ARTIFICIAL RECHARGE EXPERIENCE IN KUWAIT AND ITS FUTURE

Workshop on:

Artificial Recharge Experience in the GCC Countries

KISR, Kuwait

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Presentation Outline

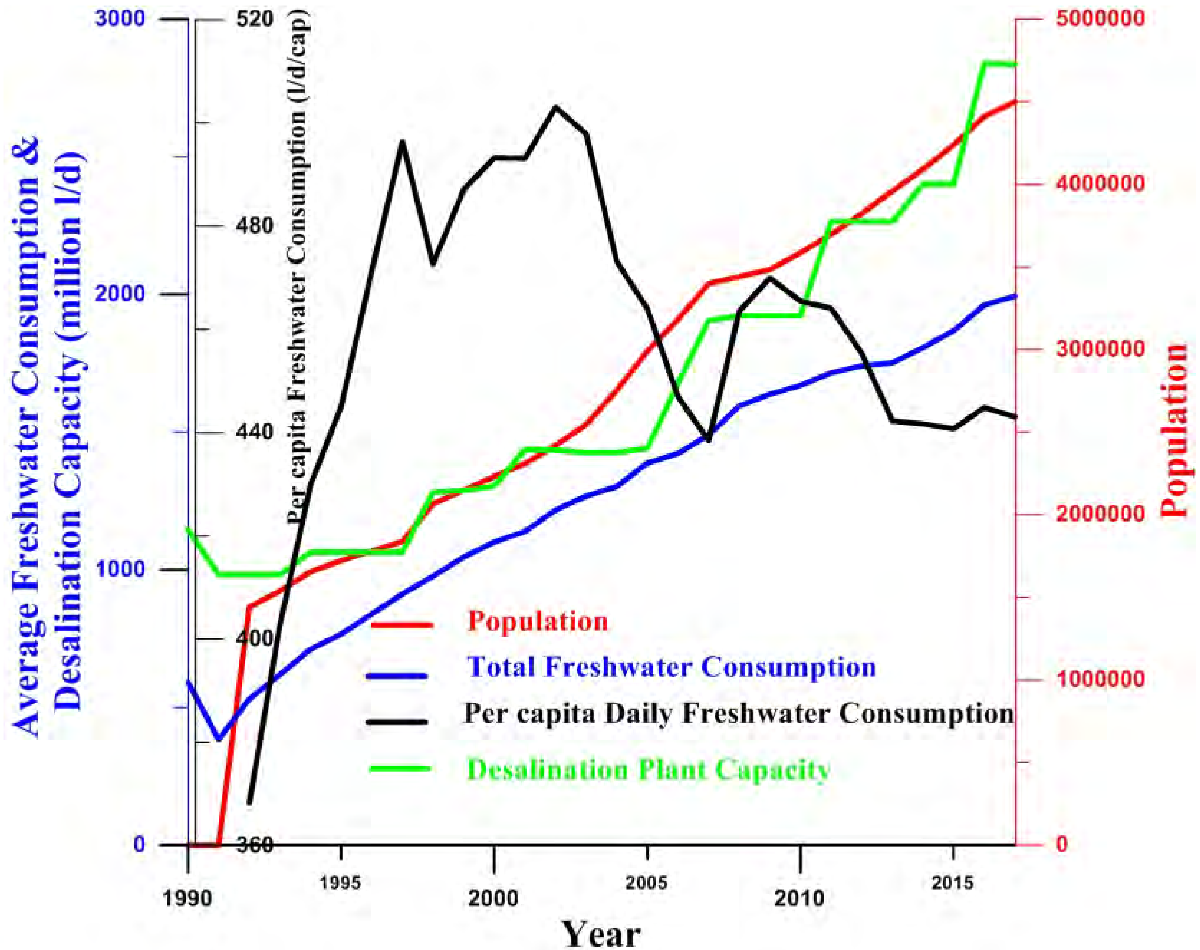
1. Relevance of AR to Kuwait
2. Past experience
3. Pilot Scale ASR Experiment in Kabd
4. Numerical Modeling of Pilot Scale Recharge – Recovery Operation
5. Planning for Full Scale Recharge
6. Conclusions
7. Recommendations

Relevance of AR to Kuwait

Current Freshwater Availability in Kuwait

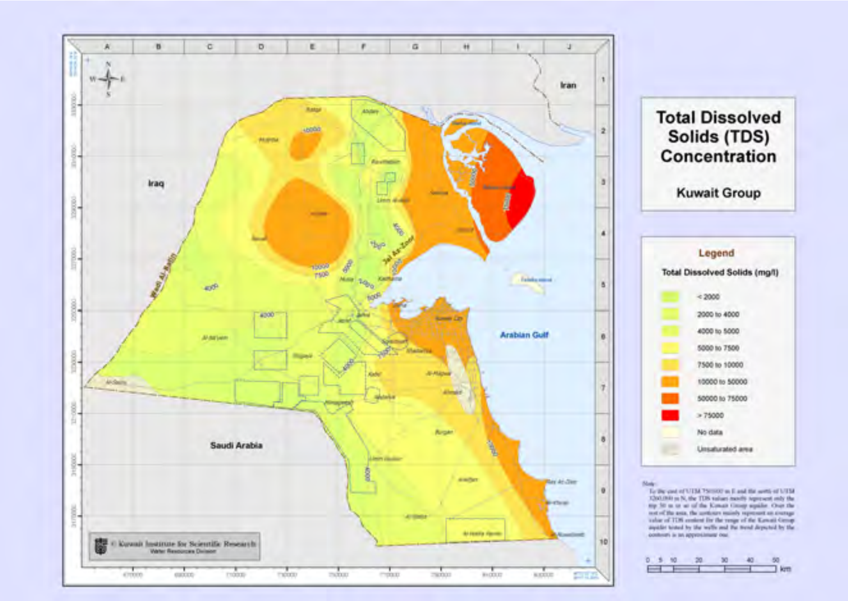
- Arid country with no surface water & very little fresh ground water (reserves in Raudhatain – Umm Al-Aish : 100 Mm^3, roughly 50 days of consumption)
- Useable brackish ground water resource limited and over exploited
- Seawater desalination meeting the freshwater demand (437.9 MIG/d; 1.99 Mm^3/d in 2018; Distillation capacity 623.8 MIG/d; 2.84 Mm^3/d in 2018)
- Available constructed storage capacity (4332.445 MIG; 19.69 Mm^3 in 2018) , enough to meet the freshwater demand (average 409.066 MIG/d; 1.86 Mm^3/d in 2018) for 10.6 days only

Supply & Demand of Freshwater

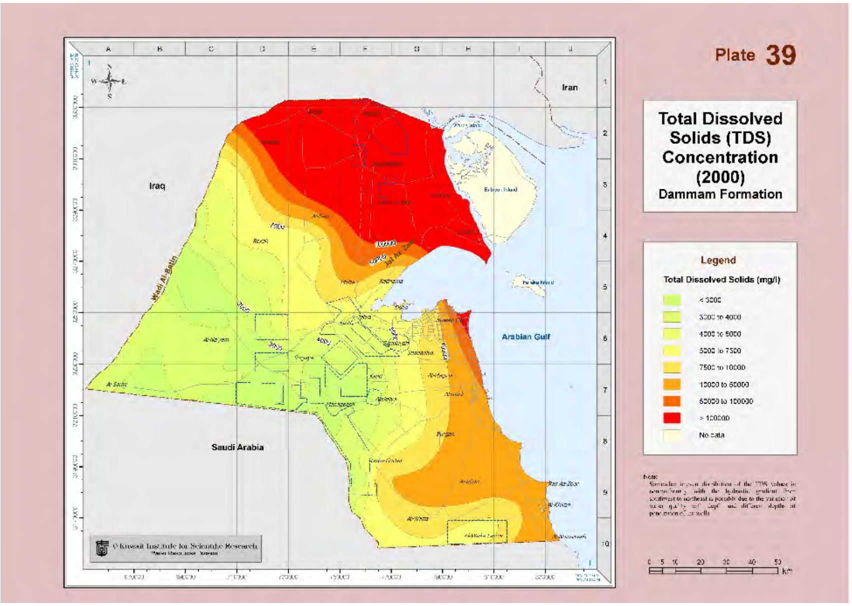


Groundwater Quality in Kuwait

Kuwait Group

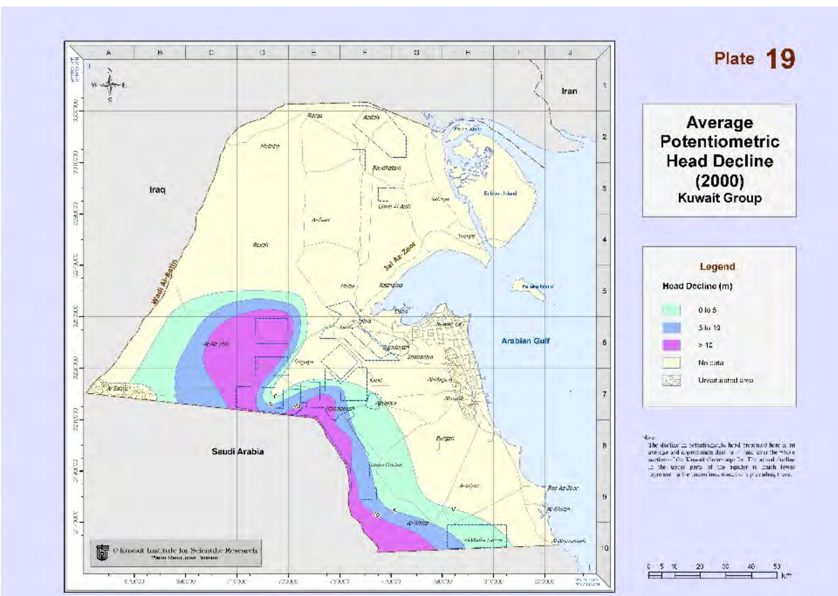


Dammam Formation

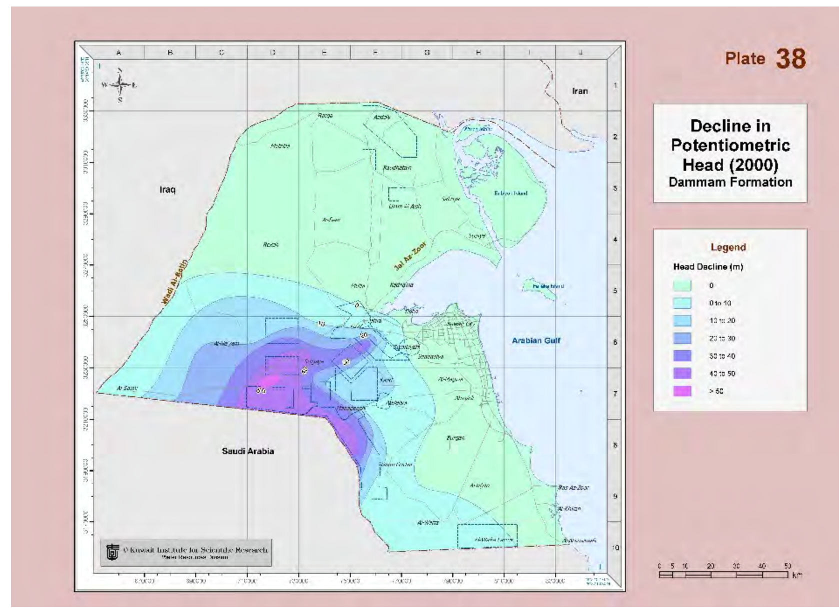


Decline in Groundwater Head

Kuwait Group



Dammam Formation



Why Artificial Recharge Is An Opportunity for Kuwait?

- AR can arrest both the drop in head and deterioration of groundwater quality caused by mining of the aquifers
- Aquifer storage free of cost, safe from sabotage and natural disasters.
- Excess RO-processed municipal wastewater of good quality can be stored for future use

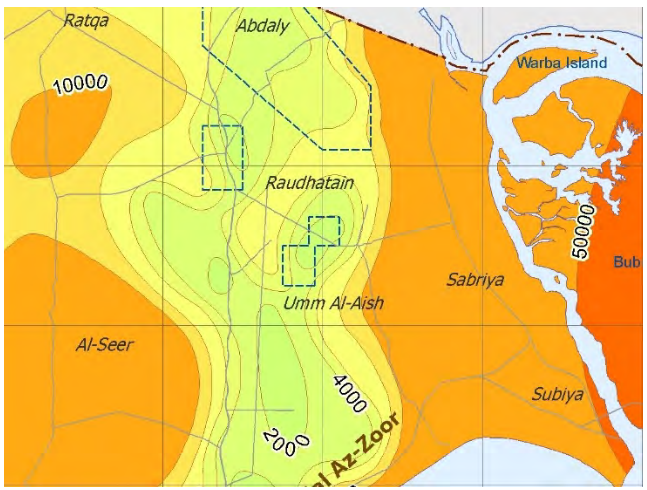
Availability of Water for Storage

- **Estimated current production capacity of RO plant for treated wastewater: 600,000 m^3/d**
- **A large part of this high quality (potable) water will remain unutilized especially during winter months.**
- **Further augmentation of desalination capacity from the current level of 2.84 M m^3/d will also make excess capacity available, especially during winter.**

Past Experience

Past Experience - MEW

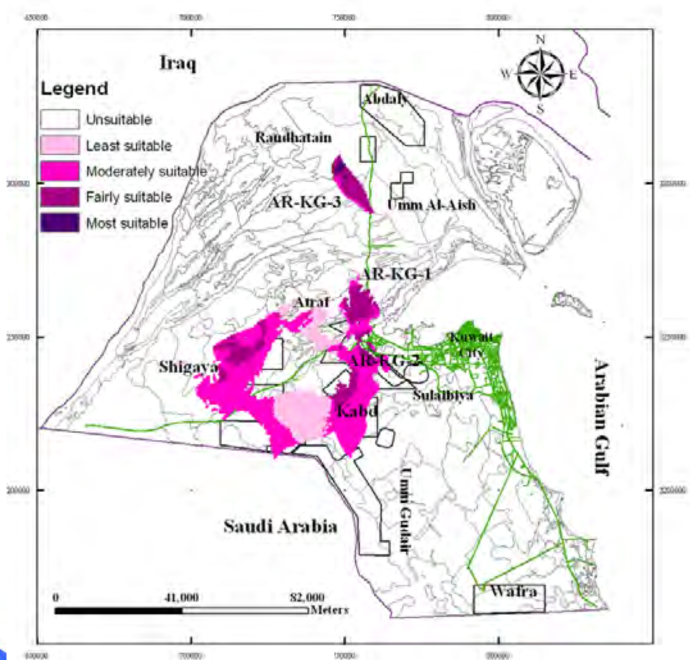
Raudhatain & Umm Al-Aish Freshwater Fields, North Kuwait



- **In 1972-73, an injection test at the production well R-53 in the Raudhatain fresh water field at a rate of 1309 m^3/d over a period of 27 days.**
- **Well clogging prevented proper test interpretation and assessment of recovery efficiency.**
- **In 1977, an injection test at production well R-63 (TDS 2500 mg/l) at a rate of 655 m^3/d (TDS 400 mg/l) over a period of 29 days.**
- **Good recovery efficiency (≈ 43% with TDS ≤ 600 mg/l and 65% with TDS ≤ 1000 mg/l) with a pumping rate of 655 m^3/d was established over a period of 40 days.**

Past Experience - KISR

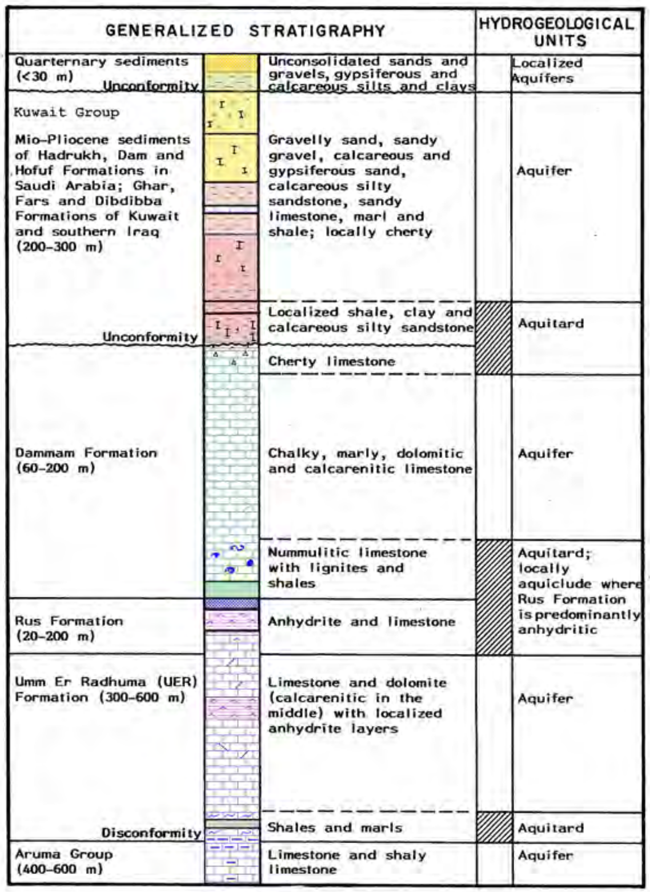
Suitable Areas for Artificial Recharge in Kuwait



- **Preliminary Field Experiments using 3 production wells (Project WH-003) in Sulaibiya and Shigaya Areas (MEW sponsored)**
- **Laboratory based Compatibility Studies (Projects WH004K; WH006C, WH010C) (KISR & KFAS sponsored)**
- **Numerical Modeling Study (Project WH012K) (KISR sponsored)**
- **Treated Wastewater Recharge through Ponds (Project WW003C) in Sulaibiya (Sponsored by the Islamic Bank of Saudi Arabia)**
- **Selection of Suitable AR Sites using GIS (General Study WM006G) (KISR sponsored)**
- **Hydrogeological Assessment of Artificial Recharge of KG Aquifer in Az-Zaqlah Area (Project WM034C) (KFAS sponsored)**

Main Conclusions from Past Studies

Hydro-stratigraphy of Kuwait



The above studies have suggested the following:

- The carbonate Dammam Formation of central and south Kuwait containing brackish water is the most suitable aquifer for artificial recharge through wells.
- In north Kuwait, the gravelly sand of the Dibdibba Formation of the upper Kuwait Group, is also a good candidate for artificial recharge.
- The clogging problem has to be controlled to make the artificial recharge of the clastic Kuwait Group aquifer of central and south Kuwait practically feasible.
- Alternate injection followed by recovery improves the recovery efficiency.

Pilot Scale ASR Experiment at Kabd

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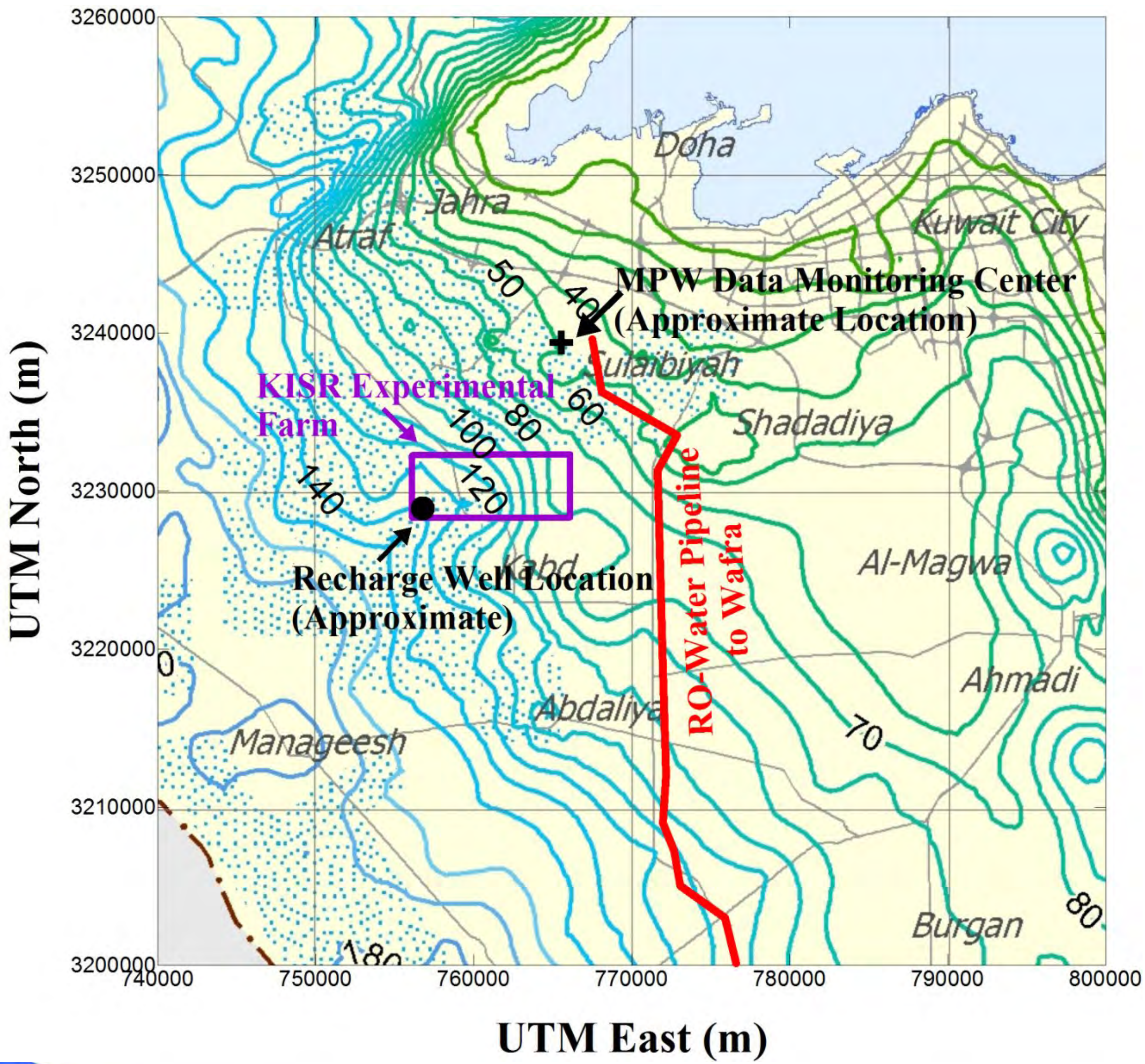
Aim for the Project

- To prove the suitability of Kabd site for creation of a strategic reserve of water in the Dammam Limestone aquifer that will be capable of meeting the demand during an emergency

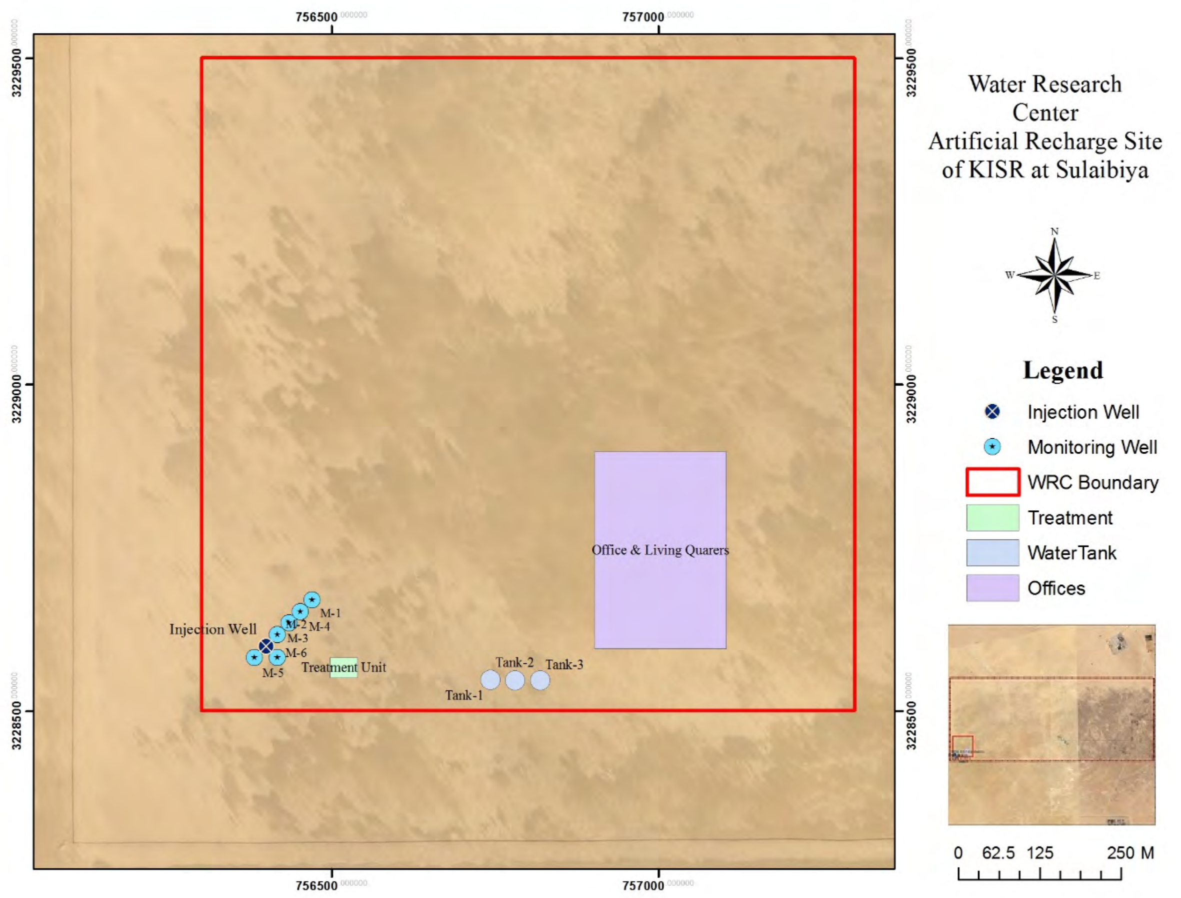
Scope of Work

- One ASR well was used for both recharge and recovery
- Six monitoring wells were used for the collection of water level and water quality data
- Membrane (reverse osmosis - RO) treated municipal wastewater from Kharafi Plant was provided by MPW for the recharge experiment (approximate rate: 500 - 700 m^3/d)
- A newly laid pipeline (20 km in length) carried the water from DMC to the recharge site at Kabd
- 4 cycles of recharge and recovery experiment were carried out over the period of 8 July 2018 – 6 August 2019
- A numerical model was developed that was calibrated with the pumping test data and validated with the data from the field experiment to arrive at reasonably acceptable hydraulic properties of the aquifers and the aquitards of interest
- The collected data were used to assess the suitability of the site for creation of a strategic reserve of water

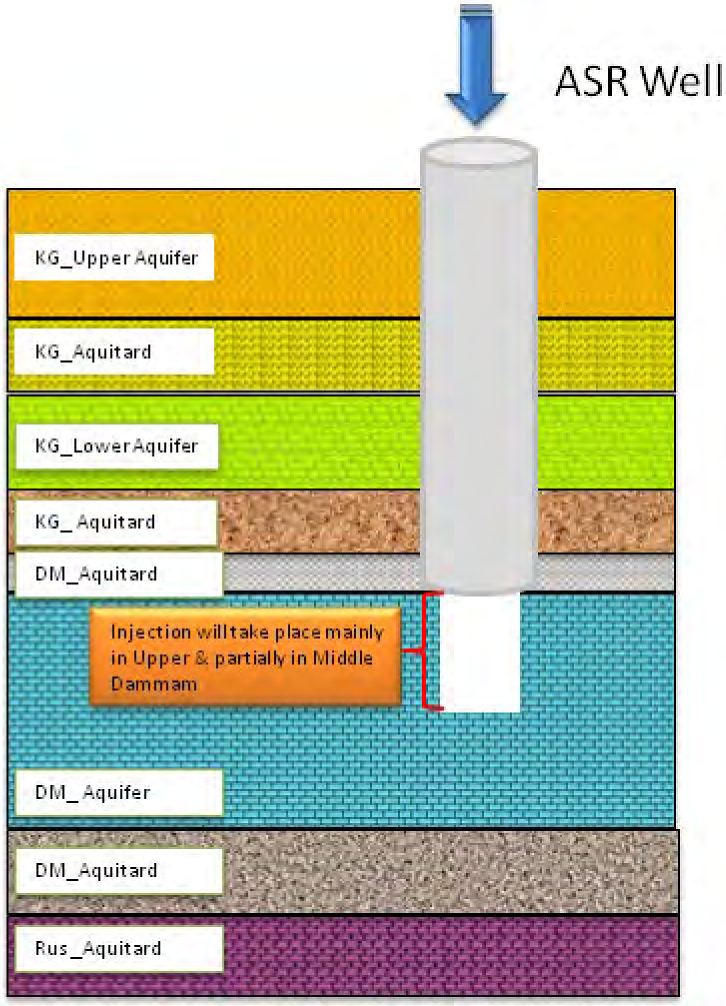
Site for Pilot Scale AR at Kabd, Kuwait



Location of Recharge Site on Google Image

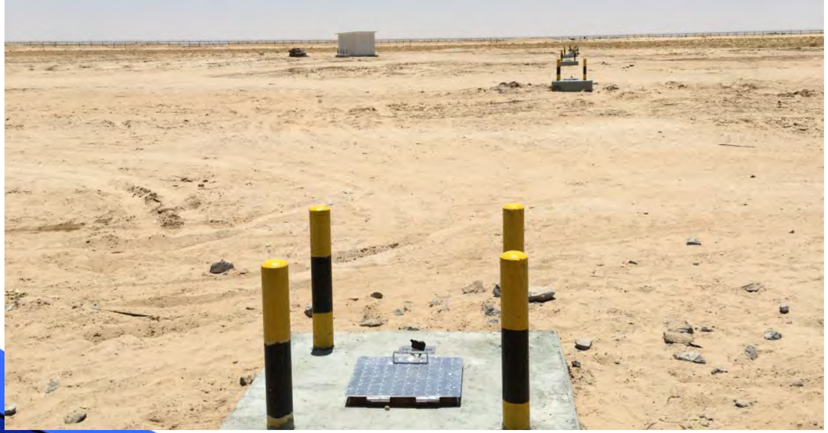


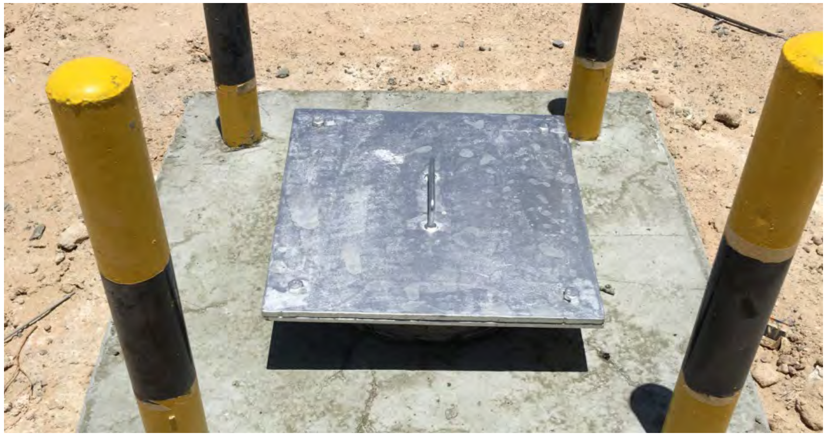
Schematics of AR at Pilot Site



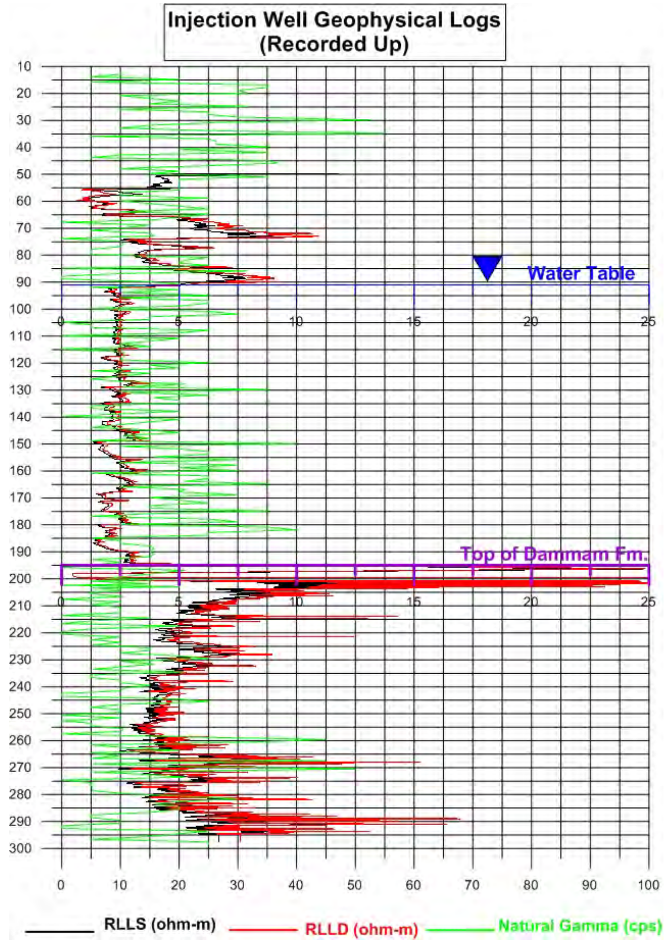
Pipeline, Pumps & Storage Tank

Well Drilling

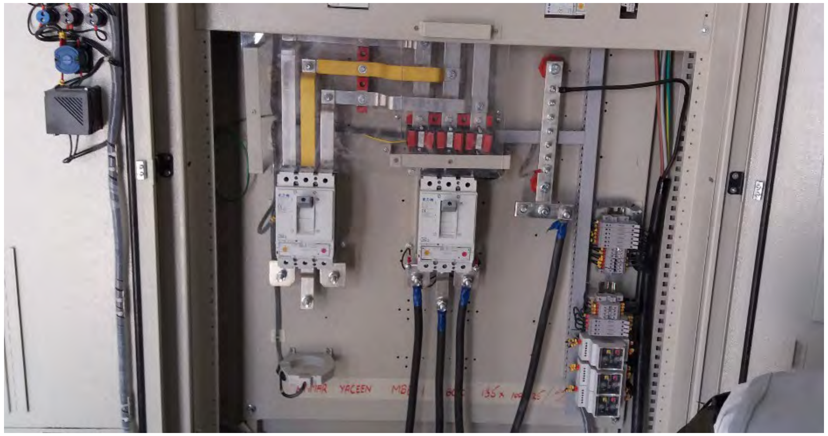


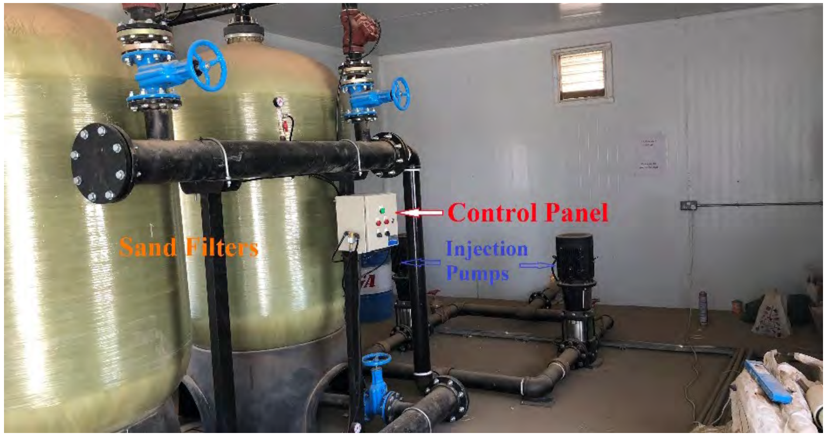


Composite Geophysical Logs



Injection System





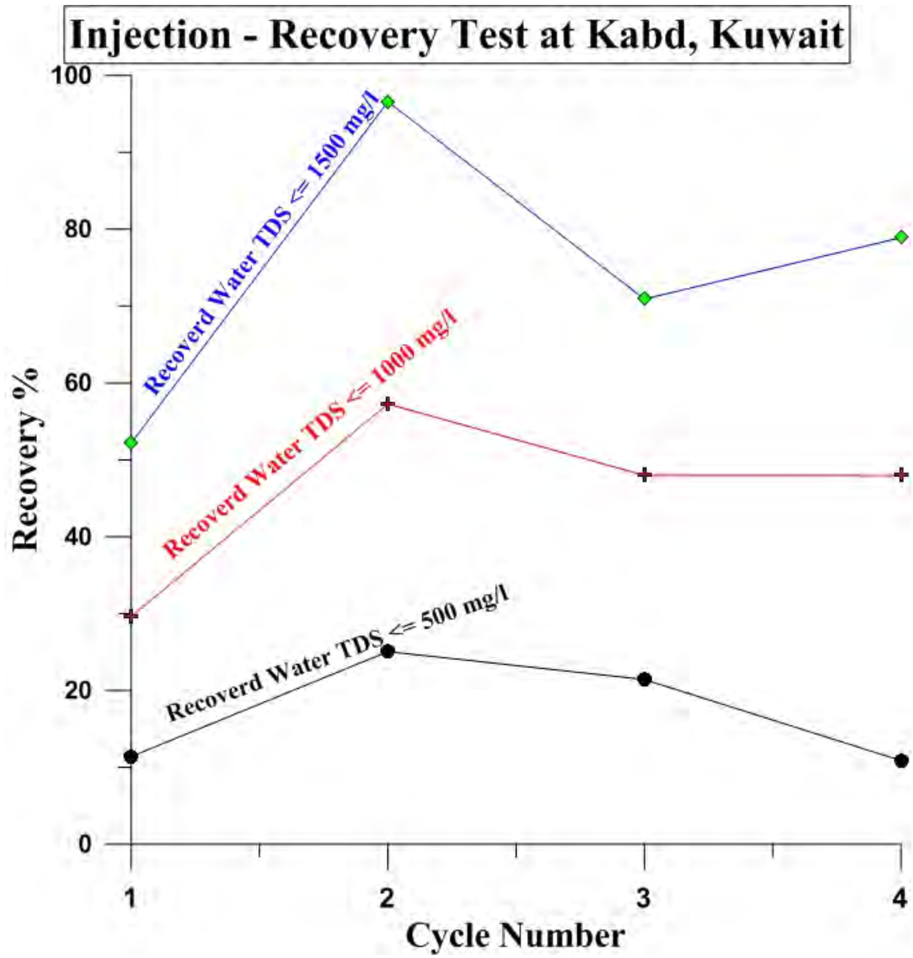
Recharge – Recovery Cycle Details

Cycle No.	Recharge				Recovery				
	Start Date	End Date	Average Recharge Rate (m^3/d)	Total Volume Injected (m^3)	Start Date	End Date	Average Pumping Rate (m^3/d)	Total Volume Pumped (m^3)	Final TDS[1] of Pumped Water (mg/l)
1	8 July 2018	15 August 2018	408	15,246	15 August 2018	30 August 2018	700	10,633	1,840
2	30 August 2018	14 October 2018	490 (with many interruptions due to tripping of pumps & power failure)	20,953	14 October 2018	13 December 2018	720 (with many interruptions due to heavy rainfalls and power failures)	20,065	1,570
3	23 December 2018 (after repair of the sump pump)	6 February 2019	707 (with a few interruptions due to power failure)	31,737	6 February 2019	11 March 2019	700 – 960 (with interruptions due to failure of power supply & fuse blowouts)	22,615	1,530
4	11 March 2019	27 April 2019	850 (with a few interruptions due to power failure)	35,319	26 June 2019 (the supplier took a long time for troubleshooting and then fixing the submersible pump that was not working)	6 August 2019	711	29,100	1,578

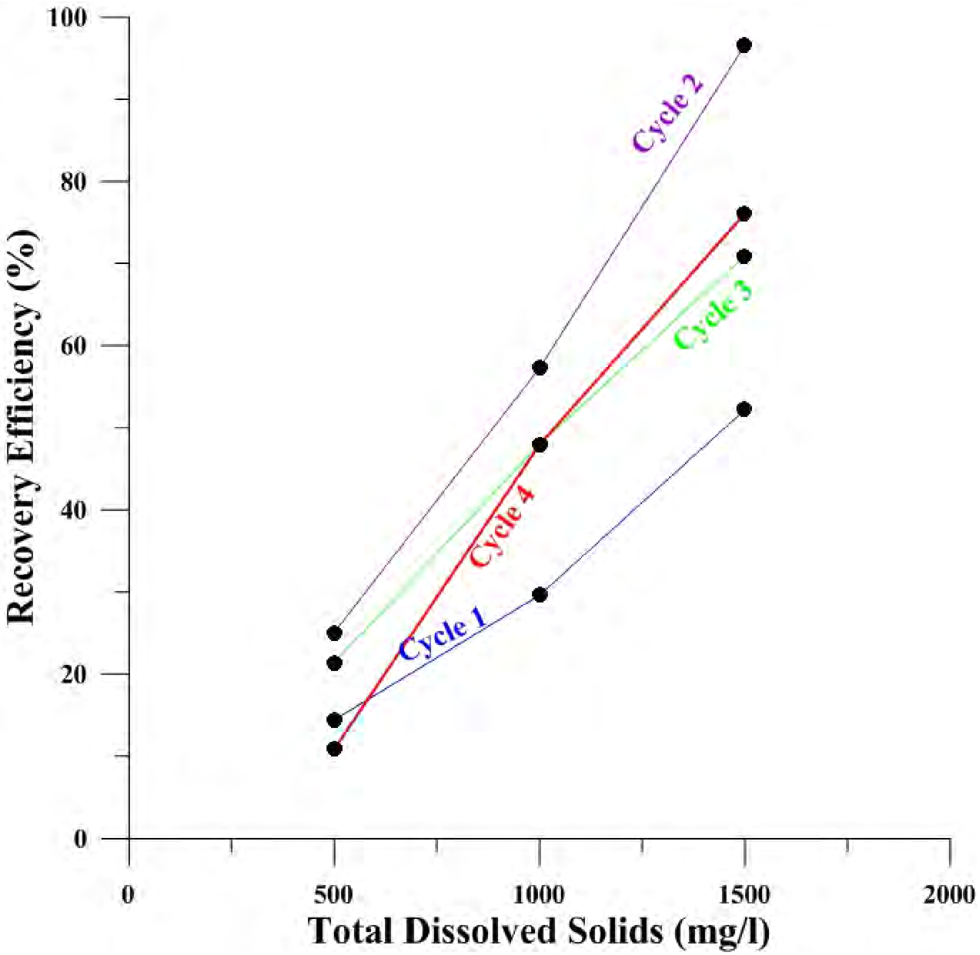
Recovery Efficiencies Observed through Cycles

Cycle No.	Volume of Water Injected (m^3)	Volume Recovered with TDS ≤ 500 mg/l (m^3)	Recovery Efficiency for Water with TDS ≤ 500 mg/l (%)	Volume Recovered with TDS ≤ 1000 mg/l (m^3)	Recovery Efficiency for Water with TDS ≤ 1000 mg/l (%)	Volume Recovered with TDS ≤ 1500 mg/l (m^3)	Recovery Efficiency for Water with TDS ≤ 1500 mg/l (%)
1	15,242	1,750	**11.48**	4,540	**29.79**	8,000	**52.49**
2	20,953	5,250	**25.06**	12,000	**57.27**	20,241	**96.60**
3	31,737	6,800	**21.43**	15,230	**48.00**	22,507	**70.92**
4	35,319	3,842	**10.88**	16,944	**47.97**	27,872	**78.91**
Average of All cycles	**103,251**	**17,642**	**17.09**	**48,714**	**47.18**	**78,620**	**76.14**

Recovery Efficiencies vs Cycle



Recovery Efficiencies vs TDS for Each Cycle

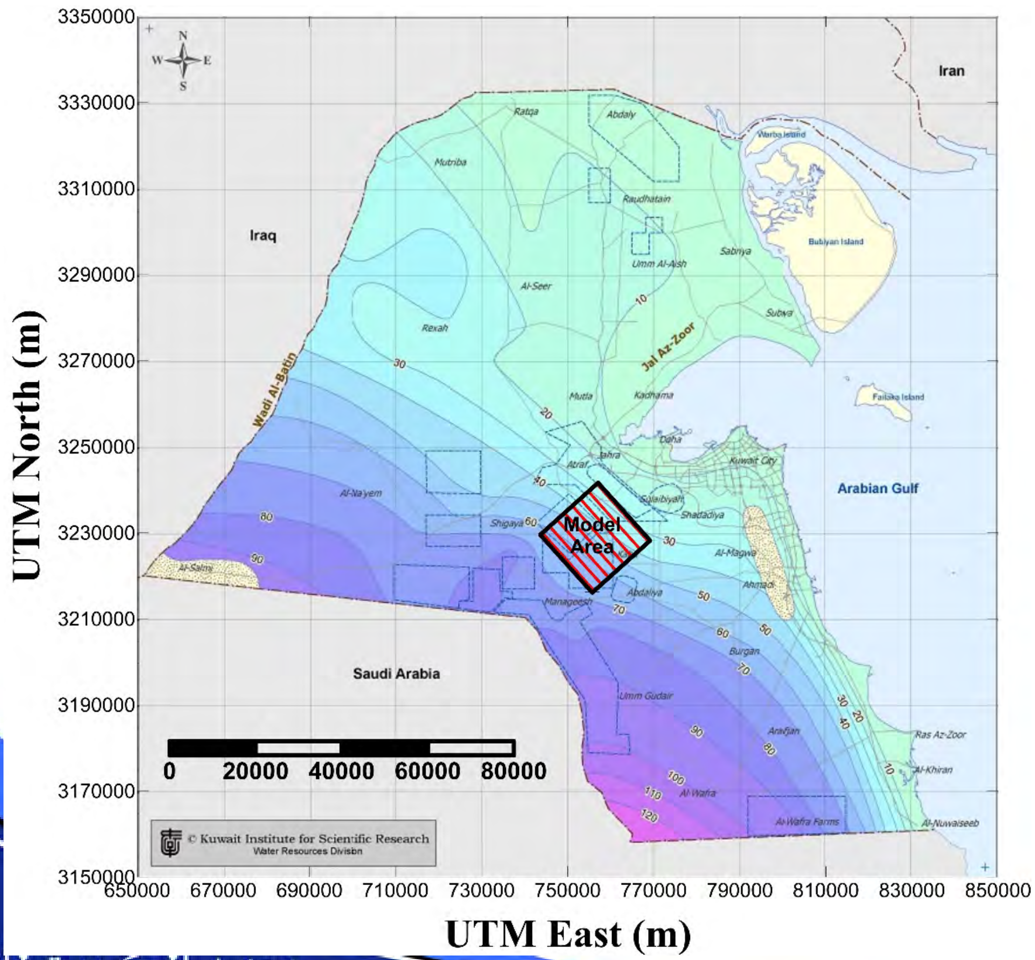


Numerical Modeling of the Pilot Scale Recharge - Recovery Operation

Description of the Numerical Model

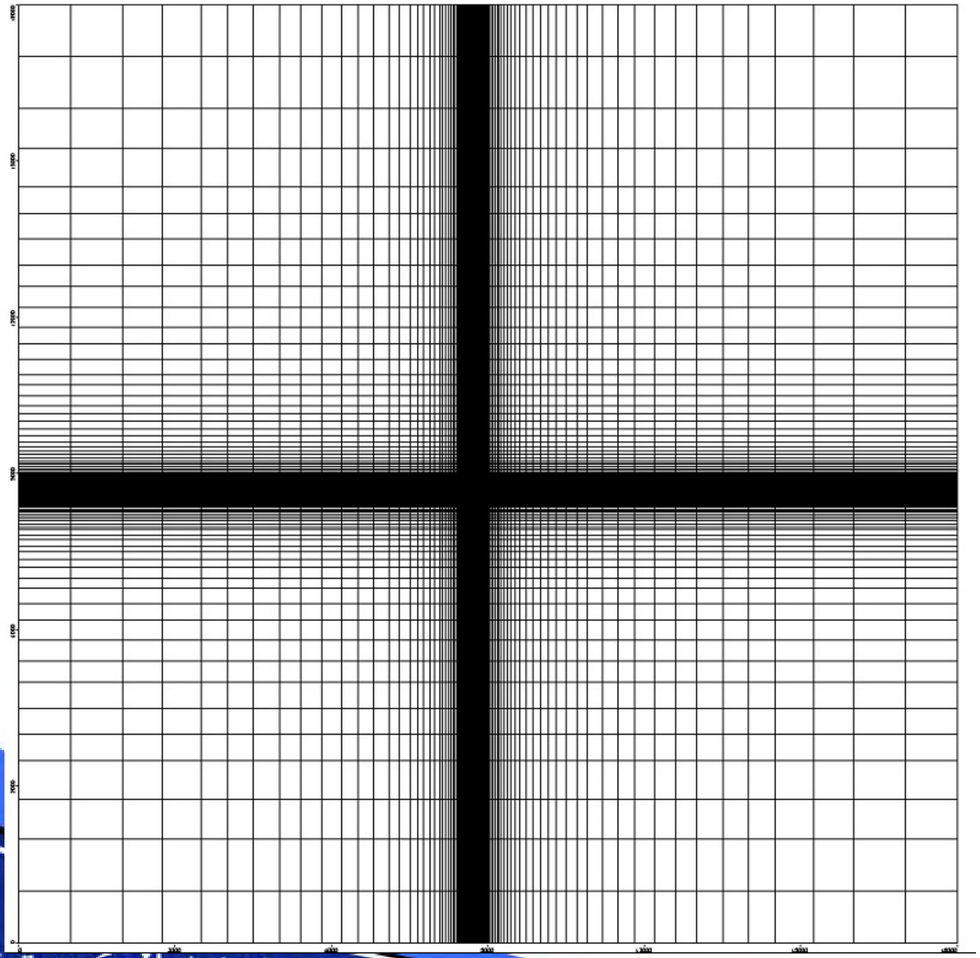
- A numerical model with spatial extent of 18 km x 18 km with the pilot ASR site at the center was set up. It extended to the base of the Dammam Formation in the vertical direction.
- Spatially, the model was divided into 167 Rows and 336 Columns with the grid size varying from 0.625m x 0.625m to 1km x 1km. Vertically it was divided in to five layers (top two representing clastic Kuwait Group and the bottom three representing carbonate Dammam Formation).
- Rotated 42^{o} clockwise with respect to the North to align parallel to the flow direction
- The main purpose of the model was to arrive at reasonable values for aquifer properties for the area that were important in the context of artificial groundwater recharge (e.g., hydraulic conductivity, storativity and longitudinal dispersivity)
- The water levels measured during the pumping test conducted prior to the injection – recovery experiment were used to calibrate the model.
- The water level and water quality (TDS) measured in the ASR and the monitoring wells were used for validation of the model and derivation of the aquifer properties.

Modelled Area (18 km x 18 km)



Model Grid – 167 Rows x 336 Columns

Grid Size: 0.625 m x 0.625 m – 1 km x 1 km



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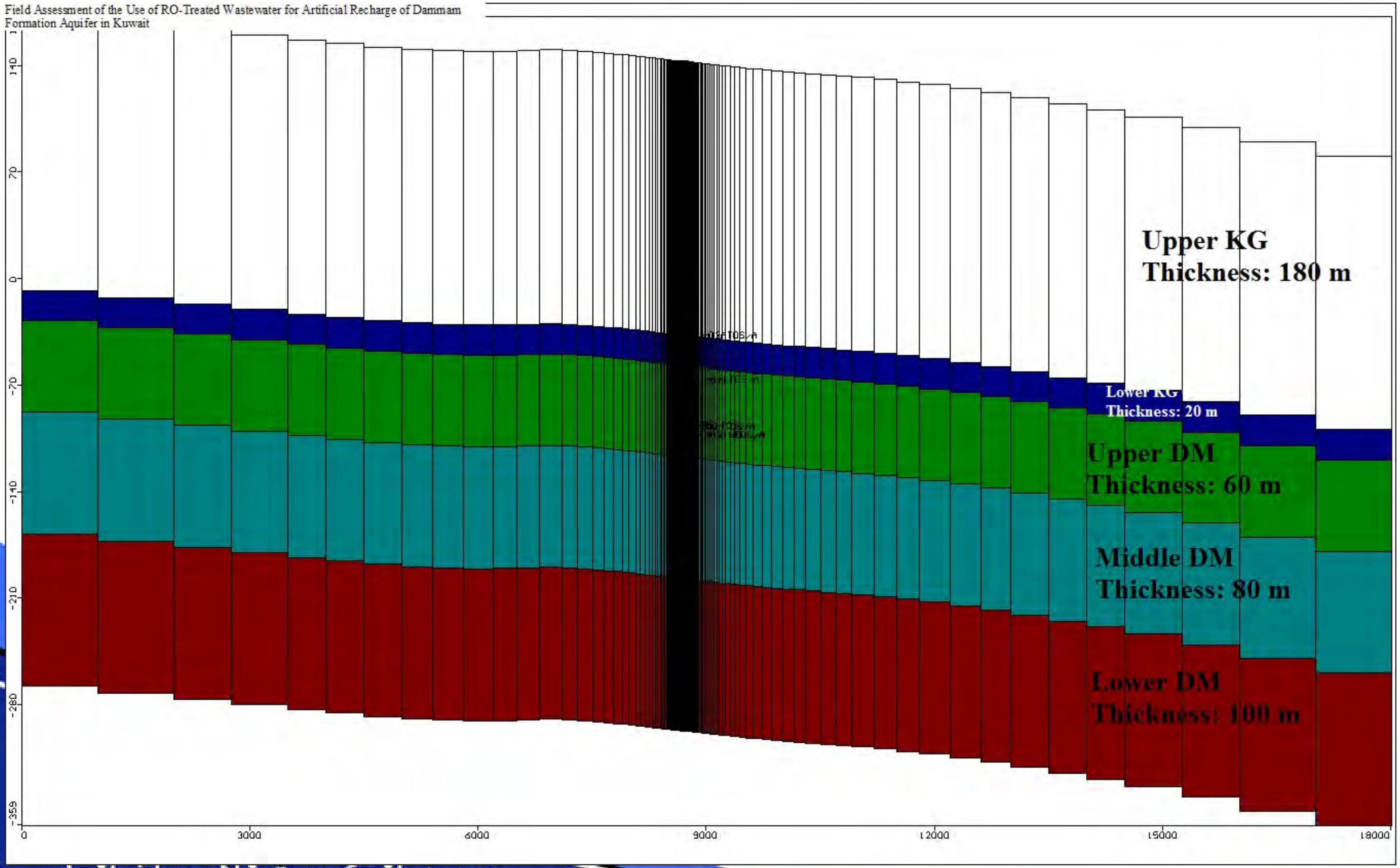
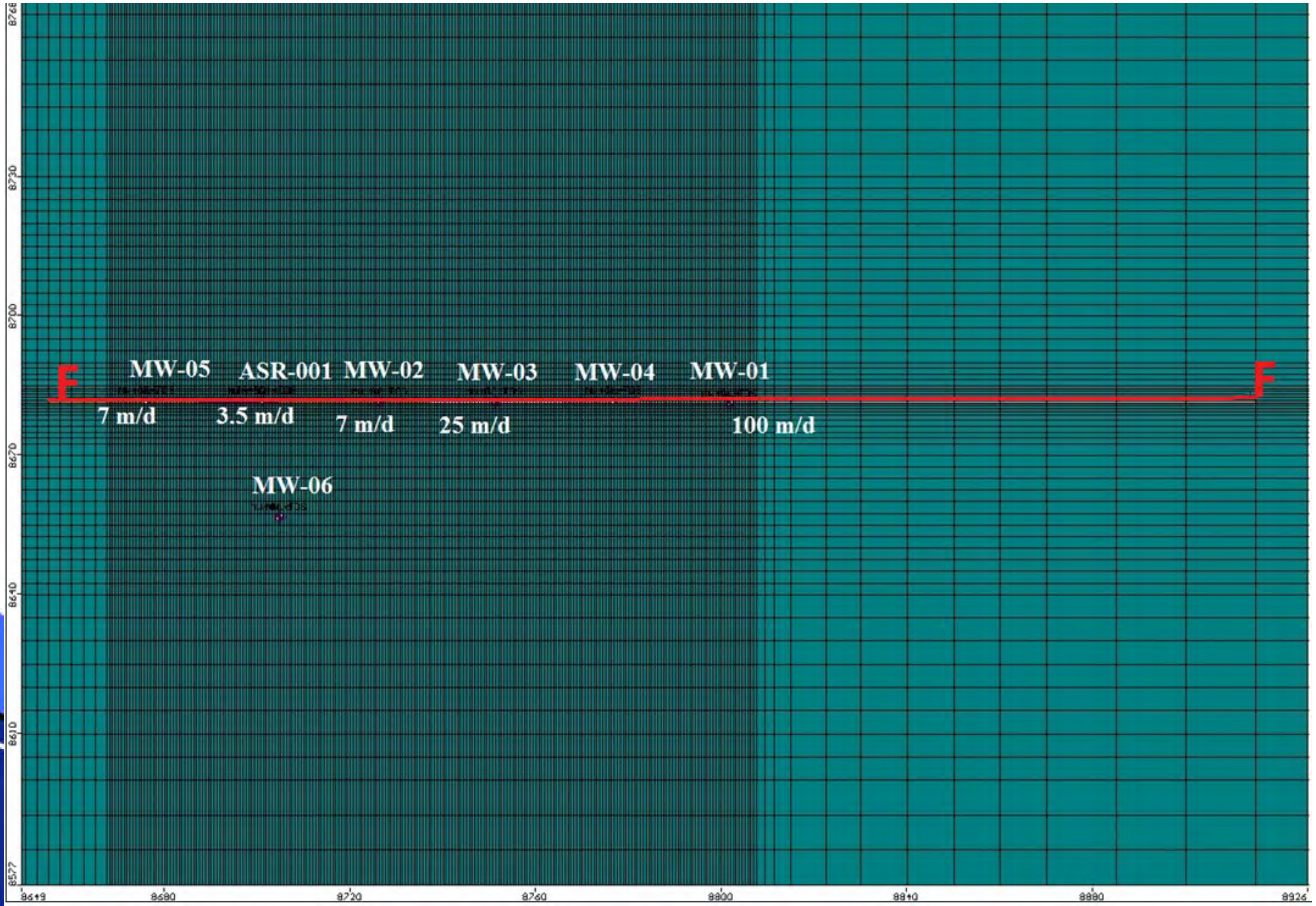
Model Cross-Section along Row 89 through the ASR Well



Assumed Fracture with Hydraulic Conductivity Distribution Along Its Length in Layer 4

(Matrix Hydraulic Conductivity: 0.3 m/d)



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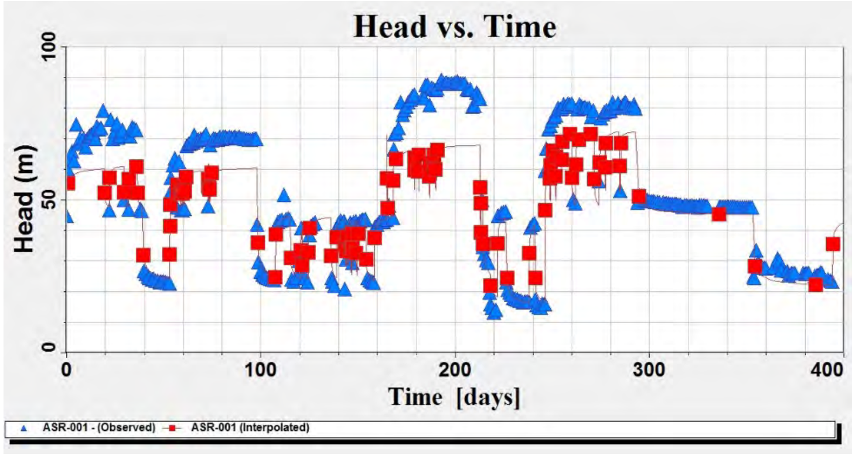
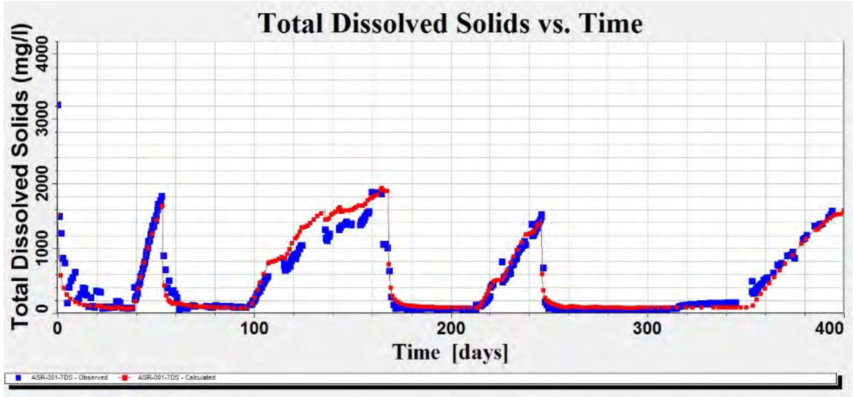
Observed and Simulated Head and TDS against Time (Well ASR-001)

Observed (Blue) vs Simulated (Red) Head (m amsl)

Observed (Blue) vs Simulated (Red) TDS (mg/l)

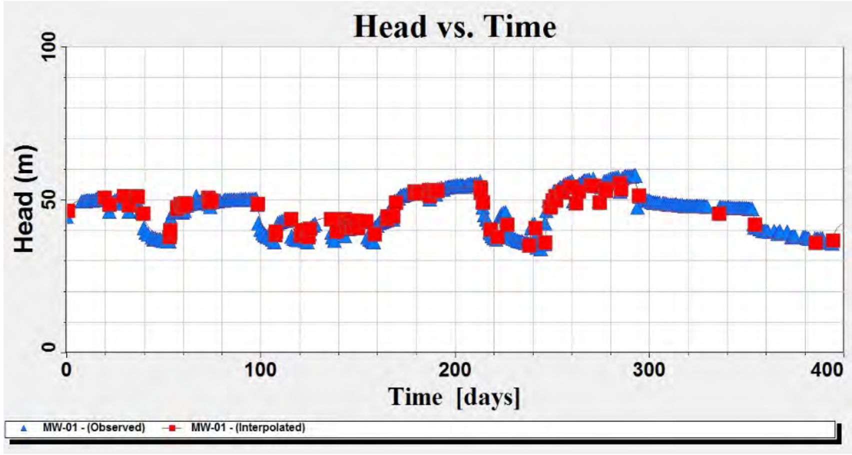


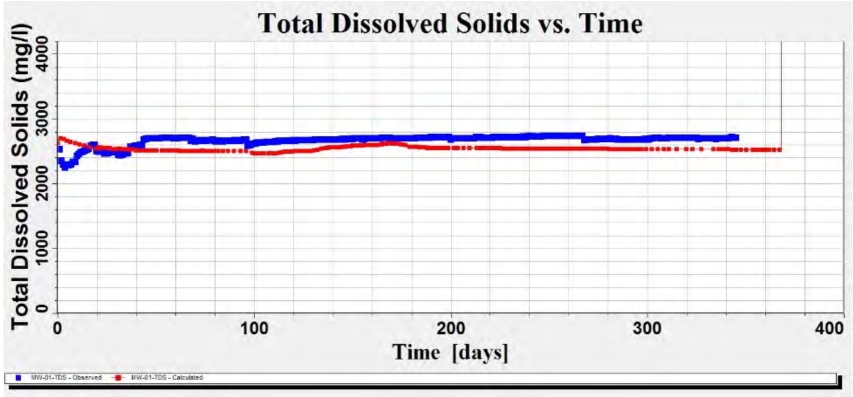


Observed and Simulated Head and TDS against Time (Well MW-01; Upper DM)

Observed (Blue) vs Simulated (Red) Head (m amsl)

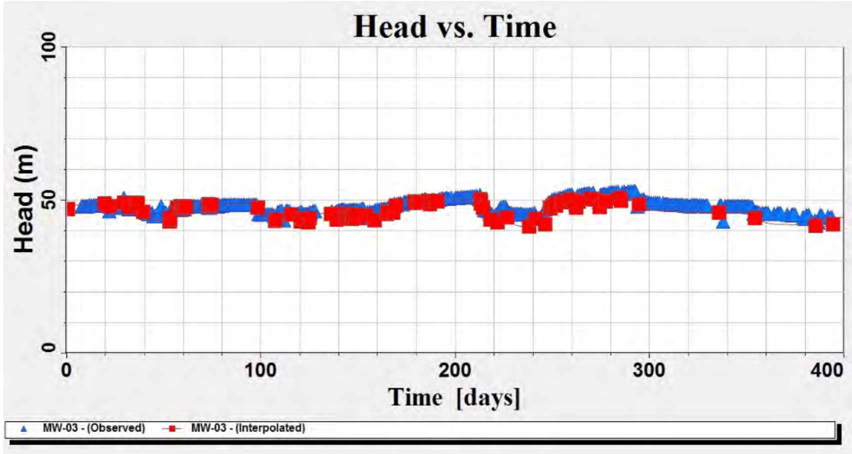
Observed (Blue) vs Simulated (Red) TDS (mg/l)



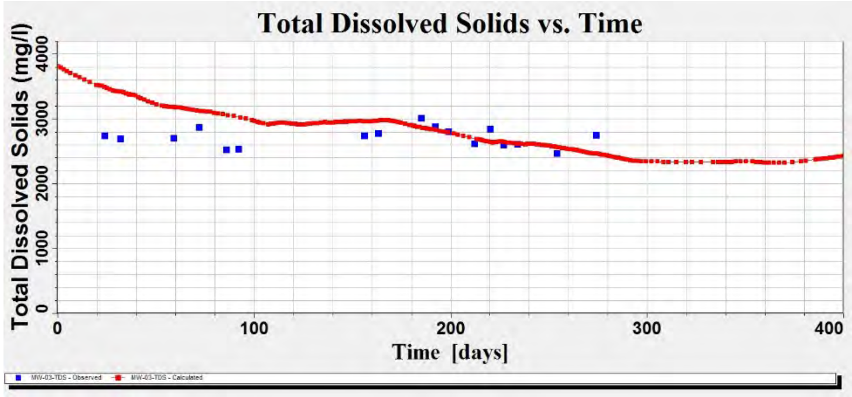


Observed and Simulated Head and TDS against Time (Well MW-03; Lower KG)

Observed (Blue) vs Simulated (Red) Head (m amsl)



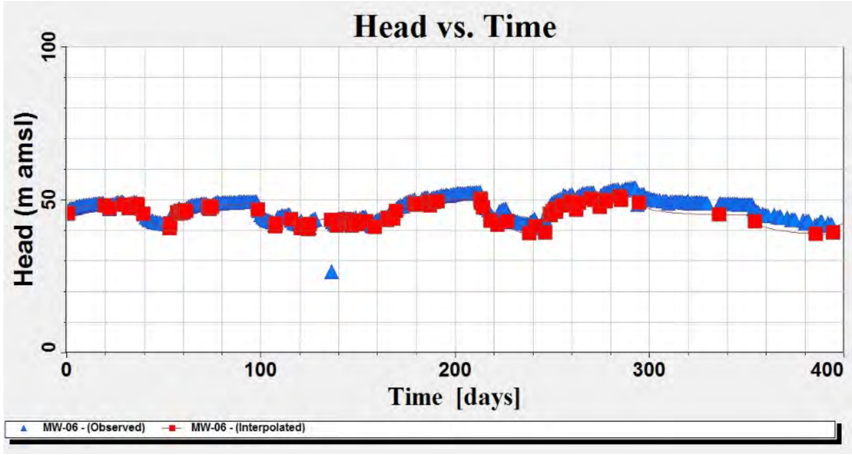
Observed (Blue) vs Simulated (Red) TDS (mg/l)

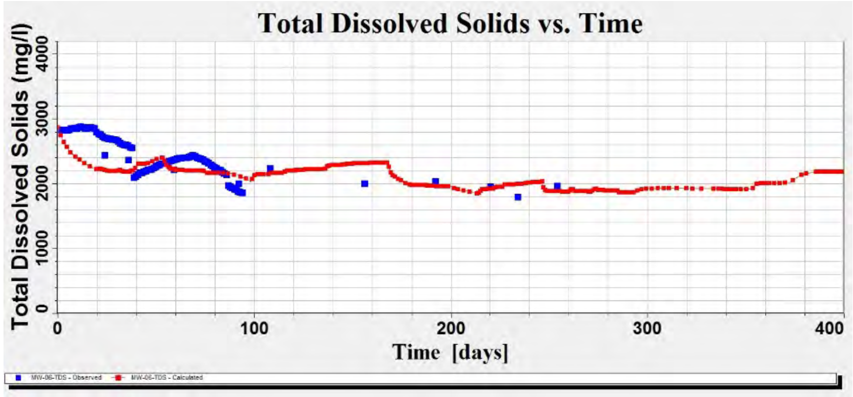


Observed and Simulated Head and TDS against Time (Well MW-06; Lower DM)

Observed (Blue) vs Simulated (Red) Head (m amsl)

Observed (Blue) vs Simulated (Red) TDS (mg/l)





Conclusions Based on the Pilot Srudy

- Even with a relatively low matrix hydraulic conductivity (0.2 – 0.3 m/d) of the DM aquifer, it was possible to achieve a reasonable injection rate (up to 950 m3/d; 145 IGPM) at that site. The numerical modeling of pumping test data and water level data collected through the injection – recovery cycles, however, suggested the presence of a fracture passing through the ASR and some of the monitoring wells.
- It was possible to attain acceptable recovery efficiencies (20 – 25%: recovered water TDS ≤ 500 mg/l; 45 – 55%: recovered water TDS ≤ 1000 mg/l; and 70 – 95%: recovered water TDS ≤ 1500 mg/l) with four cycles of injection and recovery (GW TDS: 2,650 – 2900 mg/l).
- The pumping at a much higher rate than the injection rate led to the reduction in the recovery efficiency that was possibly related to the upconing of more saline water from the bottom. Extension of the injection zone down to the top of an aquitard with very low vertical hydraulic conductivity (in this case, the Nummulitic Shale of the Lower Dammam Formation or the underlying Rus Anhydrite Formation) should minimize the problem.

Conclusions Based on the Pilot Study (Contd.)

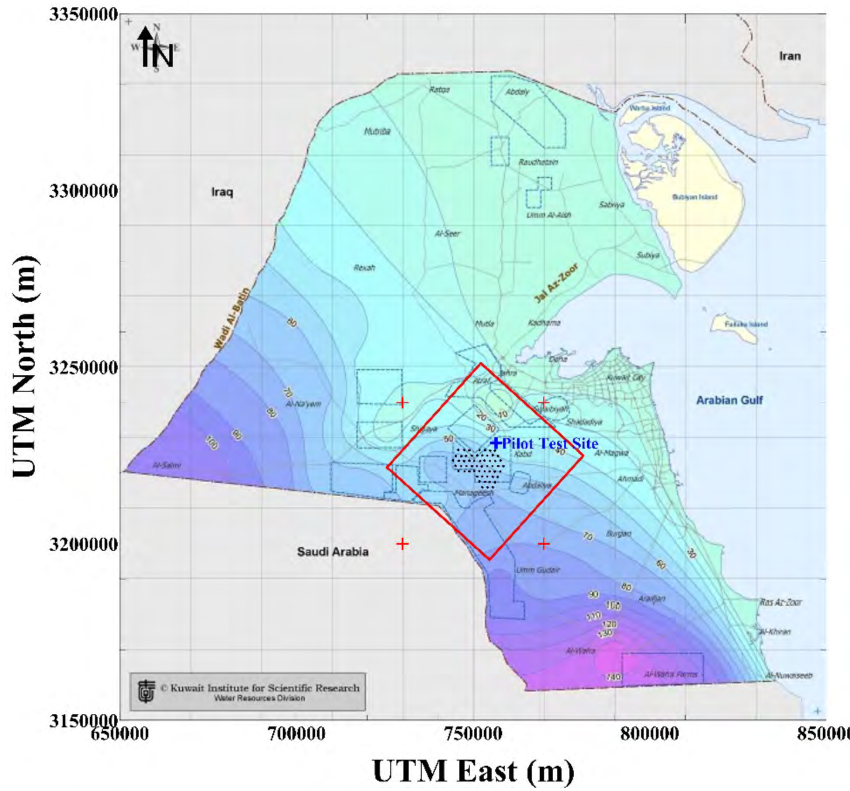
- A relatively long (60 days) waiting time between injection and recovery phase in the fourth cycle resulted in the lowering of the recovery efficiency compared to the second and the third cycles. This presumably happened due to the lateral migration of more saline water from the surrounding areas. Special steps need to be taken to prevent this to happen to the strategic reserve created through artificial recharge.
- The concentrations of emerging pollutants, such as pesticides, pharmaceuticals, halogenated hydrocarbons, personal care products, and others, in the membrane-treated municipal wastewater used as the injection water were mostly below the method detection limits. The health hazard of using the recovered water was, therefore, minimal.
- In consideration of the above, the creation of an aquifer storage of water for emergency use in the neighborhood of the project site is feasible and can be implemented in the future.

Planning For Full Scale Recharge

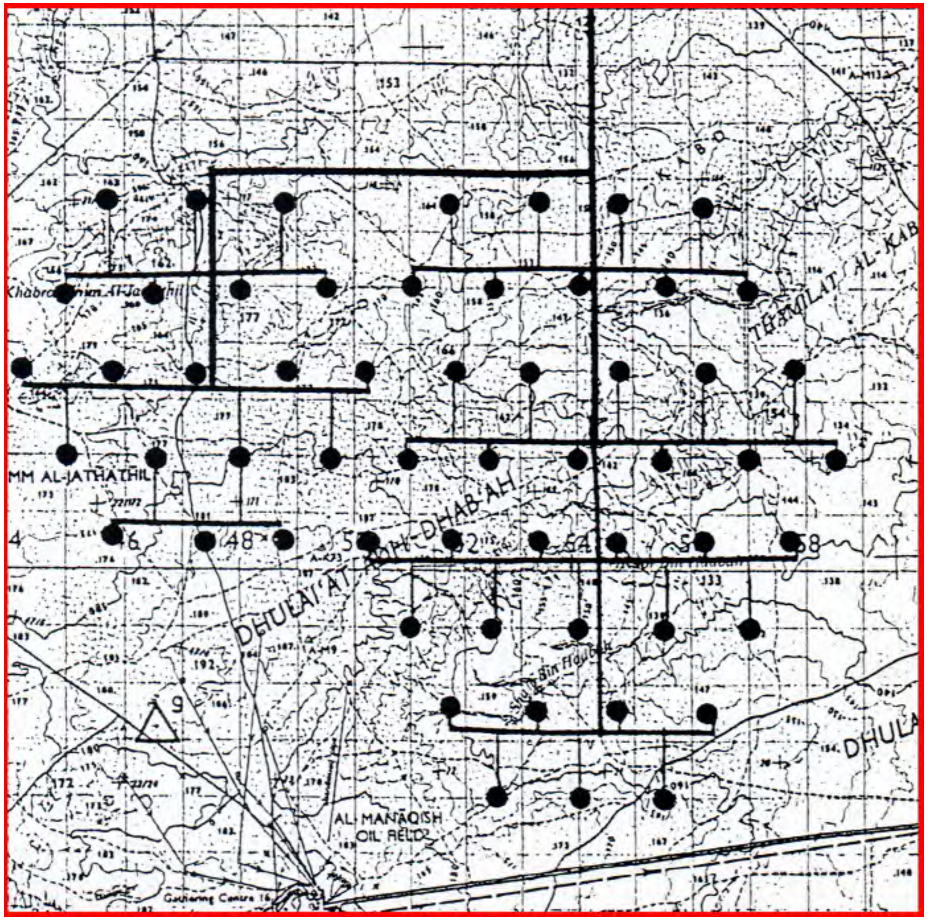
Background Information

- MEW has a plan for the creation of a strategic reserve in the DM Formation, Kabd.
- It involves injection of a total of 25 MIGPD (0.11 Mm^3/d) of water through 57 wells
- Injection will be at an approximate rate of 305 IGPM/well (2000 m^3/d per well) for a period of 10 years
- The reserve so created should be able to supply water at the rate of at least 30 l/d/capita for a population of 1.5 – 2 million people over an extended period (6 – 12 months) with quality that would be acceptable for consumption under an emergency condition (total dissolved solids [TDS] ≤ 1500 mg/l).
- Numerical modelling of the recharge – recovery operation with different well arrangements and recharge – recovery rates and durations has been carried out for the finalization of the best plan for the implementation of the recharge operation.
- Both continuous recharge and cyclic recharge and recovery operations were investigated.

- **ASR Well Field Planned by Mew**

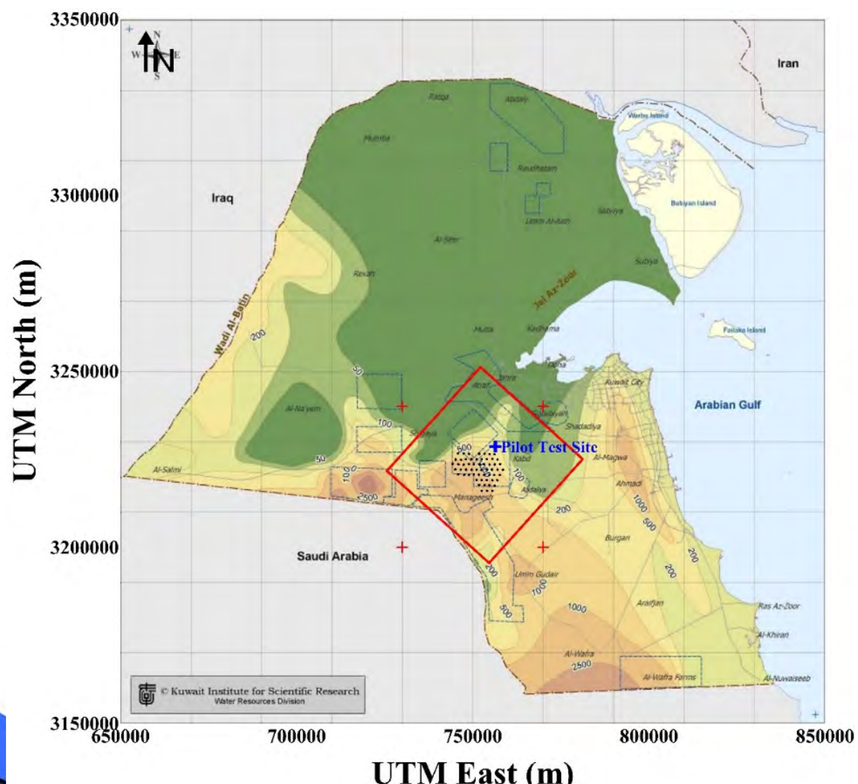


Closeup View of the MEW Suggested Well Arrangements in the Proposed AR Field

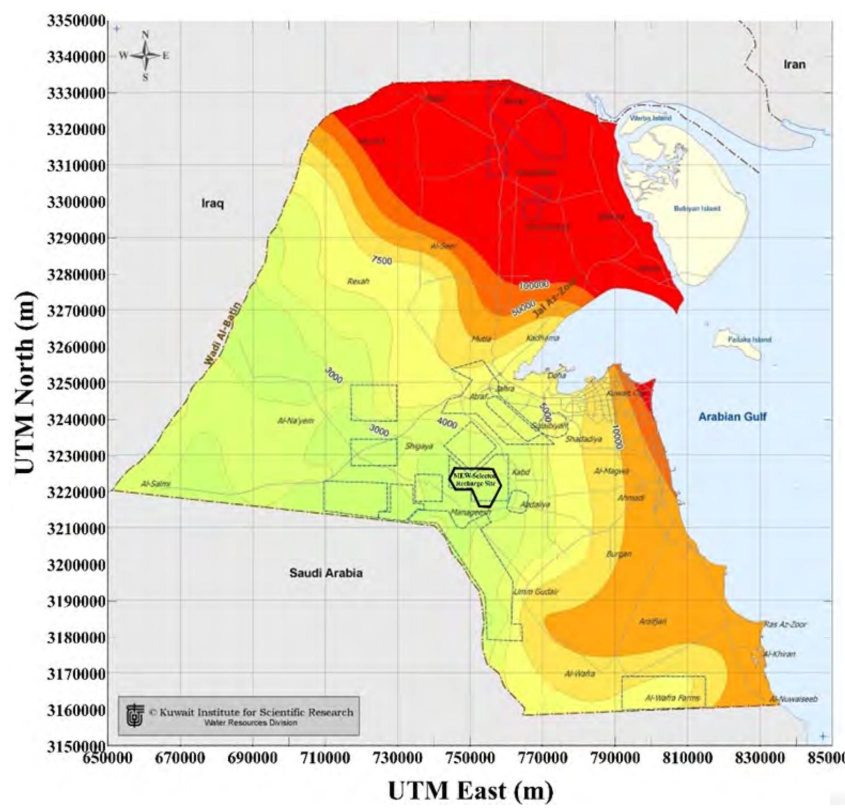


DM Transmissivity and Water Quality at the MEW Selected Site

Transmissivity (m^2/d)



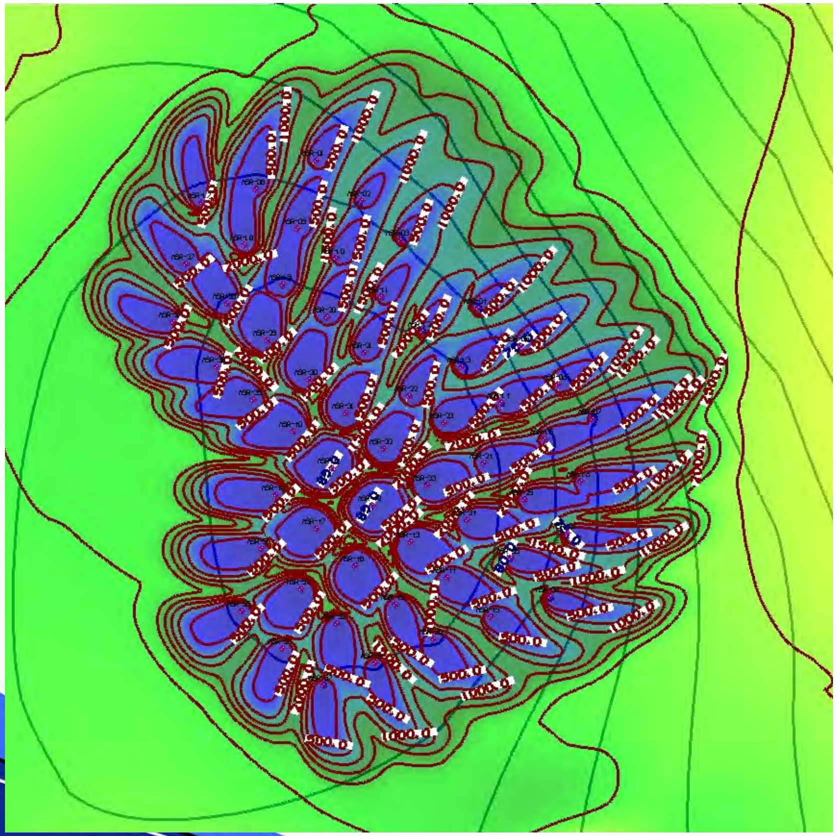
Total Dissolved Solids (mg/l)



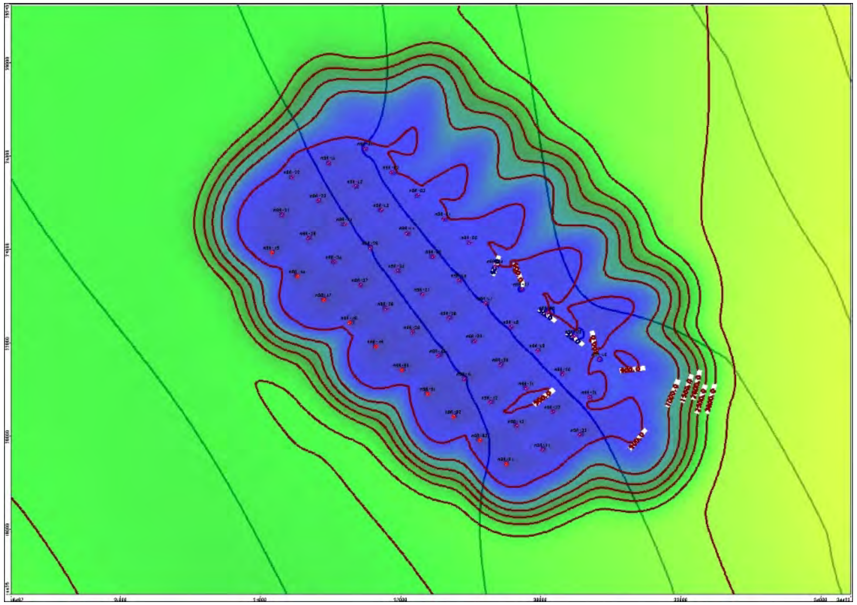
Well Arrangements Investigated

(Model Area Rotated 41^{o}C Clockwise to Align with the Prevailing Hydraulic Gradient)

Original MEW Suggested Well Distribution



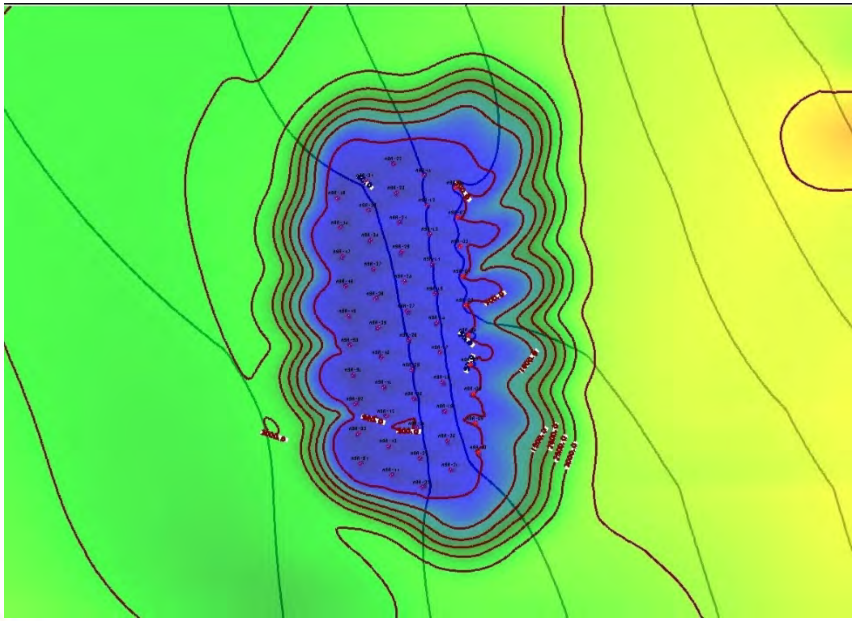
Closer Placed Wells in a Revised Hexagonal Pattern



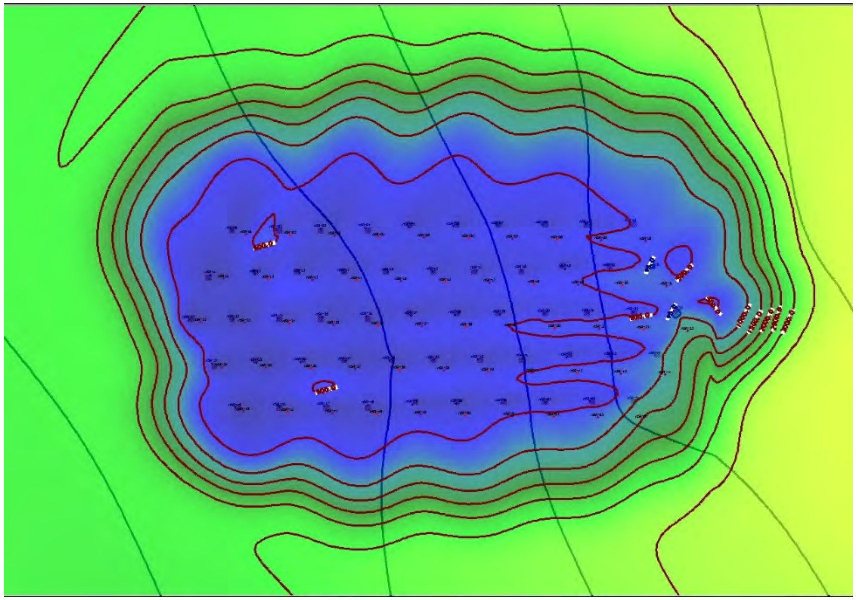
Well Arrangements Investigated (Contd.)

(Model Area Rotated 41ºC Clockwise to Align with the Prevailing Hydraulic Gradient)

Revised Well Pattern with the Elongation of the Field Semi-parallel to the Equipotential Lines



Revised Well Pattern with the Elongation of the Field Semi-orthogonal to the Equipotential Lines



Conclusions from the Numerical Modeling of Full Scale AR

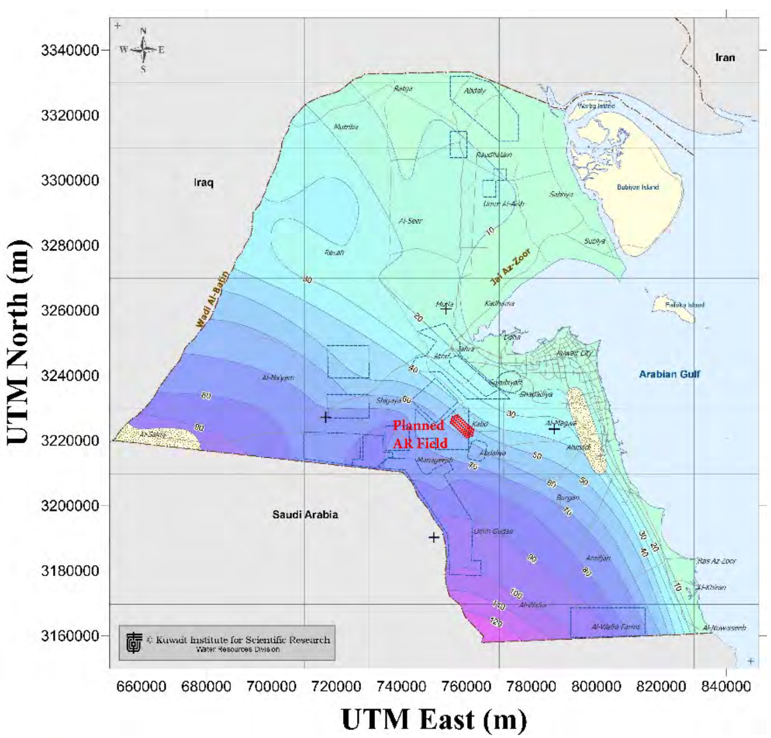
- Apart from the hydraulic parameters of the target aquifer, the quality of the recharge water and that of the native groundwater, operational parameters like well spacing, well operation schedule, the extent of coverage of the aquifer thickness for recharge, and the recharge field orientation with respect to the hydraulic gradient have important influence on the success of the artificial recharge.
- For continuous recharge strategy, simultaneous recharge through one set of wells and withdrawal of groundwater from the in-between wells help in better spread of the injection water around the recharge wells and control the rise in water levels during recharge. Moreover, the water recovered from the pumped wells during the reserve creation stage can be gainfully utilized leading to a better overall recovery efficiency.

Conclusions from the Numerical Modeling of Full Scale AR (Contd.)

- **Once the reserve is created, it may be necessary to replace continuously the water lost by flow down the prevailing hydraulic gradient by recharging the wells at a lower rate. The wells in the downgradient side of the recharge field may be pumped at the same time to recover the water that would be flowing out of the field boundary, thus improving the overall recovery efficiency and also helping in the stabilization of the reserve created at its site.**
- **As the period of injection and recovery increases, the incremental influence of the dispersivity parameter on the quality of the recovered water and the recovery efficiency diminishes.**
- **It will take a longer time to create a reserve of a given capacity using cyclic recharge and recovery, compared to that taken by the adoption of continuous injection strategy, though the overall recovery efficiency and the duration for which the recovery of required quality of water can be sustained will be higher in the former option.**

RECOMMENDATIONS

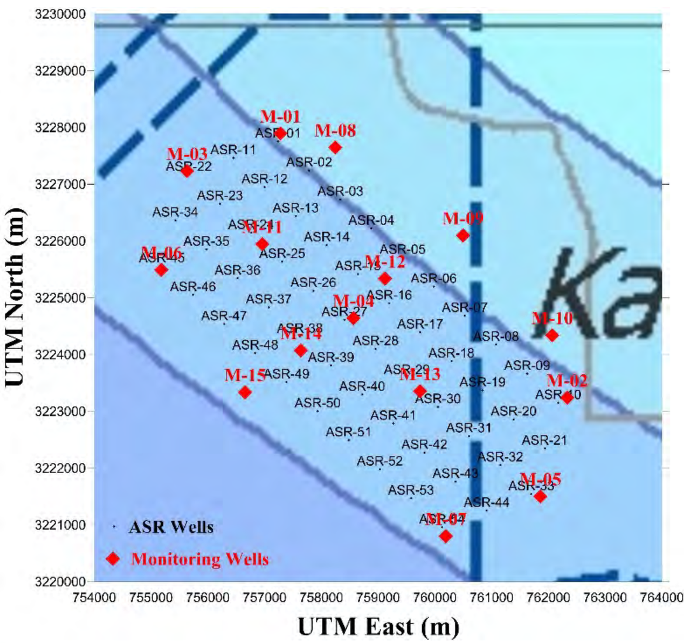
SUGGESTED AR FIELD LOCATION



- The creation of a strategic reserve in the DM Formation, Kabd, should be taken in hand soon at the same general area as suggested by MEW
- To realize maximum recovery efficiency, the wells should be so arranged that the field elongation would be perpendicular to the general hydraulic gradient prevailing in the area.
- Continuous injection and withdrawal from alternate wells for five years, followed by the maintenance of the created reserve by injection and withdrawal of water through rear and the frontal wells, respectively, at the same rate as the loss of water through flow down the hydraulic gradient is recommended as the optimum option.

RECOMMENDATIONS (Contd.)

SUGGESTED WELL ARRAGEMENT IN THE FULL SCALE AR FIELD



- **The project should be implemented in stages. Five to 10 ASR wells with a few monitoring wells should be drilled first, spread over the selected are.**
- **Aquifer parameters should be determined from these wells through pumping tests, and short scale (a few days to a month) recharge – recovery tests should be conducted in these wells to get some preliminary information about the well depth and well spacing that should be adopted, the injection and the recovery rates that would be appropriate and the order of recovery efficiencies to be achieved**
- **Once all the wells (50 – 60) are drilled, the recharge operation should start**

THE END

Thank You!