

Chapter 9

An Economically Efficient, Environmentally Sustainable and Socially Equitable Decision Support System for Asopos River Basin: A Manual of Measures

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Abstract This Chapter focuses on the development of a Decision Support System (DSS) for Asopos River Basin (RB) in order to achieve the holistic management of water resources and their ecosystems in the catchment area. As a result, the final output of this application is to identify measures that will contribute to the restoration of the ecosystem in Asopos River. The chapter at a first stage introduces the steps involved in the development of the DSS. Then the deliverables of this process are reported. Important components of the DSS include the gathering of available studies in the area, creation of a database of meteorological and hydrological parameters in the area, estimation in space and time of the parameters of the hydrological table and identification of pressures related to water resources in the area. Further components include the valuation of functions in the catchment, building of different scenarios conditional on changes on precipitation, temperature and water use, estimation in space and time of changes on the parameters of the hydrological table and pressures under the different scenarios. Finally, the DSS suggests measures for the economically efficient, environmentally sustainable and socially equal management of the basin. The considered measures involve among others a number of economic instruments such as standards and quotas, water abstraction taxes, pollution taxes, subsidies, tradable permits, voluntary agreements and liability legislation. It is expected that these instruments can provide the appropriate incentives for efficient water resources management.

Keywords Decision Support System • Basin management • Pressures on Aquatic ecosystems • Hydrological simulations • Ecosystem restoration

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1 Introduction

The Asopos River, which drains an area of 719 km², rises on Mount Lefktra, on the northern flank of the Kithairon range, collects water from tributaries in the southern part of the Theban lowlands, and continues eastward to flow into the South Gulf of Euboea near Oropos. This terrain has a particularly regular relief, with the highest ground in the southern part of the river basin; the average elevation is 357 m, and the highest point 1305 m. Land uses in the region include arable farming, especially in the upper and middle course of the river, forest and scrubland in the southern part of the basin, and a fair amount of industry.

Intense human activity, both agricultural and industrial, has developed in the river valley. Over its entire length the Asopos runs through farmed land, while the Avlona – Inofita – Inoi – Schimatari zone is heavily industrialized. As a result, the Asopos frequently receives wastes and effluents of varied composition and origin, particularly in its middle course (Giannouloupoulos 2008; Bakos 2009), the principle pollutants being hexavalent chromium, nitrates, divalent lead and chlorine ions, which are present in concentrations in excess of the parametric values established in Community law on the quality of water for human consumption.

The main water systems in the Asopos RB are the channel and mouth of Asopos River and the Oropos lagoon, which is the sole remaining coastal wetland in the area. The wetlands complex of the mouth of the Asopos and the Oropos lagoon comprises characteristic types of coastal wetlands, creating a variety of habitats and a striking physiognomic mosaic. The change in water depth inwards from the shore resulting from the local microtopography and periodic seasonal flooding during the year creates a variety of water depths favoring the appearance of many types of vegetation and species of flora and fauna.

The diversity of wildlife occurring in the region is reflected in the 120 species of birds that have been recorded in the study area (Tzali et al. 2009, Dimaki 2011 In Katsavouni et al. 2012), more than in any other wetland in Attica, including raptors, wading birds, overwintering waterfowl, and shorebirds that are found year round but in greater numbers in the winter and during the migrating season. There are also gulls, most notably the Mediterranean gull (*Larus melanocephalus*), which is in the Red Data Book of threatened species, and the little tern (*Sterna albifrons*), which nests in the area, and several species of perching birds. Forty-nine of the avifauna species found here are listed in Annex I to the Birds Directive. With regard to other fauna species, amphibians and reptiles observed in the region include the green toad (*Pseudepidalea viridis*), the Balkan water frog (*Pelophylax kurtmuelleri*), the margined tortoise (*Testudo marginata*), four lizard species [i.e. the European copper skink (*Ablepharus kitaibelii*), the ocellated skink (*Chalcides ocellatus*), the Turkish gecko (*Hemidactylus turcicus*) and the Balkan green lizard (*Lacerta trilineata*)] and the Montpellier snake (*Malpolon monspessulanus*). Certain species of mammals have also been observed in the region, such as the black rat (*Rattus rattus*) and five species of bats [i.e. the Nathusius' Pipistrelle (*Pipistrellus nathusii*), the Kuhl's Pipistrelle (*Pipistrellus kuhlii*), the Savi's Pipistrelle (*Hypsugo savii*), the Geoffroy's

Bat (*Myotis emarginatus*), and the Brandt's Bat (*Myotis brandtii*)]. The habitats for most species of reptiles and mammals are severely degraded.

2 Surface and Groundwater

The hydrographic network of the Asopos is not particularly well developed, since the extensive areas of highly karstified limestone allow the water in the torrents to percolate into the groundwater system, resulting in an uneven ramification on the two sides of the channel. Formerly, even the Asopos itself held water only for a very short period, despite its relatively large catchment area, because of the rapid percolation of surface water into the aquifer. Today, because of the effluents entering the river, parts of the Asopos have water even in the summer months.

The streams in the river basin do not have a permanent flow, and only in certain areas with impermeable formations (schists, clay deposits) are there small torrents that retain a flow of water for a certain period of time: examples include the Lantikos and the Gouras, which traverse the neopaleozoic schists north of Platy Vouno. The Liveas, northwest of Malakasa, whose course runs through the quaternary clays that drain the region, has a seasonal flow. The longest streams in the north part of the river basin are the Sklirorrema, the Potisiona and the Vathi, which drain most of its north side. The streams in the south side of the basin, the Xerias, Bresiko, Kalamata, Lykorrema and Aghios Dimitrios, drain the karst basins on the north face of Mount Pastra and the eastern slopes of the Kithairon (Bakos 2009; Tsarabaris 2010).

No systematic measurements of the discharge of the watercourses in the river basin have been made. A study carried out by Frangopoulos et al. (1992) for the Ministry of Agriculture calculates the discharge volume in the Asopos basin at 26×10^6 m³/year; this is based on limited-time observations and estimates drawn from bibliographical data, and cannot be considered representative (Bakos 2009). The mean annual discharge rate at Rapentoza over the period 1947–1956 was 0.73 m³/s (Economou et al. 2001), while for the whole of the Asopos basin the total annual discharge at the river mouth is estimated at 70.2×10^6 m³.

The bedrock in the area is represented by thick formations of Mesozoic limestones, tertiary and quaternary formations and deposits, and limited areas of Paleozoic schists. The tertiary formations comprise limestones, marls, sandstones and conglomerates, and the quaternary of diluvial formations, debris and alluvial deposits (Tsarabaris 2010). In the western part of the Asopos basin the tertiary and quaternary formations and deposits are very deep, with a thickness ranging from 150 to 300 m (Frangopoulos et al. 1992). These formations overlie a karstic aquifer, which is fed from the north slopes of Mount Parnes and from surface limestone outcrops within the Asopos basin.

In the vicinity of Aghios Thomas, the groundwater level dropped by an average of 22.5 m between 1951 and 1976 (Bakos 2009), while the pumping discharge from the boreholes was reduced by 60 %. Currently there are a large number of boreholes in the river basin, with an average discharge of 30–50 m³/h, which draw water from

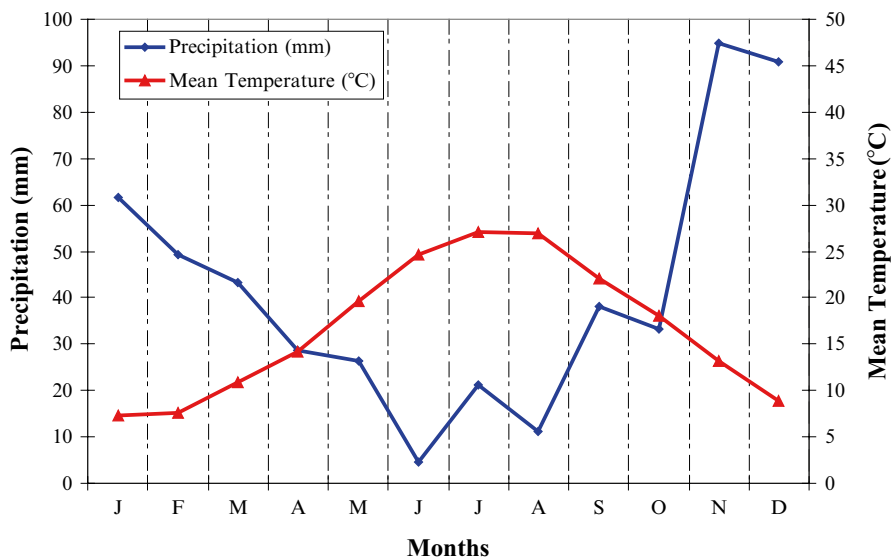


Fig. 9.1 Ombrothermic diagram in the Asopos RB

a depth of 150–160 m below ground level. The average distance between them is 150–200 m, while each borehole serves an area of approximately 12 ha.

3 Meteorological Data

Data from the meteorological stations at Kallithea, Tanagra and Marathon for the period October 1999 to September 2010 show annual average precipitation levels of 534.5 mm, 502.9 mm and 625 mm respectively. The mean annual air temperature at the Tanagra and Marathon stations is, respectively, 16.7 °C and 17.5 °C.

Based on Lang's rainfall index (Trewartha and Horn 1980), which expresses the ratio of average monthly precipitation to average monthly temperature, the climate is hyper-arid from May through September and varies from arid to wet over the rest of the year. Figure 9.1 gives the ombrothermic diagram at the Tanagra meteorological station, based on average monthly precipitation (mm) compared to the corresponding average monthly temperature (°C).

4 Evaluation of Wetland Functions and Values

Wetlands are considered invaluable natural, economic and social assets and efforts are made both to protect them and to restore their functions and values. As it relates to the functions, it is widely recognized that they can perform various, such as: (a) to store water, (b) to enrich the groundwater aquifers, (c) to change the flood peaks, (d) to

transform and remove nutrients and (e) to support the food webs. Wetland functions are physical, chemical and biological processes that they perform. Values for humans result from the structural features and functions of wetlands. These are the goods and services provided or potentially provided to humans as a result of functions that take place there.

The identification and assessment of degraded or under-degradation functions and values, is the first step in defining management objectives and the subsequent adoption of appropriate management measures to achieve them. Through appropriate interventions in wetland functions, degraded values are restored or deterioration is prevented of those values that are in danger directly or indirectly because of the declining trend in their respective functions.

A full assessment of functions and values has been undertaken on the basis of existing methods, such as Wetland Evaluation Technique-WET (Adamus et al. 1987) and EVALUWET (Maltby 2009). According to the methods, the wetland is separated into discrete hydrogeomorphological units based on topographic criteria, hydrology, soil, etc. and the functions in each of these units are evaluated (Brinson 1993a, b; Maltby 2009). In the context of the current work, we attempted identification and assessment of the functions and values of the wetlands in Asopos basin. These wetlands are: the Asopos riverbed, including its estuary, and the lagoon of Oropos. Within this approach, we assessed the ability of wetlands to perform certain functions, according to their structure and special features and those of the river basin (Marble 1992). The assessment area was divided into hydrogeomorphological units according to the method EVALUWET and for assessing functions and values we applied the method of WET. According to the method EVALUWET as *hydrogeomorphological unit* is defined part of the landscape with uniform morphology and consistent hydrological regime.

Identified and delineated in the study area were the following 10 hydrogeomorphological units (HGMUs): A. Western part of Asopos riverbed. B. Central part of Asopos riverbed. C. Eastern part of Asopos riverbed D. Estuary of Asopos. E₁₋₄. Four regions located west and east of the estuary of Asopos and in the vicinity of Oropos lagoon. Z. Oropos lagoon. H. South and east of Oropos lagoon.

The functions that were considered necessary to evaluate in the area were: (a) water storage, (b) food web support: aquatic life and avifauna, (c) nutrients removal and transformation, (d) sediment and toxic trapping, (e) floodwater attenuation, (f) groundwater recharge, (g) shoreline stabilization. The degree of performance of each function was qualitatively assessed and given the designation “high”, “moderate”, “low” or “none”. In summary, the degree of performance of wetland functions in each unit is given in Table 9.1.

In the case of study area, the following wetland values were evaluated: (a) biological, (b) scientific, (c) education (d) recreational, (e) hunting, (f) improving of water quality, (g) protection against floods, (h) protection against erosion. The evaluation was done with consideration of the degree of performance of wetland functions and the status quo, with respect to services and goods that can accrue to the man from the wetland. The evaluation leads to characterize the degree of expression of each value as a “high”, “moderate”, “low” or “none”. Below is the assessment of values, which occurred in regions: (a) Asopos riverbed (HGM includes units A, B and C in their entirety), (b) estuaries (including the HGM units D and E₁₋₄ entirely), and (c) lagoon of Oropos (HGM includes units Z and H in their entirety) (Table 9.2).

Table 9.1 Performance degree of the wetland functions in the study area

Wetland functions		Food web support:							Shoreline stabilization
HGM unit	Water storage	aquatic life	support: avifauna	Nutrient removal and transformation	Sediment and toxic trapping	Floodwater attenuation	Groundwater recharge		
	Performance degree								
A	Low	Low	Low	Low	High	Low	High	None	
B	Moderate	Low	Low	Low	High	Low	Moderate	None	
C	Low	None	Low	Low	High	Low	High	None	
D	Low	Low	High	Low	High	Low	Moderate	High	
E ₁₋₄	Low	Low	Moderate	Moderate	Moderate	Moderate	Low	High	
Z	Low	Low	High	Low	Moderate	Moderate	Low	High	
H	None	Low	Moderate	Low	Moderate	Moderate	Low	High	

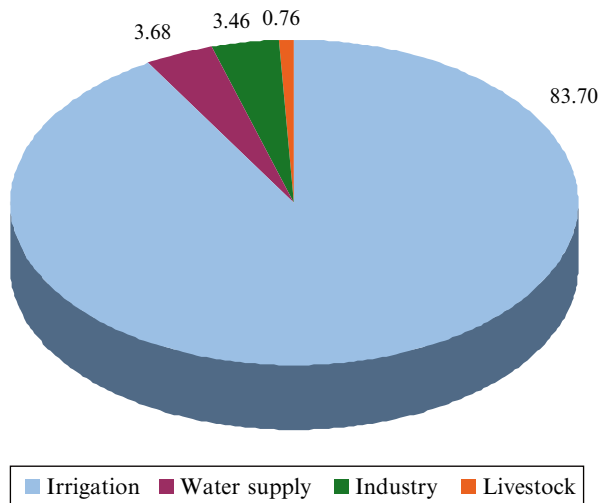


Fig. 9.2 Annual water demand by users in the Asopos RB (in million m³)

5 Determining Pressures on the Aquatic Ecosystems

Industrial activity in the Asopos RB severely degrades the quality of the river's water, while the human impact on the coastal wetlands is also very strong, chiefly from residential pressures, vehicle traffic in the summer months as bathers use the beaches, and the discarding and accumulation of rubbish. Road construction and the expansion of residential development towards the wetlands exert pressure on the Oropos lagoon. A multitude of roads form an urban grid and the pressure of residential development extends right to the shoreline. Taking all this into account, it is obvious that the wetlands complex is subject to continuous degradation, due mainly to the expansion of residential construction at the expense of the wetlands region and the pollution of the Asopos River. Moreover, evaluation of wetlands functions and values has led to recognition of the degradation of the wetlands ecosystems and the need to rehabilitate them.

Meeting the water needs generated by urban water supply, irrigation, livestock and industry exerts further pressure on the aquatic ecosystems. It is clear from the graph in Fig. 9.2, which charts water consumption for the above uses, that irrigation is by far the heaviest user (91 %).

6 Hydrological Simulation of the Asopos River Basin

6.1 Setting up an Integrated Hydrological Model

An integrated hydrological model of groundwater and surface water in the Asopos RB was developed by setting up the MIKE SHE and MIKE 11 modeling systems.

The hydrological model of the Asopos RB is part of the decision support system, and its object is to simulate the availability of water resources in order to assess the impact of pressures exerted on them by water users.

In MIKE SHE/MIKE 11 the processes of the hydrological cycle in the Asopos RB are simulated using the modules outlined in Table 9.3. The region for which the simulation system was developed is the lowlands part of the basin (Fig. 9.3), where the human-induced pressures on the aquatic ecosystems were identified.

The simulation used – *inter alia* – meteorological, morphological, pedological, geological and land-use data. Rainfall amounts and intensities are the driving force behind almost all the processes of the hydrological cycle, and the Asopos RB receives most of its rainfall (74.1 %) in the 6 months from October to March, and just 25.9 % between April and September.

The relief of the ground determines both the drainage areas and those of surface runoff, and also shapes the natural upper limit of the unsaturated and – albeit in certain conditions – the saturated zone. As regards the spatial distribution of the various land uses, these are classified as agricultural, forest or urban before being entered into the model (Fig. 9.4). The quantity of water needed for irrigation puts heavy pressure on the groundwater and is spatially distributed over the lowlands area of the river basin before being included in the model.

Table 9.3 Processes of the hydrological cycle simulated in the Asopos RB

Process of hydrological cycle	Module	Combination of modules and systems	Dimensionality of the simulation	Equations describing the process
Overland flow and storage	MIKE SHE OL	MIKE SHE SZ, UZ AND MIKE 11	1 – D	Routing overland flow based on the Manning equation and empirical formulas
Movement of water in open channels (discharge and flow depth)	MIKE 11 HD	MIKE SHE SZ, OL	1 – D	Saint Venant equation
Infiltration and storage of water in the unsaturated zone, saturated zone recharge	MIKE SHE UZ	MIKE SHE SZ, OL	1 – D	Two-layer water balance method
Evapotranspiration	MIKE SHE ET	MIKE SHE UZ, OL	–	Kristensen & Jensen
Movement and storage of water in aquifers	MIKE SHE SZ	MIKE SHE UZ, OL AND MIKE 11	2 – D	Groundwater flow based on the Darcy equation

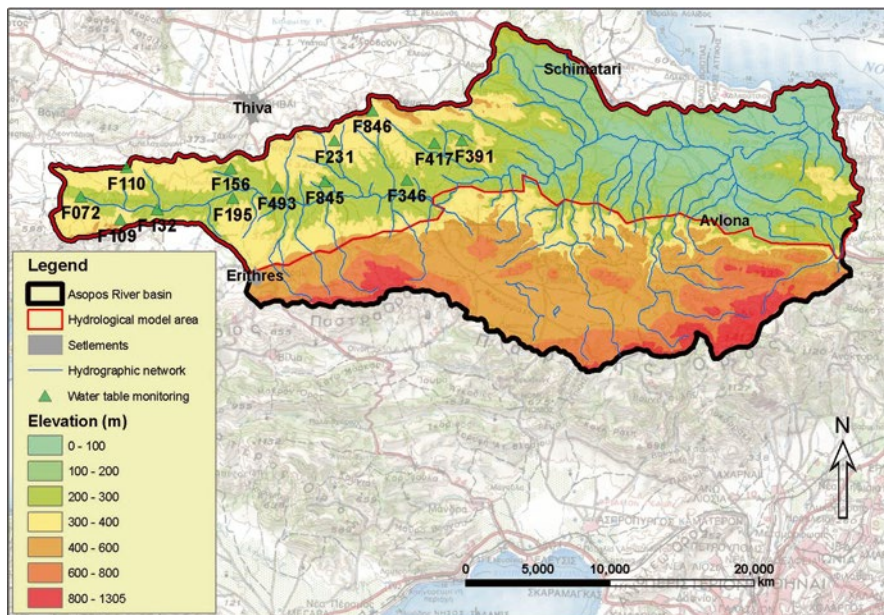


Fig. 9.3 Hydrological model area in the lowlands of Asopos RB

6.1.1 Hydrological Processes in the MIKE SHE

The hydrological processes covered by the Asopos RB model include overland flow, evapotranspiration, infiltration into the unsaturated zone and flow in the aquifers.

Overland flow occurs when there is heavy rainfall and the rate of precipitation exceeds the rate of absorption into the soil. The course and the final quantity of water in surface streams are determined by the relief and the roughness of the ground and by losses due to evapotranspiration and percolation. This process is simulated by means of the numerical solution of the continuity equation, using as auxiliary equations an empirical relationship between flow depth and ground gradient coupled with Manning's equation (Crawford and Linsley 1966).

Water flow in the unsaturated zone is simulated using a simple two-layer water balance approach, where the first layer extends from the surface of the ground to the root zone and the second from the bottom of the root zone to the groundwater table (or the ceiling of the saturated zone). In each layer the humidity conditions are considered as uniform in terms of depth. The main object of this approach is not a detailed simulation of the movement of the water in the unsaturated zone, but an estimate of real evapotranspiration, the quantity of water that is held in the unsaturated zone, and the quantity of water that percolates into the saturated zone (Yan and Smith 1994).

Evapotranspiration is calculated taking account of the following processes:

1. Part of the precipitation is intercepted by the leaf canopy, and evaporates.
2. The rest reaches the surface of the ground, where it either runs off or penetrates into the unsaturated zone.

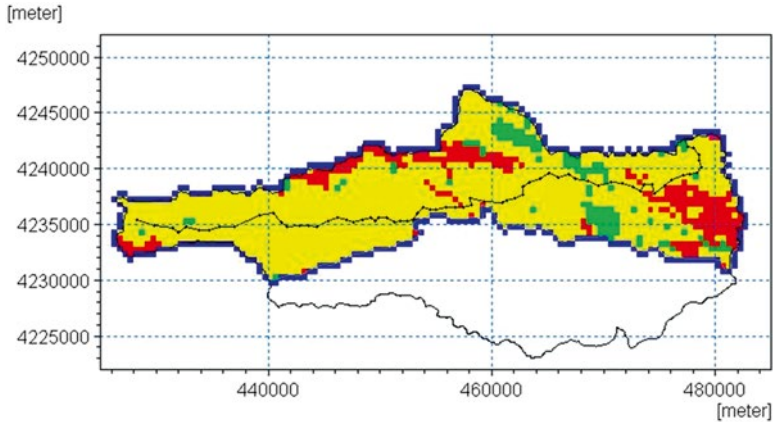


Fig. 9.4 Land use in the model area of Asopos RB (yellow: agricultural land, red: forest, green: urban and industrial areas)

3. The quantity of water that is stored in the unsaturated zone (the root zone) either evaporates or is transpired by the vegetation.
4. The remaining quantity of water that infiltrates into the soil is considered as recharging the aquifers.

The soil infiltration rate determines the ratio of surface runoff to the water percolating into the unsaturated zone; the lower the infiltration rate, the greater the quantity of water that is available for surface runoff, with a corresponding reduction in the quantity of water available to percolate into the unsaturated zone.

Water flow in the saturated zone is one of the hydrological processes of the integrated model of surface and groundwater that interacts with all the others – overland flow, flow in the unsaturated zone, evapotranspiration, stream flow – and uses them in boundary conditions.

Groundwater movement is simulated by the numerical solution of the three-dimensional differential equation:

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) - Q = S \frac{\partial h}{\partial t} \tag{9.1}$$

where h is the piezometric head on the aquifer (m), K_{xx} , K_{yy} , K_{zz} the hydraulic conductivity along the x , y , z axes (m/s), Q the volume of water that is added or abstracted per unit volume of the aquifer (s^{-1}), S the specific storage coefficient, x , y , z the axes of the Cartesian coordinate system, and t is time.

6.1.2 Interaction Between Surface- and Groundwater

The model takes account of the interaction between the groundwater and the Asopos River by coupling MIKE SHE with MIKE 11. Water movement in the Asopos is

simulated in the MIKE 11 environment by the solution of the Saint Venant equations:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{9.2}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\alpha \frac{Q^2}{A} \right) + gA \frac{\partial h}{\partial x} + \frac{n^2 gQ|Q|}{AR^{4/3}} = 0 \tag{9.3}$$

where Q is the discharge of the river (m^3/s), A the cross-section (flow) area (m^2), q the lateral inflow into the river (m^2/s), h the water level above the reference datum (m), x the longitudinal direction of flow (m), t time (s), n Manning’s coefficient of friction ($s/m^{1/3}$), R the hydraulic radius (m), g the coefficient of gravitational acceleration (m^2/s) and α the coefficient of velocity distribution ($-$). Depth of flow and discharge along the course of the Asopos are calculated by means of the solution of Eqs. 9.2 and 9.3 in a one-dimensional computational network of an implicit finite difference scheme.

The Asopos River was input to MIKE 11 taking account of the digital model of the relief of the basin used by MIKE SHE, permitting accurate hydraulic communication between MIKE SHE and MIKE 11. As the river flows through its drainage basin, it interacts with the groundwater. This interaction is bi-directional (Fig. 9.5), and groundwater recharge from the river (Q_2) and drainage from the groundwater into the river (Q_1) are calculated by means of a formula based on Darcy’s law.

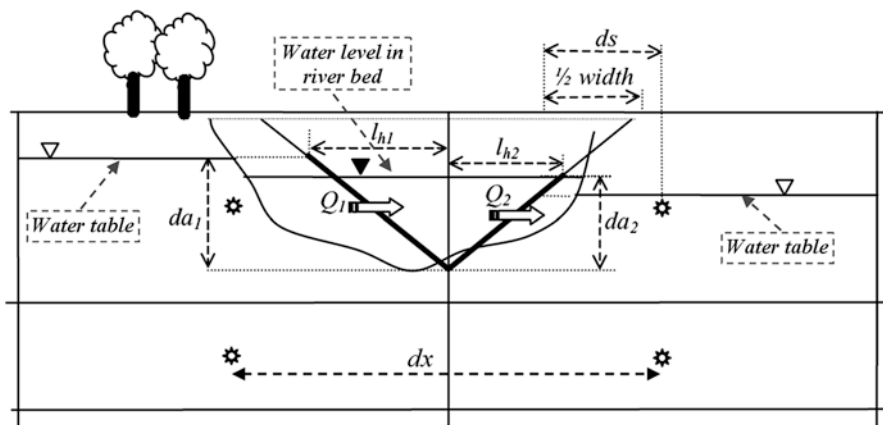


Fig. 9.5 Interaction of surface- and groundwater in a hypothetical river cross section (Source: DHI (2009))

6.2 Calibration of the Hydrological Model

The structure of the distributed hydrological simulation systems permits spatial variation of the characteristics of the basin in a network of points in the form of a rectangular grid. Frequently, the application of models to a river basin requires several thousand points, each of which is characterized by different parameters and variables. A distributed hydrological simulation system like MIKE SHE has the potential to deliver a large number of parameters, the values of which must be determined when calibrating the model. Some of these parameters can be estimated from field data, e.g. vegetation distribution charts, geological and soil sections, etc.

In calibrating the model of a river basin, the available field data should be used to determine spatial units, in each of which there is little fluctuation in the value of a specific model parameter or group of parameters. In the Asopos RB, the parameterization of the model took into account the following spatial units:

- Categories of land use, for which the leaf area index and depth of root zone are determined.
- Categories of soil type, for which the humidity at field capacity, the humidity at permanent wilting point and the hydraulic conductivity at saturation are determined.
- Areas where the hydraulic parameters determined are those relating to overland flow and flow in the saturated zone.

On the basis of the results of the model for flow in the saturated zone, the parameters of hydraulic conductivity K and specific yield S were calibrated using the measured values of the groundwater table at the monitoring points. During the calibration three sets of values were tested for hydraulic conductivity (K_1 , K_2 , K_3) and three for specific yield (S_1 , S_2 , S_3). From the adjustment of the model it was determined that hydraulic conductivity ranges from 10^{-3} m/s to 10^{-9} m/s, and specific water yield from 0.13 to 0.17.

The mean absolute error (MAE), the root mean squared error (RMSE) and the correlation coefficient (r) are the statistical criteria that were used in checking the results of the model and comparing them to the measured values of the groundwater table (Table 9.4).

Figures 9.6, 9.7, and 9.8 show the variation in the calculated model values in relation to the measured values of the groundwater table at selected monitoring points (Fig. 9.3).

6.3 Analysis of the Water Balance Parameters

The surface runoff from the river basin is collected along the length of the river's course; Fig. 9.9 gives the calculated annual surface runoff and the surface runoff coefficient (the ratio of surface runoff to amount of precipitation) at the mouth of the

Table 9.4 Mean Absolute Error (MAE), Root Mean Squared Error (RMSE) and Correlation Coefficient (r) of the observed and calculated values of groundwater table in the Asopos RB

Monitoring stations of water table	Statistical criteria		
	MAE (m)	RMSE (m)	R
F072	6.74	7.79	0.58
F109	2.0	3.13	0.81
F132	2.18	3.01	0.91
F110	10.88	12.24	0.70
F156	1.65	1.83	0.92
F195	3.79	5.67	0.48
F493	1.91	2.07	0.82
F845	1.67	2.12	0.93
F231	2.29	2.77	-0.04
F846	3.62	4.67	0.85
F346	1.68	1.87	0.89
F417	1.84	2.22	0.47
F391	1.07	1.33	0.85

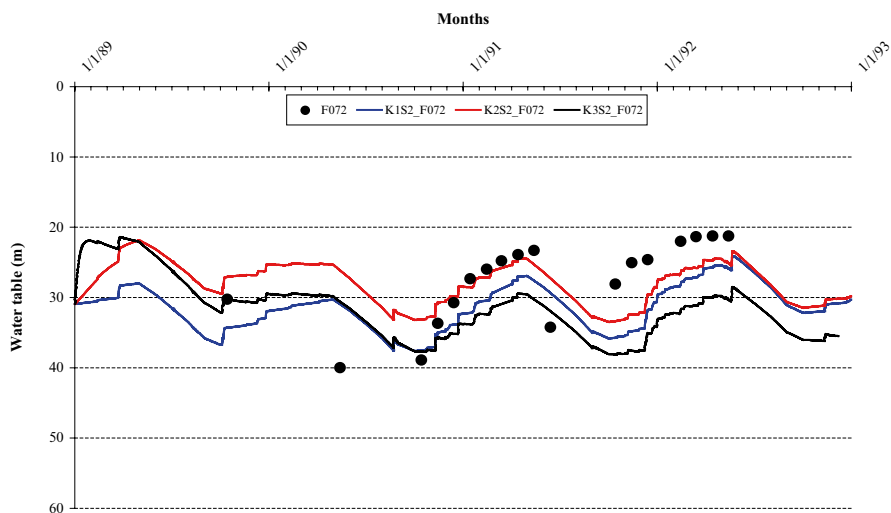


Fig. 9.6 Variation of observed and calculated (K1S2, K2S2, K3S2) values of groundwater table in the station F072

Asopos. The average value for the surface runoff coefficient is 0.2. Annual surface runoff A (mm) can be estimated from annual precipitation P (mm) based on the relationship $A = 0.2665 \times P - 31.444$ (correlation coefficient, $R^2 = 0.93$).

The water balance of surface water in the lowland part of the Asopos RB is given by the equation:

$$P + Irr = ET + RF_{-1} + \delta \tag{9.4}$$

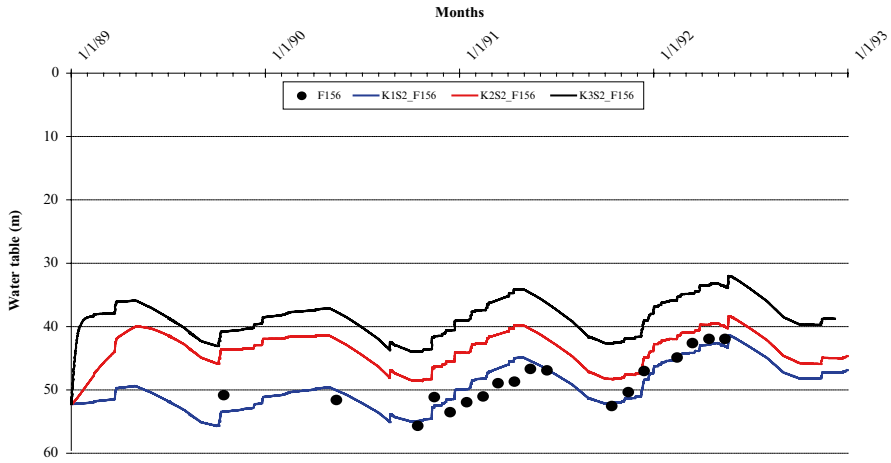


Fig. 9.7 Variation of observed and calculated (K1S2, K2S2, K3S2) values of groundwater table in the station F156

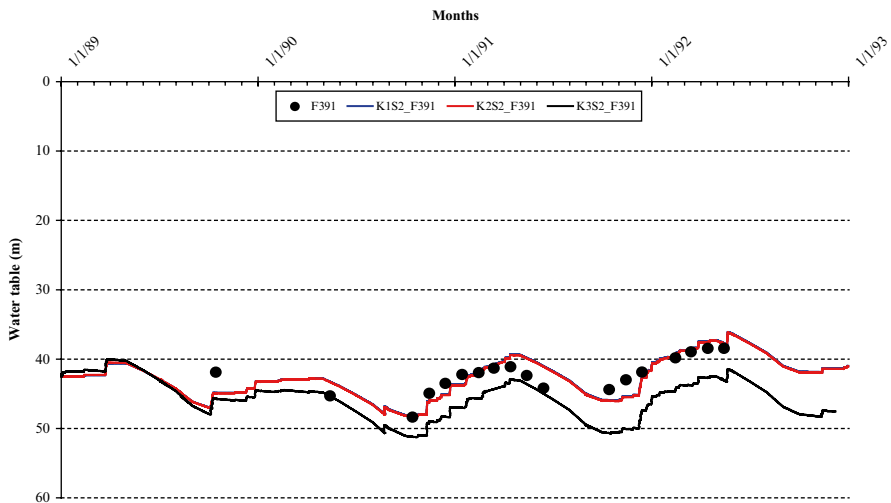


Fig. 9.8 Variation of observed and calculated (K1S2, K2S2, K3S2) values of groundwater table in the station F391

and the water balance for groundwater by the equation:

$$\delta + GW_I = Irr + RF_2 + GW_O + GW_S \tag{9.5}$$

Combining Eqs. 9.4 and 9.5 gives the balance of surface and groundwater in the lowland part of the Asopos RB, which is expressed by the equation:

$$P + GW_I = ET + RF + GW_O + GW_S \tag{9.6}$$

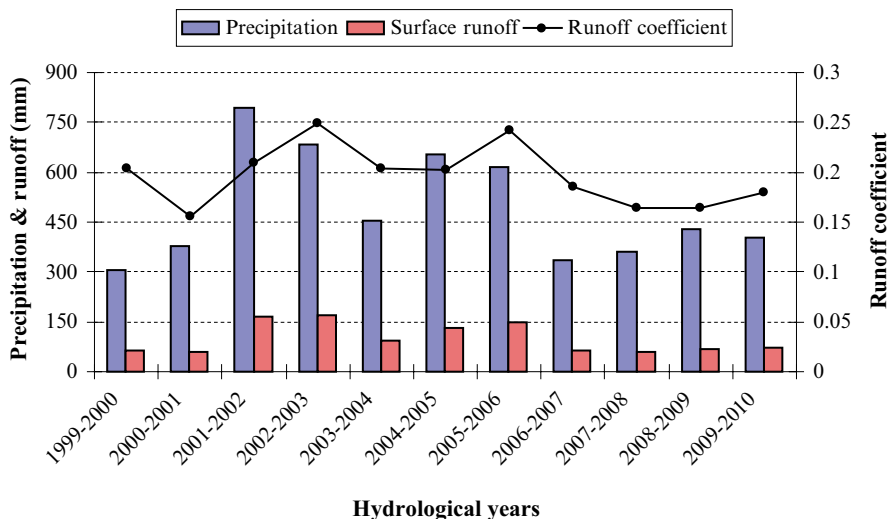


Fig. 9.9 Precipitation, surface runoff and runoff coefficient in the Asopos RB

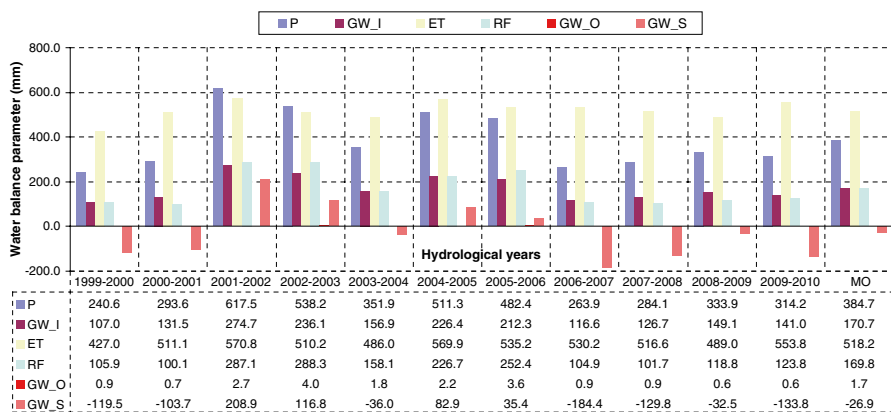


Fig. 9.10 Hydrological balance in the lowlands of Asopos RB

where P is the amount of precipitation (mm), Irr the irrigation water requirements (mm), ET evapotranspiration (mm), δ the interaction between surface and groundwater (mm), RF_1 the overland flow from the basin to the river (mm), RF_2 the subsurface flow from the basin to the river (mm), GW_I the subsurface inflow from the mountainous part of the basin (mm), GW_O the subsurface outflow to the sea (mm), GW_S the change in the volume of groundwater (mm) and (RF=RF_1 + RF_2) the flow from the basin to the river. The quantity of water lost into the atmosphere from evapotranspiration includes the water used for irrigation.

The inflow of water into the basin is the sum of the amount of precipitation (P) and subsurface inflow (GW_I); it averages 662.8 mm/year. With a total outflow from the basin (ET+RF+GW_O) of 689.7 mm/year, the result is a net loss of groundwater amounting to 26.9 mm/year (Fig. 9.10).

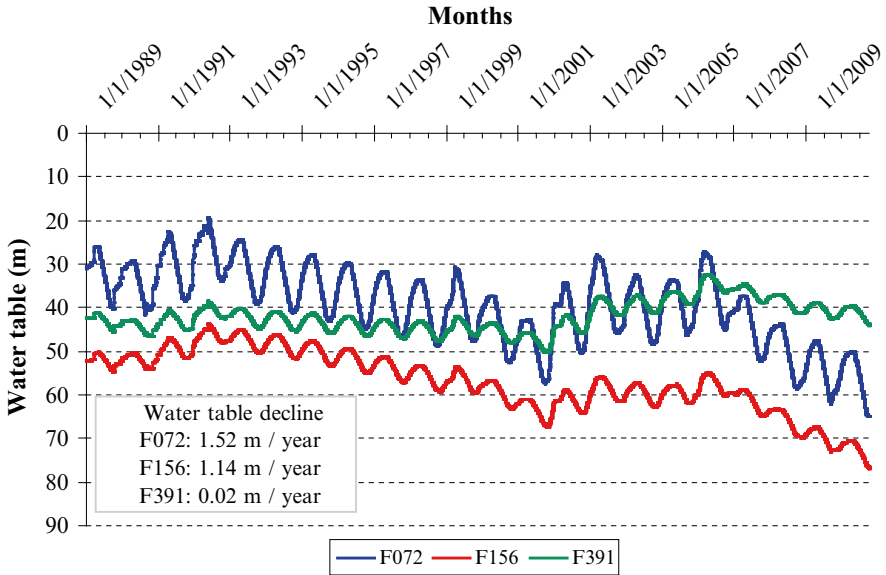


Fig. 9.11 Water table variation in the Asopos RB

The pressure on the Asopos RB caused by irrigation has led to a reduction in the volume of groundwater and hence a lowering of the water table. The magnitude of this pressure varies, with the heaviest pressures occurring in the western part of the basin, where larger quantities of water are required for irrigation. The fluctuation in groundwater levels has resulted in a continuous year-on-year decline in the water table (Fig. 9.11).

7 Proposals for Climate Change Adaptation Measures

7.1 Climate Change Scenarios and Projected Changes in Irrigation Water Requirements

The climate changes that have been observed and their effects on the human population and the ecosystems have created the need for a study of climate characteristics. Climate models are an attempt to reproduce the natural climate, and possible climate changes are studied on the basis of projected greenhouse gas emissions. The creation of these scenarios is based on the documented scientific opinion of the United Nations’ Intergovernmental Panel on Climate Change (IPCC) that the climate changes that have been observed, such as rising temperatures, are due to increased emissions of greenhouse gases, and particularly carbon dioxide.

Table 9.5 Rainfall and temperature variation in the Asopos RB for the climate change scenario A1B

Scenario/simulation period	Rainfall		Temperature	
	mm	%	°C	%
1999–2010	502.9		16.7	
A1B/2020–2031	469.7	–6.6	18.4	10.1
A1B/2070–2081	398.3	–20.8	20.4	22.1

The IPCC's Third Report presents some 40 greenhouse emissions scenarios (Nakićenović et al. 2000), based on projected developments in population size, energy policies, economic growth rates and future advances in technology (Kapsomenakis et al. 2011).

The Academy of Athens' Research Centre for Atmospheric Physics and Climatology has developed databases and simulated models based on scenarios A2, A1B, B1 and B2. In the Asopos RB, the emissions scenario used for rainfall and temperature was A1B, which has the following characteristics (EMEKA 2011):

Scenario A1B: Rapid economic growth. Particularly intense energy use, but with a parallel spread of new and efficient technologies; use of both fossil fuels and alternative sources of energy; minor changes in land use. Rapid increase in the global population up to 2050 and gradual decrease thereafter. Marked increase in the concentration of CO₂ in the atmosphere, reaching 720 ppm by 2100.

The change in the amount of rainfall in the Asopos basin associated with greenhouse gas emissions scenario A1B was plotted for the periods 2020–2031 and 2070–2081, using 1999–2010 as the reference period. The reduction in annual rainfall for the decade 2070–2081 will be greater (–20.8%) than for the decade 2020–2031 (–6.6%) compared to the reference period 1999–2010. As for temperature change, the model predicts a rise of 10.1 % for the period 2020–2031 and of 22.1 % for the period 2070–2081 (Table 9.5).

Irrigation consist a significant pressure in Asopos RB and regards almost 91 % of total water requirements. Irrigation Water Requirements (IWR) were estimated based on climate data and applying the Blaney-Criddle method, in conjunction with the future crop pattern distribution.

The crop distribution is expected to alter in the next years. To estimate the future distribution of crops, a recent study of Ministry of Development (Development of Hydroinformatic systems and tools for water resources management, 2008) is taking into account the forthcoming changes to subsidy regimes imposed by the Common Agricultural Policy (CAP) from 2013. Taking also into account the increase of temperature, and consequently the increase of crop evapotranspiration, according to climate scenario A1B, the IWR are estimated for the period 2020–2030 to 126.1 million m³ per year, named *Scenario 0* (100 %).

The decrease of Irrigation Water Requirements (IWR) could be achieved by replacing the applied irrigation techniques from sprinkler irrigation to drip irrigation and by adopting a different crop distribution in the area including fallow fields or non-irrigated agriculture. Sprinkler irrigation is the dominant method in Asopos

RB while drip irrigation is applied only to 10 % of irrigated land. Considering that the efficiency of sprinkler irrigation varies from 0.6 to 0.8 and the efficiency of drip irrigation varies from 0.85 to 0.95, it follows that applying drip irrigation could save more than 20 % of irrigation water (0.7/0.9).

In order to decrease the above estimation of IWR in Asopos RB, the following two scenarios are considered:

Scenario 1 (75 %), IWR = 94.2 Million m³

Applying drip irrigation to 75 % of irrigated land.

Assuming that 15 % of annual crops should be replaced by non-irrigated agriculture (e.g. wheat). Alternative, a fallow agriculture scheme should be adopted.

Scenario 2 (50 %), IWR = 62.6 Million m³

Applying drip irrigation to 90 % of irrigated land.

Assuming that 55 % of annual crops should be replaced by non-irrigated agriculture (e.g. wheat). Alternative, a fallow agriculture scheme should be adopted.

7.2 Impact of the Pressures on Water Resources and Proposed Measures for Their Management

Reduced rainfall and higher temperatures will have an effect on water resources in the Asopos RB and on the wetlands functions performed along its channel, at the river mouth and in the Oropos lagoon and consequently on the values deriving from them. More specifically, future observations are expected to include:

- Increased water evaporation and plant evapotranspiration.
- Decreased recharge and renewal in the groundwater table due to decreased rainfall and increased evapotranspiration.
- Increased salinity in the coastal groundwater level.
- A more concentrated pollution load in the coastal aquatic ecosystem of the Asopos due to reduced dilution, with a negative impact on the nutrient transformation and removal function due to the resulting lack of water.
- Reduced discharge at the river mouth, with consequential effects on its biota; this, coupled with the increases in the concentration of pollutants, constitutes a serious hazard for many species of plants and animals in the riverine ecosystem.
- The food web support function and consequently the biological value of the region will be negatively affected. Climate change is among the main direct causes of loss of biodiversity and will have significant implications for the several constituents of biological diversity, namely ecosystems, species and the genetic diversity of species.

Moreover, climate change will lead to a reduction in the availability of water for irrigation, which will be due on the one hand to decreased rainfall and on the other

to the lengthening of the dry period and increased demand for water for agricultural purposes. The net result will be that the region's water resources will be insufficient to meet the future water needs either of its ecosystems or of water users (urban water supply, irrigation, industry, livestock).

The measures proposed include:

- Reducing the amount of irrigated land and using crops requiring less water.
- Informing farmers about the rational use and management of irrigation water.
- Using recycled water in agriculture.
- Modernizing irrigation systems.
- Creating reservoirs.

Implementing these measures will reduce the amount of water required for irrigation, which in turn will lessen the impact of climate change on the availability of water resources in the region and consequently on the ability to meet the future water needs of the ecosystems and water users in the river basin.

Applying climate scenario A1B (2020/2021 to 2030/2031) to three irrigation needs scenarios (100 %, 75 %, 50 %) suggests that cutting irrigation requirements by 25 % will significantly slow the rate of fall in the groundwater table, although the rate of fall in the groundwater table is noticeably lower compared to the rate of fall observed when irrigation needs are met in their entirety. When irrigation needs are further reduced, to 50 %, the water table drops during the irrigation season but gradually recovers afterwards, and by the end of the simulation period is restored to roughly its initial level (Fig. 9.12).

Surface runoff in the Asopos basin increases by 9.5 % and 23.7 % respectively when irrigation requirements are reduced by 25 % and 50 % (Fig. 9.13). The increase in surface runoff resulting from the reduction of irrigation is particularly important during the irrigation season. When irrigation requirements are reduced by 25 %, surface runoff in the period from May to September increases by 17.8 %, while cutting irrigation requirements in half increases surface runoff by 42.8 %.

The fall in the groundwater table is also reduced and surface runoff increased when the three irrigation needs scenarios are run for the period 2070/2071 to 2080/2081. In this case, however, the drop in the groundwater table does not stabilize even when irrigation is cut in half (Fig. 9.14). As for surface runoff (Fig. 9.15), reducing irrigation to 75 % and 50 % of present levels results in an average annual increase of 9.7 % and 23.2 % respectively, and an increase during the irrigation season (May to September) of 22.9 % and 54.2 % respectively.

Furthermore, there are different economic tools that can assure the effective and equitable distribution of the water resources across competitive uses. These instruments can also contribute to internalize the externalities related to the use of a public good achieving a socially optimum result. These economic measures are presented in the Table 9.6 along with their main advantages and disadvantages.

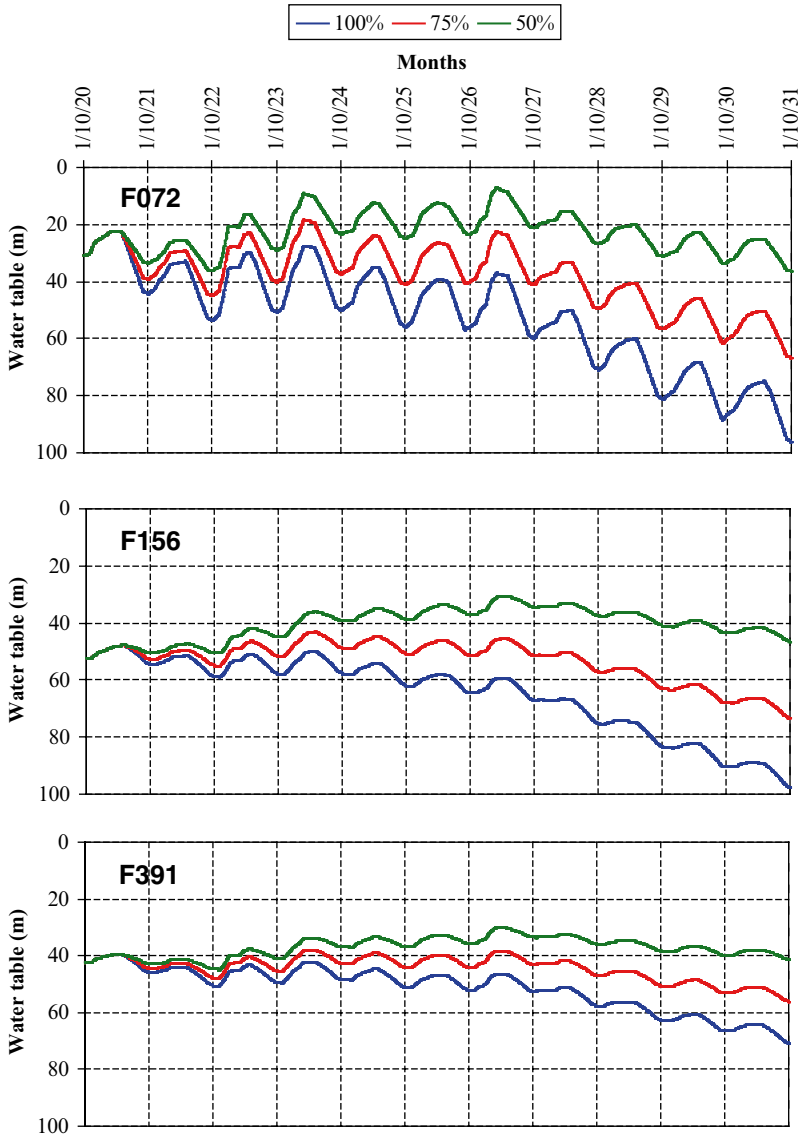


Fig. 9.12 Water table variation in Asopos RB under the climate scenario A1B (2020–2031) and the three irrigation requirement scenarios (100 %, 75 %, 50 %)

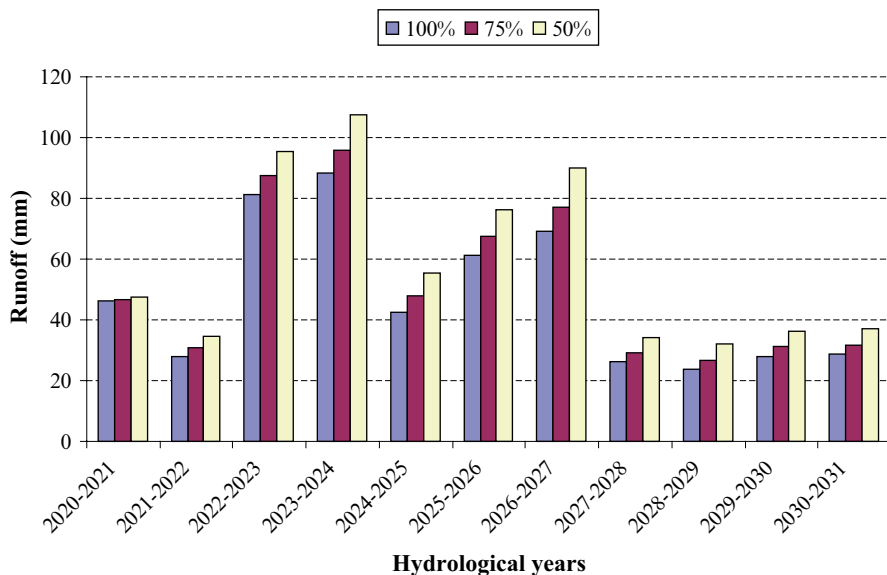


Fig. 9.13 Annual surface runoff in Asopos RB under the climate scenario A1B (2020–2031) and the three irrigation requirement scenarios (100 %, 75 %, 50 %)

Hence the search for the least cost set of measures may include: (i) economic instruments (e.g. abstraction/pollution taxes, tradable permits, subsidies), (ii) measures to increase awareness regarding water scarcity, aiming at reducing abstraction/pollution, (iii) direct controls on pollution dischargers, (iv) agri-environment programs providing financial and technical assistance for, e.g. reallocation of crop production mix over agricultural land, (v) adoption of water-saving technologies coupled with land-allocation restrictions, etc. and (vi) green investments e.g. pollution control and remediation, resource conservation and management, land use and infrastructure, renewable energy sources.

In order to restore wetlands functions and values in the region of the Asopos River and the Oropos lagoon, the measures for the management of water quantity in the Asopos basin will need to be supplemented by measures and interventions addressing water quality and control of point and non-point sources of pollution and taking into account existing socio-economic conditions in the region.

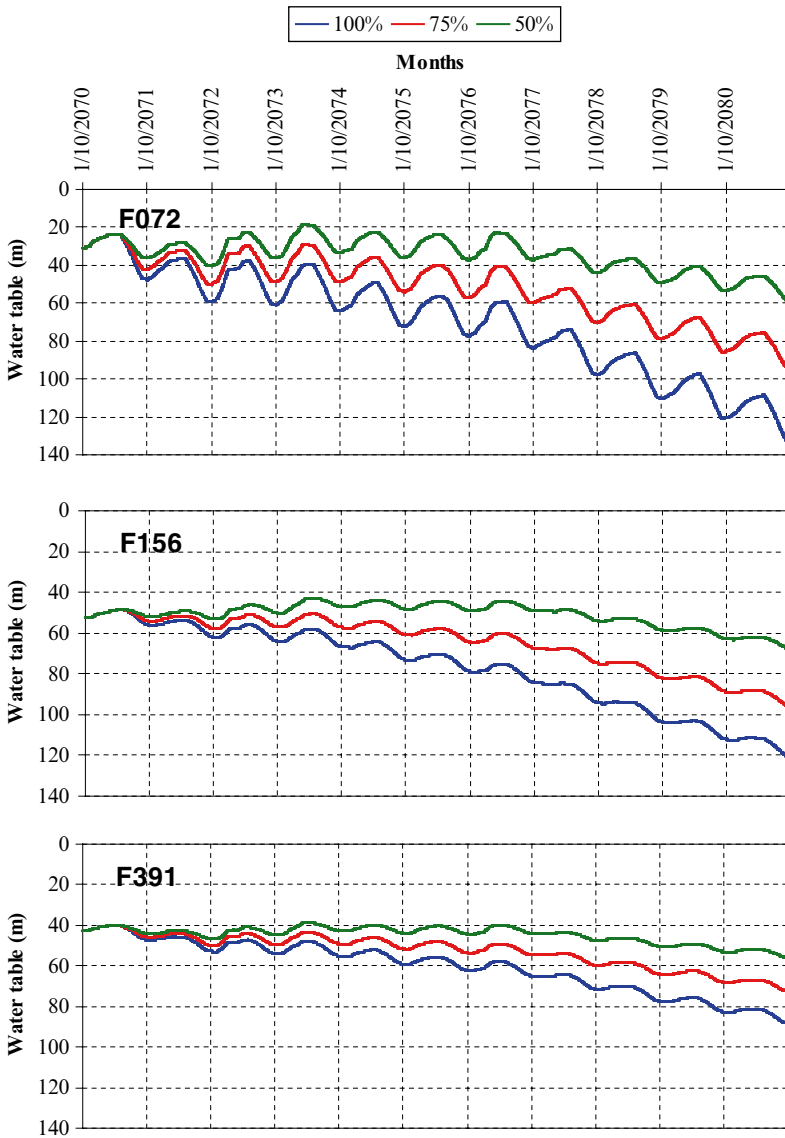


Fig. 9.14 Water table variation in Asopos RB under the climate scenario A1B (2070–2081) and the three irrigation requirement scenarios (100 %, 75 %, 50 %)

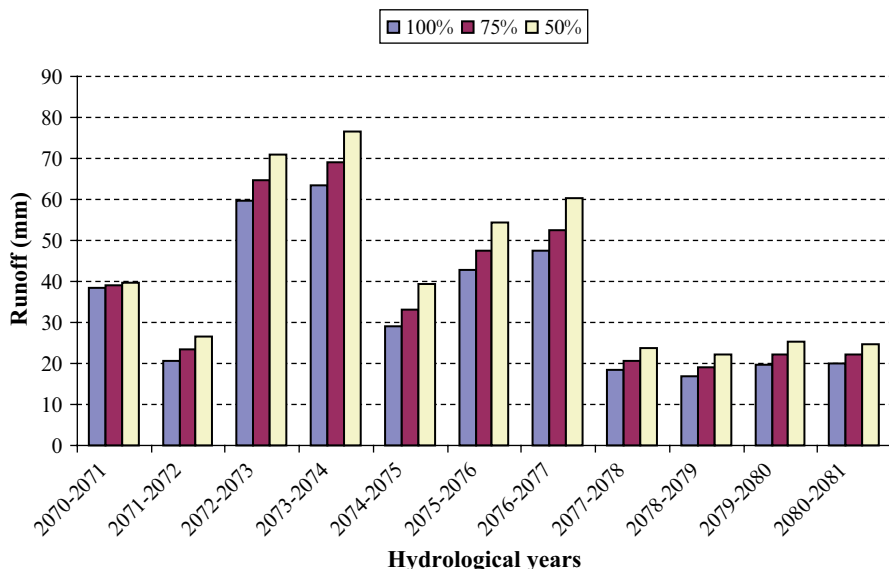


Fig. 9.15 Annual surface runoff in Asopos RB under the climate scenario A1B (2070–2081) and the three irrigation requirement scenarios (100 %, 75 %, 50 %)

Table 9.6 Classification of economic instruments^a

	Advantages	Disadvantages
1. Standards and Quotas		Not economically efficient
2. Water abstraction charges	Adjustment of price signals to reflect actual resource costs; encourage new technologies; flexibility; generation of revenues	Low charges will have minimal impact on user behavior and will continue in resource overutilization
3. Pollution charges	Same as water abstraction charges; polluter-pays principle	Same as water abstraction charges
4. Subsidies on water saving measures	Readily acceptable	Financial constraints
5. Tradable permits	Quantity based targets that are able to attain least-cost outcome. Allows flexibility.	May entail high transaction costs
6. Voluntary agreements	Readily acceptable	Needs high environmental awareness
7. Liability legislation	Assess and recover damages ex-post but can also act as prevention incentives	Require an advanced legal system; high control costs; burden of proof

^aReport on the implementation of Article 5 of the WFD (2008)

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