DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

THE POTENTIAL OF WATER SAVING IN BUILDINGS: GREYWATER REUSE

by
Elman BAĞCILAR

March, 2019
İZMİR

THE POTENTIAL OF WATER SAVING IN BUILDINGS: GREYWATER REUSE

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by

Elman BAĞCILAR

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"THE POTENTIAL OF WATER SAVING IN BUILDINGS: GREYWATER REUSE"** completed by **ELMAN BAĞCILAR** under supervision of **PROF. DR. NURDAN BÜYÜKKAMACI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Elman BAĞCILAR

THE POTENTIAL OF WATER SAVING IN BUILDINGS: GREYWATER REUSE

ABSTRACT

Greywater treatment and reuse is an alternative to provide non-potable water to households and reduce the fresh water usage. The aim of the study was to evaluate the water saving potential of buildings. A 5-story building was chosen as case study and the existed fixtures of this building were determined. The amount of total wastewater and greywater was calculated regarding to average accepted values. It was assumed that 48 people are living in this building, considering 12 apartments in the building and four people live in each apartment. Total amount of wastewater and greywater was calculated as 9600 and 5900 litre per day, respectively.

To collect greywater separately, some infrastructure modifications are required. Therefore, new fixtures were designed for the separation of greywater from black water. The cost of existing fixture implementation and new fixture installation was determined as 13,282 dolar and 13,990 dolar, respectively. It was assumed that separately collected greywater will be treated by a constructed wetland system. The treatment system was consisted of a two-way valve, a coarse filter, an equalization tank, a vegetated submerged bed wetland, and UV disinfection. It was assumed that treated greywater is pumped to the 5 cubic meters storage tank and it is used for toilet flushing and irrigation of garden. As a result, water saving potential of this building, and the investment and operational cost of the reuse of greywater were calculated. Based on these data, the amortization period of additional investments was determined as 6 years.

Keywords: Greywater, reuse, wastewater, wetland

BİNALARDA SU KAZANIMI POTANSİYELİ: GRİ SUYUN YENİDEN KULLANIMI

ÖZ

Temiz su kaynakları her geçen gün giderek azaltmaktadır. Gri suyun arıtılarak yeniden kullanılması, temiz su kaynaklarının korunması için alternatif bir kaynak oluşturmaktadır. Bu çalışmanın amacı binaların su kazanım potansiyelini değerlendirmektir. Bu amaçla 5 katlı bir bina örnek olarak seçilmiş ve mevcut tesisatı oluşturulmuştur. Binanın atıksu ve gri su hesapları literatürde yer alan değerler göz önünde bulundurularak ortalama değerlere göre yapılmıştır. 12 daireli binada her dairede 4 kişi yaşadığı varsayılmıştır. Günlük toplam atıksu ve gri su miktarları sırasıyla 9600 ve 5900 litredir.

Gri suyun ayrı toplanması amacıyla mevcut hatlarda düzeltme yapılmış ve arıtılmış gri suyun tekrar kullanımı amacıyla ayrı hat çekilmiş ve armatürler eklenmiştir. Mevcut sistemin maliyeti 13.282 dolar iken bu maliyet revizyon sonrası 13.990 dolara yükselmiştir. Ayrı toplanan gri suyun sulak alana verilerek arıtılması uygun görülmüştür. Toplanan ham gri suyun 2 yönlü vana yardımıyla sisteme alınarak önce kaba filtre ardından dengeleme tankına alınacağı ön görülmüştür. Büyük maddelerden arındırılmış gri su yüzey altı akışlı yapay sulak alan sisteminde arıtıldıktan sonra UV dezenfeksiyon uygulanacaktır. Arıtılmış gri suyun 5 m^3 lük depolama tankına pompalanarak depodan serbest akış yoluyla sisteme dağıtılması planlanmıştır. Sonuç olarak binanın su tasarruf potansiyeli, yatırım ve işletme maliyetleri hesaplanmıştır. Bu bilgiler ışığında amortisman süresi yaklaşık 6 yıl olarak hesaplanmıştır.

Anahtar Kelimeler: Gri su, yeniden kullanım, atıksu, bitkili arıtım

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Safe and sufficient amount of water is essential for life. However, the difference between water demand and supply is increasing day by day. To obtain fresh water will be a very great problem in the near future and natural water sources must be managed efficiently to meet future water demands. Water reuse applications have been applied to reduce the pressure on natural water resources and to handle increased water demand. Both treated domestic and industrial wastewater can be reused for several purposes, but reuse of domestic wastewater is more widespread.

Domestic wastewater is classified into two main groups: blackwater and greywater. Wastewater generated from the toilets is called as blackwater. “Greywater is wastewater from non-toilet plumbing fixtures such as showers, basins and taps. Depending on its use, greywater can require less treatment than blackwater and generally contains fewer pathogens” (GHR Plumbing Service, 2018). Greywater can be used both indoor and outdoor purposes. As an indoor application, it can be reused for toilet flushing and clothes washing. Garden irrigation with greywater is an example for outdoor application. In all cases, some level of treatment may require. “Greywater reuse is an effective measure for saving water on the domestic level and reducing load on wastewater treatment plant. Where water is scarce and expensive, greywater reuse may lead to considerable economic benefits” (Ghaitidak & Yadav, 2013). Typically, 60-65 % of the total wastewater flow is greywater and greywater reuse can reduce fresh water consumptions, minimize wastewater treatment expenses, and reduce investment in infrastructure.

To reuse the greywater, greywater and blackwater must be collected separately. After than sufficient greywater treatment system must be installed and treated greywater must be pumped to the fixtures connecting to toilet reservoir or elsewhere.

Although greywater is generally lower strength than blackwater, it may contain various pollutants such as organic matter, suspended solids, phosphorus, and pathogens. Therefore, greywater must be adequately treated before reuse.

Depending on the greywater properties and reuse purposes, several types of treatment units including physical, chemical and biological processes may be used. Sand filtration and membrane filtration are the most common physical processes. Chemical coagulation/flocculation, ion exchange, and adsorption are the main chemical treatment techniques applied to greywater. Several biological systems, such as constructed wetlands and membrane bioreactor, have been studied for the treatment of greywater (Counto et.al.,2015)

Greywater can contain bacteria, fecal matter, and will quickly develop disease-inducing pathogens if stored in a warm climate. Indicator bacteria are consistently detected in greywater demonstrating the potential for a range of enteric pathogenic bacteria, protozoa and viruses to persist in greywater (Winward et.al., 2008). Inadequately disinfected greywater has a pathogen risk. It must be disinfected even if it is used for toilet flushing since diseases carried by untreated greywater can be transmitted by splashing, other human-contact, and cross-contamination with the main potable water supply (The Renewable Energy, n.d.).

One of the most significant issue for reuse applications is the cost. Although greywater reuse can reduce water bill depending on the less fresh water usage, it may be expensive relating to the applied treatment methods. Therefore, cost-effective treatment technologies should be implemented. Both capital and investment costs should be taken into consideration. In addition to treatment methods, greywater collection system and effluent distribution system effects the cost of reuse applications. There are limited cost data and most of the data related to the cost of treating the wastewater prior to reuse.

1.2 Aim and Scope of the Thesis

The aim of the study was to evaluate the water saving potential of buildings via greywater reuse and calculate the cost of on-site residential greywater treatment and reuse.

For this purpose, a 5-story building was chosen as case study and the existed fixtures of this building were determined. New fixtures were designed for the separation of greywater from blackwater and the cost of new fixture installation was determined. It was assumed that separately collected greywater will be treated by a constructed wetland system and the both investment and operational cost of the treatment plant was calculated. Finally, water saving potential of this building, and the total investment and operational cost of the reuse of greywater were calculated. Based on these data, the amortization period of additional investments was determined.

CHAPTER TWO
LITERATURE REVIEW

2.1 Water Scarcity Problem

Safe and sufficient amount of water is essential for life. However, the difference between water demand and supply is increasing day by day. “The global demand for water has been increasing at a rate of about 1% per year as a function of population growth, economic development and changing consumption patterns, among other factors, and it will continue to grow significantly over the next two decades” (WWAP, 2018). The water demand for agricultural irrigation is higher than the other water consumption activities, such as industrial and domestic uses. However, the water demand for industrial and domestic uses increases sharply. The amount of available fresh water will decrease in the near future and therefore natural water sources must be managed efficiently to meet future water demands.

“The world population is expected to increase from 7.7 billion in 2017 to between 9.4 and 10.2 billion by 2050, with two thirds of the population living in the cities. Contemporary global water demand has been estimated at about 4,600 km^3 per year and projected to increase by 20%–30% to between 5,500 and 6,000 km^3 per year by 2050. Available surface water resources at continent level should remain relatively constant as opposed to the development of population, global gross domestic product or water demand. At the sub-regional level, any change would be small, ranging from -5 to +5%, due to climate change effects, but changes can be much more pronounced at the country level. Many countries are already undergoing pervasive water scarcity conditions and will likely have to cope with lower surface water resources availability in the 2050s” (WWAP, 2018).

Physical water scarcity in 2010 and projected change in water scarcity by 2050 is shown in Figure 2.1.

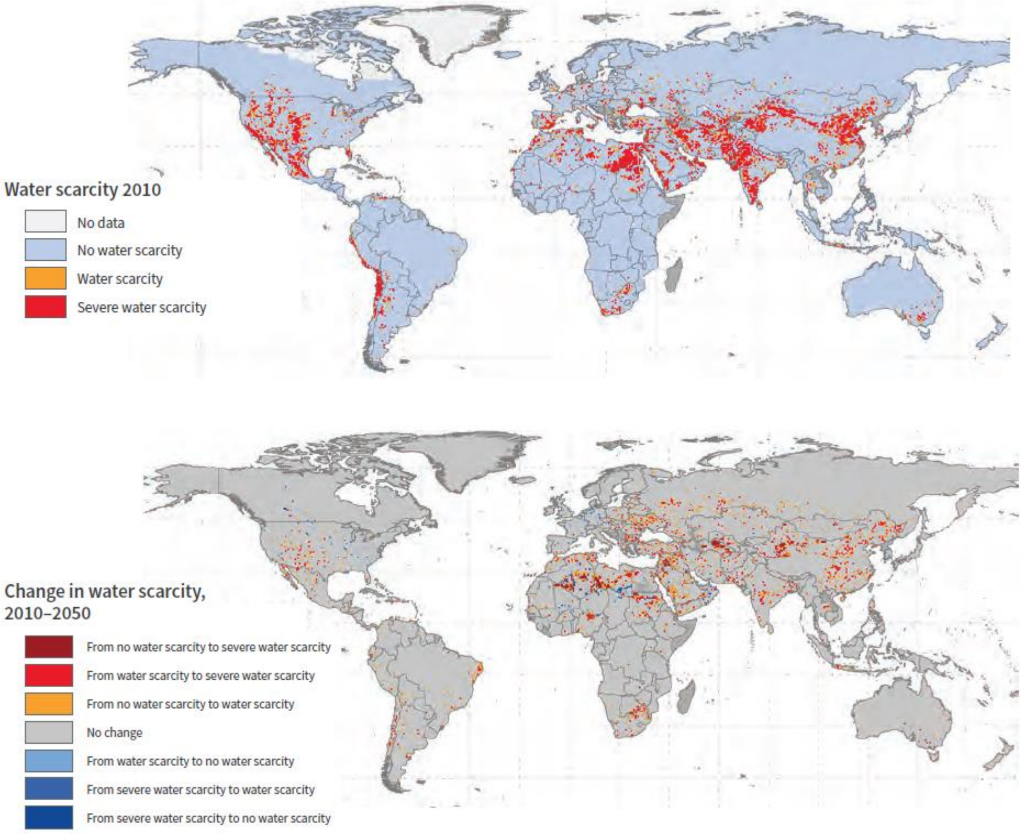


Figure 2.1 Physical water scarcity in 2010 and projected change in water scarcity by 2050 (WWAP, 2018)

“Turkey is situated in a semi-arid region, and has only about one fifth of the water available per capita in water rich regions such as North America and Western Europe. Water rich countries are those, which have 10.000 cubic meters of water per capita yearly. This is well above the 1.500 cubic meters per capita in Turkey” (Ministry Of Foreign Affairs, 2018)

According to Turkish Statistical Institute, Turkey’s population expected to around 100 million by 2030 and water availability will decrease to 1.120 m^3/capita/year (DSİ, n.d.)

Table 2.1 shows the groundwater and surface water abstraction (million m^3) for the years of 2005–2010–2015 for European Union (EU) Member State and candidate countries. In Turkey, surface water abstraction accounted for around 2.5 times the amount of water abstracted from groundwater resources. Between 2005 and 2015, there was an increase in both surface (+18%) and groundwater (+25%) abstraction (Eurostat Statistic Explained, 2018)

Table 2.1 The groundwater and surface water abstraction (million m³), 2005–2015 (Eurostat Statistic Explained, 2018)

	Groundwater abstraction			Surface water abstraction		
	2005	2010	2015	2005	2010	2015
Belgium (1)	636	612	632	5 753	5 341	:
Bulgaria	597	557	558	5 439	5 403	5 071
Czech Republic	385	377	366	1 564	1 573	1 237
Denmark (2)	628	649	737	16	5	9
Germany (3)	6 033	5 841	:	29 524	27 195	:
Estonia (2)	274	296	199	1 304	1 546	1 525
Ireland (4)	364	196	:	435	561	:
Greece (5)	3 772	5 615	5 611	5 882	4 319	4 297
Spain (2)	6 387	6 601	6 304	31 643	29 009	26 613
France	6 319	5 983	:	27 554	22 356	:
Croatia (6)	464	485	428	:	190	225
Italy	:	:	:	:	:	:
Cyprus	140	140	150	95	61	82
Latvia (7)	102	170	155	136	105	92
Lithuania	157	179	157	2 208	583	254
Luxembourg	:	23	26	:	24	20
Hungary	566	535	492	4 363	4 835	:
Malta	32	41	43	0	0	3
Netherlands	1 010	994	:	10 536	9 927	:
Austria	:	:	:	:	:	:
Poland	2 633	2 722	2 608	8 889	8 923	8 486
Portugal (8)	4 794	:	:	:	:	:
Romania	724	624	590	4 577	5 595	5 868
Slovenia	184	185	182	739	740	714
Slovakia	374	341	326	533	260	248
Finland (9)	285	:	:	6 298	:	:
Sweden	346	348	:	2 285	2 342	:
United Kingdom (2)	2 336	2 152	2 053	7 988	6 111	5 232
Iceland (2)	160	3 268	2 971	5	35	40
Norway (10)	:	:	:	2 476	:	:
Switzerland (11)	:	1 005	:	:	1 000	:
Former Yugoslav Republic of Macedonia (2) (4)	68	:	207	1 089	885	42
Albania	:	:	262	:	:	932
Serbia	554	514	469	3 234	3 377	3 603
Turkey (12)	11 622	13 138	14 600	33 062	33 818	39 113
Bosnia and Herzegovina	295	150	326	56	191	108
Kosovo	137	139	152	26	33	12

(1) Groundwater: data for 2014 instead of 2015
(2) Data for 2014 instead of 2015
(3) Data for 2004 instead of 2005
(4) Data for 2009 instead of 2010
(5) Data for 2011 instead of 2010
(6) Groundwater: data for 2006 instead of 2005
(7) Groundwater: data for 2013 instead of 2015
(8) Groundwater: data for 2007 instead of 2005
(9) Surface water: data for 2006 instead of 2005
(10) Surface water: data for 2003 instead of 2005
(11) Data for 2012 instead of 2010
(12) Surface water: data for 2014 instead of 2015

In order to overcome increased water demand and decreased fresh water sources problems, sustainable water management systems should be implemented. “Water saving efforts should be promoted. To protect water resources and reduce water pollution, appropriate national integrated basin management strategies need to be implemented. As a candidate country to EU, Turkey, in compliance with the Water Framework Directive, has been building monitoring stations for each basin and standardizing the parameters and monitoring frequency" (Ministry Of Foreign Affairs, n.d.). As mentioned a report prepared by The World Bank, "The Turkish Republic has a long and rich experience in the water sector. The 1926 Water Law places the overall responsibility for water resources management at the state level. The accession process of the Turkish Republic to the EU led to a major effort to harmonize its legislation with the EU's overarching Water Framework Directive and with Water Supply and Sanitation-related Drinking Water Directive and Urban Wastewater Directive. Consistent with the Water Framework Directive principles of "good ecological status", integrated water resources management and holistic approaches to protect and control water resources (in both quantity and quality), Turkey defined 25 river basins and prepared River Basin Protection Action Plans for each of them" (The World Bank Report, 2016).

2.2 Water Reuse

Water reuse applications have been applied to reduce the pressure on natural water resources and to handle increased water demand. In many countries, wastewater reuse is a critical factor of water management strategies. Wastewater reuse has been applied to conserve natural water sources. Reclaimed water may be used instead of fresh water for applications that do not require high-quality water. It assist to meet water demands as an alternative source (Asano et.al., 2007). Examples of water reuse programmes around the World is shown in Figure 2.2 (Voulvoulis, 2018).

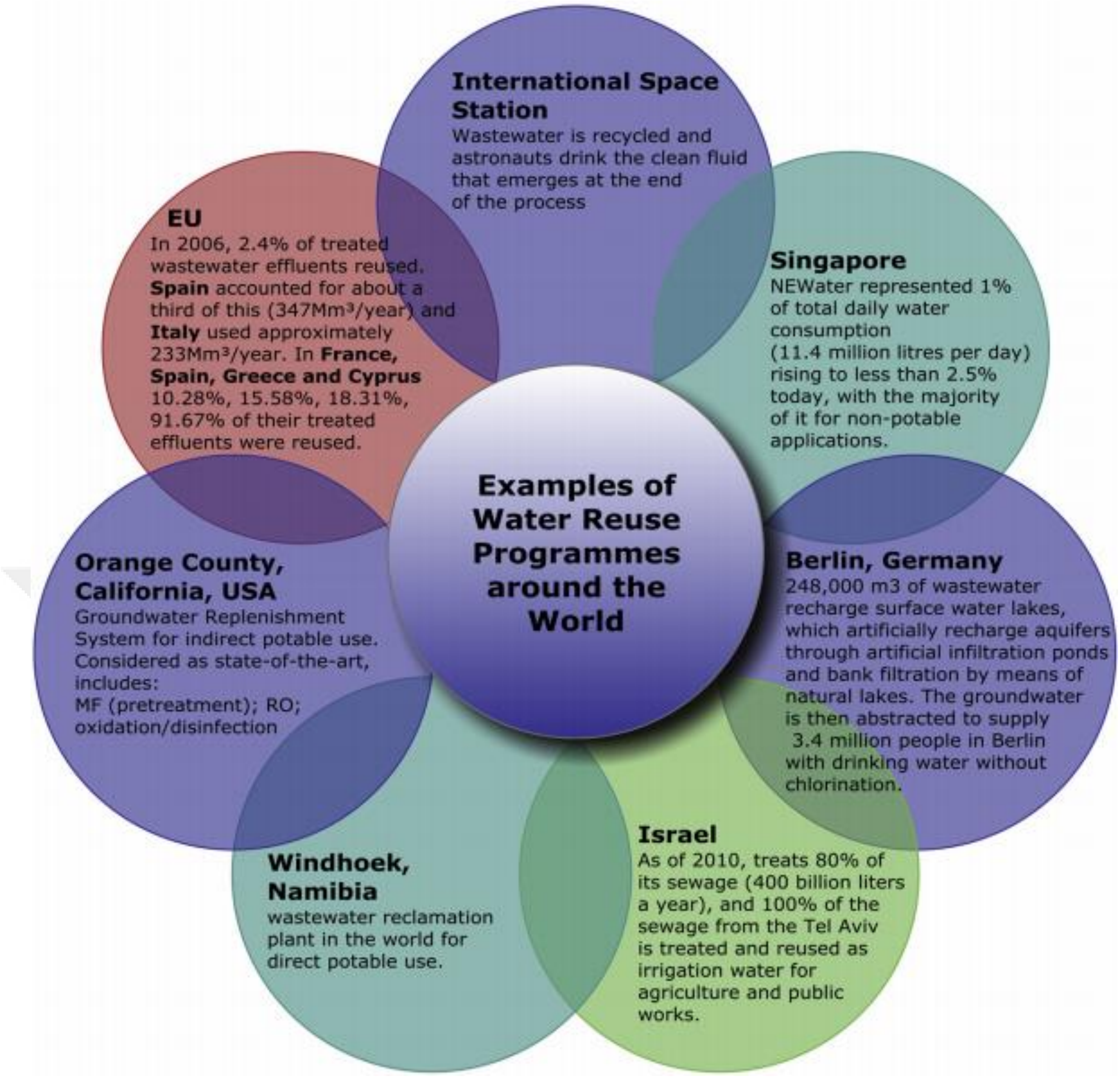


Figure 2.2 Examples of water reuse programmes around the World (Voulvoulis, 2018)

Both treated domestic and industrial wastewater can be reused for several purposes, but reuse of domestic wastewater is more widespread. In any case, wastewater must be treated to achieve sufficient quality of water regarding to reuse purposes and related regulations.

“In terms of reclamation and reuse, agriculture is maintaining the first place in terms of amount of reclaimed water reused, but other alternatives are gaining importance, like urban or industrial uses” (Salgot & Folch, 2018, pp. 64-74). Major industrial uses of reclaimed water including cooling, boiler feed, process water, stack scrubbing, and dust control. “Groundwater recharge can be designed for indirect potable reuse where groundwater is recharged with reclaimed water and replenishes portions of potable groundwater" (Asano et.al., 2007). In-building reuse applications such as toilet flushing is also possible.

There are some drawbacks of reuse applications. The most significant issue is potential health risks related to low quality reclaimed water usage. Another problem is the reduction in the amount of wastewater coming into the sewage system. So, the decrease in the total amount of wastewater will lead to a reduction in the amount of treated effluent. On the other hand, the wastewater quality of the treatment plant will change and some operational problems may be encountered in the existing wastewater treatment processes. If implemented under uncontrolled or unregulated circumstances, treated wastewater can be harmful to living beings and irrigated soil. Reduced sewer flows can result in blocked sewers whilst reduced stream flows can be detrimental to activities extracting certain flow quantities downstream (Adewumi, Ilemobade, & Van Zyl, 2010).

2.3 Greywater Characteristics and Reuse

Domestic wastewater is classified into two main groups: blackwater and greywater. Wastewater generated from the toilets is called as blackwater. "Greywater is wastewater from non-toilet plumbing fixtures such as showers, basins and taps. Depending on its use, greywater can require less treatment than blackwater and generally contains fewer pathogens" (GHR Plumbing Service, 2018). Greywater can be used both indoor and outdoor purposes. As an indoor application, it can be reused for toilet flushing and clothes washing. Garden irrigation with greywater is an example for outdoor application (GHR Plumbing Service, 2018). "Greywater reuse is an effective measure for saving water on the domestic level and reducing load on wastewater treatment plant. Where water is scarce and expensive, greywater reuse may lead to considerable economic benefits" (Ghaitidak & Yadav, 2013). Typically, 60-65 % of the total wastewater flow is greywater and the typical volume of greywater varies from 90 to 120 L/capita/day (Li, Wichmann, & Otterpohl, 2009).

Although greywater is generally lower strength than blackwater, it may contain various pollutants such as organic matter, suspended solids, phosphorus, and pathogens. The typical greywater properties are given in Table 2.2 (Li, Wichmann, & Otterpohl, 2009). The temperature of greywater changes between 18 and 35 °C. Higher temperature may be originating from warm water used for personal hygiene and cooking activities. The average BOD_5/COD ratios in greywater have ranged between 0.31 and 0.71, which is an indication that almost half of the organic matter in greywater is biodegradable (Oteng-Peprah, Devries, & deVries, 2018).

Table 2.2 The characteristics of greywater by different categories

	Bathroom	Laundry	Kitchen	Mixed
pH	6.4 – 8.1	7.1 – 10	5.9 – 7.4	6.3 – 8.1
TSS (mg/L)	7 – 505	68 – 465	134 – 1300	25 – 183
Turbidity (NTU)	44 – 375	50 – 444	298.0	29 - 375
COD (mg/L)	100 – 633	231 – 2950	26 – 2050	100 – 700
BOD (mg/L)	50 – 300	48 – 472	536 – 1460	47 – 466
TN (mg/L)	3.6 – 19.4	1.1 – 40.3	11.4 – 74	1.7 – 34.3
TP (mg/L)	0.11 – >48.8	ND – >171	2.9 – >74	0.11 – 22.8
Total coliforms (CFU/100 ml)	10 – $2.4x10^7$	200.5 – $7x10^5$	>$2.4x10^8$	56 – $8.03x10^7$
Fecal coliforms (CFU/100 ml)	0 – $3.4x10^5$	50 – $1.4x10^3$	-	0.1 – $1.5x10^8$

2.3.1 Greywater Treatment

Greywater treatment systems range from very low-tech technology, such as basic filtration, to high-tech technologies, such as membrane systems. In some cases, untreated greywater may be reused, if the quality is suitable. All types of treatment units including physical, chemical, and biological systems may be applied. Conventional treatment methods may be insufficient to ensure the high quality reclaimed water for some reuse applications. In these cases, advanced treatment technologies may require.

Greywater can include some particles such as hair or skin particles. Coarse filtration is usually applied as the physical treatment. Generally, mesh filter bag is the first step for coarse filtration. These simple devices such as metal screens and nylon socks may be used to remove large particles from greywater. If these particles are not removed, there will be clogging problems in further treatment units.

Chemical treatment can eliminate suspended solid, organics, heavy metal, and phosphorous. Coagulation and flocculation allow the deposition of suspended substances as a result of chemical addition and mixing. This method is not effective for the removal of pathogens. Therefore, filtration and/or disinfection is required after the chemical treatment.

Biological treatment units are classified into two main groups depending on the microorganism presence types in the reactor: suspended growth and fixed film. These microbial populations may be present as either a fixed film attached to some support medium, as in the trickling filter and rotating biological filter processes, or a suspended growth, as in activated sludge processes and oxidation ditches. A wide range of biological treatment units have been applied for greywater treatment, such as activated sludge, constructed wetlands, rotating biological contactor, and membrane bioreactors.

Constructed wetlands are often suggested as a low cost and energy efficient system for wastewaters. Wetlands are some of the most biologically diverse and productive natural ecosystems in the world. There are many treatment mechanisms. Firstly, since the flow rate is very low, large amount of suspended solids, can be settled out. Secondly, wetland plants take up or transform with microorganisms. In addition, plants need nutrients for life. Nitrogen and phosphorous is reduced by plants and microorganisms. Low maintenance cost and odor free is important difference. Constructed wetlands are classified into two main types: free water surface (FWS) systems with shallow water depths and subsurface flow (SF) or vegetated submerged bed (VSB) systems with water flowing laterally through the sand or gravel (Figure 2.3).

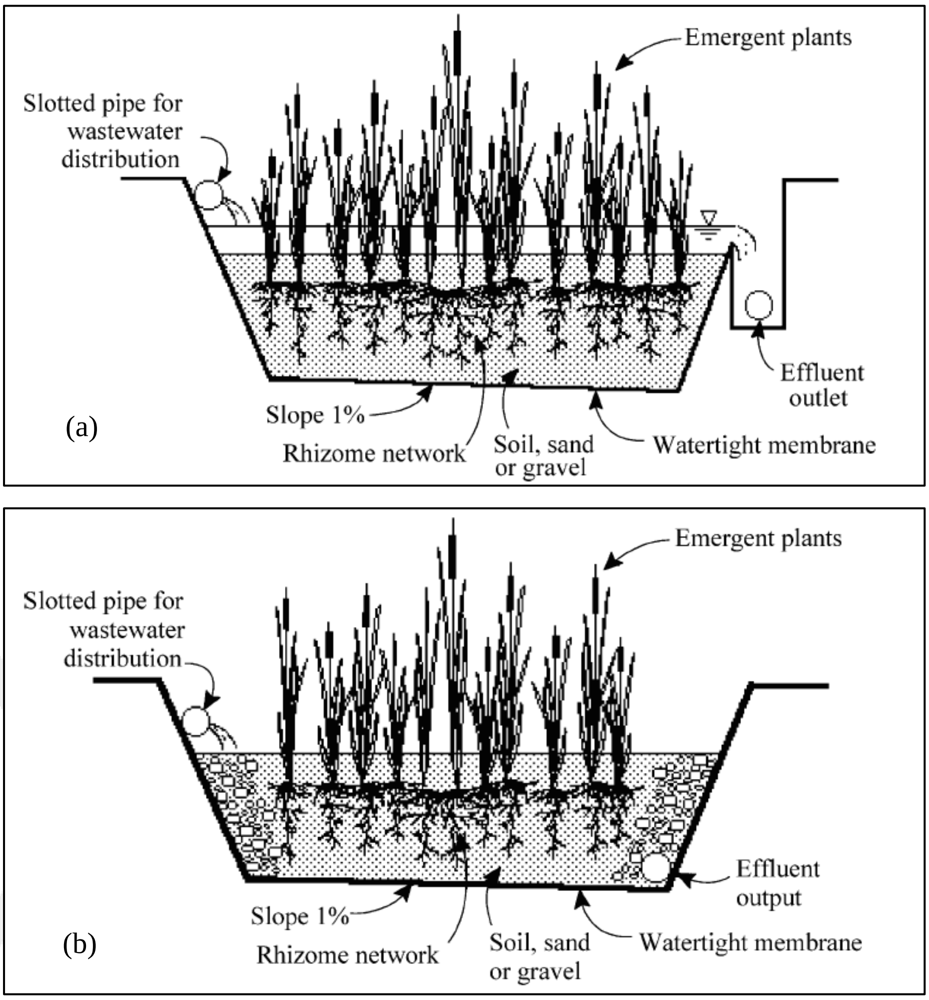


Figure 2.3 a) Free water surface (FWS) system, b) Subsurface flow (SF) system (Polprasert, 2004)

In addition to these two main types, green roof water recycle (GRW), vertical flow (VF), recycling vertical flow (RVF) and combination systems are also available. Average BOD removal rate for RVF, VF, FWS, GRW, and SF is 98%, 85%, 63%, 71%, and 87%, respectively (Arden & Ma, 2018). The most effective system is RVF and it is a modification of the VF constructed wetland using a novel set-up; wastewater is distributed to the root zone, trickles through the bed into a reservoir from where it is recirculated back to the root zone until the required effluent quality is achieved (Sklarz et.al., 2009).

Greywater can contain bacteria, fecal matter, and will quickly develop disease-inducing pathogens if stored in a warm climate. Indicator bacteria are consistently detected in greywater demonstrating the potential for a range of enteric pathogenic bacteria, protozoa and viruses to persist in greywater (Winward, Avery, Stephenson, & Jefferson, 2008). Inadequately disinfected greywater has a pathogen risk. It must be disinfected even if it is used for toilet flushing since diseases carried by untreated greywater can be transmitted by splashing, other human-contact, and cross-contamination with the main potable water supply (The Renewable Energy, n.d.).

Chlorine and its forms, such as elemental chlorine, hypochlorite and chlorine dioxide, are the most commonly used disinfection reagents for wastewater treatment. The impact of organics and particles on chlorine disinfection of grey water was studied in a research and according to their results organic concentration in greywater did not affect resistance of coliform bacteria to chlorine disinfection at fixed free chlorine residual. Particles in grey water harboured particle associated coliforms (PACs), which were highly resistant to chlorine disinfection, preventing adequate disinfection of greywater for reuse. Therefore, effective suspended solids removal is recommended to remove PACs before disinfection. Winward et al. investigated the disinfection effects of several greywater treatment systems including three configurations of constructed wetland, membrane bioreactor (MBR), and a membrane chemical reactor (MCR). Clostridia removal by the constructed wetlands was low, compared to E. coli and Enterococci, suggesting a lower potential for removal of protozoan and viral pathogens than bacterial pathogens by these treatment technologies. Clostridia were effectively removed by the MBR and pathogenic protozoa would not be expected to pass through the membrane due to their size. Viruses, however, will pass through standard 0.4 μm pore size membranes, and would be pathogens of concern in membrane-treated greywater effluents (Winward, et al., 2008).

In UV disinfection applications, the most important parameter is the applied UV dose. Gassie and Englehardt reported “that ranges of fluence for 4 log inactivation of MS2, which is a virus that infects the bacterium *Escherichia coli* and other members of the *Enterobacteriaceae*, were between 30 and 100 mJ/cm^2, while 4 log inactivation of Adenovirus, the most UV resistant microorganism known, requires 101–202 mJ/cm^2. The required fluence for MS2 are in the range of UV fluence that may be used for water and wastewater disinfection (30–60 mJ/cm^2)". Friedler and Gilboa (2010) researched the performance of UV disinfection of greywater effluent along a reuse system for toilet flushing. They found that "the added health risk associated with reusing UV-disinfected greywater for toilet flushing (regarding *P. aeruginosa* and *S. aureus*), was found to be insignificant. Considering the infection doses of these pathogens, it was assessed that in order to be infected people should be in contact with very large volumes of water, large enough to be actually quite impossible (Friedler & Gilboa, 2010). Further, the microbial quality of the UV-disinfected greywater was found to be about the same or even better than the microbial quality of "clean" water in toilet bowls flushed with potable water".

CHAPTER THREE

MATERIAL AND METHODS

3.1 Case study: Building details

A 5-story building, having six floor including ground floor, was chosen as case study (Figure 3.1). All views of the building are given Appendix 1. It was imagined that there are two flats per floor. The flat consists of two bedrooms, a living room, a kitchen, a bathroom and a balcony. Each flat area is 75 m². It was assumed that four people live in each apartment, there are 12 apartments in the building, and thus totally 48 people live in the building. The ground floor plan of the building is given in Figure 3.2.

Figure 3.1 Selected building view

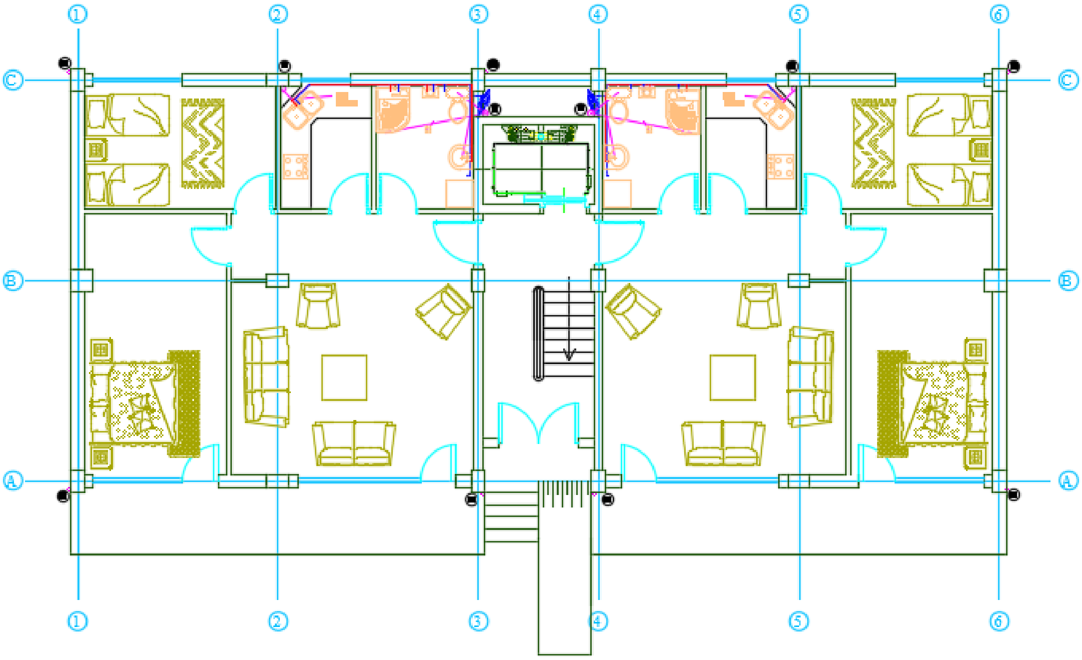


Figure 3.2 Ground Floor Plan in the Building

3.2 Greywater amount

Firstly, the amount of total wastewater was calculated from the average daily water consumption values to calculate the amount of greywater. Water consumption per capita was accepted considering the average consumption values for the biggest cities of Turkey. It is 173 L/day, 189 L/day, and 227 L/day for İzmir, İstanbul, and Ankara, respectively (TUIK, 2017). Considering these values, average water consumption was chosen as 200 L/day/capita.

It was accepted that 47%, 21%, 14%, 13%, and 5% of wastewater is generated from shower & washbasin, toilet, washing machine, kitchen, and cleaning, respectively, in the house (Figure 3.3). Wastewater produced from kitchen was not considered as greywater. Wastewater generated from the shower & washbasin (47%) and washing machine (14%) was accepted as greywater; therefore 61% of total amount of wastewater was accepted as greywater.

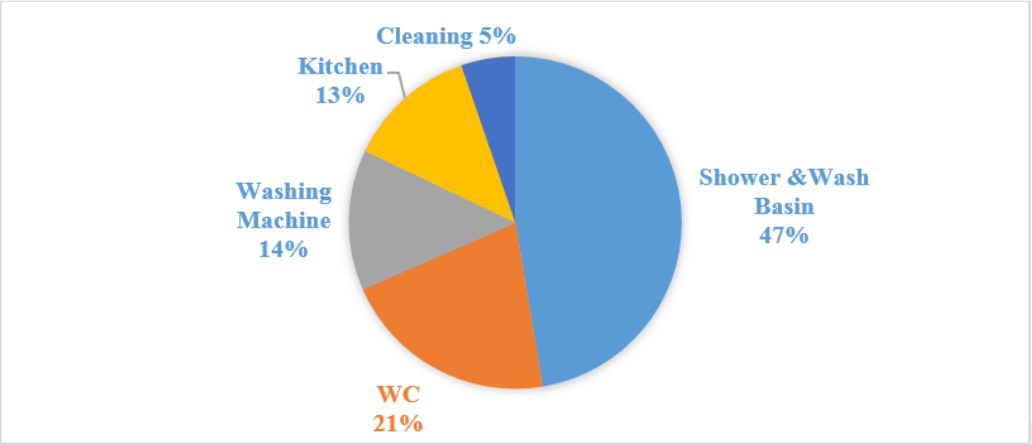


Figure 3.3 Accepted wastewater sources in the house

Using the assumptions given above, greywater amounts was calculated as 5.9 m^3/day. Calculation details are given below:

Total amount of wastewater: 48 people x 200 L/day = 9600 L/day

Total amount of greywater: 9600 L/day x 61% = 5856 L/day = 5.9 m^3/day

3.3 Greywater properties

Characteristics of greywater was accepted considering the data given in the literature. BOD_5, SS, TN, and TP concentration of greywater was accepted as 125, 50, 10, and 4 mg/L, respectively. The accepted greywater properties are given in Table 3.1.

Table 3.1 The accepted greywater properties

Parameter	**Accepted value**
BOD	125 mg/L
COD	250 mg/L
TSS	50 mg/L
TP	4 mg/L
pH	7

3.4 Target effluent quality

In wastewater reuse, the target effluent quality changes depending on the reuse applications. In this study, it was considered that effluent of greywater treatment system will be used for toilet flushing. EPA suggested that $BOD_7 < 5$ mg/L, dissolved oxygen > 50%, Total coliform <100/mL, Pseudomonas aeruginosa <1/mL for toilet flush water quality (SenStadt, 2007).

3.5 Piping System

In the scope of this study, existed fixtures were first designed. Piping system calculations of the building was done according to TS1258 standards. Flow rate, flow pressure, and loading rate for every fixture in the system is significant for these calculations.

There are a dishwasher and a single sink in the kitchen. Bathroom has a dishwasher, ½" sink, a toilet, and a shower bath (Figure 3.4). General purpose is minimum vertical flow distance covered for wastewater. If vertical flow distance increases, extra height is needed for slope and leakage chance will increase. Lateral pipes are used to collect wastewater to vertical pipes. Wastewater is collected with 4 vertical pipes. Wastewater generated from kitchen is collected with P3 and P4 pipes. P1 (Ø125) and P2 pipes (Ø125) collects bathroom wastewaters (Figure 3.5). These columns merge in R1 manhole and connect to sewage system.

According to loading rate and consumption rate, pipe diameters for both water and wastewater were determined. Piping diameters of kitchen and bathroom is seen in Figure 3.6 and 3.7, respectively.

Required materials for the existing plumbing system are given in Table 3.2 The quantities of the materials were calculated considering the current applications and required operating conditions.

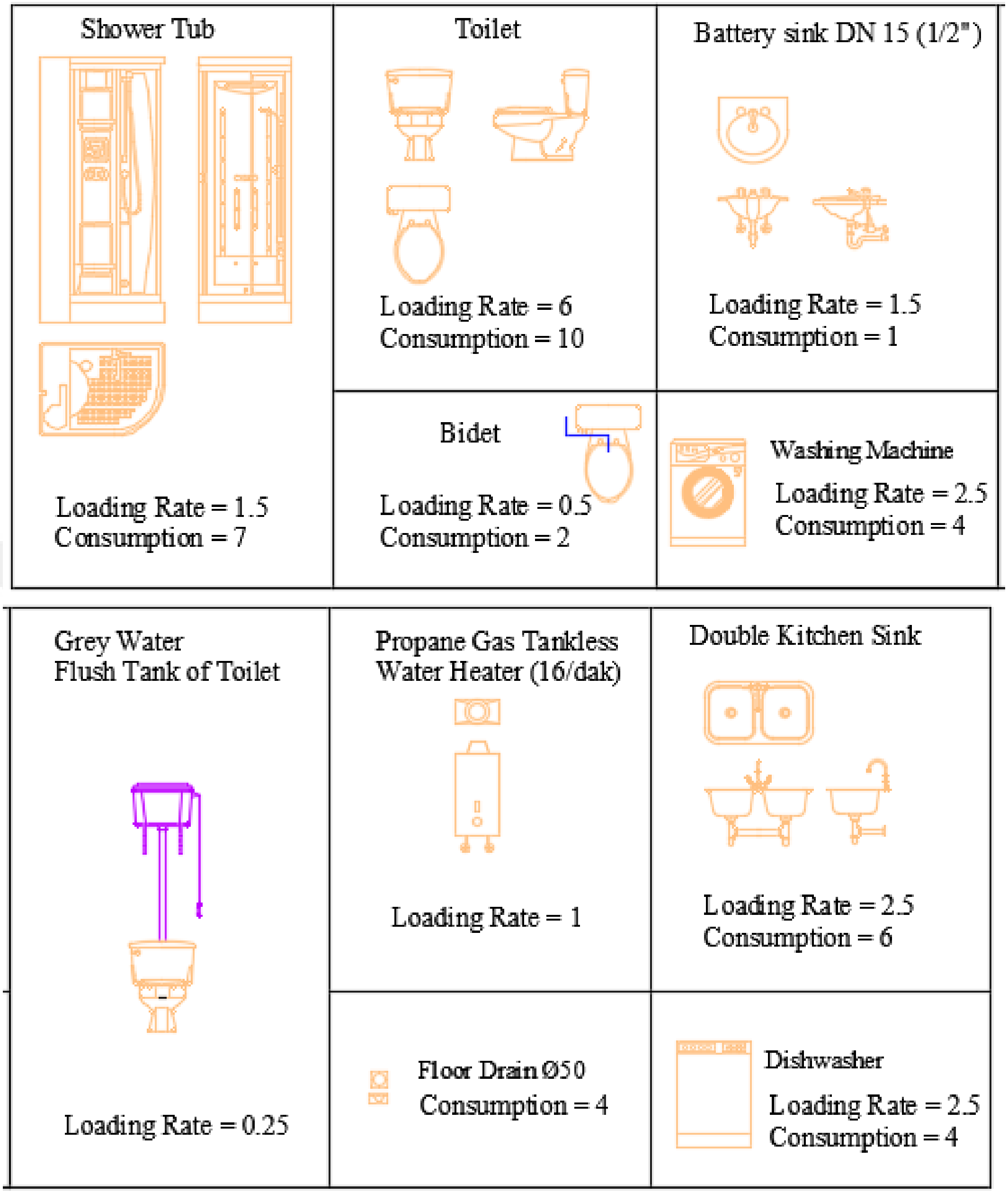


Figure 3.4 Equipment Information

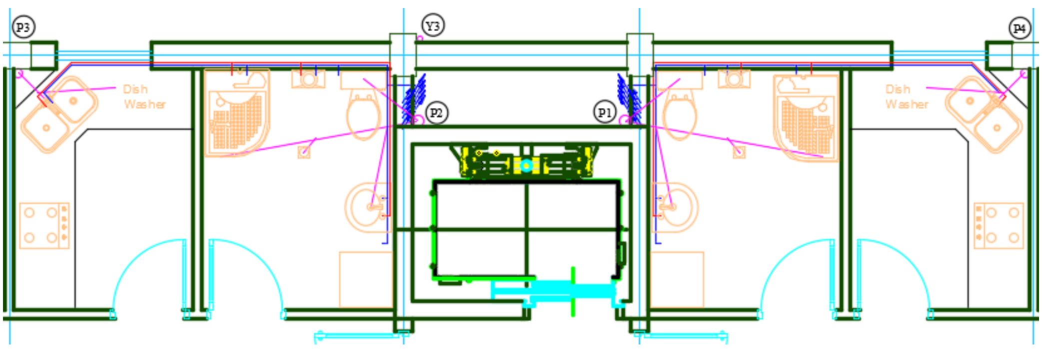


Figure 3.5 Piping plan for a flat

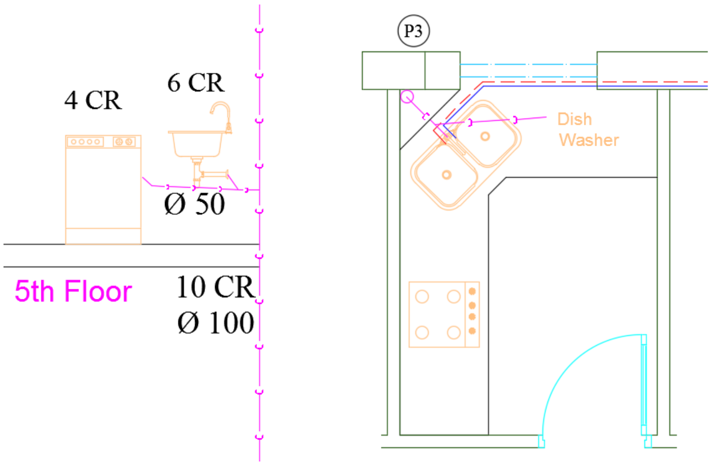


Figure 3.6 Wastewater piping diagram and plan in kitchen

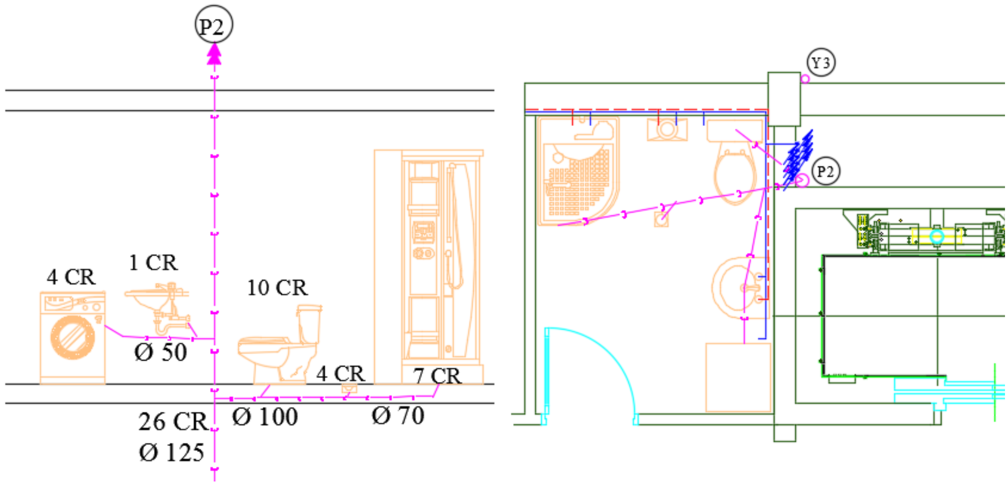


Figure 3.7 Wastewater piping diagram and plan in the bathroom

Table 3.2 Details of materials used in the existing fixture system

No	Definition	Unit	Quantity
1	Ø150 mm, t:3.2mm Tough PVC plastic waste water pipe	m	6
2	Ø125 mm, t:3.2mm Tough PVC plastic waste water pipe	m	56
3	Ø100 mm, t:3mm Tough PVC plastic waste water pipe	m	62
4	Ø70 mm, t:3mm Tough PVC plastic waste water pipe	m	130
5	Ø50 mm, t:3mm Tough PVC plastic waste water pipe	m	48
6	125 Ø mm. ventilation pipe and head	Piece	2
7	100 Ø mm. ventilation pipe and head	Piece	2
8	Brass chromium-plating screen 17 x 17 cm Floor Drain	Piece	25
9	One-Piece Toilet and plumbing almost 35x55 cm.	Group	12
10	Bidets and plumbing: Type of near the wall. almost 65x35 cm.	Group	12
11	1/2 Chromed Washing Bath. Washer seals tap	Piece	12
12	50x65 cm Pedestal Washbasin	Piece	12
13	Sink battery: Water choosed hot or cold with a tap spare	Piece	12

Table 3.2 continues

No	Definition	Unit	Quantity
14	Shelf: Ceramic glazed tile: Almost 50x10 cm.	Piece	12
15	Colorless Mirror	m²	1.6
16	Sponge tile: (Sleeved) 16x31 cm	Piece	12
17	White Acrylic Panel Shower Bathtub: 90x90x11 cm. square	Piece	12
18	Shower tube and shower head strainer with bathroom faucet;	Group	12
19	GEYSER: Natural gas / LPG hermetic geyser	Piece	12
20	Pre-Insulated Galvanized Pipes (Unit: m); 4” 200	m	12
21	Pre-Insulated Galvanized Pipes (Unit: m); 2” 125	m	4
22	Cold water meters: 40 Ø mm. (1 1/2) screwed	Piece	12
23	Gate and globe valve. brass screw. 32 Ø mm (1 1/4)	Piece	12
24	Gate and globe valve. brass screw. 50 Ø mm (2)	Piece	2
25	Gate and globe valve. brass screw. 100 Ø mm (4)	m	1
26	PN 20 polypropylene pipes diameter/Thickness (Ø mm): 20/2.8	m	96
27	Seam galvanized pipe 1 1/4”	m	135
28	Seam galvanized pipe. 1”	m	12
29	Seam galvanized pipe. 3/4”	m	60
30	Seam galvanized pipe. 1/2”	m	24
31	Floor Tile (40 x 40 cm dimensions)	m²	60
32	Floor Tile (40 x 40 cm dimensions)	m²	180

To collect greywater, a separate column will be used and collected greywater discharge to the greywater treatment plant. New fixtures were designed for the separation of greywater from blackwater. Since the wastewater generated from kitchen is not considered as greywater, there is no need to change the kitchen plumbing (P3 and P4). The wastewater from the shower, washbasin, and washing machine is collected into one plumbing in renewed infrastructure system. Since P1 is renewed to collect only the greywater, it is named as G1 (Figure 3.8). Because only the toilet wastewaters are connected to the P2’, the flowrate decreased and the diameter of P2’ reduced from Ø125 to Ø100 (Figure 3.8 and Figure 3.9).

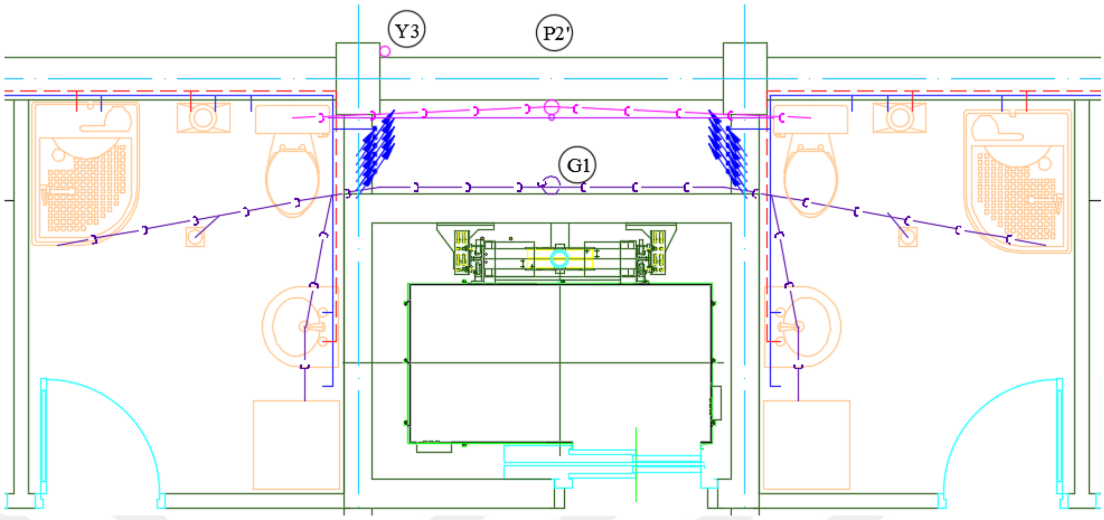


Figure 3.8 Greywater piping diagram and plan in bathroom

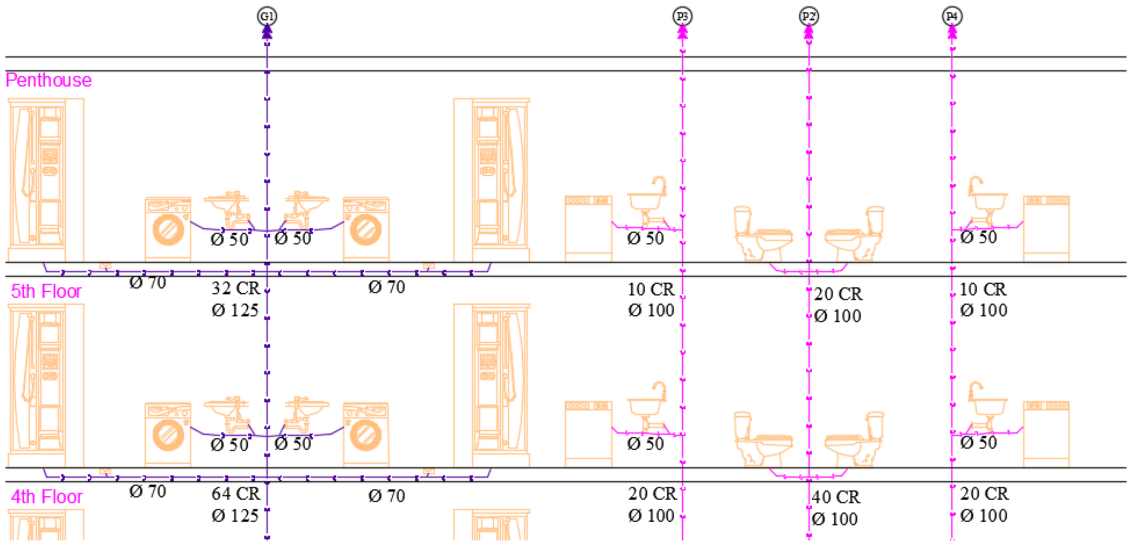


Figure 3.9 Pipe diameters after greywater separation

Collected greywater will be treated by a constructed wetland system and effluent of the treatment plant will be pumped to the storage tank constructed on the roof. Treated greywater will be distributed to the toilet reservoir by gravity. Main water supply line and treated greywater line will be connected to the reservoir by T-joint connection part. Details of the fresh water and greywater distribution system for the building is seen in Figure 3.10 Required materials for the plumbing system after the greywater separation are given in Table 3.3

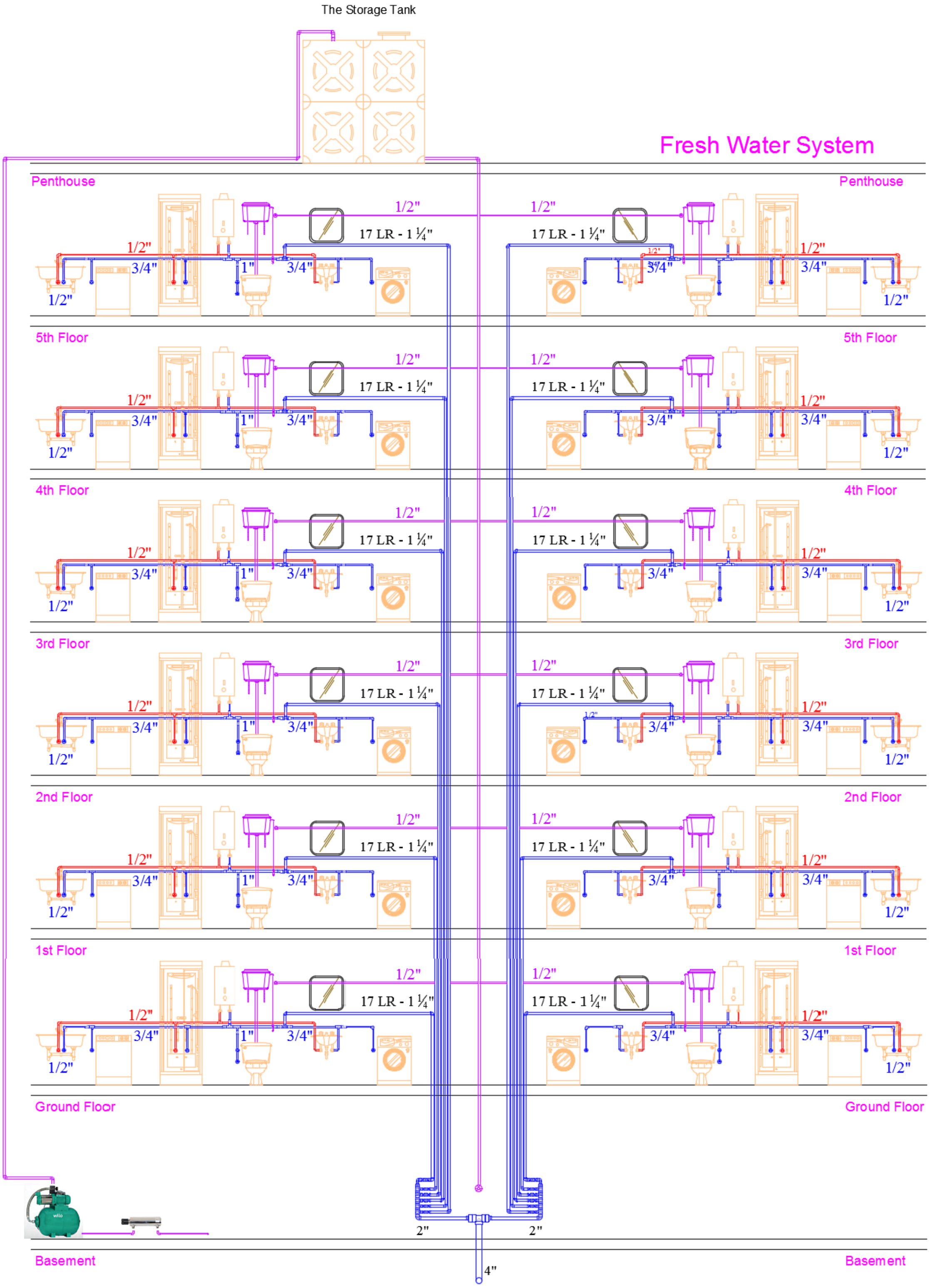


Figure 3.10 Fresh water and greywater distribution pipes

Table 3.3 Details of materials used in the fixture system after greywater separation

No	Definition	Unit	Quantity
1	Ø150 mm, t:3.2mm Tough PVC plastic waste water pipe	m	6
2	Ø125 mm, t:3.2mm Tough PVC plastic waste water pipe	m	24
3	Ø100 mm, t:3mm Tough PVC plastic waste water pipe	m	81
4	Ø70 mm, t:3mm Tough PVC plastic waste water pipe	m	142
5	Ø50 mm, t:3mm Tough PVC plastic waste water pipe	m	60
6	125 Ø mm. ventilation pipe and head	Piece	1
7	100 Ø mm. ventilation pipe and head	Piece	3
8	Brass chromium-plating screen 17 x 17 cm Floor Drain	Piece	25
9	Tile flush box	Piece	12
10	One-Piece Toilet and plumbing almost 35x55 cm.	Group	12
11	Bidets and plumbing: Type of near the wall. almost 65x35 cm.	Group	12
12	1/2 Chromed Washing Bath. Washer seals tap	Piece	12
13	50x65 cm Pedestal Washbasin	Piece	12
14	Sink battery: Water choosed hot or cold with a tap spare	Piece	12
15	Shelf: Ceramic glazed tile: Almost 50x10 cm.	Piece	12
16	Colorless Mirror	m²	1.6
17	Sponge tile: (Sleeved) 16x31 cm	Piece	12
18	White Acrylic Panel Shower Bathtub: 90x90x11 cm. square	Piece	12
19	Shower tube and shower head strainer with bathroom faucet;	Group	12
20	GEYSER: Natural gas / LPG hermetic geyser	Piece	12
21	Pre-Insulated Galvanized Pipes (Unit: m); 4” 200	m	12
22	Pre-Insulated Galvanized Pipes (Unit: m); 2” 125	m	4
23	Cold water meters: 40 Ø mm. (1 1/2) screwed	Piece	12
24	Gate and globe valve. brass screw. 32 Ø mm (1 1/4)	Piece	12
25	Gate and globe valve. brass screw. 50 Ø mm (2)	Piece	2
26	Gate and globe valve. brass screw. 100 Ø mm (4)	m	1
27	PN 20 polypropylene pipes diameter/Thickness (Ø mm): 20/2.8	m	176.5
28	Seam galvanized pipe 1 1/4”	m	165
29	Seam galvanized pipe. 1”	m	12
30	Seam galvanized pipe. 3/4”	m	60
31	Seam galvanized pipe. 1/2”	m	42
32	Floor Tile (40 x 40 cm dimensions)	m²	60
33	Floor Tile (40 x 40 cm dimensions)	m²	180

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Designing of Treatment Units

It was assumed that separately collected greywater will be treated by a constructed wetland system. Greywater may include lint, hair, and grit from several sources. They can clog pipes, pumps and treatment systems; therefore, a pre-treatment is required. The treatment system was consisted of a two-way valve, a coarse filter, an equalization tank, a vegetated submerged bed wetland, and UV disinfection. The flow scheme of the projected treatment plant is given in Figure 4.1.

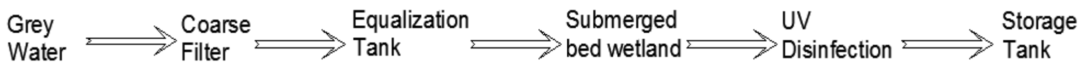


Figure 4.1 Flow Scheme

The detailed information and the designing of each units of the treatment plant are given below.

4.1.1 Equalization Basin

Greywater may include some coarse materials, such as lint from washing machines and hair from baths and showers. Therefore, coarse filtration is firstly applied. Since wastewater produced from the kitchen is not considered as greywater in this study, oil removal is not necessary. As a coarse filtration, it has been tried to produce an economical and simple solution as much as possible and basic filter bag is placed. After the coarse filtration an equalization basin is used to equalize the flow before the wetland system. Greywater comes at widely fluctuating rates and equalization basin is used to achieve a constant or nearly constant flow rate.

The equalization tank must be of sufficient capacity to hold the peak flows. In the scope of this study, it was assumed that greywater is producing during 15 hours and effluent will be discharged during 24 hours. Considering these assumptions, the volume of the equalization basin is calculated as 3 m^3. Calculation details are given below:

Influent flowrate = 5.9 m^3/day; 15 hours/day (assumed)

5.9 / 15 = 0.393 m^3/h

Effluent flow rate = 5.9 m^3 / day; 24 hours/day

5.9 / 24 = 0.246 m^3/h

Minimum Tank Volume:

0.393 – 0.246 = 0.147 m^3/15 hours

0.147 x 15 = 2.205 m^3

V_{eq} = 3 m^3 (%20 higher tank volume was selected considering peak flows)

4.1.2 Wetland System

The wetland system was designed considering the methods given by EPA (USEPA, 2000). Vegetated submerged bed (VSB) wetland system without recirculation was chosen. VSB wetlands employ a gravel bed planted with wetland vegetation. The water is kept below the surface of the gravel. Wetland system design details are given below.

Influent wastewater properties:

Flowrate = Q = 5.9 m^3/day

Influent BOD = 125 mg/L

Influent COD = 250 mg/L

Influent TSS = 50 mg/L

Phosphorus = 4 mg/L

Nitrogen = 10 mg/L

pH= 7

Assumptions:

Area loading rate (ALR) for BOD = 6 g/m²-d

Area loading rate for TSS = 20 g/ m²-d

Clean hydraulic conductivity K = 100,000 m/d

K is accepted as 1% and 10% of clean hydraulic conductivity for the initial zone (K_i, first 30% of length) and the final zone (K_f, the rest of 70% of length), respectively.

K_i = 0.01 x 100,000 = 1,000 m/d

K_f = 0.1 x 100,000 = 10,000 m/d

Slope of the bottom is between 0.5 – 1%, and 0.5% bottom slope was selected.

Water depth at inlet (D_{w0}) = 0.4 m

Water depth at the beginning of final treatment zone (D_{wf}) = 0.4 m

Media depth (D_m) = 0.6 m

Maximum allowable head-loss through initial treatment zone (dh_i) = 0.06 m

The proposed zones in a VSB is shown in Figure 4.2.

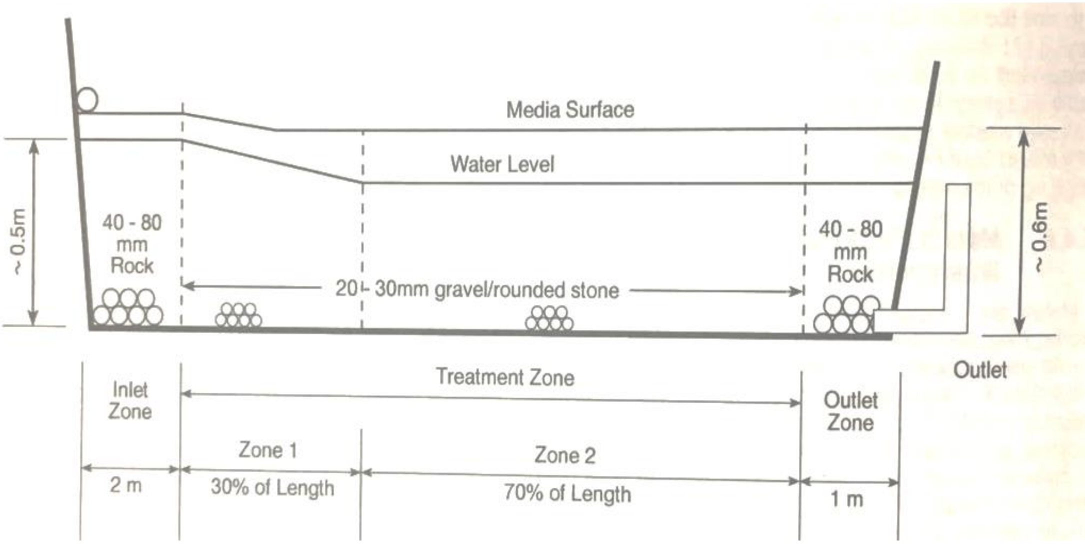


Figure 4.2 Proposed Zones in a VSB (USEPA, Vegetated Submerged Bed System, 2000)

4.1.2.1 Surface Area (A_s) of the VSB

It is calculated from influent BOD loading and area loading rate using the following equation.

$$A_s = (Q)\,(C_0)/ALR \tag{4.1}$$

For BOD A_s = (5.9 m^3/day) (125 g/m^3) / (6 g/ m^2-d) = 122.9 m^2

For TSS A_s = (5.9 m^3/day) (50 g/m^3) / (20 g/ m^2-d) = 14.8 m^2

The A_s of initial and final zone of the VSB is calculated from the total required surface area calculated from the BOD. The percentage of the initial zone is 30% of the total surface area.

The A_s for initial treatment zone (A_{si}) = 0.3 x (122.9 m^2) = 36.9 m^2

The A_s for final treatment zone (A_{sf}) = 0.7 x (122.9 m^2) = 86 m^2

4.1.2.2 Determine the Width

$$Q = (K_i)\,(W)\,(D_{w0})\,(dh_i/L_i) \tag{4.2}$$

$$L_i = (A_{si}) / (W) \tag{4.3}$$

$$W^2 = [(Q)\,(A_{si})] / [(K_i)\,(dh_i)\,(D_{w0})] \tag{4.4}$$

W^2 = [(5.9m^3/d) (36.9m^2)] / [(1000m/d) (0.06m) (0.4m)]

W^2 = 9.1 W=3 m

4.1.2.3 Dimensions of the Initial Treatment Zone

$$(L_i) = (A_{si}) / W \tag{4.5}$$

(L_i) = 36.9 / 3 ≅ 13 m (Length of the initial zone)

The headloss of the initial zone:

$$dh_i = \frac{(Q)(L_i)}{(K_i)(W)(D_{w0})} \tag{4.6}$$

$$dh_i = \frac{(5.9m^3/d)(13m)}{(1000m/d)(3m)(0.4m)} = 0.06m$$

4.1.2.4 Determine the Final Treatment Zone

$$(L_f) = (A_{sf}) / W \tag{4.7}$$

86 / 3 = 28.7 m (Length of the final zone)

The headloss of the final zone:

$$\mathrm{dh_f} = \frac{(\mathrm{Q})(\mathrm{L_f})}{(\mathrm{K_f})(\mathrm{W})(\mathrm{D_{wf}})} \tag{4.8}$$

$$\mathrm{dh_f} = \frac{(5.9\mathrm{m}^3/\mathrm{d})(28.7\mathrm{m})}{(10000\mathrm{m/d})(3\mathrm{m})(0.4\mathrm{m})} = 0.014\mathrm{m}$$

4.1.2.5 Determine Bottom Height

$$H_{bf} = (s)\ (L_f) \tag{4.9}$$

$$H_{b0} = = (s)\ (L_i + L_f) \tag{4.10}$$

H_{be} = height of bottom at the end of final zone = 0 (reference point for all heights)

H_{bf} = height of bottom at beginning of final zone = (0.005) (28.7m) = 0.14 m

H_{b0} = height of bottom at inlet = (0.005) (13 + 28.6) = 0.21 m

4.1.2.6 Water Surface Heights

$$H_{wf} = H_{bf} + D_{wf} \quad (4.11)$$

$$H_{we} = H_{wf} - dh_f \quad (4.12)$$

$$H_{w0} = H_{wf} - dh_i \quad (4.13)$$

$H_{wf} =$ height of water surface at the beginning of final zone = 0.14 + 0.4 = 0.44 m (D_{wf} is the initial recommended value, 0.4 m)

H_{we} = height of water surface at outlet = 0.44 – 0.014 = 0.43 m

H_{w0} = height of water surface at inlet = 0.44 + 0.06 = 0.50 m

4.1.2.7 Water Depths

$$D_{w0} = H_{w0} - H_{b0} \quad (4.14)$$

$$D_{wf} = H_{wf} - H_{bf} \quad (4.15)$$

$$D_{we} = H_{we} - H_{be} \quad (4.16)$$

D_{w0} = depth of water at inlet = 0.5 – 0.21 = 0.29 m (about equal to design D_{w0})

D_{wf} = depth of water at beginning of final treatment zone = *0.44* – 0.14 = 0.3 m (about equal to design D_{wf})

D_{we} = depth of water at outlet = 0.43 – 0 = 0.43 m

4.1.2.8 Media Depth

In VSB, either rounded stone with diameters between 20-30 mm or coarser rock with 40-50 mm diameter is used. To determine the media depth, media surface level or minimum water depth is considered. In the scope of this thesis, the media depth was calculated considering minimum water depth, which is 0.1 m, and the media depth was calculated as follows:

$$H_{m0} = H_{w0} + 0.1\text{m} \quad (4.17)$$

$$H_{mf} = H_{wf} + 0.1\text{m} \quad (4.18)$$

$$H_{me} = H_{we} + 0.1\text{m} \tag{4.19}$$

$$D_{m0} = H_{m0} - H_{b0} \tag{4.20}$$

$$D_{mf} = H_{mf} - H_{bf} \tag{4.21}$$

$$D_{me} = H_{me} - 0 \tag{4.22}$$

H_{m0} = height of media surface at inlet = 0.5 + 0.1 = 0.6 m

H_{mf} = height of media surface at beginning of final zone = 0.44 + 0.1 = 0.54 m

H_{me} = height of media surface at outlet = 0.43 + 0.1 = 0.53 m

D_{m0} = depth of media at inlet = 0.6 – 0.21 = 0.39 m

D_{mf} = depth of media at beginning of final zone = 0.54 - 0.14 = 0.4 m

D_{me} = depth of media at outlet = 0.53 – 0 = 0.53 m

This value is in the range of the desired media depth level, which is 0.4 - 0.6 m.

Inlet zone length = 2 m

$(L_i) = 13m$ $\quad\quad$ $(L_f) = 28.7m$

Outlet zone length = 1 m

Total Length = 2 m + 13 m + 28.7 m + 1 m = 44.7 m

Width = 3 m

Since the length of 44.7 m is too long so, two wetland treatment units were chosen.

$(L_i) = \frac{13}{2} = 6.5\ m$ $\quad\quad$ $(L_f) = \frac{28.7}{2} = 14.35m$ ~ 14.5 m

Inlet zone length = 2 m $\quad\quad$ Outlet zone length = 1 m

Total length = 2 m + 6.5 m + 14.5 m + 1 m = 24 m

As a result, two wetland units will be installed and the accepted wetland units dimensions are 24 m x 3 m x 0.7 m (Length x Width x Height) .

4.1.2.9 Planting

"The macrophyte planting density can be as close as 0.3 m (1 ft) centers or as much as 1 m (3 ft). The higher the density, the more rapid will be the development of a mature and completely functional wetland system. However, high density plantings will increase construction costs significantly" (USEPA, 2000). The planting density was selected as 0.3 m centred. So 70 x 10 = 700 rhizomes plant is needed for one wetland unit. Schematic planting is shown in Figure 4.3. Price per wetland plant changes depending on the plant type and it is about 1 $ (Tennessee Wholesale Nursery, n.d.) Totally, 1400 rhizomes are necessary for two wetland units and the total cost of planting is 1400 $.

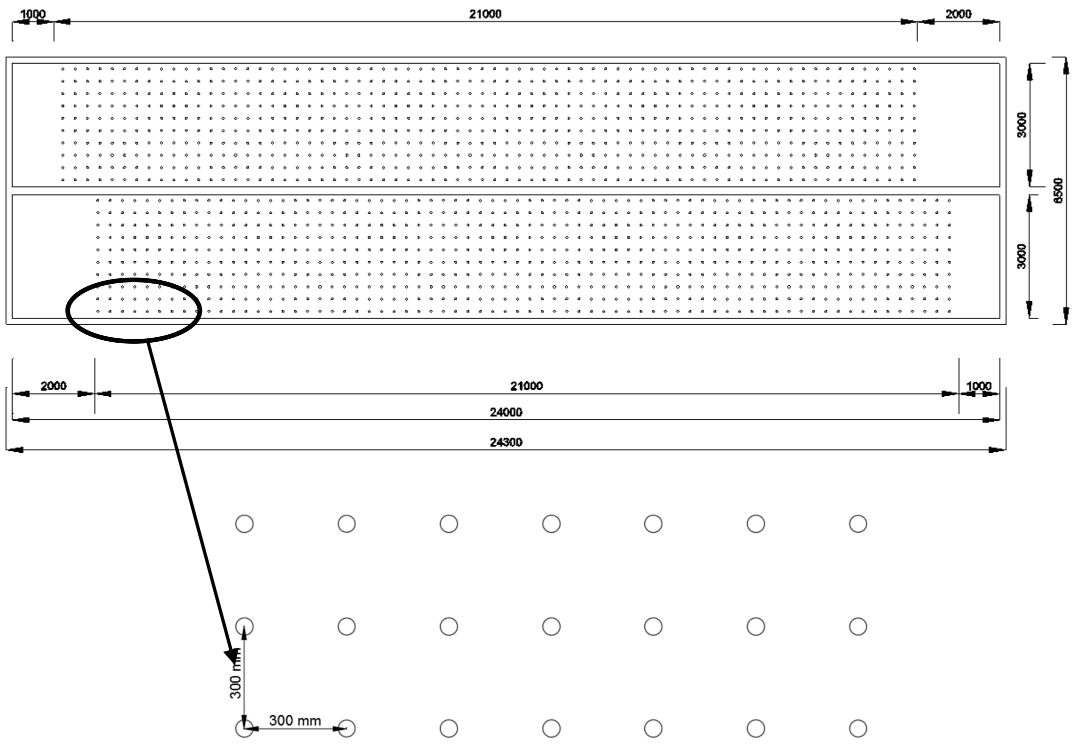


Figure 4.3 Planting details

4.1.3 UV System

Greywater may include some pathogen microorganisms and they can cause some healthy problem. Therefore, before greywater reuse applications, disinfection must be applied. For this aim, UV disinfection was selected. UV lamp was selected considering wetland effluent flowrate, which is 0.246 m³/h. Eurotech UV systems with a capacity of 0.26 m³/h was selected and the details of this system is given in Figure 4.4.

	Brand: Eurotech Capacity : 260 L/h Lamp power: 12 Watt Pipe diameter: 1/4" System Pressure: 2 – 7 bar Lamp Life: 9000 hours (~ 1 year) Price: 116 $

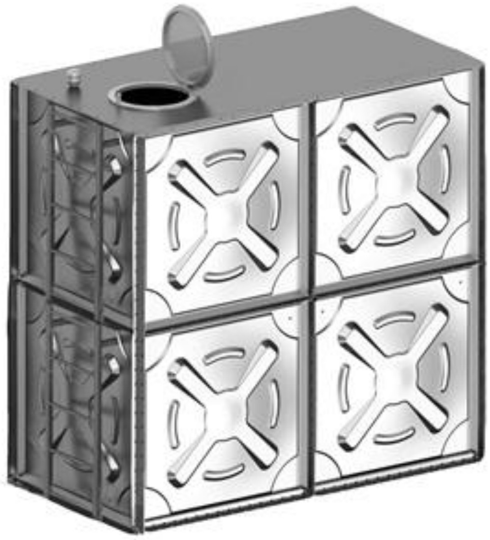
Figure 4.4 UV disinfection system (Minera Su Arıtma, 2018)

4.1.4 Storage Tank and Pump

From the quality point of view, after UV disinfection, effluent can be reused. However, effluent flowrate of 246 L/h will be used intermittently within days; therefore, a storage unit is required. Since the pressurized water is needed, the storage tank was placed on the roof. Extended storage times must be avoided in order to ensure that water quality is not impaired. The volume of the storage tank was selected as 85% of daily flowrate considering the safety margin.

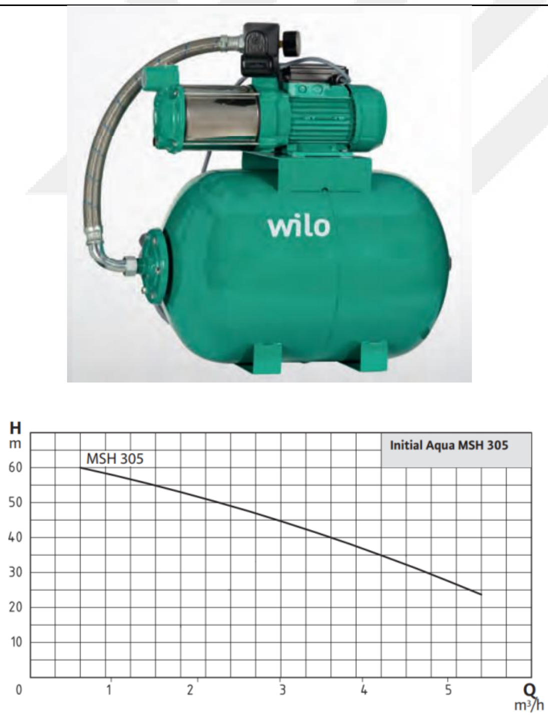
The volume of the storage tank = 5.9 m³/day x 85% = 5 m^3

Stainless steel tank was chosen as a storage tank and it is shown in Figure 4.5. Wetland unit effluent will be pumped to the storage tank by using a booster pump. The properties of the selected pump is given in Figure 4.6.



Brand: Meksis
Type: Prismatic Modular Tank
Tank Capacity : 5 m^3
Material: AISI 304 Stainless Steel
Base & Bottom Plate Thickness: 2 mm
Roof Plate Thickness: 1.5 mm
Dimensions: 1080 mm x 2160 mm x 2160 mm
Price: 3300 $

Figure 4.5 The storage tank (Su Küpü Depolama Sistemleri, 2018)



Brand: Wilo Initial Aqua MSH 50-305 M
Type: Horizontal Expansion Tank
Tank Capacity : 50 L
Cogwheel : Noryl
Pump Body: Stainless Steel (AISI 304)
Shaft: Stainless Steel (AISI 304)
Mechanic Gasket : Ceramic / Graphite
Max Water Temperature : + 35 ºC
Power Supply : 1~230V, 50Hz
Insulation Grade : F
Max. Adsorption Height: 7 m
Nominal Current : 6.2 A
Nominal Power : 1.1 kW / 1.5 HP
Price: 906 $

Figure 4.6 The booster pump (Wilo Catalog, 2018)

4.2 Cost Analysis for a Building

4.2.1 Investment Cost

As seen in the floor plan of the house (see Appendix 2), there are two apartments on the each floor. The details of the plumbing systems are given in Chapter 3. Each apartment has two plumbing. One of them collects toilet wastewaters, and another collects wastewater generated from the kitchen. Therefore, two plumbing are placed in bathroom (P1 and P2) and two plumbing are placed in kitchens (P3 and P4) on each floor. These columns merge in R1 manhole and connect to sewage system. To collect greywater, a separate column will be used and collected greywater goes to the greywater treatment plant. Since the wastewater generated from kitchen is not considered as greywater, there is no need to change the kitchen plumbing (P3 and P4).

As seen in the floor plan, the wastewater from the shower, washbasin, and washing machine is collected into one plumbing in renewed infrastructure system. Since P1 is renewed to collect only the greywater, it is named as G1. Because only the toilet wastewaters are connected to the P2, the flow rate decreased.

Considering these drain pipes situations, connection units, required materials, and unit costs; existing and renewed fixture system costs were calculated. Costs of the existing and renewed fixture system is given in Table 4.1 and 4.2, respectively. The required material including excavation, concrete, iron, concrete form, and labor quantities for wetland systems are given in Table 4.3. The cost of the construction of wetland units is given in Table 4.4.

Table 4.1 Cost of the Existing Fixture System (Unit Price, 2017)

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
1	204-405	Outer Diameter Ø150mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	6	5.01	30.06 $
2	204-405M	Outer Diameter Ø150mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	6	0.66	3.96 $
3	204-404	Outer Diameter Ø125mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	56	3.76	210.56 $
4	204-404M	Outer Diameter Ø125mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	56	0.60	33.60 $
5	204-403	Outer Diameter Ø100mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	62	2.78	172.36 $
6	204-403-M	Outer Diameter Ø100mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	62	0.54	33.48 $
7	204-402	Outer Diameter Ø70mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	130	1.82	236.60 $
8	204-402-M	Outer Diameter Ø70mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	130	0.41	53.30 $
9	204-401	Outer Diameter Ø50mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	48	1.19	57.12 $
10	204-401-M	Outer Diameter Ø50mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	48	0.35	16.80 $
11	113-203	125 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Procurement	Piece	2	3.62	7.24 $
12	113-203-M	125 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Installation	Piece	2	0.88	1.76 $
13	113-202	100 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Procurement	Piece	2	2.89	5.78 $
14	113-202-M	100 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Installation	Piece	2	0.88	1.76 $

Table 4.1 Cost of the Existing Fixture System (Unit Price, 2017)

Table 4.1 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
15	097-504	Brass chromium-plating screen 17 x 17 cm Floor Drain: (TS 327/2):	Procurement	Piece	25	23.76	594.00 $
16	097-504-M	Brass chromium-plating screen 17 x 17 cm Floor Drain: (TS 327/2):	Installation	Piece	25	3.04	76.00 $
17	079-100	One-Piece Toilet and plumbing (Unit: Group.: stock: %60) almost 35x55 cm. (Extra quality)	Procurement	Group	12	59.76	717.12 $
18	079-100-M	One-Piece Toilet and plumbing (Unit: Group.: stock: %60) almost 35x55 cm. (Extra quality)	Installation	Group	12	8.54	102.48 $
19	082-200	Bidets and plumbing: (Unit: Group.: stock: %60) (TS EN 14528) Type of near the wall. almost 65x35 cm. Extra quality	Procurement	Group	12	55.76	669.12 $
20	082-200-M	Bidets and plumbing: (Unit: Group.: stock: %60) (TS EN 14528) Type of near the wall. almost 65x35 cm. Extra quality	Installation	Group	12	8.54	102.48 $
21	089-201	Several Fittings: (Unit Piece. : stock: %60) Taps (TS EN 200) 1/2 Chromed Washing Bath. . Washer seals tap. include faucet badge	Procurement	Piece	12	6.09	73.08 $
22	089-201-M	Several Fittings: (Unit Piece. : stock: %60) Taps (TS EN 200) 1/2 Chromed Washing Bath. . Washer seals tap. include faucet badge	Installation	Piece	12	0.62	7.44 $
23	071-106	50x65 cm Pedestal Washbasin: (Unit Piece. : stock: %60) (TS 605)	Procurement	Piece	12	47.29	567.48 $
24	071-106-M	50x65 cm Pedestal Washbasin: (Unit Piece. : stock: %60) (TS 605)	Installation	Piece	12	3.95	47.40 $
25	089-504	Several Fittings: (Unit Piece. : stock: %60) Sink battery: Water choosed hot or cold with a tap spare. (valve with filter and other equipment group)	Procurement	Piece	12	40.94	491.28 $
26	089-504-M	Several Fittings: (Unit Piece. : stock: %60) Sink battery: Water choosed hot or cold with a tap spare. (valve with filter and other equipment group)	Installation	Piece	12	4.09	49.08 $
27	074-101	Shelf: (Unit Piece. : stock: %60) Ceramic glazed tile: (installing with peg) Almost 50x10 cm. Extra quality	Procurement	Piece	12	8.49	101.88 $

Table 4.1 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
28	074-101-M	Shelf: (Unit Piece. : stock: %60) Ceramic glazed tile: (installing with peg) Almost 50x10 cm. Extra quality	Installation	Piece	12	2.11	25.32 $
29	04.642/01D	Colorless Mirror (TS EN 1036-1.2) 6 mm thickness	Procurement / Installation	m²	1.6	5.63	9.01 $
30	090-300	SOAP DISH (SPONTANEOUS) (Unit Piece. : stock: %60)): Sponge tile: (Sleeved) 16x31 cm	Procurement	Piece	12	4.64	55.68 $
31	090-300-M	SOAP DISH (SPONTANEOUS) (Unit Piece. : stock: %60)): Sponge tile: (Sleeved) 16x31 cm	Installation	Piece	12	0.64	7.68 $
32	087-703	White Acrylic Panel Shower Bathtub: (Unit Piece. : stock: %60) 90x90x11 cm. square	Procurement	Piece	12	95.53	1,146.36 $
33	087-703-M	White Acrylic Panel Shower Bathtub: (Unit Piece. : stock: %60) 90x90x11 cm. square	Installation	Piece	12	6.38	76.56 $
34	086-301	SHOWERS: (Stock: %60) shower tube and shower head strainer with bathroom faucet; (TS EN 200) prime quality.	Procurement	Group	12	50.35	604.20 $
35	086-301-M	SHOWERS: (Stock: %60) shower tube and shower head strainer with bathroom faucet; (TS EN 200) prime quality.	Installation	Group	12	6.52	78.24 $
36	117-152	GEYSER: Natural gas / LPG hermetic geyser (TS- 615 EN 26) 14 L/min (24.4KW)	Procurement	Piece	12	247.06	2,964.72 $
37	117-152-M	GEYSER: Natural gas / LPG hermetic geyser (TS- 615 EN 26) 14 L/min (24.4KW)	Installation	Piece	12	11.46	137.52 $
38	204-4209	Pre-Insulated Galvanized Pipes (Unit: m); 4” 200	Procurement	m	12	24.71	296.52 $
39	204-4209-M	Pre-Insulated Galvanized Pipes (Unit: m); 4” 200	Installation	m	12	3.22	38.64 $
40	204-4206	Pre-Insulated Galvanized Pipes (Unit: m); 2” 125	Procurement	m	3.6	11.53	41.51 $
41	204-4206-M	Pre-Insulated Galvanized Pipes (Unit: m); 2” 125	Installation	m	3.6	2.28	8.21 $

Table 4.1 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
42	103-105	WATER METER: (TS-824 ISO 4064-1)(Unit: Piece; Stock:%60) Cold water meters:supply and replacement of the workplace. 40 Ø mm. (1 1/2) screwed	Procurement	Piece	12	62.59	751.08 $
43	103-105-M	WATER METER: (TS-824 ISO 4064-1)(Unit: Piece; Stock:%60) Cold water meters: supply and replacement of the workplace. 40 Ø mm. (1 1/2) screwed	Installation	Piece	12	4.56	54.72 $
44	207-104	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 32 Ø mm (1 1/4)	Procurement	Piece	12	15.53	186.36 $
45	207-104-M	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 32 Ø mm (1 1/4)	Installation	Piece	12	1.94	23.28 $
46	207-106	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 50 Ø mm (2)	Procurement	Piece	2	31.53	63.06 $
47	207-106-M	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 50 Ø mm (2)	Installation	Piece	2	2.64	5.28 $
48	207-109	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 100 Ø mm (4)	Procurement	m	1	86.82	86.82 $
49	207-109-M	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 100 Ø mm (4)	Installation	m	1	4.66	4.66 $
50	204-3101/A	Aluminum foil (oxygen barrier) composite PP-RC pipes: PN 20 polypropylene pipes (dimension : m.) Rated size: 1/2" external diameter/Thickness (Ø mm): 20/2.8	Procurement	m	96	1.15	110.40 $
51	204-3101/A-M	Aluminum foil (oxygen barrier) composite PP-RC pipes: PN 20 polypropylene pipes (dimension : m.) Rated size: 1/2" external diameter/Thickness (Ø mm): 20/2.8	Installation	m	96	0.46	44.16 $
52	201-206	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1 1/4" 32 42.4/3.25	Procurement	m	135	4.12	556.20 $
53	201-206-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1 1/4" 32 42.4/3.25	Installation	m	135	1.64	221.40 $

Table 4.1 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
54	201-205	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1” 25 33.7/3.25	Procurement	m	12	3.29	39.48 $
55	201-205-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1” 25 33.7/3.25	Installation	m	12	1.35	16.20 $
56	201-204	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 3/4” – 20 mm. outside diameter / thickness mm: 26.9/2.65	Procurement	m	60	2.52	151.20 $
57	201-204-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 3/4” – 20 mm. outside diameter / thickness mm: 26.9/2.65	Installation	m	60	1.18	70.80 $
58	201-203	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 1/2” – 15 mm mm. outside diameter / thickness mm::21.3/2.65	Procurement	m	24	2.00	48.00 $
59	201-203-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 1/2” – 15 mm mm. outside diameter / thickness mm::21.3/2.65	Installation	m	24	1.01	24.24 $
60	04.390/303	Floor Tile (I. Quality) (TS EN 14411 – Dry press ceramic floor tile-low water absorb % 0.5 special design and surface characteristic. white. Floor tile (40 x 40 cm dimensions)	Procurement / Installation	m²	60	3.51	210.60 $
61	04.390/301	Floor Tile (I. Quality) (TS EN 14411 – Dry press ceramic floor tile-low water absorb % 0.5 special design and surface characteristic. white. Floor tile (40 x 40 cm dimensions)	Procurement / Installation	m²	180	3.64	655.20 $
						TOTAL	**13,282.05 $**

Table 4.2 Costs of the Renewed Fixture System (Unit Price, 2017)

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
1	204-405	Outer Diameter Ø150mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	6	5.01	30.06 $
2	204-405M	Outer Diameter Ø150mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	6	0.66	3.96 $
3	204-404	Outer Diameter Ø125mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	24	3.76	90.24 $
4	204-404M	Outer Diameter Ø125mm t:3.2mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	24	0.60	14.40 $
5	204-403	Outer Diameter Ø100mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	81	2.78	225.18 $
6	204-403-M	Outer Diameter Ø100mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	81	0.54	43.74 $
7	204-402	Outer Diameter Ø70mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	142	1.82	258.44 $
8	204-402-M	Outer Diameter Ø70mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	142	0.41	58.22 $
9	204-401	Outer Diameter Ø50mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Procurement	m	60	1.19	71.40 $
10	204-401-M	Outer Diameter Ø50mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	60	0.35	21.00 $
11	113-203	125 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Procurement	Piece	1	3.62	3.62 $
12	113-203-M	125 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Installation	Piece	1	0.88	0.88 $
13	113-202	100 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Procurement	Piece	3	2.89	8.67 $
14	113-202-M	100 Ø mm. ventilation pipe and head: (Unit: Piece.: stock % 40):	Installation	Piece	3	0.88	2.64 $

Table 4.2 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
15	097-504	Brass chromium-plating screen 17 x 17 cm Floor Drain: (TS 327/2):	Procurement	Piece	25	23.76	594.00 $
16	097-504-M	Brass chromium-plating screen 17 x 17 cm Floor Drain: (TS 327/2):	Installation	Piece	25	3.04	76.00 $
17	076-300	SQUAT TOILET INFRASTRUCTURE ☹Unit: Piece: Stock: %60) Tile flush box:	Procurement	Piece	12	27.53	330.36 $
18	076-300-M	SQUAT TOILET INFRASTRUCTURE ☹Unit: Piece: Stock: %60) Tile flush box:	Installation	Piece	12	9.32	111.84 $
19	079-100	One-Piece Toilet and plumbing (Unit: Group.: stock: %60) almost 35x55 cm. (Extra quality)	Procurement	Group	12	59.76	717.12 $
20	079-100-M	One-Piece Toilet and plumbing (Unit: Group.: stock: %60) almost 35x55 cm. (Extra quality)	Installation	Group	12	8.54	102.48 $
21	082-200	Bidets and plumbing: (Unit: Group.: stock: %60) (TS EN 14528) Type of near the wall. almost 65x35 cm. Extra quality	Procurement	Group	12	55.76	669.12 $
22	082-200-M	Bidets and plumbing: (Unit: Group.: stock: %60) (TS EN 14528) Type of near the wall. almost 65x35 cm. Extra quality	Installation	Group	12	8.54	102.48 $
23	089-201	Several Fittings: (Unit Piece. : stock: %60) Taps (TS EN 200) 1/2 Chromed Washing Bath. . Washer seals tap. include faucet badge	Procurement	Piece	12	6.09	73.08 $
24	089-201-M	Several Fittings: (Unit Piece. : stock: %60) Taps (TS EN 200) 1/2 Chromed Washing Bath. . Washer seals tap. include faucet badge	Installation	Piece	12	0.62	7.44 $
25	071-106	50x65 cm Pedestal Washbasin: (Unit Piece. : stock: %60) (TS 605)	Procurement	Piece	12	47.29	567.48 $
26	071-106-M	50x65 cm Pedestal Washbasin: (Unit Piece. : stock: %60) (TS 605)	Installation	Piece	12	3.95	47.40 $
27	089-504	Several Fittings: (Unit Piece. : stock: %60) Sink battery: Water choosed hot or cold with a tap spare. (valve with filter and other equipment group)	Procurement	Piece	12	40.94	491.28 $

Table 4.2 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
28	089-504-M	Several Fittings: (Unit Piece. : stock: %60) Sink battery: Water choosed hot or cold with a tap spare. (valve with filter and other equipment group)	Installation	Piece	12	4.09	49.08 $
29	074-101	Shelf: (Unit Piece. : stock: %60) Ceramic glazed tile: (installing with peg) Almost 50x10 cm. Extra quality	Procurement	Piece	12	8.49	101.88 $
30	074-101-M	Shelf: (Unit Piece. : stock: %60) Ceramic glazed tile: (installing with peg) Almost 50x10 cm. Extra quality	Installation	Piece	12	2.11	25.32 $
31	04.642/01D	Colorless Mirror (TS EN 1036-1.2) 6 mm thickness	Installation	m^2		5.63	9.01 $
32	090-300	SOAP DISH (SPONTANEOUS) (Unit Piece. : stock: %60)): Sponge tile: (Sleeved) 16x31 cm	Procurement	Piece	12	4.64	55.68 $
33	090-300-M	SOAP DISH (SPONTANEOUS) (Unit Piece. : stock: %60)): Sponge tile: (Sleeved) 16x31 cm	Installation	Piece	12	0.64	7.68 $
34	087-703	White Acrylic Panel Shower Bathtub: (Unit Piece. : stock: %60) 90x90x11 cm. square	Procurement	Piece	12	95.53	1,146.36 $
35	087-703-M	White Acrylic Panel Shower Bathtub: (Unit Piece. : stock: %60) 90x90x11 cm. square	Installation	Piece	12	6.38	76.56 $
36	086-301	SHOWERS: (Stock: %60) shower tube and shower head strainer with bathroom faucet; (TS EN 200) prime quality.	Procurement	Group	12	50.35	604.20 $
37	086-301-M	SHOWERS: (Stock: %60) shower tube and shower head strainer with bathroom faucet; (TS EN 200) prime quality.	Installation	Group	12	6.52	78.24 $
38	117-152	GEYSER: Natural gas / LPG hermetic geyser (TS- 615 EN 26) 14 L/min (24.4KW)	Procurement	Piece	12	247.06	2,964.72 $
39	117-152-M	GEYSER: Natural gas / LPG hermetic geyser (TS- 615 EN 26) 14 L/min (24.4KW)	Installation	Piece	12	11.46	137.52 $
40	204-4209	Pre-Insulated Galvanized Pipes (Unit: m); 4” 200	Procurement	m	12	24.71	296.52 $

Table 4.2 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
41	204-4209-M	Pre-Insulated Galvanized Pipes (Unit: m); 4” 200	Installation	m	12	3.22	38.64 $
42	204-4206	Pre-Insulated Galvanized Pipes (Unit: m); 2” 125	Procurement	m	4	11.53	46.12 $
43	204-4206-M	Pre-Insulated Galvanized Pipes (Unit: m); 2” 125	Installation	m	4	2.28	9.12 $
44	103-105	WATER METER: (TS-824 ISO 4064-1)(Unit: Piece; Stock:%60) Cold water meters: supply and replacement of the workplace. 40 Ø mm. (1 1/2) screwed	Procurement	Piece	12	62.59	751.08 $
45	103-105-M	WATER METER: (TS-824 ISO 4064-1)(Unit: Piece; Stock:%60) Cold water meters: supply and replacement of the workplace. 40 Ø mm. (1 1/2) screwed	Installation	Piece	12	4.56	54.72 $
46	207-104	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 32 Ø mm (1 1/4)	Procurement	Piece	12	15.53	186.36 $
47	207-104-M	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 32 Ø mm (1 1/4)	Installation	Piece	12	1.94	23.28 $
48	207-106	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 50 Ø mm (2)	Procurement	Piece	2	31.53	63.06 $
49	207-106-M	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 50 Ø mm (2)	Installation	Piece	2	2.64	5.28 $
50	207-109	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 100 Ø mm (4)	Procurement	m	1	86.82	86.82 $
51	207-109-M	Gate and globe valve. brass screw. made of press (TS EN 12288) non-discharge. 100 Ø mm (4)	Installation	m	1	4.66	4.66 $
52	204-3101/A	Aluminum foil (oxygen barrier) composite PP-RC pipes: PN 20 polypropylene pipes (dimension : m.) Rated size: 1/2” external diameter/Thickness (Ø mm): 20/2.8	Procurement	m	140	1.15	161.00 $
53	204-3101/A-M	Aluminum foil (oxygen barrier) composite PP-RC pipes: PN 20 polypropylene pipes (dimension : m.) Rated size: 1/2” external diameter/Thickness (Ø mm): 20/2.8	Installation	m	140	0.46	64.40 $

Table 4.2 continues

No	Code	Definition	Type	Unit	Qty	Unit Cost	Total Cost
54	201-206	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1 1/4” 32 42.4/3.25	Procurement	m	165	4.12	679.80 $
55	201-206-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1 1/4” 32 42.4/3.25	Installation	m	165	1.64	270.60 $
56	201-205	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1” 25 33.7/3.25	Procurement	m	12	3.29	39.48 $
57	201-205-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) 1” 25 33.7/3.25	Installation	m	12	1.35	16.20 $
58	201-204	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 3/4” – 20 mm. outside diameter / thickness mm: 26.9/2.65	Procurement	m	60	2.52	151.20 $
59	201-204-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 3/4” – 20 mm. outside diameter / thickness mm: 26.9/2.65	Installation	m	60	1.18	70.80 $
60	201-203	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 1/2” – 15 mm mm. outside diameter / thickness mm::21.3/2.65	Procurement	m	42	2.00	84.00 $
61	201-203-M	STEEL PIPE: (Stock: % 60) Seam galvanized pipe. fit to TS EN 10255. material Fe33-2: (Unit : m) inner diameter 1/2” – 15 mm mm. outside diameter / thickness mm::21.3/2.65	Installation	m	42	1.01	42.42 $
62	04.390/303	Floor Tile (I. Quality) (TS EN 14411 – Dry press ceramic floor tile-low water absorb % 0.5 special design and surface characteristic. white. Floor tile (40 x 40 cm dimensions)	Procurement / Installation	m²	60	3.51	210.60
63	04.390/301	Floor Tile (I. Quality) (TS EN 14411 – Dry press ceramic floor tile-low water absorb % 0.5 special design and surface characteristic. white. Floor tile (40 x 40 cm dimensions)	Procurement / Installation	m²	180	3.64	655.20
						TOTAL	**13.990.14 $**

Table 4.3 The required material for wetland systems

No	Code	Definition	Quantity	Length (mm)	Width (mm)	Height (mm)	Total (m^3)
1	**Y.15.014/4A**	**Excavation with excavator**					
		Wetland 1	1	24800	33000	1000	81.84
		Wetland 1 Outlet Part	1	1000	1000	1000	1.00
		Wetland 2	1	24800	3700	1070	98.18
		Wetland 2 Outlet Part	1	1000	1000	1070	1.07
						TOTAL	**182.09 m^3**
2	**Y.21.001/03**	**Plywood Concrete Forms**	**Quantity**	**Length (mm)**	**Width (mm)**	-	**Total (m^2)**
		Wetland 1 the blinding concrete	1	100	23900	-	2.39
		Wetland 1 the blinding concrete	2	100	3150	-	0.63
		Wetland 2 the blinding concrete	1	100	23900	-	2.39
		Wetland 2 the blinding concrete	1	170	23900	-	4.06
		Wetland 2 the blinding concrete	1	70	23900	-	1.67
		Wetland 2 the blinding concrete	2	100	3450	-	0.69
		Wetland 1 Outside Length	1	900	24300	-	21.87
		Wetland 1 Outside Width	2	900	3150	-	5.67
		Wetland 1 Inside Length	2	700	24000	-	33.60
		Wetland 1 Inside Width	2	770	3000	-	4.62
		Wetland 2 Outside Length	1	970	24300	-	23.57
		Wetland 2 Outside Width	2	970	3350	-	6.50
		Wetland 2 Inside Length	2	770	24000	-	36.96
		Wetland 2 Inside Width	2	840	3000	-	5.04
		Wetland 1-2 Outside blinding	8	100	900	-	0.72
		Wetland 1 Outlet Part Outside	4	700	900	-	2.52
		Wetland 1 Outlet Part Inside	4	400	700	-	1.12
		Wetland 2 Outlet Part Outside	4	700	970	-	2.72
		Wetland 2 Outlet Part Inside	4	400	770	-	1.23
						TOTAL	**157.97 m^2**

Table 4.5 continues

No	Code	Definition	Quantity	Length (mm)	Unit Weight	-	Total (kg)
3	**Y.23.015**	**Ø 14 - Ø28 Rebar**				-	
		P1 - Ø14	46	901	1.208	-	50.07
		P2 - Ø14	46	942	1.208	-	52.35
		P3 - Ø14	184	1000	1.208	-	222.27
		P4 - Ø14	184	12000	1.208	-	2667.26
		P5 - Ø14	184	10000	1.208	-	2222.72
		P9 - Ø14	46	991	1.208	-	55.07
		P10 - Ø14	46	1032	1.208	-	57.35
		P11 - Ø14	169	1115	1.208	-	227.63
		P12 - Ø14	169	1015	1.208	-	207.21
		P13 - Ø14	4	620	1.208	-	3.00
		P14 - Ø14	326	1185	1.208	-	466.66
		P15 - Ø14	326	1085	1.208	-	427.28
		P16 - Ø14	8	690	1.208	-	6.67
		P17 - Ø14	146	900	1.208	-	158.73
TOTAL						-	**6824.27 kg**
4	**Y.23.014**	**Ø 8 - Ø12 Rebar**				-	
		P6 - Ø10	52	3295	0.617	-	105.72
		P7 - Ø10	68	710	0.617	-	29.79
		P8 - Ø10	68	12000	0.617	-	503.47
		P18 - Ø10	44	835	0.617	-	22.67
		P19 - Ø10	44	535	0.617	-	14.52
		P20 - Ø10	12	550	0.617	-	4.07
TOTAL							**680.24 kg**

Table 4.6 continues

No	Code	Definition	Quantity	Length (m)	Width (m)	Height (m)	Total (m^3)
5	**Y.16.050/14**	**BS20/25 Ready-mixed concrete**					
		Wetland 1 the blinding concrete	1	23900	100	3150	7.53
		Wetland 2 the blinding concrete	1	23900	100	3450	8.25
		Wetland 2 the blinding concrete	1	23900	100	170	0.41
		Wetland 1 Side wall	1	24300	150	700	2.55
		Wetland 1 Side wall	2	3000	150	805	0.72
		Wetland 1 Floor	1	23700	200	3150	14.93
		Wetland 1-2 Side wall	1	23900	200	770	3.68
		Wetland 2 Side wall	1	23900	150	770	2.76
		Wetland 2 Side wall	2	3000	150	875	0.79
		Wetland 2 Floor	1	23700	200	3350	15.88
		Wetland 1-2 Outside Part	2	1200	100	1200	0.29
		Wetland 1 Outside Part Walls	2	700	150	900	0.19
		Wetland 1 Outside Part Walls	2	400	150	900	0.11
		Wetland 2 Outside Part Walls	1	700	150	970	0.10
		Wetland 2 Outside Part Walls	1	400	150	970	0.06
		Wetland 1-2 Outside Part Floor	2	400	200	400	0.06
			TOTAL				**42.12 m^3**
6	**Y.15.140/07**	**Crushed stone which lower than**					
		Wetland 1-2 Zone1-Zone2	2	21000	3000	650	81.90 m^3
7	**Y.15.140/09**	**Crushed stone which lower than**					
		Wetland 1-2 Inlet-Outlet Zone	2	3000	3000	650.00	11.70 m^3

Table 4.4 The cost of the construction of wetland units (Unit Price, 2017)

No	Code	Definition	Type	Unit	Quantity	Unit Cost ($)	Total Cost ($)
1	Y.15.014/4A	Excavation with excavator		m^3	182.09	4.36	793.06
2	Y.21.001/03	Plywood Concrete Form	Procurement / Installation	m^2	157,97	9.32	1472.28
3	Y.23.015	Ø 14 - Ø28 Rebar	Procurement / Installation	tons	6.82	589	4016.98
4	Y.23.014	Ø 8 - Ø12 Rebar	Procurement / Installation	tons	0.68	600.5	408.34
4	Y.16.050/14	BS20/25 Ready-mixed Concrete	Procurement / Installation	m^3	42.12	38.86	1636.78
5	Y.15.140/07	Crushed stone which lower than 32mm caliber spread	Procurement / Installation	m^3	81.90	11.7	958.23
6	Y.15.140/09	Crushed stone which lower than 63mm caliber spread	Procurement / Installation	m^3	11.70	10.96	128.23
7	204-402	Outer Diameter Ø70mm t:3mm Tough PVC plastic wastewater pipe (TS 275-1 EN 1329-1)	Procurement	m	23.05	1.82	41.95
8	204-402-M	Outer Diameter Ø70mm t:3mm Tough PVC plastic waste water pipe (TS 275-1 EN 1329-1)	Installation	m	23.05	0.41	9.45
8	04.768/08D02	PE 100 Polythene Pipe(TS EN 12201-2+A1) 63mm diameter	Procurement / Installation	m	13.5	0.73	9.86
9		Wetland Plants (rhizomes)	Procurement / Installation	Pieces	1400	1	1400
						TOTAL	**10876.01 $**

All expenses for the collection, treatment and reuse of greywater are summarized in Table 4.5 The unpredictable costs were assumed as 10% of the investment cost.

Table 4.8 Summary of Required Expenditures

<table>
<tr><th colspan="2">Grey Water Reuse System Part</th><th colspan="2">Investment Cost ($)</th></tr>
<tr><td rowspan="3">Fixtures</td><td>Differences between existing and renewed system</td><td>708.09</td><td rowspan="3">4914,09</td></tr>
<tr><td>Booster Pump</td><td>906.00</td></tr>
<tr><td>Storage Tank</td><td>3300.00</td></tr>
<tr><td rowspan="3">Treatment Unit</td><td>Equalization Tank</td><td>941.18</td><td rowspan="3">11933.19</td></tr>
<tr><td>Wetland Units</td><td>10876.01</td></tr>
<tr><td>UV Lamp</td><td>116.00</td></tr>
<tr><td colspan="2">TOTAL</td><td colspan="2">16847.28</td></tr>
<tr><td colspan="2">Unpredictable Costs (%10)</td><td colspan="2">1684.72</td></tr>
<tr><td colspan="2">TOTAL PRICE</td><td colspan="2">~ 18560.00 $</td></tr>
</table>

4.2.2 Calculation of Amortization Time

Amortization time was calculated from the required expenses and possible income of greywater reuse. Firstly, the amount of water consumption and possible water invoice was calculated for the chosen building.

$$1 \text{ Residence} = 4 \text{ people} = 4 \text{ x } 200 = (800 \text{ L/d}) \text{ x } (30 \text{ d/month}) / (1000 \text{ m}^3\text{/L}) = 24 \text{ m}^3\text{/month}$$

Water consumption per capita was accepted as 200 L/d and total monthly water consumption was calculated as 24 m^3/month/resident To calculate the water invoice, total water prices including wastewater price, solid waste collection and treatment price, and tax, for the residence given in Table 4.6. was considered.

Table 4.9 IZSU Water Invoice (IZSU, 2018)

ID Num.	**Subscription Type**	**Consumption (m^3/month)**	**Water Price ($)**	**Wastewater Price ($)**	**Total Price ($)**
1a	Residence	0 – 20	0.59	0.48	1.08
		21 – Higher	1.32	1.08	2.40
1b	Not Residence	-	1.36	1.11	2.47

Extra Invoice Price	
Solid Waste Collection	10.82 $
Solid Waste Treatment	2.21 $
Tax	8%

Since the water consumption is 24 m^3, 1.08 $ of total water price was considered up to 20 m^3 and 2.4 $ was considered for the rest of the consumption, which is 4.0 m^3. As a result, total water invoice for one residence was calculated regarding to following equation:

Total invoice = Price for 20 m^3 of water consumption + price for 4 m^3 of water consumption + price of solid waste collection + price of solid waste treatment + tax

Total invoice = (20 m^3 x 1.08 + 4 m^3 x 2.40 + 10.82 + 2.21) x 1.08 = 47.77 $/month

After the greywater reuse applications, water consumption and water invoice will decrease. To calculate the water invoice after greywater reuse, the amount of water saving was considered. The accepted the amount of greywater and blackwater distributions are shown in Figure 4.7.

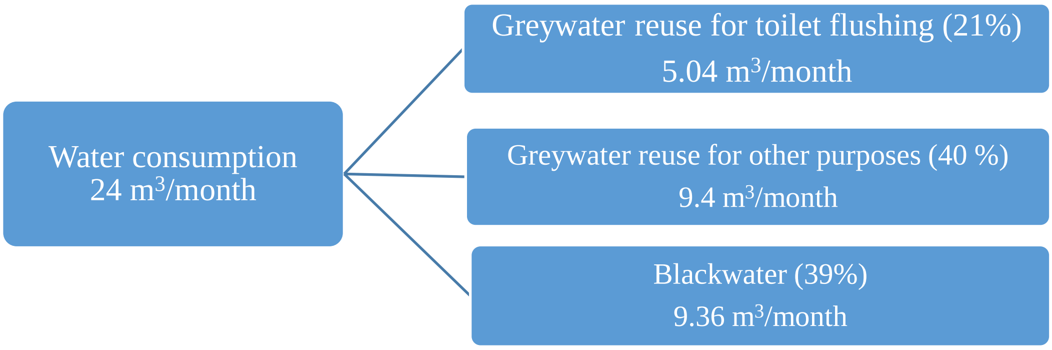


Figure 4.7 Greywater and blackwater amounts for 1 residence

As seen from Figure 4.7, 21% of wastewater (5.04 m^3/month) will be reused for toilet flushing in the residence, and 40% of wastewater (9.4 m^3/month) will be reused for other purposes at outdoor, such as car washing and irrigation. Since the price of water change depending on the indoor and outdoor usage, the amount of saving money was calculated separately. The calculation details are given below.

24 – 5.04 = 18.96 m^3/ month / resident

(18.96 x 1.08 + 10.82 + 2.21) x 1.08 = 36.19 $ / month for 1 residence

47.77 – 36.19 = 11.58 $ / month (money saving for 1 residence)

12 residence x 11.58 = 138.96 $ / month (money saving for the building)

138.96 x 12 = 1667.52 $ / year (annual money saving of the building)

40% of wastewater (9.4 m^3/month/residence) will be reused for other purposes, and the amount of this portion of wastewater is:

9.4 x 12 = 112.8 m^3/month/building (the remaining amount of greywater of a building)

Totally, 61% of wastewater is saved with greywater reuse. However, only 21% of the treated greywater can be used for toilet flushing. Two alternative solutions were produced for the rest of the treated greywater (112.8 m^3/ month).

1^{st} Alternative Solution: 112.8 m^3/month of treated greywater will be reused for the toilet flushing at another building.

112.8 / 5.04 = 22.38 ≅ 22 residence

5.04*22 = 110.88 m^3/ month (The amount of water used for flushing toilet)

11.58 x 22 residence = 254.76 $ / month (money saving for buildings)

112.8 – 110.88 = 1.92 m^3/ month (the amount of remaining treated greywater)

1.92 x 2.40 x 1.08 = 4.98$ / month

(254.76 + 4.98) x 12 = 3116.88 $/year (annual money saving of the building)

2^{nd} Alternative Solution: 78% of treated greywater will be used for car washing, 22% of treated greywater will be used for garden irrigation.

It was assumed that, 25 m^3/month water is consumed for garden irrigation, 5 m^3/month water is consumed for the cleaning of the building. Therefore, totally 30 m^3/month water is consumed by general needs of the building.

Total invoice = Price for 20 m^3 of water consumption + price for 10 m^3 of water consumption + price of solid waste collection + price of solid waste treatment + tax

Total invoice = (20 m^3 x 1.08 + 10 m^3 x 2.40 + 10.82 + 2.21) x 1.08 = 63.32 $/month

The amount of money saving from the garden irrigation was calculated using the following equations:

(5 x 1.08 + 10.82 + 2.21) x 1.08 = 19.90 $/month

63.32 – 19.90 = 43.42 $/month (money saving)

43.42 x 12 = 521.04 $/year (annual money saving)

112.8 – 25 = 87.8 m^3/ month (the amount of the remaining treated greywater, which will be used for car washing)

In a car washing plant with a daily average of 30 vehicles, 120 liters of water is consumed per vehicle washing process (Çetin & Tandıroğlu, 2014). In addition, it was assumed that 5 m^3/month water is consumed for the other purposes in this plant.

30 x 30 = 900 vehicle/month (the amount of car washing in a month)
900 x 0.12 = 108 m^3/month (the amount of water consumed for car washing)
108 + 5 = 113 m^3/month (the amount of total consumed water in a car washing plant)
(113 x 2.47 + 10.82 + 2.21) x 1.08 = 315.51 $/month
113 – 87.8 = 25.2 m^3/month
(25.02 x 2.47 + 10.82 + 2.21) x 1.08 = 81.30 $/month
315.51 – 81.30 = 234.21 $/month (money saving)
234.21 x 12 = 2810.52 $/year (annual money saving)

To calculate the amortization time, operational costs of the treatment plant should be taken into consideration. Energy is necessary for UV lamps and booster pump and the electricity consumptions for this equipment were calculated depending on the both energy requirements and operation period.

12 Watt x 24 h/day x 365 days = 105.12 kW/year (electricity consumption of UV lamps)
1.1 kW x 6h/day x 365 days = 2409 kW/year (electricity cons. of the booster pump)

Total electricity consumption = 2409 + 105.12 = 2514.12 kW/year
Annual electricity cost = 2514.12 x 0.10$ / kW = 251.41 $/year

It was accepted that, the lifetime of UV lamps is around 8000 hours and they will be renewed at each year. Therefore, UV lamp costs were also considered as expenses. UV Lamp price was assumed as 70 $/year.

It was planned that wetlands will be re-planted at every year, so planting cost of 1400 $/year was added to annual operational costs.

Annual operational cost = Electricity + UV lamps + Planting

Annual operational cost = 251.41 + 70 + 1400 = 1721.41 $

Calculation of the amortization time for the Alternative 1:

Annual net saving money = Saving money from water invoice – operational costs

Annual net saving money = 1667.52 + 3116.88 – 1721.41 = 3062.99 $

Amortization time = Investment cost / Annual saving money

Amortization time = 18560 / 3062.99 = 6.06 year ≅ 6 year

Calculation of the amortization time for the Alternative 2:

Annual net saving money = Saving money from water invoice – operational costs

Annual net saving money = 1667.52 + 521.04 + 2810.52 – 1721.41 = 3277.67 $

Amortization time = Investment cost / Annual saving money

Amortization time = 18560 / 3277.67 = 5.66 year ~ 5 year 8 month

The results of the all calculations for both Alternative 1 and 2 are given in Table 4.7.

Table 4.10 Summary of the calculation of annual net saving money

	Income – Expenses* Alternative 1	**Income – Expenses* Alternative 2**
Water saving from toilet flushing	1667,52 $	1667,52 $
Water saving from other users toilet flushing	3116.88 $	-
Water saving from irrigation	-	521.04 $
Water saving from Car Wash Corporation	-	2810.52 $
UV lamp electricity consumption	- 10.51 $	- 10.51 $
Booster pump electricity consumption	- 240.90 $	- 240.90 $
UV lamp renewal cost	- 70.00 $	- 70.00 $
Re-planting cost of wetland plants	- 1400.00 $	- 1400.00 $
TOTAL	**3062.99 $**	**3277.67 $**
* Exchange rate is: 1 $ = 4.25 TL		

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Fresh water is vital for all living organisms, but there are limited fresh water sources on the earth. Water scarcity problem will be the one of the most significant issue in the near future. Therefore, natural water sources must be managed efficiently and the amount of fresh water consumption must be reduced by applying sustainable water management programs. Water reuse applications including greywater reuse are one of the important part of these programs. Typically, 60-65 % of the total wastewater flow is greywater and if this portion of wastewater is reused, significant decreases in fresh water consumptions is achieved.

The aim of this thesis was to evaluate the water saving potential of buildings via greywater reuse. For this purpose, a 5-story building was chosen as case study and the existed fixtures of this building were determined. The amount of total wastewater and greywater was calculated regarding to average accepted values. Total amount of wastewater and greywater was calculated as 9.6 m^3/day and 5.9 m^3/day, respectively. BOD_5, SS, TN, and TP concentration of greywater was accepted as 125, 50, 10, and 4 mg/L, respectively.

To collect greywater separately, some infrastructure modifications are required. Therefore, new fixtures were designed for the separation of greywater from black water and the cost of new fixture installation was determined. It was assumed that separately collected greywater will be treated by a constructed wetland system. As a result of the calculations, it was found that two wetland units will be installed with the dimensions of 24 m x 3 m x 0.7 m (Length x Width x Height).

It was assumed that treated greywater is pumped to the 5-m^3 storage tank and it is mainly used for toilet flushing and irrigation of garden. Applicability degree of reuse applications decreases with the increasing cost. In the scope of the thesis, both investment and operational cost of greywater collection, treatment, and distribution systems was calculated and the amortization period of additional investments was determined. Investment cost of the system was calculated as 18,560 USD and the amortization time was found to be about 6 years.

If it was assumed that the lifetime of the fixture system is 50 years, about 100,000 m^3 fresh water and 100,000 USD money may be saved for 50 years by reuse of greywater.

5.2 Recommendations

In the scope of this thesis, only one building was considered and the water saving potential was calculated for this building. However, the cost of the treatment system and the amortization time may reduce for larger scale applications. Therefore, this study might be developed for larger applications. If the number of buildings and flowrate increases, more complicated treatment options, such as membrane bioreactor, may be applied.

To renew the existing fixture systems for old building is more complex and expensive than the implement the separate fixture systems to the new buildings. For this reason, legal arrangements should be made for the separation of the greywater line in new buildings.

In case of greywater reuse in larger projects, the effects of decreases in the amount of wastewater discharging to sewage system and wastewater treatment plant should be taken into consideration.

The use of harvested aquatic plants for various purposes, such as biogas production, animal feed and fertilizer production, can provide additional cost advantage.

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APPENDICES

APPENDIX 1: Building Views

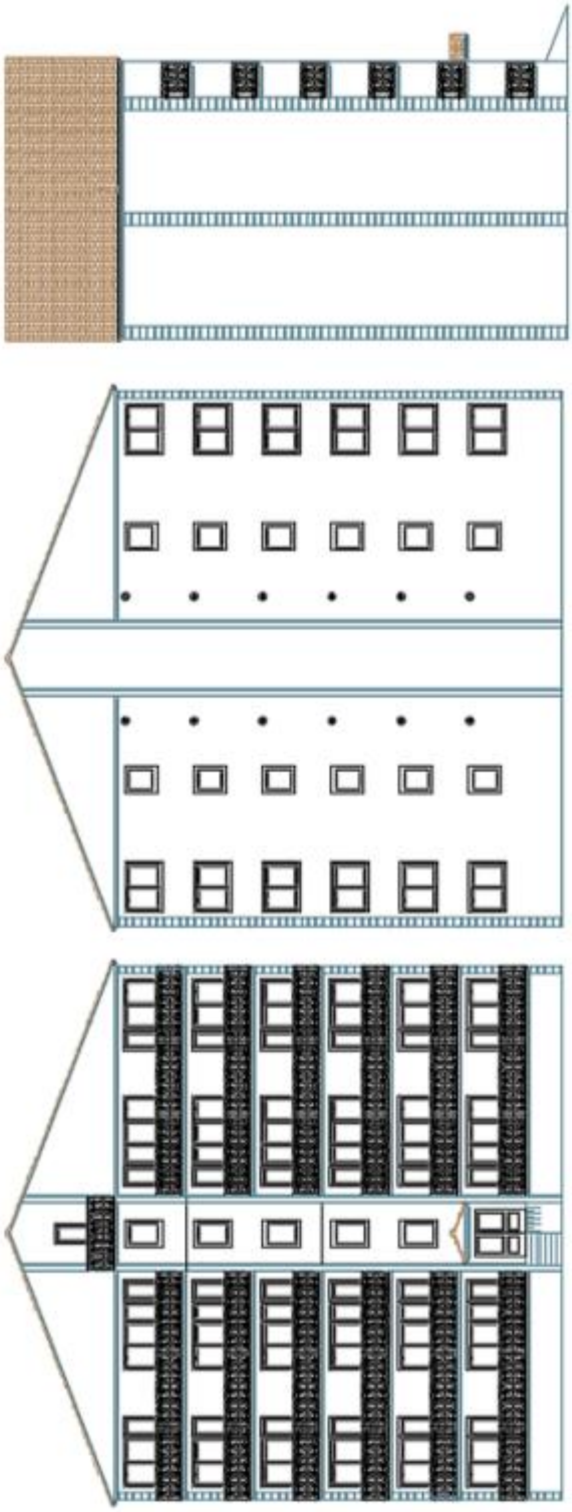

Figure A.1 Building Front View, Back View, Side View

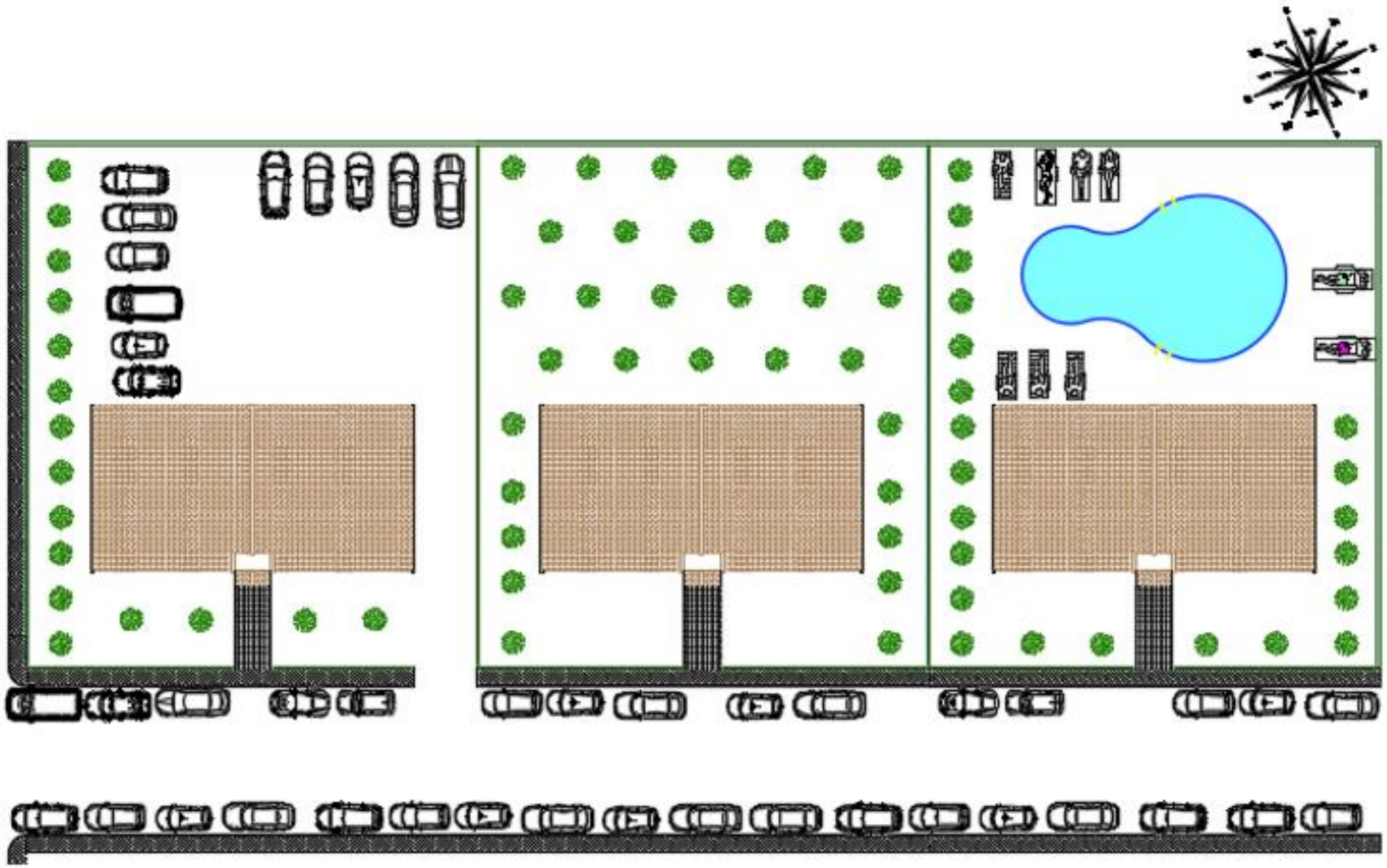

Figure A.2 Existing General Layout

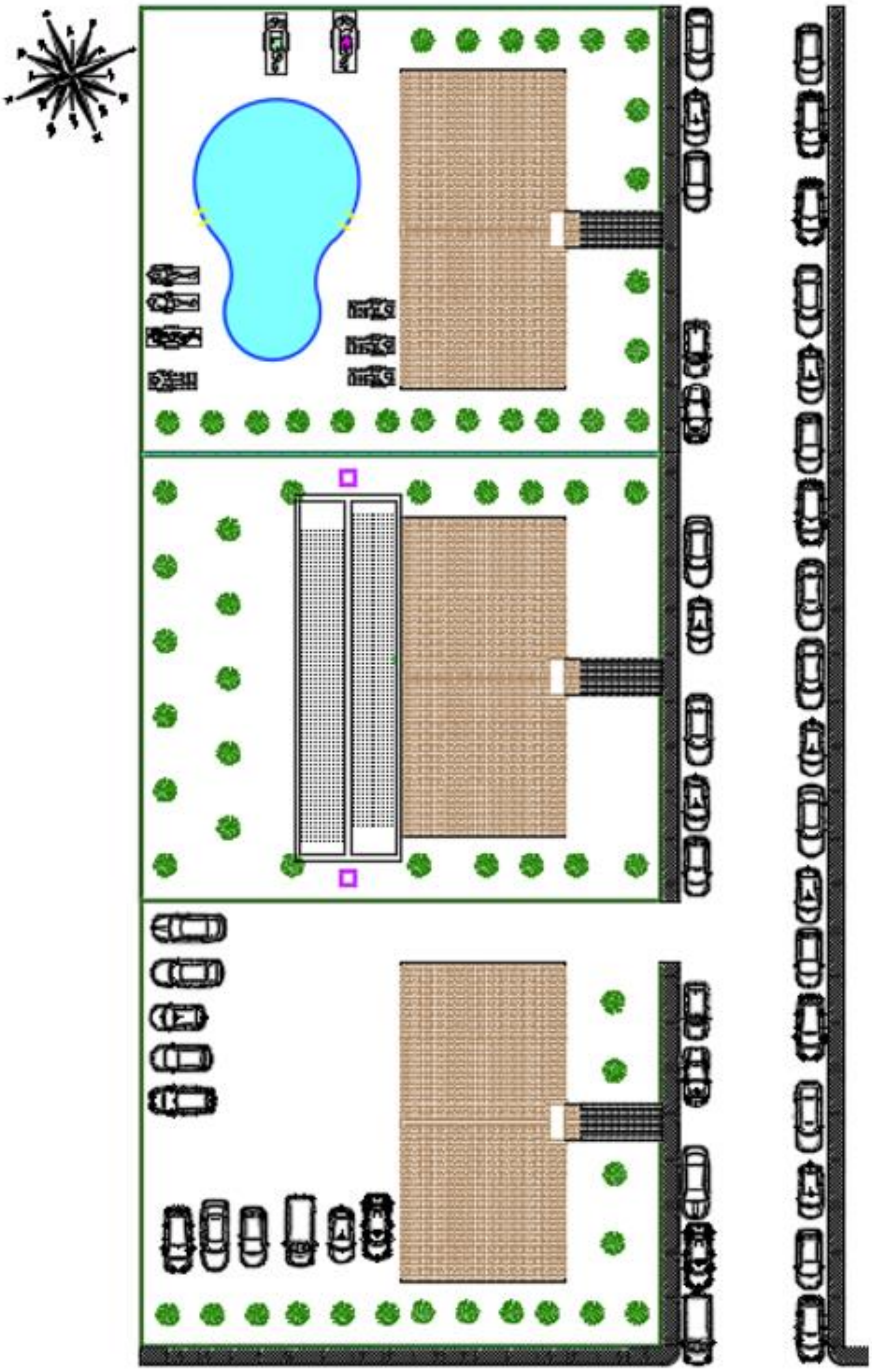

Figure A.3 New General Layout

APPENDIX 2 Building Plan Views

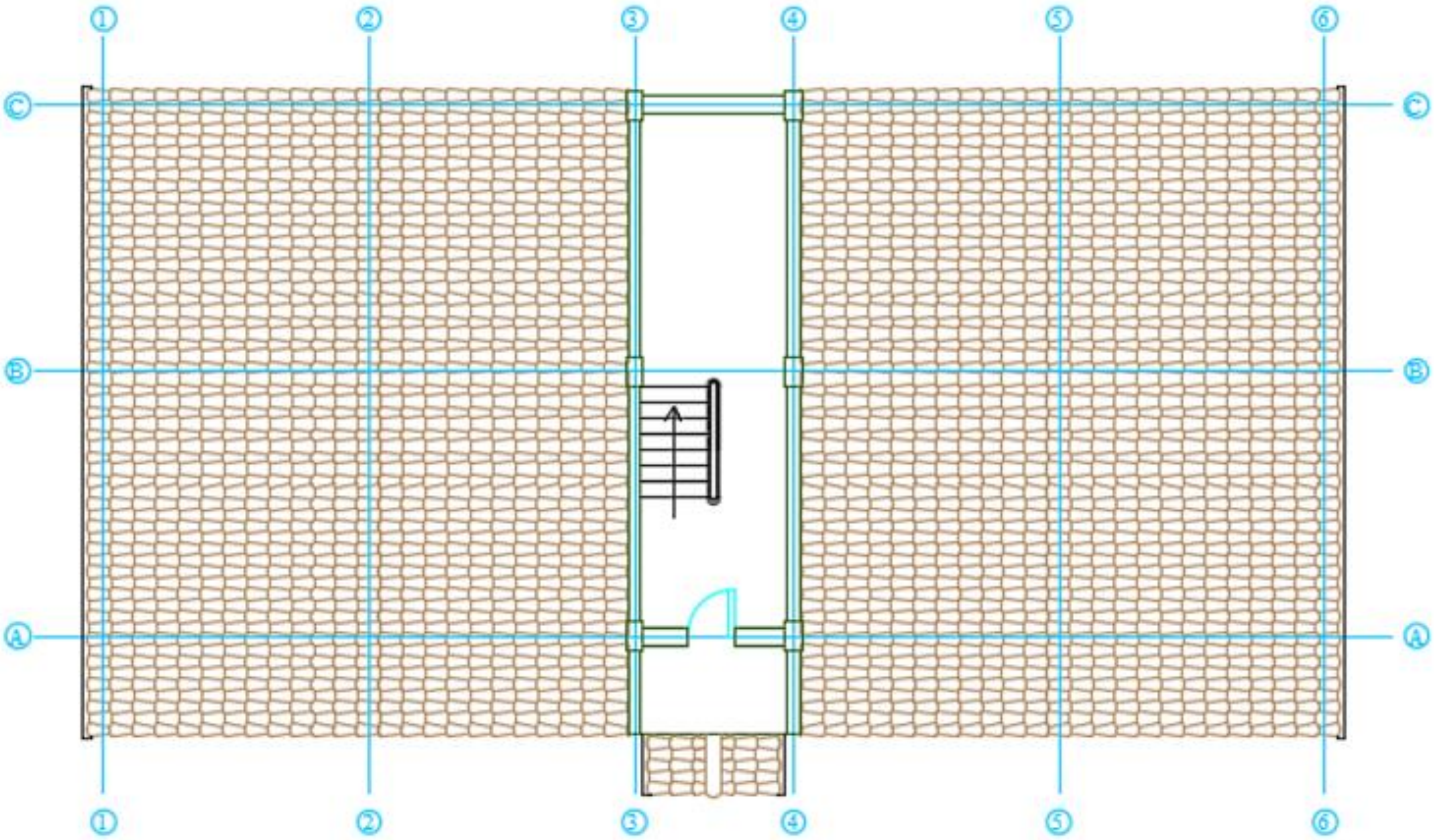

Figure A.4 Existing Penthouse Plan View

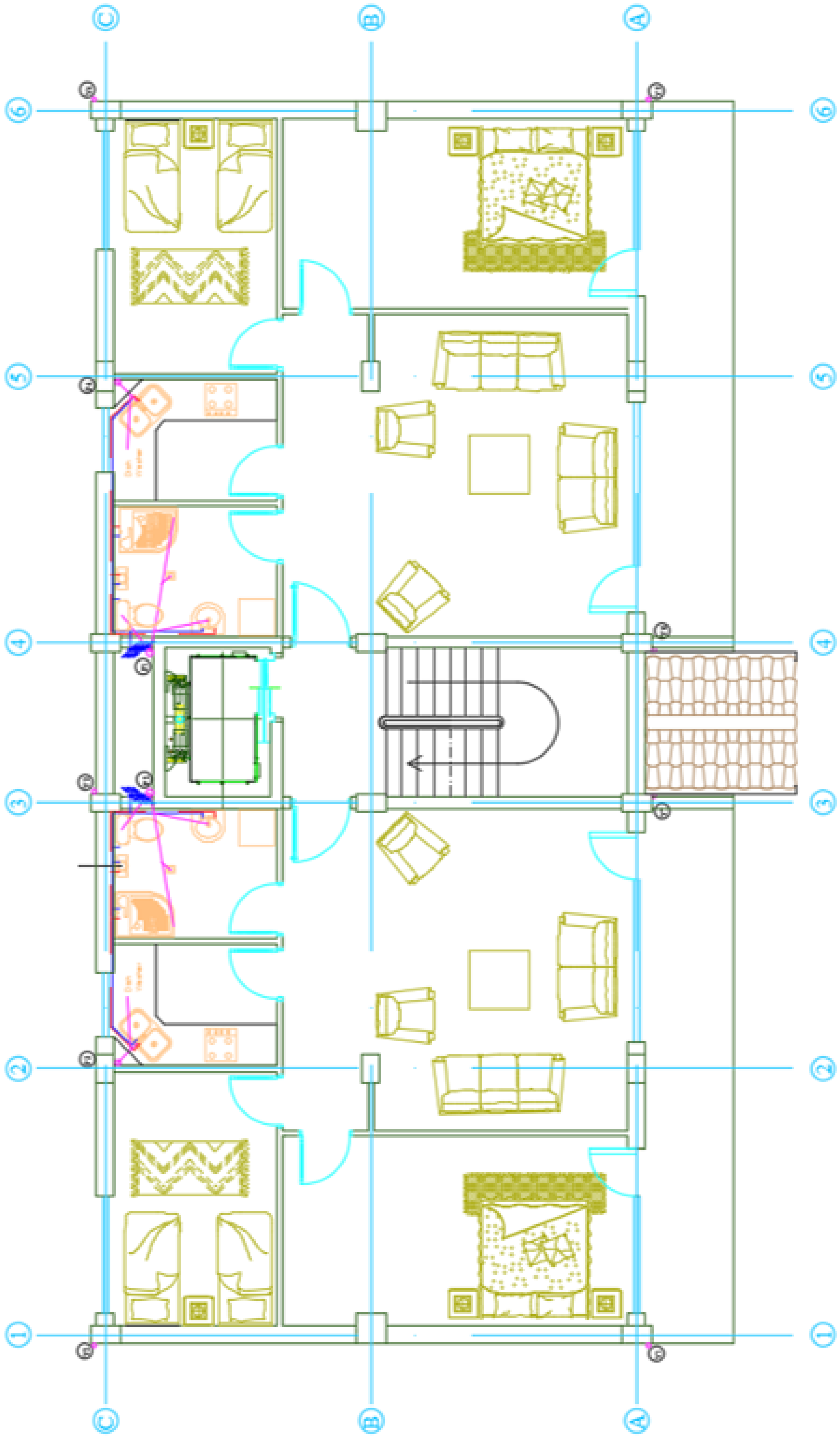

Figure A.5 Existing 1st – 5th Plan View

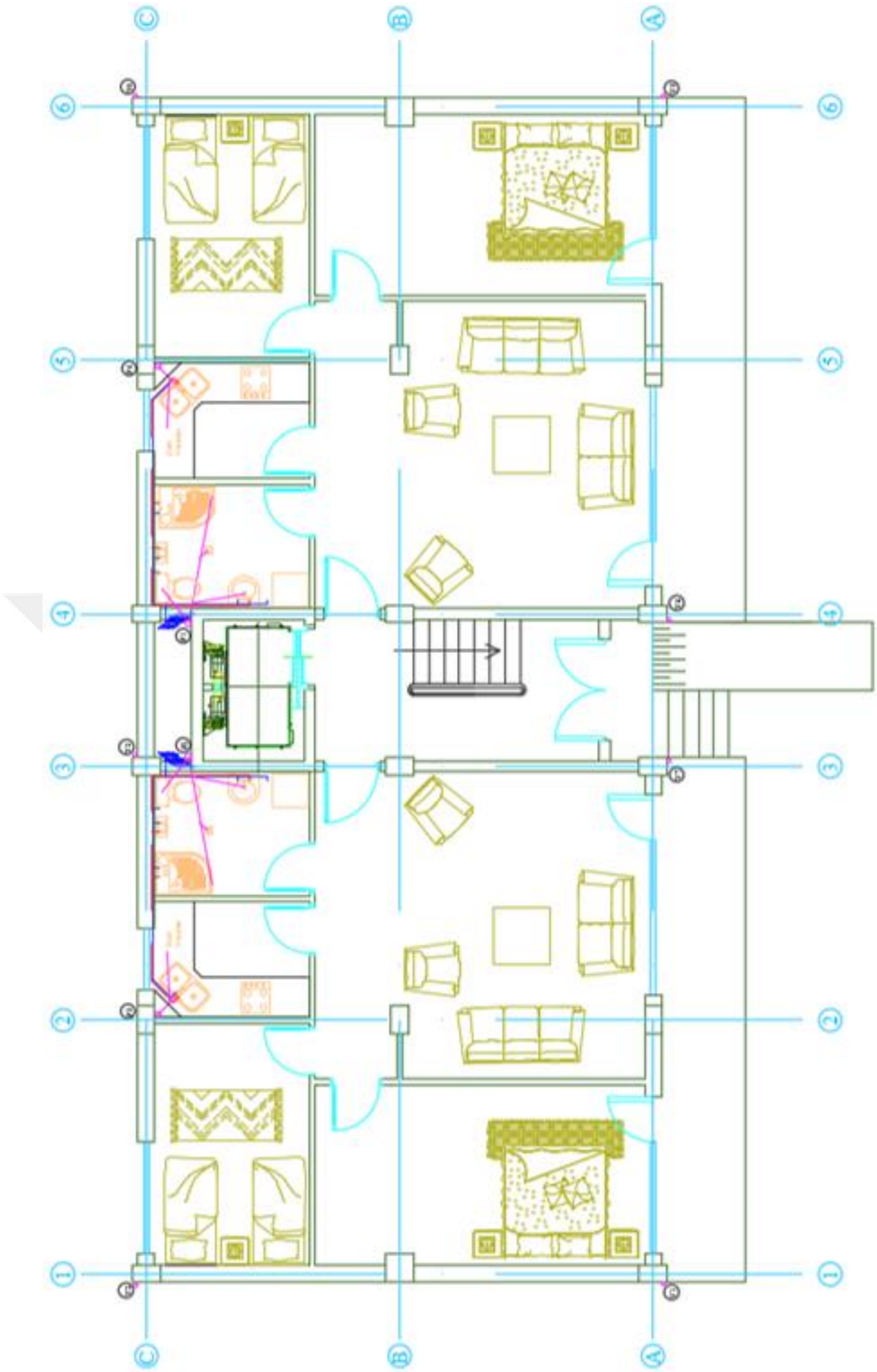

Figure A.6 Existing Ground Floor Plan View

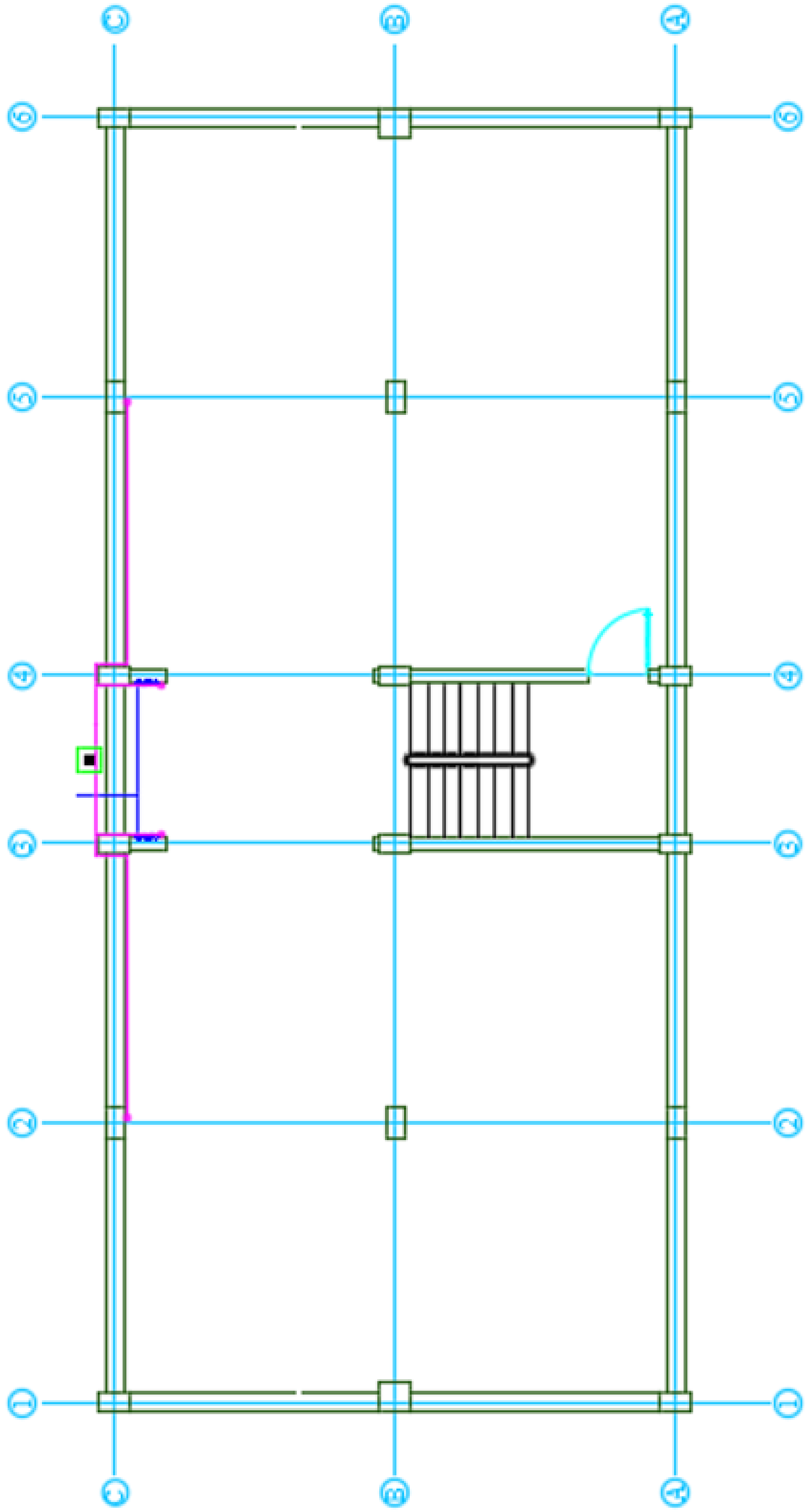

Figure A.7 Existing Basement Plan View

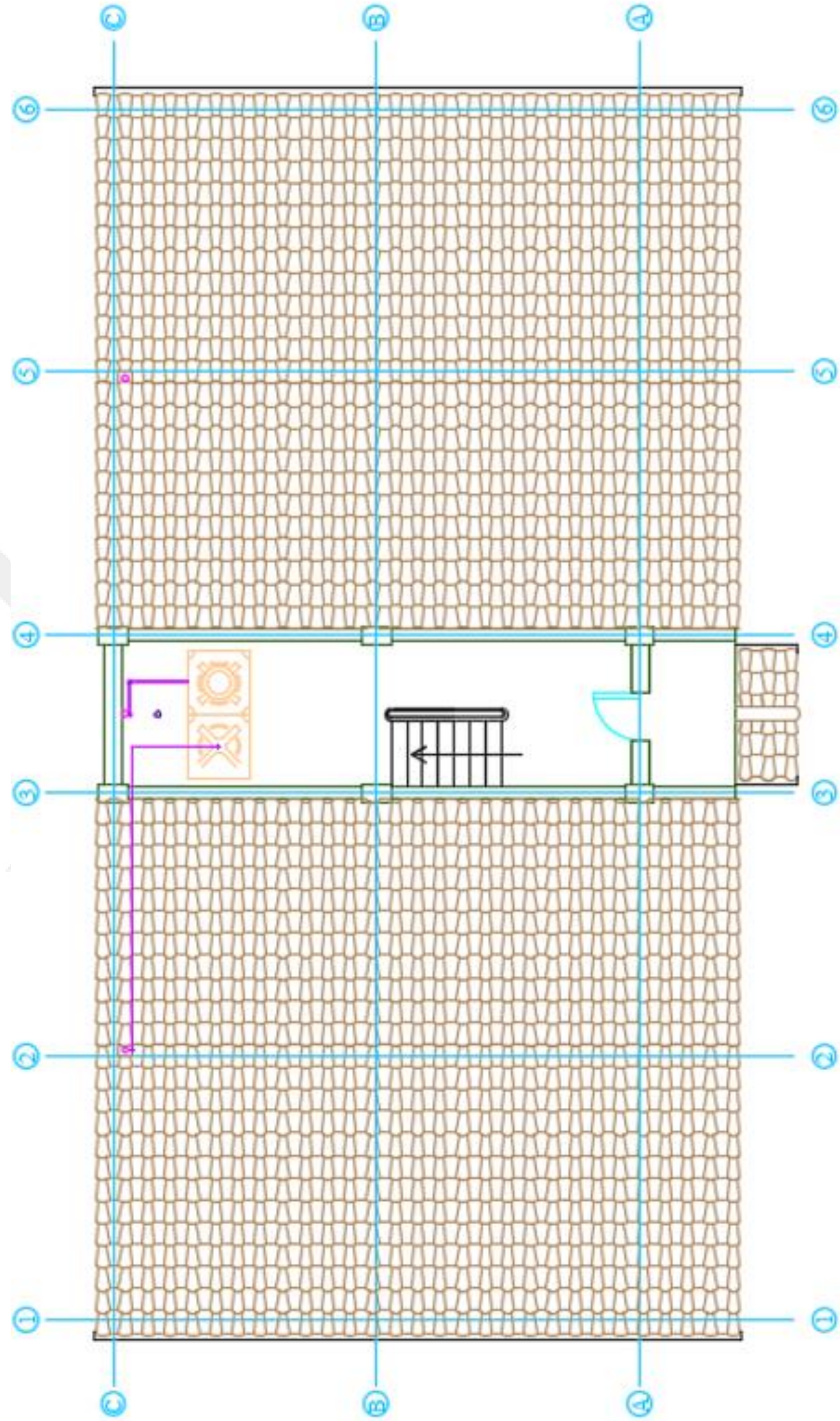

Figure A.8 New Penthouse Plan View

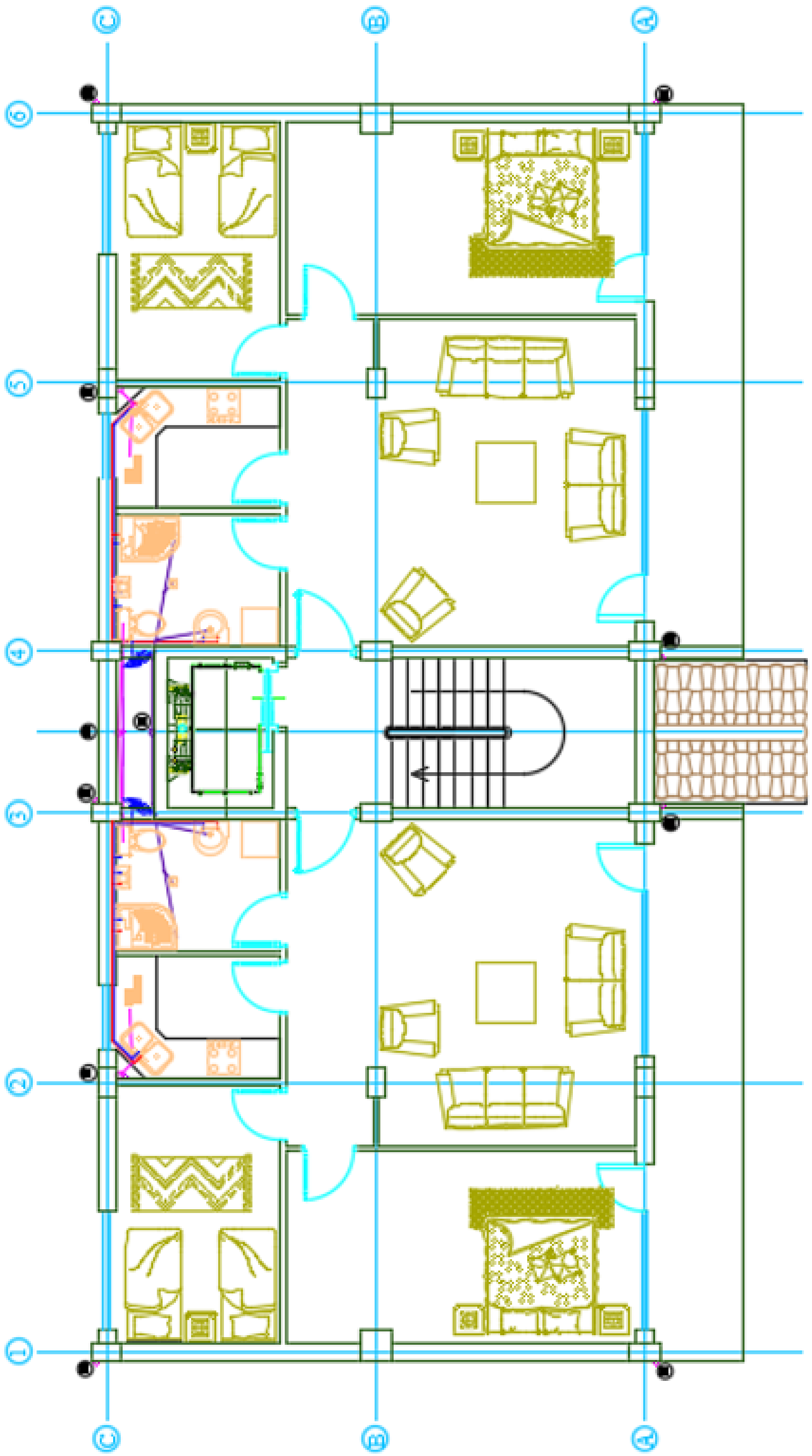

Figure A.9 New 1st – 5th Plan View

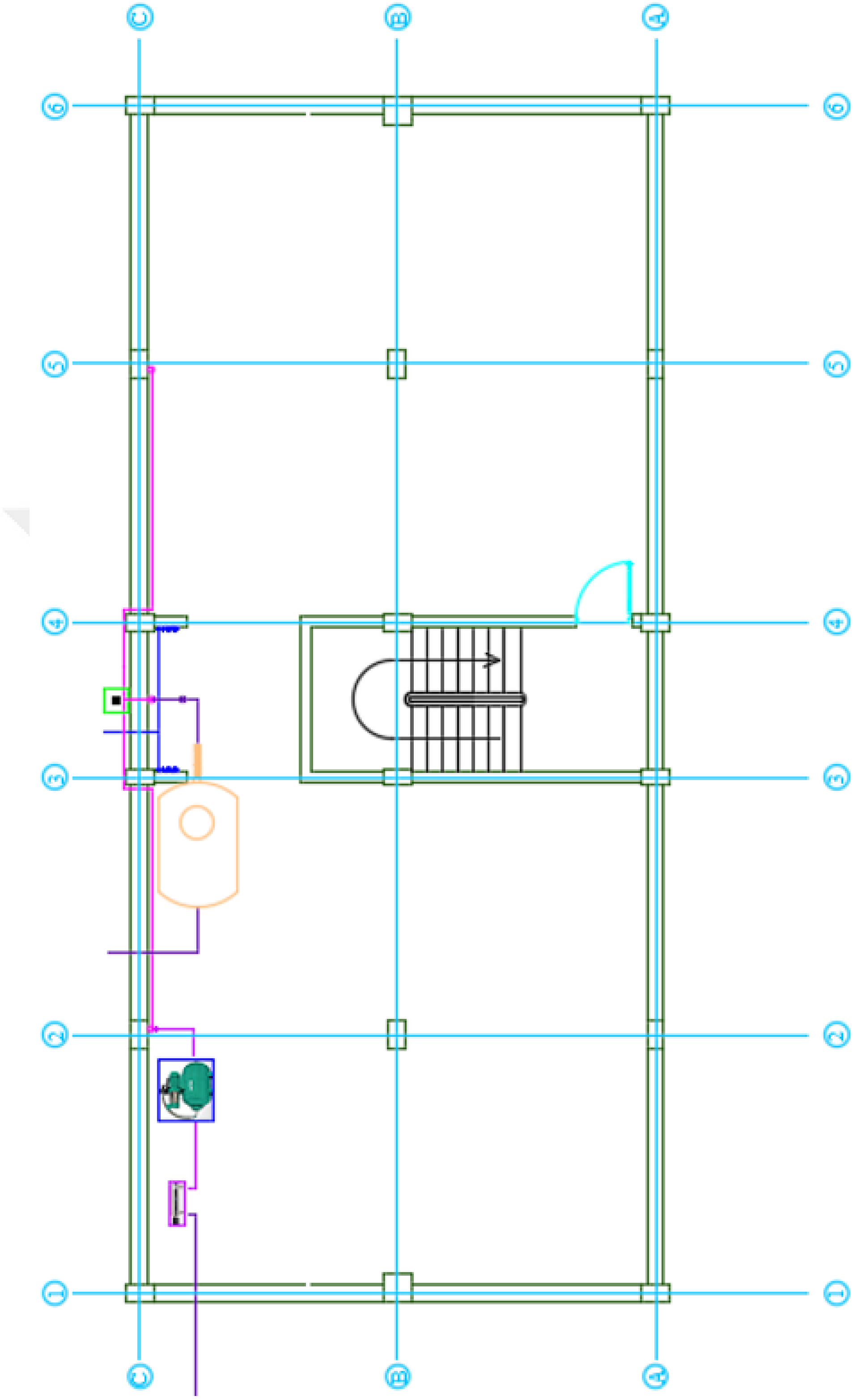

Figure A.10 New Basement Plan View

APPENDIX 3: House Water Distribution and Connections Pipes

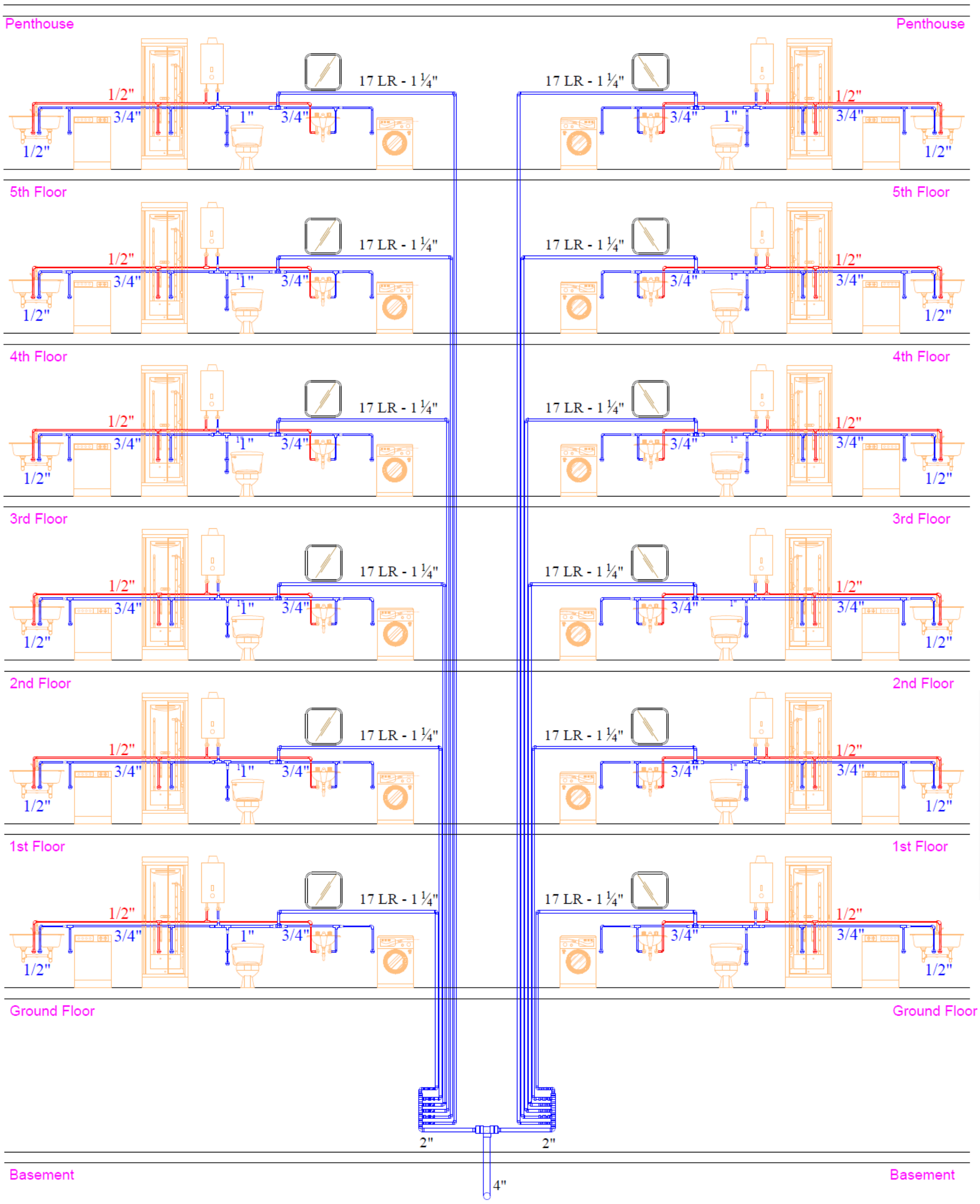

Figure A.11 Existing Fresh Water Piping System

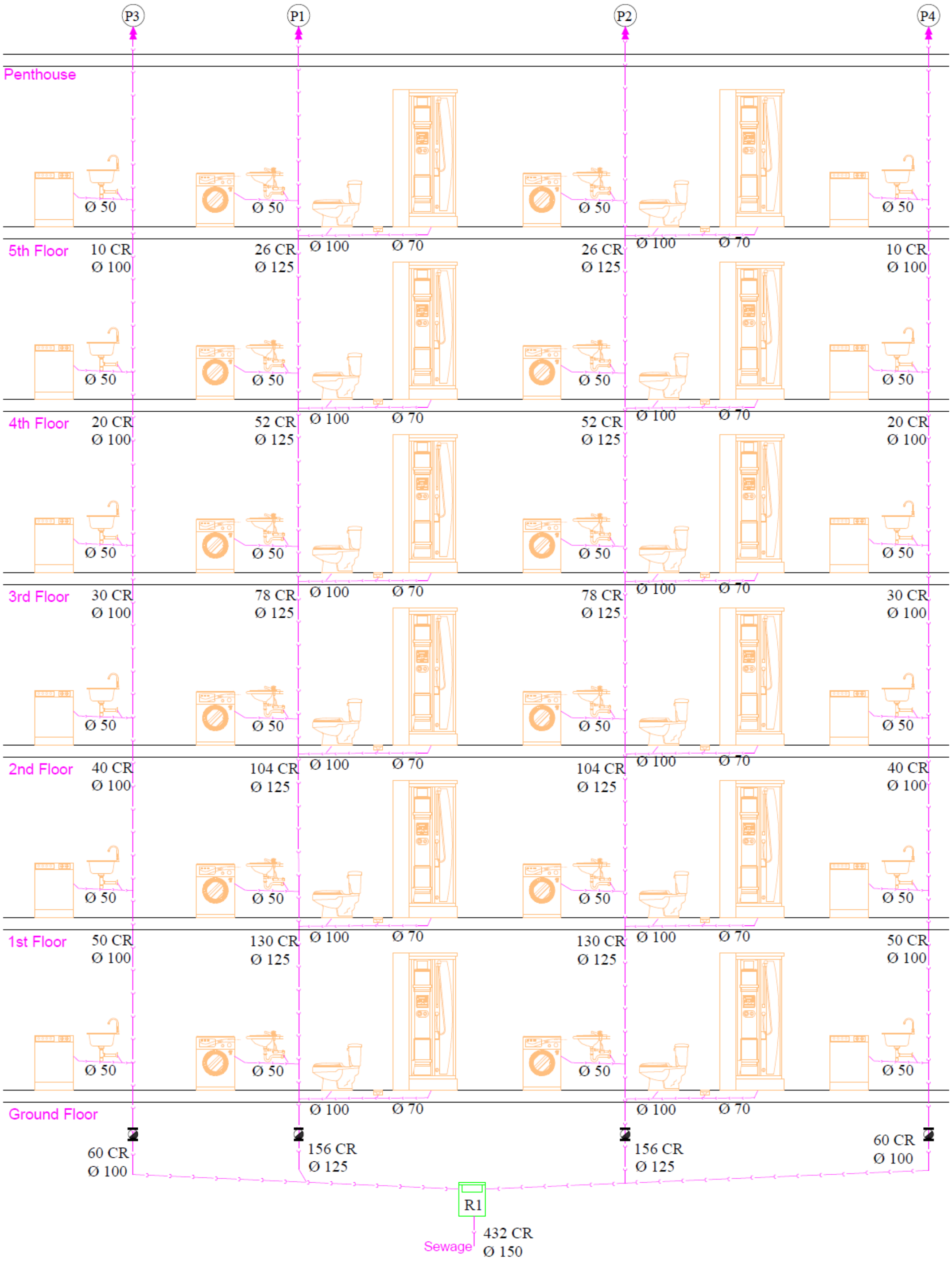

Figure A.12 Existing Wastewater Piping System

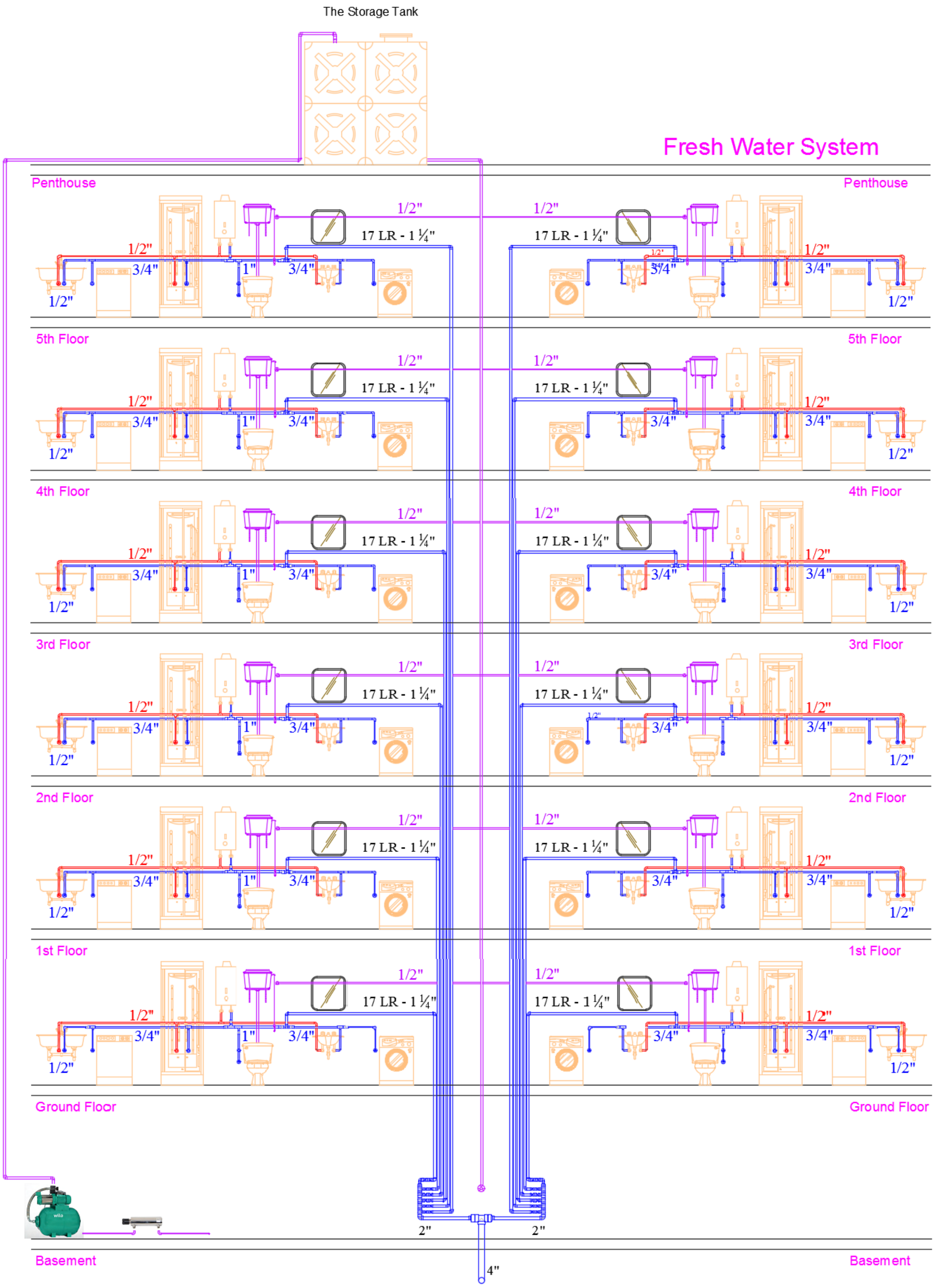

Figure A.13 Fresh & Grey Water Piping System

Figure A.14 Wastewater & Greywater Piping System

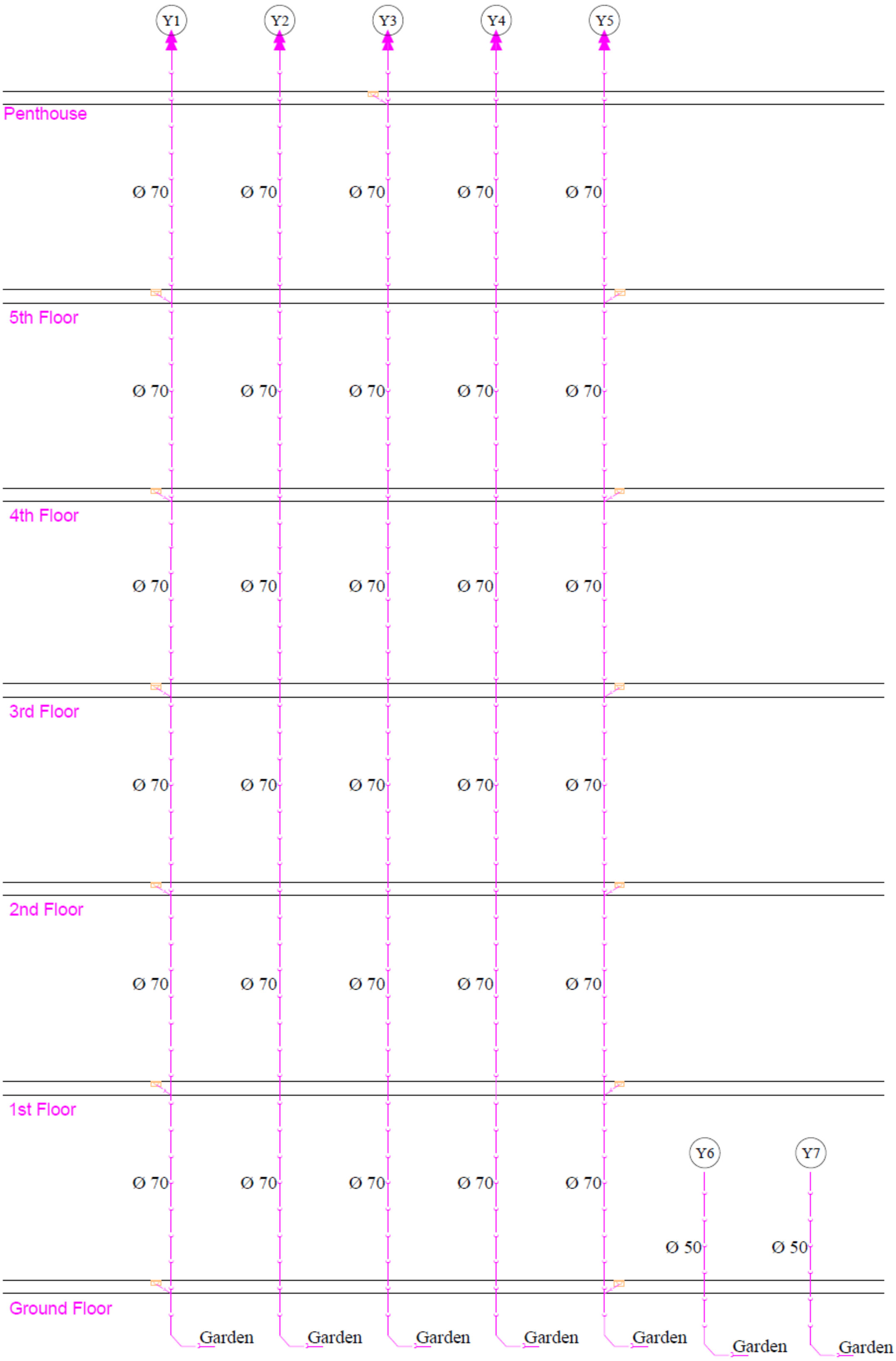

Figure A.15 Storm Water Piping System

APPENDIX 4 Wetland Detail Drawing

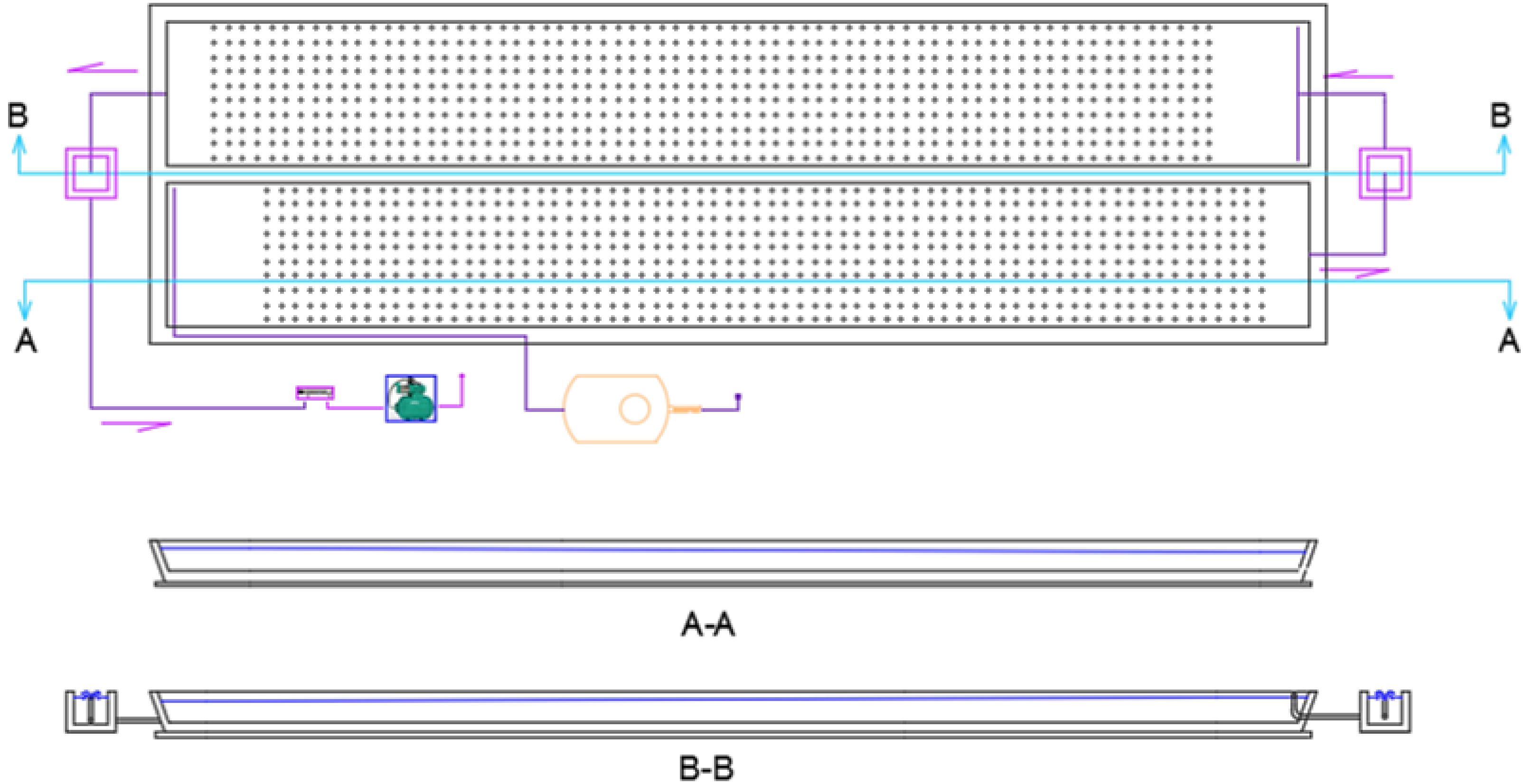

Figure A.16 Wetland Plan View, Section A-A and Section B-B