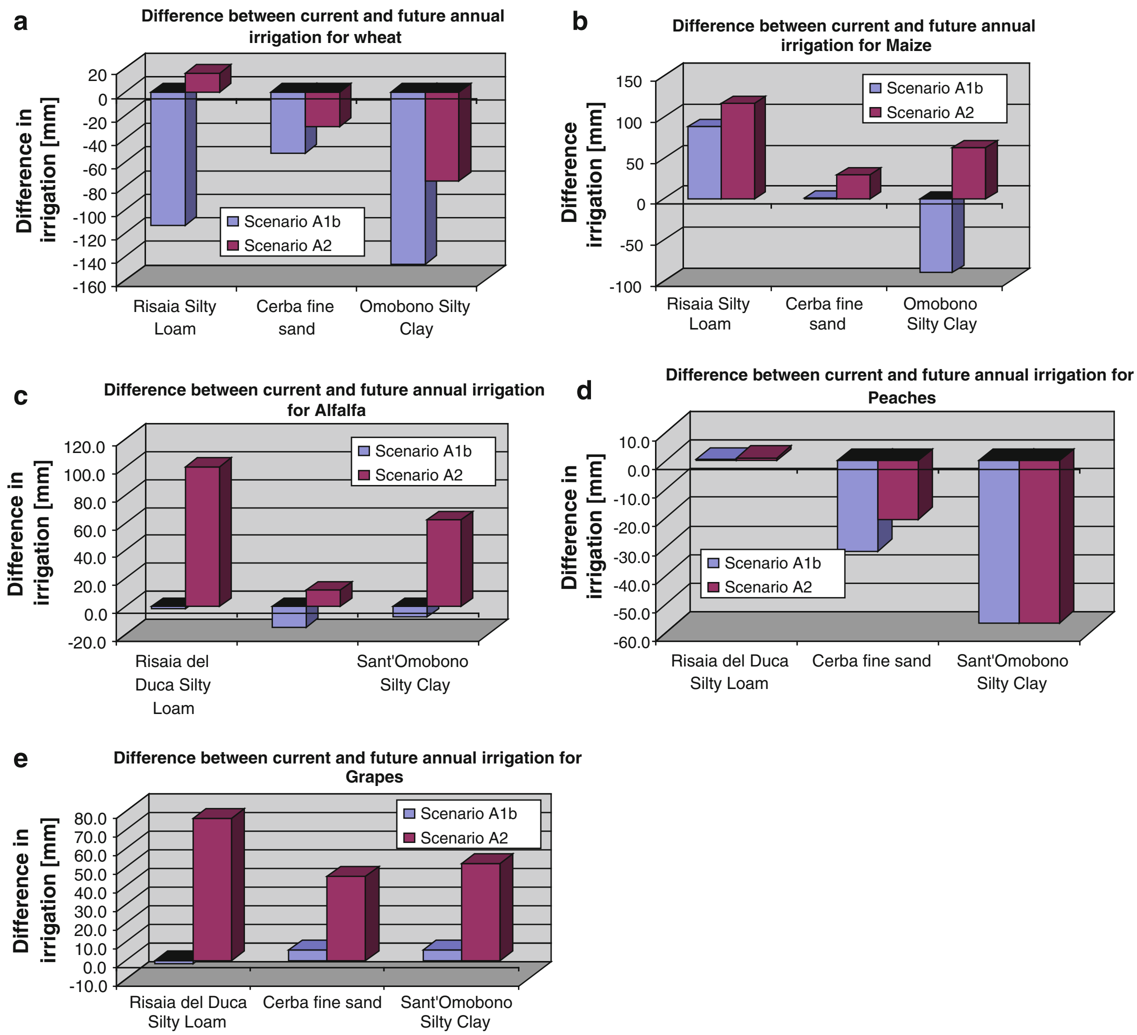


Fig. 6 Histograms showing the difference in annual net irrigation with the present, predicted by Cropwat for two different future climate scenarios. Positive values mean an increase in future irrigation, negative values mean a decrease in irrigation. **a** Wheat, **b** maize, **c** alfalfa, **d** peaches, **e** grapes

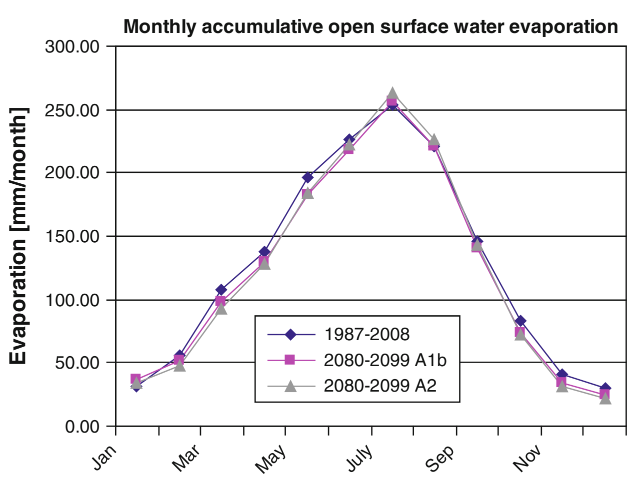


Fig. 7 Monthly cumulative evaporation for 1989–2008 and A1b and A2 (2088–2100)

The numbers of rainstorms and their intensity are very difficult to predict. These parameters have an immediate influence on the soil moisture and irrigation needs. Historical data suggest that the number of rainy days has been decreasing (Brunetti et al. 2006; Klein Tank et al. 2002; Regione Emilia-Romagna 2010). This may not be a negative factor in areas with a Mediterranean climate: perhaps a few heavy rainstorms cause more water to infiltrate into the soil and underlying aquifer than many light storms where the water evaporates before hitting the ground.

To the best of our knowledge, one variable that is not often discussed is air humidity. In the future data, that we considered, the air humidity has been increasing in winter and decreasing in summer. Open air evaporation is a function of many climate variables and it is the only land use category areas where the winter and summer deficits are foreseen to decrease compared to the present. This

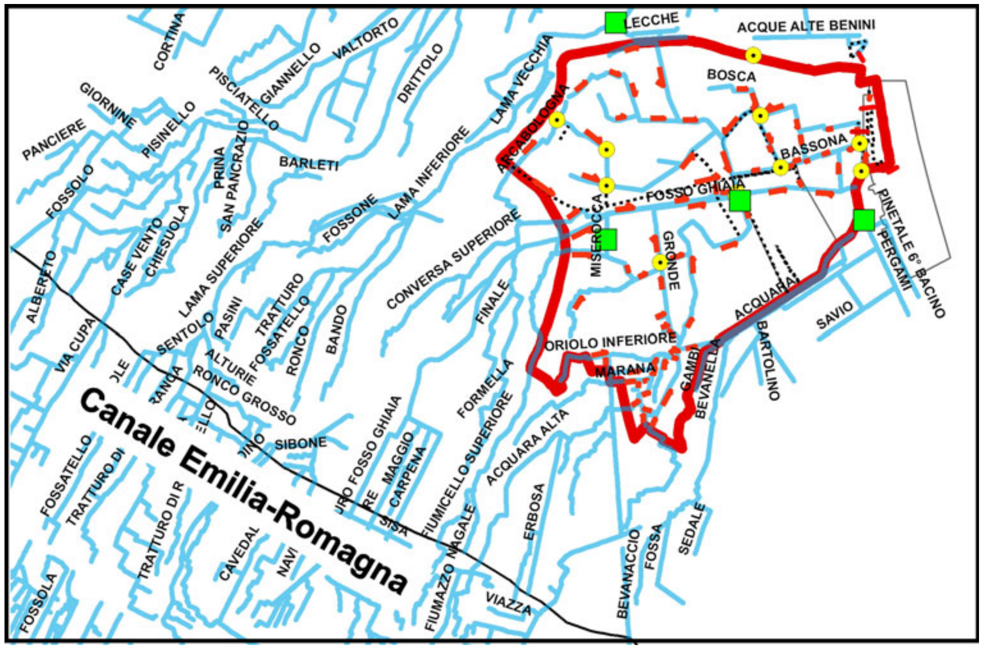


Fig. 8 Network of irrigation channels that bring water from the Canale Emilia-Romagna (CER) to the Quinto Basin

Table 9 Water volumes used for irrigation are as provided by the Romagna Central Land Reclamation Consortium

	FONTE	MC	HA	MC/HA	$Mm^3\ mm^{-2}$
CANALE TRATTURO FOSSO GHIAIA*	CER	1,305,608	453	2,882.137	288
CANALE RE	CER	1,630,029	127	12,834.874	1,283
CANALE CARPENA	CER	1,519,514	187	8,125.743	813
CANALE FIUMICELLO*	CER	5,732,716	617	9,291.274	929
CANALE ACQUARA ALTA	CER	1,553,026	289	5,373.792	537
CANALE SPADOLARO PIEVE QUINTA	CER	2,045,206	211	9,692.919	969
CANALE TORRICCHIA*	CER	0	0		
CANALE ARCABOLOGNA SUP.	F.RONCO	230,000	88	2,613.636	261
TOTALE CANALI		14,016,099	1972	7,107.555	711

yearly decrease in evaporation is controlled by the increasing humidity in winter and decreasing winds year round. Since surface water evaporation is thought to be a driving force for saltwater intrusion in the area (Mollema et al. 2010b), it may turn out to be important to understand better whether or not wind velocities and air humidity will increase or decrease in the future.

Since the goal of this paper was to understand the water budget of one watershed in all its facets, we used a simplified crop water model (Cropwat, Smith 1992). This model does not take into account among others the physiological growth of the plants that is considered in other more sophisticated models (see Wriedt et al. 2009 for an overview of models). Other issues that in this paper are not taken into account are the possibility that crop factors change with climate change or that new and more pests may make life impossible for certain crops. Cropwat, however, offers the possibility of calculating quickly the evapotranspiration of a wide variety of plant species and even bare soil evaporation. The novelty in our study is that it concentrates on many different land uses within one basin. Our approach has shown that the influence of changing climate is very much determined by soil type. This finding may help administrators and farmers together to develop regulations specifying which crop type should be cultivated on which soil type. In part, this has been already happening as a result of crop success and economic return: in the Quinto Basin, for example, most horticulture occurs on the Sant'Omobono clay soil that retains the soil moisture much better. Agricultural adaptation to climate change should combine changing planting dates and choosing drought-resistant and less water-consuming crop varieties in combination with soil maps. These kinds of details usually get lost in large-scale irrigations studies (Wriedt et al. 2008, 2009), but as we show in our paper it could help save water. This agrees with the conclusions of

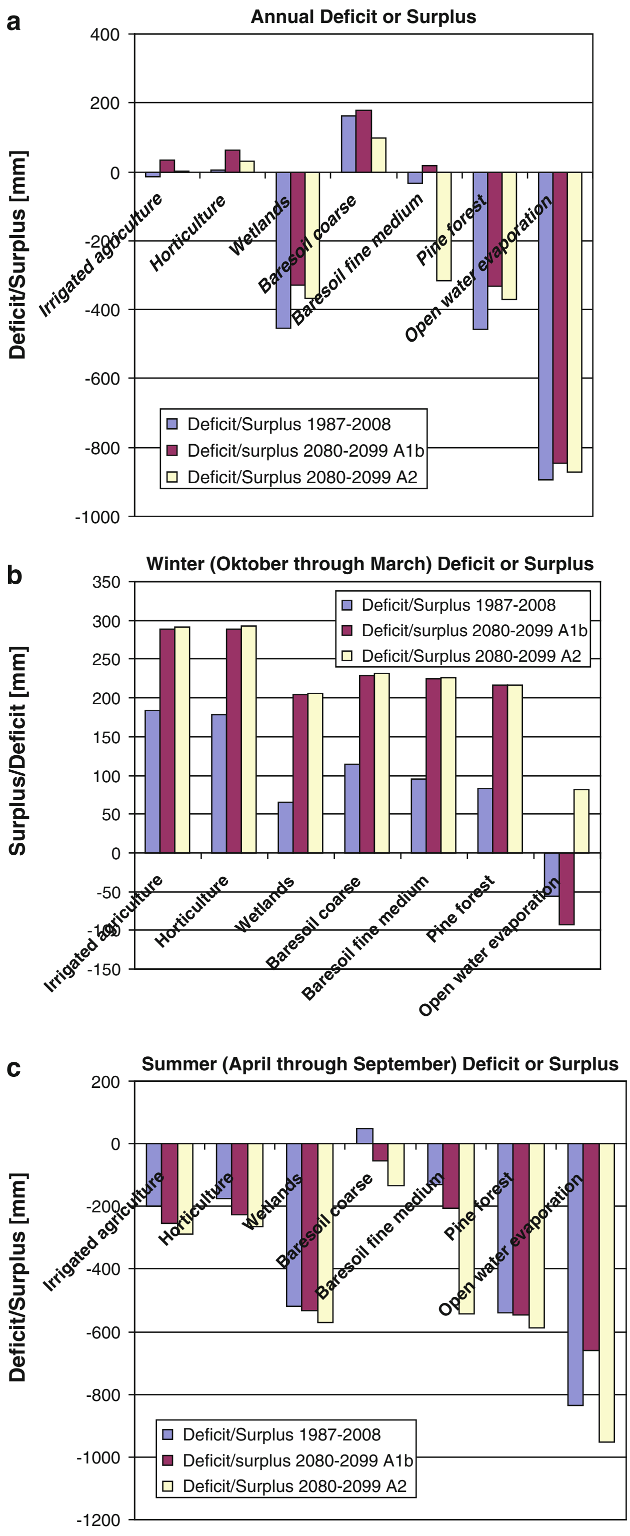


Fig. 9 Histograms showing land use during **a** annual, **b** summer and **c** winter deficit or surplus, for current as well as future climate scenarios

Reidsma (2009b) that in regions with a less favorable and more variable climate (e.g., the Mediterranean), actual adaptation is very important and the only viable solution.

Water budget and saltwater intrusion in agricultural lands, pine forests and natural areas

Even though in our climate scenarios the evapotranspiration of all land uses decreases in the period 2080–2099, the hydrological deficits increase in the summer and the surpluses increase in the winter, because a smaller portion of rain falls in summer.

Including the drainage and irrigation data for a more complete water budget for today, there is currently a surplus of 455 mm in summer and of 57 mm in winter. Assuming that this is the water that ends up recharging the aquifer, the average daily recharge in summer is 2.5 mm day^{-1} and in winter 0.3 mm day^{-1}. This large recharge in the summer may seem very strange, but could be explained in view of the irrigation practices. Traditionally, the irrigation company (Land Reclamation Consortium) guaranteed a 40-cm level of water in the irrigation channels, regardless of water use. Since the farmers usually pay for the amount of land they own rather than the water they use, there is no incentive to save water. They could use as much as they want and not pay a cent more. This could explain the abundant application of irrigation water. The average value of 711 mm for irrigation is much more than any crop needs under the current climate conditions (Table 8), whereas an alfalfa crop on Cerba needs the most water, 535 mm year^{-1} irrigation. Despite the fact that our crop water need calculations are simplified, the picture is clear: too much water is used for irrigation if the numbers given by the water company are correct.

We have also an independent indirect confirmation of the abundant irrigation. The phreatic groundwater salinity measurements done by Marconi et al. (2011) show that during the summer the freshwater lenses are larger and thicker than in the winter, and this is very likely due to recharge from irrigation water.

A different explanation of the large surplus in summer or the high average irrigation could be due to the fact that farmers pay water in relation to the amount of land they own and not for the amount of water they use. As a result, they claim to own only a smaller piece of land than they do in reality. The amount of land irrigated according to the Land Reclamation Consortium (1,972 ha in 2008) is less than one-third of the land that is used for irrigated agriculture according to the land use map (6,809 ha).

If we use 6,809 ha in the water budget calculation for the summer, the irrigation applied becomes 206 mm over the agriculture land and the balance for the summer becomes actually a deficit:

$$\begin{aligned}\Delta W \text{ summer} &= P(343 \text{ mm}) - \text{Etc } (542 \text{ mm}) \\ &\quad - \text{drainage } (67 \text{ mm}) \\ &\quad + \text{Irrigation } (206 \text{ mm}) \\ &= -60 \text{ mm}\end{aligned}$$

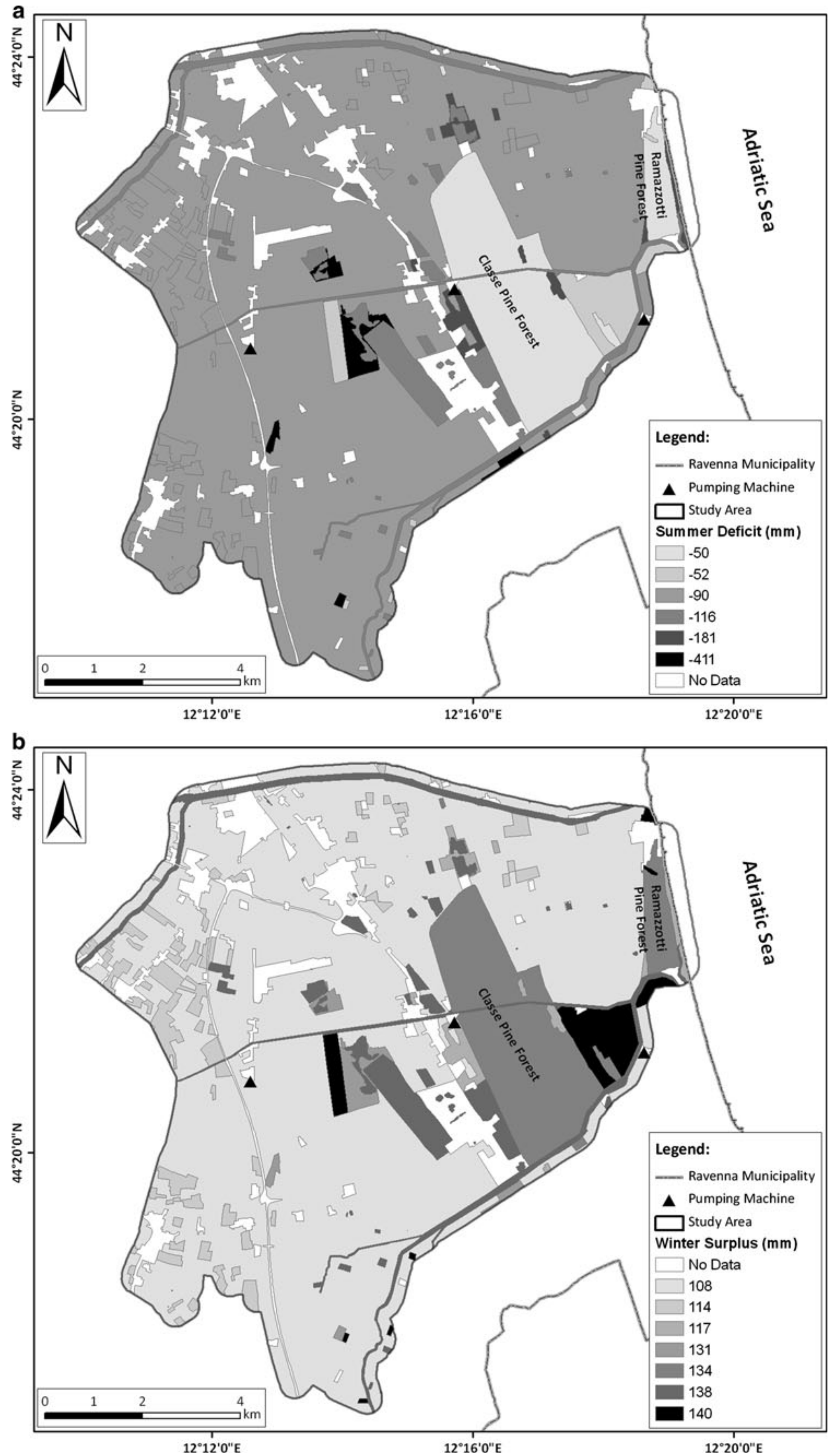


Fig. 10 **a** Difference between hydrologic summer deficit over the period 1989–2008 and 2088–2100 (scenario A2). **b** Difference between hydrologic winter surplus over the period 1989–2008 and 2088–2100 (scenario A2)

Table 10 Volumes of water drained from the Quinto Basin by the pumping station at *Fosso Ghiaia*

Month	Average monthly volume pumped 1995–2008 (m^3)	Volume divided by surface area in Quinto Bacino (mm)
January	26,55,026	25.6
February	16,00,040	15.4
March	19,02,787	18.4
April	17,50,648	16.9
May	10,68,634	10.3
June	13,07,379	12.6
July	9,41,480	9.1
August	85,78,95	8.3
September	10,01,137	9.7
October	14,11,541	13.6
November	26,59,809	25.7
December	29,55,714	28.5
Total annual	2,01,12,089	194.2
Total summer (April–September)	69,27,174	66.9
Total winter (October–March)	1,31,84,916	127.3

Table 11 Summary of whole year, summer and winter components of the hydrologic water budget for current and future climate scenarios

	Landuse	Precipitation	Etc/evap	Deficit/surplus	Precipitation A1b	Etc A1b	Deficit/surplus A1b	Precipitation A2	Etc A2	Deficit/surplusA2
Annual	Irrigated agriculture	635	650	−15	619	584	35	596	594	2
Winter	Irrigated agriculture	292	108	184	377	89	288	382	90	292
Summer	Irrigated agriculture	343	542	−199	242	496	−254	214	503	−289
Annual	Horticulture	635	631	4	619	557	62	596	567	29
Winter	Horticulture	292	114	179	377	88	289	382	89	293
Summer	Horticulture	343	517	−174	242	469	−227	214	477	−263
Annual	Wetlands	635	1,090	−455	619	947	−328	596	963	−367
Winter	Wetlands	292	227	65	377	173	204	382	177	205
Summer	Wetlands	343	863	−520	242	774	−532	214	786	−572
Annual	Baresoil coarse	635	472	163	619	441	179	596	497	99
Winter	Baresoil coarse	292	178	114	377	148	229	382	151	231
Summer	Baresoil coarse	343	294	49	242	295	−53	214	346	−132
Annual	Baresoil fine medium	635	670	−35	619	600	19	596	912	−316
Winter	Baresoil fine medium	292	197	95	377	153	224	382	156	226
Summer	Baresoil fine medium	343	474	−131	242	447	−205	214	756	−542
Annual	Pine forest	635	1,091	−456	619	951	−332	596	968	−372
Winter	Pine forest	292	209	83	377	161	216	382	165	217
Summer	Pine forest	343	882	−539	242	790	−548	214	803	−589
Annual	Open water evaporation	635	1,529	−1,399	619	1,466	−523	596	1,467	−858
Winter	Open water evaporation	292	348	−237	377	319	138	382	300	43
Summer	Open water evaporation	343	1,181	−1,162	242	1,147	−661	214	1,167	−901

One way or the other, either the irrigation practices are inefficient or the pricing practices are inefficient.

Reidsma (2009a, b) has suggested that it is difficult to establish the effect of climate change on farmers without taking into consideration crop/water management and this observation surely holds for the Quinto Basin and other similar agricultural basins in the Po Plain. Pricing, water use and irrigation needs are strictly related and will probably have to change in the near future. If water pricing remains the same, the farmers will simply use more water whenever needed, until the Po runs dry. This is foreseen to happen to some extent by all climate change scenarios that predict less flow in rivers (Lionello et al. 2006).

Assuming that irrigation is becoming more efficient out of (economic) necessity, this would have, however, also a negative feedback for the freshwater aquifer: less irrigation water would recharge the freshwater lenses in summer and so saltwater intrusion would become worse. Also saltwater intrusion in non-irrigated areas will become stronger since there is less rainfall in summer.

The summer deficit of the pine forests is one of the largest among the land uses considered (Fig. 9). Mollema et al. (2010a) have shown with independent calculations that pine trees may consume more water than that from rainfall in summer, contributing that way also to saltwater intrusion. The pine forests are drained to keep the roots dry from waterlogging and for this reason the pine trees, from a hydrologic point of view, do not really help to maintain the freshwater in the aquifer (Antonellini and Mollema 2010). It is very difficult to predict how natural areas, such as the pine forests, will respond to climate change. ET factors for natural vegetation or trees are not as well studied as those for agricultural crops. The few studies that exist show a lot of variation in water use between 1 year and another (Guidi et al. 2008). Definitely, the quantities of water used by the trees are important in the hydrologic budget of the Mediterranean areas where rainfall is limited.

Conclusions

The major conclusions that we can gather from our study are the following:

1. Climate data for our region extracted from GCMs indicate a strong increase in minimum temperature and a more distinct separation in a wet and dry season; a larger percentage of the rain will fall in winter.
2. Wind and air humidity have a large influence on open surface water evaporation, but these parameters are hardly ever discussed.
3. Soil type is a very important parameter to consider in view of climate change for agriculture, determining to a large extent how much water is needed for irrigation. It is, therefore, very important to include considerations on which crop type can be grown on a specific soil type in regulations for water management in view of climate change.
4. Water budget analysis under future climate scenarios A1b and A2 both show an increase of water deficit in the summer and an increase of water surplus in the winter. This is explained by a relatively larger portion of winter rainfall.
5. Current excess irrigation exerts a heavy toll on the water budget, but has beneficial effects in contrasting soil salinization and saltwater intrusion in the coastal phreatic aquifer. Costs and benefits of this practice need to be evaluated and may be integrated in a more extensive practice of managed aquifer recharge (MAR) and water saving.

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