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**Smart Runoff Harvesting Solution in
Jordan Groundwater Storage Dam
Wadi Ishe Pilot Site**

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1 Introduction:

Arid and semi-arid regions of the world are in need of additional unconventional water resources to match the ever growing water demand. Jordan lies in the transitional zone between the Mediterranean climate in the west and the arid desert climate to the east and south. The synoptic climatic zone is part of the Medietranian agro-climatic region, an essential feature of which the concentration of rainfall is during the cool winter season and a very marked summer drought (Bender, 1975).

Jordan is a semi arid country with very limited freshwater resources. The availability of water is classified very low on the Water Stress Index, which indicates the degree of water shortage. The total renewable freshwater resources in Jordan are estimated at 850 MCM or 167 m³/capita/year. The Kingdom of Jordan is facing an unremitting imbalance between the total sectoral water demands and the available supply of freshwater. By 2020, the total demand for water is expected to increase to 1,685 MCM because of the large increases in population, improvements in living standards and growth in economic activity. While the new sources of water supply are expected to increase the available water from the current level of 850 MCM per year to 1,289 MCM per year by 2020, a shortfall of 396 MCM representing 24 percent of total demand will remain and will have to be managed through appropriate demand-reduction programs (MWI, 1997). Besides, geographical position affects water sources directly; more than 90% of Jordan's lands are desert areas and precipitation is confined to the winter season and varies from an average of 50 mm in the desert regions to 600 mm in the eastern mountains adjacent to the Jordan Valley (IFAD, 1995). Only around 2.2 percent of Jordan's land receives an average annual precipitation of more than 250 mm; 29.1 percent receives less than 100 mm (Jordan Department of Statistics, 1999). In addition to climatic conditions, social and economic factors such as; water price combined with agricultural policies which focus on an increase and intensification of agricultural production, influence the development of land use and water consumption. The increasing pressures on the available resources represent a challenge for scientists, engineers and policy makers, since Jordan development in different fields, depends on the availability of water sources.

Climate change is expected to affect water availability and distribution implying infrastructure, and systems to manage water resources. Global water resources will exhibit different spatial and time distribution. On this respect, rainfall frequency and intensity increases are expected in Jordan. Some areas are expected to suffer from flooding. However, there is lack of sufficient studies about how different climate change scenarios may affect the availability of water resources, or what could be the better adaptation practices to mitigate the negative impacts, and better using them as opportunities in arid regions. The global climate change impacts are the most effective events with respect to sustainable water supply. The more widespread, and socially sustainable, use of groundwater storage to combat water-

demand variability resulting from persistent drought and climate change is urgently needed (Foster,2002).

Run-off harvesting techniques for freshwater augmentation have been practiced in dry areas since 400BC (J.J Botha, 2007). Rainwater harvesting in the broad sense describes all methods for storing and collecting runoff from rainwater, for domestic and agricultural uses. Those water harvesting techniques can be grouped into three main types: in-situ moisture conservation, concentration of runoff to crops in the field, and collection of and storage of runoff water (from roof or runoff areas) in different structures. In response to the various types of runoff there are various types and a different options such as dams, tanks, or reservoirs.

In spite of several thousand years of experience in rain water harvesting, a number of questions remain open, e.g. how to increase the water yield of a catchment, what impact on ecology may occur, or how to identify areas for certain techniques of water harvesting. For many years farmers have collected surface runoff, using various types of water harvesting techniques including water collection in stone wells or in form of holes for domestic or agricultural use (Poesen, 1994). Water harvesting can be a valuable technique to supplement other sources of water for irrigation. However, the selection of appropriate sites and determination of suitable methods of water harvesting on a large scale present great challenges, since the necessary data on hydrology, soils, etc, are often lacking.

Groundwater recharge enhancement (including techniques of water harvesting' and artificial recharge) is rarely practiced in arid environments. Subsurface storage has some important advantages in reducing evaporation losses and minimizing water quality problems in comparison to surface water storage structures.

Valley alluvium provides an ideal storage medium for water in most regions of the world. Alluvium is sand, gravel and coarser materials that have been deposited in valleys by streams and rivers. Without a natural artificial barrier, however, stream sediment deposition will not occur. Sediment will deposit upstream of a barrier dam and from alluvium of relatively well-sorted material. If they become saturated with water, sediment deposits that form behind stable barrier dams may function as alluvial ground-water aquifers (Van Haveren,1986, Ponce and Lindquist 1990).

A ground water dam may generally be one of two types: a subsurface dam or sand storage dam. A subsurface dam is constructed below the ground surface level and prevents the flow of natural aquifer (Heejun S., 2012). A sand storage dam impounds groundwater in sediments that are accumulated and filled up intentionally to form a dam (Hanson and Nilsson, 1986). Subsurface dams are generally constructed at a location where an aquifer is widely distributed with permeable alluvium sediments. Loss due to evaporation is considered negligible in groundwater dams, which is an important factor in semi-arid regions (Hanson and Nilsson, 1986).

Yilmaz (2003) summarized the advantages of groundwater dams in comparison to surface dams as follows: (1) they have a longer lifetime.(2) They can store a larger volume of water.(3) The ground above the stored water can be used. (4) Stored groundwater with a constant temperature and better quality can be obtained throughout the year. (5) They are easy to construct. (6) The groundwater can be effectively used. (7) Sustainable development of water resources can be achieved. Many groundwater dams have been constructed in Europe, Asia, Africa and America. According to Schumacher (1973), millions of villagers in developing countries would benefit from the availability of systematic knowledge on low-cost, self-help methods of water storage, protection, and transport. Artificial aquifers, created by construction of barrier dams community labor, hand tools, and local materials, represent an appropriate technology for delivering high-quality water to small communities in arid regions (van Haveren, 2004). In Korea, six groundwater dams have been constructed and are in operation, their storage capacity ranges from 16,000-43,000 m³ and were mainly developed for agricultural use. In Kenya, sub-surface water dams are constructed for stock watering and irrigation with height 2-5 m, and width of 30 m. In his findings, Suk 2012 found that thickness of the alluvial layer affects the storage capacity to a great extent. He also concluded that geological conditions such as distribution of alluvial zone were more important factors than an efficient groundwater dam construction.

In Malibogazi- Turkey the groundwater dam of storage capacity 55.000m³ increased the groundwater level about 2 m. In other words, the amount of groundwater increased about 6.500-7.000 m³ in the dam reservoirs (Ahmet, 2009).

Wadi Ishe pilot project is a trial to illustrate the benefits of runoff storage in groundwater dam as an alternative water supply for rural arid areas of Jordan. With growing water demand and water scarcity coupled with flood hazards of high rainfall intensity rainfall events with short duration, groundwater dams can be an option for water harvesting and in mitigating flood effects in Wadi Ishe basin.

2 Site Description:

The principle of sub-surface dam is to dig a trench across the valley reaching down to impervious, solid, impervious layer at a suitable location. In the trench an impermeable wall or barrier is constructed and the trench is refilled with excavated material. A subsurface reservoir created this way retains water during wet season and maybe used as a water resource throughout the dry periods.

The suitability of an underground dam is highly site-specific and depends on aquifer properties, hydrological conditions and geological setting of the basin. A thorough hydro geological investigation coupled with model analysis is therefore done for Wadi Ishe site.

Wadi Ishe site is known also as Wadi Madoneh is approximately nine kilometers of the city of Zarqa. Zarqa governorate is about 15 km east of Amman Fig. 1 Wadi

Ishe watershed is located within the upper reaches of the Zarqa drainage river system.

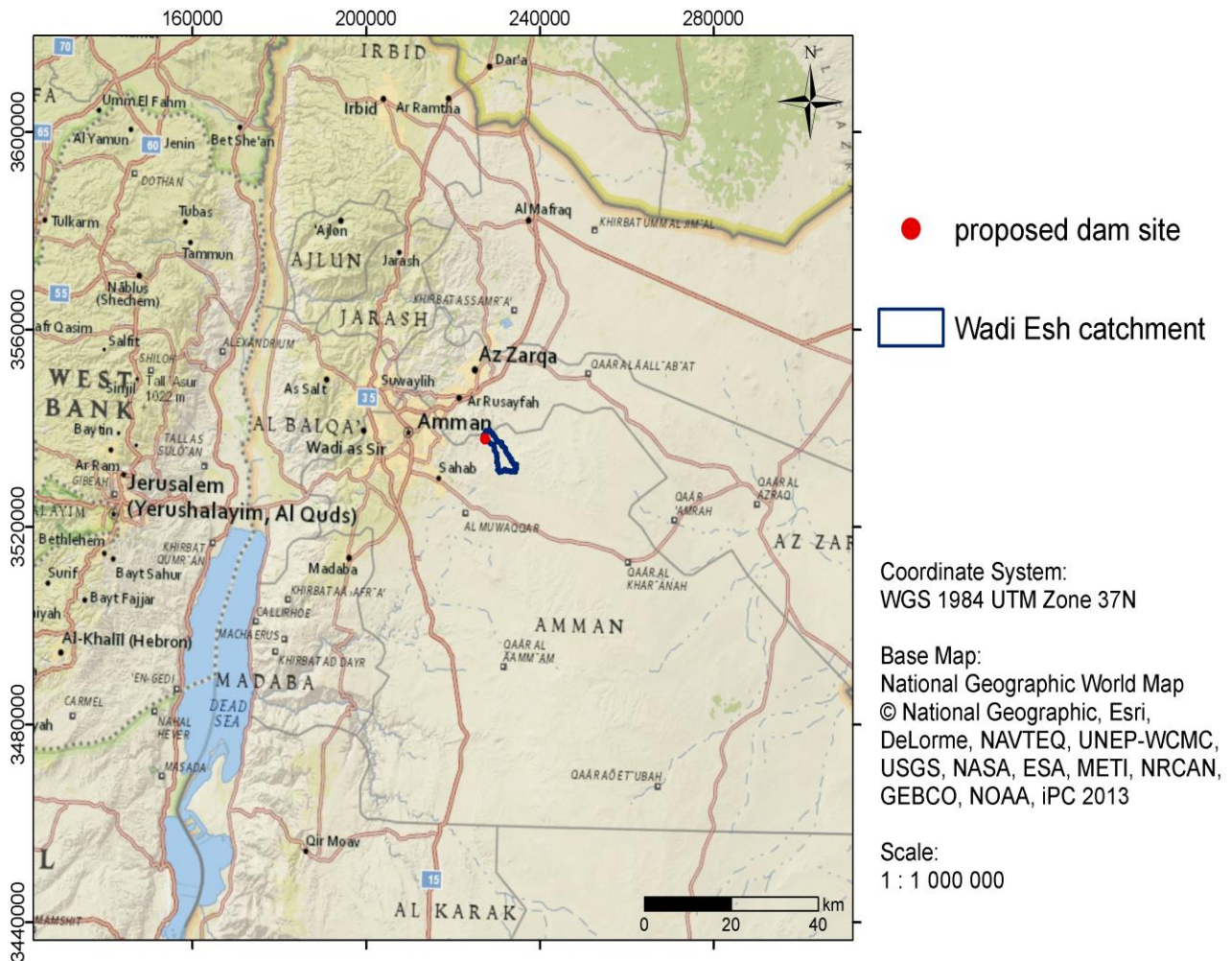


Fig.1.: The Wadi Ishe GW dam site location

2.1 Land use:

As we can see from Fig.2 land use in the vicinity of Wadi Ishe pilot site is largely unclassified. However, in the upstream areas are some cultivated area. The area at the outflow point of the watershed is undeveloped and uninhabited. There are small houses and small farms within the radius of 7 km from the general site area. Some grazing activities are around the catchment area. Wadi Ishe catchment has been classified as bush land/range land. Some industries like battery recycling plant and sulfo-chemical plant is located downstream of our site around 10 km.

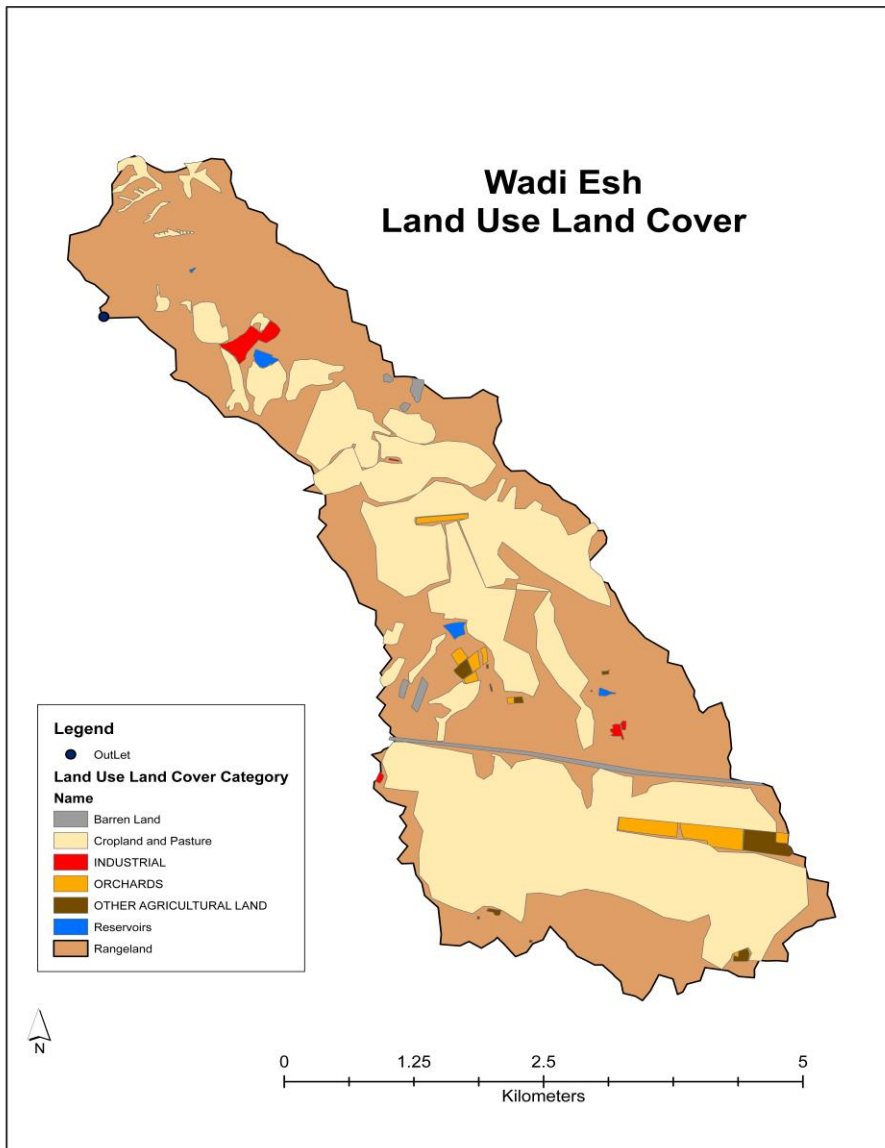


Fig.2.: Land Use map Level 1 For Wadi Ishe Catchment

2.2 Topography:

Wadi Ishe area can be classified as an unadulating to hilly area (Qaisi, 2008). The bed elevations are between 700m to 725 m above sea level, and hill top elevations range between 950m-9750m above sea level Fig.3 . Typically, groundwater storage technologies are used when the topographical gradient is between 0.2% and 4%, but in extreme cases sand dams have been constructed on slopes 10-16% (Nilsson, 1988).

Wadi Ishe slopes range up to 0%. The general topography becomes hilly towards the northern downstream. From wadi bed the topography rises steeply over a short distance and slopes range up to 25%.

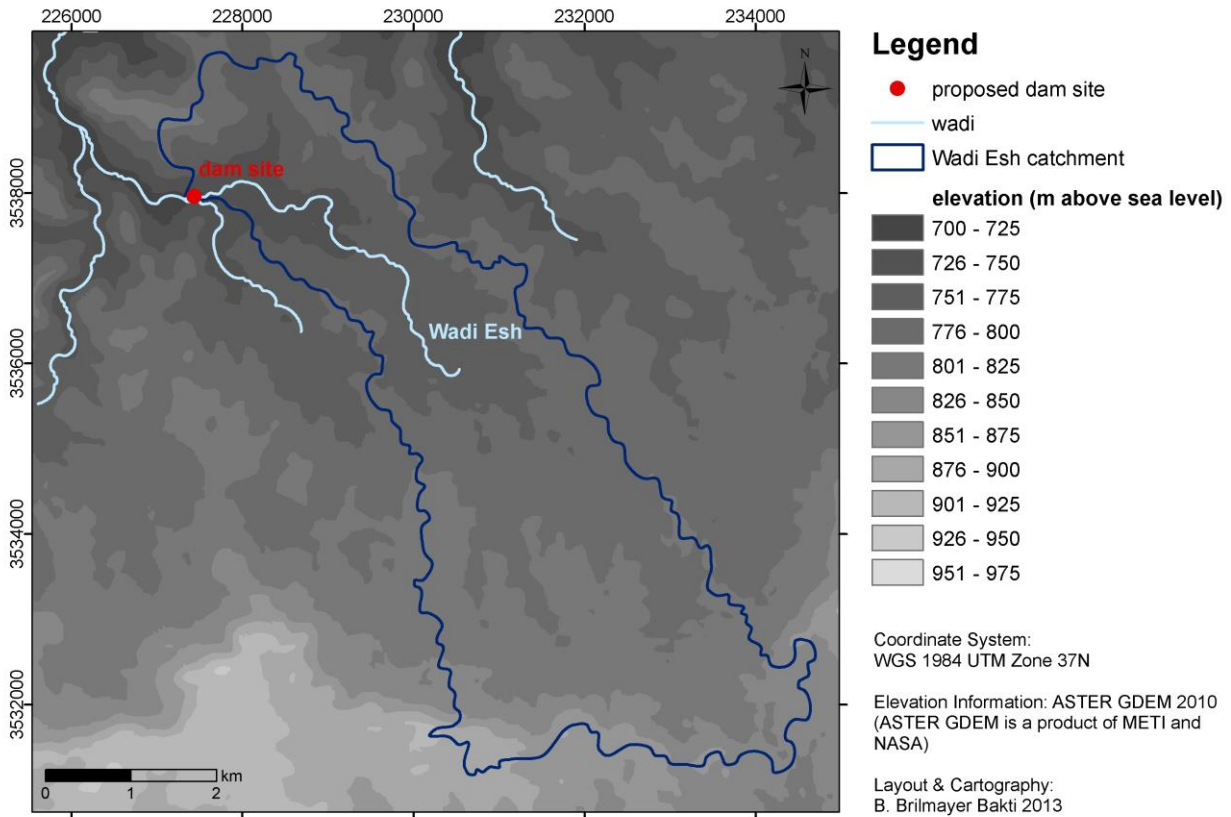


Fig.3.: base map for Wadi Ishe GW storage Dam

2.3 Geological Formations:

With regard to the Upper Cretaceous, it was subdivided into two major groups: the lower part is Ajlun Group and the upper part is the Belqa Group. The Ajloun group overlies disconformably the Kurnub Sandstone. Thick carbonate sediments (limestone, dolomite and marl) form the pre-dominant lithology and the thickness of the whole group reaches about 600 m (Abed 1982).

The upper most formation of the Ajloun group is the Wadi es Sir Limestone, which is outcropping in the northern part of Wadi Ishe Figures 4,5 and 6.

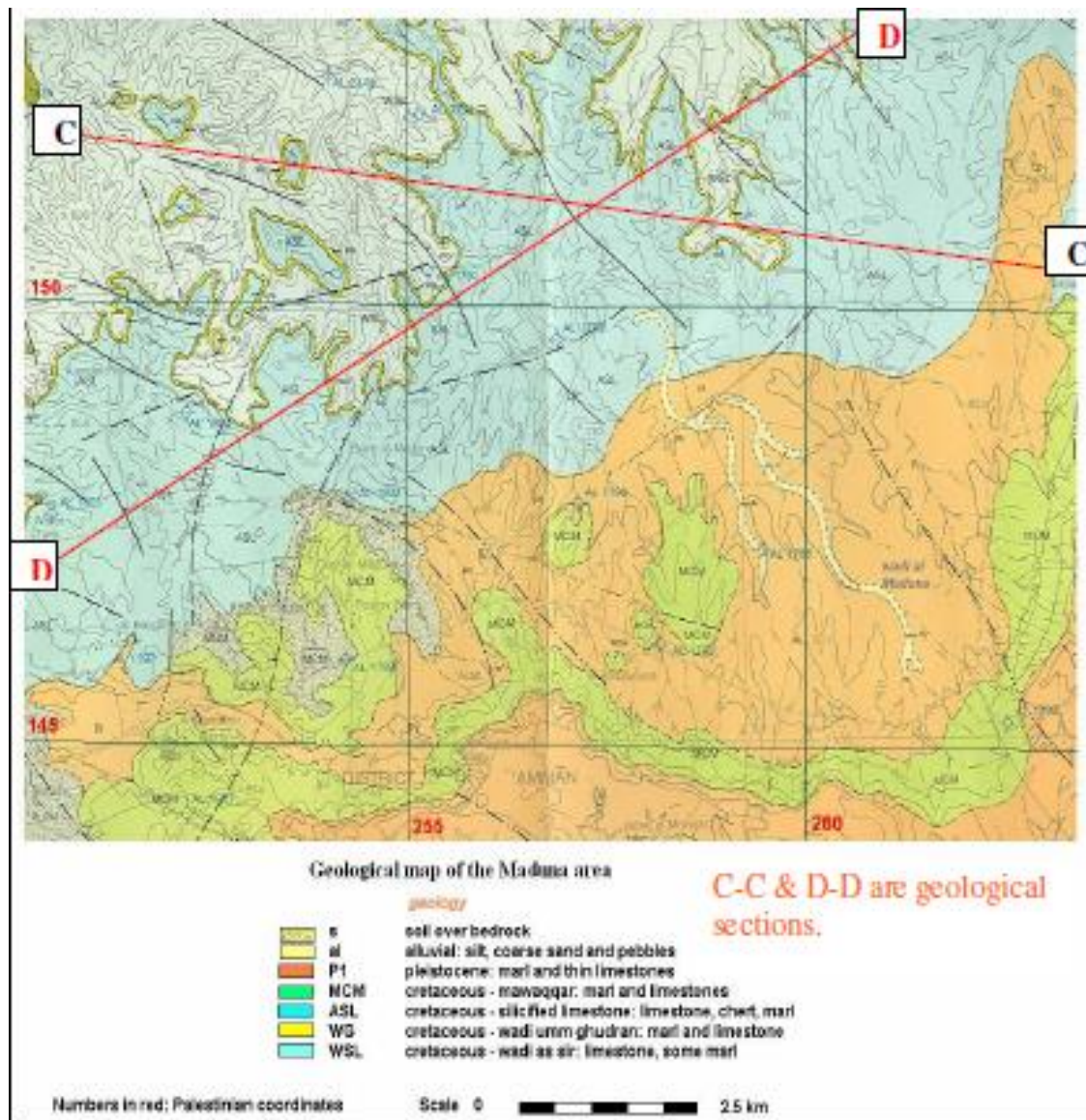


Fig.4: Geological map Wadi Madoneh with cross section location CC and DD (Qaiai 2008)

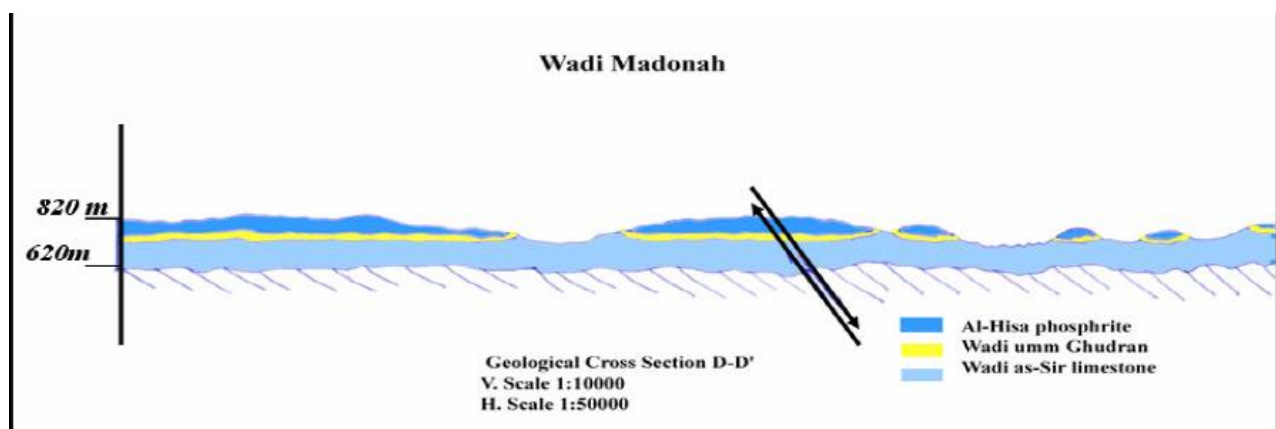


Fig.5: Southwest to northeast geological cross section (Qaisi, 2008)

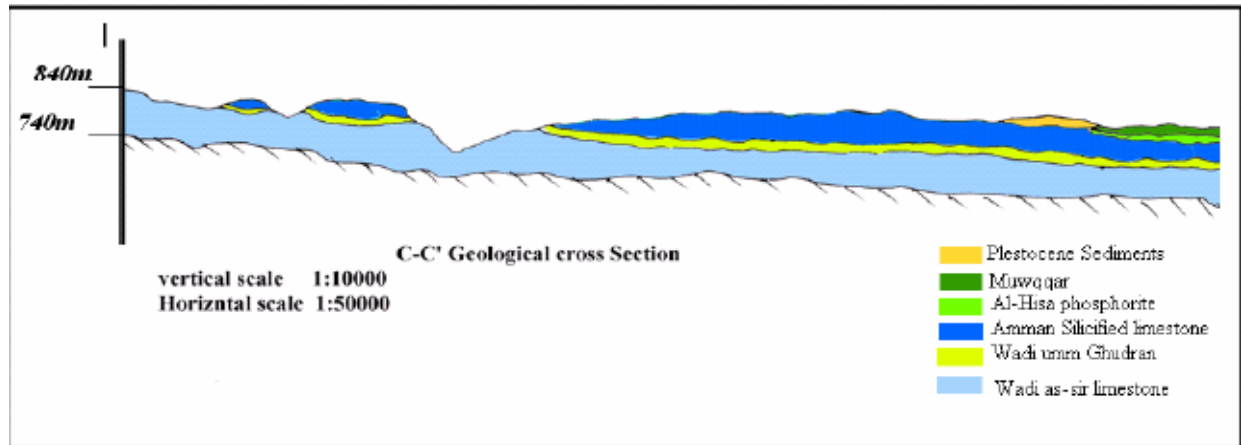


Fig.6: West to East geological Section (Qaisi 2008)

The geological map of our groundwater storage dam Fig.7 allows assessing the rock sequence from the upper part to downstream. The upper part according to the geological cross sections is covered with fluviatile and lacustrine gravels of Pleistocene age, which are underlain by Muwaqqar chalk marl. Regarding the limestone, especially when it is disturbed (faults, uplifting, rifting, geological movements in general), which leads to cracks in the stone layers and therefore facilitates the entrance of water and karstification, there is always the possibility of karstification, especially when there is enough precipitation and a Mediterranean(-like) climate with dry summers and wet winters. On the other hand, many limestones in Jordan are not pure limestone but mixed with marl or marl layers in between and this inhibits karstifications.

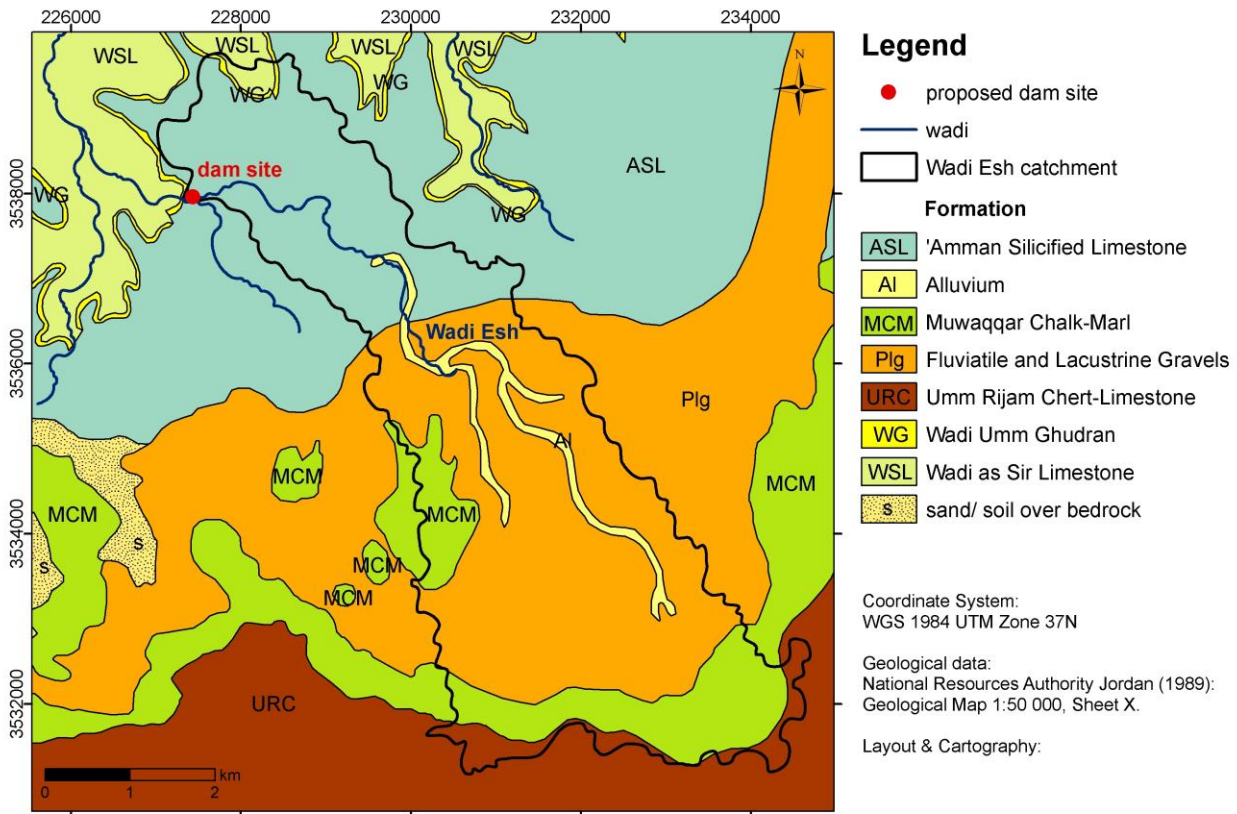


Fig.7: Geological map for the catchment of Wadi Ishe GW dam site

For the geological description in general: AI (Alluvium) and s (sand/ soil) are of holocene age and Plg (Fluviatile and lacustrine gravels) is of pleistocene age. WSL (Wadi as Sir Limestone) belongs to Ajloun Group, while the others (ASL, MCM, URC, WG) belong to the Belqa Group.

The photos below were taken during the site selction process. Through a deep insight in the profiles dug, we can see that we have mixed fine material but also larger stones. Stones seem to be uniformly limestone (which is in good accordance with the geological map). Stones of medium size seem to be rounded or at least sub-rounded, which suggests a longer transportation (with the flowing water), while larger blocks show no rounding's and therefore could be suspected to originate from the immediate surroundings of the wadi or to be generated through digging procedures.

There seem to be alternating layers of very fine material and stones/ gravel (picture 1 and 2). This would suggest torrential rainfalls creating flash flood like conditions, with much water and high flow velocities at a short time (making the water able to transport the gravel and larger stones), then subsequently slowing down very quickly as water gets less and the wadi is probably drying out - this is

when the sorting takes place (in little water remains with basically no flow), so the finer sediments settle down at the bottom, and the larger boulders and the gravel remain on top. This process has to take place repeatedly in order to create the alternating layers. However, in some other photos (e. g. 3, 4, 5) there seems to be no sorting or it is less evident and more obscured.



Photo 1
Photo 4



Photo 2

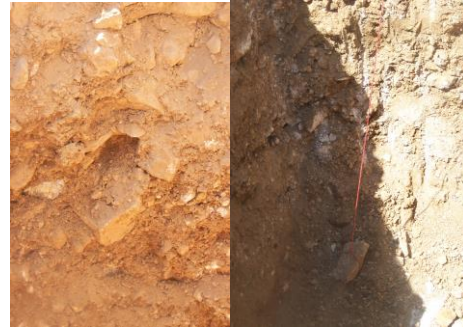


Photo 3



Photo 5

Moreover, fine material seems to be very fine, probably clay, which is washed down and into the wadi bed from the surrounding area. So there has to be a considerable soil cover with deep (and probably fertile), heavy clay soils in the catchment area. The clay very likely originates from the marl or chalk-marl formations in the catchment area. Settling down in the wadi bed, the clay seems to form a kind of "cemented" layer (at the bottom of the side wall in picture 1 and 2. The quite large thickness of this clay layer at the bottom of the profile might indicate a further sorting when clay particles from higher parts of the profile, closer to the surface, are washed out and deeper in the underground during minor rain falls, when basically no/ almost no flow occurs in the wadi.

Altogether shows that the profile(s) are in good accordance with the geological map.



Photo 6: nearby farms irrigated by GW
3.5 m



Photo 7: trench entrance on site at
3.5 m

In wadi Ishe pilot site there are some farms irrigated from groundwater well. The GW level in the project varies from 60-90m.

Photo 7 shows the trench of 3.5 m deep on the project site. And here we might want to subtract the thickness of the cemented lime hardpan/ limestone layer at the bottom of the profile, as this is not part of the storage layers.

Regarding the profile layers we would identify the following:

- The uppermost is fine material (clay, silt, sand) mixed with wadi gravel (larger and smaller stones) have a reddish color in some parts, which could be attributed to the existence of iron oxides, which need periodic moisture and drying out (contact with air) to develop. However, as this is a wadi bed, they don't need to have been developed in-situ but could also have been washed into the wadi bed from the (soils of the) surrounding area.
- Below there is a more compacted, firm layer with yellow-orange colors/ hues which seems to consist of mostly very fine material, probably mainly clay. The different colors could again be attributed to the presence of iron, but this time iron hydroxides, which suggest (together with the remaining moisture content) the permanent (all-year-round) influence/ presence of water.
- Below there is a lighter colored layer, dry and very compact and hard. The light color and the white parts suggest high lime contents and lime concretions. It could be a cemented lime accumulation layer (hardpan) or even the beginning of the bed rock, which should be Amman silicified lime stone here. There seem to be some light brown admixtures, probably clay or marl. In any case it doesn't seem to be pure limestone – probably not yet, it is the beginning of the bed rock further below. The high lime content possibly stems from the underground (limestone) and probably as well from the surface/ the above layers, from which it has been washed out into this deeper part and accumulated there.

The combination of the moist clay layer and the dry lime layer below could suggest a quite impervious layer further below or represented by the (probably) cemented lime layer itself. The colors of the different layers (due to different formations of iron) in the profile would suggest a periodical drying out of the topmost layer (gravel and fine material, red parts), which the finer textured layer below (clay) doesn't exhibit. It rather seems to be all-year-round under the influence of water/moisture.



Photo 8: layer at 2 m depth

From picture 8, we would suggest that this is a clay enrichment/ accumulation layer, with some iron (hydroxide/ oxide) content, which is related to the clay particles to which the iron is attached. As this layer is usually not exposed to the air (because it is at the subsurface and also because of the possibly all-year-round existing moisture content), the iron oxides are not precipitated but rather cling to the clay particles and develop this yellow to orange colors (hues). The clay particles themselves might originate (through weathering) partly from the limestone, which forms the underground rock, as well as from the surrounding area, from which they are washed into the wadi with the sediment load transported by the run-off. So it might be a partly in-situ and partly allochthonous (i. e. from somewhere else than it is found now) origin. This allochthonous (i. e. from the surrounding area) origin of an at least reasonable amount of the clay could also be explained with the surface cover and geology in the catchment area and the surrounding slopes (limestone, marl, alluvium and wadi sediments). The sponge-like behaviour of the clay causes the moisture retention, which very likely exists all-year-round. However, this retention is only possible in combination with the (almost) impervious layer below (here limestone or lime hardpan) that hinders further infiltration. It is this tight lime layer, which also causes the precipitation of the clay particles at the bottom of the (soil) profile. With the water the clay is mechanically transported into the underground as the water percolates deeper (through pores) and where the infiltration is hindered (by the cemented lime layer), the clay also stays and accumulates. And it soaks up the water which is ponded above the tight lime layer.



Photo 9: excavated material from the pilot site

From picture 9 , one can imagine the moisture in the excavated material regarding the color, especially in contrast to the surrounding, very dry and thus lighter colored material.



Phot 10: Inside the trench



photo 11: Inside the trench

Picture 10 and 11, show the moist clay accumulation layer with orange-brown-reddish colors (iron oxides/ hydroxides) there seems to be a lighter colored and dry layer of again mostly fine and very fine grain sizes. So the moisture of the wadi seems to be soaked up probably all by the clay layer above and does not reach deeper into this lighter colored layer. It also seems quite hard, which would be normal for a dried out fine to very fine grained layer, which probably has a high clay (and silt) content again. There seems to be also a high clay content (light and white colors) and lime concretions. This could also be part of an old soil formation, developed probably before the wadi started to flow here.

At photo 11 it seems that colors reach from red (iron oxides, upper left corner of the photo) to yellow-orange and brown (moist clay accumulation layer), showing the influence of the water, which would also suggest that it is most/ all time of the year there. It has a influence on the iron, causing the development of iron hydroxide instead of iron oxide I think.

The lighter colored below seems to be dry, hard, of fine to very fine material and with a high lime content and some lime concretions. Remains the question why this

layer is probably dry?... I think it could be due to 3 possibilities: either it lost its moisture due to deeper percolation of the water (fractures in the underground rock? Another clay accumulation layer/ buried former soil horizon below?) or there has never been any moisture, as the layer above completely absorbs all available moisture, so it stays above the dry, lighter colored layer. In the second case, this would also probably mean that this lighter colored layer acts as a quite impervious layer... However, there is also a 3rd possibility, that the light color is due to the higher lime content, accumulated here, and that this "layer" actually is part of the layer above, with similar properties (clay layer) but with higher lime content. This lime could mask the actual color of this layer in the photo and make it look dry although it is not. It could also be a kind of transitional layer between the clay accumulation layer and the limestone/ lime hardpan below...

However, I think if the geological map is right/ exact and the site is located in the area of Amman silicified limestone, there should not be any relevant deeper percolation of water. The Amman silicified limestone (as it is silicified, i. e. cemented and therefore very tight), in this position (not very rugged terrain) without much geological movements, faultings or other disturbances, should be quite impervious/ water tight.



Photo 12: Eastern side of the interior for the trench

Depicted is the contact area of the wet and the drier, lighter colored layer as shown in picture 12. There are also some areas of lime accumulation visible. The form could suggest and upward movement (soaking) of water.

2.4 Soil

The formation, types and properties of soils in Jordan are closely controlled by parent material, topography and climate. There are soil associated with the East Jordan Limestone Plateau and include limestone, chalk, calcareous sands, gypsum, marls and Tertiary cherts (Al Hmoud 1995).

Soil map Fig.8 shows the pilot site soil groups/ units which consist of different soil types each.

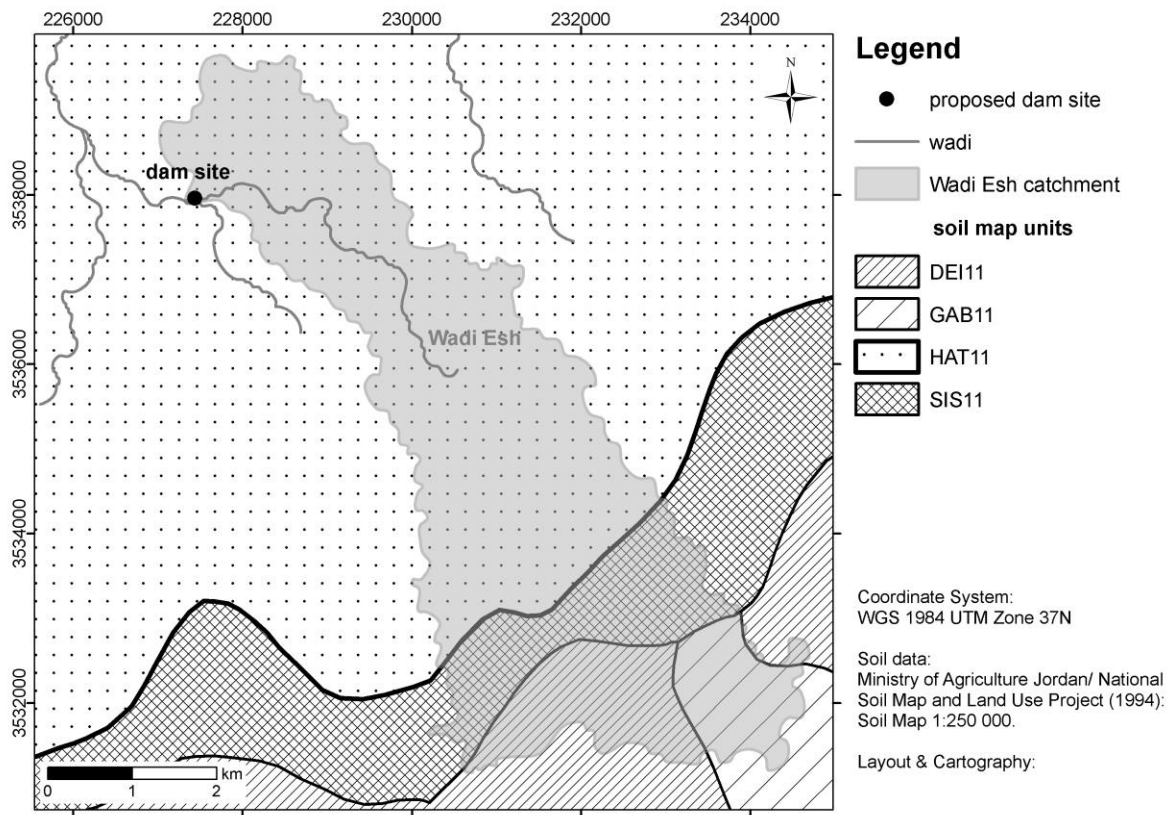


Fig 8: Soil maps shows the soil groups in Wadi Ishe pilot site

Soils in the study area as shown in the soil map are mainly three classes: HAT11 strongly dissected Amman silicified limestone, SIS11 steeply sloping eroding escarpment Umm Rejim, and DEI11 finely dissected limestone and chert plateau Umm Rejim. .

2.5 Climate

The climate of Waqdi Ishe area is characterized by hot summers and mild winter. The precipitation data for the most recent 30 years period from 2000 to 2010 water years indicate that average annual precipitation in the vicinity of the pilot site and in the upstream basin ranges from approximately 120 to 150 mm. The annual average potential evaporation is approximately 1.075mm.

3 Constructions:

Constructions started with trench excavations of 90m length, 4m width and 3 m depth as illustrated in the sketch Fig.9. The trench across the course of the wadis

Fig.13 dispelled the young wadi sediments completely, so that the marly rock layers form the ground of the trench from one side to the other side/ slope.

Filling the trench with natural sediments as second step shown in following pictures 13 and 14.



Pic. 13: Excavations showing rain filled the trench of the trench



Pic.14...: Shows the filling

For the actual Bentonite wall Fig.11 has a width of about 1.0 m at the bottom which narrows up to ca. 0.7m at the top. The Bentonite wall e sunk a little bit into the rock at the base. On both sides, the Bentonite wall is followed by a ca. 1.0 m wide sheet with unsorted material excavated from the trench. Upstream a 2.0 to 2.5 m wide sheet with washed or sieved gravel and ballast material (with high porosity and good permeability) follows. In this gravel layer a perforated well pipe of 12 inch is installed Figs.11 and 12, which was covered up with secure metal mesh to trap the sediments before entering the well Fig. 13.

The incorporation of the materials B, C and D were done in parallel from the bottom in layers of 0.5 to 0.7 m, wherein the individual layers, in particular the clay should be moist and installed compressed as shown in Figures 9-13.

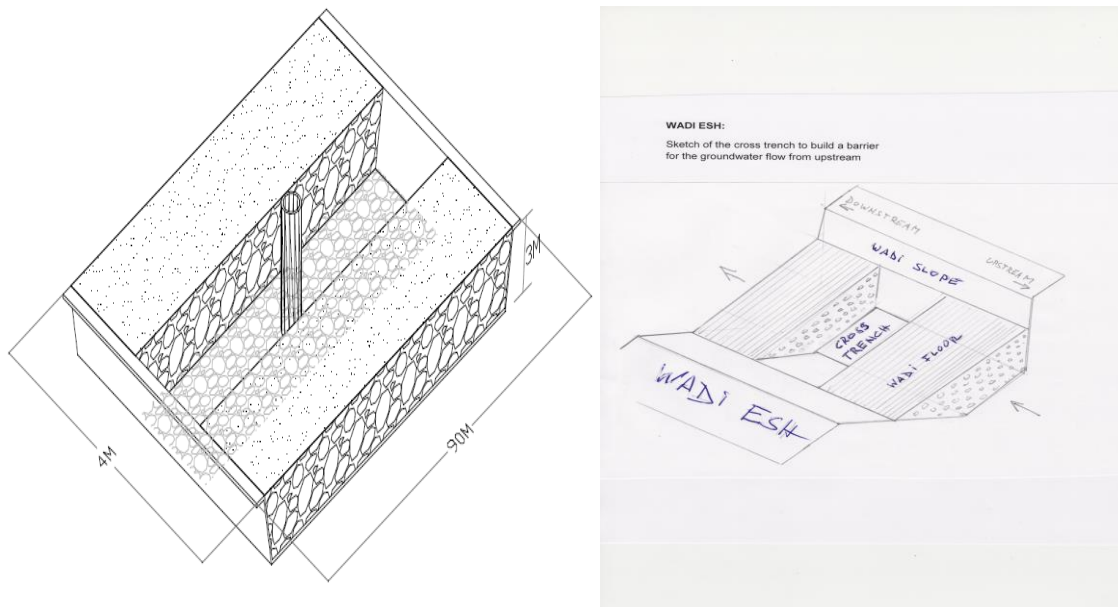


Fig.9.: Shows Wadi Ishe GW dam dimensions (90m*3m*4m)

According to Fig. 9 the filling of that 4 m is illustrated in the figure and in Fig.10

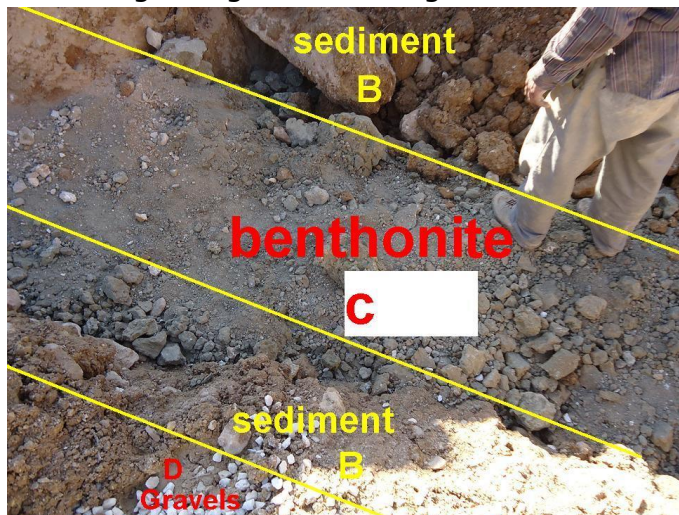
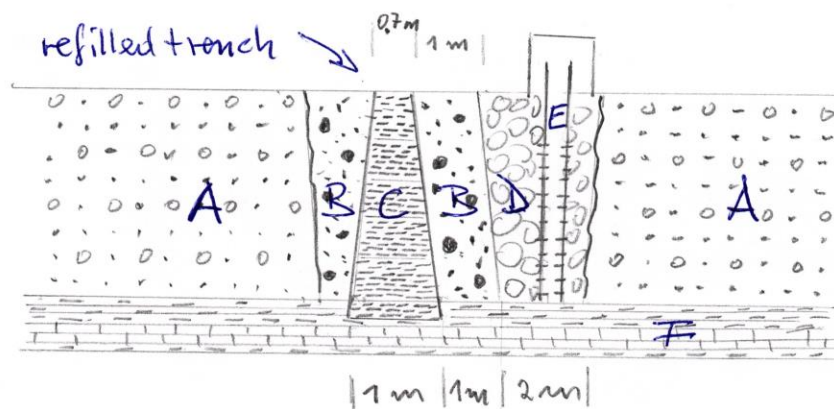
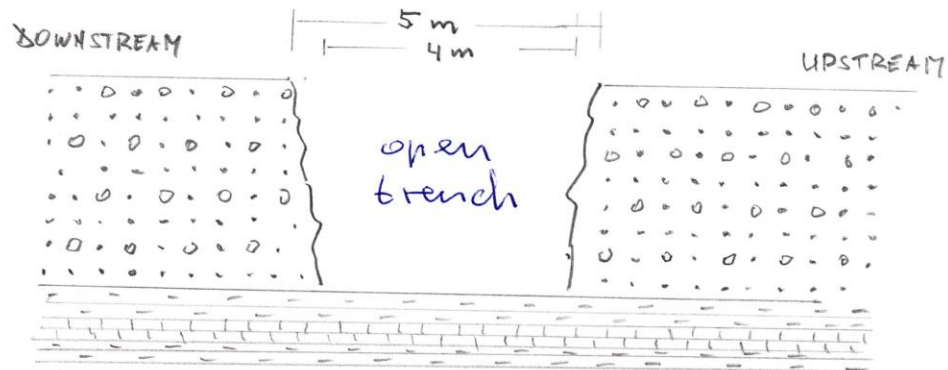


Fig.10: Showing the implementation layering of Wadi Ishe pilot site

WADI ESH: cross trench



- A natural wadi filling (gravels, sands, silts)
- B refilled wadi sediments
- C clay sealing (bentonite)
- D washed out / sieved gravels
- E observation and pump well with protection shelter
(perforated pipe: diameter about 200mm)
- F bed rocks (marls with some limestone layers)

Fig.11.: Shows the cross Section of Wadi Ishe material filling sequence (Prof Hoetzl free hand drawing))



Fig.12.: The pipe installation



Fig.13: Bentonite compaction

Bentonite which is used in Wadi Ishe GW dam, is a commercial term for a special type of clay composed essentially of crystalline smectite minerals commonly dominated by montmorillonite. It is formed from alteration of glassy igneous material either tuff or volcanic ash and deposited in shallow water lakes in the Plio-Pleistocene time. Chemically, it is a hydrous aluminium silicates with magnesium and iron that partially substitute Al in the structure. Alkalies or alkaline earth elements are also present as essential constituents. Bentonite deposit occurs in two separate areas; Q'a Al Azraq Figure 14 and Ein Al Bayda which are approximately 120km northeast of the Amman and 30 Km from Wadi Ishe pilot site. Q'a Al Azraq (mudflat) represents a closed basin and covers about 150km². Both areas have low relief about 510m above sea level. Smectite, mixed layer illite/smectite and kaolinite forming the major constituents of clay minerals, whereas quartz, feldspar and calcite are present as impurities (Mahasneh, 2012).

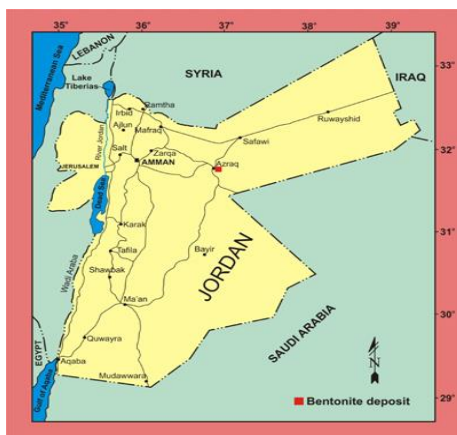


Fig.14: Map shows Azraq Governorate (Bentonite Deposit). (MOWI website)

The first rainy event after the constructions were finalized filled the pipe and transported a quantity of sediments as illustrated in the pictures 15 and 16 below.



Fig.15.: General view of the site after constructions
rain water



Fig.16: Pipe filled with

4 Surface Runoff and Rainfall-Runoff Models

In Wadi Ishe pilot site, a hydrologic model was generated to estimate the runoff potential by using the Hydrologic Modeling System of the Hydrologic Engineering Center (HEC, 1998). The HEC-HMS model provides a variety of options for simulating precipitation-runoff processes.

For HEC-HMS modeling, the following data are needed:

- 1- The Catchment and its sub-basins parameters such as Area, Slope and Main Channel Length
- 2- The hydrologic modeling methods including rainfall losses and excess rainfall calculating method and the runoff hydrograph development method.
- 3- Design storm depth

For this analysis, the catchment which has an area of 22.256 km² has been divided into three sub-basins as shown in Figure 17 and Table 1.

Table 1, summaries the modeling parameters for the sub-basins using NRCS-CN and NRCS-UH methods.

Sub-Basin	Area (km²)	Slope (%)	Main Wadi Length (km)	Initial Abstraction (mm)	Lag Time (min)
1	7.954	1.26	6.623	14.3	212
2	6.176	2.25	5.305	14.3	133
3	8.126	1.58	5.315	14.3	159
Catchment Area	22.256				

5 Rainfall Losses and Excess Rainfall:

The National Resources Conservation Services (NRCS) Curve Number (CN) Method is used to calculate rainfall losses and excess rainfall. In this Method, the CN used is 78 as found in (Hammouri and El Naqa, 2007) for a catchment in the same area and the initial abstraction is calculated as 14.3 mm using the following equations:

$$S = \frac{25400}{CN} - 254$$

$$I_a = 0.2 S$$

Where:

S is the potential storage (mm),

CN is the Curve Number,

I_a is the initial abstraction (mm),

6 Runoff Hydrograph:

The NRCS Unit Hydrograph (UH) method is used to simulate the sub-basins runoff hydrographs and the catchment's outflow Hydrograph. For this method, the lag time is calculated using the following NRCS (SCS) equation:

$$t_c = 0.136 L^{0.8} \left(\frac{1000}{CN} - 9 \right)^{0.7} S^{-0.5}$$

$$t_L = 0.6 t_c$$

Where:

t_c is the time of concentration (min),

t_L is the lag time (min),
 L is the main wadi length (m),
 CN is the Curve Number,
 S is the Sub-basin slope (%)

7 Design Storm:

The 24-hrs, 10-years return period storm is used to model the catchment's outflow. The modeling storm was found in three references for the study area. The first storm is derived using daily rainfall for stations Ruseifa and El-Muwaqqar for the years 2000 to 2010. The data were analyzed using Extreme Value distribution and the 10 years return period daily (24-hrs) storms are calculated for both stations. Thiessen polygons are derived for those stations to find the 24-hrs, 10-years storm for the study area. **Figure 18** shows the Thiessen polygons for the studied catchment.

The 24-hrs storm is distributed using National Resources Conservation Services (NRCS) (Formally known as Soil Conservation Service (SCS) Type II storm. Table 2, lists the 24-hrs, 10-years storms used in the modeling and the reference for these storms.

Table 2: The 24-hrs, 10-years storms used in the modeling of Wadi Ishe catchment and the reference for these storms

Rainfall Depth Estimation Reference	Storm depth (mm)
From daily rainfall for two stations	44.00
Consulting Engineering Center [1]	45.60
Hammouri and El Naqa [1]	42.58

8 Modeling Results:

The catchment is modeled using the three storm depths and the peak discharge and outflow volume is tabulated in Table 3, the outflow hydrograph for the catchment using the 44.0 mm storm is shown in Figure19 and Table 5

Table 3: The three storm depths and the peak discharge and outflow volume used to model the catchment

Storm Depth (mm)	Peak Discharge (m^3/s)	Outflow Volume ($1000 m^3$)
44.00	5.7	193.3
45.60	6.2	210.3
42.58	5.2	177.8

The purpose of using HEC-HMS model is to explore the surface water potential for subsurface groundwater storage in Wadi Ishe catchment basin. However, the study area is an ungauged basin, thereto HEC-HMS model with GIS were used to simulate rainfall-runoff using SCS curve number. For the results of the hydrographs, the runoff volume, peak discharge and percent loss for the 10 years return period, the total precipitation of was 44 mm, the total loss 35.3 mm the total runoff was 8.7 mm. The total precipitation volume for water years 2000-2010 within the catchment area was approximately 36.14 MCM.

For the years 2000 – 2010, the total rainfall for El Muwaqqar Station was 1647.4 mm. Only 29 storms during this period exceeded the initial abstraction of 14.3 mm and resulted in runoff as shown in **Table 4** bellow. The total rainfall depth for these storms was 689.8 mm which forms about 41.9% of the total rainfall in the same period. Each one of these storms is modeled using HEC-HMS. The total runoff depth for the years 2000 – 2010 was 52.71 mm which forms about 3.2% of the total rainfall and about 7.6% of the total storms greater than the initial abstraction.

For Wadi Al-Esh catchment that has an area of 22.256 km², it received about 36.66 MCM of rainfall during the years 2000 – 2010, only 3.2% of that was generated as runoff (about 1.17 MCM).

Table 4, Storms recorded in El-Muwaqqer Station that are greater than the initial abstraction of 14.3 mm and the generated rainfall excess and runoff coefficients for these storms:

Storm Depth (mm)	Rainfall Losses (mm)	Excess Rainfall (mm)	Storm Runoff Coefficient (%)
45.0	35.79	9.21	20.5
44.0	35.30	8.70	19.8
38.8	32.56	6.24	16.1
37.0	31.54	5.46	14.8
34.5	30.06	4.44	12.9
33.0	29.13	3.87	11.7
32.0	28.49	3.51	11.0
30.0	27.18	2.82	9.4
26.8	24.94	1.86	6.9

24.0	22.84	1.16	4.8
24.0	22.84	1.16	4.8
24.0	22.84	1.16	4.8
22.5	21.66	0.84	3.7
20.0	19.58	0.42	2.1
20.0	19.58	0.42	2.1
18.8	18.53	0.27	1.4
18.7	18.45	0.25	1.3
18.0	17.82	0.18	1.0
18.0	17.82	0.18	1.0
18.0	17.82	0.18	1.0
17.0	16.90	0.10	0.6
17.0	16.90	0.10	0.6
16.4	16.34	0.06	0.4
16.0	15.96	0.04	0.2
15.7	15.67	0.03	0.2
15.6	15.58	0.02	0.1
15.0	14.99	0.01	0.1
15.0	14.99	0.01	0.1
15.0	14.99	0.01	0.1
689.8	637.09	52.71	

9 Conclusion

Groundwater dam in arid and semi-arid countries like Jordan offers an attractive solution for water shortage challenge. Moreover, the development of groundwater basin and the concept of storing water in subsurface terrain have relatively low social and environmental impacts and present a tremendous potential.

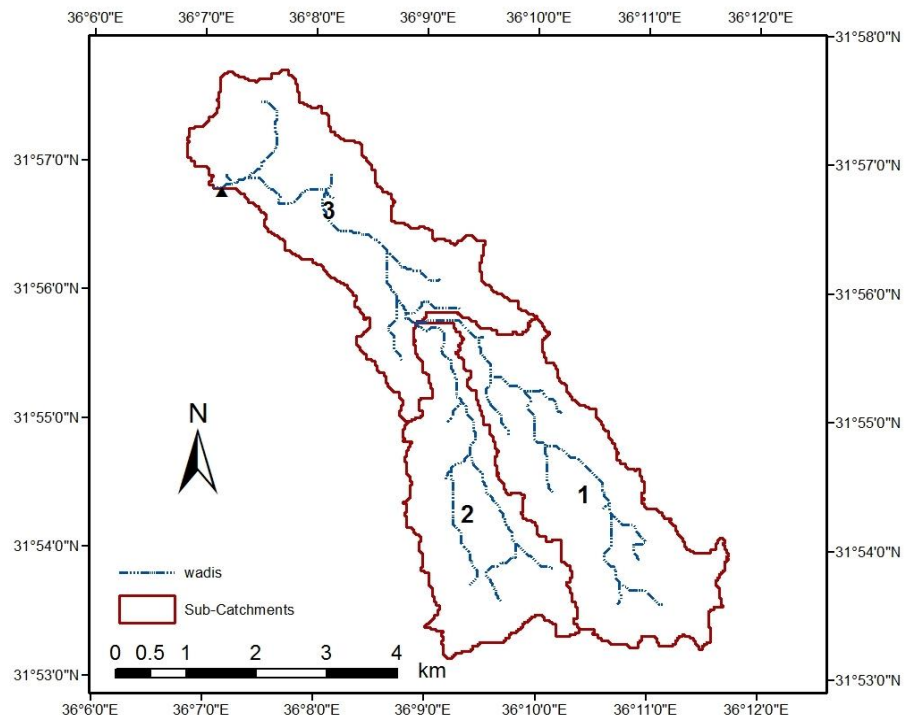


Fig.17: Wadi Ishe catchment and its sub-basins

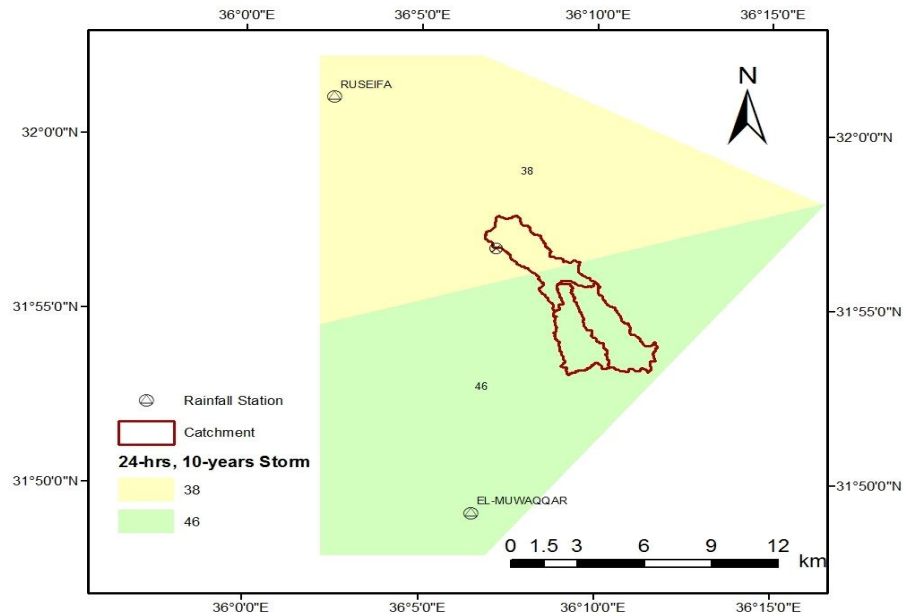


Fig. 18: Thessien Polygons

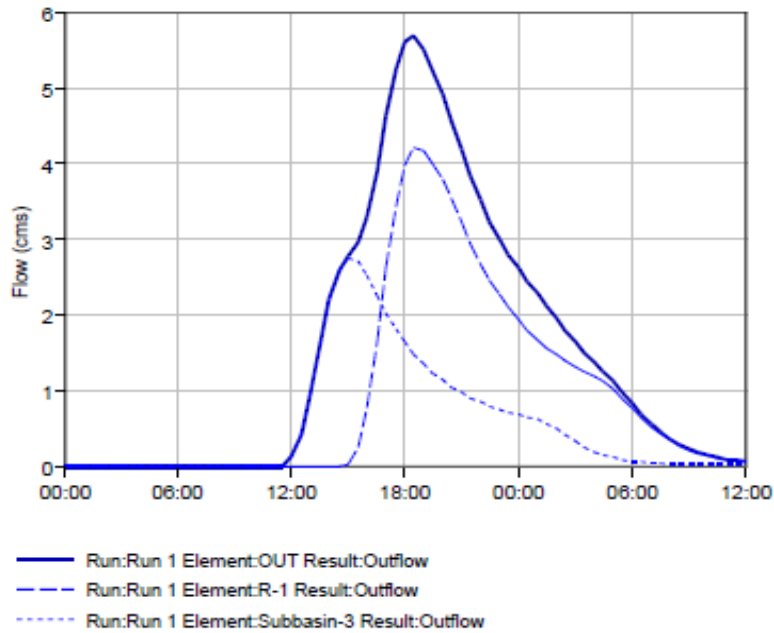


Fig. 19: hydrograph for Wadi Ishe basin for a 24-hour storm 10 years return period and its sub basins

Table 5: Simulated outflow hydrograph for the catchment using the 44.0 mm storm

Time (hrs)	Outflow (m ³ /s)	Time	Outflow
00:00	0.0	19:00	5.5
01:00	0.0	20:00	4.9

02:00	0.0	21:00	4.2
03:00	0.0	22:00	3.5
04:00	0.0	23:00	3.0
05:00	0.0	00:00	2.6
06:00	0.0	01:00	2.3
07:00	0.0	02:00	1.9
08:00	0.0	03:00	1.6
09:00	0.0	04:00	1.4
10:00	0.0	05:00	1.1
11:00	0.0	06:00	0.8
12:00	0.1	07:00	0.6
13:00	0.9	08:00	0.4
14:00	2.2	09:00	0.2
15:00	2.8	10:00	0.1
16:00	3.3	11:00	0.1
17:00	4.6	12:00	0.1
18:00	5.6	13:00	0.0

10 The Way Forward:

The next working steps include:

1. Report on the pumping test to be submitted on March 20th.
2. Protecting the well with metal box 13th March
3. Diver and Baro installation 13th March.
4. Monitoring and evaluation of the water level for the summer dry period.
Report in June will include the analysis.
5. Preparation of another implementation site to be assigned after discussions with Kit.

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