Development of a concept for the water supply of the village Hamzehlu as well as a visitor center at the salt mine Chehrabad (Iran) with process and drinking water

Master thesis – Christian Eichhorn – 1943014

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Aufgabenstellung Masterarbeit

für Herrn Christian Eichhorn
Matr.-Nr. 1943014
Studiengang M.Sc. Umweltingenieurwissenschaften
Technische Universität Darmstadt

Entwicklung eines Konzepts zur Wasserversorgung des Dorfes Hamzehlu sowie eines Besucherzentrums am Salzbergwerk Chehrabad (Iran) mit Brauch- und Trinkwasser

Development of a concept for the water supply of the village Hamzehlu as well as a visitor centre at the salt mine Chehrabad (Iran) with process and drinking water

Fachbereich Bau- und Umweltingenieurwissenschaften

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Datum
31.10.2019

Ihre Nachricht

Unser Zeichen

Problemstellung:

Im Iran ist Wasser eine knappe Ressource, weswegen mit dieser sorgsam, nachhaltig und sparsam umzugehen ist. Im Zuge des Projekts „Wasser, Bildung und Tourismus in der ländlichen Mahneshan-Region/Iran" der Gerda-Henkel-Stiftung wurde das Fachgebiet beauftragt für das in der ländlichen Region Zanjan gelegene Dorf Hamzehlu und einem noch zu errichtenden Informations-/Besucherzentrums am nahe gelegenen Salzstock die Versorgung mit Trink- und Brauchwasser zu konzipieren und die einzelnen Anlagen zu bemessen.

Aufgrund der vorliegenden klimatisch-ariden Bedingungen von etwa 270 mm Jahresniederschlag sind in der Region kaum größere nutzbare Wasservorkommen vorzufinden. Zudem besitzen die allermeisten Wasservorkommen inklusive dem Flusswasser eine Salzkonzentration von etwa 7000 mg/l TDS (EC 9000 bis 12000 μS/cm), die für Trinkwasserzwecke ungeeignet sind und deswegen eine Aufbereitung zu Trinkwasser erfordern.

Darüber hinaus ist für die Konzeption der Wasserversorgungsinfrastruktur von den in den benachbarten

Dörfern der Region vorzufindenden, funktionierenden und von der Bevölkerung akzeptierten technischen Anlagen auszugehen.

Masterarbeit:

Im Rahmen der Masterarbeit wird zu Beginn der Ist-Zustand vor Ort aufgenommen. Weiterhin soll durch Drohnenbefliegungen ein digitales 3D-Geländemodell als Basis für die Verortung und Trassierung der Anlagen in einem Geoinformationssystem erstellt werden.
Das Konzept soll die Gewinnung, den Transport, die Aufbereitung und Speicherung sowie die Abgabe des Wassers im Dorf und im Besucherzentrum umfassen. Es sollen mehrere Varianten erstellt werden, die auf die vorherrschenden Randbedingungen (Wasserdargebot, Flächennutzung, Eigentumsverhältnisse, Höhenunterschied, etc.) angepasst werden. Anhand von Wirtschaftlichkeits- und Praktikabilitätsanalysen sollen die verschiedenen Konzeptvarianten mittels Bewertungskriterien überprüft und ausgewählt werden. Als Teil der Wirtschaftlichkeitsanalyse soll der kostendeckende Wasserpreis auf Grundlage der berechneten Reinvestitions-, Wartungs- und Betriebskosten ermittelt werden.

Arbeitsschritte

- Ermittlung des Ist-Zustandes
  - Erhebung ausgewählter Strukturmerkmale und Kennzahlen
  - Pumpversuche zur Analyse des Wasserdargebots
  - Erstellen eines digitalen Geländemodells
  - Wasserbedarfsermittlung (Brauch- und Trinkwasser)
- Erstellung eines Konzepts zur (Trink-)Wasserversorgung und -aufbereitung für die ermittelten Anforderungen
  - Auswahl der Gewinnungsstandorte und Entnahmeleistung
  - Erstellen von verschiedenen Konzeptvarianten zur Trassierung der Wasserversorgungsinfrastruktur
  - Vorbemessung von Pumpleistung, Rohrdurchmesser, Speichervolumen, Aufbereitung
- Wirtschaftlichkeitsanalyse (Kostenvergleichsrechnung) der verschiedenen Konzeptvarianten
  - Berechnung des kostendeckenden Wasserpreises
- Auswahl der Vorzugsvariante
- Zusammenfassung & Ausblick

Ansprechpartner_in:
Intern: Prof. Dipl. - Ing. Dr. nat. techn. Wilhelm Urban
Extern: Dr. Natascha Bagherpour-Kashani (Archäologisches Museum Frankfurt, Deutsches Bergbau-Museum Bochum)

Bearbeitungszeit:
26 Wochen

Die Arbeit wird als externe Arbeit durchgeführt.

W. Urban

Prof. Dipl.-Ing. Dr. nat. techn. Wilhelm Urban

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Abstract

In the rural regions of Iran, the smaller villages have to make some independent efforts to build a water supply infrastructure. Since the village of Hamzehlu is located near the Douzlak salt dome, where archaeologically valuable finds are repeatedly made, the Gerda Henkel Foundation is financing the construction of an infrastructure to supply the village with both service and drinking water. During stays on site, the terrain was explored and pump tests have been carried out. Based on the villagers' water consumption, in this thesis the infrastructure is designed, its construction is planned and an economic efficiency analysis is carried out.

A total of six variants of the infrastructure were developed. Three of them refer to the different wells which are available for supply; the remaining three variants refer to the various locations for a planned visitor center which is to be realized in a further project. The evaluation of the individual variants led to the Reza abaad well being recommended as a supply well for the infrastructure. Furthermore, the location on the plateau above the village received the best rating as the location for the future visitor center.

Due to the high total concentration of dissolved solids (TDS) of the region's groundwater, only a reverse osmosis plant can be considered as a treatment plant. This relatively expensive process can produce water of sufficient drinking water quality. The difficulty here is that the price of the plant components also pushes up the price of water. The cost analysis of the preferred variant combination has shown, that the total investment costs are 21.680,26 € for the Iranian offer and additional personnel costs of 5.045,70 € are required to build the structures. The annual operating costs of 451,07 € are incurred, resulting in a price of about 1 €/m^3 drinking water, to fully cover the costs of operation and maintenance of the plant.

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1. Introduction/problem definition

The village of Hamzehlu is located in the Zanjan region in northwest Iran. In the salt mine near the village, archaeological excavations have been taking place for several years. Several mummified remains have been found, some of which are very well preserved due to the preservative effect of the salt. In the course of the project „Wasser, Bildung und Tourismus in der ländlichen Mahneshan-Region/Iran“ ("Water, Education and Tourism in the Rural Mahneshan Region/Iran") of the Gerda Henkel Foundation, a visitor center is to be built near the salt mine to exhibit some of the finds and to present the history of the salt dome. The project also includes the design and construction of a water supply infrastructure. In total, the water supply to be planned should be able to supply up to 150 people. These include up to 100 villagers as well as up to 50 workers, whom can be accommodated in the visitor center during archaeological excavations. The Water Supply & Groundwater Protection department of the IWAR institute at the TU Darmstadt was commissioned to manage this sub-project. In addition to a well, a treatment plant and a connecting infrastructure, a small-scale wastewater treatment plant shall be designed, built and commissioned in cooperation with the local authorities and companies. The present thesis deals with the conceptual design and dimensioning of the planned water supply infrastructure.

Due to the climatic conditions, water is a scarce resource in the area, where the salt dome and the village are located. By building dams it is tried to store a part of rainfall and river water in order to be able to use these reserves in the dry seasons. However, not all villages in the area can be supplied by such government projects. In addition, many of the ground and surface waters have a high salt content and have to undergo extensive treatment before use. The government is looking for water reservoirs with sufficient capacity to supply several villages with drinking water through a distribution network by means of central extraction and treatment. This approach may prevent remote villages from being connected to the grid, because they have too few inhabitants or are too far away from the nearest major water source. Thus, especially smaller villages have to take care of the supply of clean drinking water on their own. In Hamzehlu and the surrounding villages different supply concepts have been developed: Chehrabad, for example, is supplied by a spring that rises in the mountains and has a low salt concentration. The villages Mehrabad and Hesar do not have resources with low salt content and are therefore dependent on the treatment of raw water with a high salt concentration. The villages each have treatment plants that purify the water by reverse osmosis. Hamzehlu on the other hand is currently supplied with drinking water by a tanker truck, which is regularly filled by the inhabitants in one of the neighboring villages.

In the region, separate service and drinking water networks are common. The houses often have a direct connection to the service water network, while drinking water can be obtained from a central distribution point in or near the village. The advantage of this system is that expensive drinking water is only used for those applications where drinking water quality is required (cooking, drinking, etc.). In Hamzehlu such a service water structure is nonexistent, why it was included in the planning of the whole water infrastructure.

2. Approach

In this chapter, the drinking water supply situation in the Iranian village of Hamzehlu is explained in more detail. At the beginning, the general situation in Iran is examined and typical parameters are presented. Subsequently, the supply situation in rural regions of the country is dealt with in more detail, since the area surrounding the village of Hamzehlu is one such region. For this purpose, interviews were conducted with the inhabitants of Hamzehlu and the adjacent villages about their water consumption.

2.1. General situation of water usage in Iran

Iran is one of the 20 largest and most populous countries in the world. The population of around 80 million is at a similar level to that in Federal Republic of Germany. In contrast, the areas of the states differ considerably. Iran has an area of 1.648.195 km², whereas Germany only has an area of 357.578 km². This leads to a clear difference in population density: On average there are 49 inhabitants per square kilometer in Iran. In Germany the population density is about 4 times higher with 232 inhabitants per square kilometer.

Due to the climatic-arid conditions the annual precipitation in Iran is about 228 mm. This corresponds to about one third of the precipitation in Germany. According to the World Resources Institute, the water stress level in Iran is at the highest level (5, "extremely high baseline water stress"). As in other countries, water resources are unequally distributed, which leads to slight variations in water stress levels from region to region. (Food and Agriculture Organization of the United Nations)

The following figure provides an overview of the water stress level of the individual regions in Iran:

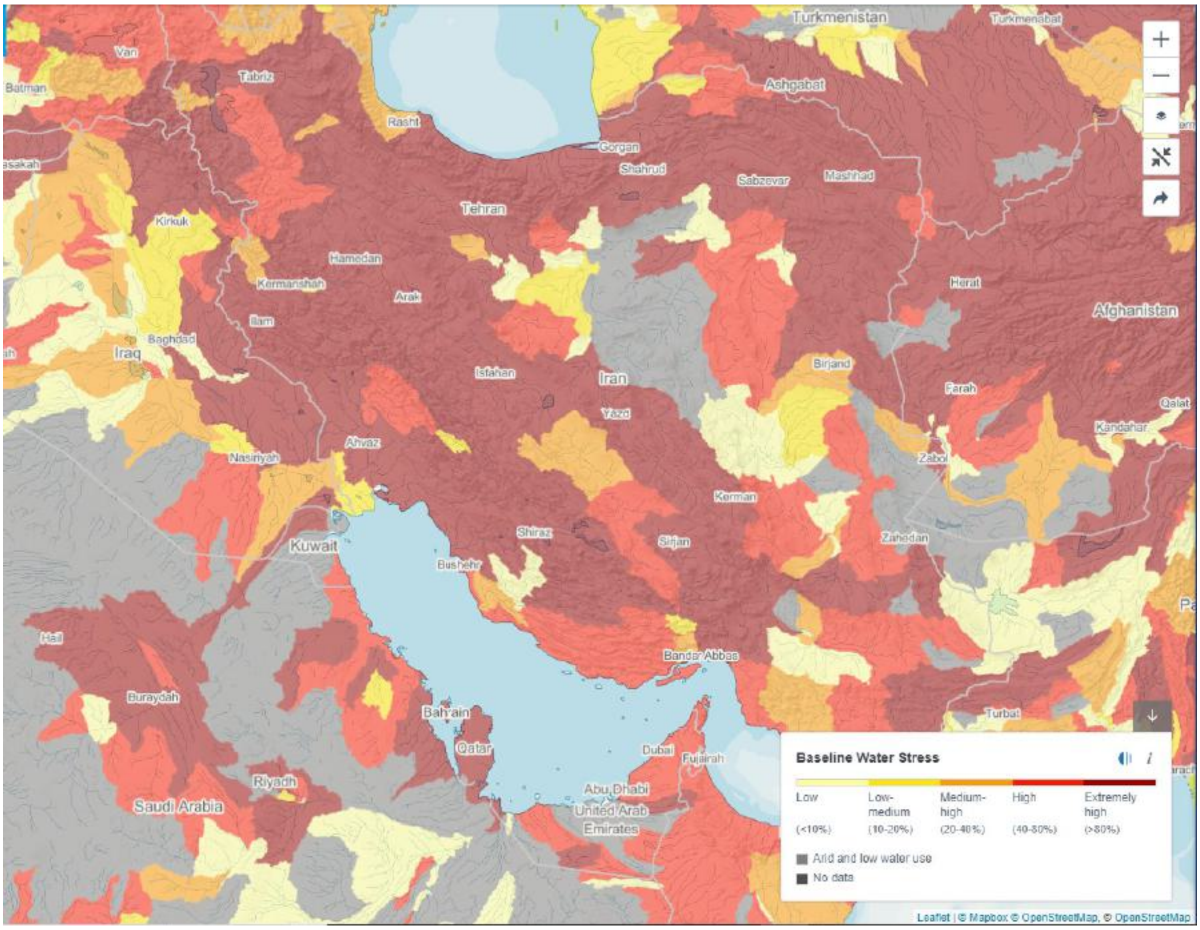


Figure 1 Overview of water stress levels in Iran (World Resources Institute)

The "Baseline Water Stress" presented here shows the relationship between total water withdrawals and available renewable water resources. The high values illustrate that water is a limited resource in Iran and must be used sustainably.

According to the available data sets of Aquastat, about $93{,}3 \cdot 10^9\ m^3$ of water are consumed in Iran annually. More than 90% of this is used for agriculture. The following pie chart shows the exact breakdown by sector:

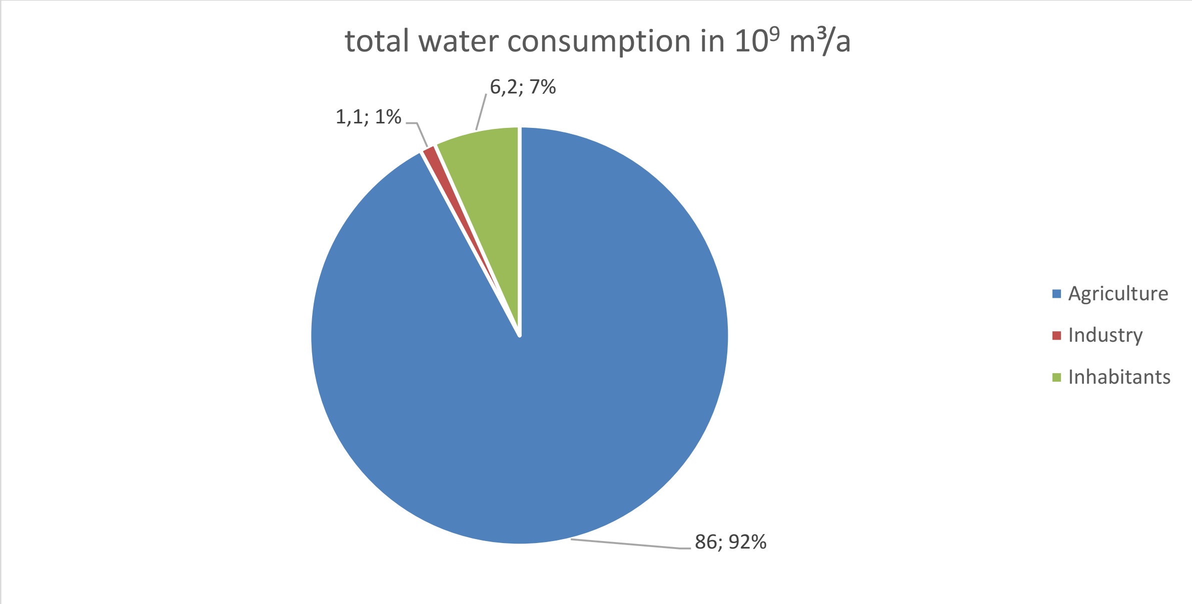


Figure 2 total water consumption by sector (Food and Agriculture Organization of the United Nations)

The total water consumption per inhabitant is calculated as $1.295\ \mathrm{m^3/(a \cdot inhab.)}$. In contrast, the renewable annual water resources available sum up to $1.902\ \mathrm{m^3/(a \cdot inhab.)}$. Based on these data, about 68% of renewable resources are consumed. According to the definition of Aquastat, a country already suffers from water scarcity if more than 60% of the available resources are consumed per year. (Food and Agriculture Organization of the United Nations)

The personal water consumption per inhabitant (q_{dm}) in Iran can be determined using the following calculation:

$$q_{dm} = 1.295 \frac{\mathrm{m^3}}{\mathrm{a \cdot inhab.}} \cdot 7\% \cdot \frac{1.000 \frac{\mathrm{l}}{\mathrm{m^3}}}{365 \frac{\mathrm{d}}{\mathrm{a}}} = 248 \frac{\mathrm{l}}{\mathrm{inhab. \cdot d}}$$

However, this average daily water consumption per inhabitant cannot be applied to the village of Hamzehlu in the Zanjan region and other rural villages. The villages visited during the preliminary exploration do not come close to the average consumption, which is partly due to the low level of development of the water infrastructure.

2.2. Current state of water infrastructure in Hamzehlu and neighboring villages

In this chapter the current state of the water supply in Hamzehlu and neighboring villages will be shown. Furthermore the water usage of the described villages will be analyzed and compared. This step is necessary to correctly dimension the water infrastructure to be built in Hamzehlu. The below aerial view of the region shows Hamzehlu and the neighboring villages.

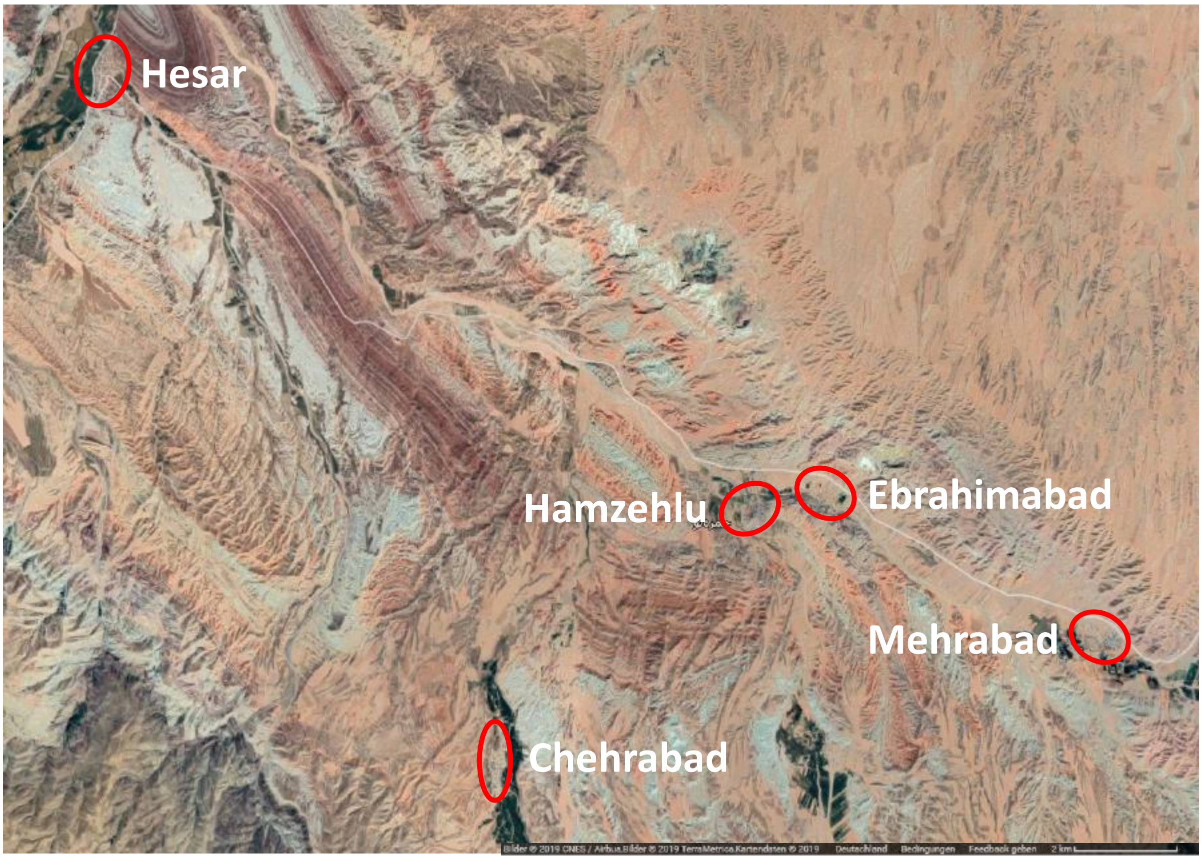


Figure 3 locations of Hamzehlu and neighboring villages (google)

In larger villages of the region, a service water infrastructure with house connections is common, while drinking water is often offered at a central distribution point in the village. Due to the high salinity, reverse osmosis plants are used to treat the water, if drinking water treatment exists in the village. Chehrabad is the only village in the region that does not need a treatment plant. It is supplied with drinking water by a freshwater spring in the nearby mountains. The water is used without further treatment.

The water supply situation of the villages Mehrabad, Hesar and Hamzehlu was further examined: Mehrabad and Hesar both own service water infrastructure and a reverse osmosis treatment plant to provide drinking water, while Hamzehlu is supplied by a mobile drinking water tank and does not possess any service water infrastructure.

2.2.1. Mehrabad and Hesar

Both villages possess service water infrastructure with house connections. The daily need of drinking water is covered by reverse osmosis treatment plants in the village centers. The below picture shows the plant located in Hesar.

Figure 4 Reverse osmosis plant in Hesar

The reverse osmosis treatment plants in Hesar and Mehrabad both provide sufficient drinking water to meet the need of the inhabitants. The drinking water distribution point as seen on the right is in front of the treatment plant. It has a terminal on which prepaid cards can be placed. This activates the terminal and the residents can select the required amount of water using various buttons. By pressing a button, the water output starts and the amount on the card used is reduced by the costs incurred.

In both villages live about 700 inhabitants, who are supplied with drinking water by the treatment plants.

Figure 5 distribution point in Hesar

2.2.2. Hamzehlu

In contrast to Hesar and Mehrabad Hamzehlu does not possess any water infrastructure. The current situation is showed in the following picture: The inhabitants use a mobile water tank (3) which gets regularly filled in one of the neighboring villages by the village headman to supply themselves with drinking water. The water from a small stream (1) running through the village is used as service water. Some inhabitants pump the river water into tanks on their roofs (2) to generate enough operating pressure for various purposes like showering and washing dishes.

Figure 6 village center of Hamzehlu

The housing situation in Hamzehlu differs from that in the other villages. About 20 inhabitants live permanently in the village. However, in spring up to 50 people are accommodated at times. These people are mainly family members of the residents who help with the cultivation and sowing of the fields. Another special case that needs to be considered are weekends during the school holidays. When relatives are visiting the inhabitants, it is possible to have up to 100 inhabitants over a short period of time.

2.3. Analysis of water usage in Hamzehlu and neighboring villages

It is necessary to know the water usage of the people in the villages in order to correctly dimension the infrastructure. To evaluate the water usage some inhabitants of the villages Mehrabad and Hamzehlu were asked about their daily usage. Based on the interviews with the inhabitants the water usage per day and person was calculated and described in the following subchapters.

2.3.1. Drinking water consumption

In addition to the interviews, the drinking water consumption of the inhabitants was also calculated from the water meter of the treatment plant in Hesar: It was recorded during the stays in March and October and the difference between both recordings portrays the total water usage of the villagers. The specific consumption was determined on the basis of these records and the population of the village.

For a better overview, the results of the surveys were summarized in a table:

Table 1 recorded drinking water usage data of the villages

Village	**Source of data**	**Total usage in l/d**	**Inhabitants in inhab.**	**Specific usage in l/(inhab. · d)**
Hesar	Treatment plant	1.300	700	1,8
Mehrabad	Interviewee 1	3,6	2	1,8
	Interviewee 2	12,5	7	1,8
	Interviewee 3	14,3	8	1,8
Hamzehlu	Mobile drinking water tank	143	20	7,1

The evaluation shows that the inhabitants of Hesar and Mehrabad merely consume about two liters a day. Whereas the inhabitants of Hamzehlu consume about seven liters per day. The difference in consumption is due to the fact that Hamzehlu does not charge a fee for drinking water. In Hesar and Mehrabad, on the other hand, the water was treated at great expense by treatment plants whose operating costs had to be covered by the water price. Since drinking water in Hamzehlu is free of charge, the handling of it is carefree and therefore much higher than in the other villages. Since the drinking water of the future treatment plant will also be subject to charges, it can be assumed that consumption will fall.

Due to the different data in the villages, average and median of the calculations deviate significantly from each other. The average is 2,9 liters per inhabitant per day, whereas the median is 1,8 liters per inhabitant per day. However, both values are too low according to the World Health Organization (WHO). In the following figure the water requirements are listed, which are the minimum according to WHO:

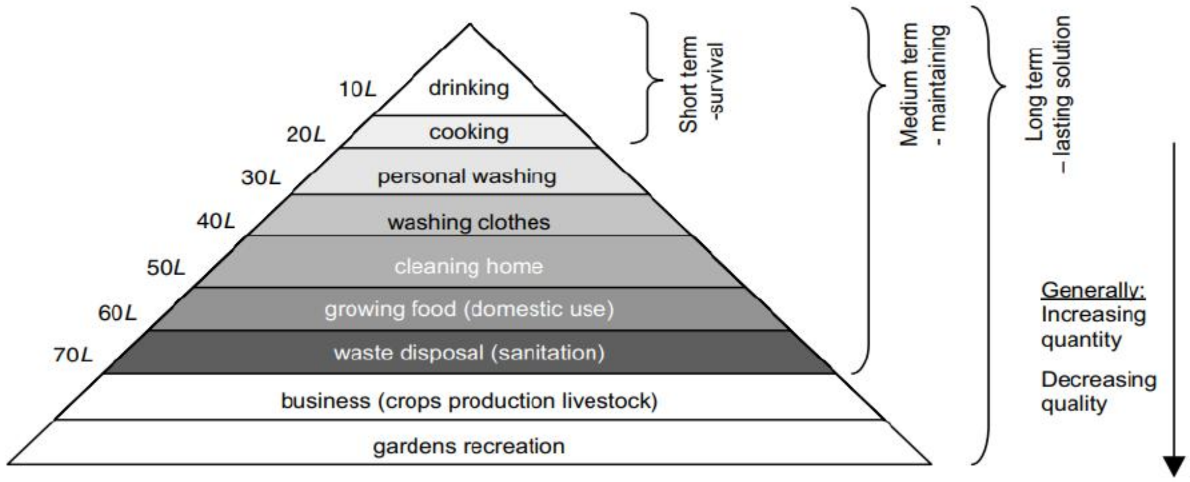


Figure 7 Hierarchy of water requirements (World Health Organization 2003)

According to this, a minimum drinking water supply amount of 20 l per day and capita should be provided to allow inhabitants to meet their needs. With increasing development of the villages the quantitative demand of water with decent quality also increases. In order to ensure a future-proof supply, it was decided to follow the recommendation of the WHO. The daily drinking water requirement per inhabitant was therefore set at 20 l and serves as a basis for the planning to be carried out.

Due to the changing population of the village Hamzehlu depending on the season the different housing situations were presented in a table:

Table 2 drinking water usage by seasons

Season	**Inhabitants in inhab.**	**Specific average Usage in l/(inhab. · d)**	**Total Usage in l/d**
Summer/winter	20	20	400
Spring	50		1.000
Holidays	100		2.000

The significantly fluctuating water consumption spread over the year must be taken into account when dimensioning the water infrastructure. Possible ways of compensating for peak loads in water

treatment are, for example, appropriately large drinking water tanks or a second treatment line, which can be switched on if necessary. In turn, the routes must be dimensioned in advance for the maximum consumption quantity.
Another point that must be considered is that the raw water is treated to drinking water with the help of a reverse osmosis plant, which function will be further explained in chapter 3.3.2. The cross-flow process used here means that only part of the raw water can be purified into drinking water. Thus, the actual demand for raw water is significantly higher than the amount of drinking water required. Based on a yield of 40%, a drinking water requirement of 2 m^3/d results in a raw water consumption of 5 m^3/d.

2.3.2. Service water consumption

Untreated service water can be used for applications that do not require drinking water quality, such as washing and toilet flushing. This reduces the use of the treatment plant and thus extends the service life of the plant components. In order to be able to dimension the service water infrastructure, interviews were also conducted with the residents for this type of water usage. These showed that an average of 62,5 liters of service water is consumed per day and inhabitant.
As it can be seen in Figure 7, for “medium term – maintaining” an amount of 70 l per day is required. Minus the first two positions, which require drinking water quality, a consumption of 50 l service water per day per inhabitant remains. Hamzehlu, at 62,5 l, is thus slightly above this value. This can have various reasons. On the one hand, the measurement of water consumption by the villagers is only rudimentary and therefore not as exact; on the other hand, the free supply of service water does not limit the use of the water and therefore the consumption is usually higher. Nevertheless, the consumption is within limits and can be used as a basis for the following dimensioning of the infrastructure. Due to the different housing situations throughout the year the service water usage fluctuates just like the demand for drinking water:

Table 3 service water usage by seasons

Season	**Inhabitants in inhab.**	**Specific average Usage in l/(inhab. · d)**	**Total Usage in l/d**
Summer/winter	20	62,5	1.250
Spring	50		3.125
Holidays	100		6.250

As before, the peak loads must be compensated. Therefore, the maximum service water consumption must be integrated into calculations for dimensioning the pipelines and the reservoir.

If drinking water and process water maximum requirements are combined, the raw water consumption is around $\boldsymbol{Q_{d,max}} = \mathbf{11,25\ m^3/d}$.

2.4. Localization

This section deals with the various relevant locations of the future water infrastructure. These include the potential wells, the potential sites for the visitor center and reservoir, the excavation site and the village center.

2.4.1. Potential wells

In the immediate surrounding of the village are three wells that are suitable for water supply. In the following picture the wells are marked and the village is highlighted.

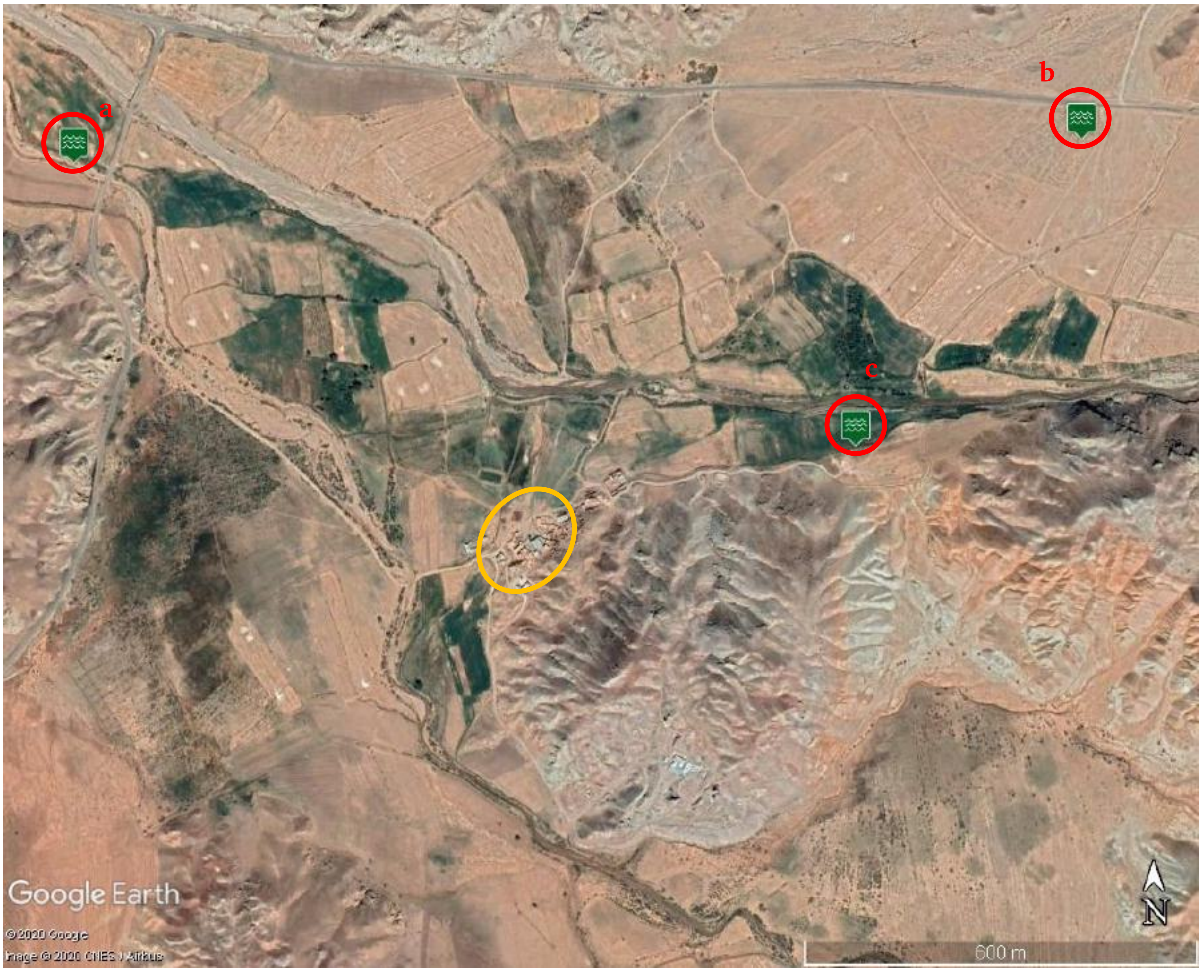


Figure 8 considered wells (google)

Three wells were considered for the water supply of the village:

a. The **Reza abaad well (a)** is located about 1 km northwest in direct line of the village. The well site was chosen based on geoelectric measurements and pumping tests carried out during the exploration.
b. Another possible well is the **Ebrahimabad well (b)**, which was originally built by the authorities to supply Ebrahimabad. However, as it does not provide enough water to supply the village the expansion was not continued, since pumping tests showed that the capacity of the well is sufficient to supply Hamzehlu. It is located about 1 km in a north-easterly direction in direct line from Hamzehlu.
c. The third well that comes into question is the **Shah alli well (c)**. It is located on a field about 500 m northeast in direct line of Hamzehlu and is currently used for irrigation.

2.4.2. Potential visitor center sites

In addition to the above mentioned possibilities for wells, three possible locations for the planned visitor center were determined. These are again shown in the following figure.

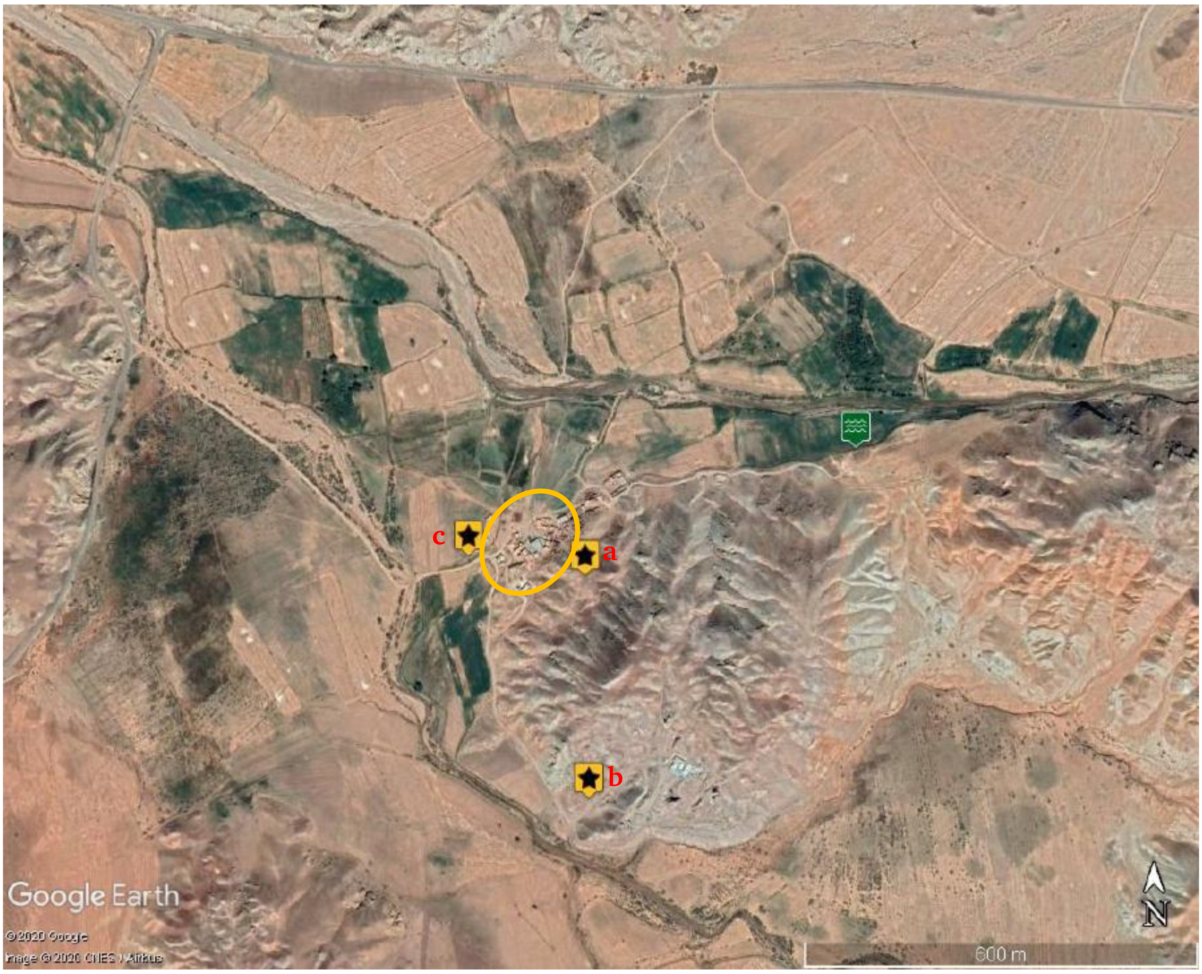


Figure 9 considered visitor center locations (google)

The possible positions are the following:

a. Above the village, on the slope of the Douzlak a plateau is located, which suitable is for the construction of a visitor center. From this plateau, visitors can overlook the village as well as the surrounding area. Furthermore, the villagers do not plan to build on this plateau, so there will most likely not be any disputes against the construction of the visitor center.
b. The first excavation camp is located at the foot of the Douzlak, where equipment and found objects are processed and stored. Since the area is spacious enough, a visitor center could also be built here. The location is particularly suitable because of its proximity to the excavation site and can also be used as a camp by the archaeologists in a second function.
c. A visitor center could be built on a field in the western part of the village. Due to its ground level location, the upcoming construction work would be facilitated. Furthermore, due to its direct location in the village, visitors could be integrated into village life as an additional experience.

2.4.3. Reservoir and treatment plant site

A plateau on the slope of the Douzlak was chosen as the location for the reservoir (a), in order to allow a gravity fed distribution of the service water. The upper edge of the plateau is about 30 m above the village, which ensures sufficient operating pressure to transport the water.

Figure 10 chosen locations of reservoir and treatment plant (google)

In turn, the treatment plant is to be built on the central village square (b) to ensure good accessibility. Due to the central location villagers can easily buy drinking water at the distribution station of the plant without having to walk long distances. Another advantage of the central location is the increased safety for the plant: For example, the villagers can react quickly in case of a malfunction and do not have to take a longer journey first. In addition, the villagers can easily monitor the plant from this location, so that unauthorized access or potential sabotage can be quickly detected and prevented.

3. Technical conduct

In this part of the thesis, the technical approach to planning is presented in more detail. As in the actual water flow, the structure follows the order in which the water passes the individual sections. Starting with the water supply (chapter 3.1), which starts at the well, the water is transported from there to the high ground reservoir (storage; chpt. 3.2). From there it is transported to the individual consumers. Service water connections will be installed in the village center, in the visitor center and at the excavation site. A further service water connection will be made to the planned reverse osmosis plant (treatment; chpt. 3.3). At the same time, distribution units (chpt. 3.4) will be set up at the same locations where people can collect drinking water. As several possible sites for the construction of the visitor center were selected during the planning stage and several wells are also possible for supply, the routing of the water supply infrastructure is only rudimentarily described here. A more detailed explanation of the routing will be given in the closing chapter of this part. There the various options are considered in more detail and the routing (chpt. 3.5) is elaborated and presented. The following diagram illustrates the described structure of the water supply infrastructure.

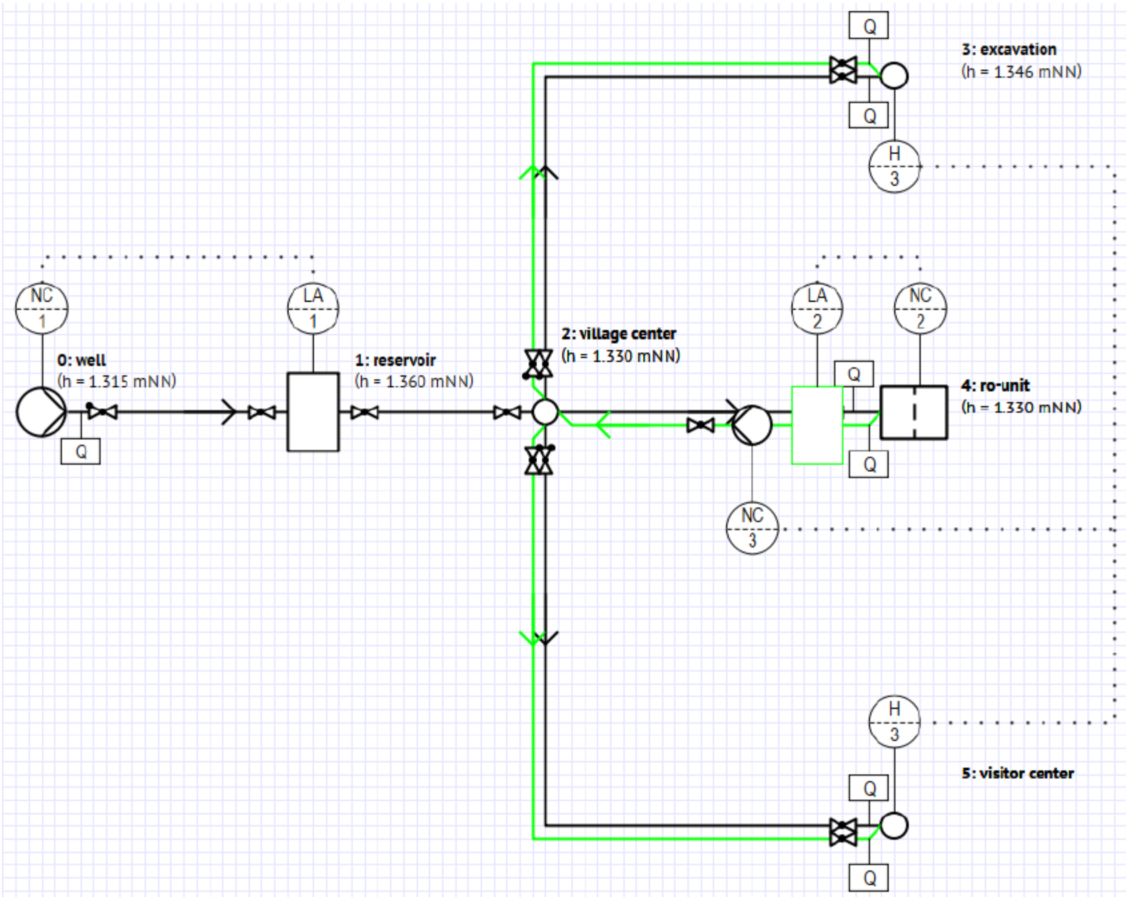


Figure 11 diagram of the water supply infrastructure

The route is divided into two parts. The pipes shown in black in the figure above are used for the transport of service water, whereas the pipes shown in green are intended for the distribution of drinking water. As it can be seen, the diagram shown above already contains various safety and control measures. Since these extend over several sections, they have been presented in this general overview.

It is planned to achieve a partially automated operation. For this purpose, for example, it is intended that the water level in the reservoir ("LA-1") determines the pump operation ("NC-1"). This should ensure that there is always sufficient water in the reservoir. A further control system of this type is also to be installed in the treatment plant. Depending on the level in the drinking water tank ("LA-2"), the treatment plant should be switched automatically ("NC-2") to ensure that drinking water is always available.

Since it is planned that drinking water can also be provided at the points further away from the treatment plant, at the excavation site and visitor center, it is required that from these points a pump in the treatment plant ("NC-3") can be switched via the distribution units ("H-3"), which will pump the drinking water from the drinking water tank to the corresponding outlets.

3.1. Supply

As presented in chapter 2.4.1 three wells are considered to supply the village with service and drinking water. In the following sections the different wells will be analyzed further. At the beginning the yield of the wells is determined and compared with each other by means of the pumping tests and the geoelectric field tests. This investigation is necessary to be able to recognize if the wells are in danger to dry out in times of low precipitation. If such a possibility exists, either the consumption during these phases must be limited or another well must be chosen for supply.

After the analysis of the wells, the constructional side is explained in more detail. In order to protect the well, its installations and necessary components against environmental influences and unauthorized access, the construction of a well housing is planned. It should have all necessary installations and connection possibilities for electricity and water to enable a smooth construction of the following infrastructure.

3.1.1. Yield of the wells determined by pumping tests

In this chapter performed on-site pumping tests will be analyzed. In the following used methodology will be described and results will be presented and evaluated.

At the pre-exploration in March 2019 pumping tests were already executed. These tests served the purpose to evaluate if the tested wells were able to support the needed water flow rate for supplying the village and the planned visitor center. During the second visit in October 2019 long term pumping tests were performed to analyze the hydraulic properties and yield of the aquifer. In total three wells were tested: the Reza abaad well, the Shah alli well and the Ebrahimabad well.

Basics

Pumping tests are carried out to determine the efficiency of the well. This allows conclusions as to whether the well provides sufficient water amounts to supply the inhabitants. In addition, the results of the tests can be used to calculate the permeability coefficient, which is a measure of the porosity of the water-bearing soil layer.

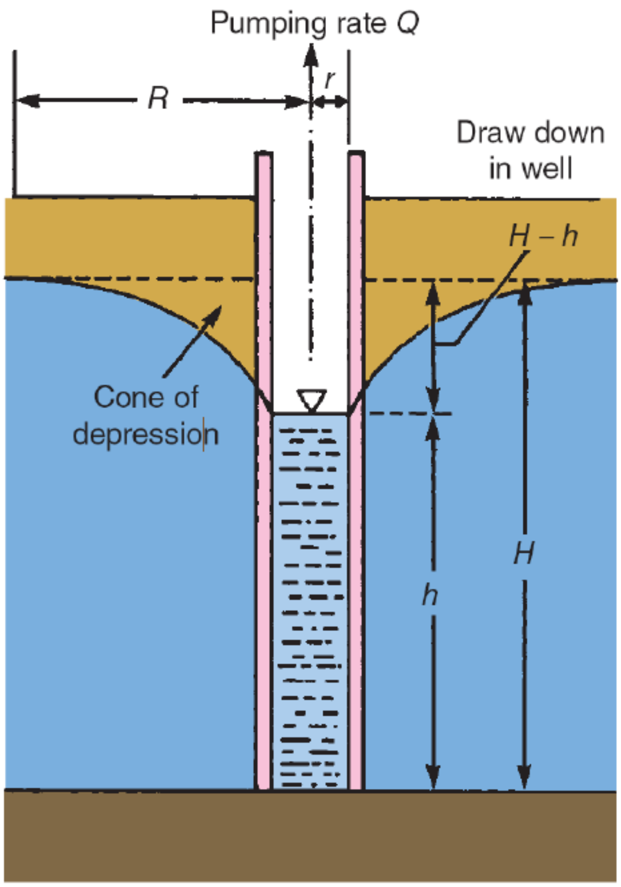


Figure 12 cone of depression during pumping test (Brassington 2017)

A pumping test consists of two phases: pumping phase and recovery. During the pumping phase, water is continuously withdrawn from the well (Q) over a certain period of time, thus lowering the water level (h). The lowering is measured in order to deduce the inflow from the aquifer into the well. Recovery begins at the end of the pumping phase. The water level in the well is constantly increased by the inflow from the aquifer until both have a similar level again. (Hölting und Coldewey 2013)

The difference in height between the water level in the aquifer and in the well (s = h - H) leads to the formation of a cone of depression around the well. The inflow into the well depends on the height difference of these water levels and increases as the difference increases.

Based on the results of the pump tests, the *Sichard* formulas can then be used to calculate various parameters for groundwater characteristics. In the following chapters, the methodology and analytical procedures are described.

Methodology

In the beginning of a pumping test the, resting water level has to be measured. To measure the water level throughout the tests an electric contact meter was used.

It consists of an measuring tape on which end two open electrodes are arranged next to each other. The circuit is closed as the electrodes contact the water surface. If the circuit is closed, a lamp at the hand section of the electric contact meter is lighting up. With this technic, it is possible to measure water levels from the top edge of a well. By measuring the distance from top edge to ground surface, the results can then universally transferred into a terrain model.

Figure 13 electric contact meter

After the at-rest water level is recorded the first phase of the pumping test can be initiated with starting the pump. Over the whole duration of the pumping phase the dropping water level has to be measured in determined intervals. Typically, the first minutes of powering the pump result in heavier dropping rates than the rest of the duration.[1] Because of this circumstance the measuring intervals in the beginning of the phase have to be smaller. When the dropping rate slows down, the intervals can be enlarged.

Either after a pre-determined duration or after reaching a constant water level while still pumping with the same flow rate, the pumping phase can be stopped. Without the outflow, the well will instantly begin recovering. Because of the high height differential between the water levels of well and aquifer the recovering process will typically rapidly increase the water level of the well in the

[1] This is caused by the difference in height between the water level in the well and in the aquifer. At first the difference is low and therefore the inflow rate into the well is slow causing higher drops of the water level in the well. Afterwards the increasing potential between the water levels provides a higher inflow rate.

first minutes after turning the pump off. As same as above in this time the measuring intervals have to be smaller than in the rest of the phase to correctly map the results in an adequate resolution. The level has to be mapped the whole time, while it approaches the original resting water level. Because of the decreasing height differential between the water levels of well and aquifer the increase rate slows further down while approaching. When the level only increases negligibly the data mapping can be stopped.

Analysis

The recorded data of the pumping tests can be used in multiple ways. Starting with the raw data a graph was plotted that shows the drawdown in pumping and recovery phase. Afterwards the data was analyzed to identify the hydraulic structure of the aquifer. After viewing the graphs of the pumping tests, it became apparent that the aquifers under consideration have to be unsaturated ones. Following this assumption the data can be processed with the formulas for unsaturated aquifers given by *Sichard*. These formulas are used to calculate the volumetric capacity Q_F and water afflux Q_A of the wells to receive the optimal outflow rate:

$$Q_F = 2r_w \cdot \pi \cdot h_w \cdot v_{\max}$$
$$Q_A = \pi \cdot k_f \cdot \frac{H^2 - h^2}{\ln\left(\frac{R}{r_w}\right)}$$

With

- $[r_w]$ = m: radius of the well
- $[H]$ = m: height of the resting water level measured from bottom side of the aquifer
- $[h] = [H - s]$ = m: height of the water column in the well ($[s]$ = m presents the drawdown)
- $[v_{\max}] = m/s$: maximum entering velocity of the water
- $[k_f] = [T/M]$ = m/s: permeability coefficient ($[M] = m$ presents the aquifer thickness)
- $[T] = \mathrm{m}^2/\mathrm{s}$: transmissivity
- $[R]$ = m: range of the cone of depression resulting from the flow conditions around the well

Besides the parameters which can be measured, it is necessary to use further formulas to calculate the remaining ones:

$$v_{\max} = \frac{\sqrt{k_f}}{30}$$
$$T = \frac{2{,}3}{4 * \pi} \cdot \frac{Q}{\Delta s} \text{ for } \Delta s \text{ within a decade of measuring}$$

$$R = 3.000 \cdot s \cdot \sqrt{k_f}$$

The used formula to achieve the transmissivity of the aquifer is based on the model function of $Jacob$. (Baur et al. 2019)

During the pre-exploration in March a team of geo-electricians recorded multiple profiles of the soil compositions. The methodology is to introduce multiple electrodes into the ground in a specific pattern along a pre-determined line. Between two electrodes a current is sent through a section of the subsurface. Electrical resistivity is a property of a material to oppose the flow of electric current. So this characteristic is used to identify the soil composition beneath. The amount of dissolved salt minerals affects the resistivity. The area around Douzlak is saturated with dissolved salt minerals resulting in a much less resistivity of the soil composition. Therefore the established resistivity scale to identify the compounds was altered to fit the actual situation. (Pfingsthorn 2020)

Table 4 original and suited resistivity of different materials (Pfingsthorn 2020)

Material	**Resistivity (original) in Ωm**	**Resistivity (adjusted) in Ωm**
Gravel (dry)	> 1.000	~ 100
Gravel (saturated with water)	200 – 500	20 – 50
Sand (dry)	> 1.000	~ 100
Sand (saturated with water)	80 – 200	8 – 20
Silt (saturated with water)	15 – 60	1,5 – 6
Clay (dry)	> 1.000	~ 100
Clay (saturated with water)	3 – 30	0,3 – 3

Two profiles (7 and 10) were laid out in such a way that the wells were located within the recorded data. With this data it was possible to assume the different aquifer thicknesses:

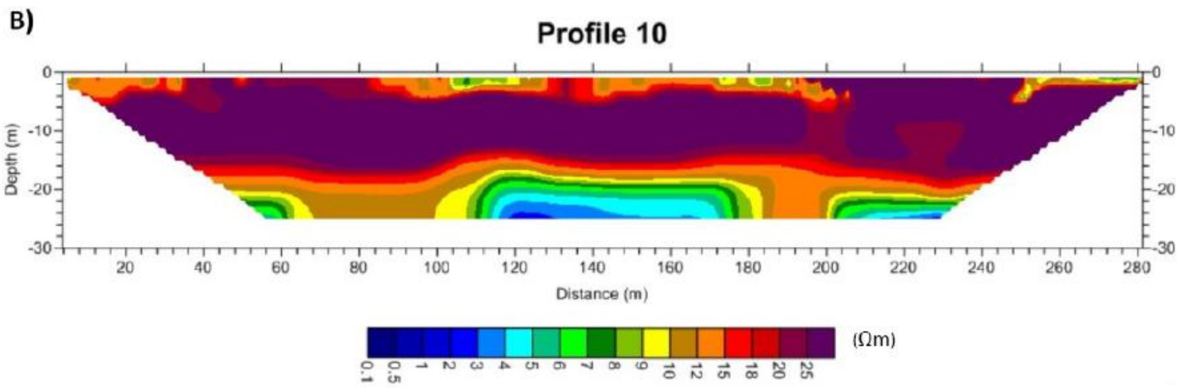


Figure 14 Profile 10 shows the soil compositions around and beneath the Reza abaad well (Pfingsthorn 2020)

The figure above shows the profile through the location of the Reza abaad well, which locates at around 220 m on the distance axis. The first layer primarily consists of gravel. The layer beneath mainly consists silt or even clay. Because layers built out of silt or clay are aquitards the transition between these layers can assumed to be the bottom side of the aquifer above. Based on this evaluation the thickness of the aquifer which consists the Reza abaad well is around 25 m.

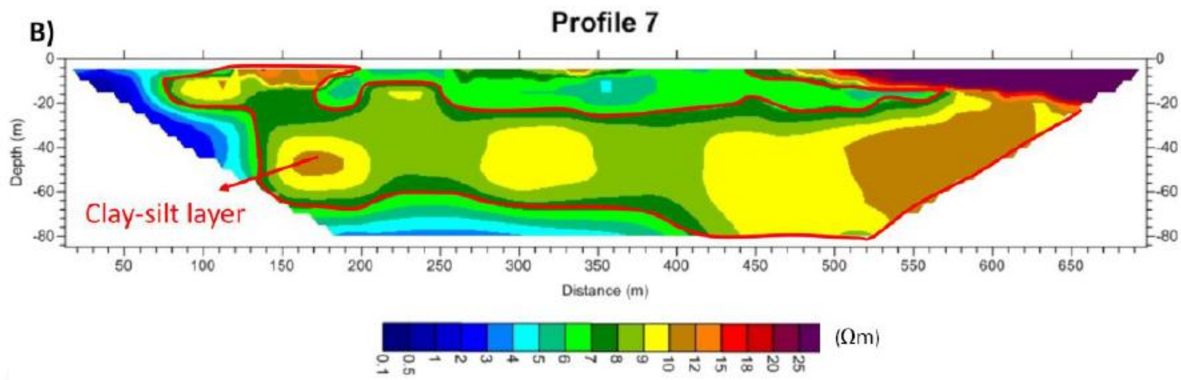


Figure 15 Profile 7 shows the soil compositions around and beneath the Ebrahimabad well (Pfingsthorn 2020)

The Ebrahimabad well is located at the end of profile 7 near 690 m on the distance axis (as seen above). Because of the resolution and caused by the positioning of the profile an exact determination of the aquifer thickness is not possible. Therefore a thickness of around 40 m is assumed based on an interpolation of the soil composition around the well.

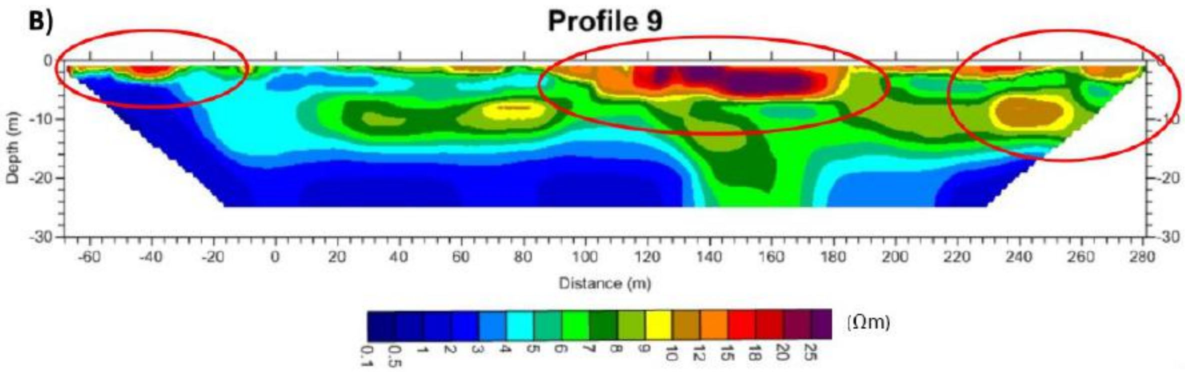


Figure 16 Profile 9 shows the soil compositions around and beneath the Shah alli well (Pfingsthorn 2020)

In this profile at around 120 m on the distance axis the Shah alli well is located. It indicates that the aquifer thickness is around 8 m.

With all parameters needed for the above *Sichard* formulas it is possible to plot graphs for the volumetric capacity and water afflux referred to the drawdown. The resulting crossing point of the two graphs represents the optimal hydraulic operating flow rate for the corresponding well.

Results

This chapter presents the results of the pumping tests done at the different wells. Giving a better oversight of the results, the pumping tests are displayed separate for each well.

Reza abaad well

The dug well has a depth of 12,2 m. Starting at a resting water level of 10,33 m below ground level an at-rest water column of 1,87 m was found to lower the pump into. During the pumping test at this well, a pump was used, which provided a flow rate of $Q = 7{,}2\ \mathrm{m}^3/\mathrm{h}$. After the duration of the pumping phase (17 h 16 min 10 sec) the drawdown tops out at 0,99 m. While recovering the well was able to increase the water level to 0,12 m below resting water level within 50 min. The following graph shows the drawdown and recovery.

Figure 17 Reza abaad well under construction

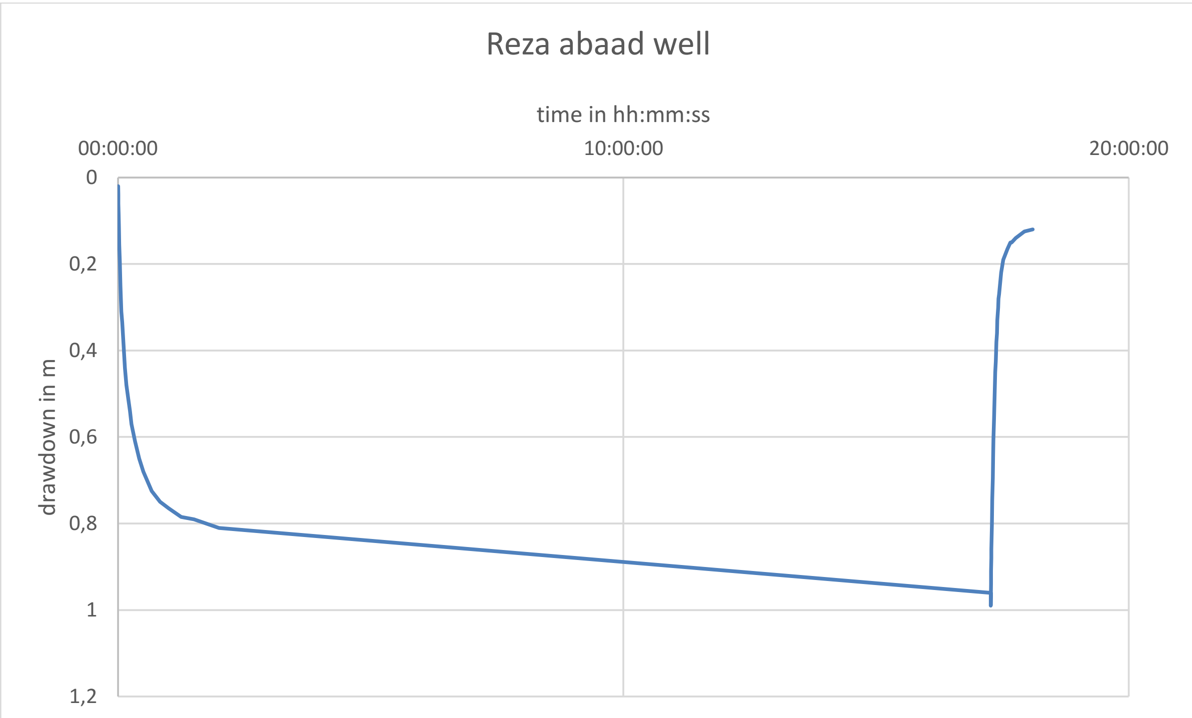


Figure 18 pumping test Reza abaad well

This data already proves that the well can deliver a sufficient amount of water to cover the need of the village and the planned visitor center. Based on the recorded data, the further analysis serves to identify the hydraulic structure of the aquifer. As described in the previous chapter the analysis was executed and led to the following results for the needed parameters:

Table 5 parameters of Reza abaad well

Parameter	**Value**
Transmissivity T in m²/s	$8{,}72 \cdot 10^{-4}$
Aquifer thickness M in m	20
Permeability coefficient k_f in m/s	$4{,}36 \cdot 10^{-5}$
Maximum entering velocity v_{max} in m/s	$2{,}20 \cdot 10^{-4}$

The calculation of volumetric capacity and water afflux is shown below. Because the drawdown s is a variable in these formulas the results are presented as a plot:

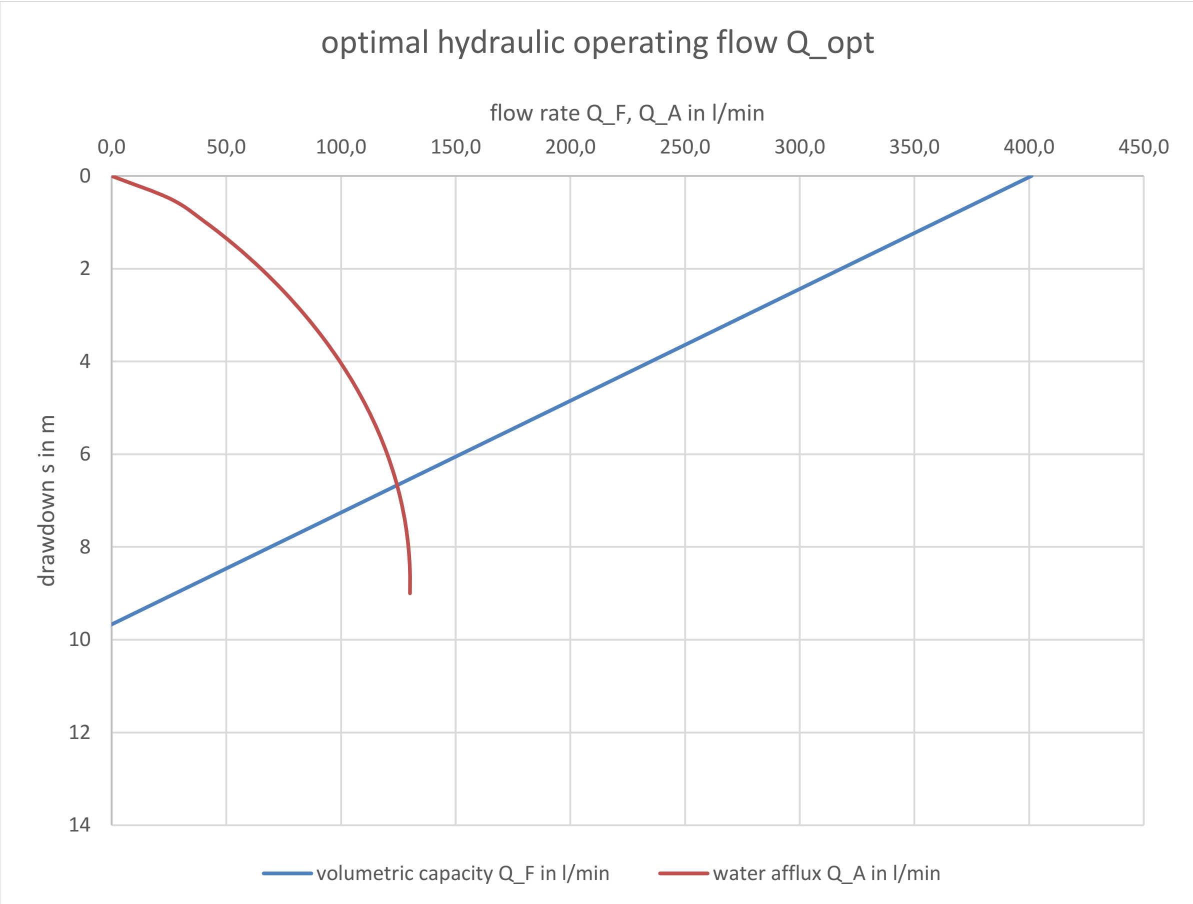


Figure 19 optimal hydraulic operation flow Reza abaad well

The crossing point of the graphs represents the optimal hydraulic operating flow at which the well is not affected by any negative effects of over usage. According to this, the well can provide a flow rate up to $Q_{opt} = 125\ \mathrm{l/min}$. At this rate a drawdown of about $\mathrm{s} = 6{,}7\ \mathrm{m}$ will be produced.

Ebrahimabad well

The resting water level before the pumping test was at 16,18 m below ground level. Because of the great depth of the well, there is no problem having a high enough water column submerging the pump into. But the diameter of the drilled well is much less in comparison to a dug well. So with a diameter of around 0,25 m a specific submerged pump had to be used. This pump provided a flow rate of $Q = 6{,}6\,\mathrm{m}^3/\mathrm{h}$. The maximum drawdown after the pumping phase (duration: 30:30:00) was 0,57 m. In the recovery phase the water level quickly increased to 0,1 m below resting water level. Over the next 60 h it increased furthermore to 0,05 m below resting water level. The following graph shows the drawdown and recovery.

Figure 20 ebrahimabad well during pumping test

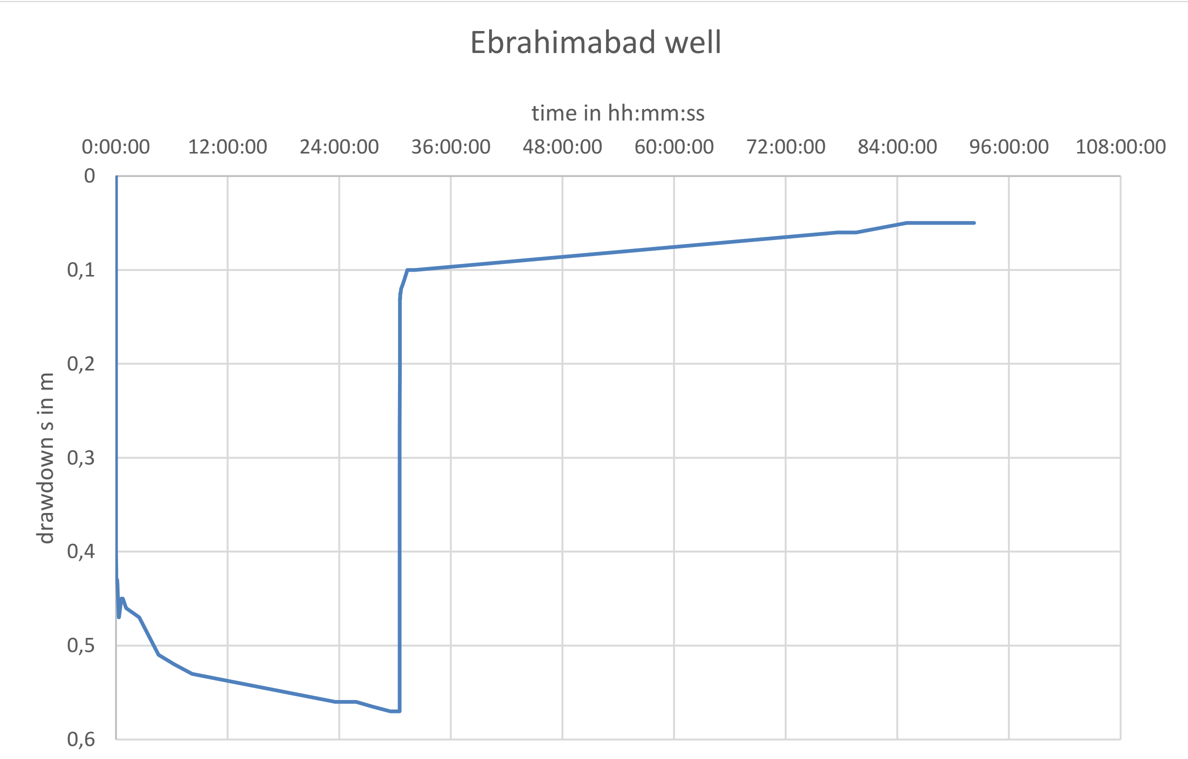


Figure 21 pumping test Ebrahimabad well

This well delivers also enough water to cover the need of the village and the planned visitor center. Based on the recorded data, the further analysis serves to identify the hydraulic structure of the aquifer. As described in the previous chapter the analysis was executed and led to the following results for the needed parameters:

Table 6 parameters of Ebrahimabad well

Parameter	**Value**
Transmissivity T in m²/s	$9{,}59 \cdot 10^{-3}$
Aquifer thickness M in m	30
Permeability coefficient k_f *in m/s*	$3{,}20 \cdot 10^{-4}$
Maximum entering velocity v_{max} *in m/s*	$5{,}96 \cdot 10^{-4}$

The calculation of volumetric capacity and water afflux is shown below. Because the drawdown s is a variable in these formulas the results are presented as a plot:

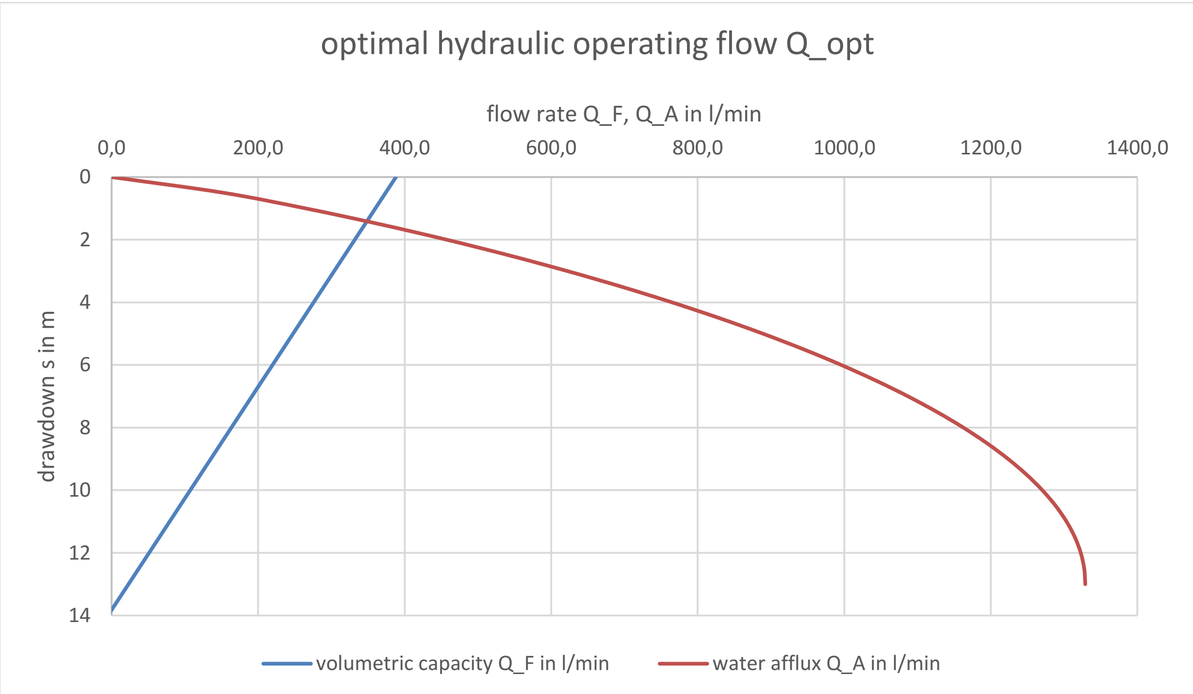


Figure 22 optimal hydraulic operation flow Ebrahimabad well

Again the crossing point of the graphs represents the optimal hydraulic operating flow at which the well is not affected by any negative effects of over usage. According to this the well can provide a flow rate up to $Q_{opt} = 350$ l/min. At this rate a drawdown of about s = 1,7 m will be produced.

Shah alli well

Like the Ebrahimabad well this well is also dug. It has a depth of 6,8 m and a resting water level of 2,42 m below ground level. The water column of 4,45 m provides enough space to lower the pump into. The used pump generated a flow rate of $Q = 21\,\mathrm{m}^3/\mathrm{h}$. The pumping phase was ended after 1 h 15 min at which the drawdown topped out at 2,87 m. While recovering the well was able to increase the water level almost to resting water level (0,01 m below) within 60 min. The following graph shows the drawdown and recovery on a logarithmical scale.

Figure 23 shah alli well during pumping test

Figure 24 pumping test Shah alli well

Like the other two wells analyzed before this well can cover the need of the village and the planned visitor center. Based on the recorded data, the further analysis serves to identify the hydraulic structure of the aquifer. As described in the previous chapter the analysis was executed and led to the following results for the needed parameters:

Table 7 parameters of Shah alli well

Parameter	**Value**
Transmissivity T in m²/s	$5{,}81 \cdot 10^{-4}$
Aquifer thickness M in m	8
Permeability coefficient k_f in m/s	$7{,}26 \cdot 10^{-5}$
Maximum entering velocity v_{max} in m/s	$2{,}84 \cdot 10^{-4}$

The calculation of volumetric capacity and water afflux is shown below. Because the drawdown s is a variable in these formulas the results are presented as a plot:

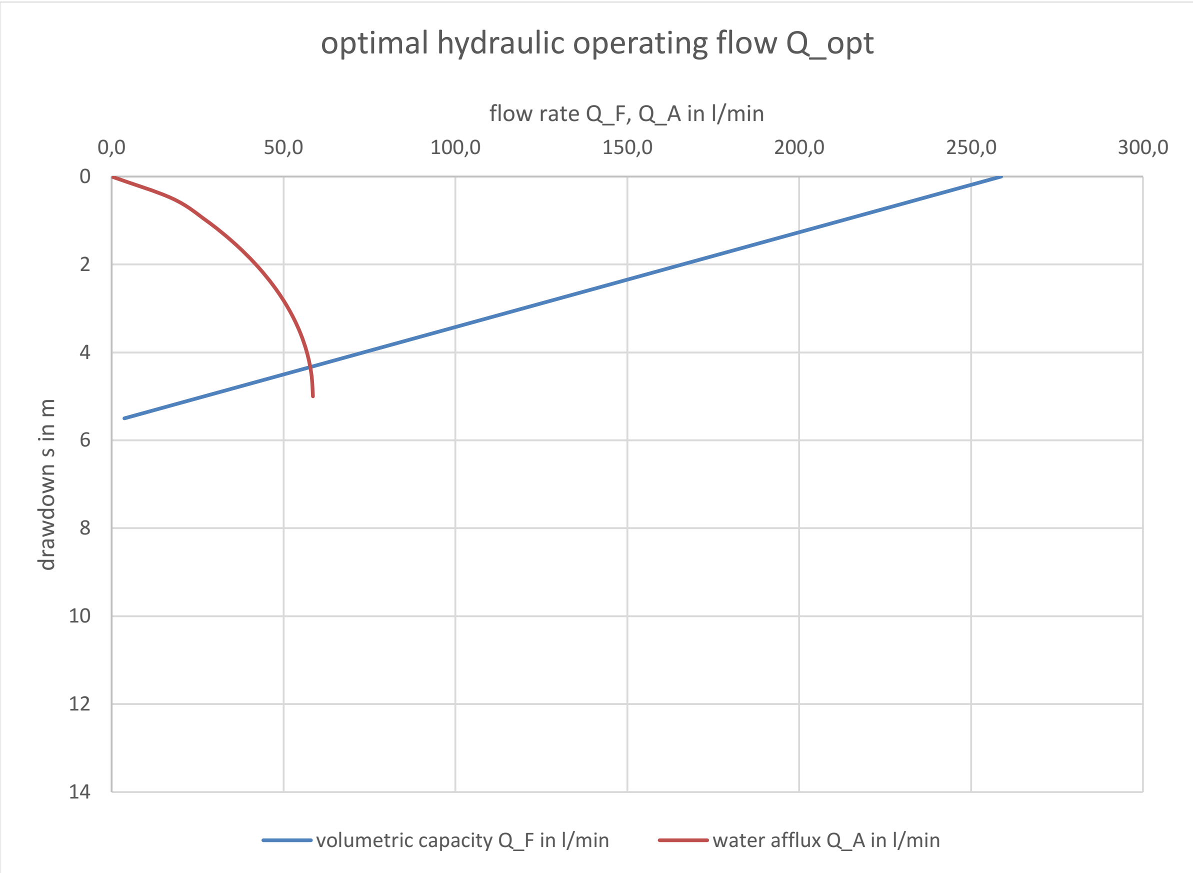


Figure 25 optimal hydraulic operation flow Shah alli well

The crossing point of the graphs represents the optimal hydraulic operating flow at which the well is not affected by any negative effects of over usage. According to this the well can provide a flow rate up to $Q_{opt} = 60$ l/min. At this rate a drawdown of about s $= 4{,}2$ m will be produced.

The pump used in the pumping test generated a flow rate of approximate $Q = 350\,\mathrm{l/min}$. This outflow is well above the optimal rate. It is highly possible that at this rate a turbulent flow is generated which leads to consequential damages like iron clogging[2] or siltation[3].

Discussion of results

The calculations are based on classical approaches and can only be applied to the existing structure of the aquifers to a limited extent. In contrast to the cases considered in the technical literature, there are probably no such discrete soil layers around the wells investigated. Therefore the approaches can only be applied to a limited degree. Due to this discrepancy, the results can only be seen as a rough approximation and do not represent absolutely reliable values. They can only serve as an orientation for the size of the expansion measures to be planned.

The thickness of the aquifer below the Shah alli Well is also a value to be considered. During the pumping tests carried out at the well site a sufficient fresh water inflow could be determined, but due to the low thickness there is still the danger that the well could dry out in times of low precipitation. The aquifers of the other investigated wells have a greater thickness and can therefore store a larger amount of water. However, it should also be considered that the recorded profiles can only be used to determine the thickness of the aquifer. They do not allow any statement about the actual total extent of the aquifer and thus no exact conclusions about the total yield of the aquifer. For its determination, further extensive tests are necessary, which could not be covered by the project.

During the construction of another drilled well it was noticed that the construction of drilled wells on site is rudimentary. The inserted iron-made well pipes are slit at the predicted height of the aquifer so that water can flow into the well. The insertion of filter material or special filter pipes is completely skipped. It is reasonable to assume that the Ebrahimabad well has the same design. This increases the input of particles when water is pumped. In addition, due to the risk of siltation the maximum operating time before an inspection of the well is reduced. In order to avoid intensive maintenance work at relatively short intervals, a filter pipe could be inserted into the existing well pipe to reduce the entry of particles into the water supply network and the connected systems. If the

[2] Groundwater typically has a very low dissolved oxygen content and potentially a low pH value. Due to these properties, large amounts of iron and manganese can be dissolved in the groundwater. If such iron- and manganese-rich water is now brought to the surface and comes into contact with atmospheric oxygen, the dissolved iron and manganese ions are precipitated as iron hydroxides and manganese oxides. These slowly clog the filter slots of the wells as well as the inlets of the pump. The other plant components can also be clogged by a possible precipitation of the iron and manganese compounds and thus be damaged. This process is known as “iron clogging”.

[3] Siltation refers to the reduction of the permeability of the surrounding subsurface in the well area. Soil particles with small grain diameter are washed into the filter material by turbulent flows. These are mainly silt and clay. These particles settle in the filter material and potentially swell. If an excessive amount of this material is brought in, the filter material can become blocked and the fresh water inflow into the well is reduced. This bears the risk that not enough water can be pumped to supply the village.

well itself is blocked, the pump must be lifted out of the well and the well must then be laboriously freed from any blockage.

The newly constructed Reza abaad well had a water column of about 2 m during the conducted pumping tests. Under full load, the pump was able to lower the water level by about 1 m, which caused the water column to drop to 1 m above the well bottom. In addition to the possibility that the pump runs dry during such an operation, there is also the danger that soil particles are thus suspended and transported into the supply network. To avoid this, the well has to be deepened so that the water column above the pump inlets is sufficient and the risk of dry-running the pump is minimized.

3.1.2. Well construction

Regardless of which well is chosen, it is important to protect the well and the necessary system components for water production from the weather and unauthorized access. For this purpose, the well and the extraction system are generally fenced in. Within this area there is usually the well itself, which has been equipped with a submersible pump, and a building containing the electrical control of the pump and other technical equipment. In Germany, various requirements apply to the construction of the final structure, which are summarized in W122 (DVGW 2013). Based on these rules and regulations, the final building is designed in the following.

For a better protection of the well it is recommended to integrate it into the structure to be built. This is illustrated in the following figure.

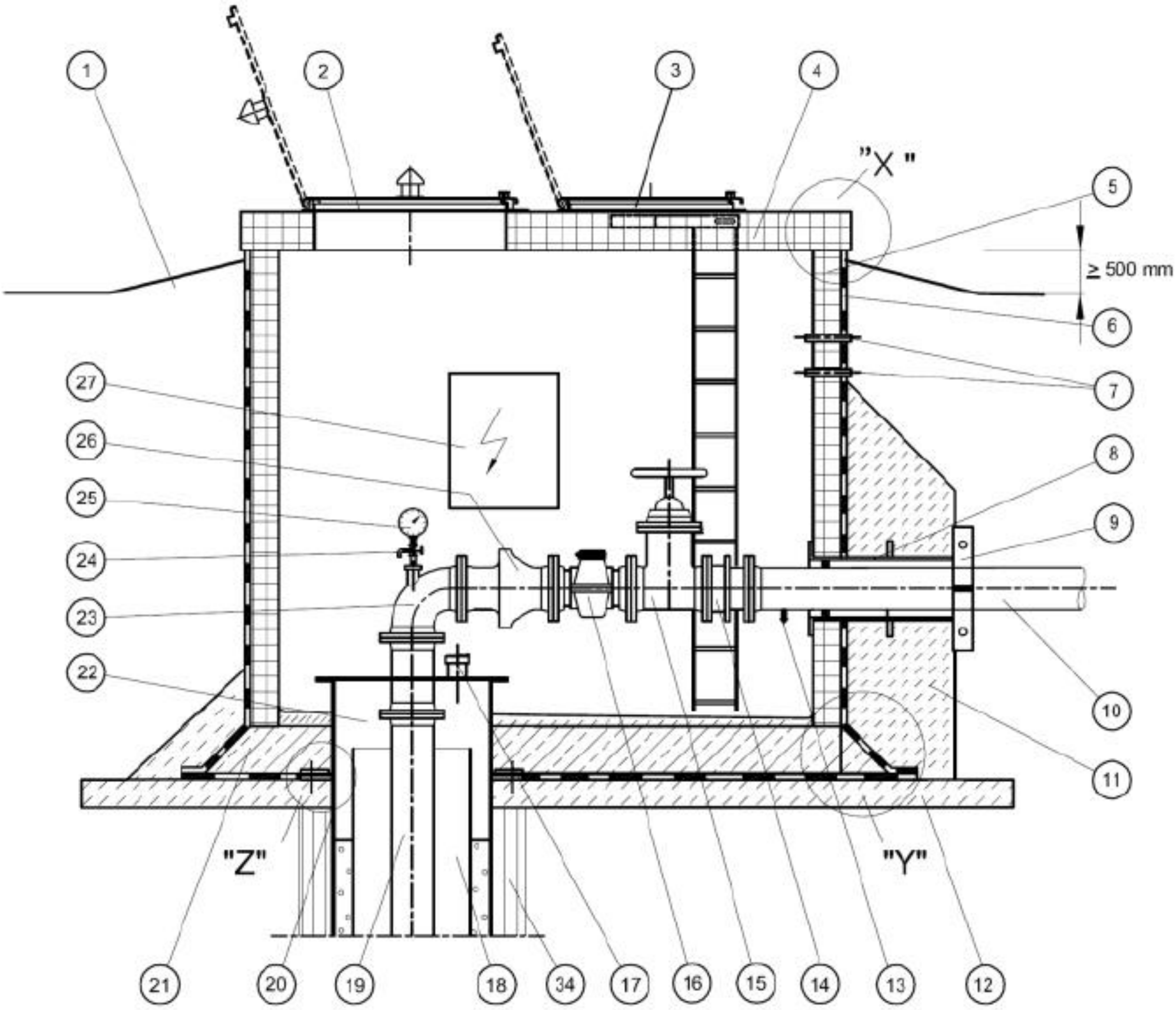


Figure 26 well housing (DVGW 2013)

In contrast to the construction method shown, the pump house on site will not be built underground but above ground. This means that some safety measures against the earth pressure are no longer necessary and the construction can be simplified. Should the Reza abaad well or the Shah alli well be chosen for supply, an underground construction is furthermore not recommended, as both wells are located in areas that could potentially be flooded. If the pump house is built above ground, this danger can be more easily included and countermeasures can be taken.

The structure requires a sufficiently stable foundation which is built of waterproof concrete (21). It is also necessary that the walls and the ceiling are also made of waterproof material. The openings in the building must all be sealed to prevent damage to the plant technology by any water ingress.

Usually submersible pumps are used to collect water, which are lowered into the wells. For future revisions of the pump as well as the well shaft, it is therefore necessary to make an opening in the ceiling (2) in the well axis to be able to lift the pump out of the well.

The control technology required for pump operation is located in a switch cabinet (27), which is mounted on the wall of the building to prevent water damage caused by escaping water. This cabinet contains all electrical connections for the pump as well as the protection devices and fuses for the required electrical systems.

From the pump water connection there is the delivery pipe, which is connected to the pump by couplings. In case of an inspection, the gate valve (15) in the pipe is closed and the pump can be disconnected from the pipe at the coupling. This design ensures easy maintenance. There are also other installations in the pipe which support the faultless operation of the pump. In the flange bend (23) there is a vent valve (24) to minimize the air entry into the transport network. Furthermore, a manometer (25) is integrated at this point to monitor the delivery pressure of the pump. A further protective measure is the installation of a check valve (26) to prevent the water column from being broken off even when the pump is switched off. This protects the pump, since the water column does not have to be built up every time the pump is started up again. Additionally the check valve prevents the water to flow back through the pump into the well and eventually causing damage to the pump itself.

In addition to installations for the transport of the pumped water, appropriate connection options for the power supply are also required. The needed power supply line can either be routed above ground to the pump house via masts, or underground via underground cable. Since trenches have to be dug for the water transport line, it is advisable to lay underground cables in the same run to avoid additional costs.

For the pumping tests that have already been carried out, a submersible pump ("Stream 4SDM4/17") was purchased that has sufficient capacity to pump the water from the wells. The characteristic curve of this pump can be found in the appendix (Figure 53). It is planned to finally use the pump as the supply pump in the well, as its performance is sufficient and costs can be saved by further use

3.2. Storage

As already mentioned in Chapter 2.4, a water reservoir is also being planned. This is intended to store the raw water pumped from the well and serve to balance peak loads. An elevated location was chosen for the reservoir in order to ensure the required water pressure due to the difference in elevation.

It is planned that the outlet will lead from the reservoir to the village center, from where it will supply the other sections of the infrastructure with service water. It is also planned to enable the villagers to connect their houses to a multi-way valve at this point.

3.2.1. Dimensioning

In areas which have a detailed record of their water consumption, exact calculations of the required reservoir size can be carried out using this data. However, since these data are not collected in Hamzehlu, the dimensioning is based on empirical values.

Since the daily demand is below 2.000 m^3 Mutschmann (Baur et al. 2019) recommends that the reservoir to be built should be based on the daily demand. The capacity of the reservoir should therefore be around 11,25 m^3, which corresponds to the daily requirement as already calculated in Chapter 2.3. This already contains the buffer capacity, which otherwise would need to be calculated separately.

Not included in this capacity is the supply of extinguishing water. This is calculated separately and in this case can also only be determined using empirical values. Mutschmann recommends that in "rural villages with up to 50 properties", a fire water supply of 100 m^3 should be maintained. However, since the extinguishing water supply is about ten times greater than the original capacity of the reservoir, the problem arises that the water in the reservoir stagnates due to insufficient exchange, allowing microorganisms to settle. Due to the substances contained in the water (chpt. 3.3.1), this danger is only slight. Nevertheless, in order to guarantee the longest possible runtime of the subsequent treatment plant, it is recommended to store the daily used capacity and the fire-fighting water supply in separate structures. This results in a capacity of 11,25 m^3 for the reservoir, excluding the fire water supply.

3.2.2. Reservoir Construction

As mentioned in the chapter above, the capacity of the reservoir has to be around 11,25 m^3 to supply an sufficient quantity of raw water which will be used as service water and for the treatment plant. The weight generated by the volume of water must be supported by an appropriate foundation so that the building does not lose its structural integrity due to unstable ground. For this purpose, the foundation of the building must be designed to withstand the weight of the water and of the building itself as well as external loads such as wind and precipitation. Furthermore, when designing the foundation, an expert opinion of the subsoil is also required to confirm that it is suitable for such loads or, if necessary, that the subsoil needs to be prepared at the beginning.

In the water supply industry, stainless steel and non-porous concrete have proven particularly suitable for the construction of water reservoirs. These materials offer a high degree of flexibility in the design of the building as well as high resistance to external environmental influences. By using these materials, a long service life of the reservoir can be expected and with appropriate maintenance low operating costs can be assumed. (DVGW 2014)

As an alternative, smaller reservoirs can also be built from various plastics. For example, polyethylene (PE) is a suitable material due to its high chemical resistance, durability and food safety. (DVGW 2016)

Since the planned reservoir is one with a low volume, the use of prefabricated PE tanks is an option. These can be housed in buildings designed for this purpose, thus enabling easy handling and maintenance. The tanks can be connected to the supply network by means of appropriate couplings. The following figure shows an example of such a prefabricated tank combination.

Figure 27 connected prefabricated water tanks (WTI 2019)

On each tank, there are four openings on the upper side, the largest of which has a diameter of 400 mm. This can be used for tank maintenance, while the others are used as an inlet. A DN80 flange connection can be fitted to the bottom of the tank, which is used as an outlet during operation and to provide a hydraulic connection between individual tanks. The shown prefabricated tanks have a volume of 4 m^3. In the case under consideration, three such tanks would therefore be enough to achieve the desired capacity of the reservoir.

A particular advantage of using the prefabricated tanks is that individual tanks can be disconnected from the network during operation via a suitable valve combination in order to have them inspected. Another application is the use of only one of the three planned tanks, should the water consumption of the villagers be too low. This ensures a sufficient water exchange in the reservoir even in cases with low water consumption.

Regardless of what material the reservoir itself will ultimately be made of, it is planned to integrate the emerging building into the village landscape. This can be achieved, for example, by using materials commonly used in the village for the lining of the facade. Alternatively, the reservoir can also be built partially recessed, for example to be hidden behind other buildings.

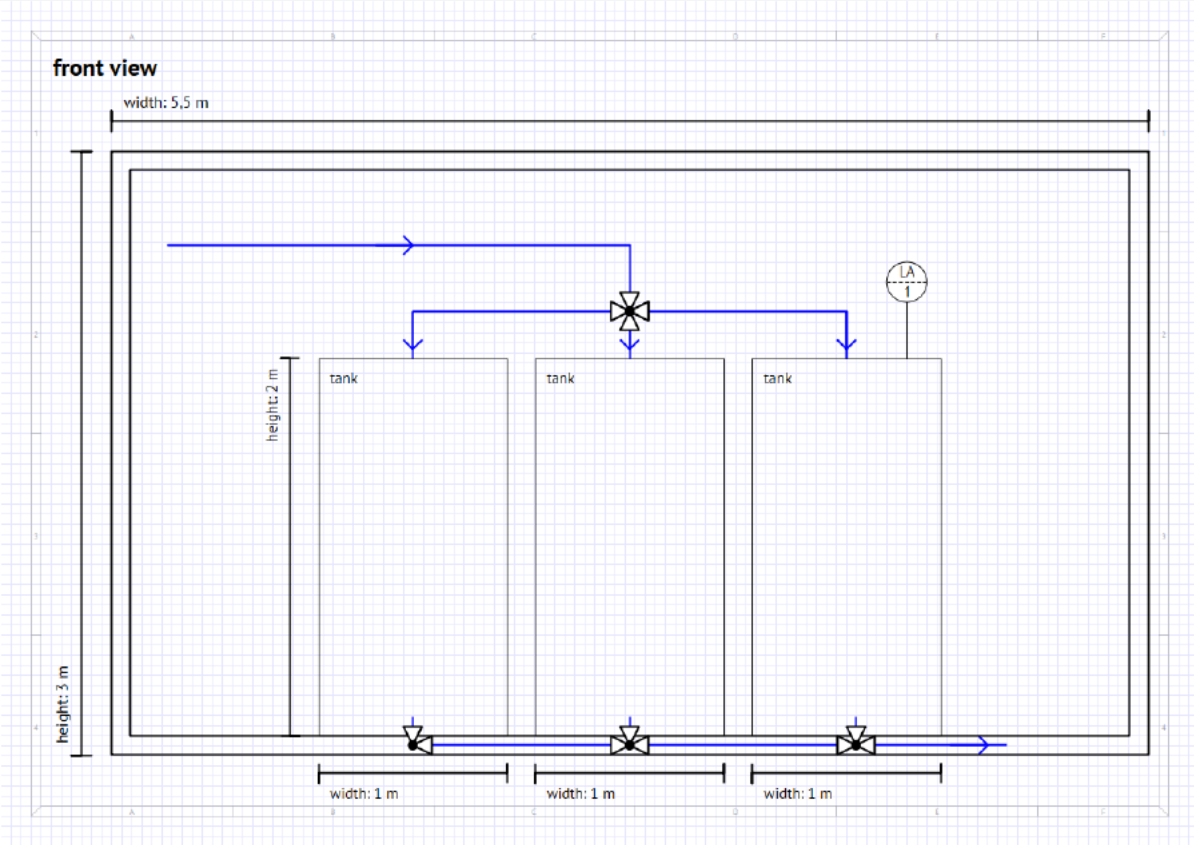


Figure 28 schematic front view of tank reservoir

The previous schematic diagram shows a possible design of the reservoir consisting of tanks. To achieve the required capacity of at least 11,25 m³, it is planned to install three of the tanks, each with a capacity of 4 m³. Through the already described inlets on the top of the tanks, it can be determined via a multi-way valve into which tank the pumped water reaches. Due to the hydraulic connection of the tanks to each other through the parallel arrangement of the outlets, the water level in all tanks is equalized. By means of the planned valves at the outlet of each tank, each individual tank can be closed. Should the need arise, this combination of valves allows individual tanks to be removed from the system without having to disconnect the entire reservoir from the infrastructure.

The dimensions of a single tank are 1 m width, 2 m height and around 2,5 m depth. In order to maintain the accessibility of the individual tanks, the housing should therefore be at least 5,5 m wide, 3 m high and 3 m deep. The maintenance accesses on the top of the tanks can still be used, for example to clean the tanks when necessary.

Due to the high weight of the fully filled reservoir, an expert opinion on the stability of the subsoil may have to be prepared in advance in order to determine potential subsidence of the subsoil under the expected load. If the stability is not given, measures for sufficient stability must first be taken before construction.

The control module with the designation "LA-1" is used to automate the well pump depending on the level of the reservoir. This installation ensures that there is always sufficient water in the reservoir to supply all consumers with service water. It is planned to install a float switch to control the water level. A float switch like in the right picture works quite reliable. The switch floats on the water surface while a counterweight pulls the attached cable under water. Depending on the inclination of the switch, the moving ball inside the switch closes or breaks the circuit. By this simple method a connected pump can be switched automatically without any further effort.


Figure 29 opened float switch (Meise)

3.3. Treatment

This part dealing with drinking water treatment is divided into three sections. At the beginning, the analyses of the water samples from the individual wells are compared with each other and with the legal limits. Then the construction of the future reverse osmosis plant and the housing required to protect the plant is described in more detail.

3.3.1. Analysis of the water samples

This subchapter deals with the analysis of the water samples. In order to be able to evaluate the values of the individual substances in the water, the local legal limits were considered. This shows how the raw water quality of the individual samples from the various wells differs from the drinking water quality in Iran. In the further course of this thesis, the performed analyses will be consulted for the planning of the treatment plant in order to optimize the choice of components.

Legal limits on drinking water quality in Iran

The legal limit values for drinking water quality are based on the international specifications of the WHO. The physical-chemical requirements have been laid down in IR Standard 1053. The microbial regulations have again been laid down in IR Standard 1011. As only a part of the limit values was analyzed in the water analysis of the submitted sample, the following table shows the legal limit for the values which were considered in the sample analysis.

Table 8 Iranian limit values for drinking water quality (excerpt from IR Standard 1053)

Parameter	**Legal limit**
Temperature in °C	-
pH value	6,5 – 9
Turbidity in NTU	5
Electrical conductivity in µS/cm	-
TDS in mg/l	1.500
Calcium (Ca) in mg/l	300
Magnesium (Mg) in mg/l	30
Sodium (Na) in mg/l	200
Potassium (K) in mg/l	12
Ammonia (NH_3) in mg/l	1,4
Sulphate (SO_4) in mg/l	400
Chlorine (Cl) in mg/l	400
Nitrate (NO_3) in mg/l	50
Nitrite (NO_2) in mg/l	3
Phosphates (PO_4) in mg/l	0,2
Fluorine (F) in mg/l	1,7

The **temperature** does not have a legally defined limit for laboratory samples, as this changes during transport and can only be measured correctly in situ. The water temperature is particularly relevant for the transport of drinking water, as bacteria can multiply more quickly if the temperature is too high and germs can reappear in the pipe system during transport to the consumer.

The **pH value** indicates how acidic or alkaline a solution is. It is calculated from the hydrogen ion concentration of the solution. A limit value of 6,5 - 9 has been set for drinking water. Outside this range, materials can become more corroded by the water and thus reduce the service life of the built water supply infrastructure. In addition to the corrosion behavior, the harmlessness and the taste of the drinking water are also influenced.

The **turbidity** of the water is perceived first by consumers and is often equated with the supposed purity of the water. As a physical limit value, turbidity is not optically assessed by the consumer, but determined in a reproducible measuring procedure. Nevertheless, the measured value is an indicator of the condition of the water. Turbidity in water is caused by particulate or colloidal substances. Those can partly be pollutants themselves, or lead to incomplete disinfection processes if the concentration is too high: Pathogens can be bound to or trapped in these particles and thus cannot be eliminated during disinfection.

Like turbidity, **electrical conductivity** is an indicator of the water condition. It can be used to estimate the ion concentration in the water. If the concentration is too high, increased corrosion may occur. High conductivity also indicates an increased salt concentration in the water.

The **sum of the dissolved solids ("total dissolved solids"; TDS value)** is the result of a quantitative measurement and has only a meaningful value for the proportion of dissolved substances in the water. Most measuring instruments determine the TDS content of the water by measuring the electrical conductivity and a conversion factor (usually 0,65 $(mg/l) \cdot (\mu S/cm)^{-1}$). Since the TDS value is proportional to the electrical conductivity, the same statements can be made about the sampled water. (World Health Organization 2003)

Calcium, magnesium, sodium, chlorine enter the water through natural cycles: if groundwater penetrates soil layers, the various compounds can be extracted from these. Together with chloride ions, calcium, magnesium and sodium compounds form and thus increase the salt content of the water. (Eidgenössisches Department des Inneren (EDI) und Bundesamt für Gesundheit (BAG) 2010)

Potassium is used in agriculture as a fertilizer in the form of potassium nitrate. If fertilizers are used in excess, anthropogenic input into surface water and/or groundwater occurs in addition to natural input. Certain potassium compounds can have a toxic effect on the human body, but such compounds are extremely rare in drinking water in dangerous concentrations. (Eidgenössisches Department des Inneren (EDI) und Bundesamt für Gesundheit (BAG) 2010)

Ammonia, as well as potassium as a component of fertilizer products, enters surface and groundwater through agriculture. It forms an equilibrium with ammonium that is changed to one side depending on the pH value of the water. Additionally the disinfection effect of chlorine during water treatment, if there is such an treatment step, can be reduced at high concentrations of ammonia and ammonium. They also serve as indicators of increased nitrite or nitrate levels.

The compounds **nitrite and nitrate** are also components of fertilizer products and are thus introduced into the water cycle. In addition to the damage that an increased concentration of these substances can cause in the environment, they also have negative effects on the human body: an increased concentration can lead to cyanosis. Nitrite inhibits the ability of hemoglobin to absorb and transport oxygen. In addition, carcinogenic nitrosamines can form in the body as a result of transformation processes.

Although **sulphates** have no negative effects on the human body, they have a highly corrosive effect on materials used to build the water supply infrastructure. Due to this negative effect, legal limits have been introduced.

Eutrophication means an increased nutrient content in the water and thus an excessive growth of organisms. In surface waters, this can result in an algae plague. In pipeline systems, an excessive supply of nutrients can cause uncontrolled growth of the biofilm on the inside of the pipe. Since **phosphates** are an essential nutrient, limit values were introduced to prevent the re-germination of the treated drinking water.

Just like nitrite, **bromine and organic bromine compounds** also have harmful effects on the human body. They are not only toxic but also carcinogenic and can occur in prey animals through bioaccumulation in increased doses. Poisoning with organic bromine compounds can damage the nervous system and attack various organs such as the kidneys or lungs. (Lenntech BV)

Fluorine enters the water cycle naturally, but is added to drinking water in certain areas or populations. In the U.S.A., for example, fluorine is added to drinking water because it makes a major contribution to caries prophylaxis. However, fluorine also has negative effects: In too high concentrations it is toxic and can cause fluorosis such as femoral neck fluorosis. Such fluorosis reduces bone elasticity and promotes bone fractures. (Eidgenössisches Department des Inneren (EDI) und Bundesamt für Gesundheit (BAG) 2010)

Results of analyses of water samples

The following table shows the results of the analysis of the water samples of the different wells compared to the requirements. The highlighted lines contain the parameters that exceed the legal limits.

Table 9 results of water analysis

Parameter	**Legal limit**	**Reza abaad well**	**Shah alli well**	**Ebrahimabad well**
Temperature in °C	-	23,6	23,2	23,1
pH value	6,5 – 9	7,55	7,47	7,61
Turbidity in NTU	5	1,19	0,72	0,38
Electrical conductivity in µS/cm	-	12.330	11.066	9.420
TDS in mg/l	1.500	8.220	7.377,3	6.280
Calcium (Ca) in mg/l	300	712,8	720,63	487,8
Magnesium (Mg) in mg/l	30	154,6	118,38	137,4
Sodium (Na) in mg/l	200	1.640,8	1.465	1.334
Potassium (K) in mg/l	12	17,85	12,7	11,4
Ammonia (NH_3) in mg/l	1,4	0,3	0,25	2,2
Sulphate (SO_4) in mg/l	400	1.237,6	1.149	1.068,8

Chlorine (Cl) in mg/l	400	3.748	3.286,5	2.759,14
Nitrate (NO_3) in mg/l	50	15,75	19,19	8,31
Nitrite (NO_2) in mg/l	3	0,02	0,01	0,05
Phosphates (PO_4) in mg/l	0,2			
Fluorine (F) in mg/l	1,7	1,33	1,14	0,73

A comparison of the analysis data shows that all wells exceed the legal limits, sometimes considerably. This makes it clear that treatment is by no means unnecessary. The high salt content alone makes treatment necessary, but other parameters also require the water to be treated before it can be used as drinking water. In most cases the measured values of the individual wells are quite close to each other, so that no well can be used preferentially for treatment.

The parameters of the water analyses listed above are also later used to select a suitable reverse osmosis membrane. Depending on the composition of the raw water, if an unsuitable membrane is selected, its operating time may be reduced caused by scaling[4] or fouling[5] of the membranes feed side.

The parameter was not included in the present analysis, but according to the analytical laboratory (probably due to the high salinity of the water in all samples) there is no contamination by biological substances such as viruses, bacteria or other microorganisms.

3.3.2. Treatment plant construction

In the previous chapter the analyses of the water samples from the three different wells were presented. The analyses showed that some parameters exceed the local legal limits and therefore require treatment. Due to the high concentration of TDS, treatment by means of a reverse osmosis plant is practically unavoidable. However, the other parameters must also be taken into account, as some of them can lead to increased wear of the plant and thus possibly reduce the service life of the plant components.

In order to achieve the most effective purification of the water and the longest possible life span of the plant components (in particular the reverse osmosis membrane), the individual plant components of the treatment are examined more closely and suitable ones are selected in the following. This is particularly relevant for the later cost efficiency analysis, in order to optimize not

[4] Due to the concentration of water constituents on the feed side of the membrane during operation of the plant, it can happen that the solubility product of some substances is exceeded. These precipitate and crystallize on the membrane surface. The resulting crystals block the membrane surface, which means that the plant can only operate with reduced efficiency. This process is called scaling and can be reduced to a large extent, for example, by adding antiscalant solution and regular backwashing cycles.

[5] Fouling describes a similar process as scaling. The retention of the membrane increases the number of microorganisms on the feed side and leads to the growth of a biofilm on the membrane. The biofilm also blocks the membrane and reduces the efficiency of the plant. Effective measures against fouling are proper pre-cleaning and regular backwash cycles.

only the investment costs but also the operating and maintenance costs by selecting the appropriate plant components.

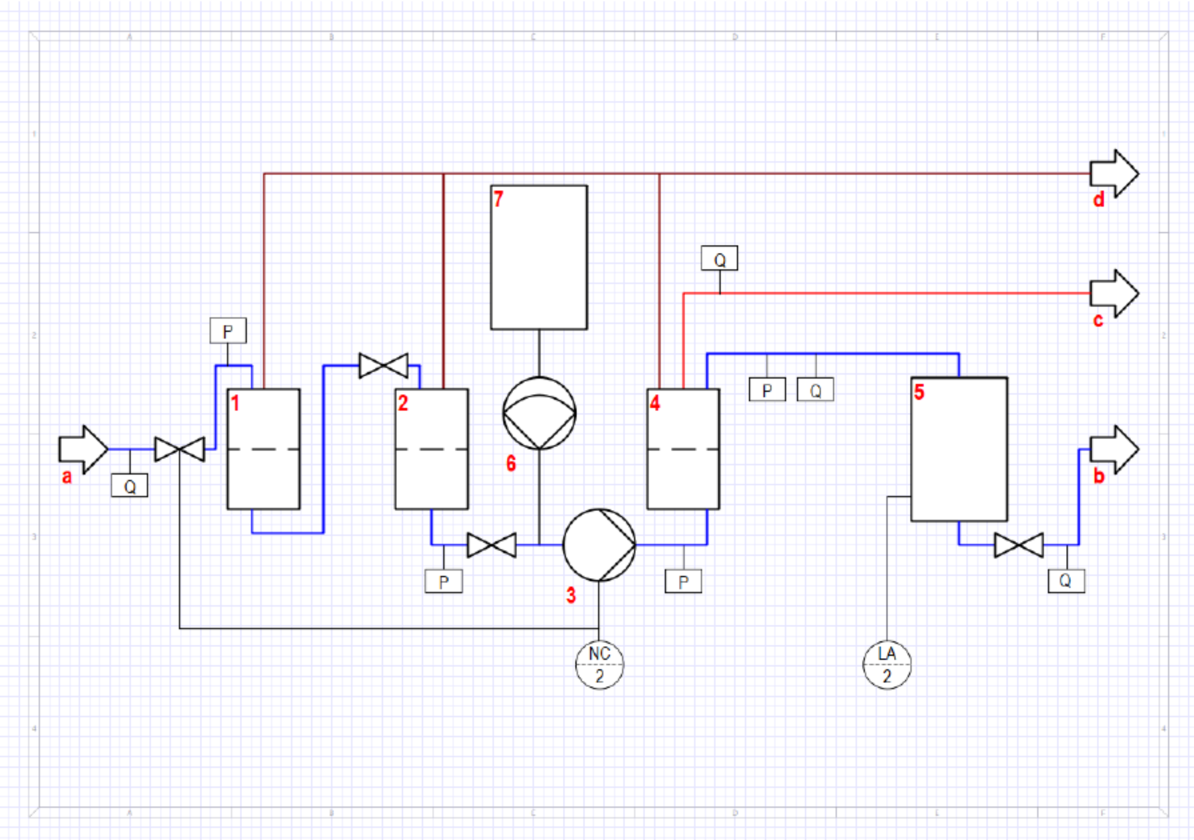


Figure 30 schematic view of treatment plant

Table 10 legend for Figure 30

Item	**Designation**
a	Feed inflow
b	Permeate outflow
c	Retentate outflow
d	Backwash outflow
1	Bulk filter
2	Membrane filter
3	Booster pump
4	Reverse osmosis membrane
5	Storage tank
6	Diaphragm pump
7	Antiscalant solution tank

In a previous work, the basic structure of a suitable treatment plant was already created, which is shown in the figure above. Based on this draft, the individual plant components and their function are now explained. In principle, the treatment plant shown can be divided into two main parts: pre-cleaning and main treatment.

Pre-cleaning

After the raw water supply (a) the water is pre-cleaned. In the pre-cleaning stage the water is pressed through a bulk filter (1) and a membrane filter (2).

Main treatment

Antiscalant solution (7) is then added to the water flow by means of a diaphragm pump (6) to minimize scaling and fouling to prepare the water for the main purification. A booster pump (3) increases the operating pressure so that the water can be forced through a reverse osmosis membrane (4) for the main purification. The raw water is divided into two streams: While one stream contains the treated and now drinkable water (permeate flow; b) which is led into a storage tank (5) and remains there until it is distributed to the consumers, the second stream (c) represents the retentate flow. This flow contains all the water constituents retained and concentrated by the membrane.

The third output flow (d) is water, which is produced during the regular backwash cycles. As with the retentate flow, this is non-potable water and must therefore be discharged together with the retentate flow.

a. **Feed inflow**

   As described above, the feed inflow represents the beginning of the water treatment process, as the plant is fed with raw water from here. Normally, the pressure of the incoming water would have to be increased by means of an inline booster pump in order to provide sufficient operating pressure for the subsequent pre-cleaning. The required operating pressure depends on the system components used in the pre-cleaning process and is usually between 2 and 4 bar. Since the treatment plant is preceded by a reservoir, which is positioned about 30 meters above the plant and thus the inlet pressure of the water is already at about 3 bar, an inline booster pump is not absolutely necessary in this case. Nevertheless, it may be required to install such a pump if the installed system components of the pre-cleaning require a higher operating pressure as 3 bar.

b. Permeate outflow

The permeate outflow represents the end of the treatment. The water from this outlet is of drinking water quality and can be used for any application requiring such quality. From here, the water can be transported to the distribution points via a separate drinking water network. From these distribution points the residents can then obtain drinking water.

c. Retentate outflow

The water retained by the reverse osmosis membrane with the unwanted, concentrated water constituents passes from the treatment plant to this outlet. From here the retentate can be subjected to further treatment if required.

d. Backwashing outflow

The water that results from the regular backwash cycles is also water with concentrated substances. Just like the retentate, it is not of drinking water quality and therefore cannot be used for most purposes. Since particles which have been trapped become detached from the system components during backwashing, the concentration of the water constituents is in most cases significantly higher than with retentate. Here as well a post-treatment of the water can be useful.

1. Combined sand carbon bulk filter

After the water has been fed into the system, the pre-cleaning process begins by forcing the water through a bulk filter. These types of filters consist of a layer of quartz sand, which is used for particle removal and as a pre-cleaning stage for reverse osmosis. The cleaning performance of such a single-layer filter is sufficient for this application and will be adopted for the planned plant based on experience. Typically quartz sand with a grain size of 0,63 to 1,0 mm is used. This fine-grained filter sand separates not only coarse particles but also medium-sized particles, which leads to a faster occupancy of the sand filter but also to a relief of the following micro filter. Quartz sand is often used in water treatment to remove particles, as it is a cost-effective and durable material with good filtering properties.

Similar conditions apply to activated carbon filters. The use of activated carbon filters serves not only to remove dissolved organic water constituents but also to remove odors, flavors and colorings. Usually grain activated carbon is used, which has a grain diameter of 0,6 to 2,36 mm.

The filter layer height is set at 1,5 m. This should ensure sufficient cleaning performance by the planned sand and activated carbon filters, whereby this value is based on experience. Relevant codes of practice such as W 213-5 (DVGW 2019) recommend an exact determination of the plant values by means of a pilot test. Nevertheless, such an approach is dispensed with because the data from the treatment plants in the neighboring villages Hesar and Mehrabad show that sufficient purification is achieved by the filters used.

2. **Micro filter**

Membrane plants operate according to the principle of surface filtration, which is similar to a screening process: Only substances with a smaller particle diameter can be transported through the pores of the membrane. When planning a micro filter, various criteria are used, which are listed below (selection according to W 213-5 (DVGW 2019))

- Raw water quality
- Net filtration capacity
- Permissible surface load
- Membrane surface

As already noted in the previous chapter, the water samples from the different wells have a turbidity between 0,38 and 1,19 NTU. The net filtration capacity amounts to about 1 m^3/h, as the plant is used in dead-end operation and thus the net filtration capacity corresponds to the flow rate of the micro filter.

The permissible surface load for micro filters with pore diameter of 5 to 10 μm is 100 to 150 $l/(m^2 \cdot h)$ (According to Baur et al. 2019). For dimensioning, the value is conservatively assumed and set at 100 $l/(m^2 \cdot h)$. Based on the flow rate and the area load, the required filter area A_F can now be calculated:

$$A_F = 1\frac{m^3}{h} \cdot \left(0{,}1\frac{m^3}{m^2 * h}\right)^{-1} = 10\ m^2$$

Consequently, 10 m^2 of active filter area are required for microfiltration for the planned application of the treatment plant.

3. **Inline booster pump**

Like any membrane process for the treatment of water, the reverse osmosis process also needs an increased operating pressure. In smaller plants this pressure ranges from 10 to 50 bar; for larger plants, a much higher pressure may also be necessary. In addition to the membrane used, the vital pressure also depends on the water constituents. The high operating pressure is necessary to overcome the osmotic pressure of the water and thus to force it through the membrane against the concentration gradient.

To increase the operating pressure in treatment plants, inline booster pumps are used, which can easily raise the water pressure from incoming 3 bar to up to 20 bar.

4. **Reverse osmosis membrane**

This part of the plant is the heart of the processing. The reverse osmosis membrane retains practically all water constituents, only pure water is able to penetrate the layer at sufficient operating pressure. By this process, any biological impurities are retained and therefore no longer represent a danger. Likewise, large parts of the inorganic ingredients are eliminated and the water thus gains in quality. The retention of salts dissolved in the water is particularly relevant in the case under consideration, since due to the high salt content, the untreated water is inedible and hardly suitable for any application. Only when the salt content is reduced by the membrane the water can also be used for purposes requiring drinking water quality.

The underlying operating principle in membrane processes such as reverse osmosis is selective retention according to the diameter of the individual particles. If the particles have a larger diameter than the pores of the used membrane, they are retained and do not get into the clean water. With an appropriate pore diameter, different fractions of particles can be retained in the water.

The design of the plants is based on the same process engineering principle. The feed water is pressed into the membrane modules by means of a high-pressure pump. If a sufficient pressure is built up, the operating pressure exceeds the osmotic pressure of the water and the water molecules can migrate through the membrane, whereas the impurities in the water cannot pass through the membrane.

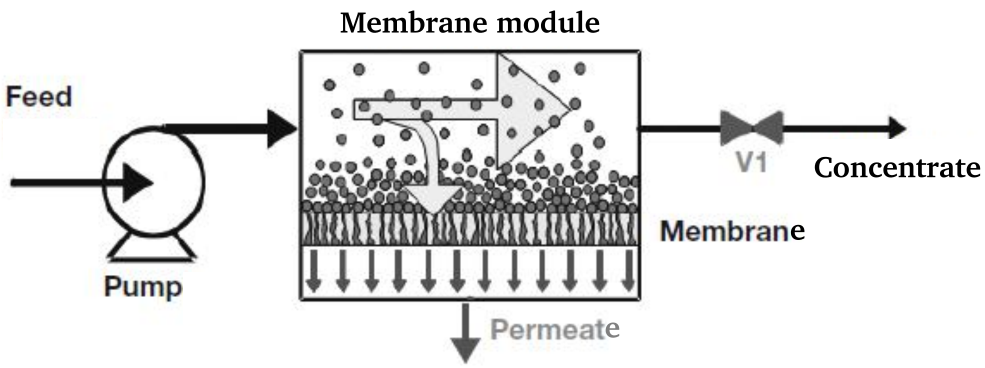


Figure 31 Process engineering principle of membrane filtration (DVGW 2009)

The inlet flow separates into two flows: The permeate (or filtrate) is the part of the water that has been forced through the membrane. The retentate (or concentrate) is the residue that results from this process. The retentate contains the collected impurities that were retained by the membrane. As the concentration of the impurities in the retentate is constantly increasing due to this operating principle, the osmotic pressure that must be overcome in order to force water through the membrane also increases. By discharging the retentate, it can be prevented that a too high concentration takes place and the process comes to a standstill. In general, the yield - the ratio between permeate and feed - is about 40%.

Based on the analyses of the water samples in the previous chapter, the membrane BW30-4040 from Dupont was selected. This membrane is characterized by reliable operation even at high TDS concentrations. As it is designed for brackish water treatment, it can be used without any problems for the raw water quality of the wells. The data sheet of the membrane is attached to the appendix of this thesis (Figure 54 to Figure 56).

5. **Drinking water storage tank**

Due to the probable discontinuous operation of the treatment plants, a storage tank in which the treated drinking water can remain is required. Since the water is of drinking water quality and must retain this quality, it is necessary to use a tank that is food-safe - i.e. cannot release any harmful substances into the water. For this purpose there are a large number of tanks available. Due to the dimensions, a 2 m³ tank of the same series was chosen, which will also be used for the reservoir. This is about 0,7 m wide, 1,7 m high and about 2 m deep. The pre-installed inlets and outlets allow the tank to be integrated into the system without considerable effort. The right figure shows an exemplary version of these tanks.

Figure 32 drinking water storage container (WTI 2019)

6. **Dosing pump**

   Diaphragm pumps are almost exclusively used as dosing pumps for the addition of antiscalant solution to the feed flow. It belongs to the group of positive displacement pumps which are used for the addition of chemicals to a delivery flow.

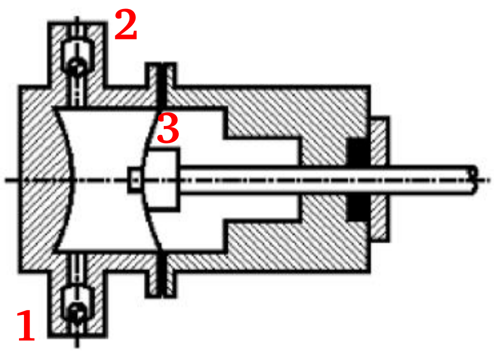


Figure 33 Diaphragm pump diagram (Baur et al. 2019)

   By a combination of valves and a mechanically moved diaphragm, fluids are conveyed through self-contained volumes. When the diaphragm (3) is retracted, the negative pressure generated opens the check valve on the inflow side (1) of the pump. When the diaphragm is completely retracted, the second partial process begins and the diaphragm is pushed back to its original position. The first valve (1) is closed by the now generated pressure and the second valve (2) opens. This process allows the addition of chemicals to be dosed very precisely.

7. **Antiscalant solution tank**

   The tank for the antiscalant solution can be the container in which the solution is delivered. This method is already used in the other plants visited and facilitates the replacement of empty tanks. With the help of a flexible hose, which is connected to the dosing pump, the solution can be delivered from the tank. To replace the containers, the hose is simply transferred to the new container and the empty container is removed. This keeps the maintenance requirements for this part of the system within limits and the storage of the solution is kept as simple as possible.

3.3.3. Treatment plant housing construction

Just as with the well, a building is also required for the treatment plant, which protects the plant from external influences and unauthorized access. In addition, the building is to be erected on the central square in the village, so it makes sense that all the piping of the water infrastructure converges underneath the building to allow easy handling and maintenance of the piping. The following diagram shows the top view of the planned building. A side view is also provided in the appendix (Figure 57) to better illustrate other aspects of the building.

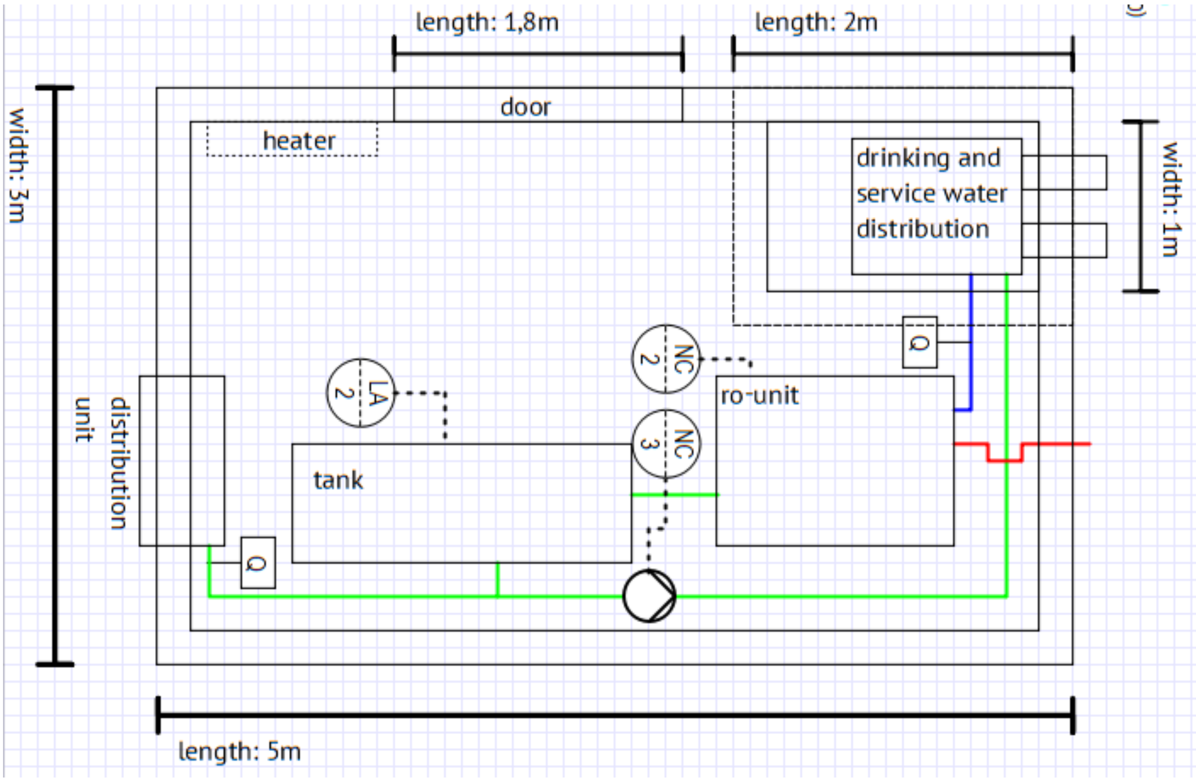


Figure 34 top view of the treatment plant housing

The building, which will house the treatment plant and the drinking water tank, has a planned width of 3 m and a length of 5 m. The height was set at 3 m to allow easy access to the tank and plant for maintenance work.

Since the entire piping system converges underneath the building, it is planned to build a partial basement. This cellar should at minimum be 1 m wide and 2 m long. For the depth, a lowering of 1,5 m is probably sufficient to accommodate all connections and valves.

Since the tank as well as the treatment plant are large in volume, it is important to ensure that the door is wide enough, otherwise the plant components cannot be transported through the door when they are delivered. Even in the event of a possible replacement of a plant part, which may become necessary in the future, it should be possible to transport the part out of the building without great effort.

As a further measure during the construction of the building, the installation of an electrical heating system is planned. Since the system components run the risk of freezing at low temperatures, the temperature in the building must always be kept at least above freezing point. This can easily be done automatically via the thermostat setting of the heating system.

The installation of a distribution system in site is also planned. As the building of the treatment plant will be erected on the central square of the village, it is advisable to include a distribution system directly in the planning, as the villagers only have to cover short distances to obtain drinking water.

In order to achieve a basic automation of the plant, some control units are also planned to be included. It should be possible to monitor the water level in the drinking water tank ("LA-2") and to automate the treatment plant depending on this level ("NC-2"). If the water level is low, the plant should switch on and produce new drinking water; if there is (again) sufficient drinking water in the tank, the plant should be switched off. For example, this control can easily be realized by a float switch (see 3.2.2). Furthermore, drinking water should also be available at the future location of the visitor center and possibly at the excavation site. As these are located much further away from the treatment plant, the water has to be pumped up to there. In order to automate this process, a control system ("H-3") has to be established at the respective distribution systems, which is able to control the pump in the building ("NC-3"). This would enable drinking water to be transported to the consumers even over longer distances.

Another point, which serves to monitor the functions of the plant, are water meters or flow meters ("Q”), which are planned before and after the treatment plant. They make it easy to detect some potential malfunctions or leakage of the system and thus to correct them in a timely manner before major problems can develop. In addition, continuous flow measurement can be used to determine the end use. With a solid data base, it will be easier and more accurate to identify and calculate the required dimensions of plant components for future projects affecting the plant or at other sites of the region.

3.4. Drinking water distribution

The distribution unit is modelled on those already existing in Hesar and Mehrabad, which were built by local companies. These are simple and robustly built:

Customers must purchase a pre-paid card at the point of sale before they can obtain water from this unit.

This card is then placed on a field (1) provided on the unit, so the unit can recognize how much credit is still on the card. Now, the customer can position a brought container under the outlet (2) and in the next step select via buttons (3) how much drinking water he wants to buy.

Figure 35 distribution unit in Hesar

In the plant housing integrated is a drinking water tank, which is connected to the distribution unit. This connection is interrupted by an electronically controlled solenoid valve. When a customer confirms the purchase of a certain amount of drinking water, the solenoid valve is opened and the drinking water can flow gravity fed from the tank to the customer's container. In order to be able to determine the exact quantity of water delivered, this arrangement also includes a water meter after the solenoid valve, which is also integrated into the electronic control system. When the ordered quantity of water has been delivered, the water meter sends a signal to the central control unit, which then closes the solenoid valve again. This ensures that only the exact amount ordered is delivered and that no drinking water is wasted, for example by overfilling the containers brought along.

At the distribution units in Hesar and Mehrabad, a loudspeaker was also installed, which makes it easier for customers to use. As soon as the unit is activated, pre-recorded auditory instructions are played over the loudspeaker, guiding the customer through the entire purchasing process until they have received the drinking water. This feature is particularly beneficial for people who would otherwise have difficulty controlling this system.

Since some variants also provide for the transport of drinking water to more distant locations, a remote-controlled inline pump ("NC-3"; see Figure 36) will be installed in the treatment plant to transport the drinking water to the desired locations. For this purpose, a control system for this pump must be integrated ("H-3") at the individual distribution units. This is to ensure that when water is dispensed at the distribution units, the pump in the treatment plant also starts up in order to transport the water to the distribution unit. This process can be integrated into the unit itself. Ideally, a consumer would still only have to press the button for the desired output quantity and the water would be output. Alternatively, the pump would have to be switched separately before dispensing, which would make the process unnecessarily complex.

3.5. Routing

As already described in chapter 2.4, there are several wells that can be used to supply the village with service and drinking water. In addition, several possible locations have been selected where the future visitor center could be built.

During the stay on site, the geographical data of the whole area were recorded to generate an exact digital replica of the terrain. On the basis of this model, the different variants of the possible route were elaborated, which are now presented and explained in this chapter.

A total of six different variants are examined in detail. Variants were developed for each of the three wells in consideration and for each of the three locations in consideration for the future visitor center. Since the variants of the wells can be combined with those of the visitor center locations independently of each other, the individual route lengths of the affected routes are calculated in each variant. Due to the similar routing of all variants, only the lengths and elevation profiles of the individual lines differ. So a single routing plan was developed to summarize the cross-variant information. This plan is shown in the following Figure 36

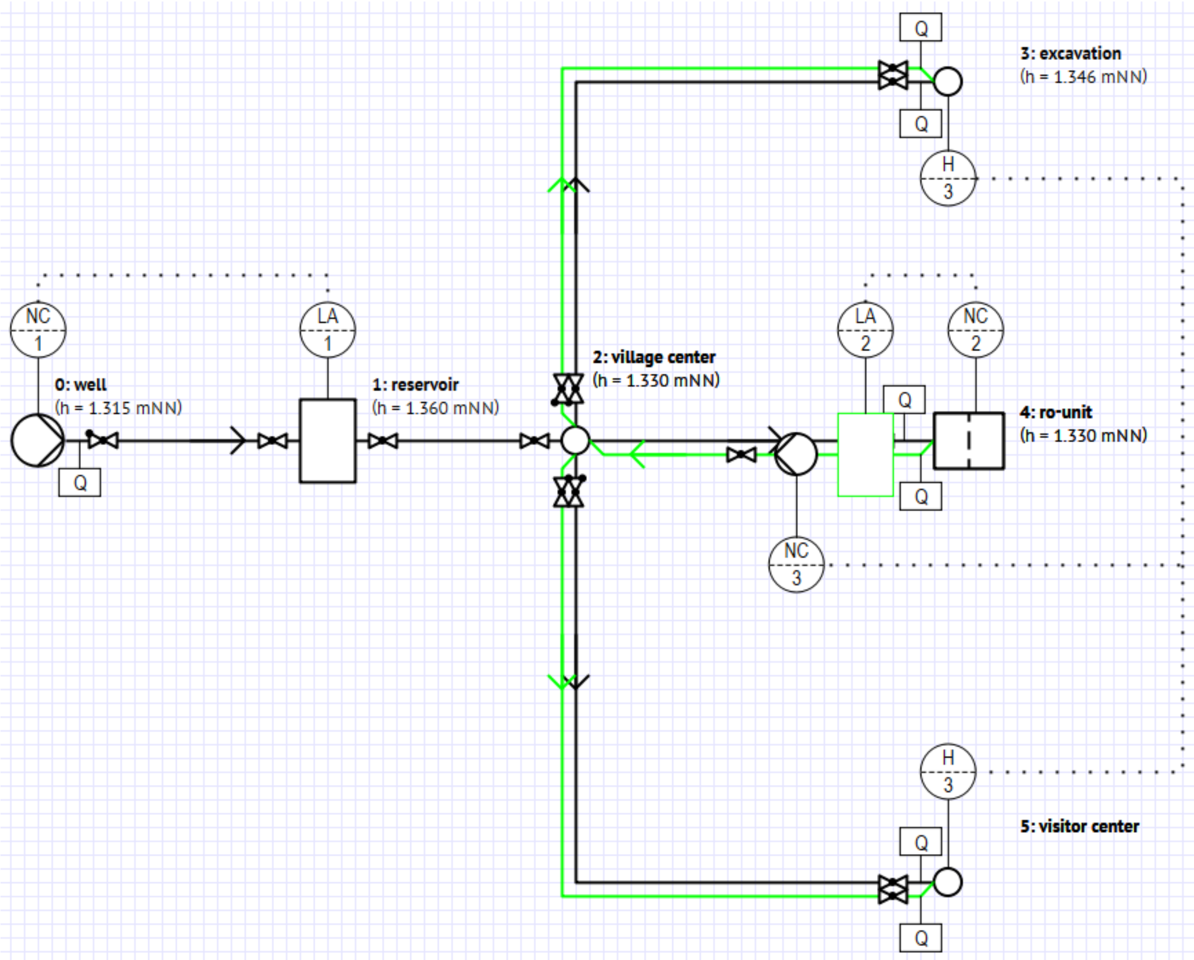


Figure 36 routing plan

The route is divided into two parts. The pipes shown in black in the figure above are used for the transport of service water, whereas the pipes shown in green are intended for the distribution of drinking water.

In all variants, the following flow path applies: The water pumped from the well is directed to the high ground reservoir. Due to the difference in height between the reservoir location and the rest of the considered points, the service water can be transported gravity fed from here to these points. Since the central place in the village should serve as a crossing point for all pipes to allow easy maintenance, it was planned to lay a central pipe from the reservoir to the village center. From there, a multi-way valve will direct the water to the individual lines. From the village center, the treatment plant, the future visitor center and the excavation site are supplied with service water.

3.5.1. Pipe trench dimensions

Earthworks are the part of the construction that generates the most costs, as the work can usually only be done slowly and laboriously. Although construction machines make the work easier, they must be rented and are usually very expensive. To minimize the cost and effort of earthworks, as little earth as possible is moved. This section deals with the necessary width and depth of trenches to estimate the costs in the economic efficiency analysis of this thesis.

In the case of water infrastructure, the depth, at which the pipeline is laid, is determined by the depth of frost in the region: To prevent the water in the pipe from freezing during the cold season and possibly causing frost blasting, the pipes are laid in a soil layer that is deep enough to prevent frost from penetrating to it.

Figure 37 exemplary trench (Baur et al. 2019)

How deep soils freeze depends on various factors. These include, for example, the water content of the soil, its composition, but also the surrounding air temperature and the precipitation rate.

As only rudimentary climate data of the last 70 years are available for the region in which the project is carried out, these data were analyzed as far as possible and the remaining required parameters were supplemented by approximate values. (National Centers for Environmental Information (NOAA))

Calculation of trench depth

The frost depth is calculated according to Norm DIN EN ISO 13793. At the beginning all climate data of the past 70 years were analyzed and the winter months were filtered out. From these, in turn, the longest, strongest cold period was evaluated in order to calculate the frost index F (in Kh) based on the temperatures of this phase:

$$F = 24\frac{h}{d}\sum_{j}(\theta_f - \theta_{d,j})$$

Here j (in d) represents the number of days of the considered cold period and $\theta_{d,j}$ (in °C) the temperature which occurred on the respective days. This is subtracted from the freezing point $\theta_f = 0$ °C to obtain a positive balance.

Since the strength of a winter naturally fluctuates, the frost index of only one year does not represent a reliable value, which is why it was calculated for all years with sufficient data basis. In order to create a basis for comparison from these values, the arithmetic mean and the standard deviation were calculated from the individual frost indices. The variable m, in this case, represents the total number of used years to calculate the parameters.

$$\bar{F} = \frac{1}{m} \cdot \sum F_i = 3.108,2 \text{ Kh}$$

$$s_F = \sqrt{\frac{\sum (F_i - \bar{F})^2}{m-1}} = 1.898,6 \text{ Kh}$$

These values can then be used to calculate the rated frost index:

$$F_n = \bar{F} + \frac{s_F}{s_y} \cdot (y_n - \bar{y}) = 8.187,9 \text{ Kh}$$

The parameters s_y, y_n and $\bar{y}$ required for the calculation can be taken from tables in the DIN EN ISO 13793. The rated value F_n calculated in this way represents a reliable parameter, as it is averaged from all available data sets. In the following it can be used to calculate the frost depth:

$$H_O = \sqrt{\frac{7.200 \cdot F_n \cdot \lambda_f}{L + C \cdot \bar{\theta}_c}}$$

With

- $[F_n] = \text{Kh}$: rated frost index
- $[\lambda_f] = \text{W}/(\text{m} \cdot \text{K})$: thermal conductivity of the frozen soil (recommended: 2,5 W/(m·K))
- $[L] = \text{J}/(\text{m}^3 \cdot \text{K})$: latent heat when freezing water in the soil (recommended: $150 \cdot 10^6 \text{ J/m}^3$)
- $[C] = \text{J}/(\text{m}^3 \cdot \text{K})$: thermal capacity of the unfrozen soil (recommended: $3 \cdot 10^6 \text{J}/(\text{m}^3 \cdot \text{K})$)
- $[\bar{\theta}_c] = °\text{C}$: mean annual outdoor air temperature (calculated: 14 °C)

Since no exact data are available for most of these parameters, the values recommended by Willems et al. 2019 were used for the calculation.

This resulted in a frost depth of approximately $H_O = 0{,}9$ m, which means that the pipes must be buried at about 1 m deep in the ground.

Recommended trench width

The width of the trenches results from the required depth. Since the depth of the trenches must be about 1 m, a width can be read off from the tables according to Mutschmann. A distinction can be made between trenches with or without an accessible working area. If no working area is required in the trench, a width of 0,5 m is sufficient. However, if work on the pipes in the trench is necessary, a width of 0,8 m is recommended. (Baur et al. 2019)

3.5.2. Dimensioning of the pipes

The pipe diameters were dimensioned in accordance with GW 303-1 (DVGW 2006) and the results were checked and confirmed via a simulation in USEPA Epanet, a software for network calculation/simulation.

As an example, the dimensioning based on Route 2-3 (between village center and excavation site) is presented here. The calculations of the other routes can be found in the appendix (Table 34).

Forecast of water consumption

The forecast of the water consumption is fundamental in order to be able to carry out the subsequent calculations in further steps on the basis of a defined input variable, since usually the pipe diameters are determined based on the maximum flow rate.

It is assumed that archaeologists have to clean the finds during an excavation and thus consume service water. Since the water supply is located in the camp, it is also assumed that the archaeologists collect the finds first and then bring them to the camp at the end of their shift and clean them there. Therefore, most of the water consumption will take place in the evening and the peak load will be present during this time. Based on this situation the maximum flow rate of this route including a safety factor was set to Q = 0,16 m^3/h.

Selection of piping material

A wide variety of materials are used for piping in the water supply system. Besides concrete or cast iron, plastics are also used. Each material has different advantages and also disadvantages, which must be weighed against each other for the respective place of use. Pipes made of plastic have become widely accepted and are also frequently used in Iran. Based on this knowledge, plastic pipes, which also withstand the high TDS concentration, were also selected for the infrastructure within the project. In particular, these are pipes made of polyethylene, which despite a high possible operating pressure have a certain flexibility, facilitating the laying of the pipes.

The raw material of the pipes influences the surface roughness of the pipes, which is relevant for the calculation of the pressure loss. The rougher a material is, the more pressure energy is lost when transporting a fluid through the pipe and the less pressure is available at the end of the conveying line. In the case of plastic pipes the roughness is between 0,01 to 1 mm. If new unused pipes are assumed, the technical literature offers a characteristic value of 0,01 mm as a basis for calculating the continuous pressure loss. This value was used for an initial calculation.

Calculation of route equation

In the first step the Reynolds number is calculated, which indicates the strength of turbulence of the fluid carried in the pipe. An empirical limit value between laminar and turbulent flow has been established, which amounts to about $Re_{krit} = 2.050$. The distinction between laminar and turbulent flow is relevant, since the pressure losses change depending on the prevailing flow behavior. The Reynolds number is calculated according to the formula

$$Re = \frac{\nu \cdot d}{V}$$

With

- $[\nu] = \mathrm{m}^2/\mathrm{s}$: kinetic viscosity of the fluid (1001,61 m²/s at 10 °C)
- $[d] = \mathrm{m}$: diameter of the tubing
- $[V] = \mathrm{m/s}$: velocity of the fluid

The calculation is carried out iteratively, since the input parameter d as the diameter of the transport pipe also represents the final result of the calculations. The calculation is shown in a shortened form at this point and is performed directly with the final diameter d = 50 mm.
Using the specified diameter, the flow velocity of the fluid in the pipe is calculated according to the formula

$$v = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} \cdot d^2} = \frac{0{,}16\,\frac{m^3}{h}}{\frac{\pi}{4} \cdot (0{,}05\,m)^2} \approx 0{,}02\,\frac{m}{s}$$

This results in a flow velocity of about v = 0,02 m/s. With this data the Reynolds number can finally be calculated, which amounts in this example to about Re = 1.103.
In the next step, the pipe friction coefficient can now be calculated using the Reynolds number and the Hagen-Poiseuille equation. It should be noted that a different formula must be used depending on the strength of turbulence. Since this is a laminar flow in this case, the following formula is used

$$\lambda = \frac{64}{Re} = \frac{64}{1.103} = 0{,}06$$

If a turbulent flow is involved instead, the form of the Prandtl equation $\lambda = 0{,}3164/Re^{0{,}25}$ can be used, as the plastic pipes applied can be regarded as technically smooth.
If the calculated parameters are inserted into Darcy-Weisbach's equation, the head loss over the transport route can be calculated

$$h_v = \lambda \cdot \frac{L}{D} \cdot \frac{v^2}{2g}$$

With

- $[L] = \mathrm{m}$: length of route
- $[D] = \mathrm{m}$: *(here)* diameter of pipe
- $[g] = \mathrm{m/s}^2$: gravitational constant (9,81 $\mathrm{m/s}^2$)

The resolution of this equation yields a total head loss of about 0,02 m respectively 0,04 m/km, which means that a pressure loss of only 2 mbar occurs over the transport distance. This ensures that water with a pressure of about 1,2 bar arrives at the excavation site. Together with the flow velocity, which in the case under investigation is v = 0,02 m/s and thus within the recommended limits of 0,005 m/s and 3 m/s, the selected diameter can be marked as acceptable. Theoretically, the diameter can even be reduced, but with the selected diameter a higher flow can be realized without any problems and is therefore also future-proof.

3.5.3. Self-ventilation

As many of the planned routes are located on uneven ground, it must also be taken into account that air pockets may occur in the high points of the pipeline. For this case, there are design principles which are summarized in DVGW W 334.

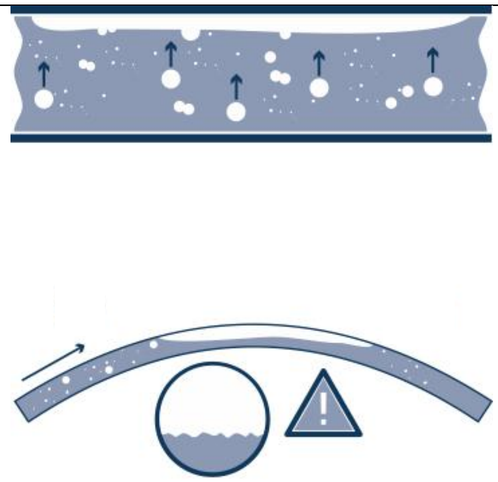


Figure 38 Air collects at the high point of the pipe (Airvalve 2019)

Air inclusions in the lines reduce the clear cross-section of the line, resulting in a reduction of the maximum flow rate. In worst case, this can lead to supply bottlenecks at the end points of the lines, which could have been avoided if sufficient safety installations had been made. Safety installations are vent valves through which the air escapes but the water is retained.

The above mentioned worksheet contains graphs from which the self-venting speed can be read. This is the speed at which the water in the pipeline carries any air it may contain to the end point. However, the graphs are only applicable for nominal diameters of 100 mm and more, so the self-ventilation speeds have been extrapolated for the nominal diameters DN50 and DN80 used in this project. If the flow velocity in the pipes is lower than the minimum velocity for self-ventilation, vent valves must be installed at the high points of the pipes. Since the required minimum speed has never been reached in any of the planned pipes, vent valves must be installed in all lines that have a discrete high point.

3.5.4. Variant independent routes

The positions of the reservoir, the village center, as well as the location of the excavation site and the processing plant do not change, so the lengths of the routes between these points are the same in all variants. The below aerial view shows these routes. In addition, the individual nodes of the infrastructure were also marked in Figure 39. These are the high ground reservoir (1), the village center (2), the excavation site (3) and the location of the treatment plant (4).

In order to keep the costs of earthworks as low as possible, it is planned to lay the piping for the service and drinking water supply in the same trench. Therefore Table 11 shows more routes than presented in this figure.

Figure 39 aerial view with variant independent routing (google)

Only the lengths of route 0-1 (between the well and the reservoir) and route 2-5 (between the village center and the visitor center) change their length depending on the combination of variants chosen. Therefore, the lengths and diameters of the unchanged routes have already been calculated and entered in the following table.

Table 11 lengths of routes

Route	Connection positions	Length	Nominal diameter	Transports
1-2	Reservoir – Village center	241 m	DN80	Service water
2-3	Village center – Excavation site	552 m	DN50	Service water
2-4	Village center – Treatment plant	3 m	DN80	Service water
4'-2'	Treatment plant – Village center	3 m	DN50	Drinking water
2'-3'	Village center – Excavation site	552 m	DN50	Drinking water

As a result, a total of at least 244 m of DN80 pipe is required in each variant combination to ensure the transport of the water from the reservoir to the village center and the treatment plant. A minimum of 1.107 m of DN50 pipe is also required, of which 555 m is for drinking water supply and must therefore be food-safe.

3.5.5. Variant Reza abaad well

Based on the geoelectric surveys, an area was selected which potentially hosts a water bearing soil layer. After the well was dug, this assumption was confirmed. The resulting Reza abaad well is one of the three wells that could be used for the water supply of the village. Therefore, in case this well is selected, a routing was planned. With the help of the village headman, a route was determined which could be used to transport the water from the well to the reservoir. The following aerial photo shows this route.

Figure 40 aerial view with routing of variant Reza abaad well (google)

As already mentioned, the route leads through the central square of the village, which is to serve as a crossroads. The water is then transported to the elevated tank on a plateau on the slope of the Douzlak.

Figure 41 elevation profile between Reza abaad well and reservoir location (google)

The illustrated elevation profile refers to the route between the Reza abaad well and the reservoir location. It can be seen that between these two points there is a steady, sometimes steep rise from well to reservoir. Because the reservoir, which serves as the end point of the pipeline, thus forms a high point, it is not necessary to vent the pipeline elsewhere. Any air introduced into the system can easily escape when it arrives at the reservoir via its venting system. If this would not be possible, a vent valve would have to be integrated into the line, as otherwise the air trapped in the system could lead to a reduction of the maximum flow rate.

Although the gradient of the terrain makes the venting of the pipe unnecessary, it must be prevented that water from the pipe can flow back through the pump into the well in phases when the pump is not in operation. For this purpose it is necessary to install a check valve directly after the pump, which prevents such a backflow. Otherwise the pump could be damaged, since such an operation mode is usually not intended. In order to still be able to drain the pipe in case parts or the entire pipe need to be inspected or replaced in the future, it is recommended to install a drain valve directly after the pump so that the pipe can be drained without difficulty.

As the elevation profile shows, the ground level of the reservoir site is about 45 m above the ground level of the well. In addition, the resting water level is about 10 m below the ground level of the well. This results in an absolute height difference between the water level in the well and the ground level of the reservoir of about 55 m. The well pump used must be able to overcome this height in order to pump the water to the reservoir. The "Stream 4SDM4/17" pump already used in the pumping tests has sufficient power to pump the water and can therefore also be used for the purpose of water supply without any problems.

In this variant, the following pipe lengths must also be added to the pipe lengths of the routes mentioned in Chapter 3.5.3:

Table 12 lengths of routes (variant Reza abaad well)

Route	Connection positions	Length	Nominal diameter	Transports
0-1	Well – Reservoir	1.227 m	DN80	Service water

3.5.6. Variant Shah alli well

As a second possibility, the Shah alli well located in a nearby field can be used for water supply. The field is located north-east of the village along the ridge of the Duzlak. The pumping tests have shown that despite a low groundwater aquifer thickness, the well has a sufficient inflow and can be used for supply. Just as with the well in the first variant, the possible route was discussed with the village headman and clarified for possible unclear ownership conditions. The following aerial photo shows the planned route from the well to the reservoir.

Figure 42 aerial view with routing of variant Shah alli well (google)

Again in this variant the village center is used as crossroads for all supply lines before the transport line is led up to the reservoir.

Figure 43 elevation profile between Shah alli well and reservoir location (google)

Starting at the well, the elevation profile of the recorded route does not describe a constant gradient, since a high point (a) of the pipeline is reached after about 200 m from the well. At this point air can easily collect inside the pipe and possibly limit the flow, thus a vent valve has to be installed in the pipe. This allows possible air pockets to escape to ensure maximum efficiency.

In addition to this high point, there is also a low point (b) in the pipe routing, which is about 500 m after the well, located in the village center. At this point it is recommended to install a drainage valve to be able to empty the pipe completely if necessary. This can be useful, for example, when the pipe or parts it are being inspected or replaced.

In this variant, the elevation profile shows a height difference of about 25 m between well and reservoir ground level. If the difference between the rest water level and the ground level of the well is added up, the absolute height difference is about 27,5 m. This value is below the height difference of the first variant and can also be overcome easily by the pump already in use.

Here the following pipe lengths must also be added to the pipe lengths of the routes mentioned in Chapter 3.5.3:

Table 13 lengths of routes (variant Shah alli well)

Route	Connection positions	Length	Nominal diameter	Transports
0-1	Well – Reservoir	873 m	DN80	Service water

3.5.7. Variant Ebrahimabad well

Also with the third possible well for the supply of the village, the possible route was walked together with the village headman. Since not all the fields between the well and the village center are owned by the villagers, but some of them are also owned by inhabitants of the neighboring village, care was taken to plan the route only on the footpaths between the fields, which are not personally owned. In addition, in this variant the unpaved bank and river bed must be crossed, which either requires the construction of a culvert or an above ground route. The following aerial photo shows the planned route from the well to the reservoir.

Figure 44 aerial view with routing of variant Ebrahimabad well (google)

Also in this variant it makes sense to use the village center as crossroads for all lines in order both to make operation and keep maintenance as simple as possible.

Figure 45 elevation profile between Ebrahimabad well and reservoir location (google)

The elevation profile shows that in this variant the start and end points of the route represent high points at which the pipeline can be vented. However, a drainage valve must be integrated into the

pipeline again in the village center (a), as the pipeline has a low point at this point. As with the previous variants, the installation of a drainage valve is also used here for easy maintenance in the event that parts of the pipeline are replaced and have to be empty for this purpose.
Since the well and the reservoir are at about the same height, only the resting water level in the well creates a height difference, which amounts to about 16 m. The pump is able to overcome this also small difference in height with ease. The following pipe lengths must also be added to the pipe lengths of the routes mentioned in Chapter 3.5.3:

Table 14 lengths of routes (variant Shah alli well)

Route	Connection positions	Length	Nominal diameter	Transports
0-1	Well – Reservoir	1.641 m	DN80	Service water

3.5.8. Variant plateau above village visitor center

The possible locations of the visitor center and routes to it were determined in the same way as the routes from the wells before. Together with the village headman, the ownership of the sites and the areas through which the route passes were clarified. The routes were also traced and recorded in order to create an elevation profile.
In this variant, a plateau on the Douzlak ridge was chosen as the location for the visitor center. This is particularly suitable as it is already on the planned route between the reservoir and the treatment plant. The following aerial photograph shows the position of the visitor center on the route already presented.

Figure 46 aerial view with routing of variant plateau above village visitor center (google)

The route for supplying the village center with service water from the reservoir passes the site of the visitor center. This makes it possible to lay the drinking and service water pipes for the visitor center in the same trench when constructing this pipeline. In order to ensure the complete supply of the visitors' center, a service water pipe from the reservoir to the visitors' center and a drinking water pipe from the village center to the visitors' center must also be laid in this trench.

Due to the high gradient of the pipeline, a check valve must be installed in the village center before the end of the drinking water pipeline to prevent unwanted backflow in it.

In this variant, the following pipe lengths must also be added to the pipe lengths of the routes mentioned in Chapter 3.5.3 and the pipe lengths of the variant whose well is finally selected:

Table 15 lengths of routes (variant plateau above village visitor center)

Route	Connection positions	Length	Nominal diameter	Transports
1-5	Reservoir – Visitor center	88 m	DN50	Service water
2'-5'	Village center – Visitor center	153 m	DN50	Drinking Water

3.5.9. Variant excavation site visitor center

The second possible location for the visitor center is on the ridge of the Duzlak mountain, which is turned away from the village, directly on the site of the excavation. Since it is planned to lay a drinking and service water pipeline to the excavation site anyway, all data of the route have already been recorded. The following aerial photo shows the planned route with the location of the visitor center.

Figure 47 aerial view with routing of variant excavation site visitor center (google)

An advantage of this routing is that two sites, the excavation site and the visitor center, can be supplied by one pipe. In this way, construction and material costs can be saved. It also makes maintenance of the routes easier, as the total number of routes is reduced.

Figure 48 elevation profile between village center and visitor center (google)

As the elevation profile shows, the visitor center or excavation site is located above the village center. As mentioned in previous chapters, check valves need to be installed in such cases to prevent unwanted backflow. Also various check valves must be installed in the drinking and service water pipes at the village center.

In addition, the installation of venting and drain valves can be useful. At position (a) there is a high point in the line where air may collect in the pipe. In order to avoid an unnecessary reduction of the possible capacity of the pipe, it is recommended to install a vent valve at this point.

Position (b), in turn, represents a low point, where a drain valve should be installed. As described above, the lines must be drained during inspection or replacement. This procedure is made considerably easier by such valves.

Based on the fact that the excavation site and visitor center are on the same position, no additional pipe lengths need to be added. Simulations have also confirmed that the pipeline is sufficiently dimensioned to support the additional consumption resulting from the combination of these positions. Therefore only the pipe lengths already mentioned in chapter 3.5.3 are required for construction.

3.5.10.Variant western village visitor center

The third possible position of the visitor center is in the western part of the village. There is a field owned by the village headman, which can be used as building land. Due to the short distance to the village center, this location is ideal, as the visitor center is easily accessible for maintenance. The following aerial photo shows the position of the visitor center and the water supply route.

Figure 49 aerial view with routing of variant western village visitor center (google)

Another advantage of this position is the even base. Since the village and visitor center are at the same level, the trench can be dug with simple means in order to lay the drinking and service water pipes. Due to the water flow, vent valves should not be necessary in any of the pipes. Drainage valves are also not necessary due to the short lengths of the pipes.

In this variant, the following pipe lengths must also be added to the pipe lengths of the routes mentioned in Chapter 3.5.3 and the pipe lengths to the selected well:

Table 16 lengths of routes (variant western village visitor center)

Route	Connection positions	Length	Nominal diameter	Transports
2-5	Village center – Visitor center	112 m	DN50	Service water
2'-5'	Village center – Visitor center	112 m	DN50	Drinking Water

4. Variant assessment

This chapter deals with the selection of the preferred variant combination. For this purpose, an assessment basis is first worked out, which is then applied to the different variants in order to select a preferred variant combination. In addition to hydraulic criteria, tourism aspects are also taken into account in order to select the location of the visitor center. To all criteria, a weighting factor was added to represent the relevance of each criterion to each other.
Since variants for the well location and the location of the visitor center can be chosen independently of each other, assessment bases are developed for both types of variants.

4.1. Well location assessment basis

The assessment basis for the selection of the well consists of five criteria:

1. **Height difference to reservoir:**
   Since the water transport from the well to the reservoir should only be carried out by the well pump, the difference in height between resting water level and reservoir is decisive for the maximum delivery rate of the pump. The higher the difference, the less water can be pumped into the reservoir per hour. In the worst case, if the delivery rate is too low, it may not be sufficient to cover consumption. However, since the reservoir has a sufficiently high storage capacity and the pump can overcome the differences in height between well and reservoir in each variant, the weighting of this criterion was set extremely low (0,02/1,0).

2. **Distance to reservoir:**
   The distance between well and reservoir is the basis for calculating the continuous pressure losses. The longer the pipeline, the higher the losses. An excessively long pipe increases the power consumption of the pump due to the higher power required, which can affect the operating costs. Also, a longer distance means that the investment costs are higher. In addition, longer lines mean a more complex search in case of leakage. The longer the lines between the individual parts of the system, the more possible positions of the leakage exist. In order to keep operating, maintenance and investment costs as low as possible, this criterion was included with a weighting of 0,3/1,0.

3. **Clear ownership of crossed areas:**
   During the inspections of the possible routes, the village headman always explained the ownership of the areas through which the respective routes run. In order to enable smooth construction of the infrastructure and to avoid future disputes due to unresolved ownership claims, it was decided to include this criterion in the basis of assessment. Based on the

statements of the village headman, values were determined for the respective variants, which were included in the evaluation with a weighting of 0,38/1,0.

4. **Problematic intersections:**

   Crossings with other structures are always a danger for water pipes. Changes in the structures can potentially damage the pipes. In the case under consideration, crossings with busy roads as well as with river courses are possible. If roads are crossed, they usually have to be opened at great expense before the pipes are laid and then sealed again. In addition, it may be necessary to close off the road completely during the work, which can lead to considerable restrictions if the construction site cannot be bypassed easily.

   The course of rivers is an equally major obstacle. Basically there are two ways to cross a river: Either the course of the river can be crossed by means of an above-ground pipeline, or a culvert can be dug to allow the pipeline to run below the river bed. Although the above-ground pipeline is usually cheaper to build, the pipeline is at risk to be damaged during flooding events. Therefore, the construction of a culvert should be preferred, but this increases the investment costs.

   Since each crossing of existing structures can mean increased investment or maintenance costs, this criterion was included in the assessment basis to include this aspect. The weighting was set at 0,2/1,0.

5. **Soil composition of routing area**

   Also the soil which has to be moved during the earthworks has an impact on the costs. A loose, non-flowing soil, for example, is much easier to move than rocky ground with a high coarse grain content. Norm DIN 18300 defines seven different types of soil, each of which means different costs for earthworks.

   The routes in the case under consideration, which lead through arable land that has already been ploughed for years, involve relatively little effort. However, some routes also run along the ridge of the Duzlak. As the rocky part of the soil tends to be higher in these areas, earthworks are also more difficult in such places.

   In order to take these conditions into account, the criterion is included in the assessment basis with a weighting of 0,1/1,0.

4.2. Well location assessment

The assessment of the individual criteria of one variant was carried out relative to the other variants, which means that for each criterion the optimum variant was determined and the other two variants were set in relation to this optimum. The following table shows the results of this assessment.

Table 17 results of well location assessment

Criteria/location	**Reza abaad well**	**Shah alli well**	**Ebrahimabad well**	Weighting
Height difference to reservoir	0,33	0,56	1	0,02
Distance to reservoir	0,68	1	0,51	0,3
Clear ownership	1	0,7	0,5	0,38
Problematic intersections	0,75	0,75	0,5	0,2
Route soil composition	0,8	0,5	0,7	0,1
Total	**0,82**	**0,78**	**0,53**	

As already explained, the difference in height between the well and the reservoir affects the maximum flow rate that can be achieved by the pump and the power consumption of the pump that is required. In order to keep the operating costs as low as possible, the height difference should be kept as small as possible. The water level of the Ebrahimabad Well is only 18 m below the reservoir, which is why this well has received the best rating. It is followed by the Shah alli well, as it has a difference of 32 m. The Reza abaad well has by far the greatest difference, as the water level in this well is 55 m below the reservoir. So, Ebrahimabad well was set as optimum, with a respective score of 1. To obtain the score of the other two variants, the ratios of the height differences were calculated.

The distance between well and reservoir is decisive for the required pipe lengths and thus the investment costs. The Shah alli well, at 800 m, is the closest to the reservoir and can therefore be considered the optimum for this criterion. The Reza abaad well is 1.180 m away from the reservoir and thus occupies second place. Due to the large distance of 1.580 m between the Ebrahimabad well and the reservoir, this variant receives the lowest score for this criterion.

For the construction and future operation of the lines it is essential that the ownership claims of the areas through which the lines pass are clear. According to the village headman, all the areas through which the Reza abaad well pipeline passes belong to his family. As the village headman is a great supporter of the project, it can be assumed that no problems will arise in choosing this option. In the case of the Shah alli well, the ownership claims are not quite so clear, as some villagers through whose fields the route runs could possibly prevent the construction. The Ebrahimabad Well is the biggest problem with this criterion. On the one hand, the well itself is not owned by the village but by the neighboring village. On the other hand, some areas required for the pipeline route are not owned by the village, which extremely restricts the routing of the pipes. Therefore the well received the lowest rating.

As mentioned above, crossovers with other structures are always expensive to build and represent potential weak points during operation. Since all well variants require the crossing of other structures, the number and severity of the crossing was considered for the evaluation of the variants. The route from the Ebrahimabad well would cross a river course, which is why, for example, a culvert would have to be dug, which means high investment costs. Although the other two variants also require the crossing of rivers, the watercourse affecting Shah alli well is much smaller. In the case of Reza abaad well, there is already a road bridge at the crossing point with the river, which could be used as a load-bearing structure for the pipeline, thus facilitating the construction work.

As a last point, the soil composition on the route was estimated. Depending on the composition, different efforts are required for the earthworks. As the route from Reza abaad well to the reservoir mostly leads through cultivated farmland, it can be assumed that the soil can be moved relatively easily. The soil was classified as class 3 or 4 after a first inspection.

The route from the Shah alli well in turn leads along the ridge of the Duzlak mountain and thus potentially consists more of stony material, which leads to increased effort. The most areas to be affected can be classified as soil class 6.

Between the Ebrahimabad well and the reservoir are also agricultural areas, but these areas have a high percentage of stony material, so that this soil must also be classified as soil class 6.

Based on the findings of the inspections of the individual routes between the wells and the reservoir, it is evident that the route of the Reza abaad well has the best soil class (3 to 4) for earthworks, whereas the other two routes (soil class 6) require more effort.

4.3. Visitor center location assessment basis

Evaluation criteria were also drawn up for assessing the possible locations of the visitor center:

1. **Height difference to reservoir**

   The height difference between the reservoir and the visitor center is relevant, as it is planned that the water transport between these points will only be gravity fed. This means that the height difference will be decisive for the incoming pressure in the visitor center. It can be roughly assumed that for every 10 m height difference, the pressure in the pipe will increase by 1 bar. Thus, for example, if there is a height difference of 20 m between the reservoir and the visitor center, the visitor center can be supplied with an operating pressure of 2 bar. This criterion was weighted with 0,15/1,0.

2. **Distance to village center**

   Since the visitor center is maintained by the inhabitants of the village, and visitors may in future use the village to buy food, souvenirs or other provisions, the distance between village and visitor center is relevant. The shorter the distance between these two points, the more the visitor center and its visitors can be integrated into village life. A weighting of 0,1/1,0 was applied here.

3. **Accessibility**

   The accessibility of the visitor center refers to how easily visitors can get there. For example, a visitor center near the village access road is easier to reach than one on the side of the Duzlak that faces away from the village. The gradient that has to be overcome to reach the visitor center has also been taken into account. This is to take into particular consideration old and disabled people, who otherwise would not have the possibility to reach the visitor center easily. The weighting here is 0,15/1,0.

4. **Positioning in terms of tourism**

   A further criterion, which partly conflicts with accessibility, is the positioning in terms of tourism. In addition to the exhibits in the visitor center, the touristic attractiveness can also be made dependent on the location. For example, a panorama worth seeing around the visitor center can increase the attractiveness, whereas a large distance to the actual excavation site can be considered a negative point. This criterion was introduced to take these characteristics into account and was given a weighting of 0,35/1,0.

5. **Flood hazard**

   As recent years have shown, during the rainy season, rivers can flood to such an extent that the banks are crossed and nearby areas are flooded. As the project aims at low maintenance operation and durable structures, such hazards must also be taken into account and were therefore included in the evaluation with a weighting of 0,1/1,0.

6. **Routing length**

   In addition to the distance to the village center, a separate criterion for the length of the routing was introduced. As some locations can already be supplied with water due to the other planned water infrastructure, thus reducing the total required routing length, this point was included as a criterion. By choosing an according location for the visitor center, investment costs can be saved. This was considered with a weighting of 0,15/1,0.

4.4. Visitor center location assessment

The assessment of the individual criteria of one variant was carried out relative to the other variants, which means that for each criterion the optimum variant was determined and the other two variants were set in relation to this optimum. The following table shows the results of this assessment.

Table 18 results of visitor center location assessment

Criteria/Location	**Plateau above village**	**Excavation site**	**Western village**	Weighting
Height difference to reservoir	0,45	0,48	1	0,15
Distance to village center	0,74	0,21	1	0,1
Accessibility	0,8	0,8	1	0,15
Positioning in terms of tourism	1	0,7	0,7	0,35
Flood hazard	1	1	0,5	0,1
Routing length	0,01	1	0,01	0,15
Total	**0,71**	**0,71**	**0,70**	

In order to be able to evaluate the individual variants height difference in the criterion "height difference to reservoir", the individual height differences were determined. It was found that the site on the plateau above the village will be only 13 m below the reservoir site. The situation is quite similar with the location of the excavation site - the difference here is 14 m. Only the third location of the visitor center in the western part of the village is clearly below the reservoir. Here a height difference of 29 m was determined, which means that the incoming pressure would be around 3 bar.

The next criterion was determined in a similar way. In the beginning, the distances between the individual locations of the visitor center and the village center were calculated. It was found that the location in the western part of the village is the closest to the village center at 109 m. Next is the location on the plateau, which is about 147 m away. The third location is the furthest away: The excavation site is about 509 m away from the village center.

The reachability was determined argumentatively. The location in the western part of the village proved to be the easiest to reach, as it is at the same height level as the access road to the village and the village itself. In contrast, to reach the location on the plateau, a steep incline must first be overcome. Also the location at the excavation site is higher than the village itself. In addition to the gradient, the access road to the site must also be overcome. Since this is located on the mountain slope, problems can occur in rainy weather because the road is not paved.

The next criterion "positioning in terms of tourism" was also determined by argument. Here, the location on the plateau is the clear winner, as the panorama from there is by far the most attractive. However, the other locations also have advantages: The location in the village is an advantage, as it allows the visitor center and its visitors to be easily integrated into village life. Thus, in addition to the exhibits and the excavation site, village life itself can become a reason for tourist visits. The third location is directly at the excavation site, which is especially relevant for visitors who come for this reason. You can easily get from the visitor center to the excavation site and follow the excavation.

Only the location in the western part of the village has a certain risk of flooding, as the other two locations are above the flood-prone areas. Therefore, these two sites can be classified as not at risk and only the third site receives a lower rating.

The last criterion relates to the investment costs required. As the excavation site is to be supplied with drinking and process water anyway, no separate supply of the visitor center at this location is necessary. For the other two locations, only small additional pipe lengths are required (plateau: 241 m; western village: 224 m), but due to the savings in one variant, the ratings of the other two variants must be downgraded.

4.5. Selection of preferred variant combination

In the previous chapters, the assessment bases were created and the variants for the well and the location of the visitor center were evaluated. In this section the results are now to be summarized.

It turned out that the **Reza abaad well** with a score of 82% should be preferred over the Shah alli well (Scoring: 78%) and the Ebrahimabad well (Scoring: 53%). However, this is not a final result, but merely a recommendation based on the evaluation criteria applied.

In choosing the location for the future visitor center, this fell on the **plateau above the village**. All variants were very close to each other in the evaluation: the selected variant achieved 71% and the "excavation site" variant also received 71%. Only the third variant "western village" was one percentage point behind the other two. Nevertheless, the first variant was chosen because it was already mentioned several times as the preferred variant in the working group.

Nevertheless, these results do not represent final conditions, but only serve as a recommendation based on the evaluation basis. The actual combination of variants will be made in cooperation with all persons involved in the project and then implemented.

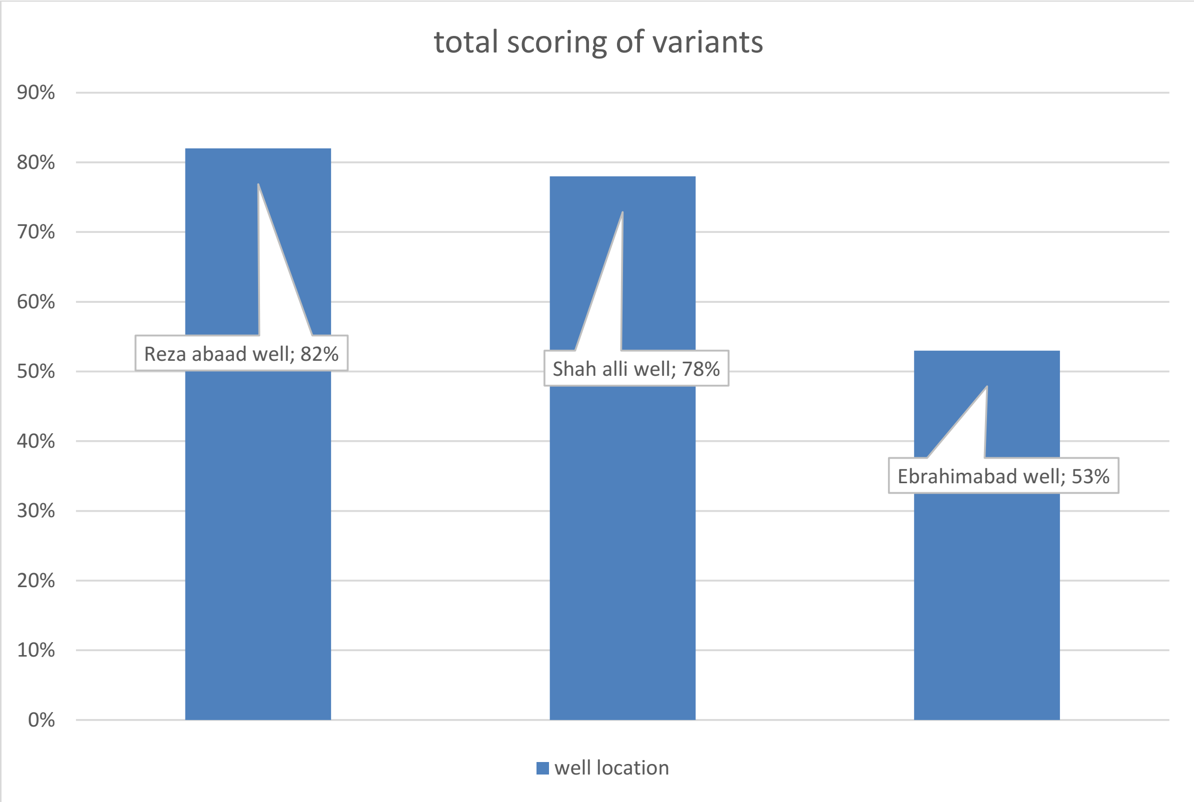


Figure 50 total scoring of variants for preferred well location

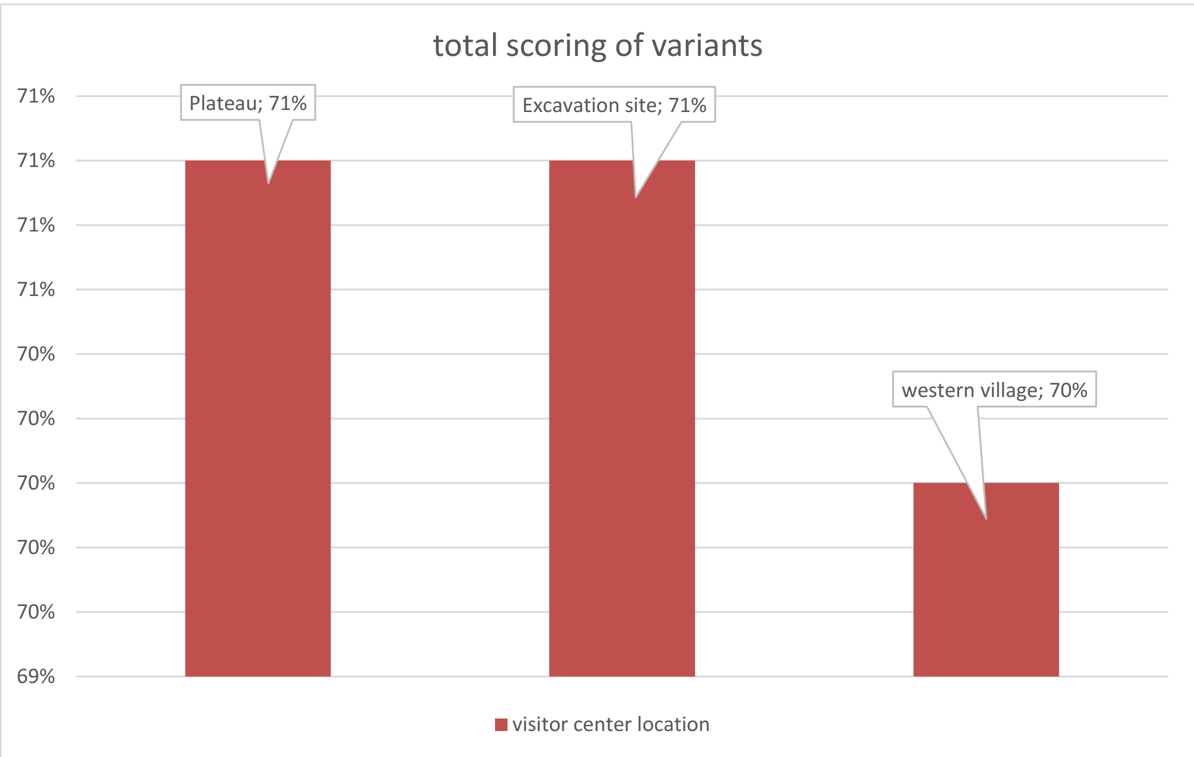


Figure 51 total scoring of variants for preferred visitor center location

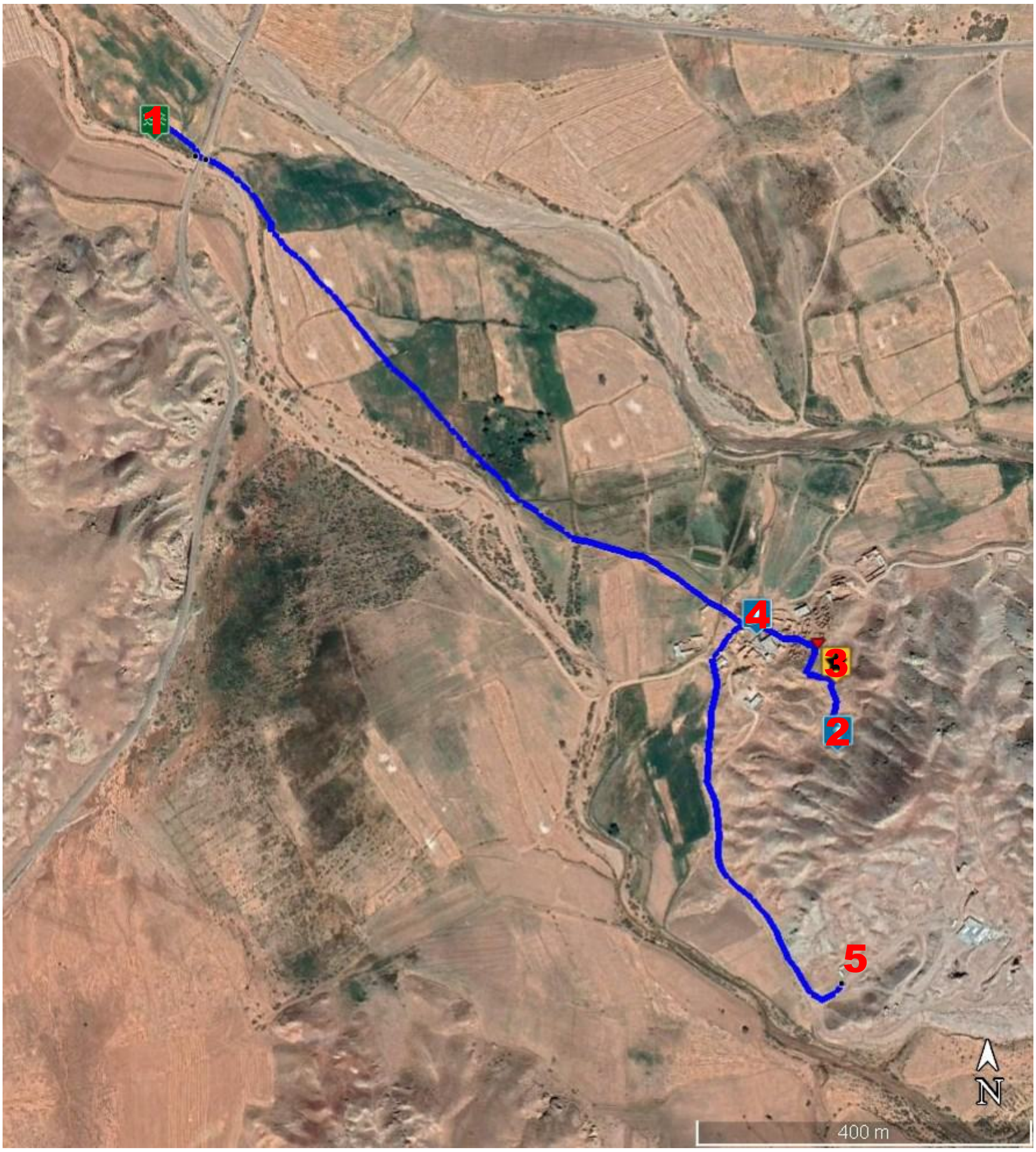


Figure 52 preferred variant combination

The route is as shown in the figure above. From the Reza abaad well pumping station (1) to be built in the northwest of the area, the transport route leads in a southeast direction through some agricultural areas of the village. From the end point of the transport pipeline in the village center (4), a riser pipe on the ridge of the Douzlak leads up to the reservoir (2). From there a pipeline leads back down to the village center (4), where it can be laid in the same trench as the riser. The visitor center on the plateau (3) is also supplied with water via this pipe. Several pipes lead from the connection point in the village center (4): The reverse osmosis plant is supplied from here, as well as a line that leads from here to the excavation site (5) to provide service water at this point as well.

For the drinking water supply, pipes are also laid in the already drawn trenches starting from the reverse osmosis plant in the village center (4). From here two pipes will be laid, one leading to the visitor center (3) and the other to the excavation site (5). In addition, a drinking water distribution unit is located directly on the outer wall of the plant housing. There, villagers and visitors can get drinking water directly on site.

5. Economic efficiency analysis

In this chapter, the costs for the preferred variant combination are determined. As previously decided, it is assumed that the Reza abaad well (see 3.5.5) is used to supply the village with service and drinking water. For the visitor center it is assumed that it is built on the plateau above the village (see 3.5.8). Based on these decisions, the routing of the pipelines was planned and their lengths determined, which have an impact on the costs. Furthermore it is also assumed that prefabricated tanks will be used as a reservoir.

The cost calculation is subdivided into several parts: Firts, the costs for the respective sections of the infrastructure, as already described in chapter 3, are calculated individually. The investment costs are also differentiated into material and personnel costs. Finally, in the respective representation of the costs in each case, an offer with German and one with Iranian prices are regarded.

It should be noted that some prices of the Iranian offer were calculated using a conversion factor as the exact prices could not be obtained by research or enquiry by local colleagues. To check the accuracy of this conversion, an existing Iranian offer for the reverse osmosis plant was used: The price of this offer is about 2.880 €, whereas the calculated price for the plant via the financial factor is about 2.900 €. The calculation via this method should therefore be sufficiently accurate to serve as a non-binding cost statement.

5.1. Investment costs

The investment costs are broken down into the various sections supply, storage, treatment, drinking water distribution and routing of preferred variant. At the end of this segment, the individual investment costs are summarized.

5.1.1. Supply

As already described in more detail in the chapter supply of the section technical conduct (3.1), the supply part of the planned water supply infrastructure includes the expansion of the Reza abaad well and the construction of a well housing. The following table shows the individual items of the material list with the costs from the two offers:

Table 19 material costs of supply section

Materials	German offer	Iranian offer
Well pump control unit	2.500,00 €	747,04 €
Power cable	5.148,50 €	1.538,46 €
Transmission cable	786,99 €	235,16 €
Well housing	n.a.	1.255,03 €

Water meter	293,65 €	87,75 €
Check valve	104,9 €	31,35 €
tubing	74,00 €	22,11 €
Sum	**8.908,04 €**	**3.916,90 €**

Since there is already a sufficiently strong well pump owned, a new purchase is unnecessary. Nevertheless, a control unit for this pump is needed to achieve the planned partial automation of the system. This control unit costs 2.500 € in Germany, whereas it would only cost about 750 € in Iran. The same applies to the power and transmission cables. In the case of the well housing, on the other hand, there was no offer from German companies, since the construction is taking place on site and therefore only local construction companies can be awarded the contract. The costs of the construction of the well housing amounts to about 1.500 €. After the building is constructed, the fixtures can be installed. These consist of a water meter and a check valve to prevent backflow through the pump into the well. In addition, the piping from the pump to the connection point to the supply network was also planned at this point. The costs for these parts amount to about 141 €. The Iranian personnel costs for the construction of the section are broken down in the following table:

Table 20 personnel costs of supply section

Task	**Manpower**	**Working hours**	**Man hours**	**salary**
Material transport	2	16	32	96,00 €
Well deepening	2	80	160	120,00 €
Housing construction	4	160	640	960,00 €
Electrical work	1	8	8	24,00 €
plumbing	2	24	48	144,00 €
Sum				**1.344,00 €**

Due to the small number of different materials, only two deliveries were assumed for the cost calculation. The first delivery includes all building materials for the well housing and the second delivery contains all technical items which will be installed after the construction of the well housing.

In the case of well deepening, a required period of two weeks with two workers was set, since the well is currently not sufficiently deep for the intended use. Due to the intensive work to deepen the well, this time span was used for the calculations.

For the construction of the well housing, four workers were scheduled to be employed for four weeks. As with well deepening, the construction of a building is labor-intensive and therefore requires the appropriate manpower and expertise. Due to the special purpose of the building, it is important to ensure that the planning is carried out precisely so as not to prolong the subsequent work steps unnecessarily. Electrician and plumbing work can be greatly simplified if the building is correctly prepared for the equipment to be installed.

The electrician and plumbing works represent the final steps in the construction of this section of the infrastructure. For the electrician work one manpower for one day was assigned, since some of the work in this section can be carried out by other people and only has to be inspected by the electrician. This should tend to be sufficient, but in the event of unforeseen problems it may be necessary to extend the employment.

The plumbing work consists mainly of connecting the pump to the pipe network and installing the necessary pipe fittings. Two workers were scheduled for three days. As already mentioned, a longer employment may also be necessary in some unforeseen cases.

5.1.2. Storage

The reservoir is a construction of hydraulically connected tanks (see 3.2). Although the initial costs are higher with this construction method, the total costs are nevertheless lower than for the complete construction of a fully built reservoir, since the simple construction method significantly reduces the amount of work required. The following table shows the material costs in comparison of the two offers:

Table 21 material costs of storage section

Materials	**German offer**	**Iranian offer**
water tanks	7.650,00 €	2.285,95 €
float switch	15,00 €	4,48 €
Reservoir housing	n.a.	500,00 €
Gate valves	279,42 €	83,50 €
T-pieces	116,28 €	116,28 €
4-way valve	69,01 €	69,01 €
tubing	74,00 €	22,11 €
Sum	**8.338,71 €**	**3.121,67 €**

As described in chapter 3.2, about 12 m^3 of reservoir capacity is required. The planned tanks have a volume of 4 m^3 each, which is why 3 tanks are needed to achieve the required capacity. In addition to the tanks themselves, this section of the infrastructure again requires various installations: Besides a float switch to control the water level, gate valves are also required to lock the individual tanks in case of needed maintenance. The various T-pieces and the multi-way valve are needed, as is the tubing, to establish the hydraulic connection between the individual tanks and to connect the section to the infrastructure.

Although the selected tanks have a high UV stability and are also fairly weather resistant, the tanks should still be encased in order to increase their service life and protect them from possible frost in winter, but also to prevent unauthorized access to the reservoir itself. Since water supply is a critical infrastructure, access to the systems should only be possible by qualified personnel.

Table 22 personnel costs of storage section

Task	**Manpower**	**Working hours**	**Man hours**	**salary**
Material transport	2	16	32	96,00 €
Housing construction	2	120	240	360,00 €
Electrical work	1	8	8	24,00 €
plumbing	2	24	48	144,00 €
Sum				**624,00 €**

The material for the construction of this section must also be delivered. Again, two deliveries were planned, because in addition to the construction material for the reservoir housing, the voluminous tanks also have to be transported.

The construction of the reservoir housing, in turn, was scheduled to take three weeks with two people, as it is merely an enclosure without complex technical building equipment.

Nevertheless, electrician and plumbing works are still needed at this point, which must be carried out by qualified personnel.

5.1.3. Treatment

The planned reverse osmosis plant for drinking water treatment requires the construction of a plant housing as well as various plant components and installations. A detailed description of the plant has already been explained in chapter 3.3, which is why it is summarized in the following table.

Table 23 material costs of treatment section

Materials	**German offer**	**Iranian offer**
Reverse osmosis treatment plant	10.720,00 €	3.203,32 €
drinking water tank	1.280,00 €	382,49 €
inline distribution pump	250,00 €	74,70 €
electric heater	57,95 €	17,32 €
plant housing complete	n.a.	1.568,79 €
float switch	15,00 €	4,48 €

water meters	587,30 €	175,50 €
tubing	74,00 €	22,11 €
Sum	**13.119,25 €**	**5.489,04 €**

The offer to build the plant by a local company amounts to a total cost of about 2.900 €. In order to be able to cover possible additional costs, as it is a non-binding offer, the plant was provided with a safety factor of 10%. The German offer consists of list prices, therefore no price change is assumed and the safety factor was waived.

Since only service water is stored in the reservoir, an additional tank had to be planned for the storage of drinking water. It is planned that this tank will also be located in the plant housing, so it was assigned to this section in the financial planning. In addition, the housing also contains the pump which is to deliver the drinking water to the distribution units. To protect the system from frost, an electric heating system will also be integrated, which should heat the room sufficiently on cold winter days to prevent frost damage to the piping or system components.

The intended installations are designed for easy handling and maintenance of the system: The float switch is intended to control the water level in the drinking water tank and to automate the system. The water meters, in turn, are used to monitor consumption and the integrity of the piping. A visibly increased consumption can be an indication of possible leaks in the system.

Table 24 personnel costs of treatment section

Task	**Manpower**	**Working hours**	**Man hours**	**salary**
Material transport	2	16	32	96,00 €
Housing construction	4	160	640	960,00 €
Electrical work	1	16	16	48,00 €
plumbing	2	48	96	288,00 €
Sum				**1.392,00 €**

As before, in addition to the supply of materials and the construction of the building, electrical and plumbing work is also planned, which must be carried out by qualified personnel. However, due to the complex composition of the plant, an increased amount of work was forecast, which will have an impact on the personnel costs of this section.

5.1.4. Drinking water distribution

As already described in Chapter 3.4, the water is distributed via a terminal which can be used by the consumers via prepaid NFC cards. Due to the control technology that has to be installed in this system, the costs amount to the following items:

Table 25 material costs of distribution section

Materials	**German offer**	**Iranian offer**
Distribution unit	1.500,00 €	448,23 €
Power cable	2.478,00 €	740,47 €
Transmission cable	378,78 €	113,19 €
Sum	**4.356,78 €**	**1.301,88 €**

In addition to the distribution unit itself, a supply of the units with power and data transmission to the treatment plant is also required, so power and data cables are listed in this section.

Table 26 personnel costs of distribution section

Task	**Manpower**	**Working hours**	**Man hours**	**salary**
Material transport	2	8	16	48,00 €
Electrical work	1	8	8	24,00 €
plumbing	1	8	8	24,00 €
Sum				**80,00 €**

Since the installation of the prefabricated distribution units should be relatively unproblematic, only one working day was planned for the respective positions of the skilled workers.

5.1.5. Routing of preferred variant

The presentation of all costs for all variant combinations would go beyond the scope of this thesis, thus only the costs incurred for routing of the preferred variant combination are presented here.

Table 27 material costs of routing

Materials	**German offer**	**Iranian offer**
Tubing	16.582,40 €	4.955,10 €
gate valves	556,45 €	166,28 €
check valves	158,84 €	47,46 €
water meters	1.174,60 €	350,99 €
Ground work machinery rental	n.a.	360 €
Sum	**18.472,29 €**	**5.879,83 €**

By far the largest cost item at this point is the purchase of the tubing. In the German offer this is around 16.600 €; in the Iranian offer, despite the lower prices, just under 5.000 € is still needed.

In addition to the pipework, various installations are also required. The gate valves are used to seal off the various pipelines in the event of an needed inspection; the check valves must be installed to prevent unwanted backflow from higher points and the water meters are required to measure the water consumption at the respective outlets. By analyzing the consumption, for example, it can be concluded how often the respective supply line has to be flushed to prevent contamination.

Table 28 personnel costs of routing

Task	Manpower	Working hours	Man hours	salary
Material transport	2	40	80	240,00 €
Ground work	5	33	165	495,00 €
plumbing	4	33	132	396,00 €
Sum				**1.131,00 €**

As more than 2 km of underground tubing have to be laid and earthworks always require a lot of effort despite machinery, the personnel costs of this section amount to about 1.131,00 €. This includes the costs for material transport, ground works and also work on the piping, which for example, consists of connecting the individual pipe segments to each other and embedding them in a suitable soil layer before the trench is filled in again.

5.1.6. Total investment costs

In the following table, the costs of the individual sections of the infrastructure are again summarized. The Iranian personnel costs are also due when the German bid is chosen, as the local companies are hired for the construction of the infrastructure. For this reason, the personnel costs are listed in a separate column and have not been combined with the material costs. In order to be prepared for unforeseen expenses, a safety margin of 10% was added to the calculated material and personnel costs. Another point to consider is that when choosing the German offer, the materials must be shipped from the storage location in Germany to Iran. Due to the sanctions to trade with Iran at the time of creation of this thesis, it is not possible to obtain an offer for the expected transport costs from the transport service providers.

Table 29 total costs

Section costs	German offer	Iranian offer	Personnel costs
Supply	8.908,04 €	3.916,90 €	1.344,00 €
Storage	8.338,71 €	3.121,67 €	624,00 €

Treatment	13.119,25 €	5.489,04 €	1.392,00 €
Drinking water distribution	4.356,78 €	1.301,88 €	96,00 €
Routing of preferred variant	18.472,29 €	5.879,83 €	1.131,00 €
Shipping	n.a.	0,00 €	n.a.
Sum	**53.195,07 €**	**19.709,33 €**	**4.587,00 €**
Safety margin	10%	10%	10%
Total	**58.514,58 €**	**21.680,26 €**	**5.045,70 €**

There is a clear cost difference between the two offers available. In addition to the disregarded transport costs, costs for a temporarily storage of the materials before shipping to Iran probably also have to be added to the German offer. Furthermore, it is questionable whether the materials used in the German offer are also available in Iran. So if a part of the system has to be replaced, it is not guaranteed that spare parts are available locally. Based on the cost difference and this assessment, the Iranian offer is recommended.

5.2. Operating costs

The operation of a water supply infrastructure also generates costs. These can be divided into several categories: On the one hand, some parts of the system (mainly the pumps) require electricity to operate. On the other hand, when considering the operating costs, it must also be taken into account that some system parts need to be replaced regularly. For example, in the reverse osmosis system, the sand in the bulk filter must be replaced if it is too clogged. On top of these expenses, personnel costs have to be added. Although the plant is run by the villagers in everyday operation, it may be necessary to employ a specialist for maintenance or repair work. The following subchapters provide detailed lists of the individual recurring costs, divided into electricity consumption and non-durable goods.

5.2.1. Electricity costs

To calculate the electricity costs, the various electrical consumers of the infrastructure were identified and their power consumption calculated. In addition to the pumps in the treatment plant, the used well pump and the feed pump to the distribution units are also electrical consumers. The electricity costs for the electric heating of the treatment plant in the winter months (approx. 6 months) must also be taken into account. The following table lists all electrical parts and their expected consumption.

Table 30 detailed power consumption

Consumer	**Power**	**Operating time per day**	**Annual consumption**
Treatment plant pumps	2.000 W	1 h/d	730 kWh
Well pump	1.500 W	1 h/d	547,5 kWh
Distribution pump	600 W	2,5 h/d	547,5 kWh
Electric heating unit	666,7 W	12 h/d	1.460 kWh
Sum			**3.285 kWh**
Safety margin			10%
Total			**3.613,5 kWh**

The expected power consumption of the various pumps was calculated on the basis of the water consumption of the inhabitants: For example, the well pump, which has an output of 1.500 W, will probably have to be activated every three days for three hours each to fill the reservoir based on the consumption behavior of the inhabitants, which has already been described in Chapter 2.3. This results in an operating time per day of 1 h/d. The operating times of the other pumps were determined in the same way.

For the consumption of the electric heating, it was assumed that operation at the most economical setting is sufficient to protect the treatment plant from frost. Thus, with a consumption of around 700 W at this level and a daily operating time of 4 h in the winter months, the total annual consumption is 1.460 kWh.

In addition to these large power consumers, electricity is also required for lighting and the control technology of the plant components. Since there is no possibility of an exact forecast of the expected consumption for these, a safety margin of 10% was added to the already calculated electricity consumption to cover their needs. This results in a total annual electricity consumption of around 3.600 kWh.

5.2.2. Non-durable goods

Various materials are used in the processing plant, which have to be renewed or replaced regularly. The following table shows all consumables of this type:

Table 31 non-durable goods

Material	**Annual consumption**
Filter sand	70 kg
Activated carbon	50 l
Micro filter cartridges	6
Antiscalant solution	0,8 kg
RO membranes	0,5 pc

The annual consumption of each material has been established based on the experience of the neighboring villages Hesar and Mehrabad. The water masters employed there, who maintain the respective plants, explained the service life of their non-durable goods, which in turn were used for the plant conceived in this thesis, since a calculation of the service life is not sufficiently exact due to special circumstances such as raw water quality and missing other operating data.

5.2.3. Total operating costs

After the resulting consumption during the operation of the plant has been determined, the total operating costs can now be calculated using previously investigated unit prices:

Table 32 operation costs

Operation costs	**Price per unit**	**Annual consumption**	**Total costs**
Electricity	0,04 €/kWh	4215,75 kWh	140,37 €
Filter sand	0,21 €/kg	70 kg	14,64 €
Activated carbon	0,96 €/l	50 l	48,06 €
Micro filter cartridge	3,26 €/pc	6 pc	19,54 €
Antiscalant solution	3,57 €/kg	0,79 kg	2,82 €
RO membranes	331,27 €/pc	0,5 pc	165,63 €
Maintenance	2,5 €/h	24 h	60 €
Sum			**451,07 €**

It turns out that about 450 € per year must be spent for the operation of the plant. In order to operate the plant at a cost-covering level, the operating costs as well as the reinvestment costs must be covered by the water price. For this purpose, a cost comparison calculation is carried out in the following subchapter, by which the cost-covering water price can be calculated.

5.3. Cost comparison calculation

As the investment costs are fully covered by project funds, the operating and maintenance costs serve as the basis for calculating the cost-covering water price. As summarized in the table above, the operating costs amount to about 450 € per year. In the case of maintenance costs, a repair-free operating life of the infrastructure of about 10 years was estimated. It is assumed that after this period, some parts of the system will have exceeded their service life and will have to be replaced – it must therefore be taken into account that these parts have reinvestment costs. Based on this assumption, the expected reinvestment costs were calculated from the original investment costs. This resulted in costs of about 2.500 € within 10 years.

Table 33 cost comparison calculation parameters

Parameter	**value**
Timespan	20 a
Investment costs	0 €
Operation costs	451,07 €/a
Reinvestment costs	2.463,67 €/10 a
Water consumption per day and inhabitant	20 l/(d · inhab.)
Average inhabitants	75 inhab.
Produced drinking water	547,5 m^3/a

With the help of these parameters, the cost comparison calculation can now be carried out according to the instructions of the DWA (Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnungen (KVR-Leitlinien) 2012). It turns out that a water price of about **1,05 €/m³** must be estimated for cost-covered production. This price ensures the operation and maintenance of the system by selling the drinking water. If the actual revenues are lower because less water per inhabitant is consumed or fewer inhabitants than assumed use the supply, an alternative source of money for the resulting reinvestments must be found.

In the neighboring villages Hesar and Mehrabad (see 2.2.1), which both also have a reverse osmosis plant for drinking water treatment, the price per liter is 250 IRR, which is equivalent to about 2,00 €/m^3. The cheaper water price of the planned plant can be explained by the investment costs, since these are paid from project funds, they do not have to be considered in the cost comparison calculation.

6. Conclusion & outlook

The project to supply the Iranian village of Hamzehlu with service and drinking water involves many elements of technical infrastructure planning and economic cost analysis. Due to this scope, various data had to be compiled partly with a very thin basis, which was a challenge for all parties involved. Nevertheless, a concept was developed which enables a sustainable and long-term water supply of the village. By building the planned infrastructure, the village is to be significantly upgraded, hopefully, making life easier for the inhabitants and giving them the opportunity to develop further.

In the end, the preferred variants are the combination of using Reza abaad well as a supply and the location of the visitor center on the plateau above the village on the Douzlak ridge. The well is distinctly owned by the inhabitants and the routes are also led only over land, belonging to them. The plateau provides an ideal location for the visitor center, as future tourists will be able to enjoy the panoramic view of the landscape and yet be close to the village. This opens up new possibilities for combining village life and tourism, which can add value for both sides.

The conceptual design of the entire supply structure was deliberately kept as simple as possible in order to achieve the greatest possible appeal to the inhabitants. On the one hand, the simple construction method should enable them to carry out many of the upcoming maintenance work themselves. On the other hand, this also allows the possibility of expanding the pipeline network relatively easily, should this become necessary in the future. Nevertheless, a partial automation was planned, which should make the operation as simple as possible. By means of various installations, for example, the well pump and the treatment plant can operate largely autonomously and provide both service and drinking water at all times.

The treatment plant in particular, but also all other system components used in the construction of the infrastructure are designed to ensure that the village can develop and flourish in the near future. Even increasing water consumption can be easily handled by the system, which also allows the influx of family members, friends or other people. In addition, when selecting the components, care was taken to choose only those that do not corrode due to the prevailing raw water quality and have the longest possible service life. This is to keep the repair and reinvestment costs, which are necessary for maintenance, as low as possible. Thus the operation costs amount to 451,07 €. The treatment plant itself has sufficient cleaning capacity to meet the legal requirements in force in Iran and to supply the villagers with clean water in sufficient quantities. Based on the daily drinking water consumption of the inhabitants a cost-covering water price of about 1 €/m^3 was calculated.

Since the Iranian offer amounts to a total of 21.680,26 €, whereas the German offer is at 58.514,58 € of the preferred variant combination it is recommended to choose the first one. Also by choosing the Iranian offer, concerning the purchase of required materials, not only the project funds are spared, but also the local companies are supported. In a construction project of such dimensions, a large number of companies are required to supply materials, carry out earthworks, build the housings for the plant components or assemble the plants themselves. All in all, the region is incorporated, which benefits all parties involved.

Despite the partly very detailed explanations, this thesis only represents a first planning draft for the construction of the water supply infrastructure in the Iranian village Hamzehlu. Before the actual start of construction, further tasks must be completed and questions answered:

- The planned routes of the pipes and the locations of the plants must be evaluated in detail with the villagers in order to cover their needs and finally clarify the ownership situation.
- Despite the remote location of the village, permits may have to be obtained from the relevant authorities. Here the circumstances must be clarified and handled properly.
- Before the trenches of the routes and the foundations of the buildings are dug, an expert opinion on the soil composition may be obtained. Based on this, the required construction machinery can be selected more precisely and the necessary foundations can be better planned.
- Once the expert opinion is available and the preliminary planning has been adjusted accordingly, the cost analysis can be carried out again together with detailed material costs and an exact price for the construction of the infrastructure can be determined.
- If the preliminary planning is completed, local companies can be involved to carry out the construction. However, a construction supervision should also be established at this point to verify the proper procedure.

7. Appendix

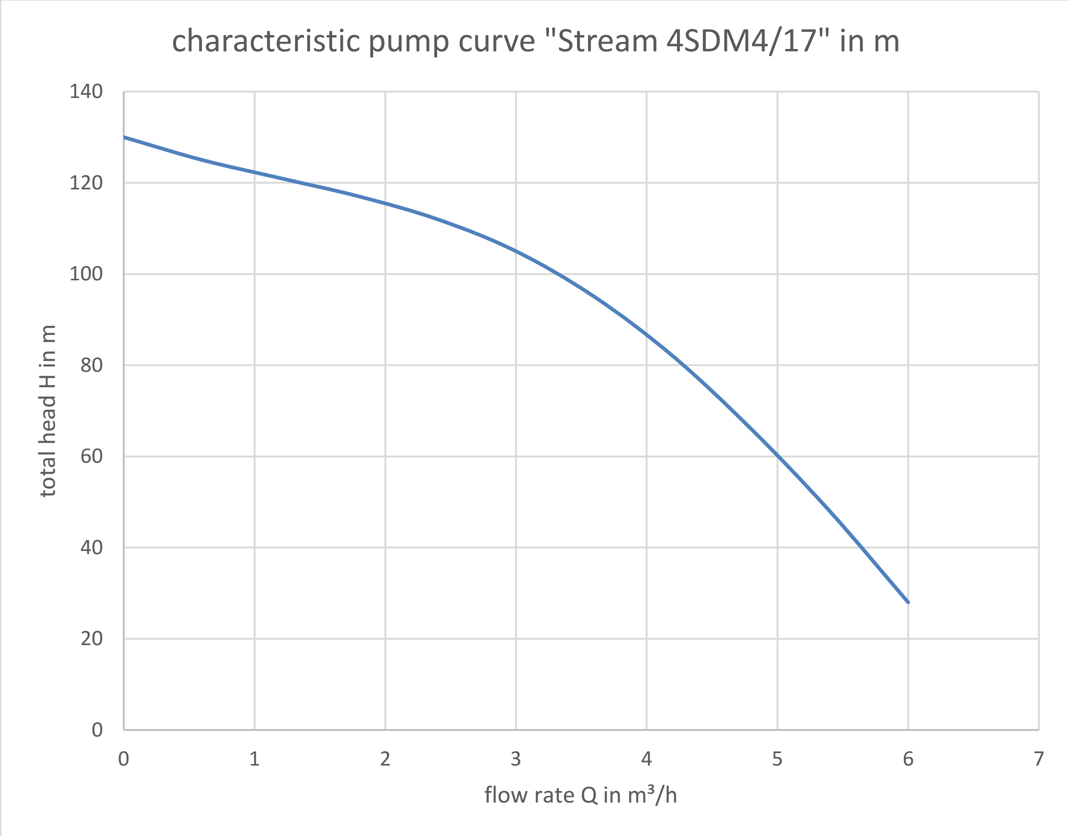


Figure 53 characteristic pump curve "Stream 4SDM4/17"

Product Data Sheet

FILMTEC™ Fiberglassed Elements for Light Industrial Systems

Description

FILMTEC™ brackish water reverse osmosis membrane elements provide consistent system performance in light industrial applications.

- FILMTEC™ BW30-4040 is an industry standard for reliable operation and production of high quality water.
- FILMTEC™ BW30-2540 elements are designed for systems smaller than 1 gpm (0.2 m^3/h) offering a hard shell exterior for extra strength.

Elements with a hard shell exterior are recommended for systems with multiple-element housings containing three or more membranes, as they are designed to withstand higher pressure drops.

Product Type

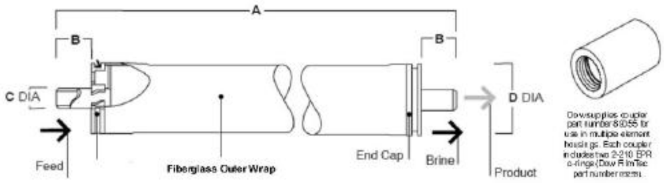
Spiral-wound element with polyamide thin-film composite membrane

Typical Properties

Product	Part Number	Feed Spacer Thickness (mil)	Permeate Flow Rate gpd (m^3/d)	Stabilized Salt Rejection %
BW30-4040	80783	34	2,400 (9.1)	99.5
BW30-2540	80766	28	1,000 (3.8)	99.5

1. Permeate flow and salt rejection based on the following test conditions: 2,000 ppm NaCl and 225 psig (15.5 bar), pH 8, 77°F (25°C) and 15% recovery.
2. Minimum salt rejection is 98.0%.
3. Permeate flows for individual elements may vary +/-20%.

Element Dimensions



	Dimensions – inches (mm)			1 inch = 25.4 mm
Product	A	B	C	D
BW30-4040	40.0 (1,016)	1.05 (26.7)	0.75 (19)	3.9 (99)
BW30-2540	40.0 (1,016)	1.19 (30.2)	0.75 (19)	2.4 (61)

1. Refer to FilmTec Design Guidelines for multiple-element systems.
2. BW30-2540 elements fit nominal 2.5-inch I.D. pressure vessel. BW30-4040 elements fit nominal 4-inch I.D. pressure vessel.

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June 2019

Figure 54 BW30-4040 membrane data sheet p.1

Operating and Cleaning Limits

Membrane Type	Polyamide Thin-Film Composite
Maximum Operating Temperature[a]	113°F (45°C)
Maximum Operating Pressure	600 psi (41 bar)
Maximum Feed Flow Rate	
4040 Elements	16 gpm (3.6 m^3/h)
2540 Elements	6 gpm (1.4 m^3/h)
Maximum Pressure Drop	15 psig (1.0 bar)
pH Range	
Continuous Operation[a]	2 - 11
Short-Term Cleaning (30 min.)[b]	1 - 13
Maximum Feed Silt Density Index (SDI)	SDI 5
Free Chlorine Tolerance[c]	< 0.1 ppm

a. Maximum temperature for continuous operation above pH 10 is 95°F (35°C).
b. Refer to Cleaning Guidelines in specification sheet 609-23010.
c. Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, it is recommended that residual free chlorine be removed by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information

Important Information

Proper start-up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock. Following the proper start-up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start-up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled "Start-Up Sequence" (Form No. 609-02077) for more information.

Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.
- Permeate obtained from first hour of operation should be discarded.

Please refer to the product technical manual.

General Information

- Keep elements moist at all times after initial wetting
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void. Refer to FILMTEC™ Reverse Osmosis and Nanofiltration Element Three-Year Prorated Limited Warranty (Form No. 609-35010)
- To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements
- Maximum pressure drop across an entire pressure vessel (housing) is 50 psi (3.4 bar)
- Avoid static permeate-side backpressure at all times

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Figure 55 BW30-4040 membrane data sheet p.2

Storage Refer to 609-02103 for further information.

Product Stewardship DuPont has a fundamental concern for all who make, distribute, and use its products, and for the environment in which we live. This concern is the basis for our product stewardship philosophy by which we assess the safety, health, and environmental information on our products and then take appropriate steps to protect employee and public health and our environment. The success of our product stewardship program rests with each and every individual involved with DuPont products— from the initial concept and research, to manufacture, use, sale, disposal, and recycle of each product.

Customer Notice DuPont strongly encourages its customers to review both their manufacturing processes and their applications of DuPont products from the standpoint of human health and environmental quality to ensure that DuPont products are not used in ways for which they are not intended or tested. DuPont personnel are available to answer your questions and to provide reasonable technical support. DuPont product literature, including safety data sheets, should be consulted prior to use of DuPont products. Current safety data sheets are available from DuPont.

Please be aware of the following:

- The use of this product in and of itself does not necessarily guarantee the removal of cysts and pathogens from water. Effective cyst and pathogen reduction is dependent on the complete system design and on the operation and maintenance of the system.
- Permeate obtained from the first hour of operation should be discarded (or in a few cases: Any concentrate or permeate obtained from the first hour of operation should be discarded).

Regulatory Note These membranes may be subject to drinking water application restrictions in some countries: please check the application status before use and sale.

Have a question? Contact us at:
www.dupont.com/water/contact-us

DUPONT

Form No. 609-00350, Rev. 4
June 2019

Figure 56 BW30-4040 membrane data sheet p.3

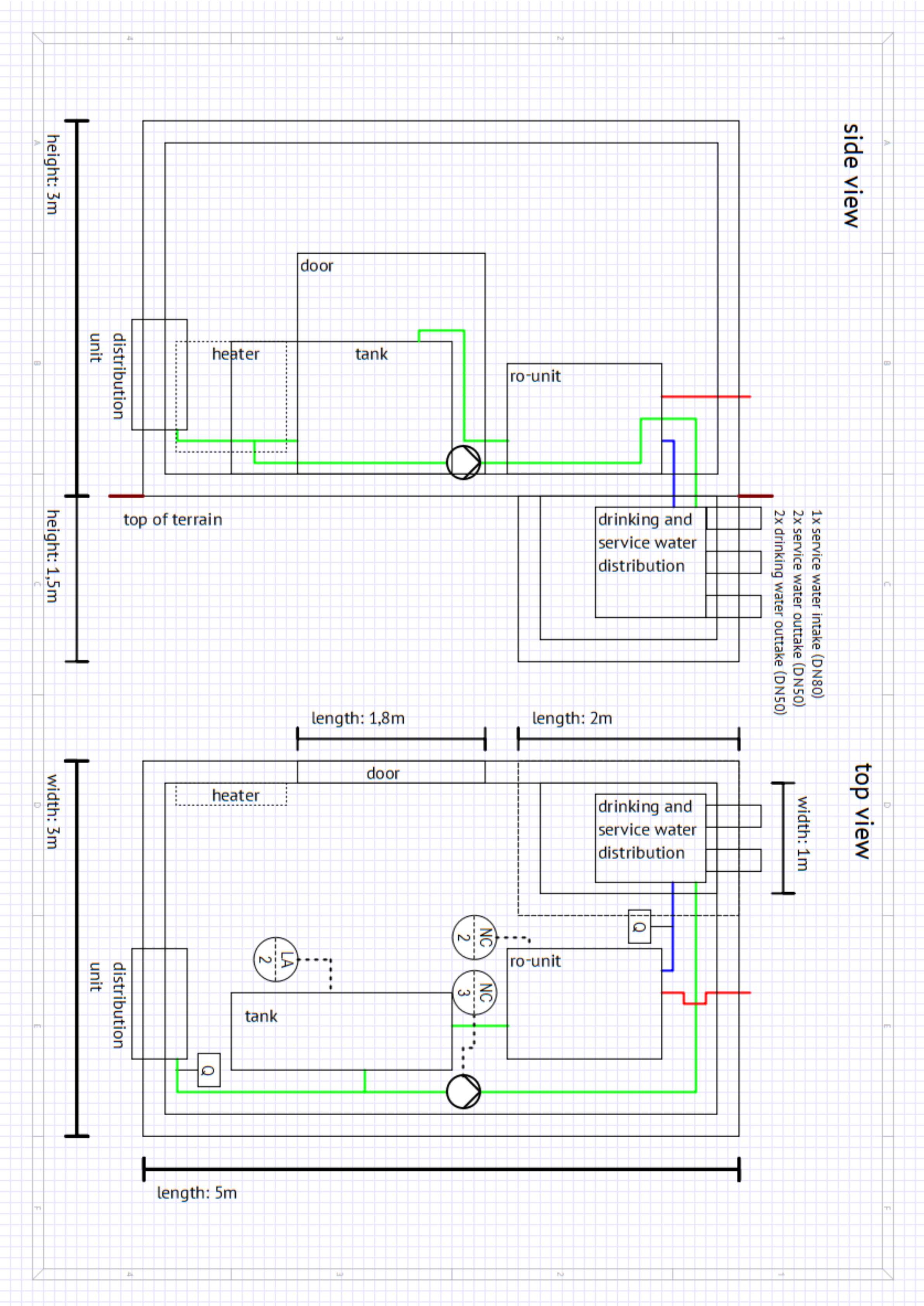

Figure 57 Treatment plant housing construction plans

Table 34 Calculation of pipe diameters

route	Length in m	Inner diameter in mm	flow rate in m³/h	flow velocity in m/s	Reynolds number	Darcy Friction factor	Head loss in m
0-1	1227	80	5,83	0,3224	25748	0,02	2,0291
1-2	241	80	5,83	0,3224	25748	0,02	0,3985
2-3	552	50	0,16	0,0221	1103	0,06	0,0159
2-4	3	80	5,00	0,2763	22069	0,03	0,0038
2-5	153	50	0,42	0,0589	2943	0,04	0,0233
4'-2'	3	50	0,17	0,0236	1177	0,05	0,0001
2'-3'	552	50	0,04	0,0059	294	0,22	0,0043
2'-5'	153	50	0,04	0,0059	294	0,22	0,0012

(Routes marked with an apostrophe (e.g. 4'-2') represent pipes for transport of drinking water.)

Table 35 complete material list for preferred variant combination (iranian offer)

	required quantity		**price per piece**		**total**
well					
Stream 4SDM4/17	0	pc	230	€/pc	0,00 €
control unit	1	pc	747,04	€/pc	747,04 €
power cable	1471	m	1,05	€/m	1.538,46 €
transmission cable	1471	m	0,16	€/m	235,16 €
well housing outer wall	75	m²	0,00	€/m²	0,00 €
well housing complete	1	pc	1255,03	€/pc	1.255,03 €
water meter 3"	1	pc	87,75	€/pc	87,75 €
check valve 3"	1	pc	31,35	€/pc	31,35 €
tubing	10	m	2,21	€/m	22,11 €
				sum	**3.916,90 €**
reservoir					
water tank (4 m³)	3	pc	761,98	€/pc	2.285,95 €
built reservoir (12 m³)	0	pc	1494,08	€/pc	0,00 €
float switch	1	pc	44,82	€/pc	44,82 €
reservoir housing	1	pc	500	€/pc	500,00 €
gate valve 3"	2	pc	41,75	€/pc	83,50 €
t-piece 3"	3	pc	38,76	€/pc	116,28 €
4-way valve 3"	1	pc	69,01	€/pc	69,01 €
tubing	10	m	2,21	€/m	22,11 €
				sum	**3.121,67 €**
treatment plant					
sand-carbon filter	1	pc	640,66	€/pc	640,66 €
micro filter	1	pc	640,66	€/pc	640,66 €

membrane pump	1	pc	640,66	€/pc	640,66 €
ro-membrane and shell	1	pc	640,66	€/pc	640,66 €
booster pump	1	pc	640,66	€/pc	640,66 €
drinking water tank (2m³)	1	pc	382,49	€/pc	382,49 €
inline distribution pump	1	pc	74,70	€/pc	74,70 €
electric heater	1	pc	17,32	€/pc	17,32 €
plant housing outer wall	60	m²	0	€/m²	0,00 €
plant housing complete	1	pc	1568,79	€/pc	1.568,79 €
float switch	1	pc	44,82	€/pc	44,82 €
water meter 3"	1	pc	87,75	€/pc	87,75 €
water meter 2"	1	pc	87,75	€/pc	87,75 €
tubing	10	m	2,21	€/m	22,11 €
				sum	**<u>5.489,04 €</u>**
distribution					
distribution unit	3	pc	149,41	€/pc	448,23 €
power cable	708	m	1,05	€/m	740,47 €
transmission cable	708	m	0,16	€/m	113,19 €
				sum	**<u>1.301,88 €</u>**
routing					
PE tube DN80 PN 6 (3")	1471	m	2,21	€/m	3.252,74 €
PE tube DN50 PN 6 (2")	705	m	0,94	€/m	665,70 €
PE tube DN50 PN 6 (2") drinking water	708	m	1,46	€/m	1.036,66 €
gate valve 3"	3	pc	41,75	€/pc	125,24 €
gate valve 2"	4	pc	10,26	€/pc	41,03 €
check valve 2"	4	pc	11,87	€/pc	47,46 €
water meter 2"	4	pc	87,75	€/pc	350,99 €
ground work machinery rental	1	pc	360,00	€/pc	360,00 €
				sum	**<u>5.879,83 €</u>**
				total	**<u>19.709,33 €</u>**

Literature

Airvalve (2019): Schutz vor Lufteinschlüssen, Unterdruck und Luftstoß. Online verfügbar unter https://airvalve.de/Service/grundlagen/luft-inleitungssystemen, zuletzt geprüft am 17.03.2020.

Baur, Andreas; Fritsch, Peter; Hoch, Winfried; Merkl, Gerhard; Rautenberg, Joachim; Weiß, Matthias; Wricke, Burkhard (2019): Mutschmann/Stimmelmayr Taschenbuch der Wasserversorgung. 17. Auflage. Wiesbaden: Springer Vieweg. Online verfügbar unter http://dx.doi.org/10.1007/978-3-658-23222-1.

Brassington, Rick (2017): Field hydrogeology. Fourth edition. Hoboken, NJ: John Wiley & Sons Inc (Engineering professional collection). Online verfügbar unter https://onlinelibrary.wiley.com/doi/book/10.1002/9781118397404.

IR Standard 1011, 2016: Drinking water - Microbiological specifications. Online verfügbar unter http://www.isiri.gov.ir/portal/files/std/1011.pdf, zuletzt geprüft am 22.04.2020.

IR Standard 1053, 2016: Drinking water - Physical and chemical specifications. Online verfügbar unter http://www.isiri.gov.ir/Portal/file/?33642/1053.pdf, zuletzt geprüft am 22.04.2020.

DVGW (2006): Arbeitsblatt GW 303-1. Berechnung von Gas- und Wasserrohrnetzen. Teil 1: Hydraulische Grundlagen, Netzmodellierung und Berechnung.

DVGW (2009): Information Nr. 72. Nanofiltration und Umkehrosmose. Bonn.

DVGW (2013): Arbeitsblatt W 122. Abschlussbauwerke für Brunnen der Wassergewinnung.

DVGW (2014): Arbeitsblatt W 300-1 (A). Trinkwasserbehälter; Teil 1: Planung und Bau.

DVGW (2016): Arbeitsblatt W 300-6 (M). Trinkwasserbehälter; Planung, Bau, Betrieb und Instandhaltung von System- und Fertigteilbehältern.

DVGW (2019): Arbeitsblatt W 213-5 (A). Filtrationsverfahren zur Partikelentfernung. Teil 5: Membranfiltration.

Eidgenössisches Department des Inneren (EDI); Bundesamt für Gesundheit (BAG) (2010): Anerkannte Aufbereitungsverfahren für Trinkwasser. Bern.

Food and Agriculture Organization of the United Nations: Aquastat. FAO's Global Information System on Water and Agriculture. Online verfügbar unter http://www.fao.org/aquastat/en/databases/maindatabase/, zuletzt geprüft am 10.09.2019.

google: google earth pro. aearial view software; geoinformationsystem. Online verfügbar unter https://www.google.com/earth/, zuletzt geprüft am 17.03.2020.

Hölting, Bernward; Coldewey, Wilhelm G. (2013): Hydrogeologie. Einführung in die Allgemeine und Angewandte Hydrogeologie. 8th ed. 2013. Online verfügbar unter https://doi.org/10.1007/978-3-662-59667-8.

Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnungen (KVR-Leitlinien). [Hrsg.: DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.] (2012). 8., überarb. Aufl. Hennef: DWA.

Lenntech BV: Filmtec Membranes.

Meise, Martin: Schwimmerschalter (Ein). Online verfügbar unter https://commons.wikimedia.org/wiki/File:Float_switch_on.jpg, zuletzt geprüft am 17.03.2020.

National Centers for Environmental Information (NOAA): Integrated Surface Database (ISD). Online verfügbar unter https://www.ncdc.noaa.gov/isd, zuletzt geprüft am 23.03.2020.

Pfingsthorn, Matias (2020): Geoelectric investigations of the detection of groundwater sources in the area of Hamzehlooh, Zanjan, Iran. Bachelor Thesis. Brandenburg University of Technology, Cottbus. Chair of Raw Material and Natural Resource Management, zuletzt geprüft am 13.04.2020.

Norm DIN 18300, 2019: VOB Vergabe- und Vertragsordnung für Bauleistungen.

Norm DIN EN ISO 13793, 2001: Wärmetechnisches Verhalten von Gebäuden.

Willems, Wolfgang M.; Schild, Kai; Stricker, Diana (2019): Formeln und Tabellen Bauphysik. Wärmeschutz - Feuchteschutz - Klima - Akustik - Brandschutz. 5. Aufl. 2019. Wiesbaden: Springer Fachmedien Wiesbaden. Online verfügbar unter http://dx.doi.org/10.1007/978-3-658-23946-6.

World Health Organization (2003): Total dissolved solids in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality (Guidelines for drinking-water quality, 2).

World Resources Institute: Aqueduct. Identify and evaluate water risks around the world. Online verfügbar unter https://www.wri.org/aqueduct, zuletzt geprüft am 10.09.2019.

WTI (2019): Behälter aus PE-HD. Online verfügbar unter https://www.wasseraufbereitung-shop24.de/de/behaelter-pe-hd-4-000-liter, zuletzt geprüft am 17.03.2020.

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