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Large scale constructed wetland implementation projects in Turkey in Salt Lake Special Environmental Protection Area

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ABSTRACT

Salt Lake, in ecological and economical terms, is one of the most important lakes in Turkey. The lake exhibits great biodiversity of plants because the lake and its basin are a natural habitat to various types of endemic plants which are resistant to a salty environment. The lake also serves as a habitat to many kinds of birds, especially flamingos. From an economic standpoint, Salt Lake meets approximately 70% of the salt requirement for Turkey. For this reason it is of great importance to preserve the natural environment of the lake. In addition to the various activities conducted for the environmental protection of the Salt Lake, a comprehensive constructed wetland (CW) project has been prepared and implemented for the towns of Sultanhani and Altinekin, where the population is expected to reach approximately 5000 by the year 2037. It entails the largest and most important subsurface-flow constructed wetland systems(CWs) in Turkey. Many site surveying research projects have also been conducted to support this detailed CWs engineering project. Each step of the project preparation and application are detailed in this study. A great deal of experience has been gained by Turkey and Mediterranean countries on large scale CWs.

Keywords: Constructed wetland; Lake ecology; Salt Lake

1. Introduction

1.1. General features of working area

According to [1] the Salt Lake report, it is one of the most important wetlands in Turkey. It covers an area of around 7,414 km^2 and is recognized as a Special Environmental Protected Area (Fig. 1). Salt Lake is located in the Central Anatolia Region, in the northeast of the lowest part of the valley and is surrounded by Kızılırmak Massive in the east, Obruk in the south, Cihanbeyli in the west and Haymana plato in the north. It is officially within the borders of the cities of Ankara, Konya and Aksaray. Located in a closed basin, the lake is geologically tectonic

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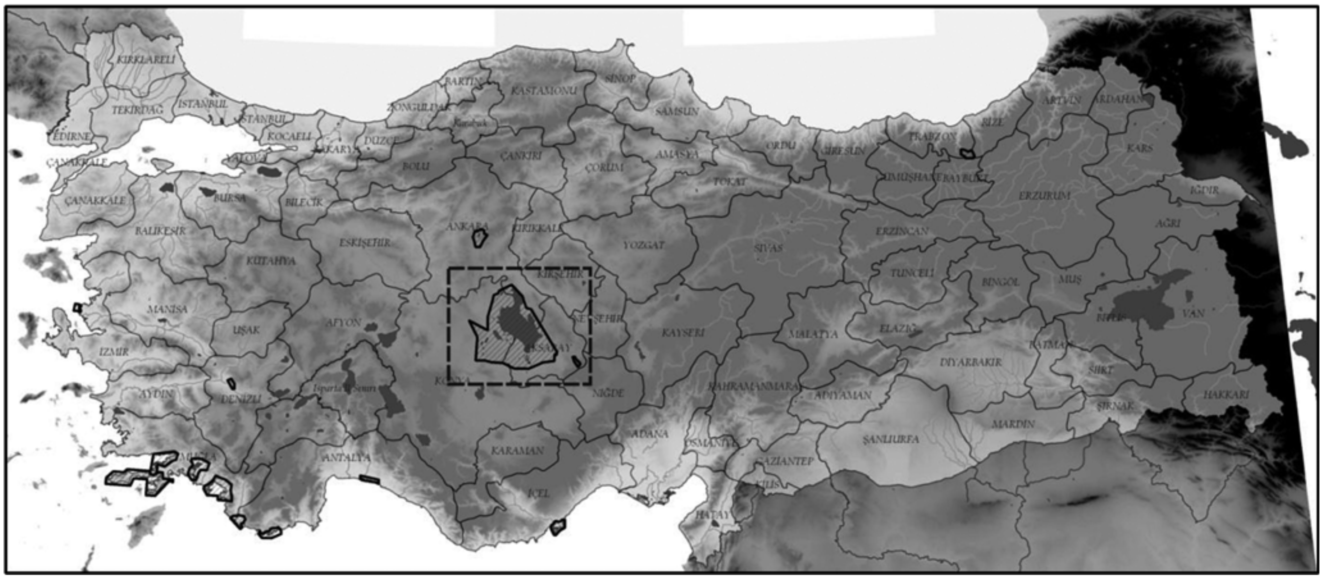

Fig. 1. Location of the studied area.

originated. In spite of its relatively large surface area, it is one of the shallowest lakes in Turkey. The depth doesn't even reach 0.5 m in many parts. In spring months when the water is abundant, the lake area reaches 164,200 hectares. This part is a closed basin and the altitude of Salt Lake from sea level is 905 m. It is located in the part of Turkey which has the least rain. The water courses carrying water to the lake are very poor in terms of water flow rates. The water courses to highlight are those of: Bağlıca, Kırdelik and Peçenek which comes from Şereflikoçhisar in the east, the General Directorate of State Hydraulic Works (SHWs) Konya drainage channel in Konya in the southwest, İnsuyu coming from Cihanbeyli in the west and Uluırmak coming from Aksaray in the southeast. Some of the water courses dry in summer months and don't reach the lake; due to the impact of excessive evaporation, almost all parts of the lake dry. A 30 cm salt layer emerges on the dried parts. It is one of the most salty lakes in both Turkey and the World. The density of water is 1–22.5 g/cm^3. The salt rate is 32.4%.

The lakes in close relationship with Salt Lake together constitute an important ecosystem. The lakes around Salt Lake are Tersakan, Lake Bulluk and Lake Kulu. With its broad water area, Salt Lake is an important wintering region for water birds. According to international criteria, it is a class A wetland. In Spring, islands emerge inside the lake and the swamp near the lake incubates Common Shelduck (*Tadorna tadorna*), Ruddy Shelduck (*Tadorna ferruginea*), Common teal (*Anas crecca*), Caspian Plover (*Charadrius asiaticus*), Stone curlew (*Burhinus oedicnemus*), Slender-billed Gull (*Chroicocephalus genei*), (Caspian Gull) *Larus cachinnans*, Collared Pratincole (*Glareola pratincola*). The ornithological importance of the lake is that it is the incubation region of the biggest flamingo colony in Turkey. 70% of the salt requirement of Turkey is provided from Salt Lake [1].

The lake is also important for economic reasons. Due to a large population around the ecologically interactive lake, Specially Protected Environment Areas and the Salt Lake Specially Protected Environment Unit have, to date, successfully accomplished many important projects in order to prevent the surroundings of the lake from being contaminated with waste. These projects can be summarized as: water quality observation conducted regularly each year, Salt Lake water resources management, Salt Lake environmental plan, various construction projects, construction plan applications of Salt Lake Special Environmental Protection Unit, various infrastructure investments such as potable water, sanitation, regular solid waste storage plants and solid waste transfer stations. In addition to this, one of the most important projects is the disposal of domestic wastewater in order to protect Salt Lake and its surroundings. As part of these projects, the construction of Sultanhanı and Altınekin natural wastewater treatment systems has been completed and these treatment systems have become the biggest two treatment systems in Turkey.

The domestic wastewater treatment requirement is the most important issue. In a test conducted on the regional land and the effect of human activity, it was seen that the heavy metal content has been increasing and an increase is especially detected in the summer months. It was pointed out that one of the reasons for this was the domestic wastewaters [2].

Studies on the treatment of domestic wastewaters with natural methods have gained impetus in Turkey since the year 2000. For this purpose, primarily, studies on the wastewater problem of the small residential areas have been carried out by public corporations. Besides this, many universities and other research institutions have also tried to develop practical projects on treatment systems [3–9].

The constructed wetland systems (CWs) are an ecological wastewater process and needed for sustainable wastewater treatment management. These systems are of great importance for both the wastewater treatment and the protection of the environment through natural methods. The CWs are commonly used in places whose population equivalent is less than 1,000 people. The number of wetland systems constructed for the treatment of domestic wastewater of residential areas whose population equivalent is more than 1,000 people is around 5 in Turkey. The systems constructed for 5,000 people are located in Sultanhanı and Altınekin residential areas and the larger natural wastewater treatment systems have not yet been constructed. Observing the practices in other parts of the world reveals that wetland systems which are especially constructed for further treatment of domestic wastewater coming from secondary treatment are located mainly in the United States of America and various European countries.

The main objective of this study is to share experience obtained from related topics on the design, construction and cost of large-scale natural treatment systems. Because the number of such large-scale systems is limited and it is also difficult to find case studies based on experiences in the available literature. So, this study will provide important contributions on the extension of the application of natural treatment systems in settlements with a population of over 5,000. It is possible to find many publications, from different sources, which address subject matters similar to the ones in this study, which aim at being a reference to researchers and practitioners by processing the experience that has been gained [10–13].

2. Materials and methods

2.1. The most suitable natural treatment system selection

For the treatment of the domestic wastewater in Sultanhanı and Altınekin located inside the Salt Lake Special Environmental Protected Area, treatment systems have primarily been constructed for these residential areas by Special Environmental Protection Corporations. Many projects have been conducted by teams in order to construct the most suitable natural purification systems at the points where sanitary systems end (Sultanhanı residential area, Kındırkova district, and Altınekin residential area Koçyiğit district) and it was decided that a "horizontal subsurface flow CWs" was the most suitable system. The reason was that it was the first time treatment systems had been proposed on such a large scale and horizontal subsurface flow CWs were acknowledged worldwide to cause fewer problems. The biggest problem in natural systems is the problem of clogging. Although there is little information about clogging, some reasons for it are assessed in relation to various factors in the available literature [14–21]. But among the existing CWs, the "horizontal subsurface flow CWs" is known to be the one that works with the fewest problems (e.g. [22].

The current population of the Sultanhanı residential area is 3,630 and according to the 30 years population projection conducted [23], it was estimated that it will be 4,892, approximately 5,000 people by then. Similarly, the projected population of the Altınekin residential area, whose current population at the centre of the residential area is 3,711, was estimated to become 5,001, approximately 5,000 people. Since reliable data could not be obtained for wastewater production reaching the sewerage system of both residential areas, it was estimated at 100 l/day per person. It was deduced that the estimated capacity for the discharge of a sewerage system judging from the Altınekin residential area's main water consumption data was a value that could also be used for Sultanhanı. According to a study on water consumption trends based on the population of Turkey [24], the water consumption per person for residential areas such as Sultanhanı and Altınekin should be taken as 70 l/person-day. But considering the changes in water consumption today, it was agreed to take this value as 100 l/person-day and it was also seen that the water consumed simultaneously reached the sewerage system.

Wastewater samples, taken from some points where wastewater discharge was carried out in sewerage systems, were tested in TUBITAK MRC accredited laboratories in accordance with Standard Methods [25]. The measured wastewater quality parameter method listed below: suspended solids (SS) (SM-2540 D.), biochemical oxygen demand (BOD_5) (SM-5210 B 5-Day), chemical oxygen demand (COD) (SM-5220 B Open Reflux Method) and a WTW Level 1 Multi Parameter brand instrument was used for pH. The wastewater characteristics of both residential areas are given in Table 1. The typical COD/BOD ratio value for municipal raw wastewater is in the range of 1.25–2.5,

Table 1
Domestic wastewater characteristic of Sultanhanı sewerage system

Parameters	Unit	Results—Sultanhanı	Results—Altınekin
BOD_5	mg/L	120	228
COD	mg/L	288	780
SS	mg/L	108	530
pH	–	7	7

while it is 10 or more for industrial wastewater [26]. So, the BOD/COD ratio value for Altınekin was slightly higher than in Sultanhanı because of industrial wastewater access to the sewerage system in some areas (such as vehicle maintenance and repair shops).

Since wastewater connections to the sewerage systems were not fully completed in Sultanhanı and Altınekin residential areas, considering the obtained wastewater characterization, the BOD_5 value constituting the basis in wastewater system design was estimated to be 250 mg/l which was a secure value for both residential areas. This estimated value has a medium strength wastewater composition according to literature on the subject [27].

2.2. Working principle of treatment systems

The working principles of treatment systems designed for both Sultanhanı and Altınekin residential areas are identical. As may also be seen in Figs. 2 and 3, following the sewerage system, wastewaters are carried to a pumping station by gravity. The wastewaters are pumped into Imhoff tanks on the upper level with submersible pumps. At the end of the hydraulic retention time in Imhoff tanks (after 6 h), wastewater is carried to main distribution manholes by gravity. The wastewater is carried to secondary manholes from main distribution manholes which reach the CWs. Effluents of CWs are discharged to the interceptor sewer after treatment, and then to the receiving environment.

2.3. Imhoff tank design

In order to minimize the biggest problem in natural treatment systems (except stabilization ponds or lagoons), which is clogging, there is a need for a settlement tank with at least two sections or an imhoff tank capable of providing a similar capacity or a septic tank. Thus, for these projects, the preferred systems for pretreatment are imhoff tanks, one per each residential area. The reason for the preference of this system is both the difficulty and cost of constructing 3 compartment septic tanks, which are widely used in Turkey, and to prove the performance of imhoff tanks by using them on a large-scale natural treatment system for the first time in Turkey. The design of the imhoff tank is conducted by considering the retention times of raw wastewaters in imhoff tanks, determined as 6 h. Before pumping wastewater into wetland systems, the minimum retention time in pre-treatment systems should be two hours (http://www.defence.gov.au/jlc/Documents/DSCC/ADF%20Health%20Manual%20Vol%2020,%20part8,%20chp2.pdf). But it was found to be better to determine it as 6 h in order to prevent clogging in wetland systems and to get better results.

2.4. Horizontal subsurface flow constructed wetland system design

For the design of treatment systems, [28], Eq. (1.1) was used.

$$A_s = \frac{Q \ln(C_o/C_e)}{K_T y n} \tag{1.1}$$

where A_s = surface area of wetland, m^2; C_o = influent BOD, mg/L; C_e = effluent BOD, mg/L; K_T = tempera-

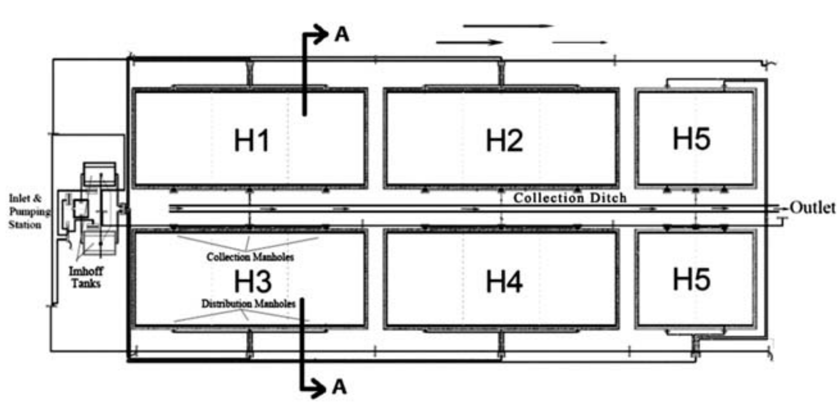

Fig. 2. Plan view of the constructed wetland systems.

ture-dependent rate constant [0 d^{-1} at 0 °C; 1.0 (1.15) $(T-20)$ d^{-1} at 1°C +)]; n = porosity of the wetland, 0.65–0.75; l = hydraulic residence time, d; y = depth of water in the wetland, m; Q = average flow through the wetland, m^3/d.

The detailed parameters for the design of treatment systems are given in Table 2. The layout plan for natural treatment systems CWs designed for Sultanhanı and Altınekin residential areas is presented in Figs. 2 and 3, as given. As may also be seen in the layout plan, the treatment systems, respectively include these compounds: screenings, wastewater pumping station, two imhoff tanks, wastewater main distribution manholes, wastewater secondary distribution manholes, constructed wetlands, wastewater interceptor manholes and interceptor sewerage discharging the treated water. In addition, the sludge taken from the imhoff tank at certain intervals will be dried at sludge drying beds.

The wastewater is first pumped to the imhoff tank by pumping stations, pre-treated with imhoff tanks and then given to distribution manholes. The wastewaters are carried by gravity to the CWs after being pre-treated. The pre-treated wastewater is distributed to wetland systems through pumping stations. In this way, it is enabled to equally distribute the wastewaters to the treatment units in the wetland systems.

Since climate is the most important factor affecting the performance of treatment systems, the local climate conditions have been taken into account for the design of the treatment systems. The minimum temperatures during the winter period have an important role in determining the dimensions of treatment systems.

Another important factor to be taken into account for the design of treatment systems is to equally distribute the wastewaters inside the treatment bed. Thus preventing short-cuts and enabling the connection of the whole treatment bed with the wastewater. For this reason, after the design of the wetland systems, the most efficient treatment system should ideally include 5 parallel beds. But in order to facilitate the graded implementation, the last purification bed was equally divided into two parts. By doing so, all the treatment beds were symmetrically divided into two parts. This type of configuration also prevents the complete system failure due to any possible future problems with the system. Moreover, since it is a mod-

Table 2
Constructed wetland design criteria

Design parameters	
Population (person)	5,000
$Q_{minimum}$ (Approximate daily flow) (m^{3}/day)	500
Maximum daily flow = $3Q_{minimum}$ (m^3/day)	1,500
Daily flow per person (l/person.day)	100
Daily organic load per capita (grBOD_5/capita-day)	25
Minimum water temperature (℃)	6
Water height inside the treatment bed (HF) (m)	0.70
Hydraulic slope inside the treatment bed (S)	0.010
Treatment bed slope (%)	1
Porosity of treatment media (n) (Note: Gravel diameter 8 mm)	0.35
Theoretical hydraulic conductivity (ks) (m^3/m^2 day)	500
Inlet organic load (after pre-treatment) as BOD_5 (mgO_2/lt)	250
BOD_5 removal at 6℃ (%)	92.7
BOD_5 removal at 14℃ (%)	98.5
BOD_5 removal at 24℃ (%)	99.94
Total treatment area (m^2)	11,000
Configuration of the systems (5 unit paralel treatment bed)	5 Horizontal flow constructed wetland
Geometry of the treatment beds	
Every single treatment bed area (m^2)	2,190
Width (m)	73
Length (m)	30
Inlet depth (m)	0.55
Outlet depth (m)	0.85
Hydraulic retention time in every single bed (day)	1.08
Total hydraulic retention time in treatment beds (day)	5.39

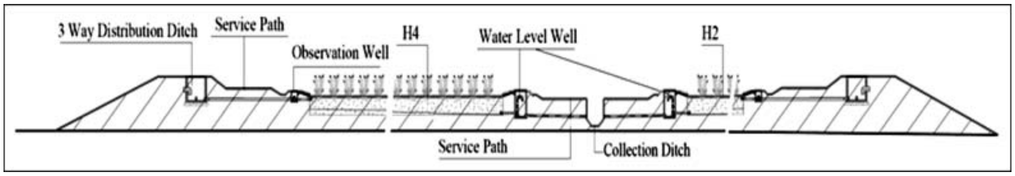

Fig. 3. A–A section of the constructed wetland systems.

ular system, according to the wastewater capacity to be allocated for treatment systems, the system could be operated on full capacity or at various ratios.

2.5. Plantation in wetland system

The plant most commonly used in wetland system is *Phragmites australis*. The root depth is approximately 70 cm and it is known that this plant could be grown in almost all climate conditions. During the start-up periods of wetland systems, it was enough to plant 4–10 plants (seedling) per m^2. The plant number per m^2 reaches 50–125, by the end of each year.

2.6. Sludge drying bed

The sludge drying bed to be planted just near the imhoff tanks will be used as a unit for both solid waste collected with a sieve system and sludge and inorganic wastes discharged from the bottom of the imhoff tanks. By using a *P. austrialis* type reed bed in this unit, it will be possible both to dry treatment sludge more quickly and to accelerate the composting process. The area suggested for sludge drying varies between 0.4 and 0.5 m^2 /person. In this project, 0.5 m^2 /person values have been selected. Therefore, sludge drying bed areas for both the Sultanhanı and Altınekin residential areas was estimated at 2,500 m^2. Feeding intervals: once a month in vegetation period, all beds will be simultaneously fed (parallel). The flow capacity of feeding systems is: 0.3–0.6 $m^3/(m^2\ h)$. Operation in climates in which vegetation is not performed: It was not recommended to continue feeding during winter months.

3. Construction of treatment systems

3.1. Construction of pumping stations

Wastewater pumping stations were constructed for both residential areas where the sewerage systems ended. Since the water level was high at the point and surrounding where the sewerage system ended in Sultanhanı residential area, special measures were needed to be taken for the wastewater pumping station. For this reason, the base of the pumping station was enforced with stakes and in order to prevent groundwater leaking to the pumping station, leak proof concrete was used. Leak proof concrete was also used in Altınekin residential area. Measures were taken against break ups and high flows and spare pumps were added to pumping stations.

3.2. Imhoff tank construction

The schematic representation of CWs constructed in the Sultanhanı and Altınekin residential areas are given in Figs. 4 and 5. The slope of land is quite low in both residential areas and the distance between the residential area and the treatment system construction point is considerable. For this reason, in order to enable both sewerage systems a certain wastewater flow slope, a deep sewerage system was constructed. A large part of the imhoff tank necessary for pre-treatment was also constructed embedded in soil. The reason for constructing 2 imhoff tanks per each residential area is both to have a spare tank to operate in case of a problem and to enable more reliable imhoff tank statics. It was also important not to build a structure that is hard to construct, fragile or bulky. In order to get sludge from the imhoff tanks and dispose of it at certain intervals, the submersible pumps were mounted.

3.3. Construction of wastewater distribution manholes

Wastewater distribution manholes (Fig. 6) are the structures that enable equal distribution of wastewater coming from the imhoff tanks to the constructed wetlands. The distribution manholes are constructed after the imhoff tank has 5 distribution cells. These structures were required to be constructed more sensitively in order to distribute wastewater equally.

3.4. Construction of subsurface flow constructed wetland systems

Since the Sultanhanı and Altınekin residential areas are close to each other, they have similar climate conditions and land features. For this reason, the same dimensioned CWs were constructed in both residential areas. Sultanhanı and Altınekin were graded considering the current wastewater flow of

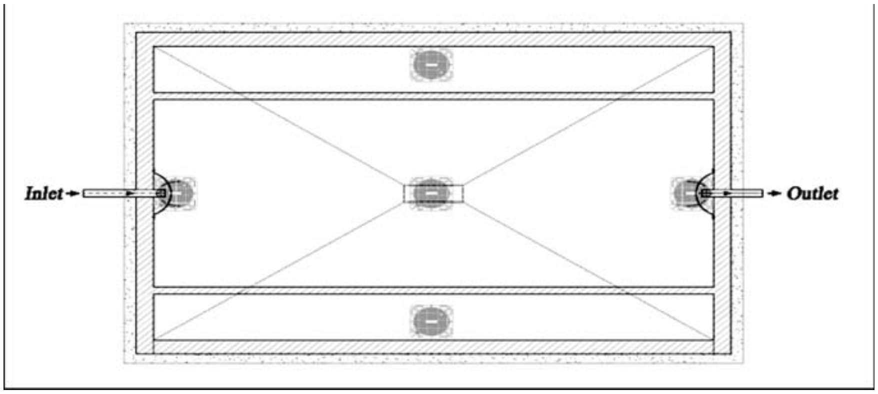

Fig. 4. Plan view of the imhoff tanks.

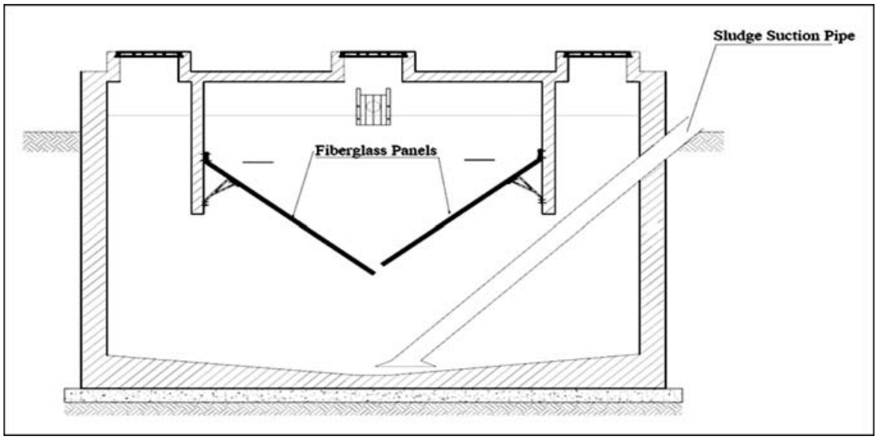

Fig. 5. A–A section of the imhoff tanks.

the CWs and the population and the first stage was constructed in the years of 2010–2011. Due to the size of treatment systems, construction costs for both systems were also high. In order to minimize construction costs, the construction necessary for treatment beds was half completed and soil was used as bank on the edges and the desired purification bed depth could be accomplished.

The construction was completed to discharge the treated wastewaters to the drainage channel near the treatment system.

3.5. Construction of sludge drying beds

In order to take sludge that would be accumulated at the bottom of the imhoff tanks, sludge drying beds were constructed inside the treatment plant site. The A–A section belonging to this system was given in Fig. 7. This system is approximately around 55 cm gravel depth. In contrast to other conventional sludge desiccation systems, the sludge drying beds were constructed after vegetation. The objective was both to enable faster drying of the sludge and treatment of the sludge.

3.6. The problems encountered during the construction of treatment systems

The treatment systems constructed for Sultanhanı and Altınekin residential areas, where it is estimated that they will have a population of around 5,000 in the near future, are naturally for large scale wastewater treatment systems. Thus, supplying gravel that will be necessary for CWs will become a problem in the future. For this reason instead of 8/10 mm dimensioned natural gravels estimated for the Altınekin CW beds project, 7/10 mm dimensioned natural gravel that was found in the region was used. Similarly, for the Altınekin sludge desiccation bed, different gravel to the project value was used as much as possible, but in the same quantities. In the Sultanhan CW beds, crushed rock was used. The natural material used for the Altınekin wetland beds and the sludge drying bed

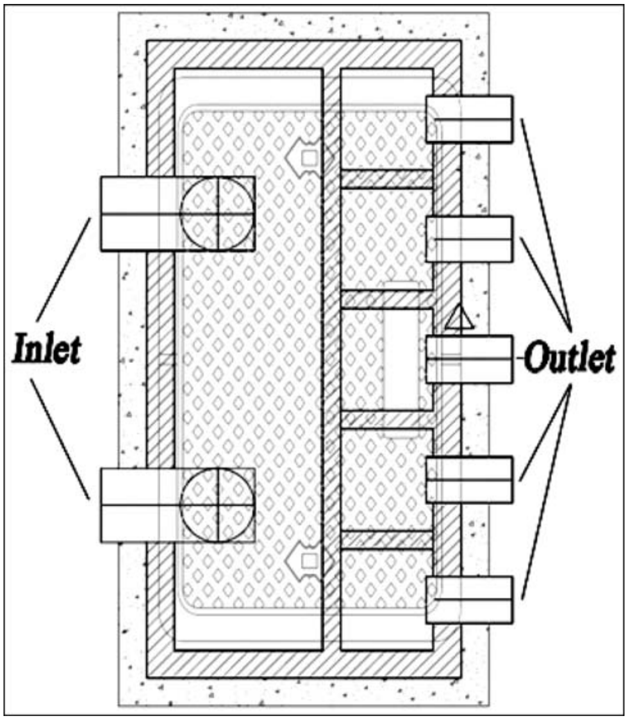

Fig. 6. Wastewater distribution manhole.

was washed in the gravel supplied area and brought to the site later. The material brought to the site and seen insufficiently washed during the control of construction was brought back to the gravel supplied area and washed again.

Since the areas of treatment systems constructed for both residential areas had almost zero degree slopes, many difficulties were experienced in hydraulic slope practice during both the construction of the sewerage system and the treatment systems. For example, the sewerage system lines were opened in a deeper location than required and pumping stations were needed. Most importantly, the cost was higher.

3.7. Costs of treatment systems

The costs of treatment systems constructed for the Sultanhanı and Altınekin residential areas was estimated at € 500,000 and €375,000 without the sewerage systems. According to this model, the per person cost for Sultanhanı was estimated at €100, for Altınekin it was estimated at €75. But as from the years of 2010–2011, the first stages of the wastewater treatment systems were constructed in each residential area. Two beds were constructed for Sultanhanı and 2.5 beds were constructed for Altınekin. Therefore, the investment cost of the Altınekin treatment system was €170,600 as from 2011. The investment cost of the Sultanhanı treatment system was €267,700 as from 2011 (€500,000 TL, VAT included, contribution of the Special Environmental Protection Unit and the tender from the Municipality).

3.8. Recommendations

The recommendations we think could be beneficial for the construction of similar systems taking into account the problems experienced during the construction of the CWs of two different residential areas and the experience gained throughout are given below:

Before starting large-scale projects, a detailed site survey should be carried out and the projecting of sewerage systems and treatment systems should be simultaneously conducted. During the construction of treatment systems, logistics should be well planned with alternatives and during the construction phase the controls must be efficient and supervised.

The other points to be highlighted during the construction of CWs can be summarized as follows:

(1) care should be taken when applying the hydraulic slope during the construction of treatment systems;
(2) in order to distribute wastewater equally by wastewater distribution structures the required sensitivity should be applied;
(3) in order to stabilize the mineralization effects of environmental conditions on the piping system for the distribution of wastewater in treatment beds, conducting leak proof tests of geo-membranes used in wastewater insulation in treatment beds is essential;

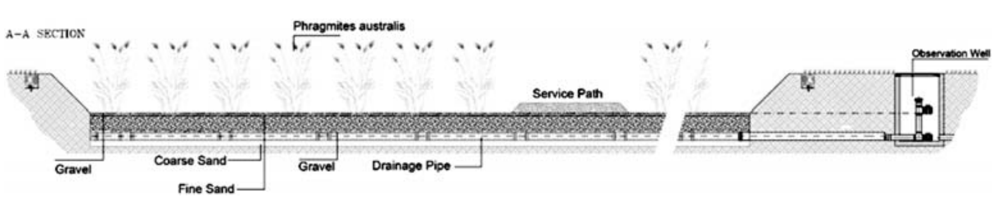

Fig. 7. A–A section of the sludge drying beds.

(4) measures must be taken to prevent the drilling of geo-membranes when filling the treatment bed with gravel;
(5) the most suitable period for vegetation should be selected for the construction (the ideal time for Mediterranean climate conditions is the first and second week of April).

4. Conclusions

The CWs constructed for the Sultanhanı and Altınekin residential areas, which it is estimated will have a population of 5,000 in the near future, are the first and largest natural treatment systems in Turkey. If the operation and maintenance of these treatment systems is carried out regularly, they will be a significant reference point for enabling the spread of similar sized CWs. In addition to this, the experience gained from the planning, construction and operation of these treatment systems will also be examples to follow for similar systems. Natural treatment systems which are ecological solutions for rural regions' wastewater treatment are alternatives to other treatment systems both in Turkey and worldwide and they will contribute significantly to the construction of full and complete treatment sites.

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