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MODELING OF GROUNDWATER RECHARGE DAMS

ISSAM ALI

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ADVISER
PROF. DR. AHMET DOĞAN

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A thesis submitted by Issam ALI in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 19.12.2017 in Department of civil Engineering, Hydraulics Program.

Thesis Adviser
Prof. Dr. Ahmet DOĞAN
Yıldız Technical University

Approved by the Examining Committee
Prof. Dr. Ahmet DOĞAN
Yıldız Technical University ______________________

Prof. Dr. Hayrullah AĞAÇCIOĞLU, Member
Yıldız Technical University ______________________

Assoc. Prof. Dr. Mehmet ÖZGER, Member
İstanbul Technical University ______________________

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Finally, I dedicate this work to my parents, my mother, whom I would not have succeeded without her prayers, and to the spirit of my deceased father, whom I ask God for his satisfaction in the other life.

December, 2017

Issam ALI

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LIST OF SYMBOLS

A	Anisotropy tensor
Kxx, Kyy, and Kzz	Hydraulic conductivity along the x, y, and z axes [LT-1]
Evap	Potential evaporation rate [LT-1]
H	Pressure head [L],
hCritA	Absolute value of the minimum allowed pressure head at the soil surface [L]
KA	The unsaturated hydraulic conductivity function
KijA	Nondimensional anisotropy tensor
Kr	Relative hydraulic conductivity
Ks	Saturated hydraulic conductivity [LT-1]
Precip	Precipitation rate [LT-1]
Q	River flow [LT-3]
Q_{100}	River flood with 100 years return period [LT-3]
S	Sink term [T-1]
Ss	Specific storage coefficient
T	time [T]
Trans	Potential transpiration rate (in absolute value) [LT-1]
V0	Water volumes in the flow domain at time zero[L3]
Vt	Water volumes in the flow domain at time t [L3]
w	Ratio of the volumes of the macropore or fracture domain
xi(i=1,2)	Spatial coordinates in i and j direction [L]
Γw	Transfer rate for water from the inter- to the intra-aggregate pores.
θ	Volumetric water content [L3L-3]
θF	Water contents of the fracture regions [L3L-3]
θ_{im}	Water contents of the immobile flow regions [L3L-3]
θ_M	Water contents of the soil matrix [L3L-3]
θ_{mo}	Water contents of the mobile flow regions[L3L-3]

LIST OF ABBREVIATIONS

1D/2D/3D	One, two and three dimension
CO2	Carbonate deoxide
ET	Evapotranspiration
FEFLOW	Finite element subsurface flow system
FEMWATER	A finite element model for water seepage analysis
GAP	“Güneydoğu Anadolu Projesi”, Southeastern Anatolia Project
GFLOW	Analytic model with conjunctive surface-groundwater flow
GIS	Geographic information system
GMS	Groundwater modeling system, an interface for groundwater modeling
GW	Groundwater
HYDRUS 1D/2D/3D	A computer program for one/two and three dimension of water flow and solute transport in variably saturated porous media.
MicroFEM	Finite-element program for multiple-aquifer steady-state and transient groundwater flow modeling
MODFLOW	A modular for three-dimensional finite-difference ground-water flow model
USGS	United States Geological Survey

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ABSTRACT

MODELING OF GROUNDWATER RECHARGE DAMS

Issam ALI

Department of Civil Engineering
MSc. Thesis

Adviser: Prof. Dr. Ahmet DOĞAN

The purpose of this research on Büyük Cırcıp recharge dam is the estimation of stored water infiltration amount and time on the dam reservoir bed by HYDRUS-1D model. Büyük Cırcıp recharge dam is one of the southeastern Anatolia projects in Turkey located on one of minor watercourse of Euphrates river. The collected water of floods and annual rainfalls (from October to May) are controlled by this small dam with 1.75 million cubic meters volume. The recharge dam reservoir bed is concluded a 15 meters alluvium and a permeable limestone under it to groundwater-surface with about 55 meters thickness under the dam. The water seepage in Büyük Cırcıp recharge dam considered vertically in the z-direction. HYDRUS-1D software is used for modeling the water infiltration and evaluates the time of dam discharging in a different status.

HYDRUS-1D model of water flow and solutes movements through the variable saturation media is one of the most widely used models. The model uses finite element method for solving the Richards flow equation in unsaturated. In addition, the model has the option to solve non-isothermal liquid-vapor flow and heat transfer functions. In this study, the model calculates amount and time of infiltration effectively with two considered situations; 1)100-years river flood and 2) annual flow.

Results show that the time to fill up the dam depends on the raised hydrograph curve while the time to empty is related to the hydrogeological character of the reservoir bed materials. A sensitivity analysis used for hydraulic conductivity of the alluvium by model. According to the results, technical recommendations suggest improving the efficiency by implementing a group of wells to accelerate water infiltration through the upper low permeability layer. The annual recharged potential groundwater of the basin was reported 97 hm^3/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.

Key words: Southeastern Anatolia, groundwater, recharge, HYDRUS-1D.

ÖZET

YERALTISUYU BESLEME BARAJLARININ MODELLENMESİ

Issam ALI

İnşaat Mühendisliği Anabilim Dalı
Yüksek Lisans Tezi

Tez Danışmanı: Prof. Dr. Ahmet DOĞAN

Bu araştırmanın amacı, Büyük Cırcıp yeraltısu besleme barajının gölünden HYDRUS-1D modeli ile sızıntı süresinin ve miktarının tahmin edilmesidir. Cırcıp Yer Altı Suyu (YAS) Besleme Bentleri, Güneydoğu Anadolu Projesinin (GAP) en önemli bölümlerinden birisini teşkil eden Mardin-Ceylanpınar Ovaları Sulama Projesi içerisinde yer alan 13 YAS Bendinden ikisini teşkil etmektedir. Söz konusu proje sahası Güneydoğu Anadolu bölgesinde Fırat behri havzasında yer almaktadır. Yağış mevsimde toplanan taşkın suları (Ekimden Mayısa kadar) 1.75 hm3 depolama hacmi ile bu küçük baraj tarafından kontrol edilmektedir. Büyük Cırcıp baraj gölünün altında kalan zeminin ilk 12 metresi alüvyon bir zemin olup alta kalan tabakalar farklı lugeon değerlerine sahip çatlaklı ortamlara sahip kireç taşı formasyonlarıdır. Bu çalışmada, besleme barajlarının haznelerindeki suyun sızarak yeraltı su tablasına doğru düşey doğrultuda (z-yönünde) hareket ettiği ve bu hareketi sırasında yarı doygun gözenekli, boşluklu ve çatlaklı karstik bir ortamdan geçtiği varsayılmıştır. Yarı doygun ortamlardaki yeraltı suyu hareketinin çatlak ve karstik ortamlarda, daha çok çatlak veya büyük boşluklara doğru hareket ettiği bilinmektedir. Bu nedenle, bu projede çatlaklı ortamlardaki yarı doygun akışı modelleyebilen bir boyutlu HYDRUS-1D modeli kullanılmıştır. HYDRUS-1D modeli değişken doygunluktaki ortamlarda su akışı ve madde taşınımı modellemesinde en çok kullanılan modellerden biridir. Model sonlu elemanlar yöntemi ile Richards akış denklemini çözmektedir. Bu çalışmada, model iki durum altında kullanılmıştır: 1) 100 yıllık taşkın debi ve 2) yıllık ortalama akımlar. yapılan araştırmada, barajın dolma süresi tamamen 100 yıllık taşkın hidrografının yükselme eğrisine bağlı iken boşalma süresi zeminin ilk 15 metresindeki alüvyon tabakanın hidrojeolojik karakterine yani hidrolik iletkenlik katsayısına bağlı olduğu gözlemlendi. Baraj gölünde hidrolik iletkenliği artırmak için düşey şaftlar inşa edilip alüvyon tabakanın bu düşey şaftlar yardımıyla hızlıca geçilmesi baraj gölünde biriken suyun ET'nin yüksek olduğu aylara kalmadan hızlıca YAS'a intikal ettirilmesi ve yeni gelecek su akımlarına yer açılması açısından önemlidir. Planlama raporuna Büyük Cırcıp besleme bendi ile 97 hm^3/yıl suyun YAS'a intikal edebileceği tahmin edilmiştir. Ancak bu çalışmada, sızan suyun GAP tarafından 13 baraj projesinden biri olan 10 hm^3 / yıl olarak planlandığını gösteriyor.

Anahtar Kelimeler: Güneydoğu Anadolu; yeraltısuyu Besleme; HYDRUS-1D.

CHAPTER 1

INTRODUCTION

The worldwide water uses 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 [1]. In order to improve the productivity of the systems in the light of sustainability, political, administrative and technological aspects, sub-sector of the irrigation is needed to consider the relevant application such as groundwater recharge [2]. Dams are structures built to retain water by forming reservoirs behind of them and 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 safe utilizing of excess surface water. This technology back to the 19th century, and has been widely used after World War II in Europe and USA. Since 1950, it has been used in UAE, Saudi Arabia, Qatar, Kuwait, Oman, and Syria [3], In these countries which are located in the arid and semi-arid zones. This technology recharges the groundwater and the reserved water is used in less Time for drinking, irrigation, and other purposes by pumping well for increases groundwater level which reserve the cost transporting as well. In the study as shown in Figure 1.1 the region has a continental climate with the influence of the Mediterranean climate [4]. 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° [5]. The natural vegetation of the area is steppe vegetation. According to the steppes of Central Anatolia, which is very poor. Southeast Anatolia is poorest areas with forests, even a large area of existing forests in the region have been destroyed [6].

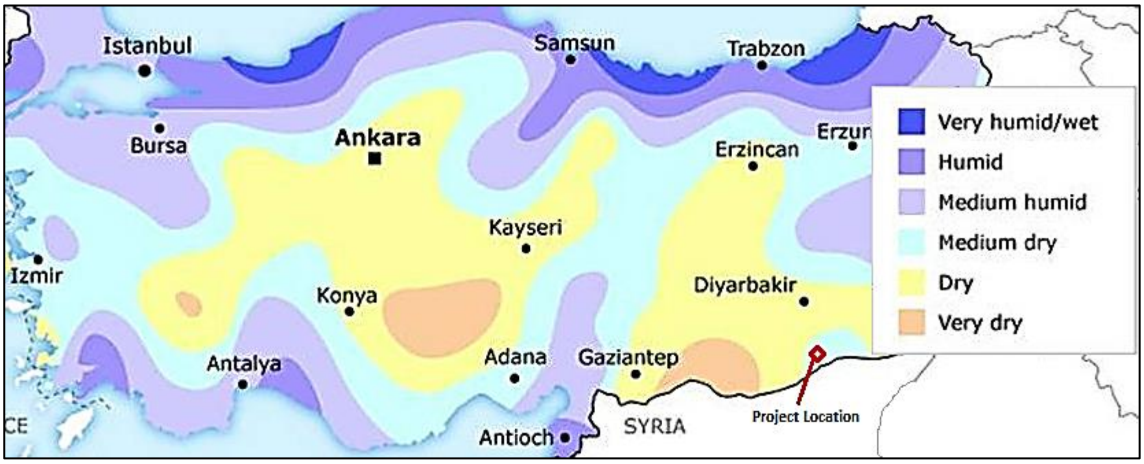


Figure 1.1 Climate zones in Turkey and study area.

1.1 Literature Review

1.1.1 Artificial Groundwater Recharge

Groundwater recharge is an aquifer replenishment with surface water. It is expressed similar to precipitation, as an average rate of millimeters of water per year. The sources of recharge to an aquifer are precipitation, irrigation return flow, inter-aquifer flows, other streams, and lake or pond seepage, and urban recharge [7]. On the other hand, artificial recharge is the use of groundwater replenishment artificially with the water supply in an aquifer. The rate of recharge as one of all the factors in the evaluation of groundwater resources is the most difficult issue to determine with confidence. The growing demand for water has increased recognition towards the use of artificial recharge to augment groundwater supplies. Artificial recharge is processed by which excess surface-water is directed into the ground – either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration – to replenish an aquifer. It refers to the water movement through man-made systems from the surface of the earth to underground water-bearing aquifers where it may be stored for future use. Artificial recharge is a way to store water underground in times of water surplus to meet demand in times of water scarcity and some factors for artificial recharge to consider are [8]:

- Wastewater availability.
- The quantity of available water source.

- Consequent of water quality.
- Available groundwater storage space.
- Depth to groundwater storage space (unsaturated zone thikness).
- Transmission characteristics of the aquifers.
- Applicable methods (injection or infiltration).
- Legal or institutional constraints.
- Costs.

1.1.2 Artificial Recharge Projects

The aim of most artificial recharge projects is to transfer water to the saturated zone. Estimation of the Feasibility of planned projects and of its efficiency requires an understanding and ability of prediction of their hydraulic and chemical consequences. It concentrates on the potential hydraulic effects of altering the saturated flow system through artificial recharge, which is mostly controlled by the hydrological and geological characteristics of the aquifer system. Field, laboratory, analytical, and simulation methods generally are combination used to promote an understanding of the hydro-geological system as a basis for predicting potential consequences. Optimization techniques may be combined with predictive models of groundwater flow and other processes to bring an effective tool for planning and management of artificial recharge projects [7].

Artificial recharge projects are implemented for many objectives in an assortment of aquifer systems. In any case of the initial distribution and trend of hydraulic heads, artificial recharge will alter these heads and related conditions. characterization of geological patterns is important in determining the viability of an artificial recharge project, especially where significant groundwater flow is required between recharge and discharge positions.

The saturated-flow of an artificial recharge system study should consider the hydrological properties which include the head distribution stress prior for project operations, hydraulic properties, the destiny of recharged water, and effects on site. The distribution of head, stress, and hydraulic properties in simulation models can be developed to help address the fate of artificially recharged water and off-site effects. Monitoring and simulation are both used to address off-site effects; however, simulation can also be used to design an effective monitoring network previous to full-scale implementation.

Simulation and optimization models are applied to groundwater problems for tens of year and are used to plan and manage artificial recharge projects. Observation of hydraulic conditions before and during an artificial recharge project is a substantial part of a management plan and an integral part of project operations. project performance measurement is one target of a monitoring program. A second target is providing the information needed for future improvement of predictive modeling capabilities and adjustment of optimization constraints. Minimize uncertainty in model results translates to increase confidence in management decisions based on these models. The volubility of artificial recharge projects lies on the possibility of a groundwater management and integrated use strategy for long-term reliability of groundwater supply, improvement of basin water quality, and for the storing of water.

Artificial recharge programs are conducted in three phases:

a. Feasibility

The feasibility of an artificial recharge techniques that can be used requires an evaluation of the groundwater flow dynamics and recharge basin. The compartmentalization identification or impermeable layers and the aquifers that prevent water recharge to the basin aquifers are the main concern in the evaluation. Also, important concerns are about hydrological variability within the aquifers, the chemical mixing of surface waters native groundwater, and the nature of probable migration of recharged water.

b. Excavation and investigation

Depending on results of the feasibility analysis, a testing program is designed, using existing facilities if it is possible. This work includes physical and chemical modelling of recharge options, detailed chemical analysis of commingled waters that have different initial chemical signatures, and measurement of recharge rates in the test program.

c. Full-Scale project implementation

Excavation results are used to recommend final, full-scale plan parameters, including sites for additional wells or infiltration ponds (if necessary), potential future options for sourcing of surface-water, planning of recharge management during regular operations, and necessary monitoring [9].

1.1.3 Artificial Recharge Methods

Artificial recharge methods can be classified into two main groups, direct and indirect methods.

1. Direct methods

Direct methods include methods that use water in the expose permeable materials of aquifer to flow in it. There are a lot of methods for direct recharge of groundwater that main of them are represented here.

a. Surface water spreading techniques:

The techniques depend on increasing water area and time to be recharged to groundwater which is including different techniques. lightly sloping land Areas without ridges or gullies are most suitable for surface-water spreading techniques [10].

Flooding:

The flood technique can be used in areas where the hydraulic and geological conditions are suitable. Recharge the excess water on the surface from streams or canals occurs by spreading it over large area for long time to be infiltrated to the groundwater. The flow sheet between the delivery canal and the return canal is the spreading zone where water is seeping as shown in Figure 1.2. The flood method is useful in lightly slope lands not more than 3% and without gullies and ridges [11].

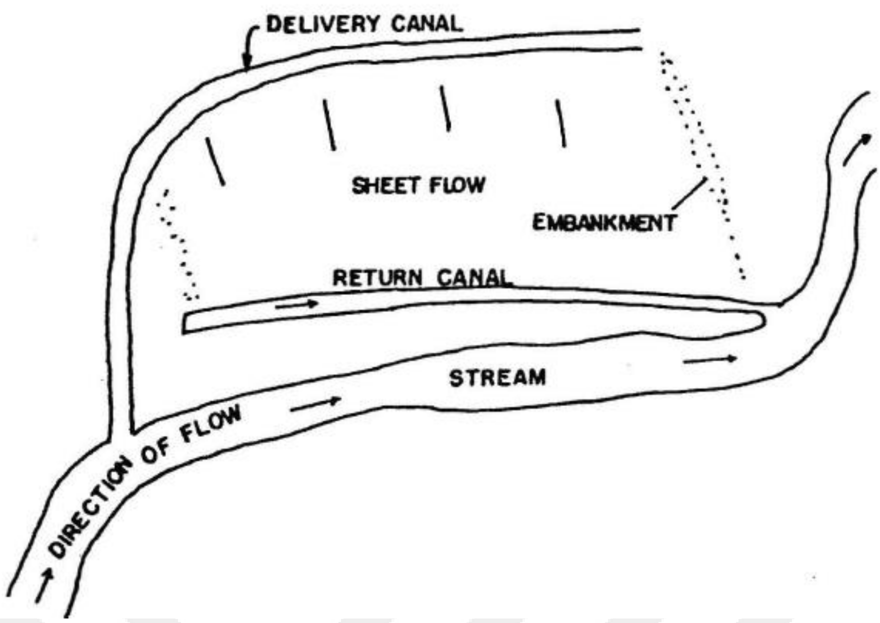


Figure 1.2 Flood recharge method [12]

Furrows and ditches:

To obtain more contact between water and area to recharge water from the stream source or canal. The ditches should have adequate slope to maintain flow velocity and minimum deposition of sediments. The width of the ditches are typically in the range of 0.30 to 1.80 m. A collecting channel to convey the excess water back to the source stream or canal should also be provided. A typical system is shown in Figure 1.3 [12].

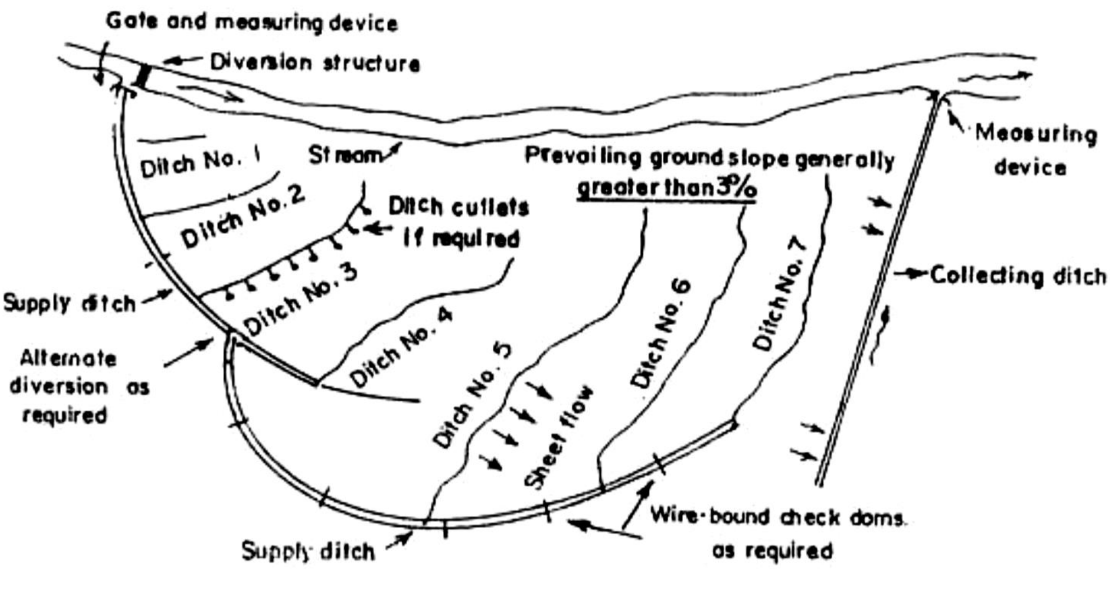


Figure 1.3 Furrows and ditch recharge system [12]

Recharge basins:

Recharge basins are usually formed on the streams and canals banks to increase contact time between soil and water from these sources. It also reduces the suspended materials in the water sources. Recharge basins can be constructed by soil excavation and be formed in divisions as shown in Figure 1.4.

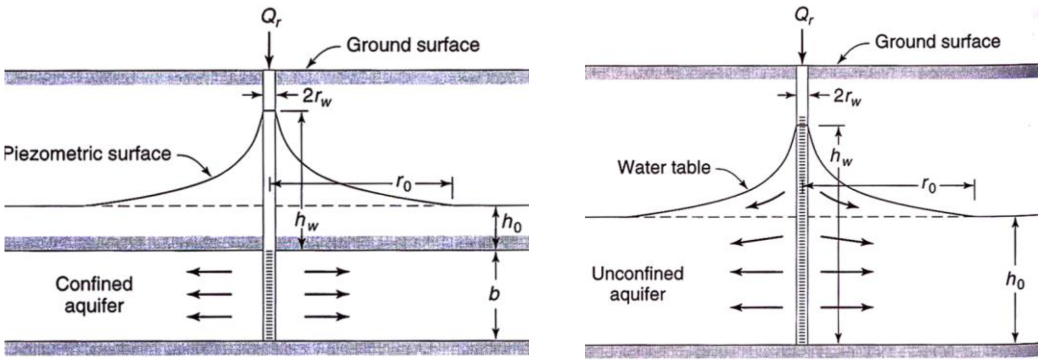
Figure 1.4 Recharge basins [13]

b. Sub-Surface techniques

There are some methods that operate water recharge groundwater artificially which main of them represented here.

Injection wells:

Subsurface groundwater recharge techniques used to directly discharge water into the groundwater storage of a confined aquifer by "pumping in" treated surface water under pressure. Recharge wells are suitable only in areas where a thick impermeable layer exists between the surface of the soil and the aquifer to be replenished. They are also advantageous in areas where surface groundwater recharge requires large areas for infiltration. The Figure 1.5 shows the injection well methods [14].



(a) Confined aquifers (b) Unconfined aquifers

Figure 1.5 Recharge wells [15].

Gravity-Head recharge wells:

Gravity-Head recharge well depends on gravity inflow. Using of this technique is suitable in areas where water levels are dropped. This technique has an economic advantage to store more water with nature gravity forces. The technique is used to facilitate the water infiltration in the upper aquifers which have difficulty with water recharging in times of surface water availability. Excavating the soils to deeper and more permeable aquifers increases the water recharging. Figure 1.6 shows a typical Gravity-Head recharge well recieves water from surface catchments and transmits it to the lower soils that have better conductivity.

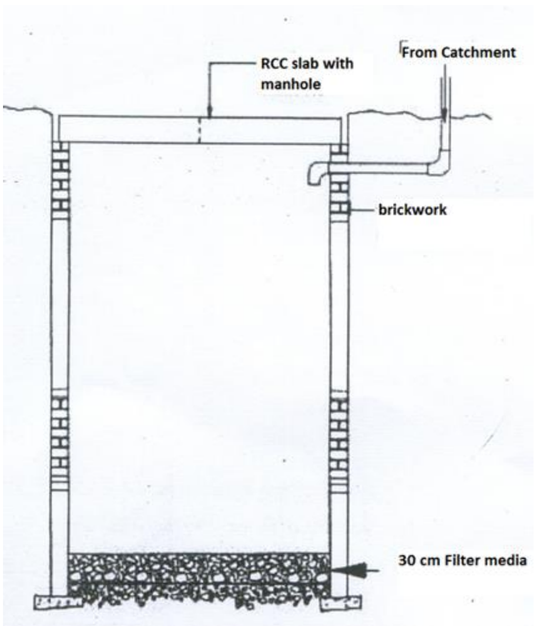


Figure 1.6 Gravity-Head recharge wells [14]

2. Indirect methods

Indirect methods of groundwater recharge are the implementation applied for some purpose and indirectly enhance the groundwater recharge. Indirect methods are concluded induced, modification and conservation methods which are explained as follow.

a. Induced recharge techniques

Induced water recharging through aquifers can be applied by pumping or draining from the aquifers which are connected to surface water being recharged. Its occurs by increasing the capacity of recharging [14]. This method is suitable in the areas of hard rock materials with abandoned channels. It also has an option of improving the water quality passing through the materials of the aquifers [16]. Figure 1.7 shows a system of an induced recharge method using a dain gallery to enhance the water infilitration from the river.

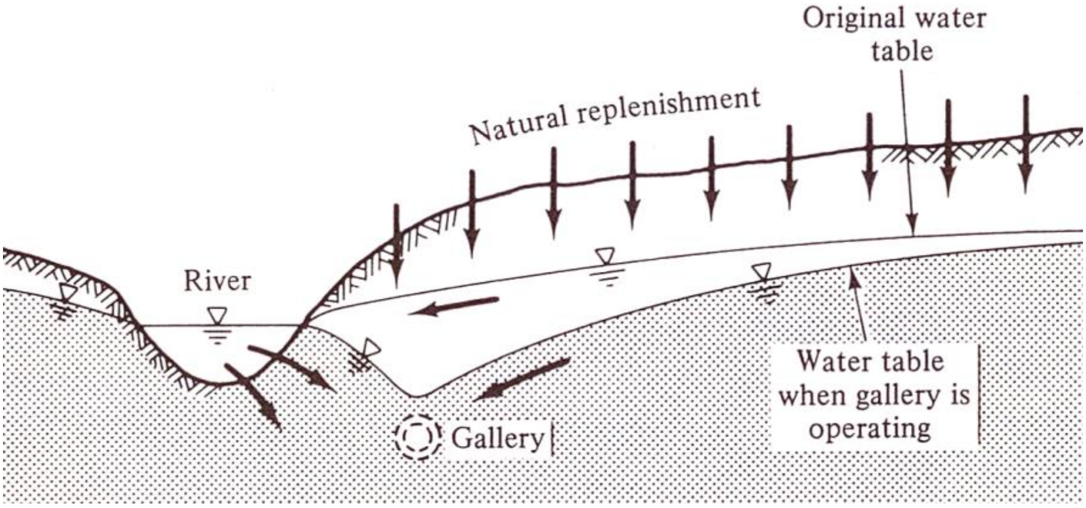


Figure 1.7 Induced recharge gallery for indirect artificial recharge [17].

Pumping wells:

Pumping wells technique of groundwater recharge is applied in the areas near to permanent streams or channels. Pumping water increases the water infiltration within the stream or canal bed as shown in Figure 1.8. The transmitted water quality from surface to the groundwater is the considerable issue in this method [18]. To increase a lake or a river bed capacity of water supplies in deposits or waterlogged areas, collector wells are constructed. The advantage of the collector wells is the economical feature with large discharges and lower lift heads.

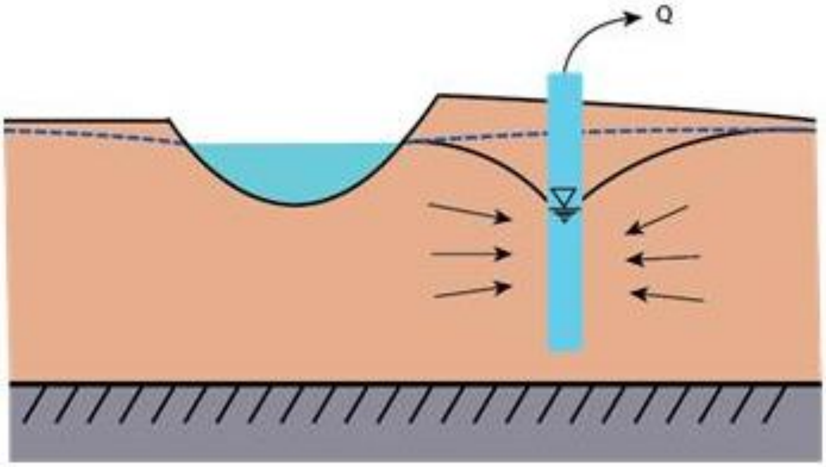


Figure 1.8 Pumping wells for indirect recharge of aquifer

b. Aquifer modification

These techniques increase the capacity of storing and transition of water by modifying the aquifer characteristics. The main techniques of aquifer modification are bore blasting technique, hydro-fracturing technique, fracture seal cementation, and pressure injection. The bore blasting method is applied on aquifer to increase the porosity with blasting holes by drilling bore holes in the required area. While in the hydro-fracturing method, water is injected into the aquifer with high pressure to expand the fractures and improve the hydraulic and storing properties in the media as shown in Figure 1.9.

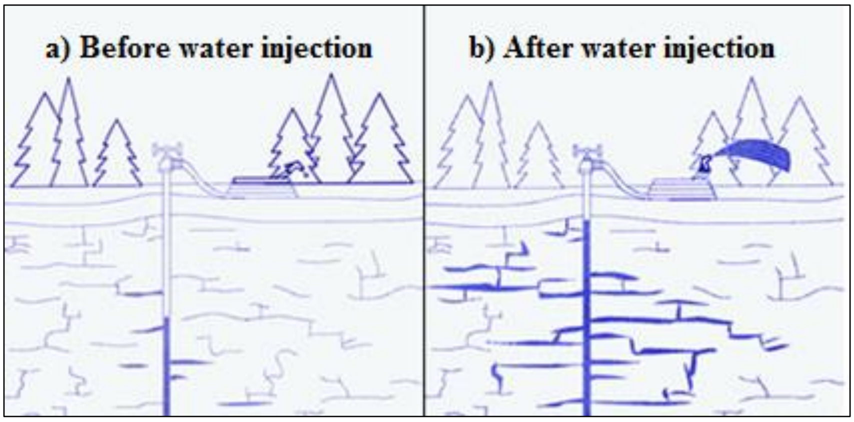


Figure 1.9 Hydro-fracturing technique

c - Groundwater conservation structures

These structures are used to control an aquifer water flow and keep the water stored for longer time [19]. Groundwater dams is an underground reservoir through the constructing a dam under the river to reserve a larger quantity of water and prevent it from passing away to be used at the time of needs as shown in Figure 1.10.

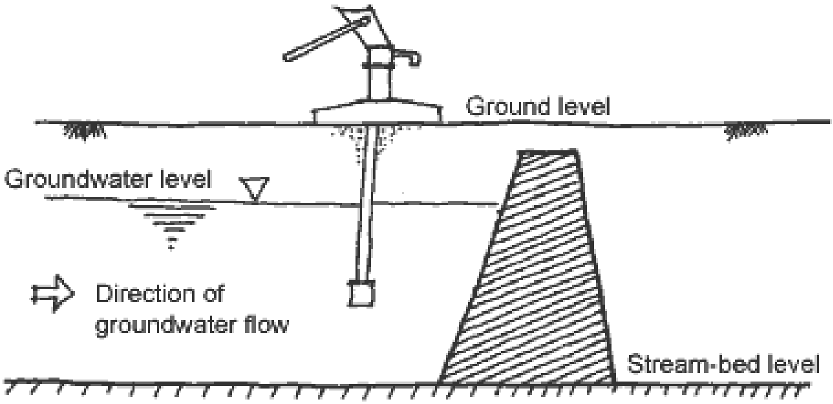


Figure 1.10 A typical scheme of groundwater dam [20]

Fracture-Sealing cementation is another technique used in areas with hard rock materials, where the groundwater movement to deeper aquifers is occurs through fault or fracture plane. This technique is suitable for water conservation in such areas. It is also can be used to prevent pollutants from different sources to join and affect the groundwater.

All the groundwater recharge methods and techniques can be summerized as shown in the Figure 1.11.

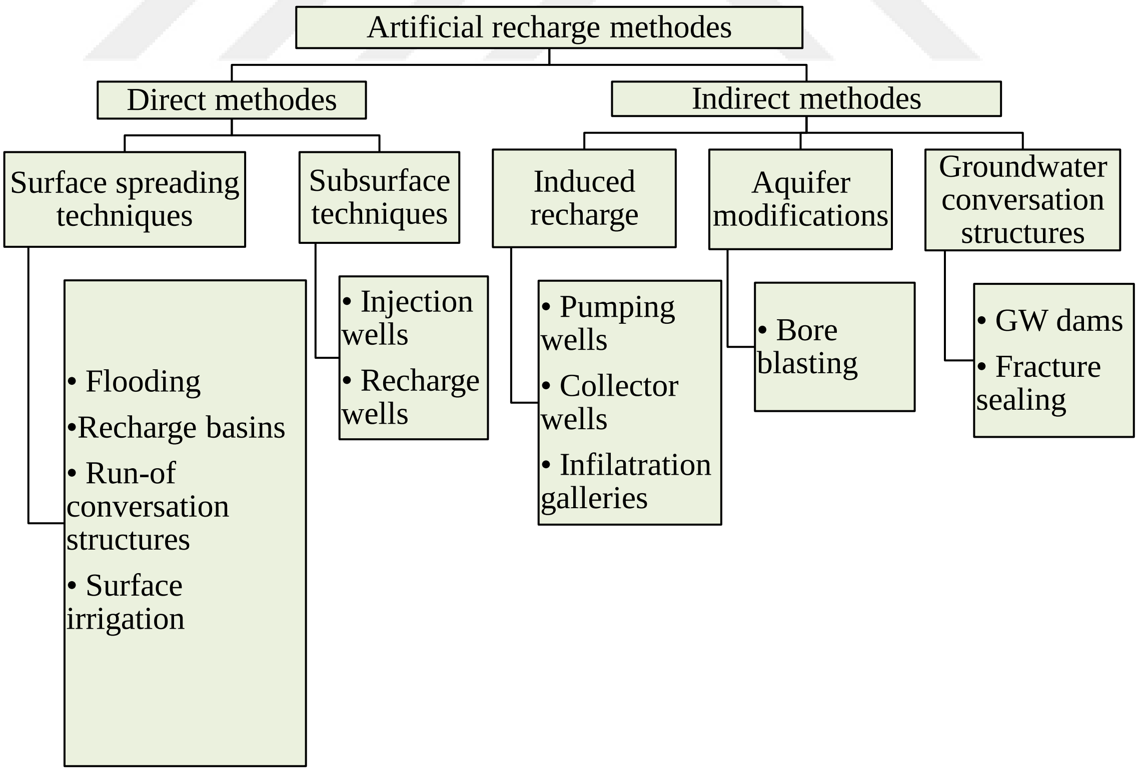


Figure 1.11 Artificial recharge methods

As a result of recharge methods, dams are classified as a direct surface artificial groundwater recharge technique. The main objective of recharge dams is forcing the collected water from the rainfall or other sources to go into the aquifer rather than going away as runoff. Surface aquifer in the recharge zone get the water easily, where the drainage to the subsurface aquifer is generally insufficient for holding all the water in heavy rain events and the remaining water flows over the surface as a runoff. Recharge dams are gathering water in floods or at time where water is plenty to be infiltrated into the Aquifer [21]. Formerly, flood control dams were built in large number and had effect of increasing recharge at same time and many studies were completed that analyzed the potential of enhanced water recharge using dams [22-27].

1.1.4 Groundwater Recharge Dams

As mentioned in previous part, recharge dams are applied for direct surface artificial recharge. In wide world the dams have been described in two types, Type I and Type II as shown in Figure 1.12 [21].

Type I dams are constructed on a permeable and productive carbonate-rock, limestone and dolostone, aquifers on streams and rivers, the catchment basin is gathering water from storm water and transmit it slowly toward the recharge zone. The disadvantage with Type I dams can be in the high costs and in the large volumes that lead to immersion lands during rainy times and leave sediments during dry times which generally classed not feasible [21], and maintain the stored water for long time which is increasing the evaporation losses in the water budget [23]. Type II dams are constructed on the recharge zone itself and stop water as it runs off, giving more time for it to go into the ground. Büyük Cırcıp dam is considred as type II dams.

The technology of ground water recharge dams back to the 19th century, and has been widely used after world war II in Europe and USA. Since 1950, it has been used in UAE, Saudi Arabia, Qatar, Kuwait, Oman, Syria, and Jordan. There are 22 dams constructed in Southestren Anatolia (Turkey) untill 2003, 19 of these dam have hydroelectric station [28].

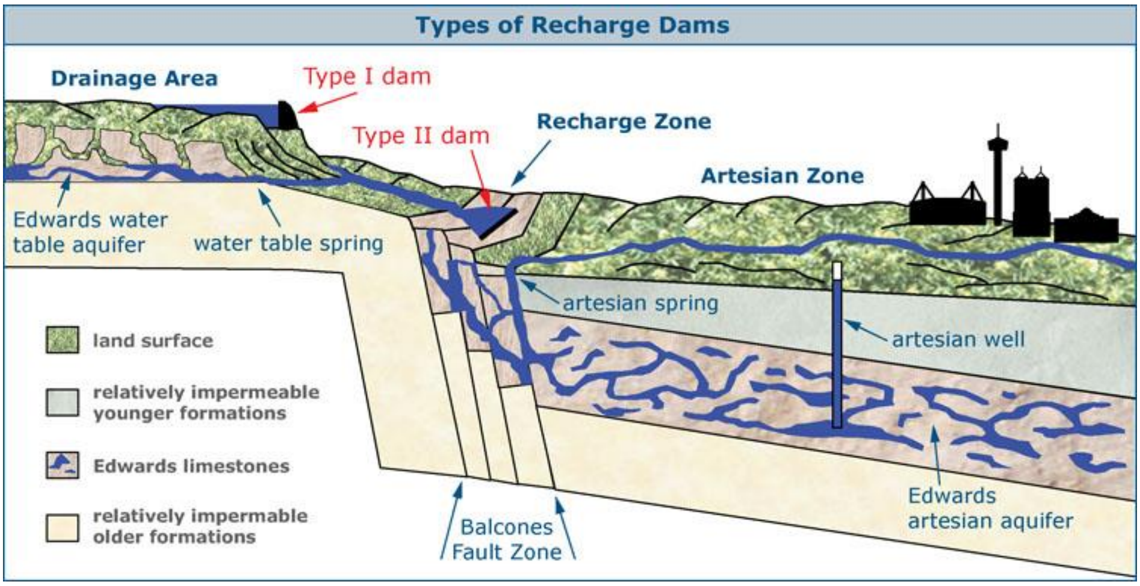


Figure 1.12 Types and objectives of recharge dams [21]

GAP has plan to construct 13 dams in the region to improve the water uses situation and increase groundwater potential amounts, while 9 dams exist in Syria side for storing and irrigation purposes [29]. The recharge efficiency for the small dams in Rajasthan, Inida varies from 12 to 88 percent of total inflow in defferent dams [3], while in Medina lake in USA shows that the recharge quantities increases with the water table in the reservoir [30].

The region of Büyük Cırcıp dam is classed as semi-arid area with annual average rainfall 250 mm in the dam location to 450 mm toward to the moutains in the east and the north region related in Khabor revir basin. The region is depending on agriculture economically in general and the main part of used water for irrigation is groundwater through pumping wells. A number of dams are constructed in both country Turkey and Syria in the region to take advantage of the rainfall water to recover the large exhaustion of groundwater. There are 9 dam constrcuted in Syrian part of region with porpose of irrigation for most of dams by collecting the flood water storing it in the resevoirs to use it in scarcity periods which promotes groundwater recharging in storing time. Also, 4 dams are constructed in the Turkish part. Dams with direct groundwater recharge target are not used in the region before except the two new dam, Büyük cırcıp dam in Mardin and Cudi dam in Şanlıurfa in Turkey as shown in figure 1.13.

Figure 1.13 Existed dam projects in Büyük Cırcıp dam region

The geological characteristics in the Büyük Cırcıp dam location is described as fractured with layers fault, which enhances the groundwater recharge and makes it suitable for such propose dam.

1.1.5 Groundwater Recharge Modeling

Models are approximations or conceptual descriptions using mathematical equations to characterize physical systems; they are not exact descriptions of physical systems or processes. By mathematically performing a simplification of a hydrogeological system, reasonable alternative scenarios can be predicted, tested, and compared [31]. The utility or applicability of a model depends on how closely the mathematical equations approximate the physical system being modeled. In order to evaluate the applicability or usefulness of a model, it is necessary to have a comprehensive understanding of the physical system and the assumptions embedded in the derivation of the mathematical equations. Complicated models can produce wrong results if they are not properly designed and interpreted. To select the appropriate model, modeling objectives should be clear and well identified. If the conceptual model is not properly designed, all modeling processes will be a waste of time and effort. To set up a proper conceptual model, hydrogeological data should be sufficient and reliable [32]. Models assumptions of Groundwater typically include the flow direction, aquifer geometry, the anisotropy of sediments or bedrock in media, the mixtures movements and chemical reactions. Also, groundwater models contain water mass balance (water quantity). Figure 1.14 summrize the development process of mdeling Which starts from defining modeling objectives to the hydrogeological characterization and make conceptualization for the model, After developing the conceptual model by completing the hydrogeological characterization of the site, a computer software is selected to build the model. The capability of simulating encountered conditions should be available in selected model. Similarly, one-dimensional, two-dimensional, three-dimensional groundwater flow and transport models should be selected based on the hydrogeological characteristics and conceptual model [33].

Examples of objectives that can be derived from applications of modeling are:

- Prediction of considered system behavior.

- Obtaining a better understanding of the considered system from the geological, hydrological, and chemical points of view.

- Providing required informations in order to comply with regulations.

- Providing informations for the design of observation networks, by predicting the system's future behavior.

- Providing informations for the design of field experiments.

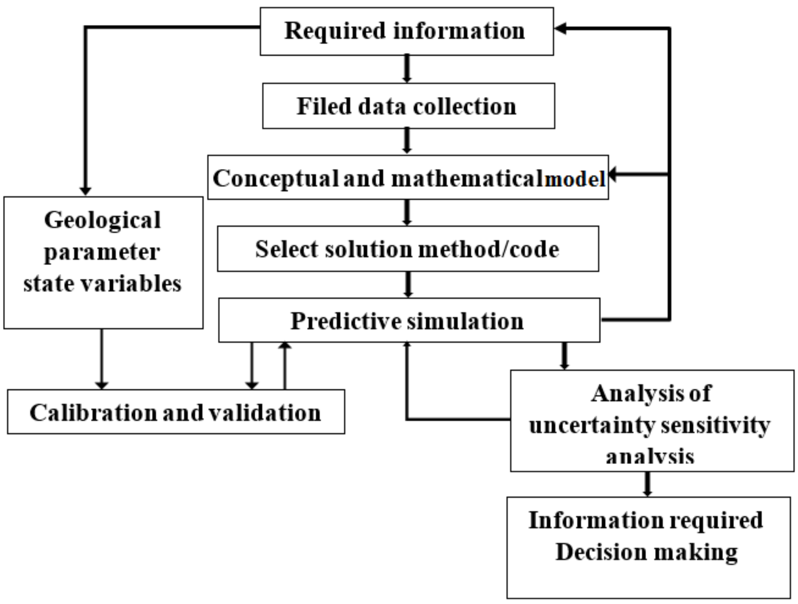


Figure 1.14 The typical groundwater modeling process [33].

1.1.6 Groundwater Flow Numerical Models

As shown in Figure 1.14 the selection of the appropriate numerical model is one of the most important modeling steps which depends on the features of the software and how it meets the required results. The most common used models are listed here with their distinguishing features.

a. Chemflo:

The model enables simulations of water movement and chemical fate and transport in saturated and unsaturated zones. The software can be used to understand unsaturated flow and transport. The model is using the Richards and the convection-dispersion equations with a numerical solution by finite differences approach [34].

b. FEFLOW:

The simulation uses finite element methods for subsurface flow system. FEFLOW simulate groundwater flow, contaminant, groundwater fate and heat transport. It has a feature to capture zone and risk assessment via groundwater-age calculation [35].

c. GFLOW:

Analytic element model with conjunctive surface water and groundwater flow and a MODFLOW model extract feature [36].

d. HYDRUS 1D/2D/3D:

Analysis of water flow and solute transport in variably saturated porous media. Simulating water, heat, and solute movement in one-, two- and three-dimensional variably saturated media [37]. The details are represented in the following chapters.

e. MODFLOW:

Three-dimensional finite-difference ground-water flow model. MODFLOW developed by USGS is considered an international standard for simulating and predicting groundwater conditions and groundwater/surface-water interactions. MODFLOW's modular structure has provided a robust framework for integration of additional simulation capabilities that build on and enhance its original scope [38].

f. GMS:

It is conceptual modeling of groundwater modeling. Construct a representation of the model using familiar GIS objects; points, arcs, and polygons and easily updatable model. Environment of Groundwater modeling for MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, SEAM3D, SEEP2D, PEST, UTCHEM, and UCODE, Figure 1.15 is a representation of GMS environment [39].

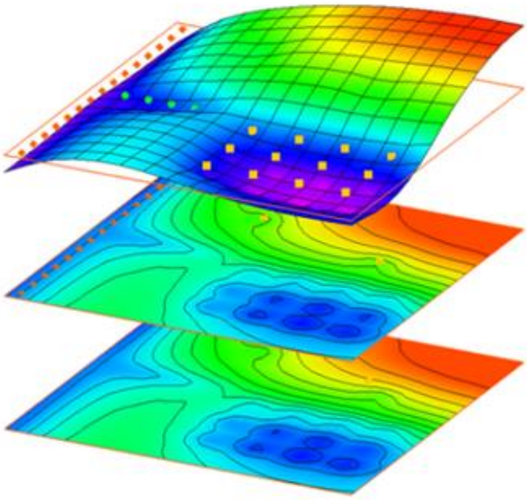


Figure 1.15 GMS model.

g. MicroFEM:

Finite-element program for multiple-aquifer steady-state and transient groundwater flow modeling [40]. Figure 1.16 shows the 2D environment of the provided model.

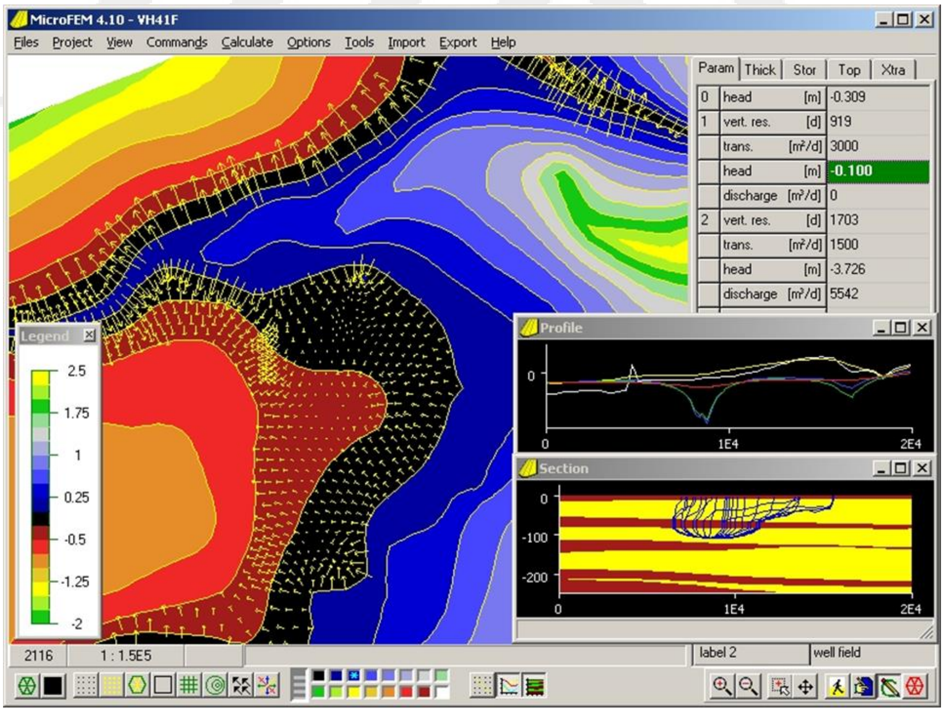


Figure 1.16 MicroFEM 2D model.

1.2 Objectives of Study

According to previous informations about the study area and recharge dams, process the main objectives of this study are:

- Estimating the recharge time of Büyük Cırcıp dam, which is considered to be the time between the full fill reservoir situation until the moment with all water seeped to the ground.

- Estimating the quantities of infiltrated water through the dam bed by studying the water movement to the groundwater through the utilized model on a section of the dam reservoir bed by HYDRUS-1D model.

- analyzing the hydraulic characteristics of the area below the dam and its impact on water movement and the capability of adjusting and developing these characteristics to achieve the objectives of the project.

1.3 Hypothesis

Büyük Cırcıp dam is a GW recharge dam planned by the Southeastern Anatolia Projects (GAP), in one of the most important regions (Mardin-Ceylanpınar) as one of 13 irrigation projects. The project area is located in Euphrates basin, Southeastern Anatolia. According to the aforementioned revised planning report Urfa-Harran and including the Groundwater Irrigation in Mardin Ceylanpınar plains [41], 509.968 hectares of land will be irrigated. For this purpose, from Atatürk dam by the derived Şanlıurfa tunnels to Urfa-Harran 1283 hm^3, Mardin-Ceylanpınar plains 2410 hm^3 with a total of 3693 hm^3 in addition to the water from basins potential groundwater 1563 hm^3, and for drinking water 67 hm^3 has been planned to be used. Accordingly, the total uses of groundwater for each plain will reach 1630 hm^3/year. According to Planning Report, 1646 hm^3/year is estimated as potential groundwater of the basin. At the same time, 355 hm^3/year of water from Urfa-Harran and Mardin-Ceylanpınar irrigated plains is estimated to be transited to the groundwater by infiltration. In this case, with no additional procedure 371 hm^3/year is expected to devolved into groundwater in Syria. Currently, 995.5 hm^3/year as groundwater is transiting to Syria. With transited groundwater 2500 hectares of land is attracted to be irrigated. In this case, for no decreases in the amount of transited groundwater to Syria 13 recharge dams has been recommended in the planning report. Büyük Cırcıp dam in Mardin-Ceylanpınar basin and the other 12 other dams will feed the groundwater. By these dams in both countries, the unused surface water can achieve the groundwater. Recharging dams will keep infiltration the flood water from rainfall and return water from irrigation to the groundwater. The amount of transited groundwater to Syria will reach 983 hm^3/year. It also avoids the inconveniences between countries and comforts the using of groundwater. According to the planning report Büyük cırcıp dam 97 hm^3/year of water is estimated to be devolved to the groundwater.

1.4 Selection of Convenient Model in The Study

HYDRUS-1D have been selected to build the model for the case of study based on the objectives and available features in the software and the capability of achieving these objectives. This model is finite element model that could simulate different boundary conditions with a high capability for coverage. Furthermore, it concluded some new features of dual-permeability, fracture, and porosity as well.

1.5 Contribution of The Research

This research provided a better understanding of the groundwater recharging and water movement through the multi hydraulic properties media. The results from this research can be useful for decision maker in water resources management to provide adaptation strategies and mitigation measures for droughts and floods control in the regions facing water scarcity. In addition, the study gives the researchers a knowledge about a new topic in terms of the implementation of the utilization of geological formations in the appropriate areas for the recharge of groundwater by recharge dams using a new saturated and unsaturated subsurface flow model.

CHAPTER 2

MATERIALS AND METHOD

In this chapter, the study area data and the subsurface flow model fundementals and concepts are presented. Farthermore, daul prosity and permeability concepts in HYDRUS-1D and computation of water balance are presented in following.

2.1 Description of The Study Area

Büyük Cırcıp dam is located in the area, between 60°315’9’’ East, 40°99’299’’ North and 60°332’3’’ East, 4°099’167’’ North coordinates, 151 km from Şanlıurfa province and 57.5 km from Viranşehir district. The project location is shown in Figure 2.1.

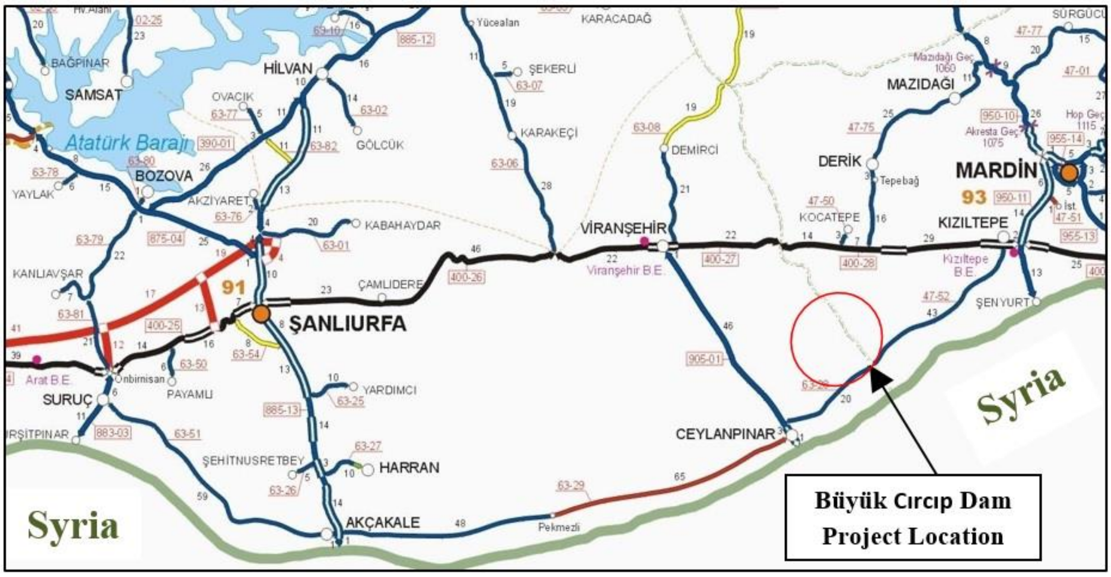


Figure 2.1 Büyük Cırcıp groundwater recharge dam project location

Büyük Cırcıp groundwater recharge dam is one of 13 small irrigation projects that has been constituted in Mardin-Ceylanpınar near to Syrian borders, in the Southeastern Anatolia Projects (GAP) on Euphrates basin. The projects are purposed for more effective use of water resources in the region respectively. Büyük Cırcıp dam and the other 12 dams will recharge the groundwater and will keep the flood water from rainfall and return water from irrigation to infiltrate to the groundwater. The geological map for the region show the general geological formations, upper layer consists of N_1^t which is assortment of undifferentiated tortonian, marls, limestone, gypsum, sandstone and calcareous clay with profile section C as shown in Figure 2.2. According to geologic study with more accurate, 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 it is in alluvium and deposited sediments of the river.

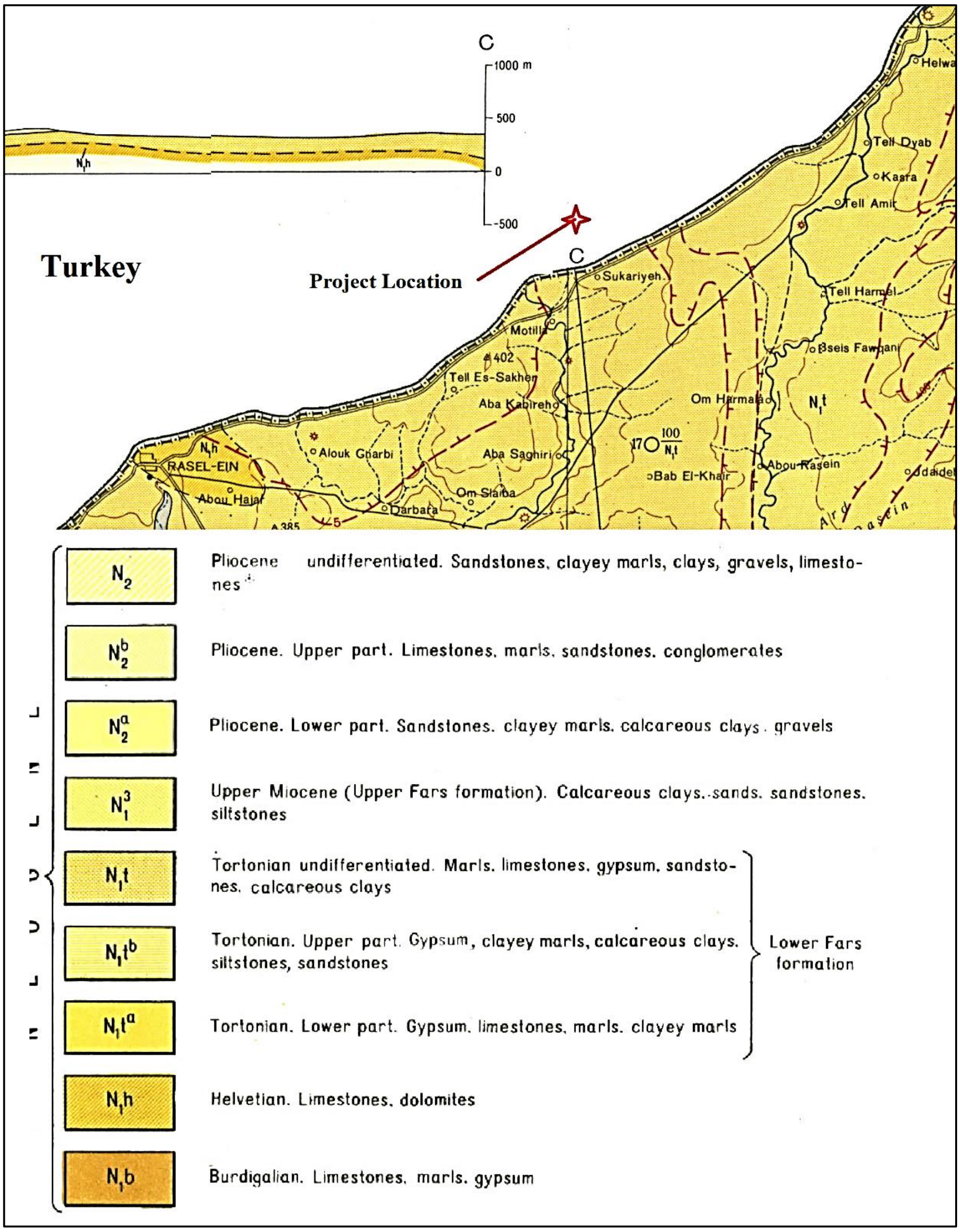


Figure 2.2 The geological map of the region [42]

The first layer underground of Büyük Cırcıp dam lake with 14 meters depth is alluvial, lower remaining layers are the formation of limestone with fractured media. The water movement exhibit non-linear behavior at beginning, so the simulation divided the first meter of soil column depth to finer grid precisely in order of accurate results. Table 2.1 shows the soil profile distribution and the hydraulic properities of these materials. Hydraulic conductivity K is estimated as an average values of the porous media and fractured media hadraulic conductivity.

Table 2.1 Material distribution and hydrogeological characteristics.

Depth from ground surface (m)	**Material properties**	**Fractured properties**	**K average hydraulic conductivity (m/s)**	**K average hydraulic conductivity (m/h)**	**K porous media (m/h)**	**K fractured media (m/h)**
0-14	alluviumchert and limestone gravel	-	0.000002	0.0075	0.0075	0.0001
14-22	Midyat form intermediately separated	fragmented	0.0001388	0.5	0.0500	3.05
22-32	Midyat form little separated	fragmented	0.000035	0.126	0.0126	0.7686
32-46	Midyat form little separated argillaceous chalky limestone	fragmented	0.000133	0.478	0.0478	2.914
46-54	Midyat form little separated argillaceous chalky	faulted	0.000017	0.061	0.0061	0.3733
54-56	Midyat form little separated argillaceous chalky	fragmented	0.000143	0.510	0.0510	3.1122
56-58	Midyat form little separated argillaceous chalky	fragmented	0.0000161	0.058	0.0058	0.3514
58-60	Midyat form little separated argillaceous chalky hollow strong limestone	fragmented	0.0000217	0.078	0.0078	0.474
60-90	Midyat form little separated argillaceous chalky hollow		0.0000139	0.050	0.0050	0.3074

2.2 Characteristics of Büyük Cırcıp Recharge Dam

Büyük Cırcıp recharge dam area is characterized by a light slope and a shallow topography in general except for river valley and stream. The hydrological study over the region shows the characteristics of basins, which have been depended on design the Büyük Cırcıp recharge dam. Table 2.2 shows stream of river in the dam site and basin area as shown in Figure 2.3.

The annual flow volume in this site is estimated 127.5 hm^3. And volume of flood with two-year return period is 22 hm^3. Also flood with 100 year return period has 100.5 hm^3 volume.

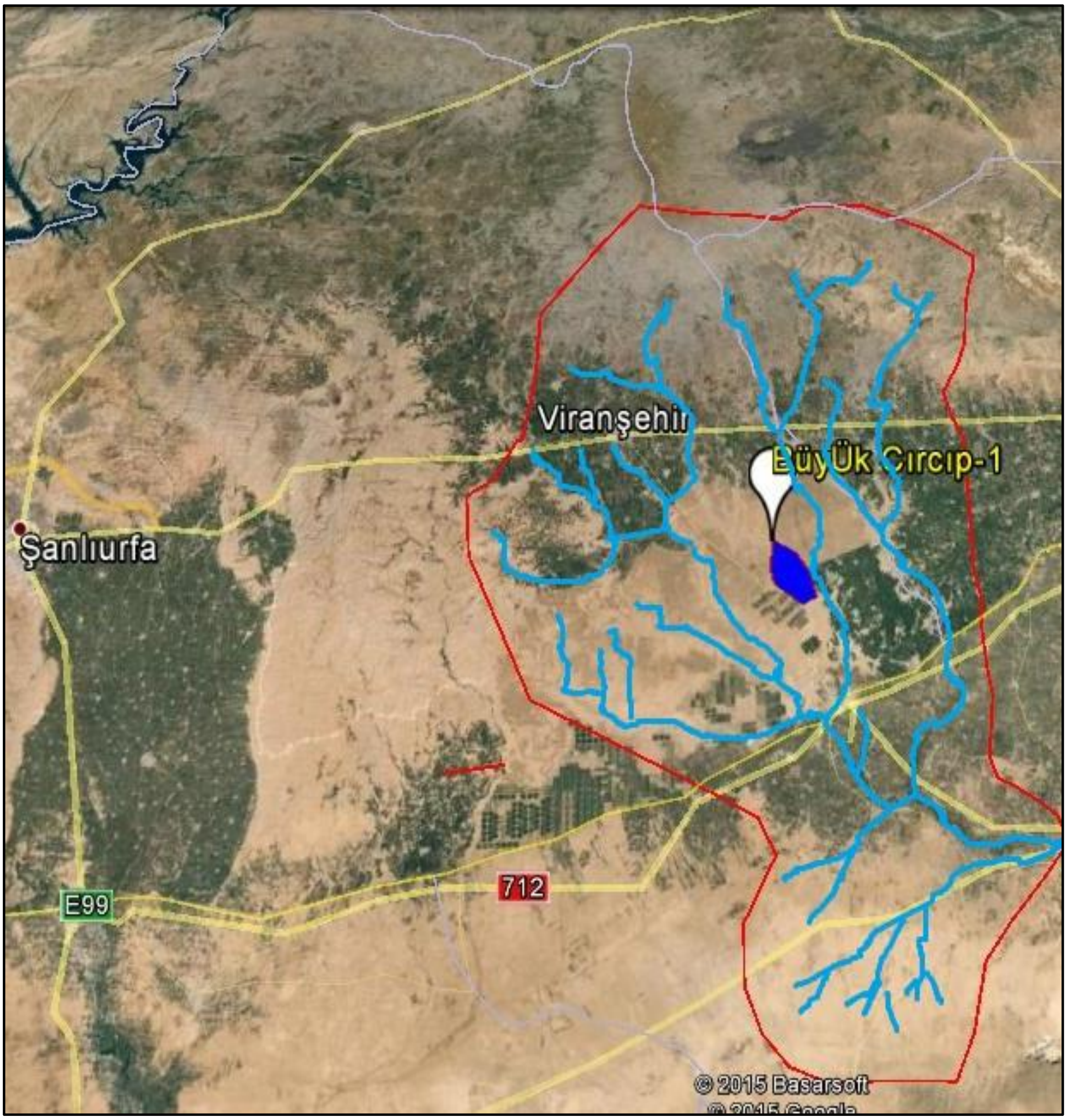


Figure 2.3 Büyük Cırcıp dam and related streams basin

Table 2.2 The hydrological characteristics of Büyük Cırcıp dam basin

Drainage area	1637.90 km^2	
Annual average flow	4.077 m^3/s	
Annual total flow	127.504 hm^3	Flood total volume hm^3
Q_2	154.00 m^3/s	22.022496
Q_5	326.00 m^3/s	38.764512
Q_{10}	462.60 m^3/s	51.938568
Q_{25}	651.90 m^3/s	70.264224
Q_{50}	802.00 m^3/s	84.851208
Q_{100}	959.50 m^3/s	100.048896
Q_{500}	1308.77 m^3/s	133.341696
Q_{1000}	1459.18 m^3/s	147.678408

According to the results of the hydrological study and the design plan of the reservoir, the water levels and the lake are shown in Table 2.3. In normal water level the reservoir capacity is 1.752 hm^3. Also, Table 2.4 contains the Büyük Cırcıp dam body specifications. The maximum and normal water levels is estimated depending on the 100-year flood flows volume that can be extract from Volume-Area-Elevation curve.

Table 2.3 The water levels and related area in Büyük Cırcıp dam lake

Maximum water level	396.84 m
Normal water level	393.00 m
Volume within normal water level	1.752 hm^3
Area within normal water level	0.462 km^2

Table 2.4 The Büyük Cırcıp dam body specifications

Thalweg elevation	383.00 m
Base elevation	368.50 m
Crest elevation	398.00 m
Height from thalweg	15.00 m
Height from base	29.50 m
Crest length	198.07 m
Crest width	6.00 m

In the design of a dam, spillways are essential issue because of the importance of spillway function and its impact over the dam life and efficiency. Table 2.5 contains the spillway design specifications, hydraulic type, location over the dam body, and the dimensions of the spillway. The water head over the spillway is 3.84 m considred in model calculation as additional level added to the crest elevation to know the maximum level of the water in the reservoir.

Table 2.5 The Büyük Cırcıp dam spillway specifications

Type	Frontal, no-gates (Free)
Place	Over the body
Discharge capacity	1459.39 m^3/s
Crest elevation	393.00 m
Crest length	90 m
Water load-H_o	3.84 m
Maximum water level	396.84 m

2.3 Methodology

In this study, the groundwater recharging occurs by the water infiltration from the reservoir to groundwater table in the vertical direction (z-direction) as shown in Figure-2.4 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 (1×1 m^2) 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 54 m. The 100-year flood flow fills the dam and subsequently infiltrated at fully discharge time in the vertical direction in 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 as shown in the conceptual model in Figure 2.4. With 0.5-2 hours interval time brings the total water volume to the dam. To determine the increments in the dam water level, Volume-Area-Elevation curve as shown in Figure 3.3 is used in terms of “known- input flow” m/s and these changes in the water level are 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. In this case the 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. The procedure of modeling and computation are as follow.

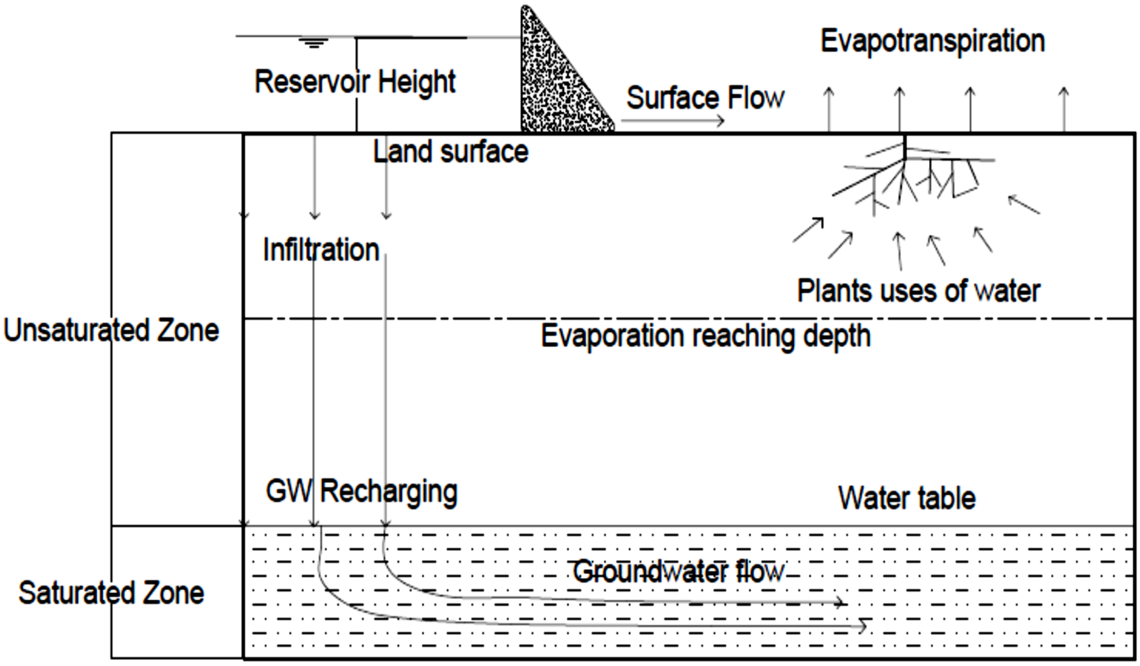


Figure 2.4 Conceptual HYDRUS-1D model of recharge dam and groundwater recharge.

2.3.1 Water Flows Equations in The Model

The first step of groundwater modeling is a conceptual understanding of the physical problem. Figure 2.5 shows cases of potential water movement according to the nature of the medias. Then translate the physical system into mathematical terms [43]. As a result, the governing flow equation for three-dimensional saturated groundwater flow in saturated porous media is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - Q = S_s\frac{\partial h}{\partial t} \quad (2.2)$$

where,

K_{xx}, K_{yy}, and K_{zz} represent hydraulic conductivity along the x, y, and z axes;

h is the pressure head;

Q is the volume of flux per unit volume;

S_s is the specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material.

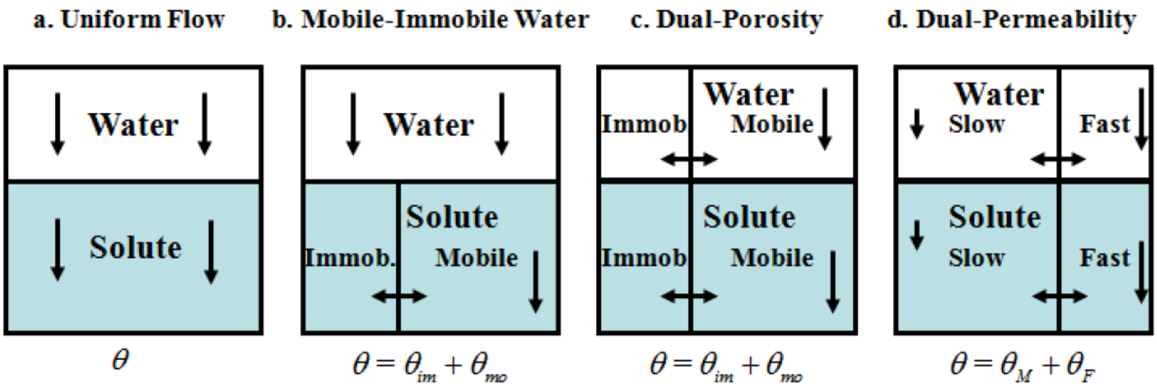


Figure 2.5 Conceptual physical nonequilibrium models for water flow and solute transport [43].

2.3.1.1 Uniform flow

The flow equation for 2D and/or 3D isothermal uniform Darcian flow of water in a variably saturated rigid porous medium with disregarding the air phase role in the liquid flow process. The governing flow equation for these conditions is given by the modified form of Richard's equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}\left(K(K_{ij}^A \frac{\partial h}{\partial x_i} + K_{iz}^A)\right) - S \tag{2.3}$$

where S is a sink term [T^{-1}], h is the pressure head [L], θ is the volumetric water content [L^3L^{-3}], x_i(i=1,2) are the spatial coordinates [L], t is time [T], K_{ij}^A are components of a nondimensional anisotropy tensor K^A, and K is the unsaturated hydraulic conductivity function [LT^{-1}] which is given by:

$$K(h,x,y,z) = K_s(x,y,z)K_r(h,x,y,z) \tag{2.4}$$

Where K_s, K_r the saturated and relative hydraulic conductivity respectively [LT^{-1}]. K_{ij} the anisotropy tensor A in (2.3) is used to account for an anisotropic medium. The diagonal entries of K_{ij} A equal to 1 and the off-diagonal entries equal to zero for an isotropic medium. x_1=x is the horizontal coordinate and x_2=z is the vertical coordinate when (2.3) is applied to planar flow in a vertical cross-section. in (2.3) Einstein's summation convention is used. Consequently, when an index appears twice in an algebraic term, this particular term must be summed over all possible values of the index [43].

2.3.1.2 Flow in a Dual-Porosity system

In models that water flow is restricted to the fractures (or interaggregate pores and macropores), it is assumed as dual porosity flow, and that water in the matrix (intra-aggregate pores or the rock matrix) does not move at all. The models assume that the matrix contains immobile water pockets, can store, exchange, and retain water, but does not allow flow to be convicted. The assumption leads to dual-porosity type flow and transport models with two regions [44], [45] that partition (flowing, inter-aggregate) the liquid phase into mobile, θ_m, and immobile (stagnant, intra-aggregate), θ_{im}, regions:

$$\theta = \theta_m + \theta_{im} \tag{2.5}$$

The first-order rate equation calculate the possible exchange of water and solutes between the two regions. Here *m* (mobile) refers to fractures, or macropores, and the *im* (immobile) refers to the soil matrix, intraaggregate pores, or the rock matrix. HYDRUS-1D is based on a mixed formulation in The dual-porosity formulation for water flow using Richards equation (2.3) to describe water flow in the macropores, and a simple mass balance equation to describe moisture dynamics in the matrix as follows [45]:

$$\frac{\partial \theta_m}{\partial t} = \frac{\partial}{\partial z}\left(K(h)\left(\frac{\partial h}{\partial x}\right) + \cos\alpha\right) - S_m - \Gamma_w \tag{2.6}$$

$$\frac{\partial \theta_{im}}{\partial t} = \qquad -S_{im} - \Gamma_w \tag{2.7}$$

where S_m and S_{im} are sink terms for both regions, and Γ_w is the transfer rate for water from the inter- to the intra-aggregate pores. An alternative dual-porosity approach, not implemented in HYDRUS-1D [46], [47].

2.3.1.3 Flow in a dual- permeability system

Different approaches of dual-permeability as shown in Figure 2.5 describes flow in structured media. Some models use similar formulations for flow in the fracture and matrix regions, others use different equations for each region. HYDRUS-1D has a typical example of the first approach, which is set by Gerke and van Genuchten [48], [49] who used the Richard equation to each of the two pore regions. The flow formulas in (2.8) describes the fracture (macropore) flow *f* and in flow in matrix *m* pore systems.

$$\frac{\partial \theta_f(h_f)}{\partial t} = \frac{\partial}{\partial x_i}\left[K_f(h_f)\left(K_{ij.f}^A \frac{\partial h_f}{\partial x_i} + K_{iz.f}^A\right)\right] - S_f(h_f) - \frac{\Gamma_w}{w} \tag{2.8.a}$$

$$\frac{\partial\theta_m(h_m)}{\partial t} = \frac{\partial}{\partial x_i}\left[K_m(h_m)\left(K^A_{ij.m}\frac{\partial h_m}{\partial x_i} + K^A_{iz.m}\right)\right] - S_m(h_m) - \frac{\Gamma_w}{w} \qquad (2.8.b)$$

Where subscripts *f* and m refer to the fracture and matrix domains, *w* is the ratio of the volumes of the macropore or fracture domain and the total soil system [-], θ is the water content volume [L^3L^{-3}], *h* is the pressure head [L], *S* is a sink term [T^{-1}], x_i (i=1,2) are the spatial coordinates [L], *t* is time [T], Γ_w is the transfer rate for water from the inter- to the intra-aggregate pores, K_{ij}^A are components of a dimensionless anisotropy tensor K^A, and *K* is the unsaturated hydraulic conductivity function [LT^{-1}] given by (2.4).

where K_r represent the relative hydraulic conductivity and K_s refer to the saturated hydraulic conductivity [LT^{-1}]. The anisotropy tensor K_{ij}^A in (2.8.a), which can be different for the two domains, is used to account for an anisotropic medium. The diagonal entries of K_{ij}^A equal one and the off-diagonal entries zero for an isotropic medium. If (2.8.a) is applied to planar flow in a vertical cross-section, $x_1=x$ is the horizontal coordinate and $x_2=z$ is the vertical coordinate, the latter taken to be positive upward. Einstein's summation convention is used in (2.8.a) and throughout this report. Hence, when an index appears twice in an algebraic term, this particular term must be summed over all possible values of the index.

Solutions of the Richards equation (1) require knowledge of the unsaturated soil hydraulic functions made up of the soil water retention curve, *θ(h)*, which describes the relationship between the water content θ and the pressure head h, and the unsaturated hydraulic conductivity function, *K(h)*, which defines the hydraulic conductivity *K* as a function of h or θ. The dual-permeability approach, as developed by Gerke and van Genuchten [49], is relatively complicated in that the model requires characterization of water retention and hydraulic conductivity functions (potentially of different form) for both pore regions, as well as a hydraulic conductivity function of the fracture-matrix interface. θ_f and θ_m represent the in fracture and matrix pore domains as in (2.9), where water contents in the dual-porosity model refer to water contents of the total pore space (mobile and immobile).

$$\theta = \theta_F + \theta_M = w\theta_f + (1-w)\,\theta_m \qquad (2.9)$$

2.3.1.4 Water balance computations

The water balance computations are performed in HYDRUS-1D code at prescribed times for several preselected subregions of the flow domain. Each subregion consists of the actual volume of water ([L^2] or [L^3]), described in the water balance information, and the rate, θ (L^2T^{-1}]) or [L^3T^{-1}]), of inflow or outflow exchanged with subregion. V and θ are given by:

$$V = \sum_e K\, A_e \frac{\theta_i+\theta_j+\theta_z}{3} \qquad \text{for 2D} \tag{2.10}$$

$$V = \sum_e V_e \frac{\theta_i+\theta_j+\theta_z+\theta_l}{4} \qquad \text{for 3D} \tag{2.11}$$

and $$O = \frac{V_{new}+V_{old}}{\Delta_t} \tag{2.12}$$

Where θ_i, θ_j θ_k, and θ_l respectively, are water contents estimated at the corner point of element *e*, and where V_{new} and V_{old} re volumes of water in the subregion computed at the current and previous time levels, respectively. The summation in (2.10) and (2.11) is taken over all elements within the subregion. The absolute error in the mass balance is calculated as:

$$\varepsilon_a^w = V_t + V_0 + S_t \int_0^t T_0 dt - \int_0^t Q_n dt \tag{2.13}$$

V_t and V_0 are the water volumes in the flow domain at time *t* and zero, respectively, as computed with (2.10). The third term refers to the amount of cumulative root water uptake, and the fourth term gives the cumulative flux through nodes, where n_Γ, located along the boundary of the flow domain at an internal source and sink nodes. The accuracy of the numerical solution is estimated in terms of the relative error, ε_r^w [%], as follows:

$$\varepsilon_a^w = \frac{|\varepsilon_a^w|}{max\left[\sum_e |V_t^e - V_0^e|, S_t \int_0^t T_a dt - \int_0^t \sum_{n_\Gamma} |Q_n| dt\right]} \tag{2.14}$$

where V_t^e and V_0^e are the water volumes in element *e* at times *t* and zero. In HYDRUS-1D the absolute error is related to maximum value of two quantities not to the volume of water flow in the domain. the summation of the absolute changes in water content over all elements represents the first quantity, whereas the second quantity is the sum of the absolute values of all fluxes in and out of the flow domain. Because cumulative boundary fluxes are often much smaller than the volume in the domain, especially at the beginning of the simulation.

CHAPTER 3

GROUNDWATER RECHARGE DAM SIMULATION

In this chapter the procedure of recharge dam modeling by HYDRUS-1D is presented. First of all, the capability of the model for unsaturated zone modeling and options are illustrated, then two method of flow routing for recharchge amount computation are explained. As mentioned in previous chapter, HYDRUS-1D is a Microsoft- Windows-based graphical and interactive user interface model solves the Richards flow equation method [45]. In addition, the model of non-isothermal, liquid-vapor flow and heat transfer. There are also options of convection and heat transfer solutions based on Fick's equation of advection and dispersion equations. The model of groundwater movement characteristic curves is calculated using hydraulic conductivity of soil moisture, pressure and water content of soil-moisture pressure relationships with Van Genuch and Brooks-Corey equations. In the model, the ground surface water is defined as the upper limit with constant pressure. In addition to, the water flow inputs are defined as atmospheric conditions (precipitation and/or evaporation). The base (bottom) boundary condition of of model is assumed as free drainage boundary. HYDRUS-1D model of the US salinity laboratory, and Riverside-California University is free, a model was developed with the partnership. 2D and 3D models are sold by PC-Progress firm and provides technical support. With this model many types of problems can be solved, some of them: water balance models, groundwater recharge estimation, the performance of the surface plant covering, nitrate and pesticide spills and other engineering problems. Properties used by the model show the following pattern input screen image Figure 3.1.

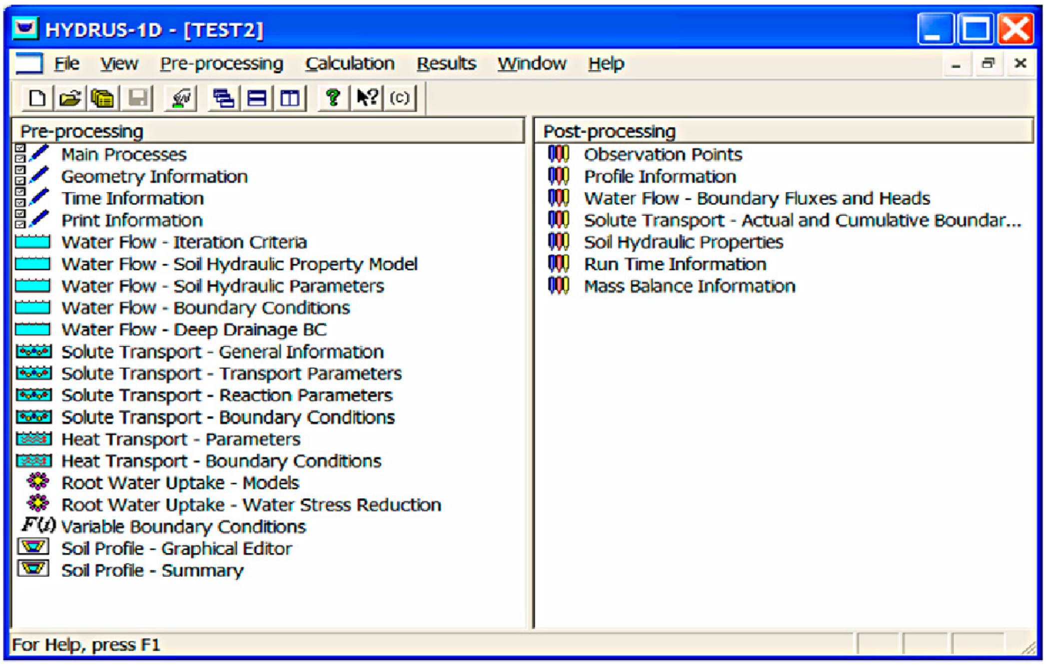


Figure 3.1 Model introduction Screenshot

HYDRUS-1D has following features to built simulation for:

- Steam flow
- Combined water, steam, and energy transport.
- Dual-permeability type, water flow, and transported materials.
- Dual-porosity type, water flow, and transported materials model.
- Potential evapotranspiration calculations with Penman-Monteith and Hargreaves equations.
- Evapotranspiration and daily changes in precipitation.

3.1 Büyük Cırcıp Stream Flows for The Return Periods

The simulation of Büyük Cırcıp recharge dam built in HYDRUS-1D model with two scenarios. The first scenario is modeling the dam with water levels occurs due to 100-year flood flows and the other is model with water level occurs by the annual flows come into the reservoir. 100-year flood has been selected as return periods according to the flood exceedance probability design recomendation and due to the estimated volume of the reservoir (1.752 hm^3) which is classed as small dam [50]. In 100-year flood flows, the water level increments in Table 3.2 are calculated depended on the flows Q associated to the reurn periods (2, 5, 10, 25, 50, 100, 500, and 1000) years. As for the flow values associated to return periods, the flow values is related to the basin characteristics and have been calculated in the planning study report, these flow are given in Table 3.1.

Table 3.1 Flood hydrograph flows associated to the return periods.

T (hours)	**Return periods (year) and associated discharge flows m^3/s**							
	Q_2	**Q_5**	**Q_{10}**	**Q_{25}**	**Q_{50}**	**Q_{100}**	**Q_{500}**	**Q_{1000}**
0	25.62	25.62	25.62	25.62	25.62	25.62	25.62	25.62
2	25.65	26.78	28.28	30.86	33.20	35.86	41.10	43.36
4	26.55	31.29	36.35	44.48	51.59	59.45	75.44	82.32
6	28.97	40.24	51.34	68.60	83.40	99.57	132.94	147.31
8	33.10	54.22	74.25	104.89	130.89	159.12	217.84	243.13
10	39.61	75.16	108.09	157.91	199.90	245.29	340.23	381.11
12	49.35	105.14	155.87	231.95	295.71	364.39	508.69	570.83
14	63.01	144.48	216.84	324.16	413.43	509.14	711.41	798.51
16	80.23	190.48	286.22	426.62	542.53	666.20	929.16	1042.39
18	99.70	235.98	350.44	515.42	650.03	792.55	1098.49	1230.24
20	117.84	272.81	399.83	580.53	726.62	880.37	1212.91	1356.11
22	132.48	299.17	433.32	622.27	773.94	932.83	1278.49	1427.34
24	143.93	317.34	454.77	646.67	799.77	959.50	1308.77	1459.18
26	151.30	326.03	462.64	651.89	802.04	958.10	1300.96	1448.61
28	154.47	325.21	456.94	638.00	780.85	928.75	1255.25	1395.85
30	153.72	315.52	438.56	606.24	737.69	873.20	1173.97	1303.49
32	149.17	297.37	408.20	557.70	673.99	793.24	1059.69	1174.44
34	140.56	271.22	367.36	495.73	594.81	695.88	923.21	1021.10
36	128.04	239.65	321.16	429.49	512.83	597.65	788.99	871.38
38	113.49	206.71	274.43	364.13	432.99	502.95	661.08	729.18
40	98.24	173.98	228.81	301.29	356.84	413.22	540.84	595.79
42	84.29	144.71	188.37	246.01	290.15	334.94	436.37	480.05
44	72.11	119.67	154.02	199.38	234.11	269.36	349.18	383.55
46	61.80	98.80	125.57	160.97	188.11	215.66	278.01	304.85
48	53.15	81.54	102.15	129.48	150.47	171.81	22001.00	240.77
50	45.99	67.37	83.00	103.81	119.84	136.18	172.98	188.83
52	40.30	56.19	67.92	83.64	95.81	108.25	136.16	148.18
56	33.72	43.29	50.54	60.39	68.11	76.07	93.73	101.34
58	32.48	40.81	47.17	55.85	62.68	69.73	85.34	92.06

Table 3.1 Flood hydrograph flows associated to the return periods **(cont'd).**

T (hours)	**Return periods (year) and associated discharges m³/s**							
	Q_2	**Q_5**	**Q_{10}**	**Q_{25}**	**Q_{50}**	**Q_{100}**	**Q_{500}**	**Q_{1000}**
60	31.57	38.99	44.69	52.50	58.66	65.03	79.10	85.16
62	30.94	37.71	42.93	50.10	55.76	61.62	74.56	80.13
64	30.52	36.80	41.66	48.34	53.61	59.08	71.14	76.34
70	29.70	34.88	38.87	44.33	48.63	53.09	62.93	67.16
72	29.45	34.26	37.94	42.97	46.92	51.00	60.04	63.93
74	29.19	33.59	36.93	41.48	45.05	48.72	56.88	60.39
76	28.90	32.85	35.82	39.85	42.98	46.21	53.39	56.49
78	28.59	32.03	34.59	38.03	40.70	43.42	49.53	52.16
80	28.23	31.12	3322.00	36.02	38.16	40.34	45.26	47.38
82	27.83	30.15	31.82	34.00	35.66	37.35	41.17	42.82
84	27.43	29.25	30.54	32.23	33.51	34.80	37.76	39.03
86	27.06	28.47	29.47	30.77	31.75	32.74	35.01	35.99
88	26.74	27.81	28.57	29.55	30.29	31.04	32.75	33.49
90	26.46	27.25	27.81	28.53	29.07	29.62	30.88	31.42
92	26.23	26.79	27.19	27.70	28.09	28.48	29.38	29.76
94	26.04	26.43	26.70	27.05	27.31	27.58	28.19	28.46
96	25.89	26.14	26.31	26.53	26.70	26.87	27.26	27.43
98	25.77	25.91	26.01	26.13	26.23	26.32	26.54	26.63
100	25.69	25.75	25.79	25.84	25.88	25.92	26.02	26.06
102	25.63	25.65	25.66	25.67	25.68	25.69	25.71	2572.00
104	2562.00	25.62	2562.00	25.62	2562.00	25.62	25.62	25.62

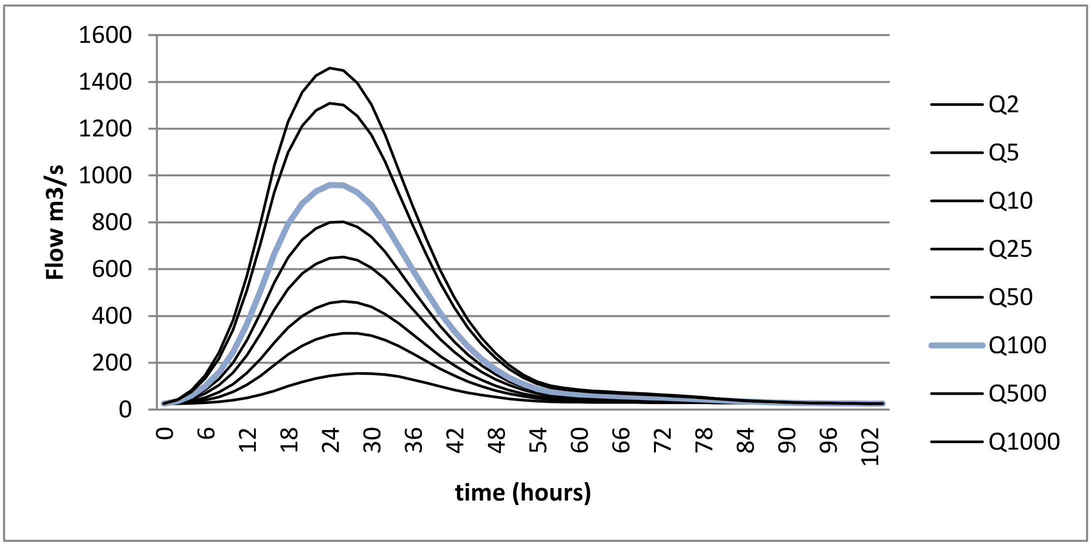


Figure 3.2 Büyük Cırcıp dam floods hydrograph

The flow values of the 100-year flood hydrograph is converted to the volume of water in dams with 0.5-2 hours interval periods. The calculations are carried out as follows [51]:

For start the calculation the value of volume and output are assumed zero. It means in the starting time the resevoir is empty.

Q_0=0

V= 0

$$V_t - V_{t-1} = \frac{I_t + I_{t-1}}{2} + \frac{Q_t + Q_{t-1}}{2} \quad m^3/s \qquad (3.1)$$

$$V_t + \frac{Q_t}{2} = V_{t-1} + \frac{I_t + I_{t-1}}{2} - \frac{Q_{t-1}}{2} \quad m^3/s \qquad (3.2)$$

Where I is the inflow, Q is outflow through the spillway.

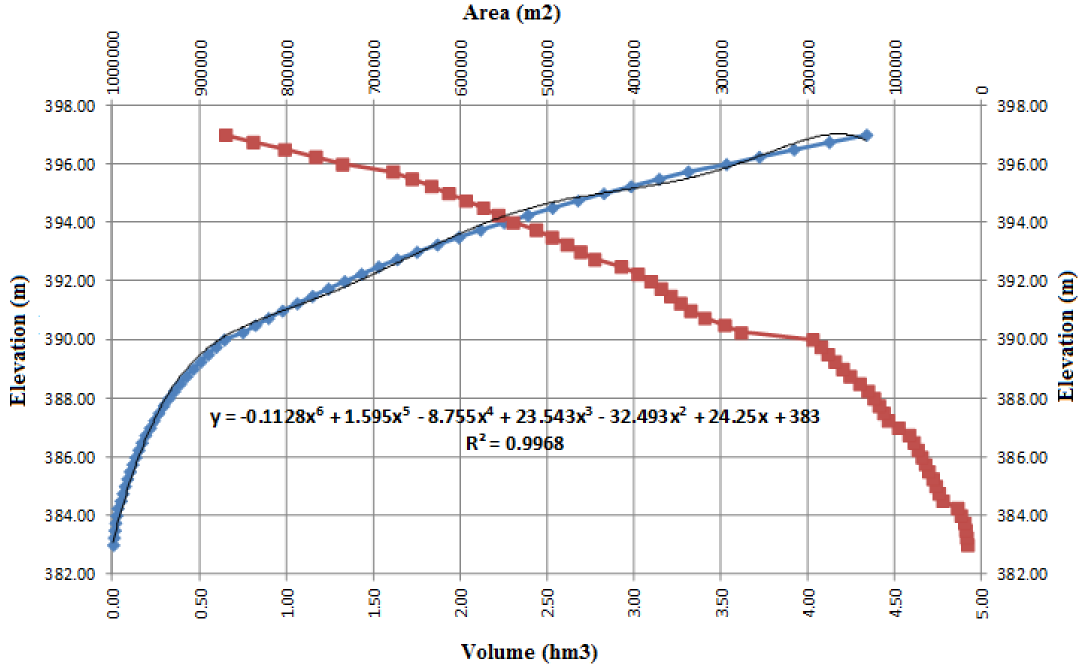


Figure 3.3 Büyük Cırcıp dam Volume-Area-Elevation curve and the best fit polynomial curve equation

Table 3.2 contains the volume increments in the reservoir and assoctiated water level depended on the 100-year flood hydrograh flows and Volume-Area-Elevation curve which is represented in Figure 3.3, and equation (3.3). Where y represents water elevation and x represents the volume of water in the reservoir subjected to y (water level).

$$y= -0.1128x^6+0.1.595x^5-8.755x^4+23.543x^3-32.493x^2+24.25x+383 \qquad (3.3)$$

Table 3.2 Büyük Cırcıp recharge dam levels increments of 100 year flood hydrograph.

Time h	**Q_{100}** (m^3/s)	**Volume increments** (m^3)	**Total V** (hm^3)	**Water level** (m)	**Level incre-ments** (m)	**spillway excess volume** (hm^3)	**explanation**
0	25.62	0	0.00	383.00	0.00	0.00	Empty dam
0.50	28.18	48420	0.05	384.10	1.10	0.00	
1	30.74	53028	0.10	385.15	1.05	0.00	
1.50	33.30	57636	0.16	386.12	0.98	0.00	
2	35.86	62244	0.22	387.01	0.89	0.00	
2.50	41.76	69855.75	0.29	387.83	0.82	0.00	
3	47.66	80471.25	0.37	388.58	0.75	0.00	
3.50	53.55	91086.75	0.46	389.23	0.65	0.00	
4	59.45	101702.25	0.56	389.77	0.54	0.00	
4.50	69.48	116037	0.68	390.22	0.45	0.00	
5	79.51	134091	0.81	390.60	0.38	0.00	
5.50	89.54	152145	0.97	390.95	0.35	0.00	
6	99.57	170199	1.14	391.33	0.37	0.00	
6.50	114.46	192624.75	1.33	391.78	0.46	0.00	
7	129.35	219422.25	1.55	392.36	0.58	0.00	
7.50	144.23	246219.75	1.80	393.06	0.69	0.00	Full dam
8	159.12	273017.25	2.00	393.62	0.56	0.07	
9	202.21	650385	2.21	394.12	0.50	0.44	
10	245.29	805491	2.31	394.31	0.19	0.71	
11	304.84	990234	2.41	394.50	0.19	0.89	
12	364.39	1204614	2.54	394.70	0.20	1.07	
13	436.77	1442079	2.71	394.89	0.20	1.28	
14	509.14	1702629	2.91	395.09	0.20	1.50	
15	587.67	1974258	3.15	395.32	0.22	1.74	
16	666.20	2256966	3.36	395.58	0.27	2.04	
17	729.38	2512035	3.51	395.84	0.25	2.36	
18	792.55	2739465	3.60	396.01	0.17	2.65	
19	836.46	2932218	3.66	396.14	0.13	2.87	
20	880.37	3090294	3.75	396.31	0.17	3.01	

Table 3.2 Büyük Cırcıp dam levels increments of 100 year flood hydrograph **(cont'd).**

Time **h**	**Q_{100}** **(m^3/s)**	**Volume increments (m^3)**	**Total V (hm^3)**	**Level (m)**	**Level increments (m)**	**spillway excess volume (hm^3)**	**explanation**
21	906.60	3216546	3.75	396.33	0.01	3.21	
22	932.83	3310974	3.78	396.40	0.07	3.28	
23	946.17	3382191	3.80	396.44	0.05	3.36	
24	959.50	3430197	3.82	396.47	0.02	3.42	
25	958.80	3452940	3.82	396.47	0.01	3.45	Max W.L.
26	958.10	3450420	3.82	396.47	0.00	3.45	
27	943.43	3422745	3.81	396.46	-0.02	3.43	
28	928.75	3369915	3.79	396.41	-0.04	3.39	
29	900.98	3293505	3.76	396.36	-0.06	3.32	
30	873.20	3193515	3.74	396.30	-0.06	3.22	
32	793.24	5999184	3.65	396.10	-0.20	6.09	
34	695.88	5360832	3.53	395.86	-0.24	5.48	
36	597.65	4656708	3.37	395.61	-0.26	4.81	
38	502.95	3962160	3.18	395.35	-0.26	4.16	
40	413.22	3298212	2.94	395.11	-0.24	3.54	
42	334.94	2693376	2.64	394.82	-0.30	2.99	
44	269.36	2175480	2.45	394.56	-0.25	2.36	
46	215.66	1746072	2.32	394.33	-0.23	1.88	
48	171.81	1394892	2.22	394.12	-0.21	1.50	
50	136.18	1108764	2.15	393.99	-0.14	1.17	
52	108.	879948	2.0908	393.84	-0.164	0.950	
54.0	88.22	707292	2.0481	393.73	-0.105	0.750	
56.0	76.07	591444	2.0196	393.66	-0.072	0.620	
58.0	69.73	524880	2.0044	393.62	-0.039	0.540	
60.0	65.03	485136	1.9896	393.59	-0.038	0.500	
62.0	61.62	455940	1.9755	393.55	-0.037	0.470	
64.0	59.08	434520	1.9700	393.53	-0.014	0.440	
66.0	56.99	417852	1.9679	393.53	-0.006	0.420	
68.0	55.05	403344	1.9612	393.51	-0.018	0.410	
70.0	53.09	389304	1.9605	393.51	-0.002	0.390	
72.0	51.00	374724	1.9553	393.50	-0.014	0.380	

Table 3.2 Büyük Cırcıp dam levels increments of 100 year flood hydrograph **(cont'd).**

Time h	Q_{100} (m^3/s)	**Volume increments** (m^3)	**Total V** (hm^3)	**Level** (m)	**Level increments** (m)	**spillway excess volume** (hm^3)	**explanation**
74.0	48.72	358992	1.9443	393.47	-0.029	0.370	
76.0	46.21	341748	1.9460	393.47	0.005	0.340	
78.0	43.42	322668	1.9387	393.45	-0.020	0.330	
80.0	40.34	301536	1.9302	393.43	-0.023	0.310	
82.0	37.65	280764	1.9210	393.40	-0.025	0.290	
84.0	34.80	260820	1.9118	393.38	-0.025	0.270	
86.0	32.74	243144	1.9049	393.36	-0.019	0.250	
88.0	31.04	229608	1.9045	393.36	-0.001	0.230	
90.0	29.62	218376	1.9029	393.36	-0.004	0.220	
92.0	28.48	209160	1.8921	393.33	-0.029	0.220	
94.0	27.58	201816	1.8939	393.33	0.005	0.200	
96.0	26.87	196020	1.8899	393.32	-0.011	0.200	
98.0	26.32	191484	1.8914	393.32	0.004	0.190	
100.0	25.92	188064	1.8895	393.32	-0.005	0.190	
102.0	25.69	185796	1.8853	393.31	-0.011	0.190	
104	25.62	184716	1.8900	393.32	0.013	0.180	

According to the computations of the flood routing, the maximum water level is about 396.84 m meets reservoir area (recharge area) in 0.462 km^2.

3.2 Büyük Cırcıp Recharge Dam Average Annual Flows

The simulation of the recharge dam according to the annual flow required the input data which are the daily average inflow volume converted to the level increments in the dam lake. The Table 3.3 contains the monthly total inflow volumes (hm^3) records for Büyük Cırcıp dam region at periods between 1970-1999. Converting these volumes to the monthly average flow (m^3/s) throught dividing the volume on time (30×24×3600 second) and multipling by 10^6 (hm^3 to m^3). The average monthly flow values are given in the Table 3.4.

Table 3.3 Total monthly inflow volume

year	Total monthly inflow volume (hm^3)												Total annual hm^3
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
1970	9.89	10.19	11.42	16.14	10.44	11.25	7.58	7.40	7.08	6.96	5.66	4.82	108.83
1971	5.37	5.13	5.35	5.18	4.73	9.13	52.33	6.63	4.26	3.74	3.40	3.23	108.50
1972	3.39	3.25	34.47	3.36	11.47	25.93	27.02	66.26	7.31	3.12	2 775	2816	160.14
1973	3.21	3.87	36.80	3.87	7.69	5.21	3.25	21.13	1.45	0.96	0.90	0.90	37.10
1974	18.89	20.79	24.08	5.37	9.62	72.78	28.99	35.01	11.78	5.71	3.13	0.46	129.26
1975	1.18	11.05	2.10	8.05	35.70	29.12	9.83	90.42	1.26	0.87	0.71	0.79	109.70
1976	1.42	1.50	5.22	64.16	79.00	44.36	173.20	19.82	5.71	1.98	1.46	1.52	399.33
1977	2.67	2.78	4.01	3.29	14.44	11.65	6.85	3.42	1.44	0.37	0.21	0.38	51.49
1978	1.54	1.70	9.87	18.90	78.71	37.56	7.62	3.64	1.87	0.67	0.43	1.12	163.62
1979	1.82	2.15	8.50	30.48	7.31	15.88	5.84	2.36	1.20	0.47	0.23	0.46	76.70
1980	1.38	2.99	14.39	13.32	42.31	42.30	19.67	3.10	1.21	0.58	0.40	0.24	141.90
1981	1.20	1.46	20.11	27.68	39.70	48.53	25.20	7.82	3.21	1.78	1.31	1.39	179.39
1982	2.19	2.08	1.98	62.06	36.07	10.46	19.80	17.25	2.86	2.06	1.93	2.05	168.60
1983	2.37	2.31	2.09	7.07	25.25	30.94	4.38	4.29	3.70	2.87	1.64	1.56	88.46
1984	2.256	1.86	2.57	1.73	5.33	11.14	3.15	1.93	0.73	0.30	0.27	0.27	31.53
1985	0.743	1.03	75.20	0.56	34.14	8.34	35.33	1.69	0.38	0.00	0.00	0.00	82.97
1986	0.56	0.83	15.85	15.42	32.66	7.43	4.20	2.74	1.11	0.45	0.22	0.36	67.57
1987	770.00	1.16	1.96	38.04	23.37	122.57	22.78	3.75	1.15	0.79	0.65	7.28	217.71
1988	48.08	12.65	52.58	48.11	53.90	92.13	93.31	21.29	10.67	8.26	6.29	4.84	408.84
1989	109.14	7.23	7.49	7.35	7.29	20.88	9.12	4.24	3.93	2.49	2.03	1.74	84.69
1990	31.34	5.22	10.30	6.02	36.15	2.10	14.38	2.84	1.53	0.73	0.47	0.23	83.09
1991	0.22	0.537	0.68	68.90	5.48	38.77	3.56	0.83	0.56	0.17	0.00	0.00	51.50
1992	0.00	0.01	14.30	0.12	50.25	104.75	16.46	4.55	0.83	0.19	0.00	0.00	177.30
1993	0.00	10.14	48.35	24.89	32.10	29.55	60.22	51.30	5.40	1.00	0.42	0.12	156.65
1994	0.20	0.61	0.72	3.77	23.94	8.46	12.30	1.49	0.45	0.02	0.00	0.00	51.94
1995	0.00	10.74	63.03	50.32	44.07	21.04	15.34	4.97	2.14	0.17	0.00	0.00	211.81
1996	0.00	0.00	0.00	19.97	22.87	61.69	37.86	9.04	1.51	0.22	0.00	0.00	153.15
1997	0.00	0.07	9.22	10.92	11.65	13.88	17.16	0.65	0.00	0.00	0.00	0.00	63.54
1998	0.00	20.97	82.46	25.07	28.63	11.64	25.82	42.88	0.31	0.00	0.00	0.00	106.10
1999	43.42	52.59	78.99	7.59	73.04	50.46	32.98	2.13	2.02	1.97	1.96	19.57	512.76
2000	1.957	1.983	2.078	3.041	4.762	3.785	2.401	2.092	1.957	1.95	1.957	1.957	29.931
Ave-rage	2.177	3.365	9.189	17.99	28.08	32.740	24.624	9.388	2.567	1.44	1.093	1.035	127.50

Table 3.4 Monthly average flow values.

YEAR	Monthly average flow (m^3/s)												Annual average flow m^3/s
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
1970	3.69	3.93	4.26	6.03	4.32	4.20	2.93	2.76	2.73	2.60	2.11	1.86	3.45
1971	2.01	1.98	2.00	1.93	1.96	3.41	20.19	2.38	1.64	1.40	1.27	1.25	3.45
1972	1.27	1.25	1.29	1.25	4.58	9.68	10.43	23.74	2.82	1.16	1.04	1.09	4.97
1973	1.20	1.49	1.37	1.44	3.18	1.94	1.25	0.79	0.56	0.36	0.33	0.35	1.19
1974	0.71	0.80	0.90	2.01	3.97	27.17	11.19	1.31	0.46	0.25	0.12	0.18	4.09
1975	0.44	4.26	0.79	3.01	14.76	10.87	3.79	3.38	0.49	0.32	0.26	0.30	3.56
1976	0.53	0.58	1.95	23.95	31.53	16.56	66.82	7.40	2.20	0.74	0.55	0.59	12.78
1977	1.00	1.07	1.50	1.23	5.97	4.35	2.64	1.28	0.56	0.14	0.08	0.15	1.66
1978	0.58	0.66	3.68	7.06	32.54	14.02	2.94	1.36	0.72	0.25	0.16	0.43	5.37
1979	0.68	0.83	3.17	11.38	3.02	5.93	2.25	0.88	0.47	0.17	0.09	0.18	2.42
1980	0.52	1.15	5.37	4.97	16.89	15.79	7.59	1.16	0.47	0.22	0.15	0.09	4.53
1981	0.45	0.56	7.51	10.34	16.41	18.12	9.72	2.92	1.24	0.67	0.49	0.54	5.75
1982	0.82	0.80	3.66	23.17	14.91	3.90	7.64	6.44	1.10	0.77	0.72	0.79	5.39
1983	0.89	0.89	0.78	2.64	10.44	11.55	1.69	1.60	1.43	1.07	0.61	0.60	2.85
1984	0.84	0.72	0.96	0.65	2.13	4.16	1.21	0.72	0.28	0.11	0.10	0.10	1.00
1985	0.28	0.40	0.28	0.21	14.11	3.12	13.63	0.63	0.15	0.00	0.00	0.00	2.73
1986	0.21	0.32	0.59	5.76	13.50	2.77	1.62	1.02	0.43	0.17	0.08	0.14	2.22
1987	0.29	0.45	0.73	14.20	9.66	45.76	8.79	1.40	0.45	0.29	0.24	0.28	6.88
1988	1.80	4.88	19.63	17.96	21.51	34.40	36.00	7.95	4.12	3.09	2.35	1.87	12.96
1989	4.08	2.79	2.79	2.74	3.01	7.80	3.52	1.58	1.52	0.93	0.76	0.67	2.68
1990	1.17	2.01	3.84	2.25	1.49	0.79	5.55	1.06	0.59	0.27	0.17	0.09	1.61
1991	0.84	2.07	0.25	0.26	2.27	14.47	1.37	0.31	0.21	0.06	0.00	0.00	1.84
1992	0.00	0.00	0.05	0.04	20.06	39.11	6.35	1.70	0.32	0.07	0.00	0.00	5.64
1993	0.00	0.39	1.81	9.29	13.27	11.03	2.32	19.15	2.08	0.37	0.16	0.05	4.99
1994	0.74	0.23	0.27	1.41	9.89	3.16	4.75	0.56	0.17	0.01	0.00	0.00	1.77
1995	0.00	4.15	23.53	18.79	18.22	7.86	5.92	1.86	0.83	0.06	0.00	0.00	6.77
1996	0.00	0.00	0.00	7.45	9.13	23.03	14.61	3.38	0.58	0.08	0.00	0.00	4.85
1997	0.00	0.03	3.44	4.08	4.81	5.18	6.62	0.24	0.00	0.00	0.00	0.00	2.03
1998	0.00	0.81	3.08	9.36	11.83	4.35	9.96	1.60	0.12	0.00	0.00	0.00	3.43
1999	1.62	2.03	2.95	2.83	3.23	1.88	1.27	0.80	0.78	0.74	0.73	0.76	1.63
2000	0.73	0.77	0.78	1.14	1.90	1.41	0.93	0.78	0.76	0.73	0.73	0.76	0.95
Average	0.84	1.30	3.33	6.41	10.90	11.54	8.89	3.33	0.98	0.55	0.43	0.42	4.08

The daily inflow volume is calculated from the monthly average flow using the triangle distribution method. The average flow is taken from the records in the period (1970 to 2000) as given in Table 3.4. Where the peak flow (maximum flow) in the records is taken as flow for the midle day (15^{th}) in the month and with triangle method are distributed over the rest of days.

The average flow in a month is taken as peak flow Q_p, for example in October is 4.08 m^3/s and being distributed over the month days.

4.08 ÷ (31÷2) =15.5

4.08 ÷ 15.5 = 0.2632 wich is the function of deacreasing for that month.

Table 3.5 Daily total inflow volume hm^3

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	0.01	0.01	0.02	0.04	0.07	0.07	0.05	0.02	0.01	0.00	0.00	0.00
2	0.01	0.02	0.06	0.11	0.22	0.20	0.16	0.06	0.02	0.01	0.01	0.01
3	0.02	0.04	0.10	0.19	0.36	0.34	0.27	0.10	0.03	0.02	0.01	0.01
4	0.03	0.05	0.13	0.26	0.50	0.48	0.38	0.14	0.04	0.02	0.02	0.02
5	0.04	0.07	0.17	0.34	0.65	0.61	0.49	0.18	0.05	0.03	0.02	0.02
6	0.05	0.08	0.21	0.41	0.79	0.75	0.60	0.22	0.06	0.03	0.03	0.03
7	0.06	0.10	0.25	0.49	0.93	0.89	0.71	0.25	0.07	0.04	0.03	0.03
8	0.07	0.11	0.29	0.56	1.07	1.02	0.81	0.29	0.09	0.05	0.03	0.04
9	0.08	0.13	0.33	0.64	1.22	1.16	0.92	0.33	0.10	0.05	0.04	0.04
10	0.09	0.14	0.36	0.71	1.36	1.30	1.03	0.37	0.11	0.06	0.04	0.04
11	0.10	0.16	0.40	0.79	1.50	1.43	1.14	0.41	0.12	0.06	0.05	0.05
12	0.10	0.17	0.44	0.86	1.65	1.57	1.25	0.45	0.13	0.07	0.05	0.05
13	0.11	0.19	0.48	0.94	1.79	1.70	1.36	0.49	0.14	0.08	0.06	0.06
14	0.12	0.20	0.52	1.011	1.934	1.840	1.466	0.53	0.15	0.08	0.06	62.00
15	0.13	0.22	0.56	1.09	1.93	1.98	1.57	0.57	0.17	0.09	0.07	0.07
16	0.14	0.22	0.59	1.16	1.79	2.11	1.57	0.61	0.17	0.09	0.07	0.07
17	0.13	0.20	0.55	1.07	1.65	1.94	1.47	0.56	0.15	0.09	0.07	0.06
18	0.12	0.19	0.52	1.01	1.50	1.84	1.36	0.53	0.14	0.08	0.06	0.06
19	0.11	0.17	0.48	0.94	1.36	1.70	1.25	0.49	0.13	0.08	0.06	0.05
20	0.10	0.16	0.44	0.86	1.22	1.57	1.14	0.45	0.12	0.07	0.05	0.05
21	0.10	0.14	0.40	0.79	1.07	1.43	1.03	0.41	0.11	0.06	0.05	0.04
22	0.09	0.13	0.36	0.71	0.93	1.30	0.92	0.37	0.10	0.06	0.04	0.04
23	0.08	0.11	0.33	0.64	0.79	1.16	0.81	0.33	0.09	0.05	0.04	0.04
24	0.07	0.10	0.29	0.56	0.65	1.02	0.71	0.29	0.07	0.05	0.03	0.03
25	0.06	0.08	0.25	0.49	0.50	0.89	0.60	0.25	0.06	0.04	0.03	0.03
26	0.05	0.07	0.21	0.41	0.36	0.75	0.49	0.22	0.05	0.03	0.03	0.02
27	0.04	0.05	0.17	0.34	0.22	0.61	0.38	0.18	0.04	0.03	0.02	0.02
28	0.03	0.04	0.13	0.26	0.07	0.48	0.27	0.14	0.03	0.02	0.02	0.01
29	0.02	0.02	0.10	0.19		0.34	0.16	0.10	0.02	0.02	0.01	0.01
30	0.01	0.01	0.06	0.11		0.20	0.05	0.06	0.01	0.01	0.01	0.00
31	0.01		0.02	0.04		0.07		0.02	0.00	0.00	0.00	0.00
Total	2.18	3.37	9.19	18.00	28.08	32.74	24.43	9.39	2.57	1.44	1.09	1.04

Depending on daily flows and Büyük Cırcıp dam reservoir Volume-Area-Elevation, water level rises were calculated and these rises as shown in Figure 3.4 are entered into the HYDRUS-1D model as atmosphere boundary conditions.

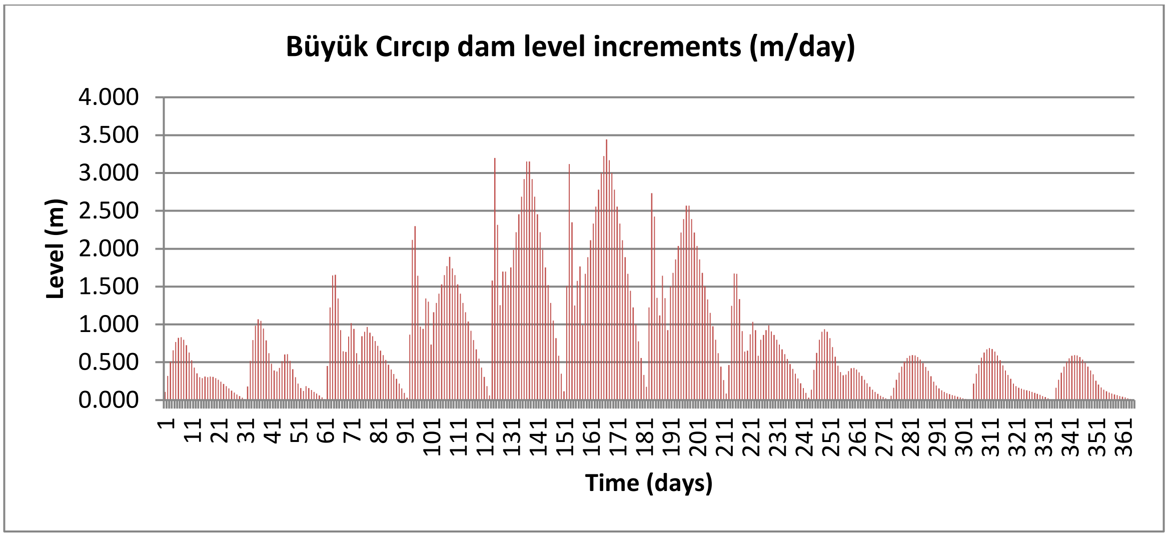


Figure 3.4 Büyük Cırcıp dam water level increments in the dam lake converted from 1st October to 30th September.

3.3 Monthly Evapotranspiration Values.

The evaporation is an important part of calculations of water balance especially in such region which has a high average of evaporation according to the high degree of temperatures and the dry climate. The Table 3.6 shows the degree temperatures for Büyük Cırcıp dam and Ceylanpınar regions with the corresponding evaporation values.

Table 2.12 Büyük Cırcıp dam region evaporation values (mm)

Month	Monthly average temperature		Total monthly rainfall		Total monthly evaporation values			Büyük Cırcıp dam net ET
	Ceylanpınar Elevation 398.00m	Büyük Cırcıp dam Elevation=400. m	Ceylanpınar Elevation 398.00m	Büyük Cırcıp dam Elevation=400.00m	Ceylanpınar Elevation 398.00m	Büyük Cırcıp dam Elevation=400.00m	Free water surface	
	(C)		mm					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = 0.7*(7)	(9) = (8)-(5)
Jan	5.31	4.47	53.2	53.2				
Feb	6.89	6.04	47.57	47.57				
Mar	10.88	10.04	47.59	47.59	77.93	6.27	4.39	
Apr	16.09	15.24	40.77	40.77	112.62	81.01	56.7	15.93
May	22.46	21.61	20.09	20.09	186.49	172.44	120.71	100.6
Jun	28.79	27.95	2.06	2.06	287.5	263.35	184.34	182.3
Jul	32.13	31.29	0.12	0.12	339.62	311.23	217.86	217.7
Aug	30.93	30.08	0.03	0.03	305.51	293.95	205.77	205.7
Sep	25.67	24.83	1.19	1.19	212.91	218.55	152.99	151.8
Oct	19.19	18.35	19.13	19.13	123.69	125.58	87.9	68.77
Nov	11.59	10.75	30.07	30.07		16.54	11.58	
Dec	6.81	5.97	47.41	47.41				
Avge	18.06	17.22	309.24	309.24	1646.27	1488.9	1042.23	942.9

The evaporation values are taken in the model as the water level increments as boundary condition in model. The values of net evaporation are calculated by the substrcution the of the average evaporation from the monthly average rainfall, as shown in the Table 2.12.

3.4 Process of Model Development In HYDRUS-1D

Selection the problem type is the first step in HYDRUS-1D in the main processes, which can be water flow, solute transport, heat transport, root water uptake, or CO2 transport. The objective of the model is simulating the water flow which is selected as shown in Figure 3.5.

The simulation is performed through the following procedures in HYDRUS-1D:

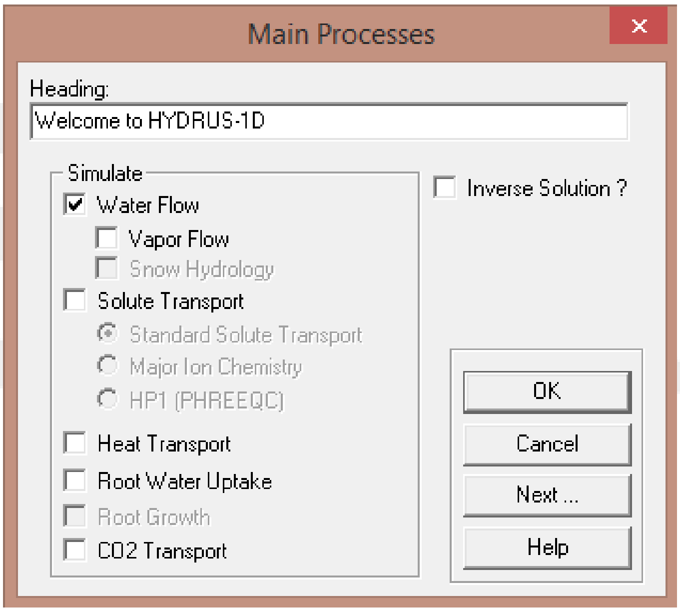


Figure 3.5 Main processes definition

3.4.1 Geometry

The first layer underground of Büyük Cırcıp dam lake with 14 meters depth is alluvial, lower remaining layers are the formation of limestone with fractured media. The water movement exhibit non-linear behavior at beginning, so the simulation divided 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 ground water has also increased. Thus, 54 m column of soil is divided into a total of 101 grid. The Table 2.1 shows material properties obtained by drilling of the log. 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 is defined as the bottom boundary condition in the simulation. 54 meters is eligible to be accepted as the water resistance of the groundwater recharge. Water infiltration through free drainage boundary 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 if the groundwater level will immediately begin to rise along the modeled soil column and become even full saturated making water reaching up to the ground surface. To prevent that, the groundwater simulation is assuming a boundary condition at the base as free drainage as percolated water goes far from the region at reaching moment. The Figure 3.6 shows the number of soil materials and the total depth for the soil profile. There are 5 different layers with different characteristics to the depth of 54m.

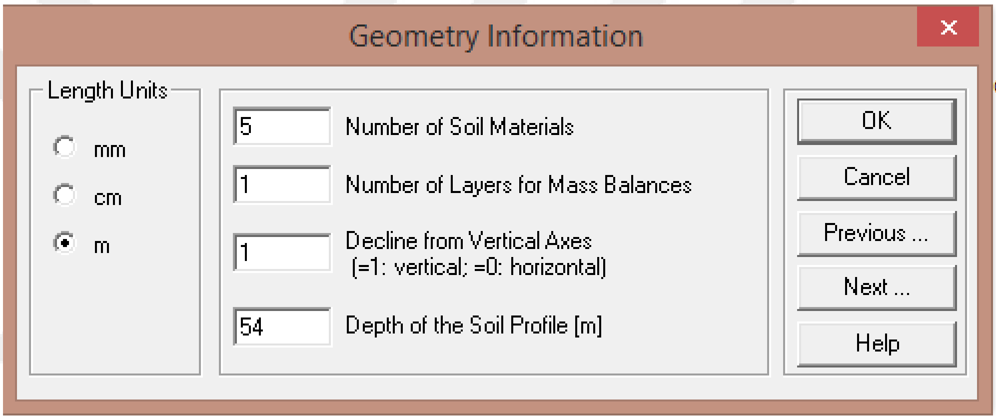


Figure 3.6 Geometry definition

3.4.2 Time Information

Time discretization which specifies the main variables time governing the time discretization. Initial time is starting time of the calculation [t], final time is the final time of the calculation [t], and initial time step which is the initial time increment, dt [t]. In this step, total time is divided into the number of records divisions, where in the simulation it is taken as 304 as shown in Figure 3.7.

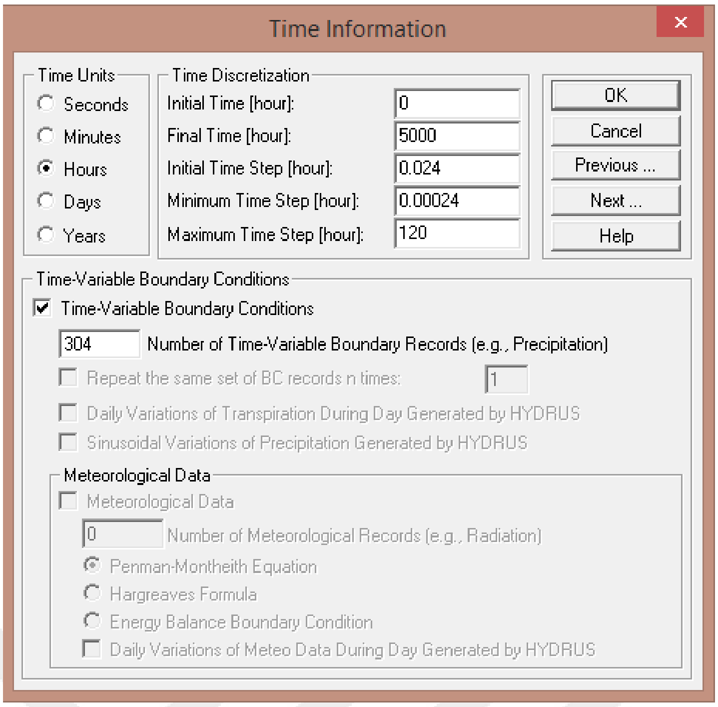


Figure 3.7 Time information definition.

3.4.3 Soil Hydraulic Model

According to the study, the conditions in the soil hydraulic model dialog window user are selected in the hydraulic model to be used for the soil hydraulic properties during the calculations. In order to fully reflect fractured medium, dual-permeability (dual permeability) option is selected in the model as shown in Figure 3.8. After dual permeability option has been selected for each of the two-hydrogeological formation, two hydraulic conductivity assumed for fractured and porous case which are contained in Table 3.7. Cracks and large voids assumed as 33% of the total space. The hydraulic conductivity of fractured environment was accepted much greater than the porous one.

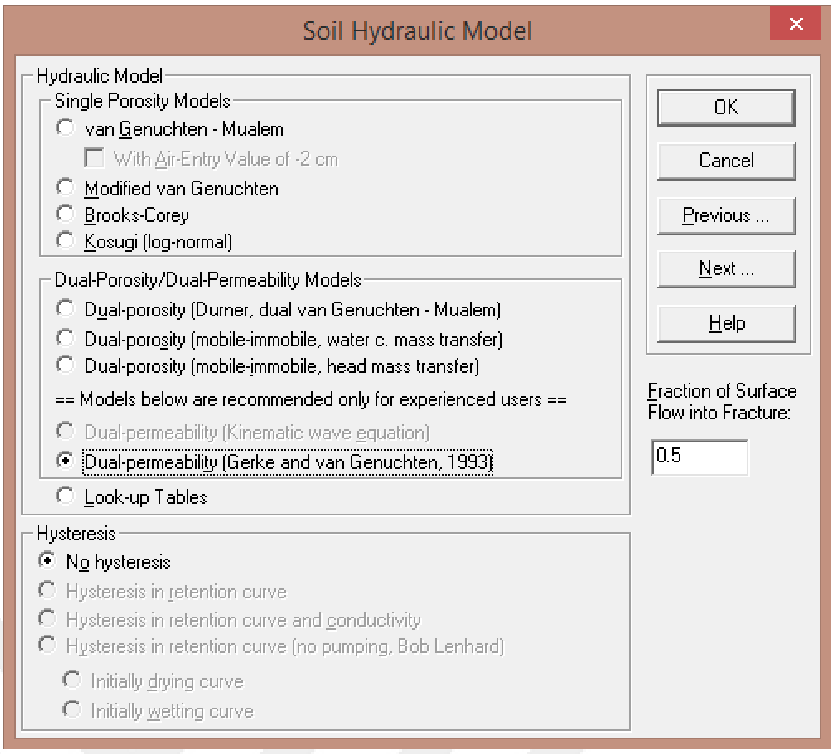


Figure 3.8 Hydraulic model for soil-water characteristics

Table 3.7 Soil hydraulic properties

M	Qr	Qs	Alp	n	Ks	l	QrFr	QsFr	AlphaF	nFr	KsFr	lFr	w	Beta	Gamma	a	Ksa
	[-]	[-]	1/m	[-]	m/h	[-]	[-]	[-]	1/m	[-]	m/h	[-]	[-]	[-]	[-]		m/h
1	0.065	0.41	1.5	1.89	0.0075	0.5	0	0.1	8	2	0.0001	0.5	0.05	3	0.4	0.05	2.05E-08
2	0.01	0.5	0.5	3	0.05	0.5	0	0.9	8	2	3.05	0.5	0.05	3	0.4	0.1	1.37E-07
3	0.01	0.6	0.5	3	0.0126	0.5	0	0.9	8	2	0.7686	0.5	0.05	3	0.4	0.1	3.45E-08
4	0.01	0.5	0.5	3	0.0478	0.5	0	0.9	8	2	2.914	0.5	0.05	3	0.4	0.1	1.31E-07
5	0.01	0.45	0.5	3	0.006	0.5	0	0.9	8	2	0.3733	0.5	0.05	3	0.4	0.1	1.67E-08

Where:

M is the material of the soil,

Qr is the residual soil water content,

Qs is the saturated soil water content,

Alpha is the Parameter α in the soil water retention function [L^{-1}],

n is the Parameter n in the soil water retention function,

Ks is the Saturated hydraulic conductivity,

l is the Tortuosity parameter in the conductivity function [-],

QrFr is the parameter Qr for the fracture region of material M, QsFr is the parameter Qs for the fracture region of material M,

AlphaFr is the parameter α for the fracture region of material M [L^{-1}],

nFr is the parameter n for the fracture region of material M,

KsFr parameter Ks for the fracture region of material M [LT^{-1}],

lFr is the tortuosity parameter in the conductivity function for the fracture region of material M [-],

w is the parameter w for material M [-]. w is the ratio of the volumes of the macropore or fracture domain and the total soil system,

Beta is the parameter b (a shape factor that depends on the geometry) for material M [-],

Gamma is the parameter g (a scaling factor) for material M [-],

A is the parameter d (an effective diffusion pathlength) for material M [L],

Ksa is the parameter Ka (the effective hydraulic conductivity Ka [LT^{-1}] of the fracture-matrix interface) for material M [LT^{-1}],

3.4.4 Boundary Conditions in The Model

In this study the upper boundary condition is taken as atmospheric and the bottom boundary condition as free drainage as shown figure 3.9.

Water infiltration through free drainage boundary 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 if the groundwater level will immediately begin to rise along the modeled soil column and become even full saturated making water reaching up to the ground surface. To prevent that, the groundwater simulation is assuming a boundary condition at the bpttom as free drainage as percolated water goes far from the region at reaching moment.

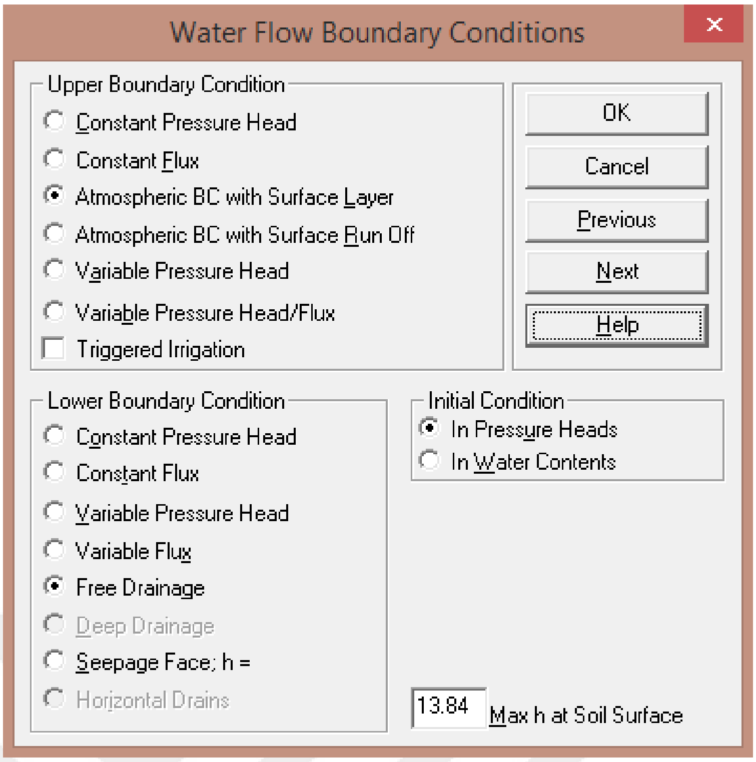
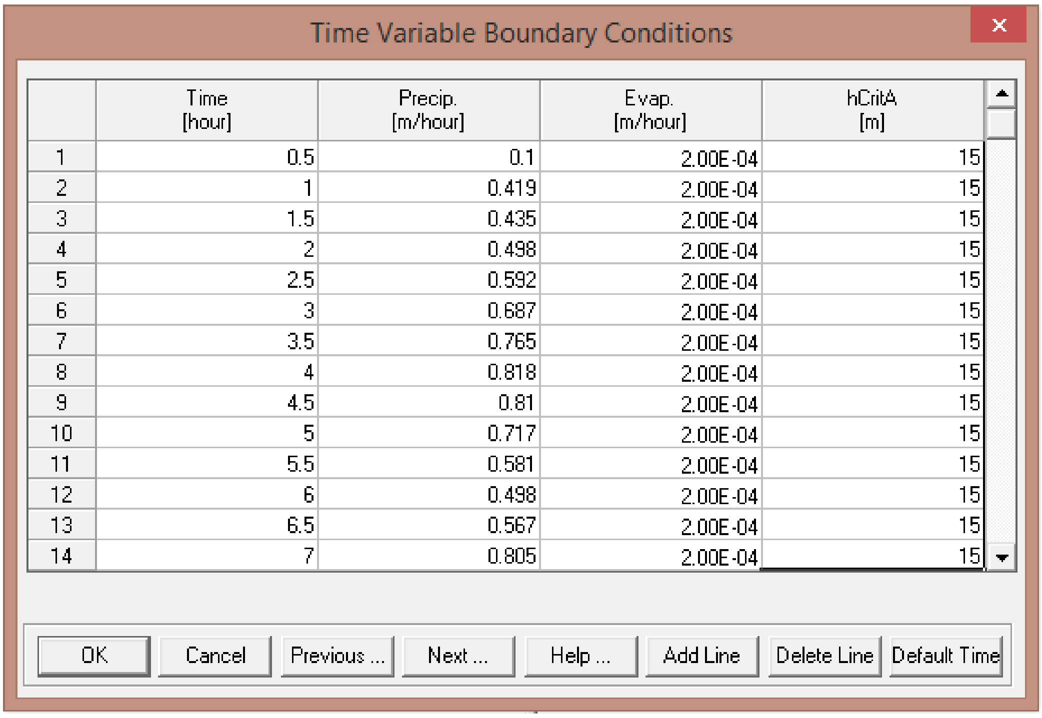


Figure 3.9 Model boundary conditions

3.4.5 Time Variable Boundary Conditions

Boundary condition values are specified for the time interval preceding time given at the same line. Thus, BC values specified in the first row are for the time interval between the initial time and time specified on the same line Figure 3.10.



	Time [hour]	Precip. [m/hour]	Evap. [m/hour]	hCritA [m]
1	0.5	0.1	2.00E-04	15
2	1	0.419	2.00E-04	15
3	1.5	0.435	2.00E-04	15
4	2	0.498	2.00E-04	15
5	2.5	0.592	2.00E-04	15
6	3	0.687	2.00E-04	15
7	3.5	0.765	2.00E-04	15
8	4	0.818	2.00E-04	15
9	4.5	0.81	2.00E-04	15
10	5	0.717	2.00E-04	15
11	5.5	0.581	2.00E-04	15
12	6	0.498	2.00E-04	15
13	6.5	0.567	2.00E-04	15
14	7	0.805	2.00E-04	15

Figure 3.10 Time variable boundary conditions

Where:

Time is the time for which a data record is provided [h]. In the sumulation the records are 104 hours with 100-year flood, but the time extended to 5000 hours with 304 division, and 365 days for annual simulation..

Precip is the precipitation rate [m/h] are taken from level increments given in Tabel 2.8 in 100-year flood simulation, and given in Tabel 2.11 for annual simulation.

Evap is the potential evaporation rate [m/d] which is asumed ,0.005 m/d as average vaule .Trans is the potential transpiration rate [m/h] (in absolute value).

hCritA is the absolute value of the minimum allowed pressure head at the soil surface [m] is taken 15 m.

3.4.6 Soil Profile Information

Initial conditions are specified for the pressure head, temperature. The following properties of the flow domain are defined in the profile module as shown in Figure 3.11:

- Material distribution of soil types with different hydraulic and solute transport properties.
- Root distribution, and root water uptake distribution in the soil profile.
- Sub region distribution used for calculating water and solute mass balances.
- Observation nodes for which a continuous record of the pressure head, water content, and temperature will be saved.

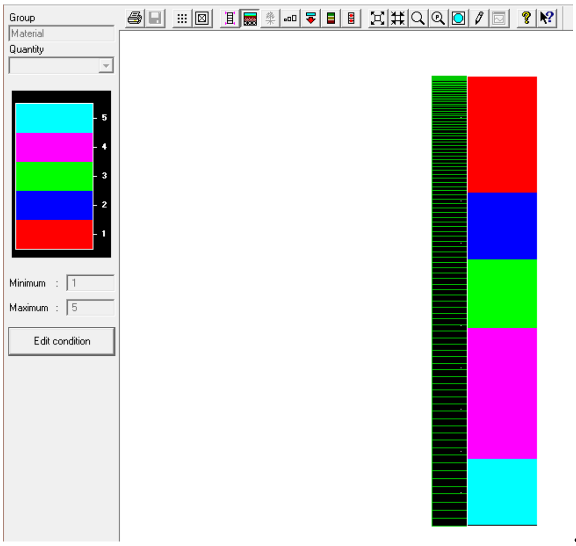


Figure 3.11 Soil profile information

3.5 Simulation According To 100-Year Flood Flows and Annual Average Flows

The simulation in the model is taken in two scenarios. The first scenario is according to income flows by the 100-year flood and the second according to income flows by average annual rainfall. The 100-year hydrograph duration period is 104 hours refers to the hydrograph duration as shown in Figure3.2, and depends on the hydrological characteristics of the basin including the routing of the streams distribution and the shape of the basin. The flood hydrograph flow is converted to water level increments depending on the Volume-Area-Elevation curve for the reservoir of Büyük Cırcıp recharge dam. These water level increments have been taken in the simulation in HYDRUS-1D model as a boundary condition to analyze the water recharge.

The simulation according to annual average flows is performed through the daily total inflow volumes obtained in Table 3.5. The volumes have been taken from the records and converted depending on the Volume-Area-Elevation curve. The values of monthly average flows are converted to level increments and taken as an upper boundary condition. The simulation is performed during 365 days and the results of the simulations are given in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Model Results According To 100-Years Flood Flows Simulation

Model results are obtained in a graphical environment for each observation point. Where observation point N1 immediately below the ground surface, N2 is at a depth of 5 meters, N3, and N4 are selected at 30 m and 50 m depth respectively as shown in Figure 4.1. The following figures shows the time-dependent pressure and water content change results which are presented in a graphical environment. Figure 4.2.(a) displays the pressure changes in the observation points with time, where the pressure in N1 increases to 13 m which is the head in the reservoir and after 500 hours becomes negative representing the discharge time of the dam.

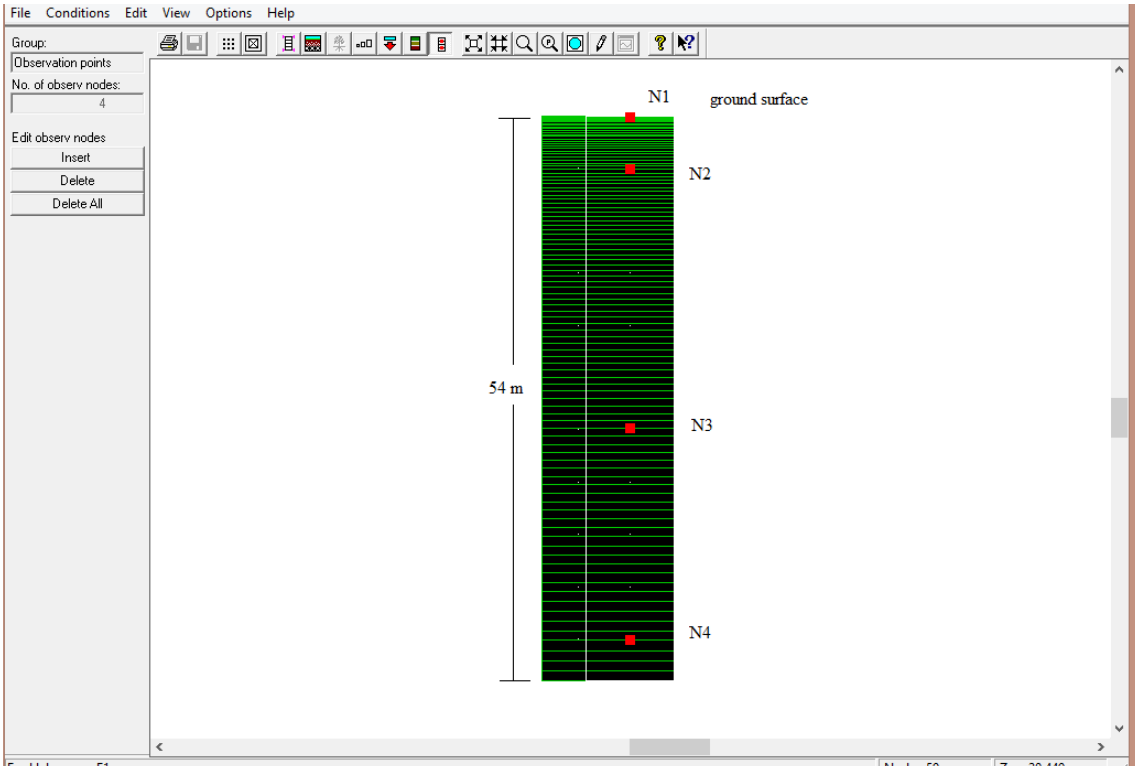
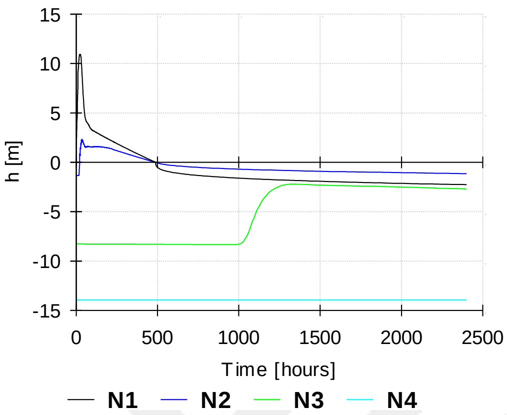
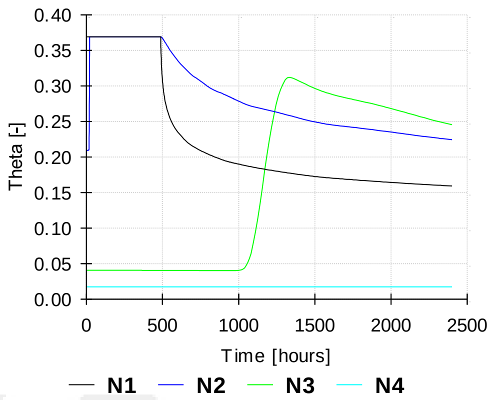


Figure 4.1 The soil profile discretization and observation points positions

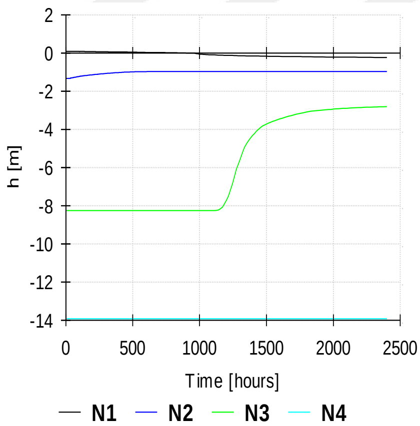
The infiltrated water reaches the observation point N3 after 1000 hours where the pressure starts increasing. relatively the water content (Theta) for the upper layer N1, N2 increases rapidly to the saturated water content value at the beginning until the time of dam discharging 500 hours where it decreases due to water movement down toward. theta in N3 starts changing positively after 1000 hours when the infiltrated water reaches the point to the saturated value.



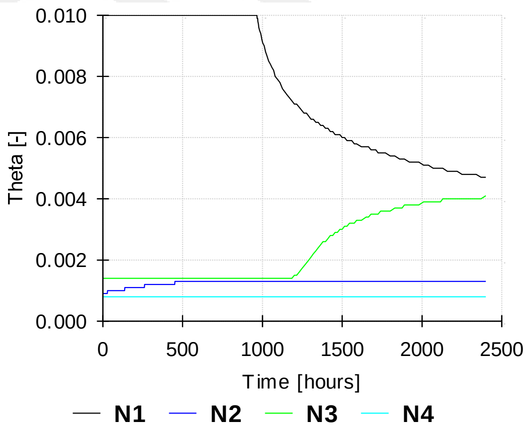
(a) Pressure heads changes



(b) Water content changes (theta)



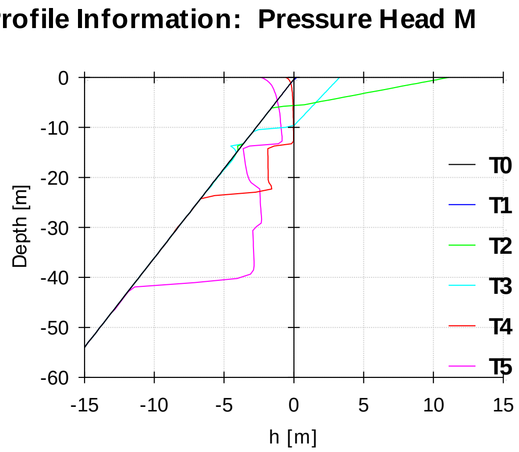
(c) Pressure heads changes in fractured situation



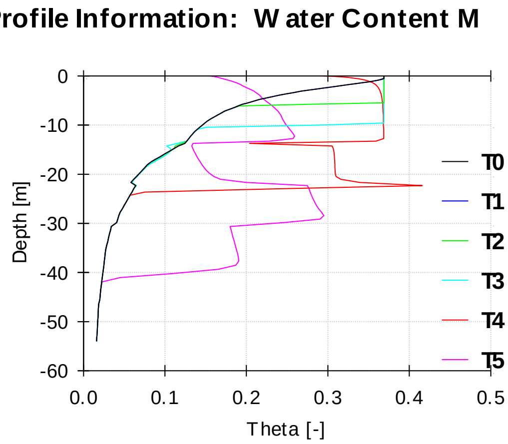
(d) Water content in fractured situation

Figure 4.2 Simulation results at the points N1, N2, N3 and N4 though 2400 hours

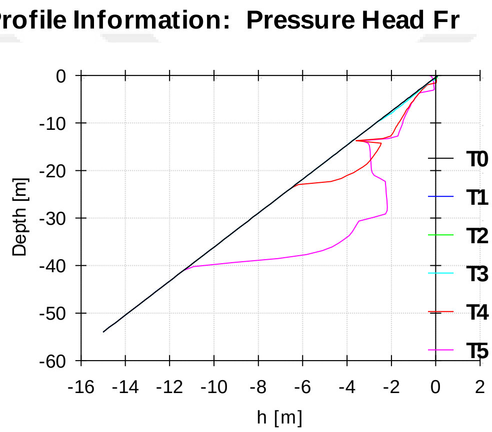
The results throughout soil profile in various time; Pressure head M and water content M for porous; Pressure head Fr and water content Fr for the fractured situation. Showed results in figures T0=0, T1=5, T2=25, T3=100, T4=500 and T5=2400 hours of pressure distribution in porous and fractured media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



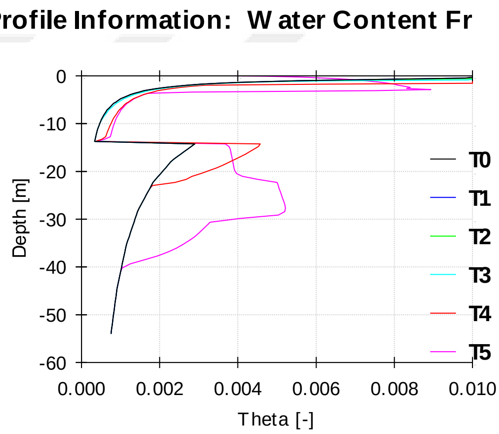
(a) Pressure head M porous



(b) Water content M porous



(c) Pressure head Fr for fractured

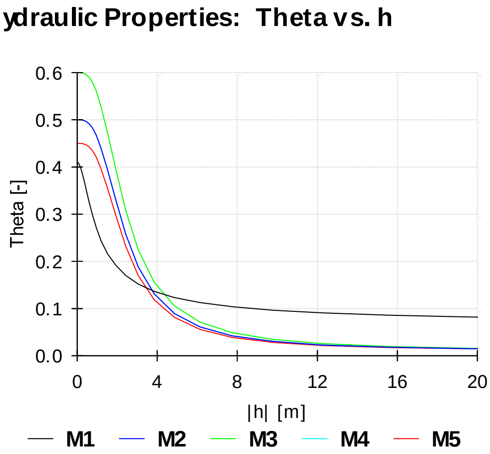


(d) Water content Fr for fractured

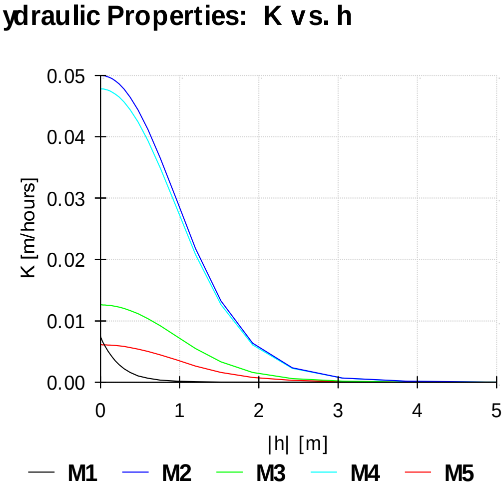
Figure 4.3 The results throughout soil profile in various time.

T0=0, T1=5, T2=25, T3=100, T4=500 and T5=2400 hours are the time for pressure distribution in porous and fractured media throughout the depth. The infiltrated water from the soil surface which is time-dependent flow entered the underground as total volumes are shown in the following figures.

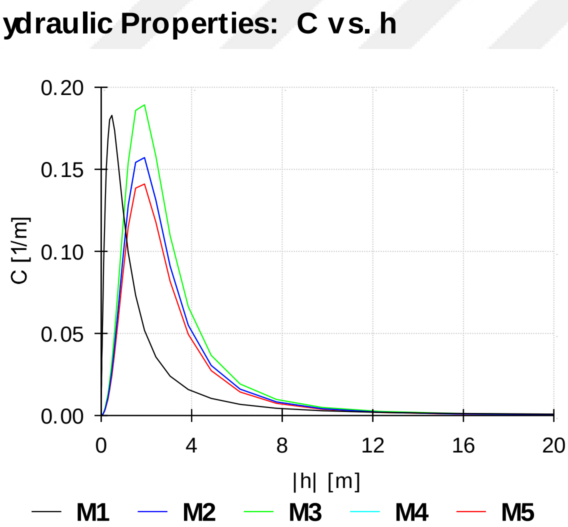
Because of the water movement in the soil, there is variability in saturation in the different soil layers M. The hydrogeological properties of each Layer M; hydraulic conductivity, water content with pressure load changes and water content with hydraulic conductivity changes. These properties can’t be obtained experimentally and the simulation shows them in the Figure 4.4.



(a) Water content with pressure load changes.



(b) Hydraulic conductivity pressure load changes



(c) Water content with hydraulic conductivity changes

Figure 4.4 The hydrogeological properties for each layer M

The water budget obtained in the simulation as a result of (1×1×54) m for a soil column at T= 2400 hours is given as shown in Table 4.1. At the end hydrograph duration to reflect the evapotranspiration in the model it has given an approximate value (0.000024 m/h) included in accounts of evaporation.

Table 4.1 Water budget of the soil column 1m x 1m x 54m for 2400 hours

Time[T] 2400 h	
Length [L]	54
W-volume [L]	8.78
In-flow [L/T]	-4.7E-06
h Mean [L]	-4.94
W-volumeF[L]	0.144
In-flow F [L/T]	-4.7E-06
h Mean F [L]	-5.36
Top Flux [L/T]	-6.27E-07
Bot Flux [L/T]	-3.76E-09
WatBalT [L]	1.43E-06

W-Volume: Volume of water in the entire flow domain or in a specified subregion [m].

InFlow: Inflow/outflow to/from the entire flow domain or a specified subregion [m/s].

W-VolumeF: Volume of water in the entire frracture flow domain or in a specified subregion [L].

InFlowF: Inflow/outflow to/from the entire fractureflow domain or a specified subregion [LT-1].

hMean: Mean pressure head in the entire flow domain or a specified subregion [m].

Top Flux: Actual surface flux [m/s] (infiltration/evaporation: -/+).

Bot Flux: Actual flux across the bottom of the soil profile [m/s] (inflow/outflow: +/-).

WatBalT: Absolute error in the water mass balance of the entire flow domain [m].

4.2 Model Results According to Annual Average Flows Simulation

Figure 4.5 shows the change of pressure head at time along depth in one dimensional model of the section taken from the lake ground. Figure 4.6 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 4.7 shows the total potential water passing by the dam reservoir bottom which is the soil profile top boundary (potTop-black graphics), the total actual amount of water passed (actTop- green curve) and GW reached 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 infiltrated water stored in the semi-saturated ground but a large amount reached the groundwater.

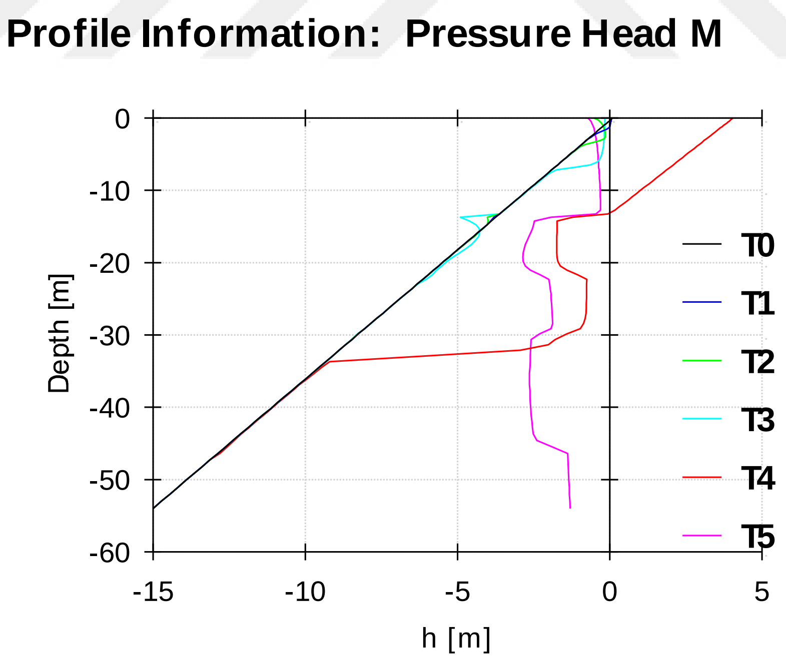


Figure 4.5 Change of pressure head along depth at different times

Where T0=0, T1=5, T2=25, T3=100, T4=500 and T5=2400 hours are the time for pressure distribution.

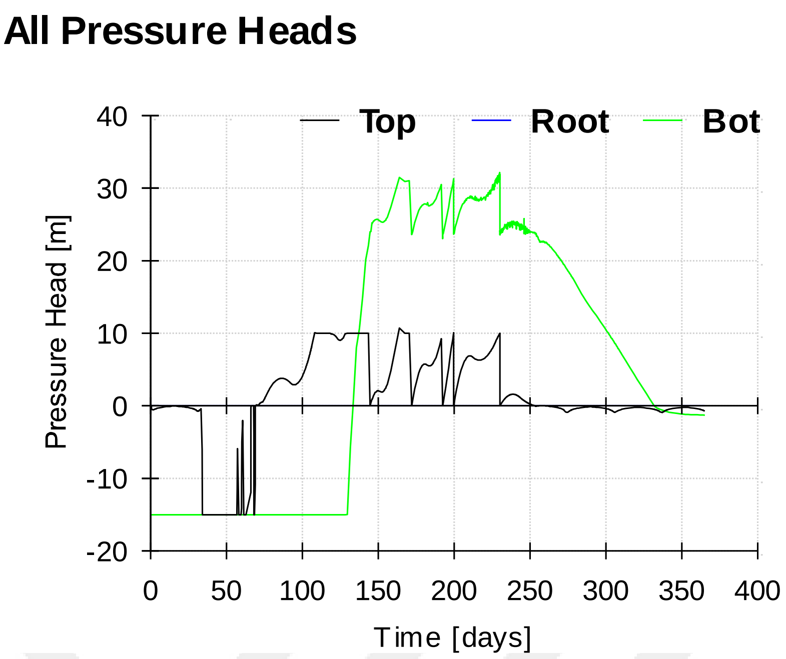


Figure 4.6 The change of pressure head at top and bottom boundaries

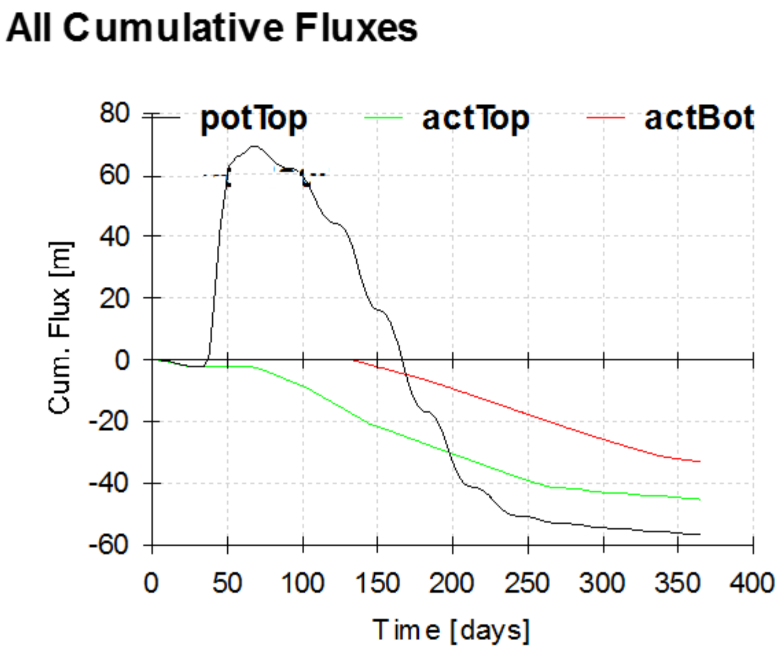


Figure 4.7 The change of cumulative fluxes at the top and bottom boundaries

4.3 Discussion of the results

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 2500 hours. In the simulation, the water increments 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 4.2 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.

As a result, it is possible to discharge the dam after filling it, in rage from 15 to 45 days after flood. The modeling in this study is one dimensional and represents a single point of the dam. As can be seen from the pressure profiles in Figure 4.2-a, the pressure at the near-surface observation point goes to zero at 1317th hour, that is, all the water on the soil surface is discharge to the soil, and the pressure profile at the bottom of the soil column shows that the water reaches that point after 1400 hours.

Table 4.2 Time of emptying the reservoir subjected to 100-year flood hydrograph under different hydraulic conductivity values of Alluvium and limestone aquifers.

Hydraulic conductivity of Alluvium layers (m/h)	Dam discharging time with infiltration (hour)	Hydraulic conductivity of limestone layers (m/h)	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)		

CHAPTER 5

CONCLUSION

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 hydrogeological character of the first 15 m aquifer of Alluvium at the dam lake ground which indicates its correlating to the hydraulic conductivity of the aquifer.

Discharge time is calculated with Alluvium hydraulic conductivity which is variable within the range of (0.001 - 0.75) m/h. Where there is a strong correlation between the discharge time and these parameters. Discharge time with 0.001 m/h conductivity is 5000 hours (208 days) and with 0.05 m/h conductivity is 349 hours (14.5 days). In this case, when the hydraulic conductivity increases 2, 10, and 15 times, the discharging time decreases to 19, 9, and 4 hours respectively. This implies that groundwater recharging is controlled by alluvium layer under the reservoir.

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

The simulation of Büyük Cırcıp groundwater recharge dam is achieved using HYDRUS-1D model of infiltration, according to the annual average water flows caused daily flows volumes coming to the dam during one year. dam simulation shows dam water collecting and infiltration into the ground during the period from December to April

The models of the dam don't represent all the dam lake ground where it is a 1x1 m^2 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 twice in the year when the water level exceeds the crest elevation and the extra volume of water going out through the spillway. The water level increases to 12 m and during 6 months and water is being collected and transferred to the ground. To increase the hydraulic conductivity of the layer and speed up the water recharge, vertical shafts are recomended whether the Alluvium layer in the reservoir these vertical shafts save the accumulated water from ET which is in high rates in the region.

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CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname	: Issam ALI
Date of birth and place	: Kamishli 26.061984
Foreign Languages	: Arabic, Kurdish, English and Turkish
E-mail	: eng.issam.ali@gmail.com

EDUCATION

Degree	**Department**	**University**	**Date of Graduation**
Undergraduate	Civil engineering	Damascus Uinversity	2010
High School	Alnabiga azubiani		2003

WORK EXPERIENCE

Year	**Corporation/Institute**	**Enrollment**
2013	Ministary of water resoures, Syria	An engineer in the water resoures management department
2012	Subh Engineering	Site engineer

PUBLISHMENTS

Papers

1. Büyük Circip Groundwater Recharge Dam Modeling With HYDRUS-1D