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An Integrated Water Resources Management of Develi Closed Basin in Kayseri - Türkiye

Fatma Ebru YILDIZ [1♠], İbrahim GÜRER [2]

[1] *Department of Planning, Research and Highway, General Directorate of Bank of Provinces, Ankara,Turkey.*
[2] *Gazi University, Faculty of Engineering & Architecture, Department of Civil Engineering, Ankara, Turkey.*

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ABSTRACT

This study describes an integrated water budget model of Develi Closed Basin. Sultansazlığı Wetland, being as one of the seven important wetlands and the second important bird habitat of Türkiye, is placed in Develi Closed Basin. In the recent years, Sultansazlığı faced with water scarcity and salinity problems, there is an intensive irrigated agricultural practice around the wetland with abundant use of water due to wild flooding. In the content of this study; an integrated water budget of Develi Closed Basin was computed with a classical approach and also a dynamic water budget of the basin was simulated by STELLA® Educational Version 8.0. Groundwater budget, Sultansazlığı Wetland water budget and basin water budget calculations were modeled together in this integrated system.

Key Words: *Develi Closed Basin, Dynamic modeling, water resources management Sultansazlığı Wetland, STELLA®, water scarcity.*

1. INTRODUCTION

Develi is a closed sub-basin of Kızılırmak River Basin (Basin no:15), its average elevation varies between 1070-1150 m above mean sea level, total area of the plain is approximately 800 km^2 and its drainage area is 3190 km^2. Develi plain has an average slope of 2 %. Sultansazlığı Wetland in Develi Closed Basin, is surrounded by Erciyes Mountain (3916 m), Develi Mountain (2074 m), Aladağlar Mountain (3373 m) and Hodul Mountain (1937 m) at the north, east, south and west directions respectively [1]. There are Yay Lake, Çöl Lake, Northern and Southern marshlands in Sultansazlığı Wetland Region as shown in Figure 1. Çöl and Yay Lakes are shallow lakes; water level of Yay Lake is about 100 cm. This wetland area is in the boundaries of Kayseri City in Türkiye and its coordinates are 38^o.05 - 38^o.40 North, 35^o.00 - 35^o.35 East. Saultansazlığı is located at the center of Develi, Yeşilhisar and Yahyalı districts. There are water shortage and water pollution problems at Saultansazlığı Wetland Region. This wetland area is a conservation area, protected by International Ramsar Agreement since 1994.

In this study; water budget of the Develi Closed Basin is computed with a classical approach and water budget of the basin is modeled by STELLA® Educational Version 8.0. STELLA® is a dynamic modeling software package that can be used for the simulation of all scientific problems using mathematics.

♠Corresponding author, e-mail: februyildiz@yahoo.com, eyildiz@ilbank.gov.tr.

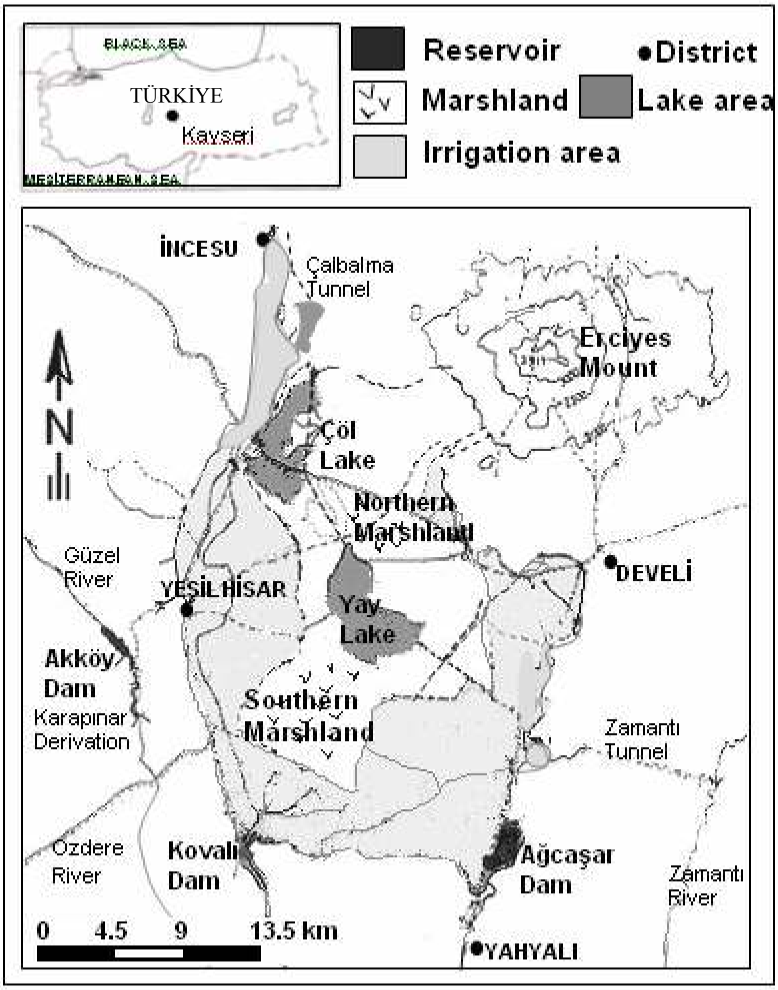

Figure 1. Develi Closed Basin and Sultansazlığı Wetland [2].

1.1. General Introduction of Stella Software

STELLA® is a dynamic modeling software package, produced by High Performance Systems and it operates under C^{++} code. STELLA® uses an artificial intelligence to read and analyze the model inputs. It is graphical modeling software, which can be operated in Macintosh & PC environment and also it is a user-friendly software. STELLA® has four basic tools; these are stocks, flows, converters and connecting arrows [3]. This software uses Runga Kutta or Euler's simulation methods, time step had to be selected to complete one simulation cycle by the user. STELLA® can be used for the qualitative and quantitative modeling; it can be used at all science branches using mathematics such as engineering, biology, pharmacology, physics, chemistry etc. Main STELLA® tools are shown in Figure 2.

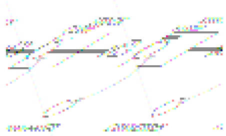

Figure 2. Basic Stella tools [3].

1.2. Stella Software Use in Water Resources Planning

A detailed literature survey was made about water resources modeling by using STELLA® software. Schallenberg [4] defines a STELLA® model for the dynamic water budget analysis of the tidal Waipai-Waihola lakes and wetland complex in New Zealand. McKelvey [5] presents STELLA® model about Mississippi and Missouri River floods of 1995. Musacchio and Grant [6] modeled rice agriculture management and wetland habitat quality simulation in a coastal prairie ecosystem in Texas, USA. Additionally water budget models using agricultural and industrial groundwater and surface water (from dam) consumptions can also be simulated by STELLA®.

2. CLASSICAL WATER BUDGET COMPUTATION OF SULTANSAZLIĞI

Conversion of mass and energy laws are valid for the hydrologic cycle; conversion of water mass is defined by the "continuity equation". Calculation of the all hydrologic cycle elements such as precipitation, runoff, infiltration and evaporation are called as "classical water budget". Main classical water budget calculations are based on the formula given below:

$$\sum X - \sum Y = \Delta S \quad (2.1)$$

where;

ΣX: Total inflow water volume, *ΣY*: Total outflow water volume, *ΔS*: volume variation in time Figure 3 shows the conceptual model, defining the interrelation among the water components of surface and subsurface water of the Develi Closed Basin. According to this conceptual model; Sultansazlığı Wetland is fed by the precipitation (rainfall and snow) and the irrigation return flow.

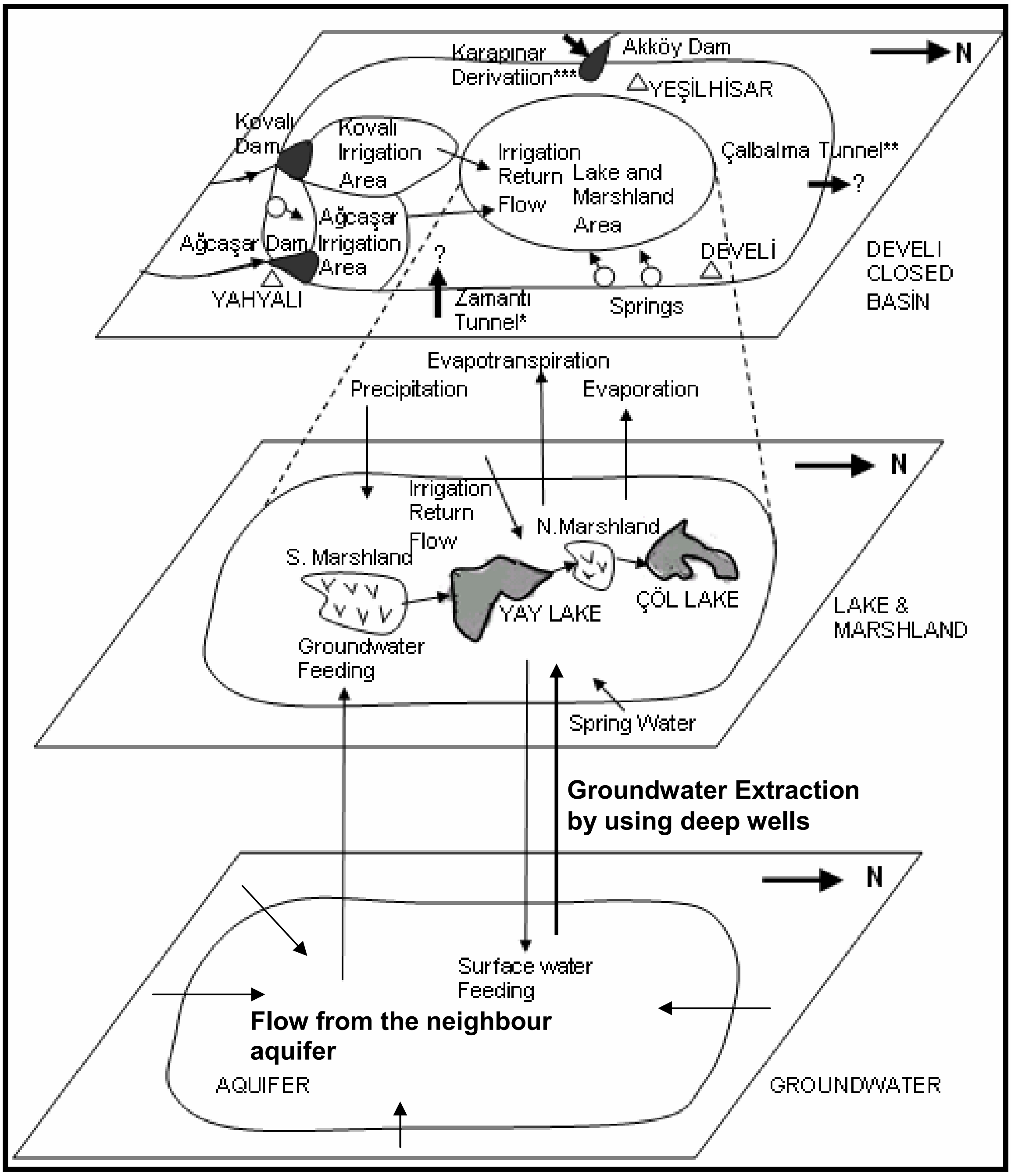

Figure 3. The conceptual model showing the interrelation among the water components of surface and subsurface water. *Zamantı Tunnel is under construction, there is no inflow yet, ** There is no excess water in the basin so there is no outflow from Çalbalma Tunnel,***There is no inflow from Karapınar Derivation Tunnel (modified from [7], [8] and [9]).

2.1. Surface Water Budget of Develi Closed Basin

Northern and Southern Marshlands, Yay Lake and Çöl Lake are entirely dry during the irrigation period because there is no required water to feed the reedfield. Additionally the evaporation and the evapotranspiration from the reedfield area are very high. The most damaging activity has been the intensification of irrigated agriculture during the last 20 years. Intensification of irrigated agriculture has caused the drainage of valuable wetland habitat, overexploitation of surface and groundwater resources together with water pollution due to the use of high levels of fertilizer and pesticide [10]. Water shortage problem of Sultansazlığı Wetland can be seen in Figure 4. Two photographs were taken during the field investigations in 2003. There is water only on April, May and June in the marshlands and the lakes. After the beginning of irrigation season; water shortage problem occurs at Sultansazlığı Wetland till the next spring. Figure 5 shows the strain gage measurements at the Southern Marshland.

Figure 4. Gage at Southern Marshland in Sultansazlığı Wetland [7].

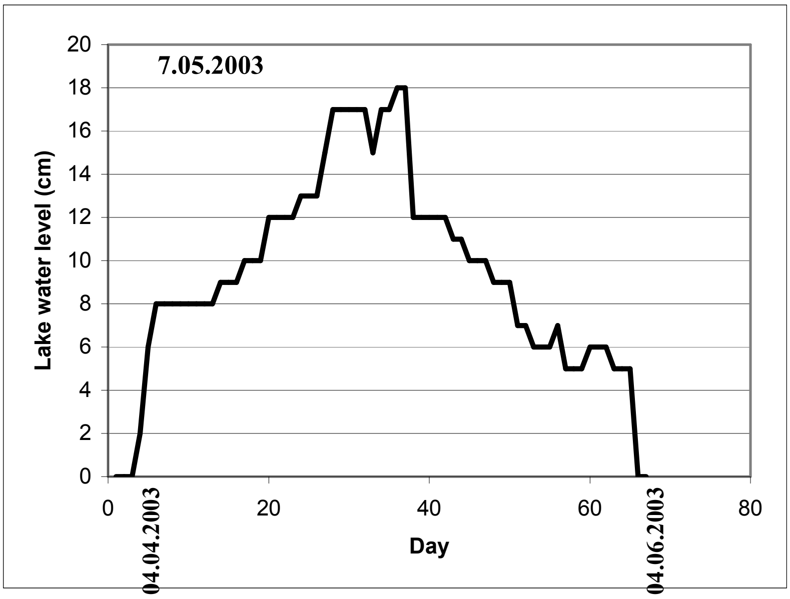

Figure 5. Water level variation at Southern Marshland in Sultansazlığı Wetland [7].

According to the isotope and water chemistry analysis, geomorphological and geophysical studies, it is determined that there is no relationship between the surface water of Sultansazlığı and the groundwater so the groundwater recharge to the wetland and the infiltration of the surface water of Sultansazlığı are eliminated at the classical water budget computations and Stella model [9].

Total irrigation area is very large in Develi Closed Basin, there are three dams for the irrigation purpose but irrigation water volume of these dams is not sufficient so many deep wells had been drilled to use groundwater for irrigation in. So there are many legally and illegally opened deep wells in Develi Closed Basin. The total number of deep wells in Develi Closed Basin is unknown but total number of deep wells is estimated in the model, according to the information taken from the local authorities. There are many springs in Develi Closed Basin, some of them are feeding dams but other springs can only feed Sultansazlığı during winter because they are being used as an irrigation water during irrigation period.

Evapotranspiration from farmlands is calculated by using Blaney Criddle Method and the total irrigation water requirement is found as 400×10^6 m^3/year. But total annual irrigation water use is below 400×10^6 m^3/year due to the restricted irrigation. During the field investigation it is learned that; 38×10^6 m^3/year irrigation water is used from Ağcasar Dam, 26×10^6 m^3/year irrigation water is used from Kovalı Dam and 4×10^6 m^3/year irrigation water is used from Akköy Dam. According to DSI report [11] 15 % of total irrigation water is feeding Sultansazlığı as drainage water but during field investigations it is observed that drainage water is being used by the farmers as an irrigation water. So it is assumed that 10 % of total irrigation water is feeding Sultansazlığı as drainage water. According to Akçakaya, Barış and Bilgin [12], *Phragmites* is the main reedfield plant in Sultansazlığı Wetland. Penman-Monteith Method is used in order to estimate the annual average evapotranspiration from *Phragmites* at Sultansazlığı reedfield area and annual average evapotranspiration from *Phragmites* is estimated as 1500 mm. The total reedfield area which is covered by *Phragmites* at the Southern and Northern Marshland is approximately 60 km^2 [13]. There are Class A evaporation pans at Ağcasar, Kovalı, Yenihayat (Yay Lake) and Musahacılı Stations which are being operated by Turkish Hydraulic Works. But Class A evaporation pan correction coefficient is not known. In order to estimate pan coefficient at Develi Closed Basin; first Penman Method is used to estimate the evaporation from free water surface of Sultansazlığı Wetland, then evaporation from free water surface values are divided by pan evaporation values and pan coefficient is estimated as 0.62. Yenihayat (Yay Lake) station is close to this wetland so pan evaporation data of this station is used. According to the evaporation data of Yenihayat (Yay Lake) meteorology station; the annual evaporation is 1447 mm from Class A Pan which is filled by salty wetland water. It is determined that free water surface area of Sultansazlığı Wetland is 55.5 km^2 and total water volume of Sultansazlığı Wetland is 18×10^6 m^3 for 1071 m water elevation by using "Volume-Elevation-Area Curves" [14]. Table 1 shows the surface water budget only for Sultansazlığı Wetland (reedfield area and Yay Lake). Since Çöl Lake is entirely dry; there is a thick mud cover at Çöl Lake area, so this lake is disregarded in water budget calculations. There is no direct relationship between the groundwater and wetland water so infiltration parameter is neglected at the wetland water budget calculations. Evaporation from free water surface and evapotranspiration from reedfield area which is covered by *Phragmites,* are very high so there will be a continuous need of water at Sultansazlığı Wetland as shown at Table 1. (-) sign shows the water shortage.

Table 1. Water storage in Sultansazlığı Wetland [9]

Annual Prepicitation P_{av} (mm)	**330**	**345**	**363**	**390**
Direct Precipitation over free water surface($\times10^6$)m^3 /year	18.315	19.148	20.146	21.645
Evaporation from free water surface ($\times10^6$) m^3 /year	49.791	49.791	49.791	49.791
Evapotranspiration from reedfield ($\times10^6$) m^3 /year	90	90	90	90
Drainage water feeding the wetland ($\times10^6$)m^3/year	40	40	40	40
Water storage in the wetland ($\times10^6$)m^3/year	-81.476	-80.643	-79.645	-78.146

2.2. Groundwater Recharge at Develi Closed Basin Aquifer

Maximum value of surface runoff discharge is :

$$Q = \frac{CiA}{3.6} \qquad (2.2)$$

where: Q: Runoff disharge (m^3/sec), C: Runoff coefficient (dimensionless)

A: Drainage area (km^2), i: Rainfall Intensity (mm/hr)

There is uncertainty about the runoff coefficient of Develi Closed Basin. Since Develi Closed Basin (3190 km^2) is a sub-basin of Kızılırmak Basin (78646 km^2) and the runoff coefficient of Kızılırmak Basin is 0.17 [15], the runoff coefficient C for Develi Closed Basin is also assumed to be 0.17, although there is a big difference in geomorphological parameters between Develi and Kızılırmak Basins. Drainage area of Develi Closed Basin except the drainage area of the reservoirs is A_d=2625 km^2 and the average annual precipitation depth is P_{av}=363 mm so the surface runoff is:

161.989×10^6 m^3 /year

There is no lysimeter in Develi Closed Basin, therefore the average infiltration index of the soil is not exactly known. According to the lithology of the basin, percentage volume of deep percolation into the aquifer is assumed as 15 % of the surface runoff [11] so the percolated water from surface runoff into the groundwater is;

$V_1=24.298\times10^6$ m^3 / year

The plain area of Develi is approximately 800 km^2. About 100 km^2 of this plain is lake and about 60% of the lake surface is covered by the reedfield. Additionally 150 km^2 of the plain is covered by the clay formation so it can be accepted that, the precipitation can only directly infiltrate into the aquifer in area of 550 km^2. 20% is assumed as direct infiltration ratio [11]. If the precipitation is P_{av}=363 mm; direct infiltration volume of the precipitation into the aquifer is:

$V_2=39.93\times10^6$ m^3 /year

There is also uncertainty in the real transmissibility values of the project area. It is accepted that at the eastern part of the basin, water is discharged from the tuff formations of the aquifer at Develi town, at the southern and the southwestern part of the basin; water is discharged from the Paleozoic limestone at Yahyalı town and at the western part of the basin; water is discharged from alluvial cone at Yeşilhisar town [11]. It is thought that at the northern side, there is no groundwater inflow from the Erciyes Mountain. According to the available DSI well logs [16], the average soil transmissibility values are computed as shown in the Table 2.

Table 2. Average transmissibility values according to each region [8], [9].

Region Name	T(m^2 /day)
Develi (East)	552
Yahyali (South)	2574
Southwest	1000
Yesilhisar (West)	1115

Darcy law states the inflow discharge as:

$$Q=G\times T\times i \quad (2.3)$$

Where; Q: Groundwater flow (m^3/day), i:Hydraulic gradient (m/m)

T: Transmissibility (m^2/day), G:Aquifer width (m)

The total volume of groundwater inflow V_3 can be computed by using the transmissibility values given in Table 2.

$$V_3= V_{EAST}+ V_{SOUTH}+ V_{SOUTHWEST}+ V_{WEST} \quad (2.4)$$

Hydraulic gradient of each aquifer is computed by using piezometric water level map and the total groundwater inflow volume is calculated as:

$V_3=90.582\times10^6$ m^3 / year

Total groundwater aquifer recharge volume: $\Sigma V= V_1+ V_2+ V_3$

For the annual precipitation depth as 363 mm;

$\Sigma V=154.810\times10^6$ m^3 /year. ΣV is shown in Table 3 for the four different annual precipitation depths.

Table 3. Total groundwater aquifer recharge volume [8], [9].

Annual Precipitation P_{av} (mm)	**330**	**345**	**363**	**390**
ΣV ($\times10^6$) m^3 / year	152.601	153.605	154.810	156.617

3. WATER BUDGET MODEL OF DEVELI CLOSED BASIN BY USING STELLA®

A deterministic model based on the water budget analysis of Develi Closed Basin was formulated by using STELLA® Educational Version 8.0. In this model there are two reservoirs (stock), these are aquifer and Sultansazlığı Wetland. Total annual spring water volume and total irrigation water volume are the other components of this simulation; these are converters in this STELLA® model. These converters are connected to the wetland and the aquifer stocks. Modeling level of this simulation can be seen in Figure 6. Total discharge of springs which are not feeding the dams is 2.6 m^3/s. During field investigation; it is learned that 3% of spring water is being used for irrigation (2.5×10^6 m^3/year). It is assumed that 27% of annual spring water volume is feeding Sultansazlığı, 30% of annual spring water volume is infiltrating to the aquifer and 40% of annual spring water volume is evaporating in STELLA model.

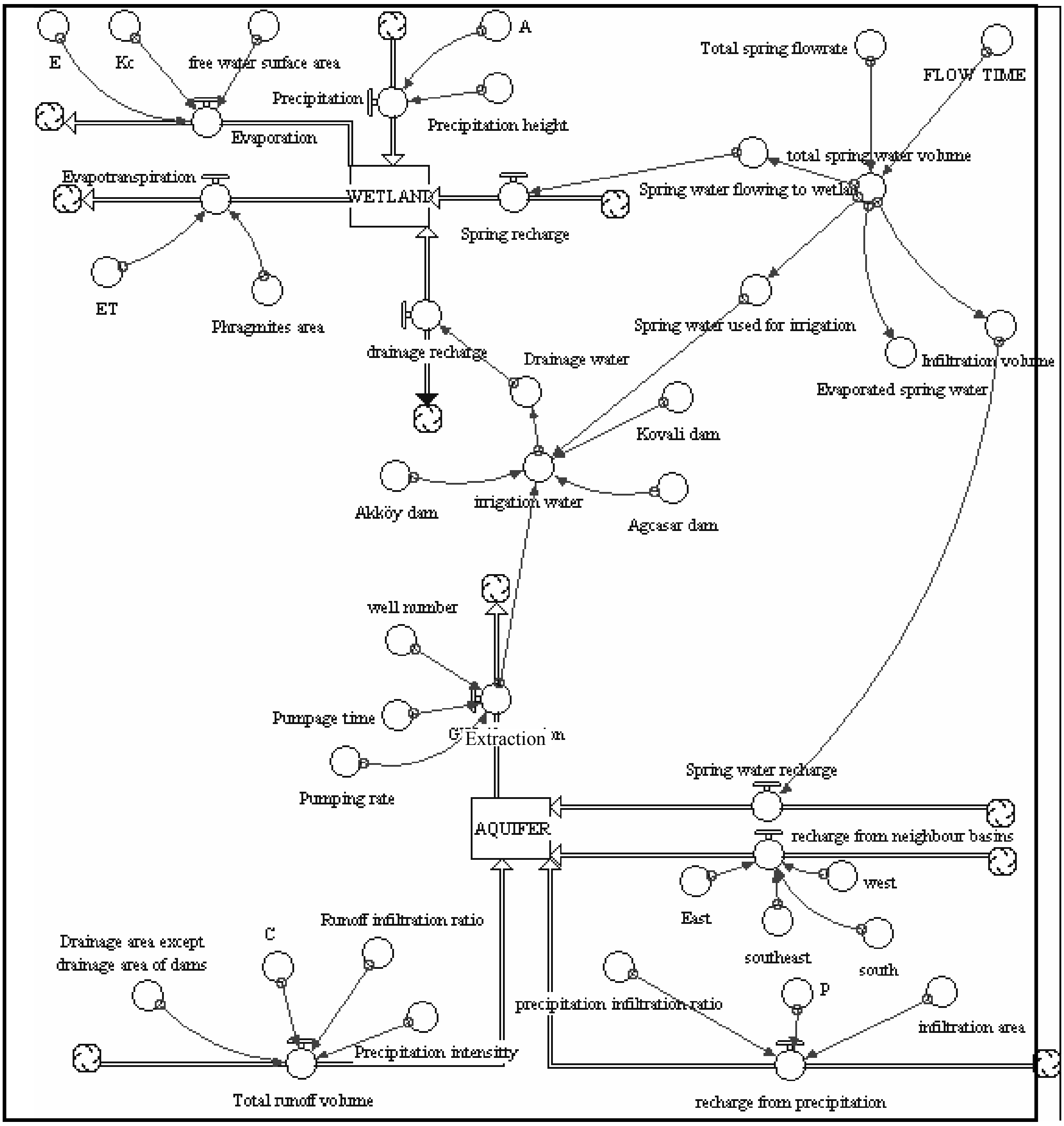

Figure 6. STELLA® Model for the integrated water budget of Develi Closed Basin.

Data used in this STELLA® model had been collected during the field investigations in 2003-2005 at Develi Closed Basin. Total simulation time is one year and the time step (increment) of the model is 0.25 year. In order to obtain the variation of the water volume in Sultansazlığı Wetland and the aquifer stocks Runga Kutta 4 Method is selected for the simulation. Unit of the model is 10^6 m^3 water volume.

3.1. Modifications and Limitations of the Program

Wetland water volume is 18×10^6 m^3 as an initial condition in the STELLA® model because total 18×10^6 m^3 water has to be stored in Yay Lake and the marshlands in order to balance the ecology of Sultansazlığı Wetland [14]. Additionally an initial aquifer water volume is accepted as 1000×10^6 m^3. Equation level for STELLA® simulation can be seen in Figure 7.

```
AQUIFER(t) = AQUIFER(t - dt) + (Spring_water_recharge + recharge_from_neighbour_basins +
Total_runoff_volume + recharge_from_precipitation - GW_Abstraction) * dt
INIT AQUIFER = 1000
 INFLOWS:
   Spring_water_recharge = Infiltration_volume
   recharge_from_neighbour_basins = west+East+south+southeast
   Total_runoff_volume =
     Runoff_infiltration_ratio*Drainage_area_except_drainage_area_of_dams*C*Precipitation_intensitty
   recharge_from_precipitation = P*infiltration_area*precipitation_infiltration_ratio
 OUTFLOWS:
   GW_Abstraction = well_number*Pumping_rate*Pumpage_time
WETLAND(t) = WETLAND(t - dt) + (Precipitation + Spring_recharge + drainage_recharge - Evaporation -
Evapotranspiration) * dt
INIT WETLAND = 18
 INFLOWS:
   Precipitation = A*Precipitation_height
   Spring_recharge = Spring_water_flowing_to_wetland
   drainage_recharge = Drainage_water
 OUTFLOWS:
   Evaporation = E*free_water_surface_area*Kc
   Evapotranspiration = ET*Phragmites_area
A = 55.5
Agcasar_dam = 38
Akköy_dam = 4
C = 0.17
Drainage_area_except_drainage_area_of_dams = 2625
Drainage_water = irrigation_water*0.1
E = 1.447
East = 6.210
ET = 1.5
Evaporated_spring_water = total_spring_water_volume*0.4
FLOW_TIME = (3600*24*365)/10^6
free_water_surface_area = 55.5
infiltration_area = 550
Infiltration_volume = total_spring_water_volume*0.3
irrigation_water = GW_Abstraction+Agcasar_dam+Akköy_dam+Kovali_dam+Spring_water_used_for_irrigation
Kc = 0.62
Kovali_dam = 26
P = 0.363
Phragmites_area = 60
Precipitation_height = 0.363
precipitation_infiltration_ratio = 0.20
Precipitation_intensitty = 0.363
Pumpage_time = (180*10*3600)/10^6
Pumping_rate = 0.05
Runoff_infiltration_ratio = 0.15
south = 58.078
southeast = 3.504
Spring_water_flowing_to_wetland = total_spring_water_volume*0.27
Spring_water_used_for_irrigation = total_spring_water_volume*0.03
Total_spring_flowrate = 2.6
total_spring_water_volume = (Total_spring_flowrate*FLOW_TIME)/10^6
well_number = 500
west = 22.79
```

Figure 7. Equation level of STELLA Model.

The main uncertainty is the unknown number of the illegally opened wells. During the field investigations it is determined that farmers are using groundwater from their wells when the surface water volume is not sufficient in arid seasons and when the surface water volume is sufficient for irrigation then farmers are only use water from irrigation canals, so the real aquifer discharge is unknown. Karapınar derivation (recharges Akköy Dam), Çalbalma Tunnel and Zamantı interbasin water transfer tunnel can be seen in the conceptual water model in Figure 3, but these components are not used in STELLA® model. Because Zamantı Tunnel is under construction and there is no inflow yet. There is no excess water in the basin so there is no outflow from Çalbalma Tunnel. Additionally there is no water inflow from Karapınar Derivation Tunnel to Akköy Dam.

3.2. Outputs of Stella Simulations

For the first simulation precipitation depth is taken as 363 mm for the normal conditions. Annual water volume variation for the first simulation can be seen in the tables and graph in Figure 8.

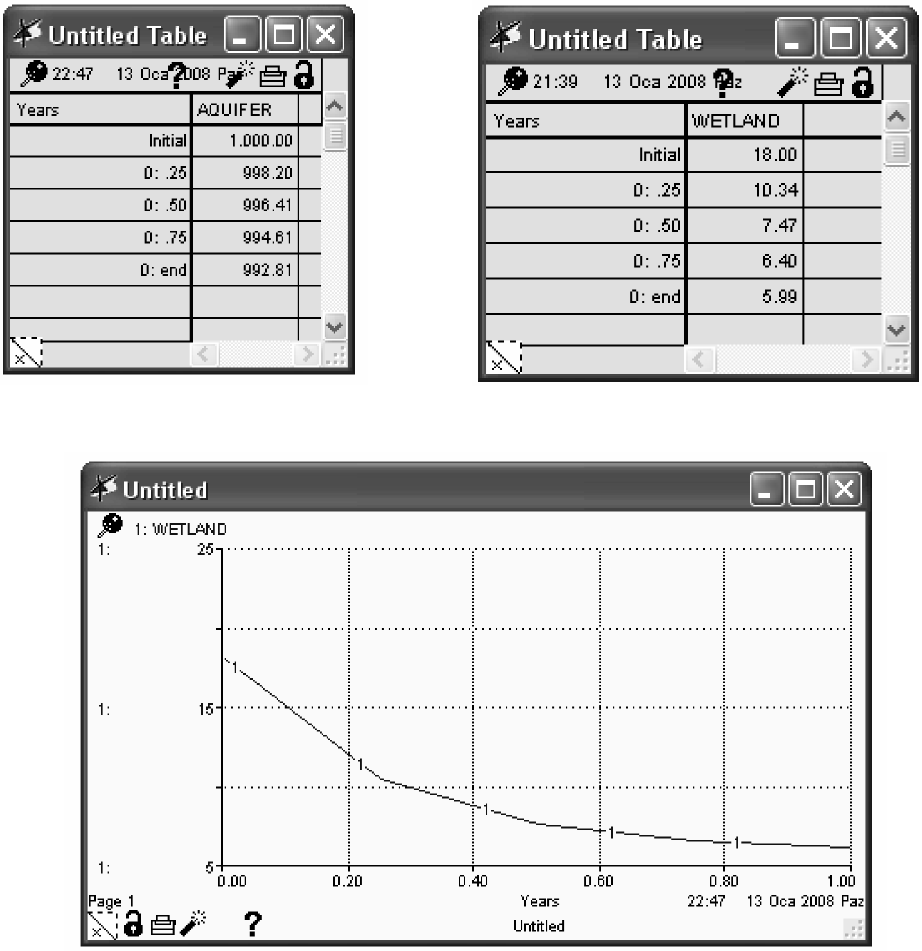

Figure 8. Annual water volume variation in the wetland and the aquifer for the first simulation.

The number of deep wells which are opened by Turkish State Hydraulic Works (DSİ), is 213 and the average well discharge is 50 lt/s but total number of illegally opened wells is unknown so in order to calculate the groundwater Extraction volume, total well number is estimated as 500 in the first simulation of STELLA model. According to the average discharge total groundwater extraction from the aquifer during the irrigation season is 162×10^6 m^3/year in the first simulation. Total well number is decreased to 200 and total groundwater Extraction from the aquifer during the irrigation season is decreased to 65×10^6 m^3/year as a second simulation. 65×10^6 m^3/year is the reliable groundwater extraction from the aquifer [16]. Annual water volume variation in the wetland and the aquifer for the second simulation is shown in Figure 9.

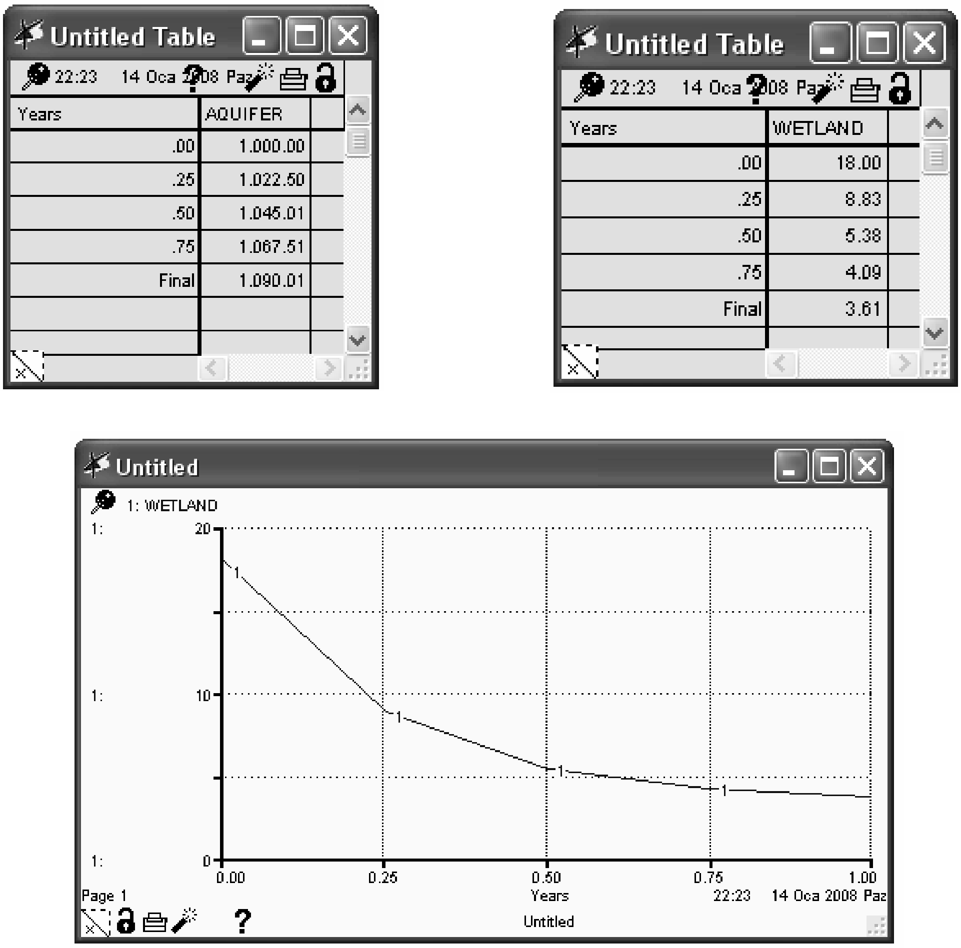

Figure 9. Annual water volume variation in the wetland and the aquifer for the second simulation.

4. CONCLUSION

When Figure 8 and Figure 9 are compared it can be said that aquifer storage is increased when the groundwater extraction is decreased from 162×10^6 m^3/year to 65×10^6 m^3/year in the second simulation. But wetland storage is not increased in the second simulation, wetland storage decreased from 5.99×10^6 m^3/year to 3.61×10^6 m^3/year in the second simulation. Because when the groundwater extraction is decreased, total irrigation water is decreased too. Drainage water which is feeding the wetland depends on the irrigation water so when the irrigation water volume is decreased, volume of drainage water feeding the wetland is decreased and total storage volume at the wetland is decreased in the second simulation. According to the isotope and chemical analysis, geological, geomorphological, geophysical and hydrogeological studies it is determined that there is no direct relationship between the surface water of Sultansazlığı and the groundwater so groundwater Extraction increase do not decrease the surface water storage at Sultansazlığı as shown in STELLA simulations. There is inverse proportion between the groundwater extraction and wetland surface water storage.

It is assumed that 27% of the total volume of spring water is going to Sultansazlığı in Stella simulations, actually percentage of spring water feeding Sultansazlığı is below %27 so there is water shortage at Sultansazlığı (*see Table 1*). If all springs which are not feeding dams can be diverted to Sultansazlığı, total 82×10^6 m^3/year spring water can feed Sultansazlığı and water shortage at this wetland can be prevented.

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