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Research Article

Modeling of Büyük Cırcıp Groundwater Recharge Dam using HYDRUS-1D

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Abstract

The purpose of this research is estimation of duration and amount of infiltration from the dam reservoir of Büyük Cırcıp groundwater recharge dam by Hydrus-1D model. Büyük Cırcıp groundwater recharge dam is one of the element of the southeastern Anatolian project in Turkey located on one of minor watercourse of great Euphrates River. The collected flood waters from rainy season (from October to May) are controlled by this small dam with 1.75 hm3 storage volume. The recharge dam reservoir bed has 15 meters thick alluvium layer overlain a permeable limestone. Groundwater depth under the reservoir is about 55 meters. The water seepage in this groundwater recharge dam is considered mainly vertical in the z-direction, therefore HYDRUS-1D software is suitable for modeling such 1-D infiltration. HYDRUS-1D, one of the most widely used models, can model water flow and solutes transport through the variable saturation media. The model uses finite element method for solving the Richards flow equation and contaminant transport equation. In this study, the model was used to calculate amount and duration of infiltration effectively under two cases: 1) 100-years flood and 2) annual flow. Results show that the time to fill up the dam depends on the hydrograph characteristics while the time to empty is related to the hydrogeological character of the reservoir bed alluvium. A sensitivity analysis for hydraulic conductivity of the alluvium was performed using the model. According to the results, technical recommendations were suggested to improve the efficiency by implementing a group of recharge wells to accelerate water infiltration through 15-m thick alluvium layer under the reservoir that has low permeability. The annual potential groundwater recharge for the basin was reported 97 hm3/year, however, this study shows that the infiltrated water into the ground through Büyük Cırcıp dam is about 10 hm3/year, which is one of 13 dam projects are planned to be implemented by GAP.

Keywords: Southeastern Anatolia; groundwater; recharge; Hydrus.

Büyük Cırcıp Yeraltısuyu Besleme Barajının HYDRUS-1D ile Modellenmesi

Öz

Bu çalışmada, Büyük Cırcıp Yeraltısuyu Barajından yeraltı suyuna sızan su miktarı ve sızma süresi Hydrus-1D sayısal modeli kullanarak belirlenmiştir. Fırat nehri üzerinde bulunan Büyük Cırcıp yeraltısuyu besleme barajı Güneydoğu Anadolu Projesinin (GAP) bir parçasıdır. Yıllık yağış miktarının yüksek olduğu Ekim-Mayıs arası dönemde toplanan taşkın suları 1.75 hm3'tür. Sızmanın z-yönüne dik tek boyutlu olduğu göz önüne alınarak,1 boyutlu infiltrasyonu modellemek üzere bu duruma uygun olarak Hydrus-1D modeli kullanılmıştır. 1 Boyutlu Hydrus sayısal modeli su akımı ve farklı doygunluktaki ortamlarda madde taşınımı modellenmesinde kullanılan en yaygın modellerdendir. Bu model Richards denklemini sonlu elemanlar metodunu kullanarak çözümlemektedir. Bu çalışmada yeraltı suyu debi miktarı ve infiltrasyon süresi 1) 100 yıllık taşkın ve 2) Yıllık yağış miktarları göz önüne alınarak hesaplanmıştır. Çalışmadan elde edilen sonuçların yorumlanması ile, baraj gölünün tabanından sızmayı artırmak için daha az hidrolik geçirgenliğe sahip 15 m kalınlığındaki alüvyon tabakada açılan kuyularla suyun yeraltısuyuna doğru infiltrasyonu artırılmıştır. Yıllık yağış potansiyeli göz önüne alındığında baraj gölünden yıllık yeraltı suyuna deşarj 97 hm3'tür. Bu çalışmada, GAP kapsamında yapılması planlanmış 13 barajdan biri olan Büyük Cırcıp baraj gölünden yeraltı suyuna sızdırılan su miktarı yıllık 10 hm3 olarak bulunmuştur.

Keywords: Güneydoğu Anadolu; Yer altı suyu; tekrar şarj

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1. Introduction

Dams are structures built to retain water by forming a reservoir behind the structure. These are usually built across, or near, naturally flowing water to manage the water for human use. The dams are classified according to the purpose to hydroelectric power, irrigation, water supply, flood protection, Navigation. As a result of all dam types and reservoirs, groundwater is recharged normally by percolated water to the aquifer. Groundwater recharge is an important technology in water resources management, particularly for utilizing excess surface water. This technology back to the 19th century, and has been widely used after World War 2 in Europe and USA. Since 1950, it has been used in UAE, Saudi Arabia, Qatar, Kuwait, Oman, Syria, and Jordan (Abdalla and Al-Rawahi 2013). In this countries which are located in the arid and semiarid zones, this technology recharge the groundwater and the reserved water is used in less Time for drinking, irrigation, and other purposes by pumping well or the increases in groundwater level feeding springs in downstream zones which reserve the cost transporting as well. The worldwide water use for irrigation Estimated as 55% - 75% of total uses, which is prompting the technical interventions to reduce that amount of irrigation water and save more fresh water. Therefore, many experts have determined the problem by promoting irrigation efficiency, water scarcity and the costs of water supply as a necessary strategy (Levidow et al., 2014). In order to improve the productivity of the systems in the light of environmental sustainability, political, administrative and technological aspects, sub-sector of the irrigation is needed to consider the relevant application (Butts,1997). For improvements in irrigation, the following directions can be handled in potential sources: technological and managerial improvements; farmer participation; institutional and political changes. Southeastern Anatolia region has a continental climate with the influence of the Mediterranean climate (Mardin İli 2014 Yili Çevre Durum Raporu). The long summers are very hot and dry, while winters are cold and rainy. The coldest month average varies from 1. 5 ° C to 6 ° C. The hottest month average is around 30 ° C. The high temperature was measured in Cizre July 17, 1978, at 48 ° C (Türkiye İklimi 2008). The natural vegetation of the area is steppe. According to the steppes of Central Anatolia, it is very poor. Southeast Anatolia is poorest areas with forests, even a large area of existing forests in the region have been destroyed (Atalay,2010).

2. Materials and Methods

2.1. Location and site description

Büyük Cırcıp Groundwater Recharge dam is one of 13 small irrigation projects that has been constituted in Mardin-Ceylanpınar near the Syria border, in the Southeastern Anatolia Projects Directorate (GAP) on Euphrates basin (Figure 1). The projects are purposed for more effective using of water resources in this region. Büyük Cırcıp and the other 12 dams will feed the groundwater and will keep the flood water from rainfall and return water from irrigation to infiltrate to the groundwater. The Büyük Cırcıp dam is located 151 km from Şanlıurfa province 57.5 km from Viranşehir district near to boundary of Syria. According to the planning report, 97 hm^3/year of water is estimated to be devolved to the groundwater by basin dams. According to geologic study, the media of the dam reservoir bed includes fluvial sediments with about 15 meters thickness in the upper layer and then a permeable bedrock (limestone) lower layer up to the 55 meters depth. The permeability of the limestone is more than the hydraulic conductivity of the alluvium and deposited sediment of the river.

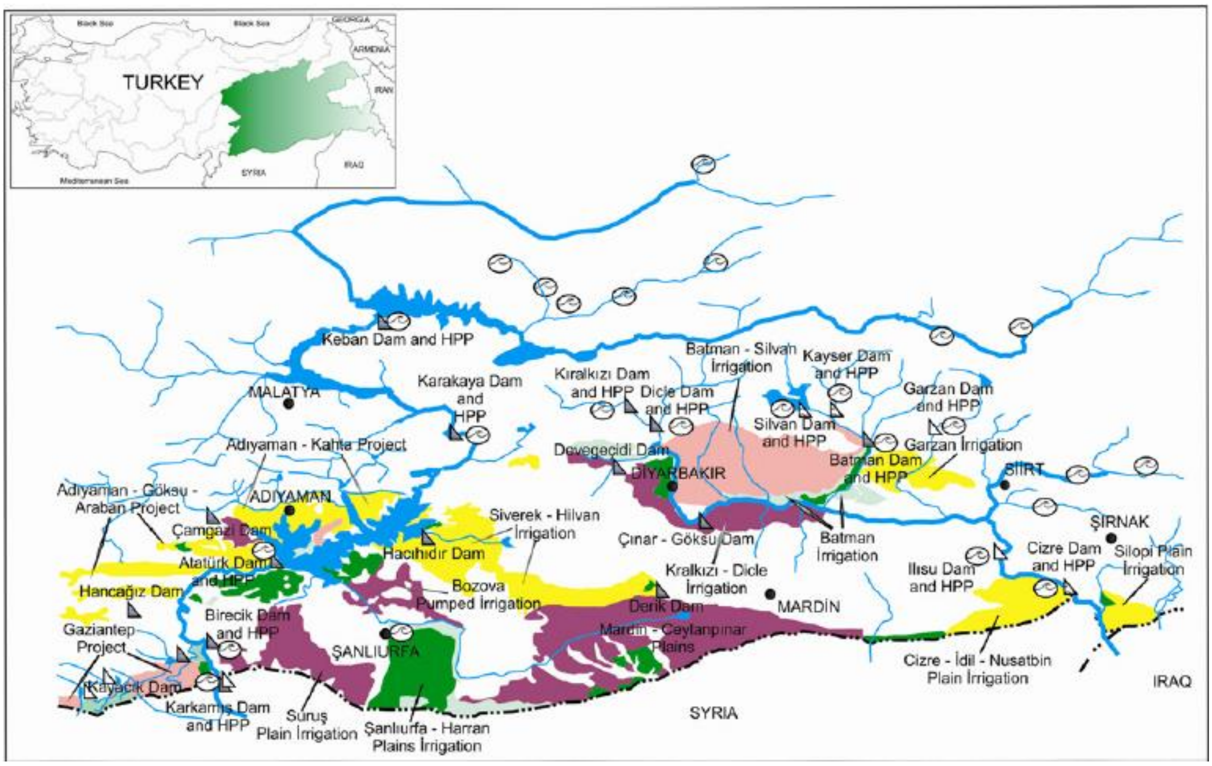
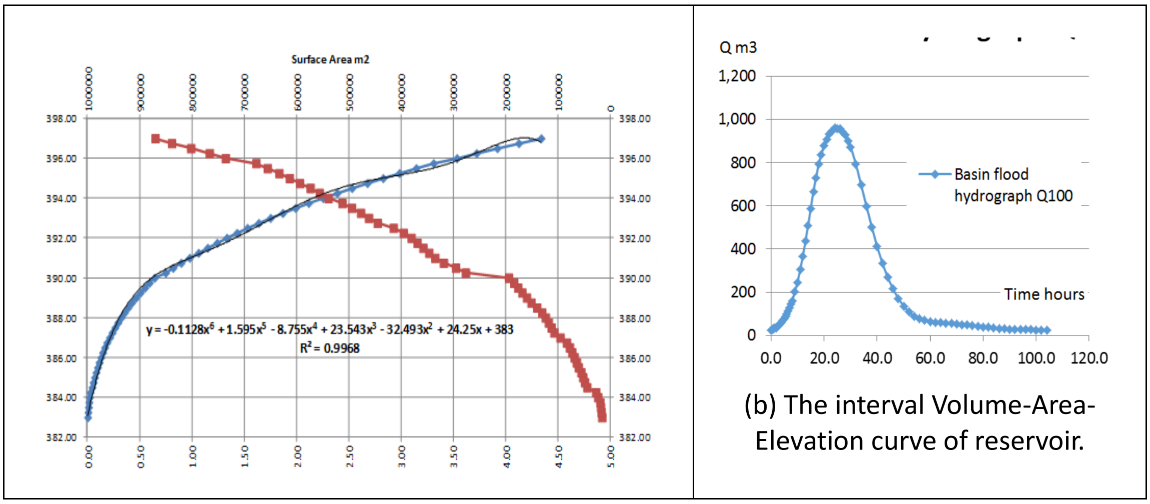


***Figure 1.** Büyük Cırcıp rechage dam location on GAP project*

2.2. Data and Measurements

A simulation is used to determine the time to Fill up and empty the dam. For this purpose, the output of the 100-year flood hydrograph is converted to the volume of water in dams with 0.5-hour interval periods and dam reservoir Figure 2 (b). The basin has area 1638 km^2, average annual flow 4077 m3/h. At the maximum water level, 396.84 m the reservoir area is 0.5 km^2.



(b) The interval Volume-Area-Elevation curve of reservoir.

Figure 2. (a) Büyük cırcıp Dam basin 100-year flood hydrograph

Table 1. Büyük Cırcıp monthly average flows

					monthly average flows m3/s							
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1970	3.694	3.931	4.262	5.025	4.315	4.202	2.925	2.764	2.731	2.597	2.113	1.859
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
2000	0.731	0.765	0.776	1.136	1.901	1.413	0.926	0.781	0.755	0.731	0.755	0.755
average	0.836	1.304	3.33	6.413	10.901	11.541	8.886	3.33	0.976	0.552	0.429	0.422

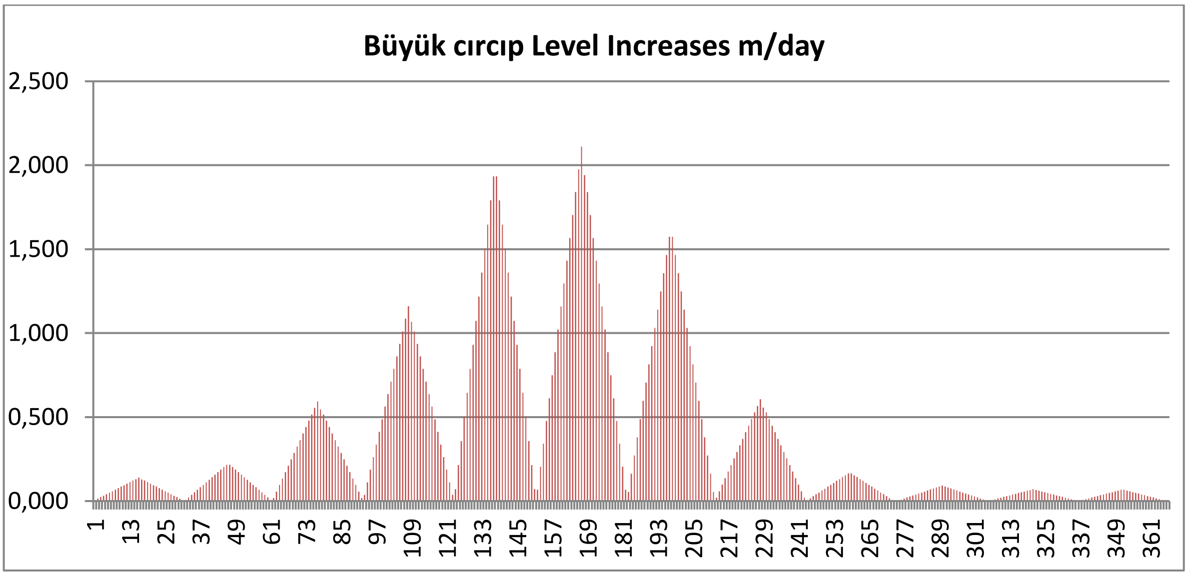


Figure 3. The water level increases converted from the daily annual flows during one year.

The material properties in aquifers are obtained by drilling and the pressure water test (Lugeon), also hydraulic conductivity values are given for both the fractured and porous media. Simulation is made up of only 54 meters. Because the water table is reached after 54 meters Table 1. With Büyük Cırcıp Dam basin 100-year flood hydrograph Figure 2. (a).

Table 2. a soil column represents the ground materials and hydraulic properties under Büyük cırcıp dam.

The Depth (m)	Material Properties	Saturated Hydraulic Conductivity (m / s)	K(m/h)	K_ porous m/h	K_ fractured m/h
0-14	Alluvium chert, limestone and gravel		0.0075	0.0075	0.0001
14-22	Midyat Formation moderately disintegrated		0.5	0.0500	3.0500
22-32	Midyat Formation, less disintegrated	0.00004	0.126	0.0126	0.7686
32-46	Midyat Formation, less disintegrated limestone, chalky clay	0.00013	0.478	0.0478	2.9140
46-54	Midyat Formation less disintegrated limestone clay	0.00002	0.061	0.0061	0.3733
54-56	Midyat Formation less disintegrated limestone clay	0.00014	0.510	0.0510	3.
56-58	Midyat Formation less disintegrated limestone clay	0.00002	0.058	0.0058	0.3514
58-60	Midyat Formation, less disintegrated hard hollow clay limestone	0.00002	0.078	0.0078	0.4740
60-90	Midyat Formation, chalky clay hollow moderately hard limestone	0.00001	0.050	0.0050	0.3074
90-100	Midyat Formation, chalky clay hollow moderately hard limestone	0.000009	0.032	0.0032	0.1976

2.3. Ground Water Modeling

In this study, the groundwater recharging occurs by the water leaks from the reservoir to underground water table in the vertical direction (z-direction) Figure 3, and this movement considered to be in semi-saturated, unsaturated and fractured karst media. The movement during semi-saturated porous, karst and fractured is more than it is in the hollows and fractured media. When the groundwater movement in semi-saturated with hollow and fractured media is modeled, it is considered as a dual permeability media in the model. Therefore, Hydrus-1D dimensional model is used for this project which can model semi-saturated flow in fractured media. The model represents a drill (1x1 m2) from the surface of land under dam reservoir to a depth of groundwater table and it is taken as general soil column for modeling. The average depth of groundwater level in the soil column is taken 70 m. The 100-year flood flow fills the dam and subsequently infiltrated to fully discharge time in the vertical direction in the one-dimensional semi-saturated groundwater flow leakage is chosen throughout this soil column in the model. This boundary condition for the maximum water height in the reservoir is taken about 10 + 3.84 = 13.84 m. The base is intended as free drainage boundary conditions. The upper boundary condition (atmosphere-soil surface) defined by 100-year flood hydrograph Figure 2. (a) With 0.5-2 hour interval time brings the total water volume to the dam. To determine the increases in the dam water level, Volume-Surface-Height Figure 2. (b) Curve which is converted to water level is used in terms of "known- input flow " m / hour and these changes in the water level entered the model as an upper boundary condition. The maximum water height is taken at normal flow over the spillway not the height at full flow spillway neither the threshold elevation. Because the infiltration is continuing even when the water elevation is at maximum height. A Large part of the water will discharge through the spillway rapidly and the other will seep into the ground. This case a value between the two levels has been accepted to take the correct approach. Such an admission is made, infiltration time accounts are more convenient to stay on the safe side.

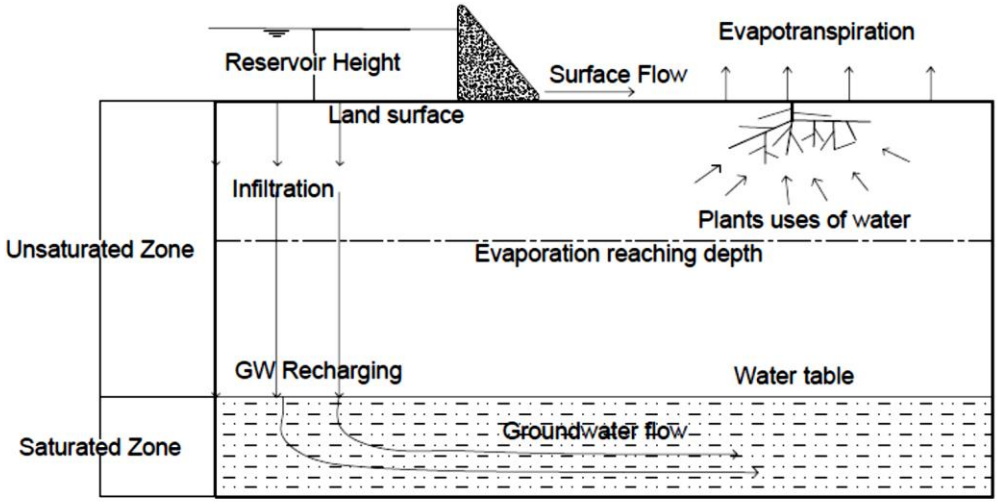


Figure 4. Conceptual Hydrus 1D model of Recharge dam and groundwater recharge.

2.3.1 HYDRUS 1D

Hydrus-1D is one of the most widely used models of water flow and sediment transport through variable media. The model solves the solute transport equation coupled with Richards flow equation with finite element method. In the model, the soil-water characteristics curves for water-soil, hydraulics conductivity – soil moisture pressure and water content –soil moisture are calculated using and (Šimůnek et al., 2003), (Van Genuch 1980) (2.3.2.b) equations.

$$\frac{\partial\theta_f(h_f)}{\partial t} = \frac{\partial}{\partial x}\left[K_f(h_f)\left(\frac{\partial h_f}{\partial x} + \cos\alpha\right)\right] - S_f(h_f) - \frac{\Gamma_w}{w} \quad 2.3.1.a$$

$$\frac{\partial\theta_m(h_m)}{\partial t} = \frac{\partial}{\partial x}\left[K_m(h_m)\left(\frac{\partial h_m}{\partial x} + \cos\alpha\right)\right] - S_m(h_m) - \frac{\Gamma_w}{1-w}$$

In the Equation 2.3.1.a the approach of Gerke and van Genuchten [1993a, 1996], who applied Richards equations to each of two pore regions, fracture zone and pore matrix, is implemented in HYDRUS-1D. The flow equations for the macropore or fracture (subscript f) and matrix (subscript m) pore systems in this approach.

$$S_e = \begin{cases} |\alpha h|^{-n} & h < -1/\alpha \\ 1 & h \geq -1/\alpha \end{cases} \qquad 2.3.1.b$$

$$K = K_s S_e^{\frac{2}{n+l+2}} \qquad 2.3.1.c$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad 2.3.1.d$$

HYDRUS permits the use of five different analytical models for the hydraulic properties [Brooks and Corey, 1964; van Genuchten, 1980; Vogel and Císlerová, 1988; Kosugi, 1996; and Durner, 1994]. The soil water retention, θ(h), and hydraulic conductivity, K(h), functions according to Brooks and Corey [1964] are given by (2.3.1.a) and (2.3.1.c), Se is effective saturation(2.3.2.d). where θr and θs denote the residual and saturated water contents, respectively; Ks is the saturated hydraulic conductivity, α is the inverse of the air-entry value (or bubbling pressure), n is a pore-size distribution index, and l is a pore-connectivity parameter assumed to be 2.0 in the original study of Brooks and Corey [1964]. The parameters α, n and l in HYDRUS are considered to be empirical coefficients affecting the shape of the hydraulic functions.

In the model, as the upper boundary condition of the ground surface, a constant pressure or water inflow can be defined, in addition to the atmospheric conditions precipitation and/or evaporation. The base as a (bottom) boundary condition is free drainage. The soil surface boundary condition during the simulation can change from the constant pressure load of the boundary conditions to water inflow boundary condition (or reverse). With this model, many types of problems can be solved: water balance models, groundwater recharge estimation, the performance of the surface plant covering, nitrate and pesticide spills and other problems Figure- 3.

2.3.3 Büyük Cırcıp groundwater recharge dam simulation.

2.3.3.1 Simulation with 100-years flood

The 100 years flood hydrograph with 104 hours Figure 2. (a) which is Variable with time corresponding to the water level increases was defined in the Hydrus model as the top boundary condition on the ground surface. According to 100 m depth of drilling at the reservoir ground and Lugeon test, the results were determined in a soil column sections was defined the dam and this section of the hydrogeological characteristics and dimensions were entered into model Table 1.

The formation under Büyük Cırcıp lake ground is alluvial 12 meters depth from the surface, lower layers are limestone with fractured media with different lugeon value. The water movement shows non-linear behavior at the beginning, so the simulation divided at the first meter of soil column depth to finer grid precisely in order of accurate results, the grid size of the first entry into the groundwater has also increased. Thus, 54-meter soil column was divided into a total of 101 grid.

In order to fully reflect fractured media, dual-permeability option selected in the model. When dual permeability option is selected, for each of the two hydrogeological formations, two hydraulic conductivity assumed for a fractured and porous situation. Cracks and large voids assumed to 33% of the total space. The hydraulic conductivity of fractured media was accepted much greater than the porous one.

Table 1 shows material properties obtained by drilling and the pressure water test (Lugeon), hydraulic conductivity values are given for both the fractured and porous media. Simulation is made up of only 54 meters. Because the water table is reached after 54 meters and free drainage boundary condition as the base boundary conditions are given in the simulation. 54 Meters will be eligible to be accepted as the water resistance of the groundwater recharge. With Free drainage boundary condition, the infiltrate water reaches the groundwater and raises the groundwater level and join the groundwater flow, moving away from the region. One-dimensional modeling in the vertical direction is more appropriate to make such acceptance, or the groundwater level will immediately begin to rise along the modeled soil column and become even full saturated and water will reach up to the ground surface.

2.3.3.1 Simulation with annual average flows

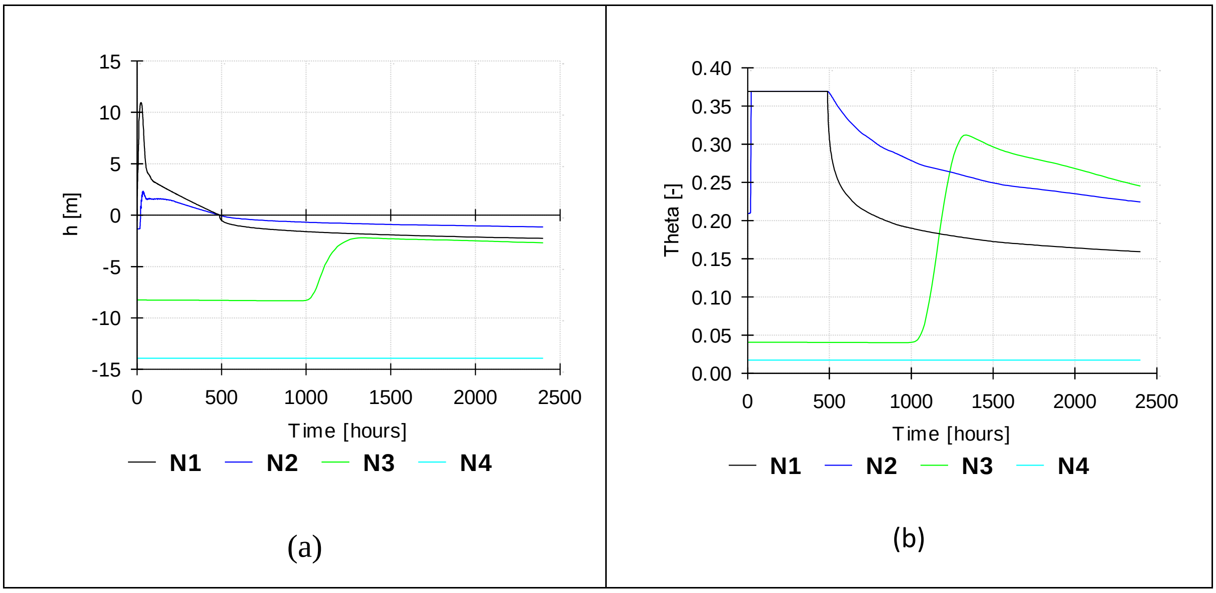
According to Büyük Cırcıp-1 average flows, i.e. with 50% probability annual dam income flows. In the Simulation of infiltration, the average flows for many years has been taken from the Büyük Cırcıp dam records (Table 2). The monthly total flows are reflected in daily flows by converting every month hydrograph using the volume-area curve Figure 2. (b) for the reservoir and entered Hydrus model as water level increases. The monthly evapotranspiration values also converted to daily values and put into the Hydrus model Figure 3.

The elevation 395 between maximum water level and the normal water level is taken in büyükcırcıp simulation for Hydrus (maximum accumulating height). The reservoir has a volume of 2.82 hm3 at this elevation. As 100-years flood simulation, the model is prepared with similar input data. While in this simulation the model works for 365 days (8760) hours.

3. Results

3.1 Results of Simulation with 100-years flood

Model results are obtained in a graphical environment for each observation point. Observation point N1 immediately below the ground surface, observation point N2 is at a depth of 5 meters, observation points N3 and N4 which are selected 30 and 50 meters respectively. The following figure shows the time-dependent pressure and water content change results which are presented in a graphical environment Figure 4.



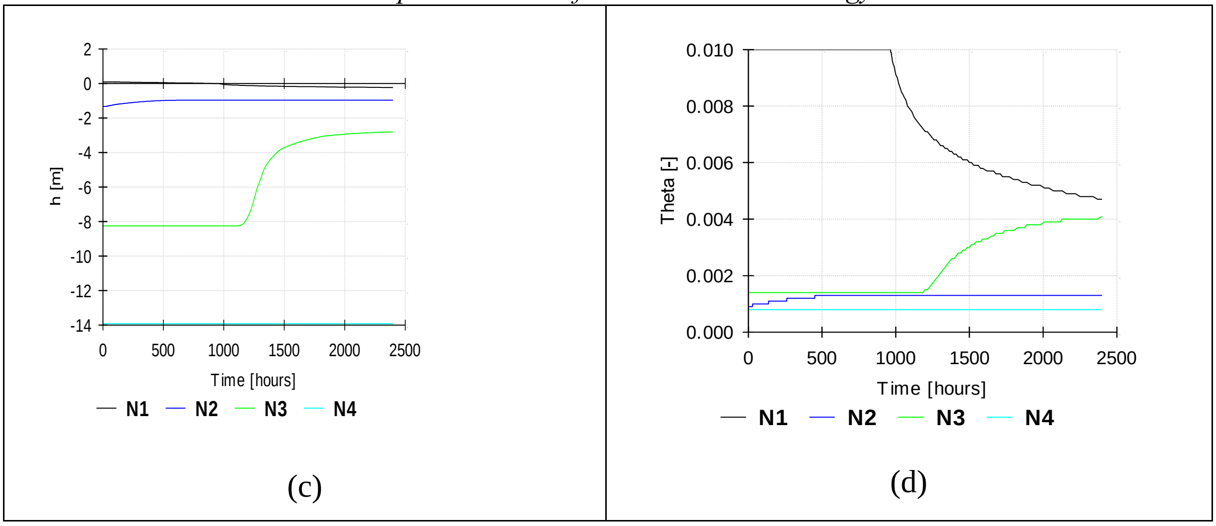


Figure 5. Observed Simulation results at the points N1, N2, N3 and N4 though 2400 hours; (a) shows pressure heads changes, (b) water content changes, (c) pressure heads changes in fractured situation and (d) water content in fractured situation.

The results throughout soil profile in various time; Pressure head M and water content M for porous; Pressure head Fr and water content Fr for the fractured situation. Showed results in figures T0=0, T1=5, T2=25, T3=100, T4=500 and T5=2400 hours of pressure distribution in porous and fractured media throughout the depth.

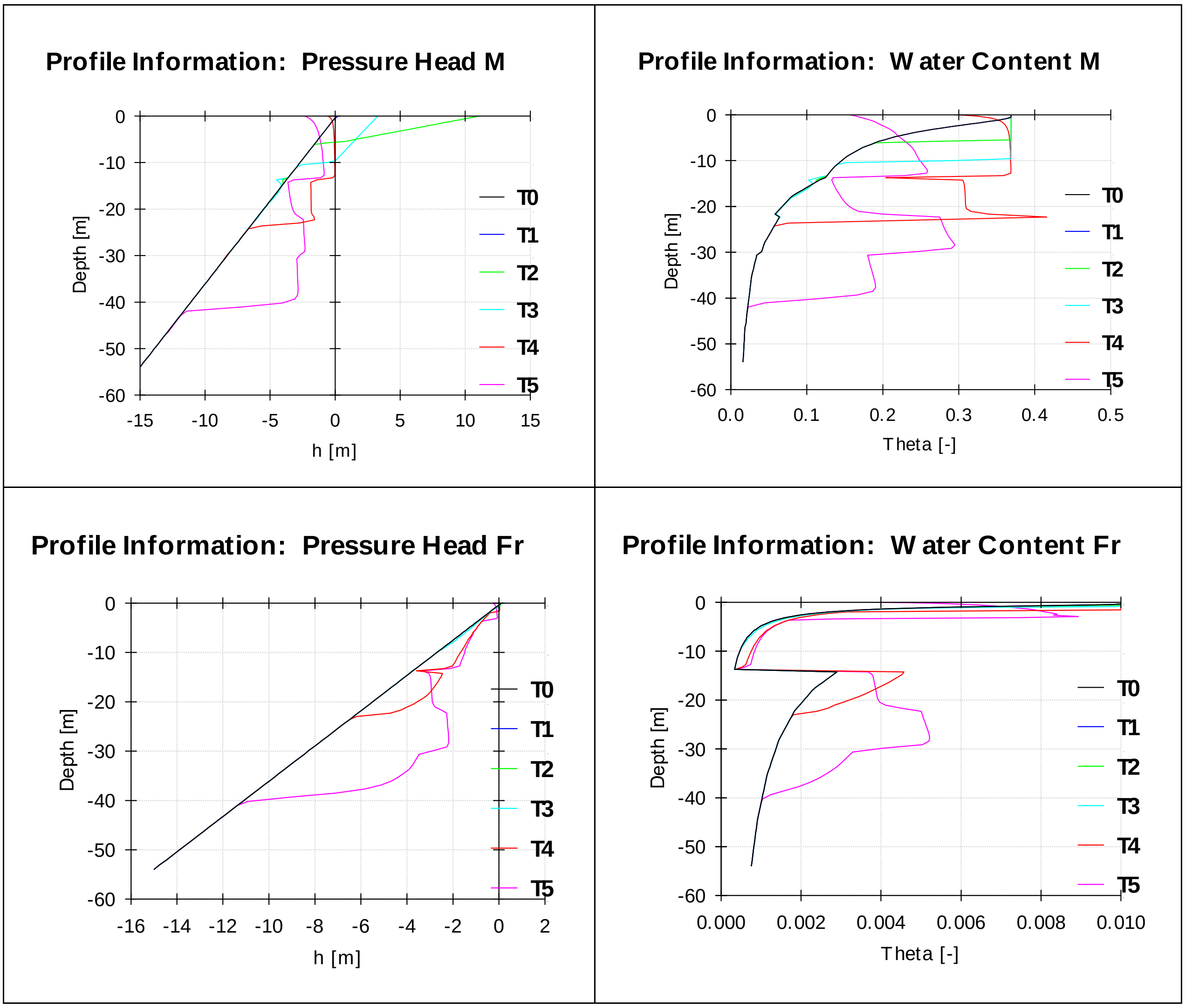
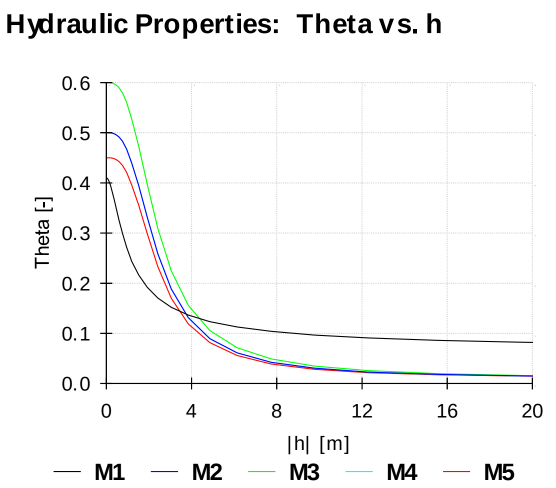


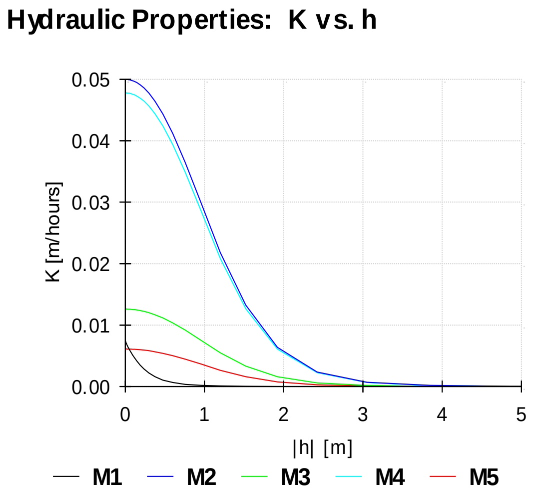
Figure 6. Observed Simulation

The infiltrated water from the soil surface which time-dependent flow entered the underground, as total volumes are shown in the following figures.

Because of the water movement in the soil, there is variability in saturation in the different soil layers. The hydrogeological properties; hydraulic conductivity, water content with pressure load changes and water content with hydraulic conductivity changes. These properties can't be obtained experimentally and the simulation shows them in the figures.



(a)



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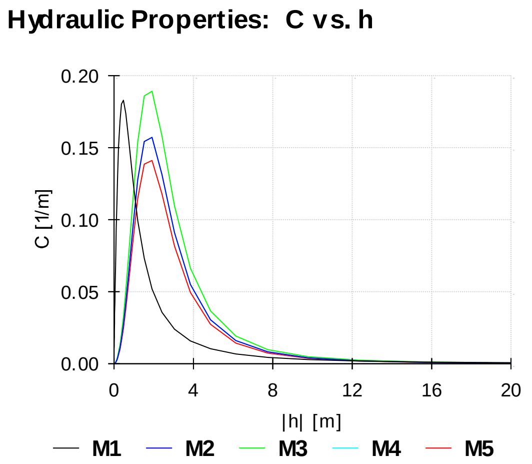


(c)

Figure 7. The hydrogeological properties

a. *water content with pressure load changes*
b. *hydraulic conductivity pressure load changes*
c. *water content with hydraulic conductivity changes*

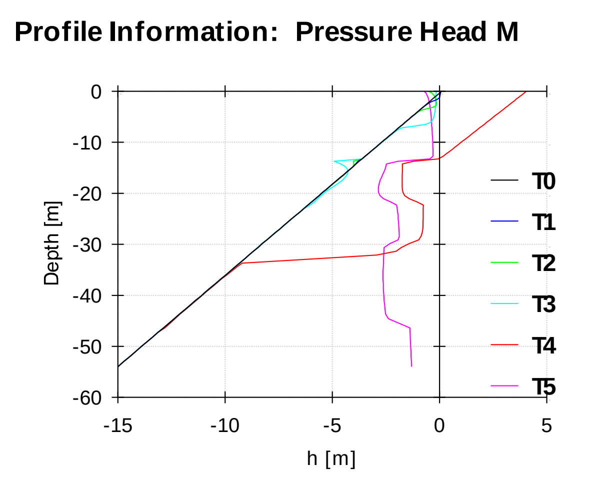
Table 3. Water budget of the soil column 1m x 1m x 54m for 2400 hours

Time[T] 2400 h		
Length [L]	54	54
W-volume [L]	8.78	8.78
In-flow [L/T]	-4.7E-06	-4.7E-06
h Mean [L]	-4.94	-4.94
W-volumeF[L]	0.144	0.144
In-flow F [L/T]	-4.7E-06	4.7E-06
h Mean F [L]	-5.36	-5.36
Top Flux [L/T]	-6.27E-07	

Bot Flux [L/T]	-3.76E-09
WatBalT [L]	1.43E-06
WatBalR [%]	0
WatBalFT [L]	-2.46E-07
WatBalFR [%]	0

4.2 Results of Simulation with 100-years flood

Figure 8-a, shows the pressure change with time in one dimensional model of the section taken from the lake ground. Figure 8-b shows the pressure change with time in the top and bottom boundary in the section for groundwater recharge dam lake ground. The pressure change in ground surface represents the water level in the GW recharge dam. The time axis during a year period starting from 1 October until 30 September a total of 8760 h simulation. From December for 6 months, the water accumulates in the dam and recharging the groundwater. In Mart and April, the water elevation reaches the crest of the spillway which is working in maximum water level. Figure 8-c shows the total potential water will pass the dam lake base surface (potTop- black graphics), the total actual amount of water passed (actTop- green curve) and GW reached the total amount of water (actBot red curve) according to time. Some of the potential water which could be infiltrated to the ground is withdrawn from the spillway and other to the atmosphere as lost in a portion of ET. Some of the leaked water stored in the semi-saturated ground but a large amount reached the groundwater.



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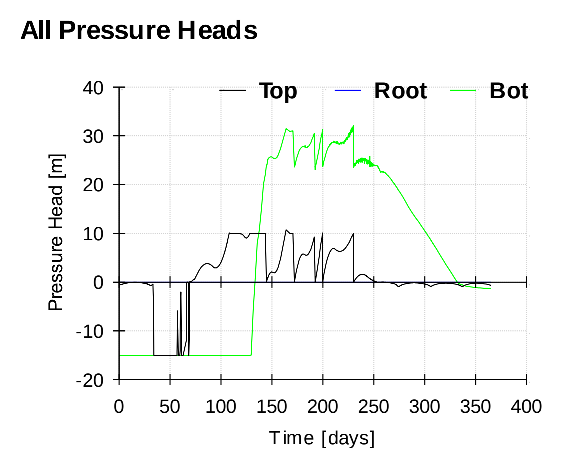
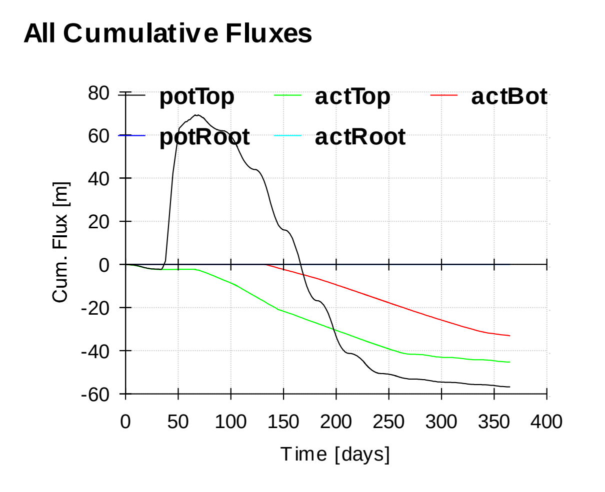


(b)



(a)

Figure 8. The hydrogeological properties

(a) **the pressure change with time**

(b) **the pressure change with time in the top and bottom boundary**

(c) **the total actual amount of water passed**

5. Discussion

The simulation of water infiltration in lake ground behind Büyük Cırcıp Recharge dam is achieved with Hydrus 1D model in the vertical direction using the information obtained from 100 meters of drilling. The simulation was carried out 5000 hours. In the simulation, the water rises to the ground surface entered the model as a boundary condition which is calculated from 100-year flood hydrograph probability comes to the dam with every half hour causes. The main target of modeling is calculating how much time it takes to fill in and empty the dam lake by water coming from the 100-year flood with infiltration and examining the dam performed fill-empty as recharge dam. For this purpose, an observation point enters the model just under the ground surface. The point observes the pressure to the time being negative where the dam got empty. At the end of this research, the results were obtained by using hydraulic conductivity values given in Table 4 for the alluvium which is different as estimated in the literature. These results give the time to empty the dam filled with the 100-year flood hydrograph when the water seeps into the ground by infiltration mechanism.

Table 4. deferent hydraulic conductivity values with corresponding values resulted from study with 100-year flood and the time of dam fill-empty.

Hydraulic Conductivity of Alluvium layers (m/hour)	Dam discharging time with infiltration (hour)	Hydraulic Conductivity of limestone layers (m/hour)	Dam discharging time with infiltration (hour)
0.001	5000 (208 Day)	0.05	956 (40 Day)
0.005	1362 (57 Day)	0.005	1071 (45 Day)
0.0075	956 (40 Day)	0.1	956 (40 Day)
0.01	750 (31 Day)		
0.05	350 (15 Day)		
0.1	340 (14 Day)		
0.5	321 (13 Day)		
0.75	317 (13 Day)		

5. Conclusions

According to the research, the time to fill the dam depends on the rising hydrograph curve of the 100-year flood while the time to empty is related to the hydrological character of the first 15 m layer of Alluvium at the dam lake ground which means it's related to the hydraulic conductivity of the layer. Discharge is time calculated with Alluvium hydraulic conductivity which is variable within the range of (0.001 - 0.75) m/hour. Where there is a strong correlation between the discharge time and these parameters. Discharge time with 0.001 m/hour conductivity is 5,000 hours (208 days) and 0.05 m/hour conductivity is 349 hours (14.5 days). In this case, when the hydraulic conductivity doubles 2,10 and 15 times the discharging time decreased to 19, 9 and 4 hours respectively. This implies that groundwater recharging is managed by alluvium layer below and the hydrograph curve.

To extend the discharge time from 955 hours (40 days) within 1071 hours (45 days), The hydraulic conductivity for cracked layers under the alluvium which is fractured as well as porous doesn't affect the discharge time even when it doubles.

The situation of Büyük cırcıp Groundwater recharge dam, according to the annual average water flows, is achieved using Hydrus 1D model of infiltration caused daily flows coming to the dam during one year. dam simulation showed that during the period from December to April, that dam collects water and infiltrate it to the ground. the models of the dam don't represent all the dam lake ground where it is a 1x1 m2 vertical column on the lake bottom because it is a one-dimensional model, but simulation has shown how the infiltration is progressing successfully throughout the year. Büyük cırcıp dam spillway has worked 2 times. The water level is increased to 12 m and during 6 months water is being collected and transferred to the ground. To increase the hydraulic conductivity of the layer and speed up the water seepage, vertical shafts are built whether the Alluvium layer in the reservoir these vertical shafts save the accumulated water from ET which is high in high rates in the region. These vertical shafts have been recommended to be formed in grid shape with 30x30m distribution in seven rows starts from the dam body. Shafts should make an open passing Alluvium layer and through the limestone with 2 meters.

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