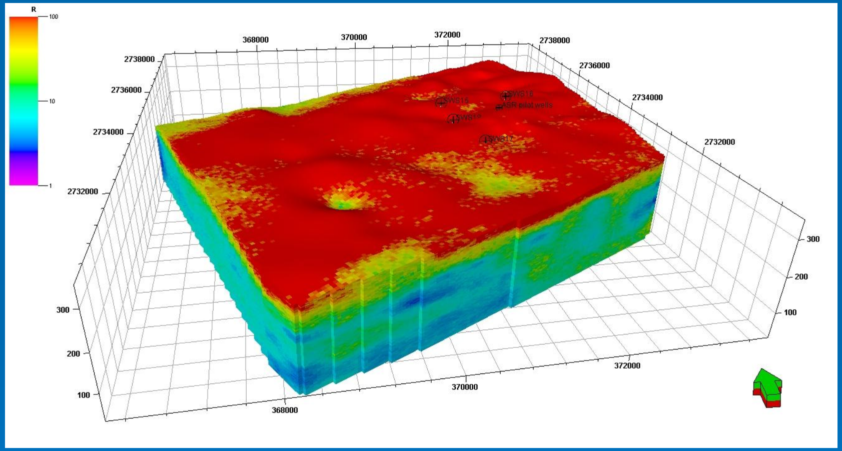
هيئة البيئة – أبوظبي

3-D Characterization of the Complexity of Groundwater Alluvial Aquifer Systems using Geophysical Logging and Geostatistical Analysis in Arid Region



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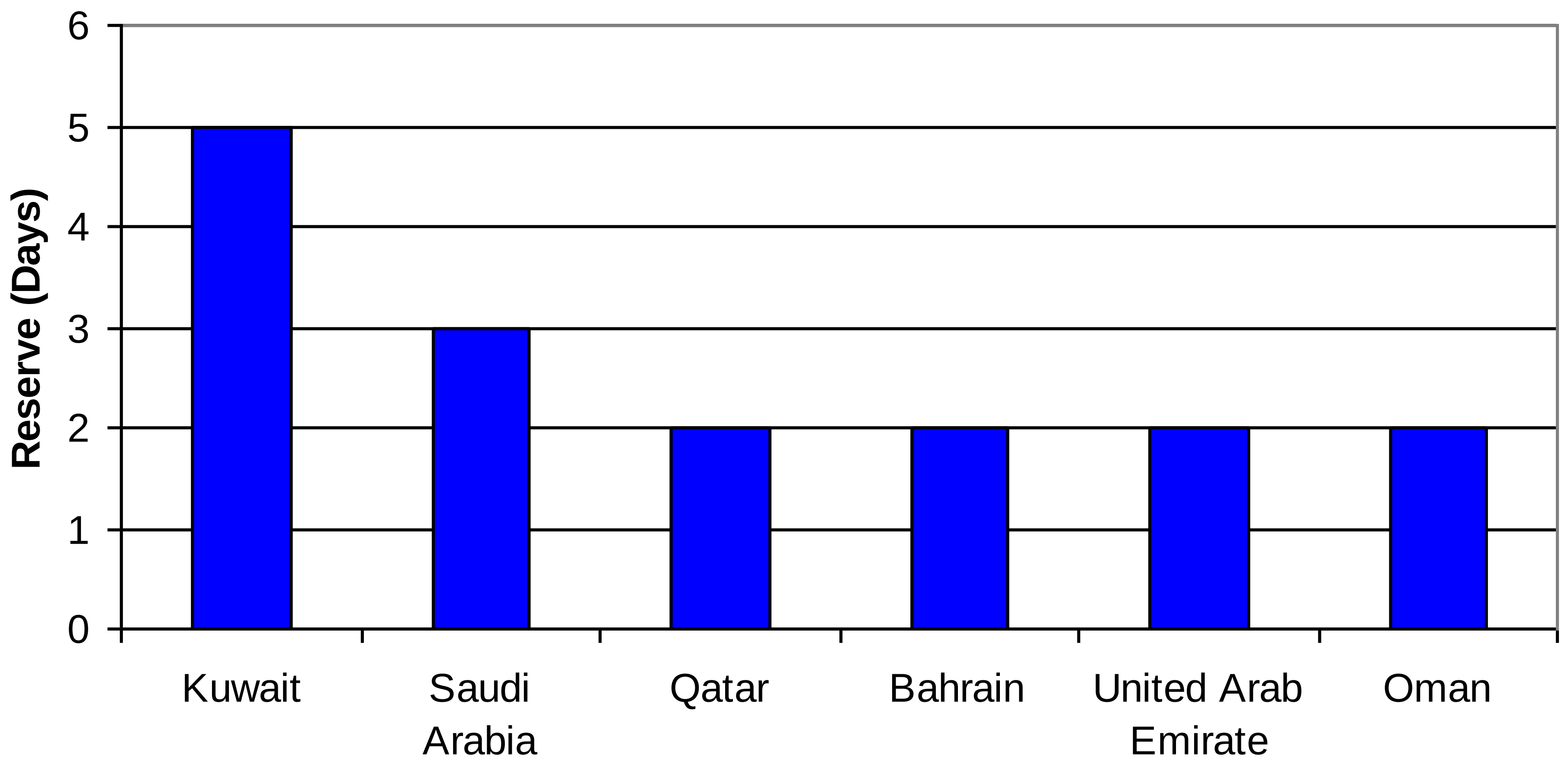
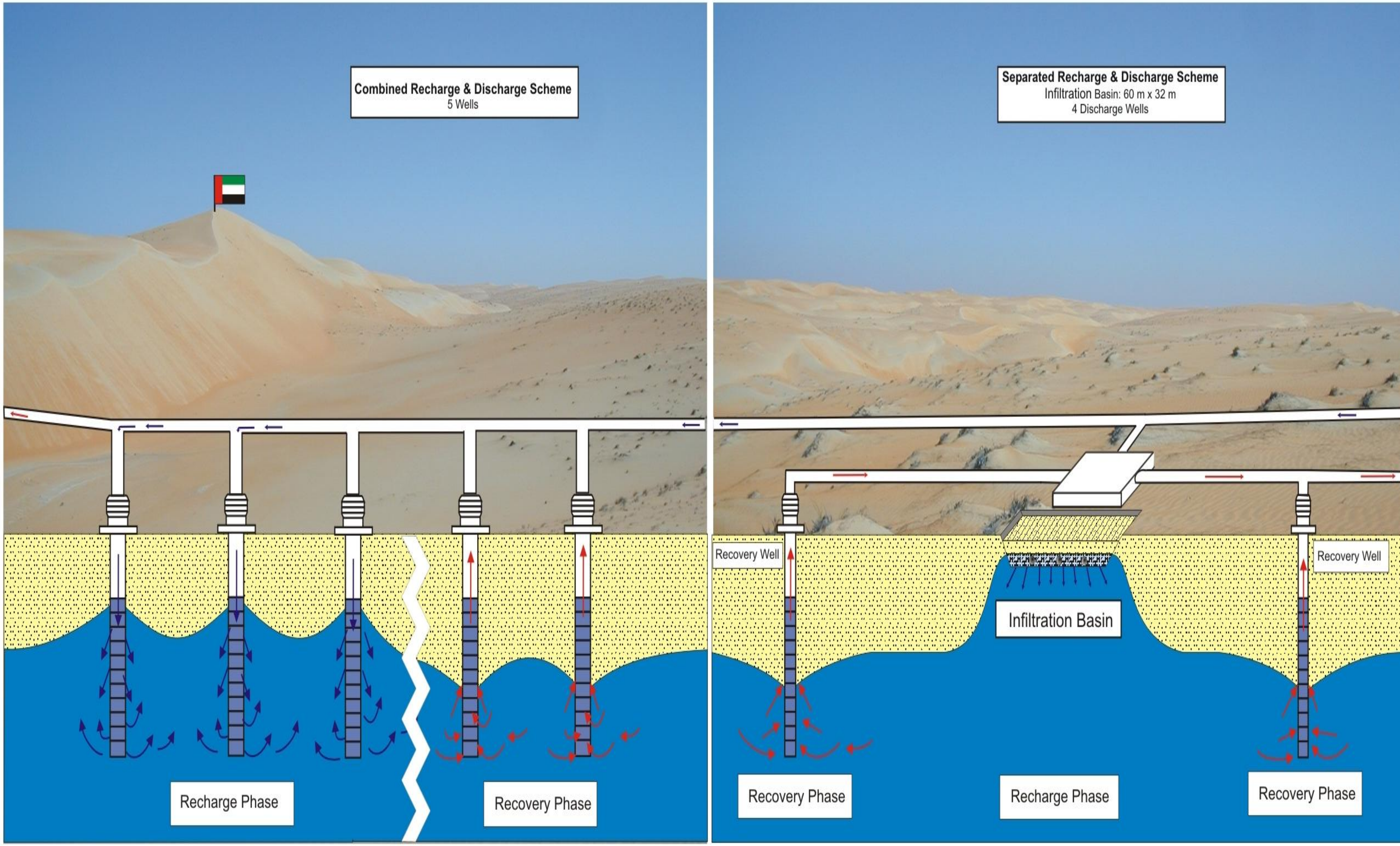
Water Resources Department
Environment Agency – Abu Dhabi
United Arab Emirates

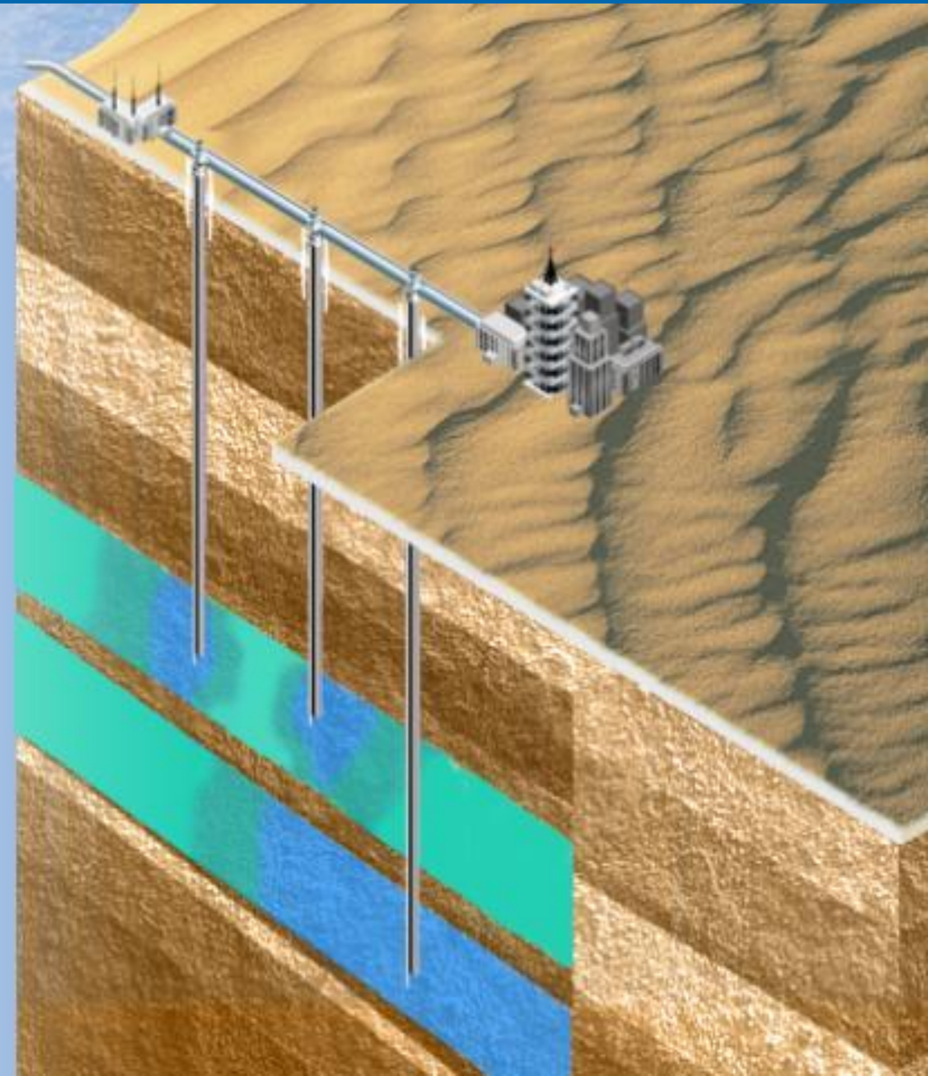
1. General Background




Combined Recharge & Discharge Scheme
5 Wells
Recharge Phase
Recovery Phase
Separated Recharge & Discharge Scheme
Infiltration Basin: 60 m x 32 m
4 Discharge Wells
Recovery Well
Recovery Well
Infiltration Basin
Recovery Phase
Recharge Phase
Recovery Phase

Needs for advanced aquifer characterization

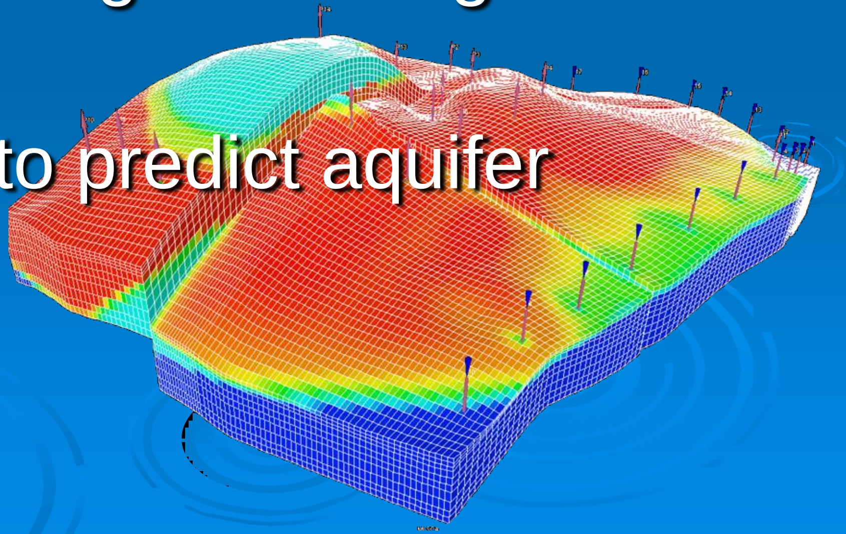
Requirements for accurate understanding, characterization and decision-making

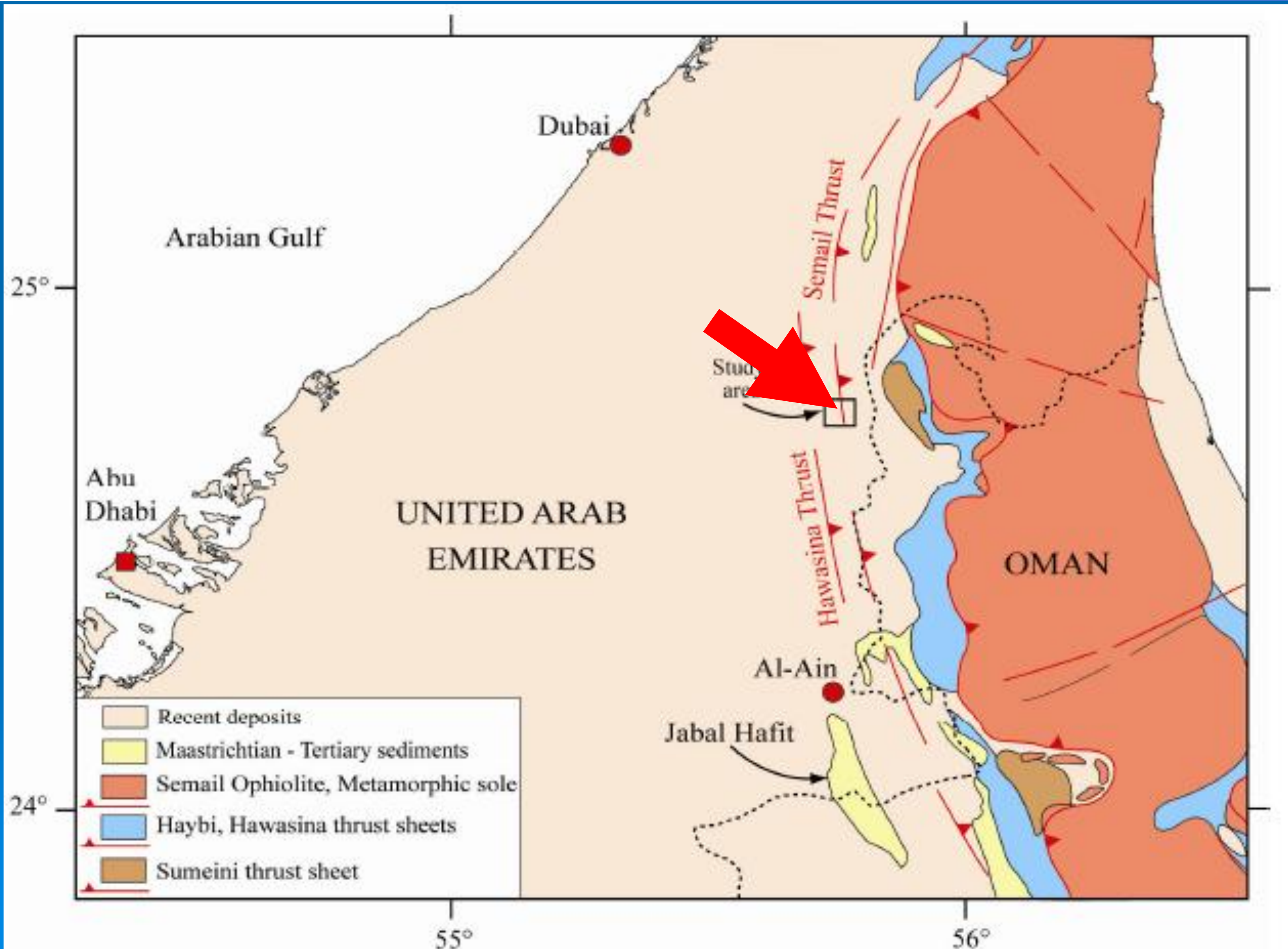


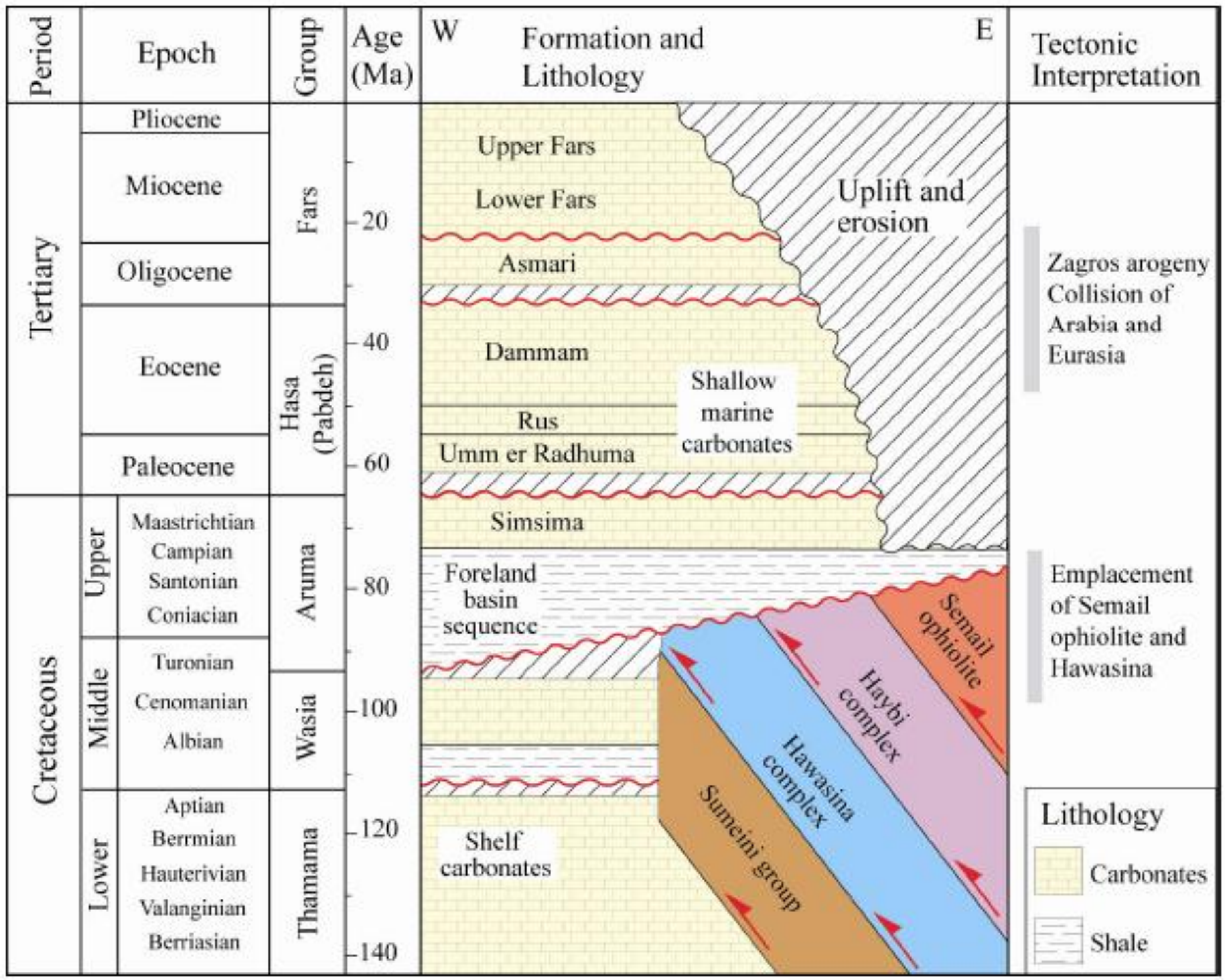
- Geophysical methods play an important role to minimize the cost and efforts for exploring and assessing groundwater aquifer systems through providing information about the physical and hydraulic properties of these aquifers.
- The 3-D geologic characterization of these aquifers a challenging task for the hydrogeologists.
- Geostatistics can be used to 3-D characterization of the complexity of alluvial aquifers in the arid region using the well geophysical logging.

Key advantages of geophysical logging

- High-resolution determination of physical, chemical and hydrodynamic parameters of a targeted aquifer
- To optimize well production and sustainability
- To understand the hydrogeological setting and the potential risks
- To build numerical models to predict aquifer management scenarios



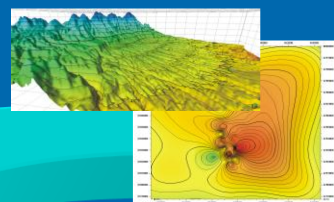

Dubai
Arabian Gulf
Semail Thrust
Abu Dhabi
UNITED ARAB EMIRATES
OMAN
Hawasina Thrust
Al-Ain
Jabal Hafit
25°
24°
55°
56°
Recent deposits
Maastrichtian - Tertiary sediments
Semail Ophiolite, Metamorphic sole
Haybi, Hawasina thrust sheets
Sumeini thrust sheet


Period
Epoch
Group
Age (Ma)
W
Formation and Lithology
E
Tectonic Interpretation
Tertiary
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Cretaceous
Upper
Maastrichtian
Campian
Santonian
Coniacian
Middle
Turonian
Cenomanian
Albian
Lower
Aptian
Berrmian
Hauterivian
Valanginian
Berriasian
Fars
Hasa (Pabdeh)
Aruma
Wasia
Thamama
20
40
60
80
100
120
140
Upper Fars
Lower Fars
Asmari
Dammam
Rus
Umm er Radhuma
Simsima
Shallow marine carbonates
Uplift and erosion
Foreland basin sequence
Shelf carbonates
Semail ophiolite
Haybi complex
Hawasina complex
Sumeini group
Zagros arogeny Collision of Arabia and Eurasia
Emplacement of Semail ophiolite and Hawasina
Lithology
Carbonates
Shale

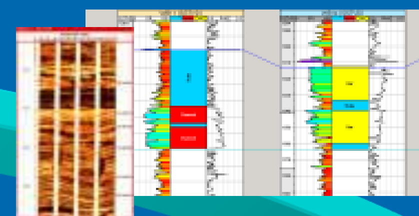
The HydroWorkflow

Data gathering/input
Information management
GIS database

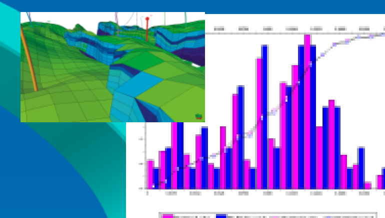
Surface imaging
Mapping
EM survey interpretation



Geophysical log interpretation
Well correlation
Surface identification
Surface/subsurface interaction

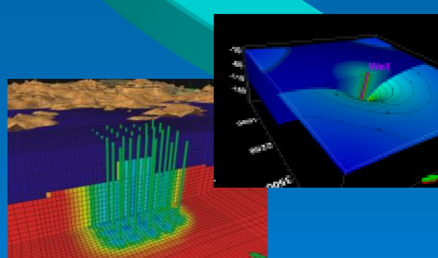


Data analysis
Facies modelling
Fault modelling
Fracture modelling
Hydrodynamic test analysis

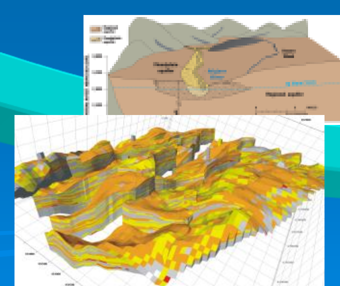


Calibration
History match
Post processing
Presentation

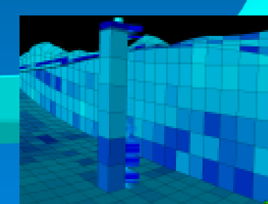
Eclipse
VModflow
Feflow



3D flow & mass transport simulation
Saturated and variably saturated conditions
Density dependent modeling
Geomechanics



3D hydrogeological model
3D geological model
Hydrogeological conceptual model



Uncertainty analysis
Upscaling processes
Aquifer property population

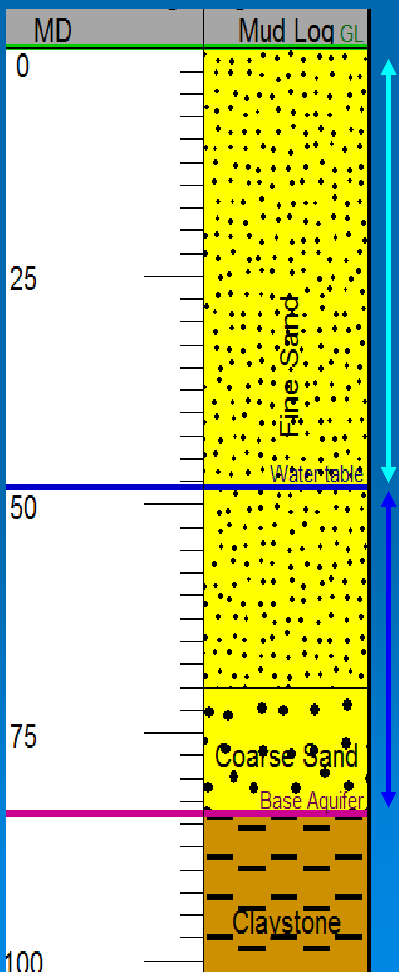
Advanced borehole geophysical logs were acquired for 12 wells

Geophysical Borehole Logging:

- PEX/AIT/ECS/GR/Caliper: Rock Density, Rock Neutron Porosity. Elemental Capture spectroscopy, Rock Electrical Resistance at varying distance from the borehole, Natural Gamma Ray, and bore hole caliper
- CMR/GR: Nuclear Magnetic Resonance, Natural Gamma Ray
- FMI/GR: Formation Micro Imager, Natural Gamma Ray

Well	Date Logged	Type of Logs*	Logged Interval (MT)
SWS01	04 June 2004	PEX/AIT/ECS/CMR/FMI	16.80 – 323.00
SWS05	11 Oct. 2005	PEX/AIT/ECS/CMR/FMI	18.80 – 102.20
SWS17	14 Oct. 2005	PEX/AIT/ECS/CMR/FMI	12.20 – 145.10
SWS15	21 Oct. 2005	PEX/AIT/ECS/CMR/FMI	11.60 – 95.10
SWS11	23 Oct. 2005	PEX/AIT/ECS/CMR/FMI	15.00 – 119.50
SWS16	26 Oct. 2005	PEX/AIT/CMR/FMI	13.70 – 98.20
SWS18	03 Nov. 2005	PEX/AIT/ECS/CMR/FMI	10.70 – 101.20
SWS08	05 Nov. 2005	CMR	10.60 – 101.20
SWS06a	15 Nov. 2005	PEX/AIT/CMR	15.00 – 110.00
SWS20	16 Nov. 2005	PEX/AIT/CMR	15.00 – 111.00
SWS09	20 Nov. 2005	CMR	12.00 – 119.00
SWS04	20 Nov. 2005	CMR	12.00 – 111.00

Unsaturated Zone Properties

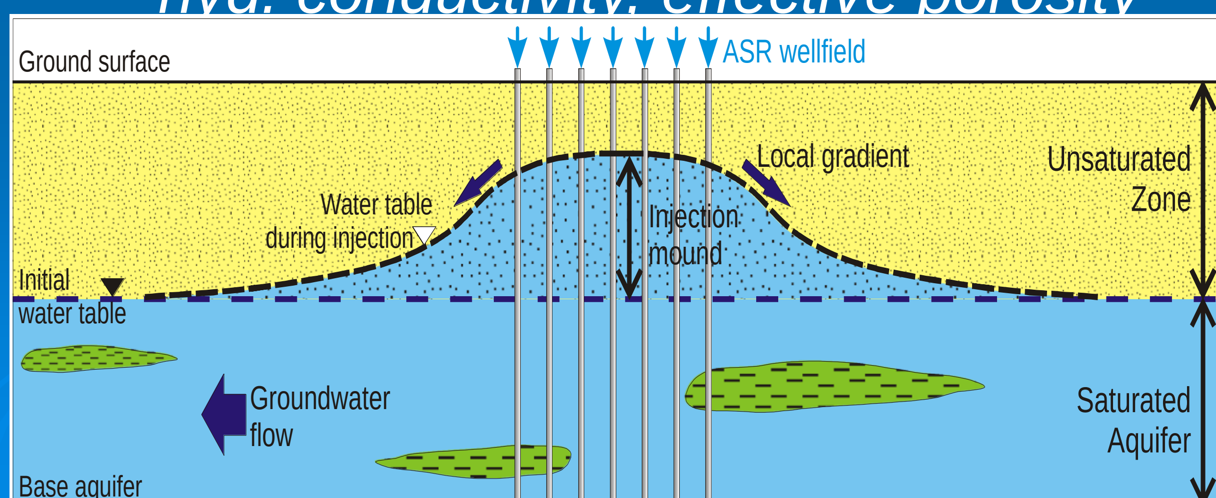


Unsaturated zone

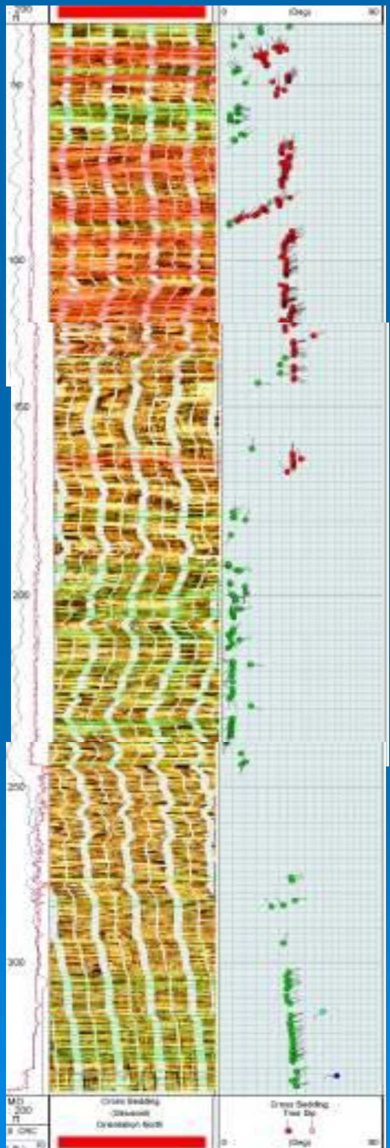
Saturated zone

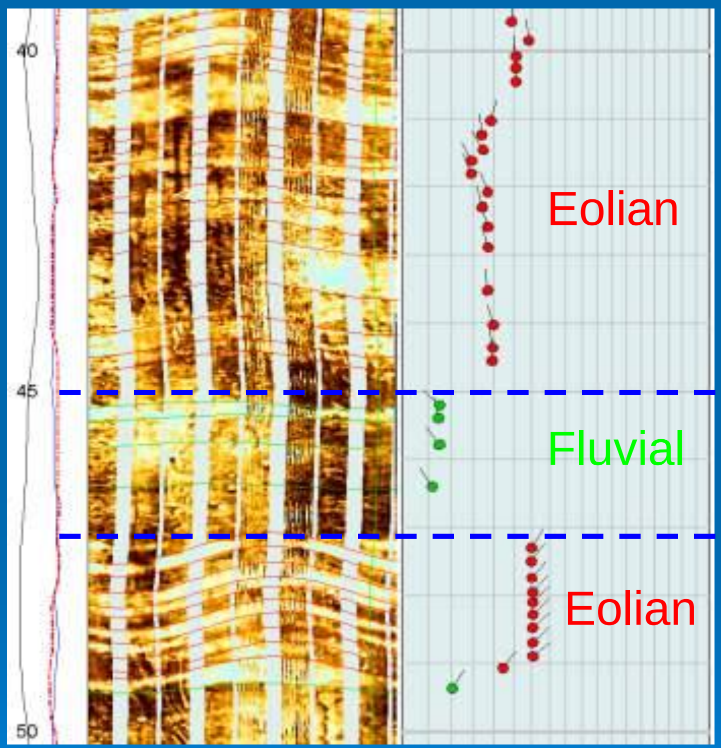
Can we extract unsaturated zone properties from geophysical logs ?

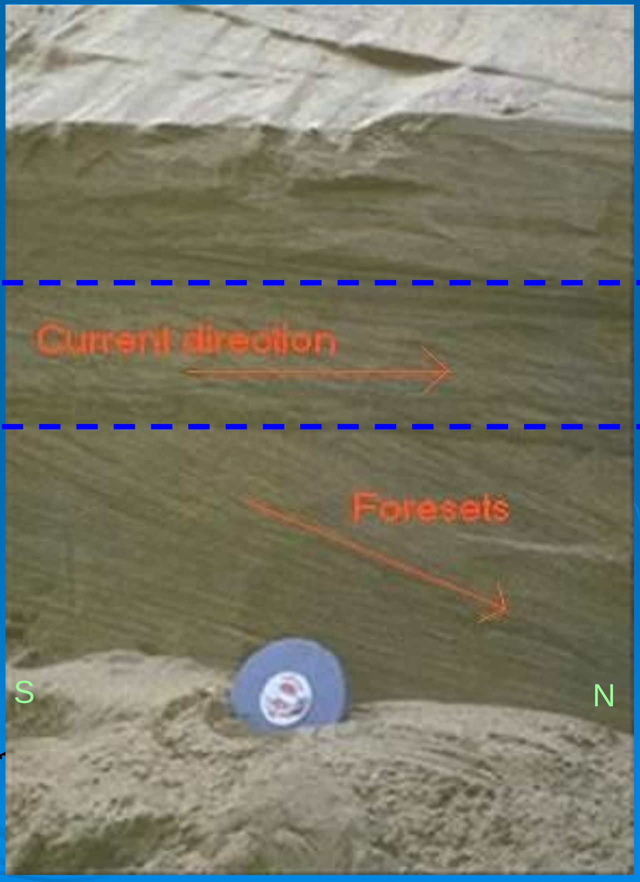
e.g. water saturation, capillary pressure, relative permeabilities, hyd. conductivity, effective porosity



Sedimentary Interpretation

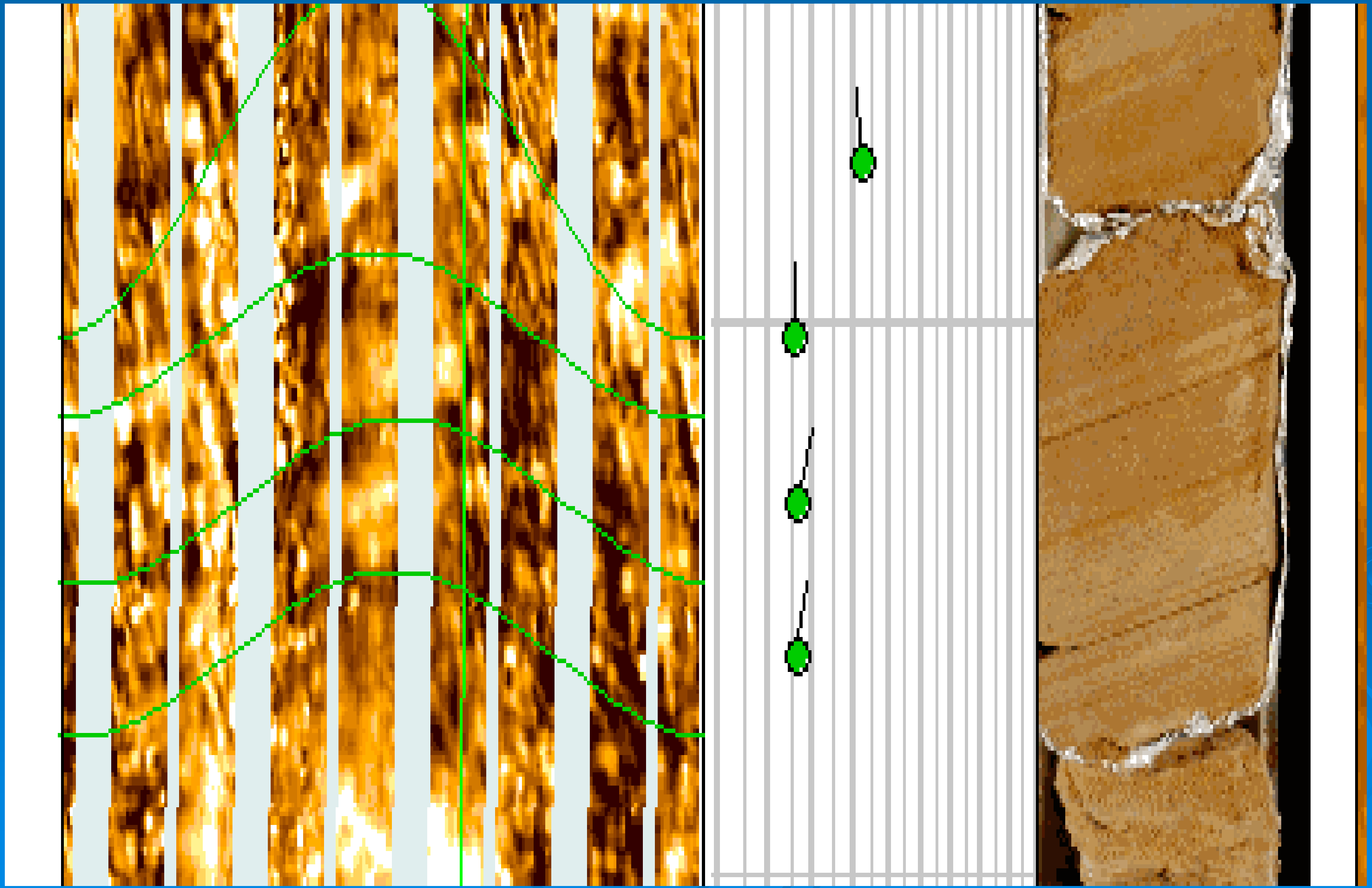






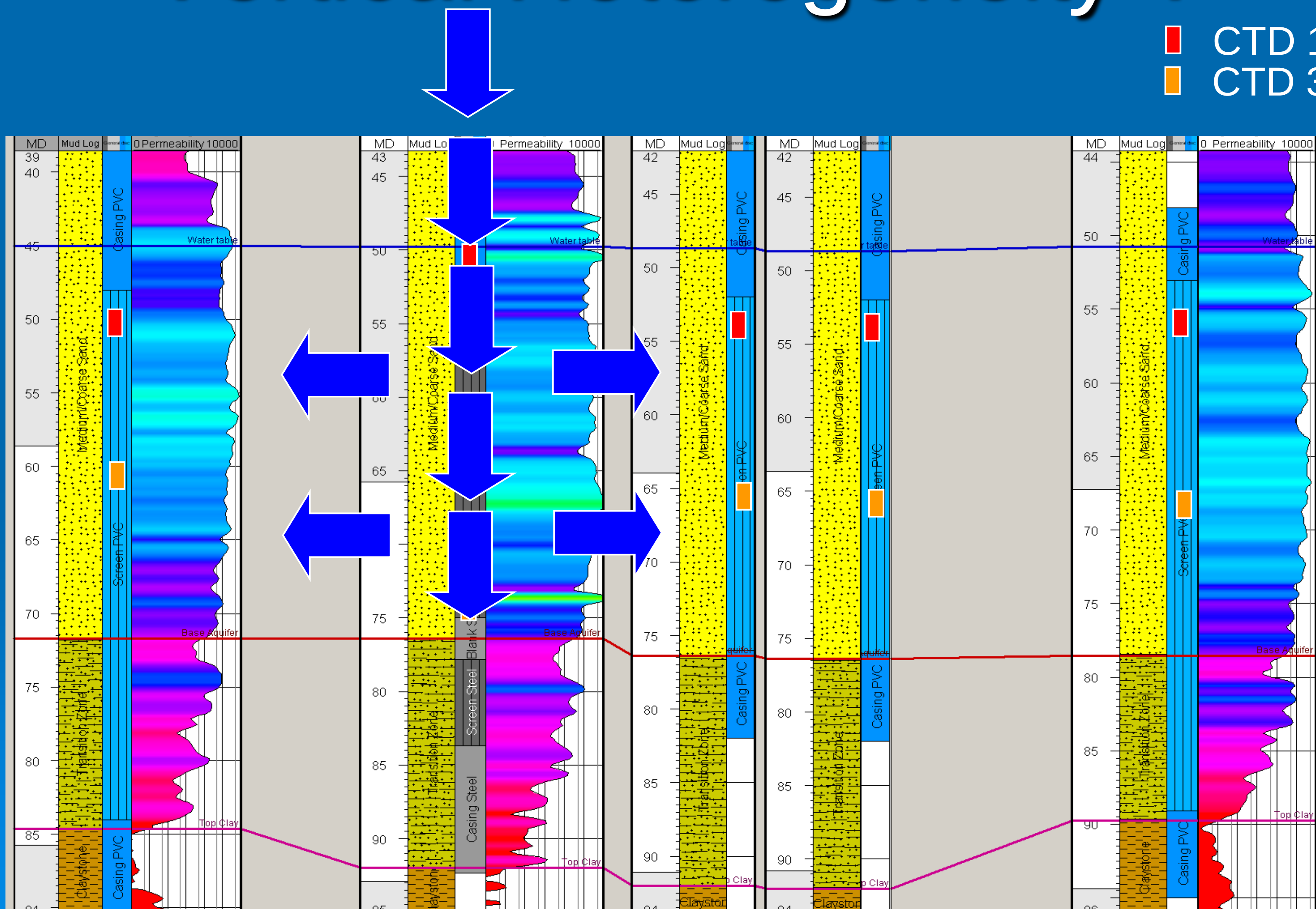
Preferred Groundwater Flow Direction =
Perpendicular to Sedimentary Dip
condX, condY, condZ - anisotropy

Core Porosity/Permeability and CMR Log



Vertical Heterogeneity ?

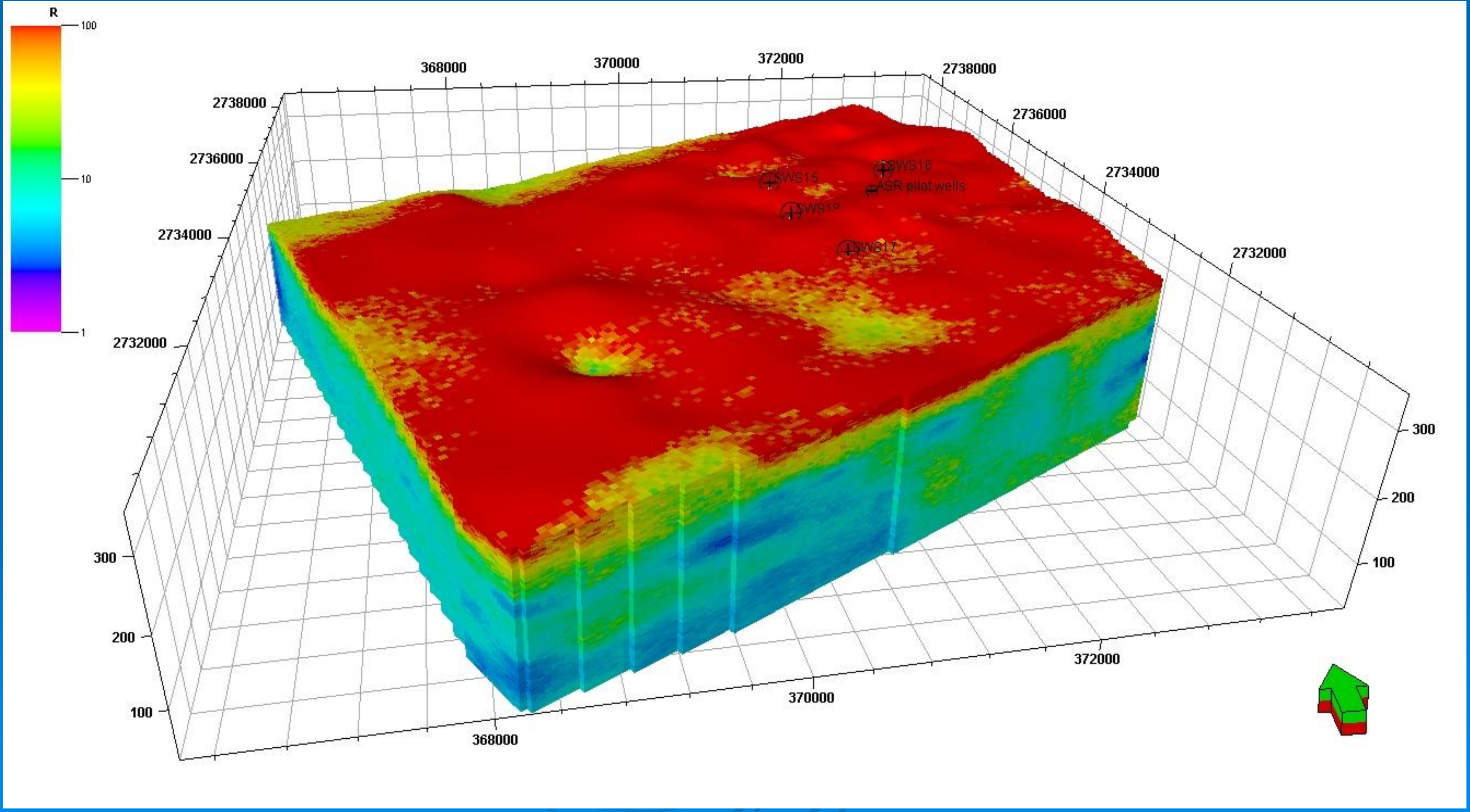
- CTD 10m diver
- CTD 30m diver



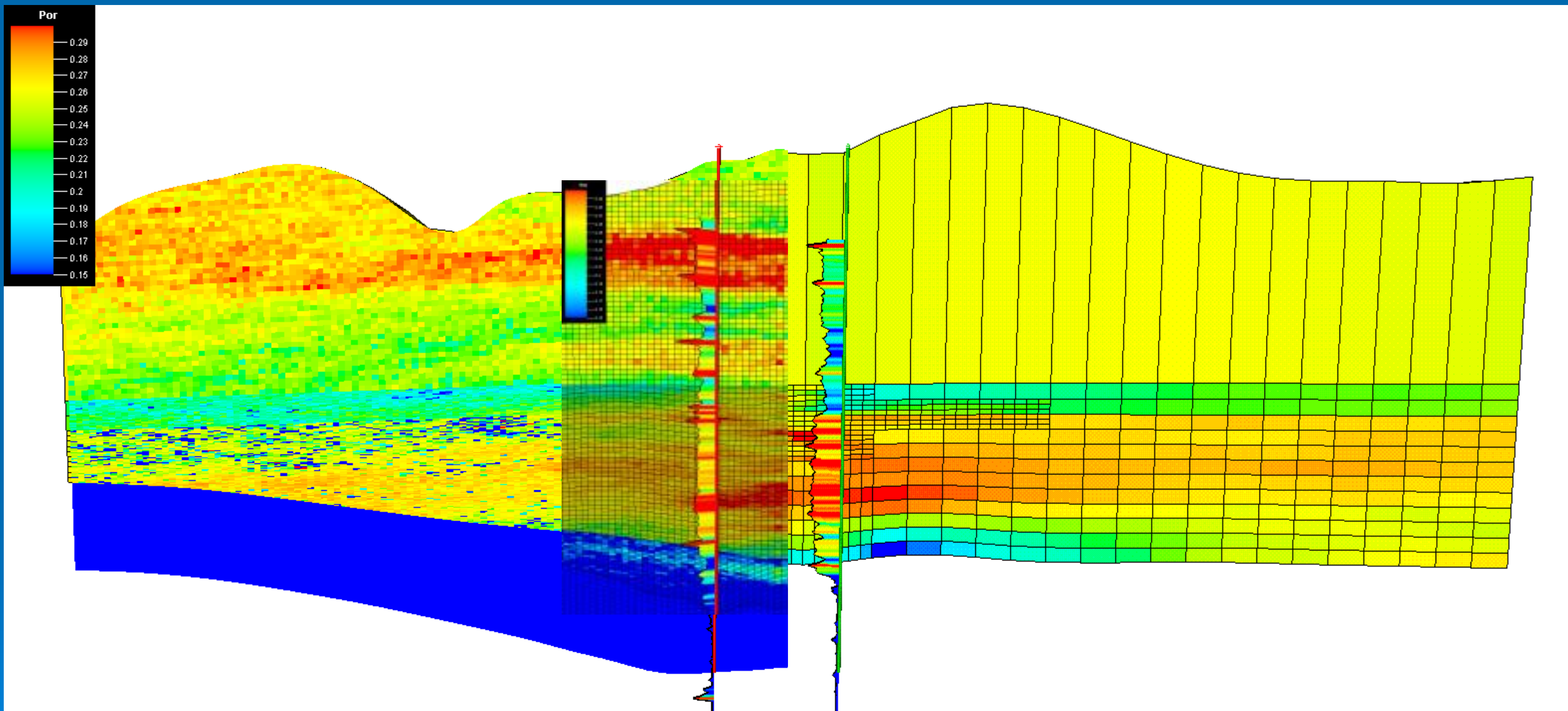
Summary of the Log Interpretation Results.

Well	Water Table mbGE	Bottom of Aquifer mbGE	Saturated thickness m	Total Porosity	Effective Porosity	Hydraulic. Conductivity m/d	Water Salinity TDS mg/l
SWS01	48.80	79.30	30.50	0.34	0.27	3.3	590
SWS08	40.80	69.60	28.80	0.35	0.28	3.6	NA
SWS04	49.50	80.5	31.00	0.32	0.25	1.6	NA
SWS06a	53.00	75.60	22.60	0.34	0.27	3.3	590
SWS15	49.40	49.40	00.00	0.30	0.24	N/A	N/A
SWS11	51.50	78.00	26.50	0.37	0.28	1.8	680
SWS16	37.50	64.02	26.52	0.36	0.29	4.5	600
SWS17	29.88	43.90	14.02	0.36	0.29	11.5	550
SWS18	29.27	48.78	19.51	0.34	0.29	3.2	550
SWS20	43.60	71.00	27.40	0.34	0.28	2.0	550

Three Dimensional Geostatistical Simulation
3-D Model of Resistivity for the study area



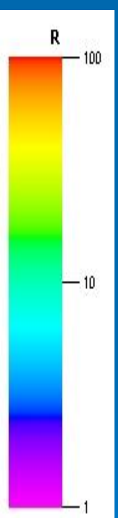
Fine Model vs Coarse Model

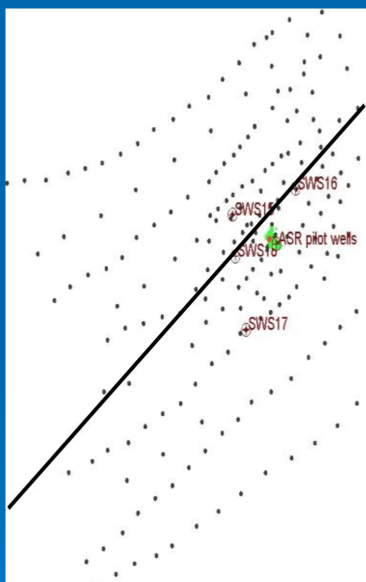


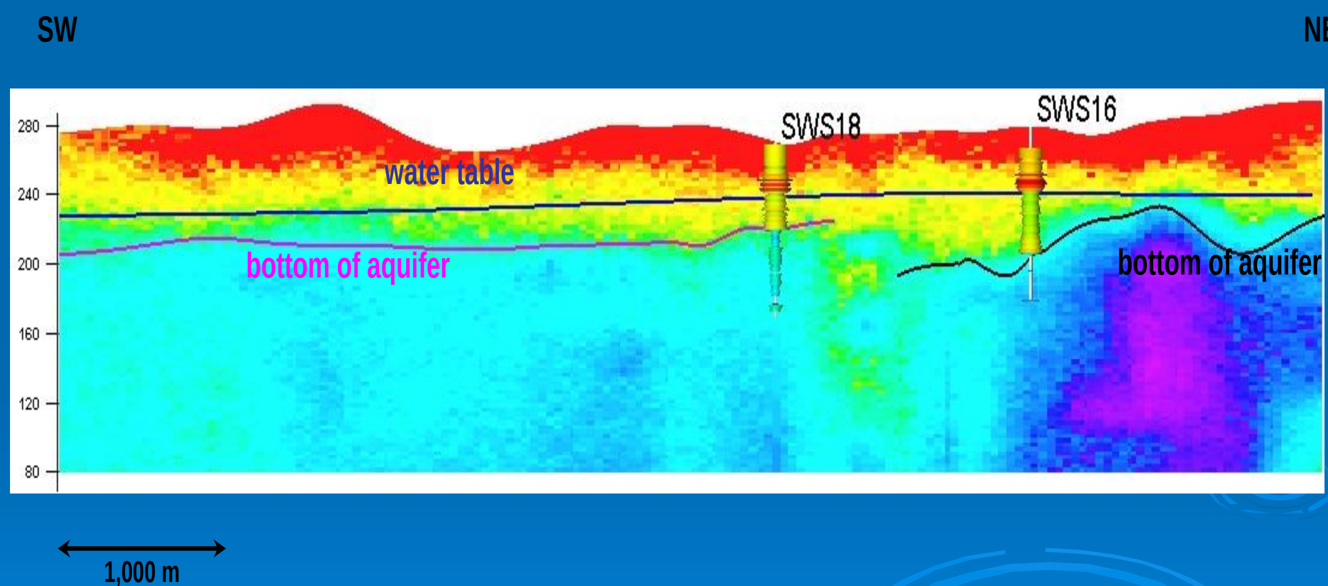
- Hydrogeological Model
- 11 Mio. cells
- 25 cm vertical layer resolution

- Simulation Model
- 170000 cells
- 1 – 3 m vertical layer resolution

SW-NE Resistivity Cross-section and Resistivity Log at SWS18 and SWS16

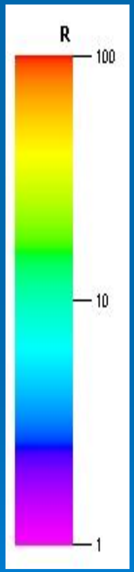


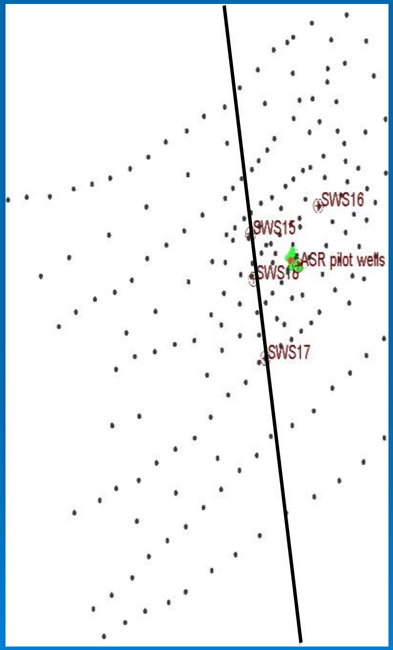


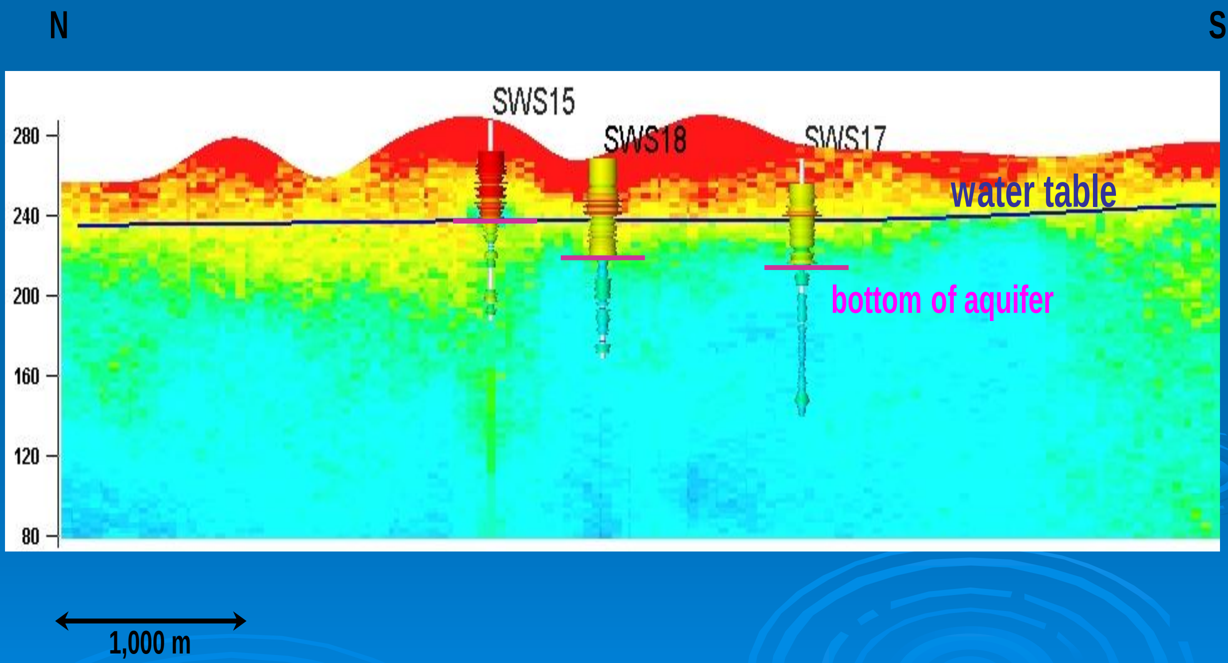


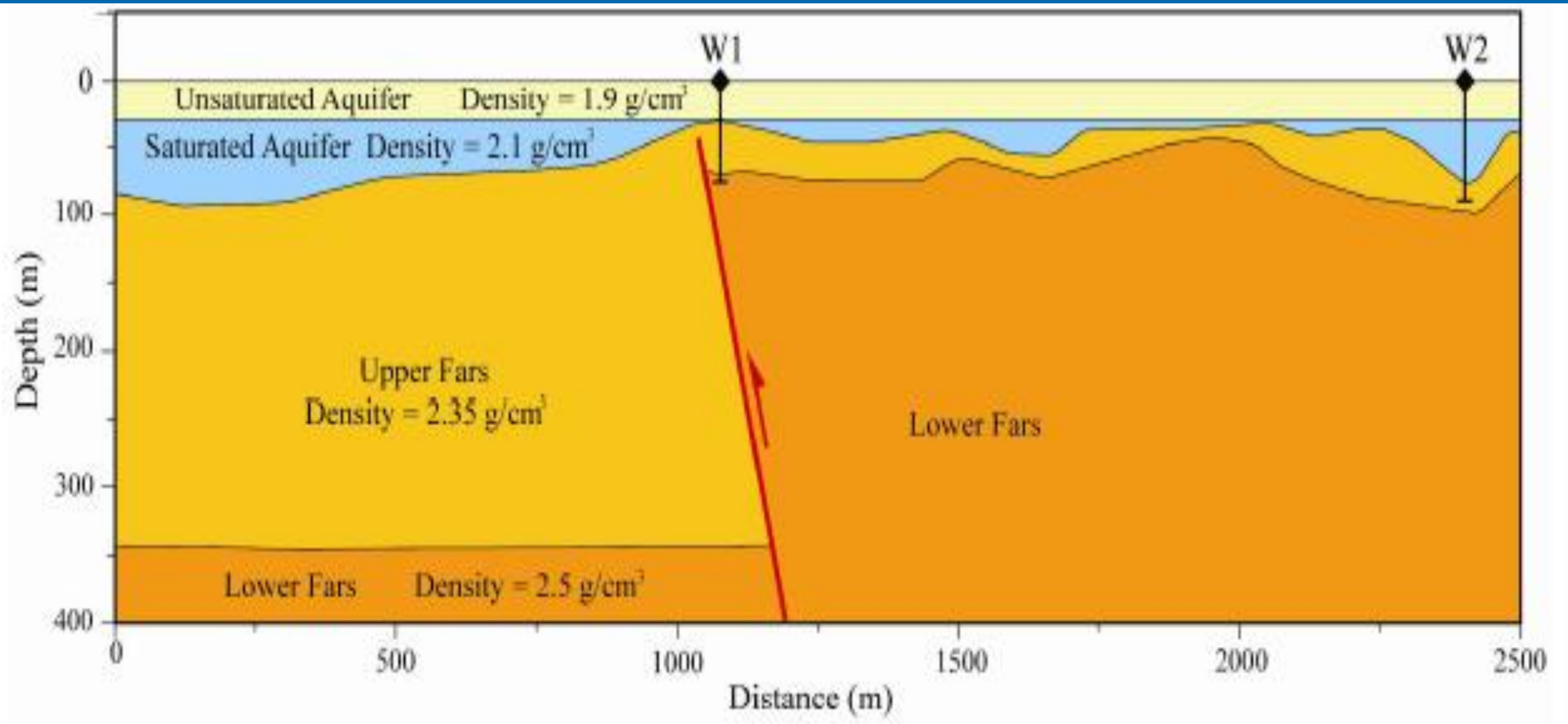
discontinuity in the clayey unit

NS Resistivity Cross-section and Resistivity Log at SWS15, SWS18 and SWS17

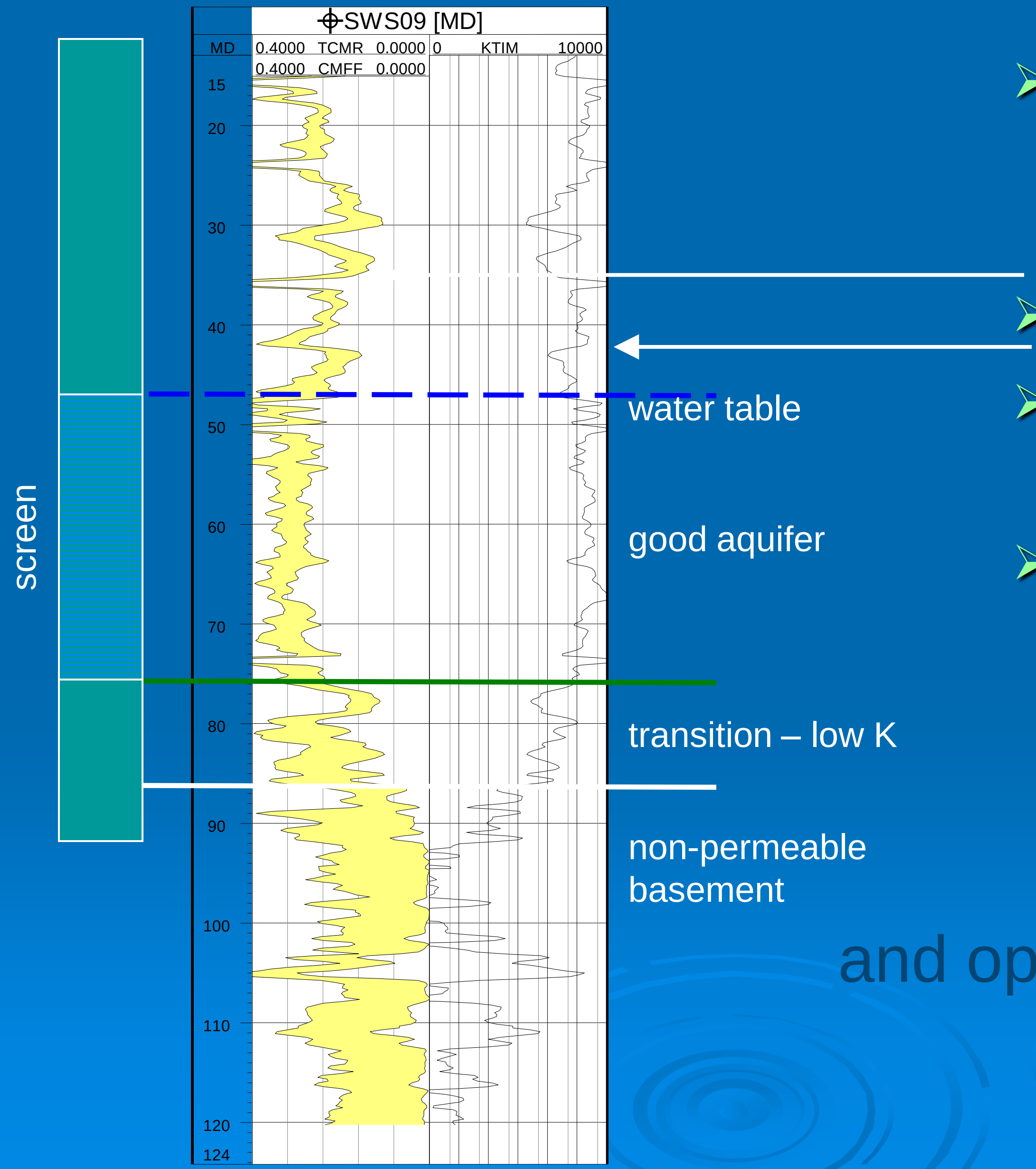







W1
W2
Unsaturated Aquifer Density = 1.9 g/cm³
Saturated Aquifer Density = 2.1 g/cm³
Upper Fars
Density = 2.35 g/cm³
Lower Fars
Lower Fars Density = 2.5 g/cm³
Depth (m)
0
100
200
300
400
0
500
1000
1500
2000
2500
Distance (m)

… to estimate hydrodynamic properties



- From NMR measurements (CMR tool)
- Porosity distribution
- Total vs. effective porosity
- Permeability log

=> improve pumping-test interpretation and model accuracy

and optimize well completion

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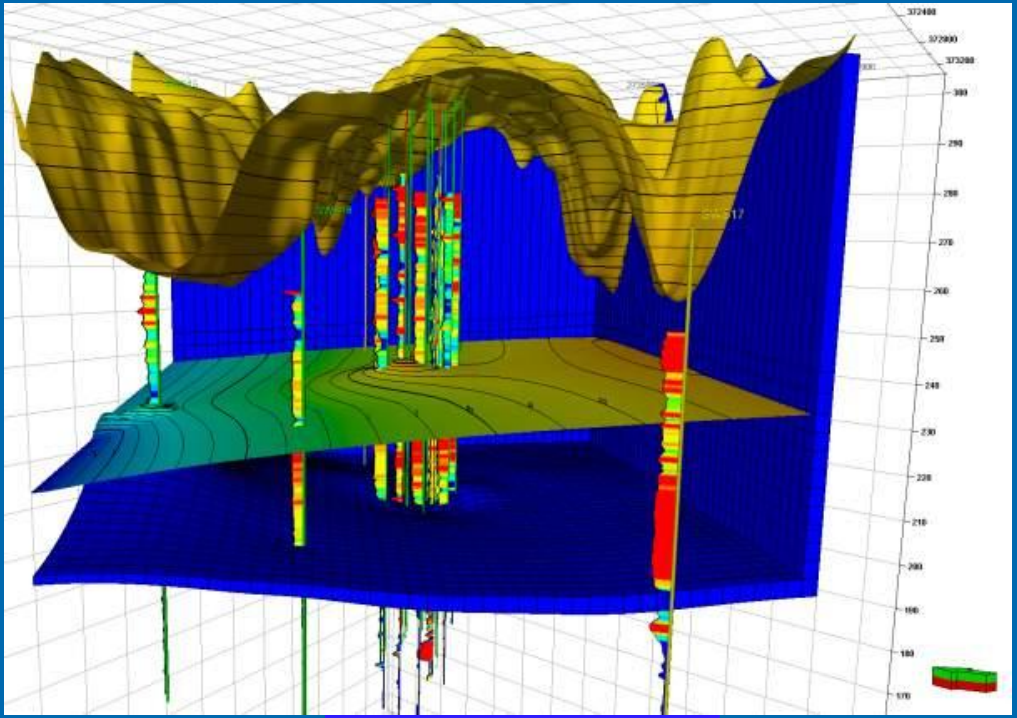
Environment Agency-ABU DHABI

RESEARCH • DEVELOPMENT • PROTECTION

Concluding Remarks

- New hydrogeological investigation techniques and analysis methods can improve considerably the reliability of the 3D hydrogeological high resolution models.
- This leads to an improved success rate for the evaluation of aquifers.
- Complex hydrogeological settings need high resolution models (e.g. heterogeneous alluvial aquifers, fractured aquifers).
- Unconfined aquifer evaluation success rate can be optimized with advanced field investigation methods and interpretation workflows.





Improved Aquifer Characterization

Thanks