RAINWATER HARVESTING SYSTEM (RHS) AND ITS APPLICATIONS ON METU CAMPUS

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ABSTRACT

RAINWATER HARVESTING SYSTEM (RHS) AND ITS APPLICATIONS ON METU CAMPUS

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The rainwater harvesting is a water management strategy that is becoming more and more common around the world. Due to the decrease in fresh water resources, development of rainwater harvesting systems (RHS) gain importance. This system, which is used to store the rain reaching the earth and use it to supply various types of water demands, is very easy to install. In this study, a water balance model (WBM) is run with different rain harvesting tank (RHT) sizes to find the best RHT sizes for a set of buildings at Middle East Technical University (METU) campus. A cost-benefit analysis is conducted to evaluate the financial feasibility of various RHT sizes and their performances are evaluated using performance indicators such as reliability, stormwater capture efficiency, water saving efficiency and overflow ratio. Generally, 25 m^3 RHTs are found to result in the maximum net benefit for building groups of METU. However, dormitory buildings which are used by relatively more residents for longer times during the year and have smaller collection areas, require more collector area for their RHSs to be profitable.

Keywords: Rainwater Harvesting, Water Balance Model, Economic Analysis, Water Saving, Sustainable Campus

ÖZ

YAĞMUR SUYU TOPLAMA SİSTEMLERİ VE ODTÜ KAMPÜSÜNDEKİ UYGULAMALARI

Kadı, Orhan Veli
Yüksek Lisans, İnşaat Mühendisliği
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Yağmur suyu hasadı, dünya çapında giderek yaygınlaşan bir su yönetimi stratejisidir. Tatlı su kaynaklarının azalması nedeniyle yağmur suyu hasat sistemlerinin (RHS) geliştirilmesi önem kazanmaktadır. Yeryüzüne ulaşan yağmuru depolamak ve çeşitli su taleplerini karşılamak için kullanılan bu sistemin kurulumu oldukça kolaydır. Bu çalışmada, Orta Doğu Teknik Üniversitesi (ODTÜ) kampüsündeki bir dizi bina için en iyi yağmur toplama tankları (RHT) boyutlarının belirlenmesi için bir su dengesi modeli (WBM) çalıştırılmıştır. Çeşitli RHT boyutlarının finansal fizibilitesini değerlendirmek için bir maliyet-fayda analizi yapılmış ve performansları, güvenilirlik, yağmur suyu yakalama verimliliği, su tasarrufu verimliliği ve taşma oranı performans göstergeleri kullanılarak değerlendirilmiştir. Genel olarak 25 m^3 RHT'lerin ODTÜ binalarını içeren gruplar için maksimum net fayda sağladığı tespit edilmiştir. Ancak, yıl içinde nispeten daha fazla sakin tarafından daha uzun süre kullanılan ve su toplama alanları daha küçük olan yurt binalarının karlı olabilmesi için daha fazla su toplama alanına ihtiyaç duyulmaktadır.

Anahtar Kelimeler: Yağmur Hasadı, Su Denge Modeli, Ekonomik Analiz, Su Tasarrufu, Sürdürülebilir Kampüs

To my mother and my father, Nuray Kadı and Ertan Kadı

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CHAPTER 1

INTRODUCTION

In many parts of the world, some living things are suffering from severe water scarcity. Increasing world population and climate change are putting pressure on water supply systems. Fresh water sources are decreasing in the world (UN, 2006). Global water consumption is more than 50% of all renewable and accessible fresh water, and it is expected to rise. Hence, there is a billion people which do not have access to basic water services (Pacific, 2009). Therefore, many water organizations and authorities are trying to develop precautions to manage fresh water for supplying the water demand (Ali, Zhang, 2020).

Different strategies have been developed to mitigate the water scarcity. Some of them are greywater and wastewater reuse, desalination, and rainwater harvesting. Rainwater harvesting is an ancient traditional water management strategy which is widespread throughout the world for over 4000 years (Londra, et al. 2015). In the early times, rain harvesting was done by traditional methods providing potable and non-potable water for users. An example ancient rainwater harvesting system (RHS) is shown in Figure 1.1. In history, the Indians built structures to catch, hold and store rainwater to be used in dry seasons (Guardian, 2015). Today, it gains more and more ground as a modern, relatively with inexpensive and simple technology. RHS have been used by many countries all over the world since it facilitates the storm water management, reduce municipal water supply stress and improve the water cycle in urban areas. On the other hand, RHS also contributes to agricultural production by enabling effective use of water. RHS, which balance the water supply and demand is a beneficial system when it is designed in an economically feasible manner.



Figure 1.1 An example RHS from ancient times (The Guardian, 2015)

RHSs are used in sustainable projects on university campuses as well. Water management strategies are used to transform the existing campus with a green initiative through effective use of water resources (Kiraz, et al., 2018). In this way, significant water savings can be achieved.

The aim of this study is to identify most beneficial and efficient RHSs for a set of selected group of buildings at METU Campus. The Water Balance Model (WBM) is used to simulate RHSs and a detailed economic analysis (used interchangeably with cost benefit analysis) is carried out to evaluate the feasibility of various RHSs with different rainwater harvesting tank (RHT) sizes. Finally, efficiency of the RHSs are comparatively analyzed using performance indicators namely reliability, stormwater capture efficiency, water saving efficiency and overflow ratio to identify the best RHT size. For most of the building groups at METU, 10 m^3, 25 m^3, 50 m^3 and 100 m^3 RHTs are identified as the most beneficial RHT capacities. RHSs with these RHT capacities are shown to have good performances as well. In addition, it is observed that for dormitory buildings to result in high net benefits, larger collector areas are required.

In this study, Chapter 2 is the theoretical background and literature review. The methodology is provided in Chapter 3. In Chapter 4, the case study scenarios are explained and, results and discussions are given in Chapter 5. Finally, conclusions of the study are provided in the last chapter.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

Water management has become very important in recent years. Due to the irregularities in the precipitation regime and drought as a result of global warming, efficient and sustainable water management strategies have been developed and implemented in many parts of the world. While climate change increases the value of global water resources, the increase in water demand threatens global water security (Vörosmarty, et al., 2000). The possibility of people reaching clean water is decreasing. Especially in underdeveloped countries, this rate is quite low. Nowadays, it is estimated that one billion people do not have access to fresh drinking water in the world (Helmreich and Horn, 2009). Mostly people living in rural areas of Africa suffer from this condition. At least one-third of the population has little or no access to safe drinking water and results in major health problems from waterborne disease (WHO, 2002).

In line with these facts, efficient and sustainable water management strategies have been searched in order to prevent this situation and to minimize its damages. Although individual water saving studies have been carried out to mitigate water scarcity, more organized water management strategies are needed. Among these strategies, the importance of rainwater harvesting has been recently increasing (Cook. S, & Sharma.A, 2003). RHS reduces the impact of water scarcity (Khudhair, et al., 2020). RHSs are very easy to install systems. These systems can be easily expanded in terms of capacity and moved to another location. RHS has five components which are collectors, filters, conveying system, RHT and pump. These components are explained in the following sections.

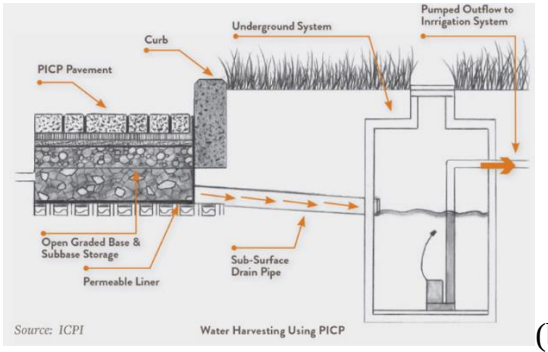
2.1 Components of the RHS

2.1.1 The Collector

Rainwater is collected from a collector which may be the roof of the building, courtyards or any kind of impervious surface. The most important criterion in the selection of the collector is that the rain should be collected without being exposed to pollution. In addition, the geometric structure of the water collection area should be suitable. Some example collector areas are shown in Figure 2.1. In this study, rainwater is assumed to be collected from the roofs of the buildings similar to the one given in Figure 2.1(a).



(a)



(b)

Figure 2.1 (a) An Example Rooftop Collector Area for a RHS (SV Group, 2021). (b) An Example Impervious Surface Area for a RHS (Belgrad, 2021)

2.1.2 The Filter

Rainwater could be used for different purposes such as potable or non-potable use. The type of filter has to be determined according to the use. While physical filtering (Omniendustri, 2021) (Figure 2.2a) is enough for non-potable purposes (Montoya, et al. 2015), chemical filtering (chlorination process) (The Prıceaeats, 2021) (Figure 2.2b) is used for potable purpose (Zang, et al. 2021). In addition, while physical filter is located at the outlet of the collector or before the RHT on pipeline system, the chemical filter is located before the demand point like faucets. In this study, since utilization of rainwater for toilet flushes is evaluated, use of physical filters similar to those given in Figure 2.2(a) are considered and associated costs of physical filters are integrated into the cost-benefit analysis.



(a) (b)

Figure 2.2 (a) An Example of Physical Filter for RHS (Omniendustri, 2021). **(**b) An Example of Chemical Filter for RHS (The Prıceaeats, 2021)

2.1.3 The Pipeline System

Rainwater is conveyed by the pipeline systems from the collector to the RHT and then from the RHT to the demand point. The pipeline system from the outlet of the

roof to the inlet of the RHT is called the Harvesting Pipe (HP) and the pipeline system from the outlet of the RHT to the demand point of building is called the Supply Pipe (SP).

2.1.3.1 The Harvesting Pipe (HP) Line

The HP is generally made of sheet steel or polyvinyl chloride (PVC pipes). The rainwater is conveyed by the HP by gravity. Therefore, there is no need for a pump system for this part. Generally, the existing pipes of the buildings are used in this system. An example HP is shown in Figure 2.3 (a) and 2.3 (b). In this study, the HP is assumed to be made of PVC pipes because it is cheaper than sheet steel. An example PVC pipe is shown in Figure 2.3 (b).



(a)


(b)

Figure 2.3 (a) An example galvanized HP (This Old House, (2021). (b) An example of PVC HP (Dekomos, (2021)

2.1.3.2 The Supply Pipe (SP) Line

The SP is generally made of Polipropilen Random Copolimer (PPRC) material. PPRC pipe is resistant to chemicals and corrosion resistant and it is suitable for use between -20 ℃ and +95 ℃ (Firat,2021). For this reason, it is preferred in building water pipelines. It can also be easily used underground between the RHT and the building in the rainwater collection system. Example PPRC pipes and fittings and shown in Figure 2.4. In this study, the SP is assumed to be made of PPRC pipes which are commonly used in plumbing works in Turkey.

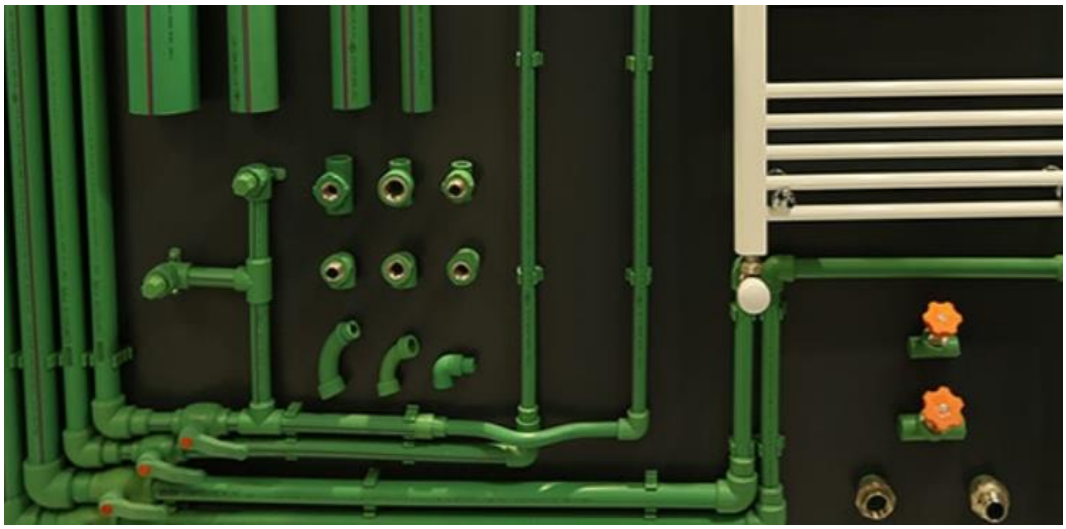


Figure 2.4 Example PPRC Pipes and Fittings (Firat, n.d.)

2.1.4 The Rainwater Harvesting Tank (RHT)

RHT is used to store rainwater before sending it to the demand points. There are several materials available for RHTs. These are; corrugated steel and enclosed metal, reinforcement concrete (RC), wooden, fiberglass and polyethylene and polypropylene. Generally, RC (Figure 2.5a) and polyethylene tanks (Figure 2.5b) are used in RHS systems. In this study an RC tank (Figure 2.5 (a)) is preferred for the RHT since especially for high capacity tanks are cheaper than other types. In addition, RC tanks are long-lasting and durable underground.


(a)



(b)

2.5 (a) An Example Concrete RHT (V. F. Medina, 2016). (b) Example Polyethylene RHTs (Avrup Su Deposu, n.d.)

2.1.5 The Pump

Generally, there are height differences between the RHT and demand points. Therefore, a pump is used to provide required energy in the RHS. It is appropriate to use submersible pumps that can operate in water in RHSs (Ghimire, et al. 2014). A typical submersible pump is shown in Figure 2.6. In this study, a submersible pump is assumed to be used in the RHSs of the Campus. Details of the RHS components used in this study and their costs are given in Section 5.



Figure 2.6 An Example of Submersible Pump (Kampa, 2021)

2.2 The Water Balance Model (WBM)

RHT is a very important component of the RHS to store rainwater before sending it to the demand points. Various approaches are used to determine the effective RHT size. The WBM is the most popular model to balance water requirements and the storage capacity. The water balance equation gives an insight about inflow, outflow and change in water storage for an area (Adham et al. 2016). A daily WBM is developed to simulate the hydrologic operation of a RHS. There are two algorithms for the WBM. These are Yield After Spillage (YAS) (Liuzzo, L., Notaro, V. & Freni, G., (2016) and Yield Before Spillage (YBS) (Ali. S., Zhang. S., & Yue., T. 2020).

The behavior of the model varies according to these algorithms. In this study, YAS algorithm is used and its details is given in Section 3.

In the rainwater harvesting studies, generally WBM is used to determine the RHT size and evaluate the RHS performance. Campisano and Modica (2012) used YAS model to find optimal size of storage tanks for domestic rainwater harvesting systems in Sicily, Italy using a set of economic criteria. In another study, using the WBM Khastagir and Jayasuriya (2010) mainly focused on the reliability and the tank size was selected according to the reliability results (i.e. maximize reliability). Generally, YAS operating rule is used in the rainwater harvesting studies, but there are studies in which the YBS operating rule was used. For example, Ali, Zhang and Yue (2020) used the YBS to assess environmental and economic of RHS in Pakistan in their studies. In recent years, Jing (2018), Zhang (2020), Ghisi and Cordova (2014) and Rocha (2009) used YAS approach to evaluate RHS. Other than WBM, the determination of the tank capacity is realized using optimization models (Sample, D. J., & Liu, J. 2014). Akintug et al. (2015) and Al-Ansari et al. (2013) also used to optimization to evaluate the RHS.

2.3 The Performance Indicators

The performance of a RHS dependents on the RHS components sizes, the rainfall regime of the region and the water demand of RHS. The performances of the designed systems are commonly evaluated using a number of indicators such as Water Saving Efficiency (%), Reliability (%), Stormwater Capture Efficiency (%) and Overflow Ratio (%) (Campisano, A & Modica, C. 2012). These indicators give information about how efficiently the designed system works. Definitions of the performance indicators used in this study are given in Section 3.4.2.

In rainwater harvesting studies first the best RHT size is identified and then its performance is evaluated using the performance indicators. The most widely used performance indicator is the reliability indicator. Imteaz, Rahman and Ahsan (2012)

focused only the reliability indicator to evaluate the performance of the rainwater harvesting tanks. There are other indicators besides the reliability such as stormwater capture efficiency, water saving efficiency and overflow ratio. Freni and and Liuzzo (2019) used the reliability and overflow ratio while evaluating and quantifying the effectiveness of rainwater harvesting in reducing flood volume and mitigating urban waterlogging problems. On the other hand, water saving efficiency and overflow ratio are used study for Sicily (Campisano, A., & Modica, C. 2012). One of the most comprehensive studies on performance indicators belongs to Ali, Zhang and Yue (2020). They used stormwater capture efficiency, water saving efficiency and reliability to assess the environmental aspect of RHS. In this study, all four indicators are used to evaluate the performance of the selected rainwater harvesting tank size.

2.4 The Economic Analysis

RHSs have many benefits in terms of the environmental and financial aspects. In this study, the most effective RHT sizes are identified and economic analysis is conducted for these RHSs. Although especially in recent years, studies investigating the environmental benefits of RHSs have been increasing, evaluation of the environmental benefits is not carried out here and left for a future study.

The water saving is the main benefit of a RHS. Generally, the life time of the project is specified and cost-benefit analysis is carried out for the life time of the project to determine the economic benefits of the RHS. In a RHS, there are two main costs; the installation and operation costs. The installation cost includes the RHT, the pump, the filter and the pipe costs. On the other hand, the operation costs are composed of the cost of electricity consumed for pumping, pumping operating and maintenance and the cleaning and maintenance costs (Martinez, et al. 2014).

Economic analysis studies are carried out in order to evaluate the rainwater harvesting projects from an economic point of view. The main analysis used on this subject are the evaluation of the payback period and cost-benefit analysis. Lani et al.

(2018) studied the performance of small and large scale RHSs in commercial buildings and carried out the payback period analysis. Similarly, Gomez and Teixeira (2017) carried out economic analysis for various RHSs. The payback periods varied from 25 to 35 years according to the characteristic inputs of the system such as rainfall, water demand and collector area (Gomez, Y. D., & Teixeira, L. G., 2017). On the other hand, the cost-benefit analysis is used in the evaluation of economic feasibility of RHSs. For example, Sample (2014) conducted cost-benefit analysis for seven different cities and five different type of buildings (Sample, D. J. & Liu, J., 2014). Although many economic analysis studies have been carried out on rainwater harvesting, detailed analysis of the costs of each component of the RHS are limited. In this study, all cost and benefit items that make up RHS are integrated into the economic analysis.

CHAPTER 3

METHODOLOGY

The RHS modeling and steps followed in the economic analysis are explained in detail in the following sections. The flowchart of the proposed methodology used in this study is given in Figure 3.1.

First, the site where RHS will be implemented is selected. Then, the buildings from which rainwater will be harvested are determined. Some buildings are grouped, and a single RHT is designed to serve each group. Thus, some RHTs serve a single building while some others serve a group of buildings. Second, the identification of the components of the RHS is carried out. A diagram representing the physical features of the RHS is prepared. RHS consists of five main components: collectors for collecting rainwater, typical filters for filtering the harvested rainwater before sending it to the RHT, pipes to convey the rainwater from the collectors to the RHT and from the RHT to the building for consumption, the RHT for storing the rainwater, and the pump system to pump water from the RHT to the building(s). Third, the site-specific data is collected and analyzed. Specifically, the historical daily time series of temperature, and rainfall are examined. Next step is the selection of the RHT size, and the assessment of the RHS's performance. In this study, the widely used and well-known Water Balance Model (WBM) is used to evaluate the performances of various RHT sizes. The RHS performance is evaluated using model indicators, namely reliability, stormwater capture efficiency, water saving efficiency and overflow ratio. At the last step, the detailed economic analysis of the system is conducted. The main contribution of this study to the existing literature is the detailed economic analysis conducted using site specific data and evaluation of the RHS performances through different performance indicators together with economic benefits.

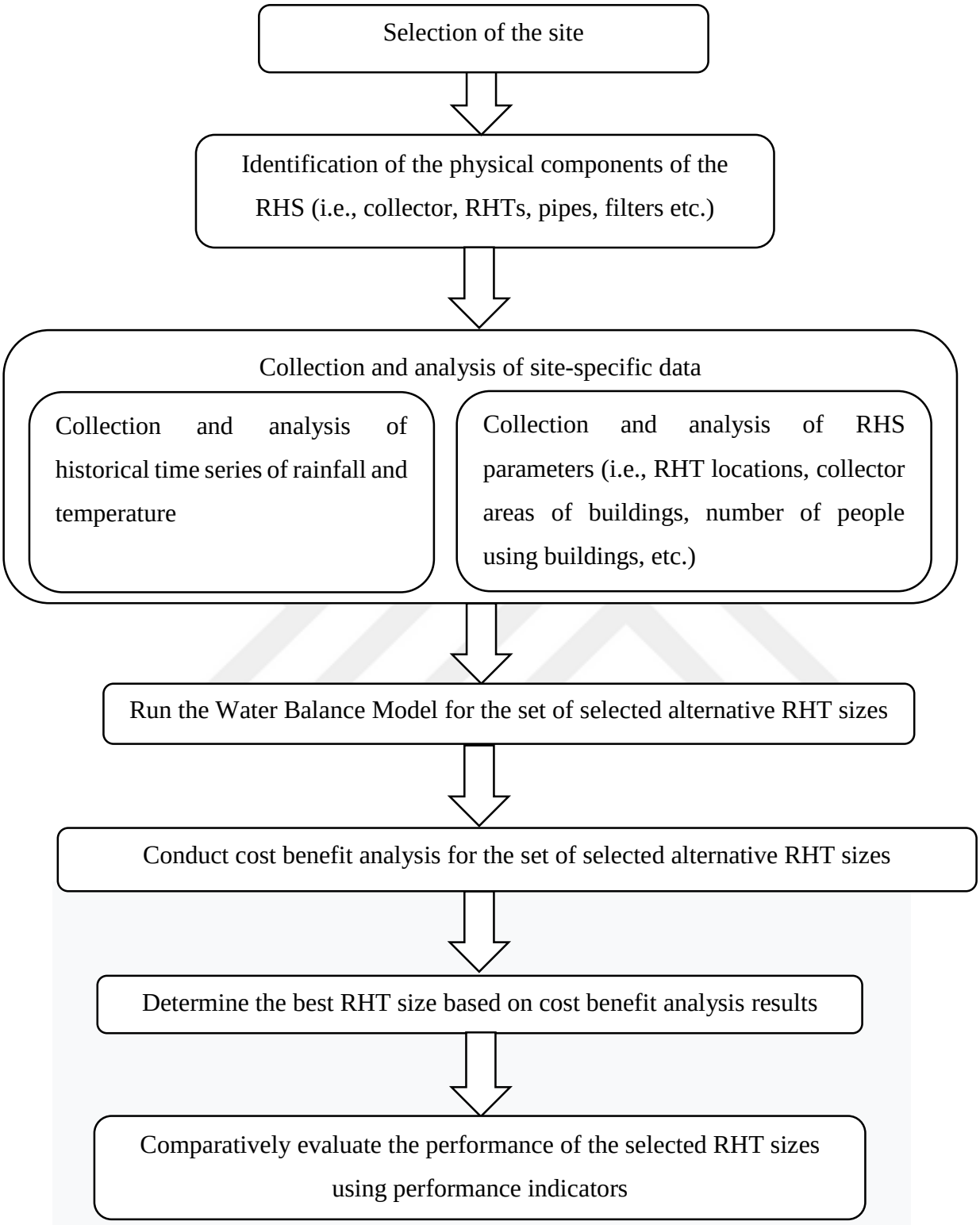


Figure 3.1 Methodology of this study

3.1 Selection of the Site

The primary source for the RHSs is the precipitation. For this reason, the most important issue is whether the geographical area where rain is planned to be harvested receives sufficient rainfall. Rainwater harvesting projects are unique projects. The design and performances of these projects differ depending on the characteristics of the project location. Therefore, the design parameters of the study area, historical rainfall data of the region, the number of people using the buildings and the frequency of these people using the toilet should be available. Considering these facts METU Campus (see Section 4.1) is selected as the case study site.

3.2 Identification of the Components of the RHS

Rainwater harvesting projects consist of five components: collectors, filters, pipeline system, the RHT, and the pump; altogether is called the RHS. Rain can be collected using a single collector or a group of collectors. Building roofs are generally used as collectors in the rainwater collection systems to obtain untouched rainwater and to minimize water cleaning costs. In this study, the buildings which are fed by the RHS are referred to as B_i where $i = 1,2,3 \ldots . N$. In this study, a RHS is designed either for an individual building or a group of buildings. An individual building or a group of buildings served by a RHS is referred to as the building(s) served by a RHS and represented by B_RHS_j where $j = 1,2,3, \ldots , J$. Thus a total of J RHTs are designed in this study. The number of buildings in each B_RHS_j is represented by n_j. All N buildings will be served by a RHS, thus $\sum_{j=1}^{m} n_j = N$. Proposed RHSs for METU Campus is explained in detail in Section 4.2.

3.3. Collection and Analysis of Site Specific Data

To design rainwater collection systems, it is necessary to collect meteorological data such as historical time series of rainfall and temperature in addition to design parameters such as RHT locations, collector areas, number of people using buildings, etc. Accurate and careful collection and analysis of data directly affects RHS design and performance.

3.3.1 Collection and Analysis of Historical Time Series of Rainfall and Temperature

Climate is one of the most critical factor for RHSs. For this reason, the historical time series of rainfall and temperature data of the study area are collected and analyzed. Daily data is used in this study because hourly data is difficult to reach and daily data commonly provides required resolution (Sample & Liu, 2014). Daily rainfall and temperature data is obtained from General Directorate of Meteorology (GDM) and the analysis results are given in Section 4.3.1.

3.3.2 Collection and Analysis of RHS Parameters

In addition to collecting and analyzing historical time series of rainfall and temperature, RHS parameters are collected and used in the WBM and in evaluating the system's performance from the economic perspective. RHS parameters are the effective roof area of each building, the number of people using the buildings, the daily water demand per capita and total daily water demand in the buildings, the RHT locations, and the quantity of the RHS components. These parameters are explained in the subsections below.

3.3.2.1 Rooftop Area and Effective Volume of Rainwater Collected from Collectors

The rooftops of the buildings are used as collector areas in this study. Rainwater collected from the roof of each building located in B_RHS_j is stored in its RHT, RHT_j. The roof areas of the buildings are measured using Google Earth program tools. After measuring the collector areas, the volume of rainwater reaching the catchment/collector (i.e., roof of the building) at each time step t is calculated using the following equation:

$$R_{i,t} = CA_i \times H_t \tag{1}$$

where $R_{i,t}$ is the volume of rainwater collected (m^3) from building i at time step t; CA_i is the collector area (m^2) of building i; H_t is the depth of the rainfall (m) at time step t. Here rainwater is collected from a total of N buildings for the simulation duration of T days; thus $i = 1,2, \dots, N$ and $t = 1,2, \dots, T$.

The total collector area, TCA_RHT_j for RHT_j, is calculated as follows:

$$TCA_RHT_j = \sum_{k \in B_RHS_j} CA_k \tag{2}$$

where k represents the buildings found in B_RHS_j and $j = 1,2, \dots, J$. Rainwater from the collectors of all the buildings located in B_RHS_j are stored in RHT_j. So the total collector area for RHT_j is the sum of the collector areas for all the building located in B_RHS_j.

While collecting rainwater from the rooftop and conveying it to the RHT some losses occur due to the roof geometry. The ratio of the volume that enters the RHT to the volume of rainfall that falls on the collector surface is assumed to be 0.9 (Farrency, 2011) in this study. This ratio is called as the runoff coefficient (ϕ). The volume of the rainwater collected is calculated using:

$$I_{i,t} = \phi \ x \ R_{i,t} \tag{3}$$

where $I_{i,t}$ is the effective volume of rainwater collected/generated from the collector (m^3) (i.e., volume that enters the RHT) at time step t from building i; ϕ is the runoff coefficient of the catchment areas (dimensionless) and it is taken as 0.9 in this study.

The total effective volume of rainwater, $I_RHT_{j,t}$ collected from B_RHS_j and entering into RHT_j at time step t is calculated as follows:

$$I_RHT_{j,t} = \sum_{k \in B_RHS_j} I_{k,t} \tag{4}$$

3.3.2.2 Daily Flushing Demand

The toilet flushing demand of each building is estimated considering the number of people using that building and how much time these people spend in that building. It is assumed that the time people spend in the building and the number of flushing are directly proportional. The daily flushing demand for each building is calculated using:

$$D_{i,t} = N_{i,t} \times NF \times FV \quad (5)$$

where $D_{i,t}$ is the daily flushing demand for building i in day t (m^3/day); $N_{i,t}$ is the number of people using building i in day t; NF is the number of flushes each person uses in one day (flush/day/person) and FV is the amount of water spend for each flush (m^3/flush). The time spent in the building varies according to the type of user (i.e., academic staff, staff, undergraduate students, master students and doctorate students). Accordingly, the number of flushing varies according to the building usage time and the type of the user. The time spent in the building and the number of flushing used are explained in detail in Section 4.3.2.3.

The total flushing demand $D_B_RHS_{j,t}$ for B_RHS_j, in day t, is calculated as follows:

$$D_B_RHS_{j,t} = \sum_{k \in B_RHS_j} D_{k,t} \quad (6)$$

3.3.2.3 Selection of the RHT Location

The location of the RHT is selected considering geographic conditions. In the selection of the RHT location, available spaces closest to the B_RHS_j without vegetation and away from infrastructure such as roads, sidewalk sewer line and buildings which are not included in the B_RHS_j are preferred. In addition, attention

has been paid to keep the RHT position as high as possible so that the power of the pump to be used in the RHT can be minimized. Considering these criteria RHT locations are selected and the coordinates and altitudes of these RHT locations are identified using the Google Earth program (see Section 4.3.2.4).

3.3.2.4 RHS Components

While designing the RHS, quantity of each RHS component (filters, pipe lengths, fittings, pumps, and RHTs) has to be determined. In each B_RHS_j, one RHT and one pump are used, but one filter is used for each collector (i.e., one filter per building). In addition, the pipe system consist of two parts, the harvesting pipe and the supply pipe. The harvesting pipe which includes pipe and fittings such as tees and elbows, conveys the water from the collector to the RHT and its length is represented by HP_RHT_j for B_RHS_j. On the other hand, the supply pipe which includes pipe and fittings such as tees and elbows conveys the water from the RHT to the toilet reservoirs and its length is represented by SP_RHT_j for B_RHS_j. The HP_RHT_j and SP_RHT_j are measured using measurement tools of the Google Earth program and the details for METU Campus buildings are given in Section 4.3.2.5.

3.3.2.5 Selection of the Pump

Submersible pumps are generally preferred in rainwater collection systems. When choosing these pumps, it is important to consider how far the pump will pump water horizontally and vertically. The technical specifications of the pumps available in the market are examined.

3.4 RHT Size Selection and Performance of the RHT

3.4.1 Daily Water Balance Model: Selection of the RHT Size

Evaluation of the RHS is carried out by simulating water balance using a model based on a yield-after-spillage (YAS) algorithm as the RHT release rule (Campisano, 2012; Freni, 2019). In the YAS strategy first the amount of spillage is calculated then the amount of water supplied from the RHT (which will be referred to as the yield from here after) is calculated (Campisano, 2012):

$$S_RHT_{j,t} = max\begin{cases} V_RHT_{j,t-1} + I_RHT_{j,t} - CT_RHT_j \\ 0 \end{cases} \quad (7)$$

$$Y_RHT_{j,t} = min\begin{cases} D_B_RHS_{j,t} \\ V_RHT_{j,t-1} \end{cases} \quad (8)$$

$$V_RHT_{j,t} = min\begin{cases} V_RHT_{j,t-1} + S_RHT_{j,t} - Y_RHT_{j,t} \\ CT_RHT_j - Y_RHT_{j,t} \end{cases} \quad (9)$$

where $S_RHT_{j,t}$ is the amount of overflow or spillage from RHT_j at time step t (m^3); $Y_RHT_{j,t}$ is the yield from RHT_j at time step t (m^3); $V_RHT_{j,t}$ is the volume of rainwater stored in RHT_j in time step t (m^3); CT_RHT_j is the storage capacity of RHT_j; t represents the end of the day, $j = 1,2,3, \dots, J$.

According to the YAS strategy, first the amount of water that will be spilled from the RHT is identified as shown in Equation (7). Then the yield from the RHT is found according to the demand as given in Equation (8). Finally, the remaining rainwater stored in the RHT at the end of each day is calculated using Equation (9).

In this study, daily time steps are used in the WBM. A set of alternative RHT sizes are identified initially and for the simulation period, the WBM is run with each of

these RHT sizes. Then the performance of each RHT size is evaluated using four different performance indicators. It is assumed that the daily precipitation regime will be similar to that of 1990-2019 for the analysis period which is 2021-2050. Thus daily precipitation data between 1990 and 2019 is used in the WBM.

3.4.2 Rainwater Harvesting System Performance Indicators

The performance of the RHS can be evaluated using indicators. These indicators are called Performance Indicators (PIs). The following four PIs are used in this study;

- Reliability (R_e,%)
- Stormwater Capture Efficiency (SCE, %)
- Water Saving Efficiency (W, %)
- Overflow Ratio (O_R, %)

Each of these PIs are calculated for each year of the simulation period and represented by $PIs_RHT_{j,y}$ where $y = 1,2,3 \ldots . Y$. Thus, Y is end of the simulation period. The average for each of the PI is calculated for each alternative RHT size and the best performing RHT size is selected based on this evaluation.

Reliability

First performance indicator is reliability. The reliability (R_e, %) is a time-dependent parameter of the RHS and it is mathematically expressed as (Ali, 2020):

$$R_e_RHT_{j,y} = \frac{N - U_RHT_{j,y}}{N} \times 100 \quad (10)$$

where $R_e_RHT_{j,y}$ is the reliability indicator for RHT_j in year y; N is the number of days in year y and $U_RHT_{j,y}$ is the number of days RHT_j cannot totally meet the daily water demand of B_RHT_j in year y.

Stormwater Capture Efficiency

Second PI is the stormwater capture efficiency (SCE, %) (Ali, 2020). It is formulated as follow:

$$SCE_RHT_{j,y} = \frac{\sum_{t \in y} V_RHT_{j,t}}{\sum_{t \in y} I_RHT_{j,t}} \times 100 \quad (11)$$

where $SCE_RHT_{j,y}$ is the stormwater captured efficiency for each RHT_j in year y; the numerator of the right hand side of the equation is the total volume of rainwater stored in RHT_j in year y (m^3); the denominator is the total effective volume of rainwater collected through the collectors located in B_RHS_j in year y (m^3). The amount of spilled water reduces SCE.

Water Saving Efficiency

Third performance indicator is the water saving efficiency (W, %) (Campisano, 2012; Ali, 2020). It is formulated as follows:

$$W_RHT_{j,y} = \frac{\sum_{t\in y} Y_RHT_{j,t}}{\sum_{t\in y} D_B_RHT_{j,t}} \times 100 \quad (12)$$

where $W_RHT_{j,y}$, is the water saving efficiency for each RHT_j in year y; the numerator of the right hand side of the equation is the total yielding water from RHT_j in year y (m^3); the denominator is the total water demand of the B_RHS_j in year y (m^3). Water saving efficiency is inversely proportional to the water drawn from the network.

Overflow Ratio

The last performance indicator is the overflow ratio (O_R, %) (Campisano, 2012). It is calculated as shown below:

$$O_R_RHT_{j,y} = \frac{\sum_{t\in y} S_RHT_{j,t}}{\sum_{t\in y} I_RHT_{j,t}} \times 100 \quad (13)$$

where $O_R_RHT_{j,y}$ is the overflow ratio for each RHT_j in year y. The numerator of the right hand side of the equation is the amount of overflow or spillage from RHT_j

in year y (m^3); the denominator is the total effective volume of rainwater collected through the collectors located in B_RHS_j in year y (m^3).

3.5 The Economic Analysis

The main advantage of the RHS is water saving. Water saving has positive economic effects. For this reason, economic analysis of the rain harvesting system is carried out to investigate the balance between benefit and cost. All cost and benefits used in the economic analysis in this study are shown in the cash flow diagram presented in Figure 3.2.

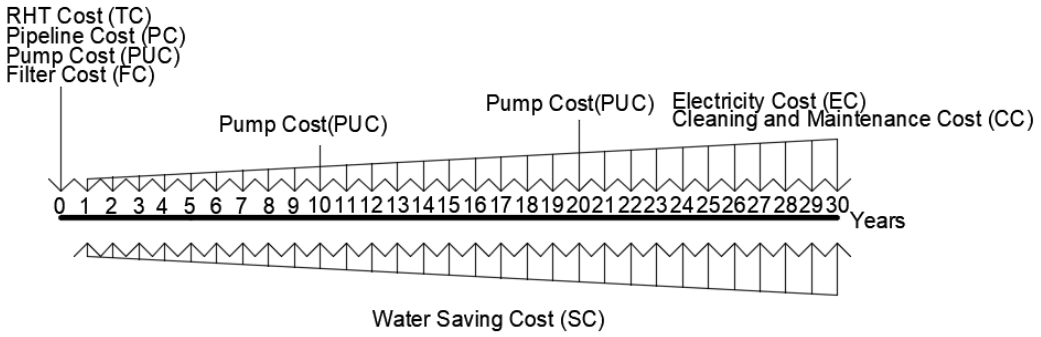


Figure 3.2 Cash Flow Diagram

3.5.1 Costs and Benefits of the Project

The cost of RHS consists of two main parts. One is the investment cost and the other is the operation cost. Investment cost includes RHT cost, system piping cost, pump and filter costs. Since the roofs of the buildings are used as the collection area, no cost is foreseen for the collection area. In this study, it is assumed that the pump will

be replaced with a new one every 10 years so three pump costs in years 0, 10 and 20 are marked on the cash flow diagram (see Figure 3.1). The operation cost includes the annual cost of cleaning and maintenance of the system and the pump electricity cost. In this study, the net present value analysis is carried out, so all the future costs and benefits are carried to the present year which is taken as 2021. The total, investment and operation costs are expressed as follows:

$$TotalCost_{2021_}RHS_j = IC_{2021_}RHS_j + OC_{2021_}RHS_j \quad (14)$$

where $TotalCost_{2021_}RHS_j$ is the total cost for the jth RHS, RHS_j (TL) in 2021; $IC_{2021_}RHS_j$ is the investment cost of RHS_j (TL) in 2021; $OC_{2021_}RHS_j$ is the operation cost of RHS_j (TL) in 2021.

The Investment Costs

The investment cost of the RHS_j is calculated as follows:

$$IC_{2021_}RHS_j = TC_{2021_}RHS_j + PC_{2021_}RHS_j + PUC_{2021_}RHS_j + FC_{2021_}RHS_j \quad (15)$$

where $TC_{2021_}RHS_j$ is initial investment cost of the RHT for RHS_j (TL) in 2021; $PC_{2021_}RHS_j$ is the initial investment cost of piping for RHS_j (TL) in 2021; $PUC_{2021_}RHS_j$ is the initial investment cost of pump for RHS_j (TL) in 2021

which is a function of the pump power; $FC_{2021}_RHS_j$ is the initial investment cost of filters for RHS_j (TL) in 2021. The initial investment cost of pump includes the cost of replacing the pump in the 10th and 20th years.

Piping Cost

Piping cost includes both harvest pipe and supply pipe's fittings, material and labor costs. It is directly proportional with pipe length for RHS_j.

$$PC_{2021}_RHS_j = (HP_RHS_j \text{ x } UCP_{2021_PVC}) + (SP_RHS_j \text{ x } UCP_{2021_PPRC}) \quad (16)$$

where HP_RHS_j is the length of harvesting pipe (m) for RHS_j, UCP_{2021_PVC} is the unit cost of PVC pipe in 2021 (TL/m) for HP_RHS_j, SP_RHS_j is the length of supply pipe (m) for RHS_j and UCP_{2021_PPRC} is the unit cost of PPRC pipe in 2021 (TL/m) for SP_RHS_j.

The Pump Cost

The appropriate pump is selected by determining the pump power that is necessary to provide the water supply in the system. The current market cost of the selected pump is obtained from Kampa (2021) as explained in Section 5.2.1.

In this study, the lifetime of the pump is assumed to be ten years. Since the lifetime of the RHS is taken as thirty years the pump will be replaced two times. Pump cost

varies depending on the exchange rate in Turkey. For this reason, future exchange rate estimation is carried out using historical data of the exchange rates and linear regression. Then the projected exchange rate is used to estimate the future cost of the pump (i.e., in year 10 and 20). Finally, the present values of future pump costs are calculated with present value analysis.

The Filter Cost

In this study, physical filters are used and it is assumed that one filter is placed at the outlet of the collector. Therefore, the number of filters is equal to the number of collectors for RHS_j.

$$FC_{2021_}RHS_j = FN_j \text{ x } UCF_{2021} \quad (17)$$

where FN_j is the number of filter for RHS_j and UCF_{2021} is the unit cost of the filter at 2021 (TL/filter).

The Operation Cost

The operation cost includes the system's cleaning and maintenance costs and the pump electricity costs. Cleaning and maintenance costs, and electricity costs are future costs that will occur annually during the lifetime of the project. These future costs are carried to the present value using the discount rate:

$$P = 1/F(1+i)^n \quad (18)$$

where P is the present worth of future value F, i is the discount rate and n is the year in which F occurs.

The Cleaning Cost

RHS is easy to clean. Therefore, it is assumed that 1 day's work of 2 workers annually will be sufficient for the cleaning of the RHS. Cleaning cost is an annual cost (i.e., it will occur every year during the lifetime of the project). Historical labor costs are obtained and a regression line is fit to predict future labor costs (see Section 5.2.2). Then cost of 2 workers are calculated for each year of the life time of the RHS and their corresponding present values are calculated using the discount rate with Equation (18). Then cleaning costs are summed up to find the present worth of cleaning costs $CC_{2021}_RHS_j$ for B_RHS_j.

Pump Electricity Cost

The electricity cost, $PE_RHS_{j,y}$ for B_RHS_j in year y is determined by multiplying total yield of water from RHT for B_RHS_j in year y (m^3) with unit cost of electricity (TL/m^3) in year y.

$$PE_RHS_{j,y} = \sum_{t \in y} Y_RHS_{j,t} \times UEC_y \quad (19)$$

where $PE_RHS_{j,y}$ is the electricity costs (TL) for B_RHS_j in year y; $Y_RHT_{j,t}$ is the yield from RHT_j at time step t (m^3); UEC_y is the average annual electricity unit cost (TL/m^3) in year y. Historic electricity costs are gathered and a regression line is fit to predict future electricity costs (see Section 5.2.2). The yearly electricity costs are then carried to the present with the discount rate using Equation (18) and summed up to calculate the present worth of pump electricity cost $PE_{2021}_RHS_j$ for B_RHS_j. The present worth of the operation cost, $OC_{2021}_RHS_j$ for RHS_j (TL) is calculated as follows:

$$OC_{2021}_RHS_j = CC_{2021}_RHS_j + PE_{2021}_RHS_j \quad (20)$$

Water Saving Benefit

The economic benefits of the RHS, $SB_RHS_{j,y}$ for B_RHS_j in year y is directly proportional with water saving in year y. Thus, the benefit of the water saving is calculated as follows:

$$SB_RHS_{j,y} = \sum_{t \in y} Y_RHS_{j,t} \times UWC_y \quad (21)$$

where UWC_y is the unit cost of municipal water (TL/m^3) in year y. Historical costs of municipal water are gathered and a regression line is fit to predict future costs of municipal water (see Section 5.2.3). The yearly water saving costs are then carried to the present using discount rate using Equation (18) and summed up to find the net present value of water saving cost, $SB_{2021}_RHS_j$ for B_RHS_j.

Net Benefit of the Project

The net benefit of the project is calculated as follows;

$$NB_RHS_j = SB_{2021}_RHS_j - TotalCost_{2021}_RHS_j \quad (22)$$

where NB_RHS_j is the net benefit for B_RHS_j (TL).

CHAPTER 4

CASE STUDY

In this study, a methodology is proposed to identify the best RHS to meet the water need in toilet reservoirs using WBM followed by the feasibility study of the best performing RHT. METU Campus is selected as the Case Study site.

4.1 Case Study Site: METU Campus

In this study, METU Campus, which is located on the Ankara-Eskisehir Roadway, in Ankara is selected as the study area. METU is a leading university located in Ankara, the capital of Turkey. METU has many department buildings, dormitories, social activity buildings, and sports fields. The campus covers 45,000 decares, of which 30,430 decares is forest (METU: General Information, 2021). Details of the METU campus are shown in Figure 4.1 (Google Map, 2020).



Figure 4.1 METU campus map (Google Map, 2020)

4.2 Proposed RHSs for METU Campus

In this study, RHSs for 76 buildings composed of department buildings and dormitory buildings are evaluated. These buildings are grouped into 43 groups as given in Table 4.1. While making this grouping, the proximity of the buildings to each other is taken into account. It is assumed that each building group is served by a RHS.

Table 4.1 Building groups

Building Group Code	**Building Name**	**Building Code**
BG_1	Department of Basic English - Block A	B_1
	Department of Basic English - Block B	B_2
	Department of Basic English - Administration Building	B_3
BG_2	Department of Basic English - Block D&E	B_4
	Department of Basic English - Block C	B_5
BG_3	Department of Basic English - Block F	B_6
	Department of Basic English - Block G	B_7
BG_4	Graduate School of Natural and Applied Sciences New Building	B_8
	Graduate School of Natural and Applied Sciences Administrative Building	B_9
	Graduate School of Natural and Applied Sciences Old Building	B_10
BG_5	Department of Business Administration	B_11
BG_6	Economics	B_12
BG_7	Department of Architecture	B_13
	Department of Architecture -2	B_14

	Table 4.1 (continued)	
BG_8	Social Science Building	B_15
	Maths	B_16
BG_9	Physics Lecture Hall Building	B_17
	Physics Building - 1	B_18
	Physics Building - 2	B_19
	Modern Language	B_20
BG_10	Biology	B_21
BG_11	Chemistry	B_22
	Statistics	B_23
BG_12	Industrial Engineering	B_24
BG_13	Computer Engineering Building - 1	B_25
	Computer Engineering Building - 2	B_26
	Computer Engineering Building – 3	B_27
BG_14	Civil Engineering Building K-1&K-7	B_28
	Civil Engineering Building K-2	B_29
	Civil Engineering Building K-3	B_30
	Civil Engineering Building K-4	B_31
	Civil Engineering Building K-5	B_32
BG_15	Electrical and Electronics Engineering - 1	B_33
	Electrical and Electronics Engineering - 2	B_34
	Lab of Electrical Engineering	B_35
	AYASLI Research Center	B_36
	METU Center Lab	B_37
BG_16	Mechanical Engineering Block - A	B_38
	Mechanical Engineering Block - B	B_39
	Mechanical Engineering Block - C	B_40
	Mechanical Engineering Block - D	B_41
	Mechanical Engineering Block - E	B_42
	Mechanical Engineering Block - F	B_43

	Table 4.1 (continued)	
BG_17	Turkish Language - 1	B_44
BG_18	Chemical Engineering - 1	B_45
	Chemical Engineering - 2	B_46
	Chemical Engineering - 3	B_47
	Chemical Engineering - 4	B_48
BG_19	Environmental Engineering	B_49
BG_20	Metallurgy and Material Engineering - 1	B_50
	Metallurgy and Material Engineering - 2	B_51
BG_21	Geological Engineering	B_52
BG_22	Mining Engineering	B_53
BG_23	Petroleum Engineering	B_54
BG_24	Aerospace Engineering Building	B_55
	Aerospace Engineering Building Lab - 1	B_56
	Aerospace Engineering Building Lab - 2	B_57
BG_25	Food Engineering	B_58
BG_26	Dormitory 1	B_59
BG_27	Dormitory 2	B_60
BG_28	Dormitory 3	B_61
BG_29	Dormitory 4	B_62
BG_30	Dormitory 5	B_63
BG_31	Dormitory 6	B_64
BG_32	Dormitory 7	B_65
BG_33	Dormitory 8	B_66
BG_34	Dormitory 9	B_67
BG_35	Dormitory of Ebi -2	B_68
BG_36	Dormitory of Osman Yazici	B_69
BG_37	Dormitory of Ebi -1	B_70
BG_38	Dormitory of Faik Hiziroglu	B_71
BG_39	Dormitory of Guest House	B_72

Table 4.1 (continued)

BG 40	Dormitory of Refika Aksoy	B_73
BG_41	Dormitory of 19	B_74
BG_42	Dormitory of Faika Demiray	B_75
BG_43	Dormitory of Isa Demiray	B_76

In this study, the roofs of the buildings are considered as the collectors of the RHSs. Each building has its own filter. There is also a pipeline system for each RHS. In addition, each RHS has a RHT to store rainwater and a pump to convey the rainwater from the RHT to the demand points (i.e., toilets) in each building.

The design of the RHS is very important for the correct operation of the model. The design criteria directly affect the efficiency and cost of the system. In this regard, the roof of the buildings in METU is used for collector. No cost is foreseen for collecting rainwater. The second components is pipeline and the PVC pipes are used for HP and PPRC pipes are used in SP. For filtering purposes, the physical filters are used for non-potable purposes. It is very cheap and useful filter for non-potable purposes. The most expensive part of RHS is the RHT. In this study, the reinforcement concrete (RC) RHTs are designed. Finally, the last part of the system is the pumps. Submersible pump is used for conveying rainwater from RHT to the toilet reservoirs.

4.3. Collection and Analysis of Site-Specific Data

RHSs are designed using meteorological and site data. While daily rainfall and temperature data are used as meteorological data, the RHS parameters like effective collector area, daily water demand per capita, etc., are used as site data. Collection and analysis of the meteorological and site data are explained in the following subsections.

4.3.1 Collection and Analysis of Meteorological Data

Ankara has a continental climate with hot and dry summers and cold and dry winters. According to General Directorate of Meteorology (GDM), the highest temperature was 41 ^{0}C, and the lowest temperature was -24.9 ^{0}C between 1927 and 2019 at Ankara (GDM, 2021). The summary of historical meteorological data between 1927 and 2019 for Ankara is shown in Table 4.2 (GDM, 2021).

Table 4.2 Summary of historical meteorological data between 1927 and 2019 for Ankara (GDM, 2021)

(1927 - 2019)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Average Temperature (°C)	0.1	1.6	5.7	11.2	16	19.9	23.3	23.3	18.8	13.1	7.2	2.4	11.9
Average Highest Temperature (°C)	4.1	6.4	11.4	17.3	22.3	26.6	30.2	30.4	25.9	19.9	13	6.4	17.8
Average Lowest Temperature (°C)	-3.2	-2.3	0.6	5.3	9.6	12.9	15.8	15.9	11.7	7	2.5	-0.8	6.3
Average Sunbathing Time (Hour)	2.6	3.8	5.1	6.6	8.5	10	11.3	10.7	9.2	6.7	4.5	2.5	81.5
Average Rainy Days	12.3	11.2	10.7	11.2	12.3	8.7	3.6	2.7	4	6.9	8.2	11.7	103.5
Total Monthly Rainfall (mm)	40.2	35.1	39.1	42.5	51.5	34.4	14.3	12.7	18	27.7	31.5	44.9	391.9
Highest Temperature (°C)	16.6	21.3	27.8	31.6	34.4	37	41	40.4	37.7	33.3	24.7	20.4	41
Lowest Temperature (°C)	-24.9	-24.2	-19.2	-7.2	-1.6	3.8	4.5	5.5	-1.5	-9.8	-17.5	-24.2	-24.9

In this study, first the Water Balance Model (WBM) is used to simulate the supply from the RHS. WBM require precipitation time series which is obtained from General Directorate of Meteorology (GDM) for the study area. The World Meteorological Organization (WMO) recommends at least 30 years of observations to representative climate information for a given region (WMO, 1989). In the study, also 30 years of precipitation data is used.

To study the temperature and rainfall regimes of Ankara, data of meteorological station 17130 is obtained from GDM for the 1990 – 2019 period. The details of the station are listed in Table 4.3 (GDM, 2021). The location of the station is shown in Figure 4.2 (Google, 2020).

Table 4.3 Details of meteorological station 17130 (GDM, 2021)

Item	**Description**
Station	Ankara Region
Station Number	17130
State	Ankara
Latitude	39°58'21.7"N
Longitude	32°51'49.3"E
Altitude	896 m
Distance to METU Campus	11.4 km
Period of Rainfall	1990 -2019
Period of Temperature	1990 -2019
Method of Station Geographic Positioning	By Staff

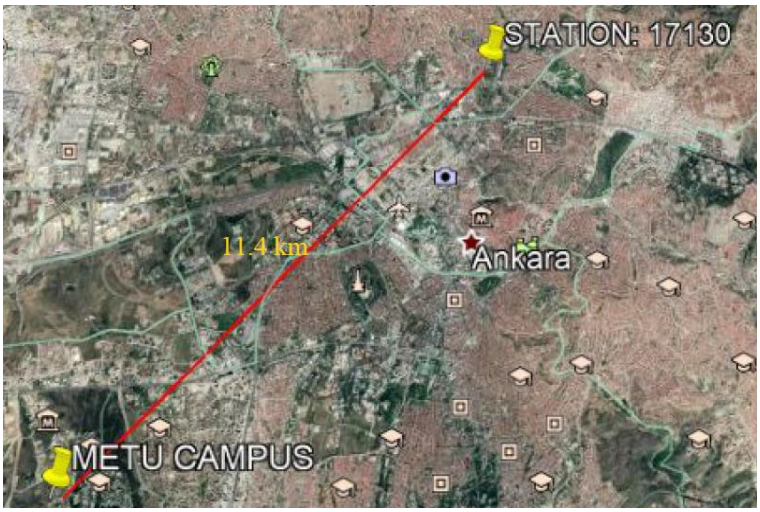
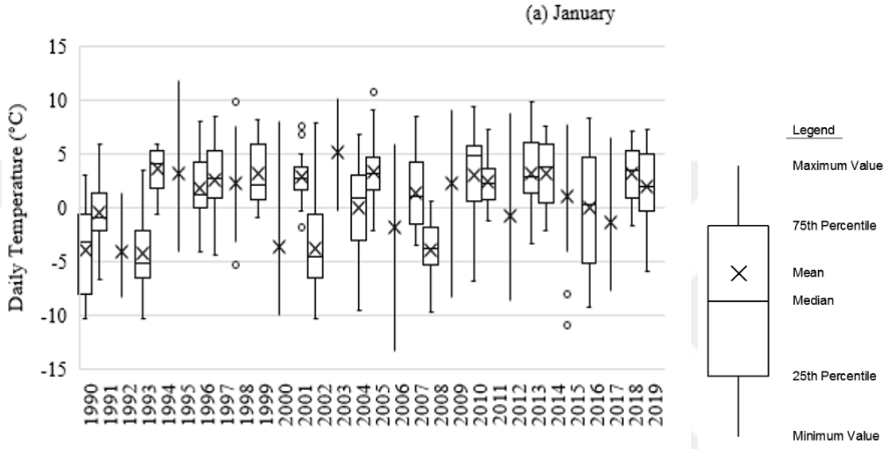
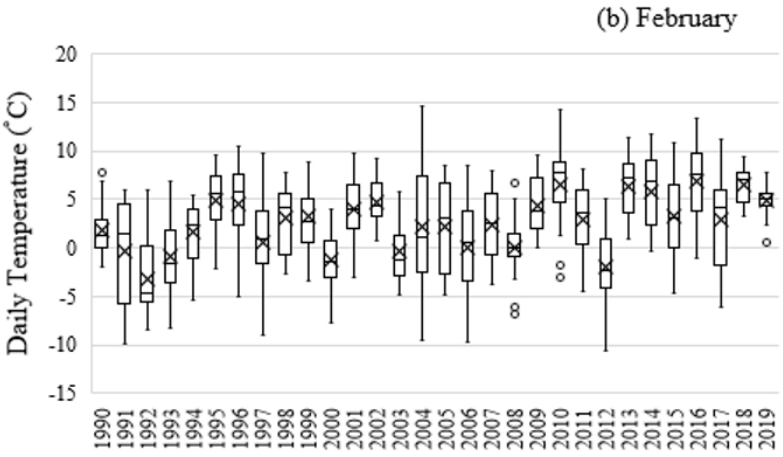


Figure 4.2 Distance between METU Campus with station 17130 (Google, 2020).

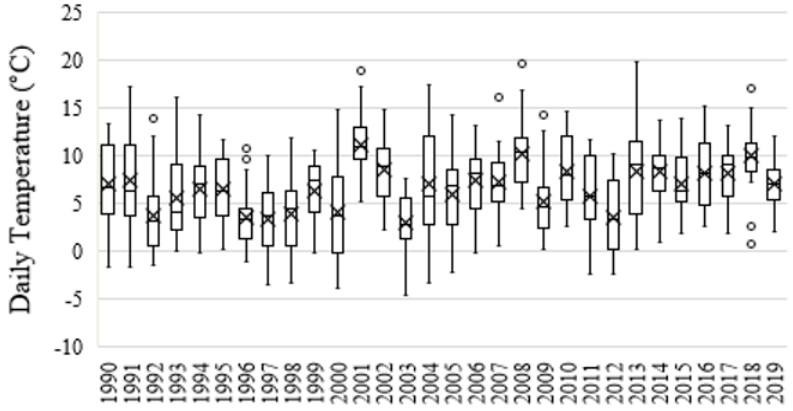
4.3.1.1 Temperature Analysis

Monthly and yearly analysis of the temperature data for 1990 – 2019 period is provided in this section. The ranges of daily temperatures for each month between 1990 and 2019 are given in Figure 4.3. The temperature is non-uniform on a monthly basis (i.e., ranges of daily temperatures for each month vary over the years).

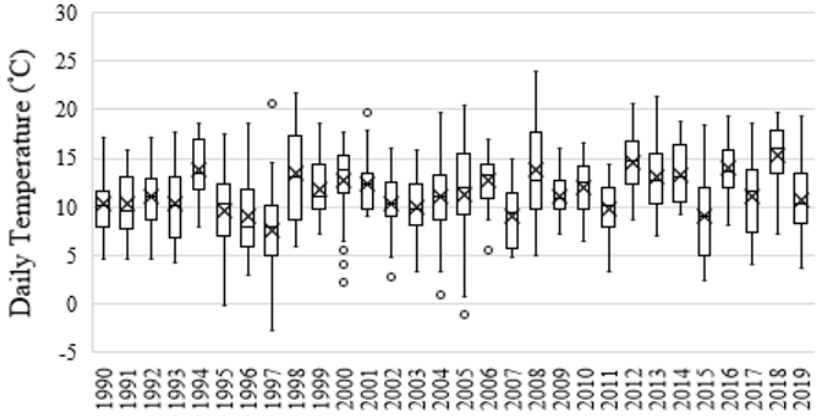




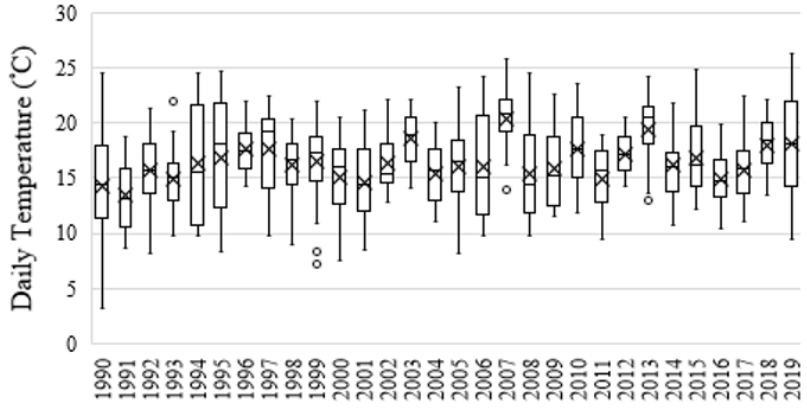
(c) March

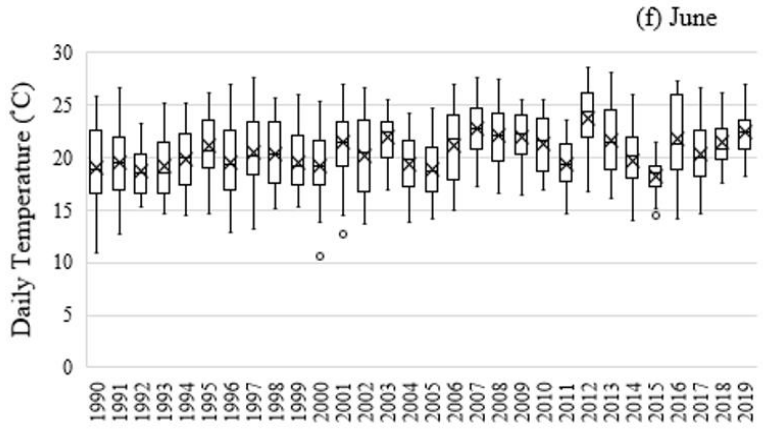


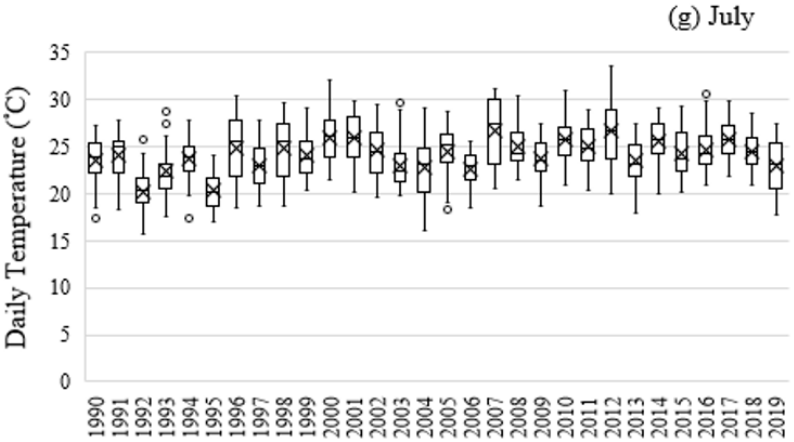
(d) April

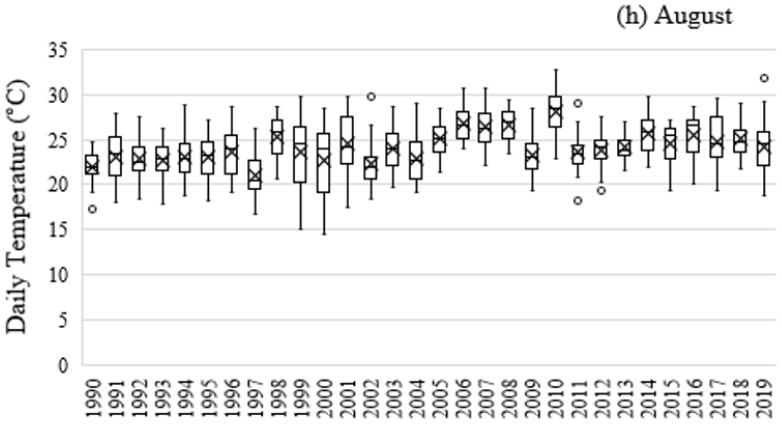


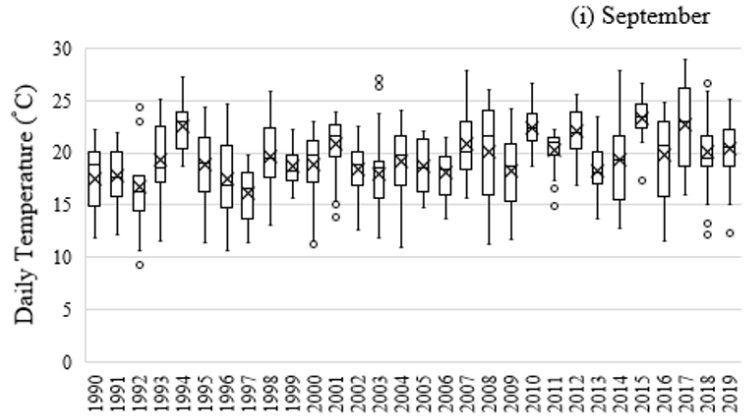
(e) May

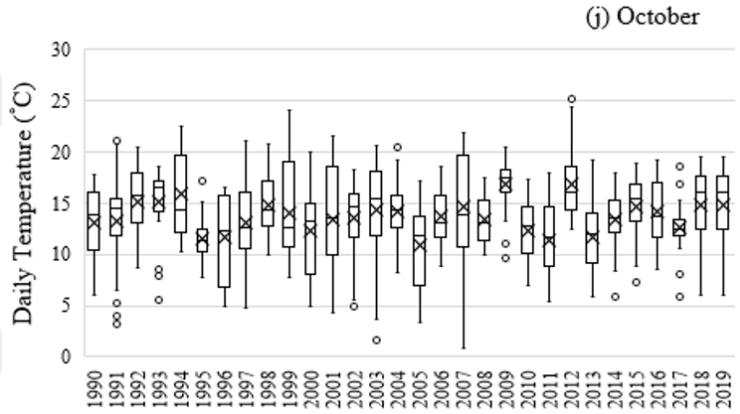


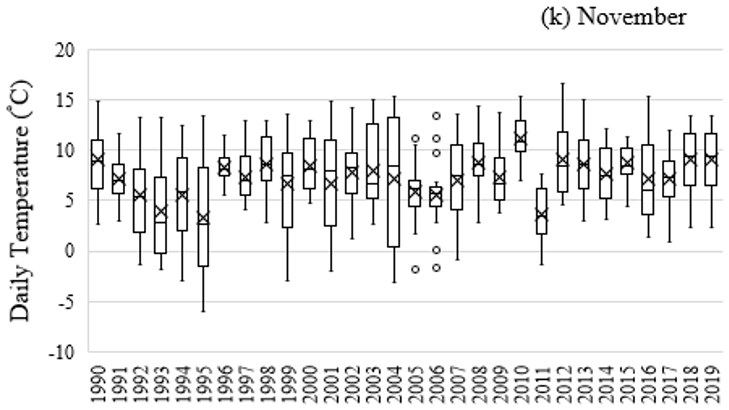

(f) June
Daily Temperature (°C)
0
5
10
15
20
25
30
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


(g) July
Daily Temperature (°C)
0
5
10
15
20
25
30
35
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


(h) August
Daily Temperature (°C)
0
5
10
15
20
25
30
35
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


(i) September
Daily Temperature (°C)
30
25
20
15
10
5
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019


(j) October
Daily Temperature (°C)
30
25
20
15
10
5
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019


(k) November
Daily Temperature (°C)
20
15
10
5
0
-5
-10
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

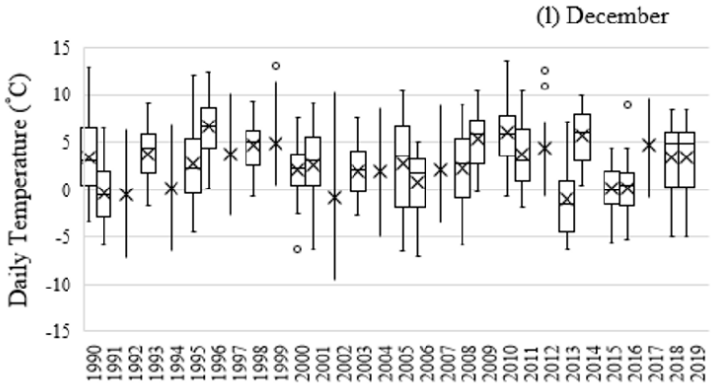


Figure 4.3 Daily temperature variations for (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December

Contrary to monthly analysis, daily temperature ranges within each year are more uniform in 1990 – 2019 period. The boxplots representing daily temperature ranges for each year are shown in Figure 4.4. Maximum daily temperature was 33.6 °C (27.07.2012), the minimum temperature was -13.3 °C (30.01.2006) while the average temperature was 12.53 °C for the period of 1990 – 2019.

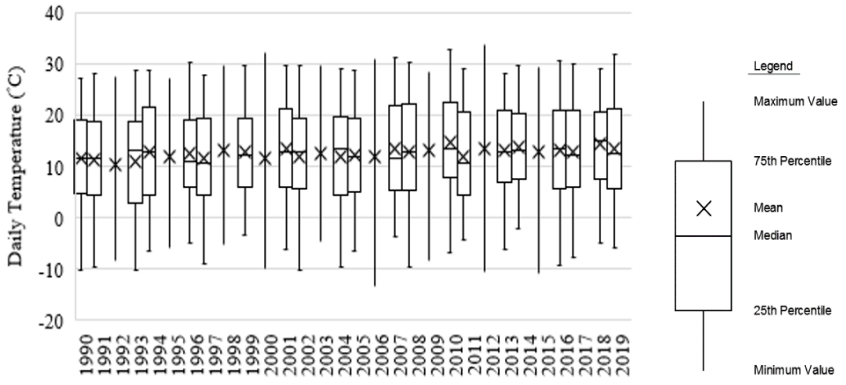
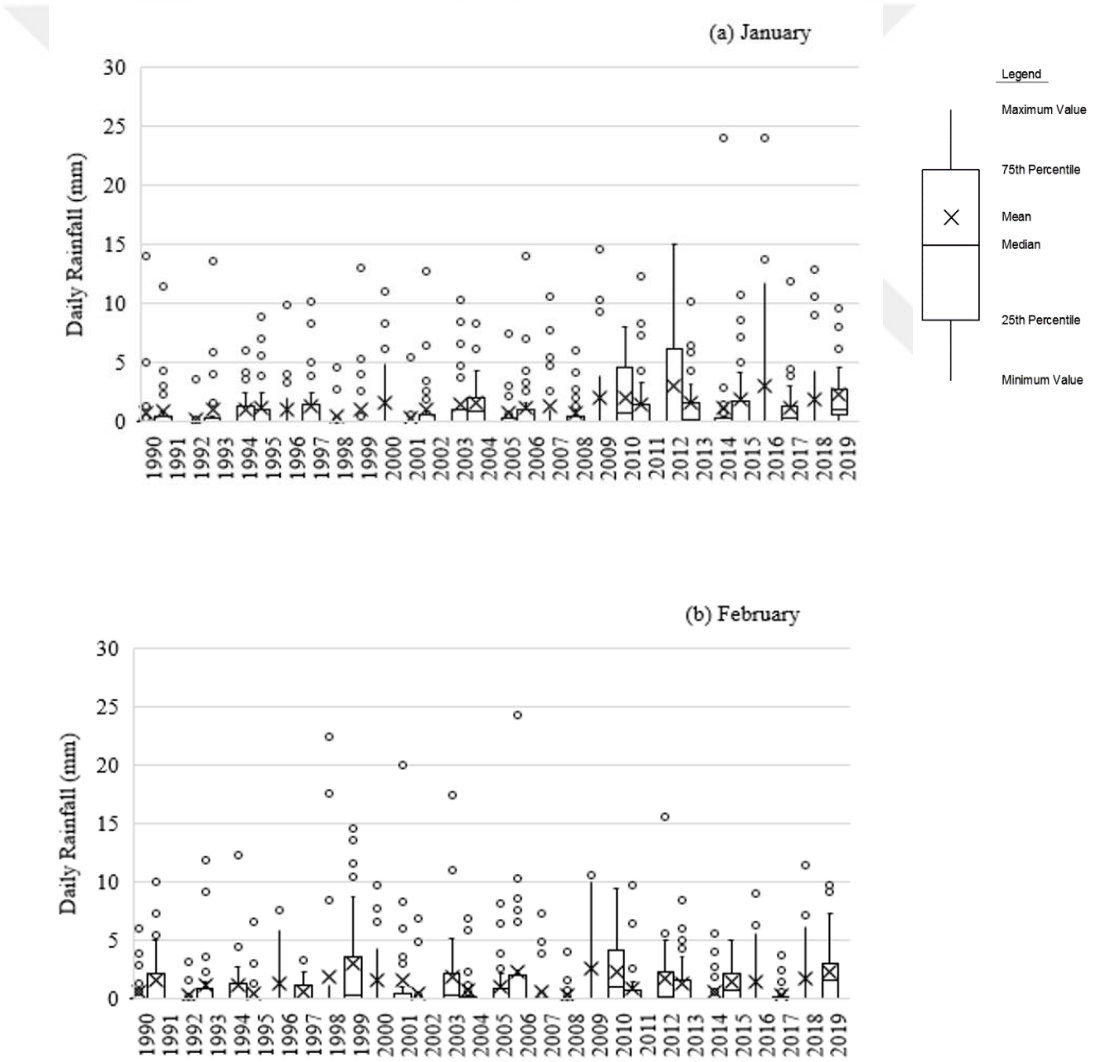
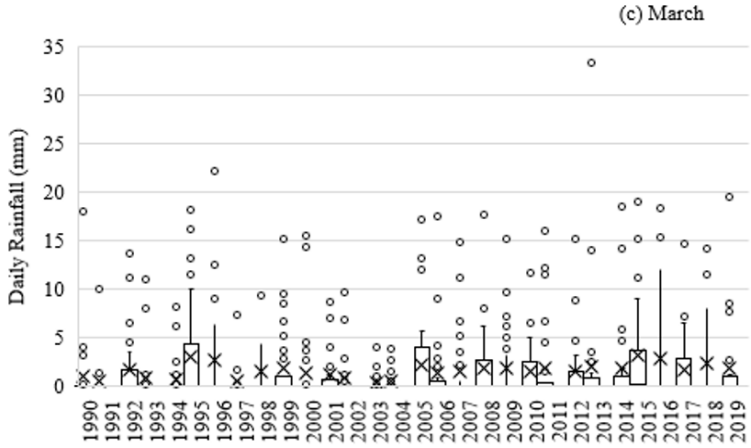


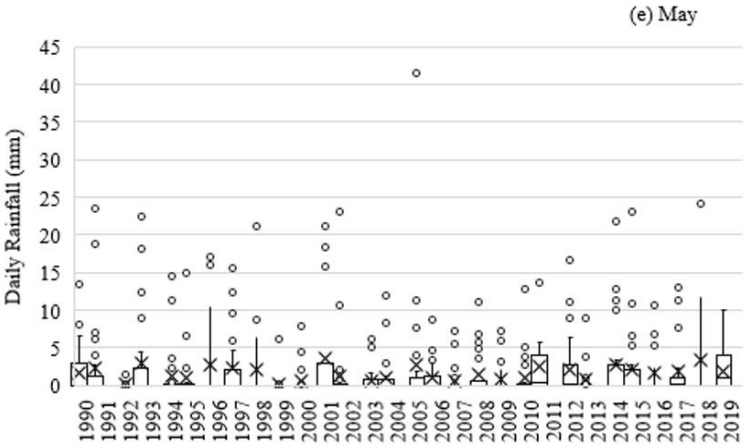
Figure 4.4 Daily temperature variations for years between 1990 and 2019

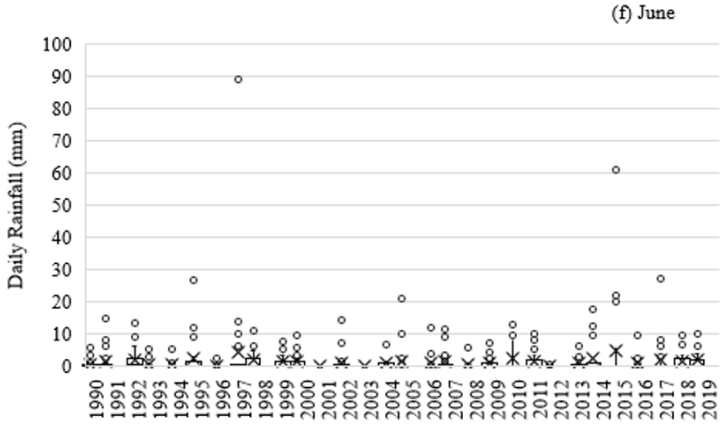
4.3.1.2 Rainfall Analysis

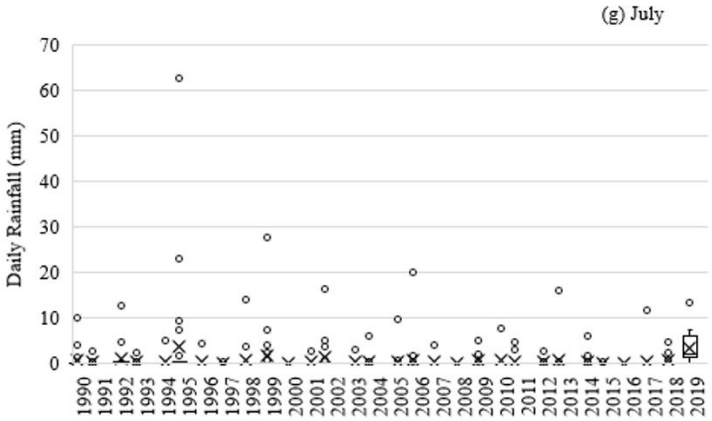
A monthly and yearly analysis of the rainfall data for 1990 – 2019 period is provided in this section. The ranges of daily rainfall for each month between 1990 and 2019 are given in Figure 4.5. Like temperature, precipitation is non-uniform on a monthly basis (i.e., ranges of daily rainfall for each month vary over the years). Due to the seasonality, the rain is more in winters than in summers and the summer season is extremely dry.

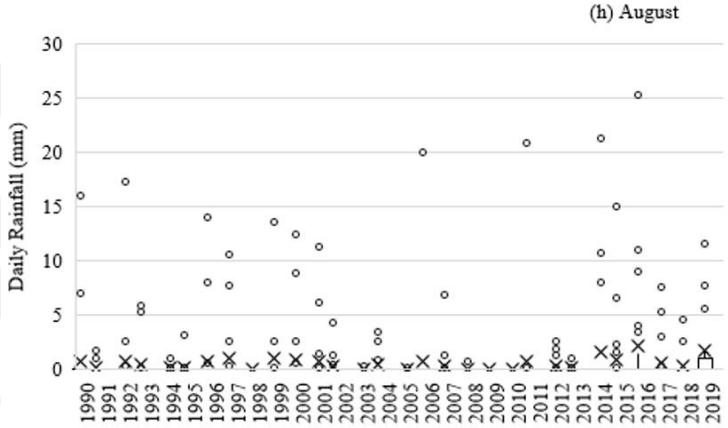


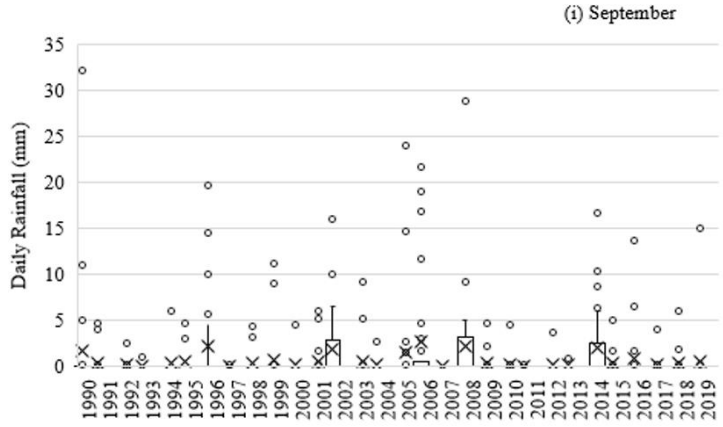

(c) March
Daily Rainfall (mm)
0
5
10
15
20
25
30
35
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


(e) May
Daily Rainfall (mm)
0
5
10
15
20
25
30
35
40
45
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


(f) June
Daily Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


(g) July
Daily Rainfall (mm)
70
60
50
40
30
20
10
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019


(h) August
Daily Rainfall (mm)
30
25
20
15
10
5
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019


(i) September
Daily Rainfall (mm)
35
30
25
20
15
10
5
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

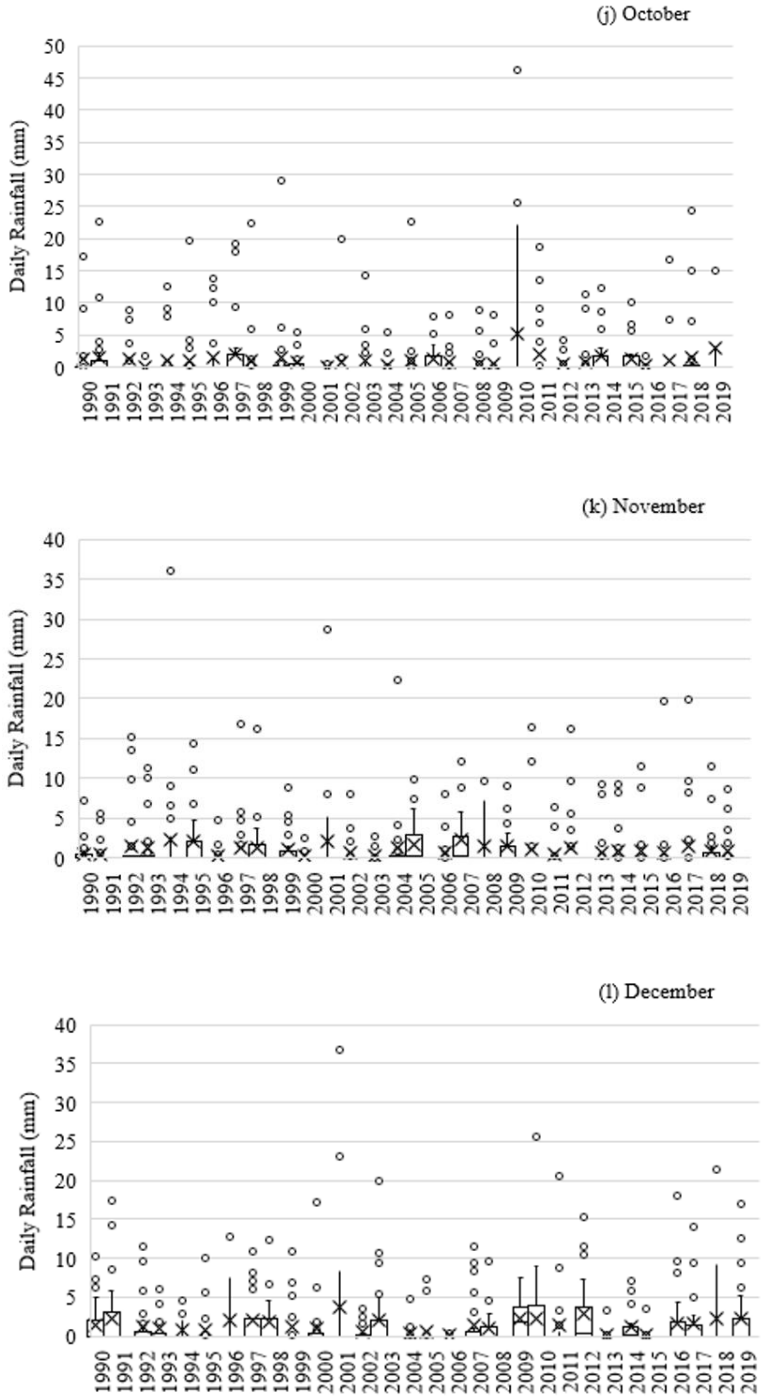


Figure 4.5 Daily rainfall variations for (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December

Contrary to monthly analysis, the daily rainfall ranges within each year are highly variable for the period 1990 to 2019. The boxplots representing daily rainfall ranges for each year are shown in Figure 4.6 (a). To better represent the 25-75 percentile range, a zoomed version of Figure 4.6 (a) to 0-25 mm daily rainfall range is given in Figure 4.6 (b). The maximum daily rainfall was 88.9 mm (11.6.2020), while the average rainfall was 1.15 mm for the period 1990 – 2019.

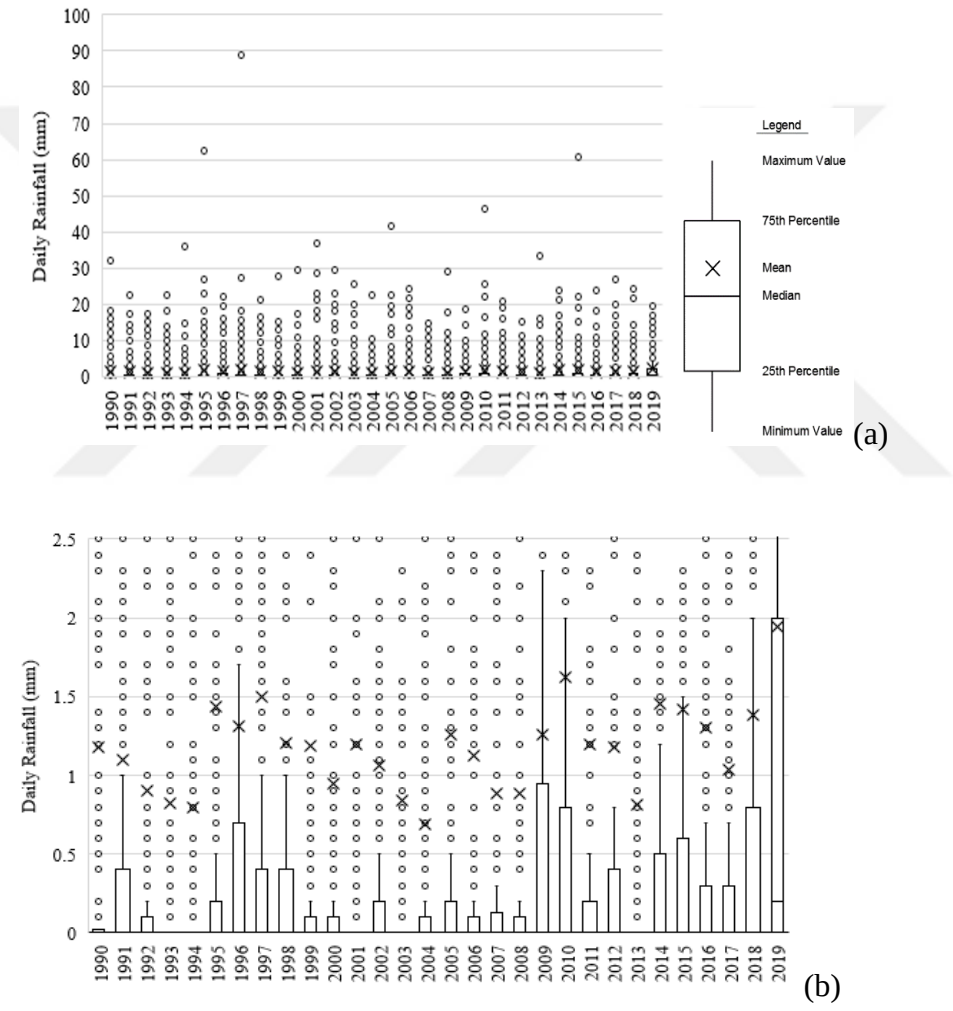


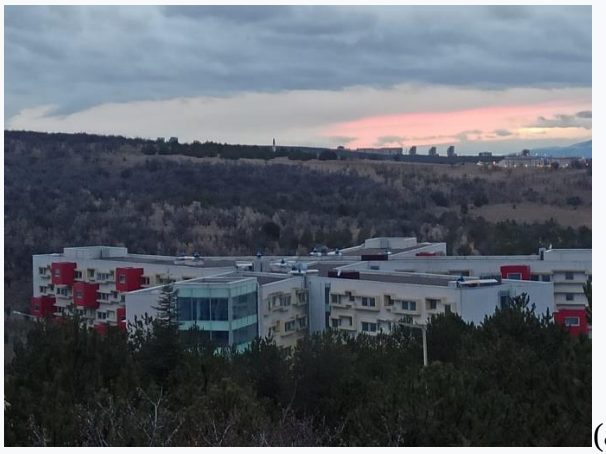
Figure 4.6 (a) Daily rainfall variations for years between 1990 and 2019, (b) Daily rainfall variations in 0-2.5 mm range for years between 1990 and 2019

4.3.2. Collection and Analysis of Site Data

METU is a very suitable campus for RHSs due to its building layouts, roof areas, and available free areas for RHT. METU buildings generally have horizontal architecture. Most buildings are three or four story buildings with quite large layouts and generally flat roofs. Therefore, the roofs of the buildings are suitable for collecting rainwater (i.e., as collectors of the RHSs). The five components of RHS, which are explained in Section 3.2 are described below.

4.3.2.1 Effective Rooftop Areas

Roofs of the buildings at METU are flat or slightly inclined. For this reason, the roofs of the buildings are suitable for rain harvesting. Examples of METU building roofs are shown in Figures 4.7(a) and 4.7(b).

(a)


(b)

Figure 4.7 (a) Flat roof of Dormitory 19 Building, (b) Slight inclined roof of the Business Administration Building (METU, 2021)

The projected roof areas of 76 buildings used in this study are measured using measurement tool of the Google Earth program. Area differences arising from slopes of the roofs are ignored due to slight inclination. While collecting rainwater, some losses occur due to the roof geometry. Therefore, the effective roof area is calculated by multiplying the roof area with the runoff coefficient (i.e., 0.9 is used in this study), which is explained in Section 3.3.2.1. The roof areas and the effective roof areas of the buildings are listed in Table 4.4.

Table 4.4 Roof area and effective roof area of the buildings

Building Group Code	**Building Code**	**Roof Area (m^2)**	**Effective Roof Area (m^2)**
BG_1	B_1	476	428
	B_2	476	428
	B_3	188	169
BG_2	B_4	785	707
	B_5	521	469

Table 4.4 (continued)

BG_3	B_6	576	518
	B_7	576	518
BG_4	B_8	1617	1455
	B_9	911	820
	B_10	1570	1413
BG_5	B_11	5700	5130
BG_6	B_12	2370	2133
BG_7	B_13	5800	5220
	B_14	910	819
BG_8	B_15	1100	990
	B_16	1450	1305
BG_9	B_17	1400	1260
	B_18	1000	900
	B_19	1575	1418
	B_20	1100	990
BG_10	B_21	1950	1755
BG_11	B_22	3170	2853
	B_23	1355	1220
BG_12	B_24	2050	1845
BG_13	B_25	468	421
	B_26	1380	1242
	B_27	510	459
BG_14	B_28	4420	3978
	B_29	1330	1197
	B_30	3560	3204
	B_31	860	774
	B_32	2310	2079
BG_15	B_33	1875	1688
	B_34	2240	2016

Table 4.4 (continued)

	B_35	1500	1350
	B_36	1345	1211
	B_37	1045	941
BG_16	B_38	1360	1224
	B_39	1980	1782
	B_40	545	491
	B_41	2525	2273
	B_42	2670	2403
	B_43	1200	1080
BG_17	B_44	2500	2250
BG_18	B_45	2285	2057
	B_46	195	176
	B_47	1060	954
	B_48	745	671
BG_19	B_49	2270	2043
BG_20	B_50	4170	3753
	B_51	1750	1575
BG_21	B_52	1585	1427
BG_22	B_53	2850	2565
BG_23	B_54	2445	2201
BG_24	B_55	2650	2385
	B_56	2585	2327
	B_57	2185	1967
BG_25	B_58	1950	1755
BG_26	B_59	1895	1706
BG_27	B_60	1725	1553
BG_28	B_61	975	878
BG_29	B_62	975	878
BG_30	B_63	968	871

Table 4.4 (continued)

BG_31	B_64	895	806
BG_32	B_65	950	855
BG_33	B_66	1990	1791
BG_34	B_67	1900	1710
BG_35	B_68	947	852
BG_36	B_69	924	832
BG_37	B_70	2195	1976
BG_38	B_71	480	432
BG_39	B_72	1600	1440
BG 40	B_73	2900	2610
BG_41	B_74	3000	2700
BG_42	B_75	2900	2610
BG_43	B_76	2900	2610
TOTAL		133093	119784

4.3.2.2 Number of People Using Each Building Group

One of the main parameters of the RHS is the water demand. The rainwater is used for toilet flushing in this study. Therefore, the number of people using each building is required to estimate the demand. The number of people using each building group is obtained from the Construction Works and Technical Department of METU (2020) and are shown in Table 4.5.

Table 4.5 Number of people using each building group (Construction Works and Technical Department of METU, 2020)

Building Group Code	Undergraduate Students	Master Student (20% of Undergraduate Students)	Doctorate Students (15% of Undergraduate Students)	Academic Staff	Staff	Total
BG_1	924	-	-	214	2	1140
BG_2	1034	-	-	-	2	1036
BG_3	1122	-	-	-	2	1124
BG_4	1870	374	280	84	30	2638
BG_5	444	90	67	40	4	645
BG_6	1060	212	159	135	14	1580
BG_7	1000	200	150	140	50	1540
BG_8	1480	296	222	231	14	2243
BG_9	360	72	54	145	15	646
BG_10	240	48	36	61	9	394
BG_11	320	64	48	118	18	568
BG_12	380	76	57	53	9	575
BG_13	420	84	63	78	8	653
BG_14	720	144	108	176	32	1180
BG_15	780	156	117	123	29	1205
BG_16	760	152	1114	107	19	2152
BG_17	515	-	-	19	1	534
BG_18	400	80	60	73	15	628
BG_19	260	52	39	64	10	425
BG_20	320	64	48	33	7	472
BG_21	240	48	36	72	13	409
BG_22	240	48	36	21	13	409
BG_23	240	48	36	28	5	409

Table 4.5 (continued)

BG_24	360	72	54	26	8	520
BG_25	340	68	51	37	8	504
BG_26		380			6	383
BG_27		372			6	375
BG_28		396			6	399
BG_29		396			6	399
BG_30		346			6	349
BG_31		338			6	341
BG_32		476			6	479
BG_33		476			6	479
BG_34		411			6	414
BG_35		316			6	319
BG_36		214			6	217
BG_37		312			6	315
BG_38		185			6	188
BG_39		227			6	230
BG 40		640			6	643
BG_41		694			6	697
BG_42		628			6	631
BG_43		604			6	607

4.3.2.3 Daily Water Demand per Capita and Total Daily Water Demand for Each Building Group

Daily water consumption per capita changes due to the nations' characteristics and habits. The daily water consumption per capita varies between 125 to 150 L/day/capita for European Nations (Environmental Agency, 2008). In addition, according to European Commission Report (2012), the average daily water consumption varies between 140 to 160 L/day/capita. Therefore, the average daily

water consumption is taken as 150 L/day/capita in this study. Water is used for multiple purposes like toilet flushing, shower, faucet, laundry, leak, and others, and according to Vitra (2014) they account for 24%, 20%, 19%, 17%, 12%, and 8% of total consumption, respectively. Based on this, the daily flushing demand is assumed to be around 36 L/day/capita.

Toilet reservoir capacities are essential parameters for RHS. The most commonly used toilet reservoir capacity is 6 L in the world (Cushman, 2019) and in Turkey as well. Larger capacity reservoirs were used previously. However, with developing technologies, the smaller capacities become popular. Thus, for the case study, it is assumed that 6 L toilet reservoirs are used at METU campus, and daily flushing demand is taken as 36 L/day/capita. This results in an average of six flushes in a day for each person.

In this study, it is assumed that rainwater collected from the roof areas of the buildings is used for only toilet flushing. METU Campus department buildings and dormitories are used by students, academic staff/faculty, and administrative staff. Therefore, daily toilet flushing water demands in the building are estimated using the occupant's information. Daily flushing water demand varies depending on the occupants' use of the buildings (i.e., student, faculty, staff). For example, assuming the faculty and administrative staff stay in the department buildings about 8 hours on weekdays during the year while undergraduate students stay an average of 4 hours on weekdays during the semester, each group consumes different amounts of water for toilet flushing. The number of hours spends in various types of buildings by multiple groups is summarized in Table 4.6.

The number of flushes per day is determined as six as explained in the previous paragraph. People are assumed to use the toilet during day time. The sleeping time is assumed to be eight hours in a day. Therefore, it is assumed that six flushes are distributed uniformly in the remaining sixteen hours. The number of hours spends, and the number of toilet flushes is summarized concerning the type of building and type of occupant in Table 4.6. The daily water demand varies within the year due to the education regulations. There is no lesson at the weekends in the department

buildings, and there is also a summer holiday. Spring break due to being relatively short is ignored. 20% of the daily weekday's water demand is assumed as the water demand at the weekend. Also, 10% of the daily weekday water demand is considered as the summer holiday's water demand. The holiday is assumed to start on 16th of June and end on 30th of September of each year. On the other hand, water usage in dormitories is taken as the same regardless of weekdays and weekends. Finally, the water demand is assumed to be zero during the summer holiday at the dormitories. The number of hours spent in the department buildings and dormitories and the number of toilet flushes concerning the type of use are given in Table 4.6. Using this information, the total water demand of each building group is estimated and provided in Table 4.7.

Table 4.6 Number of hours spend in department buildings and dormitories, and number of toilet flushes with respect to type of use

		Academic Staffs (week days)	**Staffs (weekdays)**	**Under graduate Students (weekdays during the semester)**	**Masters Students (weekdays during the semester)**	**PhD Students (weekdays during the semester)**
Department Buildings	Hours spent	8	8	4	1	1
	Flushing/day /capita	3	3	2	1	1
Dormitories	Hours spent	-	8	8	8	8
	Flushing/day /capita	-	3	3	3	3

Table 4.7 Total water demand of each RHS study group

Building Group Code	Weekdays Daily Water Demand (L/day)	Weekend Daily Water Demand (L/day)	Holiday Daily Water Demand (L/day)
BG_1	14976.0	2995.2	1497.6
BG_2	12444.0	2488.8	1244.4
BG_3	13500.0	2700.0	1350.0
BG_4	28416.0	5683.2	2841.6
BG_5	7062.0	1412.4	706.2
BG_6	17628.0	3525.6	1762.8
BG_7	17520.0	3504.0	1752.0
BG_8	25278.0	5055.6	2527.8
BG_9	7956.0	1591.2	795.6
BG_10	4644.0	928.8	464.4
BG_11	6960.0	1392.0	696.0
BG_12	6474.0	1294.8	647.4
BG_13	7470.0	1494.0	747.0
BG_14	13896.0	2779.2	1389.6
BG_15	13734.0	2746.8	1373.4
BG_16	18984.0	3796.8	1898.4
BG_17	6540.0	1308.0	654.0
BG_18	7224.0	1444.8	722.4
BG_19	4998.0	999.6	499.8
BG_20	5232.0	1046.4	523.2
BG_21	4914.0	982.8	491.4
BG_22	3996.0	799.2	399.6
BG_23	3978.0	795.6	397.8

Table 4.7 (continued)

BG_24	5688.0	1137.6	568.8
BG_25	5604.0	1120.8	560.4
BG_26	6948.0		-
BG_27	6804.0		-
BG_28	7236.0		-
BG_29	7236.0		-
BG_30	6336.0		-
BG_31	6192.0		-
BG_32	8676.0		-
BG_33	8676.0		-
BG_34	7506.0		-
BG_35	5796.0		-
BG_36	3960.0		-
BG_37	5724.0		-
BG_38	3438.0		-
BG_39	4194.0		-
BG 40	11628.0		-
BG_41	12600.0		-
BG_42	11412.0		-
BG_43	10980.0		-

4.3.2.4 Selection of RHT Location

The locations of the RHTs for each building group are selected considering geographic conditions. Generally, areas without vegetation are chosen for installing RHTs. Also, the altitude is considered while selecting the RHT location to decrease the pump head. The selected RHT locations are shown in Figure 4.8 and the

coordinates of the RHT locations are obtained from Google Earth and listed in Table 4.8.

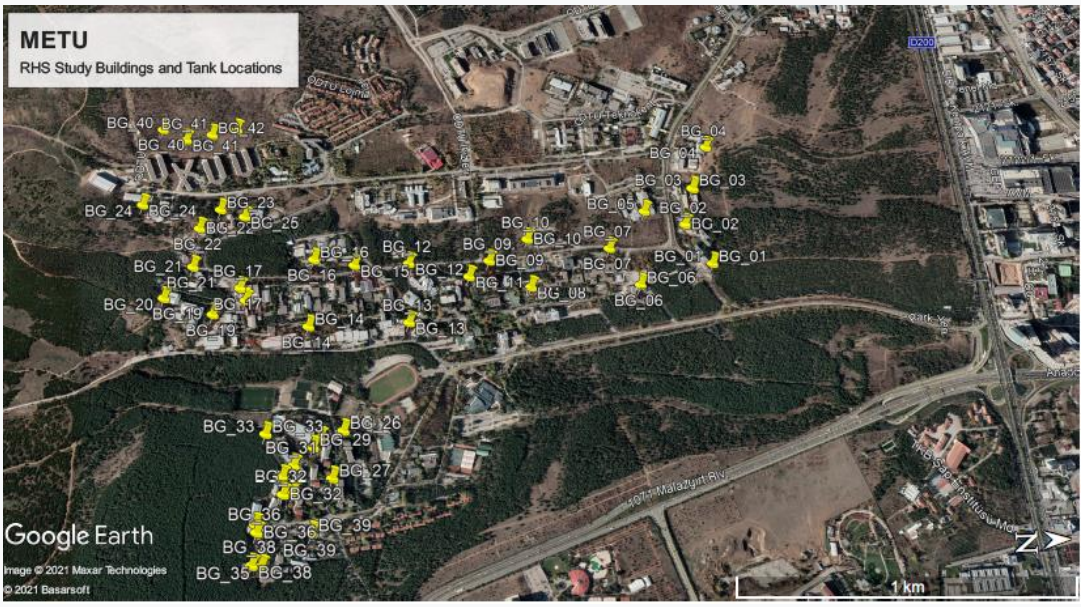


Figure 4.8 RHS study buildings and RHT locations (Google Earth, 2021)

Table 4.8 Coordinates of RHTs of the RHSs (Google Earth, 2021)

Building Group Code	**Latitude**	**Longitude**	**Altitude*** **(m)**
BG_1	39°54'2.33"N	32°46'54.56"E	907
BG_2	39°53'59.89"N	32°46'48.70"E	898
BG_3	39°54'1.03"N	32°46'43.44"E	892
BG_4	39°54'2.93"N	32°46'37.01"E	890
BG_5	39°53'55.75"N	32°46'46.50"E	897
BG_6	39°53'54.73"N	32°46'57.25"E	911
BG_7	39°53'51.78"N	32°46'51.91"E	910
BG_8	39°53'43.50"N	32°46'57.06"E	919

Table 4.8 (continued)

BG_9	39°53'39.30"N	32°46'53.09"E	917
BG_10	39°53'43.31"N	32°46'50.05"E	909
BG_11	39°53'37.22"N	32°46'55.29"E	923
BG_12	39°53'31.07"N	32°46'53.18"E	926
BG_13	39°53'31.10"N	32°47'1.37"E	927
BG_14	39°53'21.03"N	32°47'1.49"E	935
BG_15	39°53'25.53"N	32°46'53.26"E	933
BG_16	39°53'21.38"N	32°46'52.23"E	937
BG_17	39°53'14.06"N	32°46'56.01"E	945
BG_18	39°53'14.69"N	32°46'57.72"E	947
BG_19	39°53'11.47"N	32°46'59.50"E	948
BG_20	39°53'6.58"N	32°46'57.20"E	960
BG_21	39°53'9.22"N	32°46'52.87"E	947
BG_22	39°53'9.58"N	32°46'47.35"E	945
BG_23	39°53'11.54"N	32°46'44.56"E	936
BG_24	39°53'3.37"N	32°46'43.42"E	936
BG_25	39°53'14.08"N	32°46'45.78"E	938
BG 26	39°53'24.68"N	32°47'15.25"E	923
BG_27	39°53'23.73"N	32°47'21.20"E	928
BG_28	39°53'22.43"N	32°47'16.05"E	929
BG 29	39°53'21.80"N	32°47'17.25"E	931
BG_30	39°53'20.03"N	32°47'22.72"E	936
BG_31	39°53'20.03"N	32°47'19.49"E	937
BG 32	39°53'19.11"N	32°47'23.00"E	936
BG_33	39°53'17.24"N	32°47'15.40"E	940
BG_34	39°53'16.66"N	32°47'26.56"E	941
BG_35	39°53'17.37"N	32°47'31.53"E	944
BG_36	39°53'16.79"N	32°47'27.49"E	941
BG_37	39°53'19.00"N	32°47'20.84"E	937

	Table 4.8 (continued)		
BG_38	39°53'16.49"N	32°47'31.38"E	945
BG_39	39°53'21.91"N	32°47'27.79"E	933
BG 40	39°53'4.85"N	32°46'32.16"E	932
BG_41	39°53'7.36"N	32°46'33.77"E	928
BG 42	39°53'10.06"N	32°46'33.11"E	925
BG_43	39°53'12.62"N	32°46'32.31"E	918

* Obtained from Google Earth

4.3.2.5 Number of Floors at each Building

The number of toilet reservoirs is needed to calculate the required pump power as explained in Section 3.3.2.6. A total of ten toilet reservoirs per floor is assumed in this study. The number of floors at each building is determined by visiting them and they are listed in Table 4.9.

Table 4.9 Number of floors in each building

Building Group Code	**Building Code**	**Number of Floor in the Buildings**	**Total Number of Floor in Each Group**
BG_1	B_1	4	10
	B_2	4	
	B_3	2	
BG_2	B_4	5	7
	B_5	2	
BG_3	B_6	2	4

Table 4.9 (continued)

	B_7	2	
BG_4	B_8	3	10
	B_9	3	
	B_10	4	
BG_5	B_11	2	2
BG_6	B_12	3	3
BG_7	B_13	2	4
	B_14	2	
BG_8	B_15	4	7
	B_16	3	
BG_9	B_17	2	13
	B_18	3	
	B_19	6	
	B_20	2	
BG_10	B_21	4	4
BG_11	B_22	4	7
	B_23	3	
BG_12	B_24	4	4
BG_13	B_25	2	8
	B_26	3	
	B_27	3	
BG_14	B_28	2	10
	B_29	2	
	B_30	2	
	B_31	2	
	B_32	2	
BG_15	B_4	5	14
	B_34	2	
	B_35	4	

Table 4.9 (continued)

	B_36	3	
	B_37	3	
BG_16	B_38	3	17
	B_39	3	
	B_40	2	
	B_41	3	
	B_42	3	
	B_43	3	
BG_17	B_44	3	3
BG_18	B_45	2	10
	B_46	2	
	B_47	2	
	B_48	4	
BG_19	B_49	3	3
BG_20	B_50	4	8
	B_51	4	
BG_21	B_52	4	4
BG_22	B_53	3	3
BG_23	B_54	3	3
BG_24	B_55	3	10
	B_56	3	
	B_57	4	
BG_25	B_58	2	2
BG_26	B_59	5	5
BG_27	B_60	5	5
BG_28	B_61	6	6
BG_29	B_4	5	6
BG_30	B_63	6	6
BG_31	B_64	6	6

Table 4.9 (continued)

BG_32	B_65	6	6
BG_33	B_66	6	6
BG_34	B_67	6	6
BG_35	B_68	5	5
BG_36	B_69	3	3
BG_37	B_70	3	3
BG_38	B_71	4	4
BG_39	B_72	5	5
BG 40	B_73	4	4
BG_41	B_74	4	4
BG_42	B_75	4	4
BG_43	B_76	4	4

4.3.2.6 Pipe Lengths

Rainwater is conveyed with pipeline system from collector to RHT and from RHT to toilet reservoirs. The pipeline system is separated into two parts which are HP and SP. HP conveys rainwater from collector to the RHT by gravity. Therefore, no pump is needed. The PVC 100 pipe is used for HP. On the other hand, SP conveys rainwater from RHT to the buildings. Therefore, pump is needed to convey rainwater from RHT to the buildings due to the elevation differences. The PPRC 20 pipes are used for SP. The length of these pipes are important parameter for the system design and in the economic analysis. Therefore, the length of the pipes are listed as Table 4.10.

Table 4.10 Pipe Lengths for HP and SP

Building Group Code	Building Code	Harvesting Pipe (HP) Length (m)	Total HP Length (m) for the BG	Supply Pipe (SP) Length (m)	Total SP Length (m) for the BG
BG_1	B_1	37	199	97	349
	B_2	77		137	
	B_3	85		115	
BG_2	B_4	57	75	132	180
	B_5	18		48	
BG_3	B_6	8	17	38	77
	B_7	9		39	
BG_4	B_8	15	51	60	201
	B_9	16		61	
	B_10	20		80	
BG_5	B_11	27	27	57	57
BG_6	B_12	15	15	60	60
BG_7	B_13	23	59	53	119
	B_14	36		66	
BG_8	B_15	32	43	92	148
	B_16	11		56	
BG_9	B_17	12	109	42	304
	B_18	24		69	
	B_19	42		132	
	B_20	31		61	
BG_10	B_21	36	36	96	96
BG_11	B_22	37	91	97	196
	B_23	54		99	
BG_12	B_24	24	24	84	84

Table 4.10 (continued)

BG_13	B_25	14	121	44	241
	B_26	63		108	
	B_27	44		89	
BG_14	B_28	153	752	183	902
	B_29	71		101	
	B_30	14		44	
	B_31	246		276	
	B_32	268		298	
BG_15	B_33	21	91	51	211
	B_34	28		58	
	B_35	42		102	
	B_36	39		84	
	B_37	35		80	
BG_16	B_38	89	557	134	812
	B_39	84		129	
	B_40	81		111	
	B_41	96		141	
	B_42	95		140	
	B_43	112		157	
BG_17	B_44	24	24	69	69
BG_18	B_45	86	234	116	384
	B_46	67		97	
	B_47	45		75	
	B_48	36		96	
BG_19	B_49	32	32	77	77
BG_20	B_50	32	64	92	184
	B_51	32		92	
BG_21	B_52	32	32	92	92
BG_22	B_53	22	22	67	67

Table 4.10 (continued)

BG_23	B_54	24	24	69	69
BG_24	B_55	24	226	69	376
	B_56	66		111	
	B_57	136		196	
BG_25	B_58	26	26	56	56
BG_26	B_59	25	25	100	100
BG_27	B_60	25	25	100	100
BG_28	B_61	28	28	118	118
BG_29	B_62	28	28	118	118
BG_30	B_63	28	28	118	118
BG_31	B_64	28	28	118	118
BG_32	B_65	28	28	118	118
BG_33	B_66	28	28	118	118
BG_34	B_67	28	28	118	118
BG_35	B_68	25	25	100	100
BG_36	B_69	19	19	64	64
BG_37	B_70	19	19	64	64
BG_38	B_71	22	22	82	82
BG_39	B_72	25	25	100	100
BG 40	B_73	22	22	82	82
BG_41	B_74	22	22	82	82
BG_42	B_75	22	22	82	82
BG_43	B_76	22	22	82	82

4.3.2.7 The RHT Sizes

In this study, eight alternative RHT capacities are used. These are 10 m^3, 25 m^3, 50 m^3, 100 m^3, 200 m^3, 300 m^3, 400 m^3 and 500 m^3. Initial investment cost of the RHT includes all the costs such as material cost, construction cost, labor cost, etc.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 WBM Results

The WBM with daily time steps is used to evaluate the performances of alternative RHT sizes and used together with cost-benefit analysis to identify the best RHT size for selected METU campus buildings. The proposed approach is general and can be used at any site to select the best RHT size. The results obtained for METU campus buildings are provided in this chapter.

The flowchart of the proposed approach is shown in Figure 5.1. Here, we aim to select the best RHT size for the rooftop RHS for each B_RHS at METU Campus. As explained in Section 4, a total of 43 B_RHS are identified for METU Campus to be equipped with the RHSs, thus, the proposed approach is executed for each B_RHS once. Buildings at METU Campus have horizontal architecture, thus rooftop RHSs are suitable for the campus buildings. Consequently, the existing roofs of the buildings are used as collector areas. The other components of the RHS are the RHT, HP and SP, the filter and the pump.

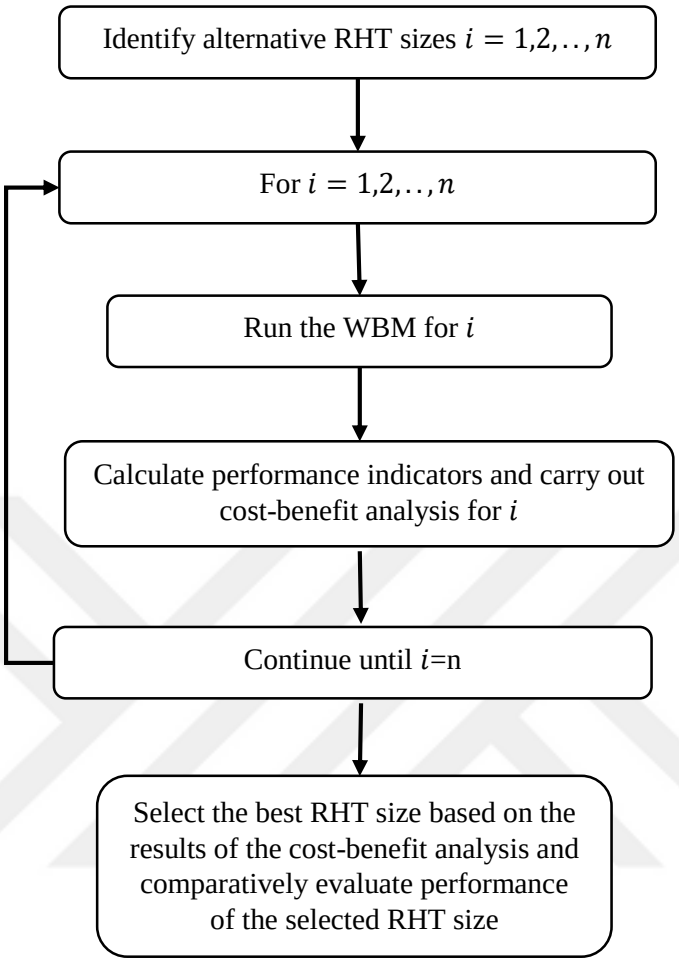


Figure 5.1 The flowchart of the calculation process

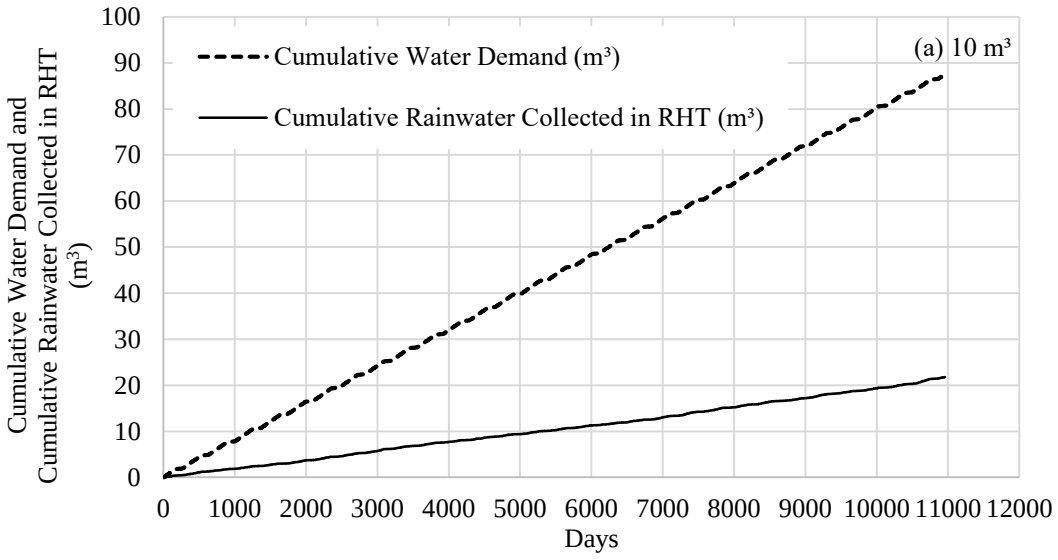
One of the 43 B_RHS, namely BG_14 is selected to demonstrate the details of the calculations. Results of all RHSs are given in Section 5.4.

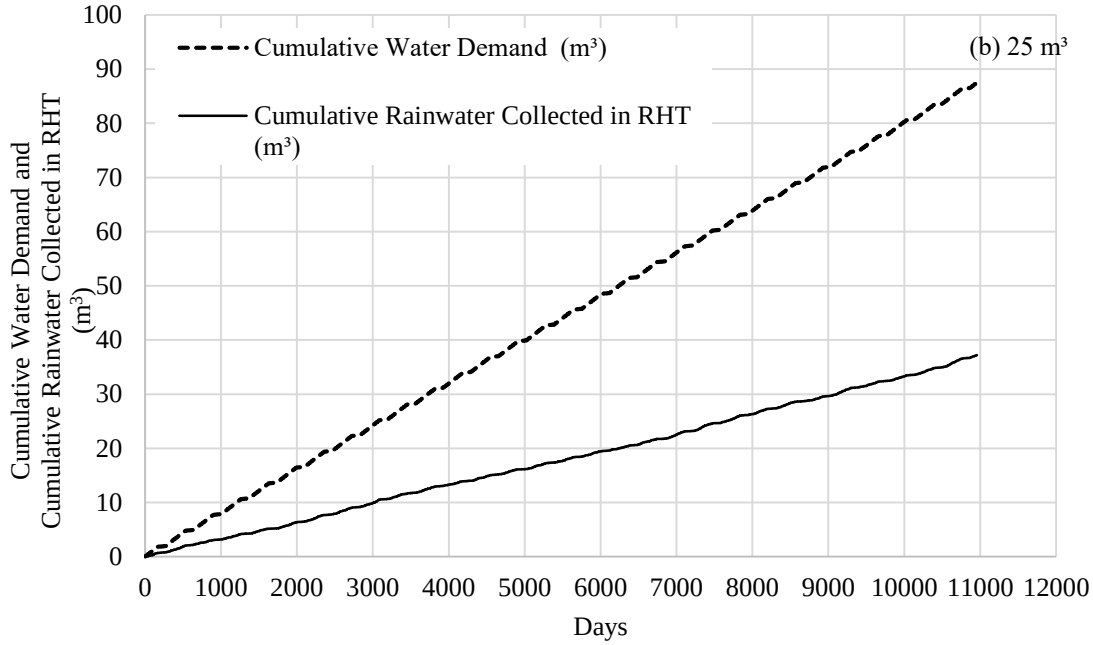
As the first step, eight alternative RHT sizes are identified as follows: 10 m^3, 25 m^3, 50 m^3, 100 m^3, 200 m^3, 300 m^3, 400 m^3, and 500 m^3. The WBM is run for each of these eight RHT sizes. Apart from the RHT capacity, there are other inputs used in the WBM. These are daily precipitation data, effective roof area and daily water demand. The inputs of the WBM for BG_14 are summarized in Table 5.1.

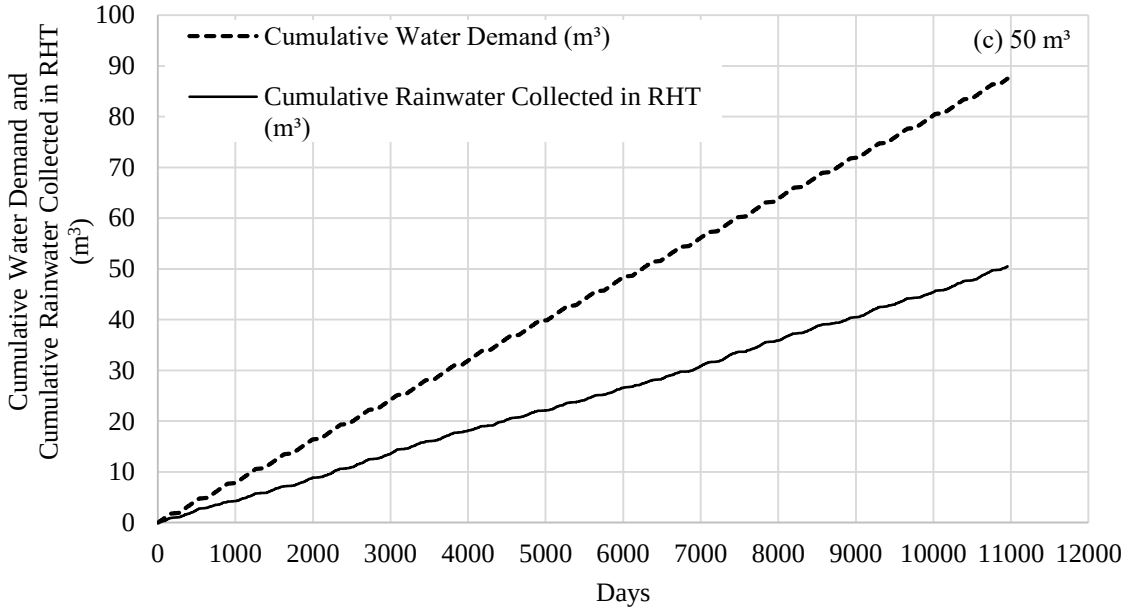
Table 5.1 The inputs of the WBM for BG_14

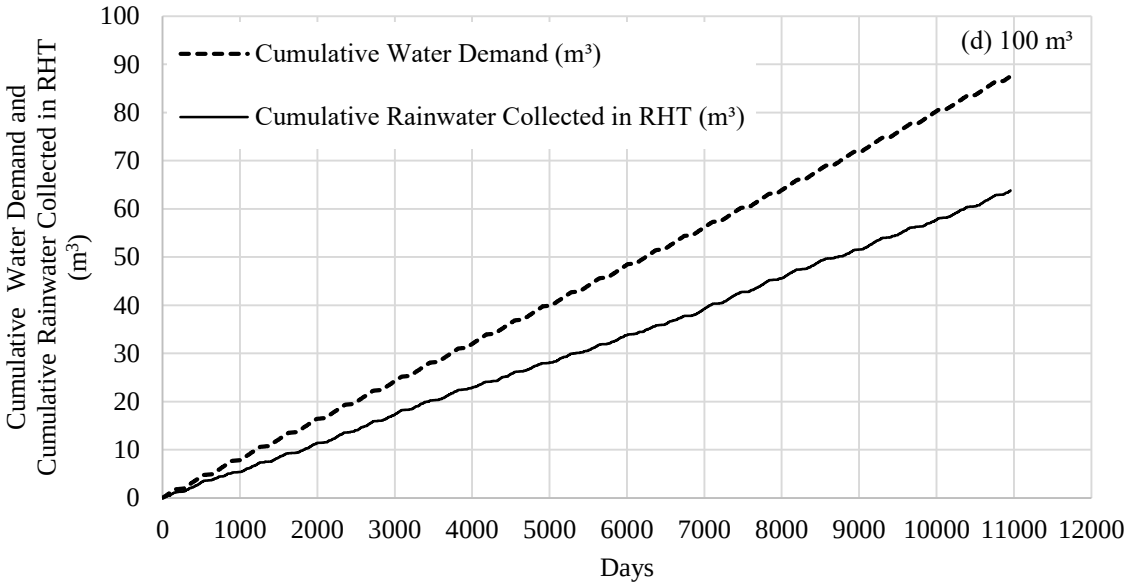
Inputs	**Values**
Daily Precipitation Data	30 years daily data is taken from GDM
Roof Coefficient	0.9
Total Roof Area (m^2)	11232.0
Effective Roof Area (m^2)	10108.8
Weekdays Daily Water Demand (L/day)	13896.0
Weekend Daily Water Demand (L/day)	2779.2
Holiday Daily Water Demand (L/day)	1389.6

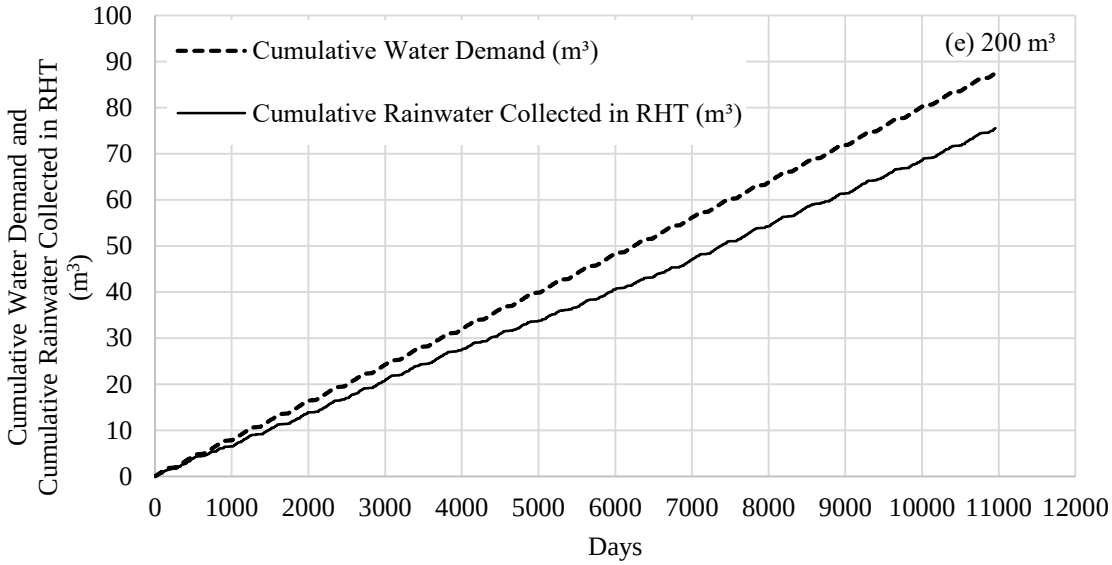
Daily rainfall data for 30 years between 1990 – 2019 is obtained from GDM and the WBM is run using this data. It is assumed that the precipitation regime will not change significantly in the near future and the results obtained using historical data will be useful for the near future. The graphs of the results of the WBM for each alternative RHT size are shown in Figure 5.2.

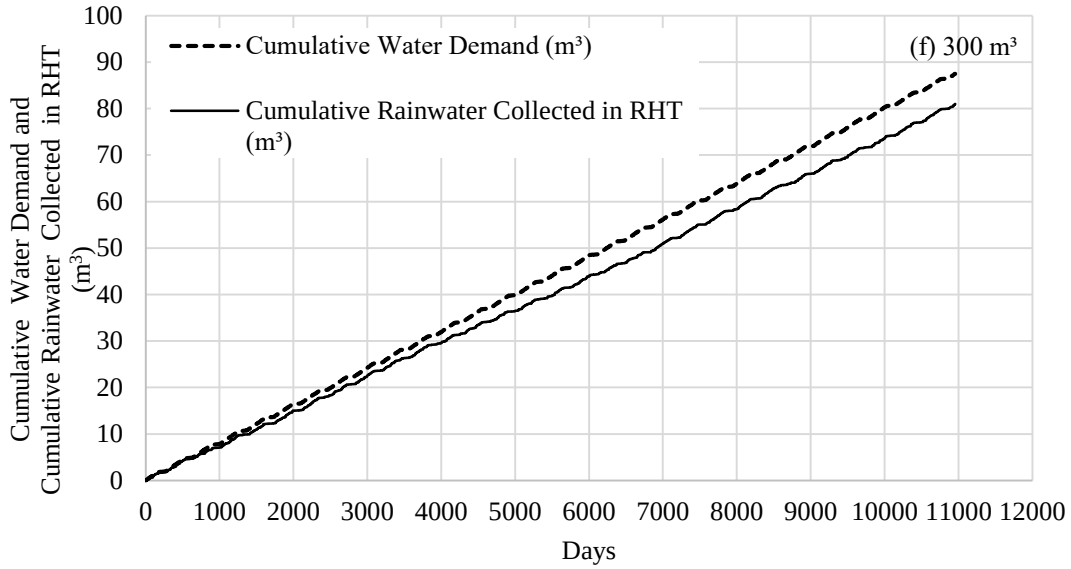


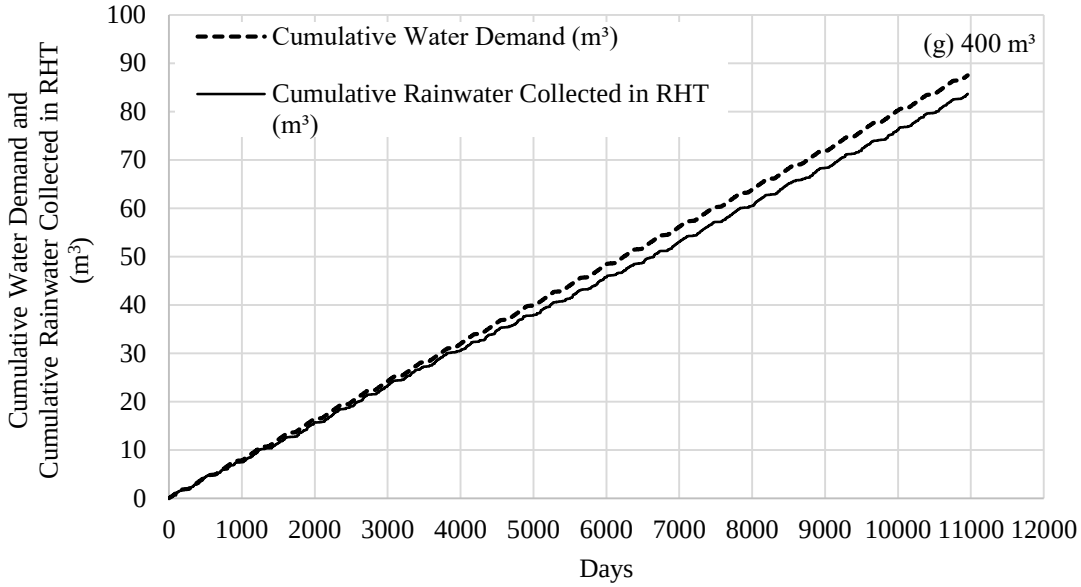

Cumulative Water Demand (m³)
Cumulative Rainwater Collected in RHT (m³)
(b) 25 m³
Cumulative Water Demand and Cumulative Rainwater Collected in RHT (m³)
Days
0
10
20
30
40
50
60
70
80
90
100
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000


Cumulative Water Demand (m³)
Cumulative Rainwater Collected in RHT (m³)
(c) 50 m³
Cumulative Water Demand and Cumulative Rainwater Collected in RHT (m³)
Days
0
10
20
30
40
50
60
70
80
90
100
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000


(d) 100 m³
Cumulative Water Demand (m³)
Cumulative Rainwater Collected in RHT (m³)
Cumulative Water Demand and Cumulative Rainwater Collected in RHT (m³)
Days
0
10
20
30
40
50
60
70
80
90
100
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000


(e) 200 m³
Cumulative Water Demand (m³)
Cumulative Rainwater Collected in RHT (m³)
Cumulative Water Demand and Cumulative Rainwater Collected in RHT (m³)
Days
0
10
20
30
40
50
60
70
80
90
100
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000


Cumulative Water Demand (m³)
Cumulative Rainwater Collected in RHT (m³)
(f) 300 m³
Cumulative Water Demand and Cumulative Rainwater Collected in RHT (m³)
Days
0
10
20
30
40
50
60
70
80
90
100
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000


Cumulative Water Demand (m³)
Cumulative Rainwater Collected in RHT (m³)
(g) 400 m³
Cumulative Water Demand and Cumulative Rainwater Collected in RHT (m³)
Days
0
10
20
30
40
50
60
70
80
90
100
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000

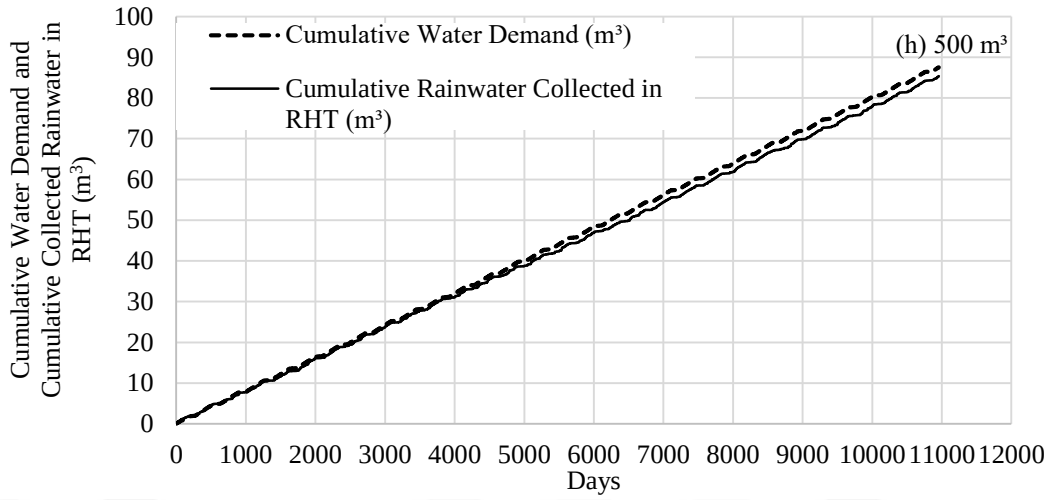


Figure 5.2 WBM Results for RHT sizes of (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³ for BG_14

As the RHT size increases, the total amount of rainwater that can be collected in the RHT increases. The ability to store more rain water in the RHT is important in providing the water demand even when there is no precipitation. The best RHS performance is achieved when the cumulative water demand and the cumulative collected rainwater are the same (i.e., all the demand is supplied from the RHS). Of course, increasing the RHT size brings additional cost and affects the feasibility of the RHS. Thus, a trade-off has to be achieved between the cost of the RHS and the amount of demand supplied by rainwater. The annual amounts of water supplied from the RHT for BG_14 during the simulation period are calculated and given in Table 5.2. The average annual water supply with respect to RHT size for BG_14 is shown in Figure 5.3. As can be seen in Figure 5.3, up to 300 m^3 storage capacity, the average annual water supply from the RHS has a logarithmic increase and then starts levelling off. For example, doubling the RHT size from 25 m^3 to 50 m^3 results in almost 36% increase in the average annual water supplied from the RHS, while doubling the RHT size from 200 m^3 to 400 m^3 only results in an increase of around 10%. Hence, the increase in the performance of the RHS (i.e., in terms of supplying the demand) decreases with increasing RHT size.

Table 5.2 Annual Amounts of Water Supplied from the RHT (m^3)

	RHT sizes							
Years	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
2021	693.30	1176.39	1585.99	2059.63	2516.19	2584.24	2584.24	2584.24
2022	790.55	1383.38	1836.60	2278.13	2598.34	2811.05	2920.23	2922.40
2023	553.89	945.98	1319.07	1715.96	2168.46	2393.06	2593.06	2743.53
2024	582.58	1046.76	1526.21	1989.80	2448.39	2698.50	2847.61	2911.29
2025	588.78	1020.87	1487.41	1944.61	2427.08	2564.24	2588.57	2624.89
2026	735.05	1239.18	1657.86	2080.72	2454.85	2762.73	2862.73	2911.29
2027	818.42	1399.45	1864.68	2362.12	2759.00	2908.10	2936.30	2936.30
2028	784.75	1350.94	1867.89	2272.52	2610.74	2740.66	2840.66	2911.29
2029	846.66	1464.74	1918.05	2322.33	2737.17	2911.29	2911.29	2911.29
2030	637.19	1094.49	1471.22	1844.20	2338.36	2659.22	2821.18	2911.29
2031	691.89	1220.31	1672.05	2118.28	2495.67	2657.78	2757.78	2857.78
2032	606.39	1052.58	1445.71	1914.95	2377.81	2572.91	2672.91	2673.64
2033	623.49	1033.55	1444.95	1864.05	2220.93	2420.93	2620.93	2801.66
2034	606.91	1054.74	1446.93	1813.38	2208.90	2436.35	2606.67	2718.28
2035	657.17	1135.33	1529.31	1934.48	2267.20	2518.17	2718.17	2891.15
2036	681.24	1156.53	1531.92	2041.54	2480.03	2617.50	2617.50	2620.06
2037	592.14	1061.92	1493.84	1918.06	2261.66	2548.58	2748.58	2873.64
2038	674.22	1244.07	1739.03	2196.78	2586.84	2707.75	2739.32	2739.32
2039	622.78	1077.84	1498.57	1856.47	2253.67	2521.98	2659.24	2759.24
2040	844.37	1462.04	1952.77	2564.09	2866.60	2911.29	2911.29	2911.29
2041	854.88	1442.48	1935.61	2410.80	2787.02	2911.29	2911.29	2911.29
2042	767.84	1328.91	1795.03	2292.37	2615.55	2728.76	2828.76	2900.17
2043	829.56	1413.43	1908.90	2390.87	2742.26	2887.09	2936.30	2936.30
2044	611.13	1053.08	1464.40	1969.63	2441.42	2588.62	2688.62	2788.62
2045	776.08	1261.93	1700.71	2174.63	2560.56	2666.21	2666.21	2666.21
2046	797.75	1367.88	1840.83	2196.05	2572.95	2762.37	2862.37	2911.29
2047	683.19	1176.86	1643.88	2121.95	2458.21	2581.04	2681.04	2821.21
2048	726.29	1254.93	1809.87	2220.45	2550.82	2800.75	2866.82	2866.82
2049	867.62	1462.63	1907.98	2269.05	2699.62	2899.01	2933.52	2933.52
2050	1219.03	1808.86	2152.95	2578.22	2859.55	2922.40	2922.40	2922.40
Average	**725.50**	**1239.74**	**1681.67**	**2123.87**	**2512.20**	**2689.79**	**2775.18**	**2829.06**

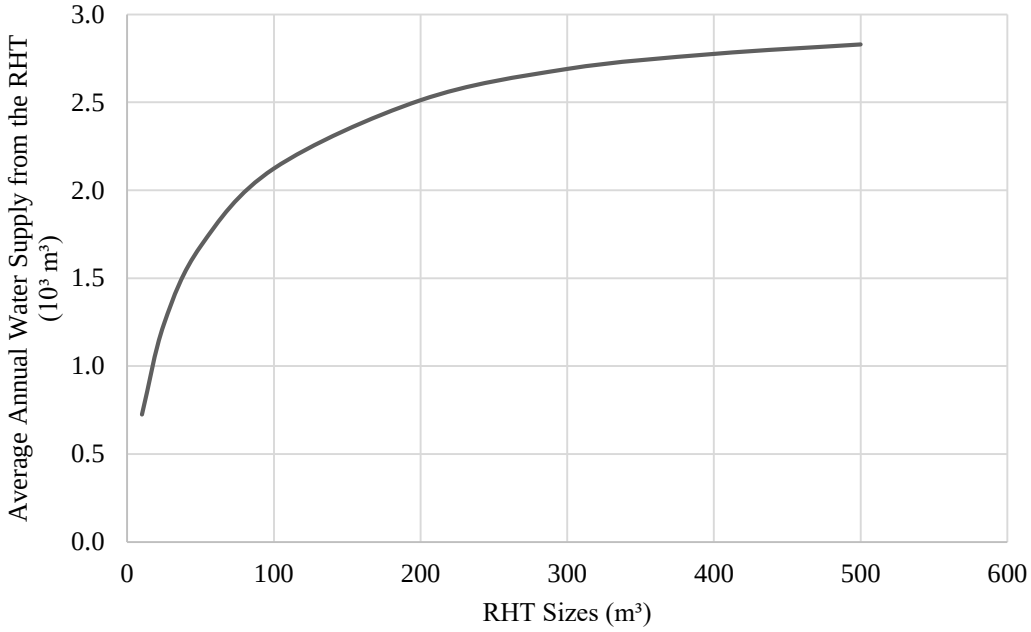


Figure 5.3 The average annual amount of water supplied from the RHS for BG_14

5.2 Economic Analysis

Economic analysis is carried out for each alternative RHT size. First, the costs of the system components are determined. The cost of the RHS is divided into two categories. First one is the investment costs which include RHT costs for each size, filter costs, piping costs and pump costs. The second one is the operation costs which include the pump electricity cost and labor cost for cleaning.

5.2.1 The Investment Costs

The costs of RHTs are taken from unit price analysis of Urbanization and Climate Change report (Republic of Turkey Ministry of Environment, 2021) and shown in Table 5.3.

Table 5.3 Costs of RHTs (Republic of Turkey Ministry of Environment, 2021)

RHT Sizes	RHT Costs (TL) (2021)
10 m³	3900.00
25 m³	9750.00
50 m³	19500.00
100 m³	39000.00
200 m³	78000.00
300 m³	117000.00
400 m³	156000.00
500 m³	195000.00

Other than the RHT cost, investment costs are fixed costs. They are fixed for all RHT size alternatives. To determine the pump cost, first, alternative pumps that can meet the required discharge for each B_RHS have been identified. The discharge requirement of the system is found by dividing the required amount of water by the maximum filling time when all toilets are used simultaneously. Since 43 different B_RHS were examined in this study, the pump selection was reduced to some alternatives.

All four alternative pumps have a head of 20 m since maximum number of floors in the B_RHS is six (Table 4.9). Six floors are approximately 18 m and an additional 2 m is used for head below ground for pumps in the RHT. All losses such as major and minor losses are included to pump head (Netpomp, 2021). In this study, it is assumed that the pump in the system is changed every 10 years (Netpomp, 2021). The selected pumps and their costs (Kampa, 2021) are shown in Table 5.4.

Table 5.4 Pump costs (2021) for different sizes (Kampa, 2021)

Pump Capacity	Pump Cost at Present Value (2021)
Q=75 m^3/h for 20 meter head 4 kW	9245.00 TL
Q=48 m^3/h for 20 meter head 4 kW	8072.94 TL
Q=30 m^3/h for 20 meter head 4 kW	7718.72 TL
Q=21 m^3/h for 20 meter head 2.2 kW	7043.23 TL

The filling time of toilet reservoirs may vary according to the current water requirement of the designed system. In this study, the pump size is calculated considering the worst-case scenario. As the worst case scenario, it is assumed that all toilets are used simultaneously and all reservoirs should be filled in 60 seconds. Therefore, the required discharge range is calculated for all building groups. The pump cost is determined by selecting three different capacity pumps in accordance with these data. Accordingly, the maximum number of simultaneous toilet flushing in BG_14 is 100. If the toilet reservoir capacity is taken as 6 L, a total water requirement to fill up all the reservoirs is 600 L. In the worst-case scenario, if the reservoirs are assumed to be filled within 60 seconds, the discharge should be 10 L/s, which is equal to 36 m^3/hr. In this case, within the specified pumps, capacity of 48 m^3/hr will be sufficient for BG_14.

The other investment cost is the filter cost. The gutter filter is used and its cost is taken as 200 TL (N11, 2021). Since there are five collectors in BG_14, the total cost of filters for BG_14 is 1000 TL.

The final investment cost is the pipe cost. In this study the PVC 100 (i.e., diameter of pipe=100 mm) pipe is used for HP and PPRC 20 (i.e., diameter of pipe = 20 mm) for SP. The harvest pipe and the supply pipe costs are shown in Table 5.5 (Firat,

2021). The lengths of HP and SP are 752 m and 902 m for BG_14 (Table 4.10). Investment costs of BG_14 are summarized in Table 5.6.

Table 5.5 Unit Cost of HP and SP (Firat, 2021)

Pipe Types	**Pipe Costs (2021)**
PVC 100 (for HP)	35.00 TL/m
PPRC 20 (for SP)	3.75 TL/m

Table 5.6 Investment Costs (TL) (2021) for different RHT Sizes for BG_14

RHT Sizes	**RHT Costs (TL) (2021)**	**Filter Costs (TL) (2021)**	**Investing Pump Costs (TL) (2021)**	**Pipe Costs (TL (2021)**	**Total Investment Costs (TL) (2021)**
10 m³	3900.00	1000.00	11166,36	29702.50	45768,86
25 m³	9750.00				51618,86
50 m³	19500.00				61368,86
100 m³	39000.00				80868,86
200 m³	78000.00				119868,86
300 m³	117000.00				158868,86
400 m³	156000.00				197868,86
500 m³	195000.00				236868,86

5.2.2 The Operation Costs

The operation costs include the labor cost for cleaning and the electricity consumption cost of the pump. Since these costs occur throughout the lifetime of the system, projected values of these costs need to be estimated. Data of past years are

collected and regression analysis is carried out to estimate operation costs for future years. However, while carrying out the net present value analysis, they are converted to present values using annual average deposit interest rate of 2021, which is taken as 17% (Central Bank of Turkish Republic, 2021).

In this study, regression lines are fitted to historic labor cost, electricity cost and exchange rate data and then they are used to forecast future values of these parameters. Although, historic cost data after 2015 present an exponential increase, it is assumed that in the long term these relations will converge to average representative values. Hence linear regression models are preferred to represent the relation between time and cost for all historic data.

First, the labor cost is estimated. Daily labor costs for the previous years for 1990-2020 are obtained from Ministry of Family, Labor and Social Services General Directorate (Ministry of Family, Labor and Social Services General Directorate, 2021) and plotted in Figure 5.4. A linear regression line is fitted to the historic time series (i.e. 1990-2020) of labor cost and used to estimate future labor costs. As explained above, the exponential increase after 2015 which is due to the unstable economy of the country is not in agreement with the general trend; thus linear regression is used in estimating future values.

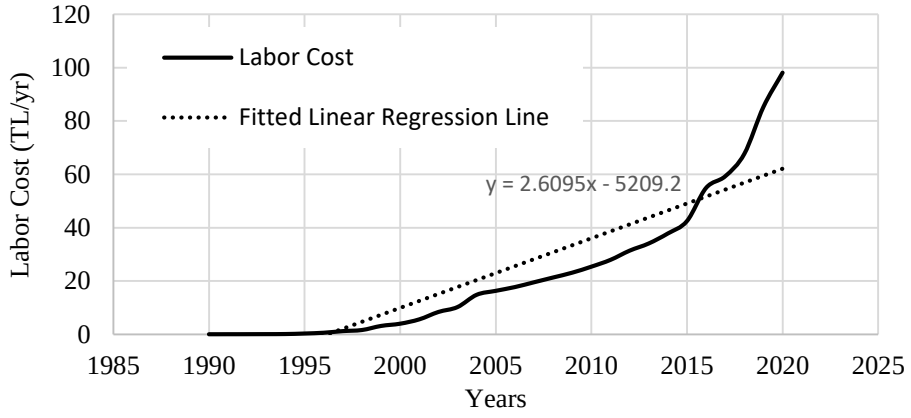


Figure 5.4 Change in Labor Cost (TL/day) in 1990-2020 (Ministry of Family and Social Services of the Republic of Turkey, 2021)

The cleaning and maintenance processes of RHSs are quite simple. For this reason, it is assumed that 2 workers in 1 day can carry out all the cleaning and maintenance duties for each year. The annual labor cost for years 2021 to 2050 is estimated using the linear regression line obtained in Figure 5.4 Then using Equation (18) the net present values are calculated and given in Table 5.7.

Table 5.7 Annual Labor Costs and Labor Costs (TL) (2021)

Years	**Annual Labor Costs (TL/day)**	**Present Value of Labor Costs (2021) (TL/day)**
2021	0	0
2022	134.42	114.89
2023	139.64	102.01
2024	144.86	90.44
2025	150.08	80.09
2026	155.29	70.83
2027	160.51	62.57
2028	165.73	55.22
2029	170.95	48.68
2030	176.17	42.88
2031	181.39	37.74
2032	186.61	33.18
2033	191.83	29.15
2034	197.05	25.59
2035	202.27	22.46
2036	207.48	19.69
2037	212.70	17.25
2038	217.92	15.11
2039	223.14	13.22
2040	228.36	11.56
2041	233.58	10.11
2042	238.80	8.83
2043	244.02	7.71
2044	249.24	6.73
2045	254.46	5.88
2046	259.67	5.13
2047	264.89	4.47
2048	270.11	3.90
2049	275.33	3.39
2050	280.55	2.96
	Total	951.67

The second operation cost is the electricity cost associated with the operation of the pump. Future electricity costs are estimated using linear regression analysis as well. Past electricity costs are taken from Turkish Electricity Distribution Company (TEDAS, 2021) and shown in Figure 5.5. Similar to labor cost, electricity tariff has a sharp increase around 2017. However, it is believed that the linear trend between 1995 and 2015 is more representative of the historic situation and a linear regression line is preferred to forecast future electricity prices.

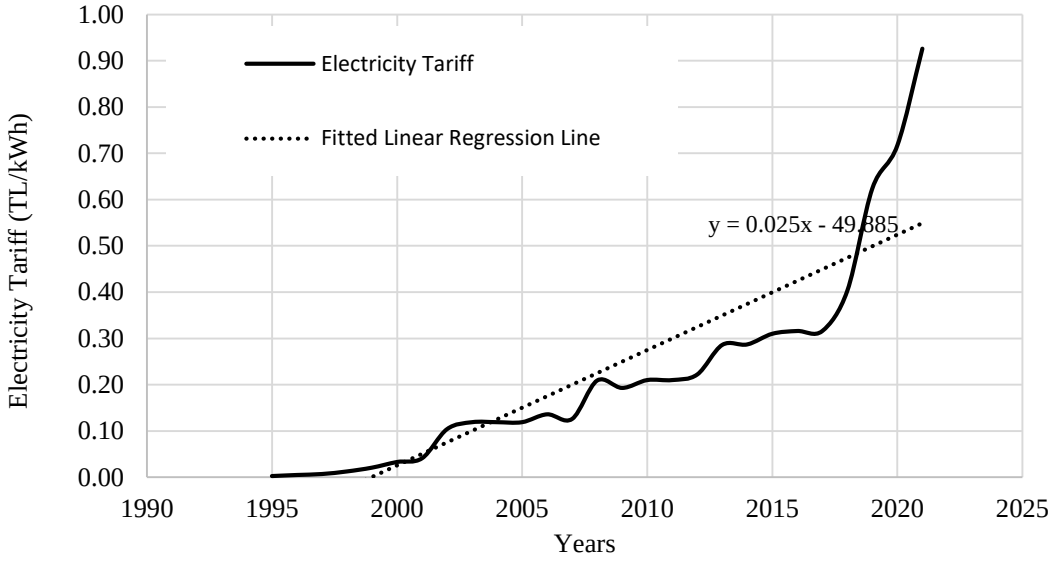


Figure 5.5 Historical Electricity Tariff (TL/kWh) (TEDAS, 2021)

The electricity unit cost for 2021 – 2050 period is listed in Table 5.8. The average electricity consumption (kWh/m³) of the selected pump (i.e., Q=48 m^3/h for 20 meter head 4 kW) is determined by dividing the energy consumption in one hour (i.e., 4 kW) by the maximum amount of water that can be supplied in one hour (i.e., 48 m^3). The supplied annual water form RHT is obtained from WBM and the average annual electricity consumption costs are calculated. The pump electricity cost is directly proportional to the amount of water supplied from the RHT. An example calculation

BG_14 with for 10 m^3 RHT is shown in Table 5.8. The electricity costs for different sizes for BG_14 are calculated and listed in Table 5.9.

Table 5.8 Average Unit Electricity Costs (TL/kWh) and the Pump Electricity Costs for 10 m^3 RHT of BG_14

Years	Average Unit Electricity Costs (TL/kWh)	Average Electricity Consumption (kWh)	Average Electricity Consumption Costs (TL)	Present Value of Electricity Cost (2021) (TL)
2021	0.64	58.77	37.61	37.61
2022	0.67	67.40	44.82	38.31
2023	0.69	47.18	32.55	23.78
2024	0.72	49.42	35.34	22.06
2025	0.74	49.87	36.90	19.69
2026	0.77	62.54	47.84	21.82
2027	0.79	69.52	54.92	21.41
2028	0.82	66.45	54.15	18.04
2029	0.84	72.03	60.51	17.23
2030	0.87	53.99	46.70	11.37
2031	0.89	58.80	52.33	10.89
2032	0.92	52.22	47.78	8.50
2033	0.94	53.16	49.97	7.59
2034	0.97	52.72	50.87	6.61
2035	0.99	56.39	55.82	6.20
2036	1.02	58.00	58.87	5.59
2037	1.04	50.34	52.35	4.25
2038	1.07	57.21	60.93	4.22
2039	1.09	53.08	57.86	3.43
2040	1.12	71.24	79.43	4.02
2041	1.14	72.32	82.44	3.57
2042	1.17	65.02	75.75	2.80
2043	1.19	70.54	83.95	2.65
2044	1.22	52.17	63.38	1.71
2045	1.24	65.89	81.70	1.89
2046	1.27	67.82	85.79	1.69
2047	1.29	58.58	75.57	1.28

Table 5.8 (continued)

2048	1.32	62.48	82.16	1.18
2049	1.34	73.43	98.39	1.21
2050	1.37	102.57	140.01	1.47
Total				274.47

*Average Electricity Consumption (kWh/m^3)=0.083

Table 5.9 Calculated Pump Electricity Costs for Different Sizes of BG_14

RHT Sizes	**Present Value of Electricity Costs (2021) (TL)**
10 m³	9677.94
25 m³	16732.36
50 m³	22906.96
100 m³	29033.80
200 m³	34687.86
300 m³	37541.02
400 m³	39024.69
500 m³	39865.55

Since the pump cost in Turkey changes based on foreign currency, the change in the dollar rate over the years is modeled by linear regression and future pump costs are estimated using this regression line (shown in Figure 5.6). Then the net present value of the pump is estimated using Equation (18). Estimated pump costs are shown in Table 5.10. Finally the total operation costs for BG_14 are calculated and the results are shown in Table 5.11.

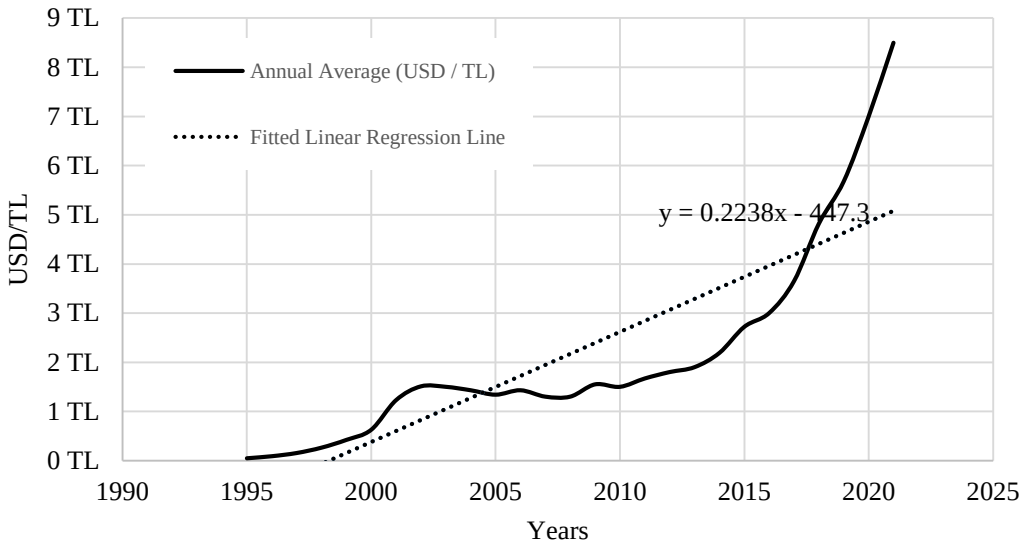


Figure 5.6 Historical Dollar Rate (USD/TL) (Central Bank of Turkey, 2021)

Table 5.10 Future and Present Pump Costs (TL) (2021)

Years	Future Pump Costs (TL)	Present Value of Pump Costs (2021) (TL)
2031	11686.53	2431.24
2041	15300.12	662.18
Total		3093.42

Table 5.11 Calculated Operation Costs and Total Operation Costs (2021)

RHT Sizes	Electricity Costs (TL) (2021)	Labor Costs (TL) (2021)	Total Operation Costs (TL) (2021)
10 m³	9677.94	951.67	10629.61
25 m³	16732.36		17684.03
50 m³	22906.96		23858.63
100 m³	29033.80		29985.47
200 m³	34687.86		35639.53

Table 5.11	(continued)		
300 m³	37541.02		38492.69
400 m³	39024.69		39976.36
500 m³	39865.55		40817.22

5.2.3 Water Saving Benefits

Historical unit water tariffs are obtained from ASKI General Directorate (ASKI, 2021) and a linear regression line is fit as given in Figure 5.7. The linear regression line is then used to forecast future water tariffs.

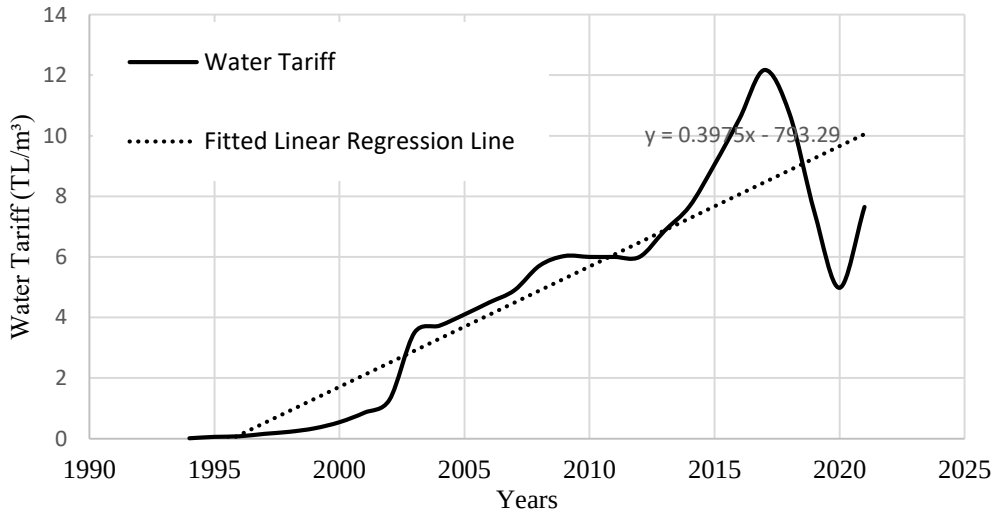


Figure 5.7 Historical Water Tariff (TL/m³) (ASKI, 2021)

The amount of water used from RHT instead of the city network is calculated using WBM results. The amount of water supplied from RHT each year is shown in Table 5.2. The benefit associated with using water from the RHT instead of the city network is found by multiplying the estimated unit water cost with the amount of water supplied from the RHT. These future values are then converted to present values using Equation (18). The results are shown with 10 m³ RHT for BG_14 in

Table 5.12. For example, for 2025, the amount saved by supplying water from the RHT instead of the city network in 2025 is calculated as follows: 588.7848x11.6575=6857.87. Then the present value is calculated using Equation (18) as follows: $6857.87/(1+0.17)^4 = 3659.70$. Since the numbers are rounded in the tables, minor differences exist. The annual water savings for different sizes for BG_14 are calculated and given in Table 5.13.

Table 5.12 Amount Saved by Supplying Water from RHT instead of the City Network with 10 m^3 RHT for BG_14.

Years	**Annual Unit Water Cost (TL/m³)**	**Annual Amount of Water Supplied from the RHT (m³)**	**Amount Saved by Supplying Water from the RHT Instead of the City Network (TL)**	**The Present Value of the Amount Saved (2021) (TL)**
2021	10.06	693.30	6972.83	6972.83
2022	10.46	790.55	8265.25	7064.31
2023	10.85	553.89	6011.06	4391.16
2024	11.25	582.58	6554.00	4092.12
2025	11.65	588.78	6857.87	3659.70
2026	12.05	735.05	8853.69	4038.27
2027	12.44	818.42	10183.20	3969.81
2028	12.84	784.75	10076.23	3357.35
2029	13.24	846.66	11207.64	3191.74
2030	13.64	637.19	8688.08	2114.71
2031	14.03	691.89	9708.95	2019.82
2032	14.43	606.39	8750.19	1555.87
2033	14.83	623.49	9244.83	1404.97
2034	15.23	606.91	9240.19	1200.23
2035	15.62	657.17	10266.56	1139.79
2036	16.02	681.24	10913.45	1035.56
2037	16.42	592.14	9721.43	788.42
2038	16.82	674.22	11337.02	785.85
2039	17.21	622.78	10719.53	635.08
2040	17.61	844.37	14869.33	752.94
2041	18.01	854.88	15394.23	666.26
2042	18.41	767.84	14132.17	522.76
2043	18.80	829.56	15597.80	493.14
2044	19.20	611.13	11733.75	317.08

2045	19.60	776.08	15209.32	351.28
	Table 5.12	(continued)		
2046	20.00	797.75	15951.01	314.88
2047	20.39	683.19	13931.93	235.06
2048	20.79	726.29	15099.66	217.75
2049	21.19	867.62	18382.68	226.57
2050	21.59	1219.03	26312.79	277.19
			Total	50819.67

Table 5.13 Annual Water Savings with Different RHT Sizes for BG_14 (TL)

RHT Sizes	**The Present Value of Water Saving (2021) (TL)**
10 m³	50819.67
25 m³	87862.30
50 m³	120284.40
100 m³	152456.11
200 m³	182144.12
300 m³	197123.99
400 m³	204913.09
500 m³	209328.69

Finally, the net benefit is calculated by subtracting the costs from the benefit and the results for BG_14 for each alternative RHT size is given in Table 5.14. According to the results, 100 m³ RHT has the highest net benefit. Thus, based on economic analysis 100 m³ RHT is the best alternative. To evaluate the performance of this tank with respect to alternative RHT sizes the performance indicators (i.e., reliability, water saving efficiency, stormwater capture efficiency and overflow ratio) are assessed and the results are presented in the next section.

Table 5.14 Present Values of Net Benefits for alternative RHT for BG_14

	The Present Value of the Investment Cost (2021) (TL)	**The Present Value of the Operation Cost (2021) (TL)**	**The Present Value of the Benefit of Supplying Water from RHT Instead of the City Network (2021) (TL)**	**The Present Value of the Net Benefit (2021) (TL)**
10 m³	45768,86	10629.61	50819.00	-5578.80
25 m³	51618,86	17684.03	87862.30	18559.41
50 m³	61368,86	23858.63	120284.40	35056.91
100 m³	80868,86	29985.47	152456.11	41601.78
200 m³	119868,86	35639.53	182144.12	26635.73
300 m³	158868,86	38492.69	197123.99	-237.56
400 m³	197868,86	39976.36	204913.09	-32932.13
500 m³	236868,86	40817.22	209328.69	-68357.39

5.3 Performance Evaluation

Performance indicators for each alternative RHT size for BG_14 are calculated and presented in Figure 5.8. As can be seen from Figure 5.8, 100 m³ RHT which has the highest net benefit has reasonable performance based on reliability, water saving efficiency, stormwater capture efficiency and overflow ratio. When the RHT capacity increases, the performance of the RHS gets better as expected; however, the net benefit decreases. The improvement in the performance of the RHS levels is limited after 200 m³ RHT capacity. Thus depending on the financial situation of the institution, 100 m³ RHT sizes seems to be reasonable choices.

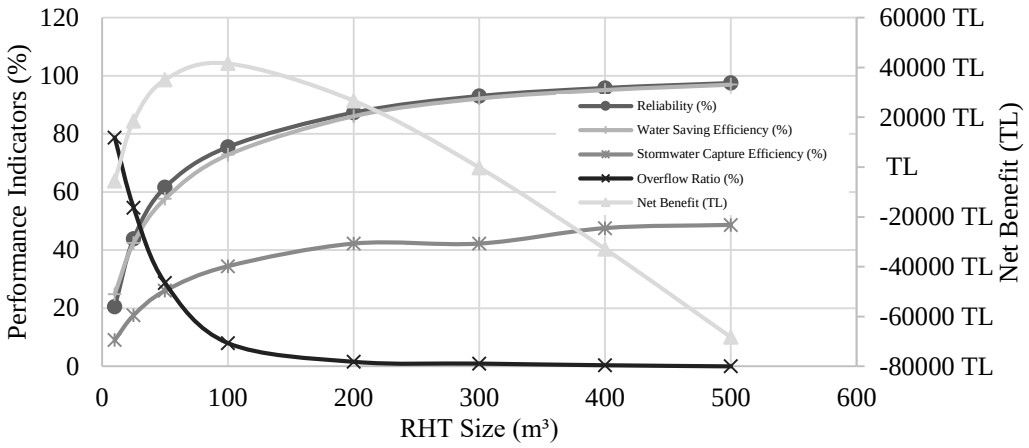


Figure 5.8 PIs and the Net Benefit for BG_14

5.4 RHSs Results

In this study, 43 different RHS groups are studied. WBM results for each of these 43 RHSs are given in Appendix-A, cost benefit analysis and PI results for each of these 43 RHSs are given in tables in Appendix-B. The PI and Net Benefit graphs for each of these 43 RHSs are given in Appendix-C and finally the distribution of costs and benefit results for all 43 BGs are given in Appendix-D. The major design inputs of RHS are the collector area (i.e., effective roof area m²) and the number of people using the buildings. The RHT sizes with the highest net benefit are given in Table 5.15 along with the major design inputs. As can be seen from Table 5.15 as the effective roof area increases RHT size increases. When larger collector area is available more rainwater can be harvested and larger tank sizes are required to increase the benefit of RHS. Similarly, generally larger RHT sizes are found to have higher benefits for building used by more people.

Table 5.15 Selected Best RHT Sizes with Major Design Inputs

Building Group Code	Effective Roof Area (m^2)	Total Number of People Using the Building Group	RHT Sizes (m^3)
BG_1	1025	1140	10 m^3
BG_2	1176	1036	10 m^3
BG_3	1036	1124	10 m^3
BG_4	3688	2638	50 m^3
BG_5	5130	645	50 m^3
BG_6	2133	1580	25 m^3
BG_7	6039	1540	100 m^3
BG_8	2295	2243	25 m^3
BG_9	4568	646	50 m^3
BG_10	1755	394	25 m^3
BG_11	4073	568	50 m^3
BG_12	1845	575	25 m^3
BG_13	2122	653	25 m^3
BG_14	11232	1180	100 m^3
BG_15	7206	1205	100 m^3
BG_16	9253	2152	100 m^3
BG_17	2250	534	25 m^3
BG_18	3858	628	50 m^3
BG_19	2043	425	25 m^3
BG_20	5328	472	25 m^3
BG_21	1427	409	25 m^3
BG_22	2565	409	25 m^3
BG_23	2201	409	25 m^3
BG_24	6679	520	50 m^3
BG_25	1755	504	25 m^3
BG_26	1706	383	25 m^3
BG_27	1553	375	25 m^3
BG_28	878	399	10 m^3
BG_29	878	399	10 m^3
BG_30	871	349	10 m^3
BG_31	806	341	10 m^3
BG_32	855	479	10 m^3

Table 5.15 (continued)

BG_33	1791	479	25 m³
BG_34	1710	414	25 m³
BG_35	852	319	10 m³
BG_36	832	217	10 m³
BG_37	1976	315	25 m³
BG_38	432	188	10 m³
BG_39	1440	230	25 m³
BG_40	2610	643	25 m³
BG_41	2700	697	25 m³
BG_42	2610	631	25 m³
BG_43	2610	607	25 m³

PIs and net benefits of selected RHT sizes for 43 RHSs are evaluated. The average reliability is found as 47.24 %. Reliability means the number of days the water demand is fully supplied from the RHT. To increase reliability, it is necessary to increase the amount of collected rainwater. Reliability also indicates how long the demand can be supplied solely from the RHT (i.e. not using the city network). Accordingly, 20 RHS groups have above average reliability. In about half of the BGs in the study, for about half of the year the water demand can be supplied entirely from the RHTs. The reliabilities for 43 RHSs with selected RHT sizes are shown in Figure 5.9.

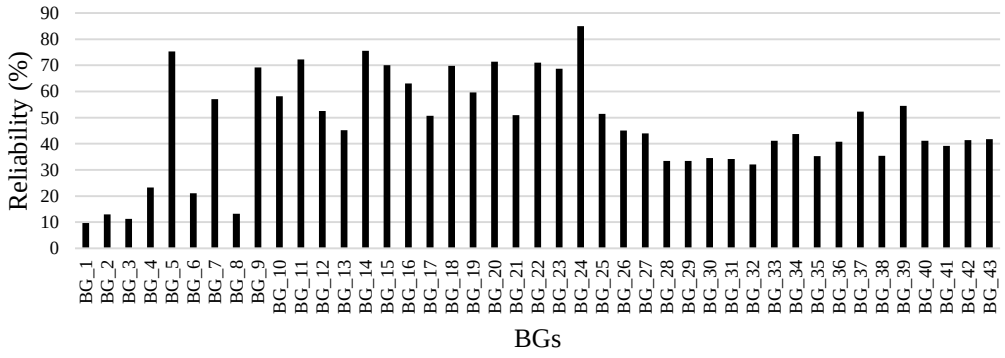


Figure 5.9 The Reliability for 43 RHSs with Selected RHT Sizes

When the water saving efficiency of the selected RHTs is examined, a similar behavior to that of reliability is observed. Water saving efficiency is the rate of supplying the water demand from the RHT. The average water saving efficiency for 43 RHSs is found as 39.62 %. It means that approximately 40% of water demand can be supplied from rainwater resulting in major savings. 21 RHSs have above the average water saving efficiency. The water saving efficiencies for 43 RHSs with selected RHT sizes are shown in Figure 5.10.

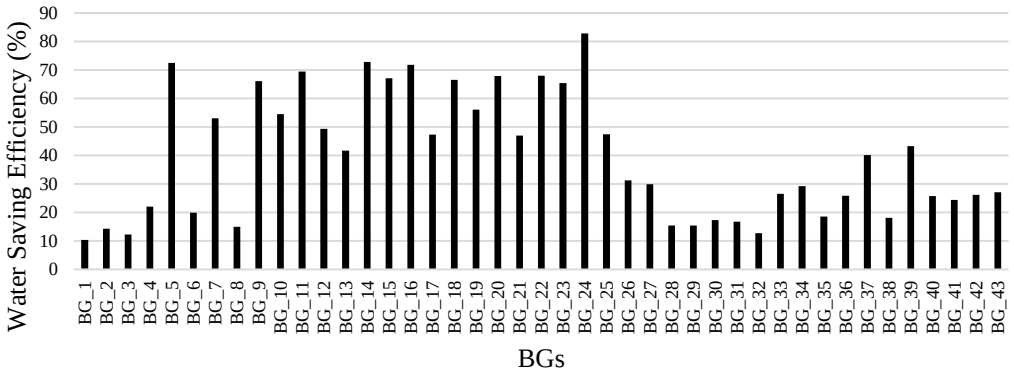


Figure 5.10 The Water Saving Efficiency for 43 RHSs with Selected RHT Sizes

Stormwater capture efficiency is the ratio of the water stored in the RHT to the total inflow into the RHT (i.e. total amount of water collected from the roof). Close to uniform precipitation regime will result in better performance of smaller RHT sizes. The average stormwater capture efficiency for METU buildings is 48.04%. 24 different RHS groups have above average stormwater capture efficiency. In addition, since RHS intercepts the rain prevents it going directly to the stormwater drainage system, it mitigates the excess load on the drainage system during high precipitation events. Consequently, RHSs contribute to the mitigation of urban flooding problems. The higher the stormwater capture efficiency, the more water can be stored in the RHTs and the less load will be on the stormwater drainage system during precipitation. The stormwater capture efficiencies for 43 RHSs with selected RHT sizes are shown in Figure 5.11.

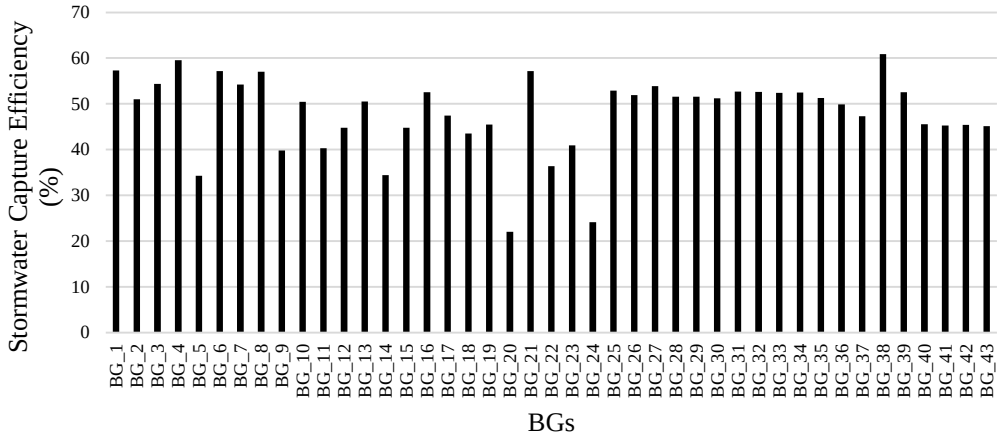


Figure 5.11 The Stormwater Capture Efficiency for 43 RHSs with Selected RHT Sizes

When the overflow ratio of the selected RHTs are examined, it is found to be 5.91% on the average. Only in BG_20, the overflow rate is 30.63%, which is much larger than the others. The roof area of BG_20 is quite high compared to the number of people using the building. Therefore, the amount of rain water that is collected is higher than the water demand. This causes excess rain water to overflow from the RHT. Although not implemented in this study, the overflowing water can be used for other purposes like irrigation or washing the school buses etc. The overflow ratios for 43 RHSs with selected RHT sizes are shown in Figure 5.12.

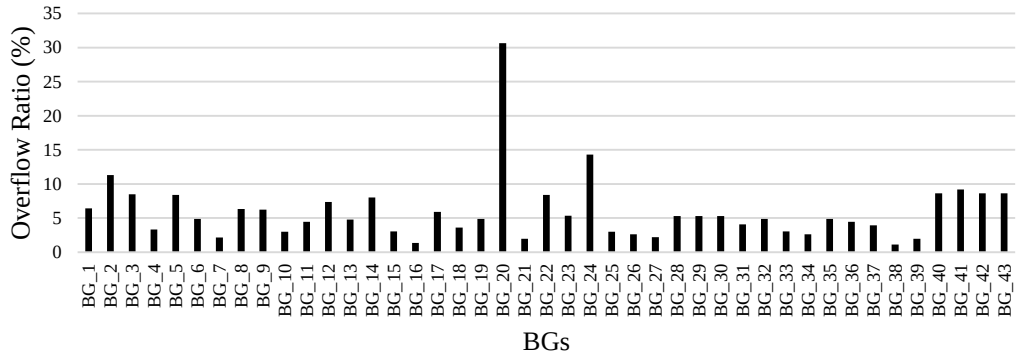


Figure 5.12 The Overflow Ratio for 43 RHSs with Selected RHT Sizes

According to the results of the economic analysis carried out in this study, it is seen that the distribution of investment costs, operation costs and benefits for 43 different BGs is different from each other. The highest cost items are RHT costs, pump costs and electricity costs. The distribution of costs and benefits for BG_14 is shown in Figure 5.13. The results of all other BGs are given in Appendix-D.

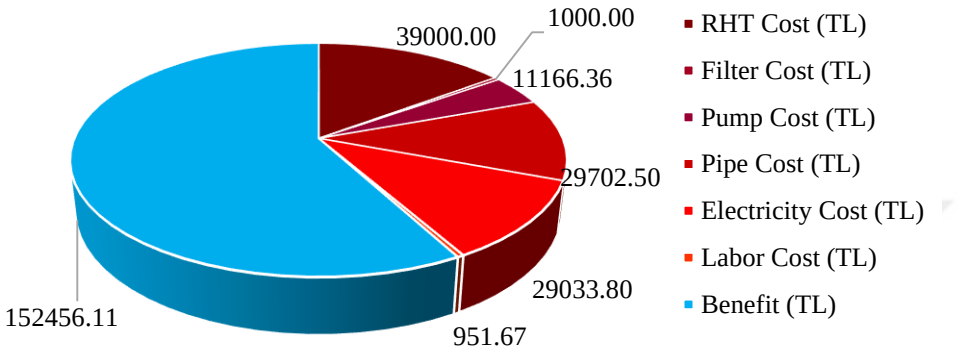


Figure 5.13 Distribution of Costs and Benefits for BG_14

The net benefits associated with RHSs for all building groups are analyzed and the discussion is provided below. It is observed that the net benefits are negative in the 6 BGs which are BG_01, BG_28, BG_30, BG_31, BG_32 and BG_38. All of these BGs have 10 m³ RHT capacity. The BG_7 has the maximum benefit which is 71997.52 TL. When all the BGs are considered, the total cost is 1510246.85 TL, while the total benefit due to supplying water demand from the RHTs instead of the city network is 2259250.55 TL for the whole simulation duration (i.e. 2021-2050). Accordingly, there is a total net profit of 749003.70 TL. The costs and benefits of 43 BGs are given in Table 5.16. In addition, the net benefits for 43 RHSs with selected RHT sizes are shown in Figure 5.14.

Table 5.16 The Costs and Benefit Results for 43 BGs

Building Group Code	RHT Sizes (m^3)	Total Investment Cost (TL)	Total Operation Cost (TL)	Total Cost (TL)	Total Benefit (TL)	Total Net Benefit (TL)
BG_1	10 m^3	23940.11	5212.05	29152.16	22372.27	-6779.89
BG_2	10 m^3	18276.41	6421.94	24698.35	25647.92	949.57
BG_3	10 m^3	14925.83	3245.80	18171.63	23957.16	5785.53
BG_4	50 m^3	33805.11	18295.92	52101.03	91078.66	38977.63
BG_5	50 m^3	30600.83	4643.28	35244.11	77097.75	41853.64
BG_6	25 m^3	20442.08	4612.20	25054.28	50968.21	25913.93
BG_7	100 m^3	51653.33	14147.57	65800.90	137798.42	71997.52
BG_8	25 m^3	22886.41	12633.10	35519.51	54769.61	19250.10
BG_9	50 m^3	36421.36	20460.47	56881.83	78800.85	21919.02
BG_10	25 m^3	21312.08	4556.16	25868.24	37639.80	11771.56
BG_11	50 m^3	34496.41	16422.42	50918.83	72533.14	21614.31
BG_12	25 m^3	20847.08	5485.76	26332.84	47347.18	21014.34
BG_13	25 m^3	26165.16	12140.70	38305.86	45902.24	7596.38
BG_14	100 m^3	80868.86	29985.47	110854.33	152456.11	41601.78
BG_15	100 m^3	56763.78	24510.67	81274.45	138068.07	56793.62
BG_16	100 m^3	75527.53	35946.02	111473.55	168894.29	57420.74
BG_17	25 m^3	20790.83	4246.61	25037.44	45876.51	20839.07
BG_18	50 m^3	41096.36	14662.64	55759.00	71996.71	16237.71
BG_19	25 m^3	21100.83	3943.38	25044.21	41654.41	16610.20
BG_20	25 m^3	23756.41	14067.15	37823.56	53803.71	15980.15
BG_21	25 m^3	21157.08	4208.66	25365.74	34011.56	8645.82
BG_22	25 m^3	20713.33	3878.89	24592.22	40756.01	16163.79
BG_23	25 m^3	20790.83	3751.73	24542.56	38985.67	14443.11
BG_24	50 m^3	40586.36	14651.17	55237.53	71935.29	16697.76
BG_25	25 m^3	20812.08	2833.21	23645.29	39296.21	15650.92
BG_26	25 m^3	20942.08	5664.10	26606.18	39368.20	12762.02
BG_27	25 m^3	20942.08	5350.92	26293.00	36751.96	10458.96
BG_28	10 m^3	16198.91	4586.69	20785.60	19883.62	-901.98
BG_29	10 m^3	15264.58	3331.74	18596.32	19883.62	1287.30
BG_30	10 m^3	16198.91	4552.82	20751.73	19698.34	-1053.39
BG_31	10 m^3	16198.91	4366.56	20565.47	18679.50	-1885.97
BG_32	10 m^3	16198.91	4542.92	20741.83	19644.21	-1097.62
BG_33	25 m^3	22048.91	8554.93	30603.84	41589.64	10985.80
BG_34	25 m^3	22048.91	8207.01	30255.92	39686.42	9430.50
BG_35	10 m^3	15092.08	3265.36	18357.44	19328.99	971.55
BG_36	10 m^3	14747.08	2281.47	17028.55	18515.61	1487.06

Table 5.16 (continued)

BG_37	25 m³	20597.08	3955.03	24552.11	41817.11	17265.00
BG_38	10 m³	14919.58	2024.89	16944.47	11207.35	-5737.12
BG_39	25 m³	20942.08	4897.89	25839.97	32967.11	7127.14
BG_40	25 m³	20769.58	6112.11	26881.69	53888.95	27007.26
BG_41	25 m³	20769.58	6254.19	27023.77	55372.67	28348.90
BG_42	25 m³	20769.58	6101.38	26870.96	53776.80	26905.84
BG_43	25 m³	20769.58	6078.96	26848.54	53542.69	26694.15
Total		1135154.91	375091.94	1510246.85	2259250.55	749003.70

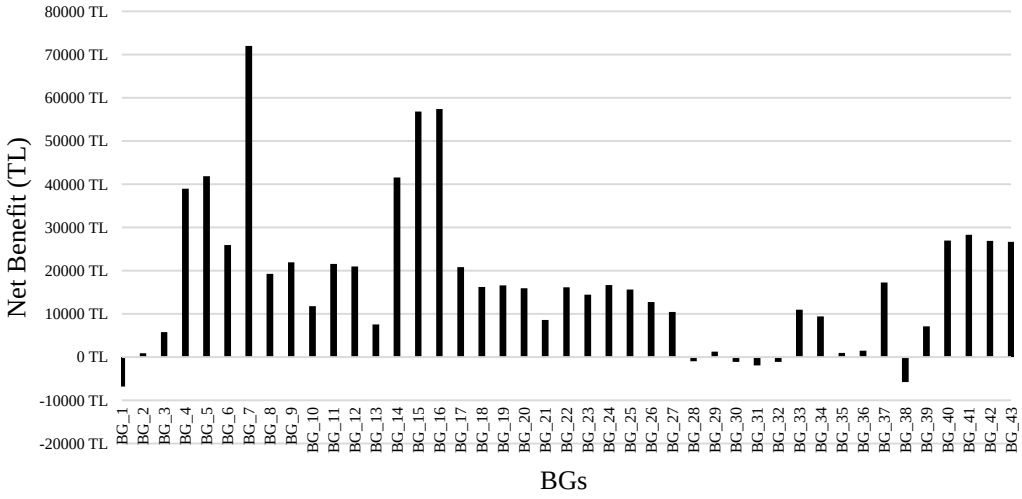


Figure 5.14 The Net Benefits for 43 RHSs with Selected RHT Sizes

For 6 BGs the benefits are negative, thus these systems are not feasible. If more rainwater is collected for these RHSs then they may become feasible. To investigate the necessary rainwater collection area that will result in beneficial RHSs for these buildings an additional analysis is conducted by iteratively increasing collector areas for these building groups. Necessary collector area increases for each of these building groups to make them economically feasible are identified and given in Table 5.17. As can be seen in Table 5.17, for BG_1, 50% increase in the collector area results in a feasible RHS. But this requires a RHT size of 25 m³ (i.e. to store the rainwater collected from a larger collector area the RHT size should be increased

from 10 m³ to 25 m^3). It is observed that the RHT sizes remained the same size for the other BGs even though the collector areas increased.

Table 5.17 Revised Results of BGs with Negative Net Benefits

Building Group Code	RHT Sizes (m³)	Net Benefit (TL)	Increase Rate of Collector Area (%)	Revised Benefit (TL)	Revised RHT size
BG_1	10 m³	-6779.89	50.00	1164.72	25 m³
BG_28	10 m³	-901.98	10.00	410.86	10 m³
BG_30	10 m³	-1053.39	10.00	220.87	10 m³
BG_31	10 m³	-1885.97	20.00	539.89	10 m³
BG_32	10 m³	-1097.62	10.00	244.84	10 m³
BG_38	10 m³	-5737.12	75.00	236.65	10 m³

CHAPTER 6

CONCLUSION

In this study, RHS with eight different RHT sizes are evaluated for 43 building groups of METU Campus. Water Balance Model is run for each RHS and associated water savings are estimated. Then the RHS with the highest benefit is identified based on a detailed cost benefit analysis. Finally, the performance of the identified RHS is comparatively evaluated using performance indicators (i.e., reliability, water saving efficiency, stormwater capture efficiency and overflow ratio). The following conclusions are derived:

- RHT costs, pump costs and the electricity costs are the highest cost items. Realistic RHS analysis require these cost items to be included in the cost-benefit analysis.
- It is observed that building groups at METU campus with larger rainwater collector areas resulted in higher economic benefits.
- The amount of rainwater that can be collected in the RHT increases as the roof area used to collect rainwater increases. For RHSs to be feasible for buildings with large number of residents, larger rainwater collector areas are required.
- For most of the building groups, 25 m^3 rainwater harvesting tank size is identified to be the most beneficial size. RHTs larger than 100 m^3 are not identified to be economically profitable. Locating smaller tanks is relatively easier at the campus. Thus construction of around 25 m^3 rainwater harvesting tanks should be considered at METU to benefit from rainwater harvesting.
- When the PIs are examined, it is seen that the reliability is 47.24% while the water saving efficiency is 39.62% on the average. The stormwater efficiency is found to be 48.04% on the average. Finally, the average overflow rate is 5.91% for 43 BGs of METU campus. Similar to the net benefits,

performances of the BGs with small collector areas are relatively poor. Performance improves as the collection area increases.

- When all 43 building groups studies at METU campus are considered, the total investment and operation cost is 1510246.85 TL, while the benefit is 2259250.55 TL for the whole simulation duration. Consequently, implementing RHSs for 43 building groups at METU campus will result in a net benefit of 749003.70 TL.

The following suggestions are made as future study topics:

- The same analysis can be conducted using hourly data. Of course data on hourly water demands should be collected by installing water meters at the toilet reservoir outlets and hourly precipitation data should be collected through automatic rain gages.
- In addition to the financial benefits, the environmental benefits of RHSs can be included into the analysis.
- Climate change effects on precipitation and consequently on RHT can be investigated.
- In addition to precipitation, water from melting snow can be collected and used in RHSs. Contribution of snow on RHS performance can be investigated.
- Instead of reinforced concrete tank other materials such as polyethylene can be used in RHT tanks. Effect of using different material for the RHT on the feasibility of the RHS can be investigated.

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APPENDICES

APPENDIX-A: WBM Results for All 43 BGs

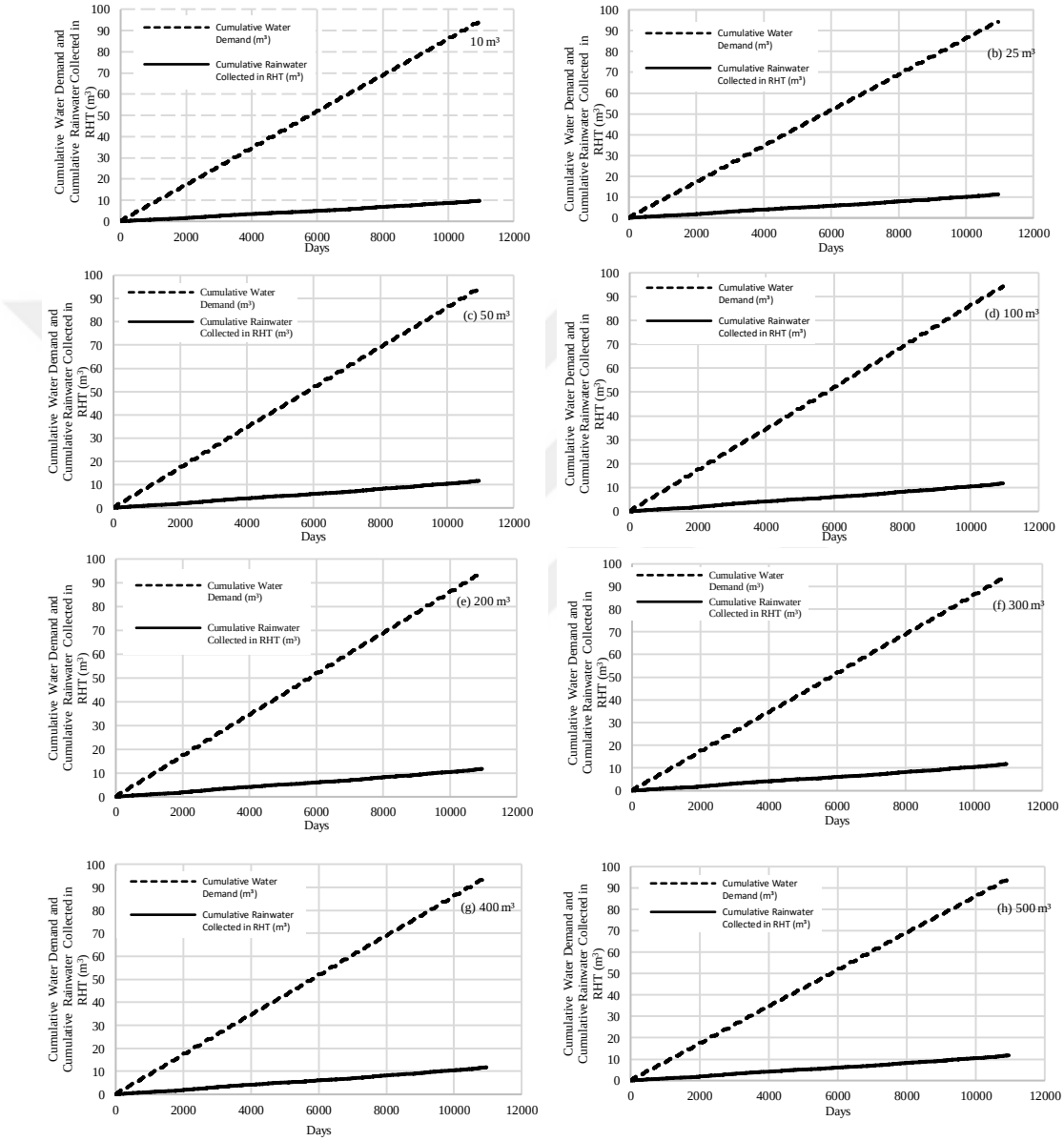


Figure A1 WBM Results for BG_01 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

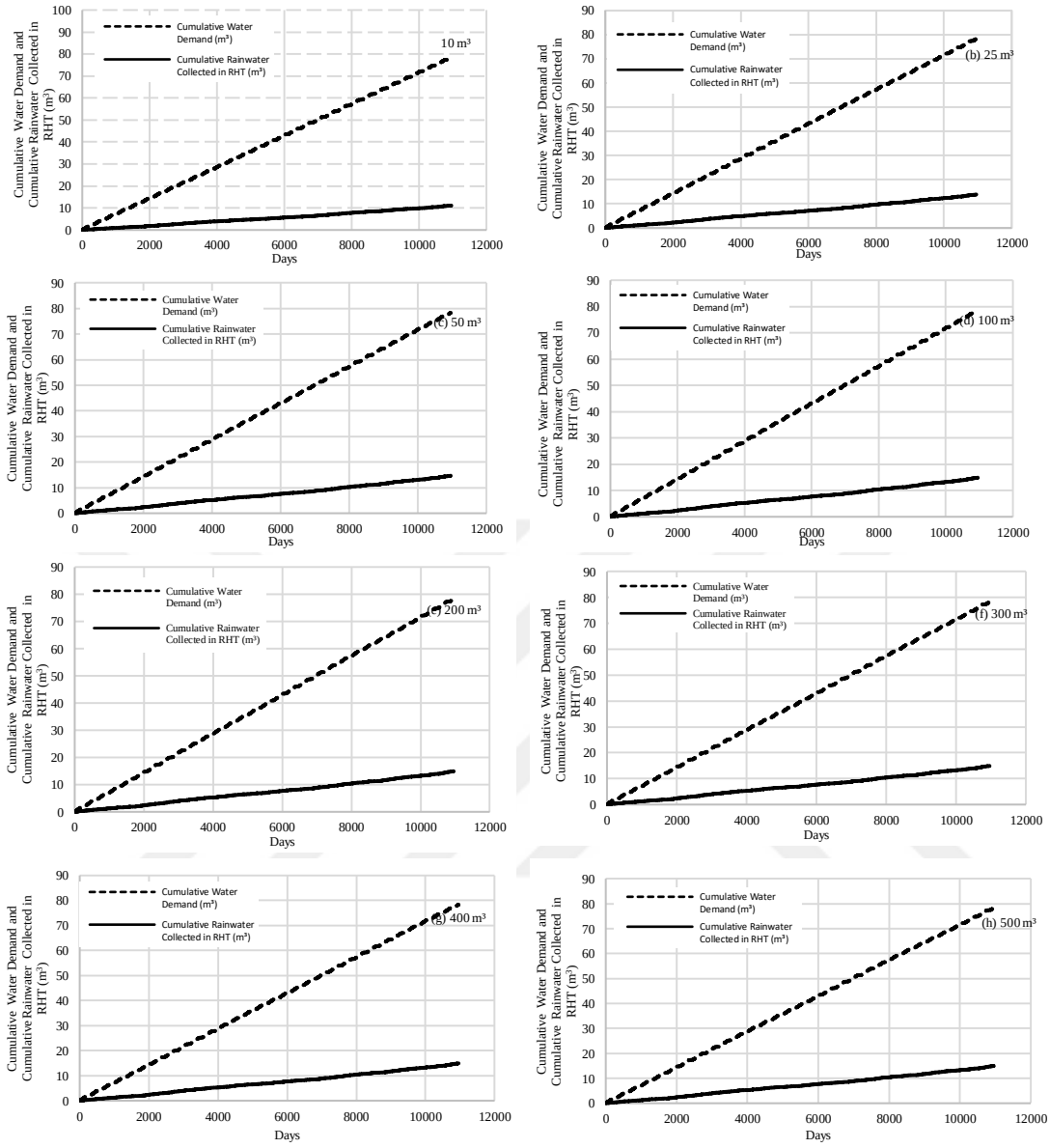


Figure A2 WBM Results for BG_02 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

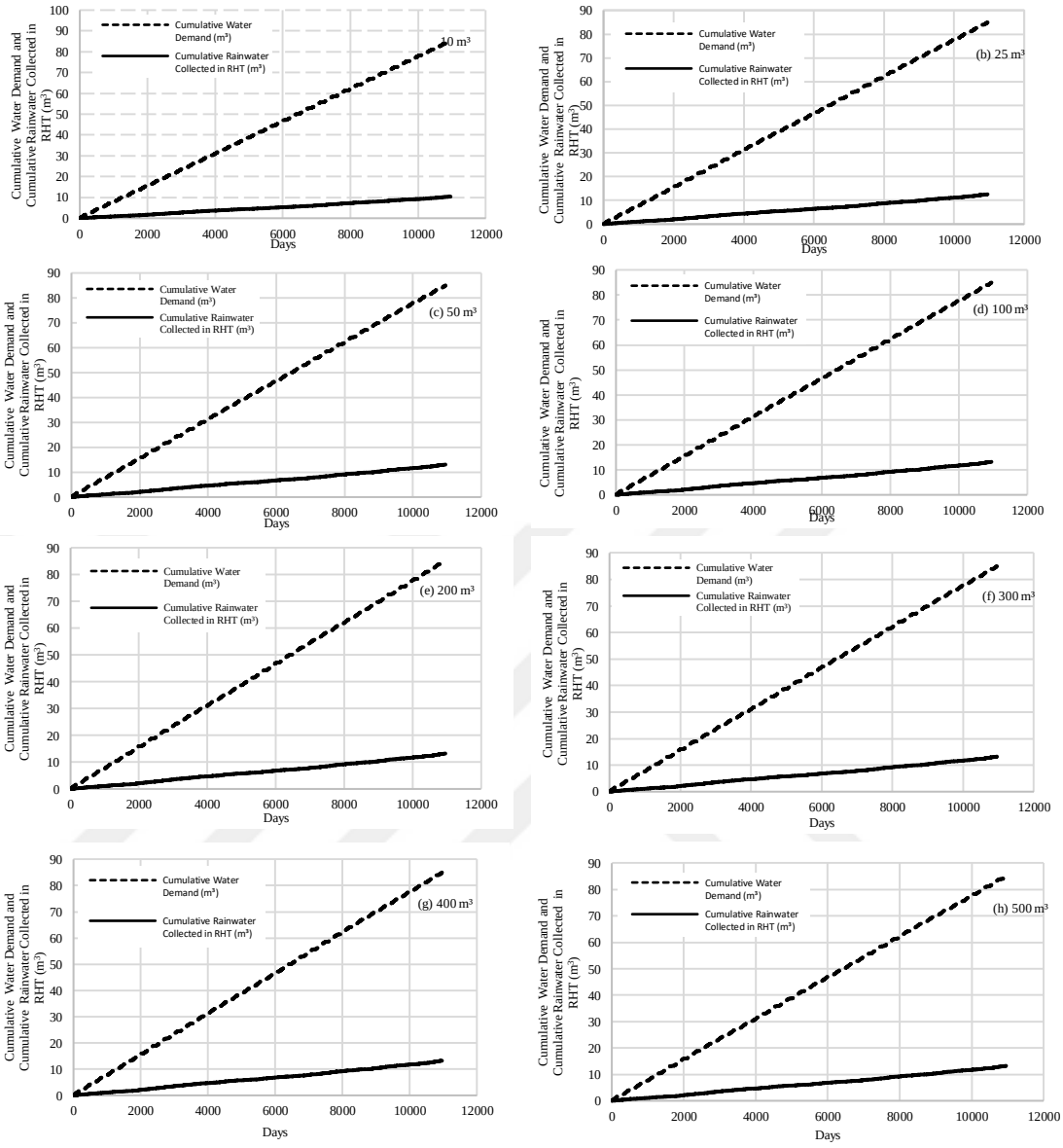


Figure A3 WBM Results for BG_03 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

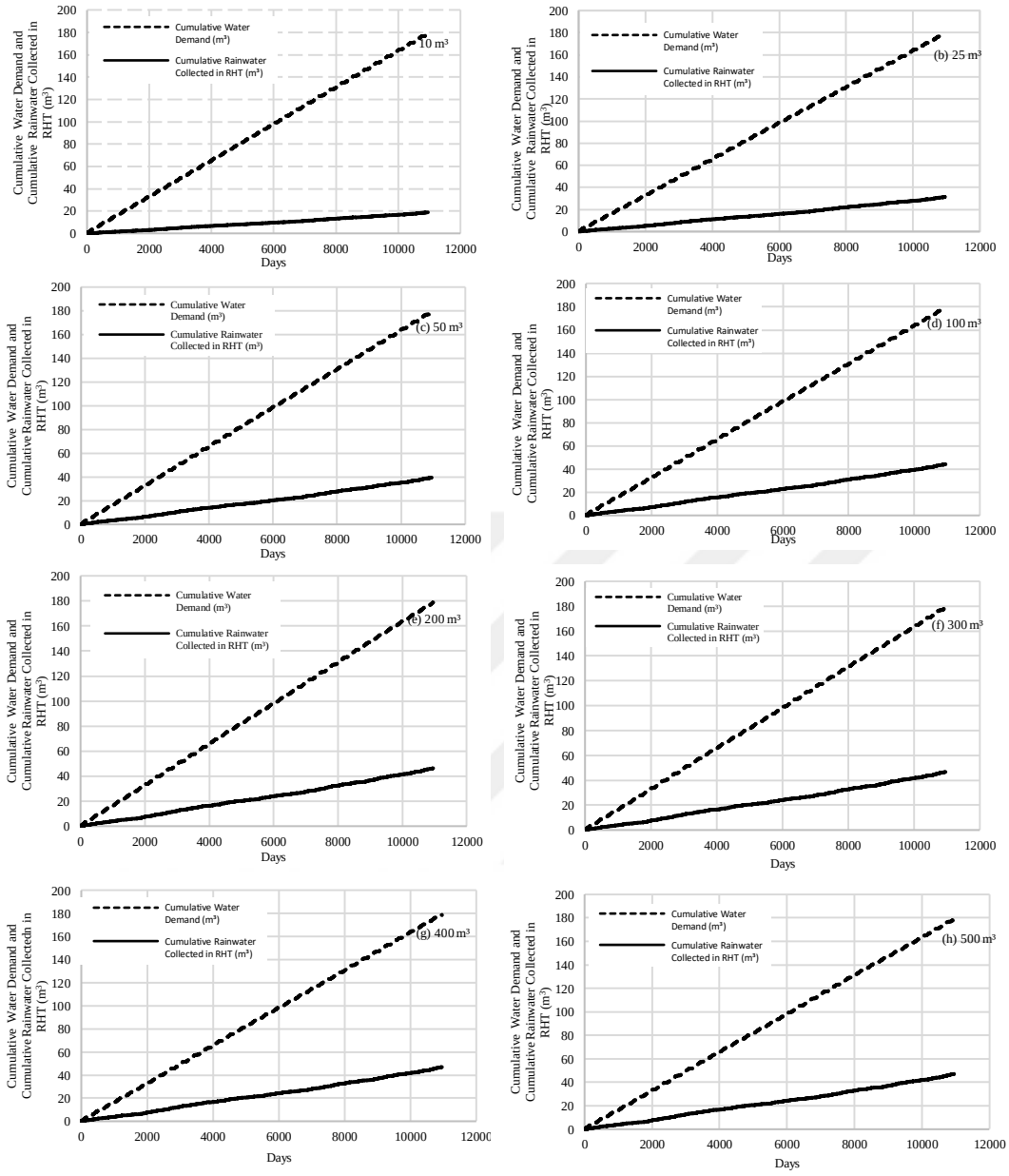


Figure A4 WBM Results for BG_04 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

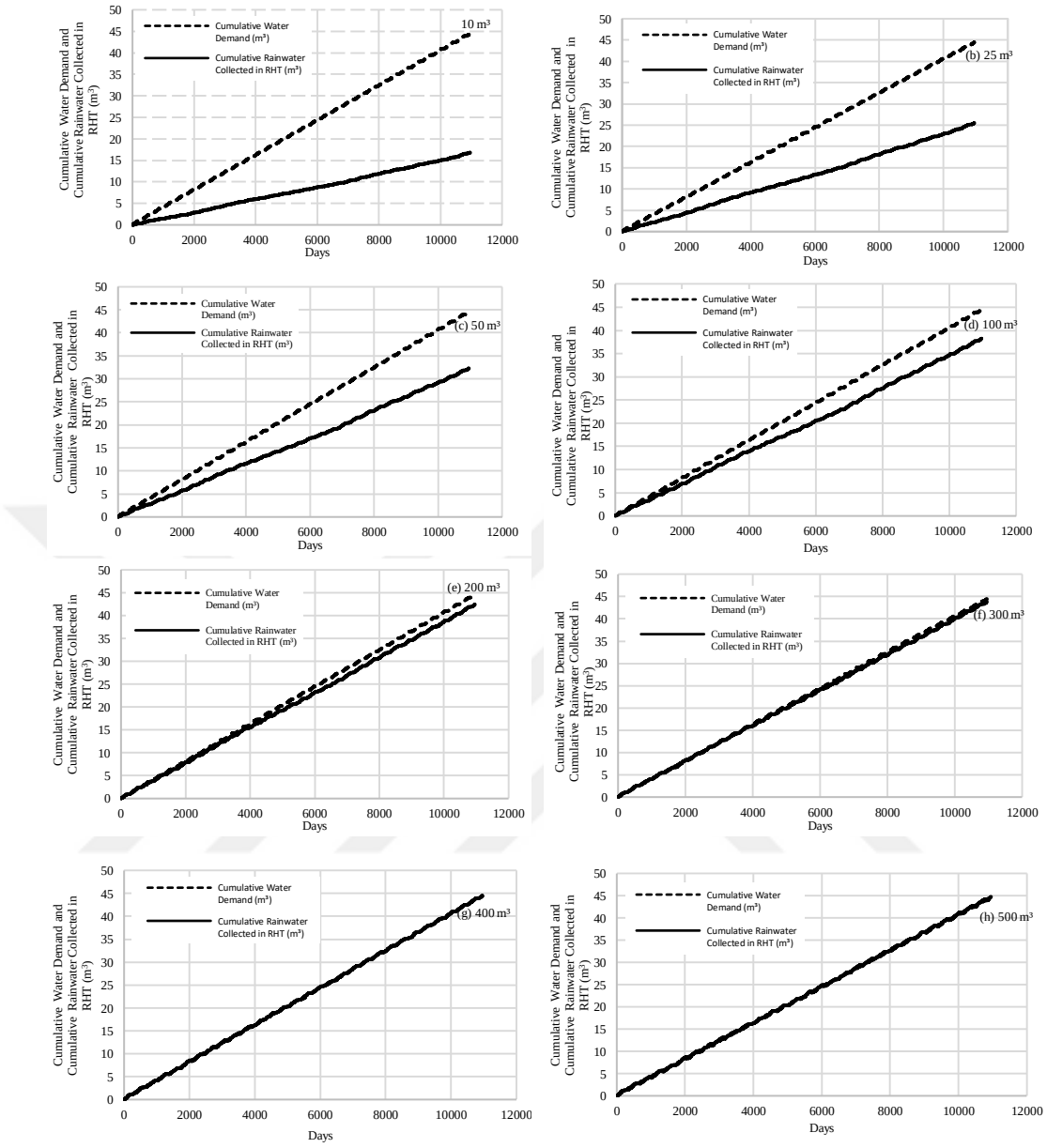


Figure A5 WBM Results for BG_05 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

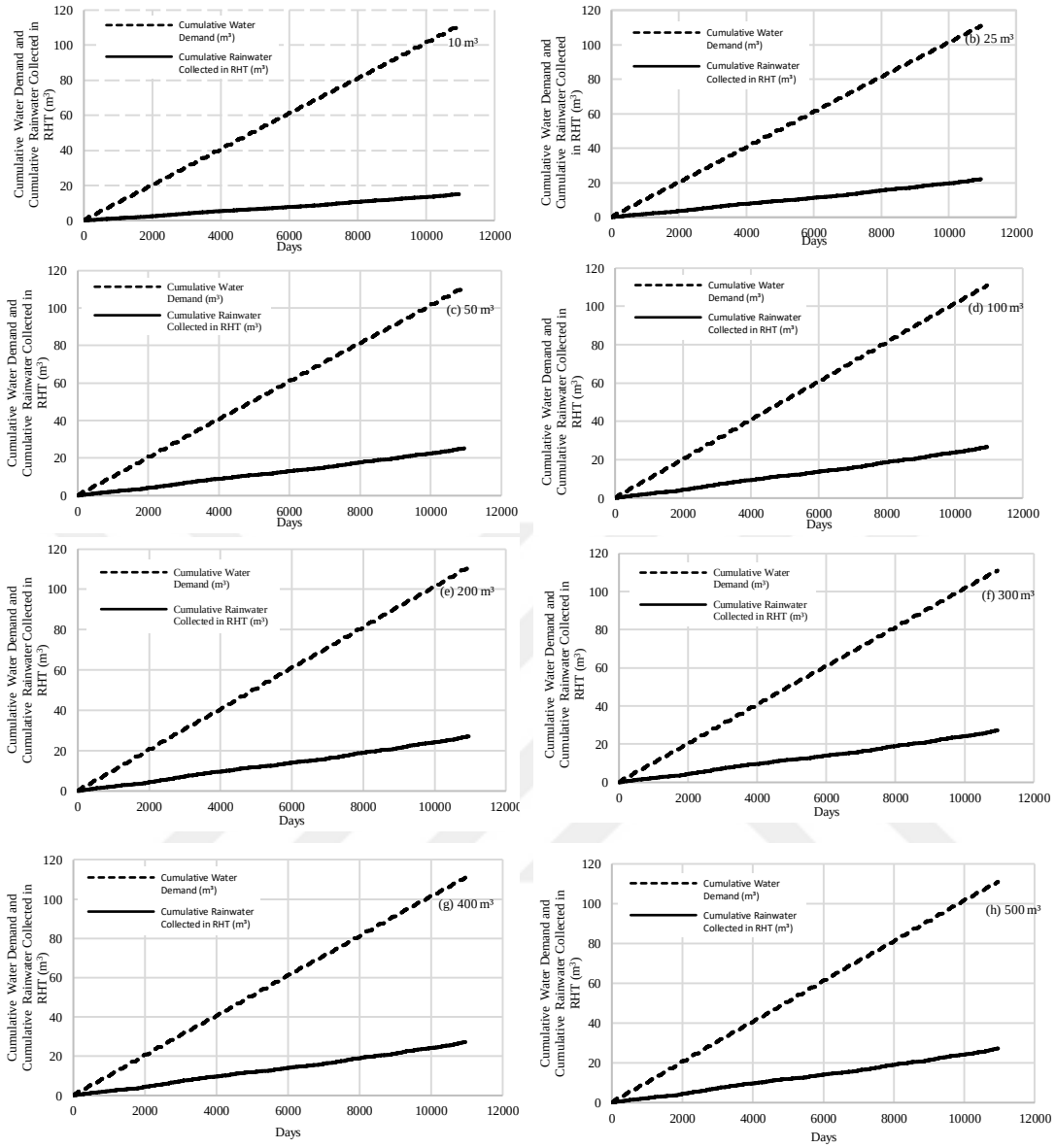


Figure A6 WBM Results for BG_06 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

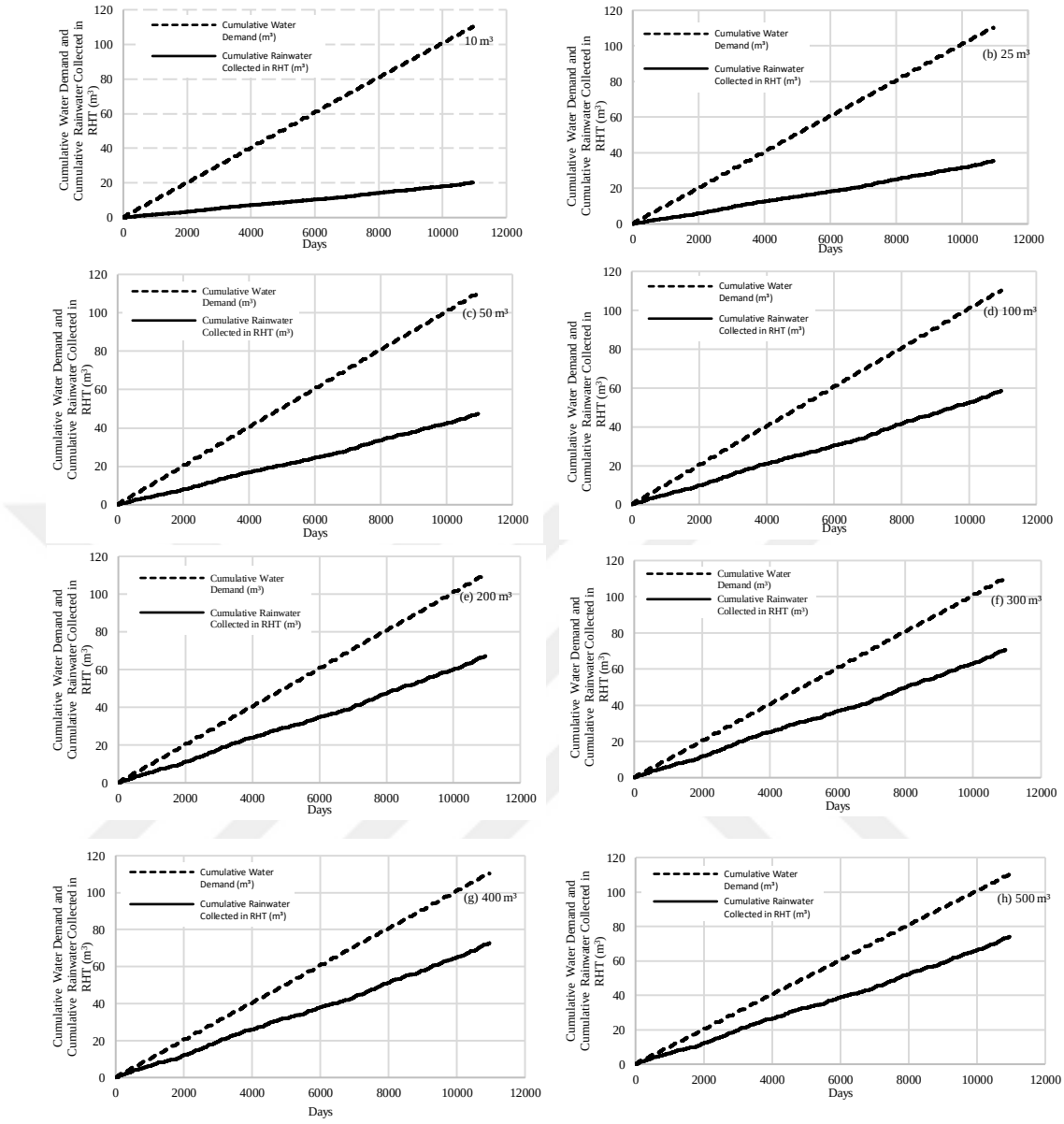


Figure A7 WBM Results for BG_07 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

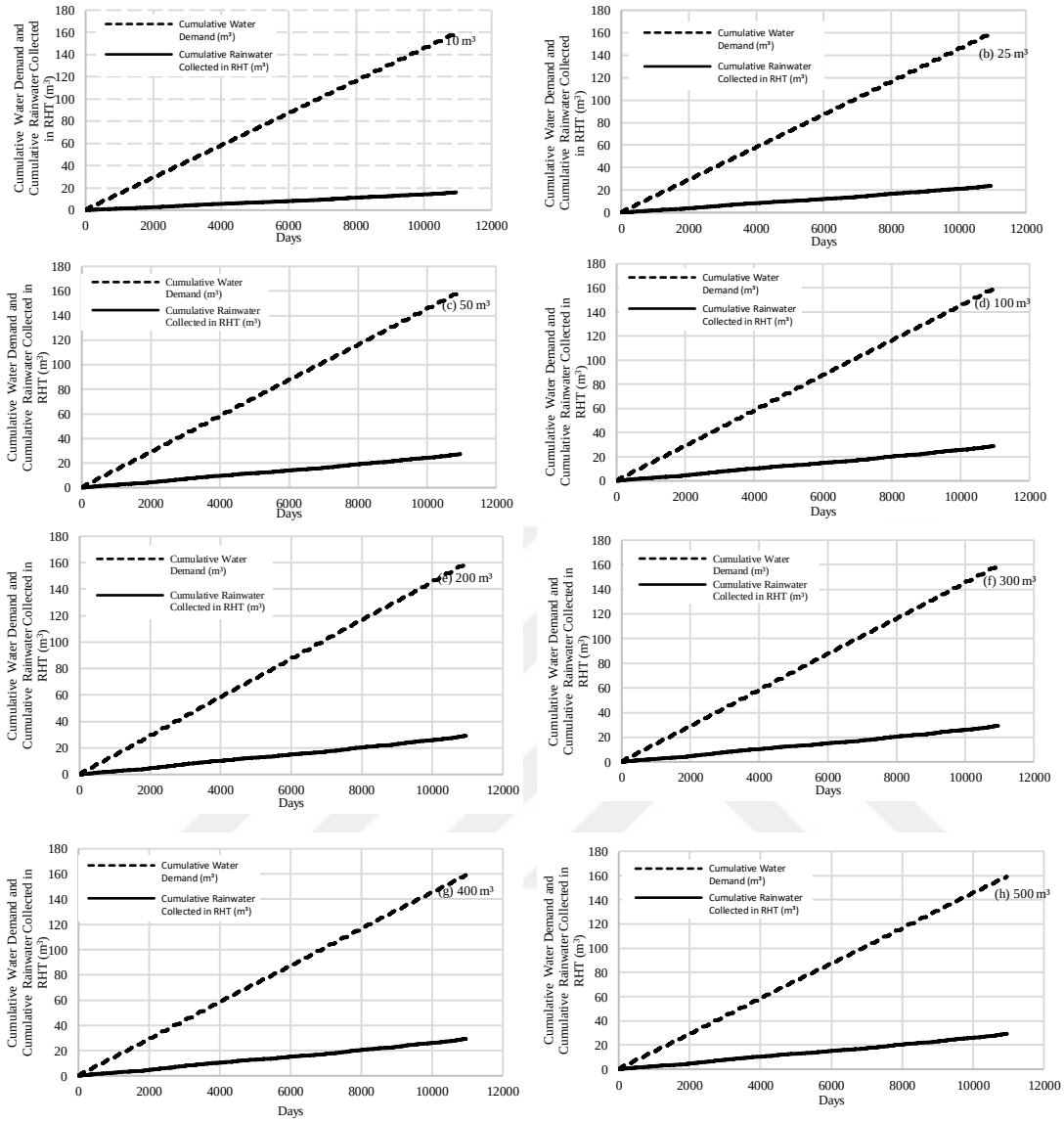


Figure A8 WBM Results for BG_08 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

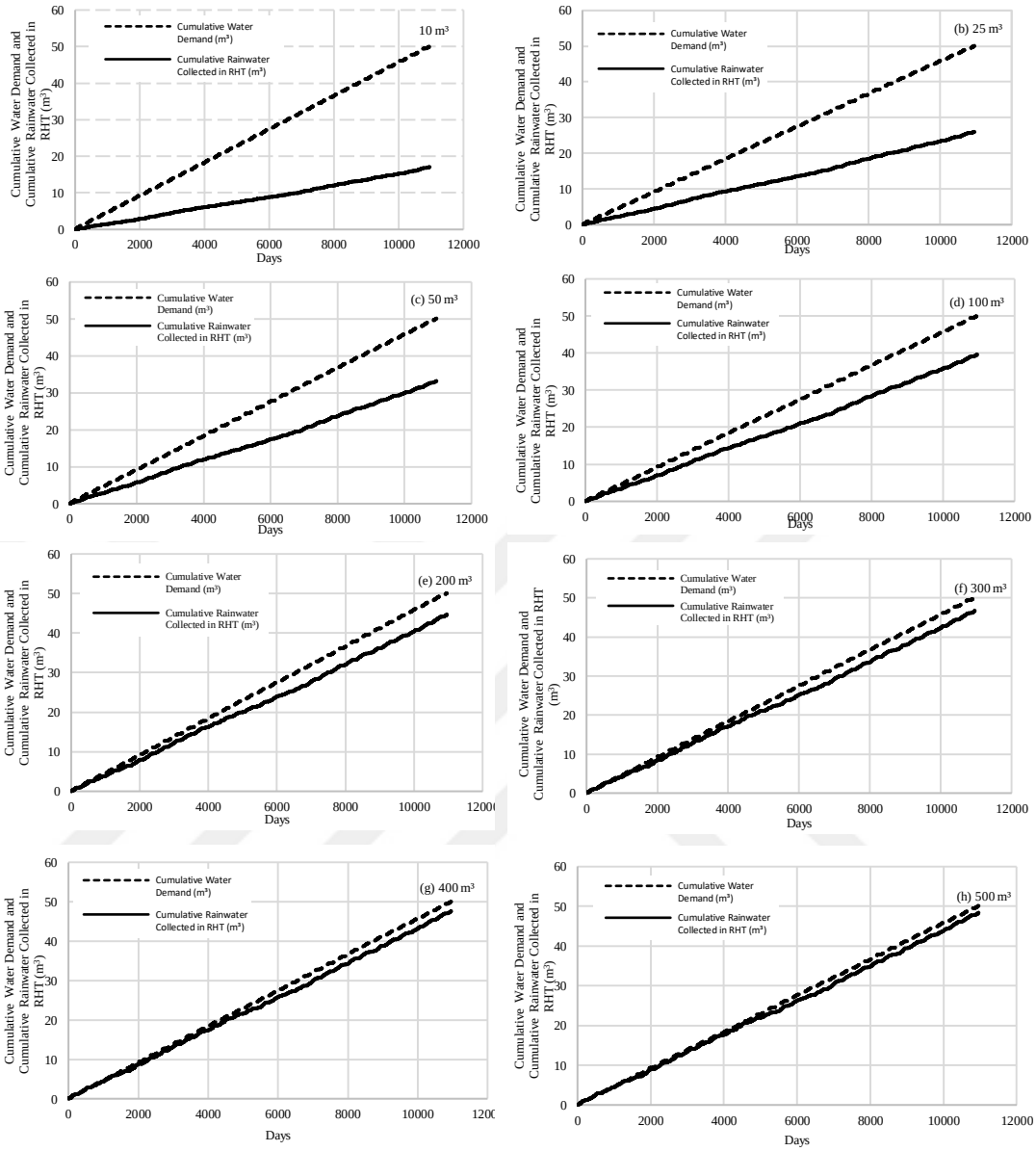


Figure A9 WBM Results for BG_09 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

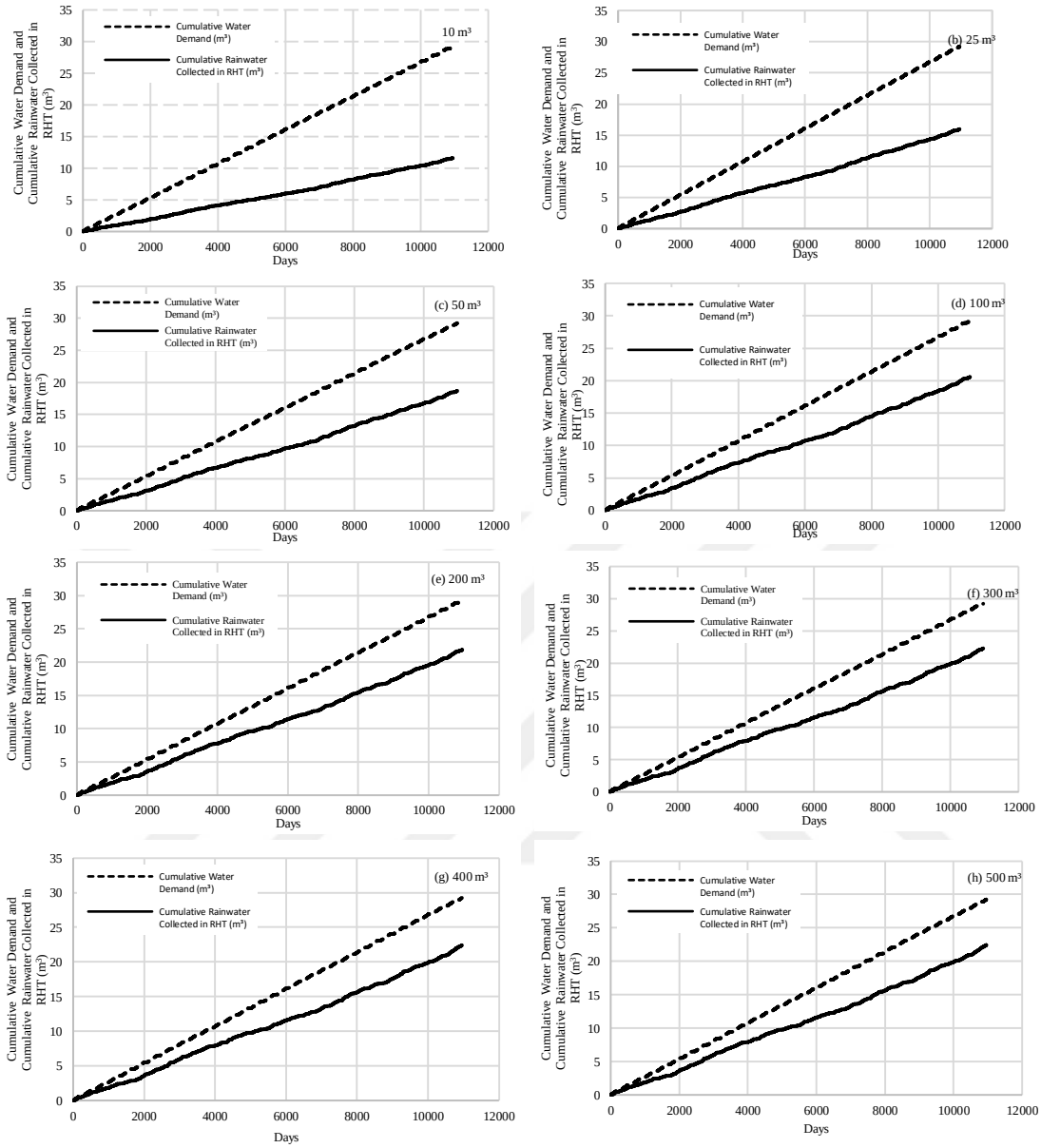


Figure A10 WBM Results for BG_10 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

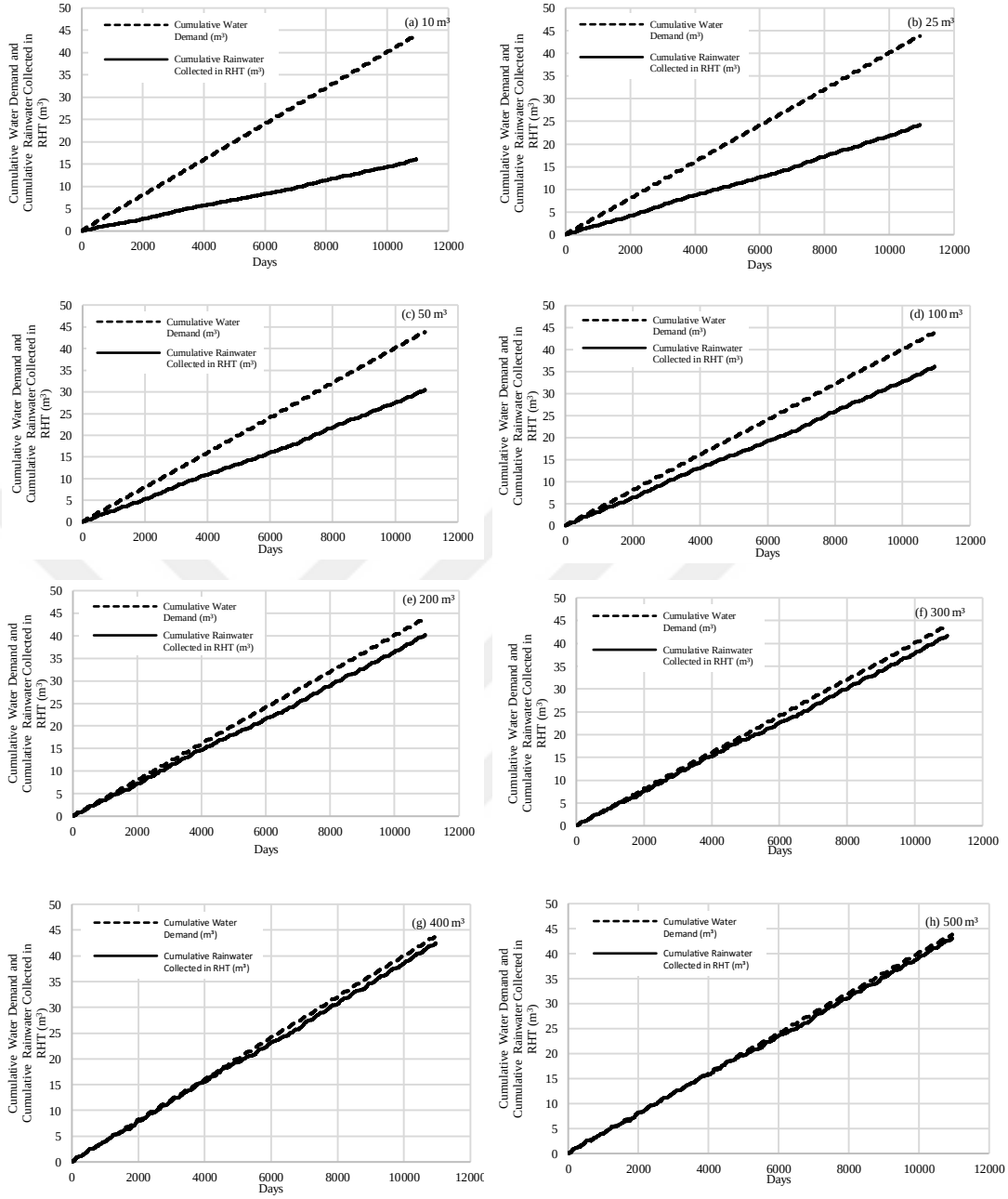


Figure A11 WBM Results for BG_11 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

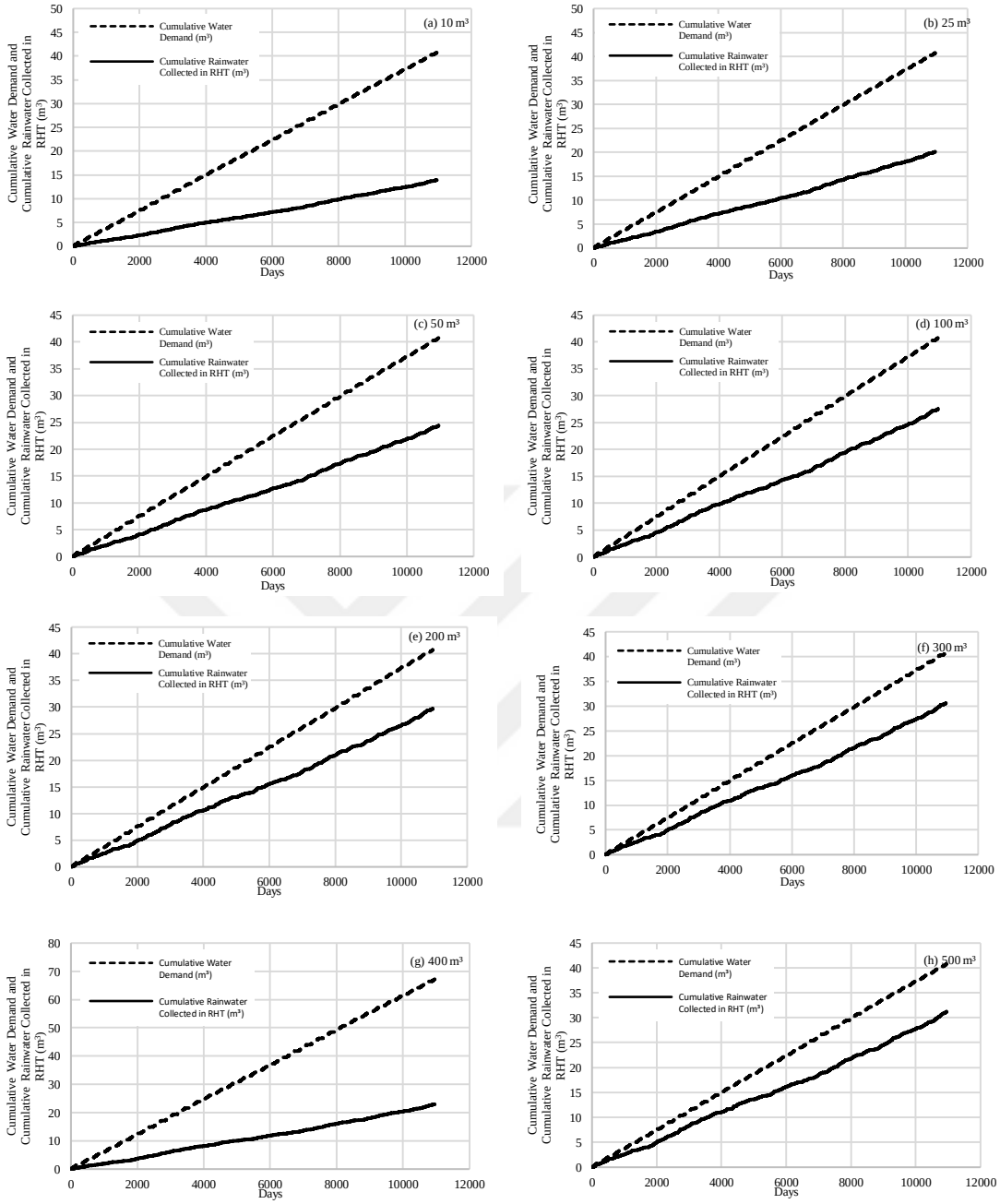


Figure A12 WBM Results for BG_12 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

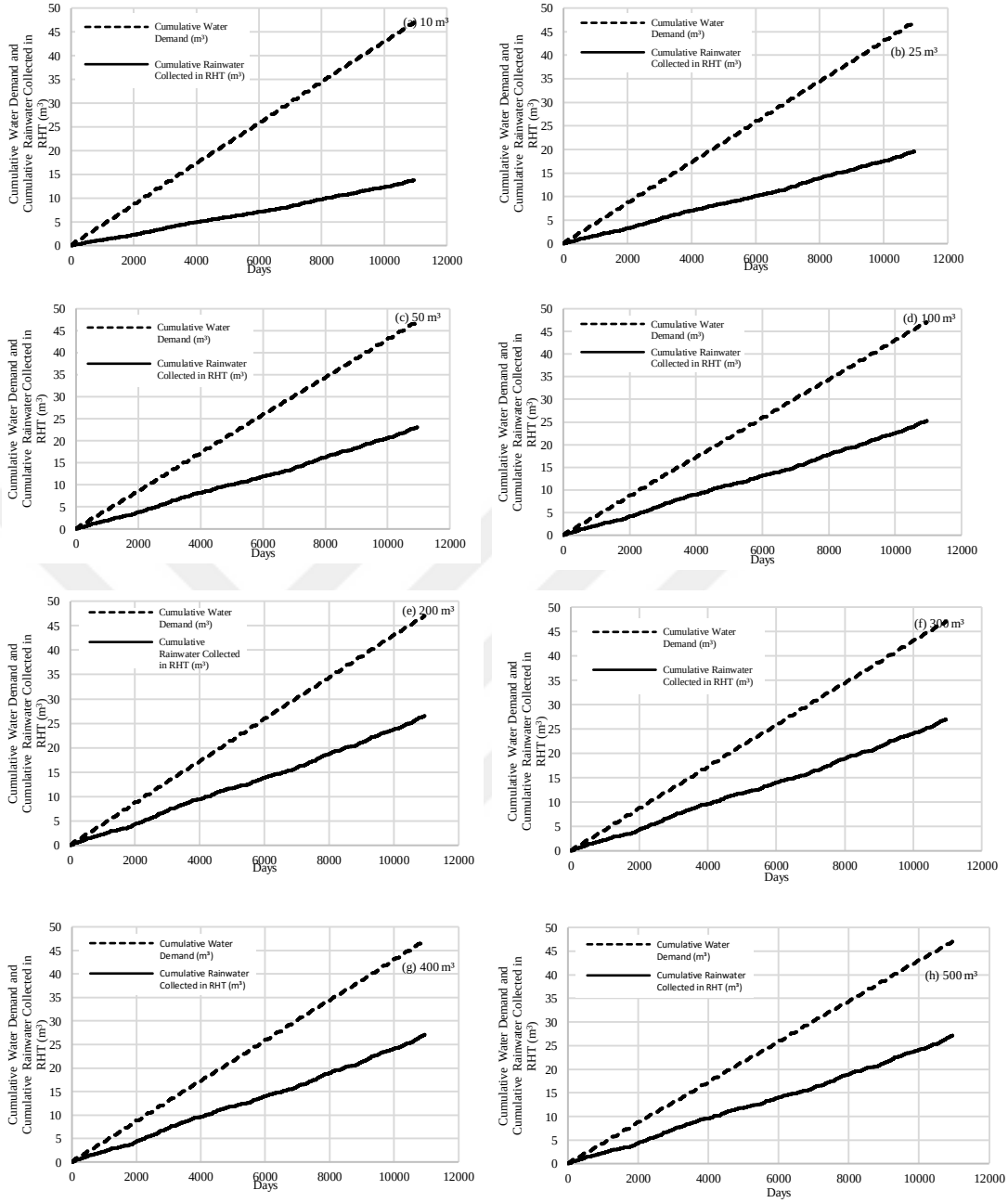


Figure A13 WBM Results for BG_13 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

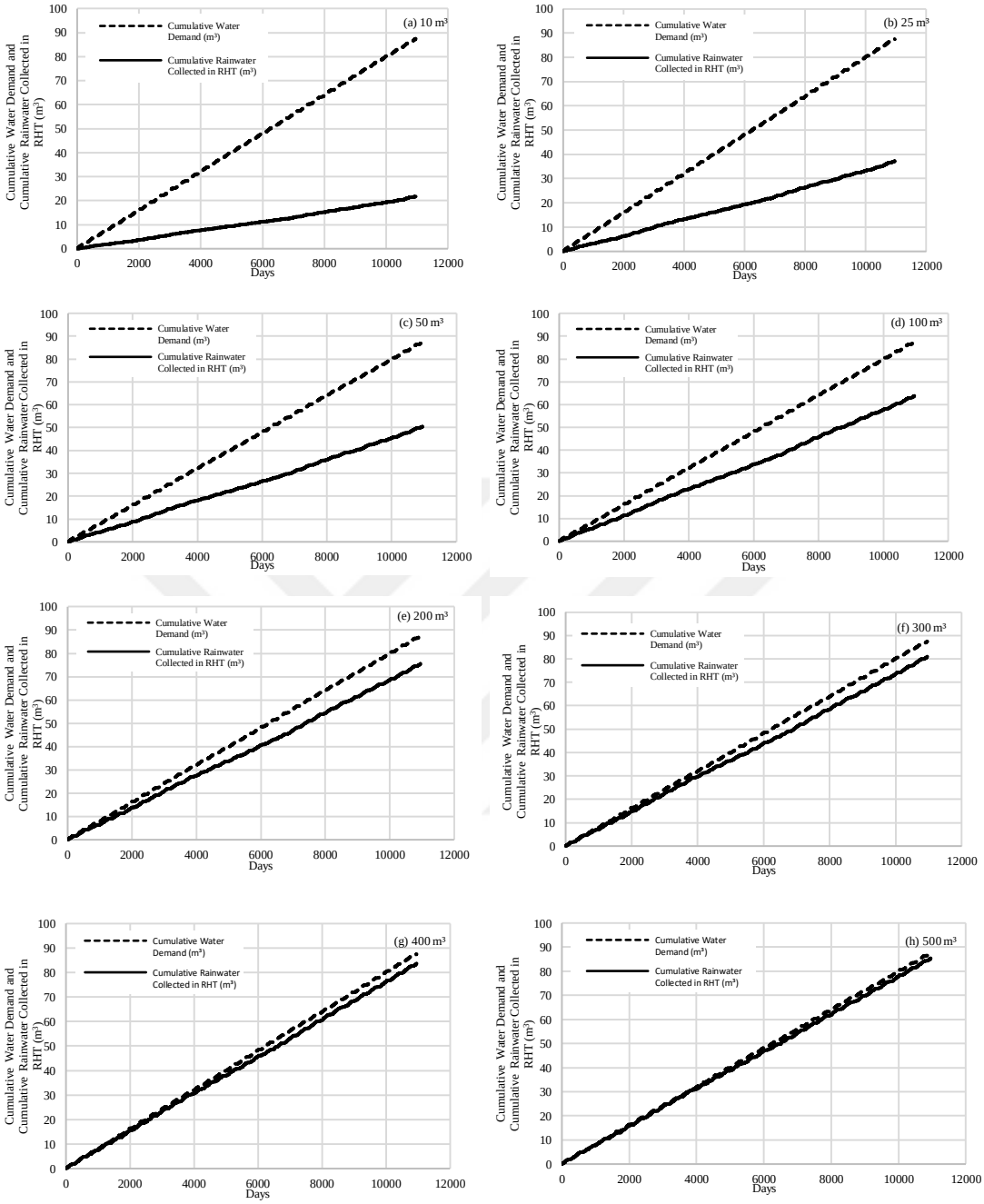


Figure A14 WBM Results for BG_14 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

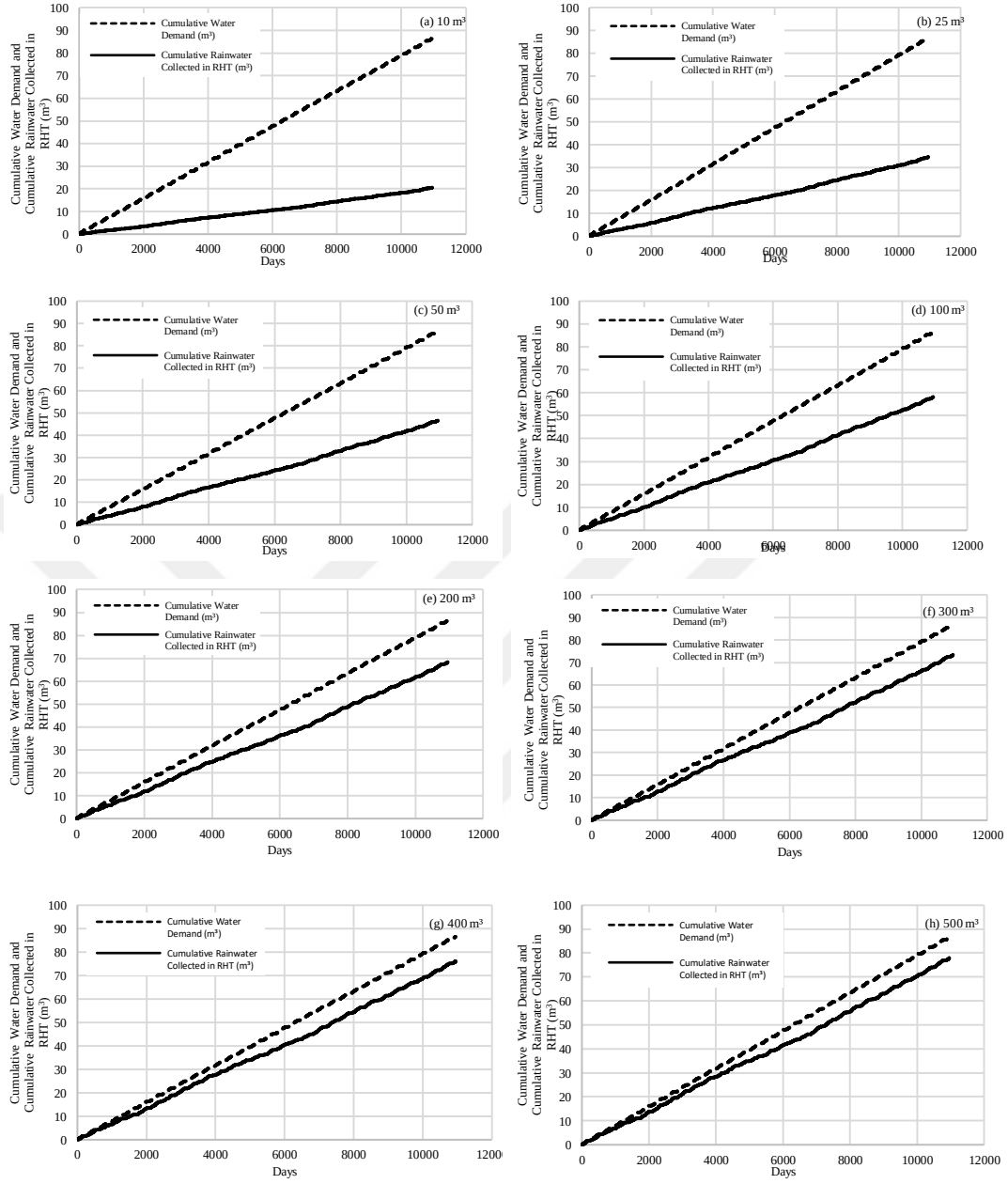


Figure A15 WBM Results for BG_15 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

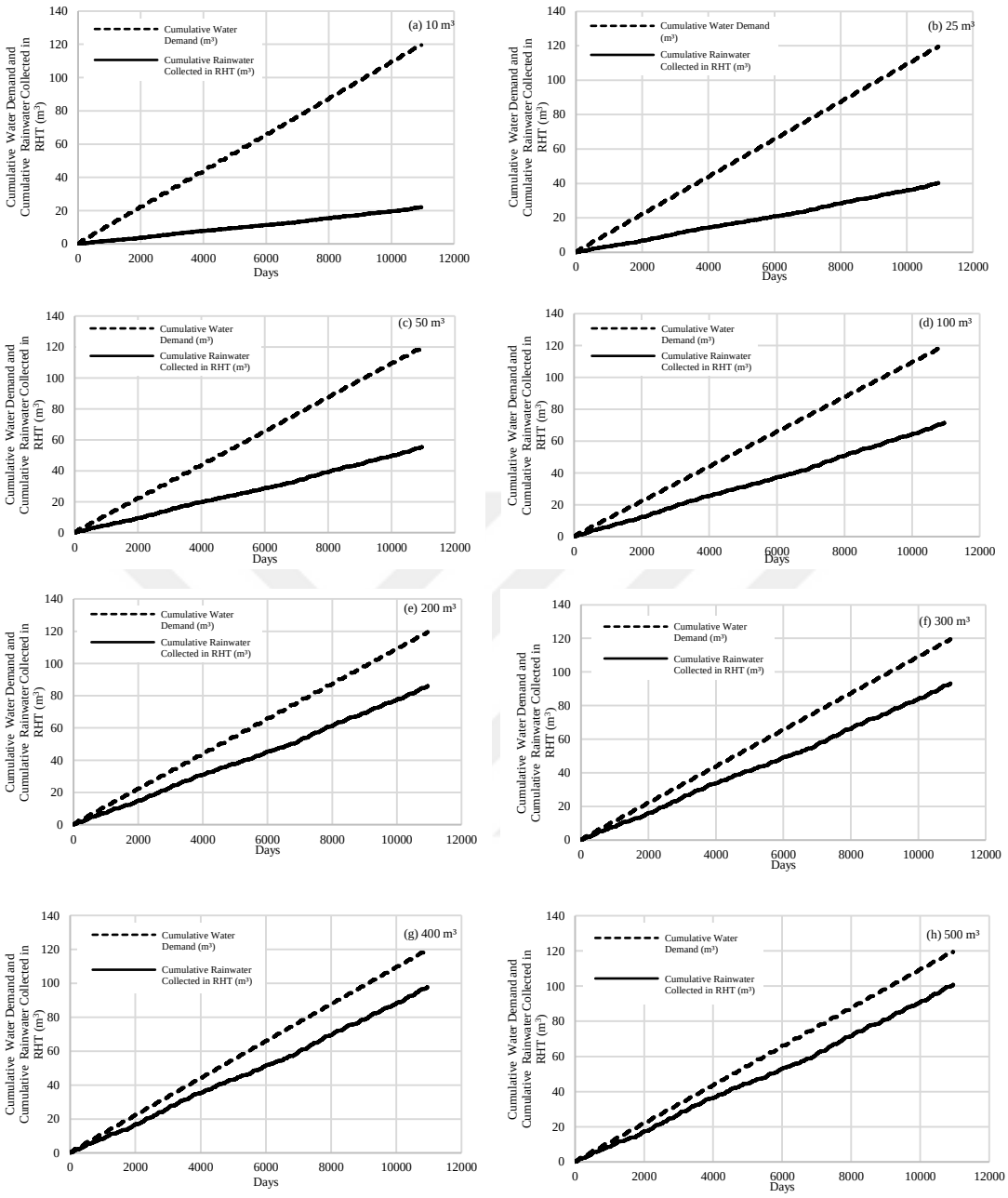


Figure A16 WBM Results for BG_16 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

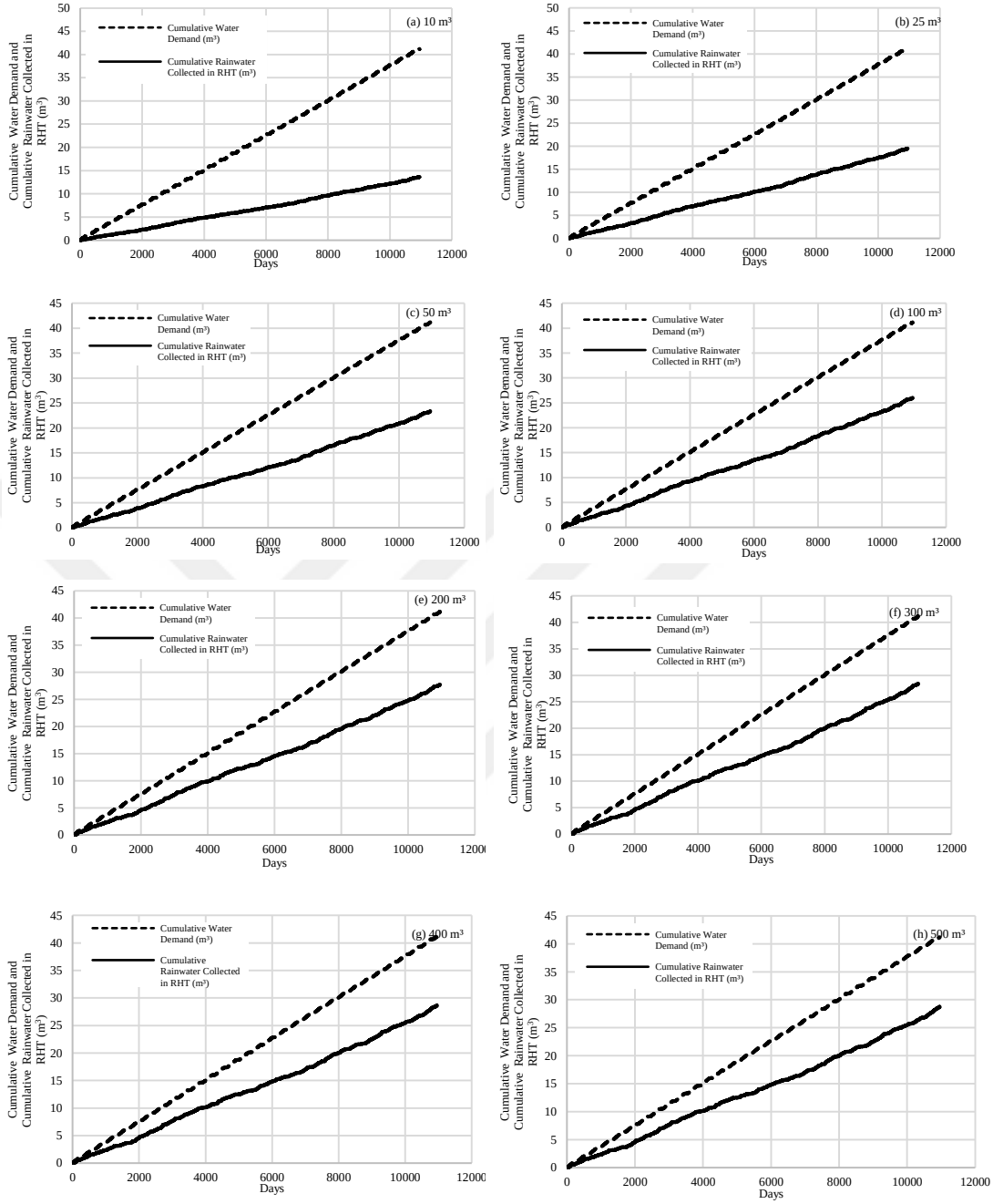


Figure A17 WBM Results for BG_17 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

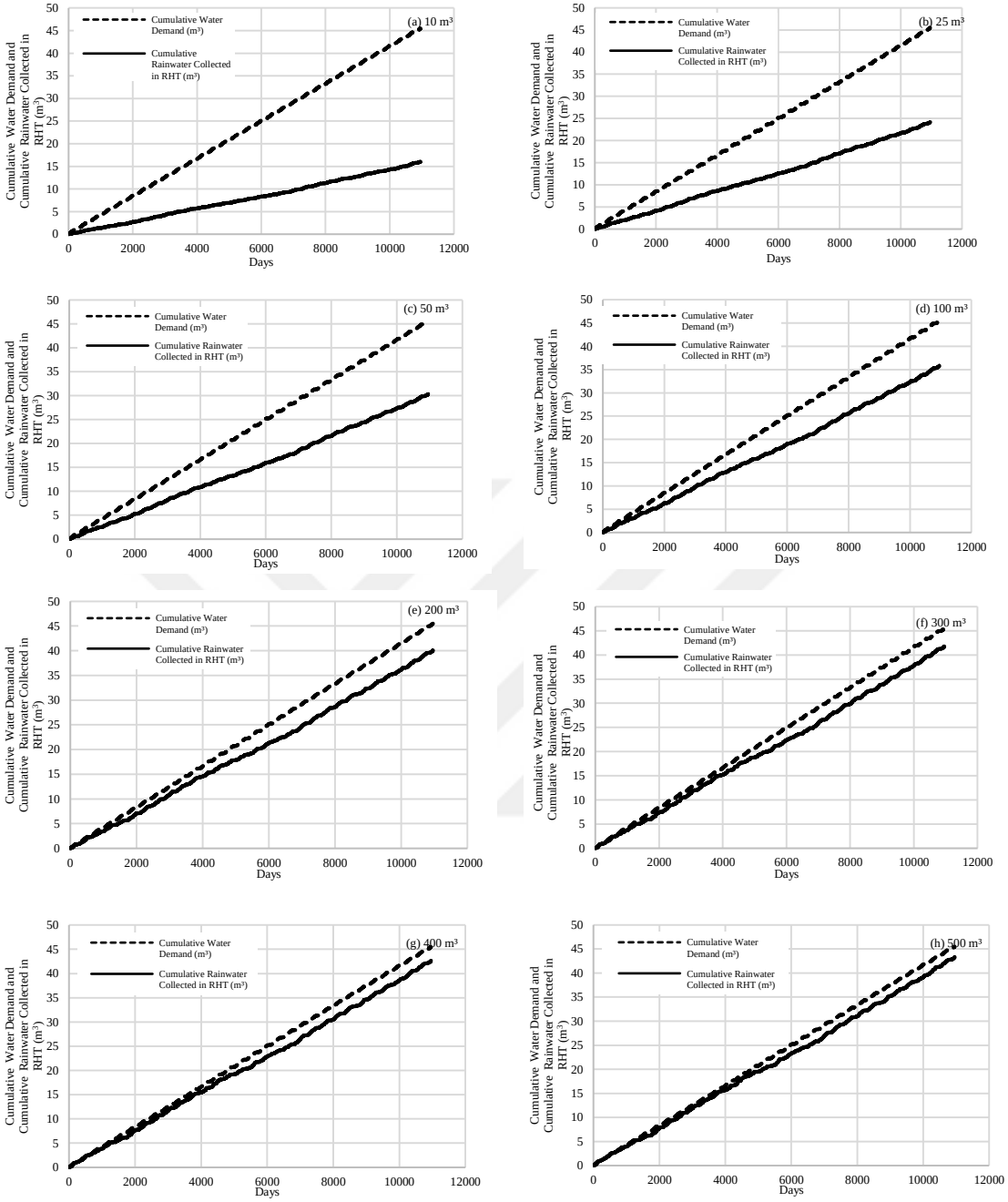


Figure A18 WBM Results for BG_18 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

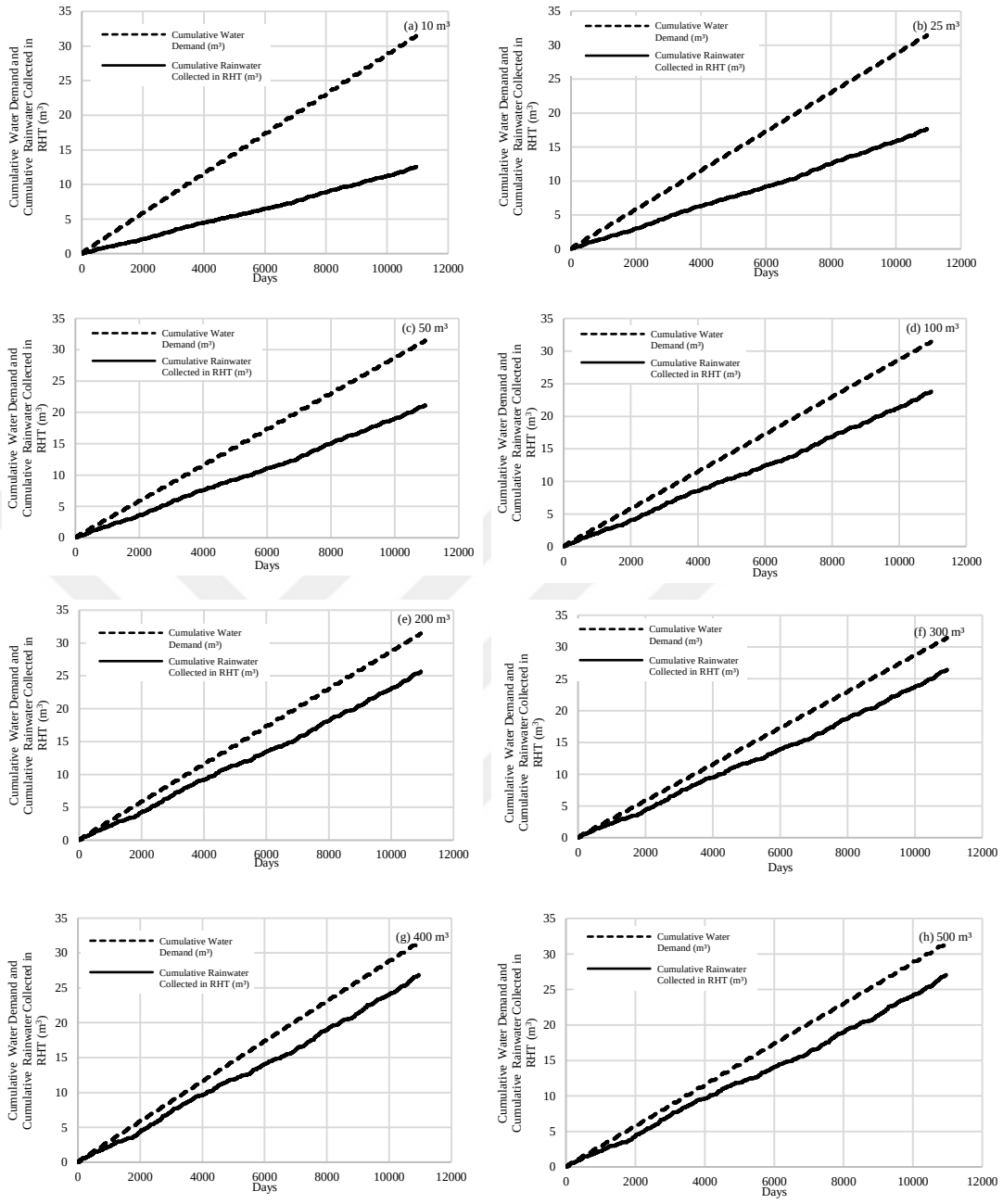


Figure A19 WBM Results for BG_19 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

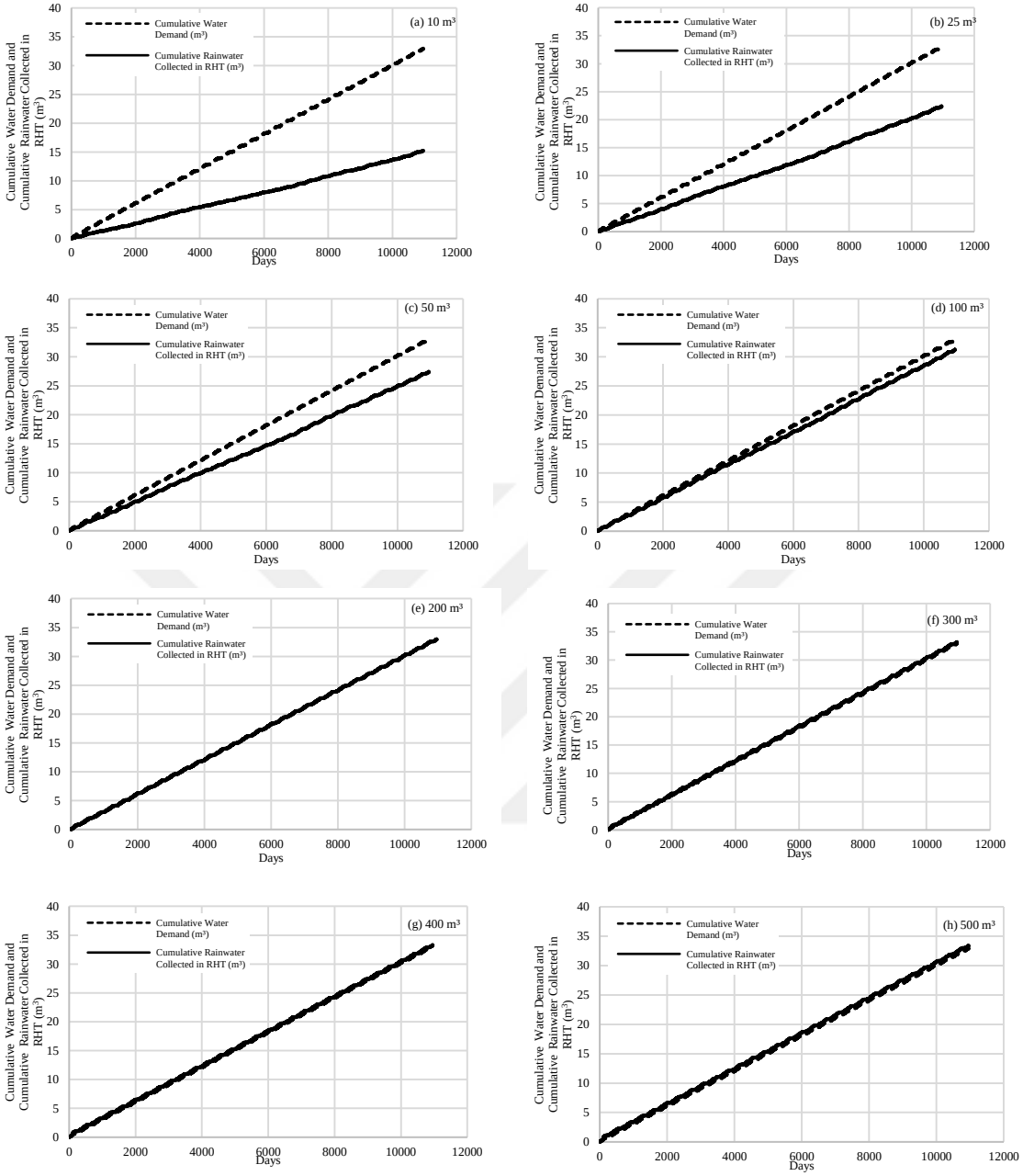


Figure A20 WBM Results for BG_20 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

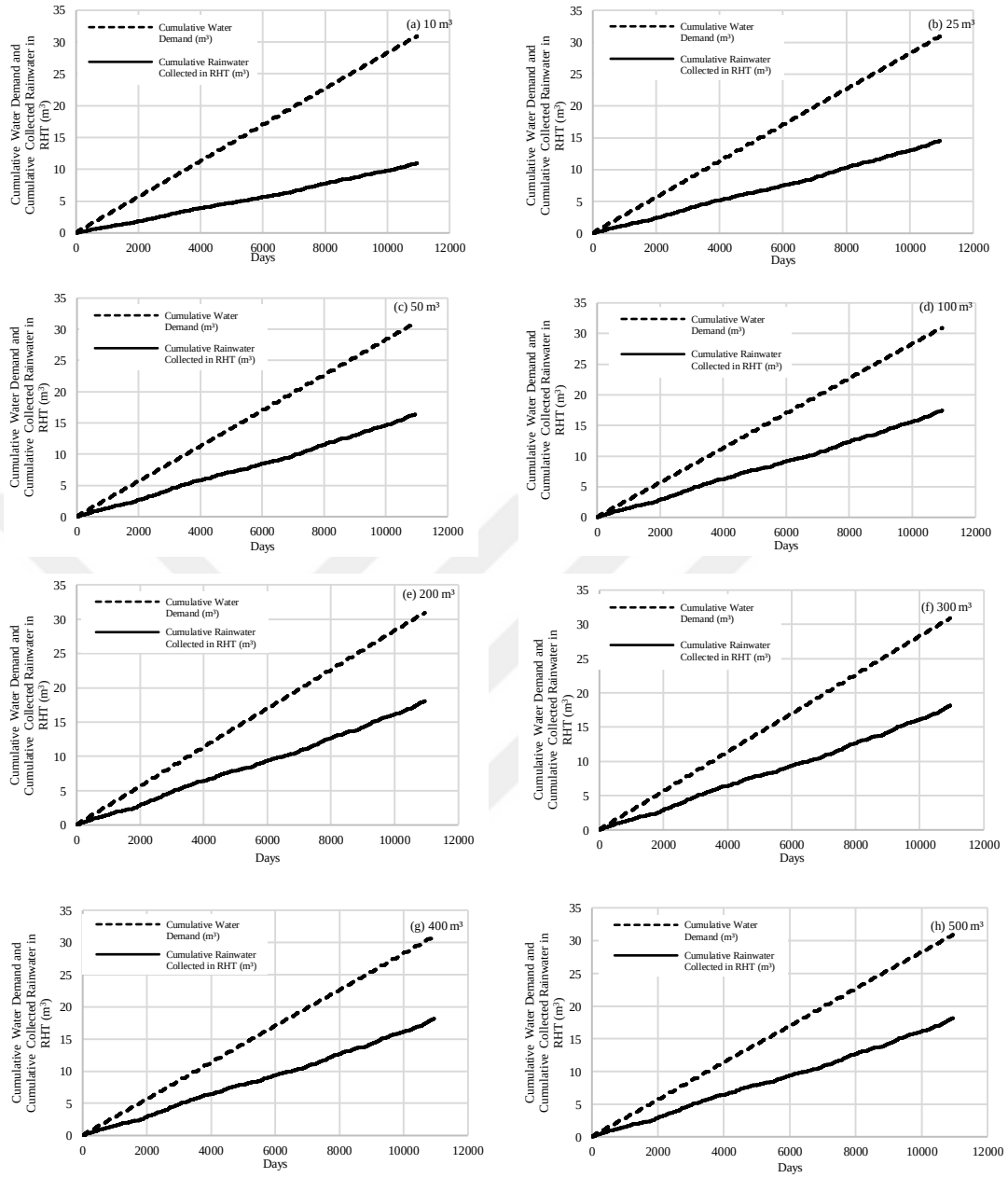


Figure A21 WBM Results for BG_21 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

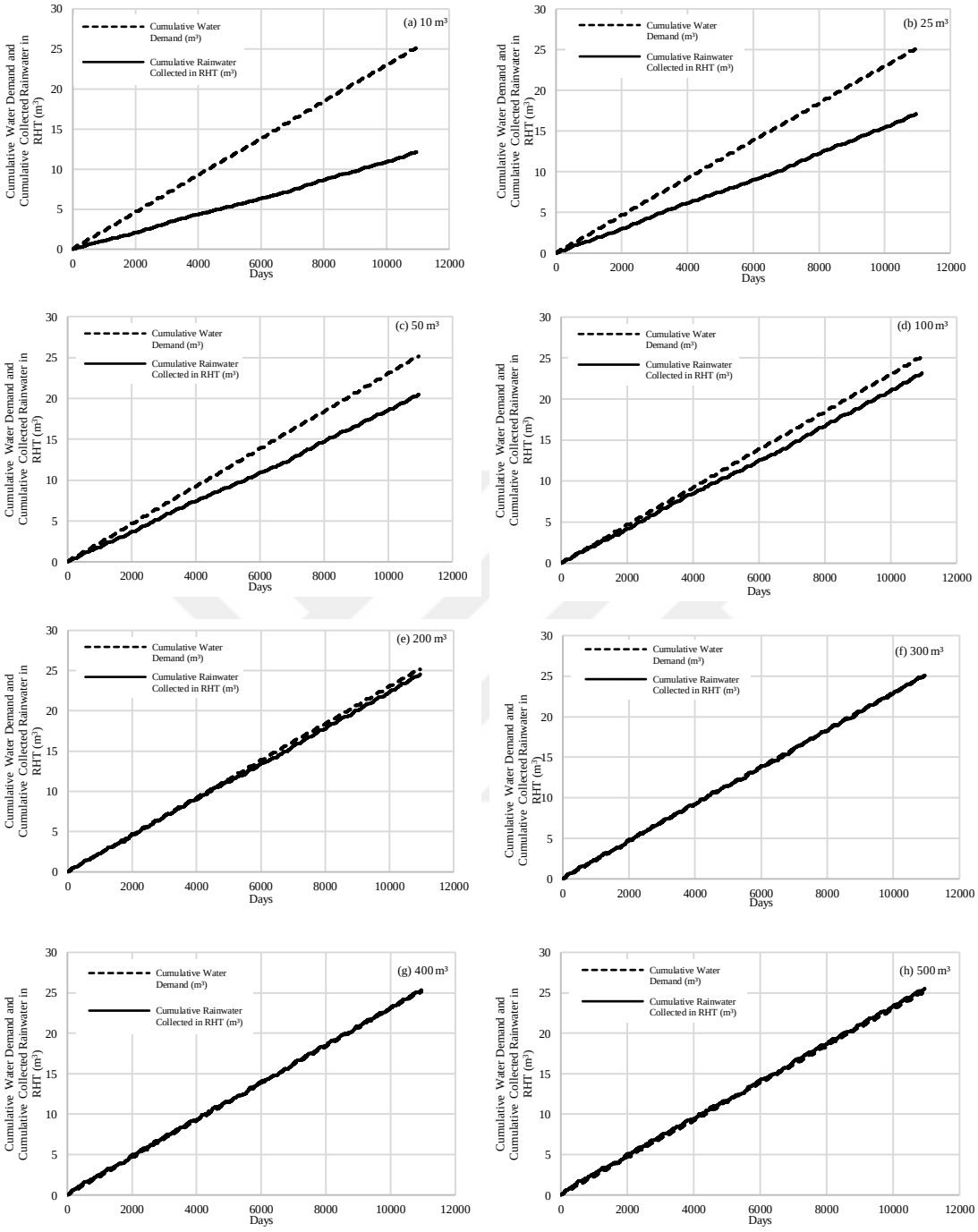


Figure A22 WBM Results for BG_22 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

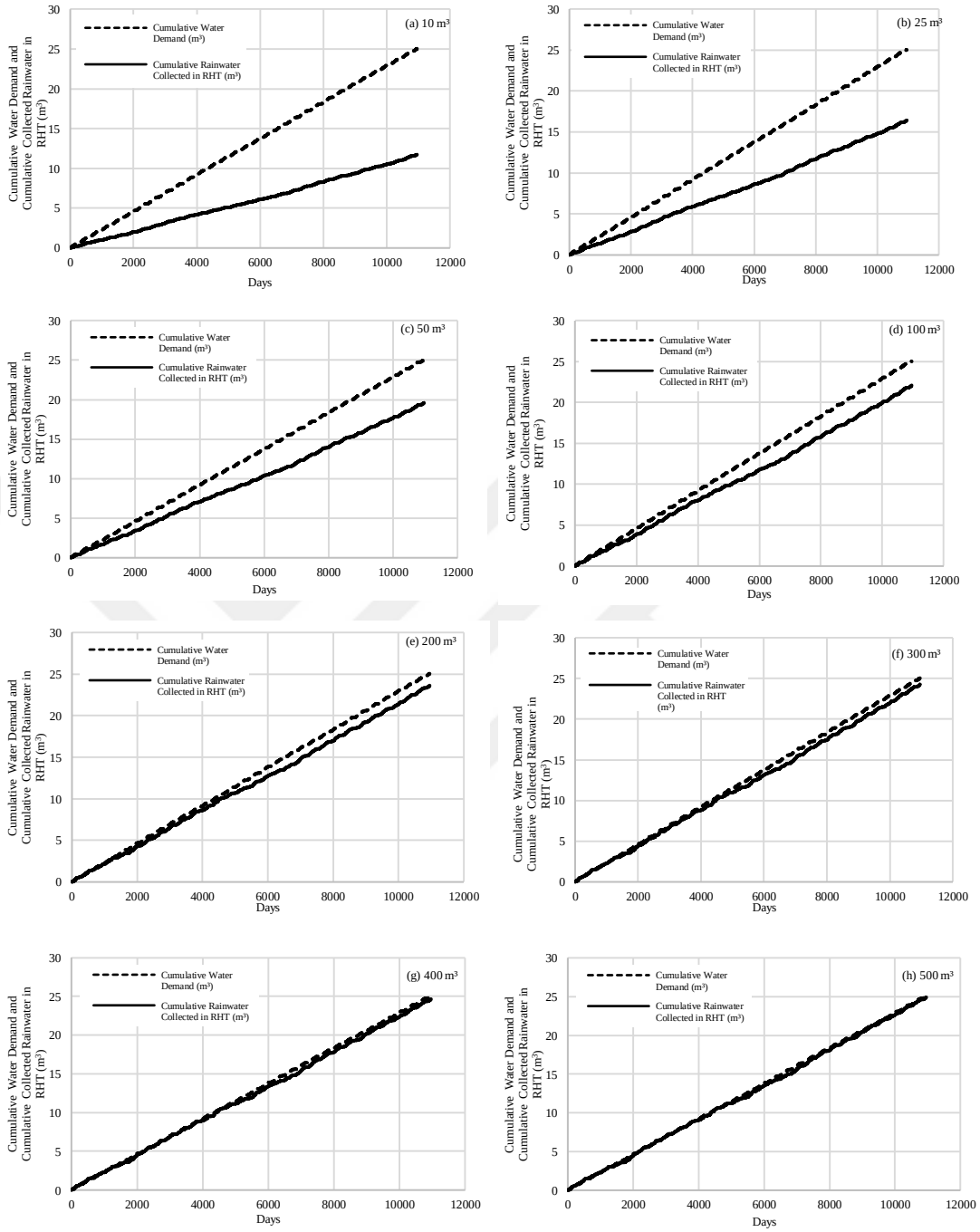


Figure A23 WBM Results for BG_23 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

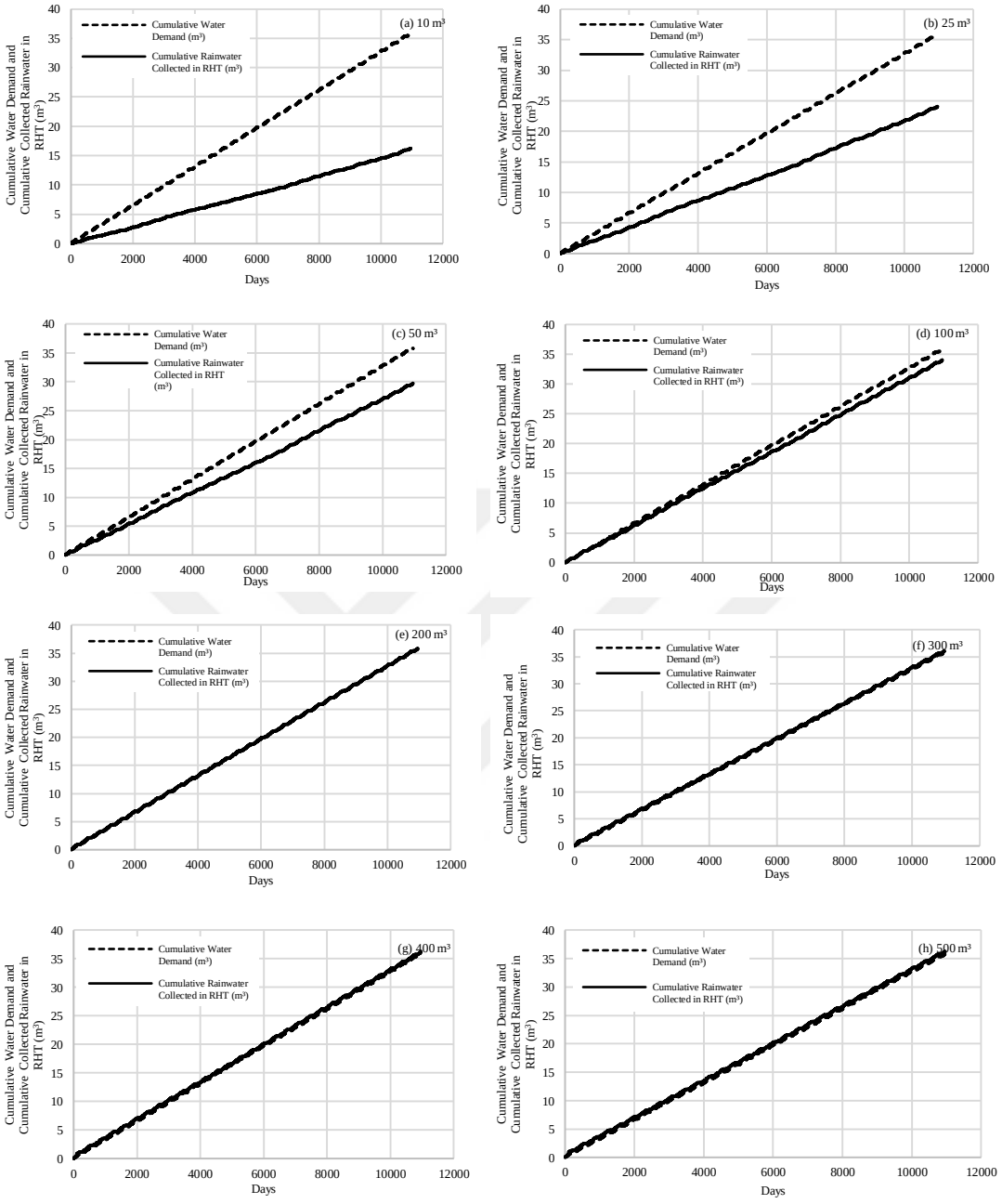


Figure A24 WBM Results for BG_24 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

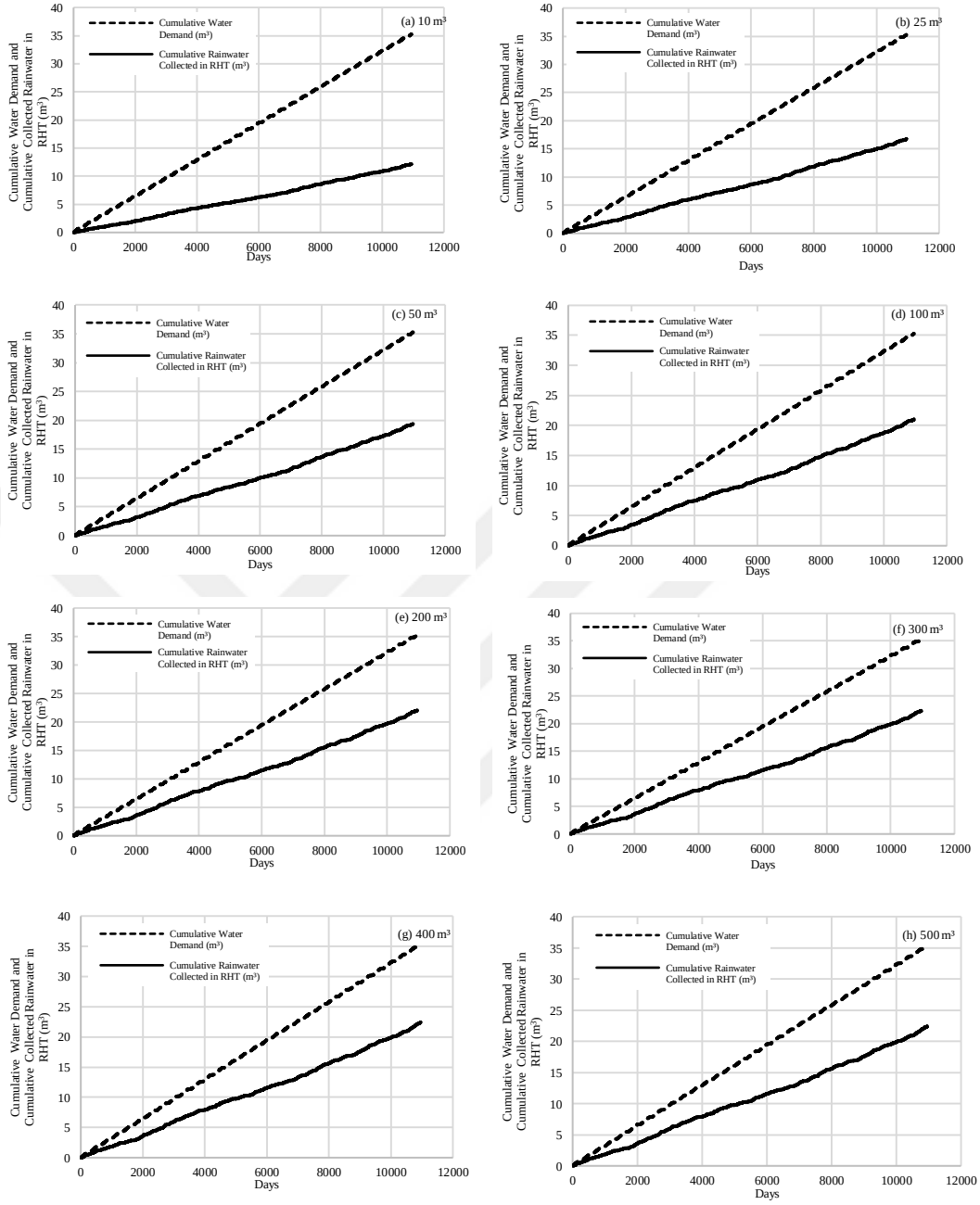


Figure A25 WBM Results for BG_25 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

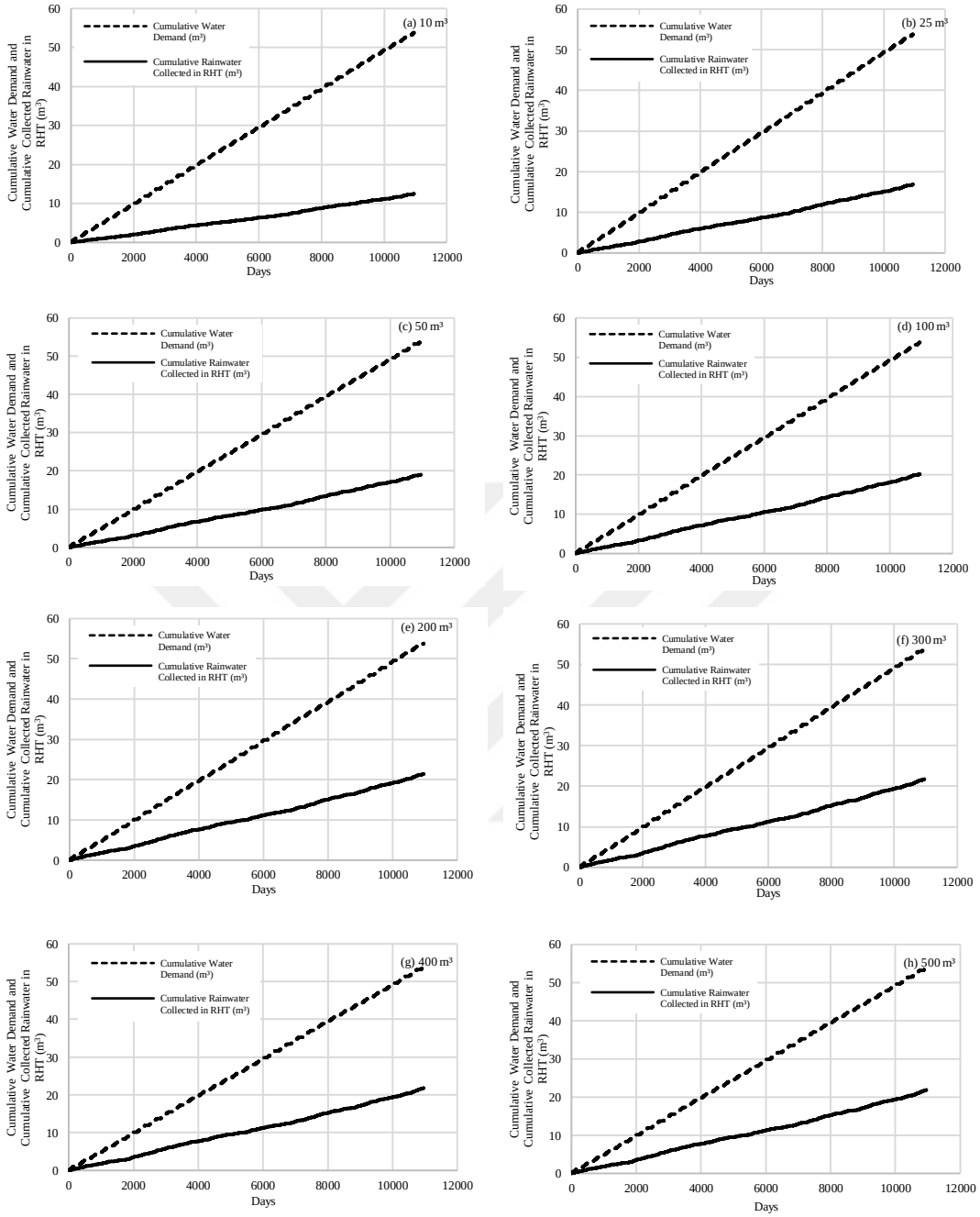


Figure A26 WBM Results for BG_26 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

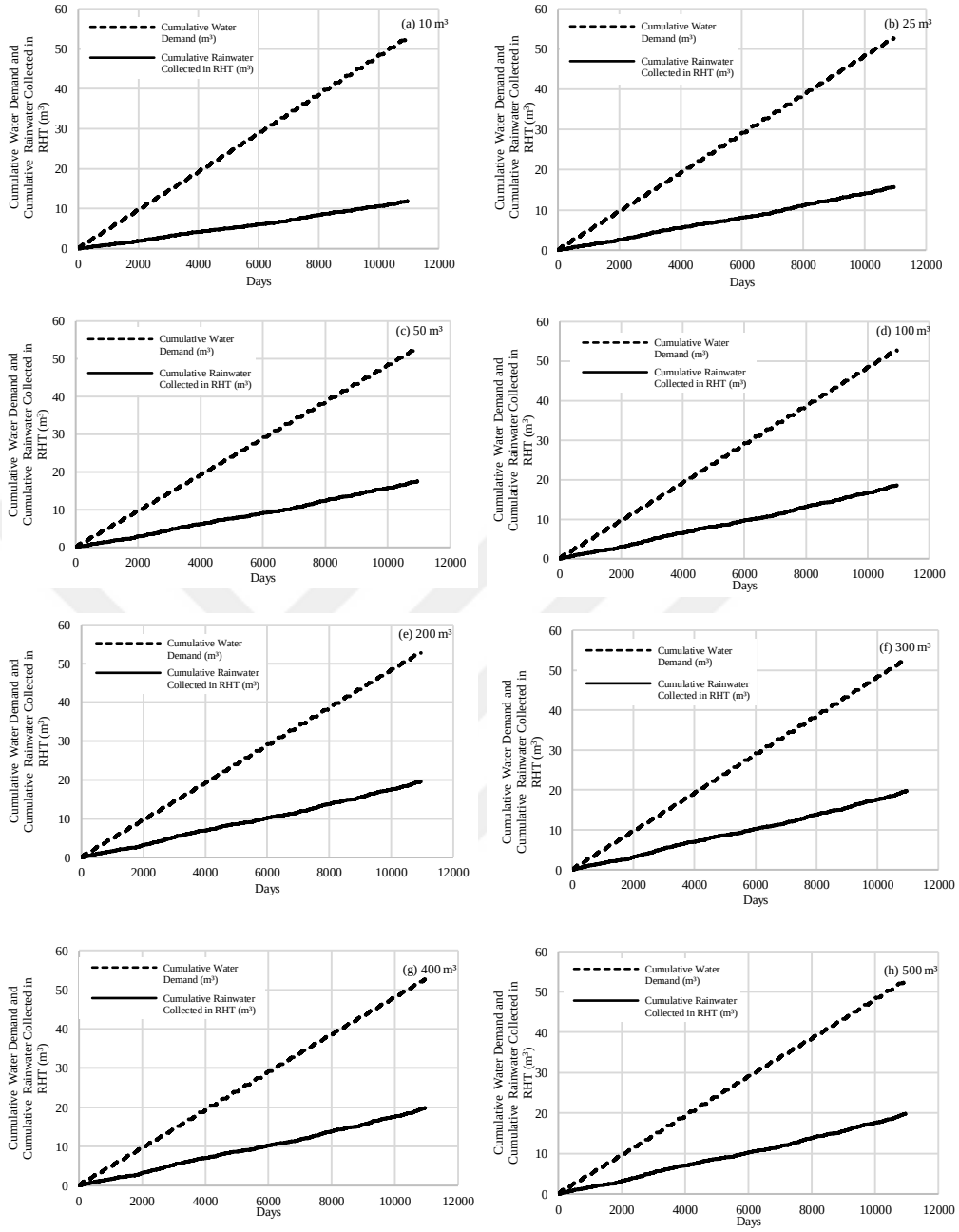


Figure A27 WBM Results for BG_27 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

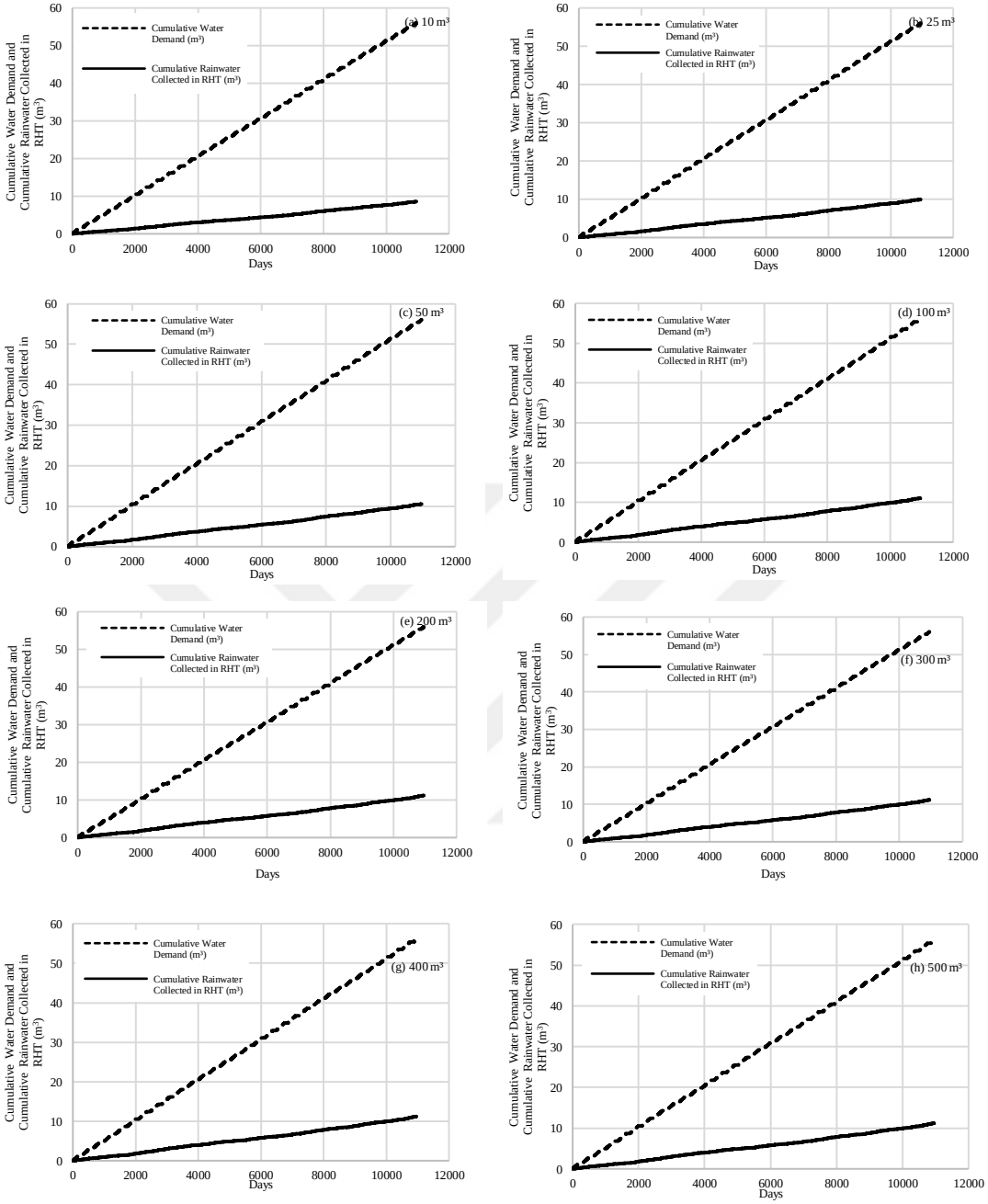


Figure A28 WBM Results for BG_28 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

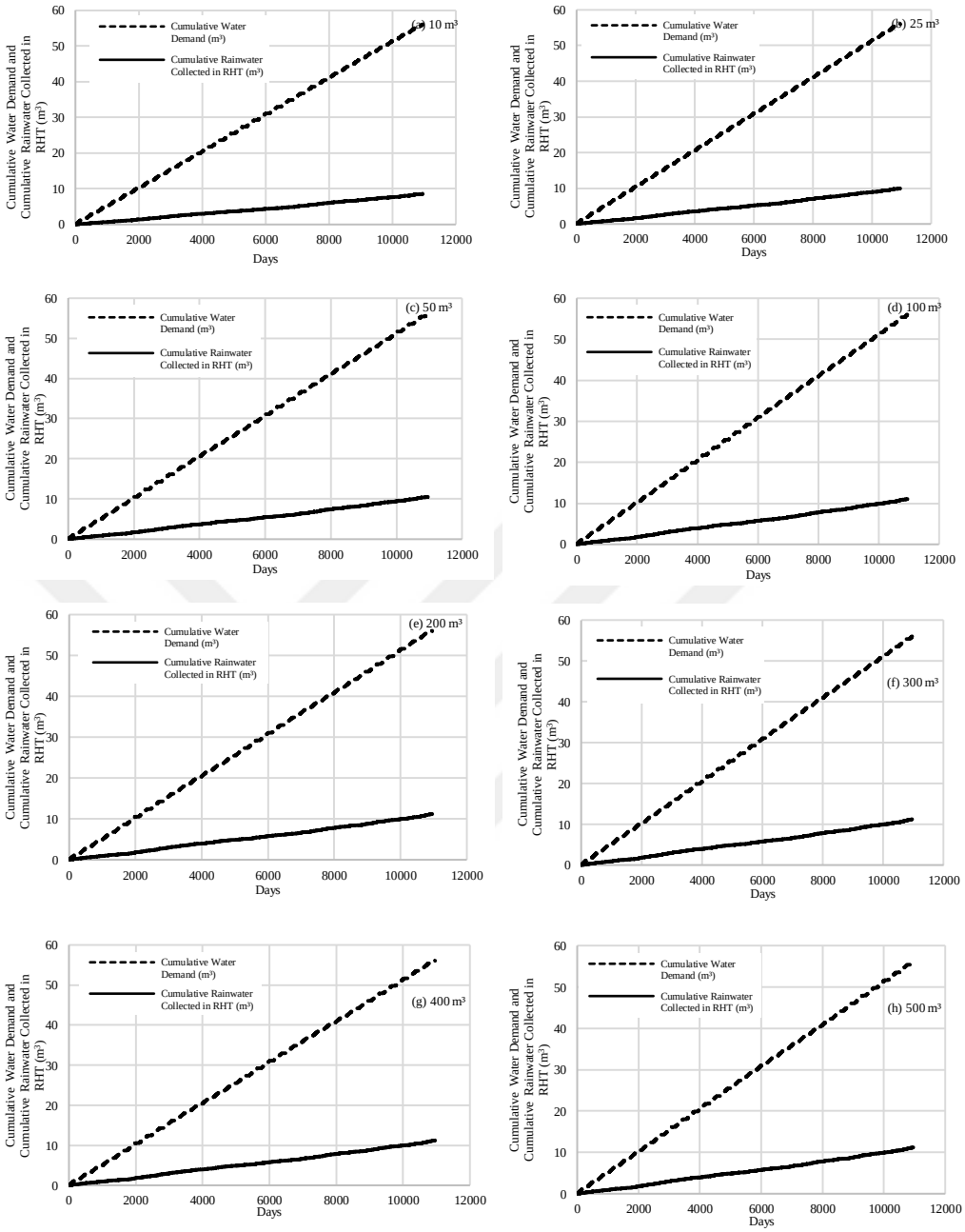


Figure A29 WBM Results for BG_29 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

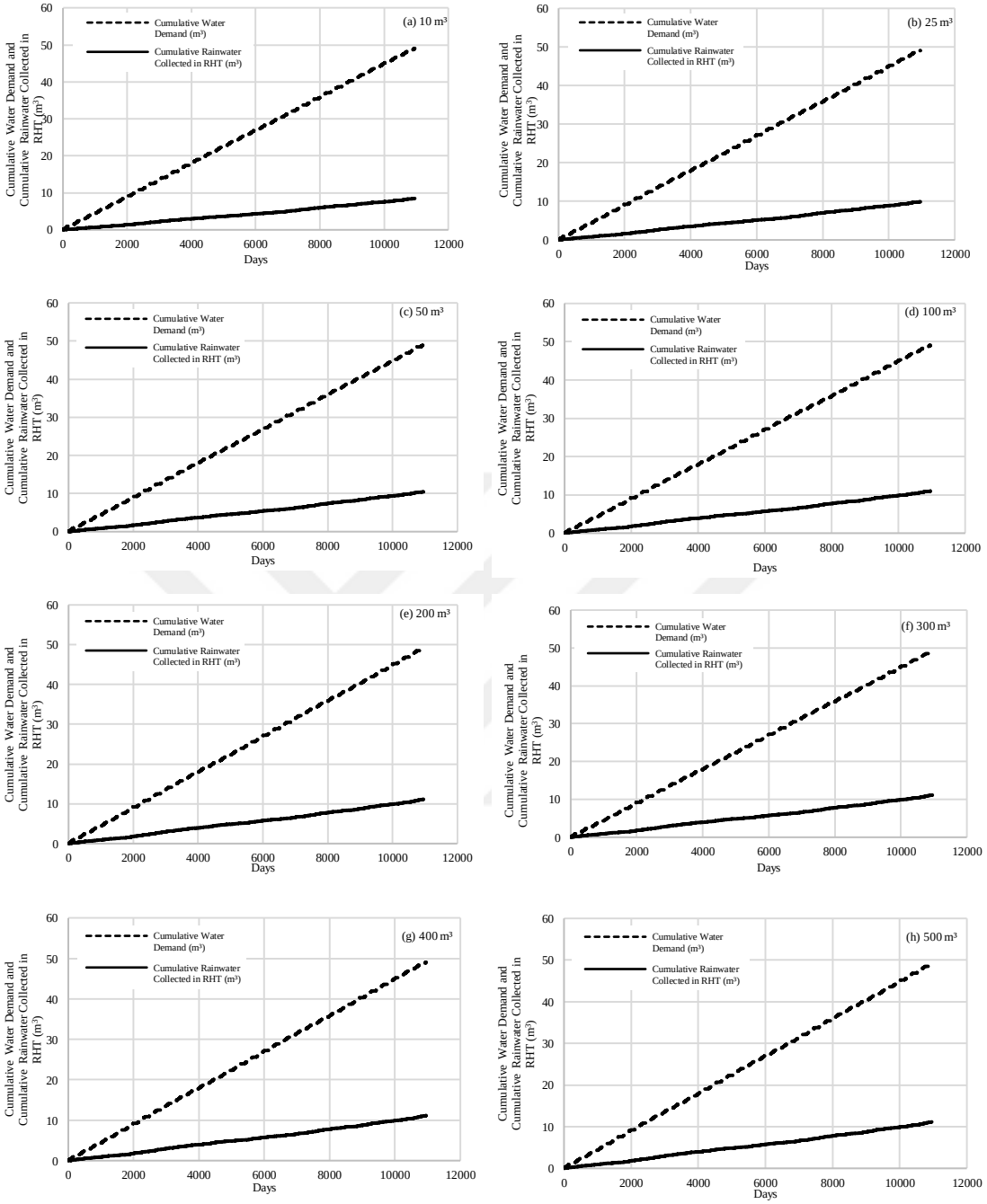


Figure A30 WBM Results for BG_30 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

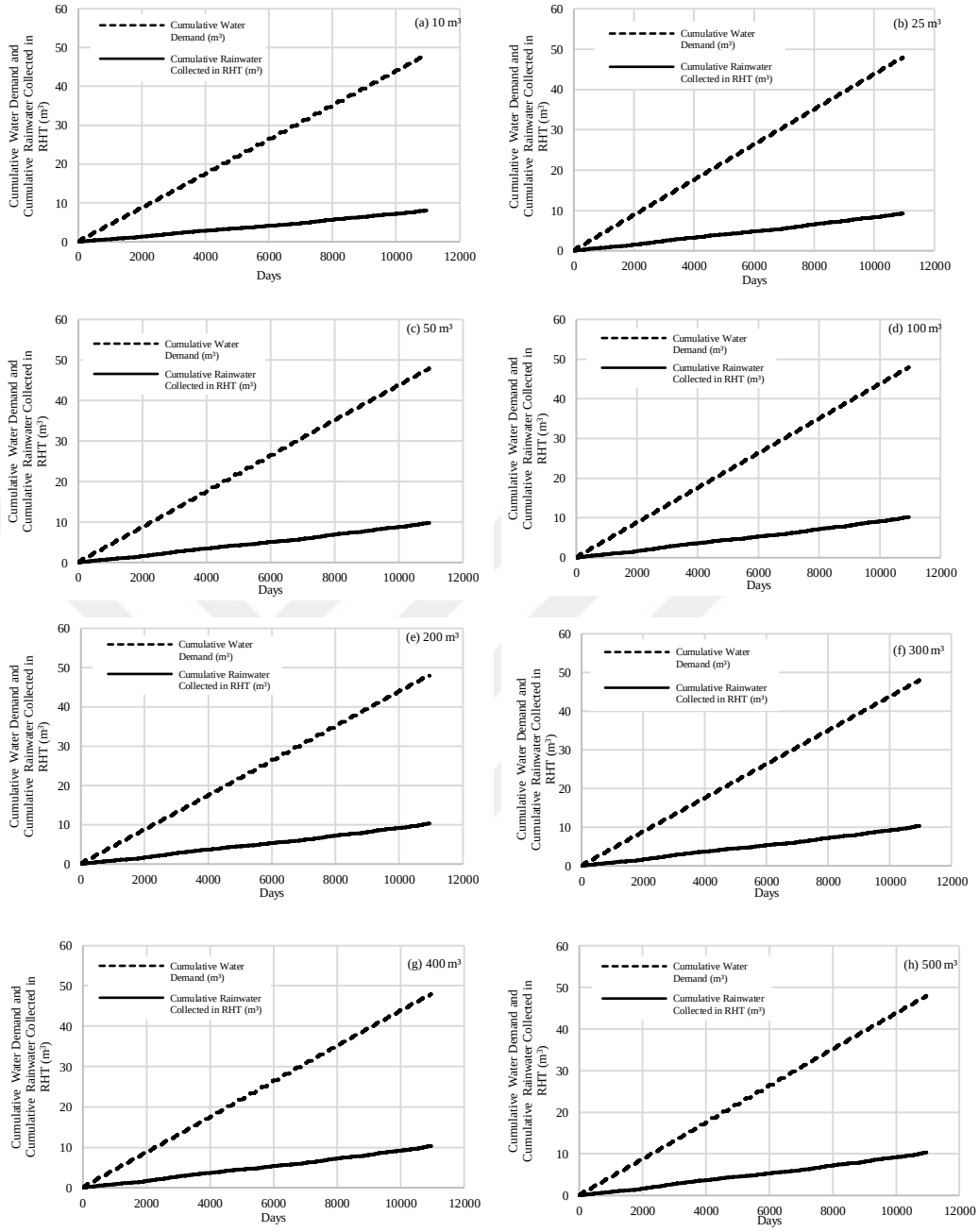


Figure A31 WBM Results for BG_31 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

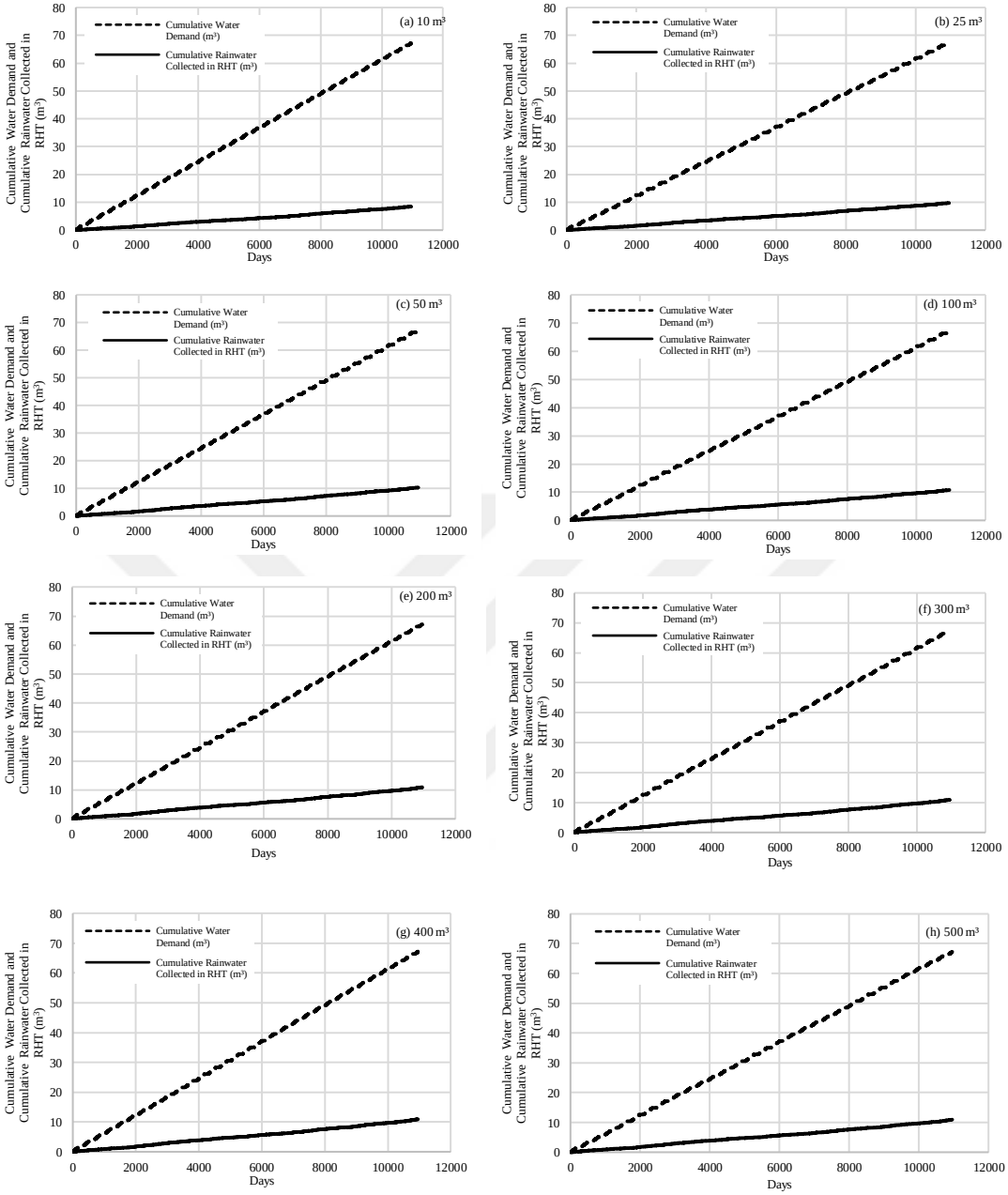


Figure A32 WBM Results for BG_32 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

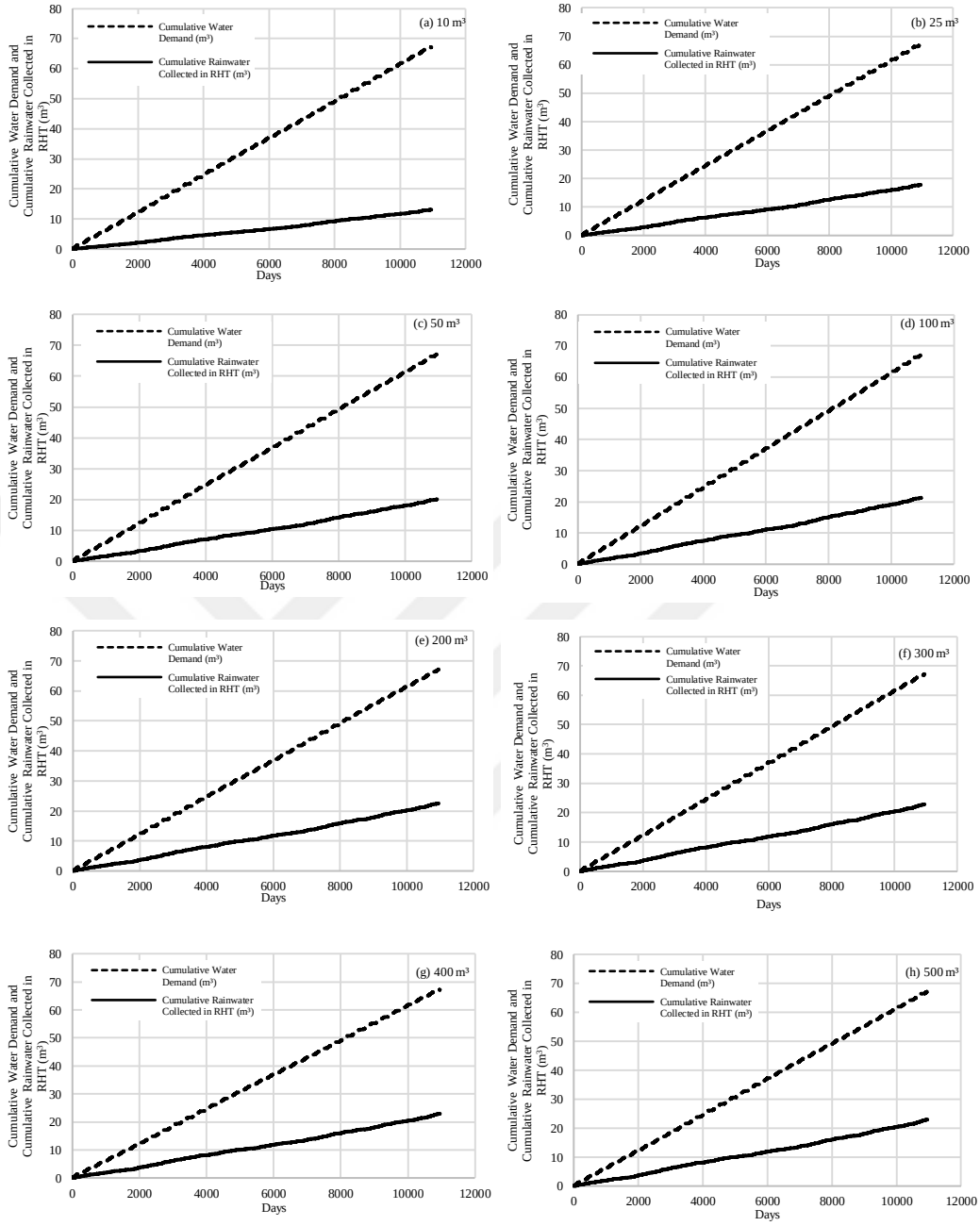


Figure A33 WBM Results for BG_33 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

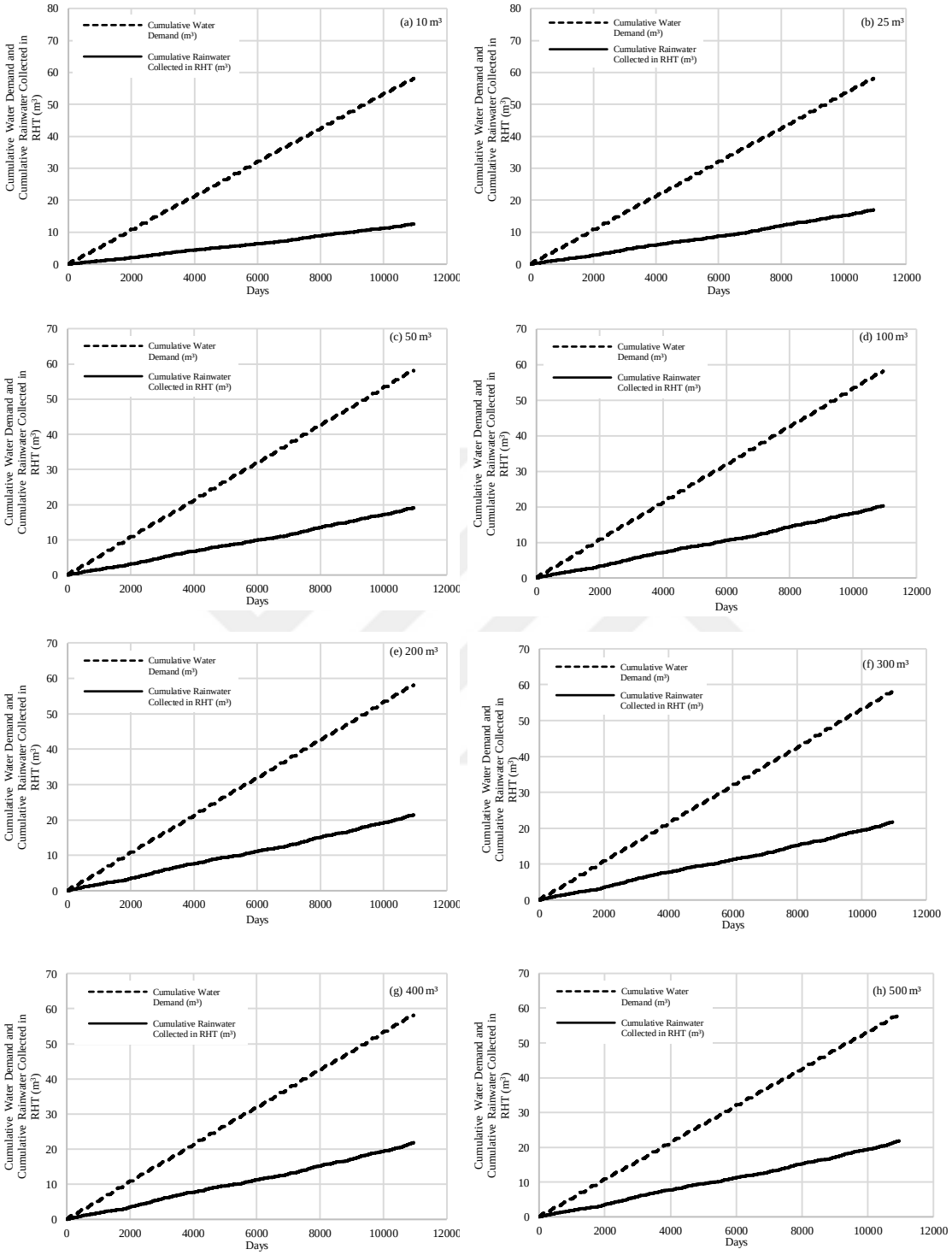


Figure A34 WBM Results for BG_34 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

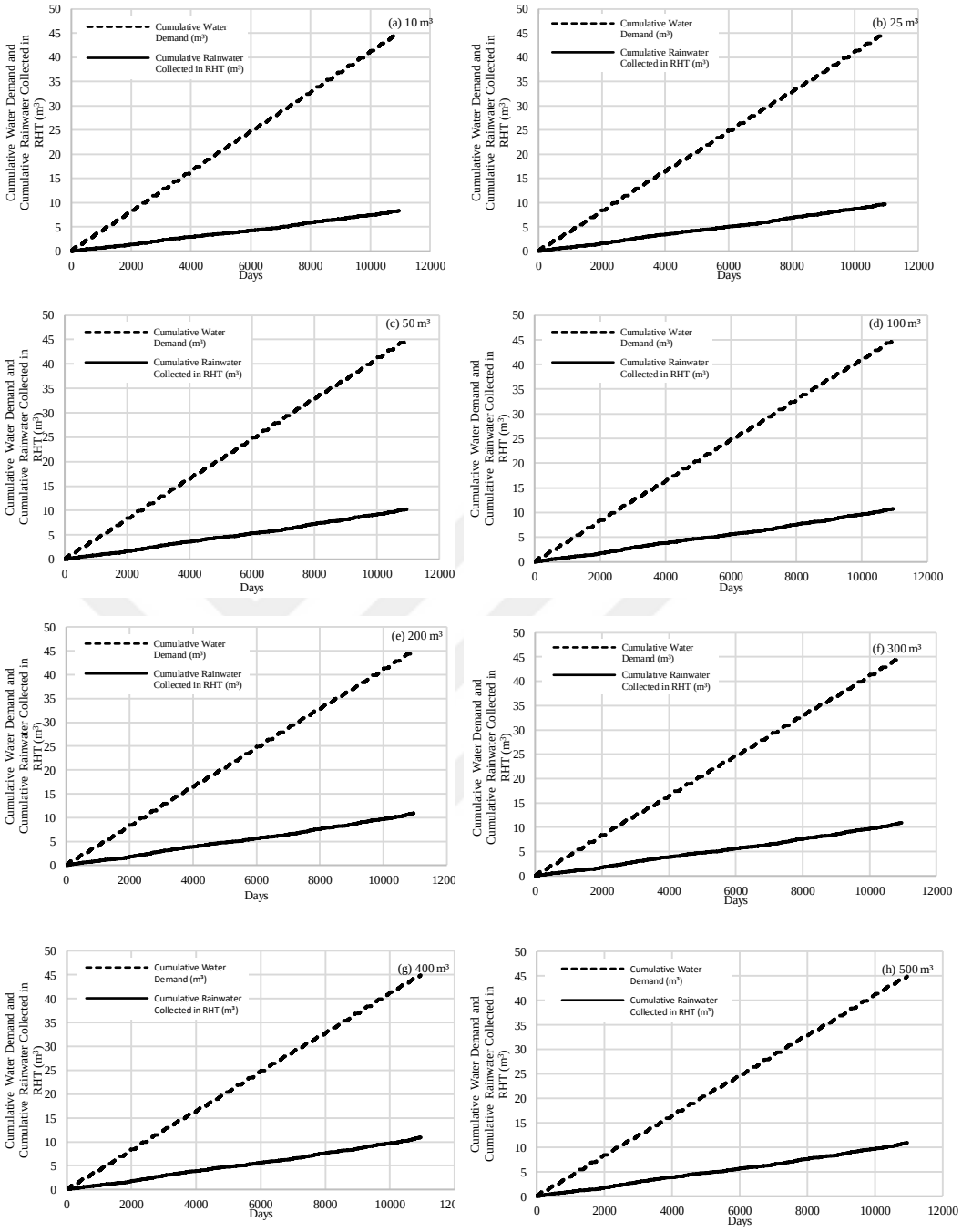


Figure A35 WBM Results for BG_35 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

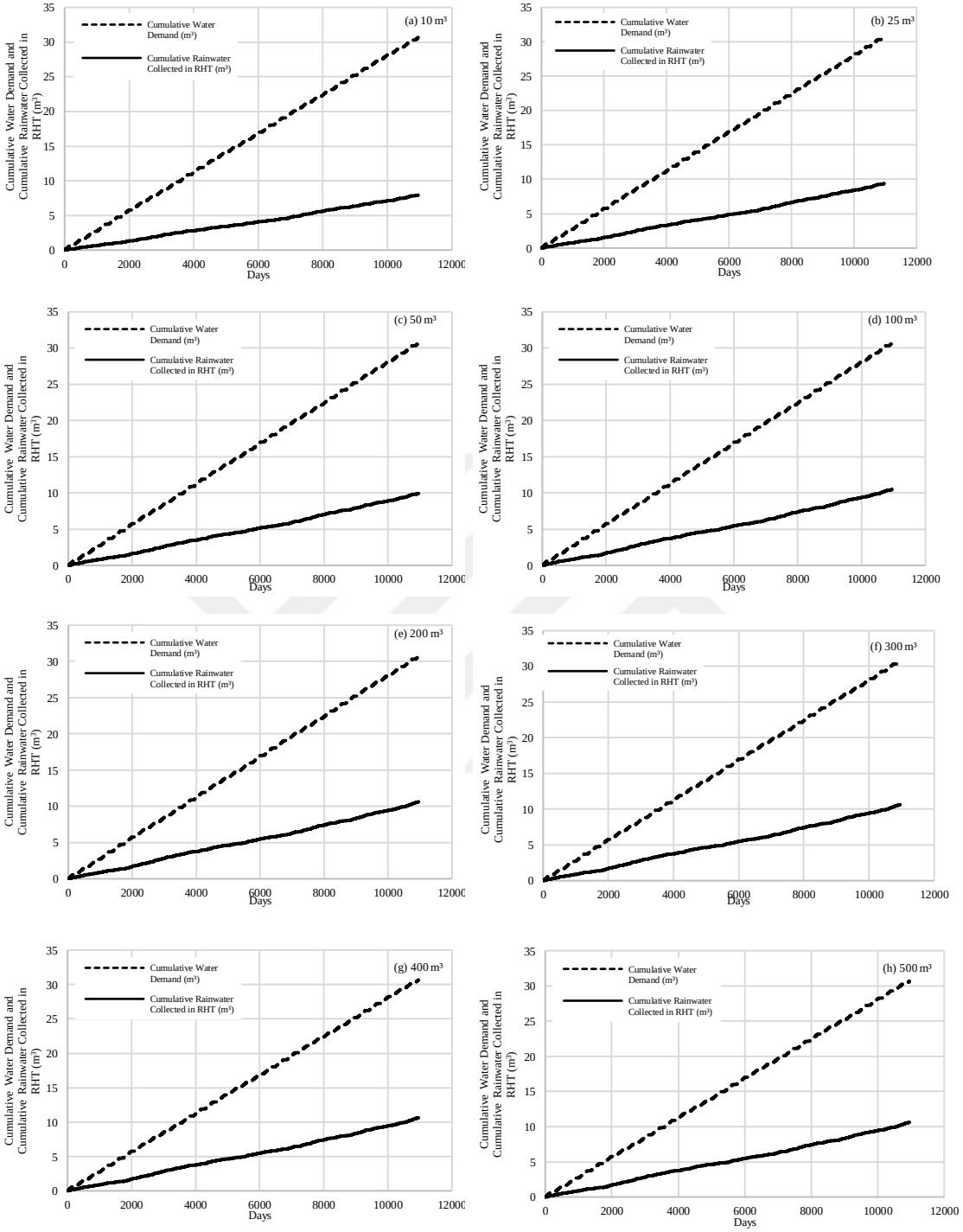


Figure A36 WBM Results for BG_36 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

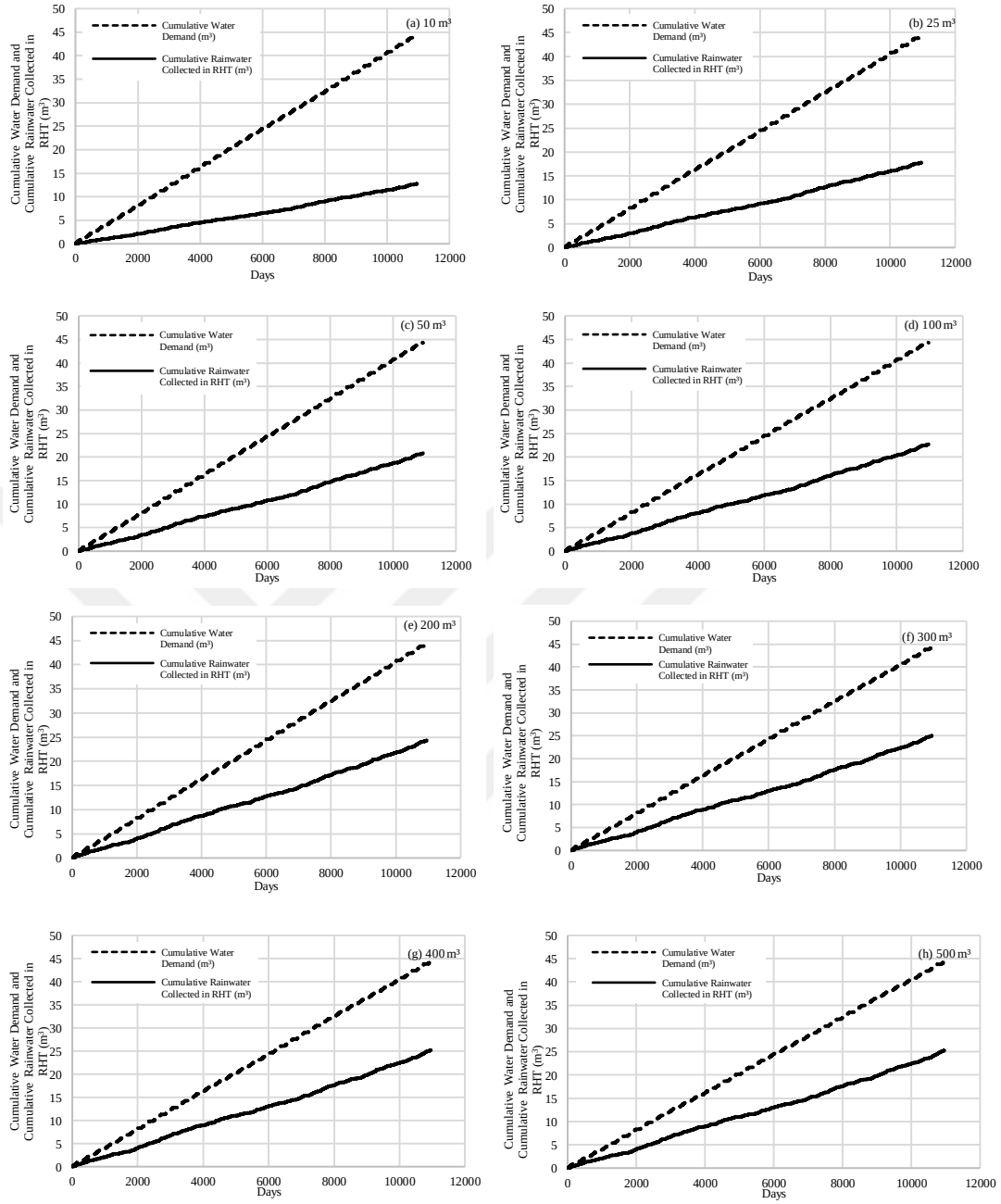


Figure A37 WBM Results for BG_37 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

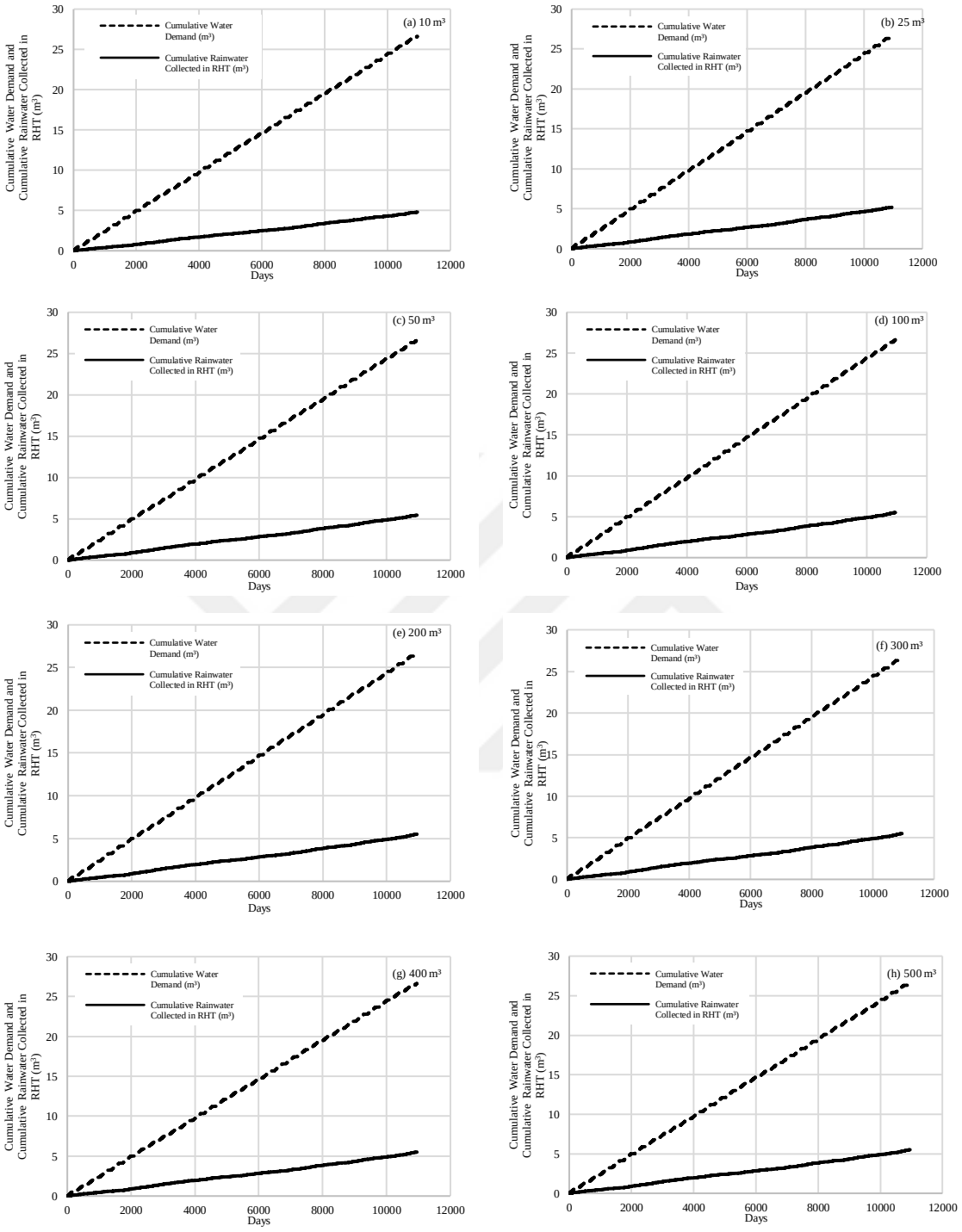


Figure A38 WBM Results for BG_38 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

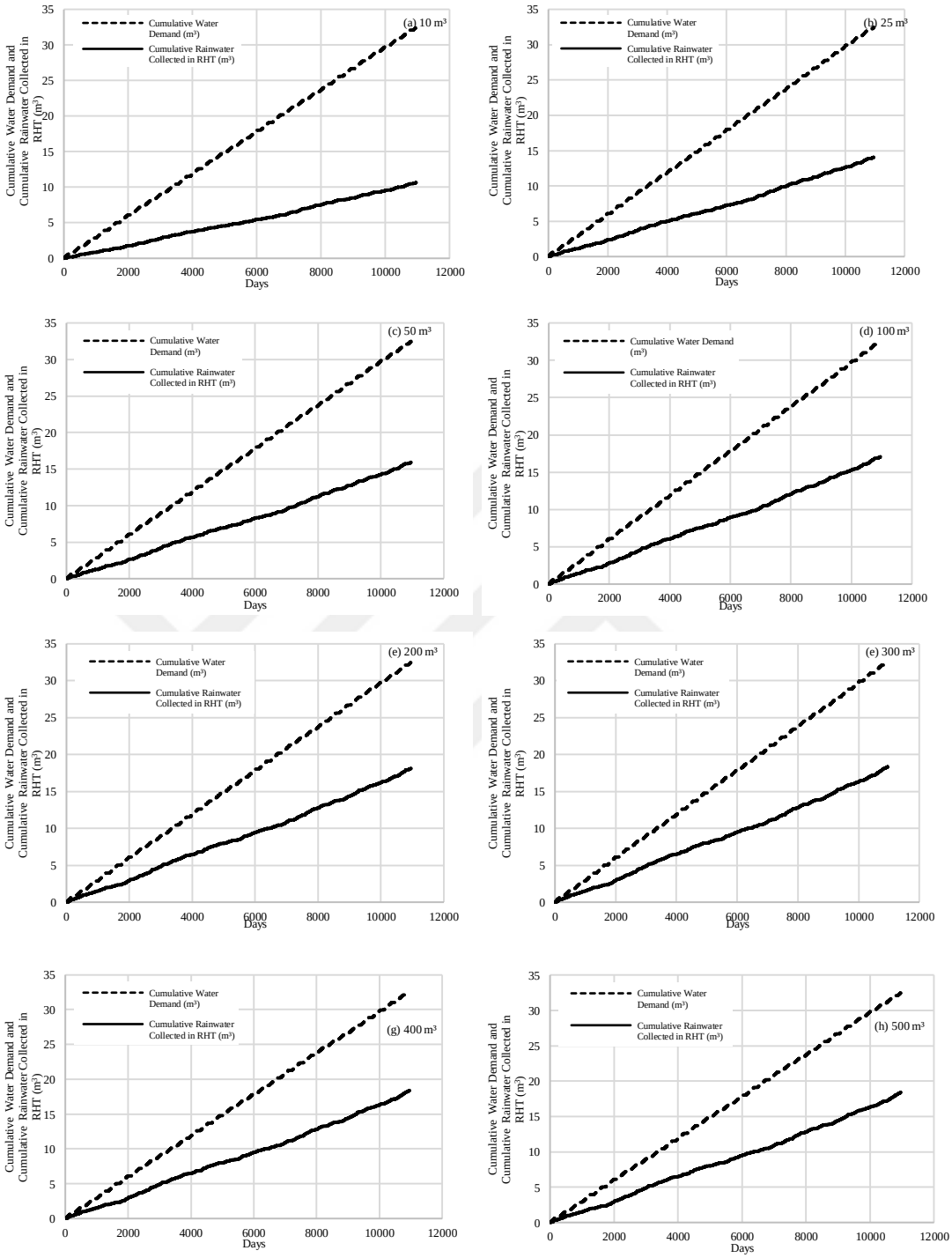


Figure A39 WBM Results for BG_39 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

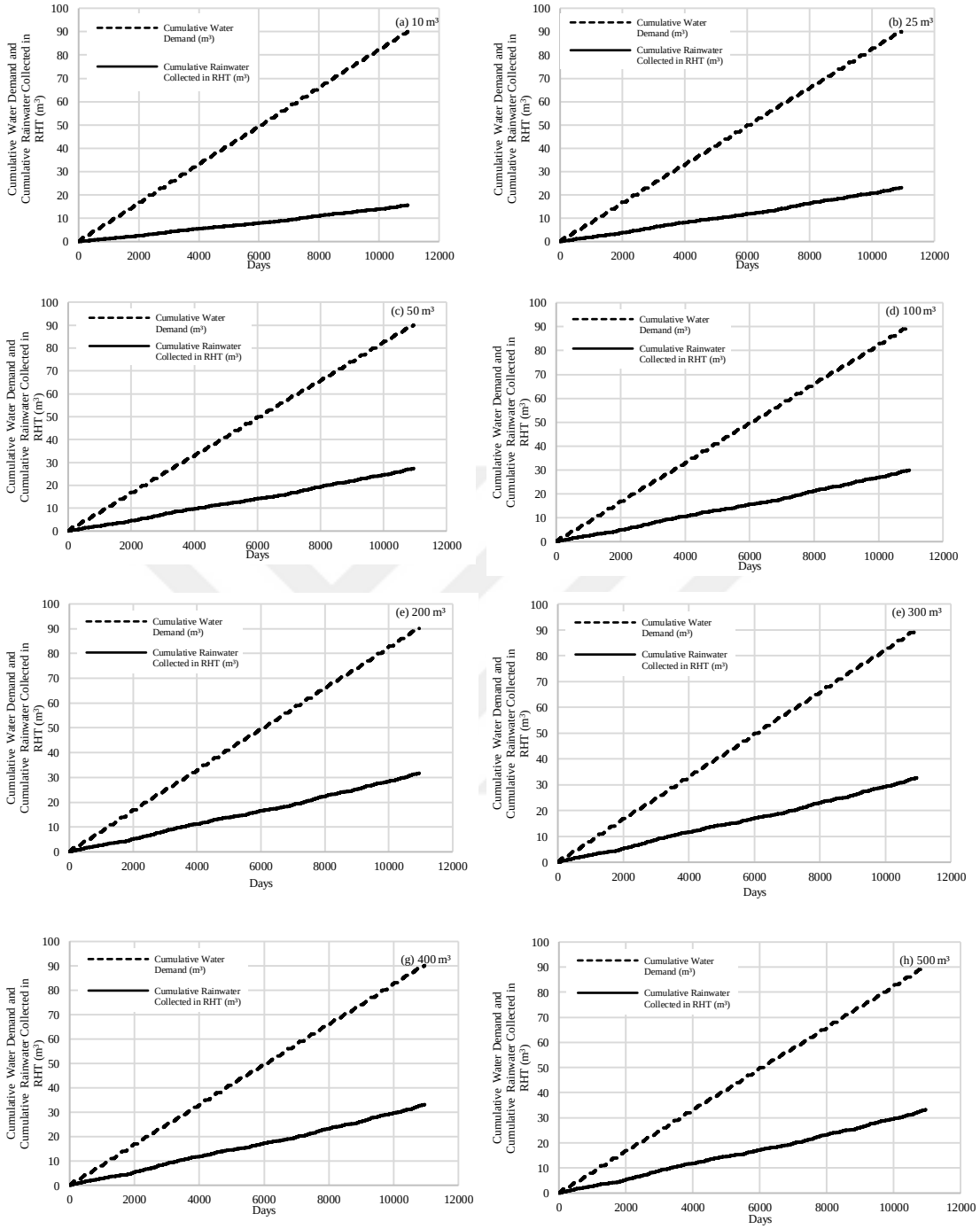


Figure A40 WBM Results for BG_40 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

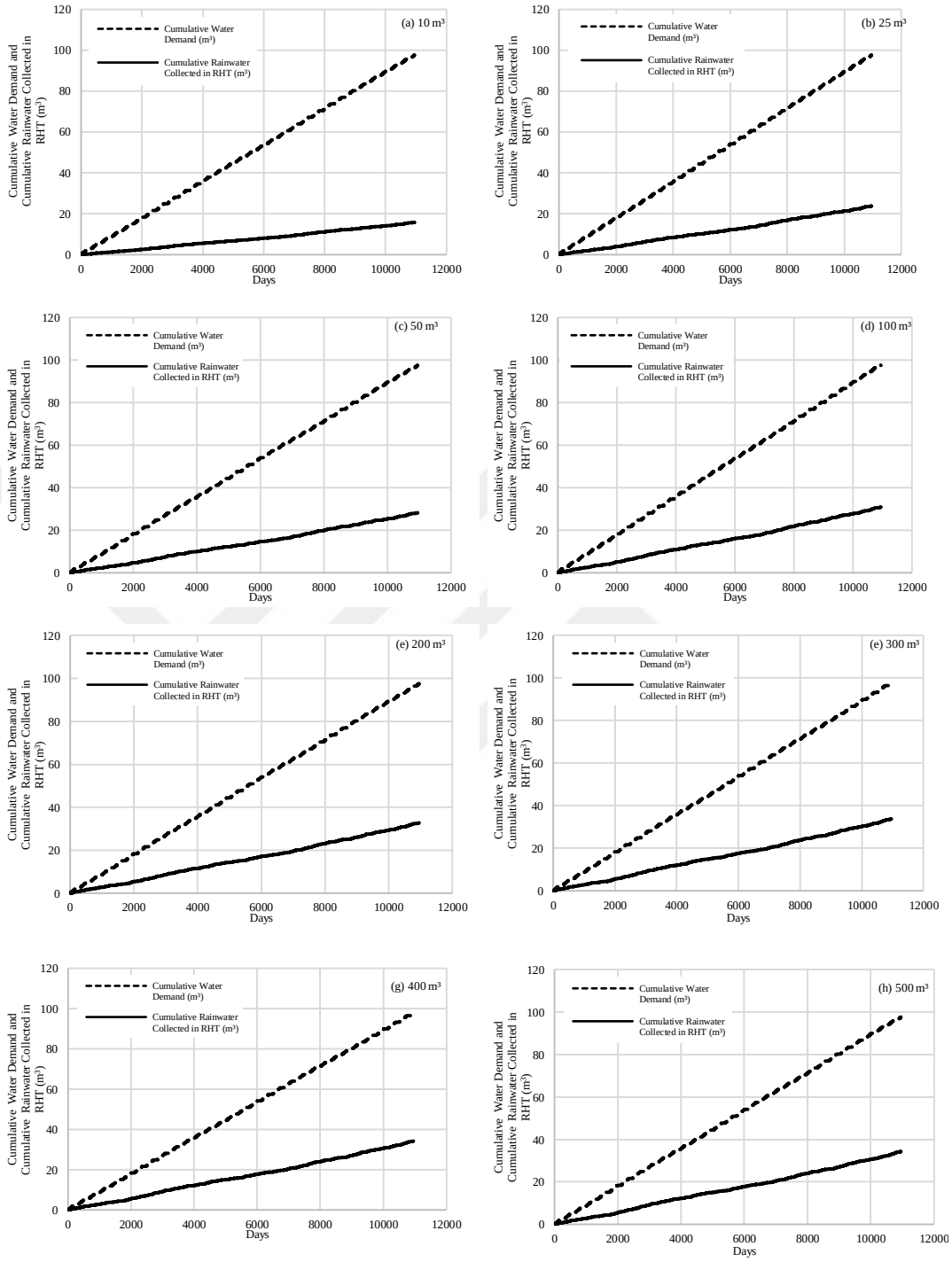


Figure A41 WBM Results for BG_41 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

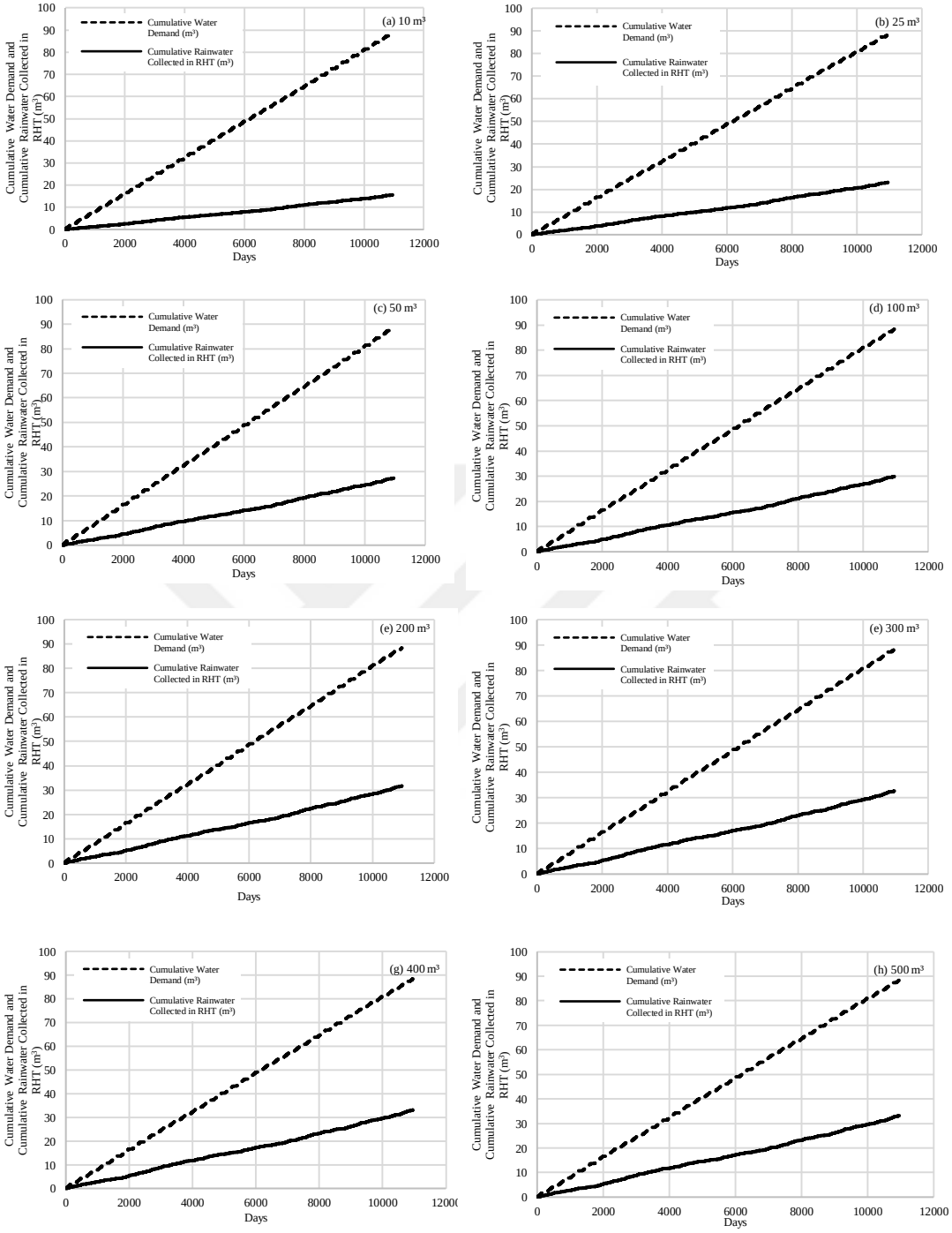


Figure A42 WBM Results for BG_42 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

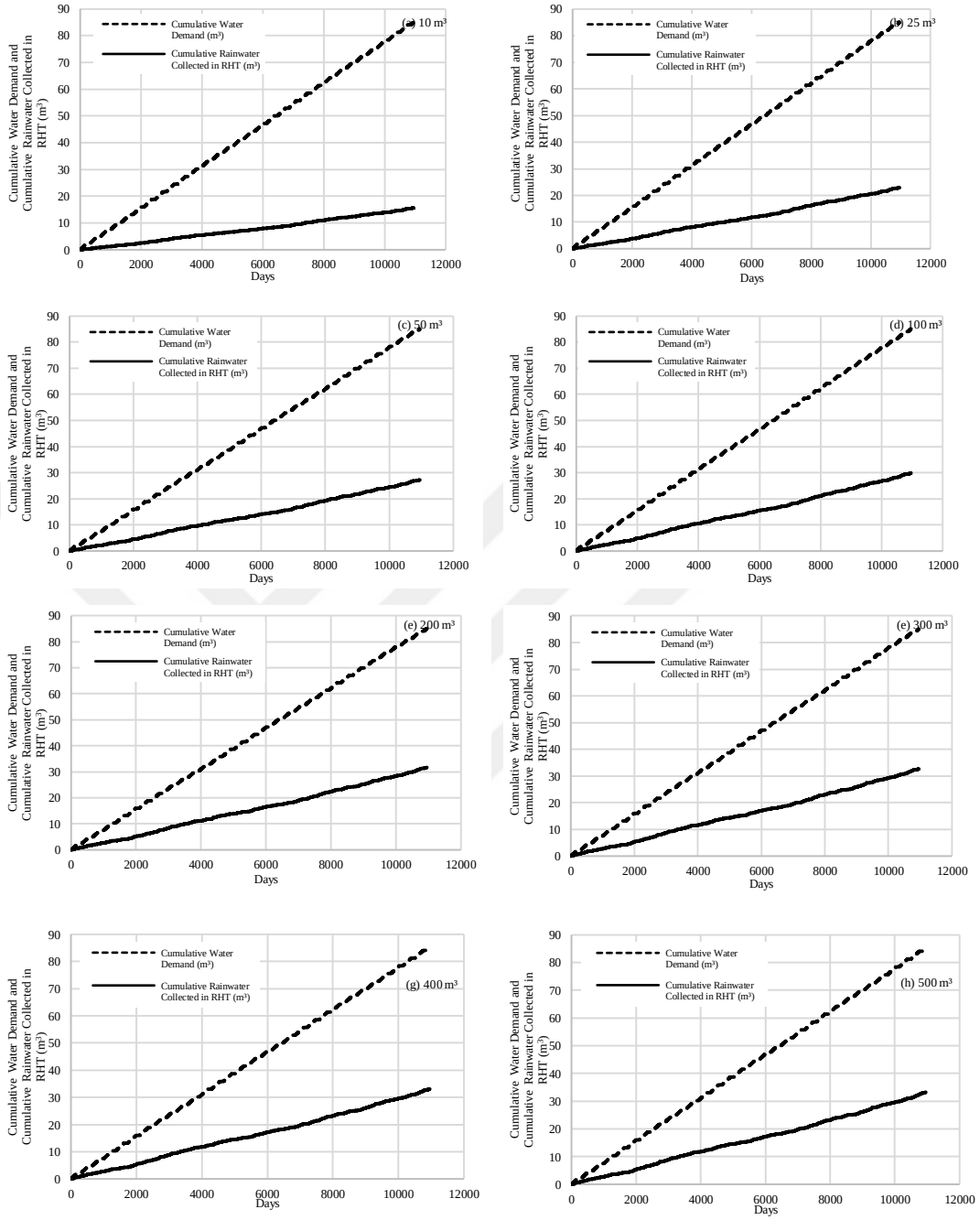


Figure A43 WBM Results for BG_43 with RHT sizes (a) 10 m³, (b) 25 m³, (c) 50 m³, (d) 100 m³, (e) 200 m³, (f) 300 m³, (g) 400 m³, (h) 500 m³

APPENDIX B: PIs and Net Benefits for all 43 BGs

Table B1 PIs and Net Benefits for BG_01 (Department of Basic English – Block A, Department of Basic English – Block B, Department of Basic English – Administration Building)

	BG_01							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	9.70	12.60	13.28	13.76	13.76	13.76	13.76	13.76
Water Saving Efficiency (%)	10.32	12.07	12.39	12.50	12.50	12.50	12.50	12.50
Stormwater Capture Efficiency (%)	57.30	70.27	72.63	73.30	73.30	73.30	73.30	73.30
Overflow Ratio (%)	6.43	1.02	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	-6779.88	-9597.66	-18825.58	-38034.40	-77034.40	-116034.40	--155034.40	-194034.40

Table B2 PIs and Net Benefits for BG_02 (Department of Basic English – Block D&E, Department of Basic English – Block C)

	BG_02							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	13.02	19.09	20.75	21.53	21.56	21.56	21.56	21.56
Water Saving Efficiency (%)	14.21	17.70	18.72	19.00	19.07	19.07	19.07	19.07
Stormwater Capture Efficiency (%)	50.99	67.47	72.34	73.56	73.93	73.93	73.93	73.93
Overflow Ratio (%)	11.28	1.35	0.36	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	949.57	45.50	-8315.25	-27381.21	-66269.59	-105269.59	-144269.59	-183269.59

Table B3 PIs and Net Benefits for BG_03 (Department of Basic English – Block F, Department of Basic English – Block G)

BG_03								
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	11.32	15.52	16.66	17.32	17.32	17.32	17.32	17.32
Water Saving Efficiency (%)	12.25	14.78	15.36	15.55	15.55	15.55	15.55	15.55
Stormwater Capture Efficiency (%)	54.37	69.26	72.80	73.80	73.80	73.80	73.80	73.80
Overflow Ratio (%)	8.50	1.09	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	5785.53	4370.69	-4406.19	-23474.13	-62463.06	-101463.06	-140463.06	-179463.06

Table B4 PIs and Net Benefits for BG_04 (Gradutate School of Natural and Applied Science New Building, Gradutate School of Natural and Applied Science Administrative Building, Gradutate School of Natural and Applied Science Old Building)

BG_04								
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	10.54	14.97	23.25	27.36	29.16	29.34	29.44	29.50
Water Saving Efficiency (%)	10.54	17.48	22.03	24.71	25.89	26.12	26.26	26.32
Stormwater Capture Efficiency (%)	23.38	44.49	59.56	68.48	72.55	72.55	73.91	74.11
Overflow Ratio (%)	51.49	17.75	3.30	1.02	0.00	0.00	0.00	0.00
Net Benefit (TL)	16251.45	33591.13	38977.63	28333.90	-6954.07	-45087.19	-83483.77	-122465.36

Table B5 PIs and Net Benefits for BG_05 (Department of Business Administration)

	BG_05							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	40.93	61.47	75.24	87.07	95.60	98.31	99.42	99.69
Water Saving Efficiency (%)	37.81	57.27	72.47	85.81	94.97	97.92	99.22	99.53
Stormwater Capture Efficiency (%)	15.06	25.82	34.30	42.09	47.49	47.49	50.20	50.52
Overflow Ratio (%)	62.27	29.19	8.38	1.58	0.39	0.00	0.00	0.00
Net Benefit (TL)	21730.13	35996.22	41853.64	36717.77	8863.29	-26715.44	-64181.26	-102988.38

Table B6 PIs and Net Benefits for BG_06 (Economics)

	BG_06							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	12.77	21.05	24.93	27.17	27.60	27.67	27.67	27.67
Water Saving Efficiency (%)	13.61	19.90	22.75	24.03	24.43	24.55	24.55	24.55
Stormwater Capture Efficiency (%)	35.12	57.14	67.38	72.17	73.65	73.65	74.12	74.12
Overflow Ratio (%)	30.84	4.86	1.11	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	16990.00	25913.93	22945.55	6310.56	-31605.29	-70452.84	-109452.74	-148452.74

Table B7 PIs and Net Benefits for BG_07 (Department of Architecture, Department of Architecture -2)

BG_07								
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	16.58	34.45	45.68	57.08	63.74	66.51	68.03	69.40
Water Saving Efficiency (%)	18.39	32.08	42.97	53.06	60.78	63.98	65.78	67.02
Stormwater Capture Efficiency (%)	14.73	28.97	41.89	54.20	63.52	63.52	69.80	71.33
Overflow Ratio (%)	66.62	35.46	12.07	2.14	0.44	0.00	0.00	0.00
Net Benefit (TL)	25215.65	51498.63	67308.26	71997.52	50378.57	18367.01	-16756.84	-53227.87

Table B8 PIs and Net Benefits for BG_08 (Social Science Building, Maths)

BG_08								
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	9.55	13.19	18.15	19.81	20.58	20.62	20.62	20.62
Water Saving Efficiency (%)	10.05	14.95	17.16	18.10	18.36	18.42	18.42	18.42
Stormwater Capture Efficiency (%)	33.90	57.00	67.81	72.47	73.62	73.62	73.93	73.93
Overflow Ratio (%)	33.87	6.32	1.34	0.35	0.00	0.00	0.00	0.00
Net Benefit (TL)	11130.48	19250.10	15889.93	-1038.78	-39188.85	-78010.53	-117010.53	-156010.53

Table B9 PIs and Net Benefits for BG_09 (Physics Lecture Hall Building, Physics Building – 1, Physics Building – 2, Modern Language)

	BG_09							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	36.80	55.59	69.23	80.59	89.70	93.08	94.50	95.92
Water Saving Efficiency (%)	34.10	51.92	66.12	78.92	88.88	92.64	94.39	95.53
Stormwater Capture Efficiency (%)	17.22	29.68	39.79	49.12	56.53	56.53	60.88	61.91
Overflow Ratio (%)	58.41	25.29	6.22	1.34	0.35	0.00	0.00	0.00
Net Benefit (TL)	8377.97	18734.25	21919.02	14256.52	-15011.61	-49648.88	-86589.72	-124409.38

Table B10 PIs and Net Benefits for BG_10 (Biology)

	BG_10							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	42.28	58.15	66.40	72.33	76.16	77.43	77.43	77.43
Water Saving Efficiency (%)	39.73	54.54	63.77	70.26	74.42	75.61	75.61	75.61
Stormwater Capture Efficiency (%)	34.14	50.42	60.56	67.90	72.89	72.89	74.97	75.02
Overflow Ratio (%)	23.77	3.00	0.99	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	8182.25	11771.56	7661.45	-8142.61	-44854.66	-83219.59	-122219.59	-161219.59

Table B11 PIs and Net Benefits for BG_11 (Chemistry, Statistics)

	BG_11							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	39.32	59.09	72.20	83.42	92.05	94.59	96.31	97.17
Water Saving Efficiency (%)	36.69	55.29	69.46	82.17	91.28	94.45	96.02	97.12
Stormwater Capture Efficiency (%)	18.10	30.71	40.31	49.38	55.87	55.87	59.52	60.52
Overflow Ratio (%)	55.31	21.32	4.43	1.10	0.00	0.00	0.00	0.00
Net Benefit (TL)	9887.14	19548.34	21614.31	13003.77	-17381.09	-52981.01	-90312.39	-128277.88

Table B12 PIs and Net Benefits for BG_12 (Industrial Engineering)

	BG_12							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	36.09	52.54	62.96	69.72	74.79	76.38	77.31	77.47
Water Saving Efficiency (%)	34.17	49.34	59.76	67.45	72.78	74.73	75.61	75.65
Stormwater Capture Efficiency (%)	28.16	44.76	56.24	64.72	70.74	70.74	74.43	74.79
Overflow Ratio (%)	36.11	7.33	1.55	0.38	0.00	0.00	0.00	0.00
Net Benefit (TL)	13546.22	21014.34	20392.95	7280.10	-27544.81	-65166.58	-103480.45	-142475.48

Table B13 PIs and Net Benefits for BG_13 (Computer Engineering Building -1, Computer Engineering Building -2, Computer Engineering Building -3)

	BG_13							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	30.97	45.14	52.64	56.68	58.79	59.53	59.54	59.54
Water Saving Efficiency (%)	29.31	41.64	49.01	53.60	56.32	57.25	57.25	57.25
Stormwater Capture Efficiency (%)	32.53	50.48	61.52	68.18	72.49	72.49	74.28	74.46
Overflow Ratio (%)	30.63	4.76	1.11	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	3061.17	7596.38	3865.23	-11944.28	-48912.27	-87274.34	-126260.85	-165260.85

Table B14 PIs and Net Benefits for BG_14 (Civil Engineering Building K-1&K-7, Civil Engineering Building K-2, Civil Engineering Building K-3, Civil Engineering Building K-4, Civil Engineering Building K-5)

	BG_14							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	20.49	43.93	61.61	75.52	87.35	93.05	95.83	97.52
Water Saving Efficiency (%)	24.87	42.50	57.66	72.82	86.13	92.22	95.15	96.99
Stormwater Capture Efficiency (%)	9.04	17.57	26.00	34.44	42.22	42.22	47.54	48.64
Overflow Ratio (%)	78.76	54.62	28.72	8.01	1.57	0.96	0.39	0.00
Net Benefit (TL)	-5578.80	18559.41	35056.91	41601.78	26635.73	-237.56	-32932.13	-68357.39

Table B15 PIs and Net Benefits for BG_15 (Electrical and Electronics Engineering – 1, Electrical and Electronics Engineering – 2, Lab of Electrical Engineering, AYASLI Research Center, METU Center Lab)

	BG_15							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	19.82	41.42	57.61	70.05	80.60	85.62	88.40	89.97
Water Saving Efficiency (%)	23.76	40.01	53.80	67.12	78.83	84.61	87.59	89.51
Stormwater Capture Efficiency (%)	12.36	23.62	34.40	44.80	54.29	54.29	61.33	63.07
Overflow Ratio (%)	71.28	41.99	17.00	3.04	1.01	0.37	0.00	0.00
Net Benefit (TL)	17186.76	39107.36	53052.45	56793.62	38406.33	9006.43	-23983.02	-58812.30

Table B16 PIs and Net Benefits for BG_16 (Mechanical Engineering Block – A, Mechanical Engineering Block – B, Mechanical Engineering Block – C, Mechanical Engineering Block – D, Mechanical Engineering Block – E, Mechanical Engineering Block – F)

	BG_16							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	17.00	36.04	49.55	63.08	73.63	79.29	82.62	85.15
Water Saving Efficiency (%)	18.48	33.71	46.31	59.69	71.82	77.80	81.63	84.11
Stormwater Capture Efficiency (%)	10.02	20.53	30.94	42.25	52.53	52.53	61.07	63.25
Overflow Ratio (%)	76.81	51.54	25.66	6.44	1.34	0.44	0.36	0.00
Net Benefit (TL)	-618.62	27671.10	46449.76	57420.74	46381.34	21100.34	-10083.55	-43633.14

Table B17 PIs and Net Benefits for BG_17 (Turkish Language – 1)

BG_17								
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	35.18	50.67	60.10	65.73	69.55	70.80	71.02	71.02
Water Saving Efficiency (%)	33.11	47.34	56.55	63.07	67.21	68.69	68.99	68.99
Stormwater Capture Efficiency (%)	30.23	47.41	58.68	66.53	71.76	71.76	74.53	74.88
Overflow Ratio (%)	33.30	5.91	1.33	0.35	0.00	0.00	0.00	0.00
Net Benefit (TL)	13698.75	20839.07	19264.79	5352.85	-30343.58	-68205.32	-106951.36	-145951.36

Table B18 PIs and Net Benefits for BG_18 (Chemical Engineering – 1, Chemical Engineering – 2, Chemical Engineering – 3, Chemical Engineering – 4)

BG_18								
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	37.47	57.10	69.81	80.35	88.68	91.49	92.82	94.11
Water Saving Efficiency (%)	35.22	53.02	66.55	78.54	87.73	91.23	92.90	94.16
Stormwater Capture Efficiency (%)	19.55	33.07	43.49	52.95	60.20	60.20	64.68	65.88
Overflow Ratio (%)	53.22	18.90	3.59	1.05	0.00	0.00	0.00	0.00
Net Benefit (TL)	3992.23	13890.96	16237.71	7569.97	-22999.69	-58021.77	-95358.44	-133196.46

Table B19 PIs and Net Benefits for BG_19 (Environmental Engineering)

	BG_19							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	42.98	59.63	69.41	76.91	82.15	84.24	85.06	85.32
Water Saving Efficiency (%)	39.84	56.06	67.07	75.50	81.12	83.30	84.34	84.66
Stormwater Capture Efficiency (%)	29.80	45.48	56.13	64.56	70.35	70.35	74.21	74.85
Overflow Ratio (%)	30.84	4.86	1.11	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	11110.25	16610.20	14630.16	659.13	-34587.76	-71942.53	-110338.29	-149310.46

Table B20 PIs and Net Benefits for BG_20 (Metallurgy and Material Engineering – 1, Metallurgy and Material Engineering – 2)

	BG_20							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	48.17	71.37	84.79	95.05	99.66	99.93	99.93	99.93
Water Saving Efficiency (%)	46.17	67.92	83.05	94.56	99.45	99.82	99.82	99.82
Stormwater Capture Efficiency (%)	13.47	22.02	28.16	32.93	35.10	35.10	35.52	35.67
Overflow Ratio (%)	63.30	30.63	8.93	1.61	0.40	0.00	0.00	0.00
Net Benefit (TL)	8453.84	15980.15	15573.21	3608.76	-31989.39	-70715.05	-109715.05	-148715.05

Table B21 PIs and Net Benefits for BG_21 (Geological Engineering)

	BG_21							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	38.16	50.89	56.13	59.08	60.57	60.58	60.58	60.58
Water Saving Efficiency (%)	35.41	46.94	52.88	56.33	58.23	58.25	58.25	58.25
Stormwater Capture Efficiency (%)	40.41	57.16	65.83	71.02	73.90	73.90	74.48	74.48
Overflow Ratio (%)	16.50	1.95	0.42	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	6835.04	8645.82	2641.40	-14711.73	-52679.08	-91656.99	-130656.99	-169656.99

Table B22 PIs and Net Benefits for BG_22 (Mining Engineering)

	BG_22							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	52.37	71.02	82.87	92.25	96.88	98.92	99.36	99.64
Water Saving Efficiency (%)	48.24	67.96	81.24	91.60	96.71	98.58	99.14	99.46
Stormwater Capture Efficiency (%)	23.86	36.39	45.01	51.96	55.55	55.55	57.76	58.29
Overflow Ratio (%)	38.04	8.38	1.58	0.39	0.00	0.00	0.00	0.00
Net Benefit (TL)	10885.46	16163.79	14074.97	1278.29	-34131.93	-71891.43	-110618.77	-149504.60

Table B23 PIs and Net Benefits for BG_23 (Petroleum Engineering)

	BG_23							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	50.68	68.63	79.80	88.80	93.59	95.83	96.79	97.48
Water Saving Efficiency (%)	46.82	65.46	78.05	87.86	93.52	95.69	96.82	97.48
Stormwater Capture Efficiency (%)	27.12	40.89	50.36	57.94	62.59	62.59	65.80	66.67
Overflow Ratio (%)	32.24	5.32	1.31	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	9829.30	14443.11	11854.33	-1901.62	-36799.04	-74477.15	-112898.14	-151675.17

Table B24 PIs and Net Benefits for BG_24 (Aerospace Engineering Building, Aerospace Engineering Building Lab – 1, Aerospace Engineering Building Lab – 2)

	BG_24							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	47.06	70.41	84.91	95.32	99.63	99.95	99.95	99.95
Water Saving Efficiency (%)	45.20	67.10	82.89	94.68	99.45	99.87	99.87	99.87
Stormwater Capture Efficiency (%)	11.17	18.60	24.13	28.36	30.15	30.15	30.53	30.64
Overflow Ratio (%)	69.00	38.99	14.30	2.37	0.95	0.00	0.00	0.00
Net Benefit (TL)	5183.66	15046.81	16697.76	6018.16	-29132.73	-67762.52	-106762.52	-145762.52

Table B25 PIs and Net Benefits for BG_25 (Food Engineering)

	BG_25							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	35.80	51.40	58.16	62.13	64.66	65.07	65.07	65.07
Water Saving Efficiency (%)	34.48	47.41	54.84	59.47	62.41	62.93	62.93	62.93
Stormwater Capture Efficiency (%)	35.56	52.88	62.84	69.14	73.12	73.12	74.58	74.58
Overflow Ratio (%)	23.77	3.00	0.99	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	11108.51	15650.92	11551.86	-4472.81	-41478.71	-80084.56	-119084.56	-158084.56

Table B26 PIs and Net Benefits for BG_26 (Dormitory – 1)

	BG_26							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	38.59	45.00	48.42	50.12	51.82	52.26	52.41	52.44
Water Saving Efficiency (%)	23.17	31.27	35.34	37.56	39.76	40.34	40.53	40.55
Stormwater Capture Efficiency (%)	35.42	51.94	60.85	65.67	70.59	70.59	72.23	72.27
Overflow Ratio (%)	22.49	2.63	0.97	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	9431.20	12762.02	7526.24	-9808.92	-46524.52	-84939.69	-123919.66	-162916.65

Table B27 PIs and Net Benefits for BG_27 (Dormitory – 2)

	BG_27							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	38.08	43.97	46.77	48.31	49.79	50.05	50.16	50.16
Water Saving Efficiency (%)	22.57	29.83	33.23	35.23	37.12	37.46	37.61	37.61
Stormwater Capture Efficiency (%)	37.68	53.86	61.89	66.56	71.17	71.17	72.25	72.25
Overflow Ratio (%)	19.06	2.17	0.44	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	8256.28	10458.96	4355.04	-13258.41	-50304.59	-88999.80	-127984.67	-166984.67

Table B28 PIs and Net Benefits for BG_28 (Dormitory – 3)

	BG_28							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	33.42	35.23	35.96	36.68	36.92	36.92	36.92	36.92
Water Saving Efficiency (%)	15.31	17.79	18.80	19.72	20.00	20.00	20.00	20.00
Stormwater Capture Efficiency (%)	51.53	62.57	67.36	71.59	72.90	72.90	72.90	72.90
Overflow Ratio (%)	5.30	0.99	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	-901.98	-4022.86	-12854.77	-31327.32	-70167.42	-109167.42	-148167.42	-187167.42

Table B29 PIs and Net Benefits for BG_29 (Dormitory – 4)

	BG_29							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	33.42	35.23	35.96	36.68	36.92	36.92	36.92	36.92
Water Saving Efficiency (%)	15.31	17.79	18.80	19.72	20.00	20.00	20.00	20.00
Stormwater Capture Efficiency (%)	51.53	62.57	67.36	71.59	72.90	72.90	72.90	72.90
Overflow Ratio (%)	5.30	0.99	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	1287.30	-1622.81	-10383.83	-28777.03	-67604.79	-106604.79	-145604.79	-184604.79

Table B30 PIs and Net Benefits for BG_30 (Dormitory – 5)

	BG_30							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	34.50	36.82	37.71	38.58	38.84	38.84	38.84	38.84
Water Saving Efficiency (%)	17.29	20.18	21.33	22.39	22.72	22.72	22.72	22.72
Stormwater Capture Efficiency (%)	51.19	62.32	67.09	71.30	72.69	72.69	72.69	72.69
Overflow Ratio (%)	5.29	0.99	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	-1053.39	-4145.54	-12975.15	-31451.52	-70276.26	-109276.26	-148276.26	-187276.26

Table B31 PIs and Net Benefits for BG_31 (Dormitory – 6)

	BG_31							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	34.19	36.37	37.17	37.89	38.08	38.08	38.08	38.08
Water Saving Efficiency (%)	16.77	19.30	20.39	21.33	21.57	21.57	21.57	21.57
Stormwater Capture Efficiency (%)	52.67	62.99	67.75	71.65	72.72	72.72	72.72	72.72
Overflow Ratio (%)	4.08	0.70	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	-1885.97	-5386.62	-14291.94	-32895.39	-71789.61	-110789.61	-149789.61	-188789.61

Table B32 PIs and Net Benefits for BG_32 (Dormitory – 7)

	BG_32							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	32.12	33.15	33.77	34.33	34.47	34.47	34.47	34.47
Water Saving Efficiency (%)	12.63	14.53	15.34	16.06	16.25	16.25	16.25	16.25
Stormwater Capture Efficiency (%)	52.64	63.30	68.10	72.33	73.41	73.41	73.41	73.41
Overflow Ratio (%)	4.87	0.97	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	-1097.62	-4416.95	-13289.95	-31831.98	-70707.12	-109707.12	-148707.12	-187707.12

Table B33 PIs and Net Benefits for BG_33 (Dormitory – 8)

	BG_33							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	36.85	41.16	44.12	45.60	47.05	47.42	47.53	47.57
Water Saving Efficiency (%)	19.53	26.51	29.89	31.73	33.53	34.00	34.15	34.20
Stormwater Capture Efficiency (%)	35.25	52.38	61.13	65.78	70.54	70.54	72.12	72.21
Overflow Ratio (%)	24.59	3.04	1.01	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	7698.53	10985.80	5581.06	-11849.52	-48634.74	-87045.62	-126027.02	-165021.16

Table B34 PIs and Net Benefits for BG_34 (Dormitory - 9)

	BG_34							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	37.89	43.67	46.43	48.05	49.62	49.99	50.14	50.16
Water Saving Efficiency (%)	21.67	29.20	32.86	34.88	36.86	37.35	37.52	37.55
Stormwater Capture Efficiency (%)	35.80	52.47	61.11	65.88	70.63	70.63	72.19	72.25
Overflow Ratio (%)	22.49	2.63	0.97	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	6722.79	9430.50	3726.04	-13803.03	-50716.89	-89209.73	-128191.13	-167188.61

Table B35 PIs and Net Benefits for BG_35 (Dormitory of Ebi - 2)

	BG_35							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	35.25	38.06	38.93	39.85	40.11	40.11	40.11	40.11
Water Saving Efficiency (%)	18.54	21.61	22.85	23.98	24.32	24.32	24.32	24.32
Stormwater Capture Efficiency (%)	51.30	62.36	67.09	71.25	72.60	72.60	72.60	72.60
Overflow Ratio (%)	4.87	0.97	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	971.55	-1986.38	-10764.62	-29190.67	-68016.16	-107016.16	-146016.16	-185016.16

Table B36 PIs and Net Benefits for BG_36 (Dormitory of Osman Yazici)

	BG_36							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	40.78	44.71	46.10	47.53	47.96	47.96	47.96	47.96
Water Saving Efficiency (%)	25.87	30.53	32.35	34.11	34.65	34.65	34.65	34.65
Stormwater Capture Efficiency (%)	49.87	61.69	66.33	70.91	72.21	72.21	72.21	72.21
Overflow Ratio (%)	4.43	0.95	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	1487.06	-1267.54	-9958.30	-28331.08	-67090.05	-106090.05	-145090.05	-184090.05

Table B37 PIs and Net Benefits for BG_37 (Dormitory of Ebi - 1)

	BG_37							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	41.80	52.34	57.61	61.05	63.80	65.01	65.17	65.17
Water Saving Efficiency (%)	28.81	40.15	46.92	51.22	54.80	56.34	56.52	56.52
Stormwater Capture Efficiency (%)	30.94	47.26	57.63	64.13	69.74	69.74	72.73	73.10
Overflow Ratio (%)	27.71	3.94	1.07	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	11916.12	17265.00	13981.08	-1438.23	-37325.82	-75189.43	-113931.26	-152931.26

Table B38 PIs and Net Benefits for BG_38 (Dormitory of Faik Hiziroglu)

	BG_38							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	35.39	36.58	37.31	37.53	37.53	37.53	37.53	37.53
Water Saving Efficiency (%)	18.05	19.50	20.44	20.72	20.72	20.72	20.72	20.72
Stormwater Capture Efficiency (%)	60.90	67.37	71.50	72.78	72.78	72.78	72.78	72.78
Overflow Ratio (%)	1.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	-5737.12	-10874.63	-20069.66	-39486.27	-78486.27	-117486.27	-156486.27	-195486.27

Table B39 PIs and Net Benefits for BG_39 (Dormitory of Guest House)

	BG_39							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	46.28	54.54	59.13	61.95	64.41	64.77	64.77	64.77
Water Saving Efficiency (%)	32.77	43.28	48.96	52.51	55.69	56.11	56.11	56.11
Stormwater Capture Efficiency (%)	36.72	52.52	61.23	66.81	71.73	71.73	73.09	73.09
Overflow Ratio (%)	17.00	1.97	0.42	0.00	0.00	0.00	0.00	0.00
Net Benefit (TL)	5800.18	7127.14	1196.11	-16151.93	-53271.43	-91983.68	-130983.68	-169983.68

Table B40 PIs and Net Benefits for BG_40 (Dormitory of Refika Aksoy)

	BG_40							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	29.32	41.11	44.63	46.72	48.32	49.19	49.52	49.61
Water Saving Efficiency (%)	17.36	25.69	30.39	33.20	35.20	36.29	36.71	36.85
Stormwater Capture Efficiency (%)	27.49	45.54	56.36	63.12	67.96	67.96	71.60	71.96
Overflow Ratio (%)	38.49	8.62	1.60	0.40	0.00	0.00	0.00	0.00
Net Benefit (TL)	16912.98	27007.26	26382.62	12070.06	-23563.39	-60557.56	-98812.34	-137646.54

Table B41 PIs and Net Benefits for BG_41 (Dormitory - 19)

	BG_41							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	29.32	39.13	43.32	45.56	47.06	47.93	48.26	48.37
Water Saving Efficiency (%)	16.23	24.39	28.95	31.68	33.55	34.61	35.03	35.17
Stormwater Capture Efficiency (%)	26.77	45.25	56.16	63.10	67.86	67.86	71.53	71.90
Overflow Ratio (%)	39.37	9.16	1.62	0.41	0.00	0.00	0.00	0.00
Net Benefit (TL)	17332.28	28348.90	28214.43	14169.77	-21412.92	-58268.29	-96470.50	-135253.86

Table B42 PIs and Net Benefits for BG_42 (Dormitory of Faika Demiray)

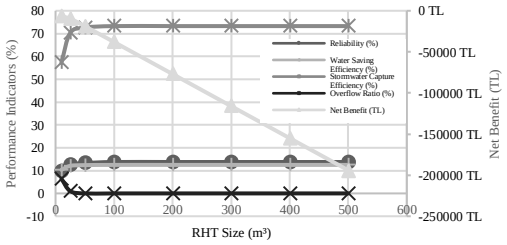
	BG_42							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	29.32	41.37	44.92	47.16	48.79	49.65	49.97	50.09
Water Saving Efficiency (%)	17.69	26.12	30.92	33.80	35.84	36.96	37.40	37.54
Stormwater Capture Efficiency (%)	27.49	45.42	56.27	63.05	67.91	67.91	71.60	71.97
Overflow Ratio (%)	38.49	8.62	1.60	0.40	0.00	0.00	0.00	0.00
Net Benefit (TL)	16912.98	26905.84	26301.68	12034.58	-23588.14	-60578.04	-98823.08	-137648.70

Table B43 PIs and Net Benefits for BG_43 (Dormitory of Isa Demiray)

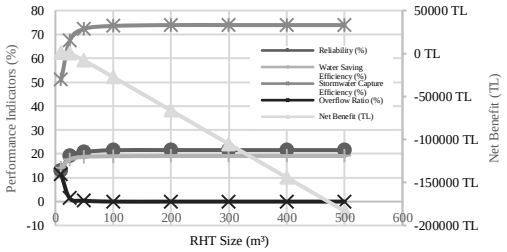
	BG_43							
RHT Size (m^3)	**10 m^3**	**25 m^3**	**50 m^3**	**100 m^3**	**200 m^3**	**300 m^3**	**400 m^3**	**500 m^3**
Reliability (%)	29.32	41.79	45.53	48.05	49.72	50.65	50.99	51.11
Water Saving Efficiency (%)	18.39	27.01	32.02	35.07	37.21	38.39	38.86	39.02
Stormwater Capture Efficiency (%)	27.49	45.15	56.06	62.93	67.79	67.79	71.61	71.92
Overflow Ratio (%)	38.49	8.62	1.60	0.40	0.00	0.00	0.00	0.00
Net Benefit (TL)	16912.98	26694.15	26121.75	11963.00	-23638.58	-60610.18	-98844.78	-137653.23

APPENDIX C: Graphs of PIs and Net Benefits for All 43 BGs

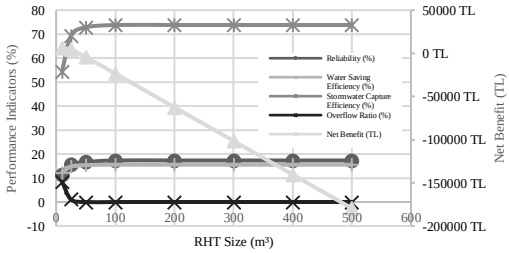
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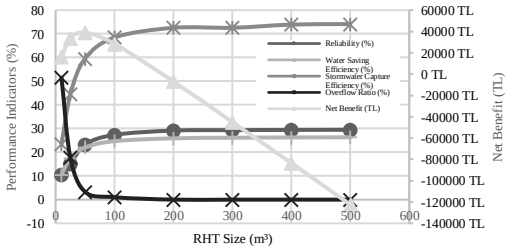
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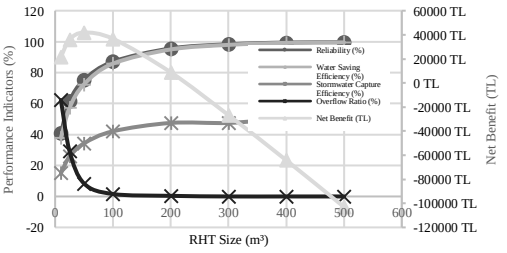
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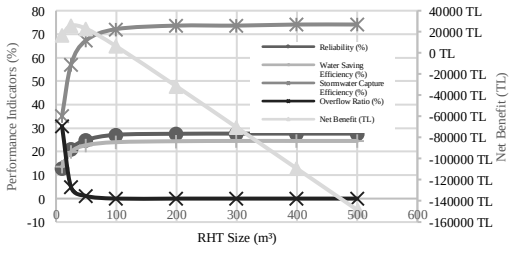
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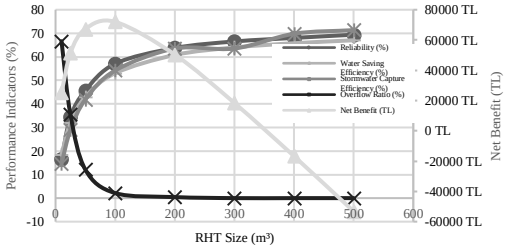
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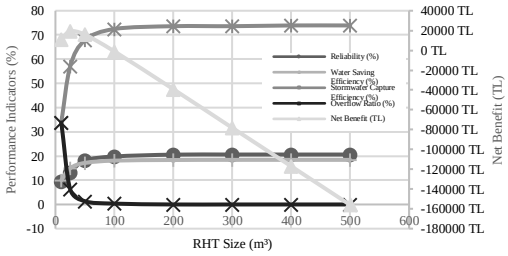
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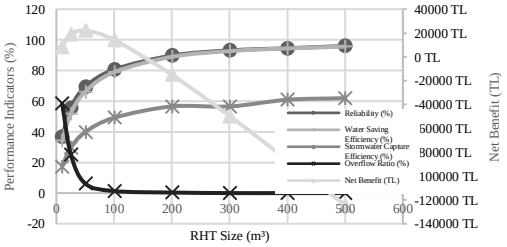
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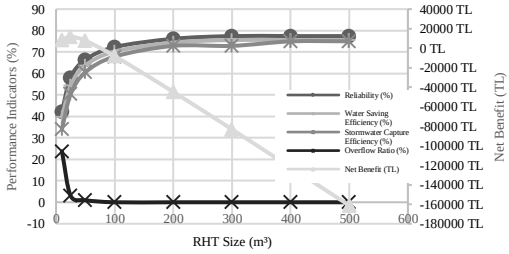
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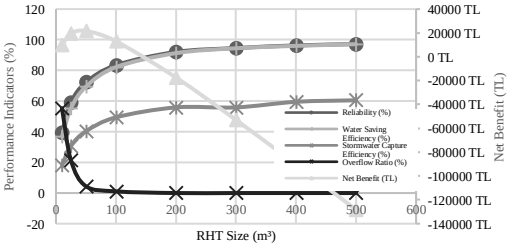
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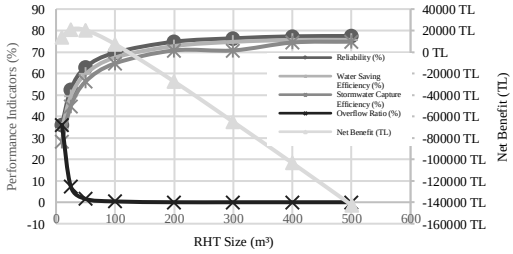
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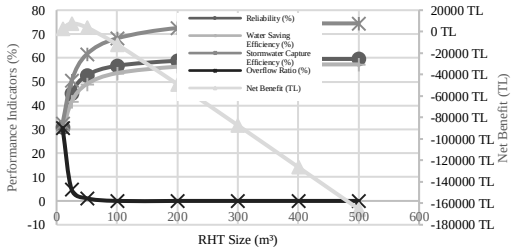
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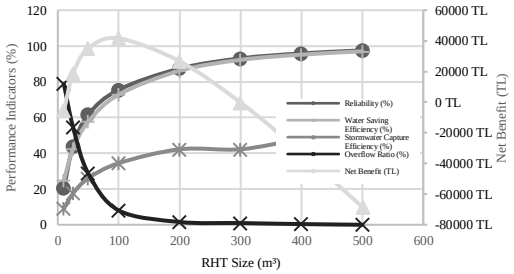
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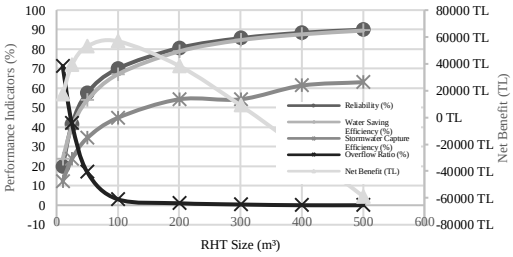
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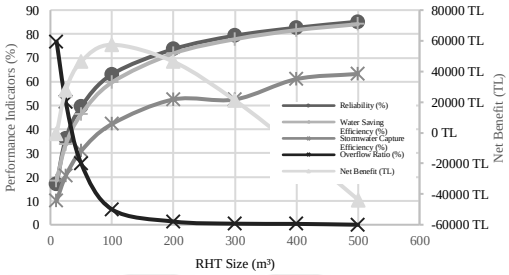
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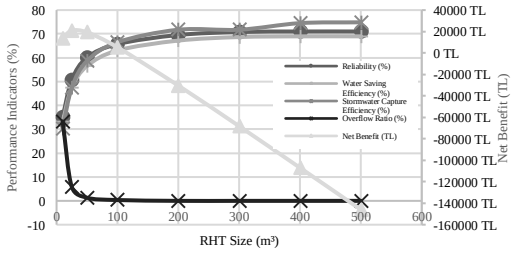
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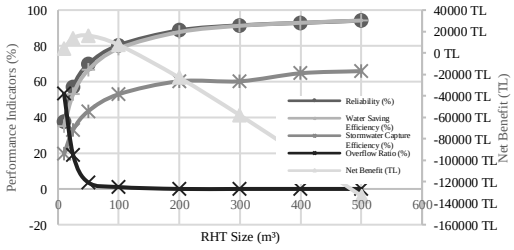
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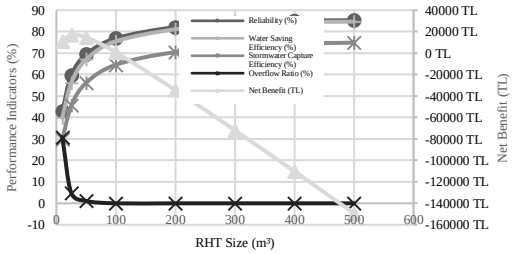
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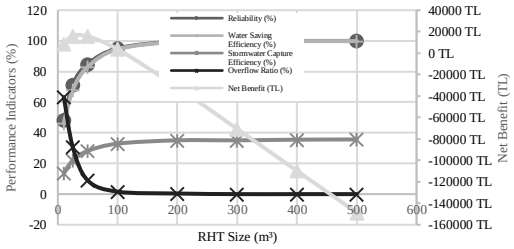
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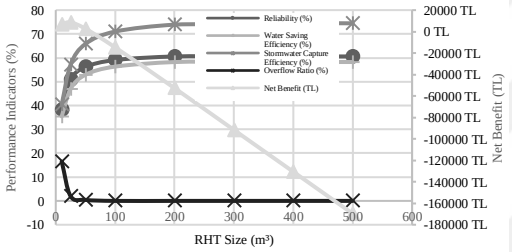
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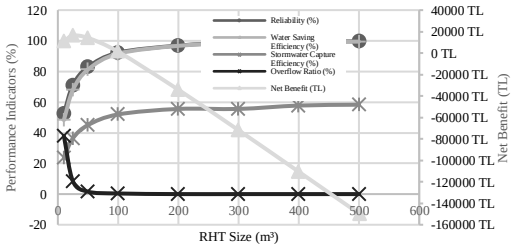
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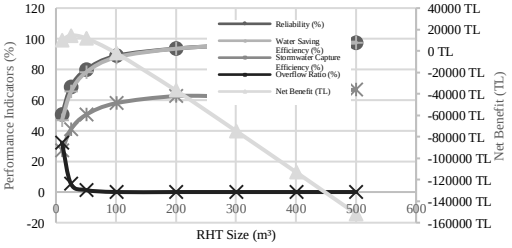
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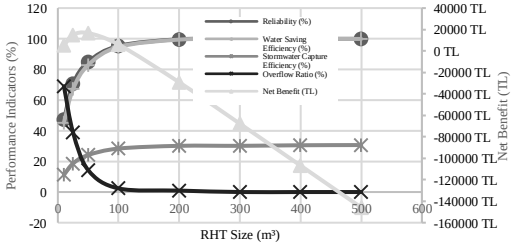
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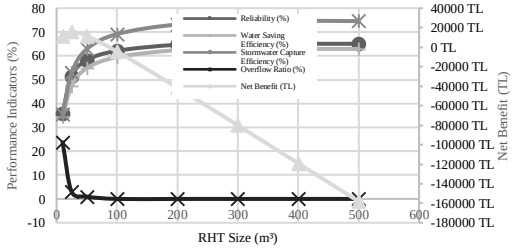
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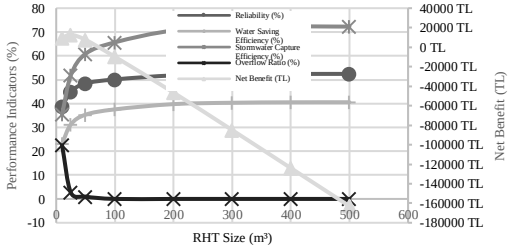
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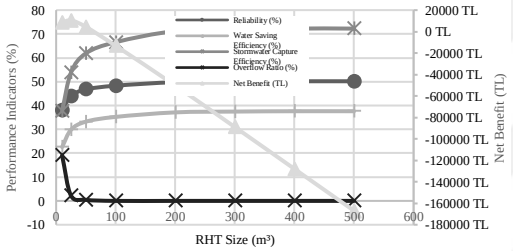
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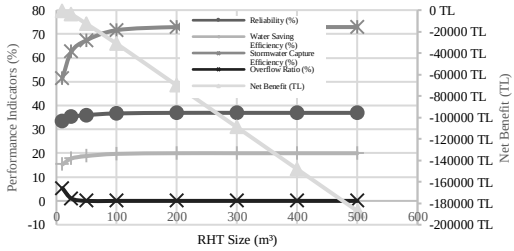
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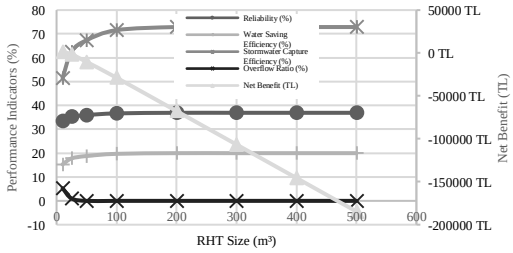
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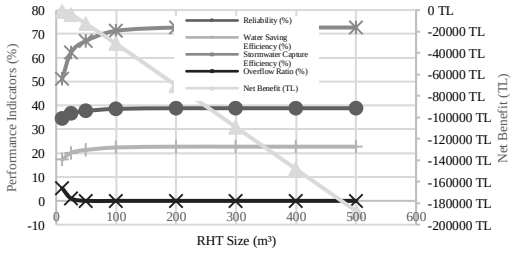
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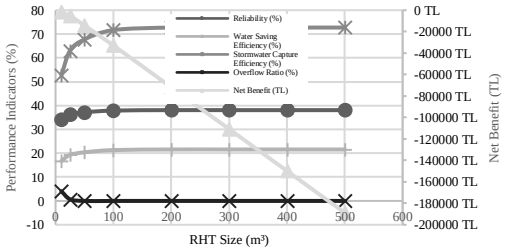
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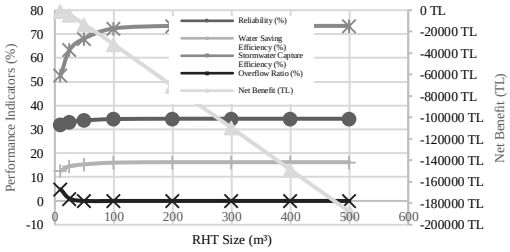
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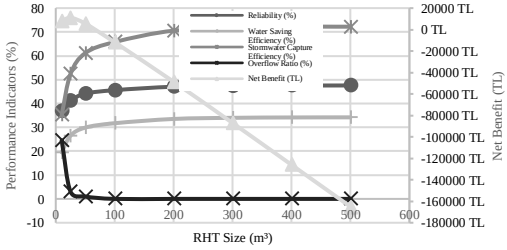
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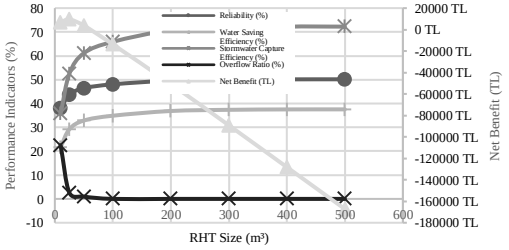
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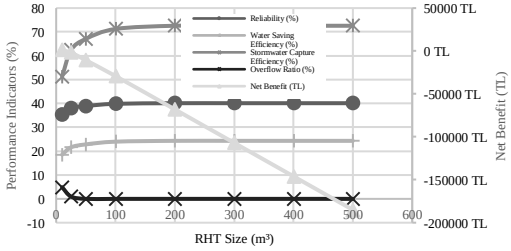
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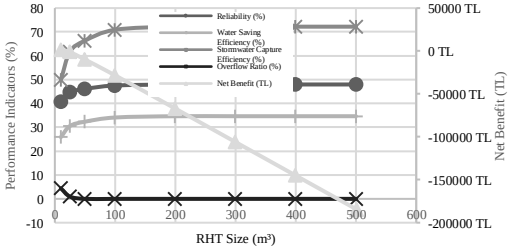
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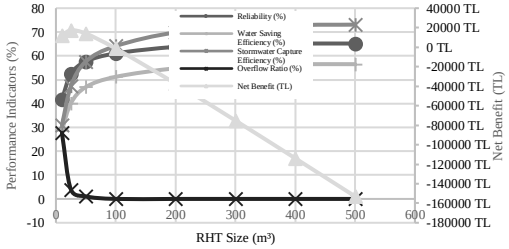
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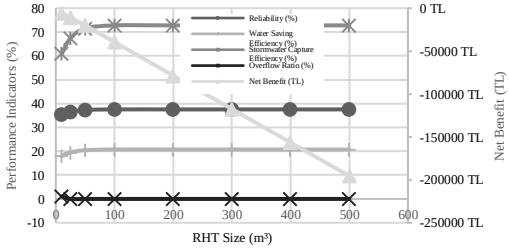
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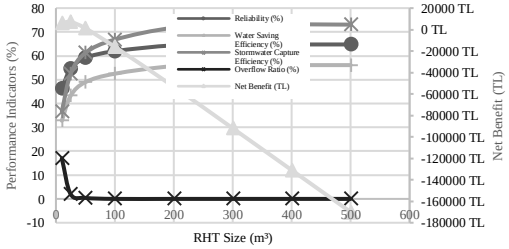
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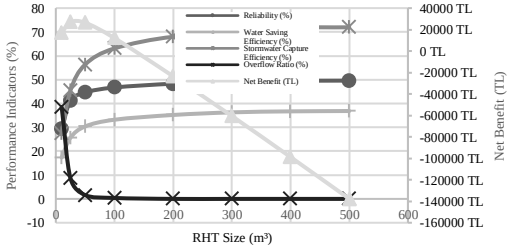
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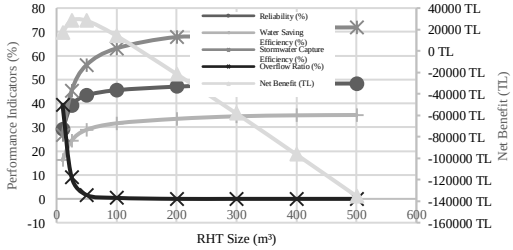
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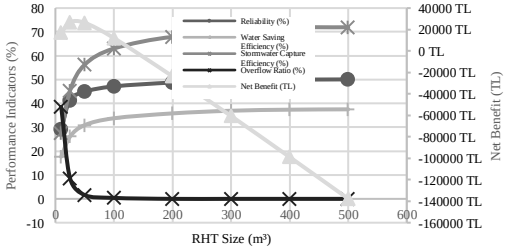
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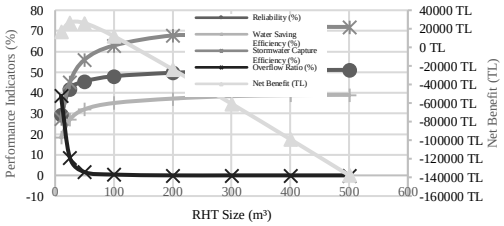
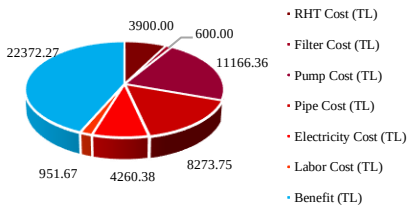


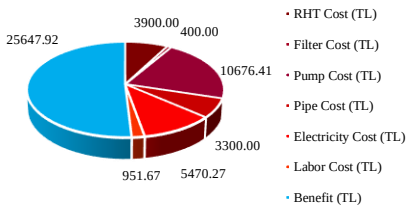
Figure C1 PIs and Net Benefits for all 43 BGs

APPENDIX D: Distribution of Costs and Benefits for all 43 BGs

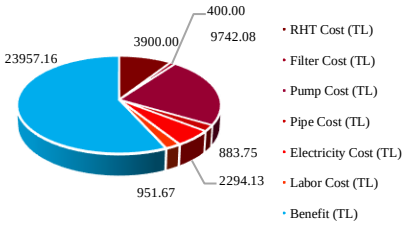
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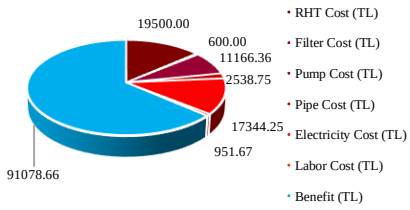
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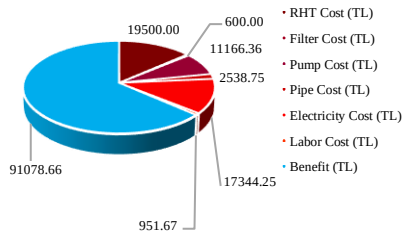
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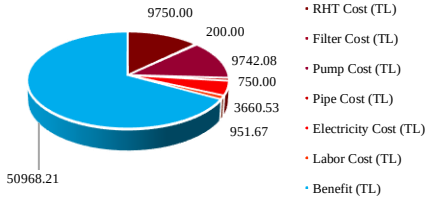
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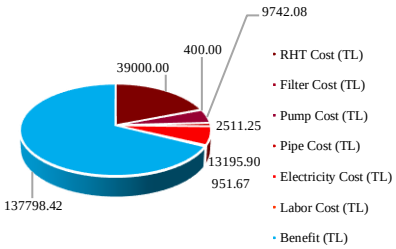
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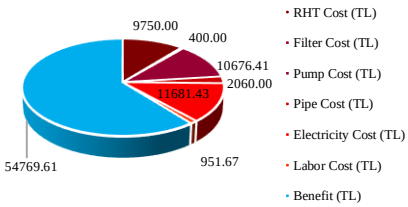
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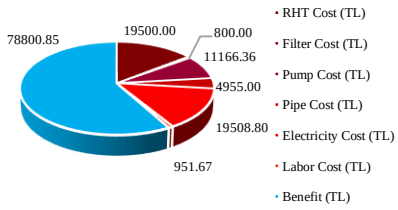
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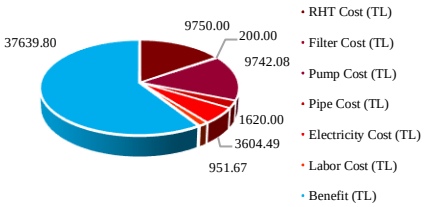
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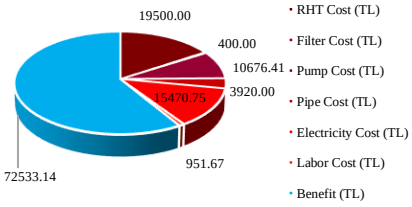
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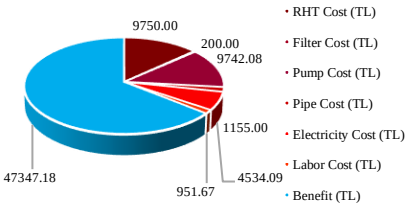
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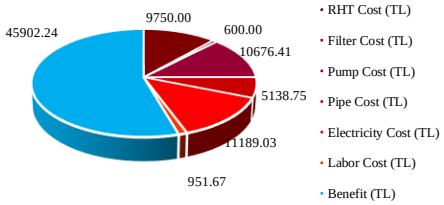
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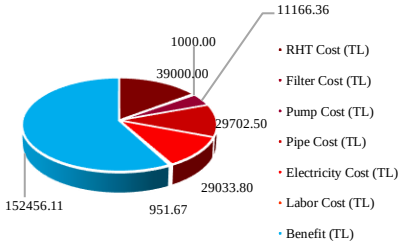
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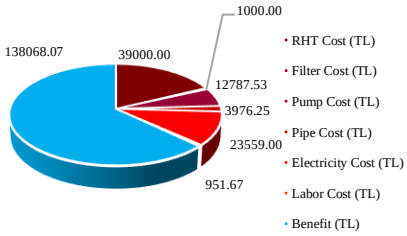
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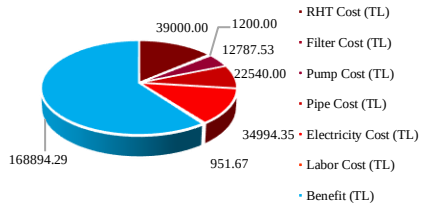
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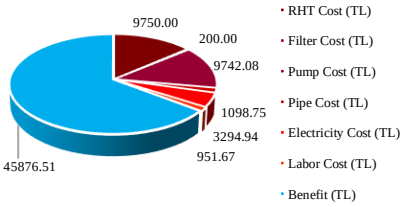
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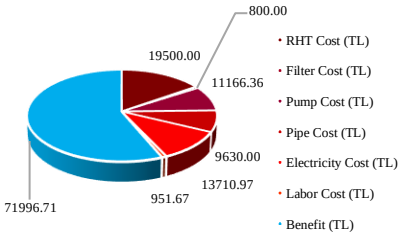
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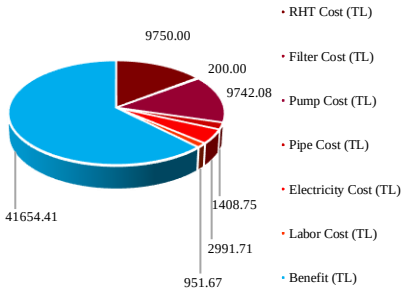
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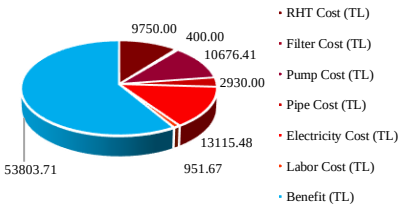
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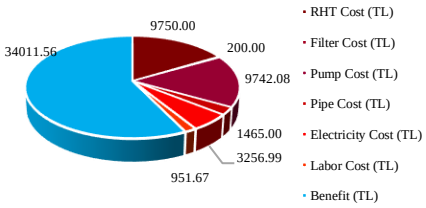
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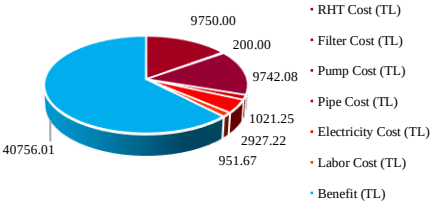
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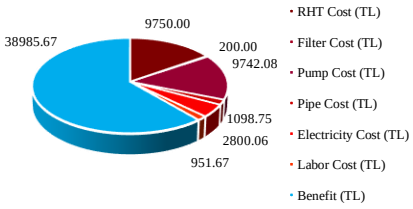
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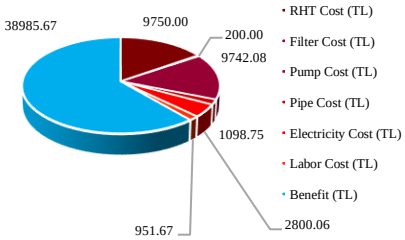
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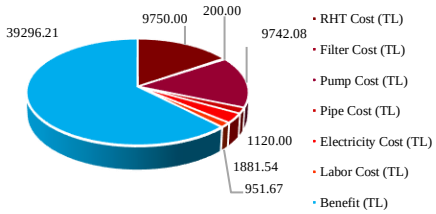
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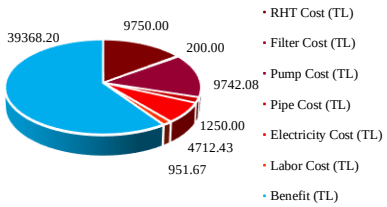
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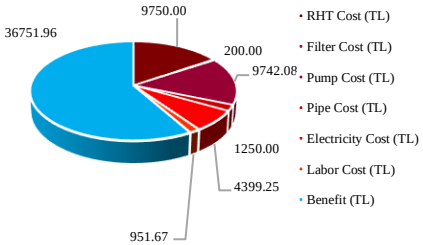
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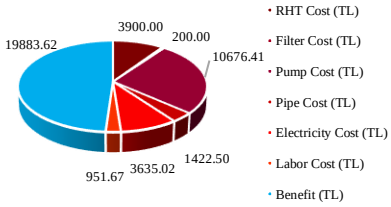
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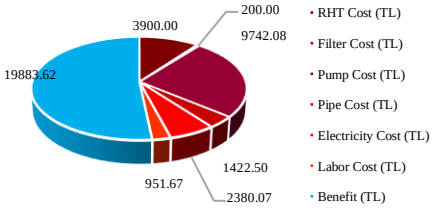
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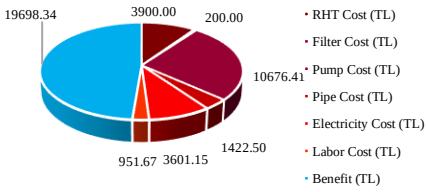
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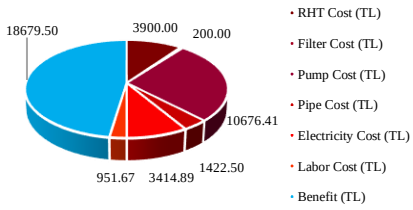
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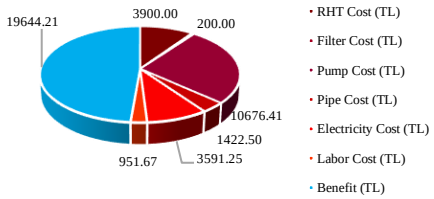
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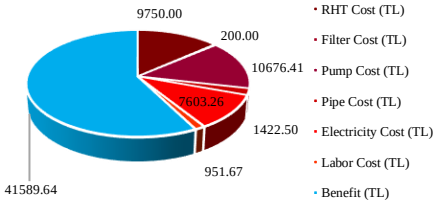
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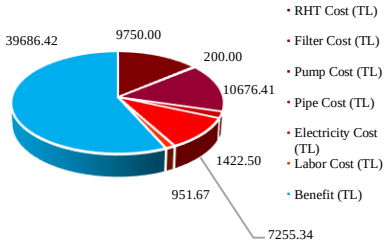
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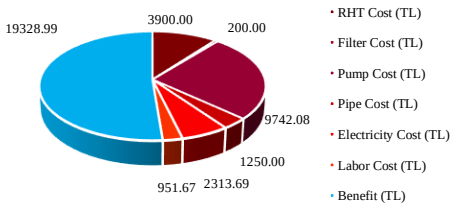
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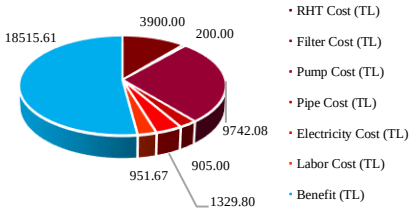
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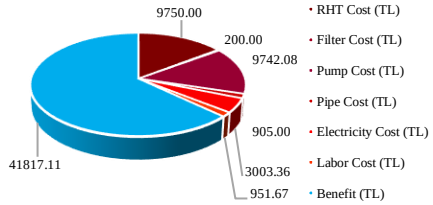
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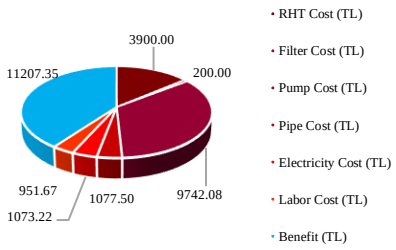
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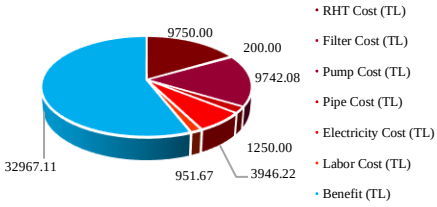
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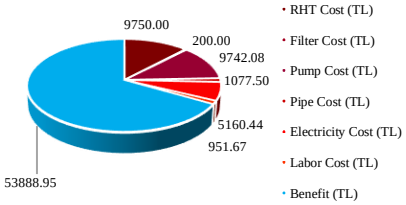
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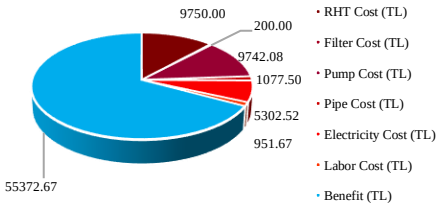
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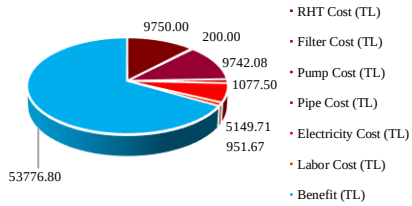
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BG_41:



BG_42:



BG_43:

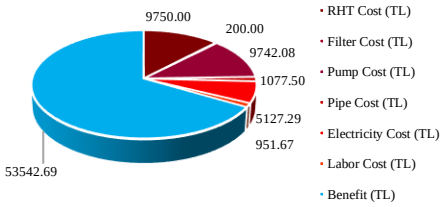


Figure D1 Distribution of Costs and Benefits for all 43 BGs