Economic Well Design using AI for Kuwait's Aquifers

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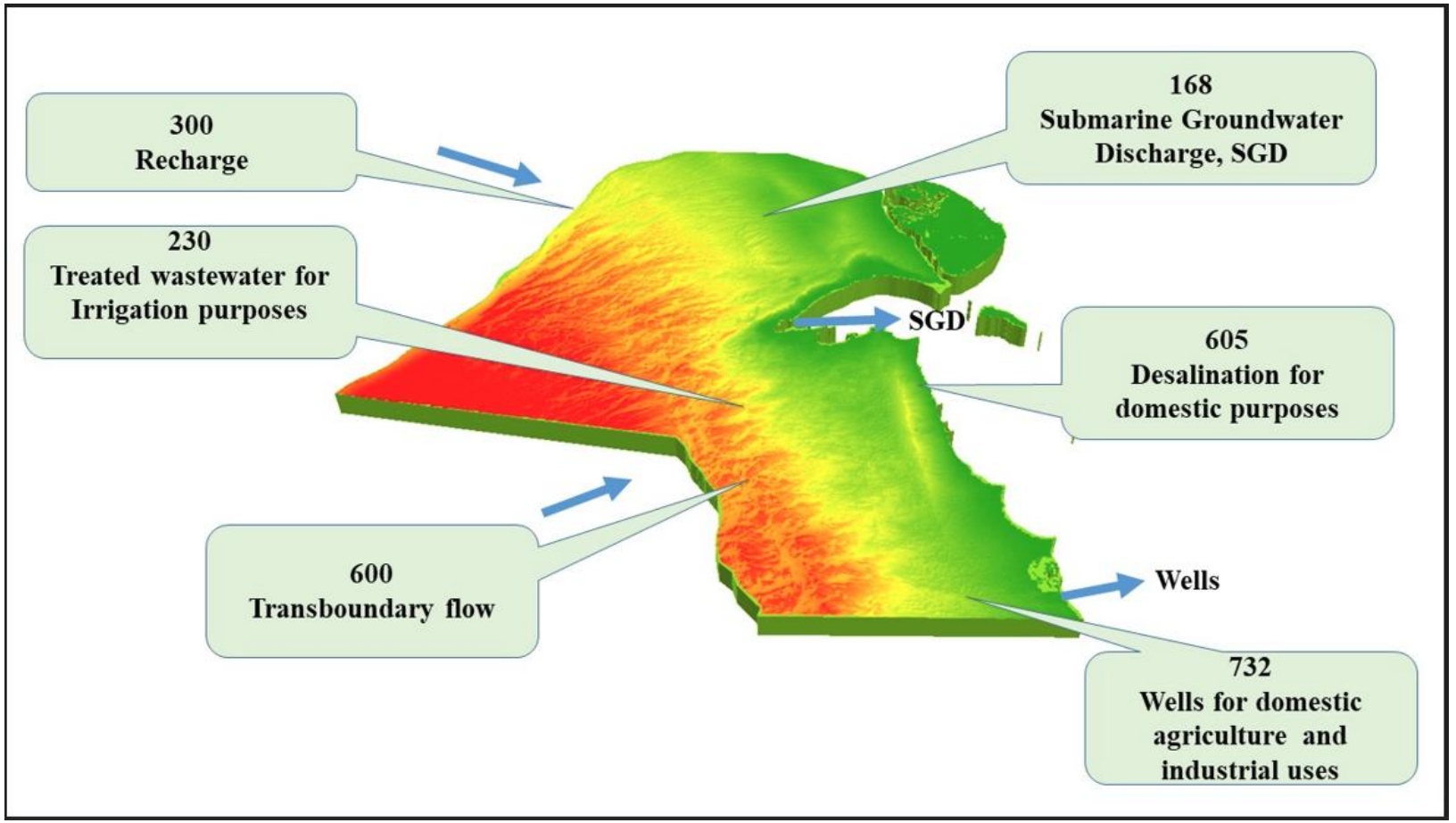
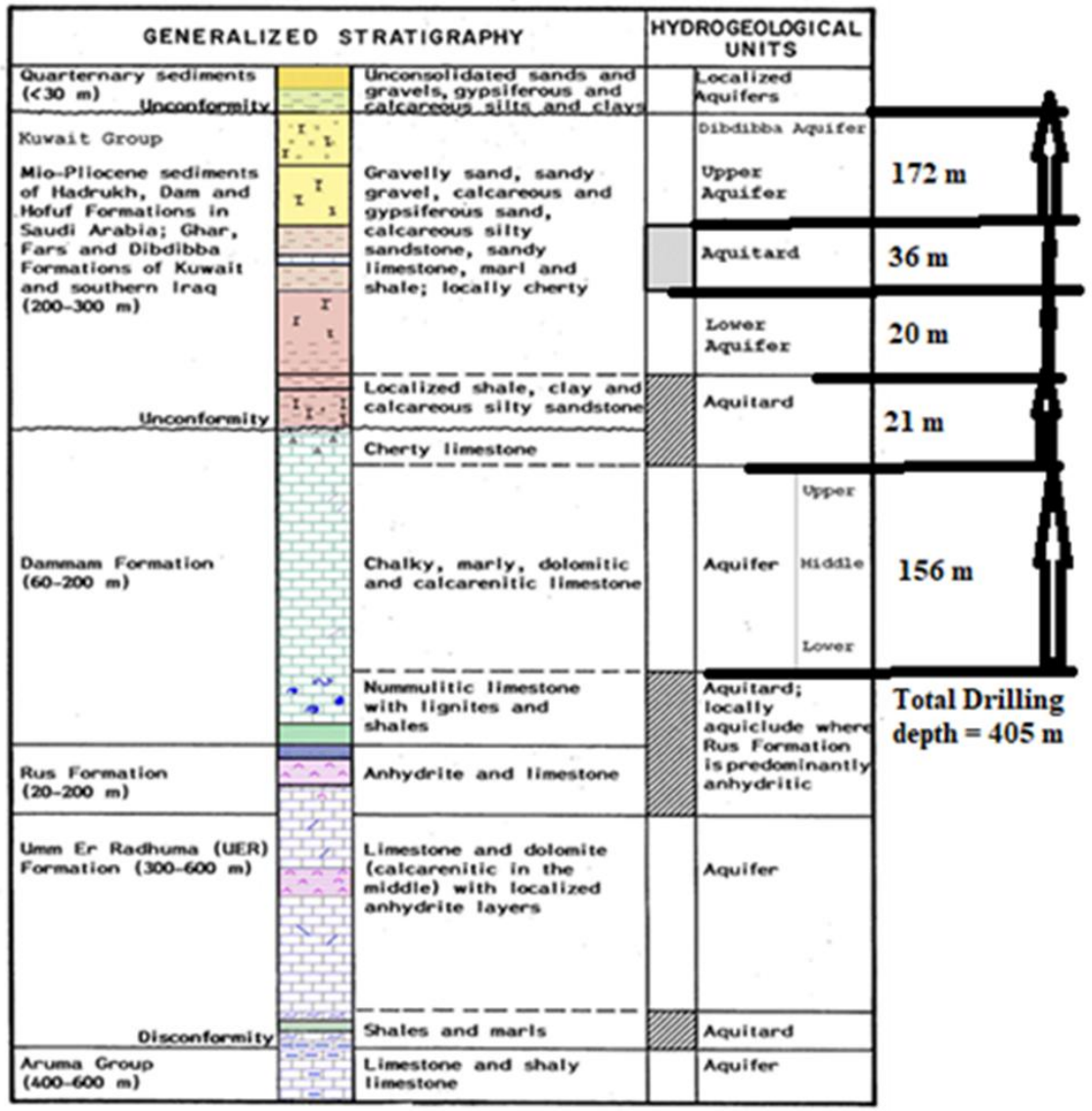
Workshop on Artificial Intelligence (AI) for Sustainable Water Resources Management (WRM) in the GCC Countries
16 – 17 December 2025

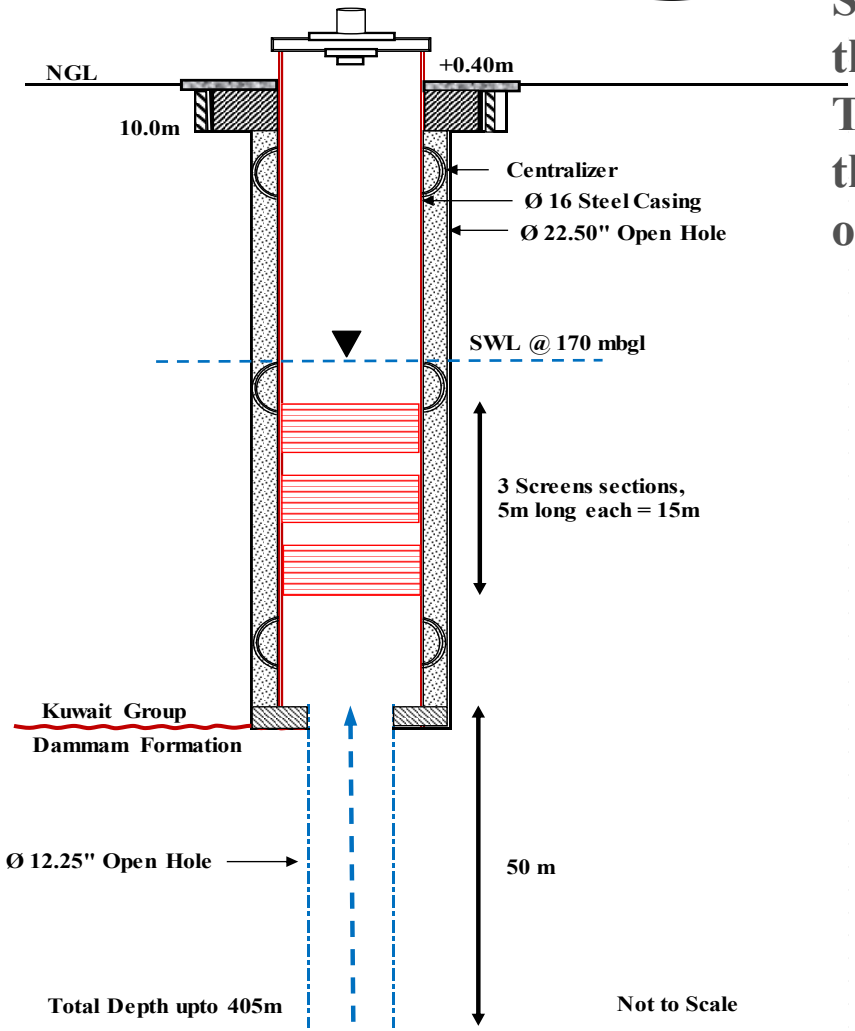
Recent water resources balance of Kuwait in Mm^3/yr



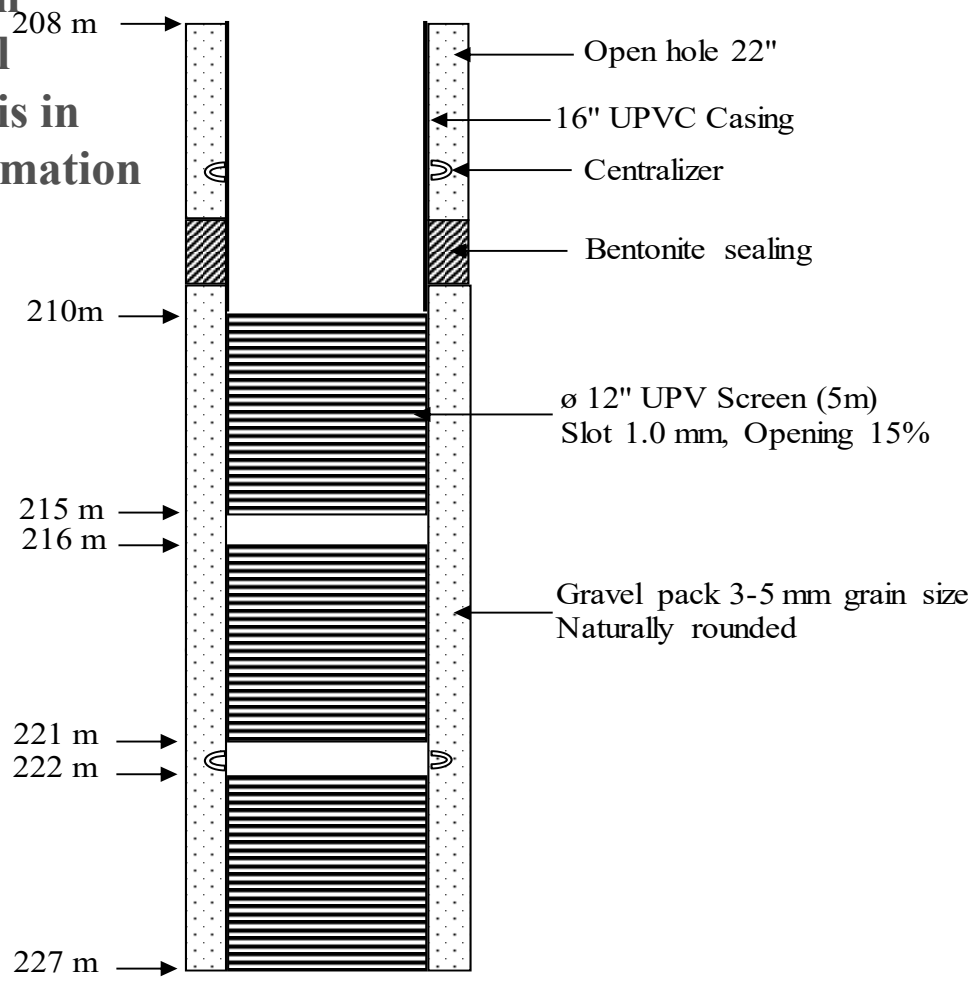
The problem statement

- Wells extract 732 Mm^3/yr from brackish groundwater well field for domestic, industrial and agricultural purposes.
- This is when Kuwait faces severe water scarcity due to its arid climate and limited natural water resources.
- Also, water demand on brackish groundwater resources increases drastically due to urbanization, industrial growth, and population increase.
- Official records state that current extraction = 220-353 Mm^3/yr meaning there is [732 – (220-353)] = 379-512 Mm^3/yr dominated by private farms.
- The design of wells has to produce the optimum not maximum quantity with least cost and least deterioration in water quality such as salinization problems.


GENERALIZED STRATIGRAPHY
HYDROGEOLOGICAL UNITS
Quarternary sediments (<30 m)
Unconformity
Unconsolidated sands and gravels, gypsiferous and calcareous silts and clays
Localized Aquifers
Kuwait Group
Mio-Pliocene sediments of Hadrukh, Dam and Hofuf Formations in Saudi Arabia; Ghar, Fars and Dibdibba Formations of Kuwait and southern Iraq (200-300 m)
Gravelly sand, sandy gravel, calcareous and gypsiferous sand, calcareous silty sandstone, sandy limestone, marl and shale; locally cherty
Dibdibba Aquifer
Upper Aquifer
172 m
Aquitard
36 m
Lower Aquifer
20 m
Localized shale, clay and calcareous silty sandstone
Aquitard
21 m
Unconformity
Cherty limestone
Dammam Formation (60-200 m)
Chalky, marly, dolomitic and calcarenitic limestone
Upper
Middle
Lower
Aquifer
156 m
Nummulitic limestone with lignites and shales
Aquitard; locally aquiclude where Rus Formation is predominantly anhydritic
Total Drilling depth = 405 m
Rus Formation (20-200 m)
Anhydrite and limestone
Umm Er Radhuma (UER) Formation (300-600 m)
Limestone and dolomite (calcarenitic in the middle) with localized anhydrite layers
Aquifer
Disconformity
Shales and marls
Aquitard
Aruma Group (400-600 m)
Limestone and shaly limestone
Aquifer



Starting from this point bgl This section is in the Ghar formation of LKG



Optimal Screen + Open hole lengths = 65 m

Core Concept: Shifting to optimum design and operation of wells

- **The Goal**: Lowest lifetime cost with sufficient (not maximum) water yield and minimum negative impacts.

- **The optimal well** yields sufficient water with lowest capital and operational costs.
  - ✓ Capital Costs (Ccap): One-time investment (drilling, casing, construction).
  - ✓ Operating Costs (Cop): Long-term energy expense for pumping.

- **The insight of that**
  - ✓ A more efficient design (e.g., longer screen and open hole) increases capital cost but reduces drawdown, drastically cutting energy costs over 20-25 years.
  - ✓ A shorter screen length and open hole lowers initial capital cost but increases long-term energy expenses (operational cost) over its 20-25 year life.

Breaking down the Capital cost (Ccap)

Ccap = Fixed Costs + Variable Costs

1. Fixed Costs (Lump Sum):

- Mobilization of drilling rig
- Conductor pipe
- Gravel pack
- Pump cost including installation

2. Variable Costs (Depend on Design):

- Cdrill: Drilling the borehole (Dbore = DSWL + 1.2*Sw + [Ls+open hole]) realizing that (Sw = 2Q / K Ls)
- Ccasing: Installing blank casing in KG formation that is suitable to accommodate the pump.
- Cscreen: Purchasing and installing the well screen.

Breaking Down the Operating Cost (Cop)

- **Operating Cost is about cost of energy used for pumping**
- The main drivers of operating cost are Depth to static water level (DSWL), drawdown (Sw), the value of the pumping rate, energy cost fact λ (normally 0.005 to 0.0005) and operating number of days with the year (t factor):

$$C_{OP} = (\lambda t D_{SWL})Q + \left(\frac{2.4\lambda t}{KLs}\right)Q^2$$

- Higher drawdown means that the pump must lift water from a greater depth meaning more energy to consume.
- Operating cost ($\mathbf{C_{OP}}$) repeats every year, it must be converted to its **Present Value (PV)** over the well's lifespan (e.g., 25 years) using an annuity factor.

Basic Equations

$$C_{cap} = C_{fixed} + \left(Coe_j^i + Coe_{casing}\right)\left(D_{SWL} + \left[\frac{2.4Q}{KLs}\right]\right) + \left(Coe_j^i + Coe_{screen}\right)Ls$$

$$PV_{Operating\ cost} = \left[\frac{(1+r)^n - 1}{r(1+r)^n}\right]\left[(\lambda t D_{SWL})Q + \left(\frac{2.4\lambda t}{KLs}\right)Q^2\right]$$

$$TPV = C_{fixed} + \left(Coe_j^i + Coe_{casing}\right)D_{SWL} + \left(Coe_j^i + Coe_{screen}\right)Ls + \frac{2.4Q}{KLs}\left[Coe_j^i + Coe_{casing} + A\lambda tQ\right] + A\lambda t D_{SWL}Q$$

$A = \left[\frac{(1+r)^n - 1}{r(1+r)^n}\right]$ which is the annuity parameter.

Drilling costs of borehole

Diameter of drilling bit (inch) (i)	Formation (j)	Coe_j^i (KD/m)
22	KG	120
17½	KG	100
12¼	KG	75
12¼	DM	120
10	DM	75
6	DM	60

Upper casing costs

Diameter of upper casing (inch)	Formation	Coe_{casing} (KD/m)
16	KG	75
12	KG	60
8	KG	50

Screen costs

Diameter of screen (inch)	Formation	Coe_{screen} (KD/m)
16	KG	150
12	KG	100
8	KG	75

Application to Kuwait's Aquifer System

- Kuwait utilizes two main aquifers:
  - ✓ **Kuwait Group (KG) Aquifer:** Soft sand/gravel
  - ✓ **Dammam (DM) Aquifer:** Hard limestone/dolomite.

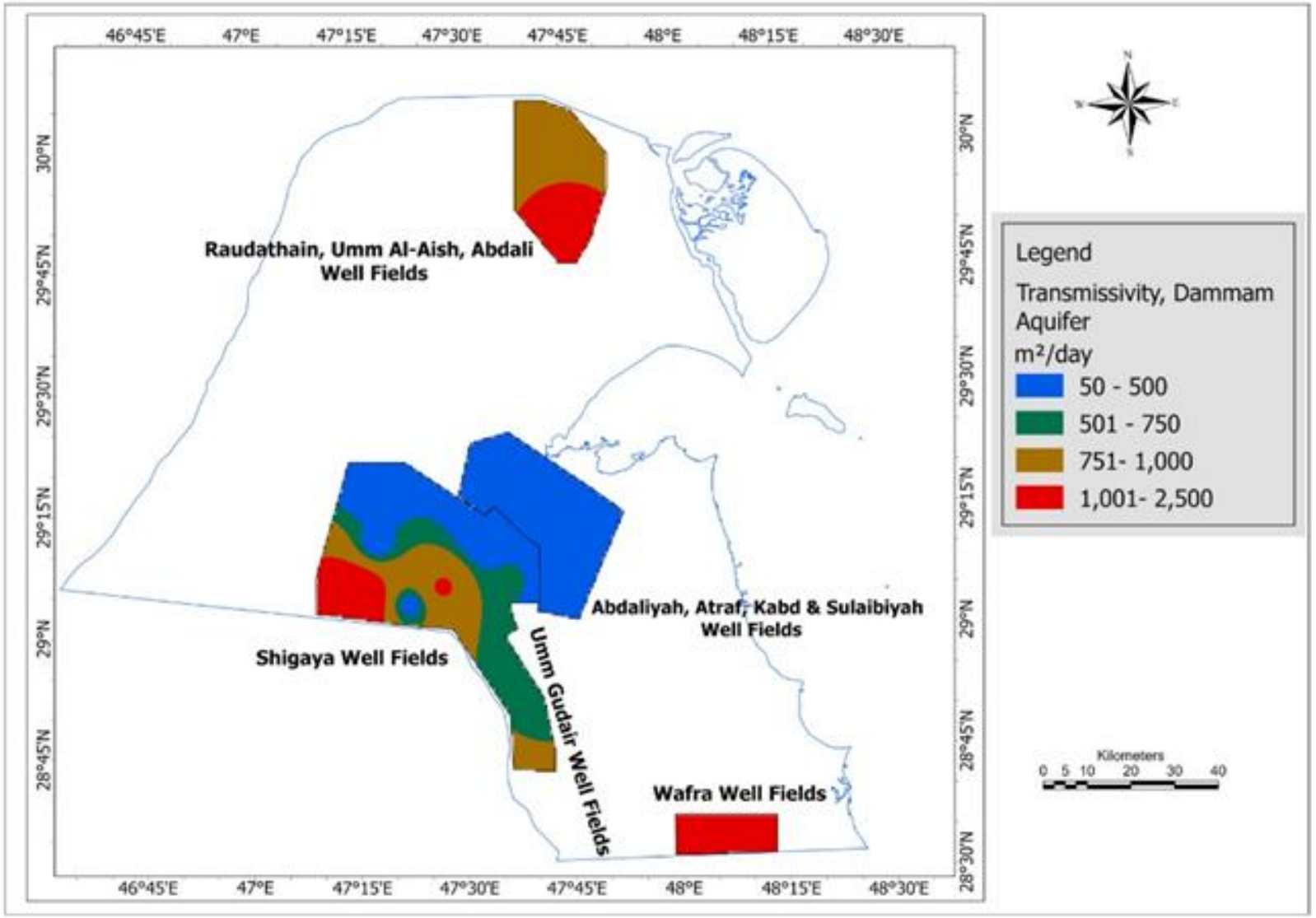
- **Optimal Strategy: Dual Wells**
  - ✓ Tap both aquifers in a single well to maximize yield.
  - ✓ **KG Section:** Requires a **screen** to prevent collapse and filter sand.
  - ✓ **DM Section:** Uses cheaper **open-hole completion** as the rock is stable.

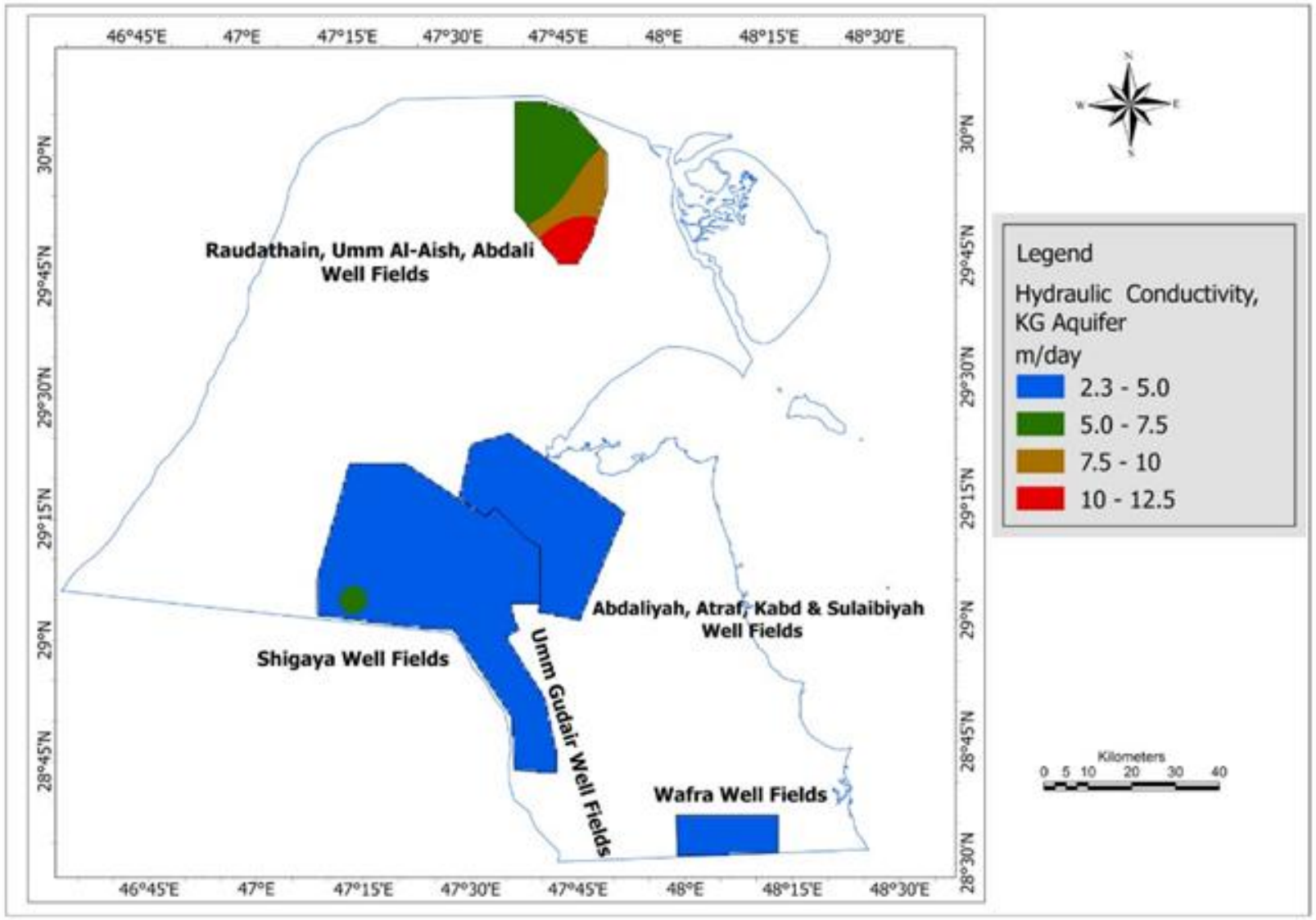
- **Optimization happens on three levels:**
  - ✓ Individual Well Design
  - ✓ Wellfield Layout (spacing between wells)
  - ✓ System Integration (connection to distribution network)

Case Study: A typical location at Shigaya Wellfield

- Static Water Level (D_{SWL}): 170 m below ground
- Hydraulic Conductivity (K): 5 to 50 m/day
- Target Pumping Rate (Q): 3,000 m^3/day
- Aquifer Layers: Combined KG & DM system with a total thickness of ~435 m.
- Well Lifespan (n): 25 years
- Interest Rate (r): 5%

- Goal: Find the optimal screen length (Ls/open hole) to minimize total cost.


46°45'E
47°E
47°15'E
47°30'E
47°45'E
48°E
48°15'E
48°30'E
30°N
29°45'N
29°30'N
29°15'N
29°N
28°45'N
28°30'N
Raudathain, Umm Al-Aish, Abdali Well Fields
Abdaliyah, Atraf, Kabd & Sulaibiyah Well Fields
Shigaya Well Fields
Umm Gudair Well Fields
Wafra Well Fields
Legend
Transmissivity, Dammam Aquifer
m²/day
50 - 500
501 - 750
751- 1,000
1,001- 2,500
Kilometers
0 5 10 20 30 40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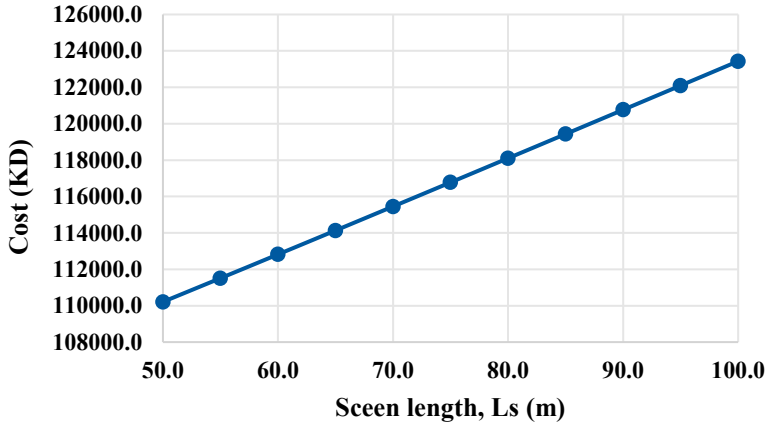
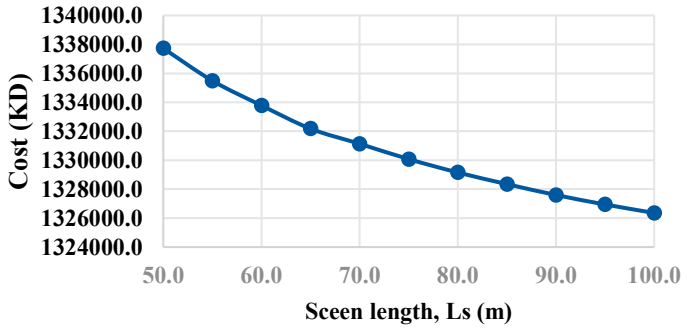
Wafra Well Fields
Legend
Hydraulic Conductivity, KG Aquifer
m/day
2.3 - 5.0
5.0 - 7.5
7.5 - 10
10 - 12.5
Kilometers
0 5 10 20 30 40

Results for Shigaya-H wellfield using AI tools

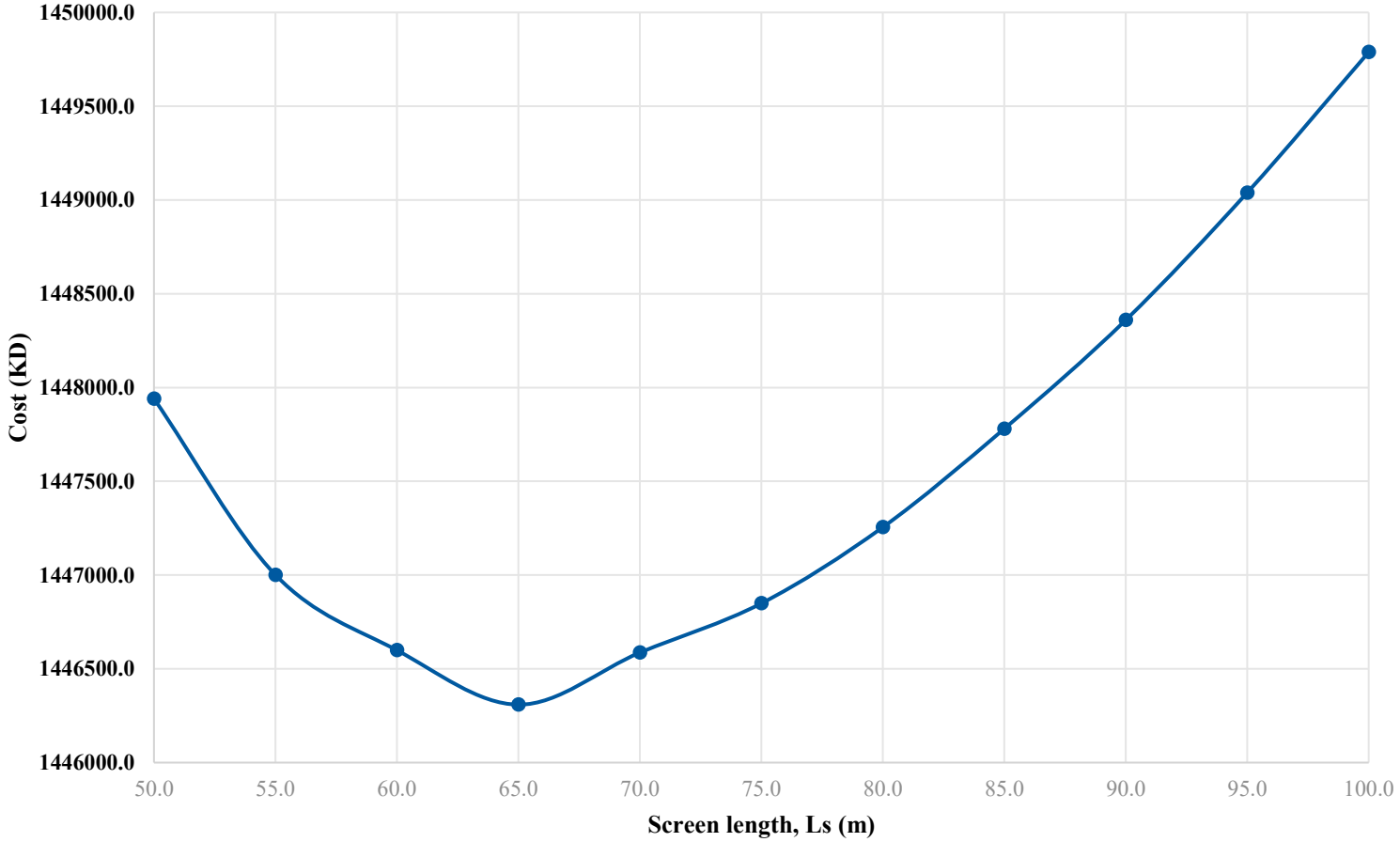
(a) Capital Cost (KD)

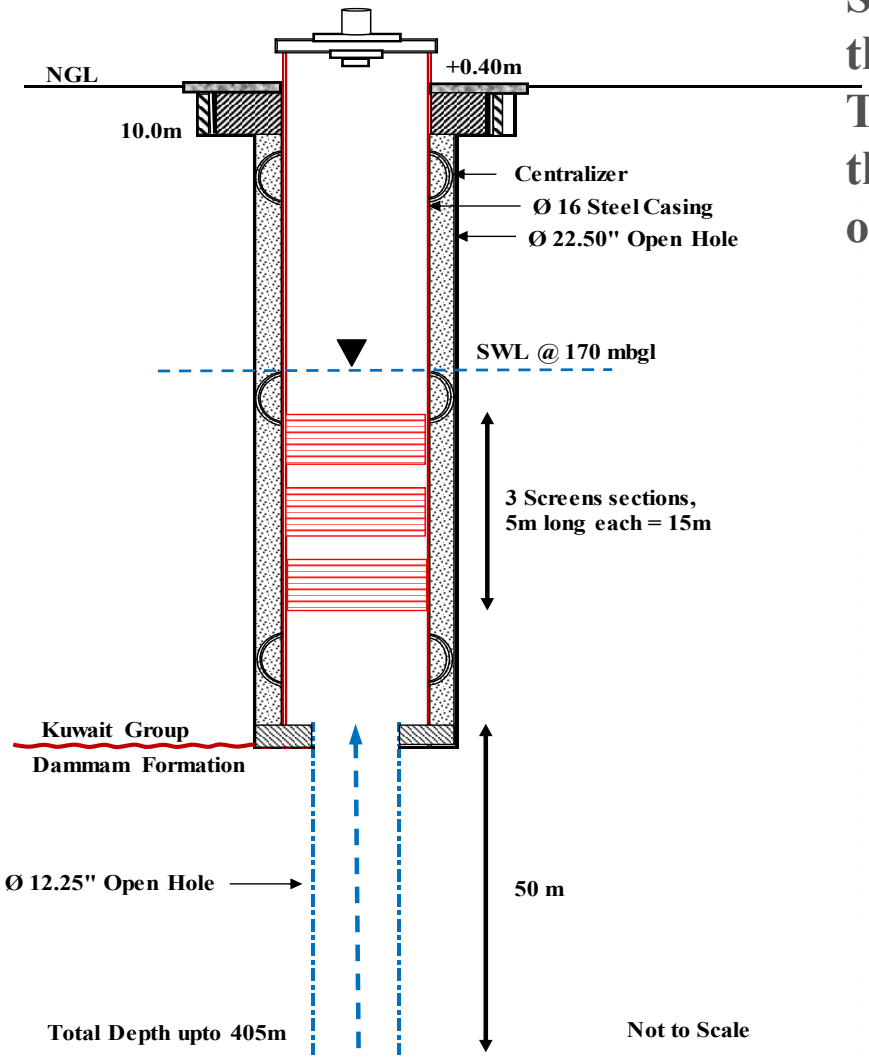


(b) PV Operating Cost (KD)



(c) TPV (KD)





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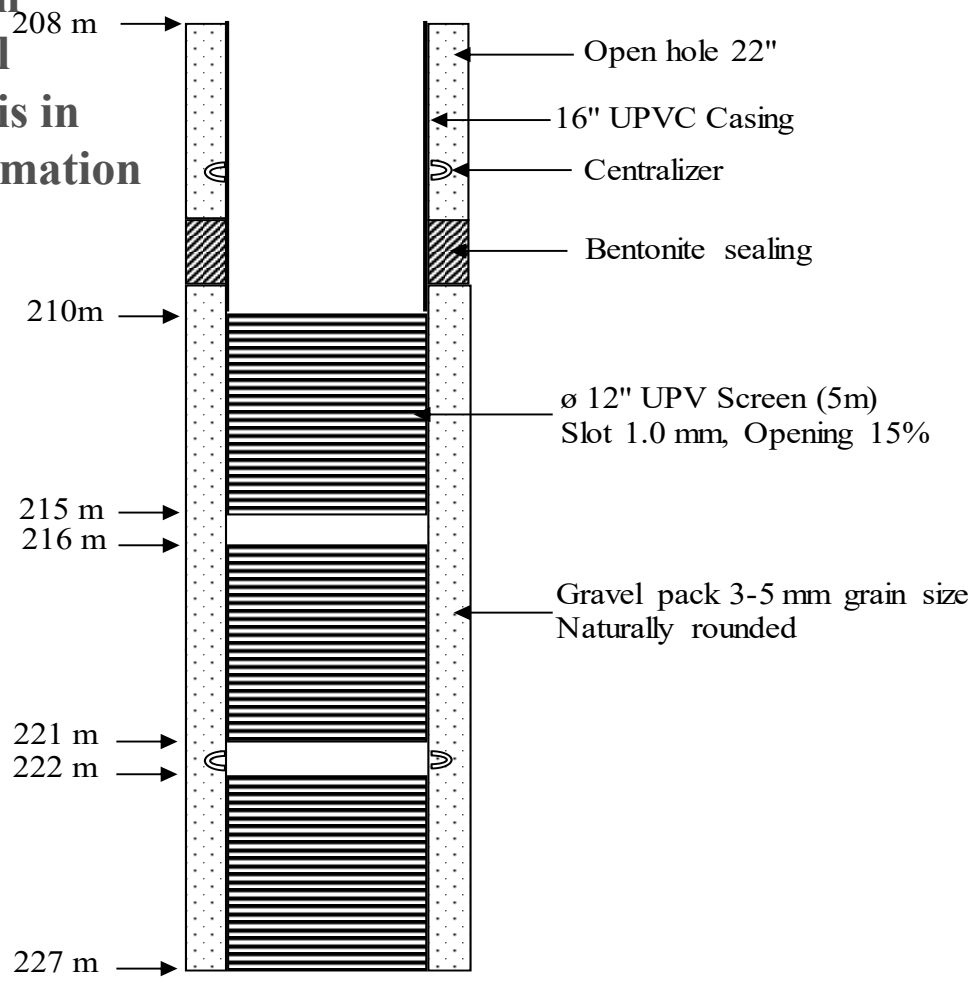

Optimal Screen + Open hole lengths = 65 m

Further discussion about the design

- This means that the 65 m screen length for the screen in KG and the open hole in DM should be divide as follows:
  - 3 screen sections (each section 5 m of total 15 m) versus permeable zones within the 20 m thick of Ghar formation of LKG
  - 50 m should be in the Dammam aquifer as open hole.
- PV of the operating cost is almost 10 folds of the construction cost:

(a) the (λ.t) factors affects heavily operating cost.

(b) Operating costs accumulates for 25 years.

Sensitivity analysis: effect on screen length and open hole length

- AI tools were used to solve **d(TPV)/dLs** = 0
- It was found that **K and Q** are the most influential parameters.
- The lower K value requires longer screens/open holes to achieve the same yield, as the drawdown increases substantially in low-permeability aquifers.

Scenario	K (m/day)	Optimal Ls (m) + open hole (m)	% Change from optimal value
Low	5	205	+216%
Medium	50	65	Optimal value
High	75	53	-18%

Sensitivity to pumping rate (Q)

Scenario	Q (m^3/day)	Optimal Ls (m) + open hole (m)	% Change from optimal value
Low	1500	33	-49%
Medium	3000	65	Optimal value
High	4500	97	+49%

The higher pumping rates require longer screens to minimize head losses and maintain efficient operation.

Sensitivity to energy cost factor (λ)

Scenario	λ	Optimal Ls (m) + Open hole (m)	% Change from Base
Low	0.0003	51	-22%
Medium	0.0005	65	Optimal value
High	0.0007	77	+18%

The higher energy costs make longer screens more economical by reducing operating costs through lower head losses.

Sensitivity to number of operating days (t) in the year

Scenario	t (days)	Optimal Ls (m) + Open hole (m)	% Change from Base
Low	300	59	-9%
Medium	365	65	Optimal value
High	365	65	Number of operating days ≤ 365

The lower number of operating days in the year make Ls shorter by 9% which is more economic for the capital cost increasing operating costs through more drawdown and head losses.

- Other parameters have minor sensitivity effect.
- In practical consideration for this well field:
  - if K < 10 m/day, then screen lengths > 200m may be optimal.
  - If Q > 4000 m^3/day, then screen lengths > 90m.
  - Energy costs significantly influence optimal design in long-term operations.

Sensitivity analysis: Effect on optimal pumping rates

- To get optimal Q, simplify as **V = TPV/Q**, then solve **dV/dQ = 0**.
- The results show that **K** and **λ** are the most influential parameters, causing variations in optimal **Q** of up to 91% and 45% respectively from the optimal case case.
- The optimal pumping rate is approximated at **Q = 7700 m³/day** for average values of the parameters such as **K = 50 m/day, Ls = 65 m, r = 0.05, n = 25 years, λ = 0.0005, t = 365 days.**

- **V = TPV / Q** is simply the **cost per m^3 of water.**
- **Solving dV/dQ = 0** is the mathematical way of finding **Q** where this cost per **m^3 of water** is the very lowest.
- The energy cost for pumping is highly dependent on **Q and Q^2** . A higher pumping rate requires more energy to overcome greater drawdown.
- Therefore, by reformulating the problem as **V = TPV / Q**, then the expression mathematically is given a much more meaningful question.
- **Solving dV/dQ = 0 guarantees that Q will never be zero.**

Parameter	Min.	Max.	Qmin m³/day	Qmax m³/day	% Change from base
K	5	75	2,500	9,500	9500-2500 = 91% of Qbase
λ	0.0003	0.0007	6,500	10,000	45%
Ls	50	80	6,500	8,500	27%
n	15	35	7,000	9,000	24%
r	0.03	0.07	7,000	8,500	20%
t	300	365	7,250	8,500	15%
C_{fixed}	50000	80000	7,250	8,300	13%
Coe_j^i	100	140	7,500	8,000	4%
D_{SWL}	150	190	7,500	7,850	3%
Coe_{casing}	60	90	7,500	8,000	2%
Coe_{screen}	120	180	7,500	8,000	2%

Thank You