Artificial Injection and Groundwater Recharge (AIR)

In

Kingdom of Saudi Arabia

وزارة البيئة والمياه والزراعة
Ministry of Environment Water & Agriculture
Kingdom of Saudi Arabia المملكة العربية السعودية

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Contents

Main challenges in water sectors are:

- Rainfall scarcity
- Increasing in water demand
- Draughts, Desertification
- Dropping in groundwater level
- Water Pollution
- Flash Floods Risks.
- Sea Water Intrusions
- Climate change

Non-renewable groundwater currently contributes about 80% (and aims to reduce it to about 40%) in 2030

Renewable groundwater also contributes about 9% (and aims to raise it to about 21%) in 2030

The Ministry of Environment, Water and Agriculture undertook the task of developing a unified frame of reference for the water sector that included a comprehensive strategy for water 2030 that was approved by the Council of Ministers in 2018.

The National Water Strategy 2030 consists of a vision, strategic goals, and associated programs and initiatives.

The Third program contains several initiatives, including:

- **The third initiative: Expanding the capacity of the strategic storage including aquifers recharge, underground storage and water recovery plans such as:**

A- Identify areas most at risk of experiencing interruptions in water supply and assess the actual storage capacity therein.

B-Evaluation the potential operational methods of storage (Water tanks, dams' reservoirs and groundwater aquifers).

C-Identify mechanisms for monitoring and extracting stored water quantities.

ARTIFICIAL INJECTION AND GROUNDWATER RECHARGE PRACTICES (AIGR)

In

SAUDI ARABIA

One of the initiatives of the Saudi National Water Strategy 2030

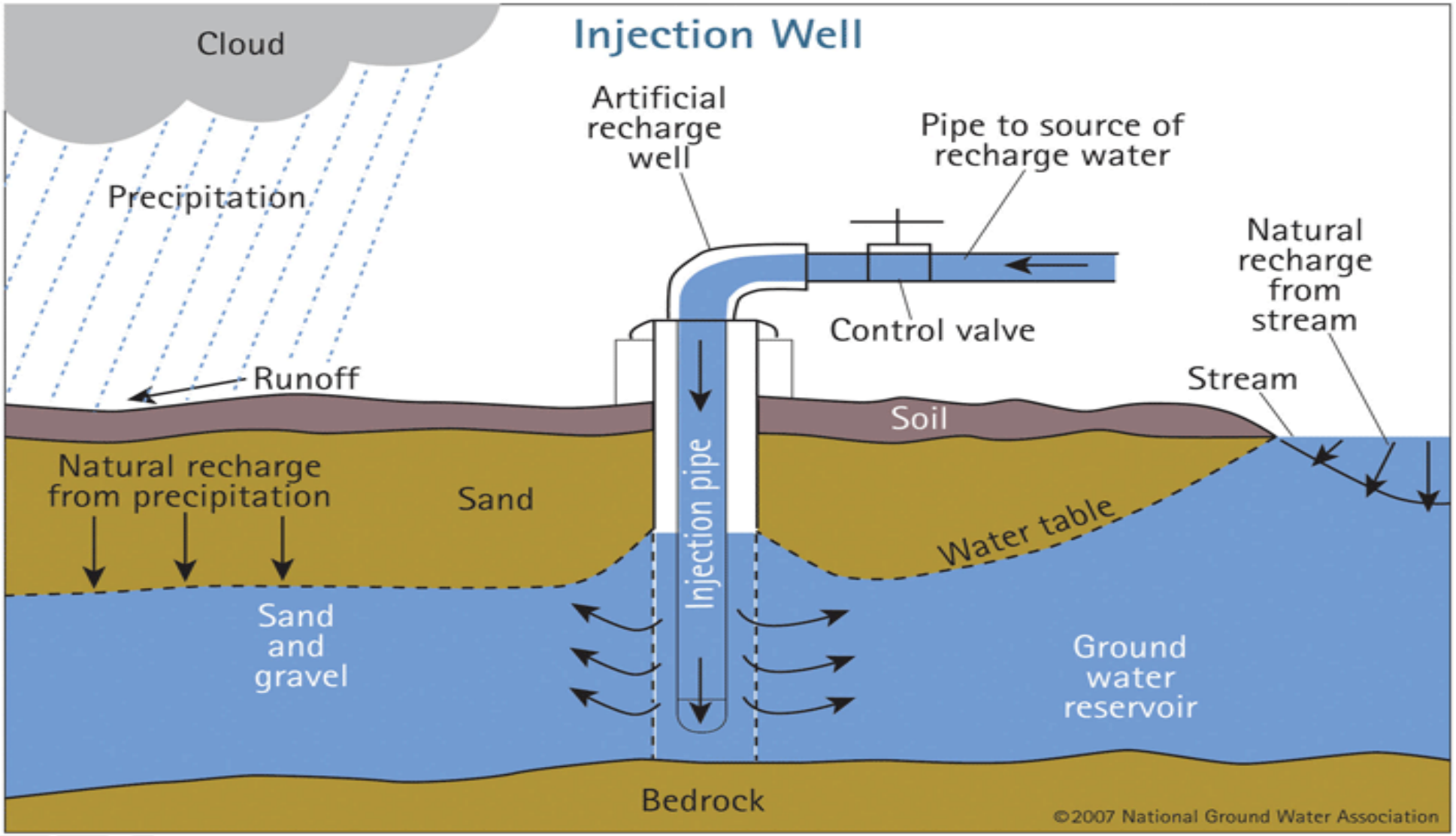
Definition of Artificial Groundwater Recharge

- ✓ The process by which the groundwater recharge is augmented at the rate much higher then those under natural condition of percolation.

- ✓ It is the use of human effort to increase the rates of surface water flows within the aquifer at rates that exceed the natural recharge rates, this mainly done for economic considerations, as it is possible that the costs of storing the surplus water below the surface of the earth may be less economic than storing it in a system of tanks above the ground.

- ✓ The successful design and operation of water injection systems into aquifers depends on the hydrogeological conditions of the site and the target aquifer that affect the flow of the injected water into the aquifer, its transport and mixing with the original groundwater.

- ✓ Also, the recharged water quality of depends on various biogeochemical processes that occur when water flows through the aquifer through the soil.


Injection Well
Cloud
Precipitation
Runoff
Artificial recharge well
Pipe to source of recharge water
Control valve
Natural recharge from stream
Stream
Soil
Natural recharge from precipitation
Sand
Injection pipe
Water table
Sand and gravel
Ground water reservoir
Bedrock
©2007 National Ground Water Association

Why the artificial injection and groundwater recharge?

- In areas that suffer from scarcity of rainfall rates and runoff, the reservoir of groundwater is stressed due to the continuous withdrawal and depletion of it, as a result, the levels of groundwater in the wells having great drop in their levels continuously, as well as the well efficiency decreases and the salinity increases.

- The accumulation of sediments in dam reservoirs, over the years of operation will lead to a decrease in the natural recharge rates of sedimentations and then the groundwater levels in downstream wells will decrease as a result of natural recharge deficiency.

- The deep foundations of high dams reaching to the bed rocks also leads to a decrease in the natural ground recharge rates in the downstream.

- Increase of evaporation losses from dam reservoirs leads to an, an increase in the rate of turbidity and a change in the physical and biochemical properties of the water, which negatively affects the efficiency of the treatment purification plants of water supply and leads more energy consumption.
- In coastal areas, as a result of decreasing groundwater levels in wells, salinity increases due to the effect of sea water interference.

Advantages of Artificial Recharge:

1. Enhancing the groundwater yield in depleted aquifers.

2. Conservation and storage of excess surface water for future uses, and thus there is sustainability for agricultural and development activities.

3. Improvement the existing groundwater quality through natural infiltration.

4. Improve bacteriological and other impurities (turbidity) from stored water in dam reservoirs, so that water is suitable for re use.
5. Low artificial injection costs compared to other alternatives such as establishing direct irrigation networks.
6. Increasing the water reserve in the water-bearing layer, expanding the geographical area, and building a water balance that annually increases.
7. Reducing evaporation losses in dam reservoirs.

8. Finding new well fields for water supply projects with suitable water quality and eliminating the problem of increasing the turbidity rate when directly use from dams.

Methodology of Artificial Injection Recharge Evaluation studies

MEWA has implemented the artificial injection and Groundwater recharge program through the following:

A. Identification the target areas needed for artificial injection and groundwater recharge.
B. Conducting detailed geological, hydrogeological, hydrological, geophysical, geotechnical and environmental studies.
C. Drilling exploratory injection and monitoring wells and conducting pumping tests to determine the hydraulic and hydrogeologic parameters and efficiency of aquifers as well as the economic feasibility of establishing artificial injection projects
D. Preparing the detailed engineering design necessary to implementation the injection and recharge program from surplus desalinated water , dam reservoirs, or from the tertiary treated wastewater (in some secondary aquifers, wadies downstream dams).
E. Applying the most updated technology and benefiting from the worldwide practices.
F. Development of groundwater models to define design standards for artificial injection system.

- **First Program:** Direct Injection using surplus desalinated water in within the targeted aquifers,

or storage in dam reservoirs, for to be used for drinking water supply in emergency circumstance(Ex. Abiar Al Mashi- Wadi Malakan well fields – Rabigh, Marawani dams).

- **Second Program:** Injection using runoff water retained in dam reservoirs:

A- Drilling injection wells inside the dam reservoirs for direct injection in alluvium layers.
B- Drilling injection wells or surface spreading basins in alluvium layers in downstream of dams (Ex. Wadi Bisha, Asir Region).
C- Groundwater recharge through opening the dam gates and releasing the water into the wadi (Ex. Wadi Hali dam, Makkah Region)
D- Ground recharge by establishing a system of surface and underground dams and well fields between them (Al-Ahsebah Dam, Baha Region).

- **Third Program:** Recharge through sinkholes and cavities within the outcrops of some aquifers (Eastern Region).

- **Fourth program:** Direct Injection using the tertiary treated wastewater (Ex Khulays, Usfan,Hada Makkah Region) .

First Program:

1- Augmenting the groundwater storage of aquifers using "pumping in" of excess desalinated water, to later use for drinking water supply in emergency circumstances:

This Program is suitable to recharge single aquifer.
It is comparatively costlier and required special techniques.

A- Abar Al Mashi well field
(Al Madeina Region)

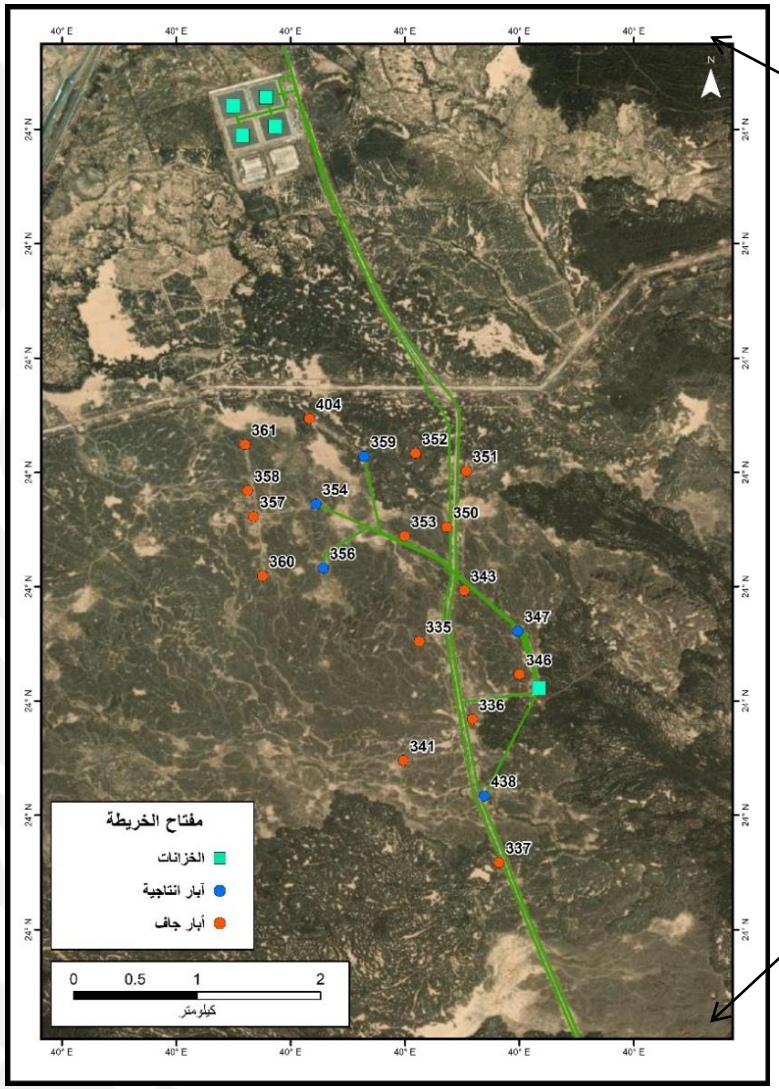
B- Wadi Malakan well field
(Makka Region)

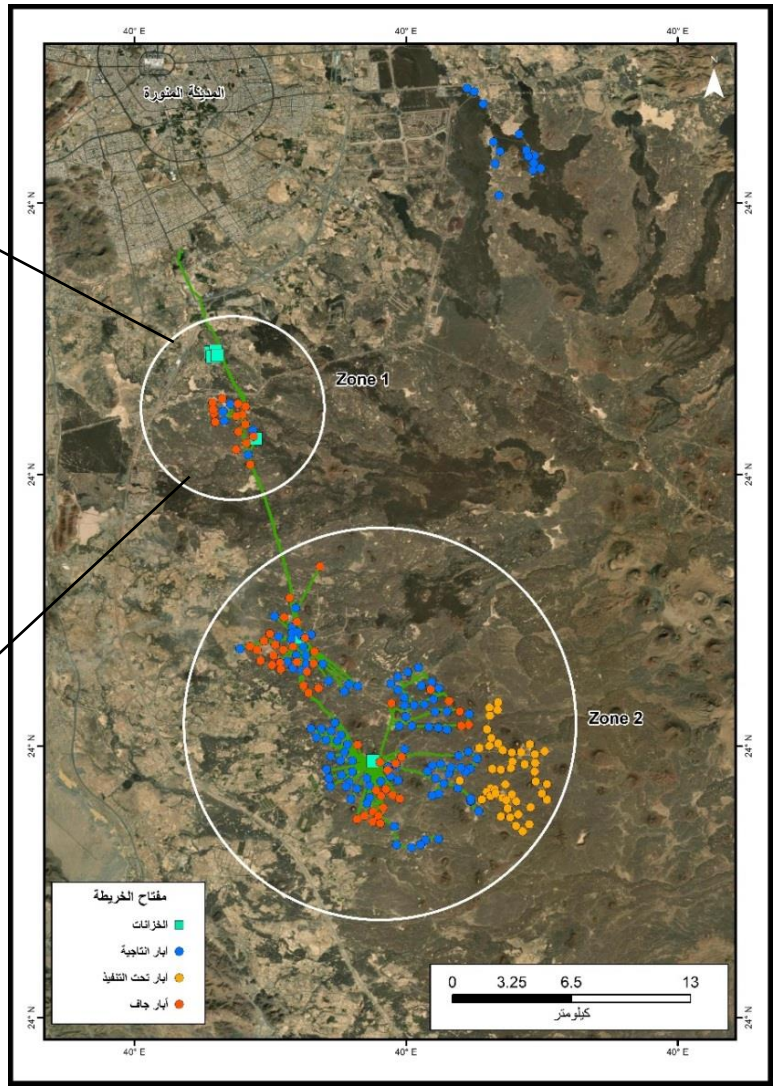
B- Storing surplus desalinated water in dam reservoirs.

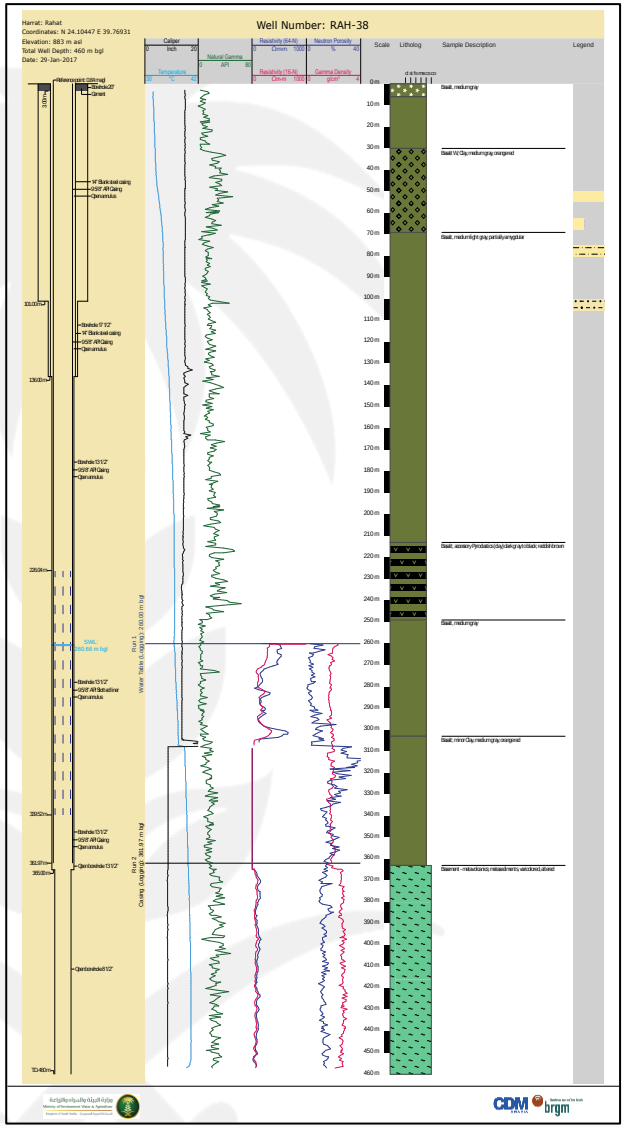
C- Rabigh Dam, D- Marwani Dam

(Makka Region)

A- Abar Al Mashi well field; (Al Madeina Region)

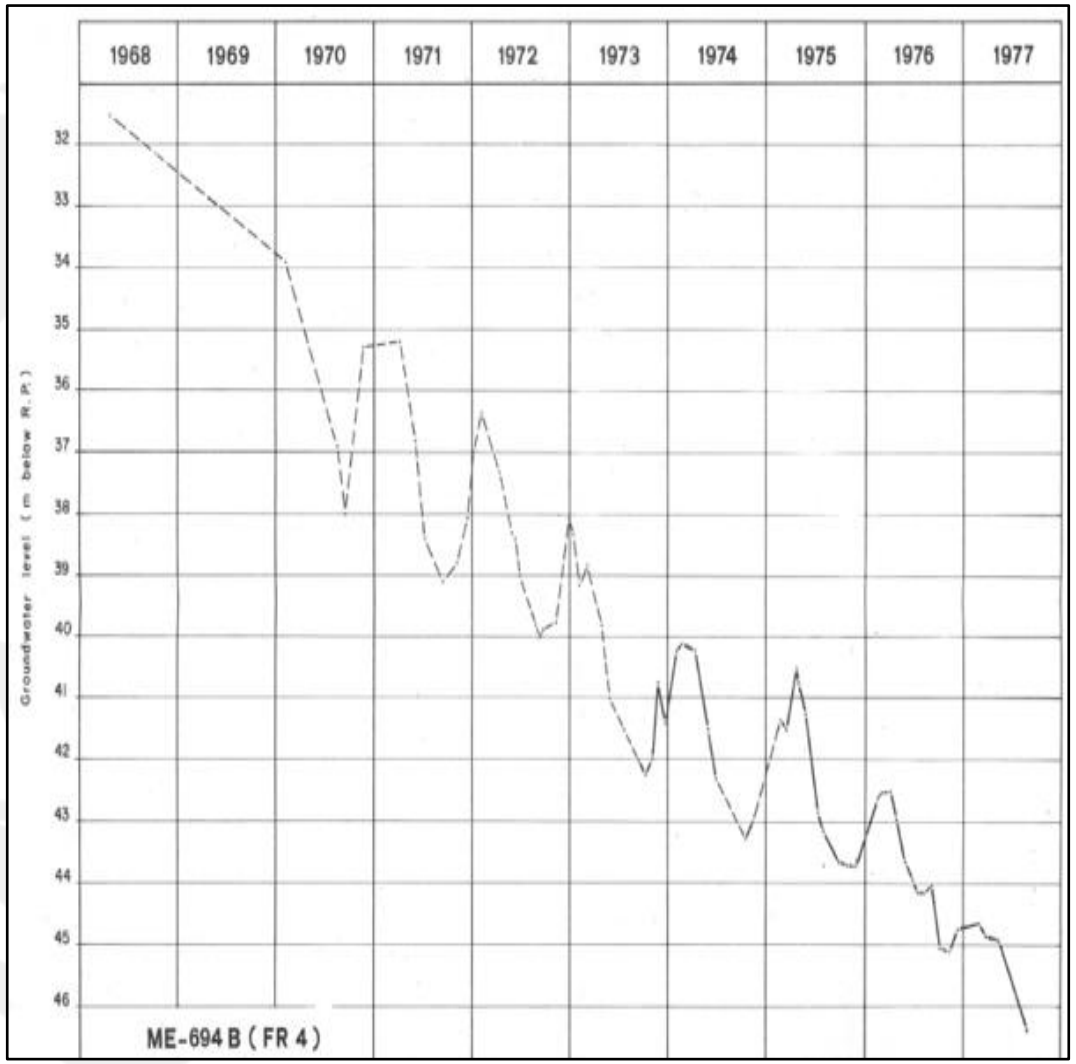


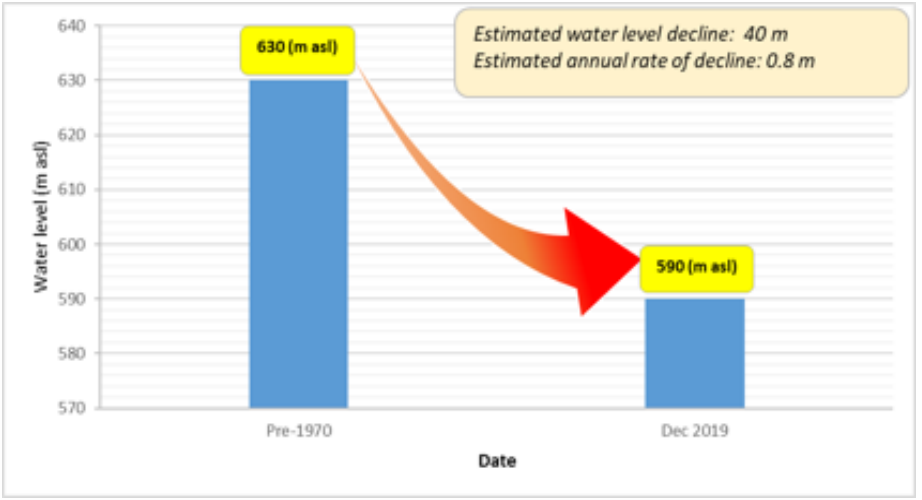


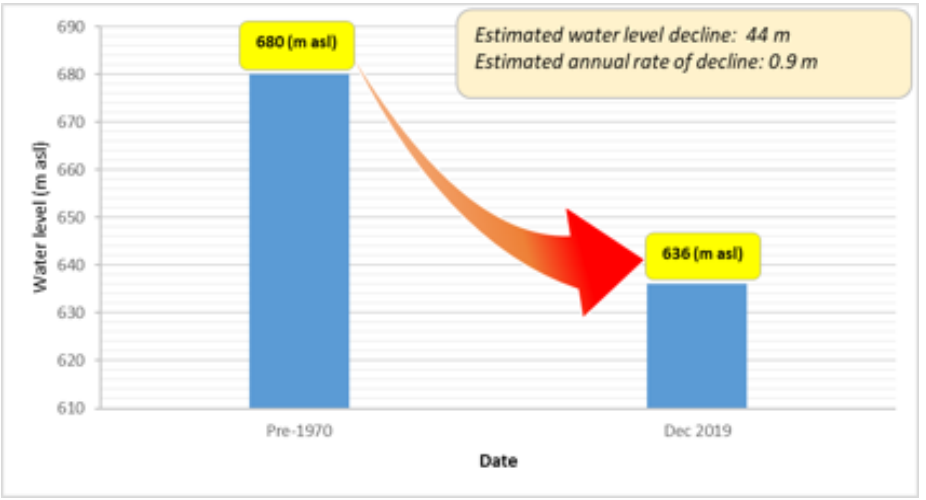


The Geographical area = (200) km²
Total Operating wells = (250)
The average well depth = (200-300 m).
Daily yield = 80,000 m³ / day = (30 MCM/ in 2019)
Saturated Zone thick = (30-50m)
Available storage volume = 400 MCM
The target daily injection rate= 100,000 m³ / day

Depression of groundwater levels in Abar Al Mashi







Annual depression of groundwater levels (0.8 – 0.9 m = 90 – 100 MCM

B- Wadi Malakan well field; (Makkah Region)

This project has been essentially constructed in 1405 H to water supply to toilets in the Holy Mosque.

It consists of Five main parts:

1- W. Malakan Well Fields:

There are about (30) wells (dug and pipe wells) distributed along the wadi course about (15) km.

2- Water collection tanks in Malakan :

It is located at the end of the wells network assembly lines in Malakan, with a capacity of (4000) m3

3- Main Treatment Station in Malakan

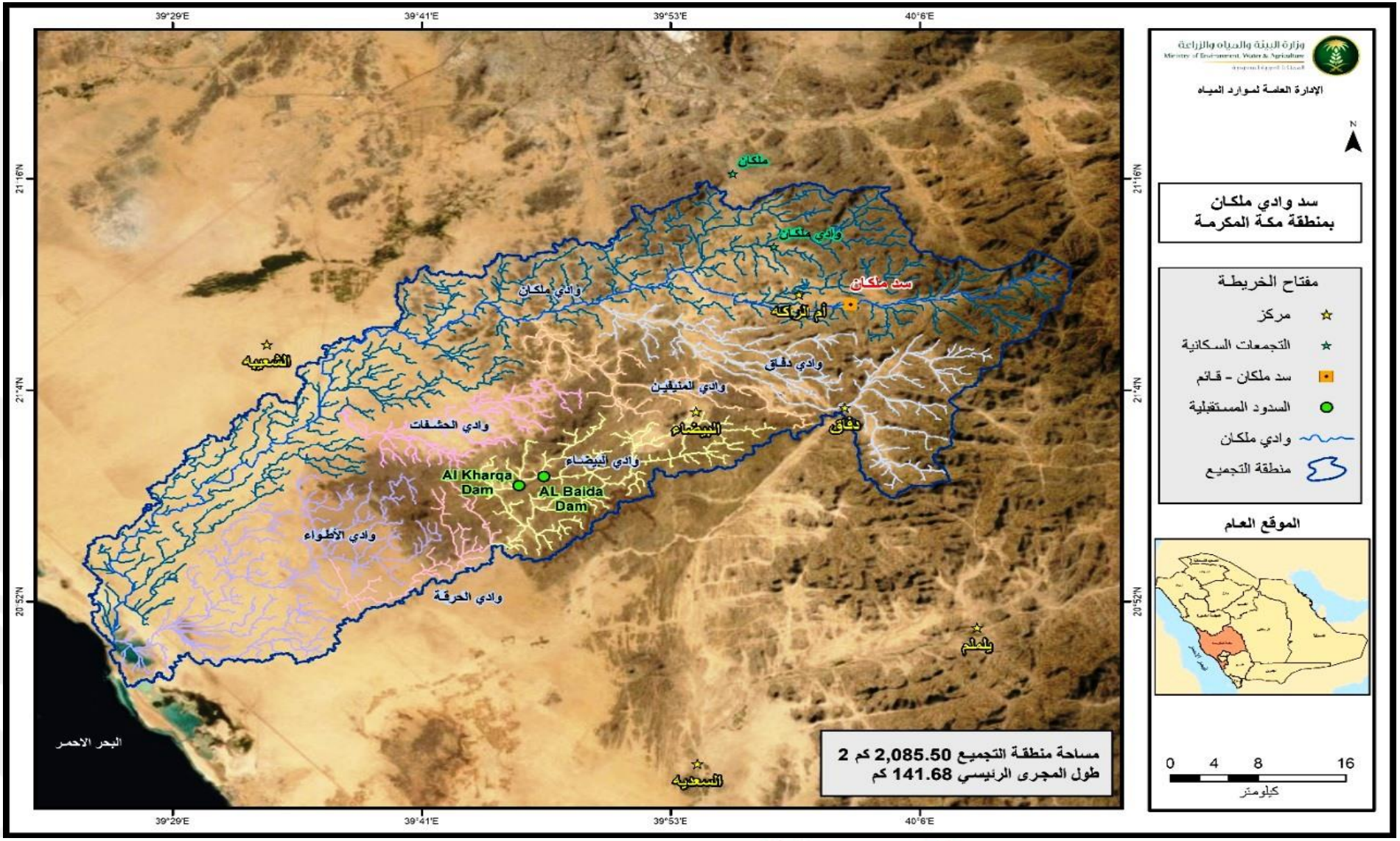
It includes a pumping station (three main pumps of energy (500 m3 / hour) each) to the water tank in Al-Kaakiya, generating electric power Unit, and a chlorination sterilization unit.

4- Transmission lines:

made of flexible cast iron with a diameter of (700 mm) from the collection tank to the lifting station in Al-Ka'akiya, Makkah Al-Mukarramah, about (45) km long by pumping by pumping.

5- Lift station in Al-Kaakiya:

It is directly linked to the main station in W. Malakan through the main transmission line and includes a pumping station, a backup generating unit, and four water tanks with a total capacity of (89) thousand m3, from which it is pumped to the kuddai station for a about (7) km , then to toilets in the Holy Mosque in Mecca.


39°29'E
39°41'E
39°53'E
40°6'E
21°16'N
21°4'N
20°52'N
ملكان
وادي ملكان
سد ملكان
أم الركة
الشعيبة
وادي دفاق
وادي المنيفين
البيضاء
دفاق
وادي الحشفات
وادي البيضاء
Al Kharqa Dam
AL Baida Dam
وادي الأطواء
وادي الحرقة
ياملم
السعدية
البحر الاحمر
مساحة منطقة التجميع 2,085.50 كم 2
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وزارة البيئة والمياه والزراعة
Ministry of Environment, Water & Agriculture
الإدارة العامة لموارد المياه
N
سد وادي ملكان
بمنطقة مكة المكرمة
مفتاح الخريطة
مركز
التجمعات السكانية
سد ملكان - قائم
السدود المستقبلية
وادي ملكان
منطقة التجميع
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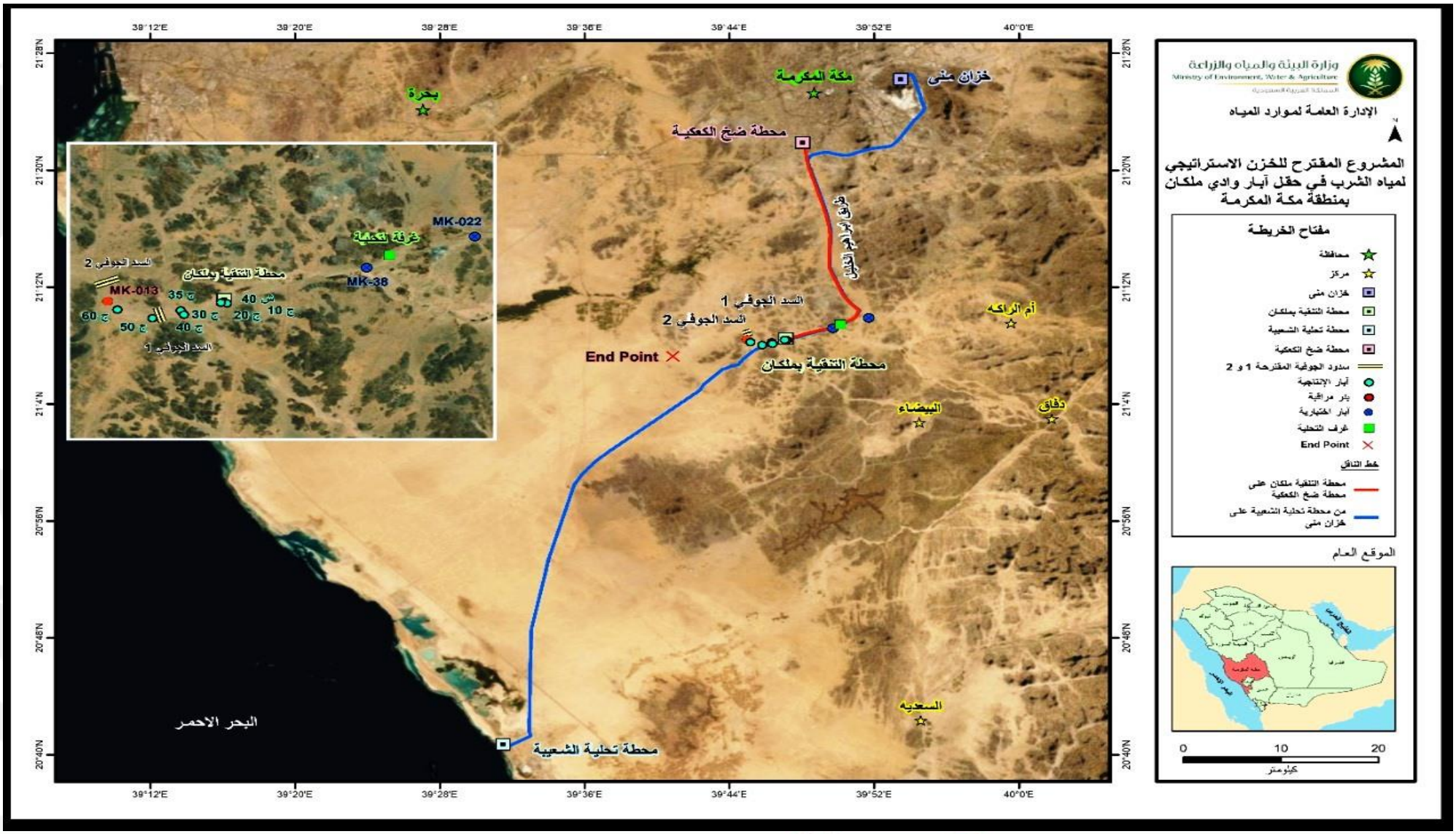
The proposed diagram for the strategic storage of water supply in W. Malakan, Makkah Al-Mukarramah



❑ Second Artificial Injection Program:

Injection using runoff water retained in dam reservoirs:

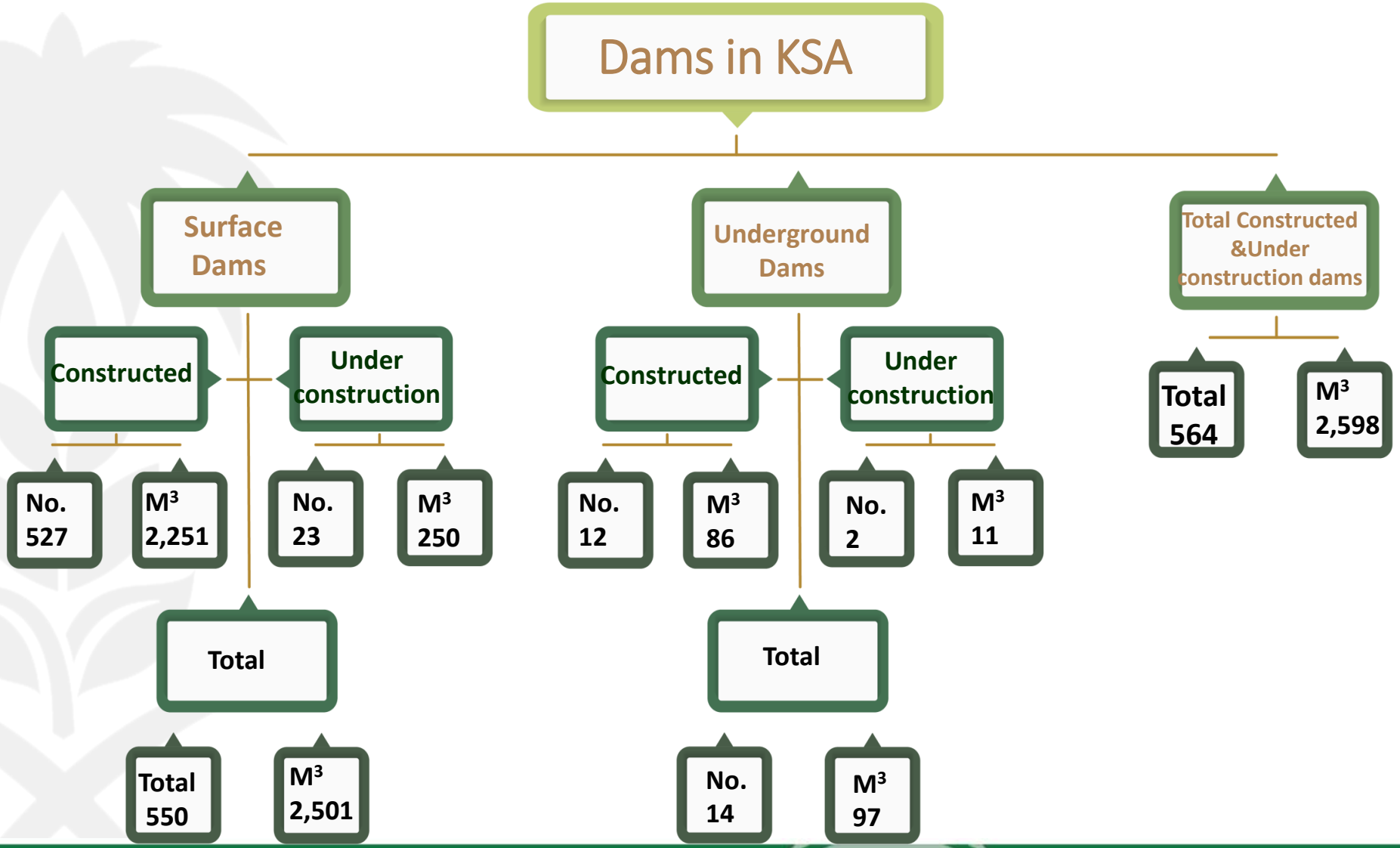
A- Drilling injection wells inside the dam reservoirs for direct injection in alluvium layers.

B- Drilling injection wells or surface spreading basins in alluvium layers in downstream of dams (Ex. Wadi Bisha, Asir Region).

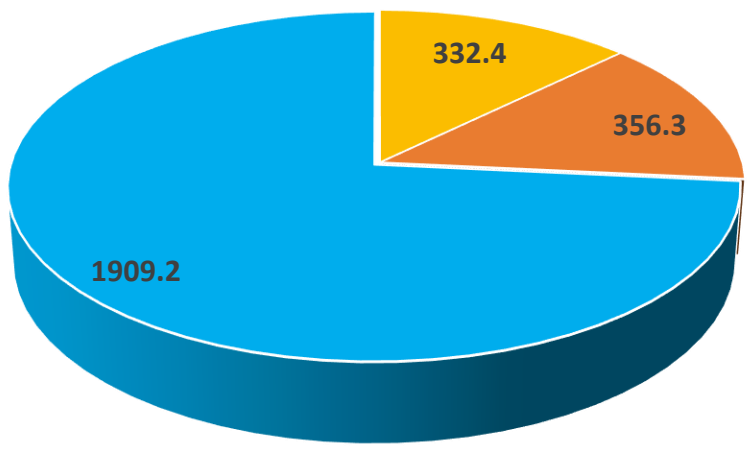
C- Groundwater recharge through opening the dam gates and releasing the water into the wadi (Ex. Wadi Hali dam, Makkah Region).

D- Ground recharge by establishing a system of surface and underground dams and well fields between them (Al-Ahsebah Dam, Baha Region).

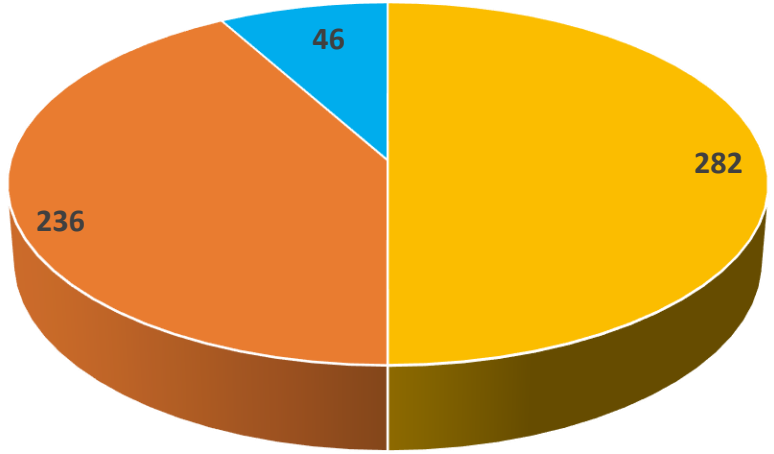
Dams in Kingdome of Saudi Arabia



Storage Capacities of Dams According Purposes (MCM)



Total Numbers of Dams According Purposes



A- Drilling of injection wells inside the dam reservoirs for direct injection through dried layers.

Prince Sultan Centre for Environmental, Water and Desert Research
Through the King Fahd project for harvesting and storing floods

Sediments accumulation in Al Elb Dam reservoir, Diriyah, Riyad Region

The accumulation of sediments during floods at the bottom of dam reservoirs will reduces natural groundwater recharge rates.

These dug wells in the dam reservoir have been be used as recharge wells, and the runoff water during flooding will guided directly through into the dried aquifer.

Artificial Recharge in Al Elb Dam reservoir, Diriyah, Riyad Region

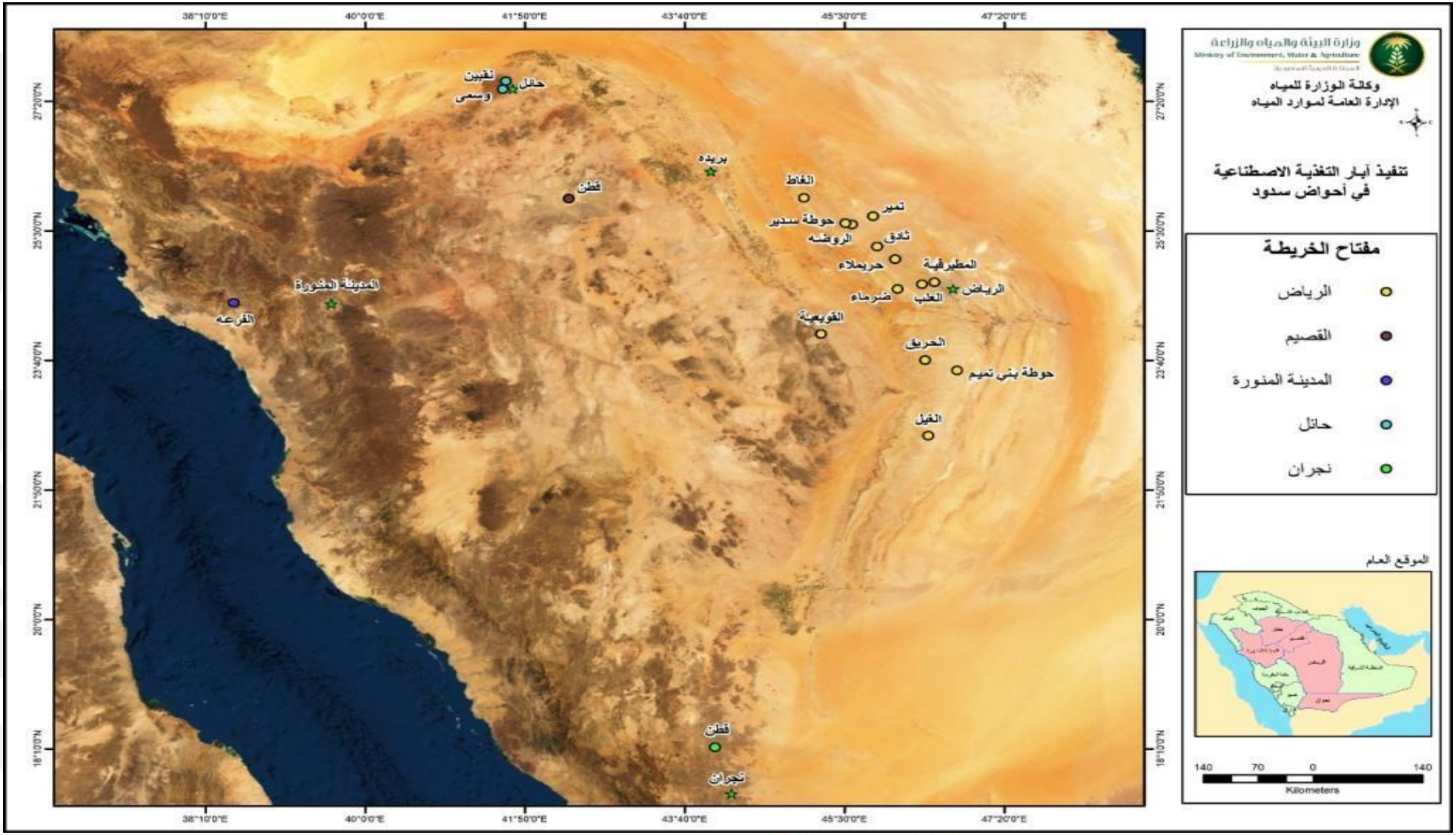
King Saud University
Prince Sultan Research Center for Environment, Water & Desert
King Fahad Project for Rainwater & Runoff Harvesting & Storage in the Kingdom

Ground water recharge in Al Ulb Dam (Ad Dariyah)

جامعة الملك سعود
مركز الأمير سلطان لأبحاث البيئة والمياه والصحراء
مشروع الملك فهد لحصد وخزن مياه الامطار والسيول في المملكة

تغذية الطبقات السطحيه فى سد العلب (الدرعيه)

Dam sites where injection projects established by the Prince Sultan Centre



Summary of Dam sites for Artificial injection projects established by the Prince Sultan Centre

Region	Number s of Dams	Storage Capacity of dams m^3
Riyad	13	30,085,702
Al Madeina	1	20,000,000
Qassem	1	280,350
Hail	2	330,000
Najran	1	500,000
Total	18	51,196,052

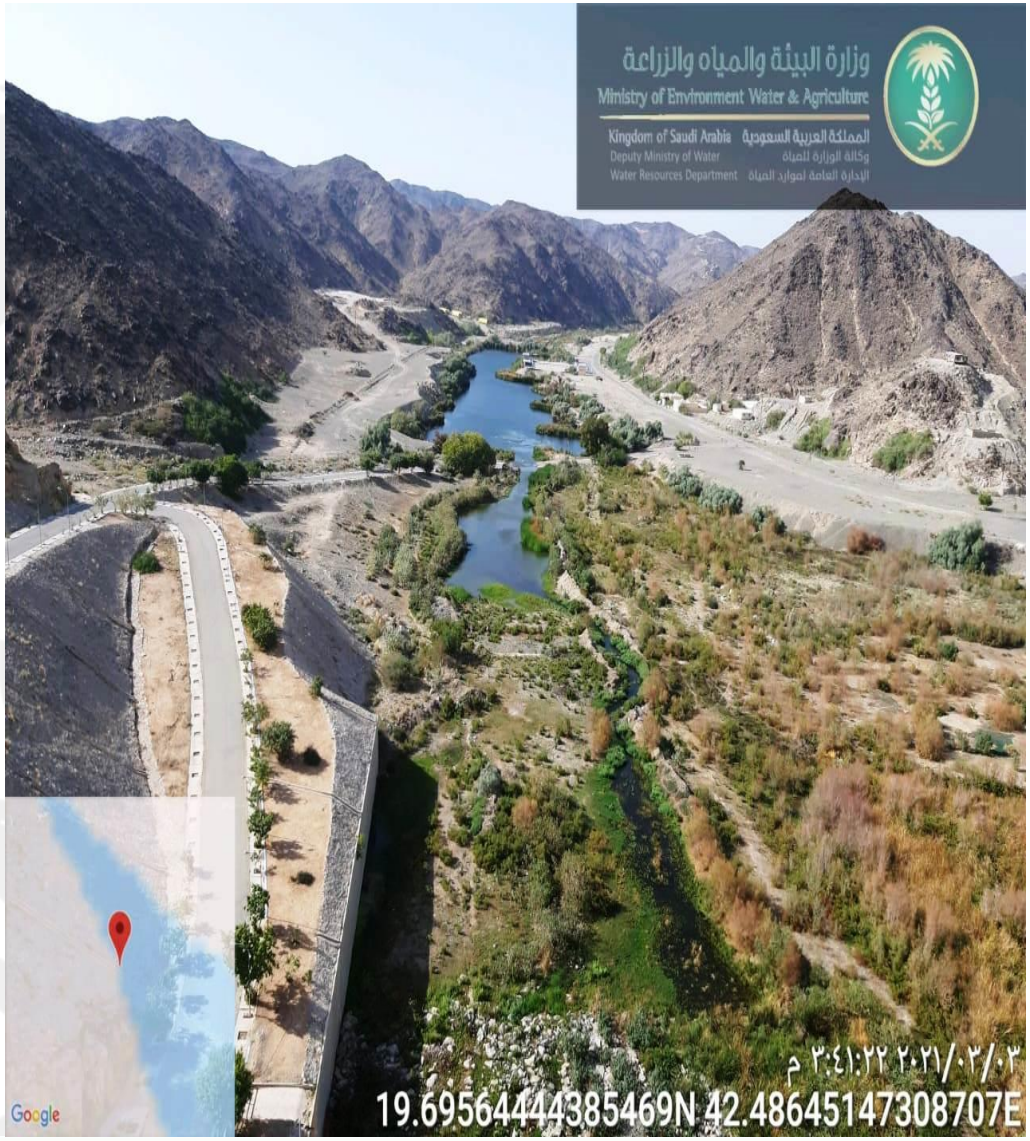
B- Artificial Injection by Drilling injection wells or Excavation of surface spreading basins in alluvium layers in downstream of dams

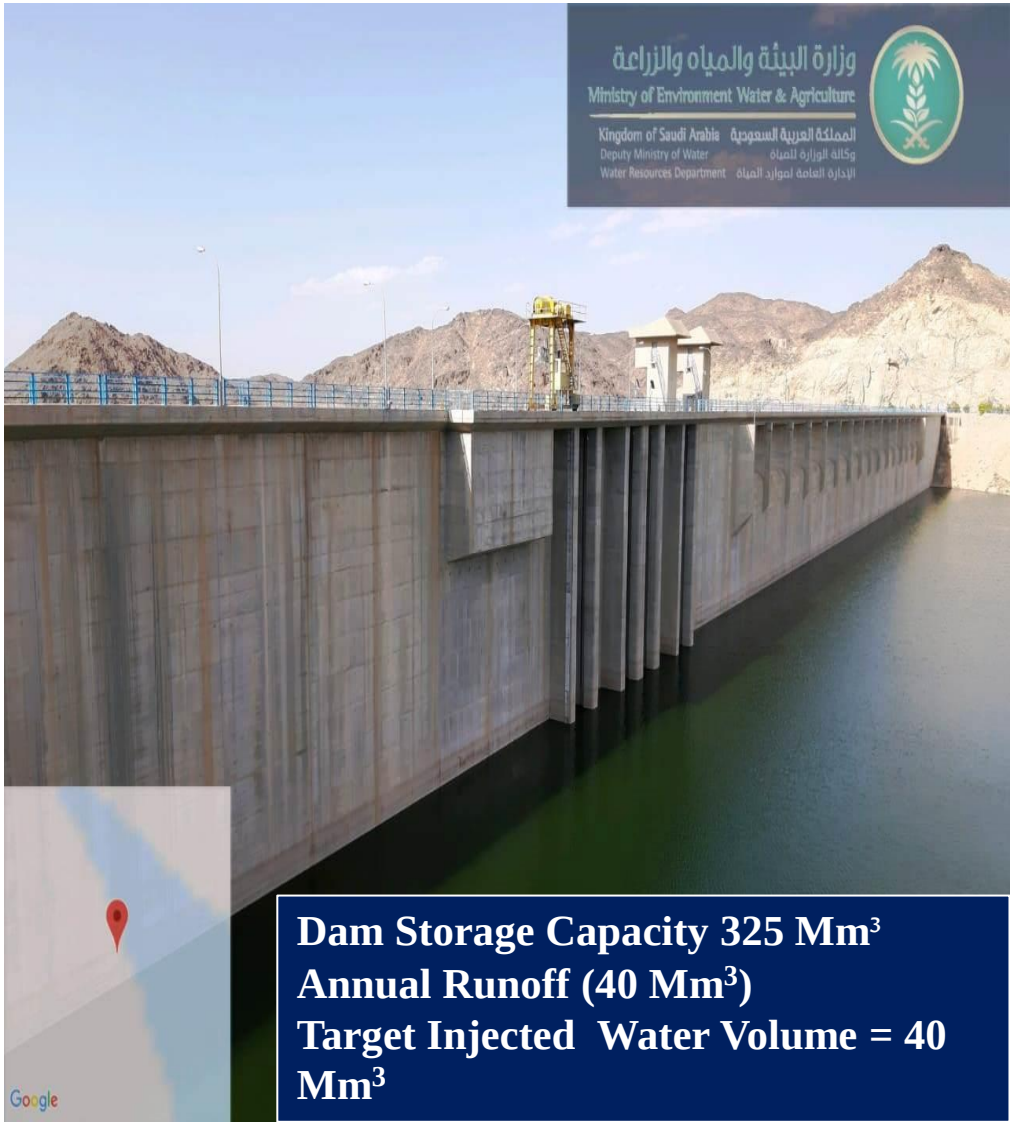
(Ex. Wadi Bisha, Asir Region).

Where the wells have been drilled within the wadi deposits (alluvium) through the main stream and the recharge can take place either under gravity or by pumping in.

These are suitable in area where impervious layer is encountered at shallow depth

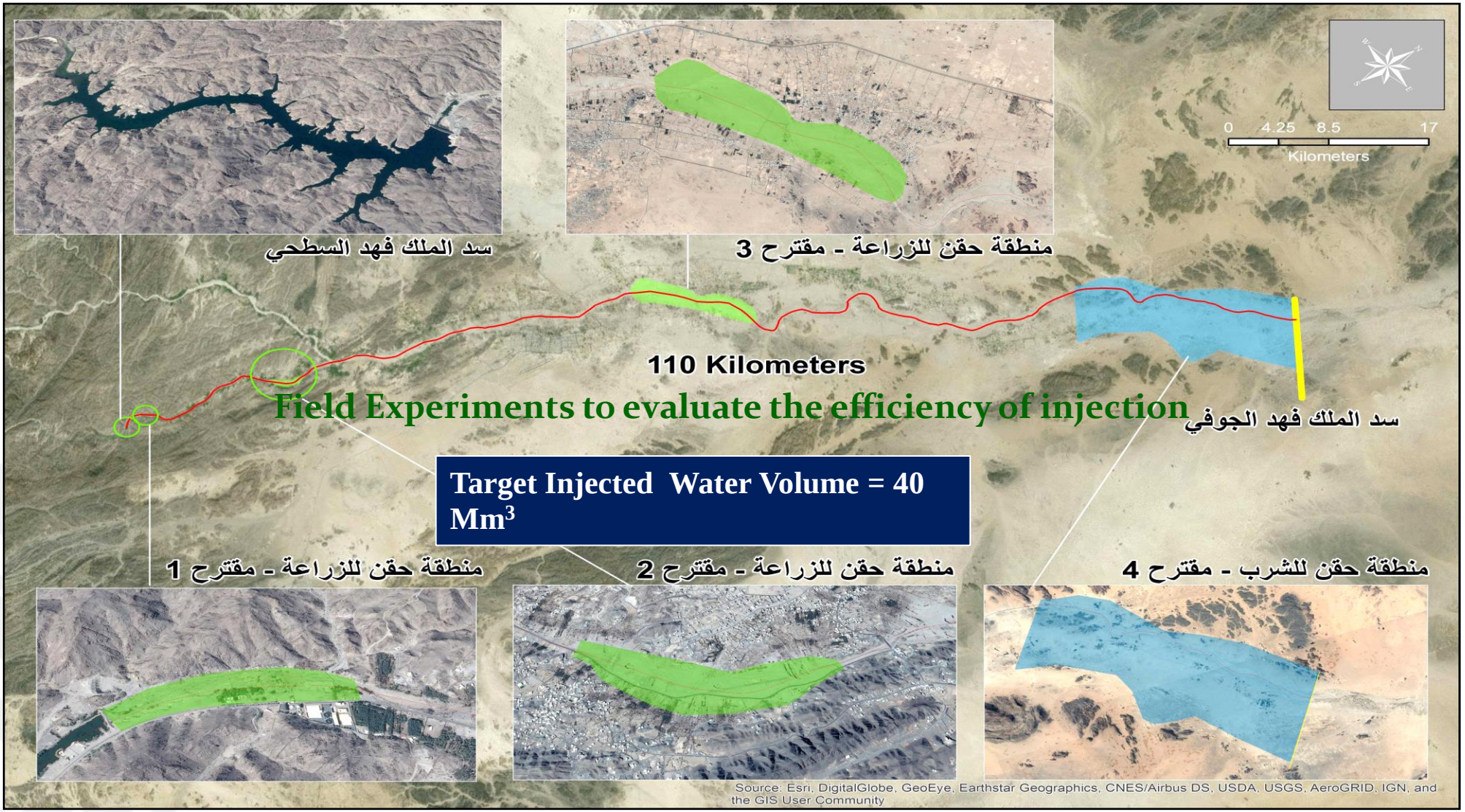
King Fahd Dam, Bisha, Asir Region



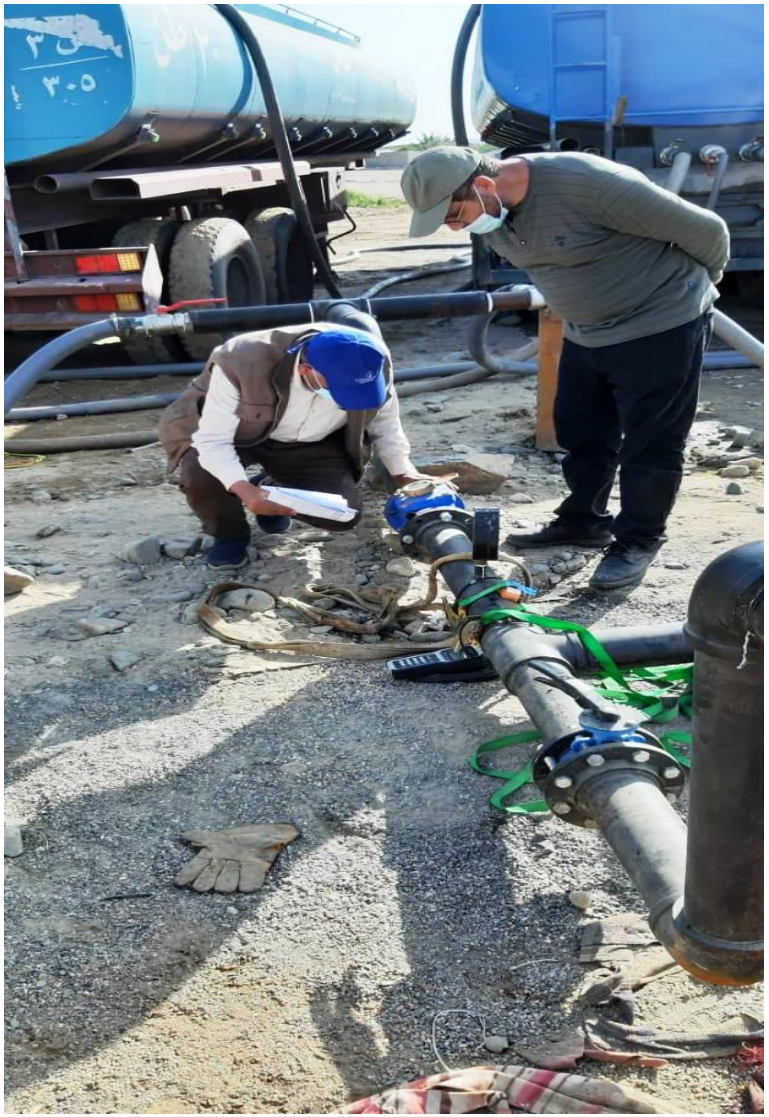


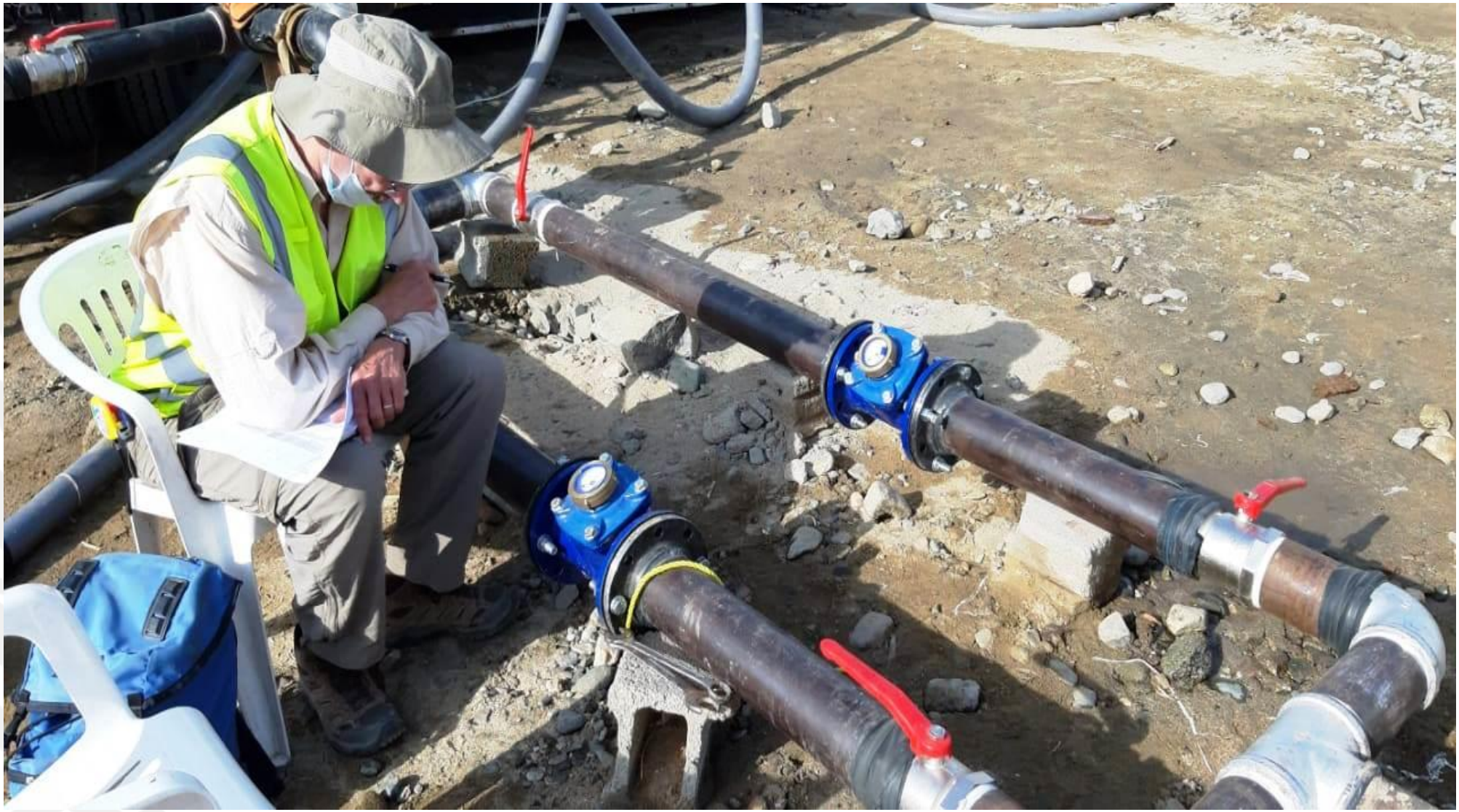
Dam Storage Capacity 325 Mm^3
Annual Runoff (40 Mm^3)
Target Injected Water Volume = 40 Mm^3

Artificial Injection Diagram downstream of King Fahad dam, Asir Region

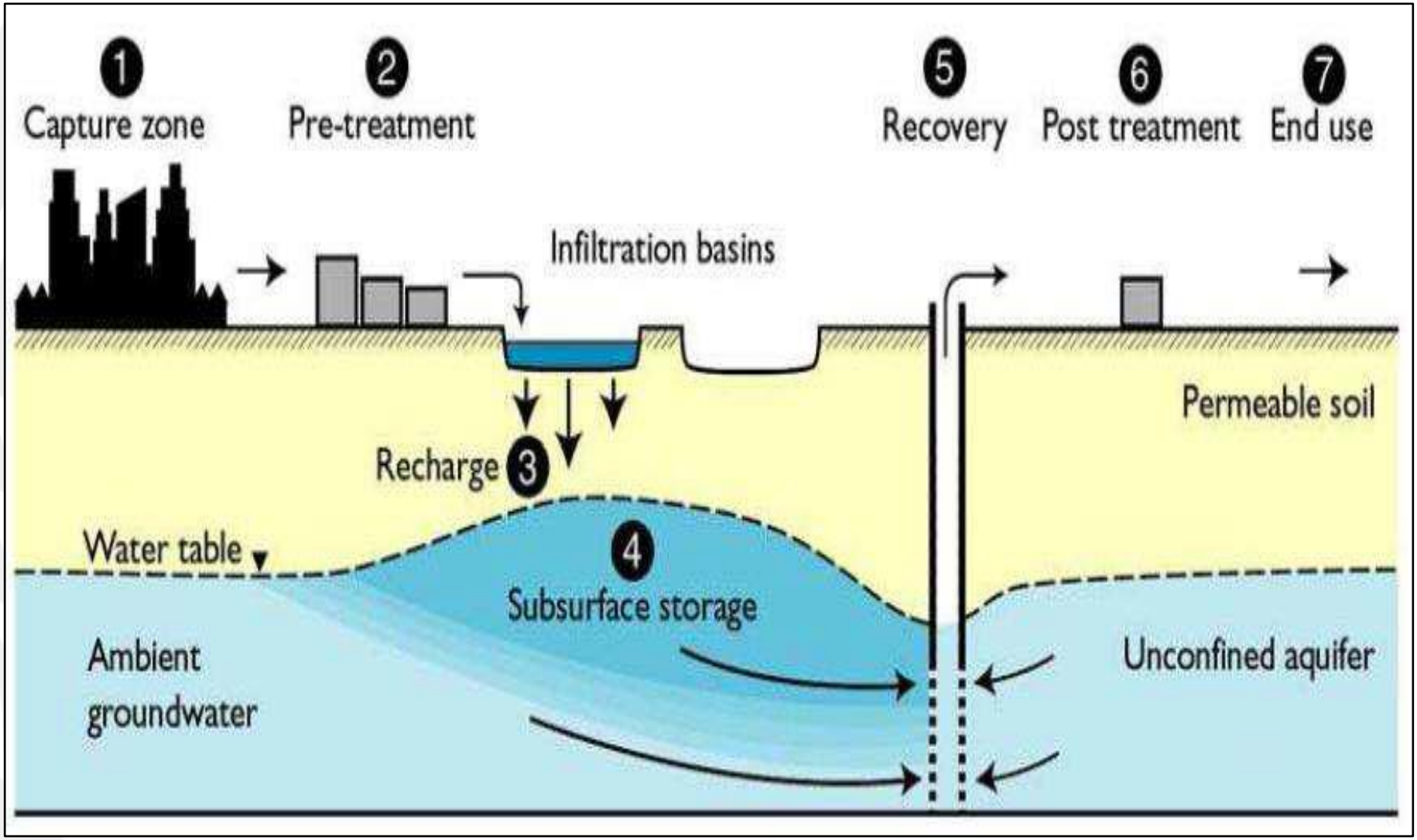


Field Experiments to evaluate the efficiency of injection in w.Bisha





Scheme showing groundwater recharge using (Infiltration basins)



Surface Spreading Basins, Wadi Bisha, Asir Region

In Spreading basins Some losses of water in form of soil moisture and evaporation

Surface Spreading Basins in Al Hifa village, downstream Wadi Bisha

When water in dam reservoir exceeds the rate of Infiltration, considerable evaporation losses have been occurred particularly in summer days.

Seepage from natural stream or rivers is one of the most important source of natural recharge of the ground water reservoir.

C- Groundwater recharge through opening the dam gates and releasing the water into the wadi

(Ex. Wadi Hali dam, Makkah Region)

- ✓ Hali Dam gates were opened on 2/15/1441 AH
- ✓ The gates of the dam were closed on 4/12/1441 AH
- ✓ Duration of opening the gates of the dam: 58 days
- ✓ The discharged volume of water from the dam : 20 Mm^3
- ✓ The discharge rate from the gates of the dam: (4 m^3/ s)
- ✓ Length of water flow path downstream: (22 km)

Flow Water path has reached (22 km) downstream Hali dam.

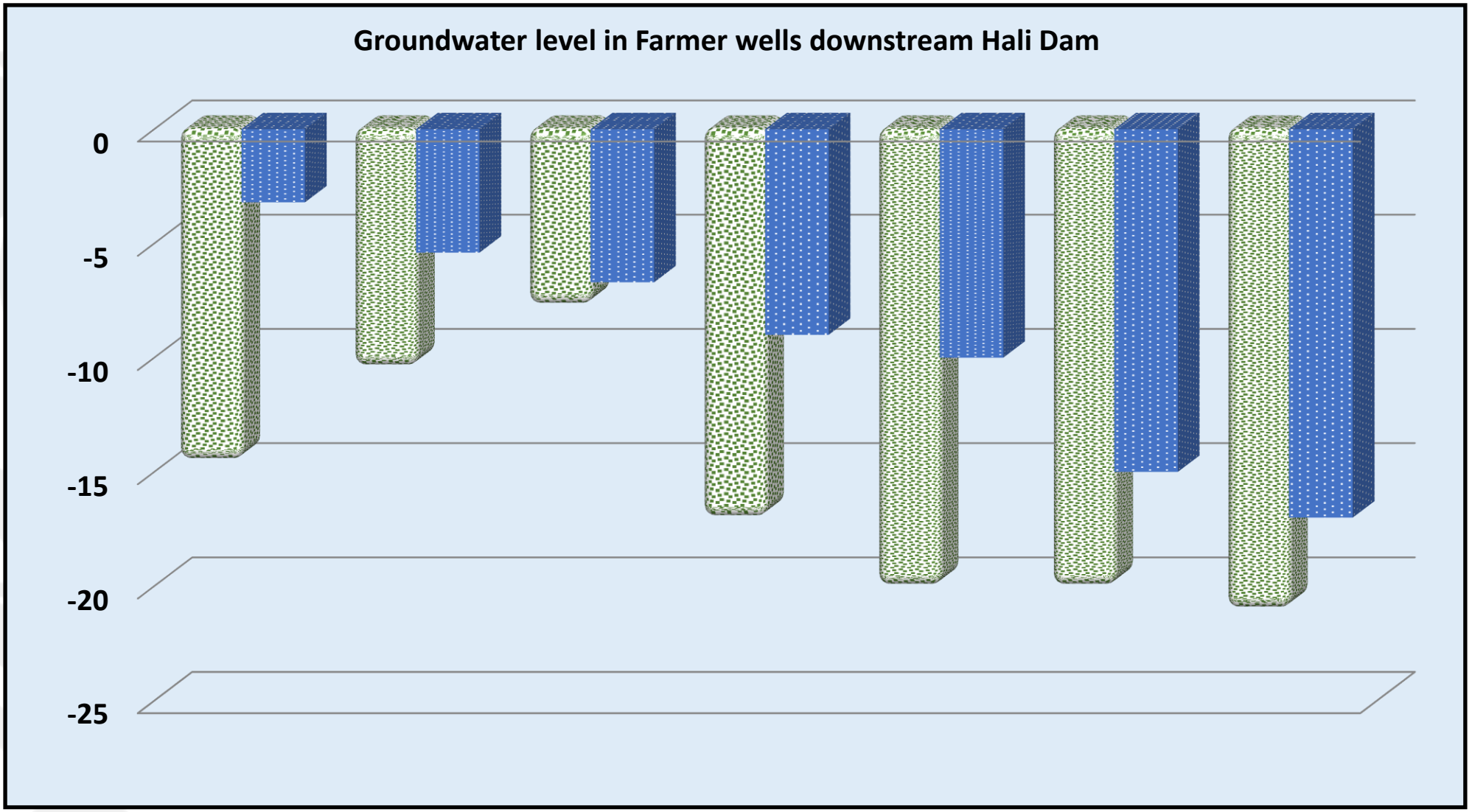
The alluvium deposits downstream of wadi is full saturated with water in this area.

Water quality improved in farmer wells, where the average total dissolved salts (TDS) in water reached about (820 ppm).

صورفتح بو ابات سد حلي بمنطقة مكة المكرمة بتاريخ 15 /2/ 1441 هـ

The water flow path and the locations of wells under the Hali Dam

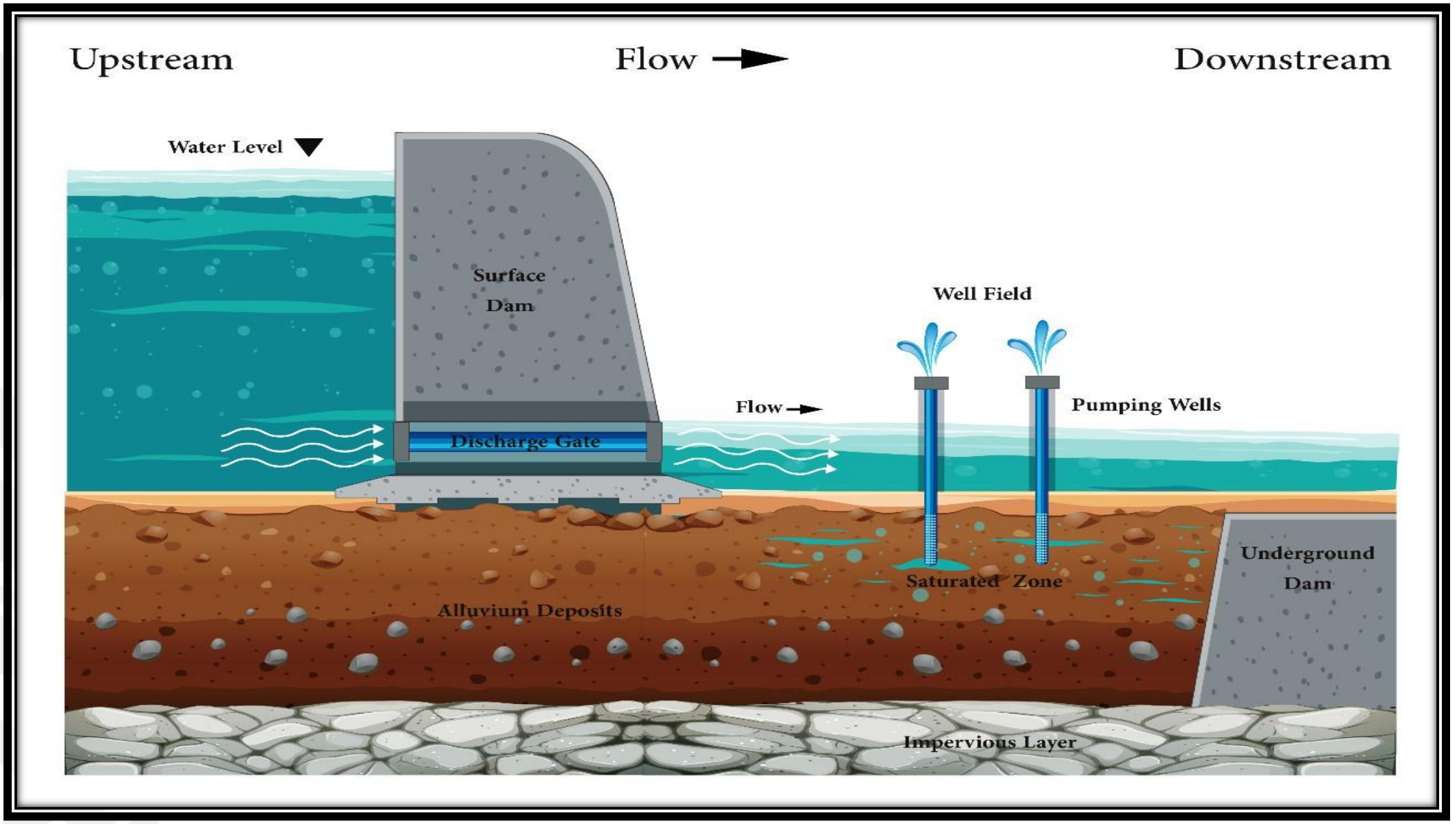
Groundwater levels in Farmer wells downstream Hali Dam before and After dam gates releasing



D- Ground recharge by establishing a system of surface and underground dams and well fields between them

(Al-Ahsebah Dam, Baha Region)

Water Supply System: (surface dam - underground dam - well field - purification plant)



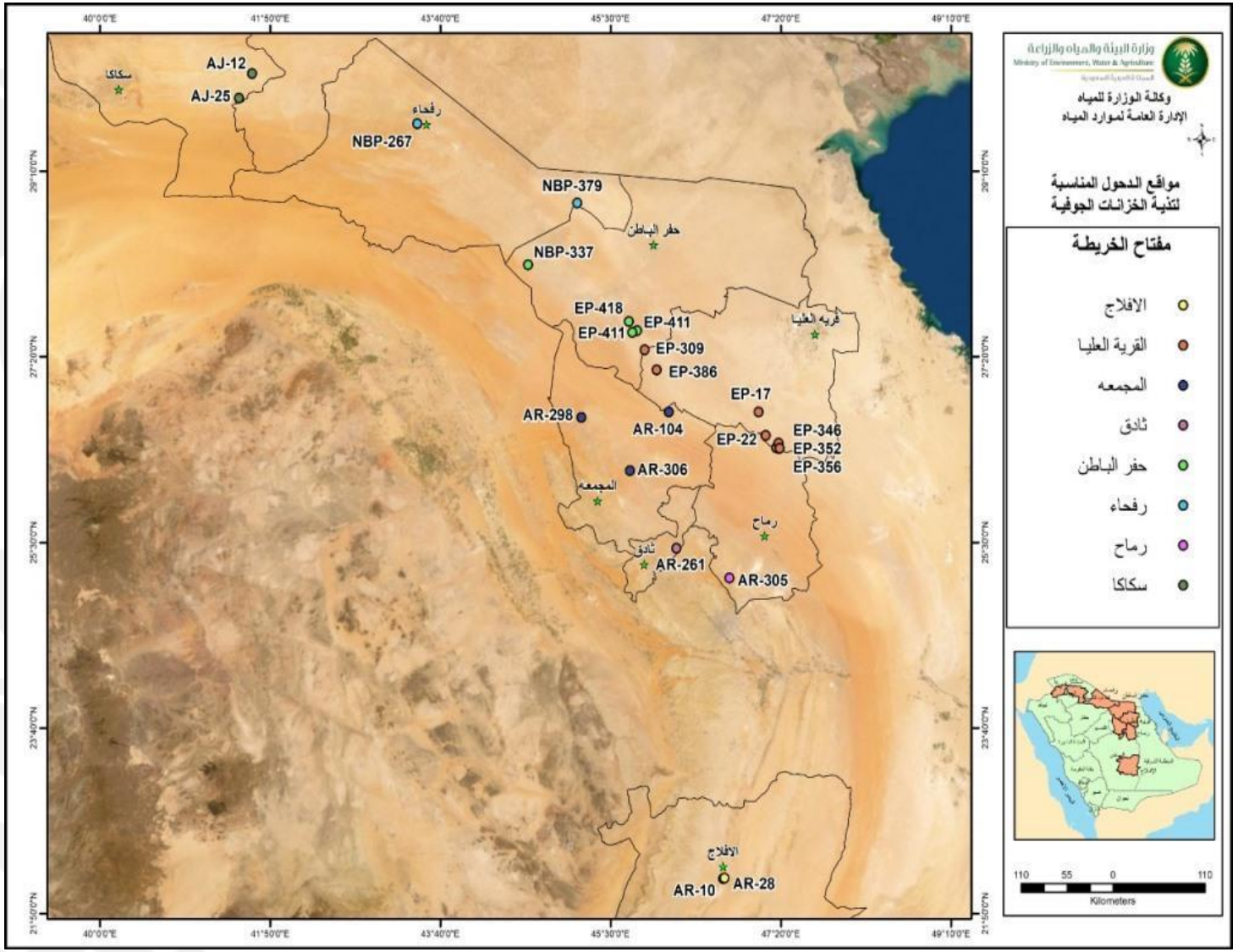

سد الأحسبة الجوفي
حقل مياه
سد الأحسبة السطحي
السعة التخزينية: (11) مليون م3
معدل السيل السنوي: (15) مليون م3/ سنة
الطاقة الإنتاجية: (12600) م3/ يوم
0 0.35 0.7
Kilometers
Source: Esri, DigitalG... the GIS User Community

Third Program:

Recharge through sinkholes and cavities within the outcrops of some aquifers

Riyadh Region
(Eastern Region).

Locations of some sinkholes and cavities within the outcrops of some aquifers in Eastern District

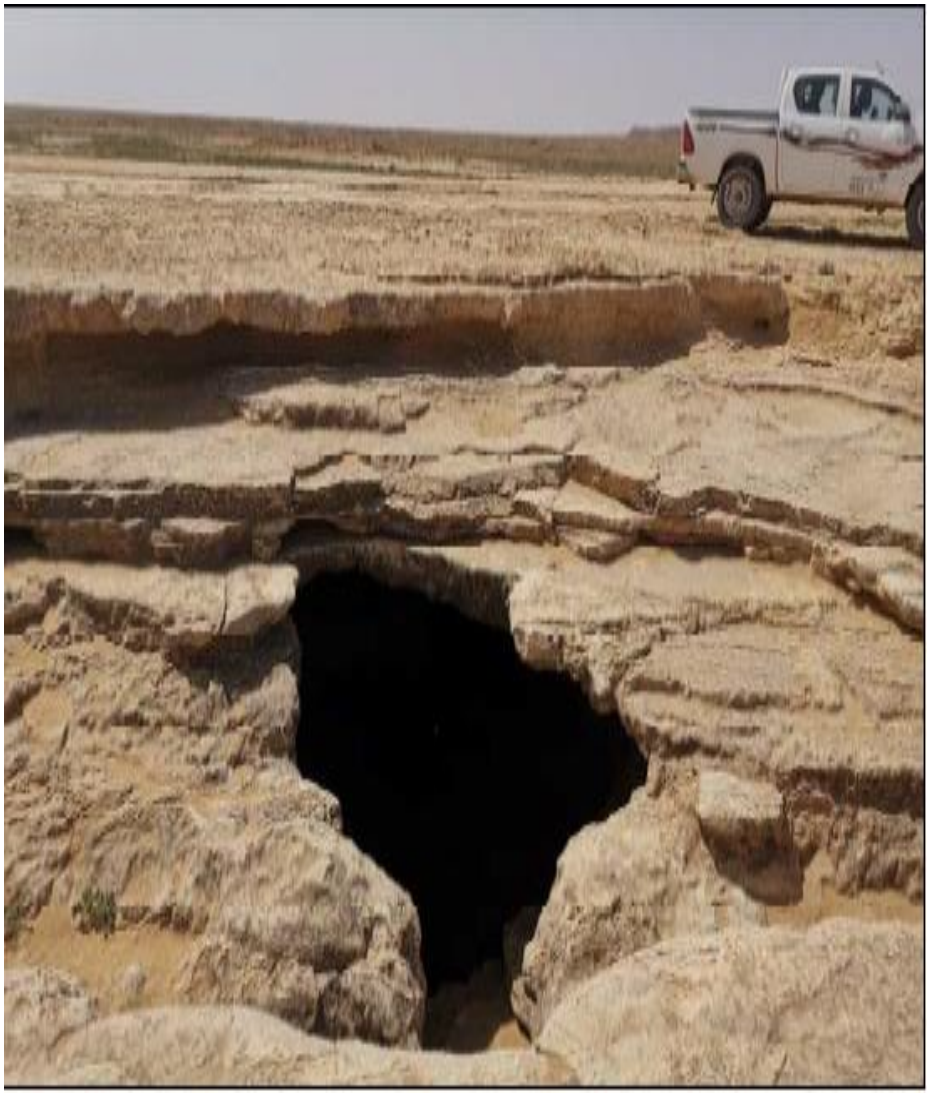


Summary of Sinkholes for groundwater for recharge projects

Region	Total Number of Target Sinkholes
Riyad	7
Eastern District	10
Al Jouf	2
Northern Borders	3
Total	**22**

Photos of some sinkholes and cavities within the outcrops of some aquifers in Eastern District

Photos of some sinkholes and cavities within the outcrops of some aquifers in Eastern District & Riyad Region



Fourth Program:

Direct Injection using the tertiary treated wastewater

- **W.Khulays Plain,**
- **W.Asfan Plain**
- **Al Hada Plain**
- **Hada Al Sham**

(Makkah Region)

Proposed Sites for Direct Injection using the tertiary treated wastewater (Makkah Region) .

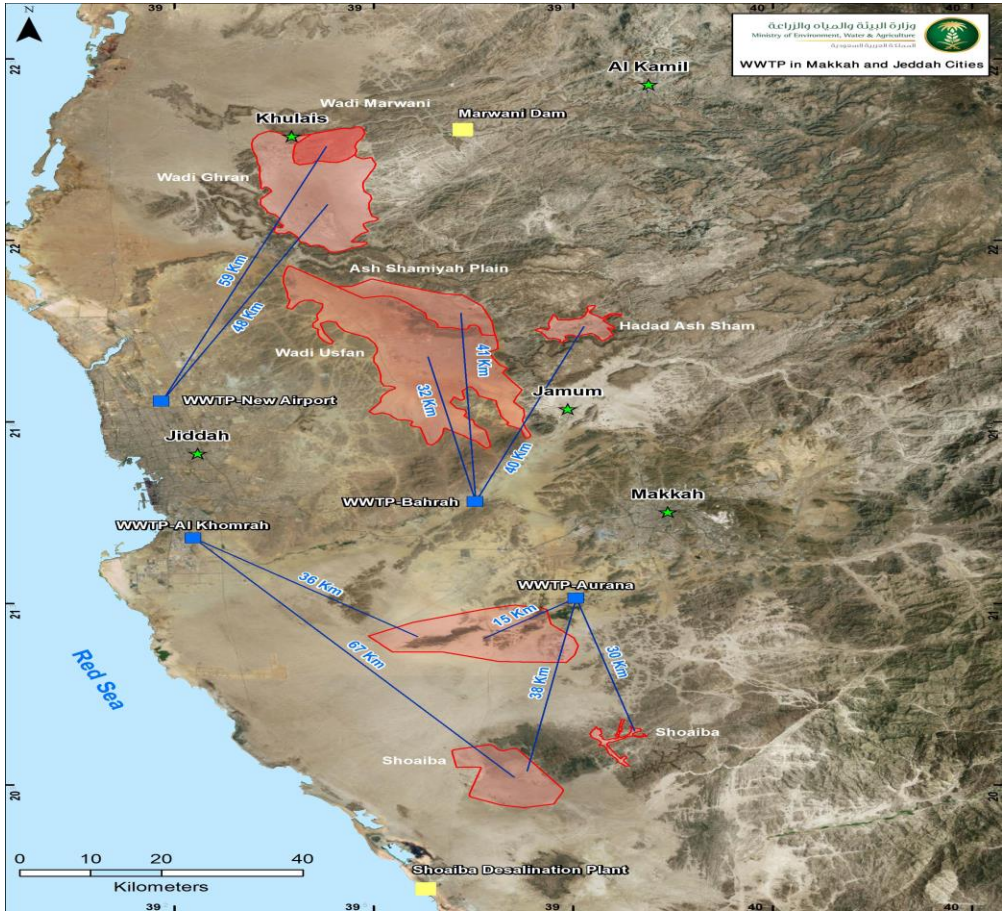
MEWA has conducted a study for artificial injection using the tertiary treated wastewater in several locations
in Makkah Al-Mukarramah region, Theses are:

Wadi Khulais plain

Wadi Asfan plain

Wadi Ibrahim plain

Hada Al-Sham Plain



Conclusion& Recommendations

- The experience of the Kingdom of Saudi Arabia in artificial injection and increasing groundwater recharge is receiving a wide attention from the Ministry of Environment, Water and Agriculture, and it is planned to expand its application and develop it as an important technique for enhancing groundwater sources.
- The application of the excess desalination water injection experiment is currently being studied in a number of targeted water fields such as (Al-Mashi wells and W. Malakan) or storing dam reservoirs such as Rabigh and Marwani dams.
- Field Experiments to evaluate the efficiency of injection are currently being conducted in the wadi Bisha, at the downstream of the King Fahd Dam, as part of the project to optimize the use of the water from the King Fahd Dam.

Conclusion& Recommendations

- The program of injecting flood water directly into dam lakes was implemented in (18) dams in (5) regions of the Kingdom by the Prince Sultan Centre.
- The Tertiary treated wastewater injection program is targeted in the city of Jeddah, Wadi Khulais Plain, Asfan, Wadi Ibrahim, and Hada al-Sham in Makkah Al-Mukarramah region.
- It is recommend increasing communication between the concerned authorities in the countries of the Gulf Cooperation Council to benefit and exchange experiences in this field.

Thanks