Soil and Water Assessment Tool, Gediz – Turkey

WatManSup project

WatManSup Report No 6

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FutureWater Science for Solutions

Soil and Water Assessment Tool, Gediz Basin - Turkey

WatManSup Report No 6

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Preface

This report is written in the context of the WatManSup project (Integrated Water Management Support Methodologies). The project is executed in two countries: Kenya and Turkey. Financial support is provided by Partners for Water. For more information on the WatManSup project see the project website: http://www.futurewater.nl/watmansup.

The Dutch consortium:
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Reports so far:
Report No.1: Water Management Support Methodologies: State of the Art
Report No.2: Water Evaluation and Planning System, Kitui - Kenya
Report No.3: Soil and Water Assessment Tool, Kitui - Kenya
Report No.4: Multi-criteria analysis, Kitui - Kenya
Report No.5: Water Evaluation and Planning System, Gediz Basin - Turkey
Report No.6: Soil and Water Assessment Tool, Gediz Basin - Turkey

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1 Introduction

The challenge to manage our water resources in a sustainable and appropriate manner is growing. Water related disasters are not accepted anymore and societies expect more and more that water is always available at the right moment and at the desired quantity and quality. Current water management practices are still focused on reacting to events occurred in the past: the re-active approach. At many international high level ministerial and scientific meetings a call for more strategic oriented water management, the pro-active approach, has been advocated. Despite these calls such a pro-active approach is hardly adopted by water managers and policy makers. One of the main reasons for this slow adoption is the lack of appropriate tools.

To be prepared for the paradigm shift, from a re-active towards a pro-active approach, Integrated Water Management Support Methodologies (IWMSM) are needed that go beyond the traditional operational support tools. Note that these IWMSM are more than only tools, but include conceptual issues, theories, combining technical and socio-economic aspects. To demonstrate and promote this new way of thinking the WatManSup project (Water Management Support Tools) has been initiated. The IWMSM approach comprises three different components: a water allocation component, a physical based component and a decision support component. This report demonstrates how the physical based component can be developed for one of the study areas included in the WatManSup project: Gediz Basin in Turkey.

The overall objective of this report is to demonstrate in which way the physical based component of IWMSM, the SWAT tool, can be used to support water managers and policy makers in a setting where irrigation is the dominant user of allocated water.

2 Methods and study area

2.1 SWAT model

SWAT is the acronym for Soil and Water Assessment Tool, a river basin model developed originally by the USDA Agricultural Research Service (ARS) and Texas A&M University, that is currently one of the worlds leading spatially distributed hydrological models. SWAT has been used extensively by FutureWater in various places and important modifications, improvements and extensions have been developed.

A distributed rainfall-runoff model – such as SWAT – divides a catchment into smaller discrete calculation units for which the spatial variation of the major physical properties are limited, and hydrological processes can be treated as being homogeneous. The total catchment behaviour is a net result of manifold small sub-basins. The soil map and land cover map within sub-basin boundaries are used to generate unique combinations, and each combination will be considered as a homogeneous physical property, i.e. Hydrological Response Unit (HRU). The water balance for HRUs is computed on a daily time step. Hence, SWAT will subdivide the river basin into units that have similar characteristics in soil and land cover and that are located in the same sub-basin.

Irrigation in SWAT can be scheduled by the user or automatically determined by the model depending on a set of criteria. In addition to specifying the timing and application amount, the source of irrigation water must be specified, which can be: canal water, reservoir, shallow aquifer, deep aquifer, or a source outside the basin.

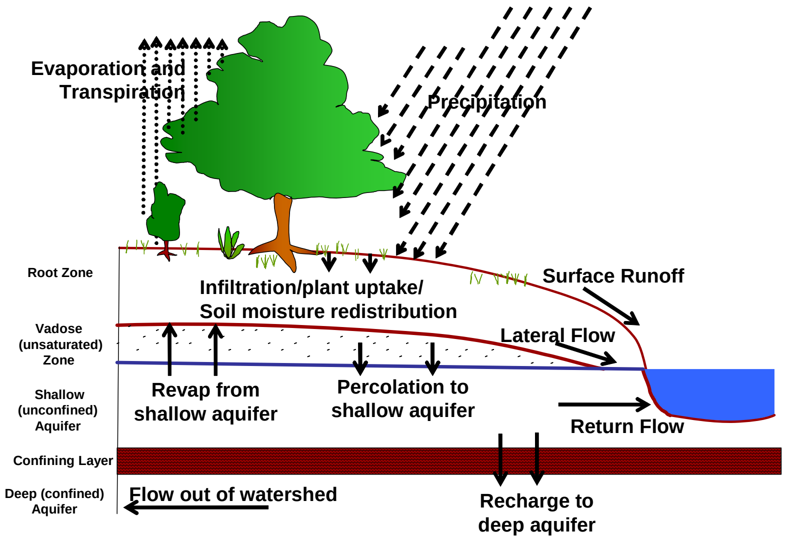

Figure 1. Main land phase processes as implemented within SWAT.

SWAT can deal with standard groundwater processes (Figure 1). Water enters groundwater storage primarily by infiltration/percolation, although recharge by seepage from surface water bodies is also included. Water leaves groundwater storage primarily by discharge into rivers or lakes, but it is also possible for water to move upward from the water table into the capillary fringe, i.e. capillary rise. As mentioned before, water can also be extracted by mankind for irrigation purposes. SWAT distinguishes recharge and discharge zones.

Recharge to unconfined aquifers occurs via percolation of excessively wet root zones. Recharge to confined aquifers by percolation from the surface occurs only at the upstream end of the confined aquifer, where the geologic formation containing the aquifer is exposed at the earth's surface, flow is not confined, and a water table is present. Irrigation and link canals can be connected to the groundwater system; this can be an effluent as well as an influent stream.

After water is infiltrated into the soil, it can basically leave the ground again as lateral flow from the upper soil layer – which mimics a 2D flow domain in the unsaturated zone – or as return flow that leaves the shallow aquifer and drains into a nearby river (Figure 2). The remaining part of the soil moisture can feed into the deep aquifer, from which it can be pumped back. The total return flow thus consists of surface runoff, lateral outflow from root zone and aquifer drainage to river.

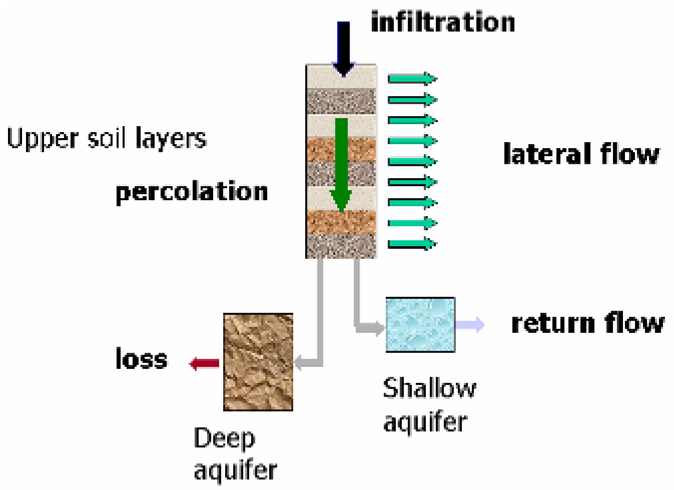

Figure 2. Schematic diagram of the sub-surface water fluxes.

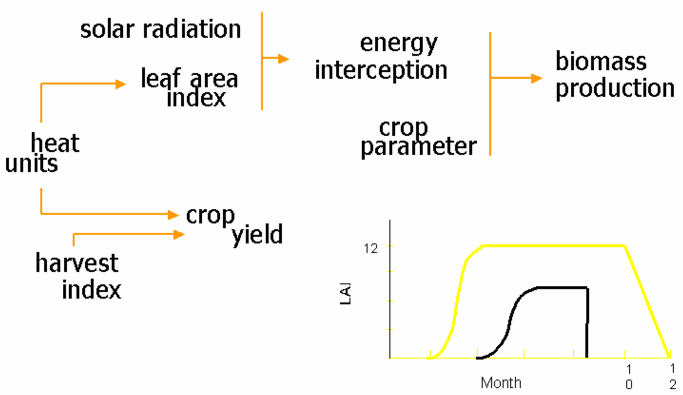

Figure 3. Parameterisation of crop production.

For each day of simulation, potential plant growth, i.e. plant growth under ideal growing conditions is calculated. Ideal growing conditions consist of adequate water and nutrient supply and a favourable climate. First, the Absorbed Photosynthetical Radiation (APAR) is computed from intercepted solar radiation, followed by a Light Use Efficiency (LUE) that in SWAT is essentially a function of carbon dioxide concentrations and vapour pressure deficits. The crop yield is computed as the harvestable fraction of the accumulated biomass production across the growing season (Figure 3).

Details of the SWAT model can be found at various background material (e.g. Neitsch, 2002a; Neitsch, 2002b). Examples of practical application can be found elsewhere (SWAT, 2007; FutureWater, 2007).

2.2 Gediz Basin, Turkey

Gediz Basin is located in the western part of Turkey, just north of Izmir. Gediz river flows from east to west into the Aegean Sea, is about 275 km long and drains an area of 17,200 km^2 (DSI, 2006). In Gediz Basin water scarcity is a significant problem due to competition for water among various uses (water allocation problems). Most conflicts arise between irrigation with a total command area of 110,000 ha, and the domestic and (fast growing) industrial demand in the coastal zone. Another problem is environmental pollution. The basin experiences droughts from time to time. Water use in the 90,000 ha irrigated agriculture of the central and delta zones is limited to 75 m^3 s^{-1} from Demirköprü reservoir and 15 m^3 s^{-1} from Göl Marmara for a release period of approximately 60 days, or a total of some 550 million cubic meters (MCM) during the year. This is equivalent to some 450 mm of irrigation water for the growing season. There are serious institutional, legal, social and economic drawbacks, which enhance water allocation and environmental pollution problems. In this study we focus on the physical processes included in SWAT to deal with water demand as well as supply in all areas and land covers in the basin.

More details about Gediz Basin and its challenges can be found in various other publications (SMART, 2007; Kite and Droogers, 1999; THAEM, 1999; WatManSup, 2007)

Figure 4: Location of Gediz Basin in Turkey.

3 Setting-up SWAT

3.1 Watershed delineation

First step required to build a SWAT model is defining the elevation related properties such as: elevation above sea level, slope, aspect, stream flow network, and distance to nearest stream, and dividing the basin in sub-catchments. The HYDRO1K (USGS, 2006) dataset was used for this and a clipped portion for Western Turkey is shown in Figure 5.

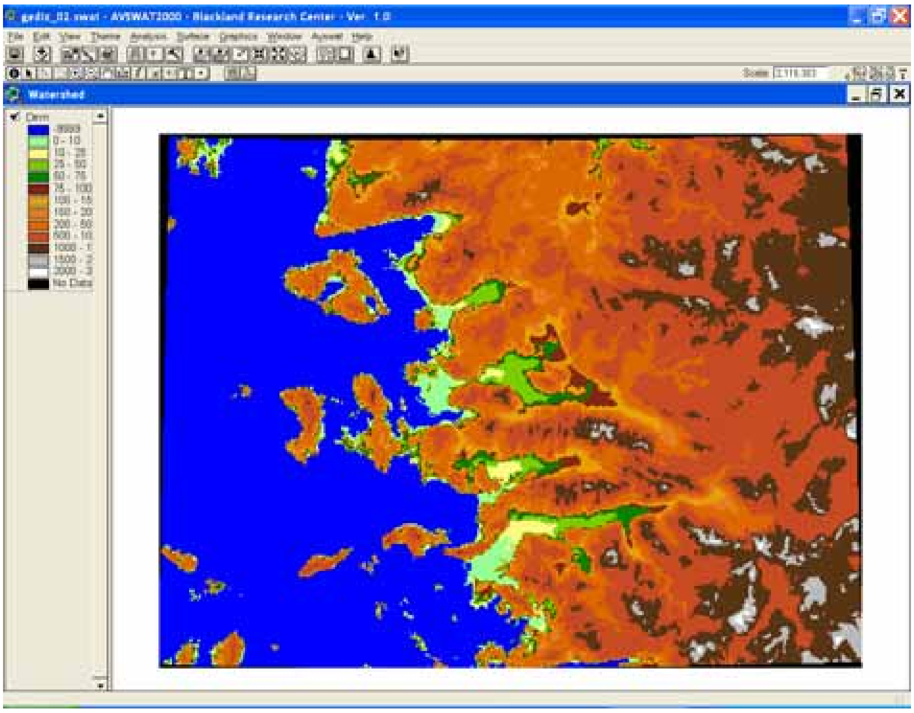

Figure 5. Elevation data for Western Turkey based on HYDRO1K.

Within SWAT one can define the number of sub-catchment to be included in the study, based on a minimum area of each sub-catchment. There is no optimal number of sub-catchments as it depends on the question to be answered, as well as time, resources and data availability. Given the nature of this demonstration case, an appropriate threshold value is somewhere between 10,000 and 50,000 ha. A lower value provided too much detail in the flat areas, while a higher value resulted in sub-catchments that were too large in the mountainous areas. Optimal sizes of sub-catchments were obtained by using a threshold value of 50,000 ha and manually adding more details in the mountainous areas, resulting in 49 sub-catchments. The final layout can be seen in Figure 6.

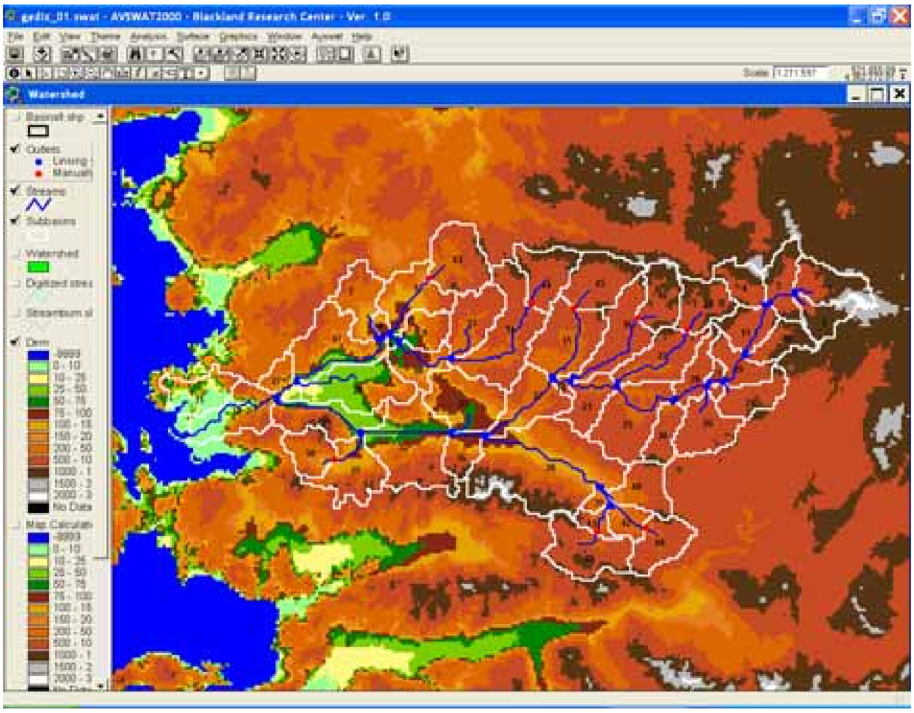

Figure 6. Final layout of streams and sub-catchments.

3.2 Land use

The type of vegetation determines many components of the hydrological cycle: total water requirement, irrigation demand, actual water consumption by evapotranspiration, surface runoff, percolation, and erosion. SWAT includes a detailed crop growth module which is based on the EPIC crop model (Williams et al., 1984). SWAT uses EPIC concepts of phenological crop development based on daily accumulated heat units, harvest index for partitioning grain yield, Monteith's approach (Monteith, 1977) for potential biomass, and water and temperature stress adjustments.

The number of vegetation types and crops that can be included in SWAT is virtually unlimited. For practical reasons it is important that the level of detail is in correspondence with the question to be answered during the modelling. Since the objective of this study is demonstration oriented, it was decided to use a simplified land cover map including seven classes. This land cover map was prepared using NOAA satellite information, a unsupervised classification method, combined with post-classification field verification. Details of this approach can be found elsewhere (Droogers et al., 1999).

The classes of the original land cover map were translated to standard SWAT classes (Table 1 and Figure 7).

Table 1. Land cover classes included in the model.

Land cover	Internal code	SWAT classes
Other	0	FRST
Water bodies	1	WATR
Maki	2	FRST
Coniferous	3	FRSE
Non-irrigated	4	AGRL
Irrigated	5	AGRI
Barren	6	RNGE
Shrubland	7	RNGB

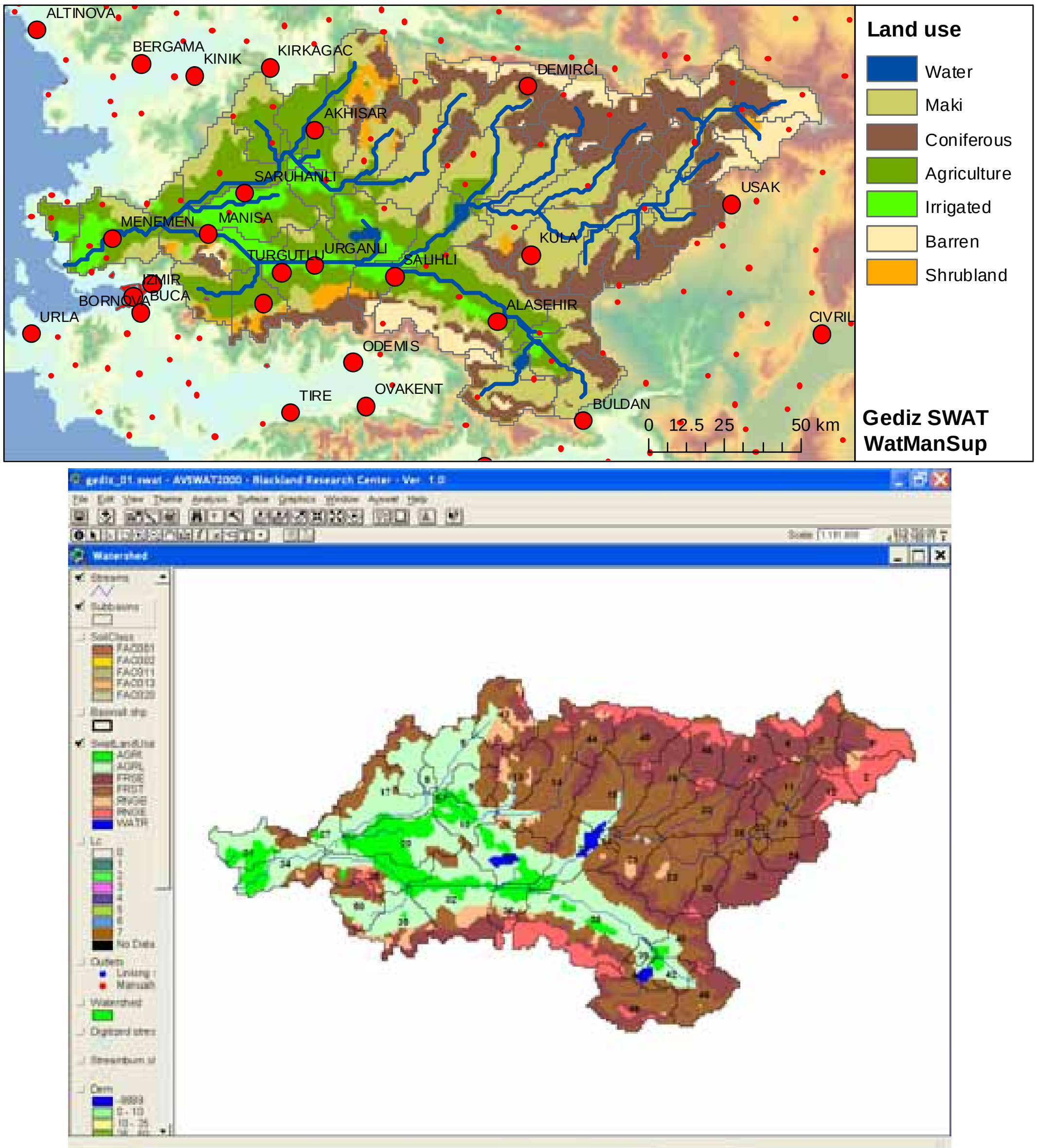

Figure 7. Land cover data (top original, bottom translated to SWAT classes).

3.3 Soils

Soils are the determining factors for hydrological processes such as: surface runoff, infiltration, percolation, lateral subsurface flow, plant water availability, etc. Since no detailed soil map was readily accessible for Gediz Basin, the FAO Soils of the World (FAO, 2000) data were used. The FAO dataset includes only qualitative descriptions, while for SWAT quantitative soil physical characteristics are required. For this demonstration case a simple transfer was used based on previous experiences with SWAT (Kauffman and Droogers, 2007; Immerzeel and Droogers, 2007; Van Loon and Droogers, 2007). The final soil data set included five classes and is shown in Figure 8.

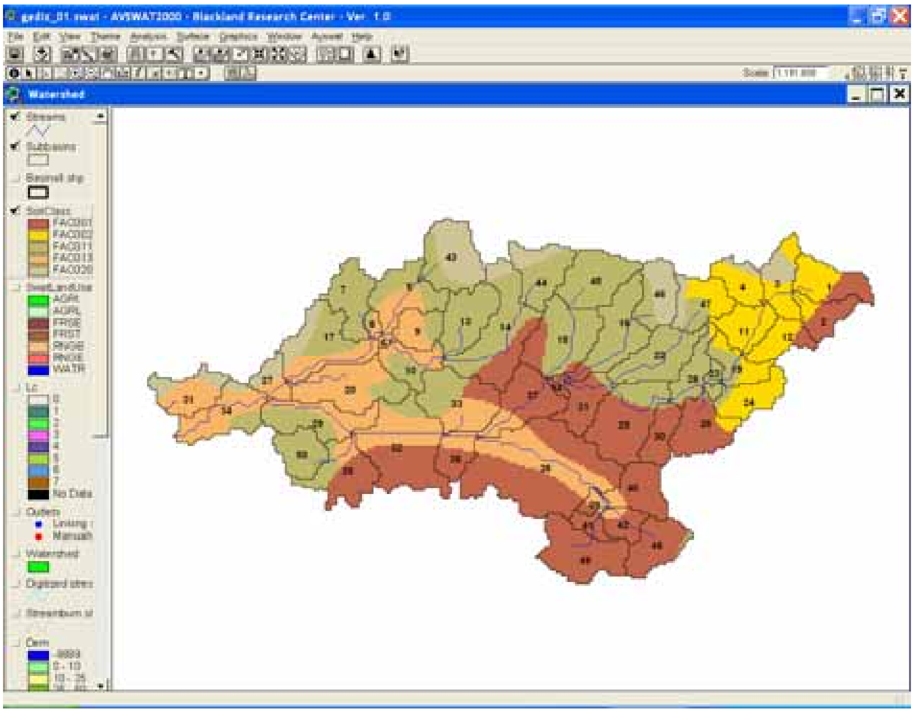

Figure 8. Distribution of the five soil classes included in the SWAT model for Gediz Basin.

3.4 Hydrological Response Units

A specific characteristic of the SWAT model is the subdivision of the study area in so-called Hydrological Response Units (HRUs). These HRUs form unique combinations of a specific soil type and land cover type within a sub-catchment. One can specify the number of HRUs required in a sub-catchment based on a threshold value, which is the area percentage of land cover and soils in a sub-catchment that can be neglected. Smaller threshold values will result in more detail. Given the nature of this demonstration case and the importance of land cover a threshold value of 5% was used for land cover and 20% for soils. Using these threshold values a total of 255 HRUs was distinguished in the basin (Figure 9).

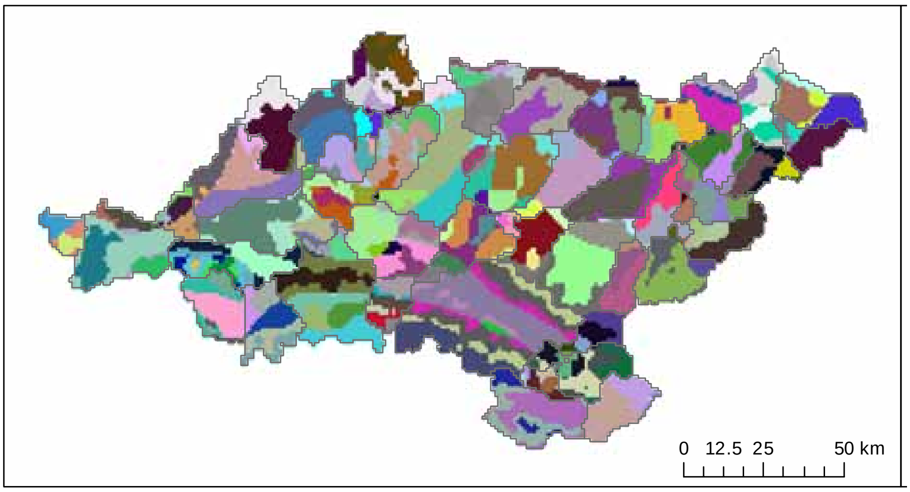

Figure 9. Hydrological Response Units (HRUs) distinguished in the Basin.

3.5 *Irrigation and Reservoirs*

SWAT includes a module for auto-irrigation where the source of water should be specified. A total of five different sources can be specified: canal water, reservoir, shallow aquifer, deep aquifer, or a source outside the basin. In the current model three reservoirs have been included: Göl Marmara, Demirköprü and the combined Afsar and Buldan as one representative reservoir. Most large irrigation schemes receive water from these reservoirs, while some upstream irrigation fields are considered to receive water from groundwater.

4 Calibration

A full calibration was not performed as the objectives of this study were to demonstrate the opportunities SWAT offers to evaluate water resources in the basin and to assist water managers and decision makers in their responsibilities. However, land cover is one of the dominant features characterising the hydrological behaviour of an area. Moreover, the standard land cover characteristics included in SWAT are all based on conditions in USA and are therefore not necessarily valid for Turkey. Therefore, a basic calibration based on expert knowledge was performed on land cover.

Figure 10 shows the input screen in SWAT where part of the growing characteristics of a vegetation type or crop are determined. In the calibration process these parameters can be adjusted. As an example of the calibration procedure followed, Figure 11 shows four steps taken during calibration of one specific crop type. The example shows the land cover type Agriculture Generic for one specific soil type, in one specific sub-catchment. By varying the total Heat Units required to harvest between 1500 and 3000, and simultaneously changing the fractions to reach the first growing point (FRGRW1) and the last growing point (FRGRW2) a more realistic growing pattern was obtained. In Figure 11 the following parameter values were used:

- A: Heat Units: 1500; FRGRW1: 0.15; FRGRW2: 1.20
- B: Heat Units: 2000; FRGRW1: 0.15; FRGRW2: 1.20
- C: Heat Units: 2500; FRGRW1: 0.15; FRGRW2: 1.20
- D: Heat Units: 3000; FRGRW1: 0.10; FRGRW2: 1.00

As a second example, the calibration of a permanent vegetation type (mixed forest) is presented in Figure 12. Here, the total Heat Units were changed from 3000 to 3500 to lengthen the growing season to obtain a more realistic LAI (Leaf Area Index) graph for the case in Gediz. Note that this mixed forest has year-round green vegetation, with some enhanced green development during spring and leaf senescence during autumn.

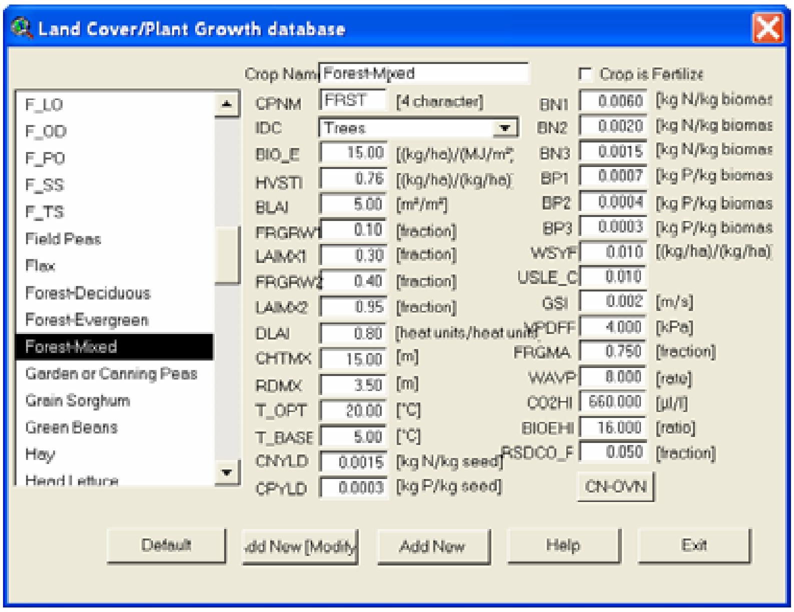

Figure 10. Example input screen for crop characteristics in SWAT.

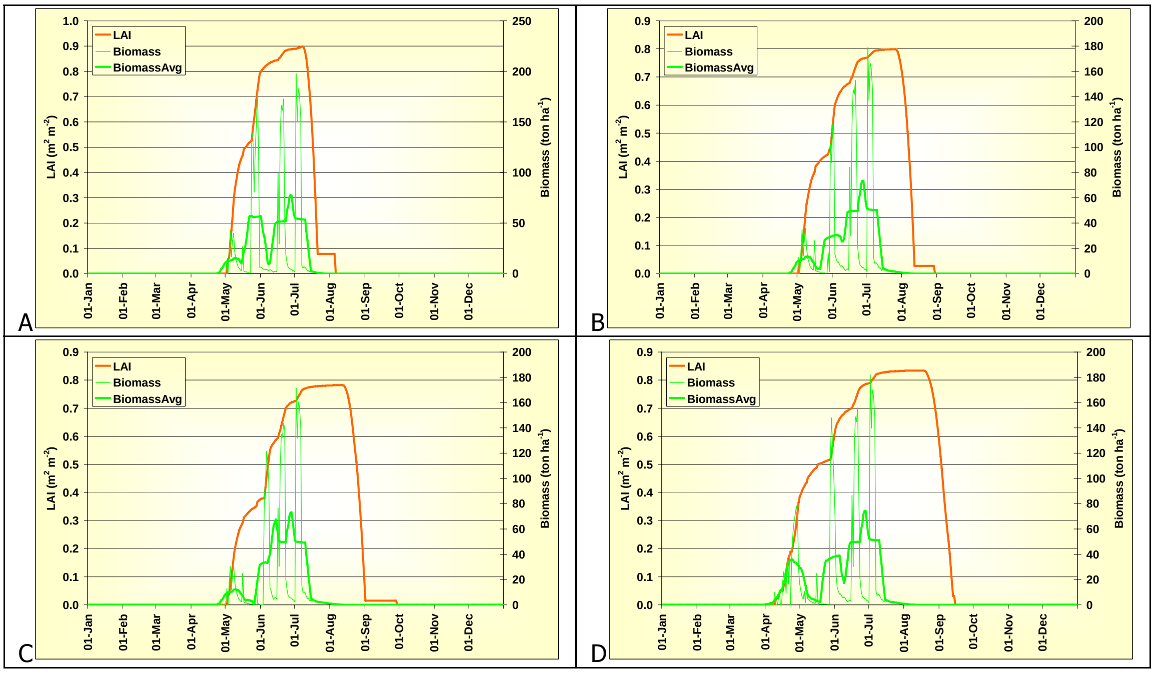

Figure 11. Calibration for HRU 80 (AGRL, FAO3139) for 1992. Red line is simulated Leaf Area Index and green line is simulated biomass.

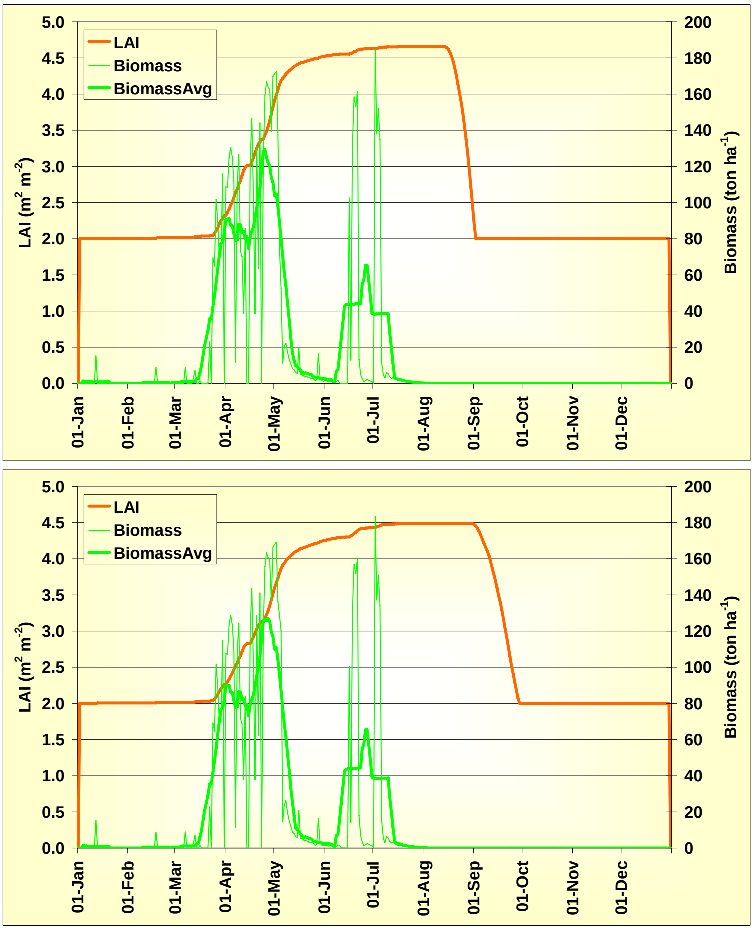

Figure 12. Refinement of crop growth for mixed forest (HRU 63, FRST, FAO3114) with Scheduled by Date 1 Jan - 31 Dec. Total Heat Units 3000 (top) and 3500 (bottom).

5 Results

5.1 Output generation

The model as developed for Gediz Basin and described in the previous sections is used to demonstrate the types of output that can be generated by SWAT. As emphasised earlier, the objective of the project was to demonstrate the opportunities SWAT offers to support decision makers and water managers, rather than to develop a complete calibrated model for the basin. Results presented here therefore do not reflect actual conditions.

Figure 13 provides an example of the option to analyse output using the AVSWAT interface. Tables, graphs and maps are generated and can be customised to a certain extent. One of the missing aspects in the AVSWAT interface is however that output can be generated only at the level of sub-catchments, in stead of at the much more relevant HRU level. Especially in areas like Gediz, where relatively large spatial differences exist, important details cannot be displayed and evaluated in the standard AVSWAT interface. A typical example of this is crop production and actual evapotranspiration differences between irrigated and non-irrigated crops. To overcome these problems a GIS tool was developed to evaluate output at HRU level (Immerzeel and Droogers, 2007).

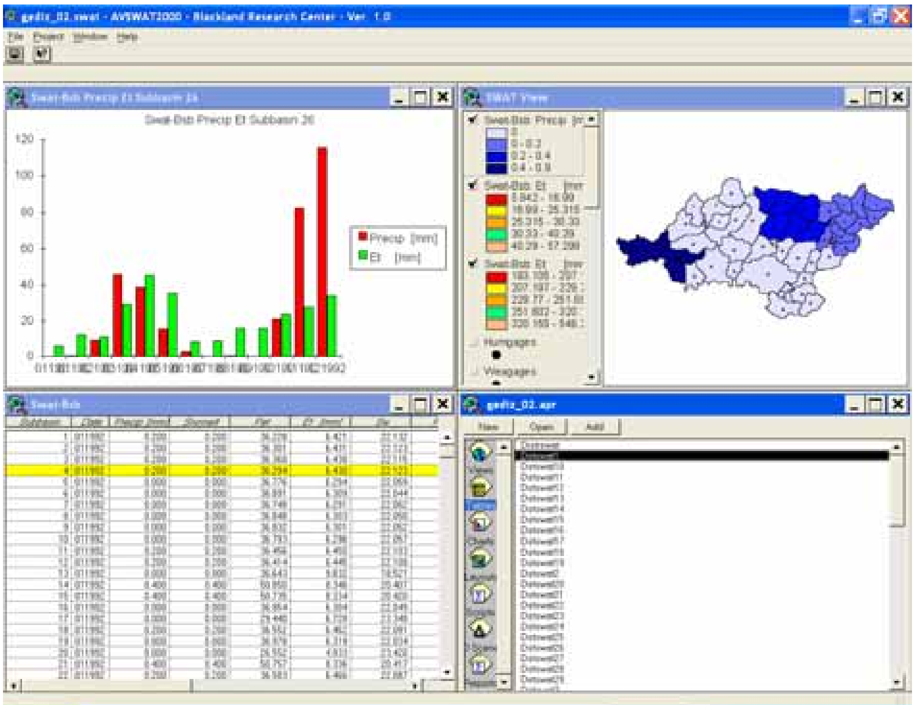

Figure 13. Example of output evaluation in the AVSWAT interface.

Output generated by SWAT is huge and sometimes somewhat overwhelming. One can select to have output written per day, month or year. Moreover, output files include results for the entire basin, for each sub-catchment and for each HRU. In addition, stream flow is provided for each sub-catchment and details on reservoir inflow, outflow and storage are given as well. Crop growth output, such as

LAI, biomass production, water and nutrient stress, and erosion are generated. Finally, all kind of output related to water quality can be evaluated.

In general, three different types of output are being generated by the SWAT model: (i) stream flow in channels, (ii) detailed soil water balances, (iii) spatially distributed output. Of each of these output types typical examples will be presented hereafter.

5.2 *Stream flow*

SWAT generates stream flow for each point in the basin at daily, monthly and annual interval. This data can be plotted using the AVSWAT interface, or exported and plotted with other software packages. As an example, Table 2 shows the average annual stream flow at four locations in Gediz Basin. These flows are higher than observed ones (see Kite and Droogers, 1999), which can be explained by the lack of good quality input data. Moreover, detailed calibration can improve the stream flow results considerably. In this preliminary study such a calibration has not been performed yet (see Section 4).

SWAT offers detailed output to enable evaluation of water resources and improvement of model performance if required. As an example Figure 14 shows stream flow at a daily interval for three locations in Gediz, upstream, middle and downstream, indicating some high peak flows downstream. In reality, peak flows are rare in downstream parts of the basin as Demirköprü stores peak runoffs from upper parts of the basin. Further analysis (Figure 15) shows the daily inflows, outflows and storage of Demirköprü reservoir. In the current SWAT model the reservoir is always full during wintertime, causing severe downstream flooding from winter and spring rains, that top the emergency spillway of the reservoir.

Further analysis, as presented in following paragraphs, indicates that the obtained soil data were not correct: permeability was too low, resulting in low percolation rates and therefore high surface runoffs. Also, storage capacity of the shallow aquifer as represented in the current model seems lower than in reality. This also reduces the amount of water stored in the soil profile, resulting in too low actual evapotranspiration rates during summers. Model refinement and calibration should therefore be undertaken before the model can be applied to real problem solving in Gediz Basin.

Table 2. Stream flow at four locations in Gediz (see Figure 8). All data in $m^3\ s^{-1}$.

Sub-catchment Location	36 Gediz	37 Alasehir	26 Kumcay	33 Outflow
1992	12	2	10	18
1993	45	15	36	91
1994	39	11	27	77
1995	56	13	51	133
1996	45	12	33	97
Aver	39	11	32	83

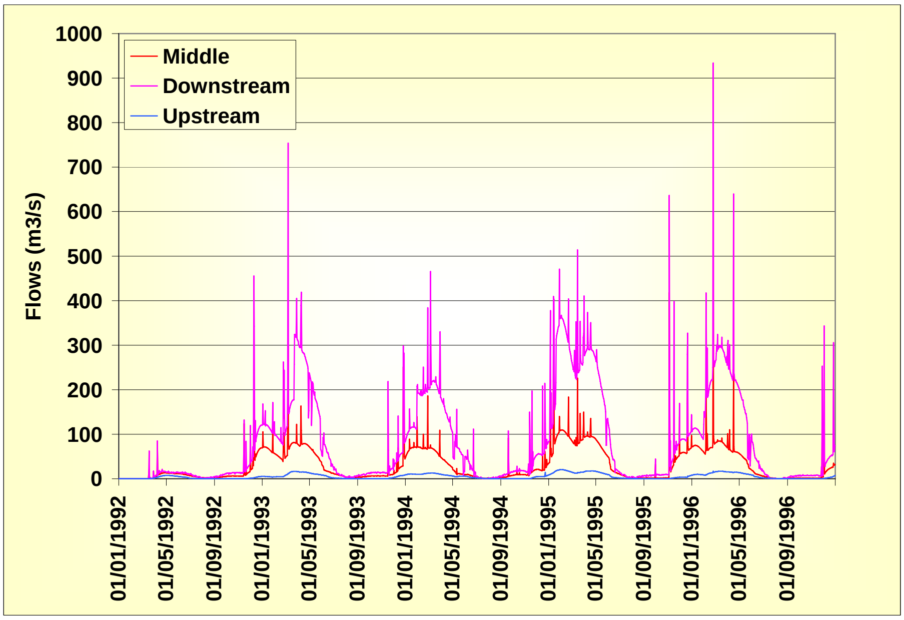

Figure 14. Daily stream flow for three locations in Gediz.

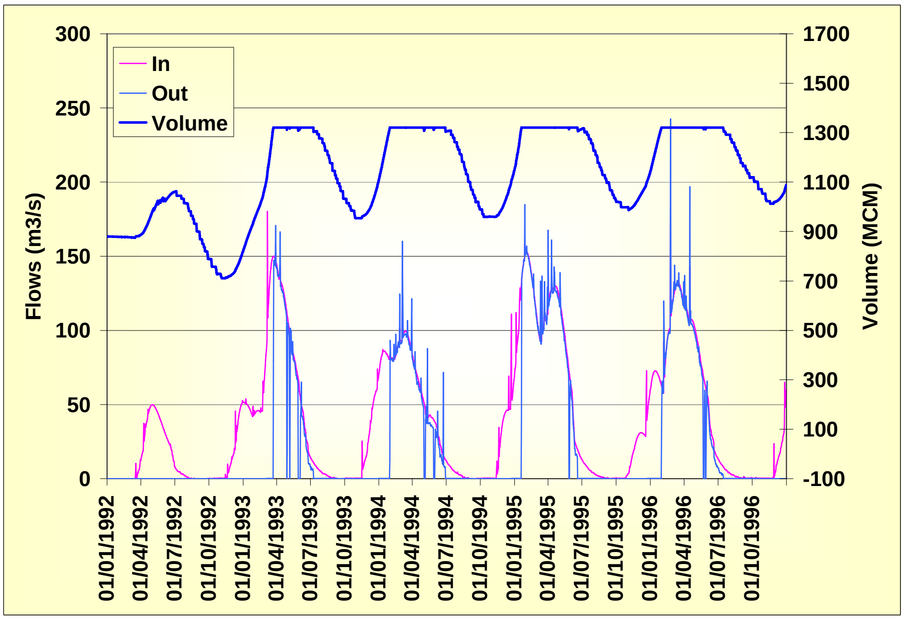

Figure 15. Daily stream flow and storage for Demirköprü reservoir (maximum storage = 1300 MCM).

5.3 Detailed soil water balances

Output per HRU is written to the so-called SBS file. File size can be enormous if output is written per day. For the Gediz case (255 HRUs, five years) a file of 300 MB is generated and special software has been developed during the project to extract specific information from the file. This software can be used to extract a particular HRU and/or a specific year, which can than be used by any plotting program.

As an example to demonstrate the opportunities SWAT offers to analyse processes in detail, Figure 16 shows daily potential and actual evapotranspiration (ET) for one HRU. It is clear that actual ET is lower than potential ET and that day-to-day variation can be quite substantial. Further analysis of the output generated by SWAT reveals that assumed soil moisture storage capacity was relatively low. Consequently, a few days after an irrigation application, water shortage was simulated by the model and irrigation water had to be supplied again. In reality, irrigation is applied with longer intervals providing a smoother graph.

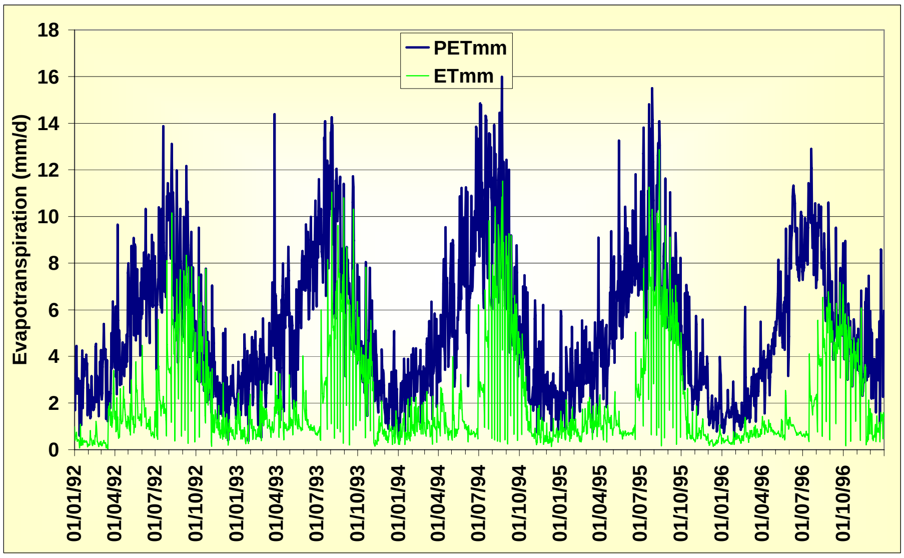

Figure 16. Potential and actual evapotranspiration for one HRU (Irrigated Agriculture, HRU 132).

SWAT simulates the complete water balance for each HRU, so all terms can be evaluated to better understand the system and to evaluate impact of scenarios. Figure 17 shows, for HRU 132, that the amount of irrigation supplied over five years was almost 4000 mm, so 800 mm per year. Rainfall over the same period was only half of this. The figure shows that most of this supply was used for evapotranspiration to sustain crop production. About 2000 mm, so 400 mm per year, percolated to the groundwater. Interesting is that most of this water is not stored in the groundwater but directly flows to the river by lateral groundwater runoff (GW_Qmm in Figure 17).

Figure 18 helps to better understand these processes by plotting storage of the three soil components included in SWAT: upper soil, shallow aquifer and deep aquifer. The figure reveals that the storage capacity of the shallow aquifer, as assumed in the model, is far too low. Model improvement should be undertaken by including better data on soils and aquifer systems.

From these analysis it is clear that SWAT offers a range of options to evaluate processes as simulated by the model. In fully validated and calibrated models simulated processes mimic reality and can be used for scenario analysis. Typical examples of such an approach were presented recently (Kauffman and Droogers, 2007).

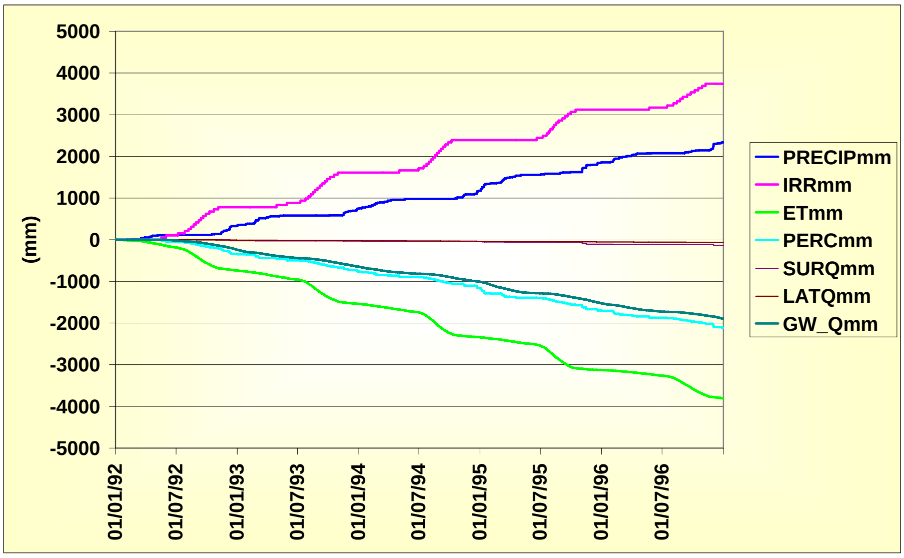

Figure 17. Cumulative daily water balance for one HRU (Irrigated Agriculture, HRU 132).

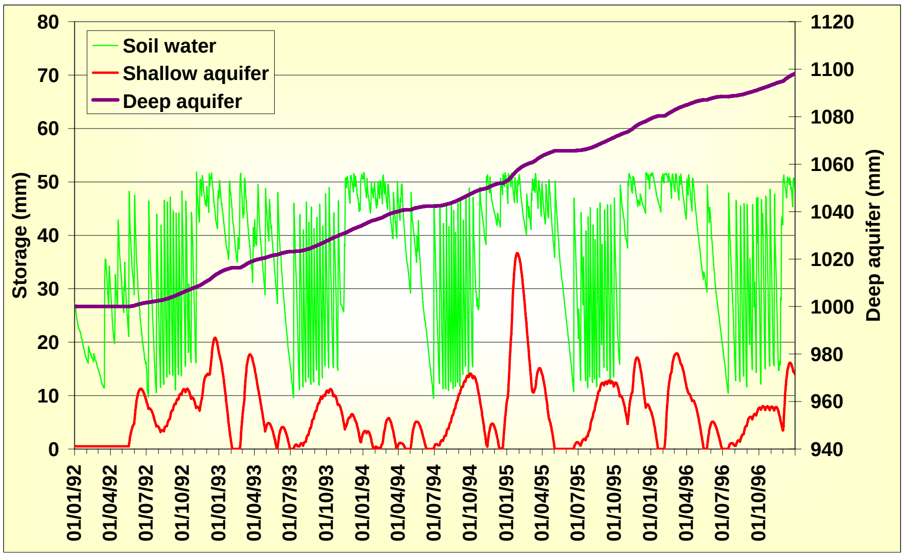

Figure 18. Storage in the three soil components (Irrigated Agriculture, HRU 132).

5.4 Spatially distributed results

One of the strongest point of SWAT, and the HRU plotting software developed by FutureWater, is that all terms of the water balance can be evaluated at high spatial resolution. A typical example is shown in Figure 19, presenting the spatial distribution in actual evapotranspiration. The Figure indicates that the ET of the natural vegetation is relatively low, which is most likely due to soil characteristics included in the model that are based on low quality data. Most likely permeability is lower than reality and storage capacity of the shallow aquifer is probably too small. Due to the low ET runoff to rivers and streams is very high and soil moisture storage is low. As indicated earlier, storage capacity of shallow aquifer systems as represented in the current model is probably also too low.

Water yield, defined as the amount of water contributing to stream flow, is plotted in Figure 20. This water yield is a composite of the following processes:

WYLD = SURQ + LATQ + GWQ – TLOSS

where WYLD is total water yield, SURQ is surface runoff, LATQ is lateral runoff, GWQ is groundwater runoff, and TLOSS is seepage losses in channels.

Interesting is that the irrigated areas (see Figure 7) dominantly contribute to the stream flow in Gediz river.

Based on data used to build the model, groundwater runoff is the dominant factor to water yield (see Figure 21 and Figure 22; note the different scale). Especially in the irrigated areas, groundwater runoff contributing to stream flow is high. In the current model setup, groundwater irrigation was only assumed for areas upstream, resulting in unrealistically high groundwater tables in the downstream irrigation areas. SWAT offers the opportunity to include this groundwater irrigation, which will result in a more realistic representation of reality.

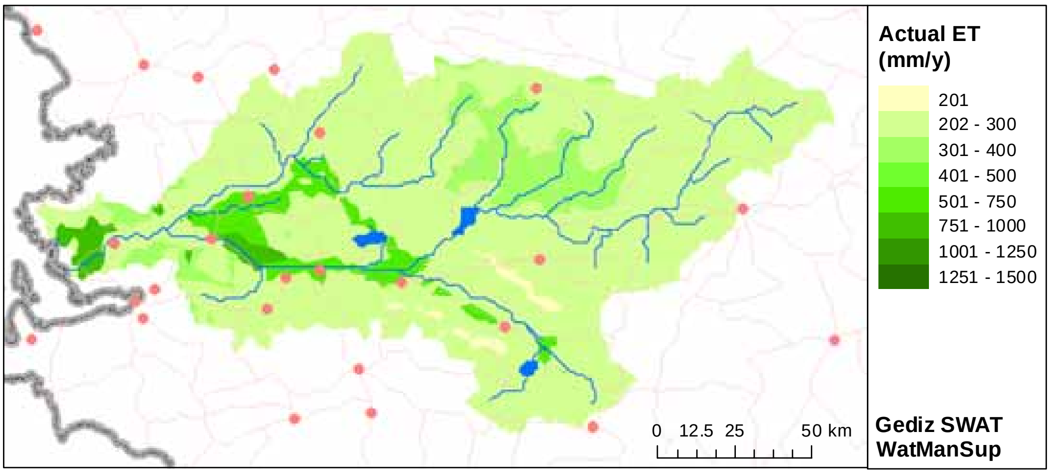

Figure 19. Actual evapotranspiration (ET) in 1993.

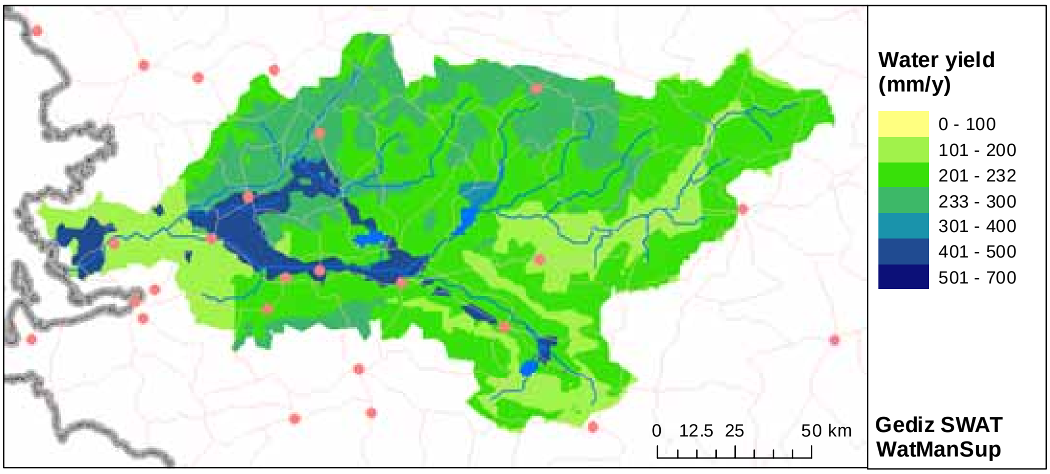

Figure 20. Water yield contributing to stream flow in 1993.

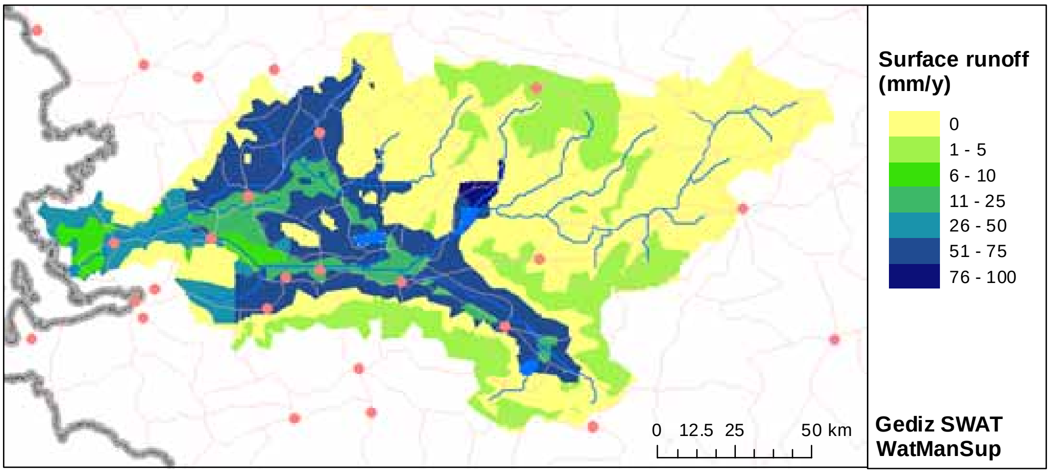

Figure 21. Surface runoff in 1993.

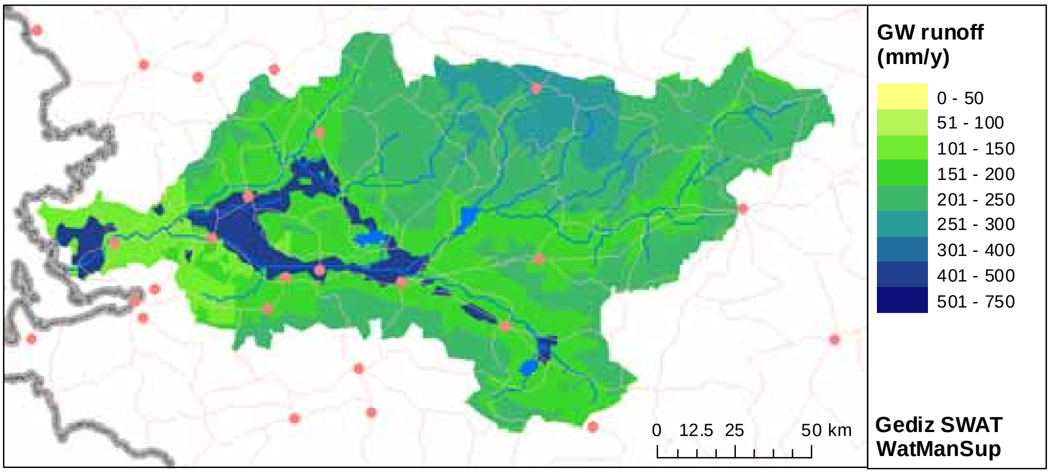

Figure 22. Groundwater runoff in 1993.

6 Conclusions

Water managers and decision makers are in need to have better tools and methods to support them. The project WatManSup was set up to demonstrate what options different tools, separately and combined, might offer. This report describes one of the components, the physical based one, for the demonstration case in Turkey. The tool used, SWAT, can be considered as state-of-the-art and has been used numerous times in other cases. SWAT has been developed further, refined and expanded by FutureWater during several modelling studies.

As indicated earlier, the model developed for Gediz Basin has not been fully calibrated and validated, and results should therefore only be considered as demonstration of the options SWAT offers to evaluate output. Examples on further model refinement and calibration can be found elsewhere (e.g. Kauffman and Droogers, 2007; Immerzeel and Droogers, 2007)

In summary the following conclusions can be drawn from the demonstration case in Gediz Basin:

- The strength of the physical component SWAT in Integrated Water Management Support Methodologies is that all physical processes are included in the model. All aspects of the hydrological cycle can be evaluated, including crop growth, irrigation, and water quality.
- The completeness of the tool makes it highly data demanding and somewhat complex. At the same time sufficient new technologies are developed and under development to overcome these data shortage problems. Remote sensing techniques, public domain data sources and improved calibration approaches are typical examples that can be applied nowadays.
- Results presented for the demonstration case of Gediz Basin reveal that more emphasis should be given to verification and calibration of the model. It is clear that characteristics of soils, especially storage capacity and permeability, are keys to improve the model. Data might be collected on these parameters, but at the same time calibration on stream flows and/or ET, estimated by remote sensing, can be used to update the model.
- The physical tool SWAT should only be used to support water managers and decision makers if their questions are related to physical processes. If problems are related to strategic planning of water allocation, the WEAP approach is preferred (see Van Loon et al., 2007). Typical examples of questions to be answered using SWAT are: impact and adaptation to climate change, improved evapotranspiration management including deficit irrigation, changes in land cover and/or crops, and contribution of rainfall to water resources.

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