# SUSTAINABLE WATER AND STORMWATER MANAGEMENT FOR METU CAMPUS

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**SUSTAINABLE WATER AND STORMWATER MANAGEMENT FOR METU CAMPUS**

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# ABSTRACT

## SUSTAINABLE WATER AND STORMWATER MANAGEMENT FOR METU CAMPUS



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As the environmental concerns increase, Sustainable/Green Campus applications with high level of environmental performance became widespread all over the world. Sustainable Campus practices include implementations regarding energy, waste, food, water, buildings and transportation. As a part of sustainable campus implementations, sustainable water management is an approach to plan, manage and use the water in the campus. In this context, METU is aware of the need to take actions for providing sustainable solutions for the campus. A comprehensive study funded by Middle East Technical University (METU) was initiated in 2014 to support METU's initiatives to develop sustainable campus strategies. In this study, three main components were focused and these were water management, stormwater management and asset management in the context of sustainability for METU Campus. First, water resource of the campus was investigated by field work and evaluation of water withdrawal and water level data. Water consumption is analyzed especially at high demand locations such as dormitories, cafeteria and swimming pool. Evaluation of consumptions in dormitories was supported by the outcomes of a survey which aimed to understand the social behavior. In the second stage, a rainfall-runoff model in SWMM is developed both to understand stormwater collection and to evaluate potential benefits of Low Impact Development applications in the campus. Finally, the current situation of the water infrastructure system in the campus is investigated through an asset management approach. It is aimed that the outcomes of this study will aid decision makers in developing sustainable water management strategies for METU Campus.

Keywords: Sustainability, water management, green campus, stormwater management, asset management

# ÖZ

## ODTÜ KAMPÜSÜ'NDE SÜRDÜRÜLEBİLİR SU VE YAĞMURSUYU YÖNETİMİ

Kiraz, Melike
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Temmuz 2018, 226 Sayfa

Çevresel problemler arttıkça, tüm dünyada yüksek düzeyde çevresel performansa sahip Sürdürülebilir/Yeşil Kampüs uygulamaları yaygınlaşmıştır. Sürdürülebilir Kampüs uygulamaları enerji, atık, gıda, su, binalar ve ulaşım ile ilgili uygulamaları içermektedir. Sürdürülebilir kampüs uygulamalarının bir parçası olan sürdürülebilir su yönetimi, kampüsteki suyu planlamak, yönetmek ve kullanmak için bir yaklaşımdır. Bu kapsamda, ODTÜ, kampüsü için sürdürülebilir çözümler sunma konusunda harekete geçmesi gerektiğinin farkındadır. ODTÜ'nün sürdürülebilir kampüs stratejileri geliştirme girişimlerini desteklemek amacıyla 2014 yılında Orta Doğu Teknik Üniversitesi (ODTÜ) tarafından finanse edilen kapsamlı bir çalışma başlatıldı. Bu çalışmada ODTÜ kampüsü sürdürülebilirliği kapsamında üç ana unsura yoğunlaşılmıştır ve bunlar; su, yağmur suyu ve varlık yönetimidir. İlk olarak, kampüsün su kaynağı, saha çalışması ve su seviyesi ve çekilen su miktarı verilerinin değerlendirilmesiyle incelenmektedir. Su tüketimi özellikle yurtlar, kafeterya ve yüzme havuzu gibi talebin yüksek olduğu yerlerde analiz edilmektedir. Yurtlardaki su tüketiminin değerlendirilmesi sosyal davranışı anlamaya yönelik yapılmış bir anketin sonuçları ile desteklenmektedir. İkinci aşamada, SWMM kullanılarak bir yağmur-yüzeysel akış modeli hem yağmur suyu toplanmasını anlamak hem de kampüste düşük etkili uygulamalarının potansiyel faydalarını değerlendirmek için geliştirilmiştir. Son olarak, kampüs içerisindeki su altyapı sisteminin mevcut durumu, varlık yönetimi yaklaşımıyla incelenmiştir. Bu çalışmanın sonuçlarının, karar vericilere ODTÜ Kampüsü için sürdürülebilir su yönetimi stratejileri geliştirmede yardımcı olacağı düşünülmektedir.

Anahtar kelimeler: Sürdürülebilirlik, su yönetimi, yeşil kampüs, yağmursuyu yönetimi, varlık yönetimi

*To my family*

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Abbreviations used in the documentation of the subject research and long forms of these are alphabetically listed below.

| | |
|---|---|
| AMSA | Association of Metropolitan Sewerage Agencies |
| ASC | Agnes Scott College |
| BMP | Best Management Practice |
| BOV | Beijing Olympic Village |
| EPA | United States Environmental Protection Agency |
| DEM | Digital Elevation Model |
| GIS | Geographic Information System |
| GRI | Global Reporting Initiative |
| IPWEA | Institute of Public Works Engineering Australasia |
| LID | Low Impact Development |
| MIT | Massachusetts Institute of Technology |
| MAE | Mean Absolute Error |
| MEAV | Modern Equivalent Asset Value |
| METU | Middle East Technical University |

| | |
|---|---|
| MSCC-4 | Manual of Sewer Condition Classification fourth edition |
| NAMS | National Asset Management Strategy |
| NRCS | Natural Resources Conservation Service |
| NSE | Nash-Sutcliffe Efficiency |
| OECD | Organisation for Economic Co-operation and Development |
| PACP | Pipeline Assessment Certification Program |
| PBIAS | Percent Bias |
| SCS | Soil Conservation Service |
| SDI | Sustainable Development Enstitute |
| SPCCM | Sewer Physical Condition Classification Manual |
| SWAT | Soil and Water Assessment Tool |
| SWMM | Storm Water Management Model |
| UCB | University of California Berkeley |
| USDA | United States Department of Agriculture |
| UTS | University of Technology, Sydney |
| UWE | The University of the West of England |
| WCED | World Commission on Environment and Development |
| WICS | Water Industry Commission for Scotland |

# CHAPTER 1

# INTRODUCTION

In recent years, sustainability term confronts in different disciplines and it is defined as creating and maintaining the living conditions for humans and nature while considering the needs of future generations (EPA, 2016). The three components of the sustainability include environmental, economic and social issues. Therefore, sustainable programs results from the commitment of an institution to environmental, social and economic health.

As the environmental concerns increase, 'Sustainable/Green Campus' applications with high level of environmental performance became widespread all over the world to provide better services to all academics, university students and graduates. A sustainable campus can be defined as a campus developing process or management systems which help to create a vibrant campus economy and high quality of life while considering the need of sustainable natural resources and environmental protection (Swiman, 2015). It provides sustainability principles in academic programs, research programs, campus life and physical operations such as renewable energy use, recycling, water saving measures and storm water management.

Mitchell Thomashow, a former college president, offered a framework for sustainability of a campus in his book published in 2014 and titled as "The Nine Elements of a Sustainable Campus" (The MIT Press, 2018). Drawing on his experiences at Unity

College in Maine, he identified nine elements for a sustainability agenda. These elements are energy, food and materials (aspects of infrastructure); governance, investment and wellness (aspects of community); and curriculum, interpretation and aesthetics (aspects of learning) (The MIT Press, 2018).

Middle East Technical University (METU) Campus having 4500 ha area (3100 ha of it is forestland) and approximately 30000 population (2289 academic staff and 28000 student) is one of the biggest university campuses in Turkey (METU, 2018). It also includes residential places which have a capacity of 7000 students, shopping center, banks, food courts, indoor sports facilities, tennis courts, football fields, swimming pool, dormitories, cafeteria and department buildings. Moreover, Lake Eymir is within the boundaries of METU Campus and the water need is supplied from the wells near the lake (METU, 2014).

As having one of the biggest and most populated campus in Turkey, METU is aware of the need to take actions to provide sustainability at its own campus. In 2018-2022 strategic plan of METU, it was emphasized that university's physical resources must be used by providing environmental protection, supporting sustainability and bringing benefits to the campus community (METU, 2017). METU was founded in 1956 as a state university. Prof.Dr. Kemal Kurdaş, the former Rector, explained the steps of the establishment of METU and the first years of the university in detail in his book titled 'ODTÜ Yıllarım, Bir Hizmetin Hikayesi' (METU Press, First Edition, 1998). In his book, he mentioned that the campus was constructed for a capacity of 15000 people (12000 students) capacity and its water need was supplied from a water spring having 3-4 L/s of flowrate coming from Yalıncak village in the first years of the university. At the present time, the campus population is 30000 people and its yearly water consumption is 1-1.2 million $m^3$. Due to these increases in population and water consumptions, METU Campus needs sustainable strategies for a comprehensive water management plan. This study aimed to develop sustainable water management strategies for METU Campus.

An afforestration campaign started in 1960 by METU and General Directorate of Forestry collaboration. After 1960s, the forestration and planting works were accelerated under the leadership of Prof. Dr. Kemal Kurdaş. 10 million coniferous and 23 million leaved trees have been planted on the campus area since 1961 and METU Forest was declared as “Natural and Archeological Protected Area” by Ministry of Culture in 1995. METU Afforestration Project was also awarded in “Innovator Concepts” category of International Aga Khan Architecture Awards in 1995 and was awarded by the Turkish foundation for combating erosion reforestation and the protection of natural habitats (TEMA) in 2003 (METU, METU, 2012). This can be accepted as the first step to bring Sustainable/Green Campus concept into METU Campus (Figure 1 ).

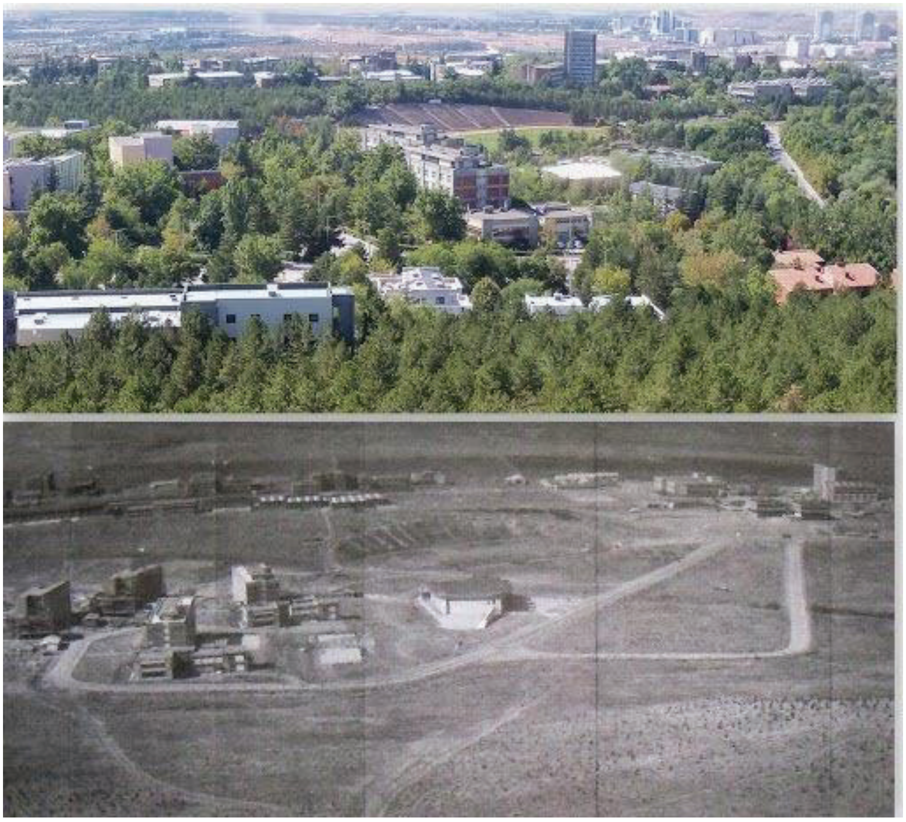


**Figure 1.** METU Campus Before (Lower one) and After (Upper one) Afforestration (Derci, 2014)

A comprehensive project titled "A Green Campus Application: Sustainable Stormwater Management in METU Campus" (Project No: BAP - 08 -11 - KB2014K120600-2) was funded by METU to support METU's initiatives to develop sustainable campus strategies. In this comprehensive project, it was focused on METU's water management, solid waste management and stormwater management challenges. This thesis study was a part of this comprehensive study which was funded by METU.

The aim of this study was to develop sustainable water management strategies for METU Campus. Water management means water resources control for less damage to life, more sustainable and beneficial resource usage (USDA, 2016). Sustainable water management is an approach to plan, manage and use the water and it includes several main components such as monitoring, developing strategies, implementing work packages, evaluating results and developing future goals. This study consisted of three main components which were water management, stormwater management and asset management in the context of sustainability for METU Campus.

In the study, the literature review of water management, stormwater management and asset management were given in Chapter 2. The methodologies of these components followed in the study were explained in Chapter 3.

In Chapter 4, water management alternatives of METU Campus were evaluated. Firstly, water resource of the campus was investigated by field work and evaluation of changes in water withdrawal and water level trends over years. Since the campus uses groundwater resource, some management alternatives were recommended for its protection. After that, water consumption was analyzed especially at high demand locations such as dormitories, cafeteria and swimming pool in the campus. Water consumption pattern in METU dormitories was evaluated based on real time measurements supported by the outcomes of a survey which aimed to understand the social behavior. Water usages for operational procedures of cafeteria and swimming pool were also investigated and some recommendations were given to decrease these usages and provide sustainable operations. In Chapter 5, developing a stormwater management plan was aimed to take action to mitigate negative effects of the surface runoff on campus. For this reason, a dynamic rainfall-runoff simulation model, was developed in Storm Water Management Model (SWMM) both to understand stormwater collection and to evaluate potential benefits of Low Impact Development applications in the campus. The model was built and calibrated by using extensive data sets such as rainfall data, measured runoff flow data, land use data and meteorological data. With calibrated model, different Low Impact Development applications were developed and their runoff reductions were evaluated. In addition to that, a regression analysis was conducted to evaluate the performance of a simpler approach and to identify the parameters that the surface runoff mostly depends on. The identified parameters can be used to predict total surface runoff volumes for the future rain events. Some important practices were also recommended to develop a sustainable stormwater management for METU Campus. In Chapter 6, the current situation of the water infrastructure system in the campus is investigated through an asset management approach. Three water pipeline systems which are potable water pipeline, sewer line and stormwater pipeline were classified according to their current states. After that, they were analyzed according to their criticalities and failure risks. Finally, an asset management methodology was recommended for these pipeline systems.

In Chapter 7, a comprehensive water management plan was proposed for METU Campus to decrease the water consumption at campus and to protect the quality and quantity of campus' water resource. It is the most important component of the study because it aims to introduce sustainable water management strategies to METU Campus. The water savings that will be done in the campus will also provide substantial energy savings in pump, treatment and heating systems. Moreover, successful storm water management will decrease the potable water usage for irrigation and supplemental purposes in the campus. A water management plan is necessary for METU Campus because the campus water is supplied from groundwater resource of Imrahor Valley. The amount of water consumed and the current situation of the water infrastructure system are unknown on campus. Therefore, it will be significant for protection of the water resource in its watershed. It will also be the starting point to quantify water consumption of campus, to prevent flooding risks in the campus and to have knowledge of the water loss due to any leakage in the water infrastructure system. It will aid decision makers in developing sustainable water management strategies for METU Campus.

# CHAPTER 2

# THEORETICAL BACKGROUND AND LITERATURE REVIEW

Sustainable development was defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." in Bruntland Report (WCED, 1987). The Global Reporting Initiative (GRI) provided one of the most widely-used sustainability reporting framework in the world and it has a significant role in sustainable development. It divided sustainability into three components which are environmental, economic and social (GRI, 2008). As the topic of this thesis was included, sustainability for campus perspective was focused in following section.

Cole (2003) stated that universities are wide and complex institutions providing learning opportunities and innovative solutions of global challenges by their research activities. They have their own campuses which include services for both educational and social life. The characteristics of each campus are different and they have different locations, sizes and services; thus every campus constructs its own definition of sustainability. However, the certain thing is that institutions need a balance between environmental, economic and social components to successfully achieve sustainability (Shriberg, 2002). University of California Berkeley (UCB) formalized its sustainability policy in 2007 by adopting the Statement of Commitment to the Environment and prepared its own campus sustainability report in 2013. The report was prepared in accordance with Global

Reporting Initiatives (GRI) Guidelines. While the environmental sustainability included energy, climate, water, built environment, waste, procurement, food, transportation and land use components, economic sustainability evaluated economic performance and indirect economic impacts of the campus. Moreover, social sustainability of UCB contained important issues such as occupational, health and safety, training and education, diversity, equal opportunity and student satisfaction (McNeilly, 2013).

Cornell University (n.d.) focused on ten areas to balance today's environmental, economic and social issues with related future needs. These areas were buildings, energy, land, water, purchasing, waste, climate action, food, people and transportation. The university created focus teams to develop program recommendations, assess progress and implement policy recommendations related to sustainability. For example, the energy team tried to reduce energy consumption through conservation, efficiency and switching to renewable and cleaner energy sources such as solar, wind and geothermal. Moreover, the water team tried to provide conservation of water and water quality in the regional watershed by researching end-use breakdowns of water, energy use in the campus and creating storm water management initiatives (Cornell University, 2013).

Plymouth University (n.d.) created a sustainable campus to reduce its impact on the environment and the plan for sustainable campus included nine areas which were carbon and energy, water, waste and recycling, construction, procurement and finance, biodiversity, travel, food and dashboard. The university tried to reduce $CO_2$ emissions by 52 % until 2020, water consumption to below 3.3 $m^3$ per student per annum and the amount waste generated to below 20 kg per student per annum. It also aimed to recycle 70 % of the waste generated at campus.

Similarly, Stanford University (2015) set some actions to provide sustainability at its campus. The university also examined its sustainability in different topics such as energy efficiency, food and housing, waste minimization and water conservation. It developed sustainable water practices such as decreasing domestic water consumption by 25 % and limiting irrigation by using potable water to two days per week. It also minimized the waste generated at campus by using less, reusing more, recycling and composting. These examples from around the world emphasize sustainable campuses have an important place to meet the needs of today and future.

**2.1.Water Management**

Evaluating and modifying water use patterns are significant for sustainable water resource management. The information available to real water consumption provides better water resource monitoring and evaluation capacities (OECD, 1998).

The first component of the study is water management. There are a number of universities that implemented water management plans for their campus to evaluate and reduce water consumption on their campuses. They included some actions into their plans. They specified and categorized these actions. Agnes Scott College prepared a water plan to provide water conservation through water infrastructure of the campus and an education plan for behavioral changes of students. The aim was to reduce the campus's water footprint to decrease its own stress on Chattahoochee River and near watersheds that may be affected. The steps of the plan were specifying missing data, determining conservation measures, recommending retrofit actions for fixtures and buildings, encouraging educational and behavioral changes, setting reduction goals and evaluating future plans (ASC Water Plan, 2012). Yale University also made its initial water management plan in 2013 with the aim of achieving 5% reduction in annual potable water use in 2016. However, the university could not achieve this goal, only 0.5% reduction in water consumption was achieved. The plan included campus metering, building, process, irrigation systems and a methodology to analyze water data (Yale Water Management Plan, 2013). These examples emphasized that while developing a water conservation plan, specifying and categorizing the action is very important.

Several of them had retrofit actions in their infrastructural systems. For example, John Hopkins University developed "Take Back the Tap", a comprehensive replacement and retrofitting plan, in 2013. As a part of this plan, the inventory of campus's water fountains and over 100 water fountains were replaced with a bottle filling station to ease refilling water bottles on campus. New water saving devices such as low-flow showerhead, faucets and toilet flushes were installed (John Hopkins University Office of Sustainability, n.d.). Similarly, Duke University started to work for sustainable conservation measures such as fixture and toilet retrofits, refurnishing single pass cooling systems, increasing the use of nonpotable water. The reason of these measures was a historic drought in 2007 since the university supplied its potable water from Lake Michie Reservoir. As a result, the university achieved 40% reduction in potable water per gross square foot (approximately 0.09 $m^2$) since 2006 (Duke University Office of Sustainability n.d.). Northumbria University has aimed to reduce yearly water usage by 2% per student and to increase grey water usage by 2020 in its water management plan. Some of the actions to achieve these goals were refurbishments/replacements of toilets, usage of low flush in toilets, monitoring of water consumption (Water Management Plan, 2016). The University of the West of England, Bristol also had some water reduction projects which were refurbishment of low-flow taps, flow regulators and urinal controls, water sub-metering in major water use areas, identification of water leaks. This university has aimed to achive 10% reduction in absolute water use, 20% reduction in relative water use per student and increase in rain harvesting capacity until 2020 (UWE Bristol, 2016). These university examples indicated that monitoring water consumption in high demand locations and some retrofit actions in water infrastructure systems are necessary to provide water conservation in a university.

Another important action in the plans is rainwater harvesting and reuse. For instance, George Washington University focused on potable water, rainfall capture, wastewater and bottled water. The University aimed to reduce potable water consumption by 25% over 10 years by adapting water saving infrastructure in campus facilities and reusing the stormwater for greywater systems, cooling towers and irrigation (GWater Plan, 2011). University of Oxford also gave importance to rainwater harvesting to use rain for different purposes such as flushing toilets and to reduce regional flooding. There was

1,512% increase in rainwater harvesting between 2009/10 and 2014/15 (Oxford Environmental Sustainability Report, 2016). University of Technology, Sydney aimed to improve the quality of stormwater runoff for reuse purposes as a part of its plan (UTS, 2014). As a result, it decreased water consumption by 26% on the campus over the past 9 years (UTS, 2017). Usage of rainfall harvesting systems and rainwater recycling were also the water conservation actions included in Northumbria University (Water Management Plan, 2016) and The University of the West of England, Bristol (UWE Bristol, 2016) plans. These examples indicated the importance of rainwater harvesting and reuse in developing water conservation plan in university campuses.

As it can be understand from different universities around world, determining the inventory of current situation in water consumption was essential in developing water conservation strategies and achieving sustainable development on campus. Table 1 summarizes the water consumption amounts of different universities upon implementation of water conservation plans.

**Table 1.** Water consumptions of different universities.

| University | Water Consumption | Year | Location |
|---|---|---|---|
| University of California Santa Cruz (2015) | 54 $m^3$/capita/year | 2005 | Campus |
| | 39 $m^3$/capita/year | 2013 | Campus |
| Princeton University (2011) | 23000 $m^3$/year | 2006 | Residence Halls |
| | 16000 $m^3$/year | 2011 | Residence Halls |
| University of California Davis (Dirksen and Marthur, n.d.) | 0.11 $m^3$/capita/day | 2013 | Emerson and Webster Halls |
| Agnes Scott College (2012) | 51600 $m^3$/year | 2012 | Campus |
| Duke University (n.d.) | 2580000 $m^3$/year | 2006 | Campus |
| | 1852000 $m^3$/year | 2017 | Campus |

There are also some water management activities made in METU Campus. Demirer et al. (2008) made a study titled as “Carbon Footprint Reduction in METU Department of Environmental Engineering”. In this study, METU Department of Environmental Engineering was aiming at reducing its own carbon footprint with the project called “Green Perspective”. Within the context of this, several activities were conducted below five main topics: energy efficiency, water use efficiency, green purchasing, laboratory waste management, solid waste management and recycle. Activities included the installation of water efficient closet-tanks, sensor fitted taps and water-free urinals providing a saving of 1050 tons of water per year. Naturally degradable bin bags were used instead of using plastic ones (Demirer et al., 2008). METU Heat and Water Management Department has started to investigate the water losses in central heating pipes and the potable water pipelines of campus buildings. Personnel in charge use a water leakage detection equipment which works as a stethoscope with an earphones. They use this equipment in silent hours to detect water leakages. After detecting, they repair them to prevent unnecessary water usages on campus. Additionally, METU Green Campus Group was founded in 2017 to conduct activities related green campus components such as food, water, energy, climate change, waste and recycling, material and transportation in METU Campus (METU Green Campus Group, n.d.). These activities were very significant to provide a sustainable water management for METU Campus.

## 2.2. Stormwater Management

There is a continuous water circulation on Earth between land, oceans and atmosphere and it is called the “Hydrological Cycle”. This cycle begins with evaporation of water from water bodies. When evaporated water rises to atmosphere, it condenses and forms clouds. Moisture is transported around globe and returns to surface as precipitation. After reaching the ground, some of the water runs as overland flow, some evaporates and some infiltrates into the subsurface to form interflow or groundwater. The subsurface flow may seep into streams, lakes and oceans or may go back to the atmosphere through transpiration.

Urban development changes the natural circulation of water between storage components of the hydrological cycle over years. It means that stormwater runoff increases due to enhanced impervious areas (buildings, roads etc.) as a result of urban development (Figure 2).

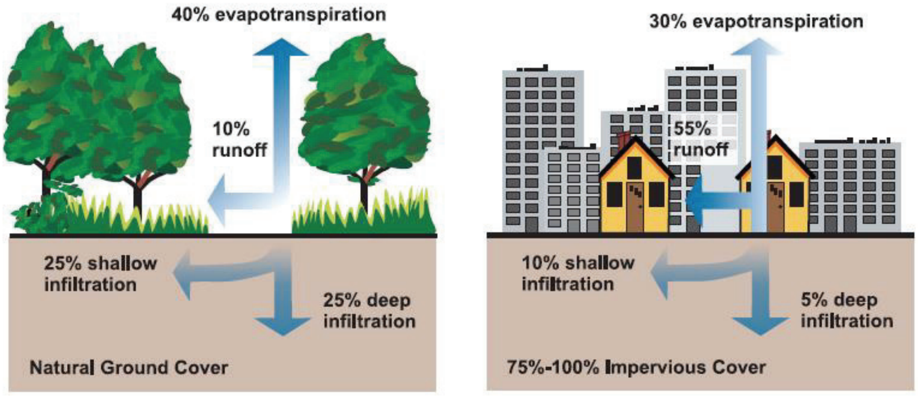



**Figure 2.** Relationship between impervious cover and surface runoff (EPA,2003)

These changes bring a necessity for taking some actions to mitigate the negative effects of this increasing surface runoff. Therefore an approach called "Stormwater Management" is developed. It includes systems and strategies to plan, manage and use the surface runoff (Ontario, 2016). Its components are collection, treatment, storage and distribution. The systems for collection, treatment and storage of stormwater include channels and pipes, grass swales and strips, porous pavements, infiltration tenches, bio-filters, sediment traps, wetlands and ponds. Additionally, pumping and sprinkling systems are used for distribution of stormwater (Smith, 2010).

Stormwater management has an important role in developing strategies for sustainability for cities and populated areas. It protects people and properties from physical damage of floods and provides the ecological integrity, quality and quantity of water resources. It also reduces the pollution of various sources entering to local waterways. In addition to its environmental benefits, it has economic benefits such as reducing and preventing the remediation costs of negative impacts to stream channels, water quality, damage to property and human health due to increased stormwater runoff (RC&D, n.d.).

**The Objectives and Limitations of Stormwater Management**

Stormwater management objectives can be categorized as environmental protection, economic development and historical protection. However, achievement of one goal may limit achievement of other goals. Commonly, there is a conflict between economic and other goals. For instance, construction of low impact development applications in a region to reduce surface runoff and to prevent floods may not be feasible economically. Some general objectives are listed below (Wanielista and Yousef, 1993).

- Prevention of floods in an area from a specific frequency storm event that may cause damage to people and properties
- Prevention of economic loss due to property damage in floods.
- Providing an alternative water source for irrigation and municipal supply
- Reducing land loss due to erosion and sedimentation
- Prevention of chemicals and suspended solids' loading to receiving water bodies and preserving the environmental quality of them.

Stormwater management also has some limitations while aiming to achieve these objectives. Some come limitations are summarized as (Wanielista and Yousef, 1993);

- Cost
- Site feasibility
- Environmental impact
- Potential reuse
- Floodplains and wetlands
- Labor and maintenance
- Institutional preferences.

Effective stormwater management plans are important guidelines to achieve best management practices in local regions for management, harvesting and reuse of stormwater. They inform local governments and other stakeholders about the environmental, economic and social impacts of their actions regarding stormwater.

Stormwater management is an important component of sustainable water management in campuses. There are a number of universities developing their own stormwater management plans. For instance, Cornell University had a Stormwater Management Program and it aimed to protect water resources of the university, to minimize any impact to the Lake Cayuga watershed and to comply with local stormwater regulations (Cornell University, 2017). The main points were reducing the effects of erosion and sedimentation from university activities and addressing impacts of construction activities on the stormwater runoff in the campus. The management team worked on some projects to reduce the pollution of stormwater runoff due to erosion and flood resulting from construction activities (Cornell University, 2017).

University of Pennsylvania also prepared its own Stormwater Master Plan to assess the feasibility of managing runoff from campus impervious areas and to find campus-wide solutions to stormwater management (Duffielld and LSRLA, 2013). The impervious surface areas of the campus and the runoff water volume generated on these areas were calculated. The university had implemented a variety of stormwater management practices such as green roofs, porous pavements, bioretention area, subsurface infiltration, subsurface detention, disconnected roof and pavement for impervious areas on the campus since 2009. It was also stated that utilizing modular green building components, stormwater capture and reuse systems, porous pavement treatments, green streetscapes and bio-infiltration systems were planned to be implemented in the future (Duffielld and LSRLA, 2013).

John Hopkins University also developed its own stormwater management master plan by the help of a consulting firm for the Homewood Campus (AKRF, 2012). The goals of this plan were enhancing the habitat on campus, reducing flood, enhancing aesthetics, and improving downstream water quality. Six or seven management zones were developed to allow the university to meet its stormwater management goals. Additionally, this plan provided a compliance with Maryland's regulations that are based on the Stormwater Management Act of 2007. Two stormwater management scenarios were developed and these were Baseline Regulatory Compliance Scenario, and Campus-wide Stormwater Management Master Plan Scenario. Regulatory Compliance Scenario provided stormwater best management practices (BMPs) only to meet regulatory requirements while the other one aimed to develop stormwater BMPs to provide both regulatory compliance and achievement of campus stormwater management targets. In addition, the plan included the design considerations of BMPs such as scale, safety, public health, aesthetics, maintenance and rain harvesting. It also provided a plan for administration, implementation and maintenance of BMPs (AKRF, 2012).

Villanova University initiated some projects to understand and improve stormwater BMPs on its campus. The disconnection of roof leaders was identified as the easiest way to decrease the impact on stormwater runoff (Gillard, 2011). University also had more than 20 stormwater capture and infiltration systems on the campus. These systems were equipped with some devices to monitor the rainwater quality and quantity. Some examples of them were bio-infiltration rain garden, stormwater wetlands, pervious concrete and porous asphalt (Villanova University, n.d.).

In the context of stormwater management, different softwares are used for predicting the quantity and quality of runoff from urban areas. These include RECARGA model, P8 Urban Catchment Model, SWMM (Jayasooriya & Ng, 2014), SWAT (Kangsabanik and Murmu, 2017) and ARNO (Todini, 1996). In this study, Storm Water Management Model (SWMM) was used. It is designed for both single storm event simulation and continuous simulation. It can obtain meaningful results with very rough to very refined inputs. In this model, catchment hydrology is well-suited to aggregation and this provides an opportunity to reflect linked catchments' characteristics during simulation.

Lastly, it is open source code and it has technical help platform on its website to help users. Therefore, SWMM was used in this study. Its literature review is given below.

**SWMM (Stormwater Management Model)**

SWMM is described as a dynamic rainfall-runoff simulation model developed by U.S. Environmental Protection Agency (EPA) in 1971 (Rossman, 2015). It is used for both runoff quantity and quality simulation for a single event or long-term events in mainly urban areas. SWMM includes the runoff component which operates on subcatchments receiving precipitation and generating runoff and pollution loads. This runoff is transported through pipes, channels, pumps and regulators by the routing portion of SWMM and its quality, quantity are calculated for each subcatchment. Additionally, the flow rate, flow depth and quality of water in each pipe and channel are simulated by using SWMM for multiple time steps (Rossman, 2015).

There are several runoff generating hydrological processes that are modeled by SWMM. Some of them are (Rossman, 2015):

- time-varying rainfall
- evaporation of standing surface water
- snow accumulation and melting
- rainfall interception from depression storage
- infiltration of rainfall into unsaturated soil layers
- percolation of infiltrated water into groundwater layers
- interflow between groundwater and the drainage system
- nonlinear reservoir routing of overland flow
- runoff reduction via low impact development (LID) controls.

SWMM includes several computational blocks that are the Runoff Block simulating the quantity and quality of runoff in a drainage basin, Transport and Extended Transport Block routing the flow and pollutant through the sewer system, the Storage and

Treatment Block characterizing the effects of control devices on flow and quality and the Receive Block indicating runoff mixing in a receiving body (Baffaut, Delleur, Member and ASCE, 1989).

While constructing a SWMM model, model input data is significant. Data requirements of SWMM are summarized in Table 2.

**Table 2**. Categories of the data for SWMM (EPA, 1995).

| TYPE | DATA |
| --- | --- |
| Weather Data | • Hourly/daily precipitation<br>• Daily/monthly evaporation rates<br>• Snowmelt<br>• Daily max.-min. Temperatures<br>• Monthly wind speeds<br>• Melt coefficients etc. |
| Surface Quantity | • Area<br>• Imperviousness<br>• Slope<br>• Width<br>• Depression storage<br>• Manning's roughness for pervious and impervious areas<br>• Horton/Green-Ampt infiltration parameters |
| Subsurface Quantity | • Porosity<br>• Field capacity<br>• Wilting point<br>• Hydraulic conductivity<br>• Initial water table elevation<br>• ET parameters<br>• Coefficients for groundwater outflow as function of stage and tail water elevations |
| Channel/pipe quantity | • Linkages<br>• Shape<br>• Slope<br>• Length<br>• Manning's roughness<br>• Invert and ground elevations, storage volumes at manholes etc. (for EXTRAN) |

**Table 2.** Categories of the data for SWMM (EPA, 1995) (Continued)

| | |
|---|---|
| Storage/sedimentation quantity | • Stage-area-volume-outflow relationships<br>• Hydraulic characteristics of outflows |
| Surface quality | • Land use<br>• Total curb length<br>• Catchbasin volume and initial pollutant concentrations<br>• Street sweeping intervals etc. |
| Storage/treatment | • Parameters defining pollutant removal equation<br>• Parameters for individual treatment options such as particle size distribution, maximum flow rates etc. |
| Storage/treatment cost | • Parameters for capital and operational, maintenance costs as a function of flows, volumes and operating time |

Precipitation is the main input data for runoff simulation model. In SWMM, precipitation data is entered by defining time series or using an external data file (Rossman and Huber, 2016). Moreover, SWMM can simulate both single rainfall events and a long-term continuous precipitation records. SWMM also needs air temperature data to simulate snow melt if needed or to compute potential evapotranspiration if Hargreaves method is used. Temperature data is in a form of time-dependent set. The data can be a user-generated time series or from a climate data file. In addition, SWMM takes into account the evaporation and it could be from the water on subcatchment surfaces, the subsurface water in groundwater aquifers, the water flowing in open channels or held in storage units and low impact development controls. While it is not important for single event simulations, it becomes an important part of water budget during continuous simulation. The evaporation rates can be stated in different forms such as a single constant value, a set of monthly average values, time series of daily values defined by a user or read from an external climate file. In addition, evaporation rates can be calculated by using the Hargreaves method if the daily maximum-minimum temperatures and the latitude of the study area are known. When a precipitation as rainfall occurs in the area that snow was accumulated, wind speed is used in SWMM to refine the melt rate calculation. The wind speed data is provided as montly average values or from the climate file that is the one used to also supply daily maximum-minimum temperature and evaporation (Rossman and Huber, 2016).

In this study, the rainfall-runoff processes belonging to Runoff Block of SWMM are focused. These processes need several modeling input data. Modeling input data are precipitation, area, imperviousness, slope, roughness, width, depression storage and infiltration parameters for hydrological simulation in the Runoff Block (SDI, 2004).

A distributed model, SWMM, is used to estimate surface runoff produced by rainfall. A study area is subdivided into subcatchment areas and SWMM simulates the runoff amount in these subcatchments by reflecting the spatial variability in topography, drainage pathways, land cover and soil characteristics on this runoff generation.

In SWMM, the subcatchment is modeled as a nonlinear reservoir having slope S and a width W and the generated overland flow is calculated in this subcatchment. The representation of the nonlinear reservoir model is given in Figure 3 (Rossman and Huber, 2016).

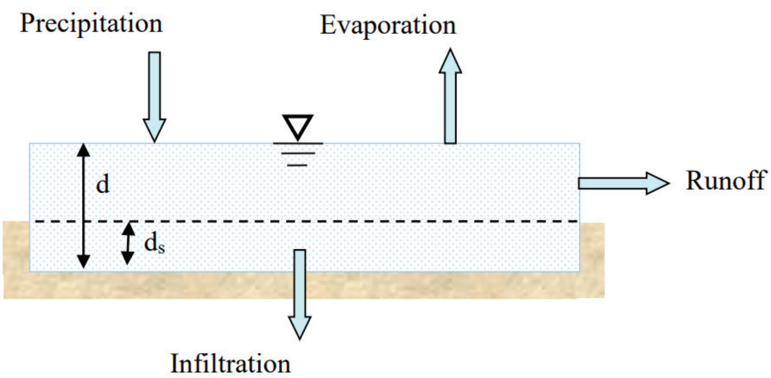



**Figure 3.** Nonlinear Reservoir Model

As seen from the figure, the input is precipitation (rainfall and snowmelt) and the losses are evaporation and infiltration. “d” represents the depth of net excess water ponded on the subcatchment surface. “$d_S$” represents the depression storage depth and the water amount becoming runoff outflow “q” is the ponded water above $d_s$. Depression storage includes initial rainfall abstractions such as surface ponding, interception by flat roofs and vegetation and surface wetting (Rossman and Huber, 2016). The equation coming from mass conservation is;

$$\frac{\partial d}{\partial t} = i - e - f - q \qquad (1)$$

*i*= rate of rainfall + snowmelt (flowrate per unit area)

*e*= surface evaporation rate(flowrate per unit area)

f= infiltration rate(flowrate per unit area)

q= runoff rate(flowrate per unit area)

The volumetric flow rate of the runoff is expressed by the Manning equation. It is assumed that there is a uniform flow across the subcatchment surface having a rectangular channel depth W and height d-$d_s$ (Rossman and Huber, 2016). So, the flow equation is;

$$Q=\frac{1.49}{n}S^{1/2}R_X^{2/3}A_X \longrightarrow Q=\frac{1.49}{n}WS^{1/2}(d-d_s)^{5/3} \qquad (2)$$

where

$A_x$= W(d-ds) (cross-section area through which the runoff passes)

$R_x$= d-ds (difference between the depth of net excess water ponded on the subcatchment surface and depth of depression storage)

Moreover, the flowrate per unit area is calculated as;

$$q=Q/A=\frac{1.49}{An}WS^{1/2}(d-d_s)^{5/3} \qquad (3)$$

where n is surface roughness, S and A are average slope and surface area of the subcatchment, respectively.

Hence, the mass balance is;

$$\frac{\partial d}{\partial t} = i - e - f - \alpha\,(d - d_s)^{5/3} \text{ where } \alpha = \frac{1.49WS^{\wedge}(\frac{1}{2})}{An} \qquad (4)$$

This equation only applies in the condition that d is greater than $d_s$ (Rossman and Huber, 2016). In opposite condition, q will be zero therefore the mass balance will be;

$$\frac{\partial d}{\partial t} = i - e - f \qquad (5)$$

A subcatchment area consists of both pervious and impervious areas and "percent imperviousness" parameter reflect the contribution of impervious and pervious areas in the subcatchment. Moreover, it does not mean that all impervious areas generate runoff. While there are impervious areas having depression storage, some of them have no depression storage. "%Zero-Imperv" parameter represents the portion of the subcatchment having no depression storage (Rossman and Huber, 2016).

SWMM model includes two different time step types and these are "wet" and "dry" steps (Huber, 2003). They are used while evaluating surface runoff according to precipitation input. If there is precipitation input or flow on any subcatchment in the study area, the wet time step is used. Wet time step is typically an integer number and less than rainfall interval. A non-integer or larger wet step than rainfall interval means that SWMM will reduce time step to make rainfall intensity constant over the adjusted time step. In other words, the wet step which is less than or equal to the response time of catchment is preferred. If there is no precipitation input and all depression storages are unfilled, long dry time steps are used. The dry time step take generally several hours or days and is used for update of the infiltration parameters, groundwater flow generation and hydrograph continuity.  A conceptual subcatchment and conceptual routing in a subcatchment are illustrated in Figure 4. Normally, the runoff of each subcatchment goes directly to an inlet or a downstream pipe/channel. In addition to that, runoff a subcatchment may be routed onto overland flow area of another subcatchment (Huber, 2003).

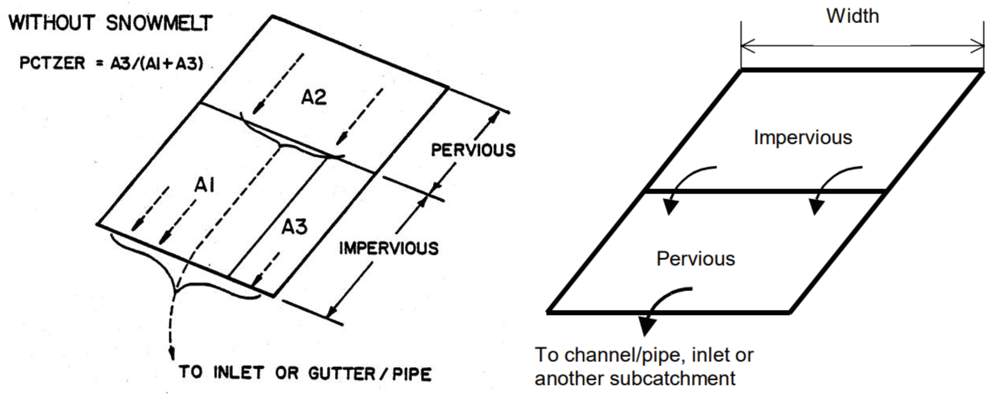



**Figure 4.** Pervious and impervious areas within a subcatchment (on left) and conceptual routing of a subcatchment (on right) (Huber, 2003).

There are also several infiltration methods to simulate infiltrated volumes and peak flows by using SWMM. These are Horton, modified Horton, Green-Ampt and SCS method (James, Rossman and James, 2010). Independently of which method is used, the soil type and condition determine the parameters defining the method. Most of soils have been classified into four different hydrologic groups as A, B, C and D the by NRCS (Natural Resources Conservation Service) according to their infiltration capacities. Drained and sandy soil, sandy and loamy soil, clay-loamy soil and poorly drained-clayey soil are classified as A, B, C and D respectively (Rossman and Huber, 2016).

Horton infiltration method is an empirical method and it is applicable only to events for which the rainfall intensity exceeds the infiltration capacity. Its modified form is developed in SWMM to find a solution to this deficiency (SDI, n.d.). Its exponential equation predicts the reduction of infiltration capacity over time. The equation is; (Rossman and Huber, 2016)

$$f_p = f_\infty + (f_0 - f_\infty) * e^{-kd*t} \qquad (6) \quad \text{where}$$

$f_p$ = infiltration capacity into soil,

$f_\infty$ = minimum or equilibrium value of $f_p$ (at $t = \infty$)

$f_0$ = maximum or initial value of fp (at $t = 0$)

t = time from beginning of storm (sec)

$k_d$ = decay coefficient (sec-1)

Moreover, total infiltrated water volume can be calculated by using the equation (7);

$$F = f_\infty * t_p + \frac{(f0 - f\infty)}{kd} * (1 - e^{-kd*tp}) \qquad (7)$$

When the new $t_p$ is known, the infiltration capacity $f_p$ can be calculated by using former equation (5). $F_{max}$ parameter can be entered optionally to limit total infiltrated water in the soil. As total infiltration exceeds $F_{max}$, it means that saturation conditions occur and the surface behaves as impermeable. Horton equation is the best known one among the infiltration equations (Rossman and Huber, 2016).

Additionally, the Green-Ampt equation is a physically-based method and not a common method used in urban hydrology studies but it has been receiving considerable attention in recent years (Rossman and Huber, 2016). The Mein and Larson (1973) formulation is applicable if rainfall intensity is less than the infiltration capacity at the beginning of the storm (SDI, n.d.). In the infiltration process of the Green-Ampt method, infiltrated water has a vertically downward direction in the saturated layer. The saturated hydraulic conductivity, the suction head at the wetting front and the maximum deficit available are the soil parameters that should be known for each subcatchment for this infiltration method (Rossman and Huber, 2016). The infiltration is calculated as;

$$F = K_s + \psi_s \theta_d \ln(1 + \frac{F}{\psi s \theta d}) \qquad (8) \quad \text{where}$$

$K_s$= the saturated hydraulic conductivity

$\psi_s$=the capillary suction head along the wetting front

$\theta_d = \theta_s - \theta_i$ where $\theta_s$ is the saturated moisture content at wetted zone and $\theta_i$ is the initial moisture content in the un-wetted zone

As the cumulative infiltration at the beginning of the time step ($F_1$) is known and the cumulative infiltration at the end of time step ($F_2$) is unknown, $F_2$ can be calculated as;

$$F_2 = C + \psi_s\theta_d \ln(F_2 + \psi_s\theta_d) \quad (9)$$ where

$C = K_s \Delta t + F_1 - \psi_s\theta_d \ln(F_1 + \psi_s\theta_d)$ is a known constant and $f_p$ (the average infiltration capacity) over time step is calculated as $(F_2 - F_1)/\Delta t$ (Rossman and Huber, 2016).

Lastly, SCS method in SWMM was derived from well-known SCS Curve Number Method used in simplified runoff methods (James, Rossman, and James, 2010). While the original curve number method combines all losses due to interception, depression storage and infiltration, SWMM uses a modified form of the method that includes only for infiltration losses because other losses modeled separately. Curve Number is the most important parameter and its values change according to type of soil and land uses (James, Rossman and James, 2010).

Curve number model uses the following equation that is;

$$Q = \frac{P^{\wedge}2}{P + Smax} \quad (10)$$ where

$S_{max}$= maximum moisture storage capacity of the soil being calculated as $S_{max} = \frac{1000}{CN} - 10$

Q= total evet runoff,

P= total event precipitation

It is assumed that the portion of rainfall that does not runoff is infiltration loss. Therefore, total infiltration is calculates as; (Rossman and Huber, 2016)

$$F=P-\left(\frac{P^2}{P+Smax}\right) \qquad (11)$$

The infiltration parameters depend on which infiltration model was selected for the study. The infiltration parameters of Horton, Green-Ampt and SCS (Curve Number) methods are given in Table 3 (James, Rossman and James, 2010).

**Table 3:** The parameters of infiltration methods

| Method | Parameter |
|---|---|
| Horton | Max. Infiltration Rate |
| | Min. Infiltration Rate |
| | Decay Constant |
| | Drying Time |
| | Max. Infiltration Volume |
| Green-Ampt | Suction head |
| | Conductivity |
| | Initial deficit |
| SCS | Curve Number |
| | Conductivity |
| | Drying time |

As the hydraulic model of SWMM, flow routing can be expressed by conservation of mass and momentum equations for gradually varied, unsteady and one-dimensional flow, known as the Saint Venant flow equations (Lockie, n.d.). There are three different flow routing methods to solve them and these are steady flow, kinematic wave and dynamic wave routing. Steady flow routing is the simplest type of routing and it assumes that flow is uniform and steady in each computational time step. Kinematic wave routing solves the continuity equation and a simplified form of the momentum equation for each conduit. For the solution of momentum equation, the slope of the water surface should be equal to the slope of conduit. Lastly, Dynamic Wave routing method is used to solve the complete one-dimentional Saint Venan flow equations and this is the method that gives the most theoretically accurate results. Its equations are the continuity and momentum equations for conduits and volume continuity equations at nodes (Lockie, n.d.).

In SWMM model development, different types of low impact development (LID) practices can also be implemented to help capture and retain rainfall on-site. LID applications are the systems and practices which are used to reflect natural processes resulting in infiltration, evapotranspiration or use of stormwater to provide a protection for water quality and associated aquatic habitat (EPA, 2017). It is aimed to preserve, restore and create green space using soils, vegetation and rainwater harvest techniques. Some examples are bioretention facilities, rain gardens, vegetated rooftops, rain barrels and permeable pavements (EPA, 2017). The land cover information was supplied to analyze and select a mix of LID controls to be applied. SWMM 5.1 has been extended to model the hydrologic performance of specific types of LID controls. There are eight LID applications which are permeable pavement, rain gardens, green roofs, bio-retention cell, rooftop disconnection, rain barrels, infiltration trenches and vegetative swales. In design part, any of these LID applications can be edited to use as a control option in "LID Controls" tab. After that, it is necessary to plan subcatchment area with the designed LID structures by using "LID Usage Editor" (SEOULTECH, 2016). After implementation, two basic comparisons can be made and these are peak runoff flow rate and total runoff volume. It is expected that LIDs reduce both of them (McCutcheon and Wride, 2013).

There are many studies in which runoff quantity and quality was modeled by SWMM. In these studies, different input data is used depending on the availability and modeling objectives. Schmidt et al. (1996) conducted a study and performed a short-term water quantity simulation for Ribault River Sub-Basin. Their input data included rainfall, antecedent moisture conditions, hydrologic parameters, boundary and initial conditions for the simulation period and conduit roughness values. In another study, Shen and

Zhang (2015) stated that there were some parameters to be calculated for each subcatchment and they were the input data for their rainfall-runoff modeling. . These parameters were physical parameters such as area, width and slope, hydrological parameters imperviousness, the Manning's roughness coefficient, depression storage for impervious and pervious fraction of subcatchment and infiltration parameters according to selected method. In another study, Waikar and Namita (2015) obtained rainfall data from a nearby raingauge station. They processed elevation and imperviousness data from the Digital Elevation Model (DEM). They calculated area, width and length by using ArcGIS to use them in an urban flood modeling. Jang et al. (2007) also used some input data which were area, channel length, watershed slope and channel slope, rainfall and discharge data in SWMM for hydrologic impact assessment.

SWMM has the capability to model infiltration with a number of approaches including Horton, Curve Number and Green-Ampt methods. The user can choose among these based on data availability and model goals. While some researchers used Horton infiltration method (Sangal and Bonema, 1994; Beling, et al., 2011; Chow, et al., 2012; Dongquan, et al., 2009; Liong, et al., 1991; Skotnicki and Sowinski, 2013), others used Curve Number method (Pittman IV, 2011; Muleta, 2012; Sun, et al., 2012) and Green-Ampt method (Brown, 2000; Rosa, et al., 2015).

There are three different flow routing models in SWMM and these are steady flow, kinematic wave and dynamic wave. Steady flow is not preferred mostly for hydraulic model of SWMM because it assumes that flow is uniform and steady in each computational time step. When the case studies are reviewed in terms of their flow routing, it can be seen that researchers used different approaches but kinematic wave routing (Chow, el al. (2012), Pittman (2011) and Muleta (2012)) and dynamic wave routing (Shao, et al. (2017) and Burger, et al. (2014) ) are the mostly preferred ones.

Calibration, validation and verification were identified as three crucial steps for proper application of a model (Dendrou, 1982). Calibration is the process of modifying model parameters to reduce the error between the simulated streamflow and the observed flow record (Knapp et. al., 1991). Calibration parameters change depending on the model software used and the objective of the study. In the calibration part of SWMM, Sangal and Bonema (1994) calibrated their model by using percentage of imperviousness (called as %imperv in SWMM), depression storage, maximum and minimum infiltration capacities, subcatchment width and Manning's coefficients for impervious areas, channels and pipes. Chow, et al. (2012) obtained the best simulation results by using %imperv, width, manning roughness for impervious and pervious areas, depression storages, Horton infiltration parameters and drying time. Pittman (2011) selected Curve Number, Manning's n values, slope and depth of storage as calibration parameters in his study. While Rosa, et al. (2015) selected conductivity, suction head, initial moisture deficit, Manning's coefficients and depression storages for calibration, Muleta (2012) used Curve Number, percent imperviousness, infiltration parameters and Manning's roughness coefficient. Moreover, Liong, et al. (1991) used a number of parameters which are flow roughness coefficient, the depression storage, the initial and ultimate infiltration rates, infiltration decay rate, widths and slopes of subcatchments, percentage of imperviousness, the percentage of imperviousness area with no depression storage and the flow roughness coefficients for the channels for their model calibration. Model validation evaluates model performance to estimate runoff for periods outside that used to calibrate the model (Knapp et. el., 1991). Model verification investigates the range of conditions over which the model will produce acceptable results. Mancipe-Munoz et al. (2014) used the first ten months of rainfall data as the calibration period, and the last five months as a validation period. They obtained lower total volume runoff errors in validation than calibration period and the model results proved to be reliable in simulating flows. Chow, et al. (2012) calibrated the model using 8–10 storm events and validated using seven new events. The calibration and validation results showed good agreement between simulated and measured data.

SWMM does not include any automatic calibration module. Therefore, model calibration is done manually in the studies. Different quantitative statistics can be used to evaluate the performance of the model for calibration and validation stages. Moriasi, et al. (2007) recommended Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS) and the ratio of the root mean square error to standard deviation of measured data (RSR) as performance measures. In a study made in Malaysia, Chow et, al. (2012) used SWMM to simulate the runoff quantity and quality in tropical urban catchments. They used the relative error, normalized objective function, NSE and 1:1 plots between measured and simulated data were used to evaluate the model performance. The results indicated a good correlation between the measured and simulated data. In another study performed in Macau, Dongquan et al. (2009) run SWMM and optimized the performance of the simulation by using a trial-and-error procedure. As a result, the calibrated model provided acceptable simulation in terms of the shape of the hydrograph, the total flow volume, and the peak flow occurrence time. In the model constructed for watersheds in Southern Brazil, Beling et al. (2011) used a manual trial and error method to observe objective function the determination coefficient ($R^2$) between the observed and simulated hydrograms. They calculated % peak runoff error and % runoff volume error for each basin.  The objective of Muleta's (2012) study was to evaluate the performance of Bayesian approach for calibration and uncertainty analysis of SWMM model. They evaluated the calibration results by using mean absolute error (MAE), NSE, PBIAS and total volume of runoff. Rosa et al. (2015) also used SWMM for runoff simulation and they found that the weekly simulated runoff volumes and peak flows showed good agreements with observed ones for both waterheds  as $R^2>0.9$ and $R^2>0.8$ respectively. In addition, NSE coefficients indicated that the performance of the simulation were well for both watersheds (NSE>0.6).

SWMM can also be used to evaluate the low impact development applications (LIDs) for urban control runoff. For example, Jia et al. (2012) worked on a case study in Beijing Olympic Village (BOV). There already were some LIDs constructed to stormwater system of BOV such as green roofs, porous pavements and rainwater cisterns. Some modifications were made in stormwater facilities t improve the landscape because BOV became a residential complex after 2008 Olympics. The pipe network hydraulics for

BOV was simulated by using SWMM before. The present study aimed to evaluate the performance of BMP modifications and future modifications to control runoff. Peak flow rate and runoff volume reductions under the three scenarios (original plan, improved landscape plan and recommended plan) were calculated by using the 2008 rainfall data. The results indicated that when compared to the existing condition, the recommended BMP plan would cause a 27% and 21% reduction for total runoff volume and the peak flow rate, respectively. In another study, Maya et al. (2010) aimed to build new modeling techniques of two selected BMPs which were implemented in EPA SWMM 5.0. They used rain barrels and rain gardens to assess the potential runoff and peak flow reduction percentage. After designing and implementing LIDs, simulation results indicated that there was a delay in runoff formation and its amount was approximately 300 L. It was concluded that rain garden had the best response in runoff and peakflow reduction. Zang and Guo (2014) evaluated the runoff reduction performance of permeable pavement systems by using LID module of SWMM model with rainfall data from Atlanta. The results indicated that permeable pavement systems were inadequate when the depths of permeable layer were less than 120 mm and the computational time steps were longer than 30 min.

These studies indicate that the SWMM model is one of the most preferred surface runoff modeling tool to calculate runoff quantity. It is widely recognized around the world, freely open to public. It gives different outputs options for different parameters in detail. After SWMM model simulation, it also gives different LID application options for further analysis. Therefore, SWMM model is chosen for this study.

There are many studies about the calculation of surface runoff by using regression analysis. For example, McIntyre et al. (2009) made a regression analysis between the flow volumes of a basin in Oman and the parameters defining rainfall characteristics. There were thirty six storm events observed and some predictive variables such as peak rainfall, total precipitation volume and precipitation spatial variability index. Relationships between estimators and predicted variables were found by using statistical analyzes of rainfall-runoff events. Silva and Oliveira (1999) also conducted a study in the Capetinga Basin, Brazil and they aimed to assess the effects of total rainfall, rainfall intensity, and the five-day preliminary rainfall on the surface flow, and to compare the calculated surface flow values with ones calculated by using the Curve Number Method. A yearly rainfall-runoff data was collected from the basin. A multivariate regression analysis was performed for thirty one storm events. In this analysis, it was found that the amount of surface flow depends only on the precipitation volume. Many other studies like these studies are carried out in different countries.

### 2.3. Asset Management

Infrastructure systems are essential to supply the structural demand of the settlements and prevent any harm to human and environment. The type, dimension and capacity of the equipments should be specified to monitor and evaluate their effects on human and environment while considering economic factors. Therefore, some studies should be done to understand the current situation of the aging infrastructure systems, their lifetimes, their assessment, the criteria and methods to evaluate them in urbanized areas.

Asset management is an approach that can be used for water infrastructure systems to make a plan for their operation and maintenance, the repair or upgrade of the capital assets (pumps, pipes etc.) and their budget allocation (EPA, 2017). It is necessary to manage the assets of the system assisting the utility and to make better decisions about the system. It also provides sustainability while meeting the water demand and service expectations of people. Moreover, it is essential in order to improve the response to emergencies.

EPA (2008) developed a framework for the asset management and it consists of five stages that are current state of assets, level of services, critical assets, minimum life cycle cost and long-term funding plan. While developing asset inventory, maps and engineering drawings of the system should be examined and used. After assets are determined and located on a map, their conditions should be specified. In simplest way, people who have current and historical knowledge of the system can be gathered and a condition ranking can be selected together. In a higher level way, additional data can be obtained about asset condition via more sophisticated means such as televising the interior sewer pipes and using leak detection technology for water pipes after initial ratings and assets can be rerated. The real value of assets is the cost to replace the assets using technology that the system would employ for replacement. A GIS map and database can be developed for the system for long-term view of asset management. Level of service is to define the level that utility owners, managers and operators want the system to perform over long term. One of the factors to determine the critical assets is level of service. Other factors are asset age, asset condition, failure history, historical knowledge and general experiences with the asset. While assessing criticality, the likelihood of failure and the consequences of failure should be examined. Life cycle asset management focuses on the management options and strategies considering all relevant economy and physical consequences from initial planning to disposal. The final step in the asset management is to determine the best manner in which to fund the operation and maintenance, repair, rehabilitation and replacement of assets (ENV, 2006). These stages and their best practices are summarized in Table 4.

**Table 4:** The stages and practices of asset management framework (EPA, 2008)

| Stages | Practices |
|---|---|
| 1) Current state of assets | - Preparing an asset inventory and system map<br>- Developing a condition assessment and rating system<br>- Assessing their remaining lifetime<br>- Determining asset values and replacement costs |
| 2) Level of services | - Evaluating the customer demand and the satisfaction with the system<br>- Considering the regulatory requirements<br>- Describing targets of system performance<br>- Monitoring the system performance over time by using level of service standards |
| 3) Critical assets | - Organizing the assets according to their criticalities for system operations<br>- Developing a failure analysis such as root cause analysis and failure mode analysis<br>- Specifying the probability of failure and sorting assets by failure type<br>- Evaluating the failure risk and results<br>- Using asset decay curves<br>- Reviewing and updating the system vulnerability |
| 4) Minimum life cycle cost | - Turning the reactive maintenance into predictive maintenance<br>- Quantifying the costs and benefits of rehabilitation and comparing them with replacement<br>- Calculating lifecycle costs for critical assets<br>- Using resources effectively according to asset conditions<br>- Specifying the causes of asset failure to develop a responce plan |
| 5) Long-term funding plan | - Revising the system structure<br>- Providing a fund for system<br>- Financing asset rehabilitation, repair and replacement |

The first step of asset management is to specify what the assets are present in the system. The accessible data are collected during the asset inventory and these data would be size/capacity, construction materials, location, installation date, original cost, replacement cost, condition and performance assessment, original service life and estimated remaining useful life. In general, all data is not available and inventory begins with existing data. It can be improved over time since it is a continuous process. Information audit is an useful way to discover what types of data are available and it can be done by contacting the related departments in the institution. Another important consideration is that which assets should be included. It is can be determined by considering criticality, cost, health and safety (AMSA, 2002).

After asset inventory, the condition of the assets is specified. This condition data is necessary to decide the need and timing of preventive/remedial actions and it is significant for prevention of service or economic loss. The condition grading standards can be simple such as 1-5 rating scale. Additionally, condition assessment can be made by using advanced methods with more sophisticated grading standards. While assessing the conditions of assets, some issues should be considered such as risk management, maintenance management planning and data collection techniques. The continuous development of condition assessment data provides verifiable predictive decay curves for specific asset types and prediction of their remaining life before failure. For condition grading system, the simple approach for passive assets are ranked 1 to 5 and while 1 represents very good condition that requires only normal maintenance, 5 represents asset unserviceable that requires replacement (Table 5). In the intermediate approach, an expanded condition rating is developed to suit asset types, failure modes and evidence distress. It ranks between 3 and 5.8, the scores between 3 and 3.8 represents level of service maintenance, between 4 and 4.8 is for major upgrade requirement and between 5 and 5.8 means that asset is basically unserviceable (Table 6). Lastly, the sophisticated approach can be used to assess the condition depending on up to ten different parameters. Its condition scores can be in between 0 and 1000 or they can be still divided into the base scores of 1 to 5 if required. While the simple and intermediate approaches help to develop predictive decay curves, the sophisticated approach generates more accurate curve thanks to using greater numbers of parameters and it gives more certainty for the asset current condition (IPWEA and NAMS.AU, 2012).

**Table 5.** Condition grading system of the simple approach (IPWEA and NAMS.AU, 2012)

| Rank | Description of Condition |
|---|---|
| 1 | Very Good Condition<br>Only normal maintenance required |
| 2 | Minor Defects Only<br>Minor maintenance required (5%) |
| 3 | Maintenance Required to Return to Accepted Level of Service<br>Significant maintenance required (10-20%) |
| 4 | Requires Renewal<br>Significant renewal/upgrade required (20-40%) |
| 5 | Asset Unserviceable<br>Over 50% of asset requires replacement |

**Table 6.** Condition grading system of the intermediate approach (IPWEA and NAMS.AU, 2012)

| Rank | Description of Condition | |
|---|---|---|
| 3.0 | Level of Service Maintenance | Minor |
| 3.4 | | Average |
| 3.8 | | Significant |
| 4.0 | Requires Major Upgrade | Minor |
| 4.2 | | Average |
| 4.4 | | Medium |
| 4.6 | | Substantial |
| 4.8 | | Significant |
| 5.0 | Asset Basically Unserviceable | Minor |
| 5.2 | | Average |
| 5.4 | | Medium |
| 5.6 | | Substantial |
| 5.8 | | Significant |

Level of Service (LOS) is defined in the Asset Management Guidance for Water Systems (2013) as the way in which the stakeholders demand from utility to serve over the long period. LOS of a utility should be within the range of minimum (regulations) and maximum (absolute capabilities of assets).

Critical asset identification is another important step in asset management. Critical assets are the ones having a high consequence of failure (IPWEA and NAMS.AU, 2012). There are some factors to determine the probability of failure and these are asset age, condition, failure history, maintenance records and knowledge about how the asset is likely to fail. There are ranking systems for the probability and consequences of failure levels (Table 7 and Table 8). The probability ranking ranges from 1 to 5 as from improbable to imminent, respectively. Consequence ranking also ranges from 1 to 5 and while level 5 represents “Catastrophic disruption”, level 1 represents “Insignificant disruption” (DEO, 2013).

**Table 7.** Ranking for Probability of Failure (PoF) (DEO, 2013)

| Description | Performance Rating | Failure of Individual Item | Type of Failure |
|---|---|---|---|
| Imminent | 5 | Likely to occur in the life of the item | Continuously experienced |
| Probable | 4 | Will occur several times in the life of an item | Will occur frequently |
| Occasional | 3 | Likely to occur sometime in the life of an item | Will occur a few times |
| Remote | 2 | Unlikely but possible to occur in the life of an item | Unlikely, but can reasonably be expected to occur |
| Improbable | 1 | So unlikely, it can be assumed occurrence may not be experienced | Unlikely to occur, but possible |

**Table 8.** Ranking for Consequences of Failure (CoF) (DEO, 2013)

| Description | Level | |
|---|---|---|
| Catastrophic Disruption | 5 | Massive system failure, severe health affect, persistent and extensive damage |
| Major Disruption | 4 | Major effect, major loss of system capacity, major health effects, major costs, important LOS compromised |
| Moderate Disruption | 3 | Moderate effect, moderate loss of system capacity, moderate health effects, moderate costs, important LOS still achieved |
| Minor Disruption | 2 | Minor effect, minor loss of system capacity, minor health effects, minor costs |
| Insignificant Disruption | 1 | Slight effect, slight loss of system capacity, slight health effects |

After estimating probability and consequences of failure, a risk analysis is necessary to evaluate risk by multiplying PoF and CoF. A standard risk matrix is shown in Table 9 (Gay & Sinha, 2014).

**Table 9.**Standard Risk Matrix (Gay & Sinha, 2014)

| | **Probability of Failure** | | | | |
|---|---|---|---|---|---|
| **Consequences of Failure** | 1 | 2 | 3 | 4 | 5 |
| 5 | Medium | Medium | High | Extreme | Extreme |
| 4 | Medium | Medium | High | Extreme | Extreme |
| 3 | Medium | Medium | High | High | High |
| 2 | Low | Low | Medium | Medium | Medium |
| 1 | Low | Low | Medium | Medium | Medium |

Life cycle costing is also essential to deal with assets over time. It includes four basic options which are operate and maintain the existing assets, repair the assets as they fail, rehabilitate and replace the assets. Since every option has its own costs and consideration, the purpose is the find optimal way to allocate the funds between each of these categories. In general, the most expensive option is replacement of assets. That's why, the most economical way is to keep the assets in service as long as possible (ENV, 2006).

As modern societies aimed to have sustainable development and environmental protection, the water infrastructure systems have gained more attention recently (Rokstad, Ugarelli and Sægrov, 2016). The water infrastructure systems include physical components such as pipes, valves, tanks, pumps, wells and hydrants. They supply water to the communities with the consideration of adequate service levels, reasonable costs and low risks. When the water system ages and deteriorates, the assets making up this system lose value, operation and maintenance costs increase. Additionally, this aging and deterioration make the delivery of the water service to people difficult. That's why an asset management plan is necessary to control the limited water resources and to balance the performance (service levels), risks and costs of these systems (Rokstad, Ugarelli and Sægrov, 2016).

Rita et al. (2007) emphasized that identifying and evaluating the assets is necessary process for determining the primary components of a sewer system. The components are named and linked with some information systems such a GIS models. In the given study located in Italy, it was aimed to describe a methodology for asset management strategies in a wastewater network. The information about the length, the types and numbers of hydraulic structures of the system were given. There were two factors decided to investigate both the structural and hydraulic performance of the system. These were the existence of serious structural problems, the extent and scale of past flooding problems. The network was modeled by using the InfoWorks hydraulic model. The database included the topology of the network, size, shape, material and invert levels of pipes and manhole cover levels. Moreover, groundwater levels, hydraulic load of surcharge, soil type, age construction techniques and some operational data such as maintenance/blockage/rehabilitation history were included. When the historical perspective on asset management is examined, it is seen that infrastructural asset management have existed in the U.S. since mid-1800s. Boston established its Cochistuate water supply system in 1846 and its administration was in charge of Cochituate Water Board. The Board prepared annual reports including information about revenues and cost, reservoir levels, list of consumers, the number of fixtures (bathtubs, water closets etc.), length of pipe laying and pipe repairs. Although enough data was provided in the annual reports, it was hard to develop meaningful assessment for the system condition (Jacobson, 2013). Moreover, Bhagwan (2009) developed an asset management for Rand Water major pipeline located in South Africa. While developing, reliable and comprehensive information approach was used. It was meant to have good records of infrastructure performance have been kept over the years (including when built, repair records, refurbishment records, leakage records) and environmental factors (including dolomitic areas, water and groundwater chemistry, surface encroachments), to link all to a common database and to back-up by a database of experience elsewhere, with comparable infrastructure in usefully similar conditions. In other study, Colorado Springs Utilities and Laramie Water generated pipe inventory and break history data by using utility's geographic information system for development of a pipe failure assessment model. It was observed that some data-related deficiencies such as missing and inconsistent pipe material, diameter, length, identification number and installation date were existed (Rogers & Grigg, 2009).

Water Industry Commission for Scotland (WICS) prepared asset inventory and system performance guidance for Scottish Water First Draft Business Plan. After asset inventory part, confidence grade guidance was developed and given to provide a reasoned basis for qualification of asset information in terms of reliability and accuracy. Reliability bands change between "A" to "D". While "A" band meant that asset information was obtained by using very reliable techniques such as sound textual records and properly documented investigations, “D” band represented unconfirmed verbal reports and cursory inspections. Moreover, accuracy bands were represented by 1 to 6 as +/- 1% to +/- 100% accuracy, respectively. As a result, if confidence grade is A4, it means that the asset information data based on sound records and estimated to be within +/-25%. In the guide, the calculation of Modern Equivalent Asset Value (MEAV) is given to estimate the standard costs required to replace assets. This value can be allocated according to asset life, condition and performance. The condition grading is ranked from 1 to 5 as “very good” to “very poor”, respectively. While “1” means that there is no internal/external degradation and bursts, “5” value is given for the water mains with extensive pipe failures and significant external and internal degredation (WICS, 2007).

Moreover, EPA (2015) explains a condition assessment program for underground pipes. In the asset assessment part, it was emphasized that a planned approach should be used to focus on high risk pipes to make the assessment easier on a short-term schedule. The details of Pipeline Assessment Certification Program (PACP) numerical grading system were also given. The numerical system ranged from 1 to 5 as from having a minor defect to a severe defect, respectively. This severity ranking was made based on the immediate defect, risk of failure and rate of deterioration. PACP also had a quick rating system using four numerical characters. While the first two numbers represented the first highest severity grade occurring along the pipe and its number of occurrence times, the last two numbers represented same things for the second highest one. This type of coding was very helpful to grade the pipe defects quickly and to prioritize the operation, maintenance, repair and replacement decisions (EPA, 2015).

Khazraeializadeh et al. (2014) made a study to evaluate and compare three condition assessment protocols for the City of Edmonton, Canada. These protocols were the Pipeline Assessment and Certification Program quick grading method (PACP), the Manual of Sewer Condition Classification fourth edition (MSCC-4) and the City of Edmonton’s Sewer Physical Condition Classification Manual (SPCCM). Every protocol had a particular range of possible values for the defect scores. Deduct values ranged from 1 to 115 in the SPCCM; from 1 to 165 in the MSCC-4; and from 1 to 5 in the PACP. In SPCCM, total, mean and peak scores were obtained from all defect scores in a pipe segment and the overall condition grade was the highest grade produced by thresholds of total, mean and peak scores. In contrast, MSCC-4 protocol used only the peak scores to grade overall condition. However, PACP protocol used a weighted average by considering the severity and frequency of each defect. In the study, twenty inspection surveys were graded by using these three protocols. The results showed that the protocols have significant differences. Since the PACP protocol used a weighted average method, it represented better conditions for sewer systems than other two protocols.

Level of Service is also necessary to set goals for the utility (DEO, 2013). Shea-Beers (2005) stated that service levels are a commitment of the utility to provide service at a specified level of reliability and quality. It can be performance-related depending on equipment failures and performance driven by faults or customer/regulatory-related depending on complaints, response times and information availability. Han et al. (2014) made a study to evaluate customer-driven level of service for water infrastructure systems based on a survey questionnaire having 800 answers from eight provinces in Korea. Safe to drink and service life of water pipes of the 13 factors considered as governing customer satisfaction with regard to water service were in the highest priority improvement quadrant in the water service improvement priority analysis. It was found that there are clear gaps between the views of customers and utility managers about the water service and maintenance budgets should be allocated in a way that provides maximized and balanced improvement in customer satisfaction and engineering performance. Baird (2011) also stated that every utility should provide assurance to the community that the water, wastewater, and storm drain systems have or will have a financially sustainable level of service at an acceptable level of risk.

Halim and Mohammed (2014) made a study to identify and developed the criteria and elements for the identification of assets' critical levels by using analytic hierarchy process. In the study, the probability and consequences of failure were also two evaluation condition as for main criticality analysis criteria. While the probability evaluation included physical condition, site, failure history, assets life, maintenance practice and historical knowledge, social, financial and environment aspects were evaluated by consequences of failure. Then, a matrix was developed at which the strengths of assets can be compared with each other. Ward (2015) also used quantitative risk analysis to provide an established platform for decision makers so that they can prioritize expenses based on criticality of assets. The parameters used for analysis were severity ranging from 1 to 5 and extent ranging from A to E. Moreover, unique weighting factors for sub-component of the assests were taken into account such as effect of pipe condition on water quality, structural stability or health and safety. In the asset management of Rand Water major pipeline located in South Africa, a disciplined approach was developed for asset management decisions and it provided comprehensive information to identify the problem probability profiles of all significant infrastructure elements. Identifying the strategic importance of all these infrastructure elements and matching the risks (i.e. consequences of infrastructure failure) with the problem probability profiles were also included in the approach. Last step was the identification of attention type in order to specify priority, namely, to consider the alternatives and options to cover the identified risks. Rand Water completed a priority ranking in 2005 of the pipelines that needed renovation over the following next five years. The priority ranking was primarily based on the importance of the pipe to provide reliable supply, the type of the pipe, the age of the pipe, the performance record of the pipe and water quality criteria (Bhagwan, 2009).

Barrie and Beste (2013) stated that utilities need to develop a comprehensive funding strategy in order to remain sustainable into the future and provide their customers with the level of service desired at the lowest cost possible. Moreover, Czegledi (2016) emphasized that investment, operational, replacement and end of life costs represents direct life cycle costs and these costs can be appropriate and practical evaluation criteria to use in procurement procedures. A long term funding plan eases to pay for replacement of the assets when they reach the end of their useful lives. It also prevents unnecessary economical expenses for the assets (Himmelberger, n.d.). For example, a utility was able to use a business case evaluation process to determine that they were going to invest $5 million dollars into the wrong capital project. By changing the project to one that was more appropriate to the system needs, they were able to achieve a greater level of service for the customers for only $50,000, a savings of $4,950,000. This change also freed up the $5 million to be spent on a project elsewhere in the state (Himmelberger, n.d.).

# CHAPTER 3

# METHODOLOGY

In this study, it was aimed to develop sustainable water management strategies for METU Campus. The study consists of three main components which are water management, stormwater management and asset management. In this chapter, the methodologies followed for these components were explained in detail.

Water resources of METU campus and major water demands in the campus were investigated in the water management part. Runoff reduction, reuse alternatives and runoff estimation were evaluated in the stormwater management part. Asset classification and risk analysis were conducted in the asset management part. Lastly, a water management plan was proposed for METU Campus. The outline of this study is summarized in Figure 5. The details of the components are given in the following sections.

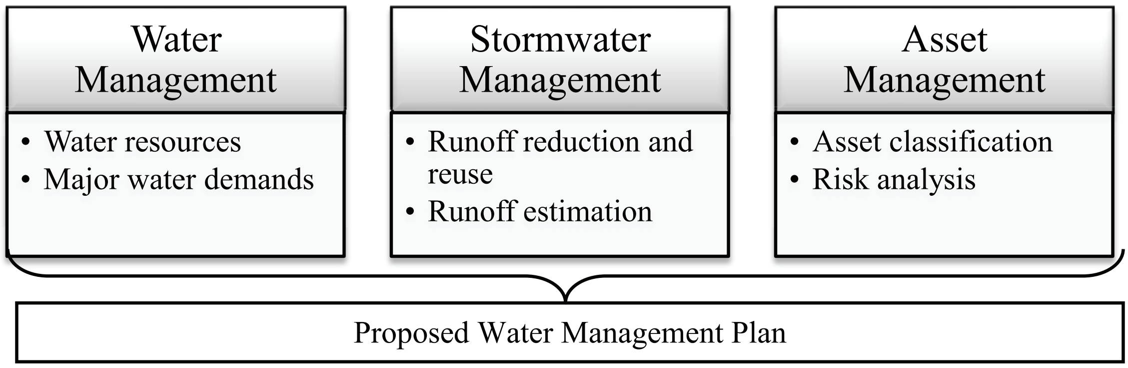



**Figure 5.** Components of the study

**3.1. Water Management**

In this section water resources and major water demands of the campus were studied. Figure 6 indicates the methodology of water management part in this study.

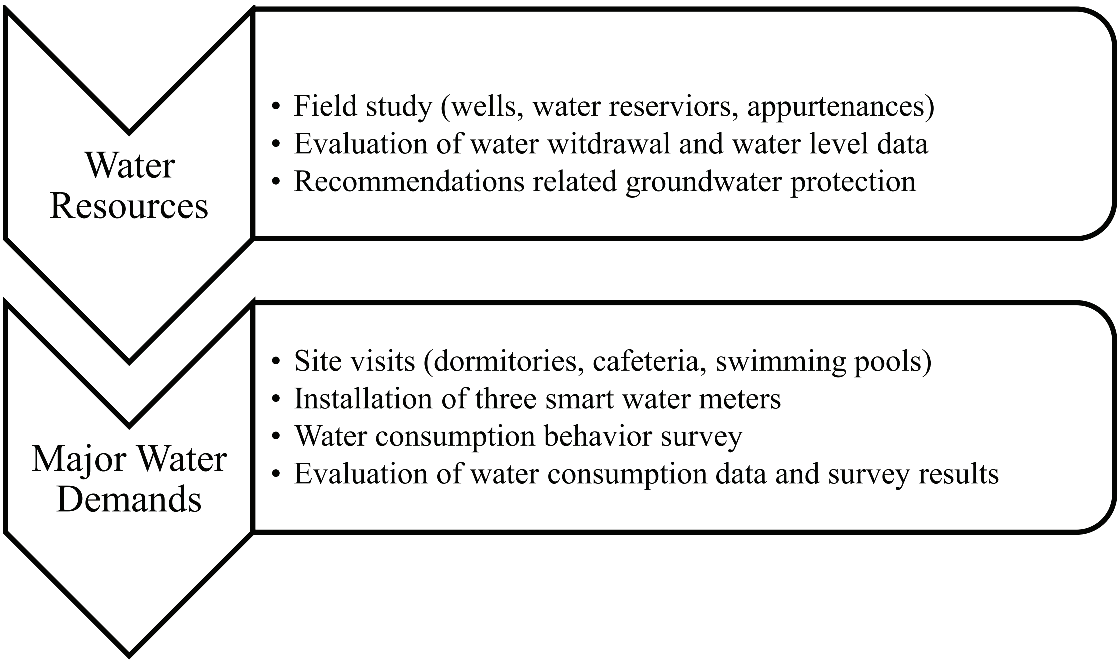



**Figure 6.** Methodology of water management in the study

**Water Resources**

In this study, it was aimed to investigate the current situation of water supply network of the campus. The water supply network of the campus is shown in Figure 7. Water is supplied to the campus from groundwater wells located near Lake Eymir. First a field study was conducted on June 11, 2015 with Bekir Bakırcı who is an experienced staff from METU Heat and Water Management Department. In field study, wells, pumping station and water reservoirs were visited and water supply network of the campus was observed (Figure 7). Information about appurtenances of the network were obtained by personal communication with İlhan Sepin who is the Manager of METU Heat and Water Management Department and Yusuf Özen who is responsible for the pumping station. In addition to that, the water level and withdrawal data for a period of 2008-2018 were obtained from the pumping station near Lake Eymir. After evaluation of these data, current status of groundwater was also studied to develop a few management strategies for its protection.

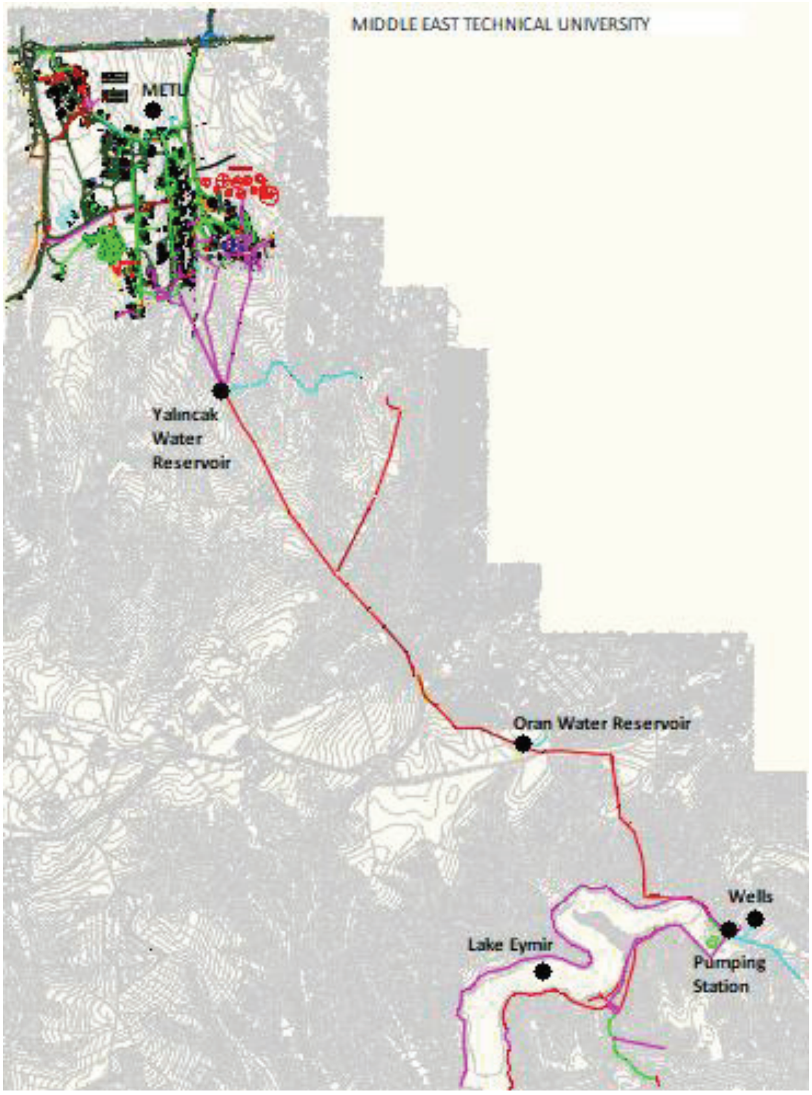



**Figure 7.** AutoCAD drawing of METU potable water supply network obtained from METU Heat and Water Management Department (the colors of these drawing have no special meaning).

**Major Water Demands**

In this part of the study, it was aimed to quantify major water consumptions of the campus and to develop some management alternatives to decrease these consumptions. Some site visits were made to high water demand locations of the campus. The dormitories were visited on March 16, 2017, cafeteria on March 22, 2017 and swimming pools on July 17, 2017. In these site visits, information about the current situation of water fixtures and operational water usages were obtained. In addition to that, three smart water meters were installed to measure water consumption in five dormitories and cafeteria in the context of the project titled 'A Green Campus Application: Sustainable Stormwater Management in METU Campus' with project number BAP - 08 -11 - KB2014K120600-2. Water consumption data between October, 2015 and February, 2018 obtained from these smart water meters was evaluated. A survey was also conducted in these five dorms to investigate students' water consumption behavior. The survey is given in APPENDIX C. Water consumption pattern in METU dormitories was evaluated based on these real time measurements supported by the outcomes of this survey which aimed to understand the social behavior. After that, different water saving strategies were evaluated for Dorm 1 and Dorm 3 as an example in order to assess effects of such measures on water consumption. Operations of swimming pools and cafeteria were also investigated in terms of water consumption. Necessary information about their operations was obtained through interviews conducted with Ebru Ercan Çelik who is the Director of Dorm 1, Nurcan Altınay who is the Assistant Manager of Swimming Pool Complex and M. Fatih Şahin who is the Food Engineer in the Cafeteria. Reasons behind the water consumptions in dormitories, cafeteria and swimming pool were specified and some management practices were recommended to decrease water consumptions at these high-demand locations.

### 3.2. Stormwater Management

In this part of the study, runoff reduction and reuse alternatives and runoff estimation were investigated (Figure 8).

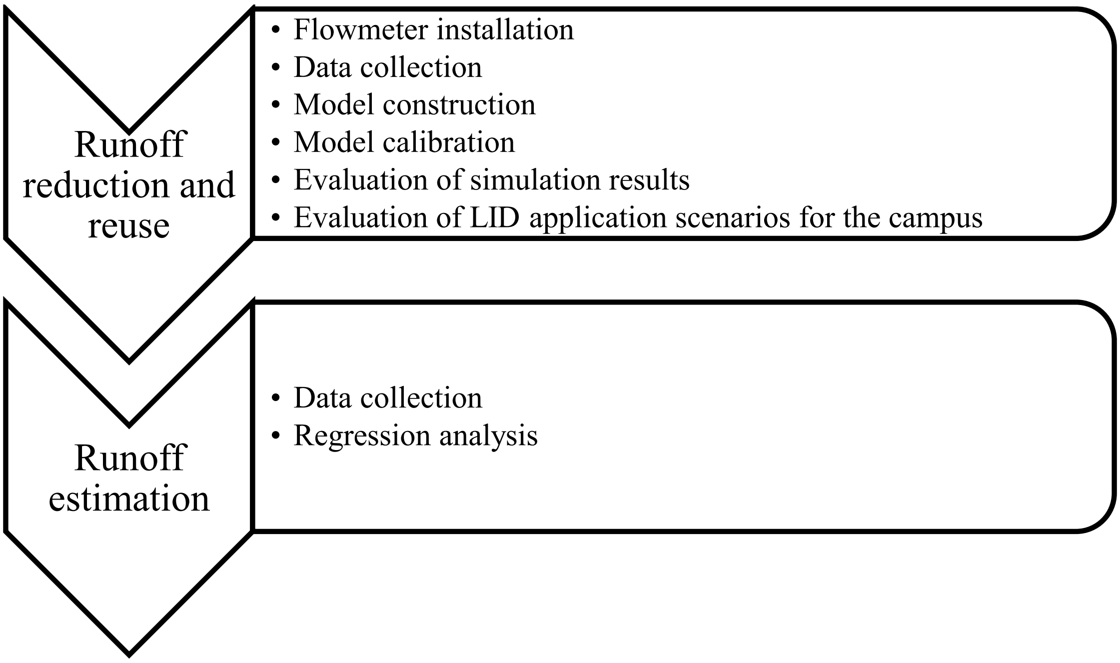



**Figure 8.** Methodology of stormwater management in the study

**Runoff Reduction and Reuse**

It was aimed to quantify the runoff to develop low impact development application alternatives so that the surface runoff can be decreased or can be reused for different purposes in the campus. A flowmeter station and a meteorological station were installed in the context of the project titled 'A Green Campus Application: Sustainable Stormwater Management in METU Campus' with project number BAP - 08 -11 - KB2014K120600-2. In this study, the location of the flowmeter station was changed three times during 2015-2017 period in which it collected data. These three changes were required due to construction activities in these regions in campus, thus was not due to our study plan. These three locations are shown in Figure 9. The surface runoff data from flowmeter station and precipitation data from meteorological station (Figure 10) were obtained and analyzed. A rainfall-runoff model was constructed for METU campus by using SWMM to investigate stormwater collection system and to evaluate potential benefits of Low Impact Development (LID) applications in the campus. In data collection part, watershed delineation was carried out to identify the subcatchments in the campus by using GIS tools. Model input data which are meteorology, land use, soil and topography data were obtained from different data resources such as meteorological and flowmeter stations and General Directorate of Meteorology by using different tools such as ArcGIS and AutoCAD. Surface runoff data obtained from the flowmeter station (FS3) (Figure 9) were used in model calibration. After obtaining satisfactory simulation results, LID application scenarios were evaluated in terms of runoff reduction and reuse potentials for the campus.

**Runoff Estimation**

In this part of the study, it was aimed to calculate surface runoff in an easier and quicker way by using an empirical method. A number of problems were experienced during the calibration of SWMM model due to data limitations and a major leakage that occurred in the pipe system. Thus, possibility of fitting a regression equation instead of developing a hydrologic model to simulate the rainfall-runoff process at the campus was tested. A regression analysis was performed as an empirical model in order to estimate total surface runoff and identify the independent variables that the total surface runoff mostly depended on. In the analysis, the total runoff data obtained from all three locations (Figure 9) and corresponding meteorological data and catchment characteristics (APPENDIX D) were used as dependent variables and independent variables, respectively. Moreover, some recommendations were given for the stormwater management of the campus for further studies.

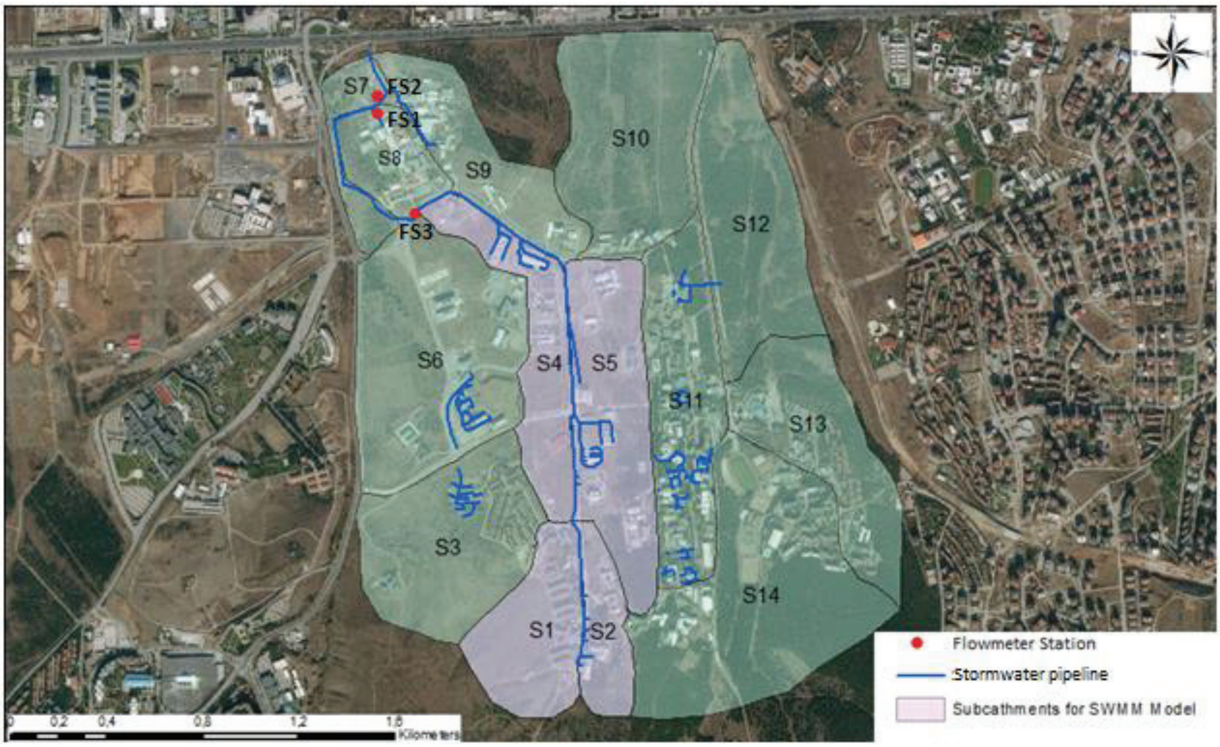



**Figure 9.** Flowmeter Station Locations, Stormwater pipeline and Subcatchments of METU Campus

**Figure 10.** Flowmeter station (at left) and meteorological station

### 3.3. Asset Management

In this study, the current situation of the water infrastructure system in the campus was investigated through an asset management approach. Firstly, preliminary preparation was made for assets. After that, they were evaluated in terms of their risks of failure (Figure 11).

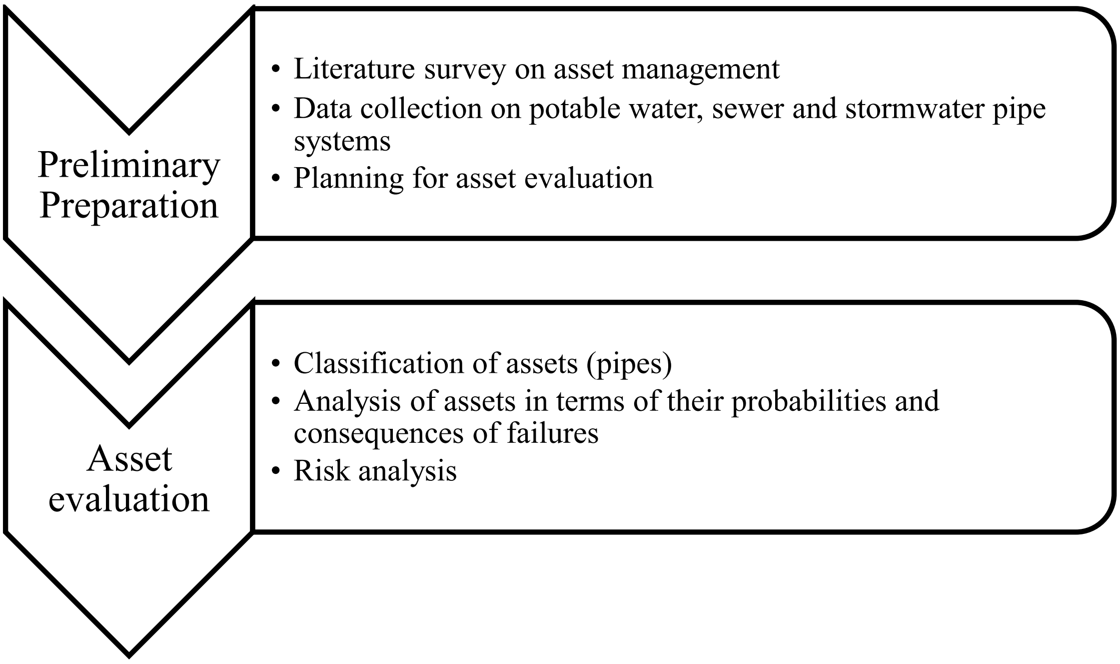



**Figure 11.** Methodology of asset management in the study

**Preliminary Preparation**

In this part, it was aimed to collect sufficient data so that water infrastructure systems of the campus can be evaluated. In preliminary preparation of this investigation, literature survey was made to review case studies from around the world. Necessary data for campus infrastructure system was obtained from an AutoCAD drawing of water pipeline systems prepared by an experienced staff and personal communication with personnel of METU Construction Affairs. After literature survey and data collection, asset evaluation steps for the campus were conducted.

**Asset Evaluation**

It was aimed to determine the critical assets of water infrastructure systems of the campus and develop some alternatives to provide their sustainable management. Assets were classified according to their characteristics such as materials and remaining lifetimes. They were ranked and analyzed according to their probabilities of failures and consequences of failures. Their risks of failure were evaluated according to the generated risk matrix that summarizes the probability of failure and consequences of failure together. Finally, a methodology for management of these pipeline systems was given to aid decision-makers.

# CHAPTER 4

# WATER MANAGEMENT IN METU CAMPUS

## 4.1 Introduction

As climate change affects and growing population simultaneously increase water demand and decrease its availability, water conservation and watershed protection becomes more important. Although water use is essential in all organizations, wasting water can contribute to water scarcity locally. Water scarcity not only affects drinking water supplies but also negatively affects agricultural activities and causes landscape degradation. Water levels can also decrease to levels where they cannot be recovered with rainfall.

Sustainable water management is the way to plan, manage and use the water. It is necessary to identify challenges facing the water resources and find solutions that promote sustainable management of water resources. It gives organizations opportunity to conserve available water and use it efficiently.

Being the biggest and most populated campus in Ankara, METU is a major water user in this area and it has responsibility to reduce its water consumption. The water of METU Campus is supplied from the groundwater of the İmrahor Valley. For this reason, besides reducing water consumption, it is also important to protect groundwater resources in order to attain sustainable water management at METU," Currently, the amount of water consumed in the campus and the current situation of the water infrastructure system of the campus are not well known and documented. That is why, developing a sustainable water management plan is necessary for METU Campus. This study is a starting point to protect the water resource in its watershed, to quantify water consumption of the campus and to gain knowledge about water losses due to leakages in its water infrastructure system.

In this part of the study, the water resource of the campus and the way to use water in high demand locations in campus were investigated. Some water conservation and efficiency alternatives were recommended to reduce water consumptions and to protect water resource.

### 4.2. Water Resources of METU Campus

Water supply of the campus originates from Elmadağ Groundwater Basin. There are three deep-water wells operated by METU near Lake Eymir (Figure 1). The ground level of these wells is 973 m and their water levels are measured daily. The water is sent to a pumping station via three pumps. A field study was conducted on June 11, 2015 to investigate the water resource of METU campus and how water is supplied to the campus.

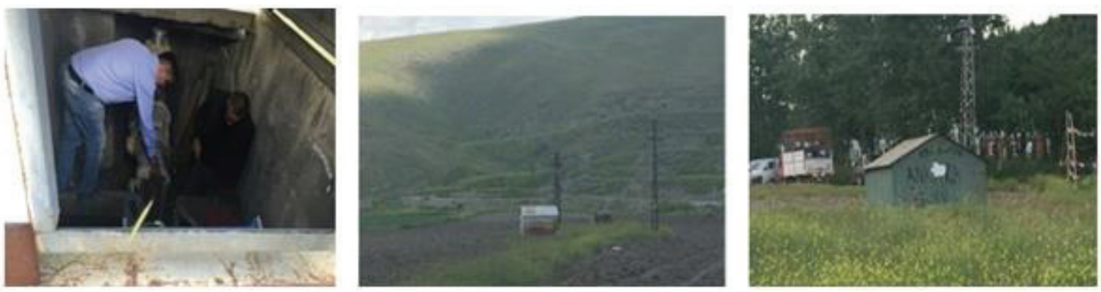


**Figure 12.** Deep Water Wells

The pumping station is located at Lake Eymir region and its ground level is 972.8 m. There are three pumps and each of them has 80 $m^3$/hr capacity. There is a water reservoir which has 200 $m^3$ capacity at the station as well (Figure 13). The water in the reservoir is chlorinated with gaseous chlorine. While the chlorine concentration is 0.5

mg/L in the reservoir, the residual chlorine is 0.1 mg/L in the water used in METU campus. The chlorinated water is pumped from the Pumping Station near Lake Eymir at 972.8 m to Oran Water Reservoir at 1191.5 m which has a capacity of 2,000 $m^3$. Daily water amount sent to Oran Water Reservoir is 2440 $m^3$. Figure 14 shows Oran Water Reservoir and the ventilation system of this reservoir. The water is then transmitted to Yalıncak Water Reservoir located at 1001.4 m by gravity. The capacity of Yalıncak Water Reservoir is 2000 $m^3$.

**Figure 13.** Pumps (left) and control panel (right) of pumping station

**Figure 14.** Oran Water Reservoir (left) and the ventilations (right)

Other than Yalıncak Water Reservoir there are two other reservoirs at METU Campus. One is near the Department of Mining Engineering and the other is in the School of Foreign Language region. Water is distributed from Yalıncak Water Reservoir to the Water Reservoir near the Mining Engineering Department and from there to the water reservoir near the School of Foreign Language. In addition, a waterline supplying water from ASKİ is connected to Yalıncak Water Reservoir and it is used in emergencies. Figure 15 and Figure 16 indicate water supply network of campus water supplied from the wells near Lake Eymir.

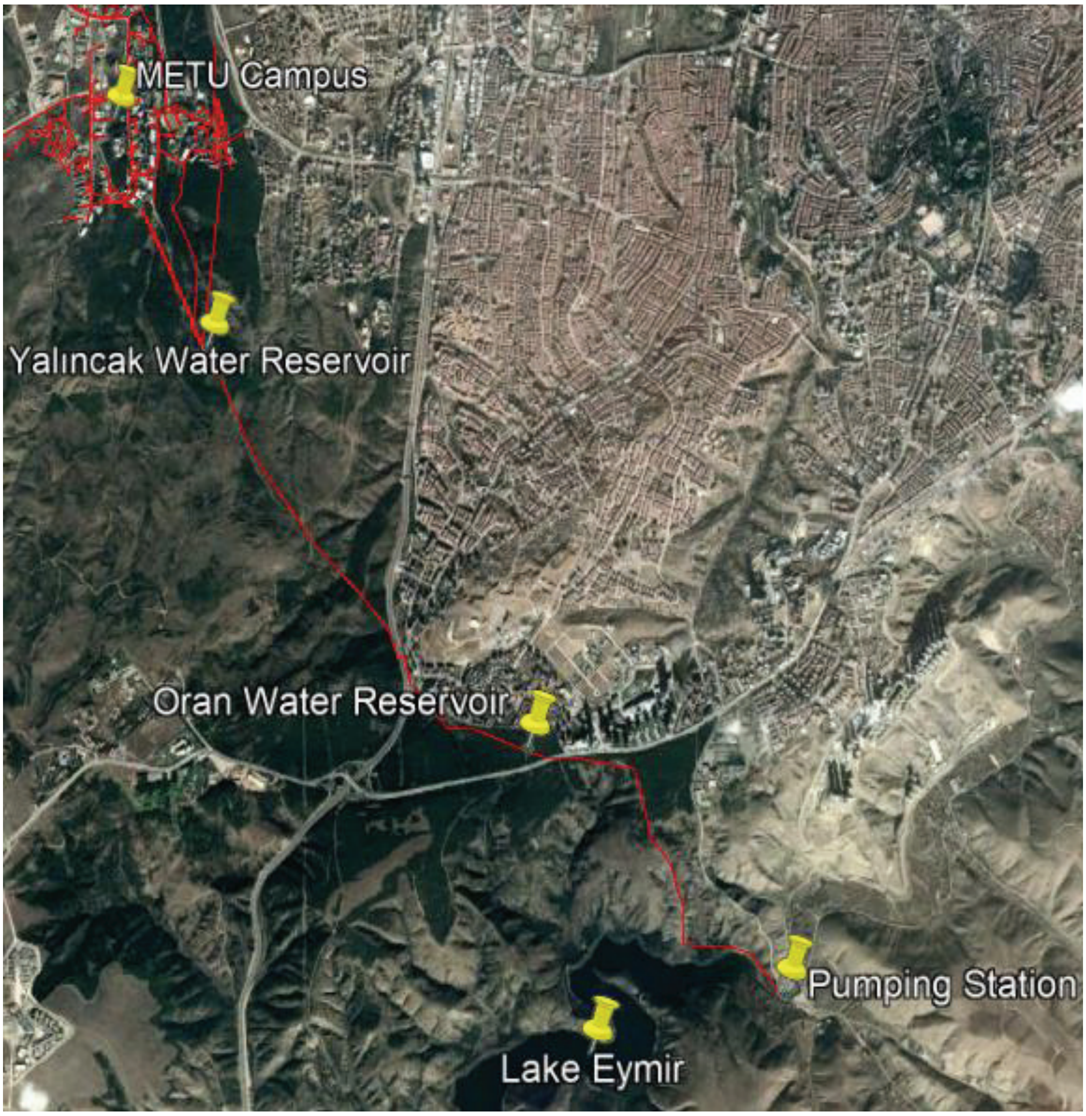



**Figure 15.** Water supply network of campus water supplied from the wells near Lake Eymir (the red line indicates potable water pipeline system of the campus)

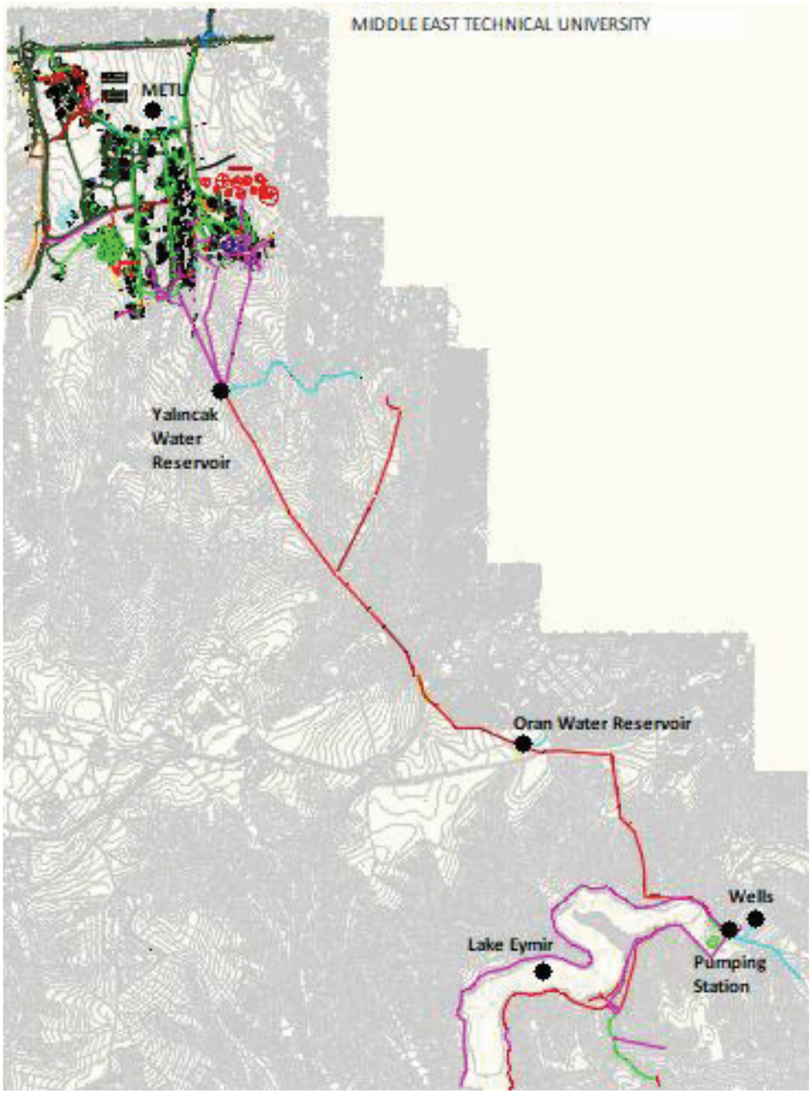



**Figure 16.** AutoCAD drawing of METU potable water supply network obtained from METU Heat and Water Management Department (the colors of these drawing have no special meaning).

Using groundwater resource instead of suppying campus water from city network is critical and it also brings economical benefits to the university. For example, water charge of ASKİ is 12 TL/m$^3$ (ASKİ, 2018). However, the cost of water supplied from wells including chlorination and electricity expenses is 1 TL/m$^3$ as an experienced staff from METU Heat and Water Management Department stated. The yearly saving of METU can be estimated as;

(12 TL/$m^3$-1 TL/$m^3$)*1200000 $m^3$ = 13.2 million TL.

The campus has 13.2 million TL yearly saving due to using groundwater resource. This indicated that this groundwater resource is very critical both environmentally and economically for METU Campus.

### 4.2.1. Water Discharges and Water Levels in the Aquifer

In this study, water withdrawals and levels in the aquifer was evaluated as a part of the current water management practice. Information and data about the quantity and quality of groundwater resource is significant since it is the water supply source of the campus. The water withdrawals and static/dynamic water level data were obtained from the daily logs of pumping station and wells. This water withdrawals and static/dynamic water level data was taken from the personnel of pumping station near Lake Eymir. Figure 17 indicates the monthly total withdrawals from the wells between 2008 and 2018. Yearly total precipitations in Ankara for 2008-2018 years were given in Figure 21 and monthly average temperatures in Ankara for 2008-2011, 2012-2015 and 2016-2018 years were given in Figure 22, Figure 23 and Figure 24, respectively.. These precipitation and temperature data were obtained from General Directorate of Meteorology.

It was observed that there is a continuous increase in withdrawals. In 2008, the water withdrawals from the wells were much less than the other years (Figure 18). The reason of that was the severe drought observed in the region in 2008. As Figure 21 indicates, total precipitation in 2008 was the lowest when compared with other years between 2008 and 2018. In addition to that, average temperatures of spring and summer months in 2008 were high (Figure 22). Therefore, some portion of campus's water demand was supplied from the city network (i.e. ASKİ). Figure 19 indicates the monthly water supplies from wells and ASKİ in 2008. As can be seen from Figure 8, on the average 25000 $m^3$/month water was supplied from ASKİ. There were not drastic changes in water withdrawals in between 2010 and 2016 (Figure 18). However, the water withdrawals increased from 2016 to 2017 (Figure 18). According to the information obtained from senior staff member Mr. Bekir Bakırcı, new vegetable and fruit gardens, and restaurants were constructed in region from Lake Eymir to Bursalı Valley and they have been using water coming from the same groundwater resource. In addition to that, there are two new dormitories and a lodging building having 40 flat capacity built in 2016 at METU Campus. The green areas around these new buildings have been irrigated using the groundwater supply. It means that water consumption in the campus also increased due to new building and additional irrigation areas. These are the reasons of increase in withdrawals from 2016 to 2017.

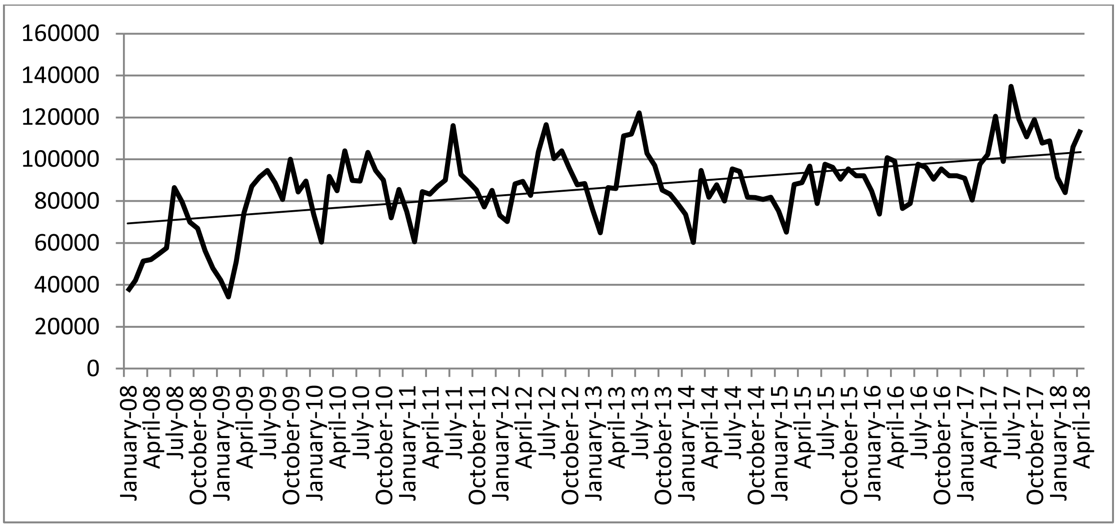



**Figure 17.** Monthly withdrawals from wells in between 2008 and 2018 (until May) years

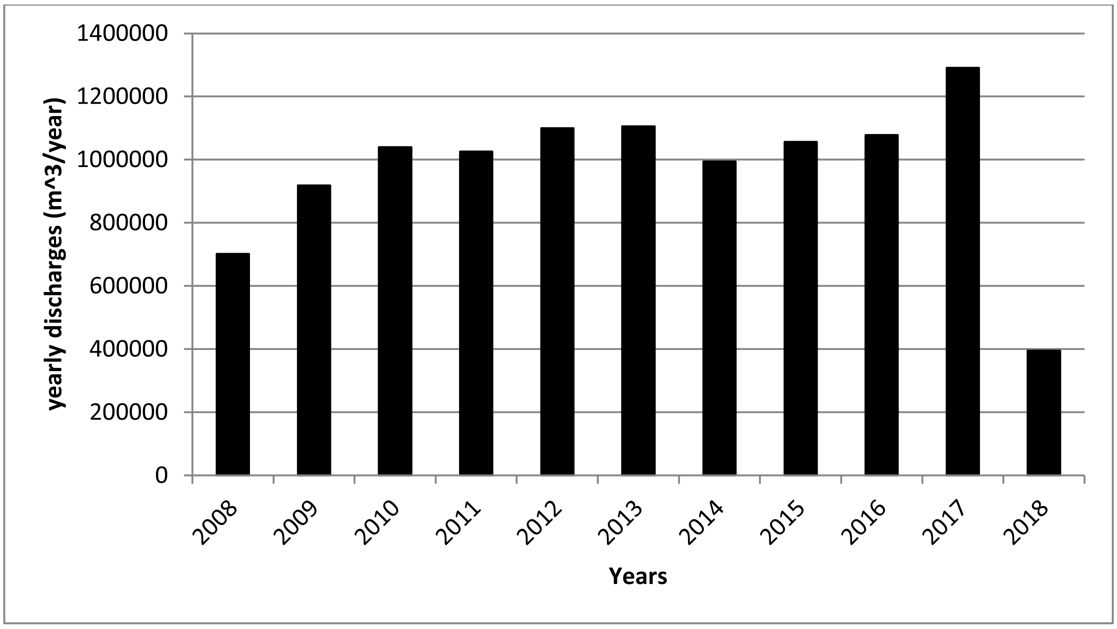



**Figure 18.** Yearly water withdrawals from wells in between 2008 and 2018 (until May) years

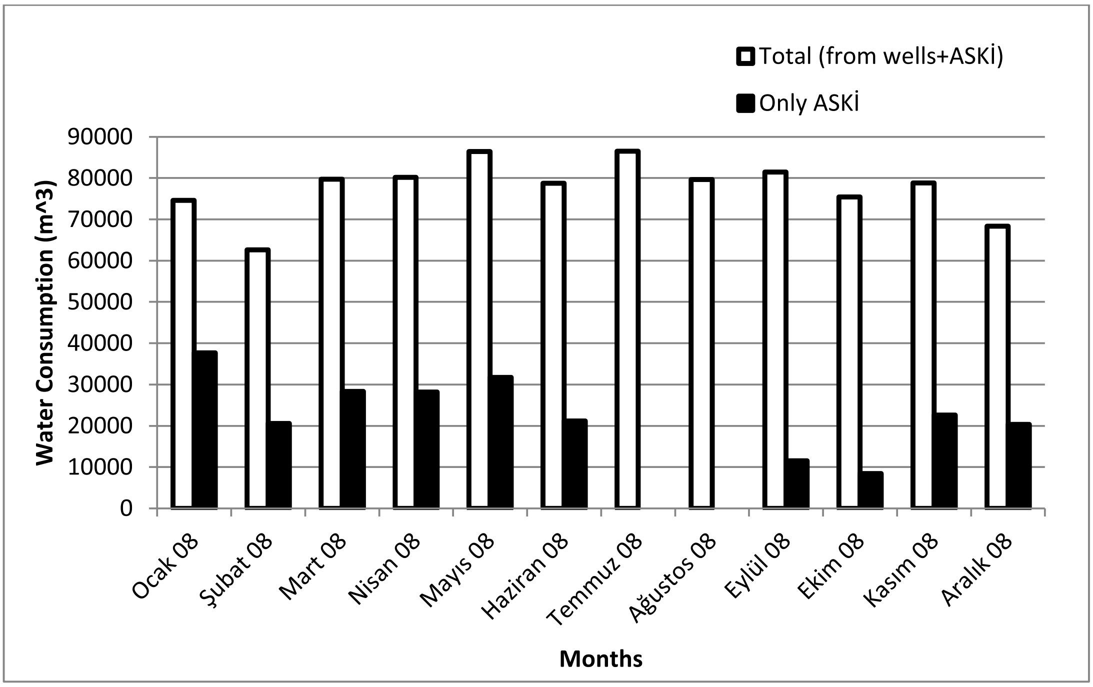



**Figure 19.** Montly total water consumptions in 2008

The static and dynamic water levels measured from 2008 to 2018 are given in Figure 20. The dynamic level in the wells indicates the water level at which the pumps are operating. While the pumps are not operating, it is called the static level. As seen from Figure 20, the lowest static and dynamic levels were observed in 2008. These low levels were due to the severe drought that occurred in this year. After that, a sharp increase was observed in 2009 and then the levels did not show any major increase or decrease until 2017. In 2017, the levels started to decrease again and even more decrease were observed in 2018. The reason of this decrease could be decrease in precipitation from 2016 to 2017 (Figure 21). The groundwater was not fed enough by the rainfall. Therefore, water levels decreased in 2017.

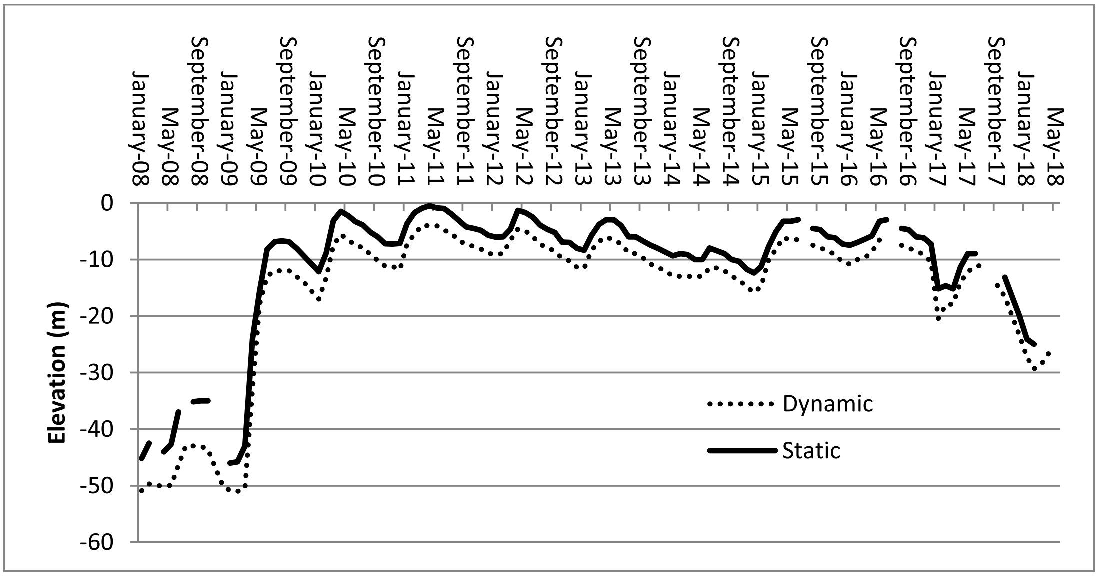



**Figure 20.** Static and water levels in the aquifer

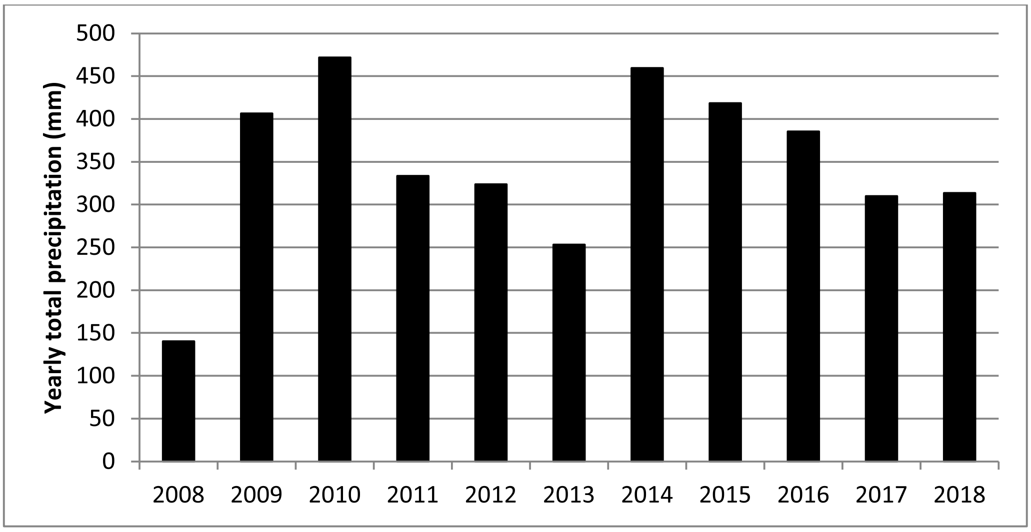



**Figure 21.** Yearly total precipitations (mm) measured in Ankara in between 2008 and 2018 (until July 2018) years (data taken from General Directorate of Meteorology)

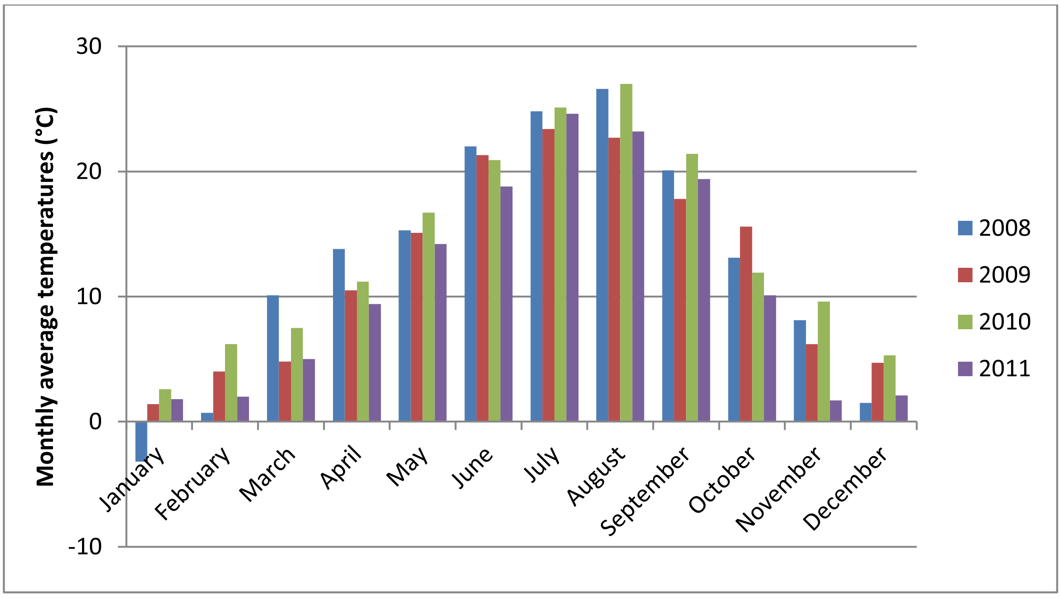



**Figure 22.** Monthly average temperatures measured in Ankara in between 2008 and 2011 (data taken from General Directorate of Meteorology)

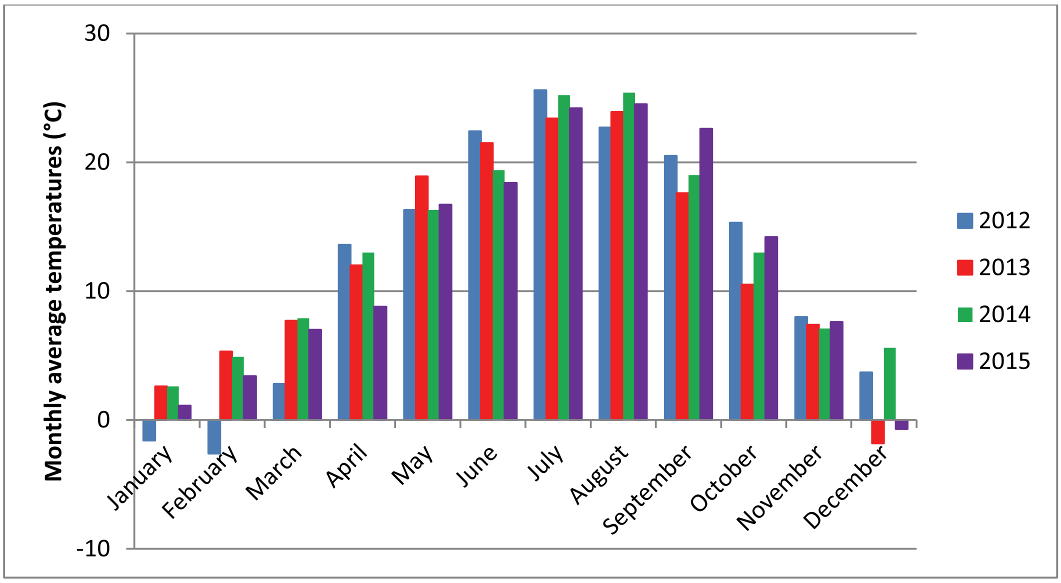



**Figure 23.** Monthly average temperatures measured in Ankara in between 2012 and 2015 (data taken from General Directorate of Meteorology)

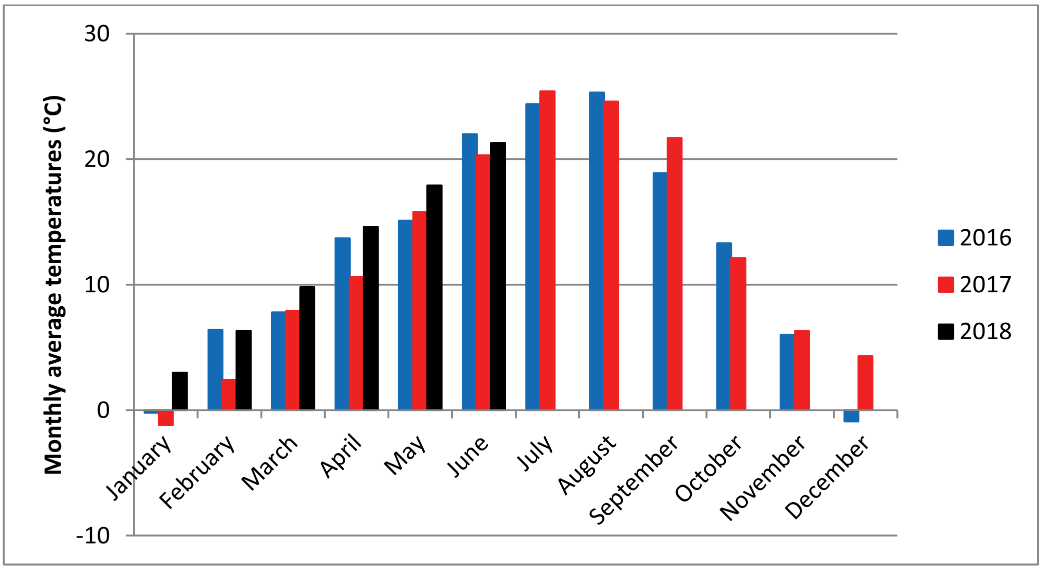



**Figure 24.** Monthly average temperatures measured in Ankara in between 2016 and 2018 (until July 2018) (data taken from General Directorate of Meteorology)

In addition to quantity, the quality of this groundwater resource is also important. The water pumped from the wells is chlorinated in the pumping station before it is sent to Oran Water Reservoir. Microbiological parameters of the water are analyzed regularly in every two months by personnel in the laboratory of Environmental Engineering Department. If there is any complaint about the water such as odour and color from the users, they are also analyzed more frequently. Chemical parameters of the water are also analyzed once in every year. These analysis results are checked with respect to the drinking water quantity standards (TS 266) given by Turkish Standard Institute (APPENDIX A) by the authorities and it complies these standards.

### 4.2.2. Recommendations for Groundwater Resource Protection

Due to the increase in the population of the METU campus, the water demand continuously increases as can be seen from Figure 18. The groundwater level oscillates within a year, and there is a slight decreasing trend in the groundwater level as shown in Figure 20. 2007 and 2008 were very dry years and impact of the drought in these years was critical on the groundwater. Groundwater levels dropped to -50 m in 2008. Thus, it can be concluded that amount of precipitation in and around the groundwater well area effects the groundwater level significantly. Therefore, some groundwater protection actions are necessary for this region. The groundwater protection actions consists of data management, water appropriation and use permitting, demand management, water conservation and reuse, and drought management. A number of authorities are needed to be involved with the protection of this groundwater resource. These are Ministry of Forestry and Water Affairs, Ministry of Food, Agricultre and Livestock, municipalities and universities. They need to coordinate to provide necessary data by continuous monitoring of groundwater's water quality and quantity, to develop some management programs. Some initial recommendations for these fields are provided in following parts.

In terms of data management;

- GIS based maps of existing land use for the region should be generated.
- The existing information such as water withdrawals and water levels should be used to develop GIS based groundwater and aquifer mapping. Some additional monitoring should be provided to accumulate necessary information for sustainable planning and mangement.

- Water quality of the groundwater resource should be monitored regularly.
- The relationship between existing regional development and the problems associated with the impact of rapid urbanization and its effects on groundwater resources should be evaluated, characterized and categorized to support risk assessment and developement of risk management strategies.

In terms of water appropriation and use permitting;

- The groundwater data and modeling should be used to assess whether the water amount requested is reasonable for proposed uses and whether the proposed uses will adversely impact the resource and other users through a vulnerability analysis.
- Groundwater use permit requests in the region should be evaluated by demand analysis, aquifer testing and water level monitoring.
- If it is necessary, withdrawals should be limited in the region or they should be directed to a different aquifer.

In terms of demand management, water conservation and reuse;

- Commercial and residential users and industries should be encouraged by water authorities to implement water conservation strategies and reuse technologies to reduce the water demand. This should be preferred to making changes on the water supply side.
- Guidelines of best management practices for water uses in the region should be developed to provide certain conservation and reuse measures. For example, some guidelines should be developed for treatment of municipal wastewater so that high quality effluent can be used in public areas such as parks and sports fields for cleaning and irrigation purposes.

In terms of drought management;

- Drought conditions should be evaluated on a regional basis. Drought status should be assessed by using regional indicators such as rainfall, streamflow, groundwater levels and reservoir storage
- During a period of drought emergency, coordination should be established with the local government and water suppliers to minimize the detrimental effects of drought on groundwater resources of the region.

### 4.3. Major Water Demands at METU Campus

In this part of the study, METU dormitories, cafeteria and swimming pool center were investigated in terms of water usages for their operational procedures. The aim was to specify water-related problems in these locations and to identify some recommendations to solve them.

Three smart watermeters were installed within the scope of the project titled “A Green Campus Application: Sustainable Stormwater Management in METU Campus” funded by METU. Water consumptions of 5 dormitories (Dorm 1, Dorm 3, Dorm 17, Dorm 18 and Dorm 19) and cafeteria were recorded at these installed smart water meters. The first meter measures the total water consumption of Dorm 1 and Dorm 3 since these dorms’ pipes are connected. The second one measures the total water consumption of Dorm 17, Dorm 18 and Dorm 19. These dorms can mostly represent water consumptions of dorms in Teknokent region and their pipes are also connected. Third one measures the water consumption of cafeteria since it is one of the high water demand locations. The water consumptions belonging to time period between October 16, 2015 and February 5, 2018 were measured and evaluated. Descriptive statistics of these water consumptions are given in APPENDIX B. Water consumption of swimming pools was not obtained since there is not any smart water meter in there. However, water usages of pools’ operational procedures were obtained by having administrative communication.

The meter’s readings can be followed through a web site (Figure 25). Hourly water consumptions were monitored for two and a half years from October, 2015 to February

2018. At the same time, hourly water consumption data was evaluated to understand the degree of possible water leakages (losses) that causes water consumption to increase.

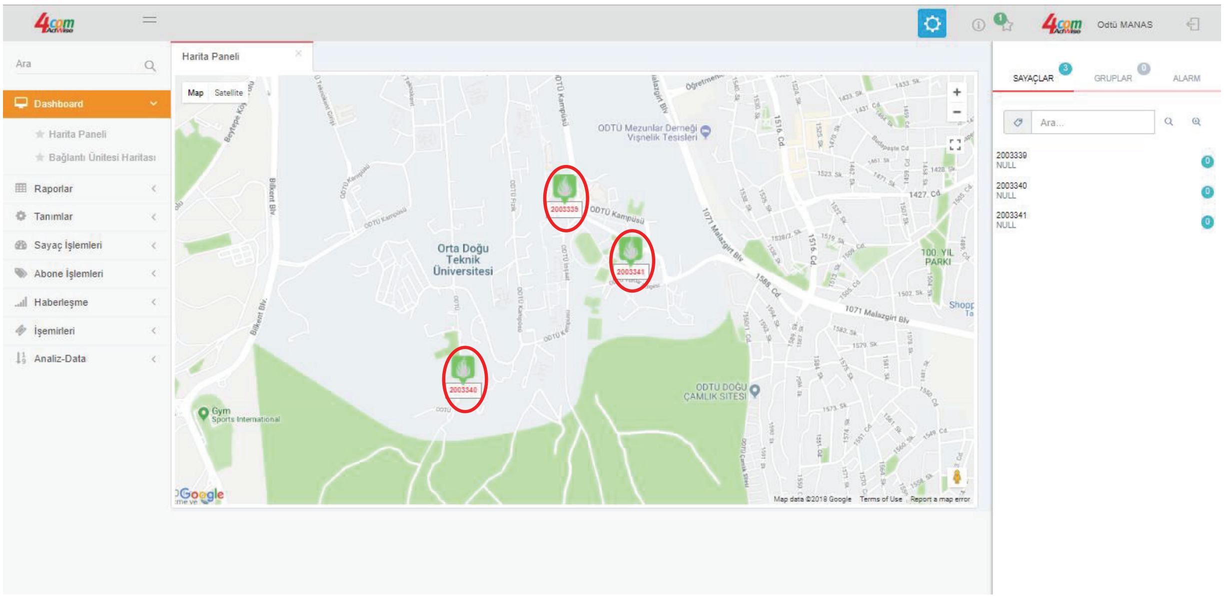



**Figure 25.** The interface used to obtain and evaluate water consumption data from smart water meters and locations of smart water meters (indicated in red circles) installed in METU Campus

Smart water meters are water consumption measurement devices that measure hourly, daily and yearly water consumptions and they provide useful information for developing water consumption control measures. In the process of a typical smart water meter, a wire runs from the water meter into the building then to a communications module located outside the building, which in turn wirelessly communicates interval data to the smart electrical meter. The electrical meter later sends the data to the user. Smart meters can also detect excessive flow and can identify continuous water usage, which might be a sign of leakages in the pipeline (Smart Grid Awareness, 2015).


**Figure 26.** A Smart Water Meter installed in the METU Campus

### 4.3.1. METU Dormitories

There are 19 dormitories in METU Campus and they provide housing for 7000 students. Water is mostly used at toilets, showers and for cleaning purposes. In this study, it was aimed to investigate the current water consumption in dormitories and to recommend some actions for sustainable water management. The flowchart given in Figure 27 summarizes the steps of water consumption evaluation for METU dormitories.

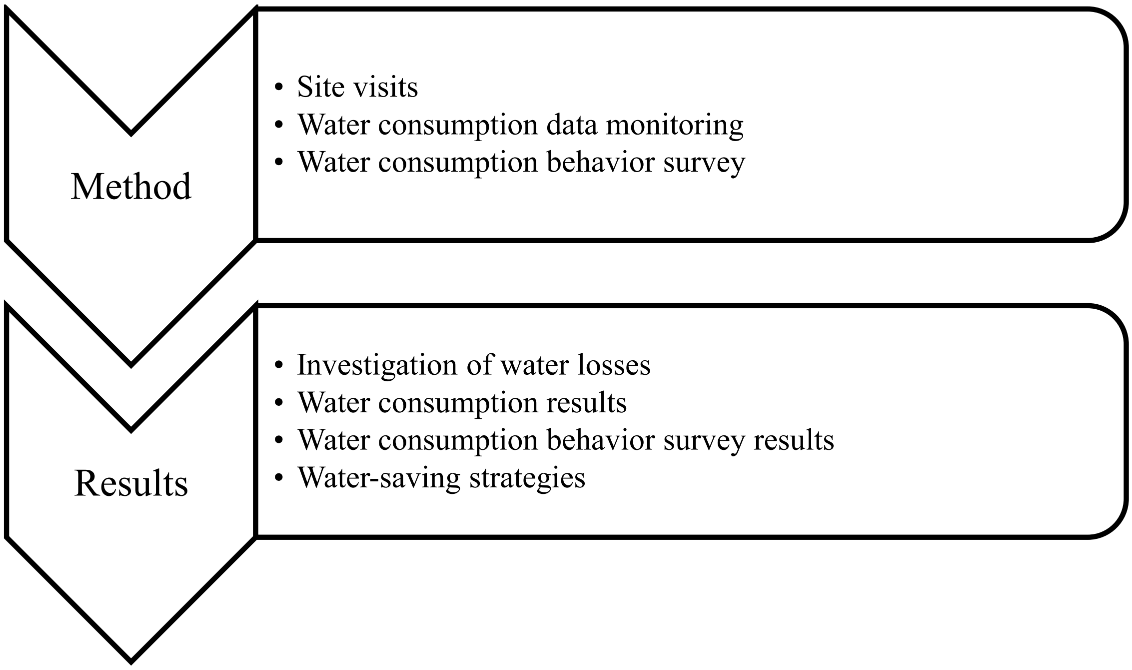



**Figure 27.** Flowchart for water consumption evaluation for METU dormitories

**Method**

Firstly, dormitories were visited to investigate water consumptions at METU dormitories. Observations were reported and evaluated with both water consumption data obtained from smart water meters and water consumption behavior survey.

**Results**

General observations from site visits to Dorm 1 and Dorm 3 are given in this part. In Dorm 1, bathrooms, toilets and kitchens are cleaned in detail on Mondays and Thursdays every week during regular semesters. General cleaning is carried out twice in a week. Cleaning starts at 07:00 in the morning and finishes at 15:30. Daily cleaning of bathrooms, toilets and kitchens is done when necessary. In Dorm 3, toilets, bathrooms and kitchens are cleaned every day in the morning from 10:00 to 11:00 and in the afternoon from 13:30 to 14:00. Since the dormitories were built in 1960s, water-efficient shower heads and faucets were not installed (Figure 28). Most of toilets have single-flush systems.

**Figure 28.** Shower heads and faucets in dorms

Water losses were observed in both Dorm 1 and 3 in March 16, 2017. These losses are due to water leakages from faucet and siphon defects in toilets or urinals. It was stated by the dorm manager that these water losses happen frequently. Figure 29 shows the toilets with broken siphons found in Dorm 1 and Dorm 3 in March 16, 2017.

**Figure 29.** Water losses observed due to toilets with broken siphons observed in Dorm 1 and Dorm 3 in March 16, 2017

The total student capacity of Dorm 1 and Dorm 3 is 776. The total hourly average water consumptions per student in Dorm 1 and Dorm 3 are given in Figure 30. The data was obtained from the smart water meter measuring the cumulative consumption at Dorm 1 and Dorm 3. This hourly variation graph was obtained by calculating average water consumption for every hour during the monitoring period. Water consumptions started to increase at 06:00 in the morning and this sharp increase peaks around 10:00. In these hours, students use toilets, bathrooms and showers mostly before going to their classes. Moreover, the toilets, bathrooms and kitchens are also cleaned in these hours. High consumptions were also observed in between 20:00 and 00:00. Lowest consumptions, approximately 0.001 $m^3$/capita, were measured between 03:00 and 06:00.

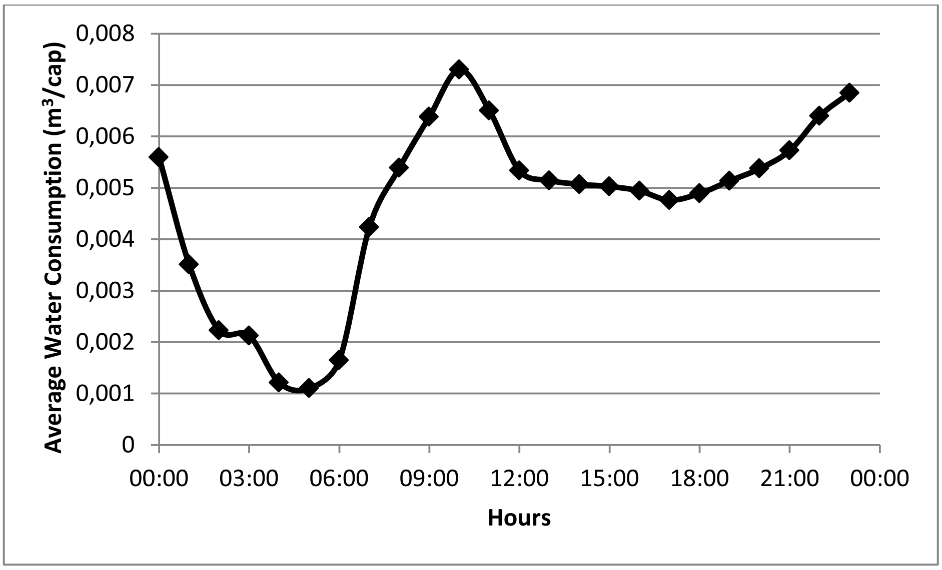



**Figure 30.** Hourly average water consumptions in Dorm 1 and Dorm 3

The graphs in Figure 31 and Figure 32 were obtained by calculating average daily water consumption for every day and month during the monitoring period. When daily average water consumptions were examined, it was observed that there were not major differences between water consumptions in the days of a week. Highest daily consumptions were measured on Wednesday. The reason could be that general cleaning was conducted on Wednesdays. The consumptions in weekends were a little lower than in weekdays. It can be deduced that students spent their free time off campus instead of staying at the dorms during weekends (Figure 31).

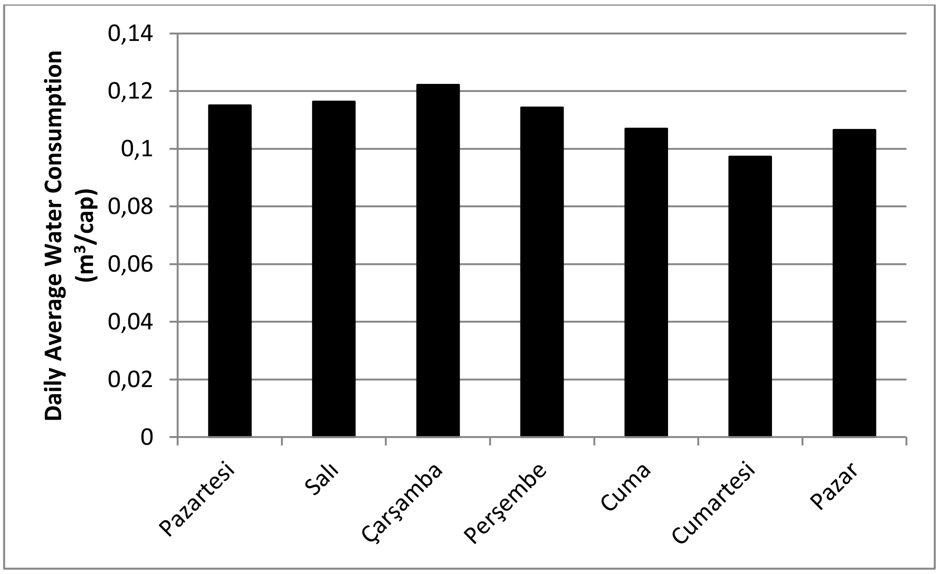



**Figure 31.** Daily average water consumptions in Dorm 1 and Dorm 3

Figure 32 indicates daily average water consumptions according to months. As can be seen from Figure 32, low consumptions were measured in both January-February and June-September periods because these periods are the mid-term and summer breaks, respectively. On the other hand, there were not major differences between water consumptions in other months.

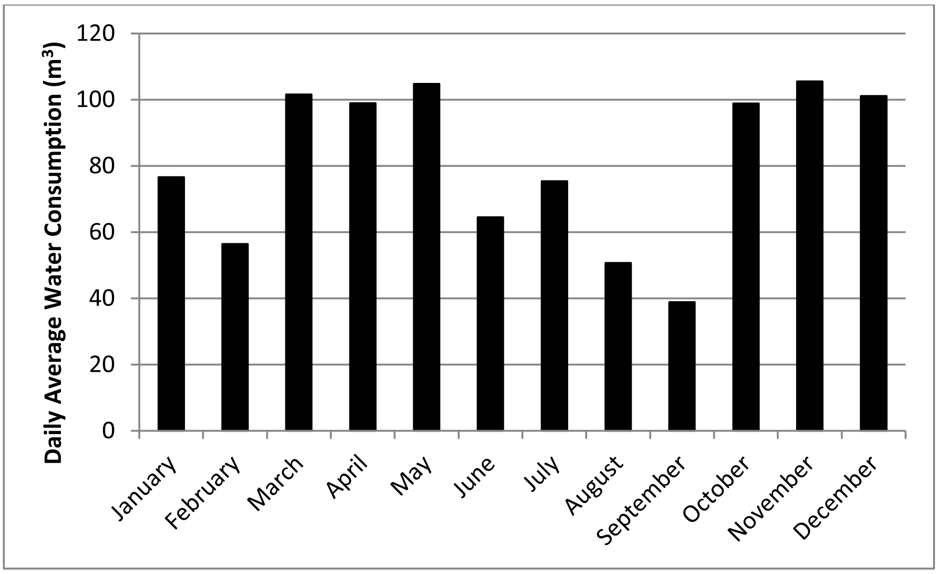



**Figure 32.** Monthly variation of daily average water consumptions in Dorm 1 and Dorm 3

Monthly variations were also observed in terms of total monthly water consumptions. As seen from Figure 33, higher water consumptions were observed in between October and January than in between March and May. The reason of increase in water consumptions from June to July could be start of summer school. Lower consumption were also observed in monthly total water consumptions due to the mid-term and summer breaks.

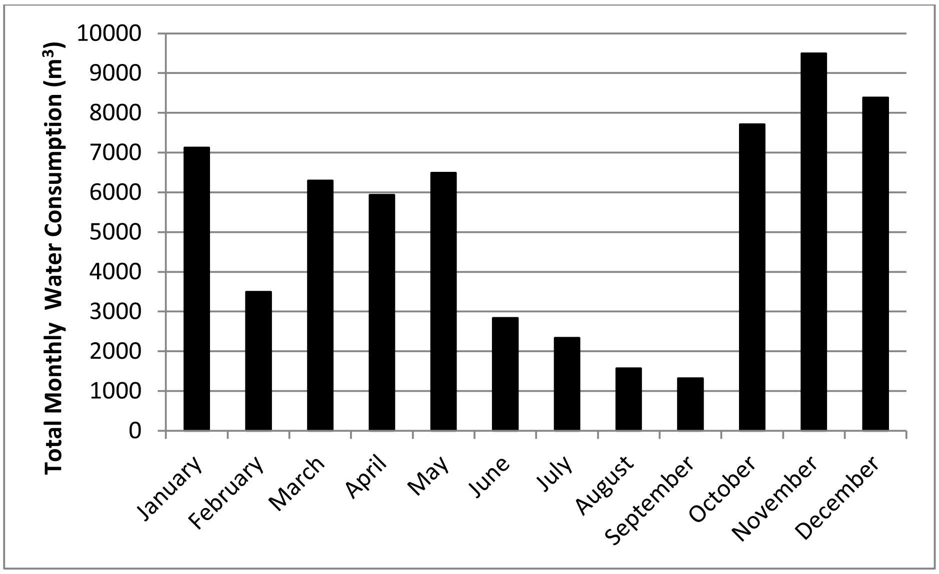



**Figure 33.** Total monthly water consumptions in Dorm 1 and Dorm 3

The water consumption data belonging to Dorm 17, Dorm 18 and Dorm 19 is collected by the second meter. The total student capacity of Dorm 17, Dorm 18 and Dorm 19 is 1962. The cumulative hourly average water consumptions belonging to these dorms are given in Figure 34. This hourly variation graph was obtained by calculating average water consumption for every hour during the monitoring period. Water consumptions started to increase at 06:00 in the morning and peaks round 10:00. In these hours, students use toilets, bathrooms and showers mostly before going to their classes. Moreover, the toilets, bathrooms and kitchens are also cleaned in these hours. Lower consumptions were observed in between 20:00 and 00:00 than the morning hours. Lowest consumptions were measured as approximately 2 $m^3$ in between 03:00 and 06:00.

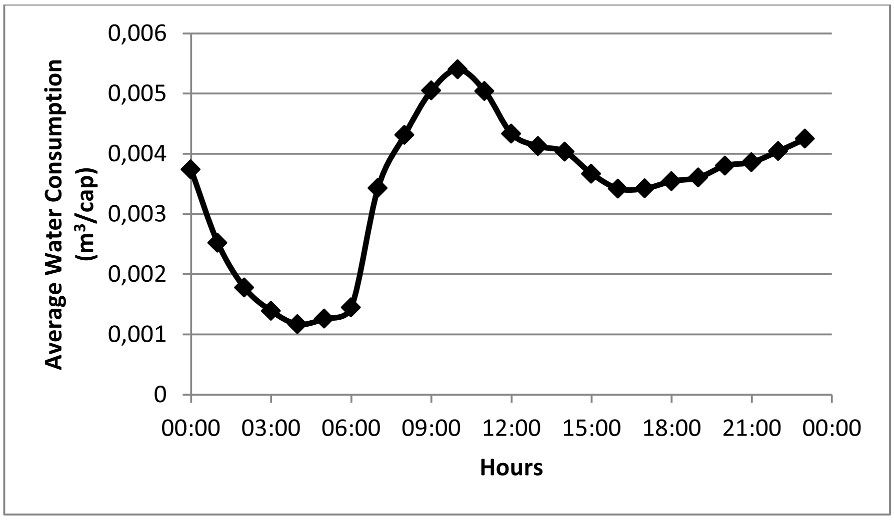



**Figure 34.** Hourly average water consumptions in Dorm 17, 18 and 19

The graphs in Figure 35 and Figure 36 were obtained by calculating average daily water consumption for every day and month during monitoring period. When daily average water consumptions were examined, it is observed that there were not major differences between water consumptions in days of a week except Saturdays. Highest daily consumptions were measured in Wednesdays similar to Dorms 1 and 3.

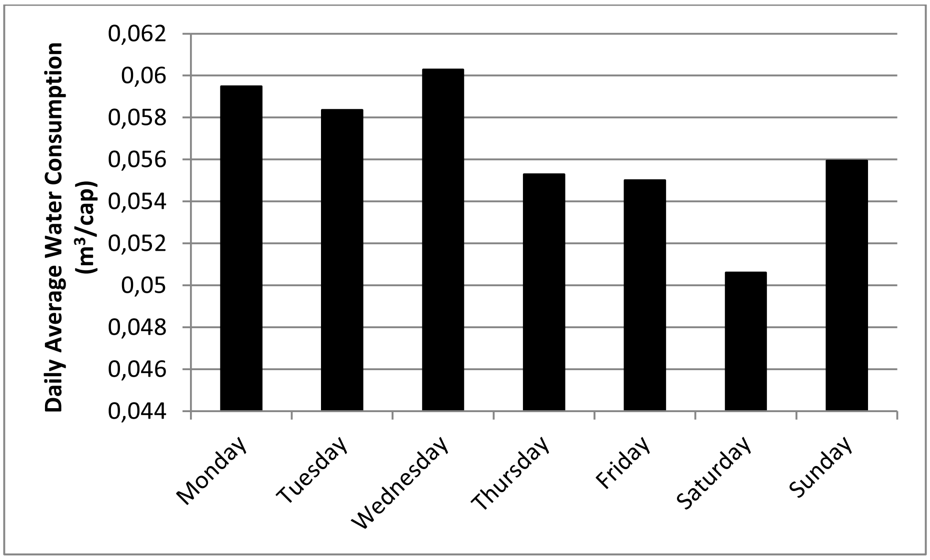



**Figure 35.** Daily average water consumptions in Dorm 17, 18 and 19

Figure 36 indicates daily average water consumptions according to months. As can be seen from Figure 36, low consumptions were measured in both January-February and June-September periods because these periods are the mid-term and summer breaks, respectively. On the other hand, there were not major differences between water consumptions in other months.

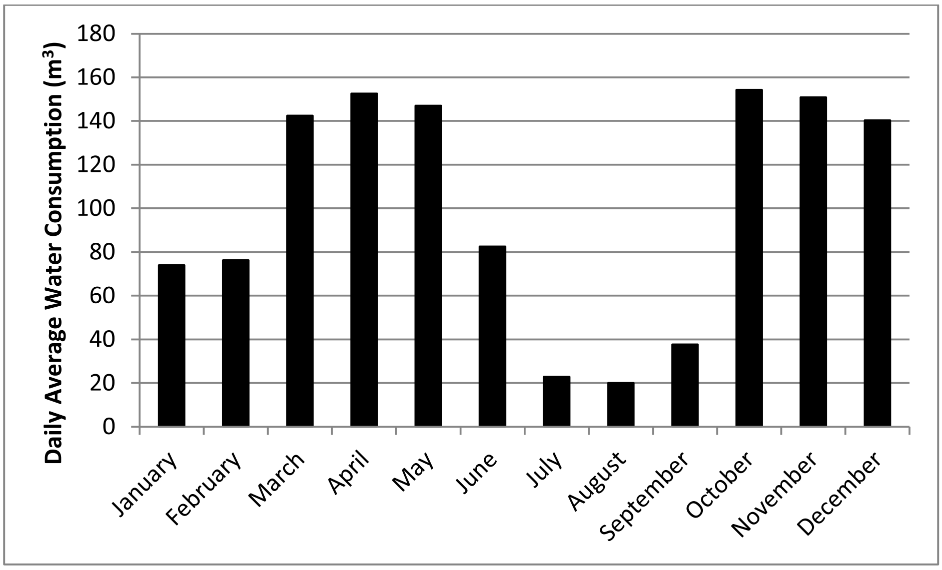



**Figure 36.** Monthly variation of daily average water consumptions in Dorm 17, 18 and 19

Monthly variations were also observed in terms of total monthly water consumptions. As seen from Figure 37, water consumptions during education period of university are much more than the ones during the mid-term and summer breaks.

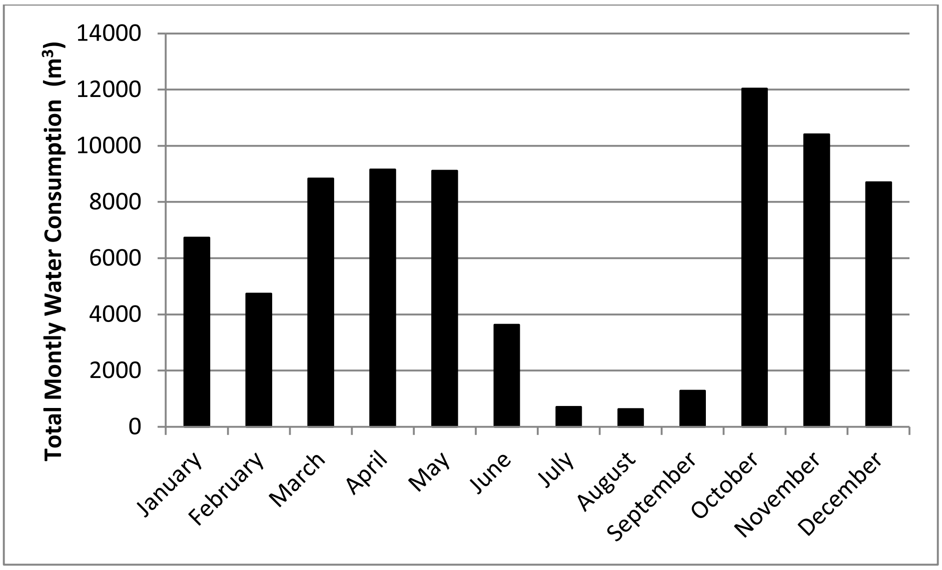



**Figure 37.** Total monthly water consumptions in Dorm 17, 18 and 19

These results gave information about hourly, daily and monthly changes in water consumptions of students living in Dorms 1, 3, 17, 18 and 19. When comparing the hourly (Figure 30 and Figure 34) and daily (Figure 31 and Figure 35) water consumption variations of Dorm 1-3 and Dorm 17-18-19, it was observed that the water consumptions of Dorm 1 and 3 are more than that of Dorm 17, 18 and 19. The reason of that postgraduate students and summer school students stay at Dorm 1 and Dorm 3, respectively during breaks. This can be observed also by comparing water consumptions on July, August and September months in Dorms 1-3 and Dorms 17-18-19 (Figure 33 and Figure 37).

In addition to water consumptions, evaluation of student's water consumption behaviors is quite important to develop behavioral and structural water conservation strategies.

In addition to site visits and water consumption monitoring, a water consumption behavior survey was conducted on 150 students living in Dorms 1, 3, 17, 18 and 19 (APPENDIX C). The survey was conducted in between April 24 and May 6, 2017. The aim of conducting this survey was to learn students' water use frequency and duration in toilets, showers, kitchens, their daily and weekly water consumption patterns, their precautions to save water, their participation to sustainability activities and their opinions about water reuse and stormwater capture. Results of this survey contributed to the evaluation of water consumption data of these dorms.

The results were evaluated statistically by using SPSS software. SPSS has a flexible and easy-to-use platform and it is used for advanced statistical analysis including machine learning algorithms, integration with big data, open source extensibility and text analysis (IBM, n.d.). Interpretation of survey results is given in following part.

Table 10, Table 11 and Table 12 shows the students' responses to the water consumption frequency and duration questions. Even though the survey was conducted on 150 students, the total frequencies of some questions were less than 150 since some students did not answer these questions. Their details were given in following paragraphs.

**Table 10.** Descriptive statistics of METU students on the water consumption frequency

| Frequency question | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | more than 10 | Minimum | Maximum | Mean | Median | Std. Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toilet usage in a day | 1 | 14 | 32 | 39 | 39 | 2 | 4 | 5 | 1 | 5 | - | 1 | 39 | 14.2 | 5 | 16.0 |
| Flushing in every toilet use | 61 | 52 | 14 | 7 | 9 | 2 | 1 | 1 | - | 2 | - | 1 | 61 | 16.6 | 7 | 23.2 |
| Sink use in a day | 5 | 8 | 16 | 25 | 41 | 5 | 6 | 7 | - | 7 | 10 | 5 | 41 | 13.0 | 7.5 | 12.3 |
| Taking shower in a week | 1 | 11 | 41 | 53 | 10 | 15 | 18 | - | 1 | - | - | 1 | 53 | 18.8 | 13 | 18.7 |
| Doing laundry in a month | 19 | 53 | 36 | 27 | 3 | 6 | - | 2 | - | 2 | 1 | 1 | 53 | 16.6 | 6 | 18.9 |

**Table 11.** Descriptive statistics of METU students on the water consumption duration

| Water use duration question | less than 0.5 | 0.5 | 1 | 1.5 | 2 | 3 | more than 3 | Minimum | Maximum | Mean | Median | Std. Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brushing teeth (min) | - | 4 | 74 | 1 | 43 | 18 | 10 | 1 | 74 | 25.0 | 14 | 28.3 |
| Washing hand/face (min) | - | 2 | 66 | - | 47 | 20 | 15 | 2 | 66 | 30.0 | 20 | 26.0 |
| Shaving (min) | 2 | - | 20 | - | 12 | 9 | 8 | 2 | 20 | 10.2 | 9 | 6.6 |
| Leaving tap open to reach preferred water temperature (min) | 11 | 17 | 82 | - | 25 | 8 | 1 | 1 | 82 | 24.0 | 14 | 29.6 |

**Table 12.** Descriptive statistics of METU students on the water consumption duration (Cont'd)

| Water use duration question | less than 5 | 5 | 7 | 10 | 15 | more than 15 | Minimum | Maximum | Mean | Median | Std. Deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Taking shower (min) | 1 | 5 | 1 | 30 | 63 | 50 | 1 | 63 | 25.0 | 17.5 | 27.0 |
| Cooking/doing dishes in kitchen (min) | 88 | 29 | 16 | 12 | - | 5 | 5 | 88 | 30.0 | 16 | 33.6 |

Out of 150 students, 37% of the respondents were male and 63% of the respondents were female. Respondents were studying in 32 different departments from engineering, education, architecture, arts and sciences, economic and administrative sciences faculties.

When the students' knowledge about the water resource of the Campus was questioned, it was found that only 11 students (7%) know the water supply source of the campus. This indicated that most of the students are not aware of the Campus's water supply.

Students were asked about the frequency of their toilet use in a day and flushing in every toilet use (Figure 38). Majority of the students use toilets 3 times (23%), 4 times (27%) or 5 times (27%) in a day. In every toilet use, 41% of them flush once and 35% of them flush twice.

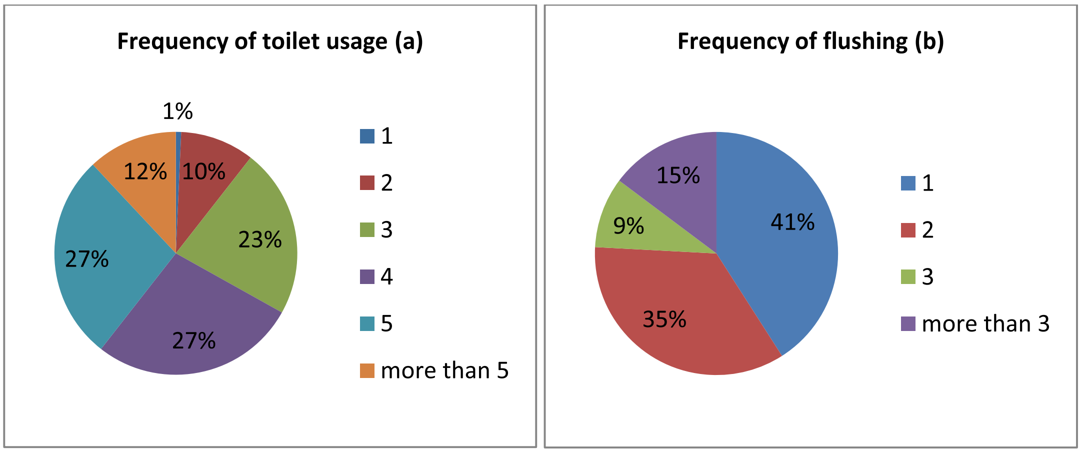



**Figure 38.** (a) The frequencies of toilet use, (b) The frequency of flush uses for each toilet use

Moreover, they were also asked about using bathroom sinks (Figure 39). The survey results indicated that 32% of them use bathroom sinks 5 times in a day. While using bathroom sinks, almost half of the students (i.e., 49% and 44%) stated that they use water for 1 minute to brush their teeth and to wash their hands/face, respectively. According to the survey results, 39% of the male students also use water for 1 minute to shave.

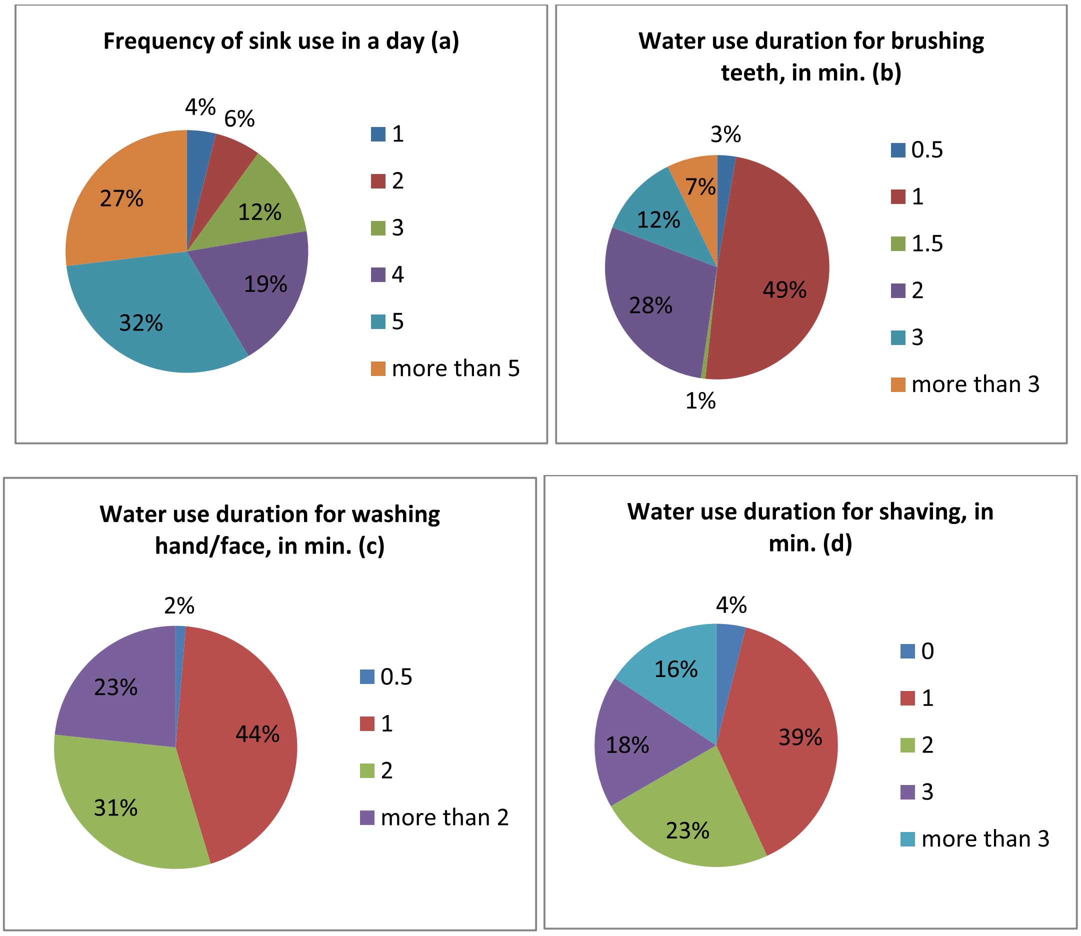



**Figure 39.** (a) Frequency of sink use in a day, (b) Water use duration for brushing teeth, (c) Water use duration for washing hands/face, (d) Water use duration for shaving

In the survey, students were also asked about whether they show conscious behavior while using water or not. When they were asked about their flush volume preference in a toilet having double-flush system, 36% and 37% of them stated that they prefer to use high and low volume flush button, respectively. Remaining 27% of them stated that they do not care about it. It was concluded that approximately one third of the students give importance to use of low volume flush systems. They were also asked about whether they leave the tap open during brushing teeth, shaving and washing hands/face. 9% and 65% of students stated that they leave tap open during brushing teeth and washing hands/face and they turn of the tap, respectively. 5% of male students stated that they leave tap open during shaving. This survey results showed that most of the students pay attention to conserving water by closing the tap while brushing teeth and shaving. However, most of them leave tap open while washing their face/hands.

Having knowledge of hourly water consumption variation in a day was also significant while evaluating water consumption data. Therefore, students were asked about which hours they are using toilets, washbowls and showers (Figure 40). The results indicated that students use toilets, washbowls and showers mostly during 06:00-12:00 and 18:00-00:00 hours. Only 1-2% of students also use them during 03:00-06:00 hours. This hourly variation was also observed in hourly variation of water consumption data obtained from meters for Dorm 1, Dorm 3, Dorm 17, Dorm 18 and Dorm 19 (Figure 30). While students use toilets and washbowls more during morning and afternoon hours (06:00-12:00), they use showers more especially during 21:00-00:00 hours.

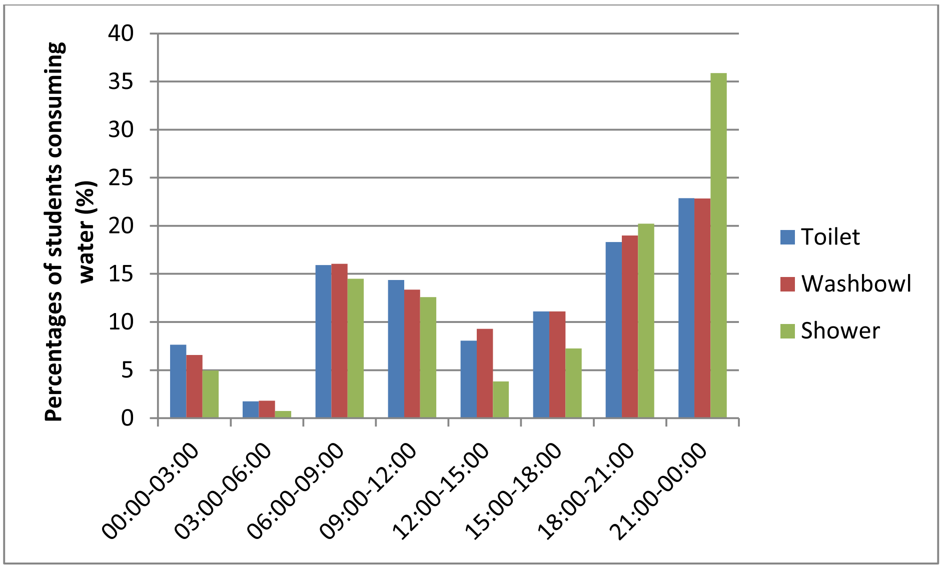



**Figure 40.** Distribution of students depending on their water consumption in toilets, washbowls and showers during different hours.

Additionally, students were asked about their frequency of taking shower in a week and which days they mostly prefer to take shower and its duration. The duration of leaving the tap open to reach preferred water temperature was also asked (Figure 41). 35% of the students stated that they take a shower on the average 4 times a week. They stated that they did not have a day preference. However, the most preferred day was Sunday (18%). The survey results also showed that 42% of the students take a shower in 15 minutes and 57% of the students leave the tap open for 1 minute to reach preferred temperature.

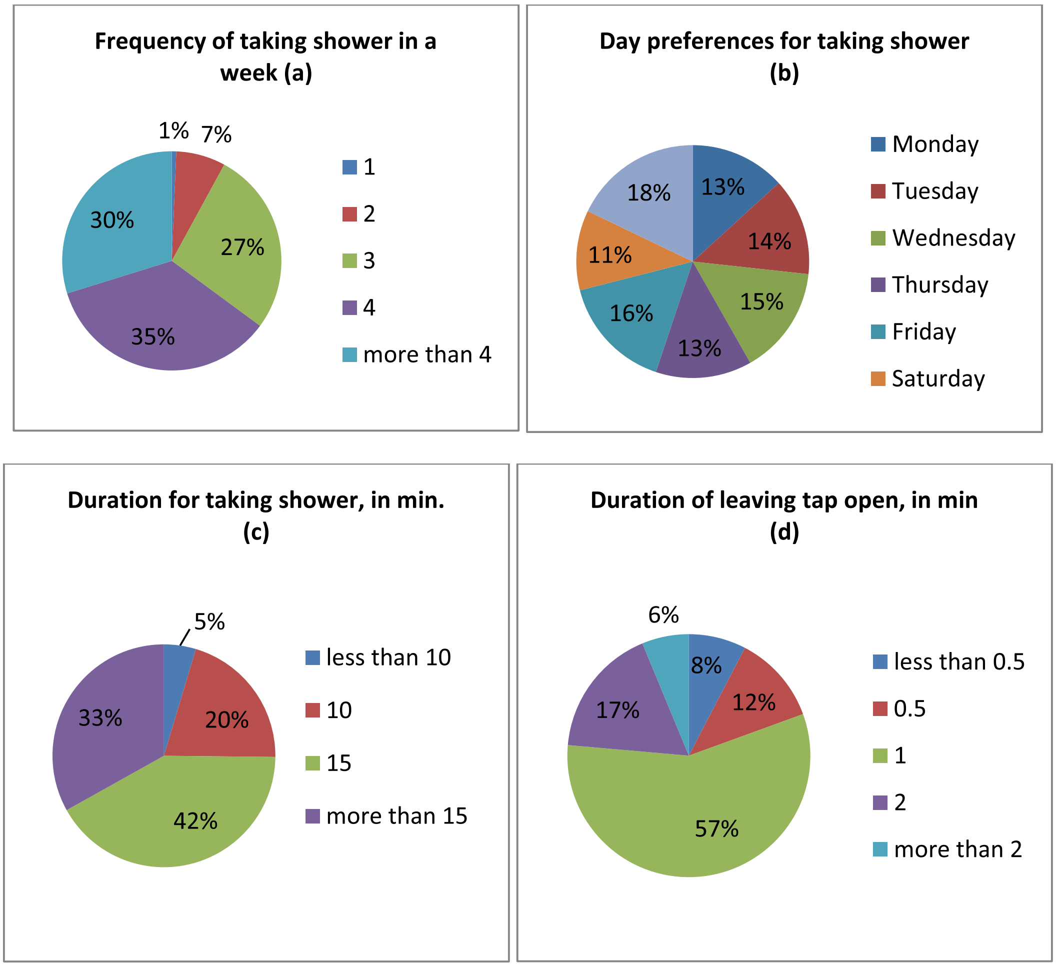



**Figure 41.** (a) Shower frequency, (b) Preferred day for showering, (c) The duration of the shower, (d) The durations of leaving the tap open to reach preferred water temperature

In the survey, frequencies of doing laundry in a month were also questioned. Results indicated that 35% of students do laundry twice in a month. 24% of them do laundry thrice in a month (Figure 42).

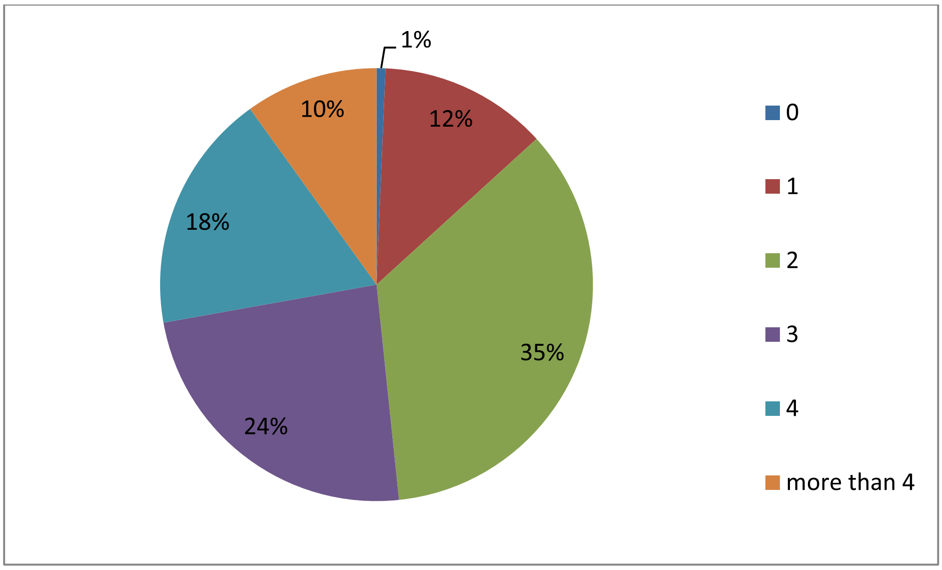



**Figure 42.** The frequency of doing their laundry in a month

When their daily average drinking water consumptions were asked to students, almost half of them stated that they consume 1.5-2 L of water in a day. The duration of their water consumption in kitchen was also asked and the results showed that 28% of them use water for 3 minutes in kitchen and 24% of them does not use kitchen (Figure 43).

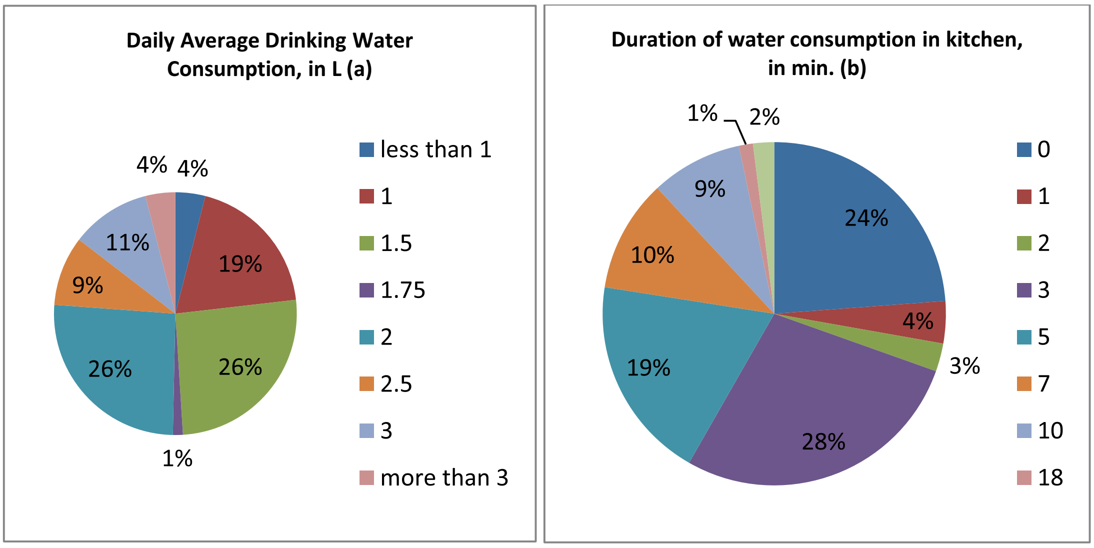



**Figure 43.** (a) Daily average drinking water consumption, (b) The duration of water consumption in the kitchen

The awareness of students about water saving techniques was also questioned in this survey. One of the question in survey (APPENDIX C) was “Do you know that while conventional shower heads lead to average 15-20 liters of water consumption per minute, it is 9-10 liters of water for low-flow shower heads?” and only 12 (8%) students answered it as “Yes”. Another question was “Do you know that you can save 12 tons of water per person per year from the tap that is turned off while you are shaving and brushing your teeth?” and 77 (51%) students answered it as “Yes”. These results demonstrated that higher number of student have awareness about benefits from turning off taps than benefits from using low-flow shower heads on water saving. When students were asked about the precautions that they take to save water, 44% and 37% of them stated that they turn off taps while brushing teeth and doing dishes, respectively (Figure 44).

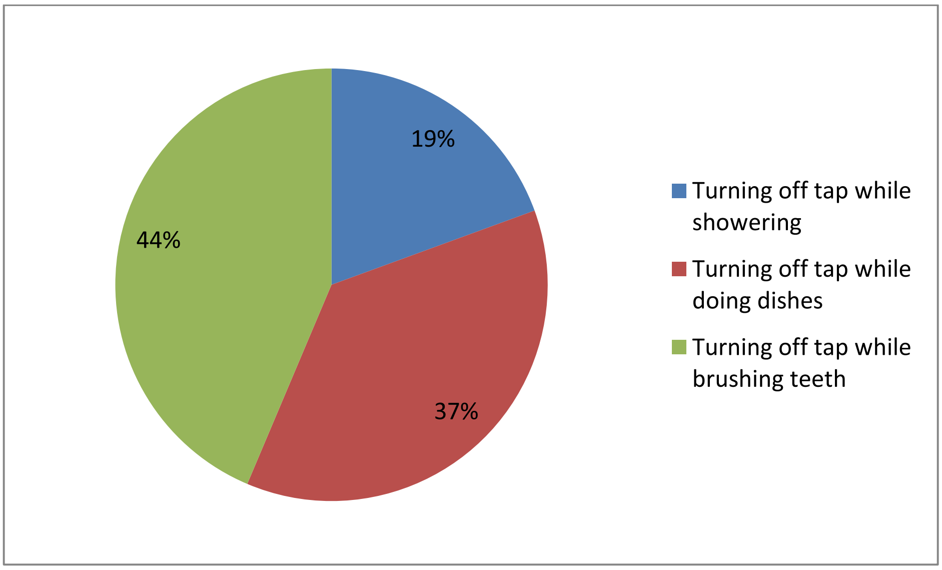



**Figure 44.** Precautions for water saving

In the survey, students’ opinions about water reuse and rainwater use were also asked. 33% of the students stated that treated wastewater should be used for both agricultural irrigation and recreational area irrigation. 20% of them agree on that it should be used for toilet flushing (Figure 45). Moreover, these percentages were 27%, 28% and 13% for agricultural irrigation, recreational area irrigation and toilet flushing, respectively (Figure 46). While percentages of treated wastewater use for toilet flushing and irrigation of recreational areas is more than percentages of rainwater use, rainwater use for showering is morely preferred than treated wastewater.

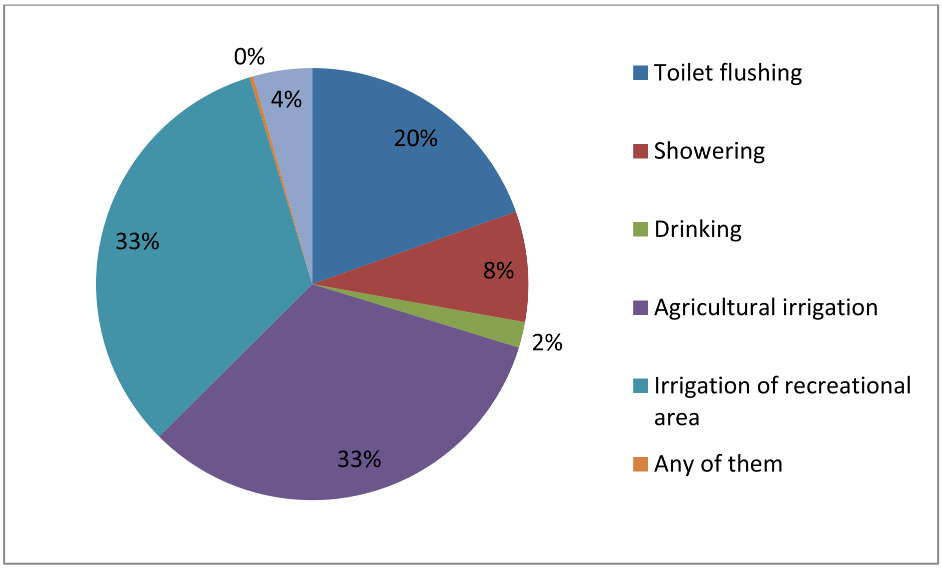



**Figure 45.** Treated wastewater use preferences for different purposes

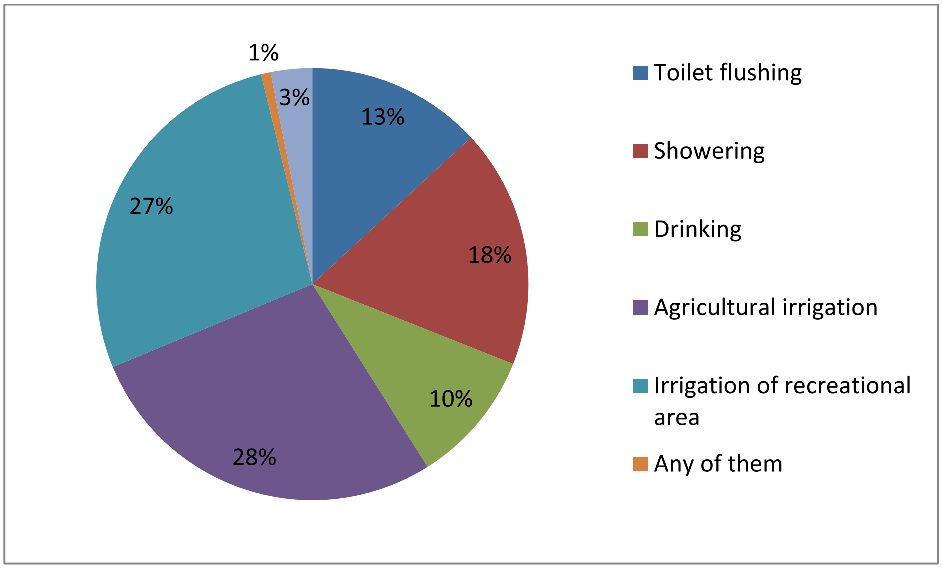



**Figure 46.** Rainwater use preferences for different purposes

Lastly, the survey results showed that 42% of the students turn unnecessary lights off, 34% of them do recycling and 24% of them prefer bicycle or walking instead of driving as the sustainability activities (Figure 47).

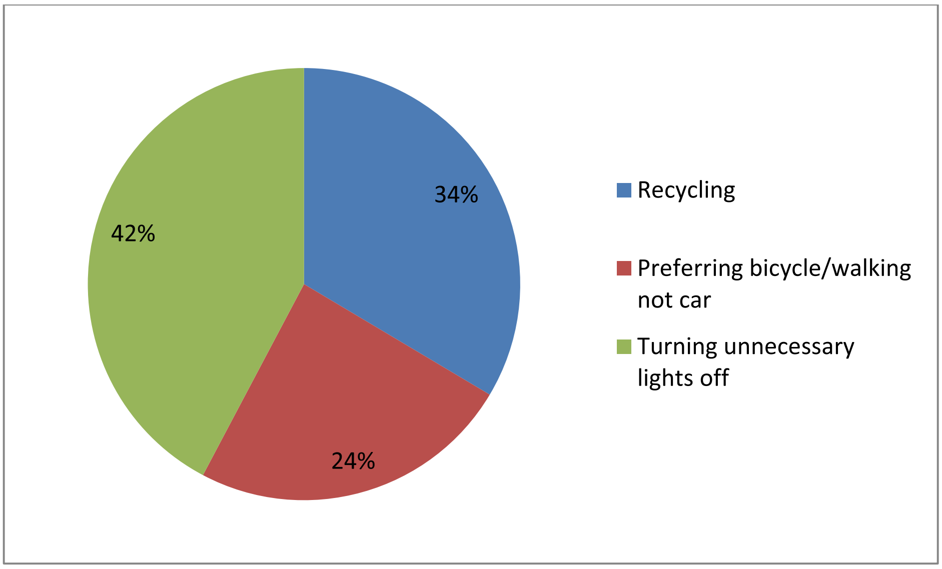



**Figure 47.** Participation to different sustainability activities.

These survey results provide useful information about student's water consumption behavior. It was understood that they mostly give importance to consume less water in bathrooms, showers and kitchens. For instance, most of them turn taps off while brushing teeth, shaving, taking shower and doing dishes. However, they do not have enough knowledge about the water resource of the campus and the benefits of water-efficient equipment use in dormitories. It means that developing some awareness-raising education programs may be beneficial for water conservation in the Campus.

These results also explain hourly water consumption variation in dormitories. When the water consumption data was analyzed, it was observed that most of the water was consumed in the morning and evening hours. In the survey, students also stated that they mostly use toilets, washbowls and showers in morning and evening hours. This survey also helped to detect possible water losses. For instance, only 1-2% of them use toilets between 03:00-06:00 hours. However, the average water consumption was almost 1

$m^3$/hour even though very few students consumed water during these hours (Figure 30). It meant that there might be some water losses due to water leakages in the pipeline or water outlets from toilets and faucets.

In this part of the study, some water-saving approaches were also evaluated for METU dormitories according to water consumption data and behavior survey results.

In this study, only water consumption data obtained from smart watermeter of Dorm 1 and Dorm 3 were used since the data belonging to remaining three dorms (Dorm 17, Dorm 18 and Dorm 19) was similar and only a smart water meter's data was enough to evalutate the effects of and water-saving approaches on water consumption. Statistical values for water consumption of Dorm 1 and Dorm 3 are given in Table 13. In this statistical analysis, water consumptions during mid-term and summer breaks were excluded.

**Table 13.** Statistical analysis of daily total water consumption in the studied dorms

| Average ($m^3$) | Median ($m^3$) | Standard Deviation ($m^3$) | Minimum ($m^3$) | Maximum ($m^3$) |
|---|---|---|---|---|
| 100.8 | 103.6 | 16.6 | 11.9 | 136.3 |

Average water consumption in studied dorm is 100.8 $m^3$/day. The number of people who lives in these dorms (i.e. Dorm 1+Dorm 3) is 776. The daily water consumption per student is calculated as 130 L (i.e. (100.8 $m^3$/day /776 students)*(1000 L/1 $m^3$)). Thus, each student in the dormitory consumes approximately 46800 L (46.8 $m^3$) in a year.

These values can be compared with other universities' water consumption values to be able to compare the situation of the campus. For example, a student in the campus of University of California Santa Cruz (UCSC) consumed averagely 148 L in a day (54000 L/capita in a year) in 2002-2005 year period before any water conservation studies were done (USCS, 2015). It means that a METU student consumes less water than a UCSC student without any water conservation measure is implemented. Moreover, another example for water consumption is from University of California Davis (UC Davis). The water consumption per capita in two dormitories (Emerson and Webster Halls) was approximately 100 L/day (Dirksen and Marthur, n.d.). It is seen that a METU student consumes almost 30 L more water in a day than a US Davis student. These comparisons emphasize that water consumption amounts change from university to university. Developing some practices to decrease water consumptions is essential for every university's campus.

Two different water management practices can be applied in the dormitories to decrease the water consumption: i) water conservation and ii) water efficiency approaches. Water conservation approach is about changing behavior of the end users. In this approach, durations of water consumptions and number of flushes were decreased. On the other hand, water efficiency approach includes improving the efficiency of an appliance. Installation of higher efficiency devices such as faucets, shower heads and toilets will result in reduced water flow rates (Dirksen and Marthur, n.d.). These two approaches are explained in detail in the following sub-sections.

**Water Conservation Approach (Behavioral Changes)**

In water conservation approach, the effect of behavioral changes on the water consumption is aimed. While calculating the water consumption, standard consumption values of equipments are used. Standard consumptions of equipments and their frequency and/or durations are given in Table 14.

**Table 14.** Comparison of METU student statistics with standard consumptions

| Equipment | Standard Consumption** | Frequency of flushes and/or Water Use Duration of a METU Student* |
|---|---|---|
| Faucet | 0.0039 ($m^3$/min-cap) | 6 min |
| Shower | 0.0056 ($m^3$/min-cap) | 15 min |
| Toilet | 0.0061 ($m^3$/flush-cap) | 4 flush |

*: Obtained from water consumption behavior survey results

**: (Dirksen and Marthur, n.d.)

Some measures can be taken to reduce water consumption by the help of behavioral changes in the water consumption. For example, a US Davis student takes shower for 10 minutes (Dirksen and Marthur, n.d.). It means that 10 minutes are enough to provide hygienic requirements for a person taking showers. Therefore, it is recommended that students can take shower for 10 minutes instead of 15 minutes, they can decrease their faucet usage time from 6 minutes to 4 minutes and they can reduce the usage frequency of flush from 4 to 3 in toilets to consume less water (Table 15).

**Table 15.** Comparison of METU student statistics with standard consumptions for water conservation approach

| Equipment | Standard Consumption** (I) | Frequency and/or Duration Standard Use of a METU student* (II) | Frequency and/or Duration with water conservation approach (III) | Frequency and/or Duration The difference (IV= II-III) |
|---|---|---|---|---|
| **Faucet** | 0.0039 ($m^3$/min-cap) | 6 minute | 4 minute | 2 minutes |
| **Shower** | 0.0056 ($m^3$/min-cap) | 15 minute | 10 minute | 5 minutes |
| **Toilet** | 0.0061 ($m^3$/flush-cap) | 4 flush | 3 flush | 1 flushes |

*: Obtained from water consumption behavior survey results

**: (Dirksen and Marthur, n.d.)

So daily total water savings per capita by water conservation approach is calculated as;

(2 min*0.0039 $m^3$/min)+( 5 min* 0.0056 $m^3$/min)+ (1 flush* 0.0061) = 0.0419 $m^3$/day per capita = 41.9 L/day-cap

The detailed water savings are given in Table 16. When standard consumptions of equipments are multiplied by the difference between their frequency and/or duration before and after behavioral changes, total water saving of water conservation approach can be calculated.

Table 16. Summary of water saving with water conservation approach

| Equipment | Standard Consumption* (I) | Frequency and/or Duration The difference (II) | Total amount of water saved in water conservation approach (III= IxII) |
|---|---|---|---|
| **Faucet** | 0.0039 ($m^3$/min-cap) | 2 minute | 7.8 L/student/day |
| **Shower** | 0.0056 ($m^3$/min-cap) | 5 minute | 28 L/student/day |
| **Toilet** | 0.0061 ($m^3$/flush cap) | 1 flush | 6.1 L/student/day |
| | | TOTAL SAVINGS | 41.9 L/student/day |

*: (Dirksen and Marthur, n.d.)

**Water Efficiency Approach**

As it is mentioned before, water efficiency approach is about using water efficient equipments to reduce water consumption. For example, the vacuum-assist flush mechanism provides effectively flushing to clean a significant amount of waste by using less water in toilets (Wilson, 2010). Moreover, EPA developed a partnership program with WaterSense label and retrofitting WaterSense labeled showerheads helps to save considerable amount of water (EPA, 2016). EPA also released a specification for faucets and faucet accessories such as aerators and laminar devices to decrease their flow rate and to save water (ENERGY.GOV, n.d.).

In this study, the amount of conservation is estimated when 20% increase in efficiencies of faucets, shower heads and toilets' current flowrates are achieved. Total savings of equipments are given in Table 17.

**Table 17.** Water savings of equipments and their frequency and/or durations for water efficiency approach

| Equipment | Water Savings with water efficiency approach (20 %) | Frequency and/or Duration in *water efficiency approach* |
|---|---|---|
| Faucet | 0.00078 ($m^3$/min-cap) | 6 minute |
| Shower | 0.00112 ($m^3$/min-cap) | 15 minute |
| Toilet | 0.00122 ($m^3$/flush-cap) | 4 flush |

So daily total water savings per capita by water efficiency approach is calculated as;

(6 min*0.00078 $m^3$/min)+( 15 min* 0.00112 $m^3$/min)+ (4 flush* 0.00122) = 0.0264 $m^3$/day per capita =26.4 L/day-cap

The detailed water savings are given in Table 18. When water savings of equipments are multiplied by their frequency and/or duration for water efficiency approach, total water saving of water efficiency approach can be calculated.

**Table 18.** Summary of water saving with water efficiency approach

| Equipment | Water Savings with water efficiency approach (20 %) (I) | Frequency and/or Duration (II) | Total amount of water saved with *water conservation approach* (III= IxII) |
|---|---|---|---|
| Faucet | 0.00078 ($m^3$/min-cap) | 6 minute | 4.68 L/student/day |
| Shower | 0.00112 ($m^3$/min-cap) | 15 minute | 16.8 L/student/day |
| Toilet | 0.00122 ($m^3$/flush-cap) | 4 flush | 4.88 L/student/day |
| | | TOTAL SAVINGS | 26.4 L/student/day |

**Water Conservation and Water Efficiency Approach Together**

Finally, when both approaches are applied at the same time, total daily water savings per capita by both water conservation and water efficiency approach is calculated as;

(4 min*0.00078 $m^3$/min) + ( 10 min* 0.00112 $m^3$/min) + (3 flush* 0.00122)+ (2*0.0039)+(5*0.0056)+(1*0.0061) = 0.0599 $m^3$/day per capita = 59.9 L/day-cap

**Water Losses**

In addition to these water saving approaches, METU also considers to find solutions for aging structures that result in leakage in the water pipeline system.

When the hourly average water consumption graph for the studied dorms is examined (Figure 30), it is seen that approximately 1000 L/hour water is consumed between 3:00 and 5:00. Actually, during these hours, much lower consumptions are expected in the dorms as confirmed by the behavior survey results which indicated that only 1-2% of students use toilets and bathrooms between these hours. The reason of the measured water consumptions may be water leakage from toilets and faucets or leakages in the pipeline system. After leakage detection by using some methods such as sonic-leak detection equipment and repair of these aging water pipeline systems, additional daily water saving of the studied dorm will be (1000 L/hour)* (24 hour/ 1 day) = 24000 L. At the end, total water savings in the studied dorm (total of 776 students) is summarized in Table 19.

**Table 19.** Total water savings of the studied dorm

| Practices | Daily Water Saving (L) | Yearly Water Saving ($m^3$) |
|---|---|---|
| **Water Conservation** | 41.9*776 = 32514 | 11867.8 |
| **Water Efficiency** | 26.4*776 = 20455 | 7466.2 |
| **Water Conservation + Water Efficiency** | 59.9*776 = 46467 | 16960.4 |
| **Preventing Water Losses** | 1000* 24 = 24000 | 8760 |

By using both approaches and preventing water losses, ((46467+24000)/ 102598)*100 = 68.7 % reduction in water consumption is achieved.

After these management practices, the daily water consumption of a student can be calculated as (102598-(46467+24000))/776 = 41.4 L. As a result, if both approaches is used to reduce water consumption and water losses are prevented, 70466.88 L/day water is saved and this water saving can be used to supply the water needs of people. For example, water usage in sustainable cities is 100 L/day-cap (Novotny, 2016). Hence, the number of families (including four people) that can use this water saving for their daily water need can be calculated as (70466.88 L/day) / (100 L /day-cap * 4 cap/family) = 176 family

This study was made for Dorm 1 and Dorm 3 that are housing for 776 students and some changes made in water usage habits or efficiency of equipment can save large water amounts. Therefore, some actions need to be taken to save water in dormitories.

### 4.3.2. METU Cafeteria

In this study, METU Cafeteria was visited to obtain information about its operations and water consumption. Mehmet Fatih ŞAHİN who is the food engineer in METU Cafeteria provided all the necessary information about the water uses in the cafeteria. The cafeteria is one of the high water demand locations on the campus. More than 1 million meals are prepared per year for students, administrative personnel and academicians. Lunch and dinner are served everyday except weekends. The weight of one meal per person is 800-1000 g.

The water consumption data of cafeteria was obtained from the smart water meter installed on the pipe entering the cafeteria and evaluated for hourly and daily consumptions. In the cafeteria, cleaning and food preparations start at 7:00 in the morning and food is served between 11:30 to 14:00 and 17:00 to 18:30 during the day. Therefore, water is consumed by students and dirty dishes are washed during these hours. The water consumption during the day is mostly observed during these hours as shown in Figure 48. This graph was obtained from water consumption data collected between between October, 2015 and February, 2018. After dinner, until 23:00 the personnel of cafeteria work on washing the dishes and preparations for the next day's food. After each meal is cooked, prepared and served, benches and floors are washed. A more thorough cleaning is done on Fridays in the cafeteria. Figure 48 indicated that there is water leak which is almost 1.5 $m^3$/hour observed on cafeteria since there is water consumption even though cafeteria is not working in between 00:00 and 06:00.

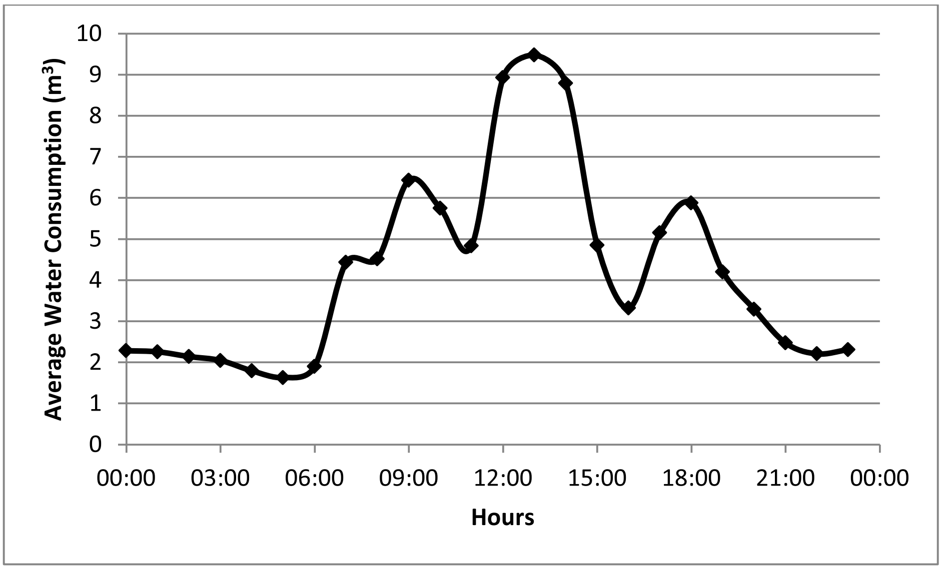



**Figure 48.** Hourly variation of average water consumption in the cafeteria

Water is consumed in the cafeteria generally for dish washing, cooking, drinking, flushing the toilets, washing vegetables and cleaning purposes. In every meal, generally four plates, a glass, a tray, a fork, a spoon and a knife is used by each person. These are washed in dishwashers. There are 6 dishwashers in the cafeteria. Cooking boilers and trays are washed with hoses. Sixteen cooking boilers and 7 cooking boilers are used for each lunch and dinner, respectively (Figure 49). The cafeteria also has 2 potato peeling machines and 1 vegetable washing machine, and these machines also use water. Moreover, there are a total of 24 toilet siphons (13 of them urinal siphon) and 49 faucets in the cafeteria building.

**Figure 49.** Dishwasher (at left) and cooking boilers, trays used while cooking (at right) in METU Cafeteria

When it was investigated in terms of water losses, a leak was detected by authorities at the recirculation of the solar energy system on the roof of the cafeteria and it was repaired between March 6th and March 10th, 2017. The water consumption data was checked for this period and it was observed that this repair saved 20 $m^3$/day of water (Figure 50). While the daily average water consumption on March 9, 2017 was 140 $m^3$, it decreased to 120 $m^3$ on March 13, 2017. March 11-12, 2017 was weekend.

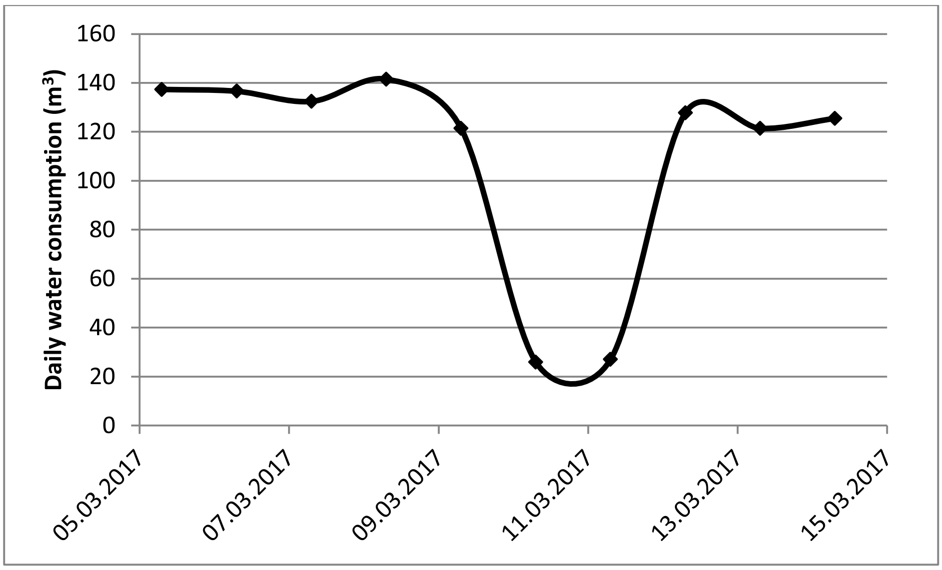



**Figure 50.** Daily average water consumption in cafeteria between March 6th and March 14th, 2017 (during repair time)

There is also a channel in the lower part of the cafeteria where used water and wastewater are collected. It has been observed that water enters this channel even though the cafeteria is not used at the weekend. In addition, water leaking from the old water pipes was observed on the top of gallery. These water losses were also observed at weekends. Figure 51 indicates average water consumptions measured in cafeteria for the days of week. The graphs show that there is averagely 40 $m^3$/day water loss during the weekends. While the water consumptions in weekends were measured as approximately 20 $m^3$/day, it increased to 80 $m^3$/day after 24$^{th}$ June 2017 (Figure 52). This water loss was detected and its infrastructure system was repaired by authorities on May, 2018. However, the amount of water saved after repair could not be calculated since water consumption data after repair was not available.

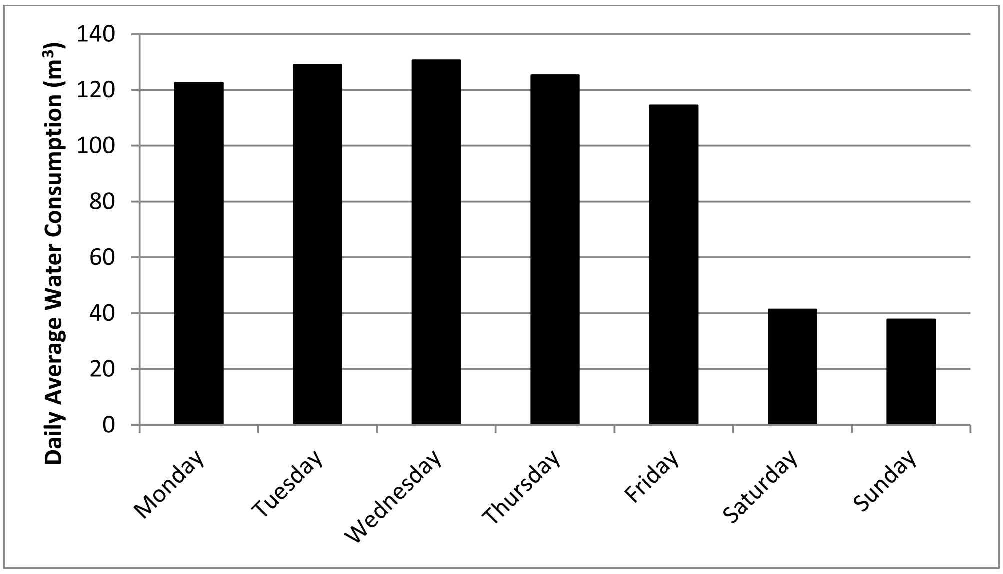



**Figure 51.** Daily average water consumptions measured in cafeteria for each day

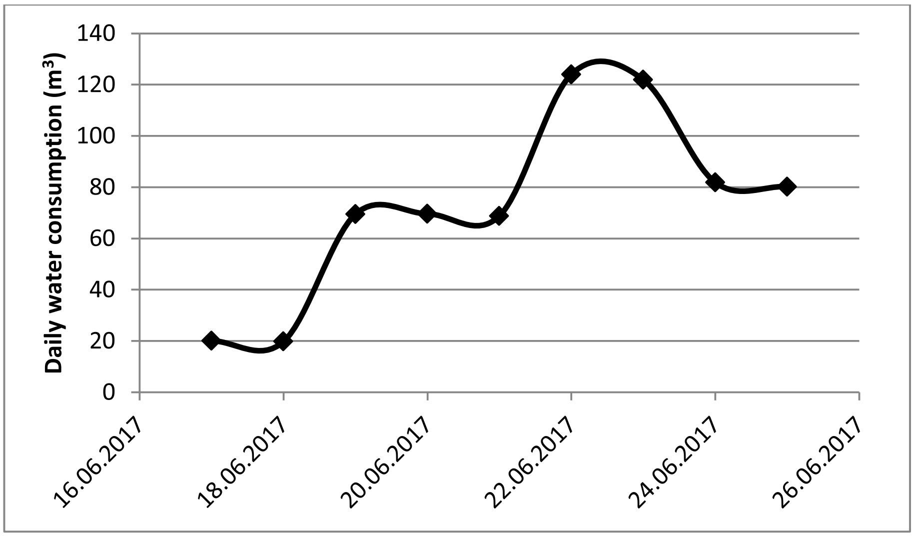



**Figure 52.** Daily water consumptions in Cafeteria for June 17-24, 2017 period

Figure 53 shows montly water consumption variations in METU Cafeteria. It was observed that the water consumptions between September and February that is fall semester is more than the ones in between March and June that is spring semester during education period. Low water consumptions in February and in between June and September was expected since they represent semester and summer breaks.

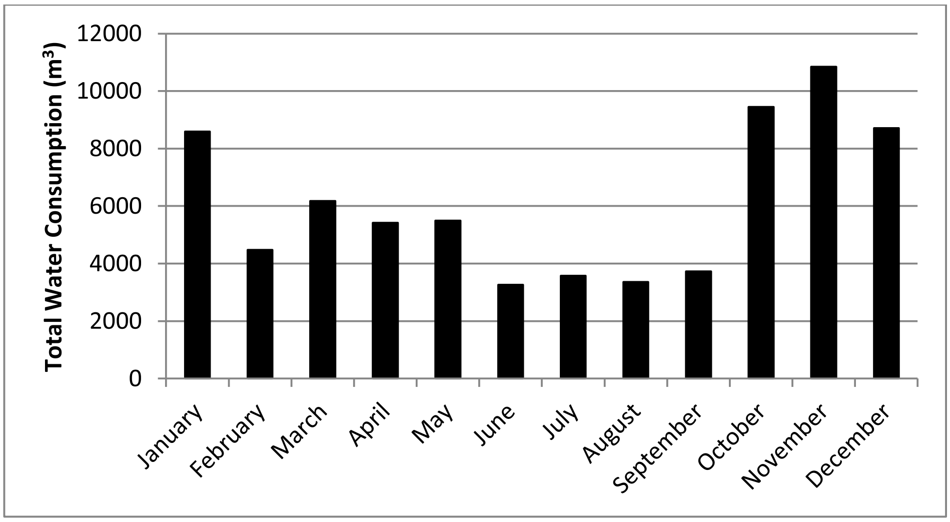



**Figure 53.** Total monthly water consumptions in Cafeteria

Evaluation of water consumptions in cafeteria indicated that there are hourly, daily and monthly differences observed in the water consumptions. These differences are due to the working hours and days of the cafeteria, semester and summer breaks. In addition to that, these measured consumptions showed that there were water leakages in the water pipeline system. Therefore, some renovations and repair studies are necessary to decrease the water consumptions and to prevent water losses in the cafeteria.

#### 4.3.3. METU Swimming Pools

In this study, METU Swimming Pool Complex was visited to collect information on its operation and water consumption. Nurcan Altınay who is the head manager of METU Swimming Pool Complex provided all the necessary information about the water uses and treatment processes of the pool water. There are two swimming pools in the complex; one is an outdoor pool while the other is indoors. Commonly the outdoor pool is only used during summer months. Both pools are operated according to Regulation on Health Rules and Conditions for Swimming Pools and designed according to the overflow technique. The overflow technique provides a quick way to remove pollution and chlorination is also used to provide disinfection in both pools.

The pool water goes through the equalization tank, sand filters, chlorination, pH equalization and then given to the pool. The polluted water coming from the pool with the overflow technique and additional water supplied from METU Campus water are collected in the equalization tank. This additional water is supplied from potable water pipeline system of the campus to feed pools' water. After that, water passes through sand filters, which provide a physical treatment. Five sand filters are connected in parallel. The pollution and the flocs forming due to chlorine shock loadings are retained by filters and removed via backwashing. Backwashing is carried out twice a week. After passing through equalization tank and sand filters, the water is chlorinated and its pH is equalized via chlorine dosage and acid tanks. Then, it is sent back to pool (Figure 54 and Figure 55).

**Figure 54.** Chlorine Dosage and Acid Tanks (Left) and Sand Filters (Right).

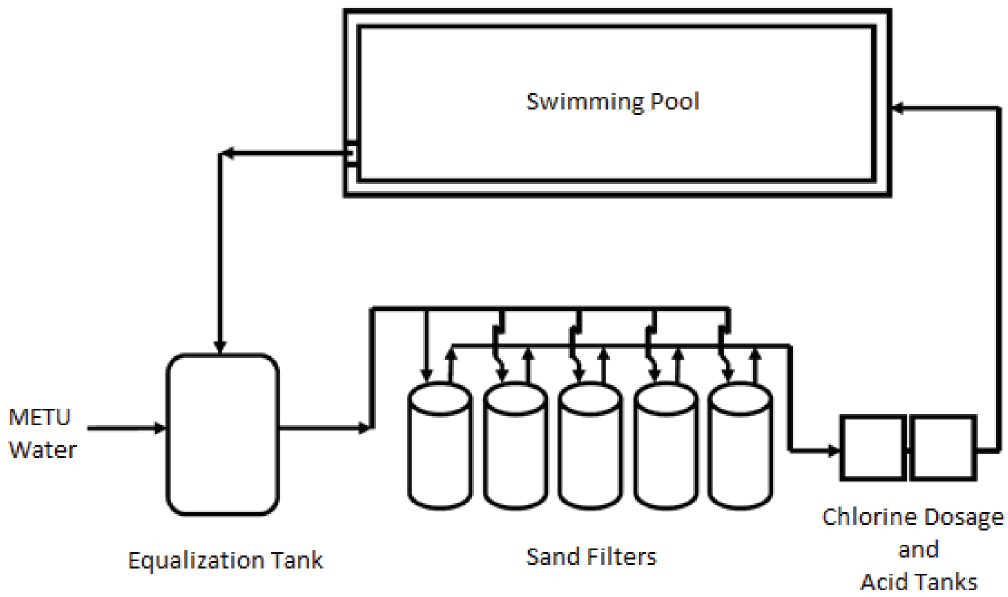



**Figure 55.** Units of swimming pool water treatment in METU Campus.

The outdoor and indoor pools have 600 tonnes and 2700 tonnes water capacity, respectively. Temperature, pH, combined and free chlorine values of the pools are measured daily. Pool temperature and its surrounding temperature are measured every hour. Chlorination and pH equalization is realized via an automatic system. Chlorine values are also measured manually three times in a day and checked with the values obtained from the automatic system. Necessary chlorine amount is decided with the help of sensors in the pool. Daily chlorine consumption is 6-15 kg in the pool. Moreover, pool water quality analysis is conducted once in 15 days and results are checked with the limits given in the related regulation. In addition to chlorination, the base of the pool is cleaned via vacuum a cleaner during the night. The chemicals used in METU swimming pools and for pool water analysis are given in Table 20.

**Table 20.** The Chemicals used in METU Swimming Pools and for Pool Water Analysis

| Chemical | Content of Chemical |
|---|---|
| Powder Chlorine without Stabilizer | Calcium Hypochlorite |
| pH Decreaser | Based on inorganic acid and sulfuric acid |
| Fast Precipitant | Polyaluminium chloride or aluminum chlorohydrate |
| Algaecide | 5% alkyldimethyl chloride or polymeric quaternary ammonium and copper sulfate |
| Filter and surface cleaner | Phosphoric acid |
| Free chlorine measuring tablet | N, N diethylbenzene-1,4 diammonium sulphate |
| Total chlorine measuring tablet | Potassium chloride, potassium iodine |
| pH measuring tablet | Sodium chloride |
| Cyanuric acid measuring tablet | Citric acid |

Both indoor and outdoor pools are heated via steam exchanger during day and night for 8 month. In summer months, natural gas is used for heating system. The heat used for the water in showers and toilets is supplied from METU steam generator.

**Water Related Problems in METU Swimming Pools**

There are two main problems related with water consumption observed in METU swimming pools. One of them is high combined chlorine concentrations in the pool. The maximum limit for combined chlorine is given as 0.2 mg/L in the Regulation on Health Rules and Conditions for Swimming Pools (Ministry of Health, 2011). However, it is a difficulty to keep combined chlorine concentration under upper limit for METU swimming pools. Currently, to reduce the combined cholorine concentration in the pool, water is added to dilute the content of the pool. This requires large amounts of water addition to the pool based on excess combined cholorine concentration.

In normal conditions, the daily additional water supplied from METU water is changing between 50 and 120 tonnes depending on combined chlorine concentration in the pool, backwashing time and usage of showers. However, it is stated that additional water supplied from METU sometimes reaches to 400 ton/day to meet the standards for combined chlorine which is 0.2 mg/L given in the regulation.

Figure 56 indicates yearly water consumptions in Swimming Pool Complex. This data was obtained from Directorate of Swimming Pool Complex. The total water consumption of the complex was 32663 $m^3$ in 2014.

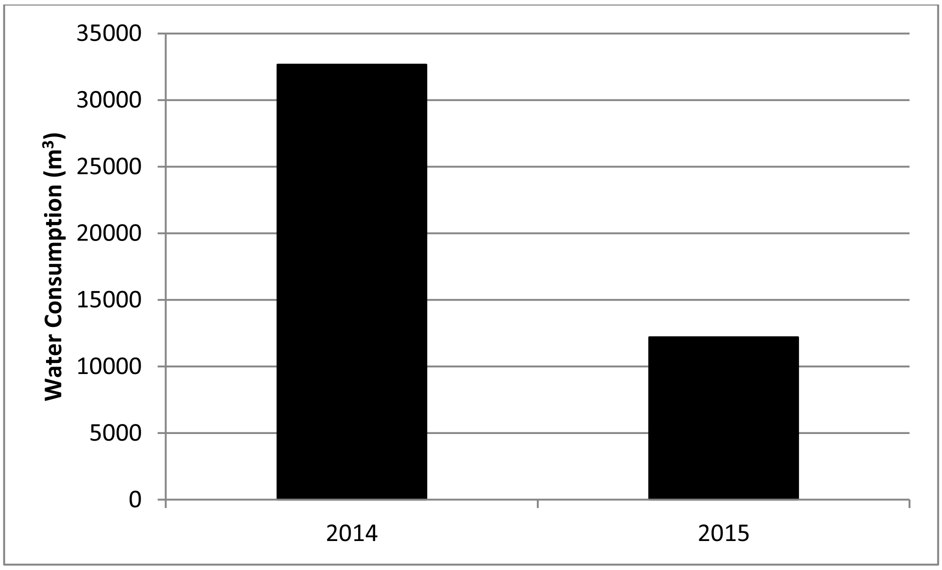



**Figure 56.** Yearly water consumptions in Swimming Pool Complex in 2014 and 2015 (until July)

Another problem is related with the backwash water. Backwashing of filters is done twice in a week and total weekly backwash water amount is approximately 160 tonnes. The backwash water is discharged to a small creek which passes through the campus center and its quality is not known. Moreover, there no reuse alternatives are developed for this water yet.

**Water Management Alternatives for METU Swimming Pools**

Regarding the problems stated in the previous paragraphs, developing some water conservation measures is necessary for METU swimming pools. These water conservation opportunities can be classified as simple water saving techniques and some modifications for the disinfection or water treatment systems of the pools.

Simple water saving techniques consists of installation of water efficient devices. Motion sensors can be installed for taps in the swimming pool facility. It saves water up to 70%. Showers heads used in the facility can be replaced with low flow shower heads to have water saving up to 60%. Lastly, dual-flush systems can be installed for toilets (Marinopoulos and Katsifarakis, 2017).

Reducing the additional water amount supplied from METU water is important. The main reason behind this high water consumption is high combined chlorine concentrations observed in the pools. High additional water amounts are needed to reduce combined chlorine concentrations. Combined chlorine is formed when free chlorine reacts with ammonia like compounds. It is also known as chloramine, which is poor a disinfectant. It causes eye stinging and irritates respiratory systems (Environmental Health, 2013). Some alternatives for reduction of combined chlorine concentrations in swimming pools are given in following paragraphs. Of course, feasibility and water requirements of these alternatives should be evaluated in comparison to the present system before their implementation.

An alternative can be utilization of medium pressure (MP) ultraviolet (UV) lamps in the operation system of swimming pools to reduce combined chlorine concentration. However, it can result in more chloroform formation after chlorination. In order to solve this problem, hydrogen peroxide is used in combination with UV (Spiliotopoulou et al., 2015). In a study made by Tardif et al. (2017), it was found that UV contributed to reduce the level of chloramines in the air (1.6 fold) and N-nitrosodimethylamine (NDMA) in the water (2.1 fold). In addition, direct photolysis of hypochlorous acid

(HOCl) can produce hydroxyl and chlorine radicals when the water is chlorinated. These radicals are used to remove contaminants. Exposure to UV light also creates hydroxyl radicals especially for natural waters due to already present nitrate in natural water (Spiliotopoulou et al., 2015). Therefore, adding UV light to the system can be a good alternative to decrease combined chlorine concentration. However, a more detailed feasibility analysis should be performed considering the performance of such as system in terms of suitability of the resulting water quality for human health.

Another alternative is to use biologically active filtration such as Granular Activated Carbon (GAC) instead of sand filter. When GAC and two sand filters were compared at a single plant, it was found that GAC have greater efficiency in removing N-nitrosodimethylamine (NDMA) than sand filters (Bukhari et al., 2016). Moreover, Tang and Xie (2016) made a pilot study to evaluate the performance of biologically active filtration for swimming pool waters. The results of the study indicated that removal of haloacetic acids (HAAs) was 57.7% when the chlorine residuals $1.7 \pm 0.9$ mg/L. As a result, biologically active carbon can be used instead of sand filter as an alternative.

Ozone is also an alternative to control chloramines and it has good disinfection properties. However, it may be useful when it is used in addition to, not instead of chlorination. After pool water is filtered, ozone in low doses (up to 2 g/hr) can be pumped with air through a venture into a mixing chamber and reaction vessel in the circulation system (Environmental Health, 2013). Provided the ozone is thoroughly mixed and dissolved, it reacts rapidly to destroy chloramines and disinfection by-products to reduce tastes, odors and eye stinging compounds (Environmental Health, 2013).

Lastly, ventilation can be given as an alternative for efficient removal of chloramines and other air impurities. When given off from a pool in the form of a gas, chloramines will redissolve in the pool unless removed by an efficient ventilation system. A ventilation system needs to be well designed without causing drafts, to expel stale air, induce fresh air and lower humidity (Environmental Health, 2013). The results of the study made by Tardif et al. (2017) showed that air stripping had a positive effect on reducing DBP levels of air and N-nitrosodimethylamine (NDMA) in pool water.

In this study, the aim was to decrease additional water supplied from METU potable water network due to high combined chlorine concentrations. If one of these alternatives were used and this alternative does not require any water consumption to obtain combined chlorine concentrations in accordance with the standard (i.e. 0.2 mg/L) given in the regulation, additional water supplied to decrease combined chlorine concentration can be saved and this amount is approximately 400 tonnes/day-120 tonnes/day= 280 tonnes/day.

In addition to alternatives for reduction of combined chlorine concentrations, some reuse alternatives can be evaluated for the backwash water. The filtered backwash water can be used for irrigation if the heat contained in the backwash water is captured by the use of heat exchangers (Seneviratne, 2007). Another alternative can be recycling of the backwash water into the pool. According to Australian Guidelines for Water Recycling (Environmental Health, 2012), recycling of swimming pool backwash water should involve treatment to a suitable standard to allow recycling into the pool. Reverse osmosis, ultrafine filtration and/or granular activated carbon are the recommended as treatment processes for the backwash water (Environmental Health, 2012). Moreover, optimization of backwashing frequency based on filter pressure rather than fixed intervals can reduce water consumption for backwashing by over 50 %. For example, backwashing sand filter once every three days for five minutes, instead of once every day for five minutes, could reduce water consumption by 1500 L/day or 550 $m^3$/year (Styles et al., 2017). Lastly, backwash water can also be reused for toilet flushing via a holding tank if it has enough quality for this use (Brisbane City Council, 2008).

#### 4.3.4. Irrigational Water Consumptions in METU Campus

The lawn areas of the campus which represents approximately 300,000 $m^2$ area are irrigated by using automatic irrigation systems between May and October. While the lawn areas are irrigated with springer irrigation systems, the planted plants are irrigated with the drip irrigation system in the campus. Averagely 30,000 ornamental plants planted in the near-landscaping areas in one year are irrigated once a week by the first 3 years with drip irrigation systems. 20 liters of water were used to irrigate averagely 30,000 plants per week for 27 weeks during the 6 month period.

In addition, irrigation is made once a week for plants produced and purchased in two nurseries within the university for the entire season. While approximately 48,600 $m^3$ of water is consumed with the surface irrigation for the averagely 60,000 plants in the Eymir lake saplings, 43,000 $m^3$ of water is consumed weekly by the irrigation method with hose for 80,000 plants in Central nursery. The total amount of water consumed per year for existing plants in nurseries is 91,800 $m^3$. All these irrigation water amounts are supplied from METU water supply network.

The monthly average water withdrawals from groundwater resource belonging to 2008-2018 period are given in Figure 57. It showed that water withdrawals are lowest in February since minimum number of students stays in campus in this month. In addition to that there is no irrigation in February. In constrast, water withdrawals in July, August and September were as high as the withdrawals in education terms of campus although low population of students stayed at campus due to summer break. However, water was used for irrigational purposes during these months. Therefore, the difference between water withdrawals in February and other three months (July, August and September) was considered as irrigation water which is about 103,000 $m^3$. It represents 10% of yearly average water withdrawals from the groundwater resource..

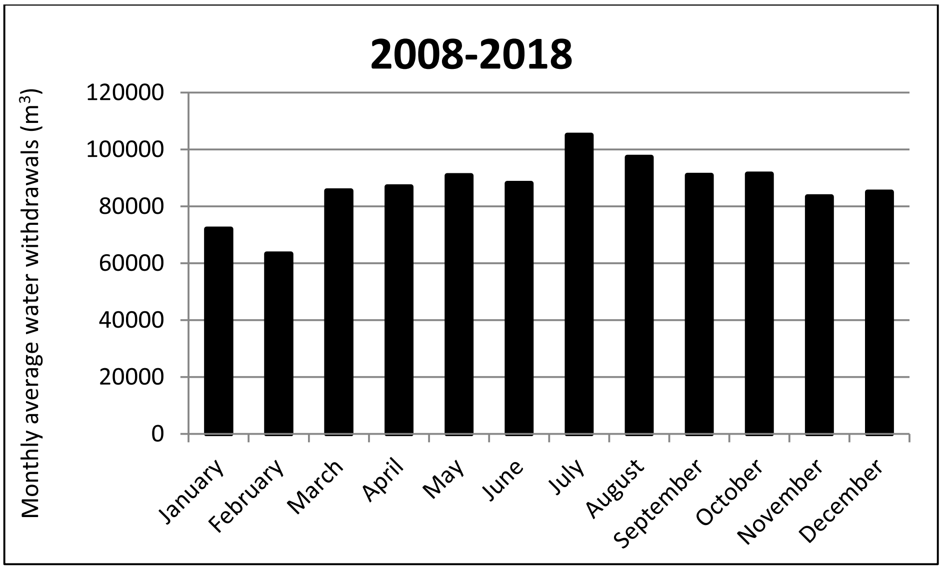



**Figure 57.** Monthly average withdrawals for 2008-2018 period.

### 4.3.5. Recommendations

Some recommendations are given in the following sections for water management in METU dormitories, cafeteria and swimming pools. In this study, the costs of these applications were not considered while they were recommended since economical evaluations were not included in the context of this study. However, decision-makers should consider their costs before deciding to implement them.

**Recommendations for Water Management in METU Dormitories**

The METU dormitories were visited and some information was obtained about the reasons and durations of water uses. Additionally, water consumption data and water consumption behavior survey results were evaluated. Two water-saving approaches were evaluated in terms of water-saving potentials. In the light of these studies, further recommendations are given for the water management in METU dormitories.

- Smart water meters should be installed for each dormitory to monitor water consumptions.

- Detailed analysis of water consumptions and consumer habits in each dorm should be carried out, the infrastructure systems providing water consumption, and accordingly water saving potentials for each dorm should be investigated.
- High flow showerheads should be replaced with low flow showerheads, motion sensors and dual flush systems should be installed for faucets and toilets. More efficient washing machines should also be used.
- Alarm systems should be installed at the showers to prevent excessive water consumptions such as 10 minutes alarms for students.
- Water losses in all dormitories should be detected with a detail investigation in the water infrastructure system and evaluation of the water consumption data.
- Students should be informed about their water consumptions and the importance of water-saving actions to decrease these consumptions.
- Information stickers should be placed on the mirrors in the bathrooms of dormitories to get students' attention about how the change in their water consumption habits can save high amounts of water.
- Some alternatives should be evaluated for water recycling and reuse such as utilization of harvested stormwater in showers and toilets.

**Recommendations for Water Management in METU Cafeteria**

In the light of the information given in Section 4.3.2 (i.e. METU Cafeteria), some recommendations are given for the water management in METU Cafeteria.

- Low flow and high-pressure systems should be used when washing large boilers, trays and doing cleaning.
- Use of double-flush systems and waterless urinals should be evaluated in the toilets of cafeteria.
- Instead of using multiple plates and trays while serving the meals, use of only one wide plate should be evaluated without trays to decrease water used for washing.

- Use of narrower hoses and the controllable pressure hoods in the kitchen should be evaluated.
- Maintenance program should be conducted to detect and repair leaks regularly.

**Recommendations for Water Management in METU Swimming Pools**

The operation and maintenance of METU swimming pools were reviewed and the water-related problems were identified. The best available techniques to solve these problems were explained in previous part. In the light of this information, some recommendations were given for the water management in METU swimming pools.

- High flow showerheads should be replaced with low flow showerheads, motion sensors and dual flush systems should be installed for taps and toilets.
- Some pilot studies should be made to determine the best alternative among processes given in Section 4.3.3 to reduce combined chlorine concentrations in METU swimming pools. Cost-benefit analysis should also be carried out to aid decision-makers.
- Pressure indicator should be installed in order to optimize the length/duration of backwashing.
- The backwash water should be analyzed and the best alternatives should be specified for its treatment and/or reuse.
- A regular maintenance program should be conducted to detect and repair leaks.
- A water meter should be installed and water consumption should be monitored to detect unusual water usage.

# CHAPTER 5

# STORMWATER MANAGEMENT IN METU CAMPUS

As explained in Section 3.2., stormwater management has an important role in developing strategies to provide sustainability for cities and populated areas. It protects people and properties from physical damages of floods and provides the ecological integrity. Thus, developing stormwater management strategies for cities is crucial. Being a component of this, stormwater management plan for METU Campus is important and investigated in this chapter.

Big floods have been observed in Ankara in the past decade. For example, big storm events were observed in 2011 and 2014 summers and they damaged the infrastructures of the city (Figure 58). There are runoff accumulations observed during heavily rainy days also in METU Campus and they may result in damages of infrastructures in the campus as well (Figure 59). Therefore, a stormwater management plan is necessary for METU Campus to protect stormwater quality, to decrease the runoff and mitigate flood risks, structural damages on the campus.

In this study, a rainfall-runoff simulation model was developed for METU Campus to evaluate the effect of different low impact development (LID) applications on reducing surface runoff in the campus. In addition to that, a regression analysis was performed to specify the variables that mostly affect the surface runoff in the campus.

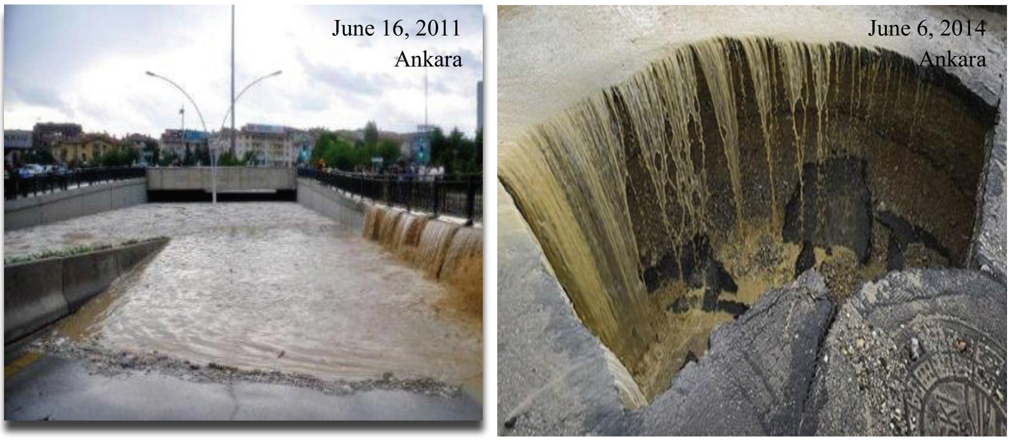



**Figure 58.** Big Floods observed in Ankara (Evrensel, 2011 and AnkaraHaber, 2014)

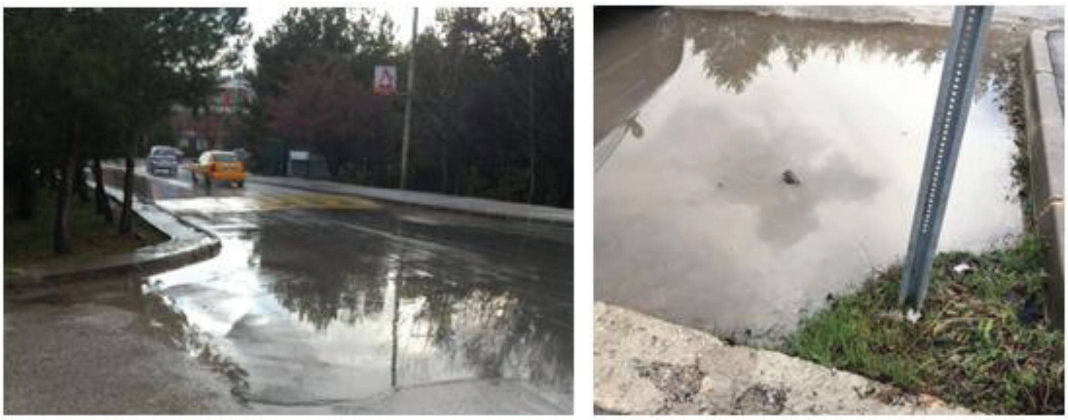


**Figure 59.** Runoff accumulations observed in METU Campus

(Photographed by Melike Kiraz)

### 5.1. Application of SWMM Model in METU Campus

The objective of this study is the evaluation of effectiveness of potential low impact development (LID) options. LIDs which are rain gardens, rain barrels and green roofs in METU Campus to decrease negative flood effects of rainfall and to provide rain harvesting were investigated. In this study, two approaches were used: SWMM as a deterministic model and regression analysis as an empirical model. SWMM was used to simulate and calibrate the surface runoff by using measured flow data belonging to 2017 and to evaluate the effects of LIDs on surface runoff in the campus. In addition to that, a regression analysis was carried out by using data belonging to 2015 and 2017 as a simplified approach and to specify the variables that mostly affect the surface runoff.

SWMM, a dynamic rainfall-runoff simulation model, was developed for METU Campus and calibrated with the flow data obtained from the flowmeter station within the funded project installed in stormwater line of the campus for the time period between May and November 2017. While building the model, Digital Elevation Model (DEM), soil data from European Soil Data Center (ESDAC), meteorological data and land cover/use data were obtained and entered as input data. The input data and their sources are given in Section 5.1. (see Data and Methodology part). The details about characteristics of study area, input data and calibration are provided in the following sections. Moreover, different LID applications were developed and evaluated by using the calibrated model. The details about the procedure and scenarios of LID applications are also given in the following sections.

The steps followed during model development are summarized in Figure 60. In the first step, the subcatchments and the structures of stormwater line such as conduits and junctions were drawn. Necessary input data were entered into model and model was run. After simulation, model results were evaluated and certain parameters of the model were selected to calibrate simulated flow data based on the measured flow data obtained from the installed flowmeter station. Model calibration is a process of systematically adjusting model parameter values to get a set of parameters which provides the best estimatae of the observed runoff flow. Commonly, validation is the step that follows calibration and it is a process of using the calibrated model parameters to simulate runoff over an independent period outside the calibration period if a large number of data is available. In this study, runoff flows of only 21 storm events belonging to time period between May and November, 2017 were used for calibration. Validation was not performed in this study due to limited data. When satisfying simulation results were obtained with calibration, LID application scenarios were developed and evaluated in terms of rain harvesting and runoff reduction potential on the campus.

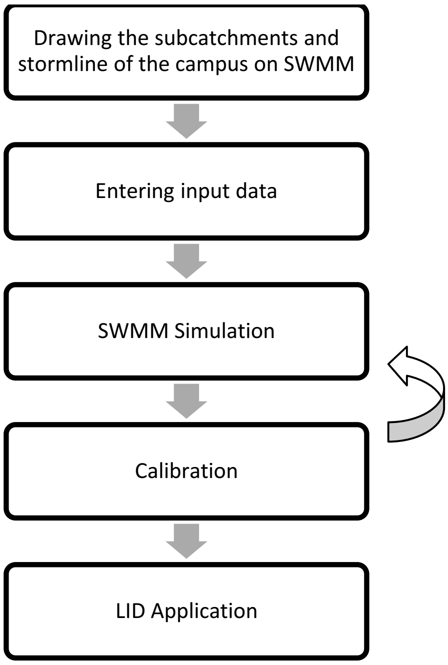



**Figure 60.** Steps of SWMM Model Development for METU Campus

**Climate**

Examining the study area in terms of climate reveals that continental climate dominates in Ankara. While the weather is cold and rainy/snowy in winters, it is dry and hot in summers. Highest and lowest monthly average temperatures were measured as 30.3°C and -3.3°C measured in August and January for 1927-2017 period (General Directorate of Meteorology, 2018). In terms of precipitation, highest and lowest average precipitation amounts were obtained in May and August as 51.2 mm and 11.5 mm for 1927-2017 period, respectively (General Directorate of Meteorology, 2018). Moreover, monthly average evaporations in Ankara are between 100 and 260 mm in May-October period. While the highest evaporation was measured in July 2016, the lowest one was observed in October 2016 (General Directorate of Meteorology, n.d.). Meteorological data for 2016 is summarized in Table 21.

**Table 21.** Summary of meteorological data for Ankara (General Directorate of Meteorology, 2018)

| Months | Max. Temp. (°C) | Min. Temp. (°C) | Ave. Temp. (°C) | Ave. number of rainy days | Monthly average precipitation (mm) | Monthly average evaporation (mm)* |
|---|---|---|---|---|---|---|
| **1** | 4.1 | -3.3 | 0.2 | 12.1 | 39.5 | - |
| **2** | 6.3 | -2.4 | 1.6 | 11.1 | 35.0 | - |
| **3** | 11.4 | 0.5 | 5.7 | 10.7 | 38.6 | - |
| **4** | 17.3 | 5.2 | 11.3 | 11.0 | 42.3 | - |
| **5** | 22.3 | 9.6 | 16.1 | 12.1 | 51.2 | 175 |
| **6** | 26.6 | 12.8 | 20.1 | 8.4 | 34.2 | 200 |
| **7** | 30.2 | 15.7 | 23.5 | 3.4 | 13.7 | 260 |
| **8** | 30.3 | 15.9 | 23.4 | 2.6 | 11.5 | 250 |
| **9** | 25.9 | 11.7 | 18.8 | 4.0 | 17.8 | 240 |
| **10** | 19.8 | 7.0 | 12.9 | 6.8 | 27.6 | 100 |
| **11** | 12.9 | 2.4 | 7.1 | 8.0 | 31.7 | - |
| **12** | 6.4 | -0.8 | 2.4 | 11.6 | 43.9 | - |
| **Yearly** | 17.8 | 6.2 | 11.9 | 101.8 | 387.0 | - |

* Data belongs to 2016

### Topography

In terms of topographical characteristics, it is seen that the study area slopes from southeast to northwest. While the highest elevation of southeastern part is approximately 945 m, lowest elevation of the area is 855 m measured in the northwestern part. The Digital Elevation Model (DEM) of the region was created in the project titled “A Green Campus Application: Sustainable Stormwater Management in METU Campus” (2013-2016) as given in Figure 61. Slopes, flow directions and flow accumulations of the region were calculated by using Hydrology and Surface tools of ArcGIS. After that, watershed delineation was carried out in order to discretize subcatchments of the campus and the average slopes of them were also calculated in ArcGIS.

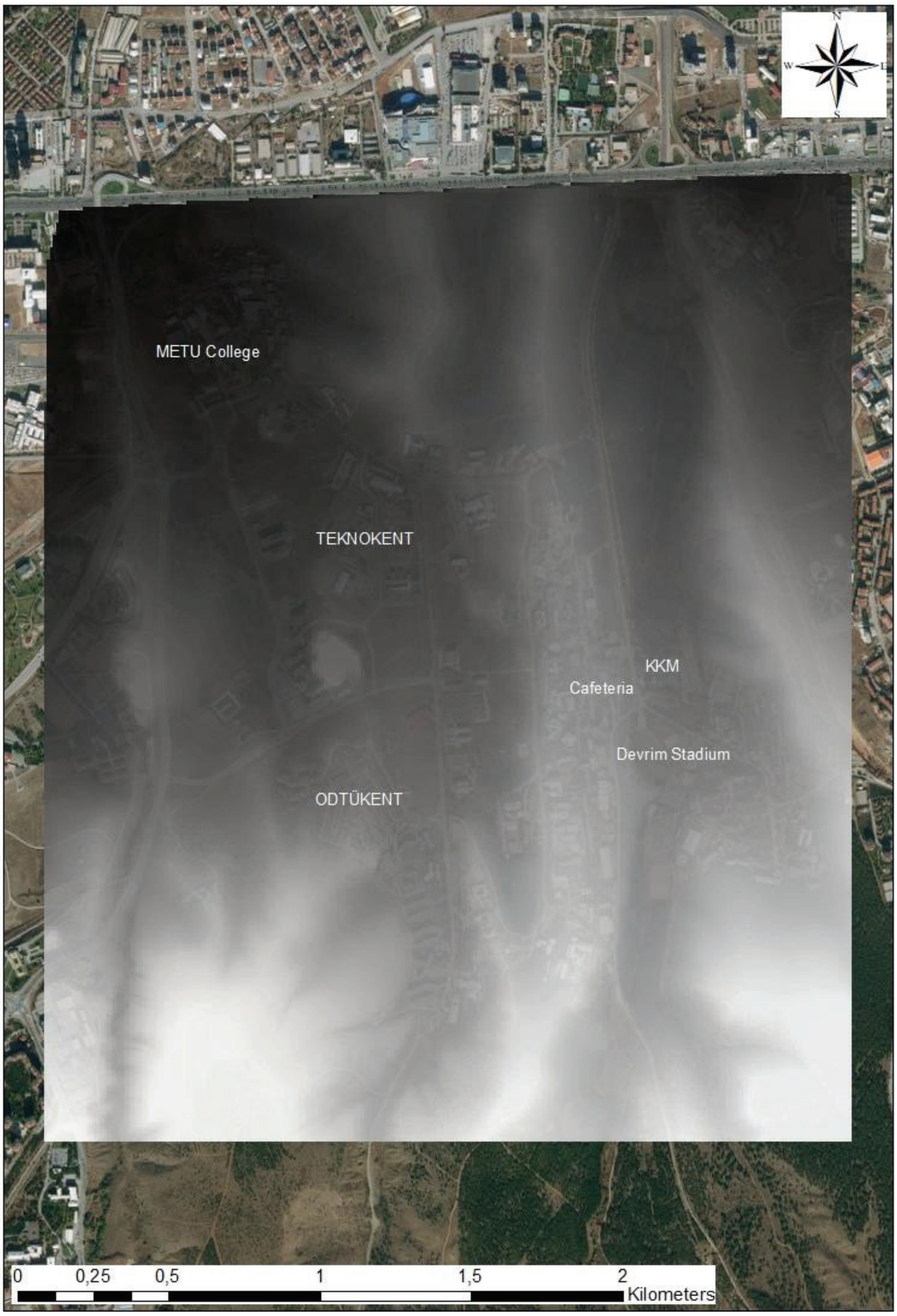



**Figure 61.** DEM of METU Campus

**Soil Properties**

Soil properties effect infiltration characteristics of the area. In this study, 3D Soil Hydraulic Database of Europe prepared by European Soil Data Center (ESDAC) was used to find saturated hydraulic conductivities of the area. The tiff files of saturated hydraulic conductivity in 1 km resolution were downloaded from the ESDAC website: https://esdac.jrc.ec.europa.eu/content/3d-soil-hydraulic-database-europe-1-km-and-250-m-resolution. They were processed in ArcGIS (Figure 62).

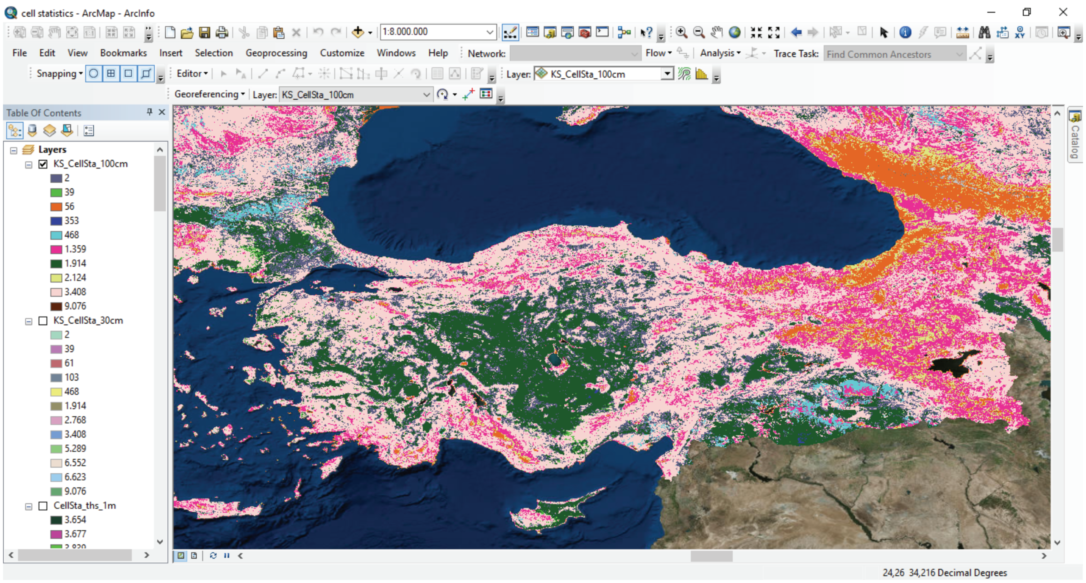



**Figure 62.** Saturated Hydraulic Conductivity Profile of Turkey

After calculating the saturated hydraulic conductivity in 1 m depth of the study area, the table prepared by United State Department of Agriculture (USDA) summarizing the criteria for assignment of Hydrologic Soil Groups according to saturated hydraulic conductivity was used to decide the hydrologic soil group of the region (Table 22). The depth to water impermeable layer and depth to high water table were accepted as 1 m. Hence, the hydraulic saturated conductivity of METU Campus was calculated as 22.2 µm/s at the first 1 m depth of soil. Therefore, this value satisfies the Hydraulic Soil Group B.

**Table 22.** Criteria for assignment of hydraulic soil groups (NRCS, 2009)

| Soil Property | Hydrologic soil group A | Hydrologic soil group B | Hydrologic soil group C | Hydrologic soil group D |
|---|---|---|---|---|
| Saturated hydraulic conductivity of the least transmissive layer | >40.0 μm/s | ≤40.0 to >10.0 μm/s | ≤10.0 to >1.0 μm/s | ≤1.0 μm/s |
| | and | and | and | and/or |
| Depth to water impermeable layer | 50 to 100 cm | 50 to 100 cm | 50 to 100 cm | <50 cm |
| | and | and | and | and/or |
| Depth to high water table | 60 to 100 cm | 60 to 100 cm | 60 to 100 cm | <60 cm |

### 5.1.1. Data and Methodology

In this study, SWMM was used to simulate the runoff amount on campus and to evaluate different LID application scenarios. Therefore, necessary input data were obtained from different sources as shown in Table 23.

Table 23. SWMM Model Input Data Information

| Data Type | Data Source | Data Description |
|---|---|---|
| Meteorology | The meteorology station installed on the roof of Environmental Engineering Department and General Directorate of Meteorology | Precipitation, temperature and monthly evaporation rates were used in the model. |
| Land Use | AutoCAD drawing of the campus taken from Directorate of METU Heat and Water Management and Google Earth | Land use types and areas were required to calculate areas, width, percentages of imperviousness and curve numbers of subcatchments. |
| Soil | 3D Soil Hydraulic Database of Europe prepared by European Soil Data Center (ESDAC), the table for hydrological soil groups criteria and table for runoff curve numbers prepared by U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) | Saturated hydraulic conductivity was required to specify hydrologic soil group of the campus area. After that, curve number of each subcatctment was calculated by using their land use areas and the curve numbers specified for these land uses according to the hydrologic soil group. |
| Topography | Digital Elevation Model of METU campus and AutoCAD drawing of the campus created by Directorate of METU Heat and Water Management | Slope of subcathments were calculated from DEM of the region and invert elevations of junctions were obtained from AutoCAD drawing of the campus. |

**Precipitation Data**

The five-minute-interval precipitation data was obtained for METU Campus from the weather station (Figure 63) installed on the roof of the Environmental Engineering Department for 5 May- 31 October 2015 and 18 May-28 November 2017 period. The data was converted into 30-minute-interval form (Figure 64 and Figure 65). The precipitation data of 2015 and 2017 years were used in the regression analysis. However, data belonging to 2017 year was used as an input data for SWMM model development.

During this period, total precipitation was 152.8 mm. Moreover, highest total precipitation was observed in June while there is no precipitation observed in September (Figure 66). The heaviest rain event was observed in 19 June, 2017 and total precipitation of that storm was 18.8 mm.

**Figure 63.** Davis Instruments Vantage Pro2 Weather Station installed at roof of Environmental Engineering Department

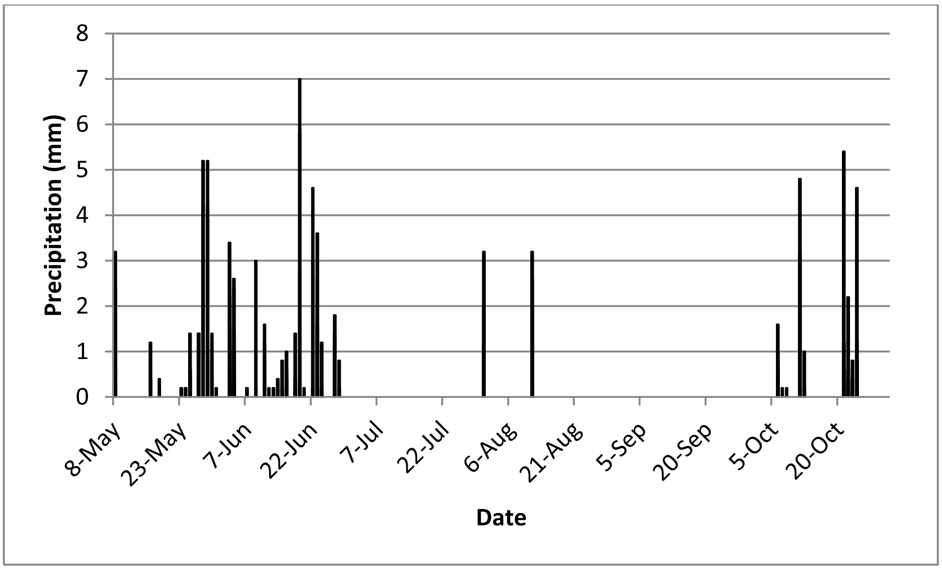



**Figure 64.** 30-minutes-interval precipitation measured in the period of 8 May-31 October, 2015

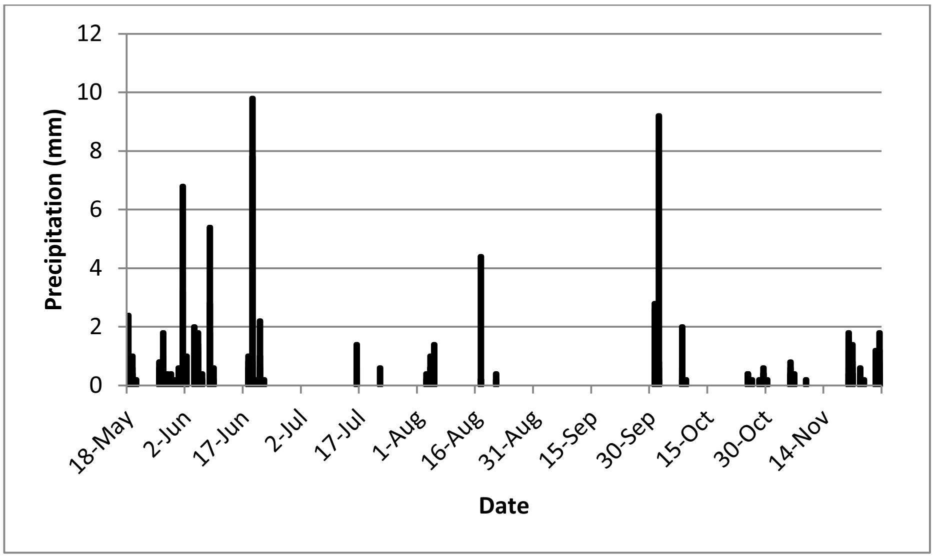



**Figure 65.** 30-minutes-interval precipitation measured in the period of 18 May-28 Novermber, 2017

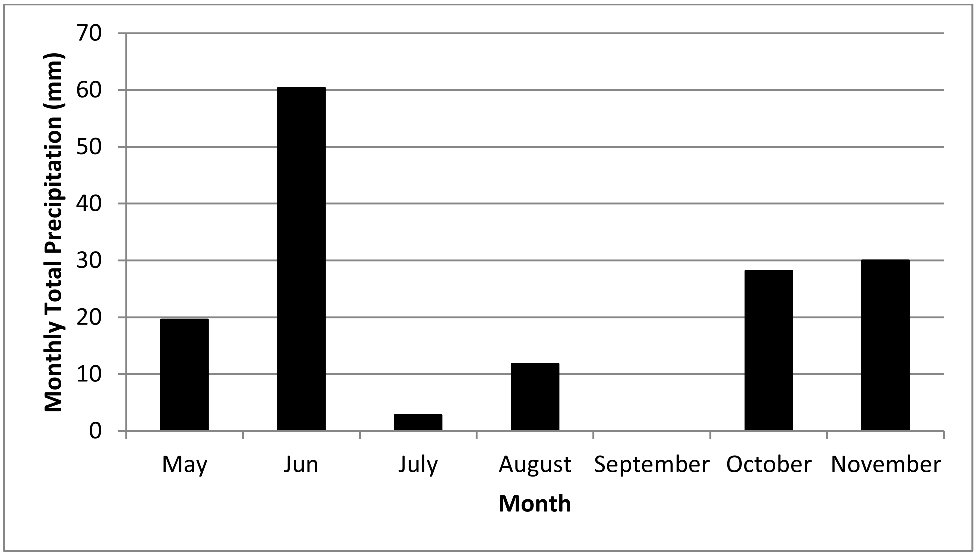



**Figure 66.** Monthly total precipitation between 18 May and 28 November, 2017

**Subcatchment Discretization and Land Use Calculations**

Campus is represented in terms of subcathments in SWMM. In order to define these subcatchments in SWMM, it is necessary to divide the campus into its subcathments and to calculate land uses of these subcatchments. In SWMM model development, the surface runoff is calculated according to these subcatchments' characteristics for each rain event. Firstly, DEM of the campus was used in the hydrology tool of ArcMap for subcatchment discretization. After specifying 14 subcatchments (see Figure 67), land uses of these subcatchments were calculated as areas by using both AutoCAD drawing of the campus and Google Earth. Among these subcatchments, only 4 of them (i.e. S1, S2, S4 and S5 as shown in Figure 67) were drawn and their characteristics were defined in SWMM since the measured flow data from the gage located at flowmeter station (FS3) represents the surface runoff of these subcatchments (Table 25). Land uses and slopes of these 4 subcatchments were given in Table 24.

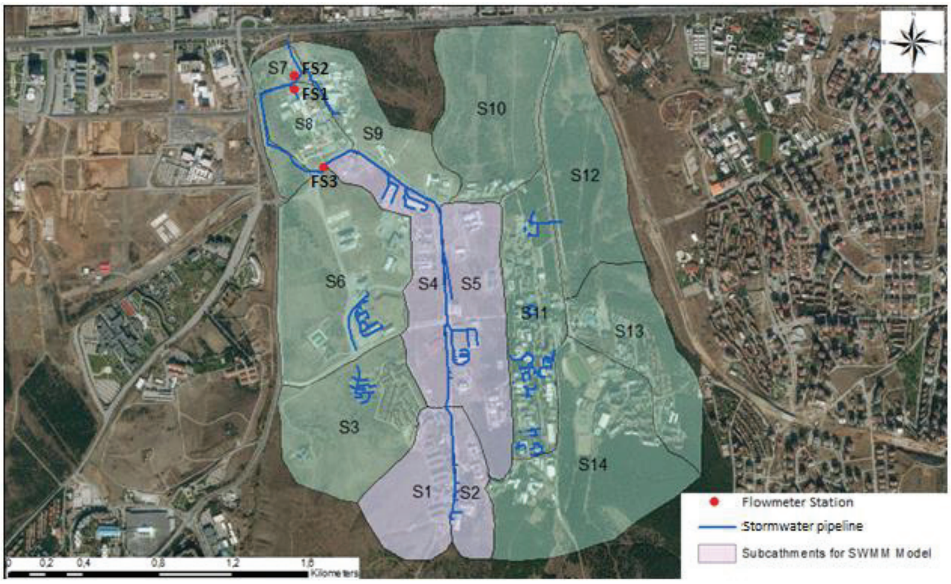



**Figure 67.** Flowmeter Station Locations, Stormwater pipeline and Subcatchments of METU Campus

**Table 24.** Land uses and slopes of the subcatchments

| **Subcatchments ($m^2$)** | **S1** | **S2** | **S4** | **S5** |
|---|---|---|---|---|
| Total Area | 123701.5 | 104820.6 | 281870.9 | 364188.5 |
| Asphalt | 3904.3 | 7516.1 | 17092.3 | 17497.3 |
| Building | 18989.4 | 9470.9 | 22683.2 | 39051.8 |
| Pavement | 837.4 | 3393.3 | 1202.4 | 7083.3 |
| Parking area | 4066.8 | 2551.2 | 17492.1 | 18747.7 |
| Field* | 3778.5 | 98.9 | 0 | 15000.5 |
| Forest | 9704.3 | 16203.5 | 64447.6 | 134329.1 |
| Grassland | 82420.8 | 65586.6 | 158953.4 | 144895.9 |
| Impervious Area | 31576.4 | 23030.5 | 58469.9 | 97380.6 |
| Pervious Area | 92125.1 | 81790.1 | 223401.0 | 279225.0 |
| Average Slope (%) | 9.5 | 12.9 | 5.3 | 8.7 |

* Parks, basketball/football courts, construction field

**Stormwater Line Flow Data**

The flowmeter station was originally installed at flowmeter station FS1 (see Figure 67) which collected streamflow data of catchment DM1 (see Table 25). Then the location of the flowmeter station was changed to flowmeter station FS2 and finally to flowmeter station FS3. The flowmeter station had to be moved in these three different locations due to construction activities on campus. The runoff flow data obtained from each of these three different locations were limited and they represented three different catchments as DM 1, DM 2 and DM3. Therefore, SWMM model was calibrated by using the flow and precipitation data belonging to only May-November 2017 period obtained from the gauge located at FS3. S1, S2, S4 and S5 (DM3) are the subcatchments used for SWMM model development and calibration process. While DM1 represents only S8, DM2 represents S1, S2, S4, S5 and S8 subcatchments. Catchments (DM), flowmeter stations (FS) and subcatchments (S) are summarized in Table 5. Figure 68 indicates the flowmeter station installed in METU Campus.

**Table 25.** Measurement periods, flowmeter stations and the subcatchments

| Measurement Periods | Flowmeter Station | Subcatchments |
|---|---|---|
| May-July 2015 | FS1 | DM1=S8 |
| October-November 2015 | FS2 | DM2=S1+S2+S4+S5+S8 |
| May-November 2017 | FS3 | DM3=S1+S2+S4+S5 |

**Figure 68**.Flowmeter Station installed in METU Campus

**Infiltration Data**

As explained before, there are different infiltration methods used in SWMM and these are Horton, Modified Horton, Green-Ampt, Modified Green-Ampt and Curve Number (CN) method. In this study, the infiltration method chosen for SWMM model development is the Curve Number method according to available data of the infiltration parameters and method suitability. Because the data about abstractions are unknown for the region and CN values include all type of abstractions in it according to land uses and soil groups of the region. It is the selected method for this case.

The CN values of the subcatchments were calculated using hydrologic soil group and land uses of the region. As given in the previous section, hydrologic soil group of the region was found as B. Moreover, land uses of the region were calculated as shown in Table 24. Natural Resources Conservation Service of United States Department of Agriculture (NRCS) prepared a table indicating runoff curve numbers for urban areas for different cover types and hydrologic soil groups (see Figure 69). In the table, CN of impervious areas are given as 98 while the ones for open spaces for different grass cover percentages are changing between 61 and 79 for hydrologic soil group B. High curve number values cause most of the rainfall to appear as runoff with minimal losses.

**Table 2-2a** Runoff curve numbers for urban areas [1]

| Cover description | | Curve numbers for hydrologic soil group | | | |
|---|---|---|---|---|---|
| Cover type and hydrologic condition | Average percent impervious area [2] | A | B | C | D |
| ***Fully developed urban areas (vegetation established)*** | | | | | |
| Open space (lawns, parks, golf courses, cemeteries, etc.) [3]: | | | | | |
| Poor condition (grass cover < 50%) | | 68 | 79 | 86 | 89 |
| Fair condition (grass cover 50% to 75%) | | 49 | 69 | 79 | 84 |
| Good condition (grass cover > 75%) | | 39 | 61 | 74 | 80 |
| Impervious areas: | | | | | |
| Paved parking lots, roofs, driveways, etc. (excluding right-of-way) | | 98 | 98 | 98 | 98 |
| Streets and roads: | | | | | |
| Paved; curbs and storm sewers (excluding right-of-way) | | 98 | 98 | 98 | 98 |
| Paved; open ditches (including right-of-way) | | 83 | 89 | 92 | 93 |
| Gravel (including right-of-way) | | 76 | 85 | 89 | 91 |
| Dirt (including right-of-way) | | 72 | 82 | 87 | 89 |
| Western desert urban areas: | | | | | |
| Natural desert landscaping (pervious areas only) [4] | | 63 | 77 | 85 | 88 |
| Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders) | | 96 | 96 | 96 | 96 |
| Urban districts: | | | | | |
| Commercial and business | 85 | 89 | 92 | 94 | 95 |
| Industrial | 72 | 81 | 88 | 91 | 93 |
| Residential districts by average lot size: | | | | | |
| 1/8 acre or less (town houses) | 65 | 77 | 85 | 90 | 92 |
| 1/4 acre | 38 | 61 | 75 | 83 | 87 |
| 1/3 acre | 30 | 57 | 72 | 81 | 86 |
| 1/2 acre | 25 | 54 | 70 | 80 | 85 |
| 1 acre | 20 | 51 | 68 | 79 | 84 |
| 2 acres | 12 | 46 | 65 | 77 | 82 |
| ***Developing urban areas*** | | | | | |
| Newly graded areas (pervious areas only, no vegetation) [5] | | 77 | 86 | 91 | 94 |
| Idle lands (CN's are determined using cover types similar to those in table 2-2c). | | | | | |

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

**Figure 69.** Runoff Curve Number for Urban Areas (NRCS, 1986)

After the CN of each land uses was determined in subcatchments, a generalized CN value was calculated for every subcatchment using:

$$\text{CN}_{\text{subcatchment}} = \sum_{i=1}^{n} \frac{CNi * Ai}{Atotal} \qquad (12)$$

where CNi is the CN value specified for land use $i$ of a subcatchment, Ai is the area of each land uses in this subcathment, i is the index for land use in the subcatchment and Atotal is the total area of the subcatchment. The CN values for the land uses of subcatchments in DM3 and their overall CN values are shown in Table 26. Overall CN values were calculated using areas (Table 24) and CN values of each land use.

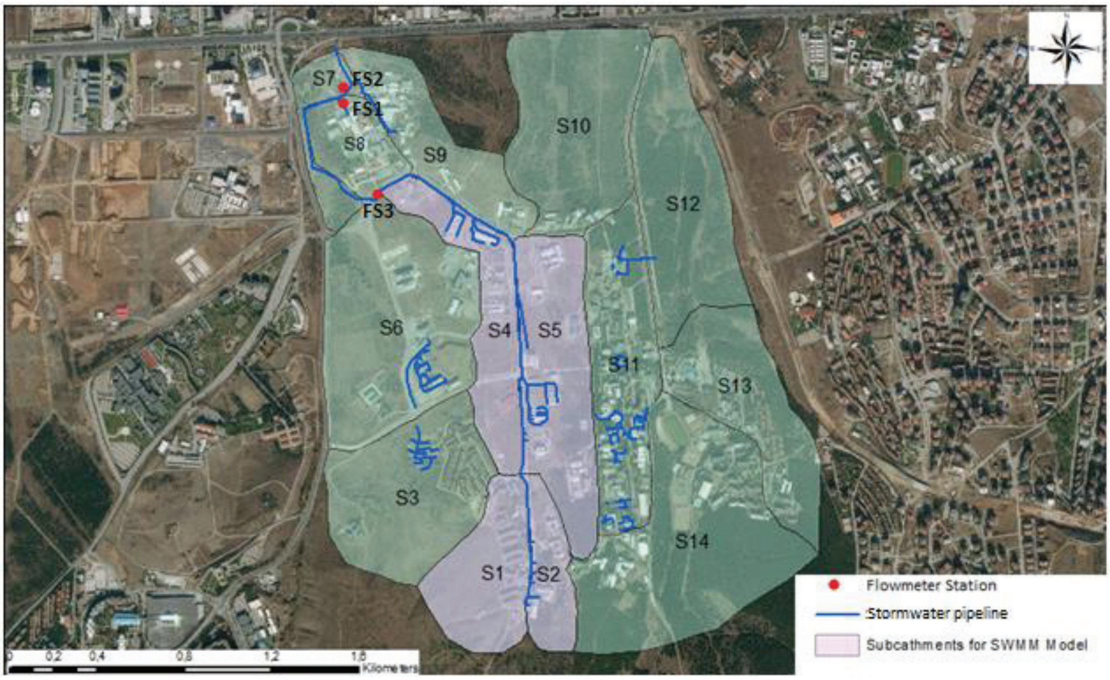



**Figure 70.** The stormwater pipeline, flowmeters stations and subcatchments of METU Campus

**Table 26.** CN values land uses and overall CN values of subcatchments

| | Subcatchments | | | |
|---|---|---|---|---|
| **Landuse** | **S1** | **S2** | **S4** | **S5** |
| Asphalt | 98 | 98 | 98 | 98 |
| Pavement | 98 | 98 | 98 | 98 |
| Parking area | 98 | 98 | 98 | 98 |
| Field* | 79 | 79 | 79 | 79 |
| Forest | 61 | 61 | 61 | 61 |
| Grassland | 61 | 61 | 61 | 61 |
| **Overall** | **64.7** | **66.2** | **63** | **66.8** |

### 5.1.2. Model Construction

After obtaining necessary input data such as rainfall, temperatures and evaporation rates, watershed delineation was performed for METU Campus and the areas, landuses, slopes and widths of subcatchments were calculated. Later, SWMM model was constructed for METU Campus. The steps followed during model development were given in Figure 60. In the first step, the subcatchments and the structures of stormwater line such as conduits and junctions were drawn (Figure 71). Necessary input data were entered into model and model was run. After simulation, model results were evaluated and certain parameters of the model were calibrated based on the measured flow data obtained from the installed flowmeter station. When satisfying simulation results were obtained with calibration, LID application scenarios were developed and evaluated in terms of rain harvesting and runoff reduction potential on the campus.

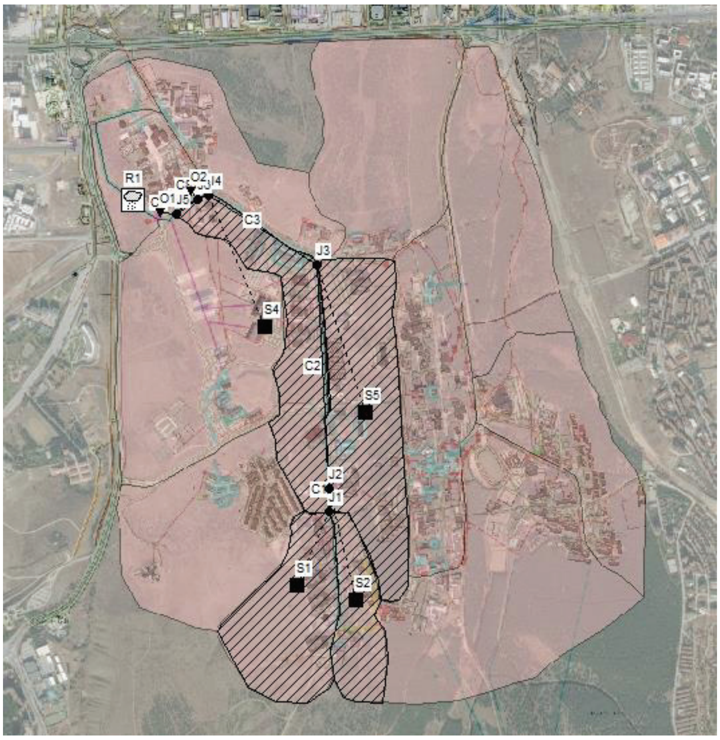
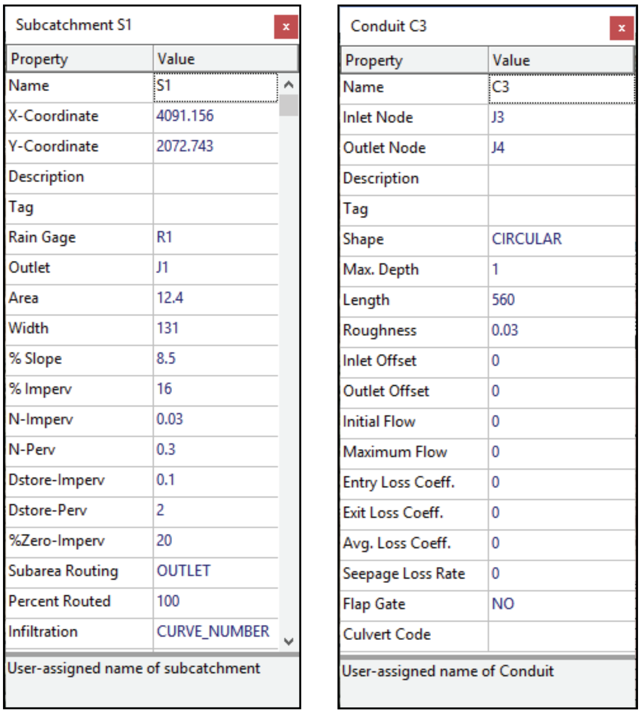



**Figure 71.** Drawings of subcatchments

In SWMM model construction, units of variables should be chosen firstly. Cubic meter per second (CMS) ($m^3/s$) was chosen as the unit of flow. Moreover, units of precipitation, area and length were chosen as millimeters (mm), hectares (ha), and meters (m), respectively. For infiltration process, Curve Number (SCS) method was selected as explained earlier. In addition, Dynamic Wave is chosen as the routing model in the study because dynamic wave routing can also account for specific cases such as flow splitting, entrance/exit losses, backwater and pressurized flow when compared to kinematic wave option.

After specifying general simulation options, subcatchments of the campus were drawn in SWMM. The calculated parameters which are their areas, widths, average slopes, percentages of imperviousness and curve number values were entered for subcatchments. The other input data which are N-Imperv (Mannings N for impervious area), N-perv (Mannings N for pervious area), Dstore-Imperv (depth of depression storage on impervious area), Dstore-Perv (depth of depression storage on pervious area) and %Zero-Imperv (percent of impervious area with no depression storage) were initially used as their default values. Subarea routing was selected as outlet which means that runoff generated on both pervious and impervious areas in each subcatchment routes directly to the outlet of the subcatchment. After drawing subcatchments, they were connected to their outlet nodes and these outlet nodes were connected to each other by conduits defined in SWMM. The outlet of main catchment (DM3) were also defined and connected to end of these conduits. Invert elevations of nodes were obtained from AutoCAD drawing of the campus and entered into the model. In the conduit editing part, lengths of conduits were entered and their roughness values were initially entered as the default value. Subcatchment and conduit editor windows of SWMM are shown in Figure 72.



Subcatchment S1

| Property | Value |
|---|---|
| Name | S1 |
| X-Coordinate | 4091.156 |
| Y-Coordinate | 2072.743 |
| Description | |
| Tag | |
| Rain Gage | R1 |
| Outlet | J1 |
| Area | 12.4 |
| Width | 131 |
| % Slope | 8.5 |
| % Imperv | 16 |
| N-Imperv | 0.03 |
| N-Perv | 0.3 |
| Dstore-Imperv | 0.1 |
| Dstore-Perv | 2 |
| %Zero-Imperv | 20 |
| Subarea Routing | OUTLET |
| Percent Routed | 100 |
| Infiltration | CURVE_NUMBER |

User-assigned name of subcatchment

Conduit C3

| Property | Value |
|---|---|
| Name | C3 |
| Inlet Node | J3 |
| Outlet Node | J4 |
| Description | |
| Tag | |
| Shape | CIRCULAR |
| Max. Depth | 1 |
| Length | 560 |
| Roughness | 0.03 |
| Inlet Offset | 0 |
| Outlet Offset | 0 |
| Initial Flow | 0 |
| Maximum Flow | 0 |
| Entry Loss Coeff. | 0 |
| Exit Loss Coeff. | 0 |
| Avg. Loss Coeff. | 0 |
| Seepage Loss Rate | 0 |
| Flap Gate | NO |
| Culvert Code | |

User-assigned name of Conduit

**Figure 72.** Subcatchment (left) and conduit (right) editor windows in SWMM

In order to run simulations, a rain gage should be introduced and rainfall data should be added into the model. In the study, half-hourly rainfall data and temperature data obtained from the meteorological station installed on the roof of Environmental Engineering department were added as external file data in a time series format. Lastly, monthly evaporation rates (mm/day) taken from General Directorate of Meteorology were entered. Figure 73 indicates the input rainfall data format and climatology editor in SWMM.

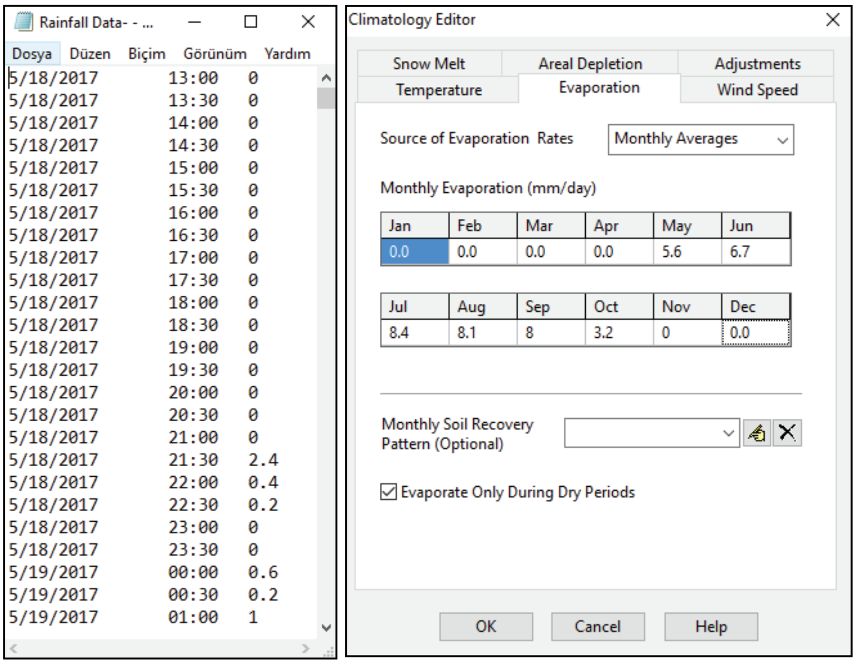



**Figure 73.** The input rainfall data format (at left) and climatology editor (at right) in SWMM

### 5.1.3. Model Calibration

Obtaining good field data for the calibration is very important. Evaluating and selecting good flow data can save plenty of time during calibration process (Sangal and Bonema, 1994). Therefore, monitoring and data collection was made carefully in order to obtain successful simulation results.

In this study, the simulated total runoff volume was almost four times more than the measured one at the beginning of calibration (Table 27). In order to understand whether there is a measured data-related problem or calculation-error, the total runoff volume was also approximately calculated by multiplying impervious portion of total campus area by the total precipitation during the period. When simulated and calculated values were compared, it is observed that they were close to each other (Table 27). Therefore, it was realized that there could be a problem related with measured data. After personal communication with Directorate of METU Heat and Water Management Unit, it is understood that there was a fracture in the pipe that is located right before the pipe where the flowmeter station was installed (Figure 74). That is why, a large amount of runoff water was lost from the pipe and this leakage was unfortunately detected after flow data was collected. As a result, it was confirmed that obtaining quite lower measured runoff amount than simulated one was due to leakage from the pipe.

To represent the loss due to the fracture explained in the previous paragraph on the simulation, an additional node is put in the middle of the pipe and it is linked to an outfall (Figure 74). The invert elevation of this outfall was entered as an elevation of a point near to this additional node. In the simulation, the flow from this outfall accounts for the leakage of this pipe (Dickinson, 2012). According to this elevational difference between the additional nodel and its outfall, the leakage of the pipe was calculated in SWMM. After reflecting this leakage effect, calibration was carried out and the model performance improved.

**Table 27.** Calculated total flow from impervious area, simulated and measured total flows at the beginning of calibration

| Total Rain (mm) | Total impervious area ($m^2$) | Total flow formed in impervious area ($m^3$) | Simulated total flow ($m^3$) | Measured total flow ($m^3$) |
|---|---|---|---|---|
| **142.8** | 90195.2 | 12879.9 | 11412.1 | 3139.3 |

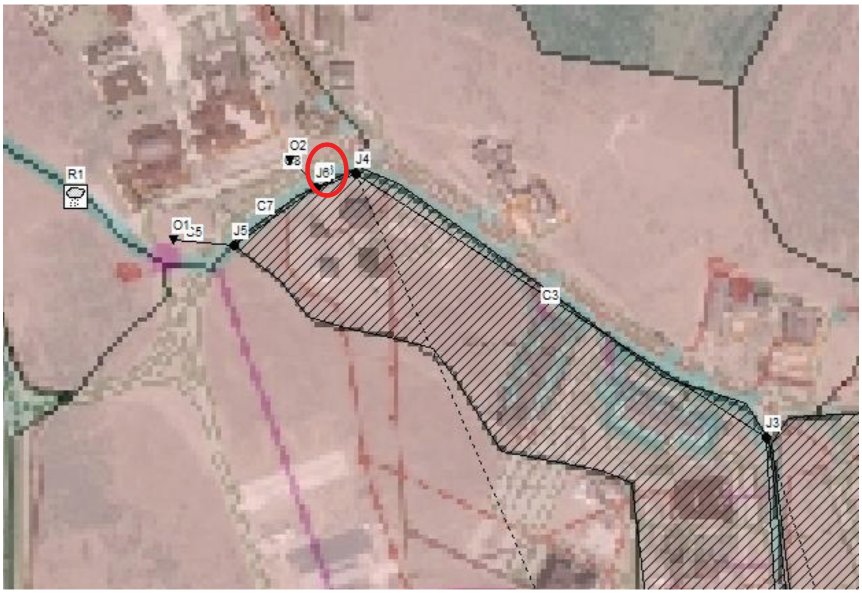



**Figure 74.** Additional node (J6) out in the middle of pipe (C7)

After putting the additional node, model was run with default values of parameters before calibration. The subcathment parameters are width, average slope (% slope) and imperviousness percentage (% imperv) of subcatchment, Manning's n values for impervious (N-Imperv) and pervious (N-perv) areas, depth of depression storage on impervious (Dstore-Imperv) and pervious (Dstore-Perv) areas and percent of impervious area with no depression storage (%Zero-Imperv) and CN values. In addition to that, conduit roughness was the important parameter for the flow in the conduit. Effects of these parameters on runoff flow were evaluated by trying to use different values of them. According to evaluation results, subcatchment width and conduit roughness were the most important parameters affecting peak time of rain events during simulation. Manning's n values (N-perv and N-imperv) and depths of depression storage (Dstore-Imperv and Dstore-Perv) were the parameters affecting the total runoff amount significantly. However, changes in CN values of subcatchments did not affect runoff flow much. After trying different values for all these parameters, the parameters which were mostly sensitive for runoff flow were selected as calibration parameters.

In the study, model calibration was performed for METU Campus based on half-hourly data obtained from five-minutes data measured in the flowmeter station for a period of May 18 - November 28, 2017. The aim of the calibration is to make the output model results closely agreed with the measured data. Nine parameters were selected for calibration. These are width, % slope, % imperv, N-Imperv, N-perv, Dstore-Imperv, Dstore-Perv, %Zero-Imperv and roughness values of conduits. These selected parameters were used to calibrate runoff flow until obtaining the optimum simulation results. Width, % slope, % imperv were measured and calculated by using Google Earth, AutoCAD drawing of campus and ArcGIS. The errors of these parameters were mainly attributable to the measurement methods. The values of these three parameters in the various subcatchments were different. Therefore, the three parameter values for all the subcatchments were increased or decreased simultaneously in the calibration. The percentage change scales for these three parameters during calibration are listed in Table 28. The table also shows the default values and final optimum values of other calibration parameters.

**Table 28.** The default values, calibration intervals and final optimum values of calibration parameters

| Calibration Parameter | Default Value | Calibration Interval | References | Final Optimal Value |
|---|---|---|---|---|
| Width | - | ± 15% | - | -10% |
| %Slope | - | ± 15% | - | -10% |
| %Imperv | - | ± 15% | - | +5% |
| N-Imperv | 0.01 | 0.01-0.033 | Engman (1986) | 0.03 |
| N-perv | 0.1 | 0.02-0.8 | Dongquan et al. (2009) | 0.3 |
| Dstore-Imperv | 0.05 | 0.06-0.11 | Rossman and Huber (2016) | 0.1 |
| Dstore-Perv | 0.05 | 2-5.1 | Huber and Dickinson (1988) | 2 |
| %Zero-Imperv | 25 | 5-20 | Dongquan et al. (2009) | 20 |
| Conduit Roughness | 0.01 | - | - | 0.03 |

### 5.1.4. Evaluation of Calibration Results

The agreement between the simulated and measured data is evaluated to assess the model performance. There are some likelihood functions to evaluate simulation results quantitatively. In this study, Nash-Sutcliffe efficiency (NSE) factor was selected as the objective function. Additionally, coefficient of determination ($R^2$) was also calculated while assessing simulation results.

Nash and Sutcliffe (1970) developed a normalized statistics named as Nash-Sutcliffe efficiency (NSE) and it indicates the relative magnitude of the residual variance compared to the measured data variance. NSE factor ranges from $-\infty$ to 1.0. In general, NSE factors between 0.0 and 1.0 are seen as acceptable levels of performance while the ones less than 0.0 are unacceptable. However, NSE value closer to 1.0 means better model performance (Table 29). It is calculated by using the formula (Moriasi et al., 2007).

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y,obs - Yisim)^\wedge 2}{\sum_{i=1}^{n}(Y,obs - Ymean)^\wedge 2}\right] \qquad (13)$$

where $Y_i^{obs}$ is $i^{th}$ observed value, $Y_i^{sim}$ is $i^{th}$ simulated value and $Y^{mean}$ is mean value of observed data.

Coefficient of determination ($R^2$) shows the degree of collinearity between simulated and measured data. It ranges from 0 to 1 and higher values means less error variance (Moriasi et al., 2007).

**Table 29.** Recommended NSE value intervals for general Performance ratings (Moriasi et al., 2007)

| **Performance Rating** | **NSE** |
|---|---|
| Very good | $0.75 < NSE \leq 1.00$ |
| Good | $0.65 < NSE \leq 0.75$ |
| Satisfactory | $0.50 < NSE \leq 0.65$ |
| Unsatisfactory | $NSE \leq 0.50$ |

During the simulation period, 21 storm events were observed and 4 of them (June 1, June 8, June 19 and August 5, 2017) were large events in these months and are selected to be used for calibration (Figure 75). Evaluating stormwater drainage systems using larger, less frequent events is essential for engineers and planners because the effect of LID applications during large events must be considered to decrease flood risks (Rosa, et al., 2015). Therefore, correct modeling of larger flood events and obtaining satisfying NSE values for these events are aimed here. The precipitation amonts of rain event belonging to 2017 were given in Table 30.

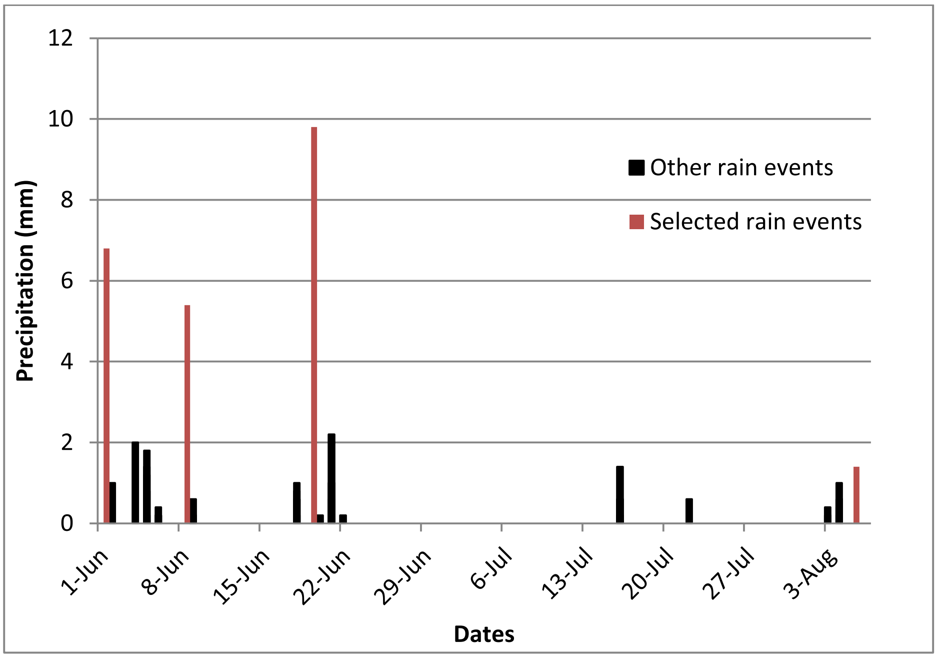



**Figure 75.** Precipitation (mm) of selected large events in June 1, June 8, June 19 and August 5, 2017

**Table 30.** Rain events observed on the METU Campus in 2017

| No | Rain events | Max. Rain (mm/30 min) | Rain Duration (hr) | Total Rain (mm) |
|---|---|---|---|---|
| **1** | 18.05.2017 | 2.4 | 7 | 7 |
| **2** | 26.05.2017 | 0.8 | 5 | 5.2 |
| **3** | 27.05.2017 | 1.8 | 3.5 | 4.6 |
| **4** | 28.05.2017 | 0.4 | 1.5 | 0.8 |
| **5** | 31.05.2017 | 0.6 | 1.5 | 1.2 |
| **6** | 01.06.2017 | 6.8 | 1.5 | 11 |
| **7** | 08.06.2017 | 5.4 | 2 | 10.2 |
| **8** | 09.06.2017 | 0.6 | 1 | 0.8 |
| **9** | 18.06.2017 | 1 | 5 | 4.2 |
| **10** | 19.06.2017 | 9.8 | 2.5 | 18.8 |
| **11** | 20.06.2017 | 0.2 | 1 | 0.4 |
| **12** | 04.08.2017 | 1 | 2.5 | 3 |
| **13** | 05.08.2017 | 1.4 | 1 | 1.8 |
| **14** | 17.08.2017 | 4.4 | 2 | 5 |
| **15** | 01.10.2017 | 2.8 | 1.5 | 5.8 |
| **16** | 02.10.2017 | 9.2 | 3.5 | 11.4 |
| **17** | 25.10.2017 | 0.4 | 3 | 1.6 |
| **18** | 29.10.2017 | 0.6 | 3 | 2.2 |
| **19** | 20.11.2017 | 1.8 | 20.5 | 12.2 |
| **20** | 23.11.2017 | 0.6 | 1.5 | 1.2 |
| **21** | 27.11.2017 | 1.8 | 8 | 10.2 |

Before calibration, the comparisons of observed and calibrated flows for these four rain events are given in Figure 76, Figure 77, Figure 78 and Figure 79. Without calibration, model does not simulate the peak, time of peak and the trend in the flow successfully. These results also indicated that calibration is necessary for this simulation.

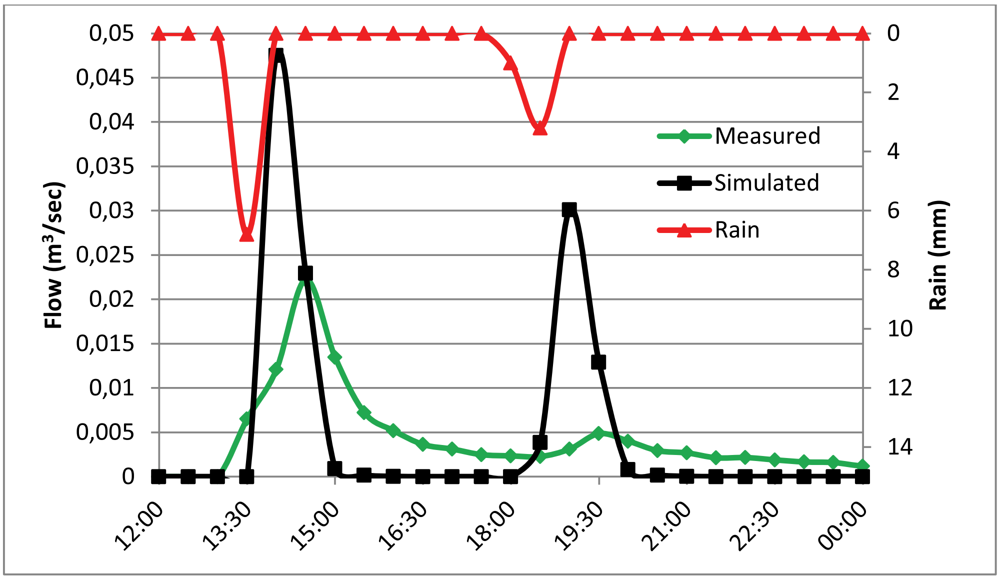



**Figure 76.** Measured and calibrated flow variations belong to 1st June, 2017 before calibration

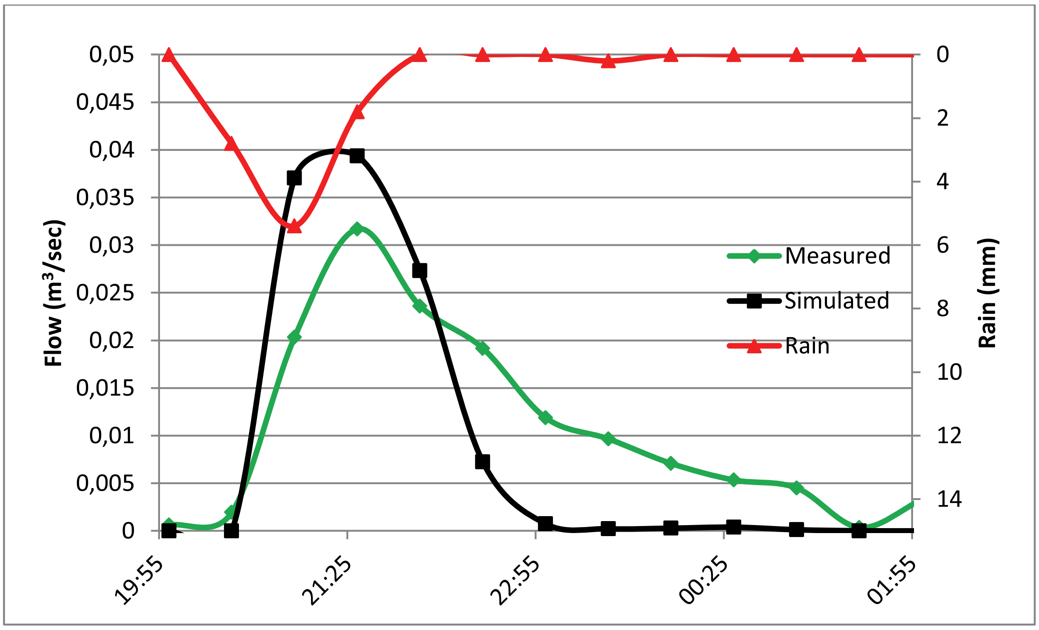



**Figure 77.** Measured and calibrated flow variations belong to 8st June, 2017 before calibration

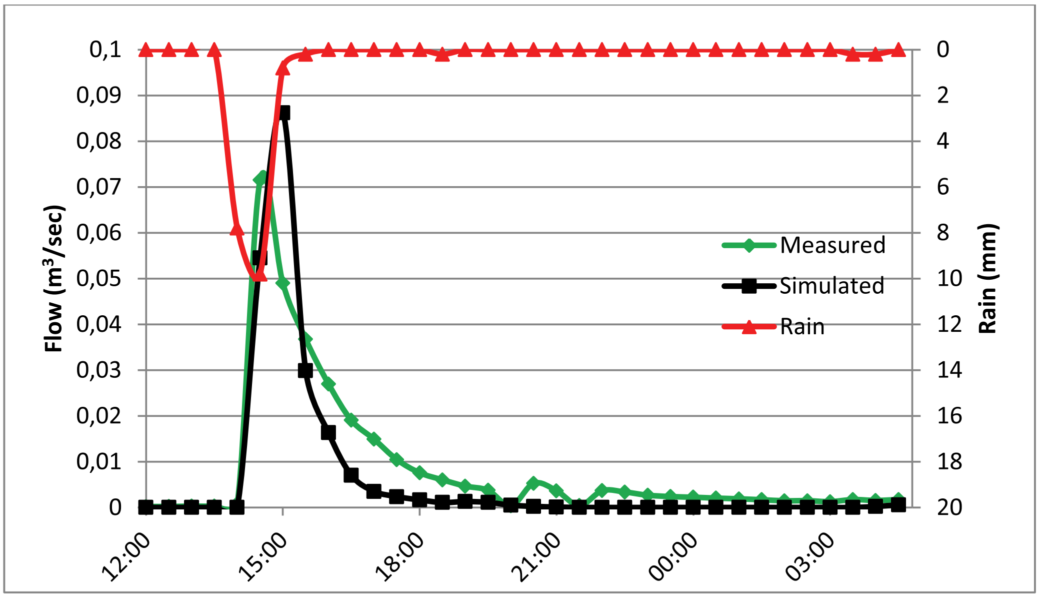



**Figure 78.** Measured and calibrated flow variations belong to 19st June, 2017 before calibration

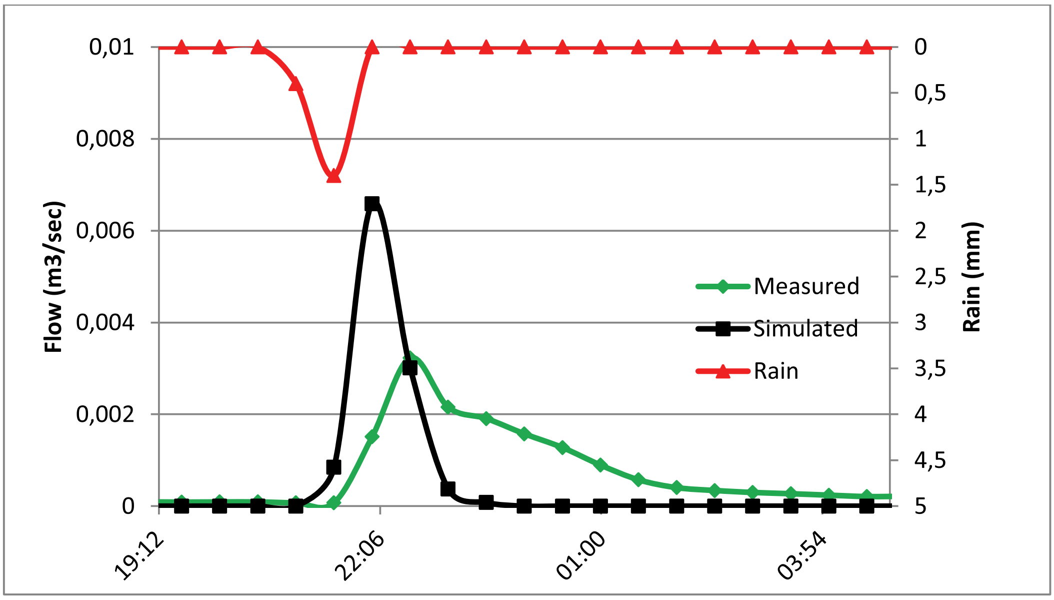



**Figure 79.** Measured and calibrated flow variations belong to 5st August, 2017 before calibration

After calibration, the comparisons of observed and calibrated flows for these four rain events are given in Figure 80, Figure 81, Figure 82 and Figure 83, Largest storm event was in June 19, 2017. The calibrated model successfully simulates the peak and the trend in the flow. Results follow the trend of observations.

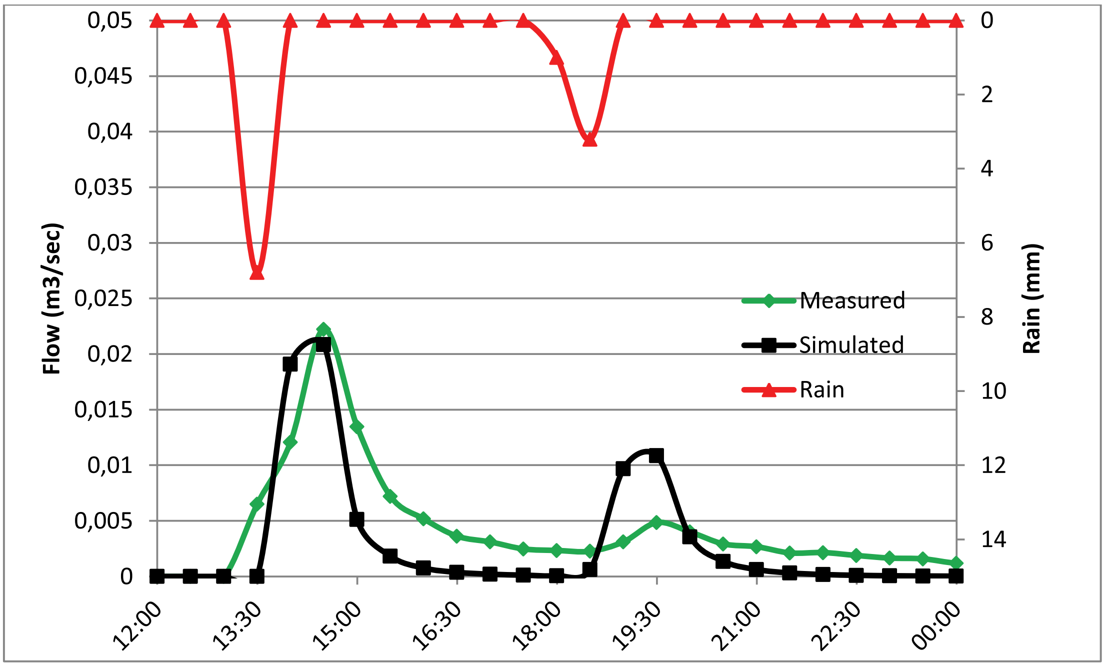



**Figure 80.** Measured and calibrated flow variations belong to 1st June, 2017 after calibration

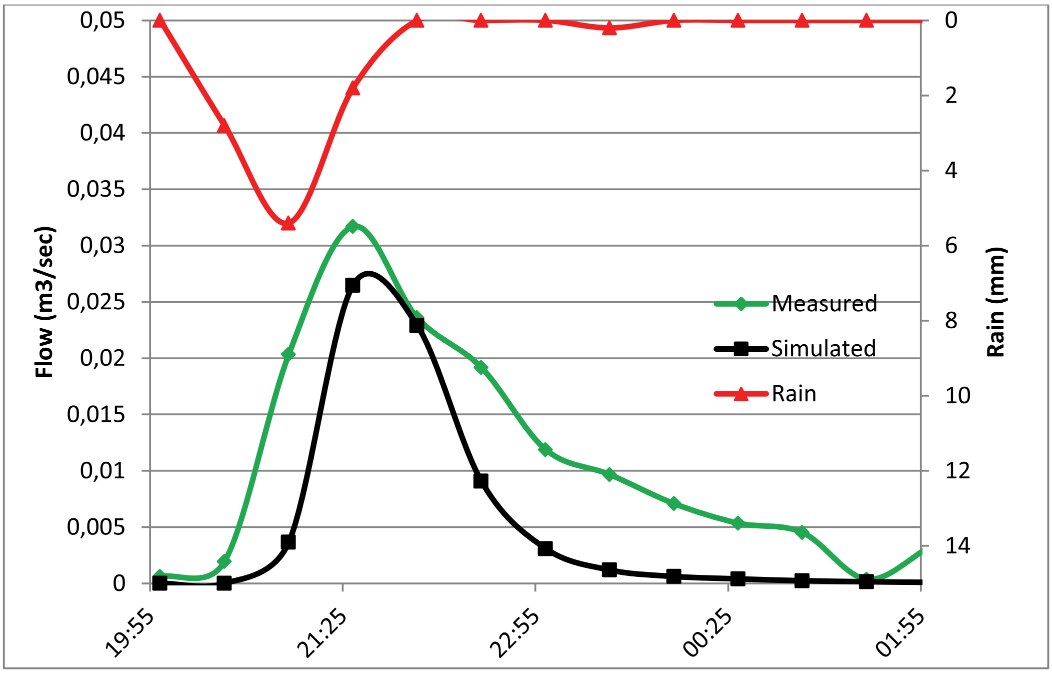



**Figure 81.** Measured and calibrated flow variations belong to 8th June, 2017 after calibration

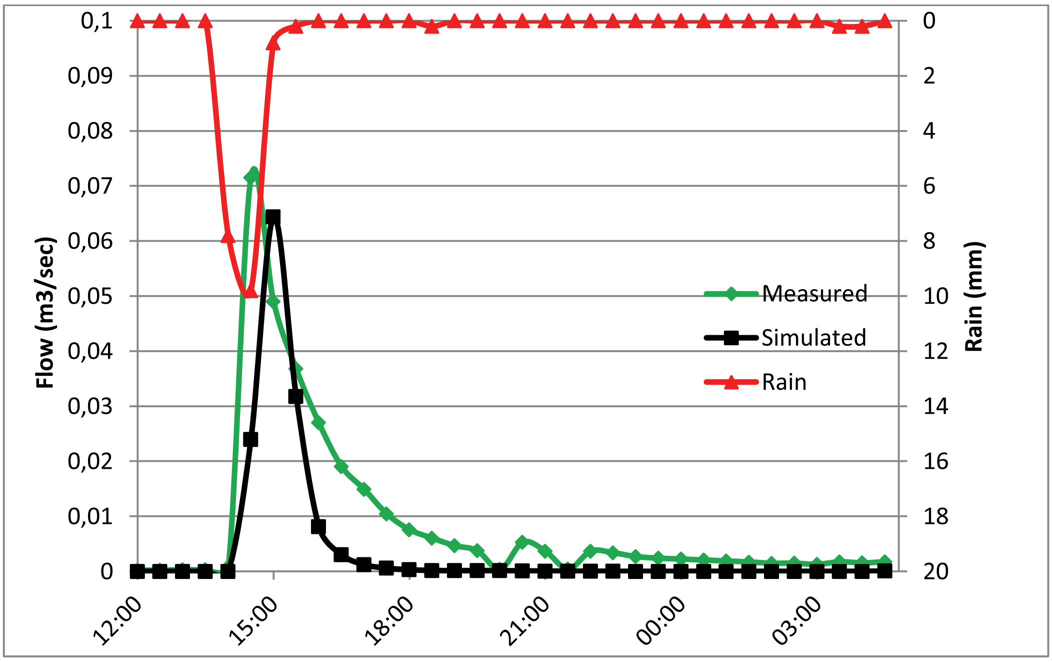



**Figure 82.** Measured and calibrated flow variations belong to 19th June, 2017 after calibration

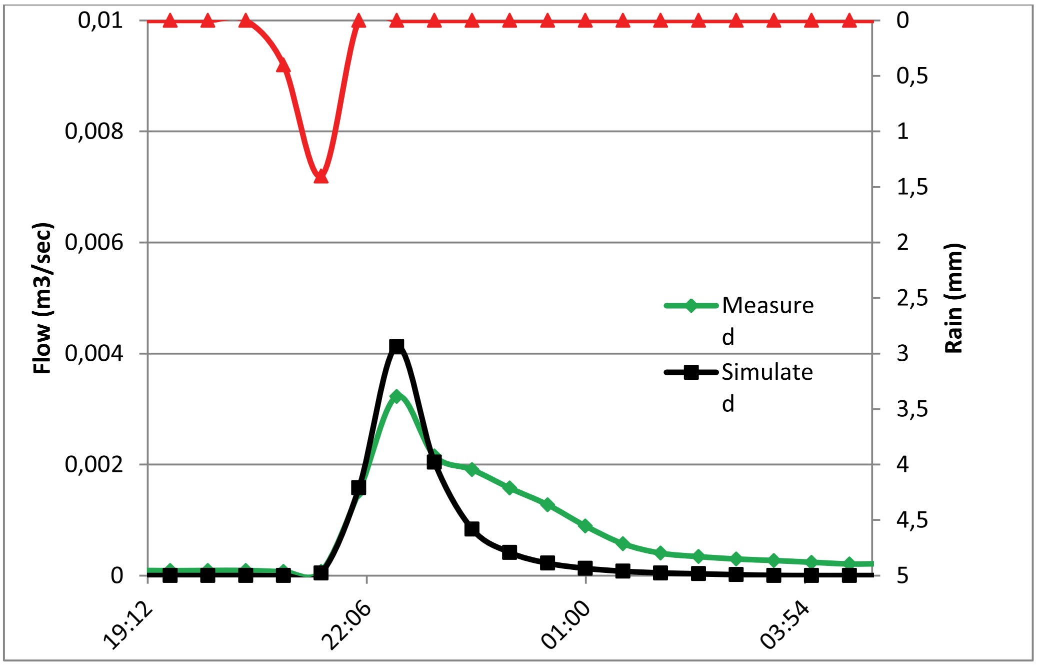



**Figure 83.** Measured and calibrated flow variations belong to 5th August, 2017 after calibration

NSE values for each of the modeled rainfall events are given in Table 31. According to Moriasi et al. (2007), the model performance can be rated as satisfactory according to NSE and $R^2$ values.

**Table 31.** NSE and R2 values of best simulation

| Rain Events | NSE | $R^2$ |
|---|---|---|
| Overall* | 0.56 | 0.60 |
| 01.06.2017 | 0.50 | 0.67 |
| 08.06.2017 | 0.54 | 0.80 |
| 19.06.2017 | 0.51 | 0.63 |
| 05.08.2017 | 0.63 | 0.81 |

* All rain events between May 18 and November 28, 2017

For smaller rain events, there are some discrepancies between observation and simulation results. Such differences may be observed due to limitation of data. Since only the half hourly total rainfall depth and temperature is used as the measured inputs, the uncertainties may be high. In this study, verification cannot be performed due to the limited measured data.

When the results of surface runoff simulation for METU campus were compared with the results in study of Rosa et al., it was observed that the results of both studies were acceptable. However, the results of Rosa et al.'s simulation study show better agreements than the results of runoff simulation for METU campus.

Although acceptable results were obtained, simulation results was not very accurate. There were some reasons for this, the flowmeter station had to be moved in three different locations due to construction activities on campus, therefore enough data could not be obtained to develop very accurate deterministic model. Additionally, the measured flow data used in calibration process was not actual runoff of these regions due to the pipe fracture in the pipeline system.

Harmel et al. (2014) divided the intended model uses into three category; Exploratory, Planning, and Regulatory/Legal (Figure 84). While the explotary categpry aim to make preliminary screening or approximate comparisons, the regulatory/legal category includes legal regulatory or human health implications. From explotary to regulatory, the required accuracy in model predictions is expected to be more critical. . The main aim of this model was an approximate evaluation of LID applications' efficiency on surface reduction. According to this classification, the present study can be placed within the exploratory category where low model accuracy is tolerable. As a result, the model performance for these four events is satisfactory.

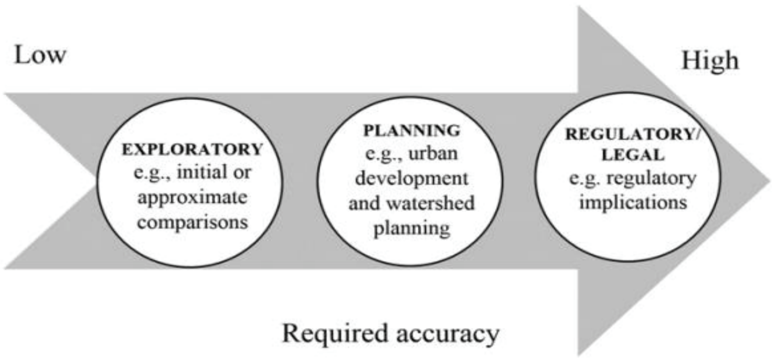



**Figure 84.** Continuum of model's intended use from least accuracy to most required accuracy (Özcan et al., 2017) (adapted from Harmel et al. (2014))

### 5.2. Evaluation of LID Application Scenarios for METU Campus

After obtaining satisfying results in SWMM model calibration, the next step was to develop and evaluate different LID applications on METU Campus in order to reduce runoff. As explained before, the campus area includes 14 subcatchments. However, the stormwater line of the campus collects the stormwater from only 8 of them which are S1, S2, S3, S4, S5, S6, S7 and S8 (Figure 85). There is not any stormwater line constructed to collect stormwater from the remaining subcatchments. In this part, stormwater lines were drawn in SWMM for also the remaining subcatchments to observe the effect of LID applications on their runoff flows. The subcathments and their outfalls are listed in Table 32.

**Table 32.** The subcatchments and their outfalls

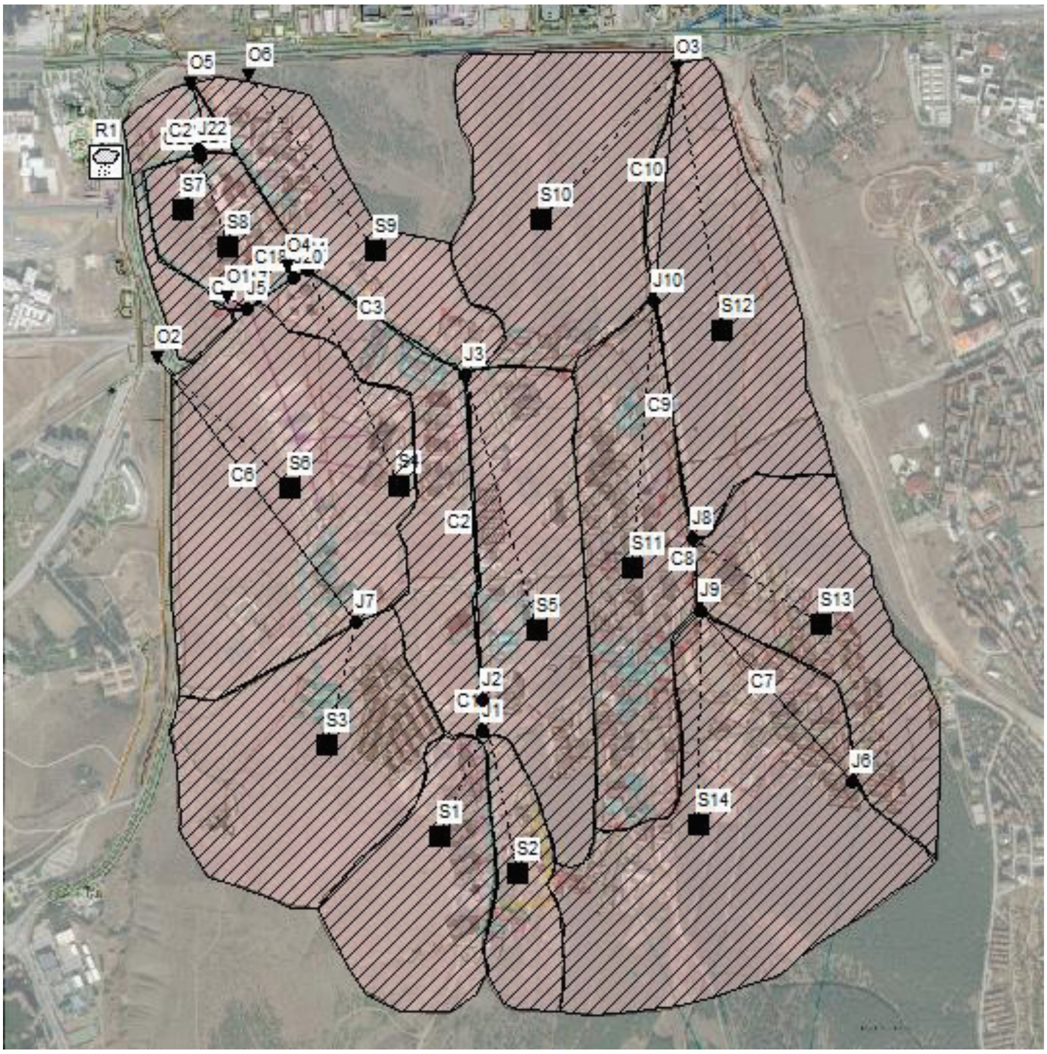



**Figure 85.** Subcatchments of METU Campus in SWMM study area map

**Table 32.** The subcatchments and their outfalls

| Outfall | Subcatchments |
|---|---|
| O1 | S1+S2+S4+S5 |
| O2 | S3+S6 |
| O3 | S10+S11+S12+S13+S14 |
| O5 | S7+S8 |
| O6 | S9 |

In this study, different LID alternatives were applied in all subcatchments of the campus. Rain gardens, green roofs and rain barrels were selected and used as LID applications (LIDs). There are some considerations while designing the LIDs and these considerations are listed in Table 33, Table 34 and Table 35.

**Table 33.** Rain garden design considerations (The University of Rhode Island, n.d.)

| Factor | Preferred |
|---|---|
| Distance from well > 64 cm (25') | Yes |
| Distance from septic system > 38 cm (15') | Yes |
| Distance from foundation > 25 cm (10') | Yes |
| Predominant Soil Texture | Sandy loam or loam |
| Infiltration Rate of Native Soil | 2 inches/hour (5 cm/ hour) |
| Slope-less than 8% | Less than 8% |
| Proximity to drainage area | Within 30 feet (9 m) |
| Solves existing stormwater problem (i.e. flooding, downspout into drain)? | Yes |
| Location within drinking water supply area? | Yes |
| Visibility of location | High |
| Opportunity to use in education programs (i.e. school location) | Yes |
| Municipal support (labor, cost) | Yes |
| Overflow area | Yes |
| Full sun to partial sun | Yes |

**Table 34.** Rain barrel design considerations (Kraai et al., n.d. and SLO-COAT, 2010)

| Factor | Preferred |
|---|---|
| Location | It should be placed as close to the rainwater catchment area and be located as close to the desired use as possible |
| Distance | From septic tanks and leach fields: 50 feet (15 m) |
| Suitable of roofing material to collect rainwater | Tile, metal (treated to remove zinc), membrane with waterproof coatings, galvalume, concrete, asphalt shingle, tar and gravel (not newly installed) |

**Table 35.** Green rood design considerations (Natural Stormwater Management Techniques, n.d.)

| Factor | Preferred |
|---|---|
| Weight | Roof load-bearing capability > 83 kg/m$^2$ |
| Roof Slope | < 25 degrees (mostly flat surfaces is preferred) |
| Climate | For cold climates, the roof under-drain system must be designed to handle the excess water caused by the melting of large volumes of snow |
| Soil type | lightweight "engineered" soils that are manufactured so as to be devoid of weeds, pollutants and other potential problems |

In this study, LIDs were placed on the campus by considering some of these factors since enough information such as roof load bearing capabilitiy, slope of roofs and full sun to partial sun to consider all of them were not available. LID control unit of SWMM was used. In every subcatchment, rain gardens, rain barrels and green roofs were added according to the land and building availability. A rain barrel was placed for each building since most of the roofs are concrete which is suitable for rain barrel design. There are a total of 237 building existing in the campus. 38 of them are lately constructed with flat roofs. For green roof replacement, there is no information about load-bearing capacity of buildings' roofs in the campus. Therefore, lately constructed buildings with flat roofs were selected to be modeled as green roofs. Lastly, rain gardens were placed depending on availability of land on subcathcments and it was aimed to divert flow on the roofs of building into these rain gardens. Therefore, closeness to the building was also a consideration. The numbers of these LID units and percentages of impervious area that these LIDs treated were summarized in Table 36.

**Table 36.** Number of LID units and the percentage of impervious area treated by using LIDs

| LIDs | Rain Garden | | Green Roof | | Rain Barrel | |
|---|---|---|---|---|---|---|
| Subcatchment | # of units | % of imperv. area applied | # of units | % of imperv. area applied | # of units | % of imperv. area applied |
| S1 | 7 | 5 | 2 | 5 | 8 | 5 |
| S2 | 5 | 5 | 1 | 5 | 4 | 5 |
| S3 | 6 | 5 | 3 | 5 | 44 | 5 |
| S4 | 5 | 5 | 3 | 5 | 11 | 5 |
| S5 | 5 | 5 | 3 | 5 | 15 | 5 |
| S6 | 3 | 5 | 1 | 5 | 8 | 5 |
| S7 | 1 | 5 | 3 | 5 | 5 | 5 |
| S8 | 10 | 5 | 3 | 5 | 13 | 5 |
| S9 | 7 | 5 | 2 | 1 | 13 | 5 |
| S10 | 2 | 5 | 1 | 5 | 9 | 5 |
| S11 | 15 | 5 | 6 | 5 | 47 | 5 |
| S13 | 9 | 5 | 6 | 5 | 37 | 5 |
| S14 | 6 | 5 | 4 | 5 | 23 | 5 |

Before and after placing these LIDs in the subcatchments of campus, the constructed models were run for the same period. The percentages of peak and total runoff reductions in outfalls were calculated and listed in Table 37. As seen from Table 37, decreases in the peak flows of outfalls were more than those of total flows. While percentages of peak flow reductions vary from 17 to 22%, the total flow reductions are in between 10 and 21%.

**Table 37.** The percentages of peak and total runoff reductions in outfalls

| Outfalls | % of peak flow reductions | % of total flow reductions |
|---|---|---|
| O1 | 21.9 | 11.3 |
| O2 | 21.1 | 10.2 |
| O3 | 18.8 | 14.3 |
| O4 | 17.3 | 21.2 |
| O5 | 21.3 | 17.2 |

These reductions can also be observed in storm event scale. Two graphs given in Figure 86 and Figure 87 for different storm events indicate that lower flows were observed in storm events after LIDs are placed in the campus. As observed from Figure 86 and Figure 87, LID applications did not have any retardation effect on the peak flows. The reason of that the size of METU Campus catchment is small. Therefore, LID applications provide drastic decreases without retardation. These drastic decreases in storm runoff flows also show that constructing LIDs will help to prevent floods on the campus.

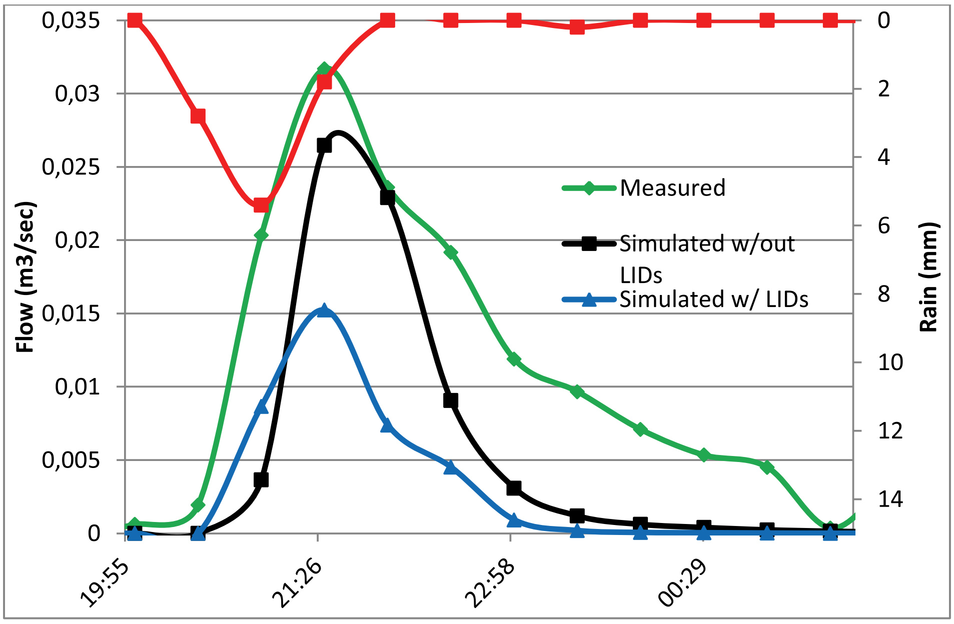



**Figure 86.** Measured and simulated (with and without LIDs) half hourly flow variations belong to 8$^{th}$ June, 2017

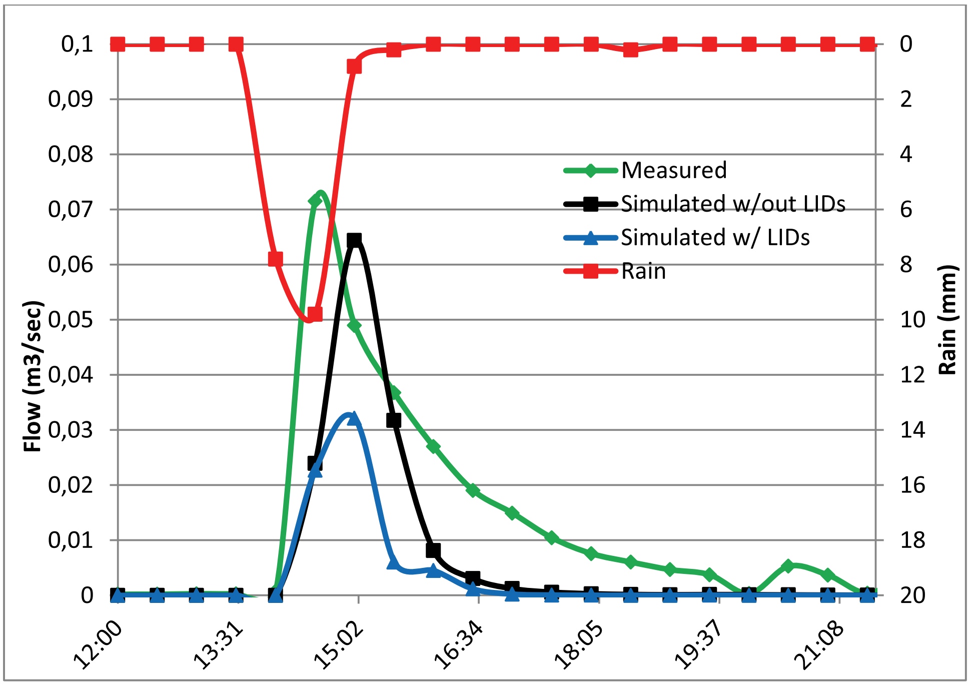



**Figure 87.** Measured and simulated (with and without LIDs) half hourly flow variations belong to 19th June, 2017

Constructing these LIDs provides not only surface runoff reduction, but also stormwater harvesting and reuse opportunities. The collected water can be used for different purposes on the campus such as irrigation of green lands or toilet flushing in dormitories.

For example, the water that is collected in rain barrels can be used for irrigation of Devrim Stadium which has 10,200 $m^2$ area and needs 120 $m^3$/day irrigation water (METU Heat and Water Management Department, 2018). Before simulating with LIDs, it was found that if there was no pipe leakage in the system, the stormwater volume obtained in May 18 - November 28 period would be approximately 11,000 $m^3$. According to the simulation results of constructing only rain barrels for the same period, 4% of runoff volume in O1 outfall is reduced in the campus. As a result, the collected water amount from the existing stormwater line (reduction in O1 outfall) after rain barrel installation was calculated as 11000*(0.04) = 440 $m^3$. This water is enough to irrigate Devrim Stadium daily for almost 4 days.

In this part of the study, a rainfall-runoff model was constructed by using SWMM and some LIDs were evaluated to reduce surface runoff and to develop different rain harvesting alternatives for the campus.

There were a number of limitations in this study. In SWMM development, values of some inputs were not known. Moreover, there was a leakage in the pipe system and therefore an artificial discharge was added to reflect this leakage effect on the system. Although satisfying calibration results were obtained and effect of different LIDs on campus's surface runoff was evaluated in SWMM, the real surface runoff volume could not be calculated due to this leakage.

However, these results indicated that constructing different LIDs in the available places of campus is an effective way to decrease surface runoff and to use stormwater for different purposes. These applications are really important and necessary to establish sustainable stormwater management in the campus.

### 5.3. Regression Analysis

In this part of the study, it was aimed to calculate surface runoff in an easier and quicker way by using an empirical method. A number of problems were experienced during the calibration of SWMM model due to data limitations and a major leakage that occurred in the pipe system. Thus, possibility of a fitting a regression equation instead of developing a hydrologic model to simulate the rainfall-runoff process at the campus was tested. A regression analysis was performed as an empirical model in order to estimate total surface runoff and to identify the independent variables that the total surface runoff mostly depended on.

The rainfall-runoff relationship in a watershed depends on the parameters that show temporal and spatial changes. Therefore, it is necessary to understand the relations of these parameters so that runoff can be calculated. Regression analysis is a technique used to determine the relationship between the values of the parameters and the outcome variables that depend on these parameters (Boston University School of Public Health, 2013).

In this study, regression analysis was conducted using SPSS tool to identify the parameters that the surface runoff mostly depends on. The flow data belonging to DM1, DM2 and DM3 catchments (APPENDIX D) were used in this analysis. 66 storm events were observed while obtaining flow data on METU Campus. The dependent variable was total flow and the independent variables were rain, rain intensity, rain duration, imperviousness percentage, area, width, average slope and curve number of the catchments, evaporation rate and the time interval between current and previous rain event. Firstly, both independent and dependent variables were normalized and then used in the regression analysis to understand which variables impact the surface runoff significantly. The details of variables are given in APPENDIX D. As started from the rain, different parameters and their combinations were evaluated as independent variables in the regression analysis. According to their regression results, the total surface runoff volume was predicted by using different independent variables. The independent variables and their regression equations were given in Table 38. The NSE and $R^2$ values were calculated for them to evaluate the agreement between the predicted and measured total runoff volumes (Table 39). The highest NSE and $R^2$ values were obtained when the independent variables were rain, rain duration, evaporation rate, average slope of catchment and time interval between current and previous event.

**Table 38.** Independent variables and their regression equations

| Independent variables | Regression Equations |
|---|---|
| Rain (a) | Total Flow= 14.7*a-8.5 |
| Rain (a) + Rain duration (b) | Total Flow= 17.2*a-6.7*b-2.8 |
| Rain (a) + Average slope of catchment (c) | Total Flow= 13.9*a+10*c-59.4 |
| Rain (a)+ Evaporation rate (d) + Average slope of catchment (c) + Time interval between current and previous event (e) | Total Flow= 14 *a+16.2*c+11.3*d-0.06*e-145.9 |
| Rain (a) + Evaporation rate (d) + Average slope of catchment (c) + Time interval between current and previous event (e) + Rain duration (b) | Total Flow= 16 *a-5.8*b+15.8*c+9.2*d-0.05*e-128.4 |

**Table 39.** NSE and $R^2$ values for different independent variable combinations

| Independent variables | NSE | $R^2$ |
|---|---|---|
| Rain | 0.50 | 0.50 |
| Rain + Rain duration | 0.55 | 0.55 |
| Rain + Average slope of catchment | 0.60 | 0.60 |
| Rain + Evaporation rate + Average slope of catchment + Time interval between current and previous event | 0.70 | 0.70 |
| Rain + Evaporation rate + Average slope of catchment + Time interval between current and previous event + Rain duration | 0.73 | 0.73 |

In addition to NSE and $R^2$ values, descriptive statistics, coefficients and the significance values obtained from stepwise regression of these five independent variables (rain, rain duration, evaporation rate, average slope of catchment and time interval between current and previous event) are given in Table 40. Significance values indicates that rain, evaporation rate, average slope of catchment, time interval between current and previous event and rain duration are the best estimators to calculate total runoff volume. Their significance values were very close to zero (in between 0 and 0.03). Therefore, the total surface runoff volumes for 66 storm events were calculated by using the coefficients of these five independent variables given in Table 40. The graph (Figure 88) indicates the correlation of predicted and calculated runoff volumes by using regression equation of these five independent variables.

**Table 40.** Descriptive statistics, coefficients and significance values of independent variables

| Independent variables | Mean | Std. Deviation | N | Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| **Rain (mm)** | 4.4 | 3.8 | 66 | 16.1 | 10.0 | 0.00 |
| **Rain Duration (h)** | 2.5 | 2.9 | 66 | 15.8 | 6.3 | 0.00 |
| **Average slope (%)** | 5.4 | 2.6 | 66 | -5.8 | -2.7 | 0.01 |
| **Evaporation rate (mm/day)** | 5.3 | 2.2 | 66 | 9.2 | 3.1 | 0.00 |
| **Time interval between current and previous event (hr)** | 117.7 | 230.3 | 66 | -0.1 | -2.2 | 0.03 |
| **Constant** | | | | -128.4 | -4.9 | 0.00 |

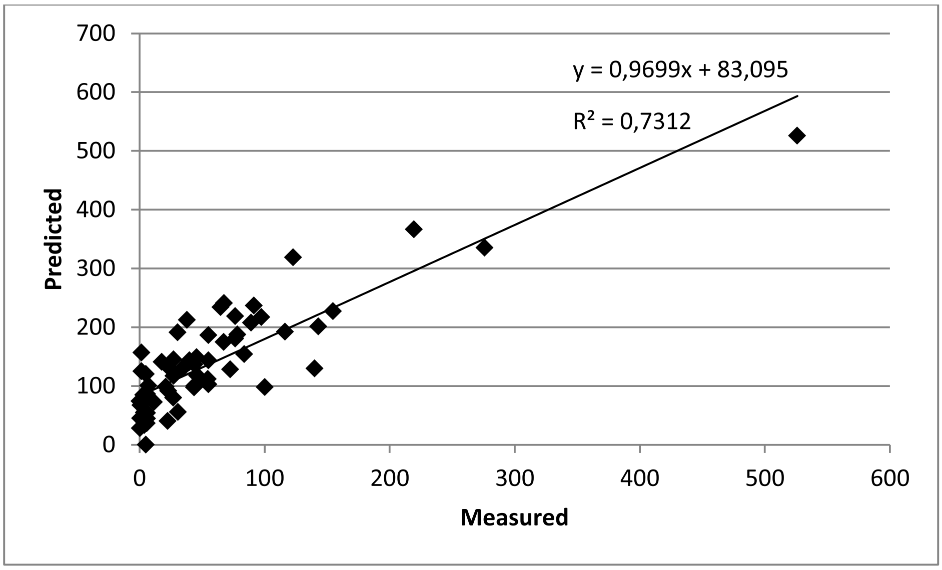



**Figure 88.** The correlation between predicted vs. measured total runoff volumes

As a result, it was understood that rain, rain duration, evaporation rate, average slope of catchment and time interval between current and previous event are the variables that the total surface runoff mostly depended on. These variables can be used to predict total surface runoff volumes for the future rain events. This study showed that regression analysis is an effective technique for estimating the surface runoff.

### 5.4. Recommendations for Stormwater Management in METU Campus

In the past, stormwater management mostly focused on collecting and conveying runoff in an efficient way. Nowadays, stormwater is considered as a groundwater recharge resource and an alternative water source for different uses rather than a wasted discharge. Therefore, some important practices are necessary for a sustainable stormwater management in university campuses. Some recommendations are given in below for METU Campus.

- An engineering drawing of existing storm line should be prepared and updated when a change is realized in the system.
- In addition to existing storm line, additional storm lines should be designed for remaining parts of the campus where storm line does not exist.

- Rainfall and runoff at selected points should be continuously monitored at the campus to be used in modeling rainfall-runoff process.
- A detailed feasibility assessment should be carried out for different LID applications such as green gardens, green roofs, porous pavements, and rain barrels on campus to reduce surface runoff and to provide stormwater reuse.
- Green gardens should be constructed according to their design considerations and land availability on campus.
- Stormwater should be collected from rooftops and stored by constructing rain barrels in campus buildings.
- The collected stormwater should be analyzed in terms of water quality to assess its suitability for different purposes such as irrigation, showering, toilet flushing and washing cars.
- Green roofs and porous pavements should be constructed in available areas on campus.
- These practices should be included in the strategic plans of METU, future targets should be determined by decision-makers and necessary funding should be raised for their implementations.

# CHAPTER 6

# INFRASTRUCTURAL ASSET MANAGEMENT IN METU CAMPUS

There are three water pipeline networks in METU Campus and these are sewer line, stormwater pipeline and potable water pipeline. These water pipelines include different assets such as pipes, manholes and water reservoirs. However, only pipes were investigated as assets in this study. In this chapter, the current situation of the water and wastewater infrastructure system in METU Campus was investigated through an asset management approach. Methodology developed for METU Campus is given in Figure 89. In "Classify" step, an asset inventory and system map was prepared. Pipes' remaining lifetimes, maintenance, break histories and water losses were documented in order to classify assets. They were also investigated in terms of level of service such that any complaints about odor/taste of water and any contamination possibility exist on campus. Any water losses/leakages observed in the pipe systems were specified. Moreover, these water pipelines were also investigated in terms of their compliance with provisions of the regulations such as water quality regulation. In "Analyze" step, pipes' remaining lifetimes, break histories and water losses were assessed and ranked. They were organized according to their criticalities. A failure analysis was developed depending on their criticalities. A risk ranking was specified by developing a risk matrix. In "Recommend" step, some recommendations were given about developing condition control systems, preventive actions and funding strategies.

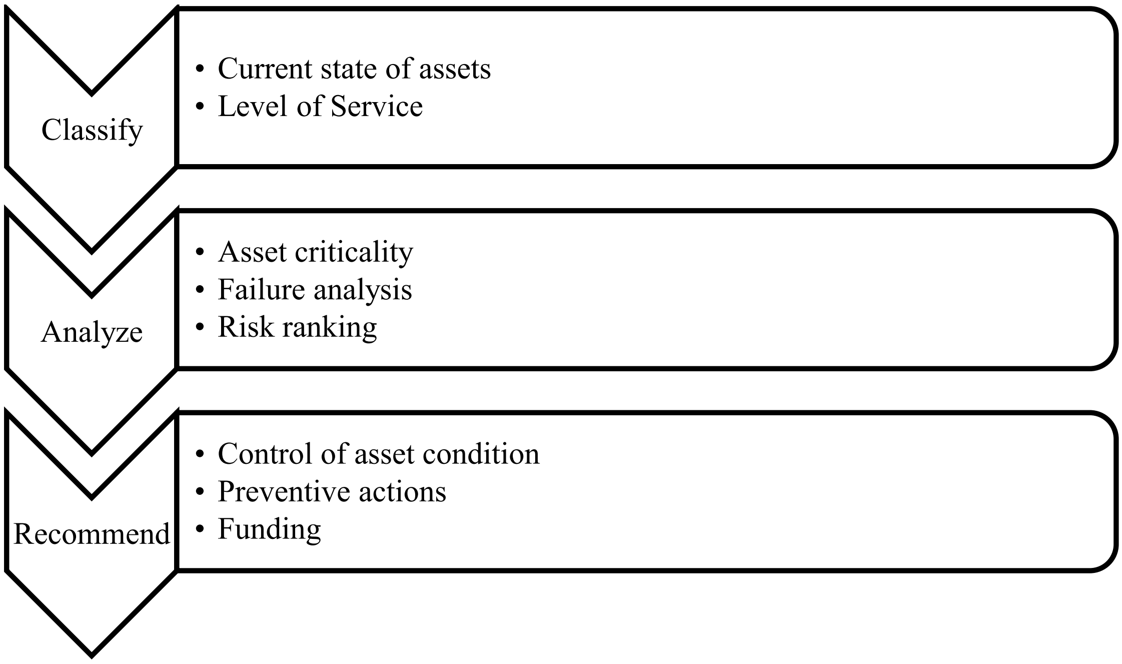



**Figure 89**. The methodology for investigation of the water wastewater infrastructure system in METU Campus

### 6.1. Classify

In this step, ArcGIS maps were prepared for three water pipelines of the campus (Figure 90, Figure 91 and Figure 92). While preparing these maps, the necessary information regarding the pipe lines such as pipe location, material, length and diameter were obtained as an AutoCAD drawing prepared by Bekir Bakırcı from METU Water and Heat Management Department. Since there is not any documentation prepared for maintenance and repair of pipe systems, information about break histories and installation years of the pipes was obtained from highly experienced staff (Bekir Bakırcı). These data were entered into attribute tables of the maps (Figure 93). Additionally, the age and material information of all pipes are not available. Details about length, age and material of water pipelines are also given in Table 41. Potable water pipeline is the oldest pipeline since almost 50% of the system is more than 50 years old. Stormwater is the youngest system since it is less than 15 years old. While the east side of the campus including shopping center region, library and cafeteria region, department buildings around alley has combined sewer pipeline system, the west side including Odtükent, Teknokent, dormitories around Odtükent region has separated water pipeline system (stormwater pipeline and sewer line).

**Table 41.** Details about length, age and material of water pipelines

| Water Pipelines | Length of pipelines (m) | % of pipes depending on their age | | | | | % of pipes having material information |
|---|---|---|---|---|---|---|---|
| | | more than 50 years | 25-50 years | 15-25 years | less than 15 years | Not available | |
| Potable Water | 49422 | 47 | 0 | 19 | 11 | 23 | 77 |
| Wastewater | 23291 | 26 | 42 | 32 | 0 | 0 | 12 |
| Stormwater | 10202 | 0 | 0 | 0 | 100 | 0 | 18 |

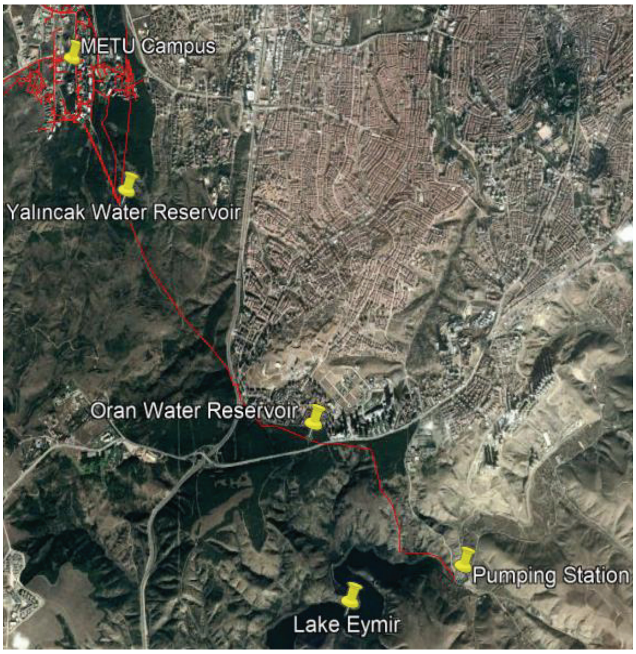



**Figure 90.** Potable water pipeline of METU Campus

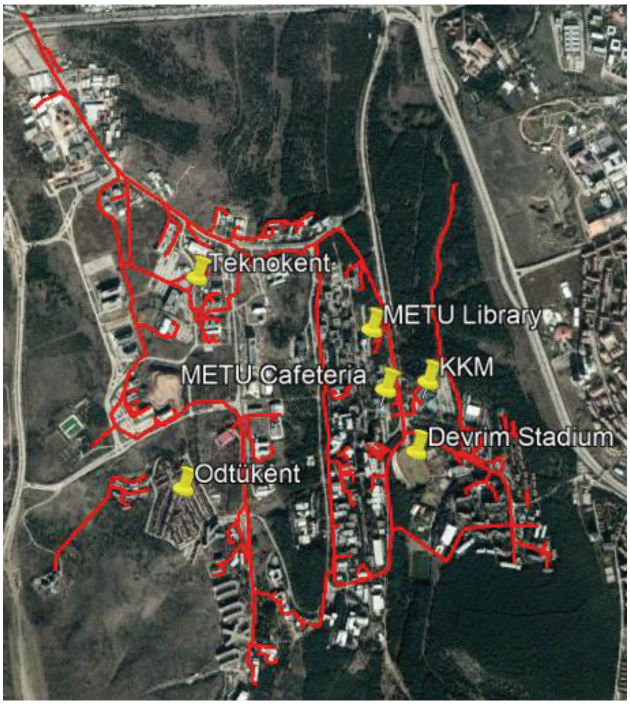
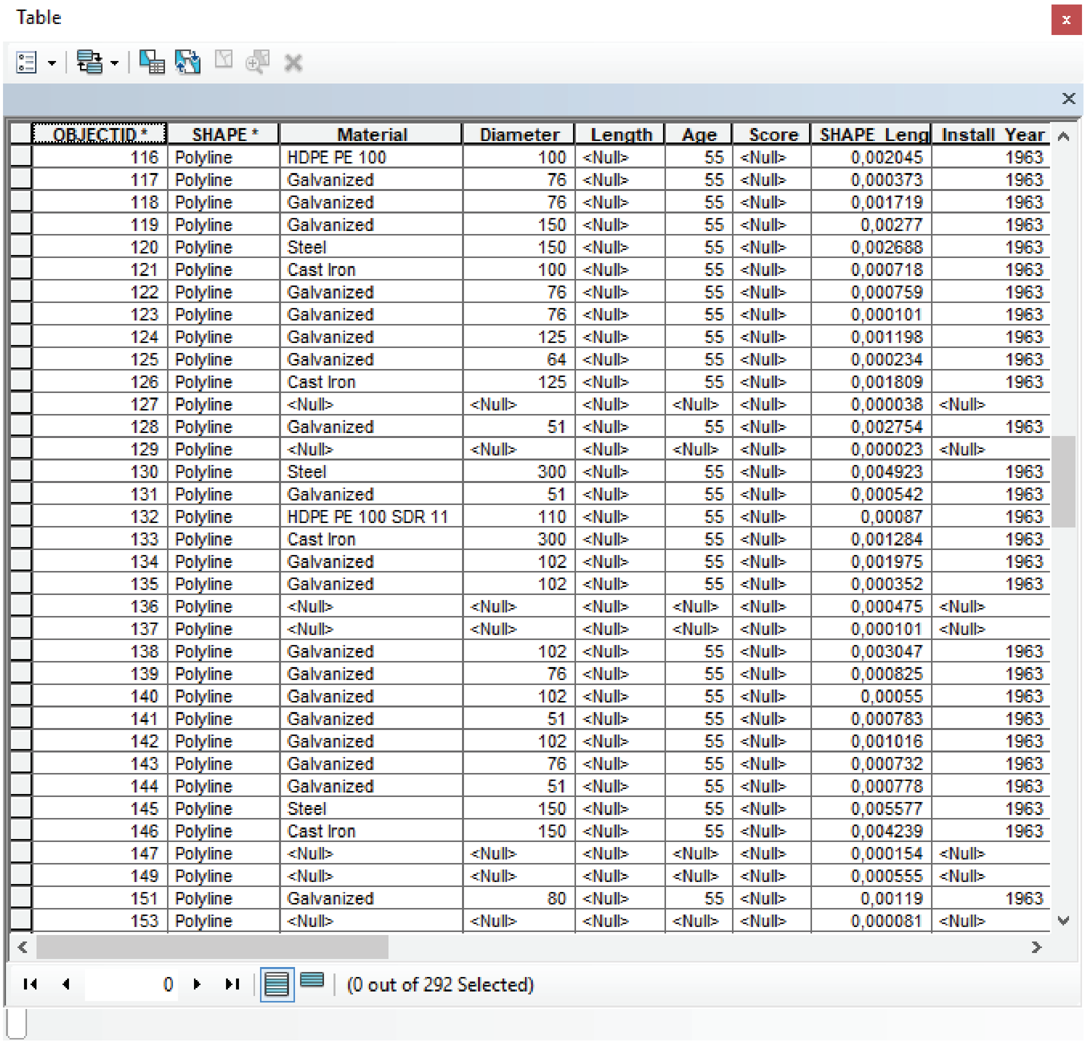



**Figure 91.** Sewer line of METU Campus


**Figure 92.** Stormwater pipeline of METU Campus



Table

| OBJECTID * | SHAPE * | Material | Diameter | Length | Age | Score | SHAPE_Leng | Install_Year |
|---|---|---|---|---|---|---|---|---|
| 116 | Polyline | HDPE PE 100 | 100 | <Null> | 55 | <Null> | 0,002045 | 1963 |
| 117 | Polyline | Galvanized | 76 | <Null> | 55 | <Null> | 0,000373 | 1963 |
| 118 | Polyline | Galvanized | 76 | <Null> | 55 | <Null> | 0,001719 | 1963 |
| 119 | Polyline | Galvanized | 150 | <Null> | 55 | <Null> | 0,00277 | 1963 |
| 120 | Polyline | Steel | 150 | <Null> | 55 | <Null> | 0,002688 | 1963 |
| 121 | Polyline | Cast Iron | 100 | <Null> | 55 | <Null> | 0,000718 | 1963 |
| 122 | Polyline | Galvanized | 76 | <Null> | 55 | <Null> | 0,000759 | 1963 |
| 123 | Polyline | Galvanized | 76 | <Null> | 55 | <Null> | 0,000101 | 1963 |
| 124 | Polyline | Galvanized | 125 | <Null> | 55 | <Null> | 0,001198 | 1963 |
| 125 | Polyline | Galvanized | 64 | <Null> | 55 | <Null> | 0,000234 | 1963 |
| 126 | Polyline | Cast Iron | 125 | <Null> | 55 | <Null> | 0,001809 | 1963 |
| 127 | Polyline | <Null> | <Null> | <Null> | <Null> | <Null> | 0,000038 | <Null> |
| 128 | Polyline | Galvanized | 51 | <Null> | 55 | <Null> | 0,002754 | 1963 |
| 129 | Polyline | <Null> | <Null> | <Null> | <Null> | <Null> | 0,000023 | <Null> |
| 130 | Polyline | Steel | 300 | <Null> | 55 | <Null> | 0,004923 | 1963 |
| 131 | Polyline | Galvanized | 51 | <Null> | 55 | <Null> | 0,000542 | 1963 |
| 132 | Polyline | HDPE PE 100 SDR 11 | 110 | <Null> | 55 | <Null> | 0,00087 | 1963 |
| 133 | Polyline | Cast Iron | 300 | <Null> | 55 | <Null> | 0,001284 | 1963 |
| 134 | Polyline | Galvanized | 102 | <Null> | 55 | <Null> | 0,001975 | 1963 |
| 135 | Polyline | Galvanized | 102 | <Null> | 55 | <Null> | 0,000352 | 1963 |
| 136 | Polyline | <Null> | <Null> | <Null> | <Null> | <Null> | 0,000475 | <Null> |
| 137 | Polyline | <Null> | <Null> | <Null> | <Null> | <Null> | 0,000101 | <Null> |
| 138 | Polyline | Galvanized | 102 | <Null> | 55 | <Null> | 0,003047 | 1963 |
| 139 | Polyline | Galvanized | 76 | <Null> | 55 | <Null> | 0,000825 | 1963 |
| 140 | Polyline | Galvanized | 102 | <Null> | 55 | <Null> | 0,00055 | 1963 |
| 141 | Polyline | Galvanized | 51 | <Null> | 55 | <Null> | 0,000783 | 1963 |
| 142 | Polyline | Galvanized | 102 | <Null> | 55 | <Null> | 0,001016 | 1963 |
| 143 | Polyline | Galvanized | 76 | <Null> | 55 | <Null> | 0,000732 | 1963 |
| 144 | Polyline | Galvanized | 51 | <Null> | 55 | <Null> | 0,000778 | 1963 |
| 145 | Polyline | Steel | 150 | <Null> | 55 | <Null> | 0,005577 | 1963 |
| 146 | Polyline | Cast Iron | 150 | <Null> | 55 | <Null> | 0,004239 | 1963 |
| 147 | Polyline | <Null> | <Null> | <Null> | <Null> | <Null> | 0,000154 | <Null> |
| 149 | Polyline | <Null> | <Null> | <Null> | <Null> | <Null> | 0,000555 | <Null> |
| 151 | Polyline | Galvanized | 80 | <Null> | 55 | <Null> | 0,00119 | 1963 |
| 153 | Polyline | <Null> | <Null> | <Null> | <Null> | <Null> | 0,000081 | <Null> |

0 (0 out of 292 Selected)

**Figure 93.** Attribute table of the ArcGIS map for a water pipeline

Level of service is also a consideration for classify step. As explained in theoretical background and literature review chapter (see Chapter 2), level of service is defined as the way in which the stakeholders demand from utility to serve over the long period. If there are water losses currently observed in pipeline systems or any complaints from users, it means that the level of service is low. In METU Campus, there were some water losses observed by evaluating water consumption data obtained from smart water meters in some locations such as cafeteria. While classifying pipes, this information was also considered.

When the water pipelines were investigated in terms of their compliance with provisions of the regulations, it was seen that there is not legislative regulation for stormwater in Turkey. There are water quality standards only for potable water. As mentioned in Section 4.2., microbiological parameters of METU potable water are analyzed in every two months. Chemical parameters of the water are also analyzed once in every year. These parameters and the frequency of analyses comply with the water quality limit values and the standard frequencies of water quality monitoring given in the regulation on water for human use purposes by Ministry of Health. In the case of any complaint about odour or color of the water, analysis is done more frequently. The quality of water also meets the drinking water standards given in Turkish Standards (TS 266).

### 6.2. Analyze

In this step, pipes' criticalities were evaluated, failure analyses were made. Their failure risks were evaluated by using risk matrix and their risk maps were prepared by using ArcGIS.

In this study, there are three factors that influence asset criticality;

- Pipes' remaining lifetime
- Current water loss/leakage observations
- Break history

The most important factor to determine pipes' criticality is their remaining lifetime since it is the best information that could be obtained for most of the pipes in the campus. The remaining lifetimes were obtained as much as possible by using installment years of pipes and their average lifetimes according to their materials. The lifetimes of different pipe materials are listed in Table 42. Second-most important factor is current water loss/leakage observations. If there is current water loss/leakage observed in a pipe, it means that it has high probability of failure. This information was obtained from the water consumption data measured by using smart meters and from the people in charge of water and wastewater infrastructure systems in the campus. Lastly, break history of the pipes were also taken into account. As for the pipes having break history, only one break was known. This information was also given by the people in charge of water and wastewater infrastructure systems in the campus. The probabilities of pipes' failure were ranked according to Table 43 by considering these factors.

**Table 42.** The lifetimes for different pipe materials

| Pipe Material | Lifetime (year) | References |
|---|---|---|
| PVC | 50 | Breen (2006) |
| Concrete | 75 | Davis et al. (2008) |
| Cast iron | 50-65 | Accurate Leak and Line (2017) |
| Corrugated | 10-35 | Rinker (n.d.) |
| Galvanized | 40-80 | Ault (2003) |
| Ductile Iron | 100 | EPA (2002) |
| PE | 100 | Gecker (2010) |
| HDPE | 75 | Rumpca (1998) |
| Steel | 50-100 | Water World (1999) |

**Table 43.** Scoring for Probability of Failure

| Score | Criticality Level (Probability of Failure) | Description |
|---|---|---|
| 1 | Very low | Long remaining lifetime + no break history |
| 2 | Low | Moderate remaining lifetime + no break history |
| 3 | Moderate | Moderate remaining lifetime + break history |
| 4 | High | Little/any remaining lifetime and/or current water loss/leakage observations+ no break history |
| 5 | Very high | Little/any remaining lifetime and/or current water loss/leakage observations+ break history |

The consequences of pipes' failure were also ranked according to Table 44. The consequences of failure includes environmental, economical and social aspects and pipes are ranked according to these factors if these information about them is available. For example, "Catastrophic" consequences could be loss of life or injury to people. "Critical" could be significant damage to the building and component. In METU Campus, there is not any observed case related the damage to human health and buildings currently. Therefore, the water pipelines of METU campus were evaluated by considering other factors affecting human health or physical structures of the campus indirectly. For sewer line, consequences of failure mostly depend on any break or water loss/leakage currently observed in the pipes. If pipes are broken and water spreads on campus, it can lead to health problems and this affects the level of service negatively. For potable water, there were not any break histories of pipes and only remaining lifetimes were known. The scoring is made by only considering the remaining lifetimes of pipes. This is because when the pipes ages, they have high possibility to break. If main pipes in the potable water pipeline are broken, the potable water supply will stop and the level of service will be minimum. For the stormwater pipeline, the level of service is not as important as for the sewer line and potable water pipeline since stormwater causes less contamination compared with wastewater. In addition, stormwater pipes have higher remaining lifetimes comparing with other water pipelines. Therefore, low scores were given for consequences of the stormwater pipeline's failure.

**Table 44.** Ranking for Consequences of Failure

| Score | Consequences of Failure | Description |
|---|---|---|
| 1 | Insignificant Disruption | Slight effect, slight loss of system capacity, slight health effects |
| 2 | Minor Disruption | Minor effect, minor loss of system capacity, minor health effects, minor costs |
| 3 | Moderate Disruption | Moderate effect, moderate loss of system capacity, moderate health effects, moderate costs, important LOS still achieved |
| 4 | Major Disruption | Major effect, major loss of system capacity, major health effects, major costs, important LOS compromised |
| 5 | Catastrophic Disruption | Massive system failure, severe health affect, persistent and extensive damage |

After giving scores for probabilities and consequences of pipes' failure, a risk analysis was made by multiplying these scores. According to the matrix given in Table 45, the risk maps were prepared for METU water pipelines as given in Figure 100, Figure 101 and Figure 102.

**Table 45.** Risk matrix used for water pipes of METU

| | Probability of Failure | | | | |
|---|---|---|---|---|---|
| **Consequences of Failure** | 1 | 2 | 3 | 4 | 5 |
| 5 | Medium | Medium | High | Extreme | Extreme |
| 4 | Medium | Medium | High | Extreme | Extreme |
| 3 | Medium | Medium | High | High | High |
| 2 | Low | Low | Medium | Medium | Medium |
| 1 | Low | Low | Medium | Medium | Medium |

The following example explains how to use the risk matrix table for METU Campus. For example, a Cast Iron pipe having 1809 m length and 250 mm diameter (constructed in 1963), is 55 years old. It is one of the main pipes carrying potable water from wells to campus. The scores for its probability and consequence of failure are given in Table 46. The score for probability of failure is 5 since it is one of the oldest pipe in the system. Average life time of a cast iron pipe is approximately 55 years as shown in Table 42. It means that this pipe is almost end-of-life. When considering this factor, it was understood that it has high criticality. Therefore, 5 was given for its probability of failure.

The score of its consequence of failure is 4. The reason is that when the pipe fails, all users will be out of water since it is one of the main pipes carrying potable water from wells to campus. In addition to that, pipe is in a critical roadway so repair is relatively hard. Therefore, it will affect the level of service negatively and its repair will have economical consequences. Therefore, 4 was given for its consequence of failure.

When the probability of failure and consequence of failure was multiplied, it was found that it has extreme risk of failure (Table 47). These evaluations were also made for sewer line and stormwater pipeline of the campus.

**Table 46.** Probability of failure and consequences of failure for given pipe

| Probability of Failure (PoF) | Consequences of Failure (CoF) |
|---|---|
| 5 | 4 |

**Table 47.** Failure risk of given pipe

| | Probability of Failure | | | | |
|---|---|---|---|---|---|
| **Consequences of Failure** | 1 | 2 | 3 | 4 | 5 |
| 5 | Medium | Medium | High | Extreme | Extreme |
| 4 | Medium | Medium | High | Extreme | Extreme |
| 3 | Medium | Medium | High | High | High |
| 2 | Low | Low | Medium | Medium | Medium |
| 1 | Low | Low | Medium | Medium | Medium |

According to these failure analyses, the probability of failure and consequence of failure maps for the water pipelines were prepared and given in Figure 94, Figure 95, Figure 96 Figure 97, Figure 98 and Figure 99.

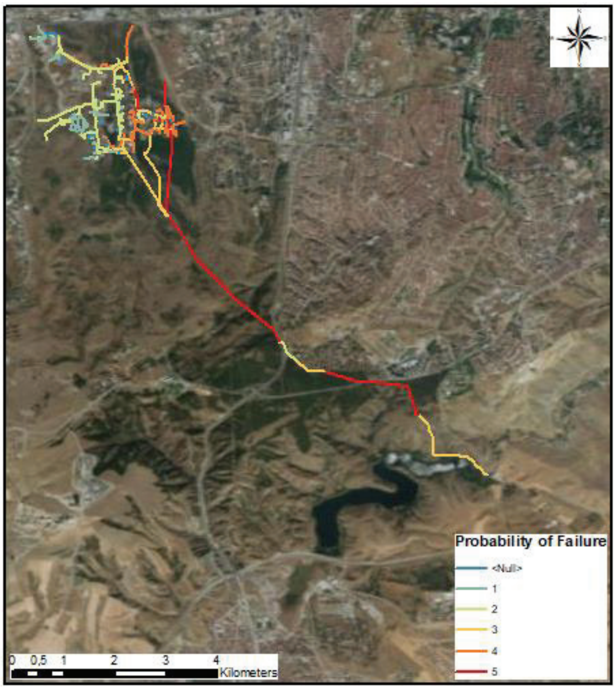



**Figure 94.** Probability of failure of potable water pipeline

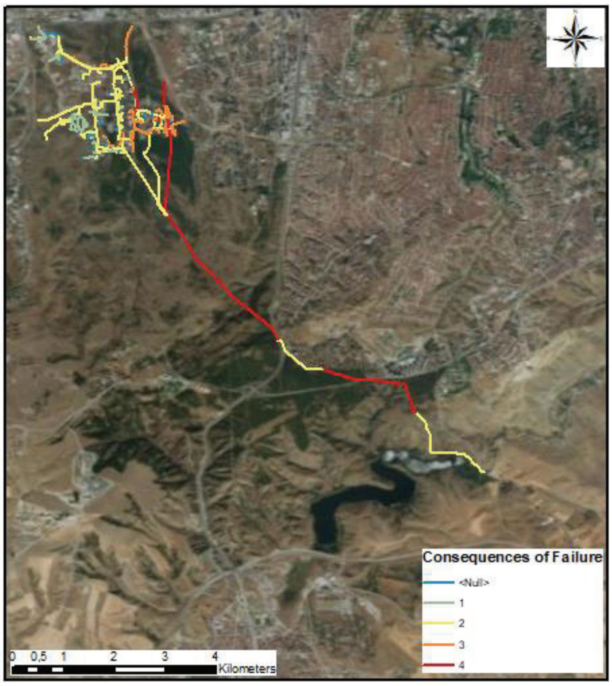



**Figure 95.** Consequence of failure of potable water pipeline

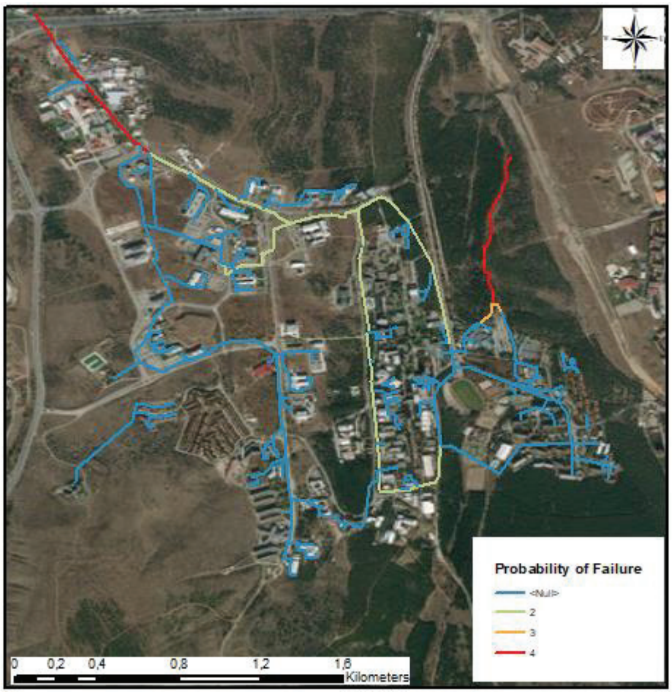



**Figure 96.** Probability of failure of sewer line

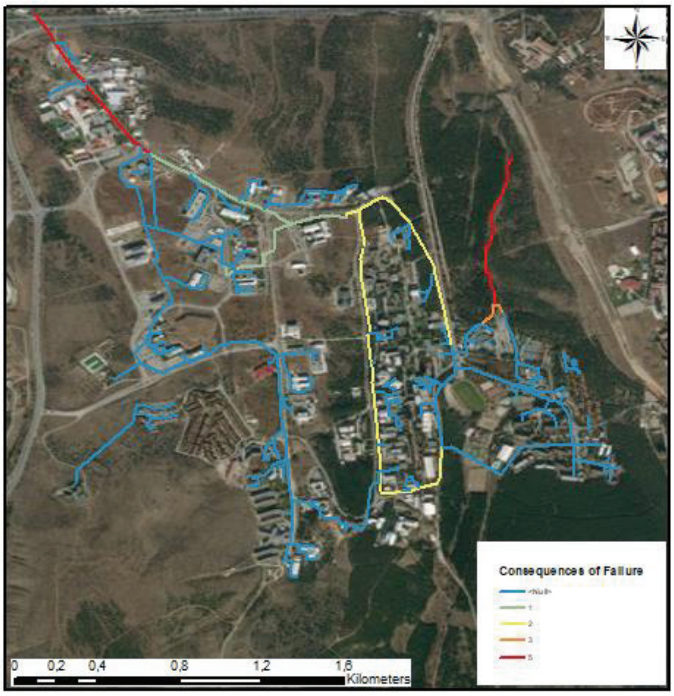



**Figure 97.** Consequence of failure of sewer line


**Figure 98.** Probability of failure of stormwater pipeline


**Figure 99.** Consequence of failure of stormwater pipeline

After evaluating probabilities and consequences of failure for these pipelines, risk maps of them were prepared. As seen from the risk maps (Figure 100, Figure 101 and Figure 102) different colors represent different levels of risk for pipes. In the map of potable water pipeline (Figure 100), it was observed that most of the pipes in between pumping station and Yalıncak Water Tank have high risk. In addition, the parts of the line from Yalıncak to Department of Metallurgical and Materials Engineering and to METU shopping center region have high risks. While east region of the campus has high and medium risk, the west region has mostly low risk. The reason of that the west region is more recently-constructed than the east region.

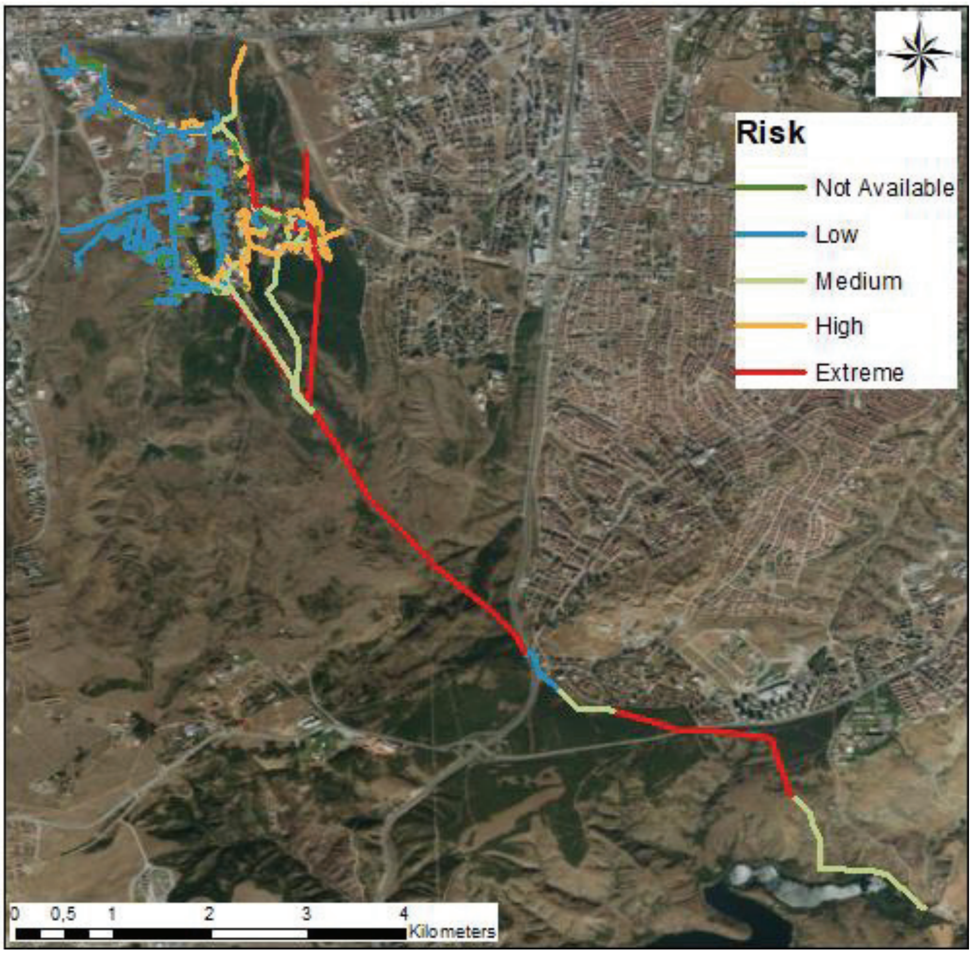



**Figure 100.** Risk map of potaple water pipeline

When it comes to sewer line of the campus, it was seen that it is different from potable water pipeline. The difference is availability of information about pipes. As seen from the map in Figure 101, the information such as pipe material, length and diameter of most pipes in sewer line was not known. Therefore, their failure risks could not be evaluated. However, the pipes from METU Culture and Convention Center to the point close to Konya Road in the east region and from METU Science and Technology Museum to the point close to Eskişehir Road in the west region have the highest risks. The pipes having blue color have low risk.

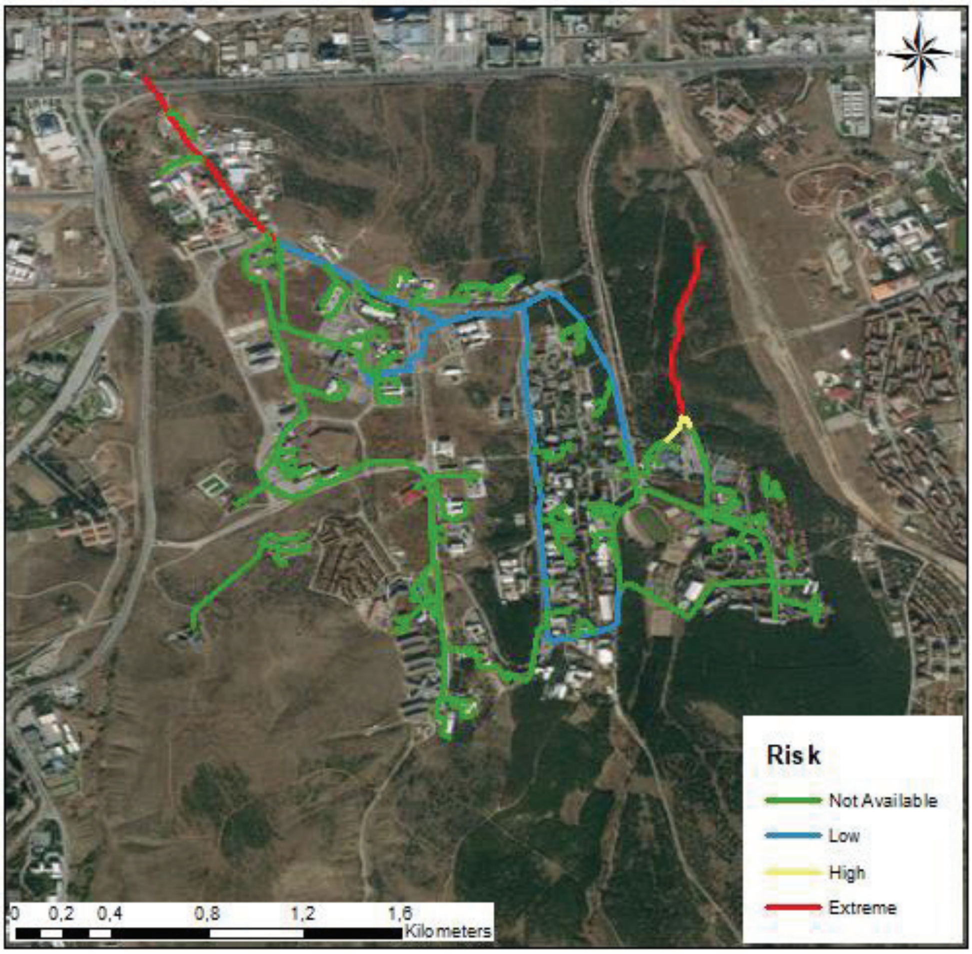



**Figure 101.** Risk map of sewer water pipeline

When the stormwater line of METU Campus was examined, it was observed that it is shorter and newer when compared with the other water pipelines. In addition to that, stormwater pipeline pipes have high remaining lifetime since most of pipes are concrete. Therefore, pipes of stormwater pipeline have low risk as seen in Figure 102. The risk of green pipes is not known since necessary information to evaluate their failure risk is not available.


**Figure 102.** Risk map of storm water pipeline

As a result, these three water pipelines include a number of pipes having different materials, installation years and break histories. Therefore, they differ from each other in terms of failure risks. In this study, it was also understood that there is lack of information about pipes' material, length, diameter, break history and water loss. Therefore, developing a complete asset management for these water pipelines is not possible. Therefore, a asset management plan was recommended for METU water pipelines in the next step.

### 6.3. Recommend

In this step, an asset management methodology (Figure 103) was recommended for METU water pipelines. In addition to this, it is important to specify problems and deficiencies about METU water pipelines. These problems and deficiencies observed are listed below.

- Engineering drawings of potable water pipeline, sewer line and stormwater pipeline prepared with necessary technical information do not exist for METU campus.
- The materials, lengths and diameters of some pipes are not known. The total lengths of these water pipelines are also unknown.
- These water pipelines are not monitored systematically unless there is a water leakage/loss due to any cracks in pipes.
- -If there is any problem in the pipe system, it is detected and repaired, but these repairs are not being recorded. There are not past break reports and their dates are not officially documented.
- While a new structure is being constructed in a region of the campus, some parts of pipes have been removed from the infrastructure system. There is a risk of damaging the buildings in that area since those missing pipes are not completed in the infrastructure system.
- In some regions, it is observed that pipe fractures and water leaks have occurred in stormwater pipeline such as METU Sport Center region due to the fact that the tree roots spread into the pipes.

- The grease traps of the cafeteria and the shopping center are not working properly. For this reason, the grease leaks into sewer line and it sticks to the edges of the pipes and and make them clogged.
- During the afforestation work made by Directorate of METU Forestration, soil is poured over the manhole covers mistakenly and they disappear from ground surface. When there is pipe crack and water leak, this situation makes the repair difficult.

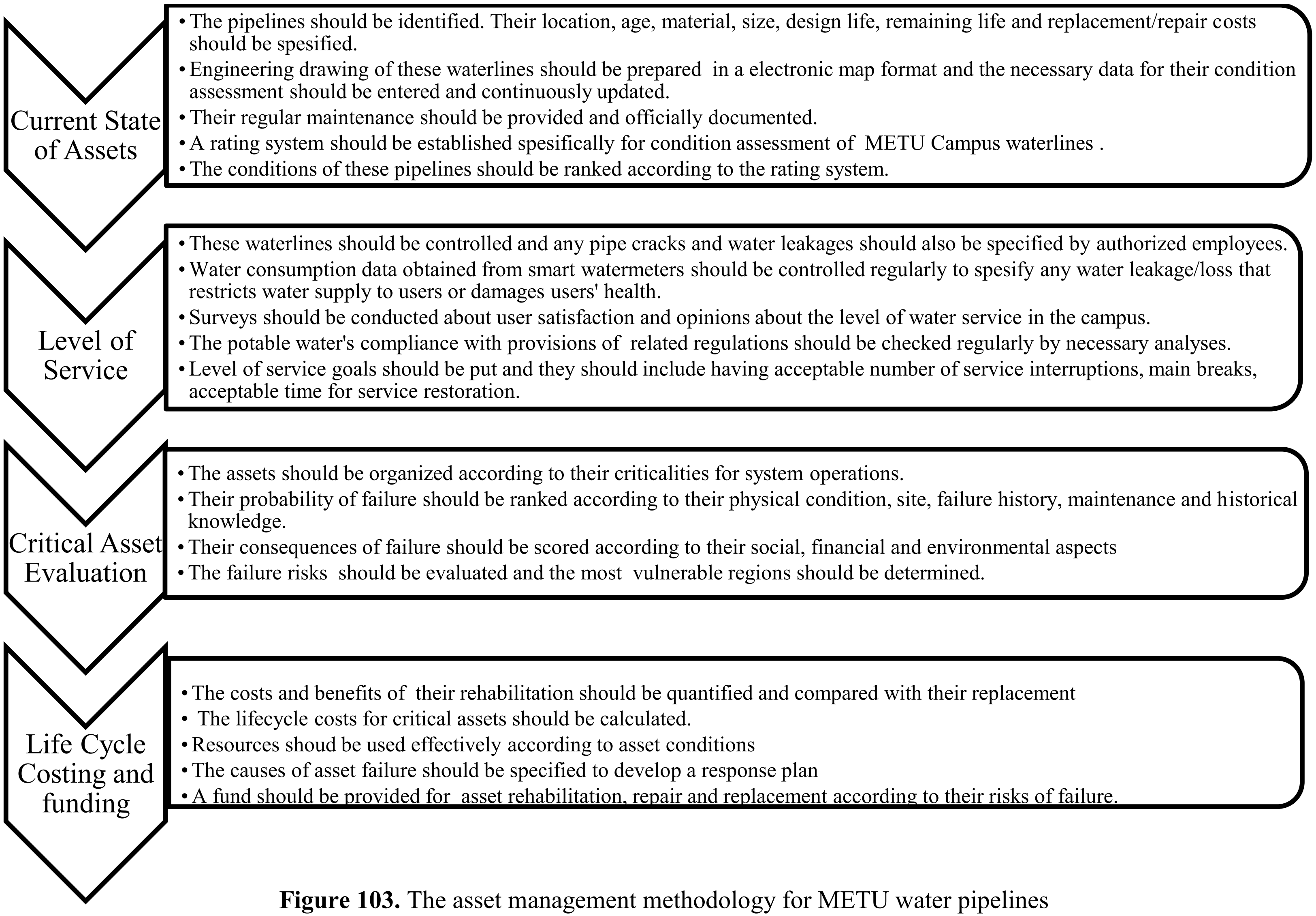



**Figure 103.** The asset management methodology for METU water pipelines

# CHAPTER 7

# PROPOSED WATER AND STORMWATER MANAGEMENT PLAN FOR METU CAMPUS

Climate change and population factors simultaneously increase water demand and reduce availability. Although water use is essential in universities, they can contribute to water scarcity locally, nationally and even globally by wasting water. Therefore, providing water efficiency, protecting their waterways and groundwater resource are important. It is necessary to pay close attention to the way how to consume water in buildings and landscapes of the campus.

This study indicated that developing a comprehensive water management plan for METU campus is necessary. In this chapter, four main water and stormwater management strategies were developed to decrease the water consumption at the campus and to protect the quality and quantity of campus' water resource (Figure 104). While developing these strategies, the campus examples from around the world were reviewed and the ones, which are applicable for METU Campus, were specified. These are:

**Investigate:** It is the first strategy and it is about discovering and examining the water infrastructure systems of the campus for asset inventory and condition assessment.

**Reduce:** It is about taking necessary actions and establishing cooperation to reduce water consumption, stormwater runoff and wastewater generation on campus.

**Innovate:** On top of “reduce”, it is about developing sustainable and innovative water resources utilization and supply strategies to sustain continuity.

**Partner:** While developing these strategies, establishing partnerships with students, academic and administrative staff, local stakeholders and other relevant external groups to enhance dialogue on water sustainability on the campus and water problems in the region.

After developing strategies, some management actions were proposed for the campus. These actions were specified for potable water, stormwater and wastewater. They were also classified according to their urgency as shown in Figure 105. Urgent represents the first two years, short-term represents a time period in between 2 and 5 years and long-term actions are expected to perform in between 5 to 10 years. While classifying these actions according to their urgency, their simplicities and criticalities for the campus were considered.

In “Investigate” strategy, the goals related to potable water, stormwater and wastewater of METU campus were put to investigate their pipelines, to detect their assets and to quantify their amounts. In infrastructural asset management part (see Chapter 6), it was determined that there are serious problems related with information about current situations of water pipeline systems. Therefore, the actions proposed for these water pipelines were urgent. These were undertaking physical audits for them and mapping them for their condition assessment.

In “Reduce” strategy, it was important to emphasize that the university must have a better understanding of how it uses water in order to develop a sustainable water management plan. The water amount supplied from wells and the water consumptions in five dormitories and cafeteria where the smart water meters were installed are known, but metering of other facilities or uses is currently not available. Therefore, the university should aim to monitor and reduce potable water consumption, stormwater surface runoff and wastewater generation. For example, the daily water consumption of a METU student was calculated as 130 L. According to “Reduce” strategy, METU should be put goal to reduce the water consumption in its campus. Water usage in sustainable cities is 100 L /day-cap (Novotny, 2016). Therefore, [(130-100)/130]*100 = 23.1% ~ 25% reduction in water consumption per person is the proposed target. Taking some water conservation actions is necessary to reach this goal and to provide water sustainability for campus in both short and long terms. Monitoring and quantifying water consumptions data, replacing high-flow showerheads and taps with the low-flow ones were some of the proposed short-term actions to achieve this target. Some actions were also proposed for stormwater and wastewater as shown in Figure 105. For example, the goal related to stormwater is to capture stormwater to reduce surface runoff and the actions proposed are constructing rain barrels and designing rain gardens. Similarly, reducing the wastewater generation on campus is the goal related to wastewater.

In “Innovate” strategy, the goal for potable water is to provide new water reclamation technologies to use in high water demand locations on campus since reuse is one of the key elements in water conservation. There is not any specified water reuse action currently in METU Campus. The long term actions can be related to conserving greater volume of water by increasing water reuse across the campus. For example, one of proposed long-term action is specifying and using the most suitable water treatment technique to reuse greywater coming from washing machines and faucets for irrigation, steam generation and toilet flushing. In addition to that, some goals and targets were also set for stormwater and wastewater of campus. Increasing permeable areas by using LIDs is the goal related to stormwater since surface runoff reduction effects of different LIDs were investigated in Chapter 5. Some proposed long-term actions are analyzing opportunities for permeable pavements and designing green roofs.

Lastly, “Partner” strategy is very significant for all strategies since establishing partnerships is essential in order to implement the proposed actions. Students, academic and administrative staff and local/external relevant groups are important partners to provide a sustainable water management for METU campus.

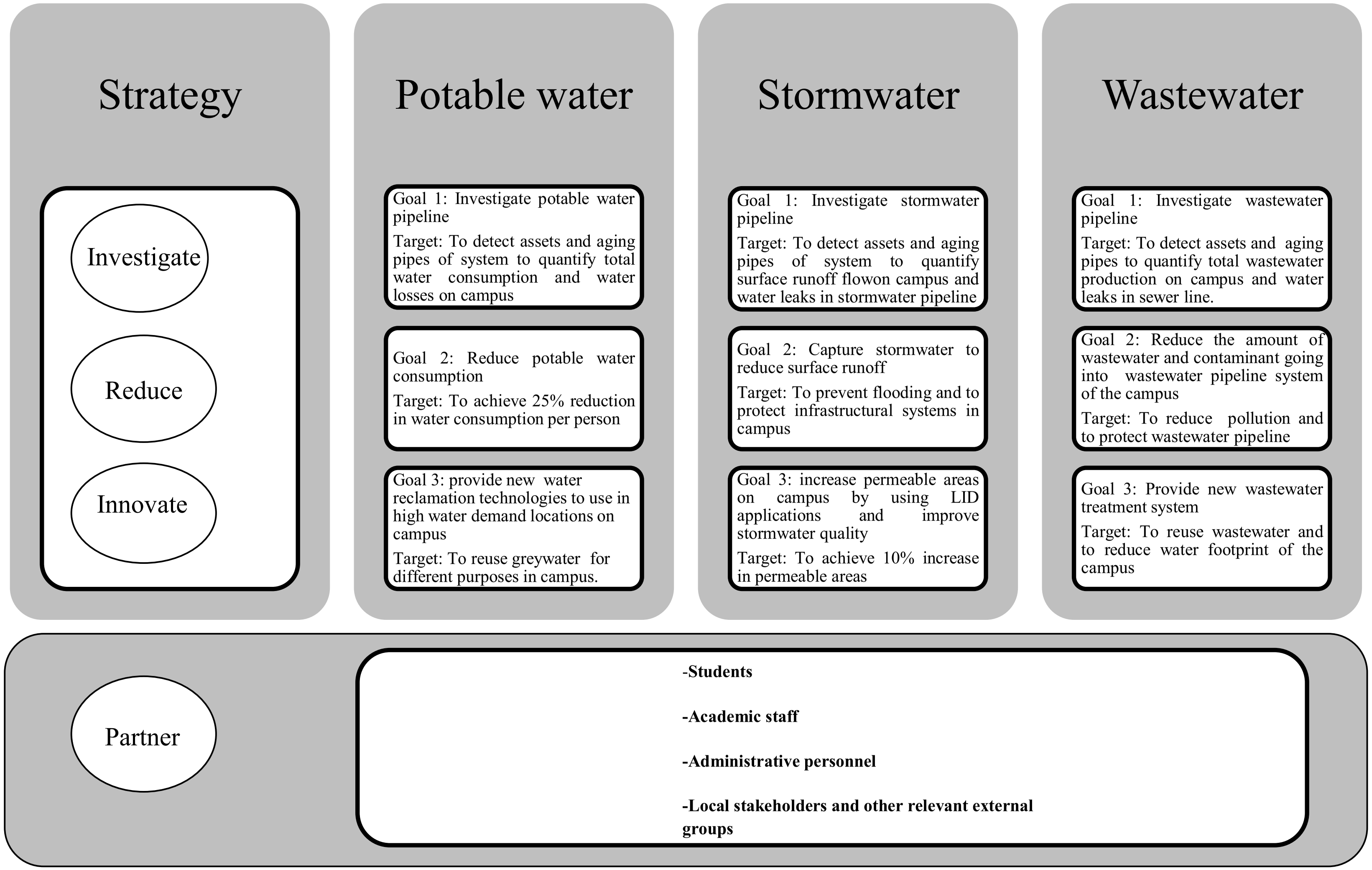



**Figure 104.** Sustainable water management strategies developed for METU Campus

| Time period | Actions related potable water | Actions related stormwater | Actions related wastewater |
| --- | --- | --- | --- |
| Urgent | -undertake physical audit for potable water pipeline of campus<br>-mapping of the pipeline including necessary data for condition assessment<br>-control of irrigation and heating systems by site visits<br>-start installation of water metering systems over the campus<br>-start investigation of the factors impacting on the quality and quantity of groudwater resource | -undertake physical audit for stormwater pipeline of campus<br>-mapping of the pipeline including necessary data for condition assessment<br>-start installation of a permenant flowmeter systems on stormwater pipeline<br>-start investigation of current water quality of stormwater on campus | -undertake physical audit for wastewater pipeline of campus<br>-mapping of the pipeline including necessary data for condition assessment<br>-detect and control of current water leakage in the wastewater pipeline system on campus<br>-start installation of flowmeter at the ends of wastewater pipelines over the campus to calculate toplam wastewater production |
| Short term | -monitor and evaluate the water consumption data<br>-replace high-flow showerheads and taps with the low-flow ones<br>-install motion sensors and dual flush systems for toilets<br>-use more efficient washing machines in cafeteria and dormitories<br>-provide continuous water quality monitoring | -start constructing rain barrels for all buildings in campus to reuse stormwater for toilet flushing and irrigation<br>-design rain gardens accordign to land availability and their desing considerations to decrease surface runoff and to improve stormwater quality<br>-increase planting areas oncampus | -undertake physical audit for the grease traps of the cafeteria and shopping center to prevent grease leakage into the wastewater pipeline system |
| Long term | -spesify and use the best alternative for treatment of backwash water coming from swimming pool<br>- specify and use the most suitable water treatment technique for reuse of greywater coming from washing machines and faucets<br>- Use treated greywater for irrigation, steam generation and toilet flushing | -analyze opportunities for permeable pavements<br>-start designing green roofs by considering their design factors, suitability of roofs on the campus | -constructing new wastewater treatment plant to reuse wastewater for different purposes such as steam generation, irrigation and toilet flushing |

**Figure 105.** Proposed actions for sustainable water management of METU Campus

# CHAPTER 8

# CONCLUSIONS

In this study, it was aimed to develop sustainable water management strategies for METU Campus. Water infrastructure networks of the campus were also evaluated in asset management approach. In the water management part, groundwater resource of the campus and the management alternatives for its protection were investigated. High water demand locations which are dormitories, cafeteria and swimming pool were visited and the water-related problems in their operations were investigated. Additionally, the water consumption data belonging to dormitories and cafeteria were analyzed. Then water consumption pattern in METU was evaluated based on real time measurements supported by the outcomes of a survey which aimed to understand the students' behavior. Some water saving strategies, water conservation, water efficiency approaches and water loss prevention strategies were proposed and their water saving potentials were evaluated for METU dormitories. Results indicated that by using water conservation, water efficiency approaches and preventing water losses, 68.7% reduction in water consumption (70466.88 L/day water is saved) can be achieved. This water can meet the daily water need of 176 family (including four people). According to observations and evaluation of water consumption data for dormitories, cafeteria and swimming pools, some water management alternatives were recommended. Retrofitting of water saving utilities such as low-flow showerheads, taps and dual-flush systems for toilets was mostly recommended for these locations. In addition to that, some water losses were observed especially in dormitories and cafeteria. Therefore, a detail investigation of their water infrastructure systems was recommended. Lastly, alternative effective processes for treatment of swimming pool water were recommended to reduce high water consumptions due to high combined chlorine concentrations and some reuse alternatives were recommended for backwash water.

In stormwater management part, a rainfall-runoff model, SWMM, was developed both to simulate stormwater collection system of the campus and to evaluate effectiveness of LID applications to reduce surface runoff in the campus. SWMM was ustilized to simulate the surface runoff. The model was calibrated and model performance was satisfactory in simulating surface runoff. The NSE and $R^2$ values are 0.56 and 0.6, respectively. The calibrated model was used to develop LIDs on campus. Rain gardens, rain barrels and green roofs were applied for all subcatchments of the campus in proper numbers by considering their design factors and land availability. Their combined application achieved reductions as in between 17.3% and 21.9% for peak flows and in between 10.2% and 21.2% for total flow. When the water collected by rain barrels was calculated, it was concluded that Devrim Stadium can be irrigated for 4 times by using this stored stormwater. These results emphasized that LID applications are really important and necessary to establish a sustainable stormwater management. As an alternative to SWMM model, a regression analysis was also conducted to estimate surface runoff. The results of regression analysis showed that rain, rain duration, evaporation rate, average slope of catchment and time interval between current and previous event are the variables that the total surface runoff mostly depended on. These variables can be used to predict total surface runoff volumes for the future rain events. The $R^2$ value was 0.73 when the correlation was calculated between measured and predicted total runoff volumes by using these independent variables. It was understood that regression analysis is an important technique in terms of determining the relationship between independent parameters and variables that depend on these parameters.

In asset management part, the current situation of the water infrastructure system in the campus was investigated through an asset management approach. A methodology was developed to investigate three water lines in the campus. The results indicated that high risks are mostly observed in the potable water line. The reason probably is that it is older than other waterlines. Similar to potable water line, high risks were observed in sewer line since more pipe breaks were experienced than other water lines. The failure risk of stormwater line is low because it is newer than others. The important problems related documentation of assets in campus and irregular maintenance were specified and an asset management methodology was recommended.

In conclusion, the current situation of the campus was investigated in terms of water, stormwater and asset management. The observations of water consumption patterns in water demand locations, the simulation and LID application results and investigations of water pipeline systems in campus indicated that there are certain problems and deficiencies related with the sustainable use of water on campus. Firstly, increases in water withdrawals and decreases in water levels of the groundwater wells showed that groundwater resource of the campus is running out day by day. According to observations in dormitories, cafeteria and swimming pools, the water fixtures in most of the places are old and not water-efficient. Water leakages exist due to these aging fixtures and this leads to unnecessary water consumption in these places. In addition to that, the current situation of water pipeline systems is quite serious. For example, several main pipes in potable water pipeline system were classified as extreme in terms of failure risk. Similarly, there were also leakages detected in some parts of the stormwater pipeline system. Besides, one of these leakages led to obtain mismeasured surface runoff flow data in SWMM development part of the study. Because of this leakage, the actual total surface runoff amount could not be simulated during SWMM simulation. The calculated surface runoff reduction potentials of LID applications implied that a detailed investigation of LID applications on the campus should be performed in further studies.

To sum up, METU Campus needs some water conservation, rain harvesting actions and infrastructural renovation activities in order to maintain water sustainability. As the outcomes of this study, some strategies and actions were proposed as a water management plan for METU Campus. The urgent actions are mostly related to the infrastructural system of the campus because preventing water leakages due to aging infrastructure will be the primary step to protect water resource of the campus and to provide water sustainability. Some retrofiting studies in the water fixtures and rain harvesting activities will be expected in short-term period according to proposed management plan. Lastly, new treatment technologies were recommended to treat the backwash water coming from swimming pools, wastewater and greywater for reuse purposes in long-term period.

In future studies, some vulnerability analysis, modeling and risk analyses should be implemented to protect the quality and quantity of METU groundwater resource. Irrigation water of the campus should be quantified by installing water meters for continuous monitoring. Moreover, different water reuse alternatives should be evaluated to decrease potable water usage for irrigation purposes. In order to implement these actions, it is necessary to set up a Campus Sustainability Office and to provide continuous environmental monitoring and performance evaluation in the campus. It is expected that the outcomes of this study will aid decision makers such as METU President's Office in developing sustainable water management strategies and action plans for METU Campus.

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# APPENDICES

## APPENDIX A

| İÇME SUYU KALİTE PARAMETRE DEĞERLERİ (Kabul Edilebilir Maksimum Değerler) | | | |
|---|---|---|---|
| STANDARTLAR | TSE 266 Türk Standartları Enstitüsü | EC Avrupa Birliği | WHO Dünya Sağlık Teşkilatı |
| **Mikrobiyolojik EMS/100 mL** | | | |
| Toplam Koliform | 0 | 0 | 0 |
| Escherichia Coli (E. Coli) | 0 | 0 | 0 |
| C.perfringens | 0 | 0 | 0 |
| Enterokok | 0 | 0 | 0 |
| **Kimyasal mg/L** | | | |
| Nitrat (NO3) | 50 | 50 | 50 |
| Nitrit (NO2) | 0.50 | 0.50 | 0.50 |
| Bor (B) | 1 | 2 | 2 |
| Nikel (Ni) | 0.02 | 0.02 | 0.02 |
| Arsenik (As) | 0.01 | 0.01 | 0.01 |
| Kadmiyum (Cd) | 0.005 | 0.005 | 0.003 |
| Krom Toplam (Cr) | 0.05 | 0.05 | 0.05 |
| Florür (F) | 1.50 | 1.50 | 1.50 |
| Kurşun (Pb) | 0.01 | 0.01 | 0.01 |
| Siyanür (CN) | 0.05 | 0.05 | 0.07 |
| Bromat (Br) | 0.010 | 0.010 | 0.025 |
| Benzen (C6H6) | 0.001 | 0.001 | 0.010 |
| Selenyum (Se) | 0.010 | 0.010 | 0.010 |
| Antimon (Sb) | 0.005 | 0.005 | 0.005 |
| Bakır (Cu) | 2,0 | 2,0 | 2,0 |
| **Gösterge mg/L** | | | |
| pH (pH) | 6.5-9.5 | 6.5-9.5 | 6.5-8.5 |
| Renk(Co-Pt birimi) | 20 | 20 | 15 |
| Bulanıklık(NTU birimi) | 5,0 | 4,0 | 5,0 |
| İletkenlik 20' (uS/cm) | 2500 | 2500 | 2500 |
| Koku | Kokusuz | | |
| Demir (Fe) | 0.2 | 0.2 | 0.3 |
| Mangan (Mn) | 0.05 | 0.05 | 0.10 |
| Alüminyum (Al) | 0.20 | 0.20 | 0.20 |
| Amonyum (NH4) | 0.50 | 0.50 | 1.50 |
| Sodyum (Na) | 200 | 200 | 200 |
| Klorür (Cl) | 250 | 250 | 250 |
| Sülfat (SO4) | 250 | 250 | 250 |
| Sertlik(CaCO3) | | | 500 |

**Figure 106.** Potable Water Quality Parameters' Limit Values

## APPENDIX B

**Table 48.** Descriptive Statistics of Water Consumption in Dorm 1 and Dorm 3

| Month | Total Water Consumption (m^3) | Average | Minimum | Maximum | Standard Deviation | # of data |
|---|---|---|---|---|---|---|
| January | 7124,7 | 76,6 | 10,3 | 122,2 | 38,8 | 93 |
| February | 3497,2 | 56,4 | 11,8 | 114,9 | 38,2 | 62 |
| March | 6296,3 | 101,6 | 78,7 | 125,2 | 10,3 | 62 |
| April | 5933,1 | 98,9 | 49,7 | 128,6 | 16,4 | 60 |
| May | 6492,9 | 104,7 | 75,8 | 123,9 | 11,9 | 62 |
| June | 2835,4 | 64,4 | 14,0 | 118,9 | 37,3 | 44 |
| July | 2336,1 | 75,4 | 43,4 | 102,1 | 12,2 | 31 |
| August | 1571,0 | 50,7 | 12,5 | 96,1 | 28,9 | 31 |
| September | 1322,2 | 38,9 | 13,2 | 83,7 | 21,7 | 34 |
| October | 7710,1 | 98,8 | 12,0 | 136,3 | 24,1 | 78 |
| November | 9498,8 | 105,5 | 54,5 | 132,9 | 11,6 | 90 |
| December | 8387,1 | 101,0 | 18,9 | 135,1 | 13,6 | 83 |

**Table 49.** Descriptive Statistics of Water Consumption in Dorm 17, Dorm 18 and Dorm 19

| Month | Total Water Consumption (m^3) | Average | Minimum | Maximum | Standard Deviation | # of data |
|---|---|---|---|---|---|---|
| January | 6733,1 | 74,0 | 0,0 | 274,0 | 99,4 | 91 |
| February | 4731,9 | 76,3 | 4,4 | 262,0 | 87,7 | 62 |
| March | 8834,3 | 142,5 | 26,9 | 284,0 | 113,5 | 62 |
| April | 9157,3 | 152,6 | 20,5 | 306,0 | 123,1 | 60 |
| May | 9114,3 | 147,0 | 29,0 | 302,0 | 112,7 | 62 |
| June | 3630,6 | 82,5 | 7,9 | 292,0 | 103,0 | 44 |
| July | 710,6 | 22,9 | 15,8 | 28,7 | 3,1 | 31 |
| August | 622,7 | 20,1 | 14,2 | 28,8 | 3,4 | 31 |
| September | 1280,0 | 37,6 | 13,4 | 248,0 | 59,8 | 34 |
| October | 12033,1 | 154,3 | 28,6 | 302,0 | 111,7 | 78 |
| November | 10409,0 | 150,9 | 21,6 | 278,0 | 113,1 | 69 |
| December | 8697,4 | 140,3 | 19,9 | 278,0 | 114,4 | 62 |

**Table 50.** Descriptive Statistics of Water Consumption in Cafeteria

| Month | Total Water Consumption (m^3) | Average | Minimum | Maximum | Standard Deviation | # of data |
|---|---|---|---|---|---|---|
| January | 8598,6 | 92,5 | 8,8 | 209,5 | 54,7 | 93 |
| February | 4478,0 | 72,2 | 5,6 | 148,6 | 42,3 | 62 |
| March | 6176,3 | 99,6 | 10,1 | 151,1 | 48,8 | 62 |
| April | 5423,2 | 90,4 | 10,0 | 153,8 | 51,3 | 60 |
| May | 5500,5 | 88,7 | 10,8 | 151,7 | 51,5 | 62 |
| June | 3267,0 | 74,3 | 3,6 | 124,2 | 38,3 | 44 |
| July | 3577,2 | 115,4 | 82,7 | 135,6 | 20,8 | 31 |
| August | 3363,2 | 108,5 | 80,6 | 131,5 | 20,3 | 31 |
| September | 3732,5 | 109,8 | 77,2 | 169,2 | 26,0 | 34 |
| October | 9447,9 | 121,1 | 3,6 | 217,0 | 69,0 | 78 |
| November | 10851,6 | 120,6 | 8,1 | 220,3 | 60,6 | 90 |
| December | 8714,9 | 105,0 | 7,9 | 221,9 | 63,8 | 83 |

# APPENDIX C

WATER CONSUMPTION BEHAVIOR SURVEY

*Within the scope of the Sustainable Green Campus Applications Project at METU, which was initiated by Environmental Engineering Department and funded by METU, the following survey was conducted to observe the water consumption behaviors of the students staying in the dormitories to provide sustainable water management within the campus. The answers to this questionnaire will only be used for scientific purposes and personal information will be kept confidential. Read the questions carefully, answer them, and select the option/ options that are appropriate for the compliant questions.*

1) What is your gender?

   ………………………

2) Which department and which grade that you are studying?

   ………………………

3) Do you know what is the water resource of METU Campus? (İf you know, write it to the given gap)

   a)Yes, I know: …………………………… b) No, I do not know.

4) Which METU dorm do you stay in ?................................ How long have you been staying? …………

5) Show the frequency (times) / water use duration (minutes) corresponding to the questions in the table below with a cross mark (X), or write the amount corresponding to the question in the "Other" column.

| | 1 | 2 | 3 | 4 | 5 | Other |
|---|---|---|---|---|---|---|
| How many times do you use the dormitory toilet during the day? | | | | | | |
| How many times are you flushing each time you use toilet? | | | | | | |
| How many times do you use the bathroom sink taps during the day? | | | | | | |
| When you brush your teeth, how many minutes of water do you use water? | | | | | | |
| When you brush your teeth, how many minutes do you use water? | | | | | | |
| When you wash your hands or face, how many minutes of water do you use in each time? | | | | | | |

6) If there is a double siphon system in the toilet, how do you use it?
   a) I use the siphon having small volume of water.
   b) I use the siphon having big volume of water.
   c) I do not care.
   d) Other:………………….

7) Mark the corresponding response to the questions in the table below.

| | Yes | No |
|---|---|---|
| Do you leave the tap open when brushing teeth? | | |
| Do you leave the tap open when shaving? (Male students) | | |
| Do you leave the tap open while you wash your hands or your face? | | |

8) Show the time intervals corresponding to the answers for the questions given in the table below with a cross mark (X). (You can mark more than one for each question.)

| | 00:00-03.00 | 03:00-06:00 | 06:00-09:00 | 09:00-12:00 | 12:00-15:00 | 15:00-18:00 | 18:00-21:00 | 21:00-24:00 |
|---|---|---|---|---|---|---|---|---|
| What are the time intervals you usually use the toilet during the day? | | | | | | | | |
| What is the time interval you usually use the bathroom sink taps during the day? | | | | | | | | |
| What are the time intervals during which you shower during the day? | | | | | | | | |

9) When you use the taps, do you leave the tap open so that the water can reach the desired temperature?
a) Yes b) No

10) If you are leaving, how long (in minutes) do you leave the water open while waiting for it to reach the desired temperature? (Fill in the given blank if you mark "Other" option.)
a) 1 b) 2 c) 3 d)4 e) Other: ………………

11) How many times in a week do you take shower? (Fill in the given blank if you mark “Other” option.)

a) 1 b) 2 c) 3 d)4 e) Other: ………………

12) 12) On which days of the week do you take shower? (You can mark more than one.)

a) Monday b) Tuesday c) Wednesday d) Thursday e) Friday f) Saturday g)Sunday

13) How many minutes do you shower in average? (Fill in the given blank if you mark “Other” option.)

a) 5 b) 10 c) 15 d)30 e) Other: ………………

14) How many times do you do laundry in a month? (Fill in the given blank if you mark “Other” option.)

a) 1 b) 2 c) 3 d)4 e) Other: ………………

15) How many times do you use washing machines in every laundry? (Fill in the given blank if you mark “Other” option.)

a) 1 b) 2 c) 3 d)4 e) Other: ………………

16) On average, how many kilograms of laundry are you washing each time you use a washing machine? (Please consider that the machines used in dorms have 5 kg capacity.) (Fill in the given blank if you mark “Other” option.)

a) 1 b) 2 c) 3 d)4 e) Other: ………………

17) According to the type of laundry you wash, please specify which program you are using and in which temperature you wash it.

| Type of laundry | Program (Cotton, Synthetic etc.) | Washing Temperature (°C ) |
|---|---|---|
| White | | |
| Black | | |
| Colourful | | |

18) Which of the following options do you use as drinking water in your dorm? (You can mark more than one.)

a) Tap water
b) Plastic bottle water
c) Other: ……………

19) How many liters of water do you drink per day?

………………….. (L/day)

20) Do you use kitchen in your dorm?

a) Yes b) No

21) If so, how many minutes is your average water usage in the kitchen? (Fill in the given blank if you mark "Other" option.)

a) 3 b) 5 c) 7 d)10 e) Other: ……………

22) Do you know that while conventional shower heads lead to average 15-20 liters of water consumption per minute, it is 9-10 liters of water for low-flow shower heads?

a) Yes b) No

23) Do you know that you can save 12 tons of water per person per year from the tap that is turned off while you are shaving and brushing your teeth? (Fill in the given blank if you mark "Other" option.)

a) Yes b) No c) Diğer:…………

24) Mark the measures you have taken to save water in the options below. (Fill in the given blank if you mark "Other" option.)

a) Closing the tap while taking shower
b) Closing the tap while washing dishes
c) Closing the tap while brushing teeth
d) Using low flow shower heads in bathrooms
e) Using double flush systems in toilets
f) Other: ………………

25) Mark the following options if you have any sustainability activity on campus. (Fill in the given blank if you mark "Other" option.)

a) Recycling
b) Prefer cycling or walking instead of driving
c) Using energy-saving electric lamps
d) Turning off unnecessarily open lamps
e) Other: ……………

26) Which of the following activities should be used for the reuse of treated wastewater? (You can mark more than one.)

a) Shower
b) Drinking
c) Agricultural irrigation
d) Irrigation of recreational areas
e) Any of them
f) I do not know anything about it.
g) Using toilet flush water
h) Other: …………….

27) Which of the following activities should be used for the use of collected stormwater? (You can mark more than one.)
   a) Shower
   b) Drinking
   c) Agricultural irrigation
   d) Irrigation of recreational areas
   e) Any of them
   f) I do not know anything about it.
   g) Using toilet flush water
   h) Other: …………….

THANK YOU FOR YOUR CONTRIBUTION TO THE PROJECT BY FILLING IN QUESTIONNAIRE

**Table 51.** The details about the rain events and subcatchments

| Date | Basin | Measured Total Flow (m3) | Rain (mm) | Rain Intensity (mm/hr) | Rain Duration (hr) | % of impervious areas | Basin area (m2) | Width (m) | Average slope (%) | CN | Time interval between previous rain event (hr) | Monthly Evaporation rate (mm/day) | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8.05.2015 10:30 | DM1 | 67,3 | 8,2 | 3,3 | 2,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 0,0 | 5,6 | 16,1 |
| 25.05.2015 00:30 | DM1 | 5,0 | 0,6 | 1,2 | 0,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 398,0 | 5,6 | 16,1 |
| 25.05.2015 11:30 | DM1 | 43,7 | 4,8 | 1,6 | 3,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 11,0 | 5,6 | 16,1 |
| 25.05.2015 14:30 | DM1 | 3,6 | 2,4 | 1,2 | 2,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 3,0 | 5,6 | 16,1 |
| 27.05.2015 20:30 | DM1 | 30,6 | 2,8 | 1,1 | 2,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 54,0 | 5,6 | 16,1 |
| 28.05.2015 15:00 | DM1 | 1,8 | 5,2 | 10,4 | 0,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 18,5 | 5,6 | 16,1 |
| 29.05.2015 18:30 | DM1 | 67,6 | 11,2 | 5,6 | 2,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 27,5 | 5,6 | 16,1 |
| 30.05.2015 01:30 | DM1 | 34,3 | 8,8 | 0,9 | 10,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 5,0 | 5,6 | 16,1 |
| 3.06.2015 17:30 | DM1 | 97,6 | 11,2 | 1,9 | 6,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 112,0 | 6,7 | 20,1 |
| 4.06.2015 02:30 | DM1 | 78,2 | 10,0 | 1,3 | 7,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 9,0 | 6,7 | 20,1 |

| Date | Basin | Measured Total Flow (m3) | Rain (mm) | Rain Intensity (mm/hr) | Rain Duration (hr) | % of impervious areas | Basin area (m2) | Width (m) | Average slope (%) | CN | Time interval between previous rain event (hr) | Monthly Evaporation rate (mm/day) | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.06.2015 13:30 | DM1 | 5,9 | 0,6 | 0,6 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 11,0 | 6,7 | 20,1 |
| 4.06.2015 20:30 | DM1 | 2,4 | 1,0 | 1,0 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 7,0 | 6,7 | 20,1 |
| 9.06.2015 15:00 | DM1 | 3,2 | 3,2 | 3,2 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 114,5 | 6,7 | 20,1 |
| 11.06.2015 18:30 | DM1 | 21,1 | 4,0 | 2,0 | 2,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 51,5 | 6,7 | 20,1 |
| 12.06.2015 14:00 | DM1 | 0,4 | 0,4 | 0,3 | 1,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 19,5 | 6,7 | 20,1 |
| 14.06.2015 18:00 | DM1 | 3,9 | 0,4 | 0,8 | 0,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 52,0 | 6,7 | 20,1 |
| 16.06.2015 14:30 | DM1 | 4,0 | 0,6 | 1,2 | 0,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 44,5 | 6,7 | 20,1 |
| 16.06.2015 17:30 | DM1 | 5,7 | 1,4 | 1,4 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 3,0 | 6,7 | 20,1 |
| 18.06.2015 18:30 | DM1 | 4,4 | 2,2 | 0,9 | 2,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 49,0 | 6,7 | 20,1 |
| 22.06.2015 15:00 | DM1 | 6,2 | 3,2 | 3,2 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 92,5 | 6,7 | 20,1 |
| 22.06.2015 | DM1 | 40,1 | 5,6 | 5,6 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 7,5 | 6,7 | 20,1 |

| Date | Basin | Measured Total Flow (m3) | Rain (mm) | Rain Intensity (mm/hr) | Rain Duration (hr) | % of impervious areas | Basin area (m2) | Width (m) | Average slope (%) | CN | Time interval between previous rain event (hr) | Monthly Evaporation rate (mm/day) | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22:30 | | | | | | | | | | | | | |
| 23.06.2015 03:00 | DM1 | 40,0 | 5,8 | 2,9 | 2,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 4,5 | 6,7 | 20,1 |
| 23.06.2015 06:30 | DM1 | 45,7 | 6,2 | 3,1 | 2,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 3,5 | 6,7 | 20,1 |
| 24.06.2015 13:30 | DM1 | 6,1 | 1,4 | 0,7 | 2,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 31,0 | 6,7 | 20,1 |
| 24.06.2015 18:00 | DM1 | 6,1 | 1,2 | 2,4 | 0,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 4,5 | 6,7 | 20,1 |
| 27.06.2015 08:00 | DM1 | 27,1 | 2,8 | 2,8 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 62,0 | 6,7 | 20,1 |
| 27.06.2015 14:30 | DM1 | 0,9 | 2,2 | 1,5 | 1,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 6,5 | 6,7 | 20,1 |
| 28.06.2015 02:00 | DM1 | 0,6 | 0,8 | 1,6 | 0,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 11,5 | 6,7 | 20,1 |
| 31.07.2015 16:00 | DM1 | 22,5 | 2,4 | 2,4 | 1,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 806,0 | 8,4 | 23,5 |
| 31.07.2015 18:00 | DM1 | 1,7 | 5,4 | 3,6 | 1,5 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 2,0 | 8,4 | 23,5 |
| 11.08.2015 19:00 | DM1 | 55,1 | 8,0 | 4,0 | 2,0 | 35,8 | 147691,6 | 281,6 | 2,8 | 67,6 | 265,0 | 8,1 | 23,4 |

| Date | Basin | Measured Total Flow (m3) | Rain (mm) | Rain Intensity (mm/hr) | Rain Duration (hr) | % of impervious areas | Basin area (m2) | Width (m) | Average slope (%) | CN | Time interval between previous rain event (hr) | Monthly Evaporation rate (mm/day) | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6.10.2015 14:30 | DM2 | 7,2 | 1,2 | 1,2 | 1,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 0,0 | 3,2 | 12,9 |
| 6.10.2015 17:00 | DM2 | 55,1 | 3,4 | 1,7 | 2,0 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 2,5 | 3,2 | 12,9 |
| 11.10.2015 20:00 | DM2 | 91,6 | 8,0 | 5,3 | 1,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 123,0 | 3,2 | 12,9 |
| 12.10.2015 21:30 | DM2 | 55,1 | 1,4 | 0,9 | 1,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 25,5 | 3,2 | 12,9 |
| 21.10.2015 00:00 | DM2 | 140,2 | 3,4 | 1,7 | 2,0 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 194,5 | 3,2 | 12,9 |
| 21.10.2015 08:30 | DM2 | 27,2 | 2,0 | 1,3 | 1,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 8,5 | 3,2 | 12,9 |
| 21.10.2015 22:00 | DM2 | 76,6 | 6,6 | 6,6 | 1,0 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 13,5 | 3,2 | 12,9 |
| 23.10.2015 13:30 | DM2 | 45,2 | 1,6 | 0,8 | 2,0 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 39,5 | 3,2 | 12,9 |
| 23.10.2015 20:30 | DM2 | 23,2 | 0,8 | 0,5 | 1,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 7,0 | 3,2 | 12,9 |
| 24.10.2015 04:00 | DM2 | 43,9 | 1,2 | 0,8 | 1,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 7,5 | 3,2 | 12,9 |
| 24.10.2015 | DM2 | 100,3 | 2,0 | 0,5 | 4,0 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 2,5 | 3,2 | 12,9 |

| Date | Basin | Measured Total Flow (m3) | Rain (mm) | Rain Intensity (mm/hr) | Rain Duration (hr) | % of impervious areas | Basin area (m2) | Width (m) | Average slope (%) | CN | Time interval between previous rain event (hr) | Monthly Evaporation rate (mm/day) | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06:30 | | | | | | | | | | | | | |
| 24.10.2015 20:30 | DM2 | 89,3 | 6,8 | 2,3 | 3,0 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 14,0 | 3,2 | 12,9 |
| 10.11.2015 20:00 | DM2 | 46,3 | 4,8 | 9,6 | 0,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 407,5 | 0,0 | 7,1 |
| 10.11.2015 21:00 | DM2 | 54,6 | 3,2 | 6,4 | 0,5 | 24,5 | 1022273,0 | 354,2 | 7,4 | 66,4 | 1,0 | 0,0 | 7,1 |
| 18.05.2017 21:00 | DM3 | 154,7 | 7,0 | 1,0 | 7,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 0,0 | 5,6 | 16,1 |
| 26.05.2017 06:30 | DM3 | 116,3 | 5,2 | 1,0 | 5,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 177,5 | 5,6 | 16,1 |
| 27.05.2017 13:00 | DM3 | 143,1 | 4,6 | 1,3 | 3,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 30,5 | 5,6 | 16,1 |
| 28.05.2017 03:00 | DM3 | 43,9 | 0,8 | 0,5 | 1,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 14,0 | 5,6 | 16,1 |
| 31.05.2017 05:00 | DM3 | 17,9 | 1,2 | 0,8 | 1,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 74,0 | 5,6 | 16,1 |
| 1.06.2017 13:00 | DM3 | 219,6 | 11,0 | 7,3 | 1,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 32,0 | 6,7 | 20,1 |
| 8.06.2017 20:00 | DM3 | 275,9 | 10,2 | 5,1 | 2,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 175,0 | 6,7 | 20,1 |

| Date | Basin | Measured Total Flow (m3) | Rain (mm) | Rain Intensity (mm/hr) | Rain Duration (hr) | % of impervious areas | Basin area (m2) | Width (m) | Average slope (%) | CN | Time interval between previous rain event (hr) | Monthly Evaporation rate (mm/day) | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.06.2017 06:30 | DM3 | 83,8 | 0,8 | 0,8 | 1,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 10,5 | 6,7 | 20,1 |
| 18.06.2017 17:30 | DM3 | 76,5 | 4,2 | 0,8 | 5,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 227,0 | 6,7 | 20,1 |
| 19.06.2017 13:30 | DM3 | 526,1 | 18,8 | 7,5 | 2,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 20,0 | 6,7 | 20,1 |
| 20.06.2017 03:00 | DM3 | 27,3 | 0,4 | 0,4 | 1,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 13,5 | 6,7 | 20,1 |
| 4.08.2017 17:30 | DM3 | 24,1 | 3,0 | 1,2 | 2,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 1094,5 | 8,1 | 23,4 |
| 5.08.2017 20:30 | DM3 | 30,5 | 1,8 | 1,8 | 1,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 27,0 | 8,1 | 23,4 |
| 17.08.2017 16:30 | DM3 | 64,9 | 5,0 | 2,5 | 2,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 284,0 | 8,1 | 23,4 |
| 1.10.2017 19:00 | DM3 | 38,9 | 5,8 | 3,9 | 1,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 1082,5 | 3,2 | 12,9 |
| 2.10.2017 02:00 | DM3 | 122,9 | 11,4 | 3,3 | 3,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 7,0 | 3,2 | 12,9 |
| 25.10.2017 16:00 | DM3 | 0,0 | 1,6 | 0,5 | 3,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 566,0 | 3,2 | 12,9 |
| 29.10.2017 | DM3 | 5,2 | 2,2 | 0,7 | 3,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 86,5 | 3,2 | 12,9 |

| Date | Basin | Measured Total Flow (m3) | Rain (mm) | Rain Intensity (mm/hr) | Rain Duration (hr) | % of impervious areas | Basin area (m2) | Width (m) | Average slope (%) | CN | Time interval between previous rain event (hr) | Monthly Evaporation rate (mm/day) | Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06:30 | | | | | | | | | | | | | |
| 20.11.2017 18:30 | DM3 | 72,7 | 12,2 | 0,6 | 20,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 540,0 | 0,0 | 7,1 |
| 23.11.2017 16:30 | DM3 | 11,6 | 1,2 | 0,8 | 1,5 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 70,0 | 0,0 | 7,1 |
| 27.11.2017 22:00 | DM3 | 38,1 | 10,2 | 1,3 | 8,0 | 22,6 | 874581,5 | 368,1 | 8,1 | 66,2 | 101,5 | 0,0 | 7,1 |