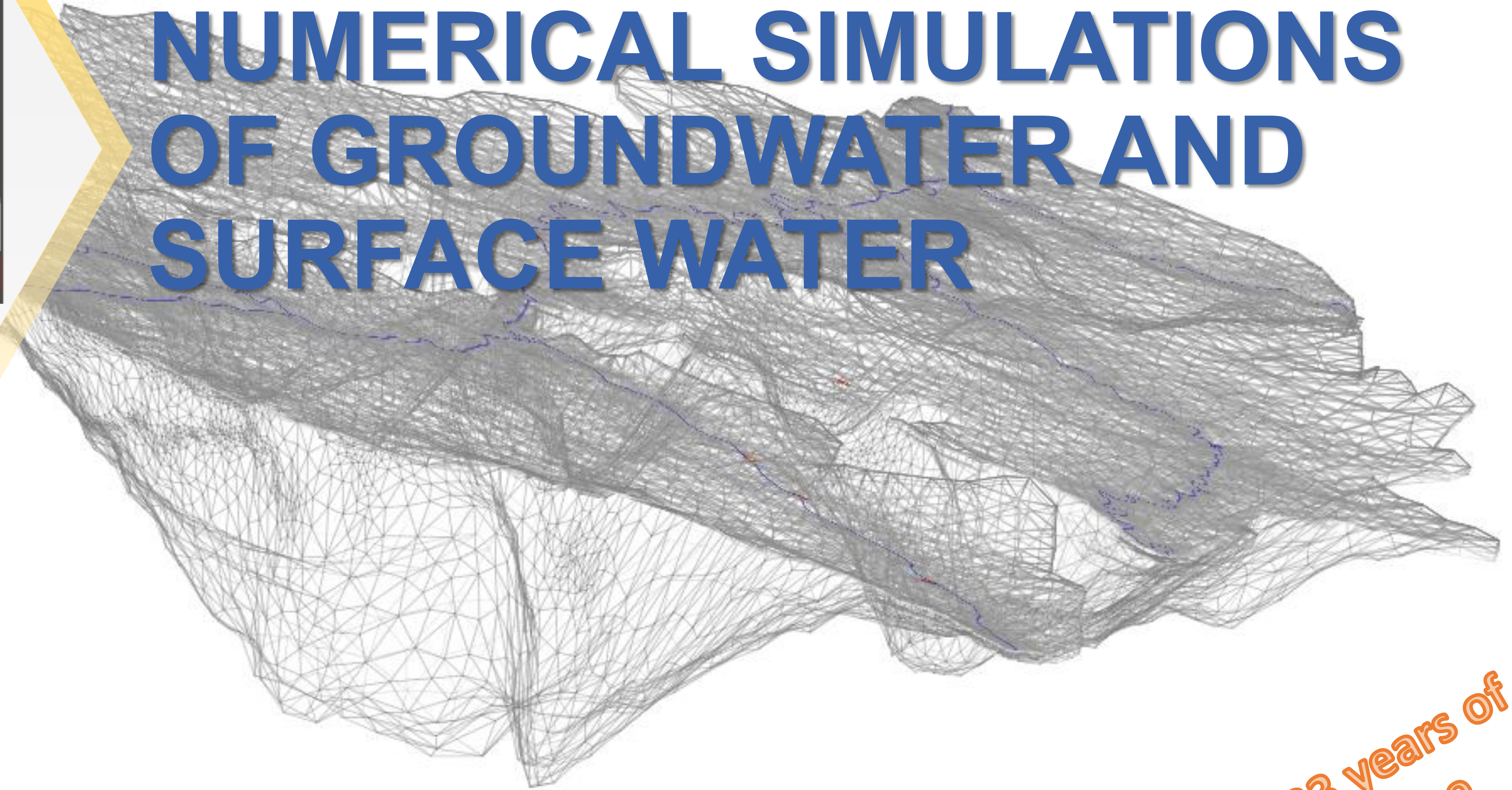
NUMERICAL SIMULATIONS OF GROUNDWATER AND SURFACE WATER



Dr Boris Matti, MAI 2025

2025 - 23 years of experience

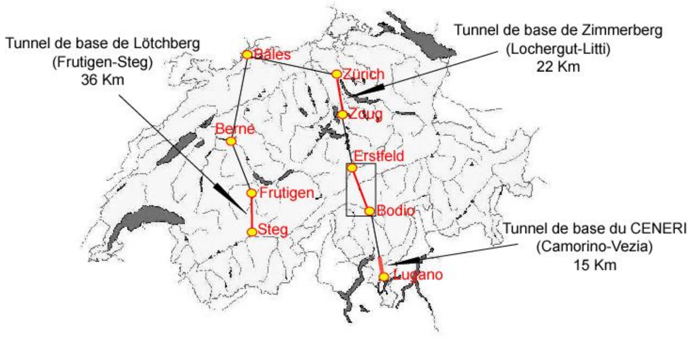
FLOW, THERMAL and MASS TRANSPORT MODELS

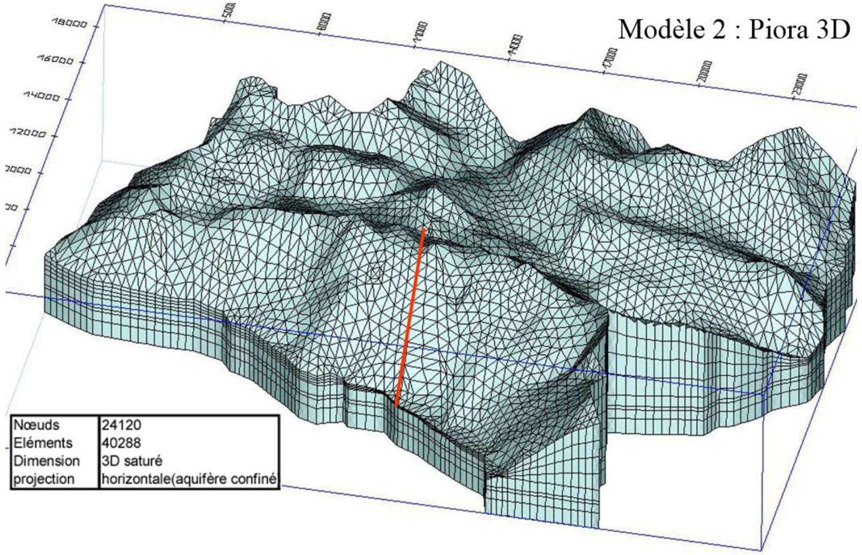
Type of Models and Objectives	References
Flow and **thermal** at the level of the Alpine massif	Piora gallery, Gothard Base Tunnel (TI, CH)
Flow and **hydro-mechanical** coupling of landslides	La Frasse (VD, CH)
Flow and **thermal** for the study of heat pumps	Sion Hospital and SUVA (VS, CH), San Vittore (GR, CH), Migros Aigle (VD, CH), Osogna (TI, CH), Giubiasco (TI, CH), Cadempino (TI, CH), Stabio (TI, CH)
Flow for the **mining sector**, sustainability study of water resources, pumping strategy and long-term groundwater drawdown with regional impact study	As Suq, Ad Duwahyi and Humaymah Gold mines (KSA)
Flow at urban scale for construction of metro lines or tunnels	Riyadh (KSA), Doha (QA), Pian Magadino Tunnel (TI, CH)
Flow at the urban scale for dewatering, drawdown and water table control	Dubaï DEWA (UAE) , DIP and BESIX (UAE), Beach Well System (Brunei), Hassya (UAE), Emaar (UAE), Shuraya Island (KSA)
Flow at the peri-urban scale for drawdown water table control	Dubaï AL MAKTOUM INTERNATIONAL AIRPORT (UAE)
Flow and **mass transport** for environmental studies impact, incl. pumpings	Beach Well System (Brunei), NEOM Development (KSA), Trojena catchment (KSA)
Flow at an urban/regional scale for the study of the water resources and manage/recharged aquifer project	Kabul (AF), Saq and Dawadmi Aquifers (KSA), Wilaya El Menia (Algeria), Niger (NIGER)
Flow at a local scale with coupling of surface water and groundwater for aquifer recharge study	Kabul (AF), Wadi Al Alb (KSA), Al Ghat (KSA), Bishah (KSA)
Flow and **mass transport** at a regional scale for the study of the reinjection of treated sewage effluent (TSE) and storage in hypersaline environments	Lusail, ECS, Messaimeer Graveyard, Al Rayyan Stadium (Doha, Qatar), Aquifer Storage and Recovery (ASR) (QATAR), NEOM Development (KSA)
Flow and **mass transport** at a local scale for the study of the interactions between lake water and aquifer	Maroggia (TI, CH)
Flow for **geotechnical** studies, dewatering estimations, sheet piling, retention basin	Koweit, BESIX (UAE), Bégnins (VD, CH), Stazione di pompaggio-ARM (TI, CH), IDA Vacallo (TI, CH), IDA Giubiasco (TI, CH)

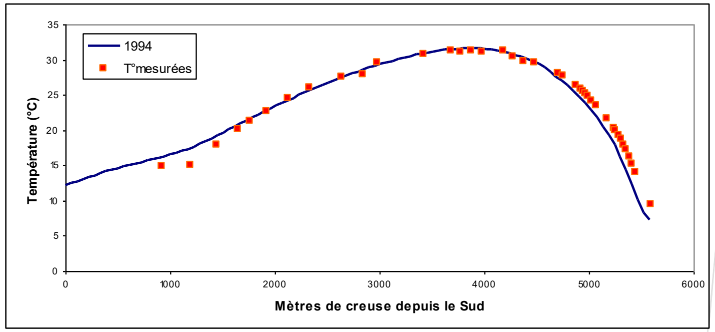
FEFLOW

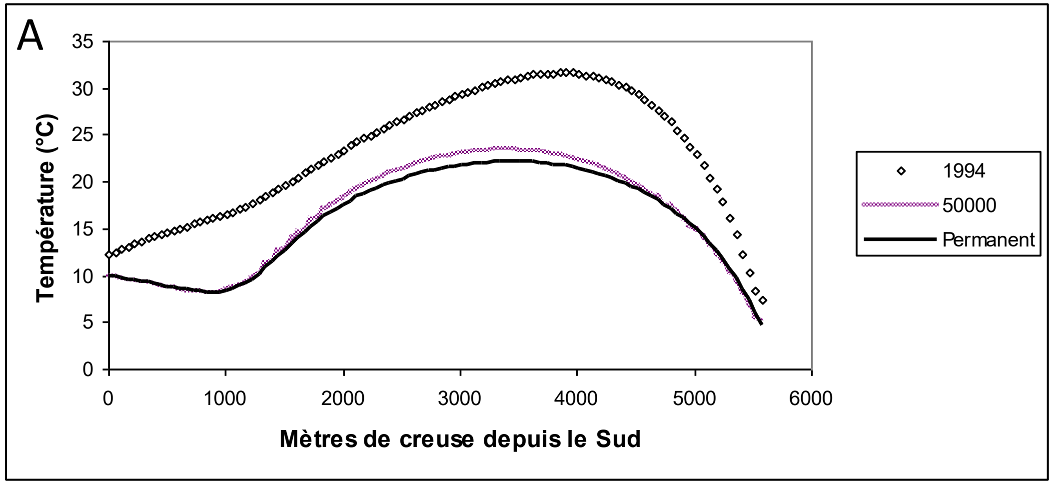
CASE 1 PIORA – ALPTRANSIT (TI, CH) – 3D HYDRO-THERMAL (2001-2002)

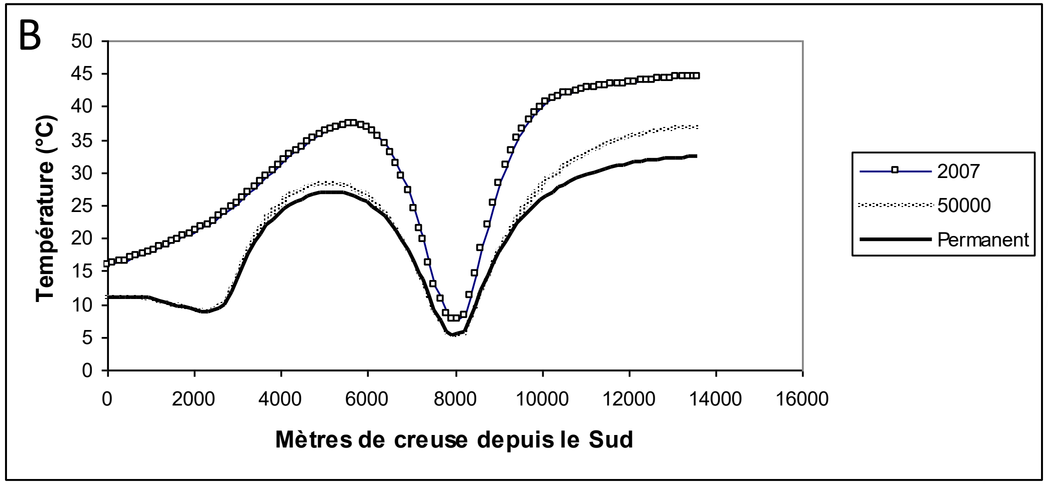
Objectives: To calibrate a 3D hydro-thermal model of the Gotthard massif and to estimate the temperatures during the drilling of the Alptransit base tunnel. Approach point: La Piora gallery.









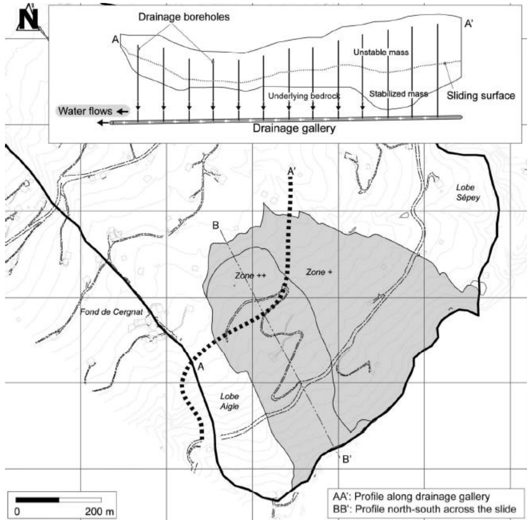


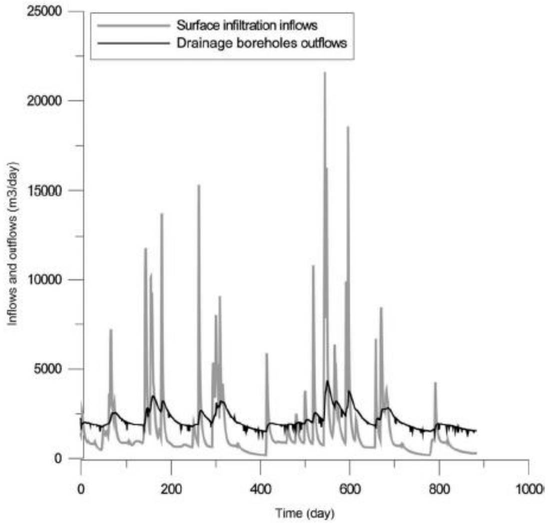
GeoBM Sagl

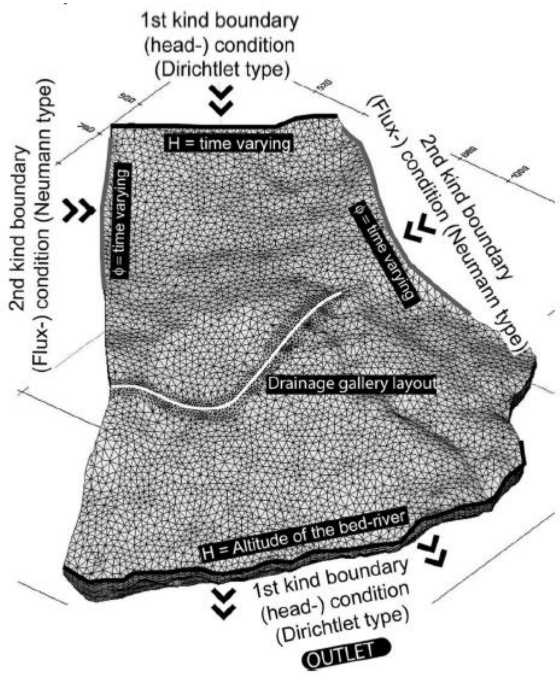
FEFLOW

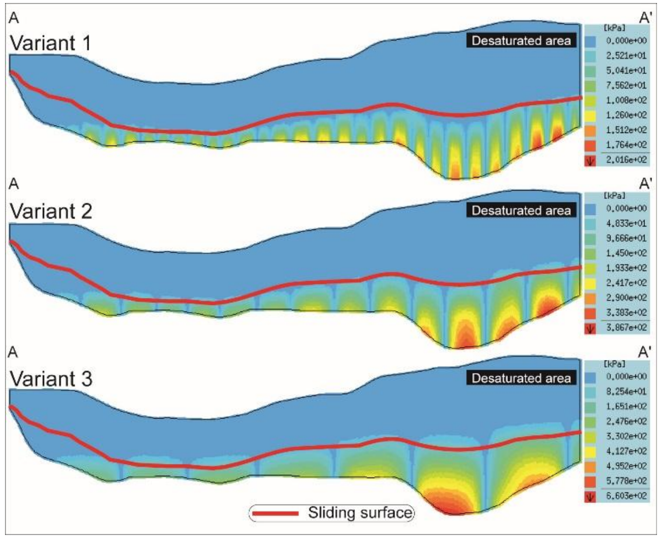
CASE 2 LA FRASSE LANDSLIDE (VD, CH) – 3D FLOW AND HYDRO-MECHANICAL COUPLING (2005-2008)

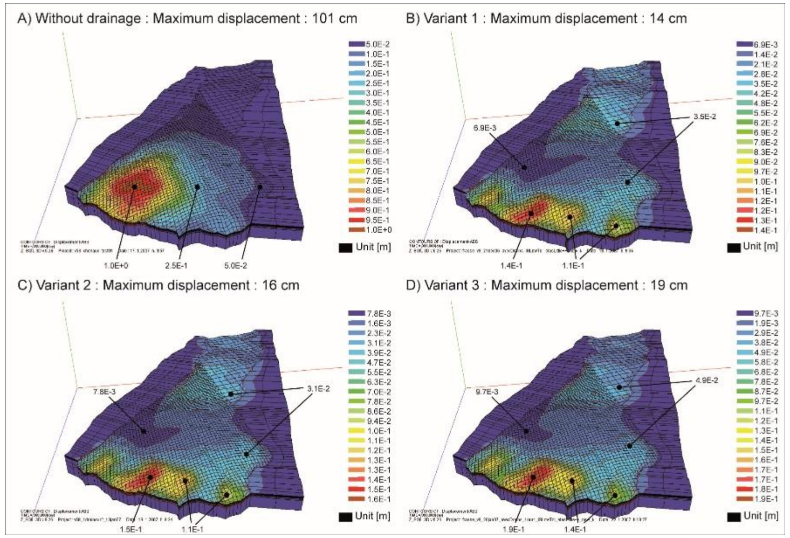
Objectives: To calibrate a 3D flow model (hydro-mechanical coupling) of the Frasse landslide to design the drainage gallery (by sub-vertical gravity drains), to estimate the outflows (drain contribution) and the residual movements.











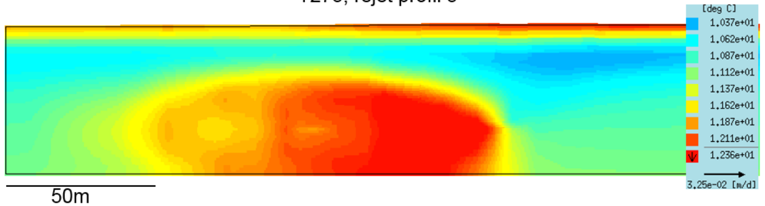
FEFLOW

CASE 3 SION HOSPITAL AND SUVA (VS, CH) – 3D HYDRO-THERMAL (2007)

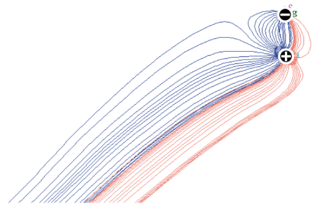
Objectives: To calibrate a 3D hydro-thermal model of the Rhone aquifer to assess the thermal potential of the aquifer and to study the feasibility of additional heat pump systems. Study of thermal interferences and thermal plume path.

Modélisation thermique - PAC – rayon d'action - SUVA

T275, rejet profil 5

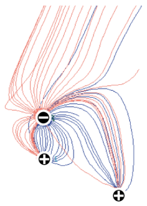


Champ d'action des puits de réinjection



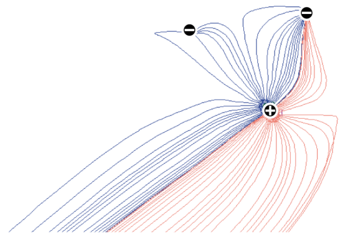
Ce qui est réinjecté est en partie pompé et distribué en aval.

Champ d'action des puits de pompage



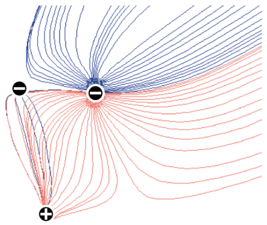
Ce qui est pompé provient en partie d'autres systèmes

Champ d'action des puits de réinjection



Ce qui est réinjecté est en partie pompé par par d'autres systèmes

Champ d'action des puits de pompage



Ce qui est pompé provient en partie de la surface

⊖ Puits pompage
⊕ Puits réinjection
100m

Bilan thermique en automne

Flux entrant par la face amont	2.87E+11 $[J.j^{-1}]$
Flux entrant avec les précipitations	3.20E+11 $[J.j^{-1}]$
Flux entrant par le Rhône	2.70E+10 $[J.j^{-1}]$
Flux géothermique à la base	4.61E+10 $[J.j^{-1}]$
Flux sortant par la face aval	- 4.81E+11 $[J.j^{-1}]$
Flux sortant par le sommet	- 2.95E+11 $[J.j^{-1}]$
Flux sortant par exfiltration vers le Rhône	- 9.19E+11 $[J.j^{-1}]$
Puits de prélèvement ICHV PAC	- 8.20E+09 $[J.j^{-1}]$
Puits de réinjection ICHV PAC	8.39E+09 $[J.j^{-1}]$
Puits de prélèvement SUVA PAC	- 5.85E+10 $[J.j^{-1}]$
Puits de réinjection SUVA PAC	4.58E+10 $[J.j^{-1}]$
Total	**- 1.14E+12 $[J.j^{-1}]$**

Bilan thermique en hiver

Flux entrant par la face amont	3.42E+11 $[J.j^{-1}]$
Flux entrant avec les précipitations	4.73E+11 $[J.j^{-1}]$
Flux entrant par le Rhône	1.73E+10 $[J.j^{-1}]$
Flux géothermique à la base	4.64E+10 $[J.j^{-1}]$
Flux sortant par la face aval	- 4.59E+11 $[J.j^{-1}]$
Flux sortant par le sommet	- 2.47E+11 $[J.j^{-1}]$
Flux sortant par exfiltration vers le Rhône	- 9.11E+11 $[J.j^{-1}]$
Puits de prélèvement ICHV PAC	
Puits de réinjection ICHV PAC	
Puits de prélèvement SUVA PAC	- 4.61E+10 $[J.j^{-1}]$
Puits de réinjection SUVA PAC	4.00E+10 $[J.j^{-1}]$
Total	**- 7.44E+11 $[J.j^{-1}]$**

Bilan thermique en été

Flux entrant par la face amont	5.77E+11 $[J.j^{-1}]$
Flux entrant avec les précipitations	7.60E+11 $[J.j^{-1}]$
Flux entrant par le Rhône	9.14E+11 $[J.j^{-1}]$
Flux géothermique à la base	6.58E+10 $[J.j^{-1}]$
Flux sortant par la face aval	- 4.85E+11 $[J.j^{-1}]$
Flux sortant par le sommet	- 1.26E+12 $[J.j^{-1}]$
Flux sortant par exfiltration vers le Rhône	- 2.21E+11 $[J.j^{-1}]$
Puits de prélèvement ICHV PAC	- 8.51E+10 $[J.j^{-1}]$
Puits de réinjection ICHV PAC	9.66E+10 $[J.j^{-1}]$
Puits de prélèvement SUVA PAC	- 1.82E+11 $[J.j^{-1}]$
Puits de réinjection SUVA PAC	1.75E+11 $[J.j^{-1}]$
Total	**3.55E+11 $[J.j^{-1}]$**

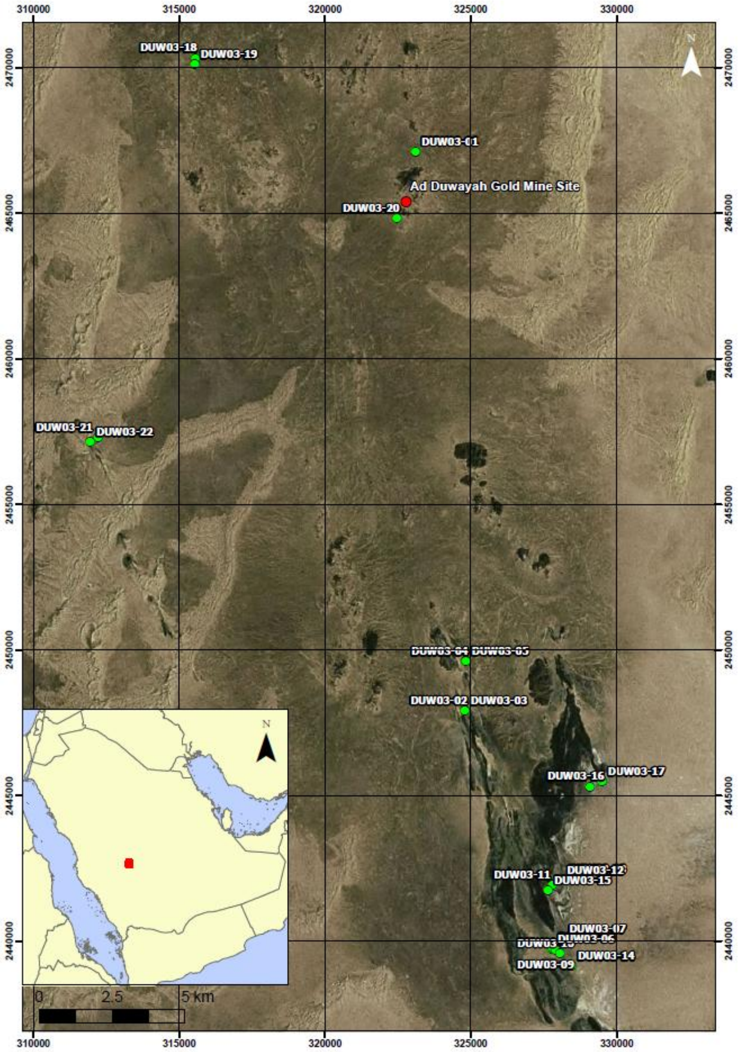
Bilan thermique au printemps

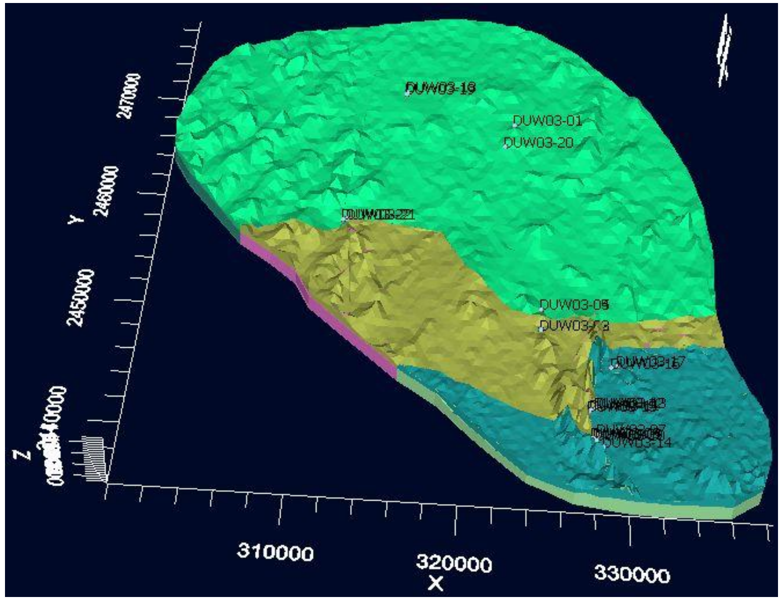
Flux entrant par la face amont	7.72E+11 $[J.j^{-1}]$
Flux entrant avec les précipitations	6.06E+11 $[J.j^{-1}]$
Flux entrant par le Rhône	1.11E+12 $[J.j^{-1}]$
Flux géothermique à la base	6.56E+10 $[J.j^{-1}]$
Flux sortant par la face aval	- 3.93E+11 $[J.j^{-1}]$
Flux sortant par le sommet	- 1.24E+12 $[J.j^{-1}]$
Flux sortant par exfiltration vers le Rhône	-2.94E+10 $[J.j^{-1}]$
Puits de prélèvement ICHV PAC	-4.68E+10 $[J.j^{-1}]$
Puits de réinjection ICHV PAC	5.97E+10 $[J.j^{-1}]$
Puits de prélèvement SUVA PAC	- 1.23E+11 $[J.j^{-1}]$
Puits de réinjection SUVA PAC	1.25E+11 $[J.j^{-1}]$
Total	**9.06E+11 $[J.j^{-1}]$**

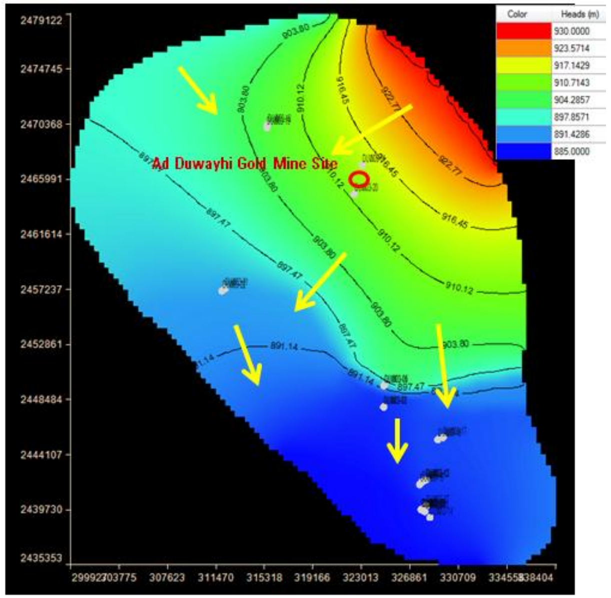
GeoBM Sagl

CASE 4 AD DUWAHYI GOLD MINE (KSA)– 3D FLOW (2013-2014)

Objectives: To calibrate a 3D flow model of the aquifer related to the Ad Duwahyi Gold Mine (KSA). Water resources sustainability study and long-term strategy.

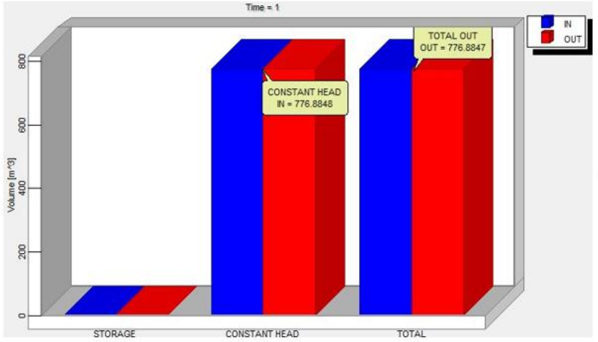






Sensitivity analysis

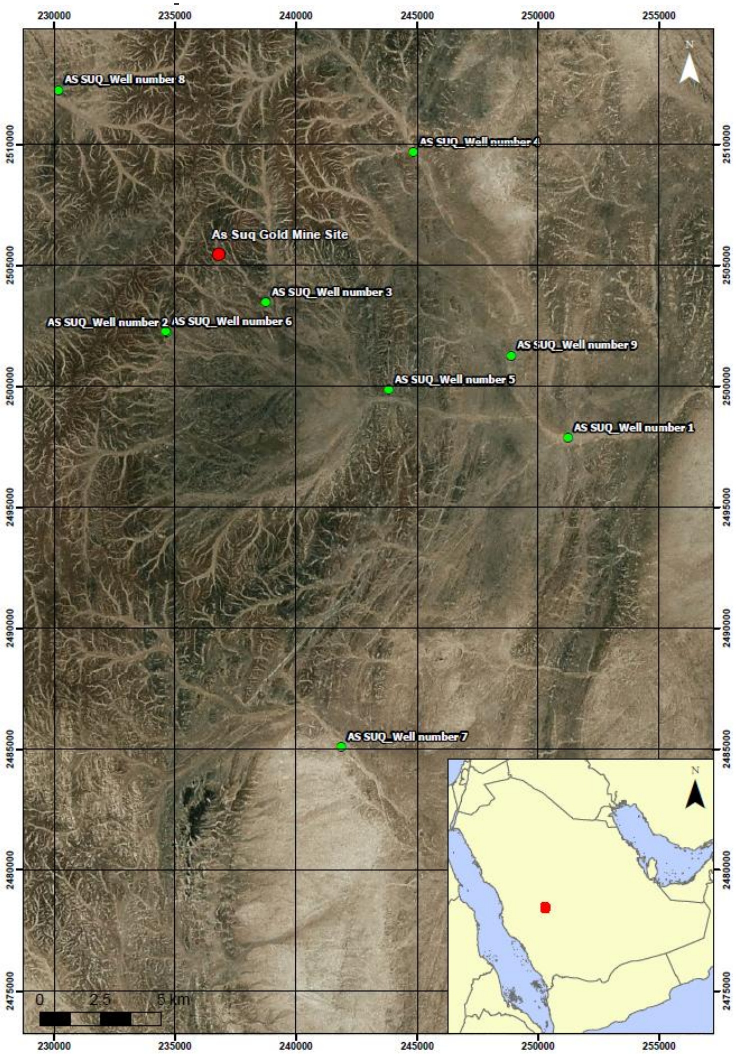
		RUN 29			RUN 30			RUN 31				RUN 33			
Analytical matrix	Hydraulic Conductivity (m/s)														
	Estimated			> 20 %			< 20 %			Random					
	Kx	Ky	Kz	Kx	Ky	Kz	Kx	Ky	Kz	Kx	mult. Factor	Ky	mult. Factor	Kz	mult. Factor
Diorite	1.00E-07	5.00E-06	1.00E-07	1.20E-07	6.00E-06	1.20E-07	8.0E-08	4.0E-06	8.0E-08	1.00E-07	1.0	1.00E-06	0.2	1.00E-06	10.0
	1.00E-11	5.00E-11	1.00E-11	1.20E-11	6.00E-11	1.20E-11	8.0E-12	4.0E-11	8.0E-12	1.00E-12	0.1	1.00E-11	0.2	1.00E-11	1.0
Limestones	1.00E-06	1.00E-05	1.00E-06	1.20E-06	1.20E-05	1.20E-06	8.0E-07	8.0E-06	8.0E-07	1.00E-06	1.0	1.00E-05	1.0	1.00E-05	10.0
	1.00E-08	1.00E-07	1.00E-08	1.20E-08	1.20E-07	1.20E-08	8.0E-09	8.0E-08	8.0E-09	1.00E-08	1.0	1.00E-07	1.0	1.00E-07	10.0
Greywakes	2.00E-05	3.00E-05	2.00E-05	2.40E-05	3.60E-05	2.40E-05	1.6E-05	2.4E-05	1.6E-05	1.00E-05	0.5	1.00E-04	3.3	1.00E-05	0.5
	1.00E-05	1.00E-05	1.00E-05	1.20E-05	1.20E-05	1.20E-05	8.0E-06	8.0E-06	8.0E-06	1.00E-06	0.1	1.00E-06	0.1	1.00E-05	1.0
Water balances (m3/year)	281,000			318,645			212,430			62,800					
Difference					113.40%			75.60%				22.35%			
Gain/Loss					13.40%			-24.40%				-77.65%			



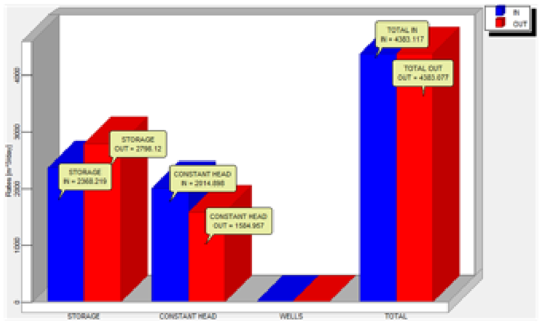
Global water budget of around 770 m3/day, i.e. **around 281,000 m3/year**

CASE 5 AS SUQ GOLD MINE (KSA)– 3D FLOW (2013-2014)

Objectives: To calibrate a 3D flow model of the aquifer related to the Ad Suq Gold Mine (KSA). Sustainability study of water resources and long-term pumping strategy.

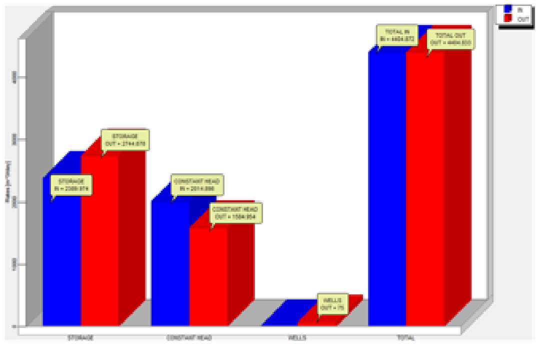


Scenario 1 – WITHOUT WELL – Mass balances



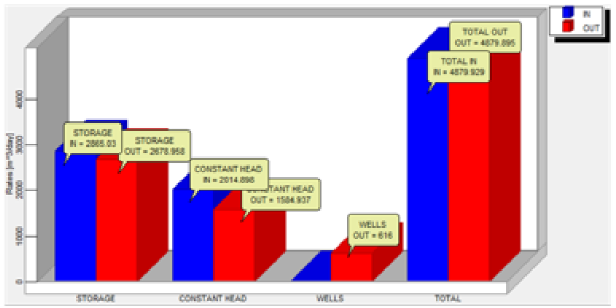
- Global water budget of around 4,383 m3/day, i.e. **around 1,600,000 m3/year**

Scenario 2 – ACTUAL PUMPING=75 m3/day – Mass balances



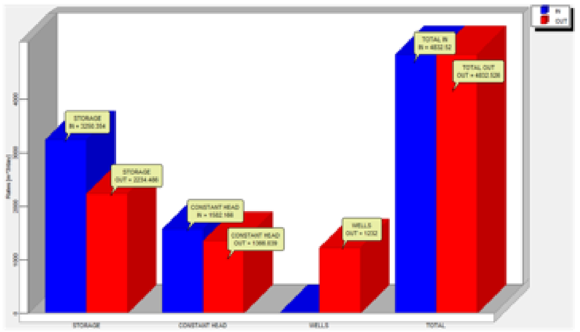
- Global water budget of around 4,403 m3/day, i.e. **around 1,607,460 m3/year**

Scenario 3 – PUMPING 50% mine requirement =616 m3/day – Mass balances



- Global water budget of around 4,880 m3/day, i.e. **around 1,781,200 m3/year**

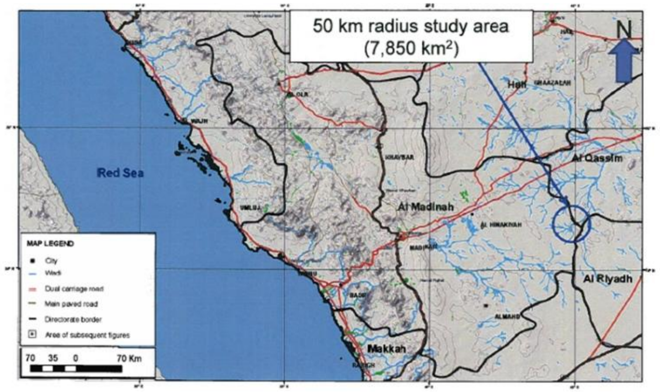
Scenario 4 – PUMPING 100% mine requirement =1,232 m3/day – Mass balances

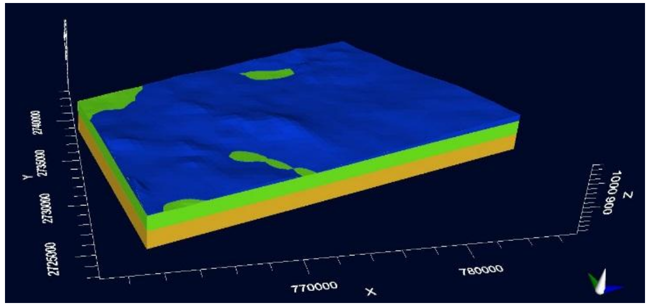


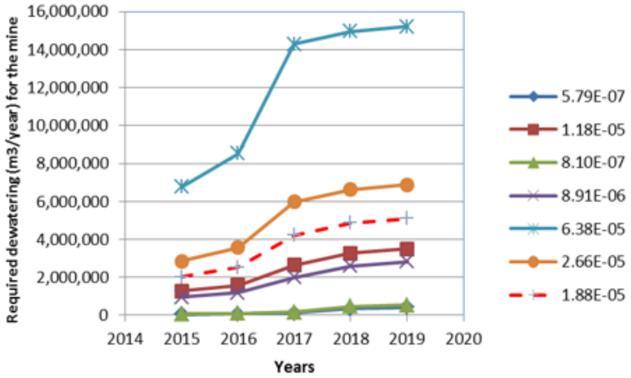
- Global water budget of around 4,832 m3/day, i.e. **around 1,763,680 m3/year**

CASE 6 HUMAYMAH GOLD MINE (KSA)– 3D FLOW (2013-2014)

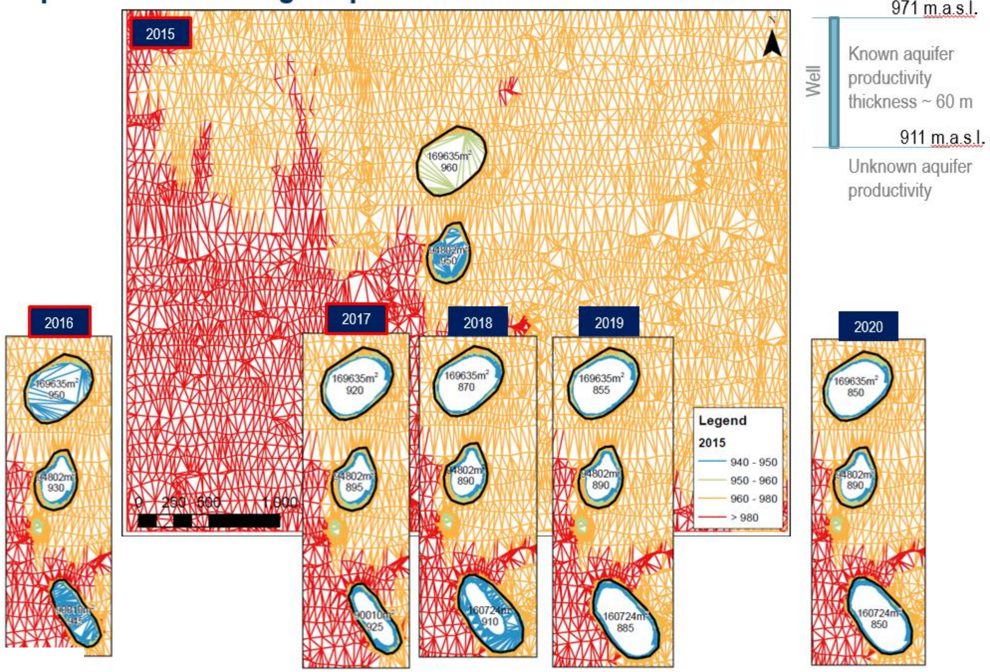
Objectifs du problème: To calibrate a 3D flow model of the aquifer realted to the Humaymah Gold Mine (KSA). Water resources sustainability, long-term mining strategy, dewatering/groundwater drawdown and regional impact.







Open Pit Dewatering Requirement

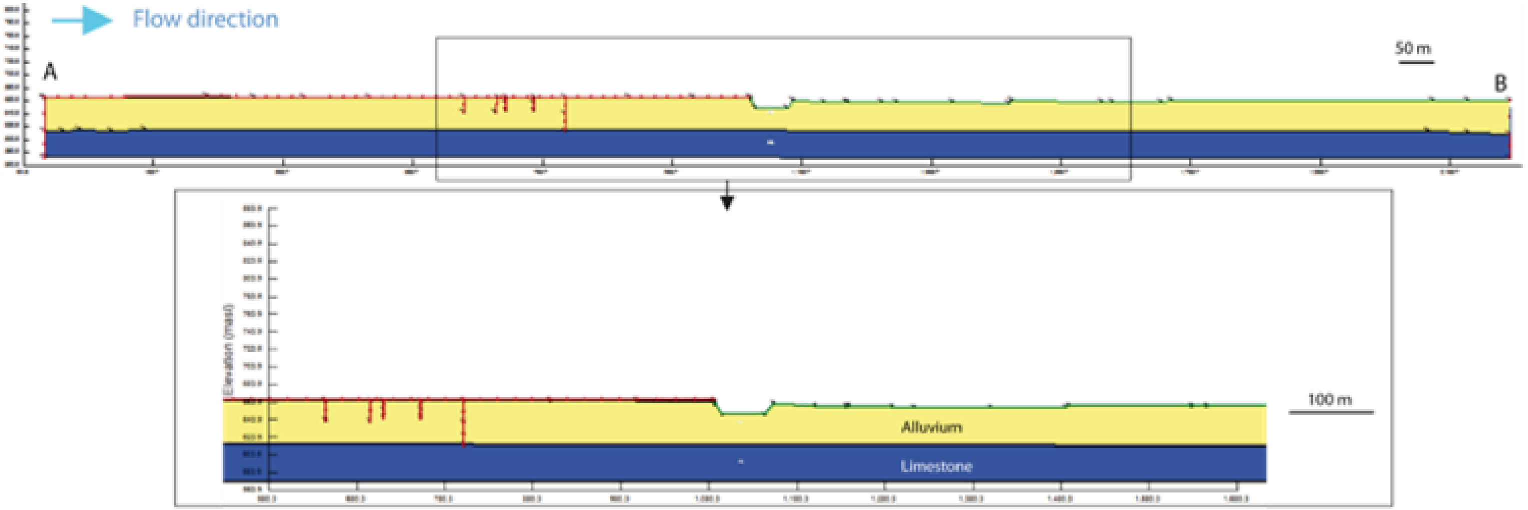


Dewatering requirement

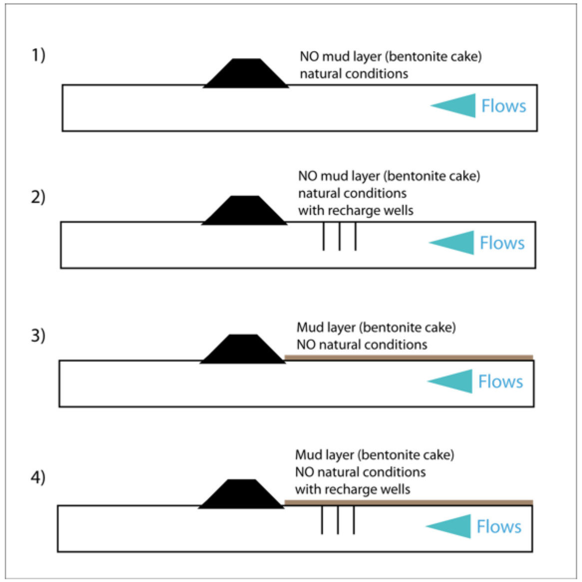
2015	2016	2017	2018	2019	2020
m3/year	m3/year	m3/year	m3/year	m3/year	m3/year
/ ?	2,000,656	2,509,155	4,205,299	4,867,929	5,107,045
m3/day	m3/day	m3/day	m3/day	m3/day	m3/day
-	5,481.25	6,874.40	11,521.37	13,336.79	13,991.90

CASE 7 WADI AL ALB (KSA) FORCED RECHARGE – 2D FLOW (2014)

Objectives: To calibrate a 2D flow model of the Wadi Al Alb (KSA) aquifer to assess the potential for seasonal recharge by forced recharge combining retention dam and gravity wells.



Modeling Scenarios



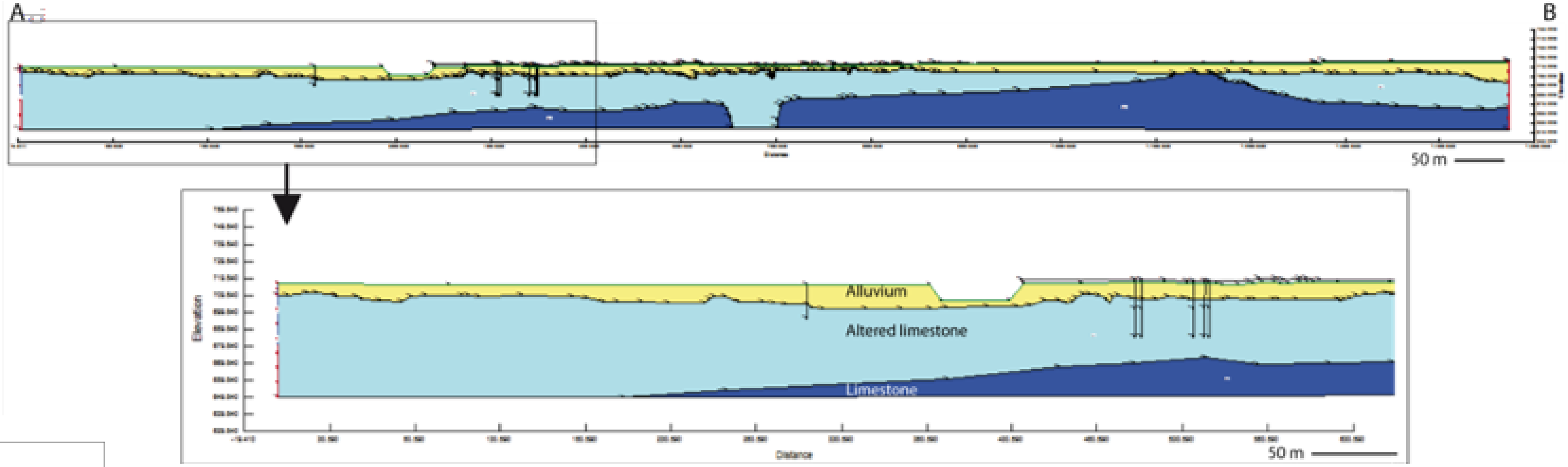
		Water Budget				*Recharge Efficiency*			
		1	2	3	4	5	6	7	8
#	Al Alb	Water budget - Baseline flow (m³/day)	Recharge days (Nov-Mar)	Total Recharge (m³)	Average Recharge per day during recharge period (m³/days)	Average available water per day during recharge period (m³/days)	Recharge efficiency (%)	Wells input (%)	Bentonite Effect (%)
1	Transient no Bentonite no wells	3,928	133	1,368,245	10,288	14,216	33%		
2	Transient no Bentonite with wells	3,928	133	1,563,809	11,758	15,686	37%	14%	
3	Transient Bentonite no wells	3,928	133	61,000	459	4,387	1%		-96%
4	Transient Bentonite with wells	3,928	133	1,324,347	9,957	13,885	32%		-15%

** the recharge efficiency is based on a total annual volume of annual surface water calculated in the model of 4,200,000 m³, for an aquifer width of 200 m*

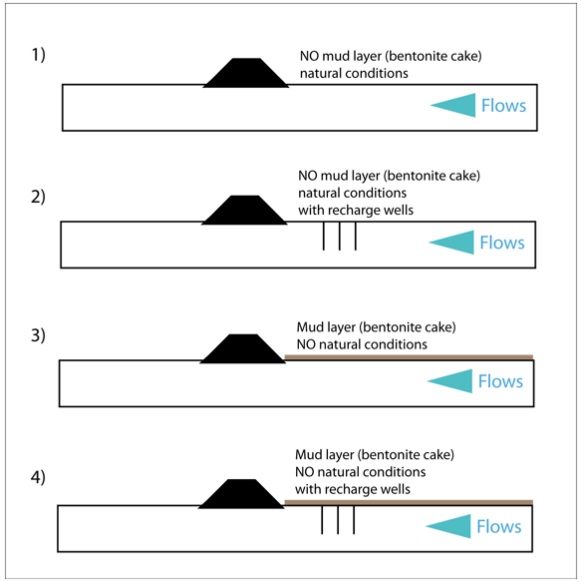
SEEPW

CASE 8 WADI AL GHAT (KSA) FORCED RECHARGE – 2D FLOW (2014)

Objectives: To calibrate a 2D flow model of the Wadi Al Ghat (KSA) aquifer to assess the potential for seasonal recharge by forced recharge combining retention dam and gravity wells.



Modeling Scenarios



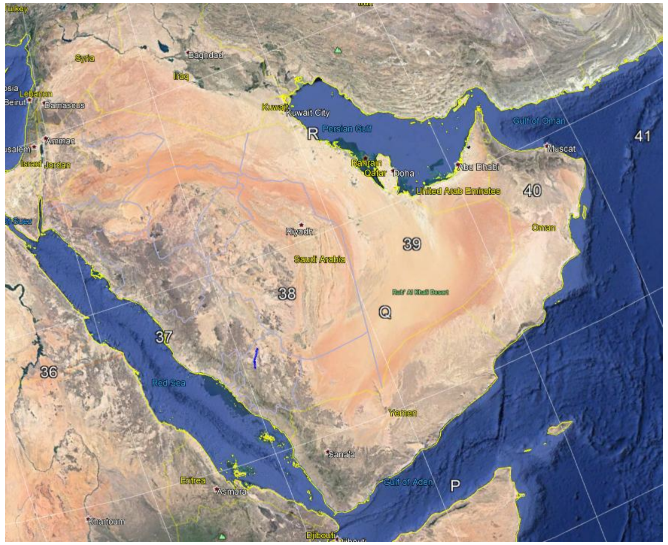
		Water Budget				*Recharge Efficiency*			
		1	2	3	4	5	6	7	8
#	Al Ghat - Alluvium K=0.13 m/d	Water budget - Baseline flow (m³/day)	Recharge days (Nov-Mar)	Total Recharge (m³)	Average Recharge per day during recharge period (m³/days)	Average available water per day during recharge period (m³/days)	Recharge efficiency (%)	Wells input (%)	Bentonite Effect (%)
1	Transient no Bentonite no wells	112	133	27,351	206	318	20%		
2	Transient no Bentonite with wells	112	133	33,184	250	362	24%	21%	
3	Transient Bentonite no wells	112	133	1,143	9	121	1%		-96%
4	Transient Bentonite with wells	112	133	32,830	247	359	23%		-1%

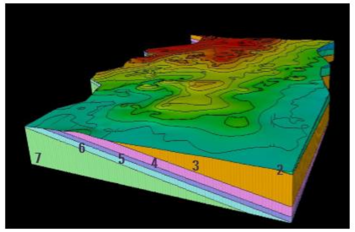
** the recharge efficiency is based on a total annual volume of annual surface water calculated in the model of 125,000 m³, for an aquifer width of 200 m*

FEFLOW

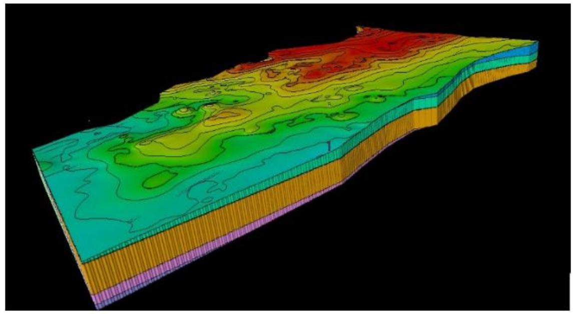
CASE 9 RIYADH METRO REGIONAL MODEL – 3D FLOW (2014-2015)

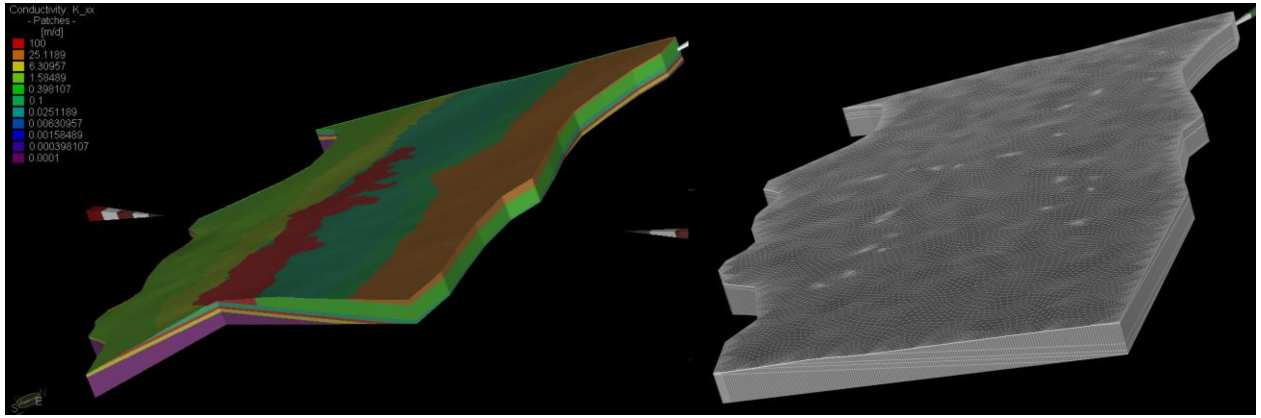
Objectives: To calibrate a 3D flow model of the Riyadh aquifers (KSA) to assess the flow conditions and water table elevation during the construction of the various metro lines.

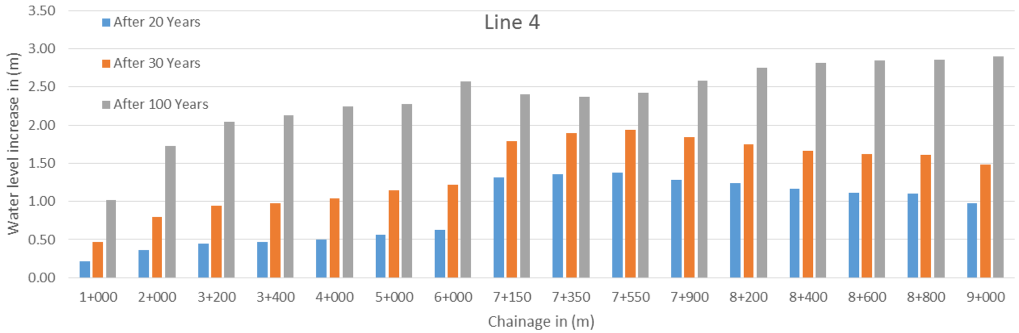


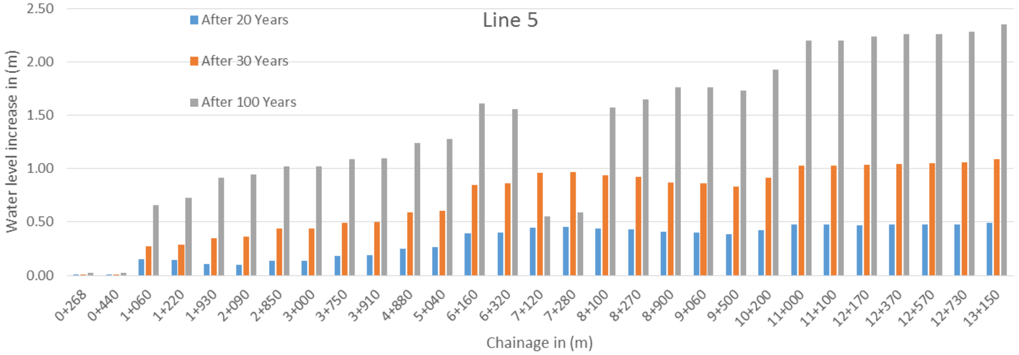


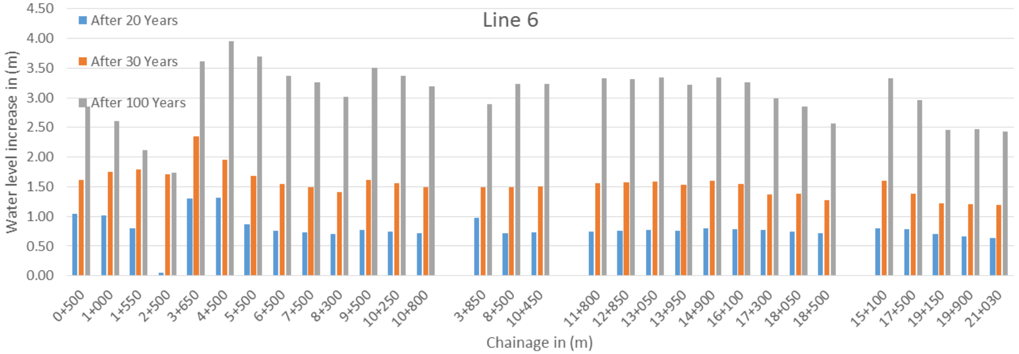
1. Quaternary units
2. Yamama Formation
3. Sulay Formation (KJs) + Sulay alluviums not shown on this map, see Figure 3-4)
4. Arab Member B (Incl. Arab Member A)
5. Arab Member C
6. Arab Member D
7. Jubaila Formation







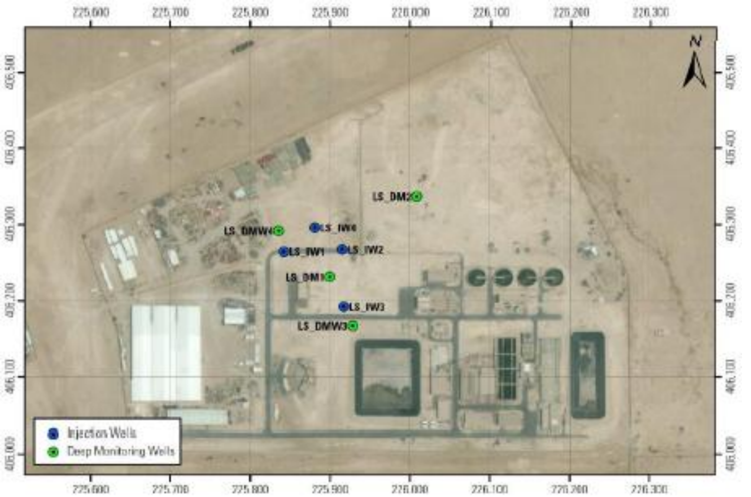


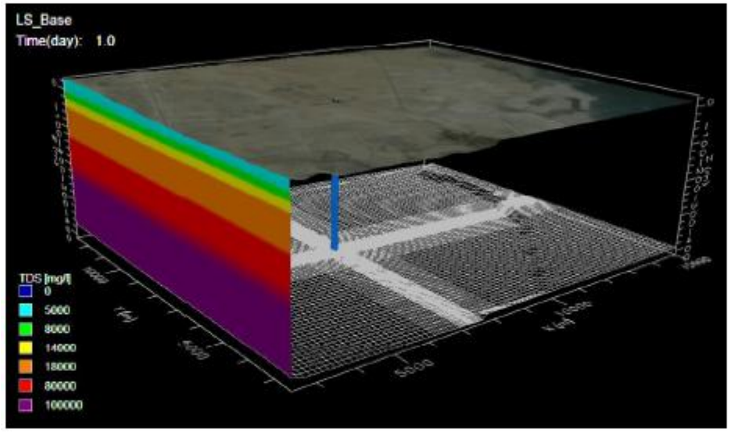


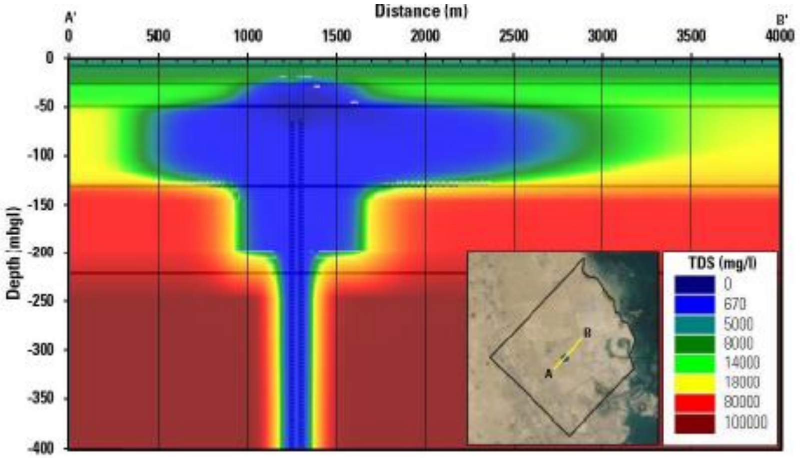
MODFLOW

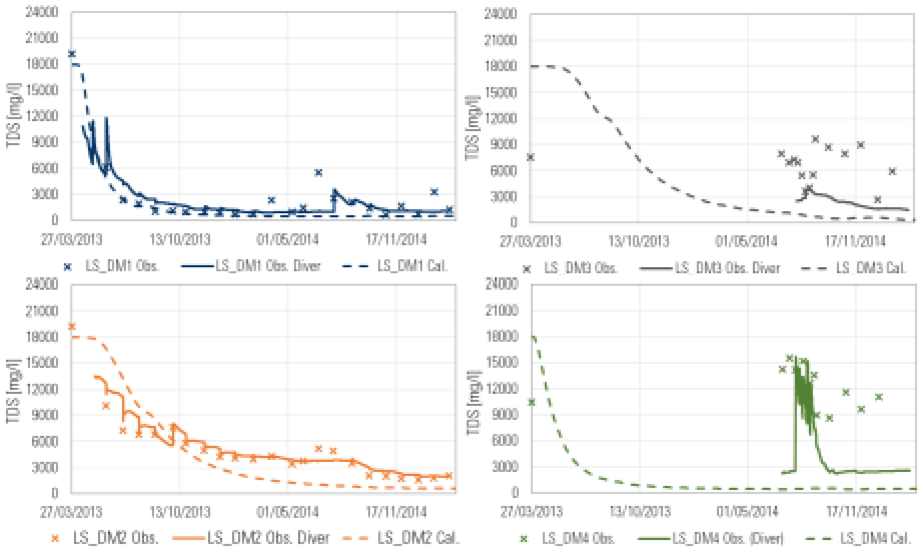
CASE 10 TSE REINJECTION LOCAL MODEL FOR LUSAIL (DOHA) – 3D FLOW - MASS TRANSPORT (SALINITY) (2015)

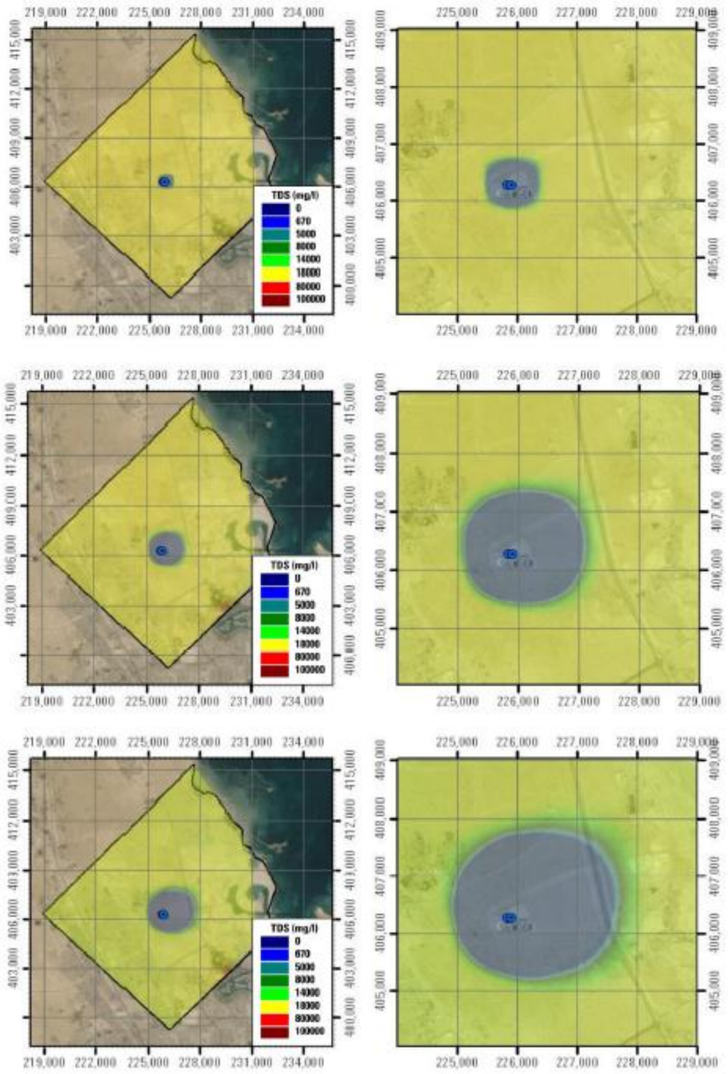
Objectives: To calibrate a 3D flow-mass transport model at Lusail in the industrial zone of Doha, for the study of the reinjection of treated sewage effluents (TSE) in the hypersaline aquifer.







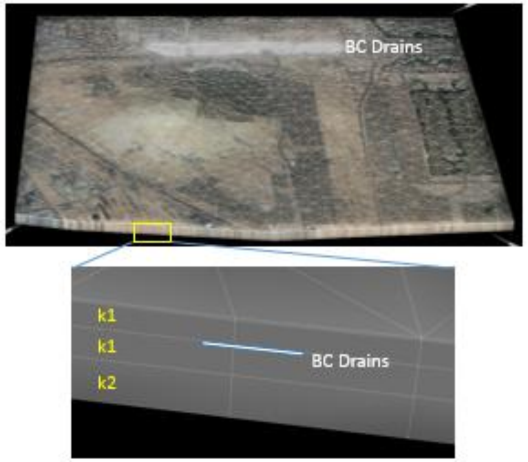




GeoBM

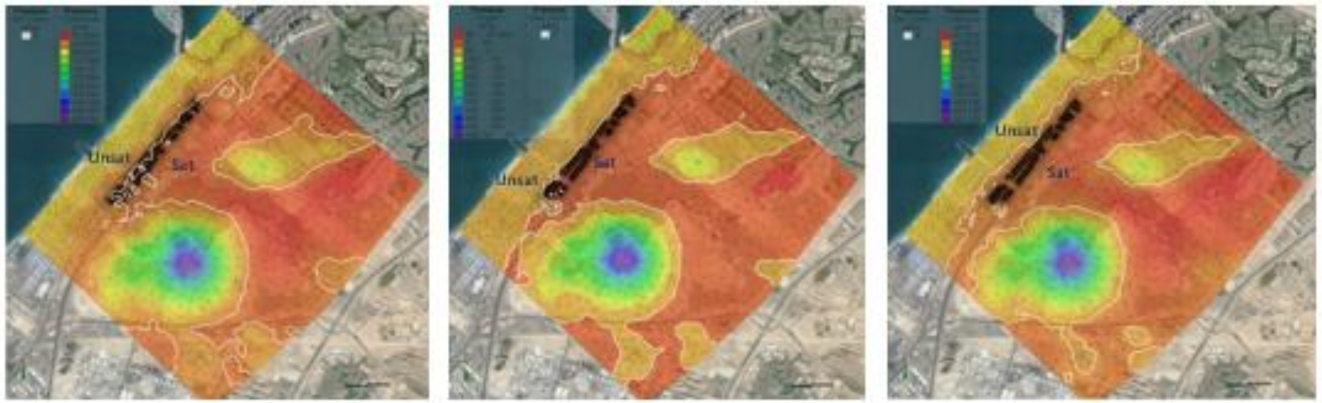
CASE 11 DUBAÏ "DEWA" FRENCH DRAIN DEWATERING – 3D FLOW (2016)

Objectives: To calibrate a 3D flow model of Dubai's coastal aquifers to design a permanent French drain system to control the groundwater levels.



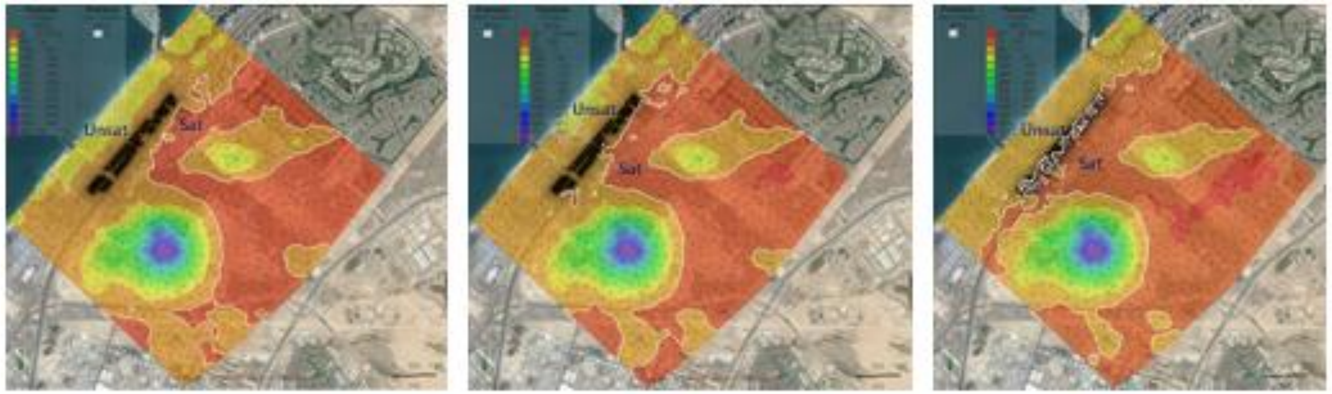
Actual Situation

Saturation at Surface | Saturation at – 0.7 m | Saturation at – 1.5 m



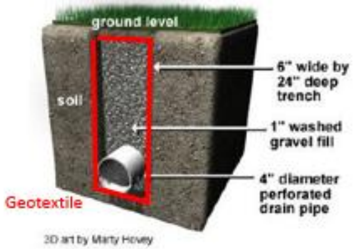
Actual Situation with drainage

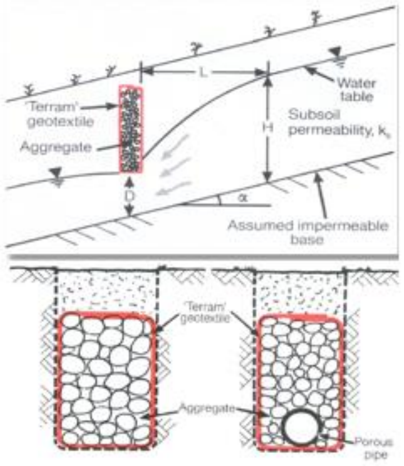
Saturation at Surface | Saturation at – 0.7 m | Saturation at – 1.5 m



French Drains

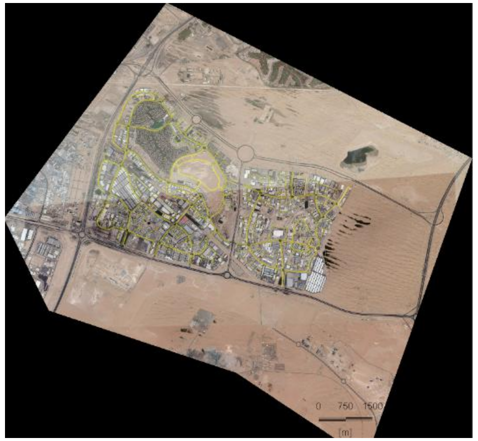
is a popular term that refers to outdoor trench covered in rocks and linked to a series of pipes that carry water far from a site, mostly by gravity

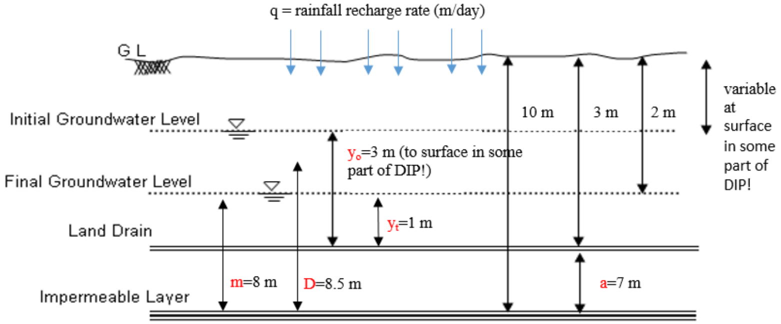




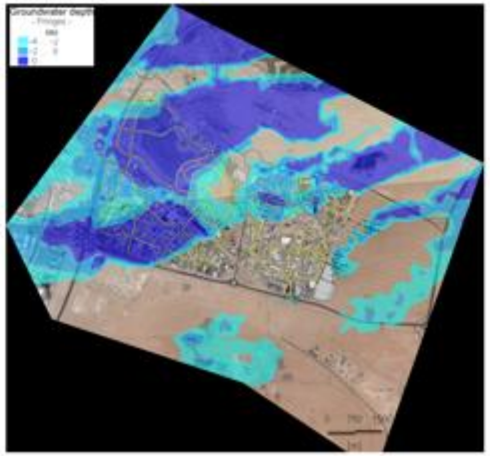
CASE 12 DUBAÏ “DIP” FRENCH DRAIN DEWATERING – 3D FLOW (2016)

Objectives: To calibrate a 3D flow model of Dubai's coastal aquifers to design a permanent French drain system to control the groundwater levels.

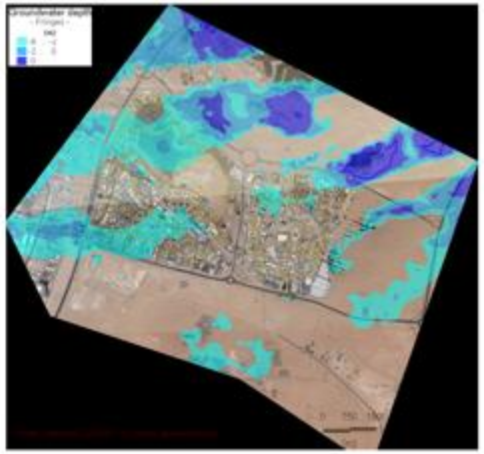




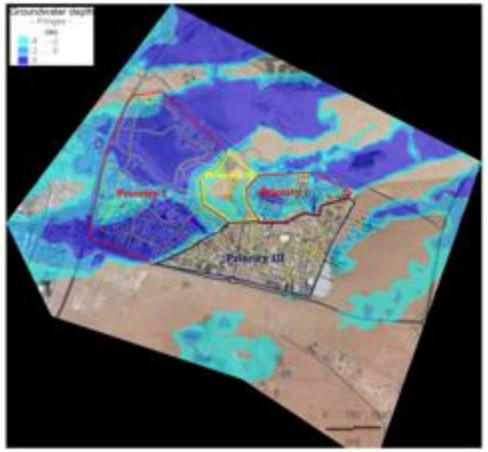
steady state conditions – Actual without dewatering



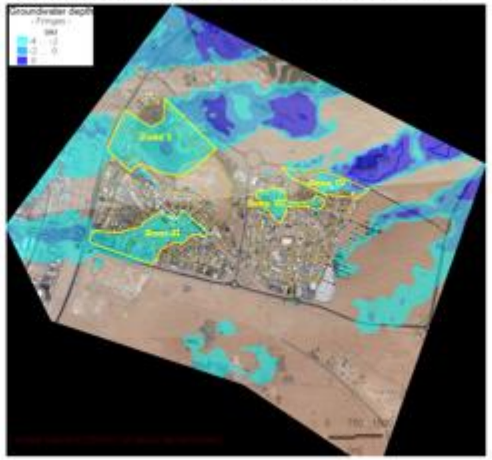
steady state conditions - with dewatering

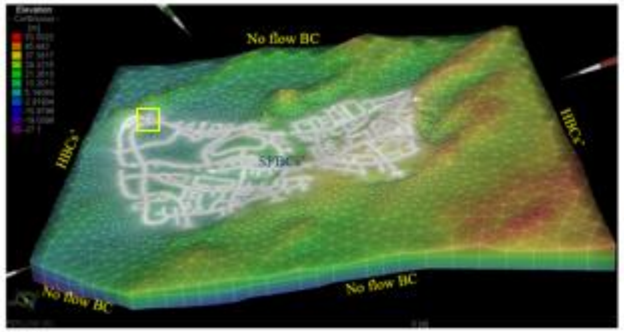


Construction Priority – phase I



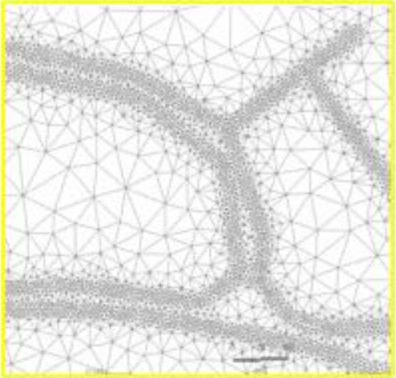
Additional Land Drains required in phase II





3 layers
Total mesh elements: 1,733,724
Total of nodes: 1,156,004
Phreatic type toping an unconfined aquifer

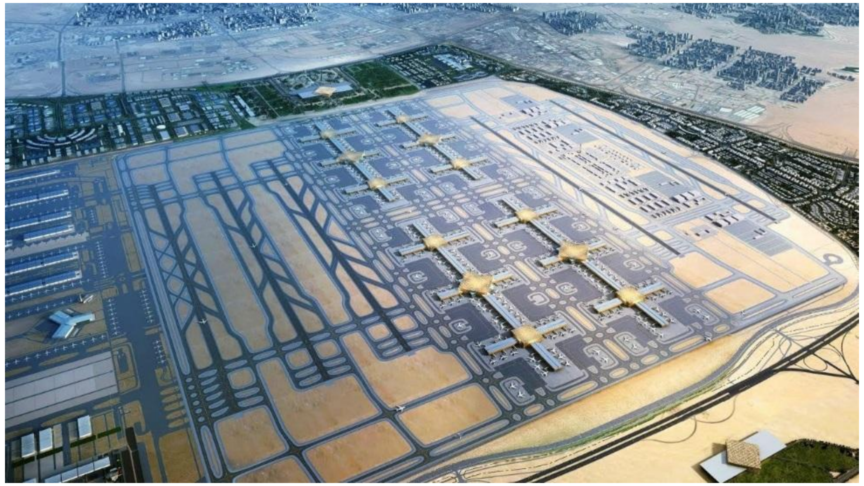
Mesh refinement at land drains



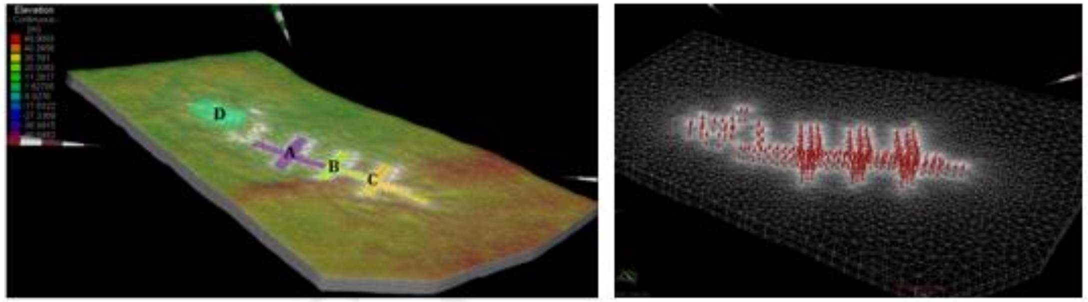
FEFLOW

CASE 13 DUBAI “AL MAKTOUM INTERNATIONAL AIRPORT” DEWATERING – 3D FLOW (2018)

Objectives: To calibrate a 3D flow model for the future Al Maktoum international airport (Dubai, UAE) to design the dewatering deep wells system to control the water table during the excavation and construction stages.

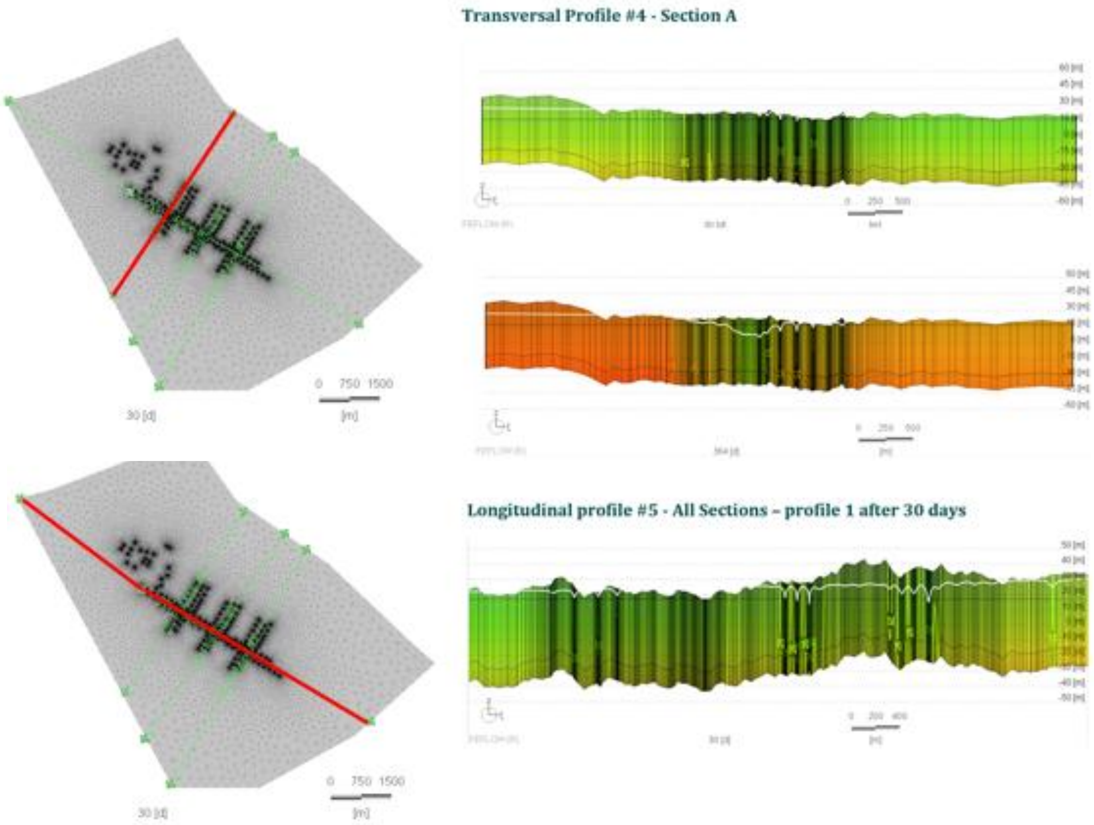


Dewatering Wells Network



A total of 200 dewatering wells have been imported into the model. As indicated, 4 dewatering Section have been defined:

- Section A contains 77 wells
- Section B 53 wells
- Section C 53 wells and
- Section D 17 wells



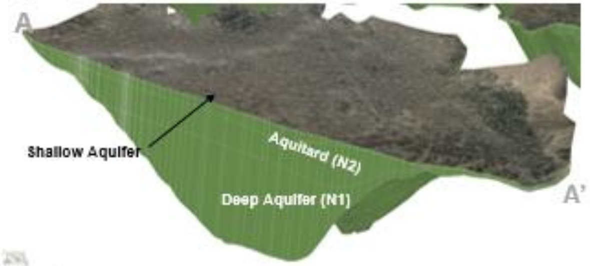
Inflows rates in m³/d		Inflows rates per well in m³/d	
Section A	2280.00	Section A	**30** (pump capacity = 1.23m³/h)
Section B	1870.00	Section B	**35** (pump capacity = 1.47 m³/h)
Section C	4160.00	Section C	**78** (pump capacity = 3.27 m³/h)
Section D	1350.00	Section D	**79** (pump capacity = 3.31 m³/h)
Total:	9660.00	Average	**56 (pump capacity = 2.32 m³/h)**

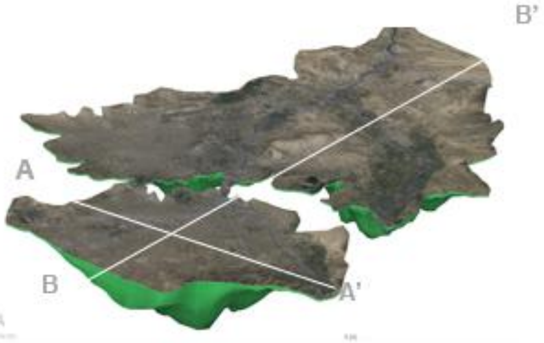
GeoBM Sagl

FEFLOW

CASE 14 KABUL AQUIFER MANAGED RECHARGE – 3D FLOW (2017-2019)

Objectives: To calibrate a 3D flow model of the regional aquifer of the city of Kabul (Afghanistan) for the study of the water availability and regional analyses of water resources.





4 Main layers:

Layer 1 – Reworked Loess series (ca. 1 – 15 m)

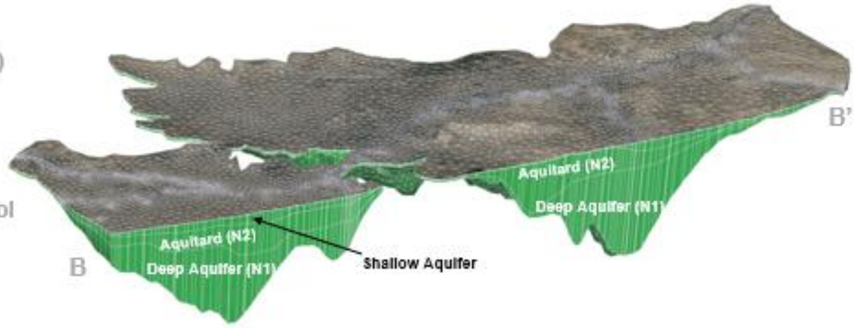
Layer 2 – Shallow Quaternary Aquifer

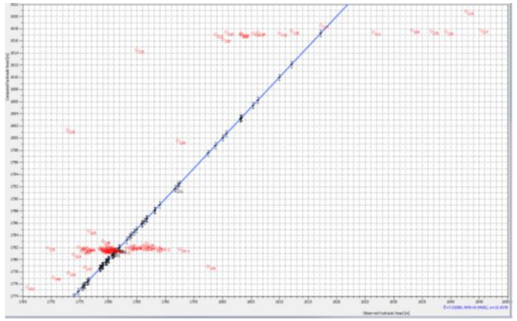
Layer 3 – Aquitard (*Neogene N2*)

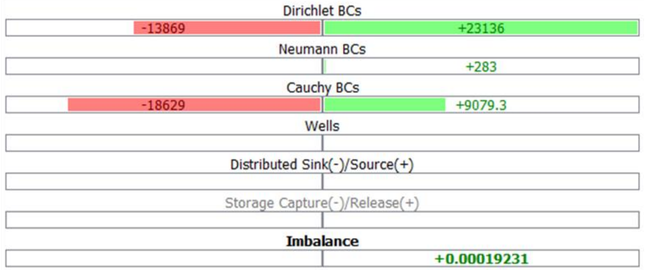
Layer 4 – Aquifer (*Neogene N1*)

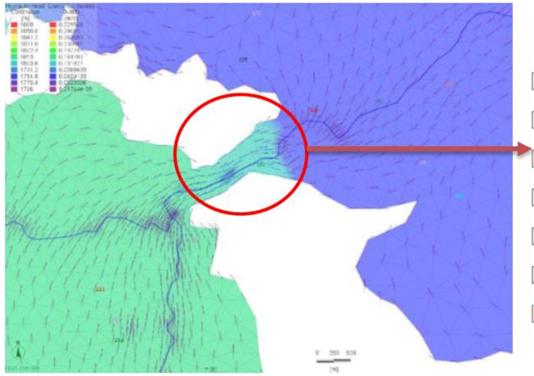
Top of layer 1 – use DEM with enhanced accuracy using topographical maps and control points.

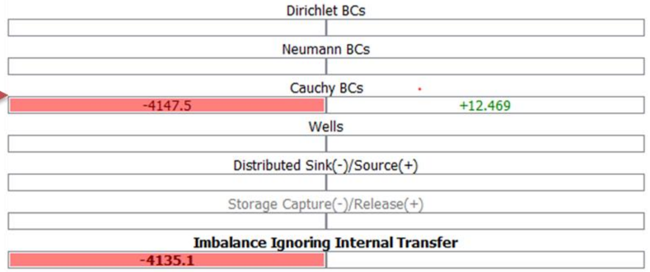
Tops of layers 3 – 4 use available litho-stratigraphic data, cross sections, maps, existing wells and TDEM surveys from JICA 2011







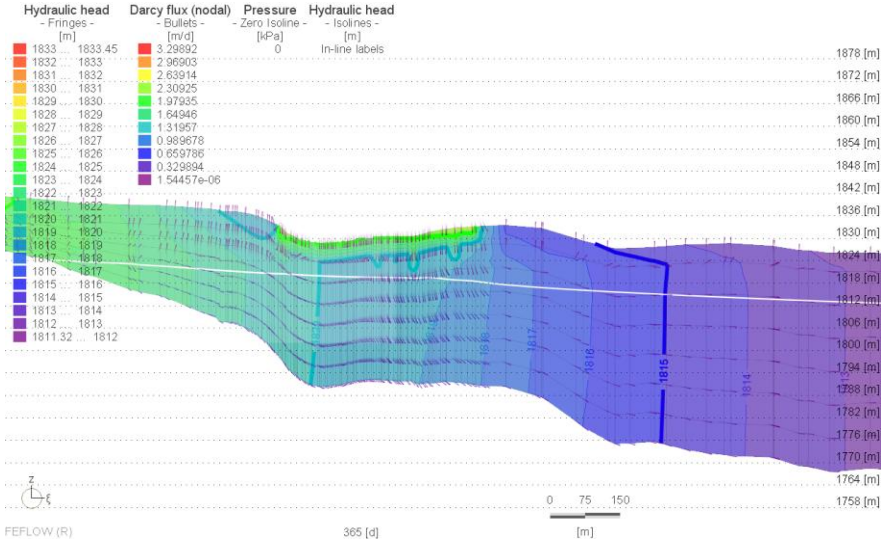


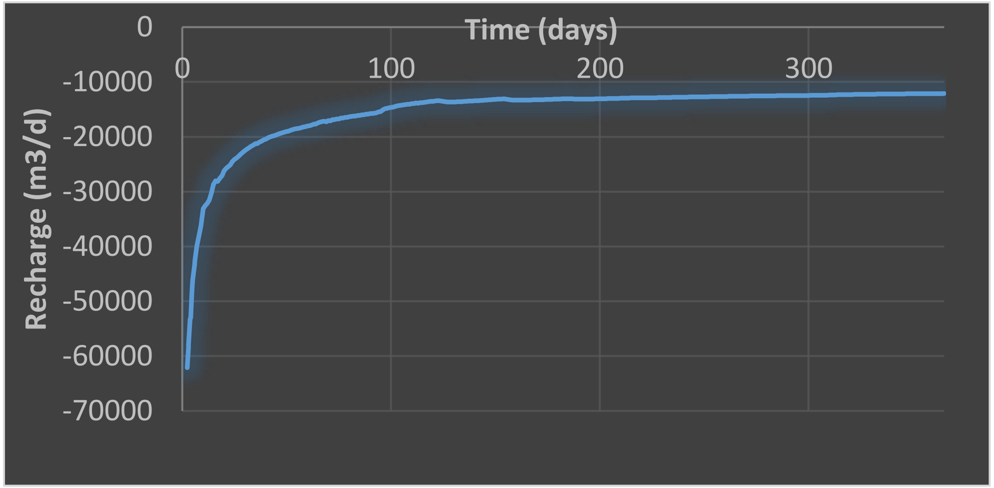


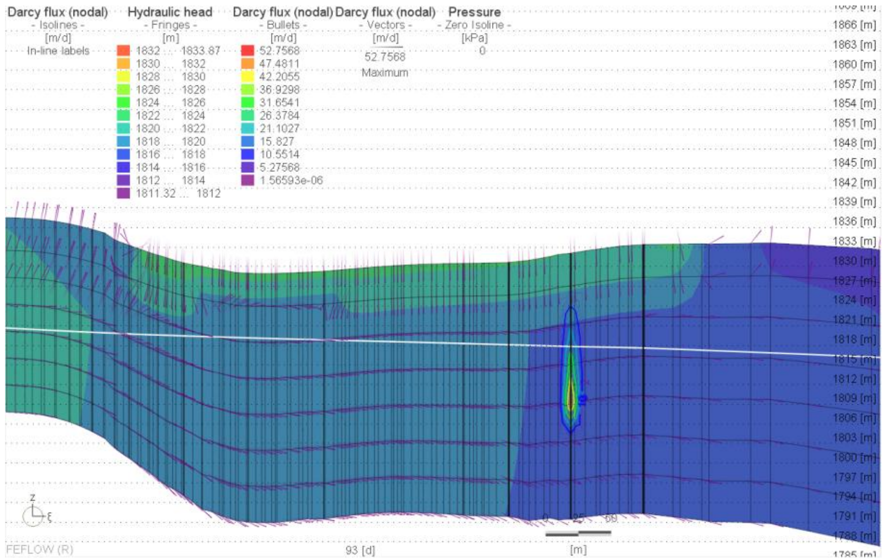
GeoBM

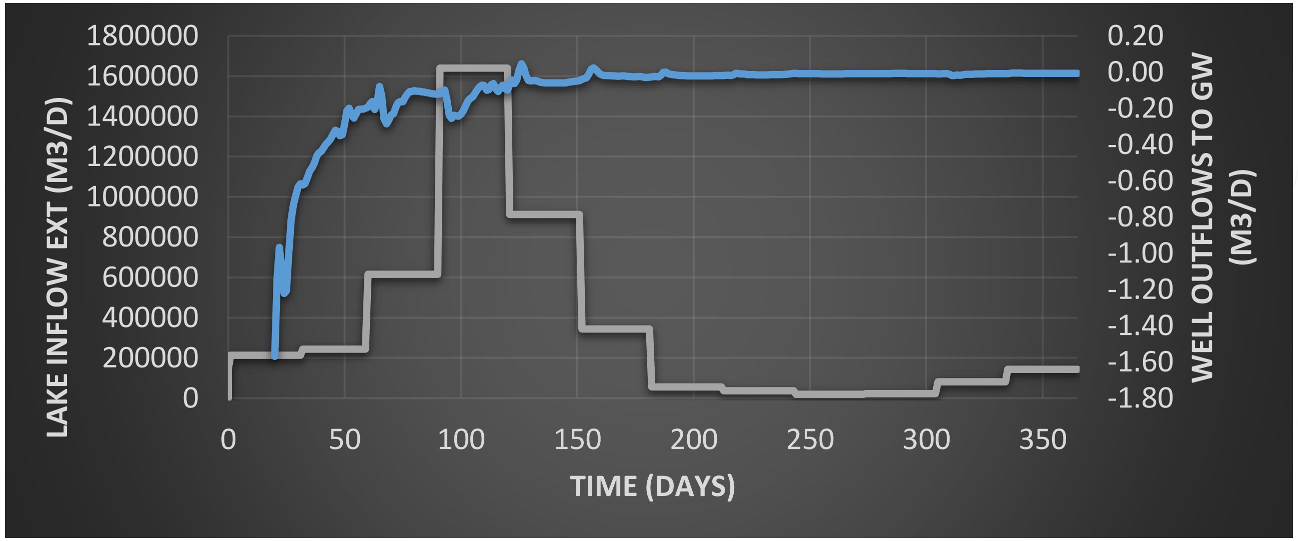
CASE 15 KABUL AQUIFER MANAGED RECHARGE – 3D FLOW (2017-2019)

Objectives: To calibrate local 3D flow models at each forced recharge pilot site, with surface water (retention ponds) / groundwater coupling using IfmLake Module (FEFLOW plug-in).





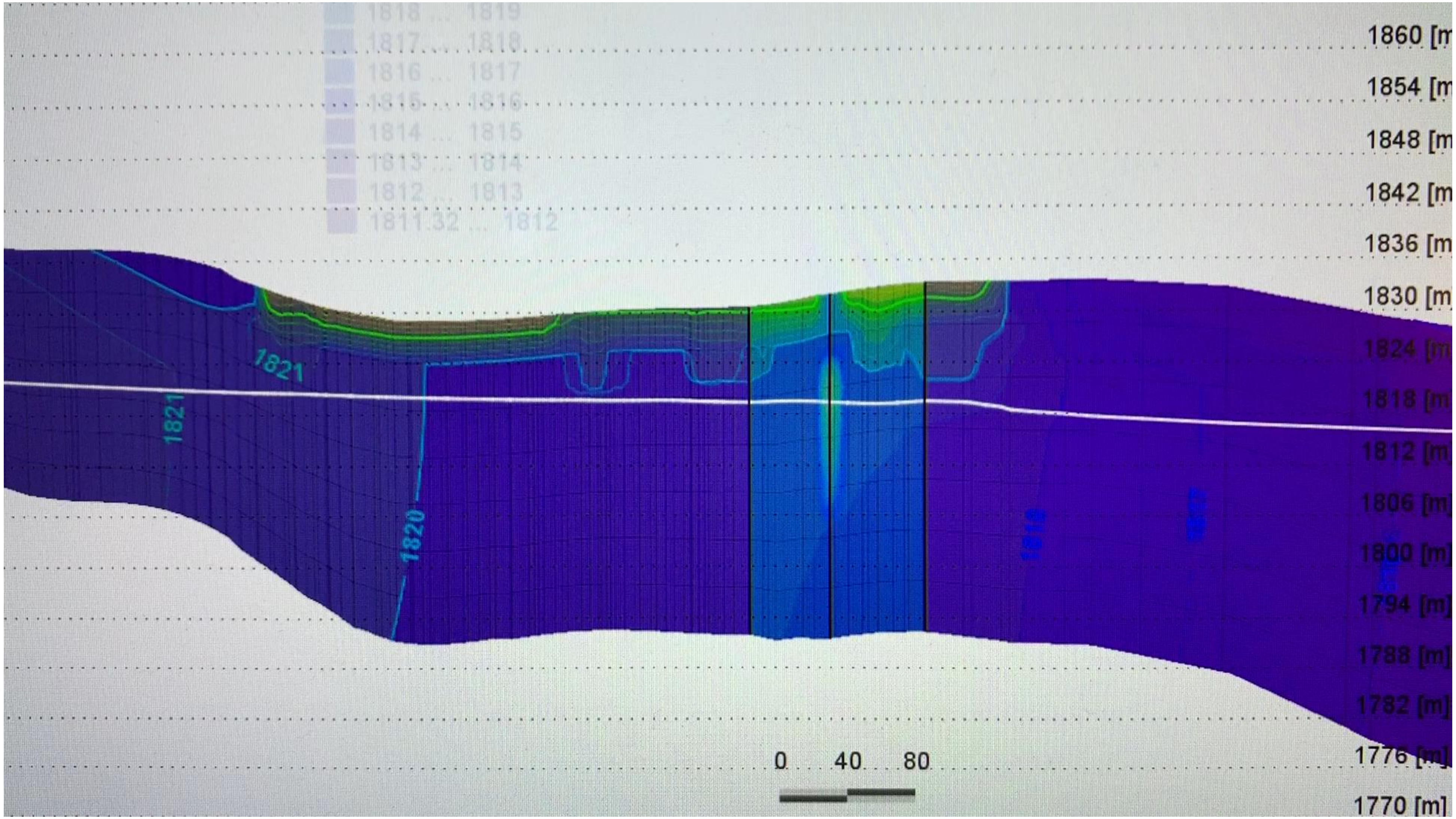




FEFLOW

CASE 16 KABUL AQUIFER MANAGED RECHARGE – 3D FLOW (2017-2019)

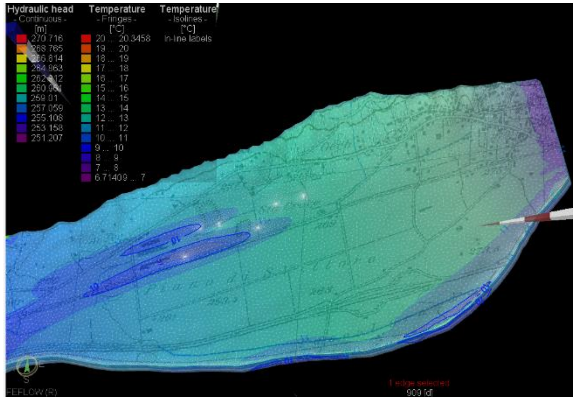
Objectives: To calibrate local 3D flow models at each forced recharge pilot site, with surface water (retention ponds) / groundwater coupling using IfmLake Module (FEFLOW plug-in).

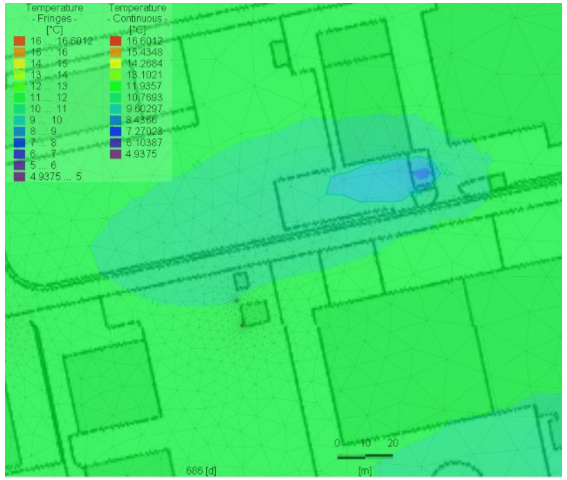


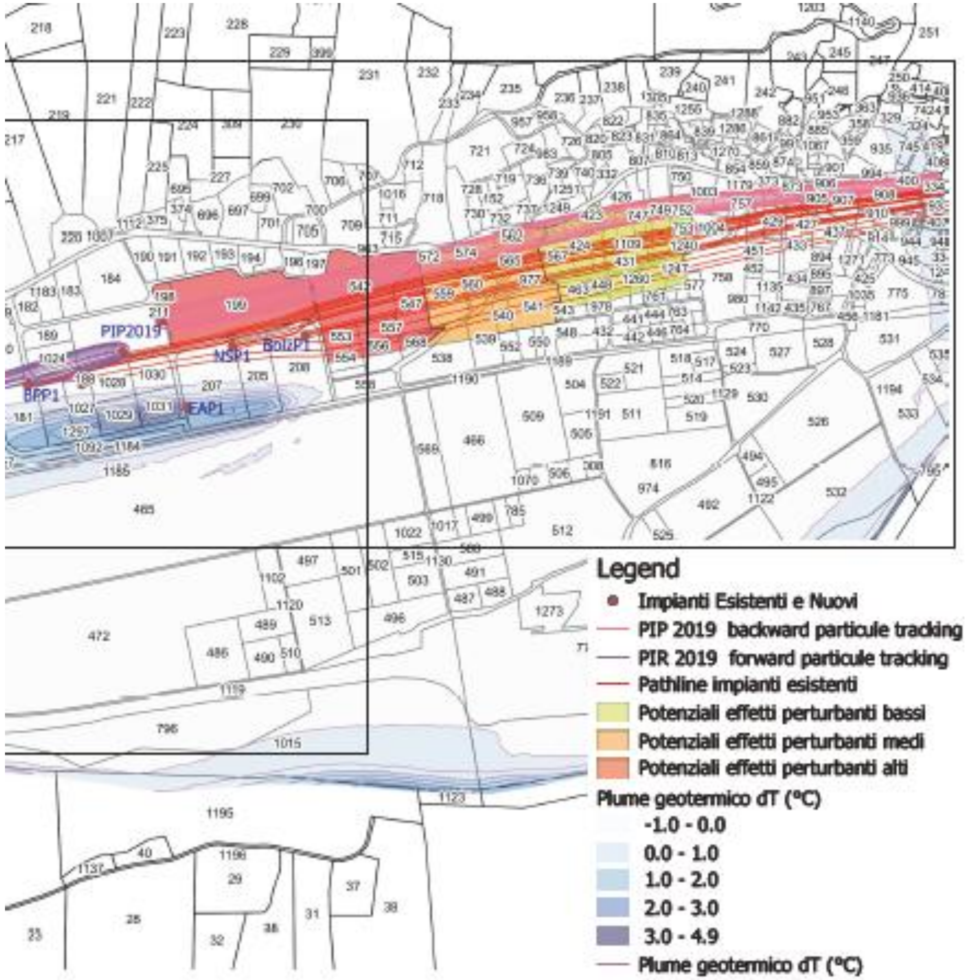
GeoBM

CASE 17 SAN VITTORE (GR, CH) HEAT PUMPS – 3D HYDRO-THERMAL (2017-2019)

Objectives: To calibrate a 3D hydro-thermal model of the San Vittore (GR) aquifer for the assessment of the thermal seasonal effect of heat pumps, and the study of the sustainable use of the thermal resources.







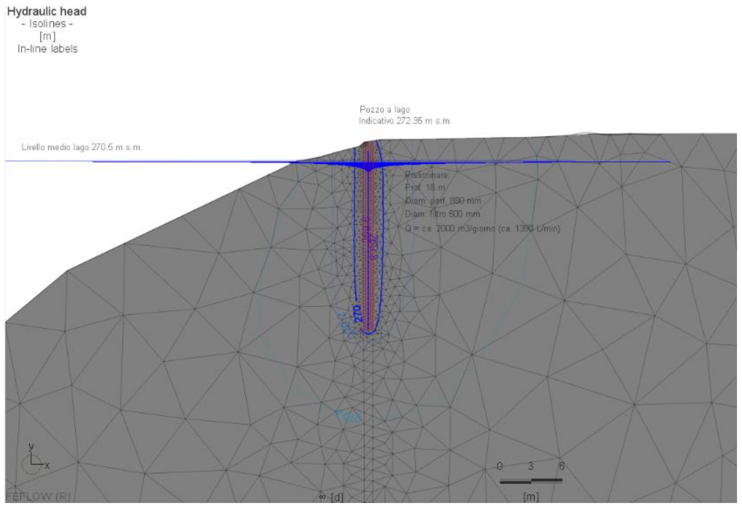
Settore 1	Settore 2	Settore 3	Settore 4
Nessuna controindicazione. *Nuovi impianti di pozzi termici fattibili.*	**Nessuna controindicazione, però.** *Nuovi impianti di pozzi termici fattibili. Richiede una breve valutazione e uno studio complementare* principalmente sul posizionamento	**Nuovi impianti di pozzi termici generalmente controindicati.** *Richiede una valutazione e uno studio complementare approfondito* sul posizionamento, dati termico-tecnici e sulle portate di esercizio	**Nuovi impianti di pozzi termici controindicati.**
146, 153, 181, 346, 470, 471, 473, 474, 475, 477, 478, 482, 483, 484, 485, **578, 584, 585, 586, 587, 588, 589, 685, 687, 688, 690,** 691, **692,** 693, 694, 793, 794, 971, 972, 973, 1025, 1028, 1030, 1125, 1126, 1127, **1182,** 1185, 1283, 1284	08, **177, 184**, 212, 465, **592**, 794, 1091, 1175, 1184, 1257	81, **178, 179, 182, 183,** 205, 207, 1026, 1027, 1089, 1092, **1183, 1295**, 1297	**180, 189, 1024,** 1029, 1031, 1307

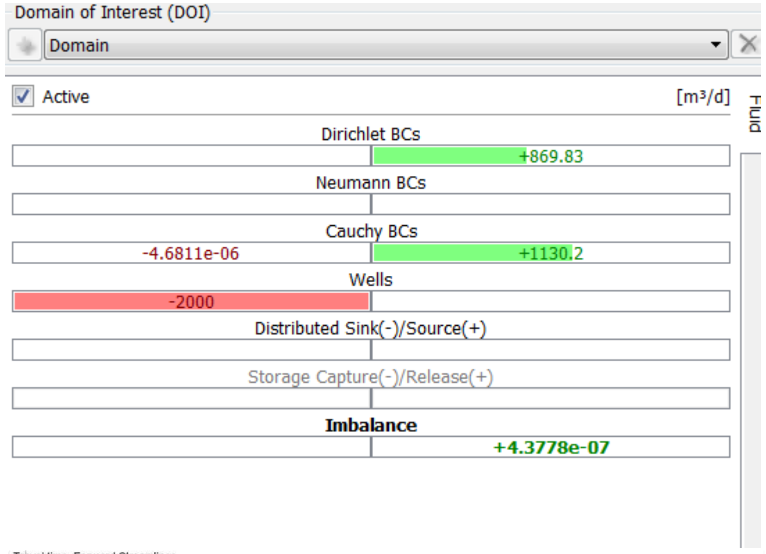
Settore 1: zona verde	Settore 2: zona arancione	Settore 3: zona rossa
Nessuna controindicazione. Nuovi impianti di pozzi termici sono fattibili. Nell'ambito del rilascio della concessione è necessaria una valutazione sul miglior posizionamento degli impianti.	**Nuovi impianti di pozzi termici fattibili, con riserve. Necessario uno studio di fattibilità approfondito** *con simulazioni numeriche volte a valutare ogni richiesta di concessione.*	**Nuovi impianti di pozzi termici presso i quali non è possibile una re-iniezione delle acque direttamente nell'acquifero. Vanno valutate assieme all'autorità cantonale eventuali altre possibilità di scarico verso ricettori superficiali. E quindi necessario uno studio di fattibilità approfondito.**
423, 424, **426**, 431, 448, 463, 543, 544, 545, **564**, 567, 747, 749, 752, 753, 759, 760, 762, 803, **978, 985**, 1105, 1106, 1107, 1108, 1109, **1177**, 1240, 1247, 1252, 1260, 1267, 1290, 1291,	538, 539, 540, 541, 559, 560, 561, 562, 563, **564,** 565, 570, 571, 572,573,575, 977, **1177**	**198, 199, 211,** 542, 547, 553, 554, 556, 557, 568

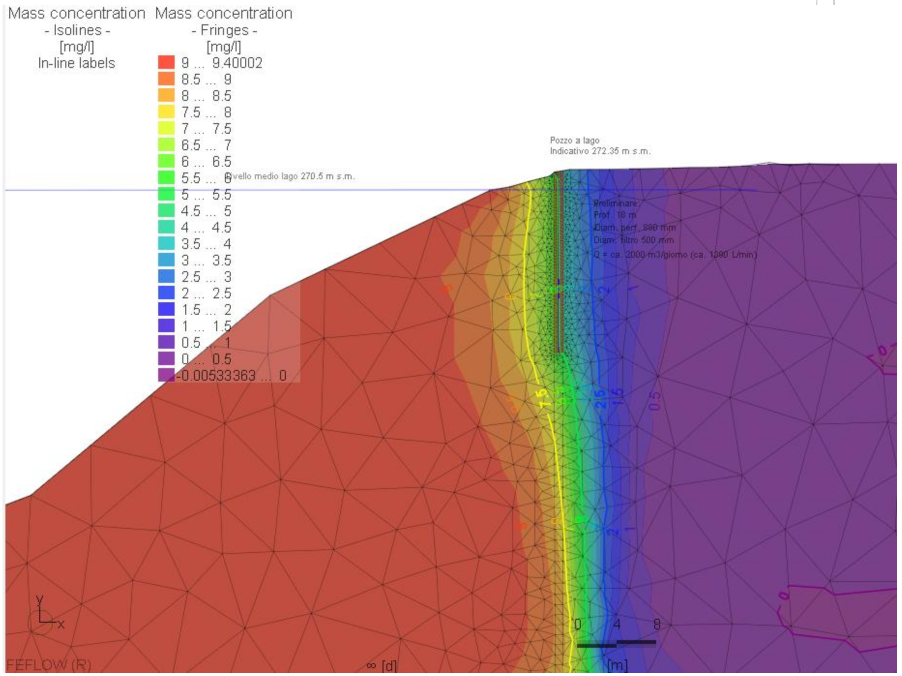
FEFLOW

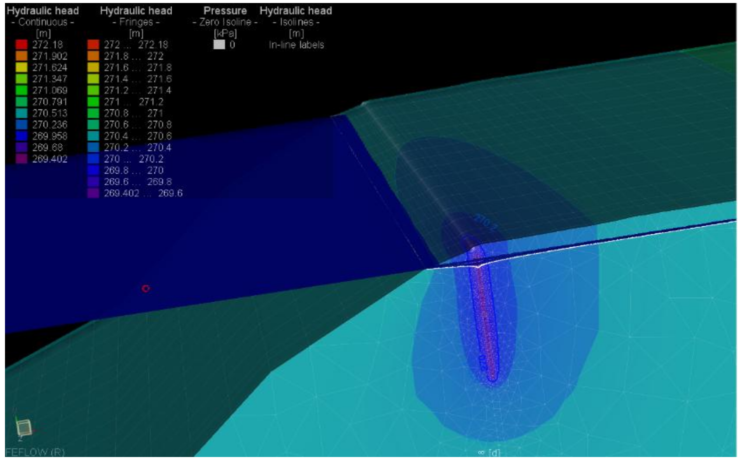
CASE 18 MAROGGIA LAKE-PUMPING-CONTAMINATION – 3D FLOW (2019)

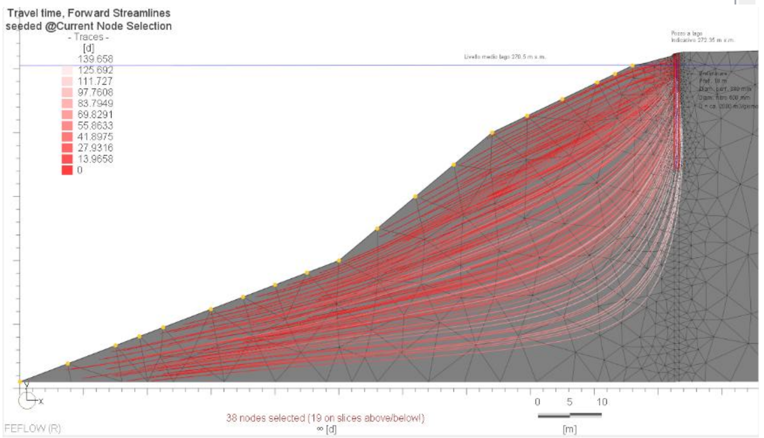
Objectives: To calibrate a pseudo-3D flow model of the coastal aquifer of Maroggia (TI) and the municipality well to assess the aquifer/lake contribution and the impacts of possible pollution (mass transport).







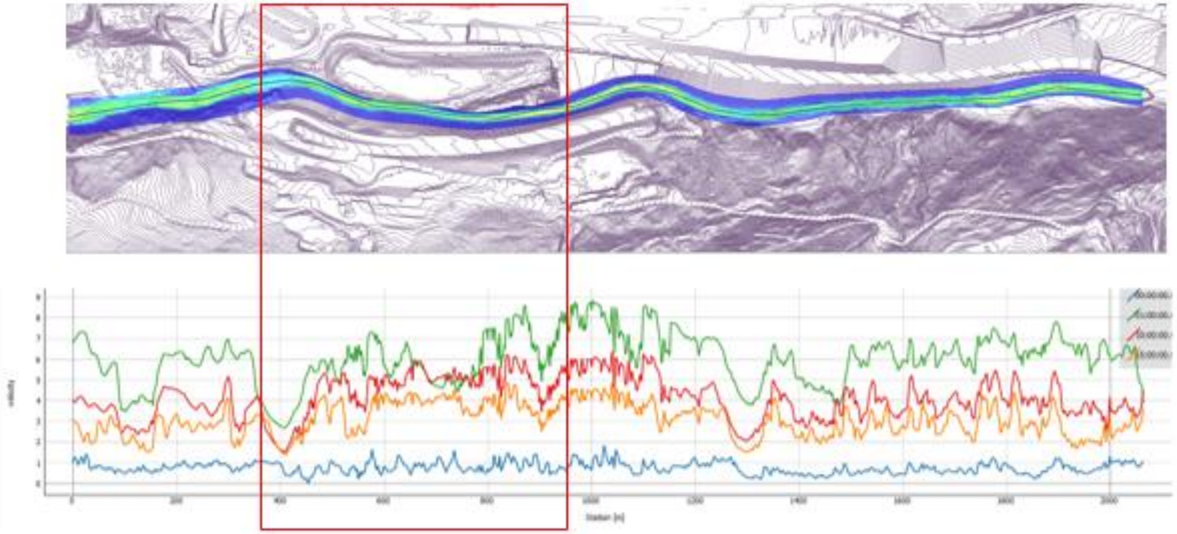


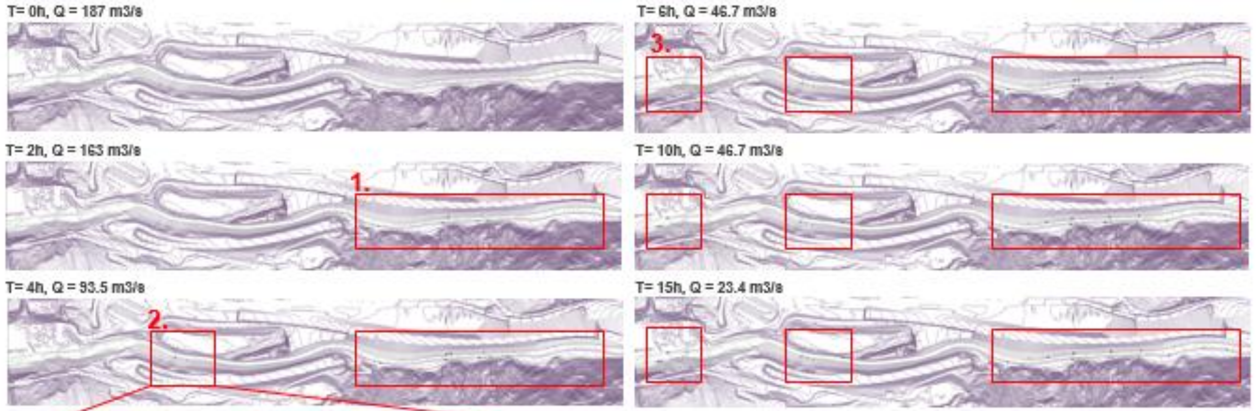


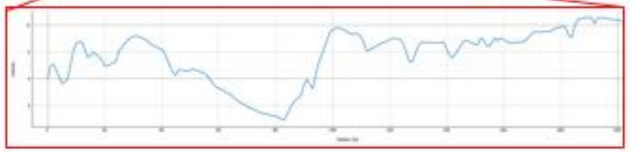
GeoBM

CASE 19 RIVIERE TICINO (TI) DIKE EVALUATION – 2D FLOW (2017)

Objectives: To calibrate a 2D flow model of the Ticino river in Airolo (TI, CH) to study sediment transport related to several fluvial redevelopment options.



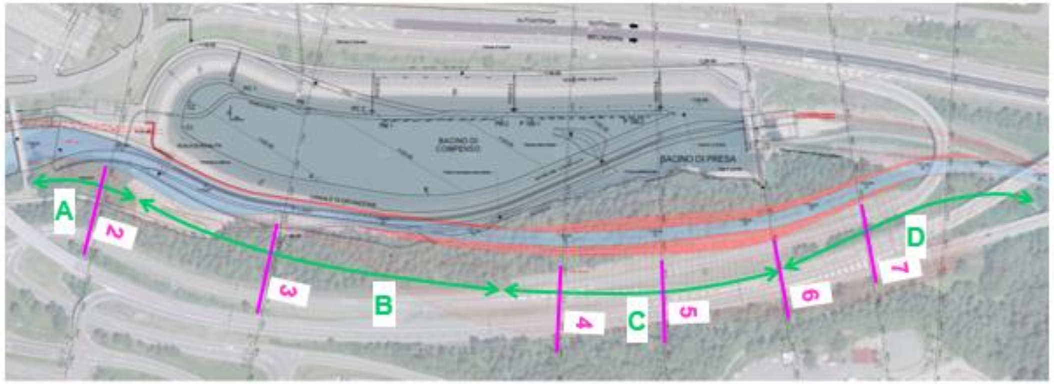




→ Pto. 1: Depositi a valle (già dopo 2h)

→ Pto. 2: Depositi nel tratto di riprofilo (dopo 4h)

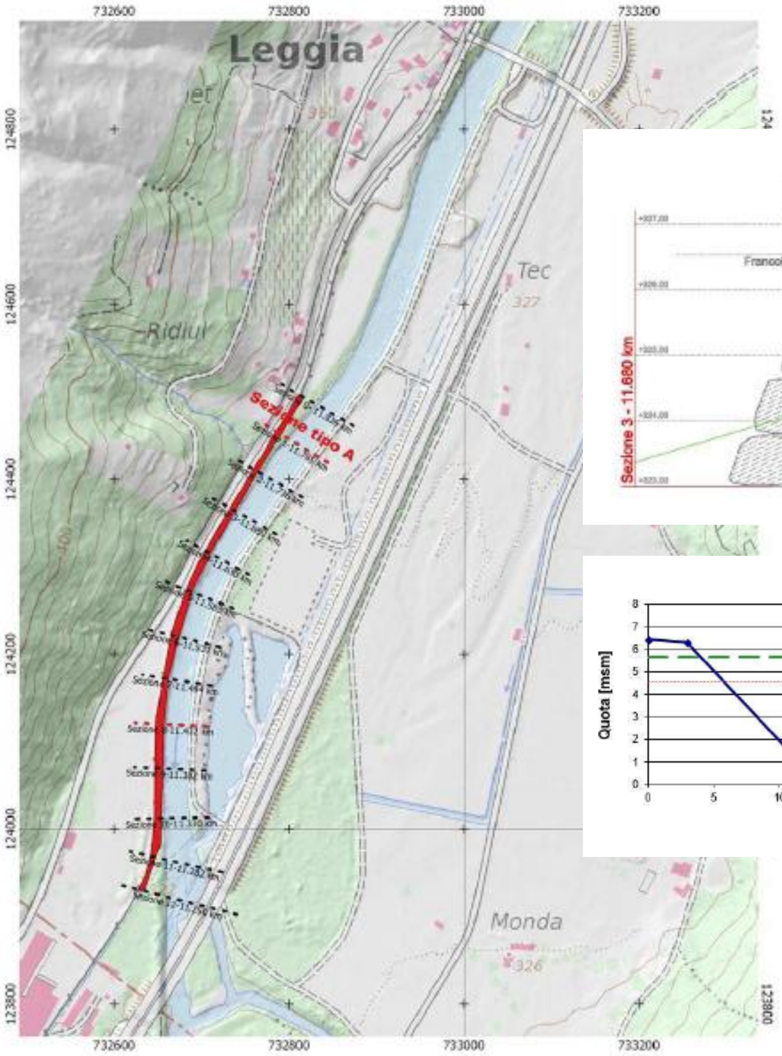
→ Pto. 3: Depositi a monte (dopo 6h)

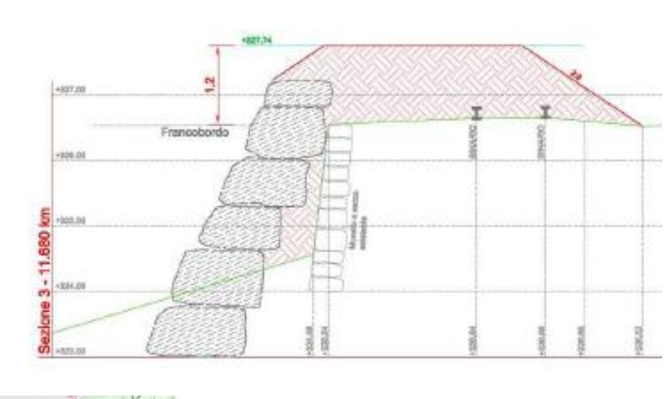


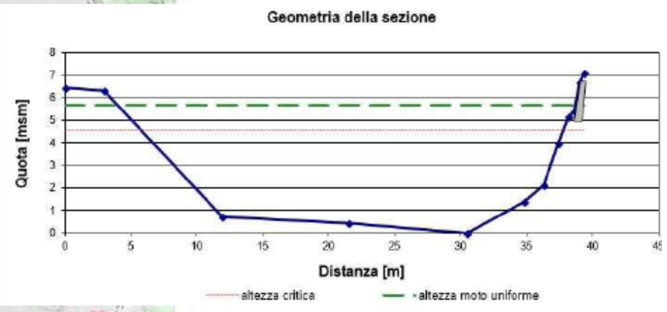
BASEMENT

CASE 20 MOESA (GR, CH) RIVER DIKE STABILITY EVALUATION – 2D FLOW (2018)

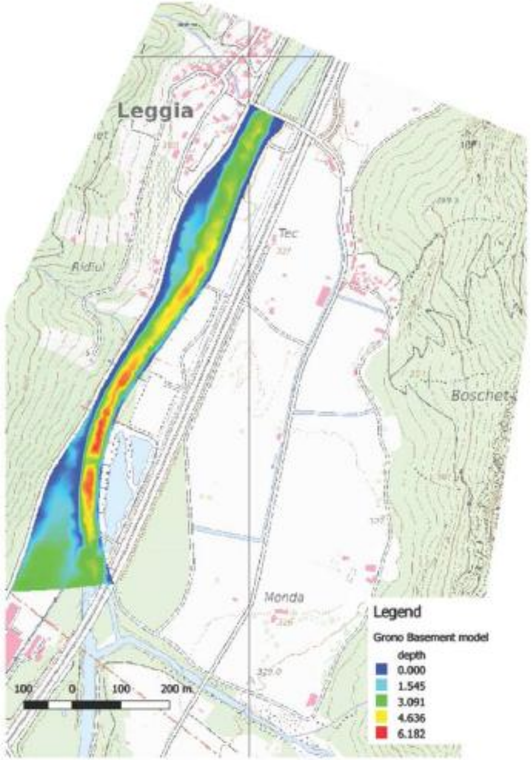
Objectives: To calibrate a 2D flow model of the Moesa (GR, CH) river to study sediment transport related to several fluvial redevelopment options and dike stability studies.

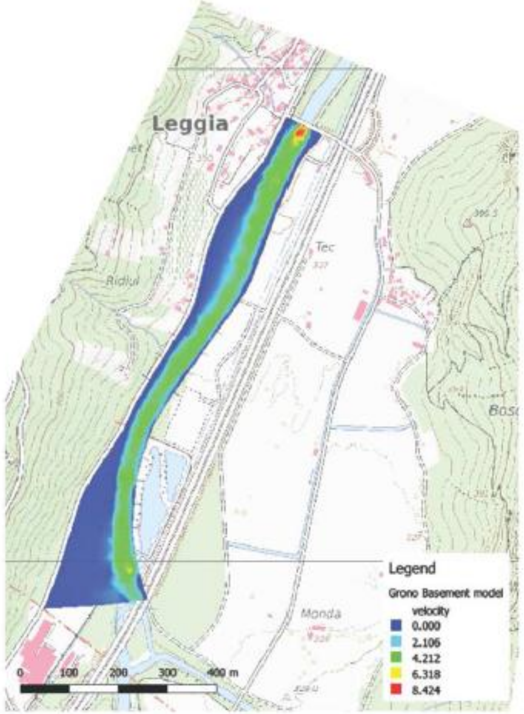






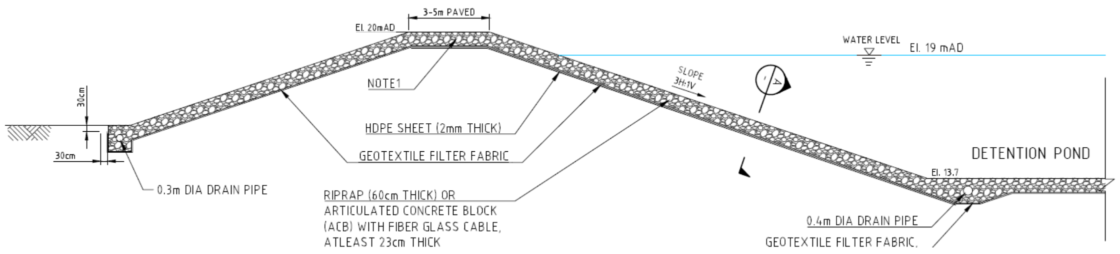
HQ300 (655 m3/s)

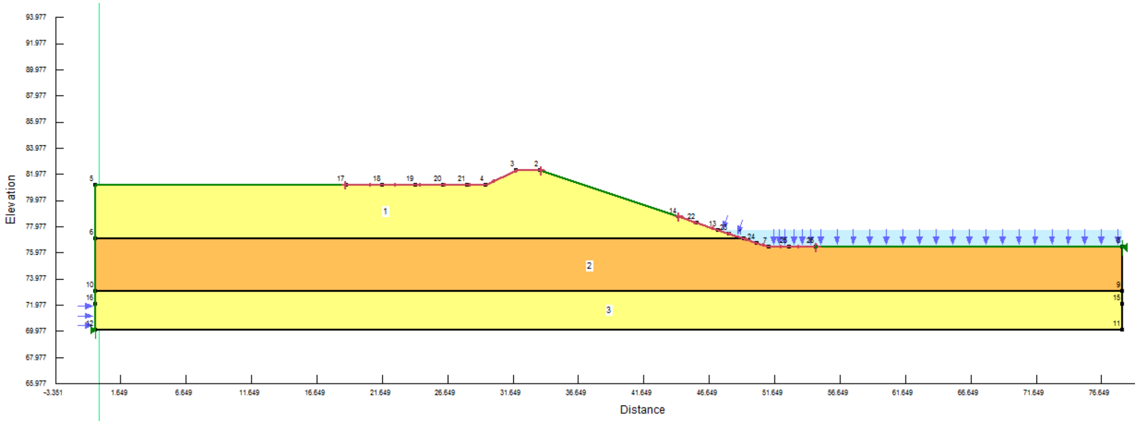


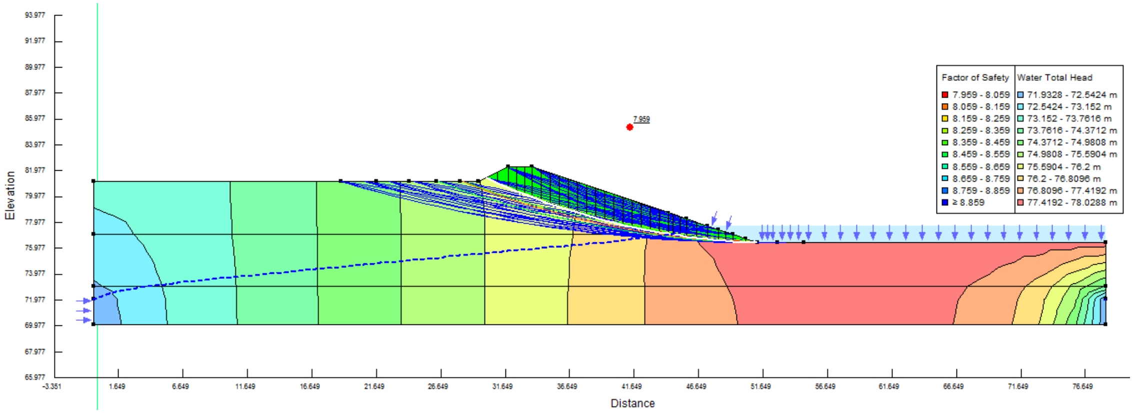


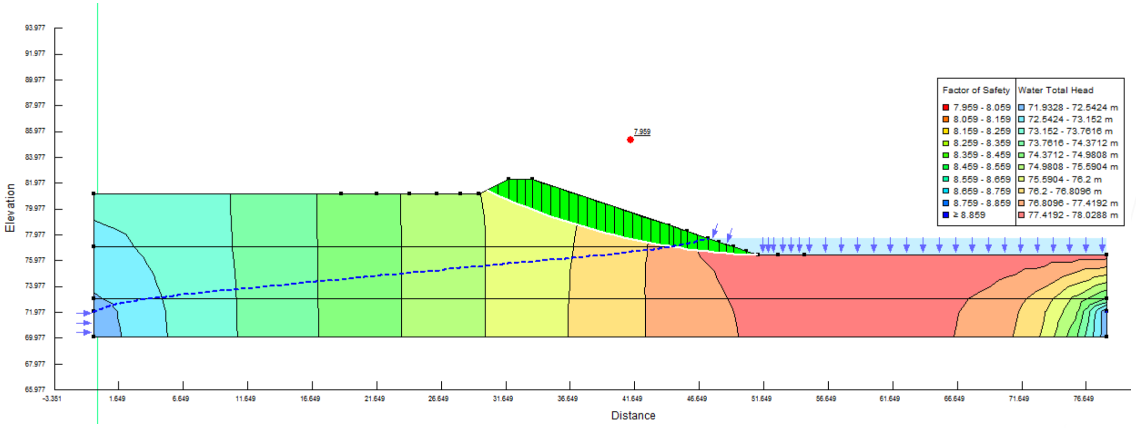
CASE 21 RETENTION POND IN KOWEIT – 2D FLOW (2019)

Objectives: Design of retention pond including bank stability calculation and seepage analyzes. Program: GEOSTUDIO, SEEPW + SLOPE.



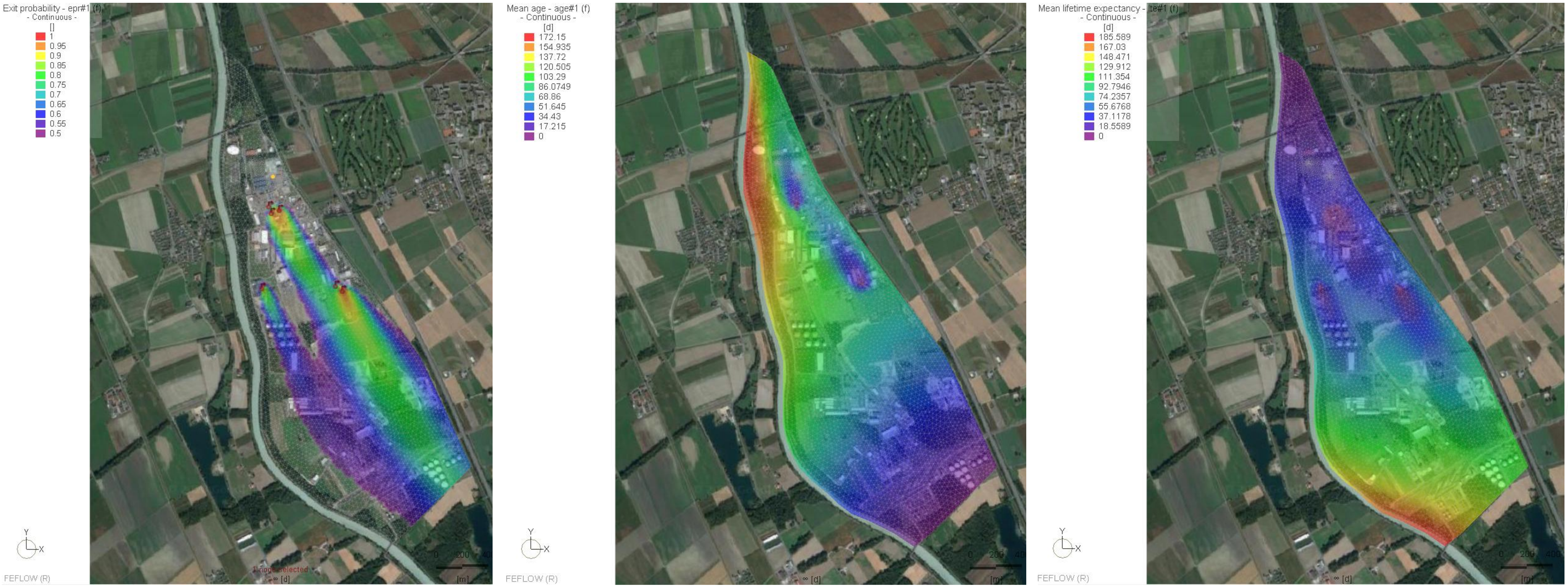






CASE 22 HEAT PUMPS – MIGROS, CH – 3D HYDRO-THERMAL (2020)

Objectives: To calibrate a 3D hydro-thermal model for the feasibility study of thermal exploitation by pumping the water table of the Rhône within the framework of the CC CHABLAIS CENTER 2020 project. The system must allow the production of heat and cold. In addition to the flow steady-state solutions towards a well described by Dupuit's analytical solution, the statistical distribution of the random variable 'age' of the groundwater has been modeled using the classical advection-dispersion equation for the transport of a conservative and non-reactive tracer.



FEFLOW

CASE 23 KABUL AQUIFER MANAGED RECHARGE – INJECTION WELL – 3D FLOW (2020)

Objectives: To calibrate local 3D flow models for each pilot site related to deep wells forced recharge.

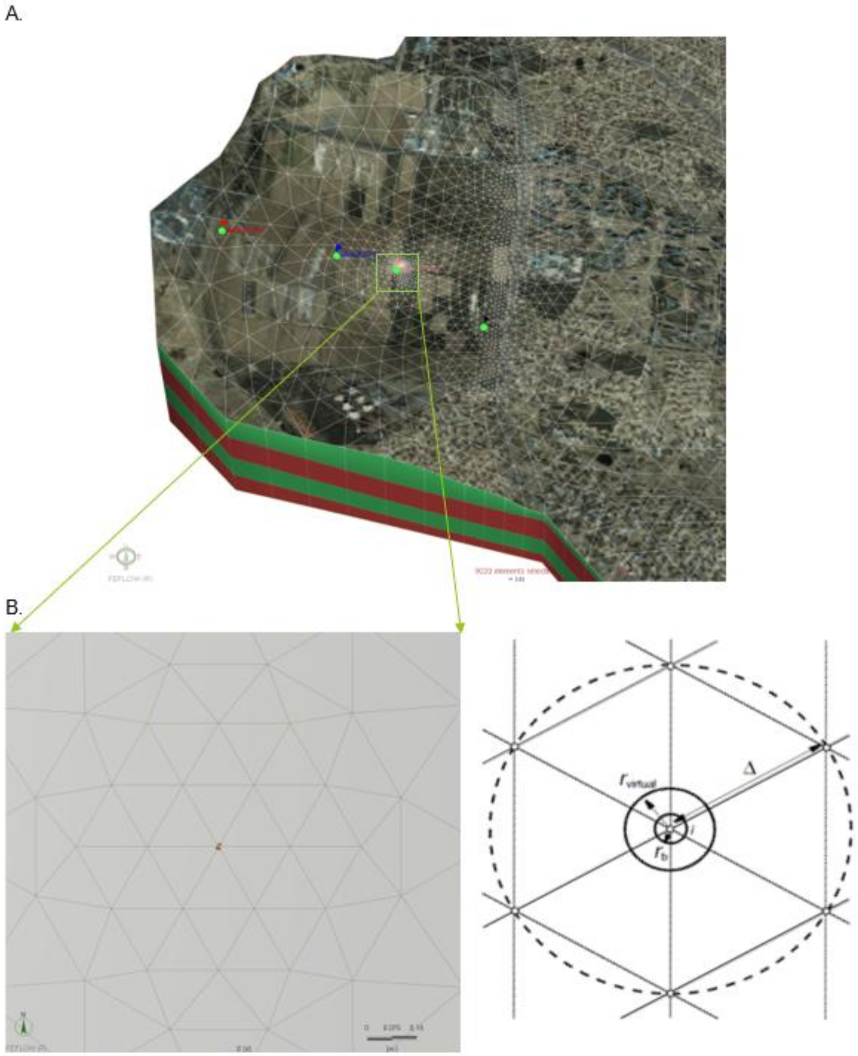


Figure 8: A) Numerical mesh at Badem Bagh (MAR Site 4) with (B) mesh refinement details at the infiltration borehole

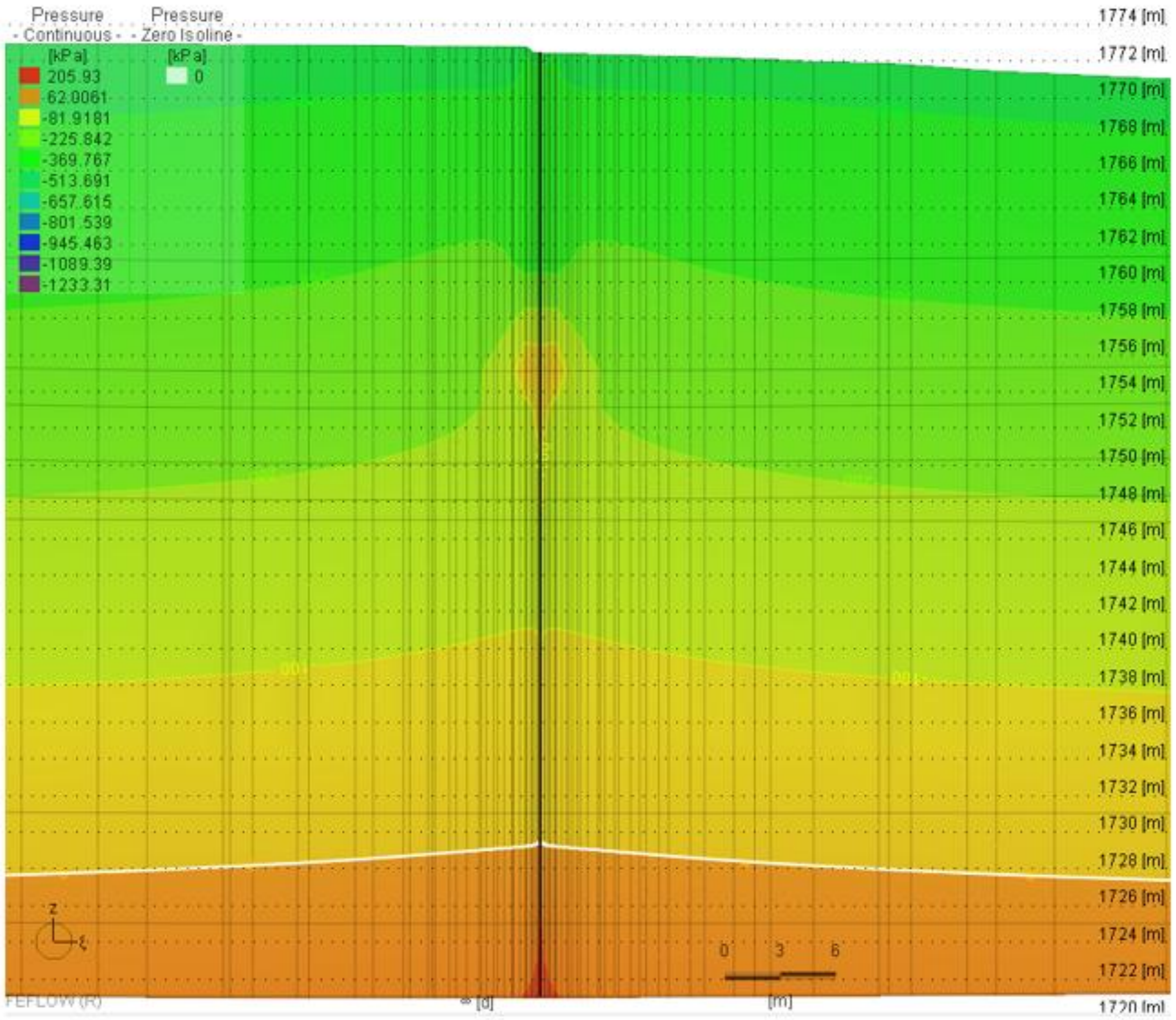
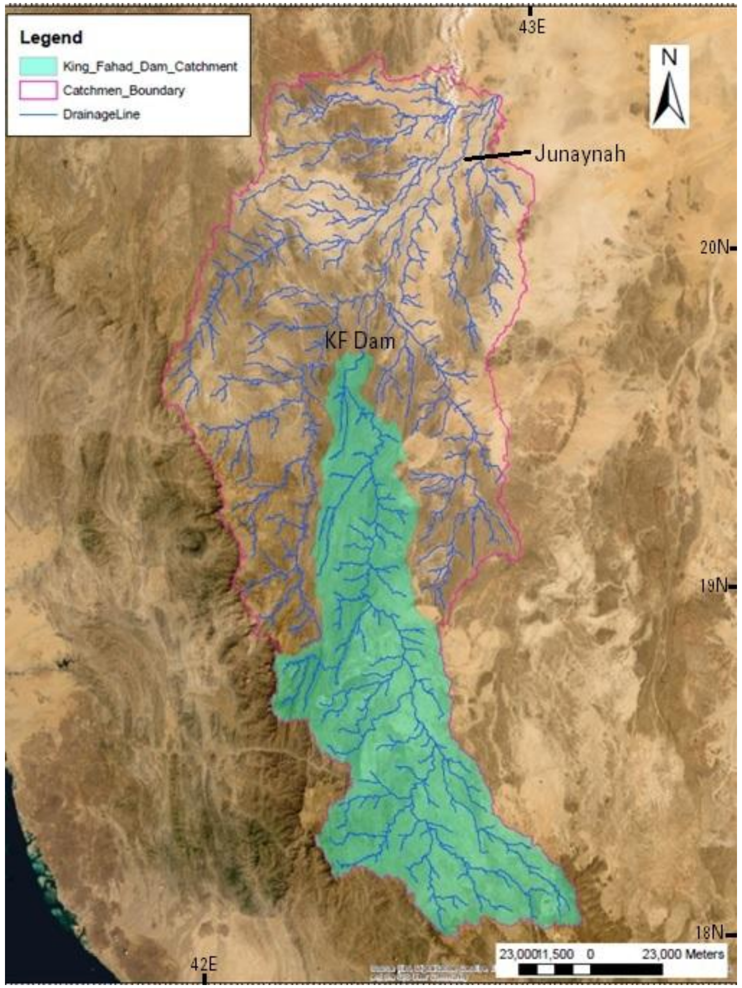


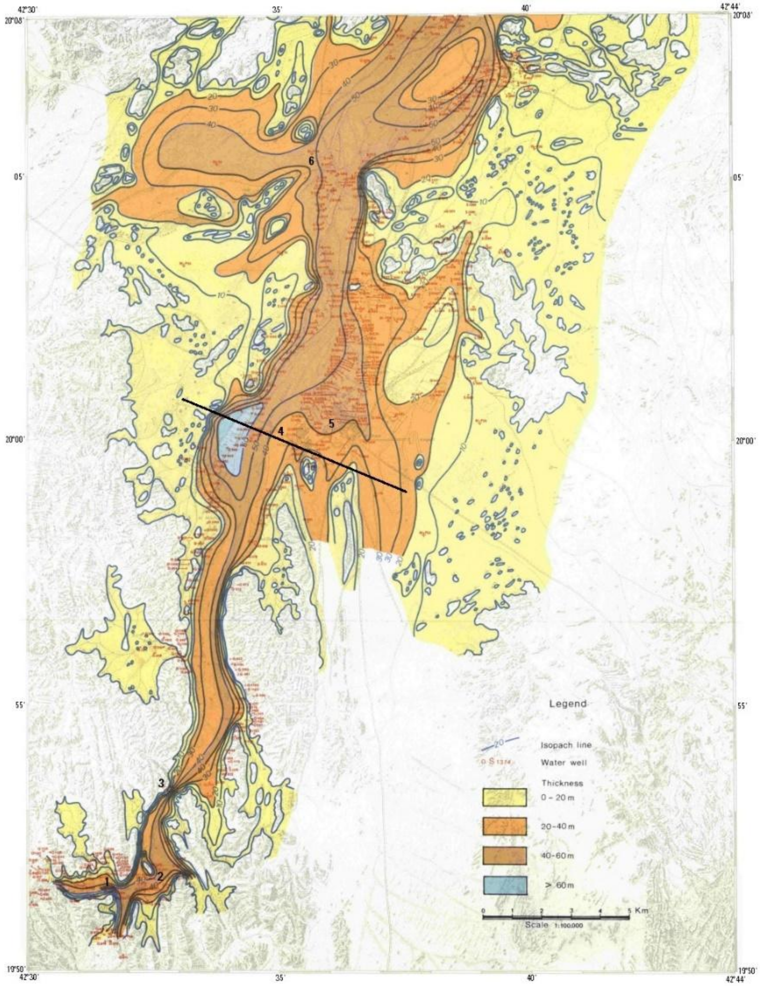
Figure 20: Pressure build-up in injection well (MAR4-INW-1)

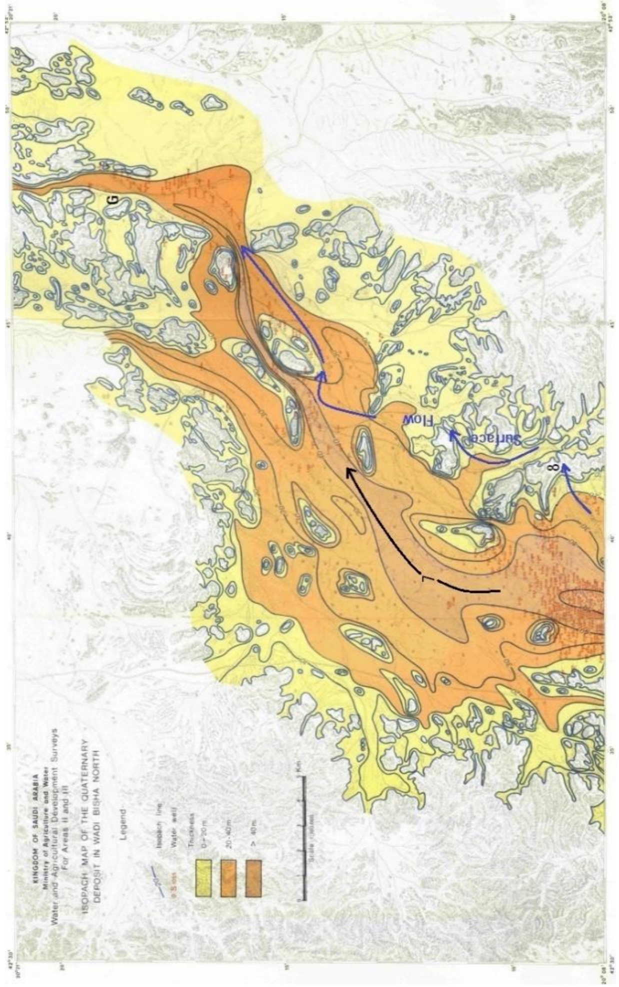
FEFLOW

CASE 24 AQUIFER RECHARGE – WADI BISHA KSA- 3D FLOW (2020)

Objectives: A 3D groundwater flow model was developed to identify the optimal distribution strategy for the water stored behind the King Fahad Dam. The model aimed to quantify the area's groundwater balance, including key recharge sources and rates, natural outflows, and additional losses due to anthropogenic abstractions.







GeoBM

FEFLOW

CASE 25 SHEET PILES STUDY– BÉGNINS, CH – 2D FLOW (2020)

<u>Objectives</u>: To calibrate a vertical 2D digital flow model and identify the interactions between a sheet piles wall and the Césille water resources.

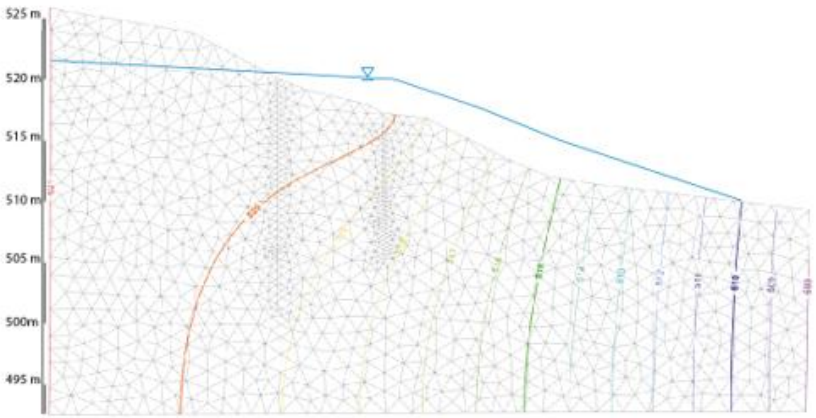


Figure 2 : Courbes isopièzes – Situation actuelle

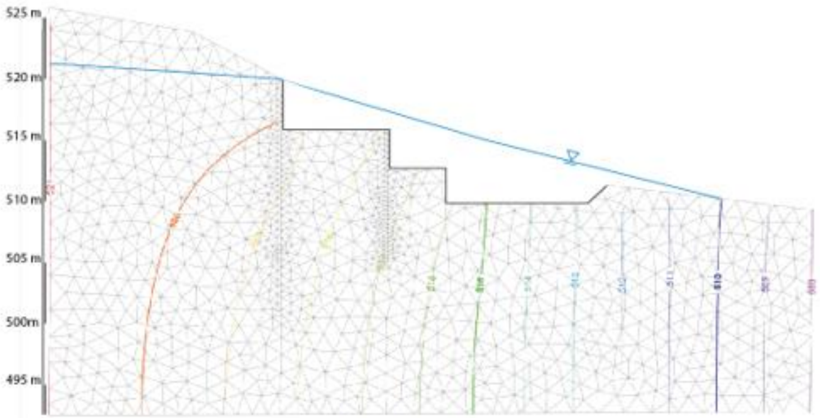


Figure 3 : Courbes isopièzes – Avec excavation sans pieu sécant

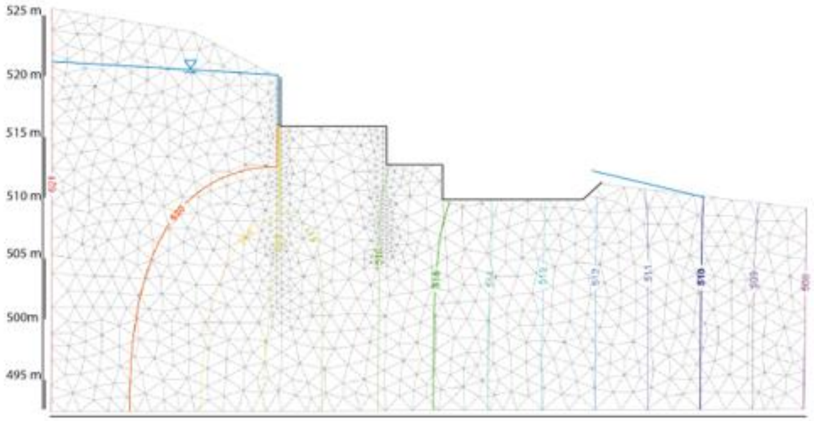


Figure 4 : Courbes isopièzes – Avec excavation et pieux sécants 13 mètres

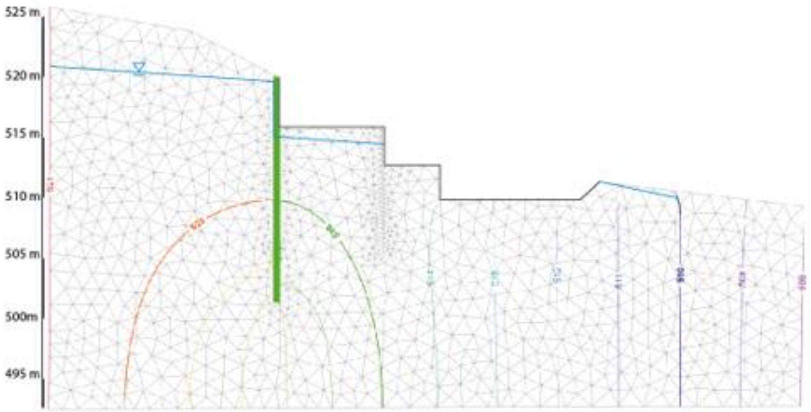
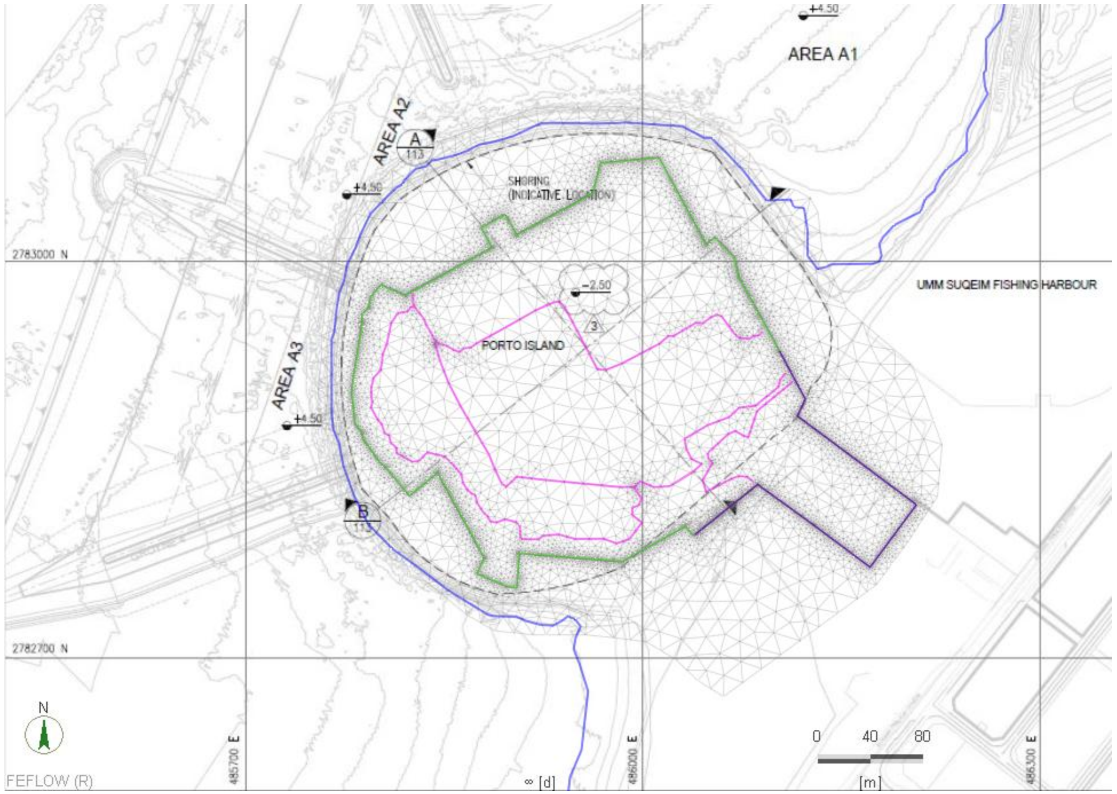
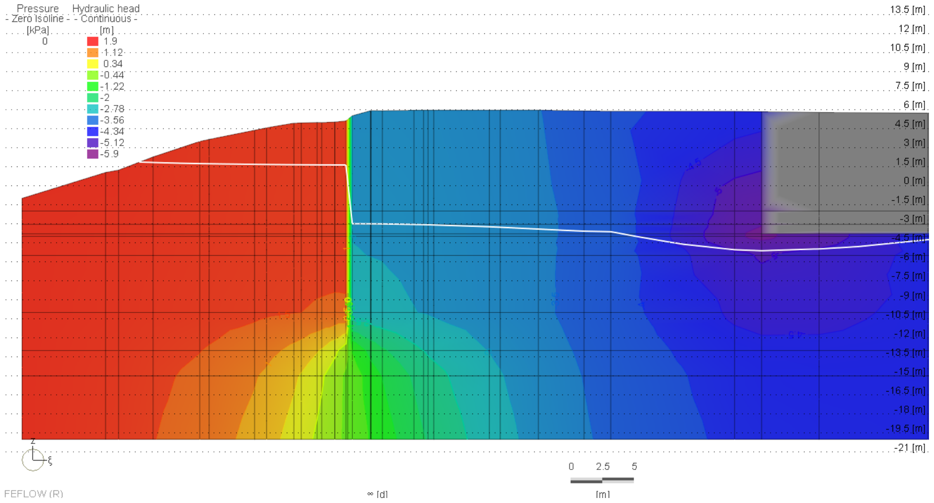


Figure 5 : Courbes isopièzes – Avec excavation et pieux sécants 18 mètres

CASE 26 WATER TABLE DRAWDOWN – DUBAI (UAE) – 3D FLOW (2020)

Objectives: To calibrate a 3D flow model for enabling works construction dewatering.





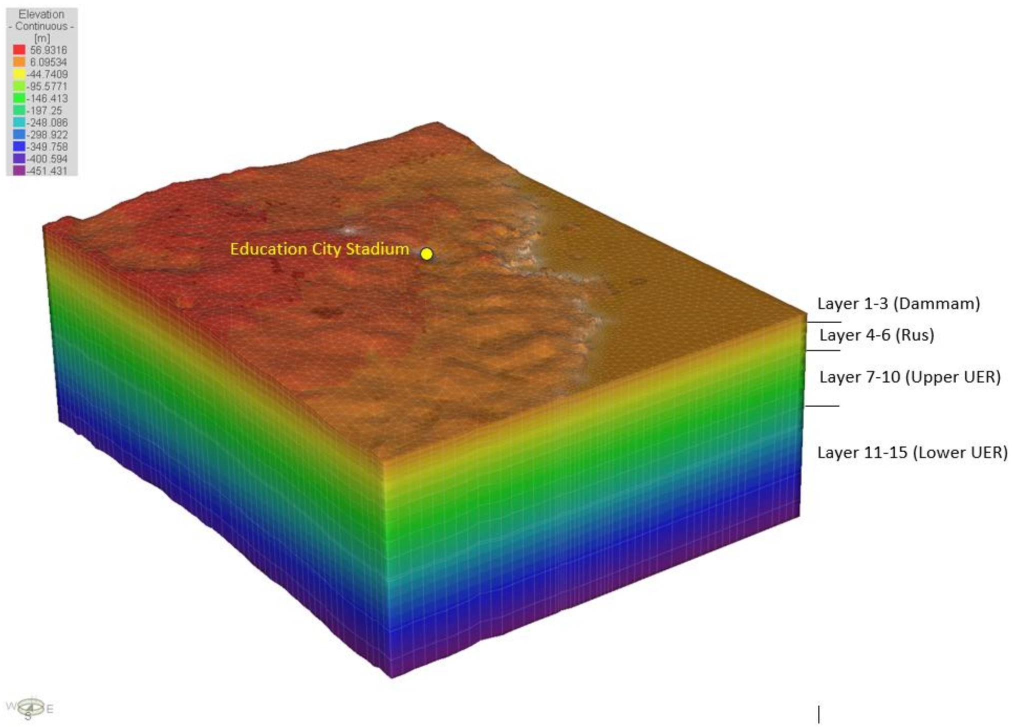
Scenario	Description	Permeability (m³/s)		Dewatering Level	Predicted dewatering requirements (m³/day) based on 3D modeling	
		Sand	Sandstone		Shoring	No shoring
1a	Tender Permeability	2.50E-06	2.50E-06	Tender	517	706
1b				EI001	526	725
1c	Tender Permeability – Contractor-Assessed	1.20E-04	1.00E-05	EI001	5,071	20,283
2a	Post-award permeability (pumping test)*	4.10E-04	1.00E-05	Tender	6,866	64,073
2b				EI001	7,053	65,821

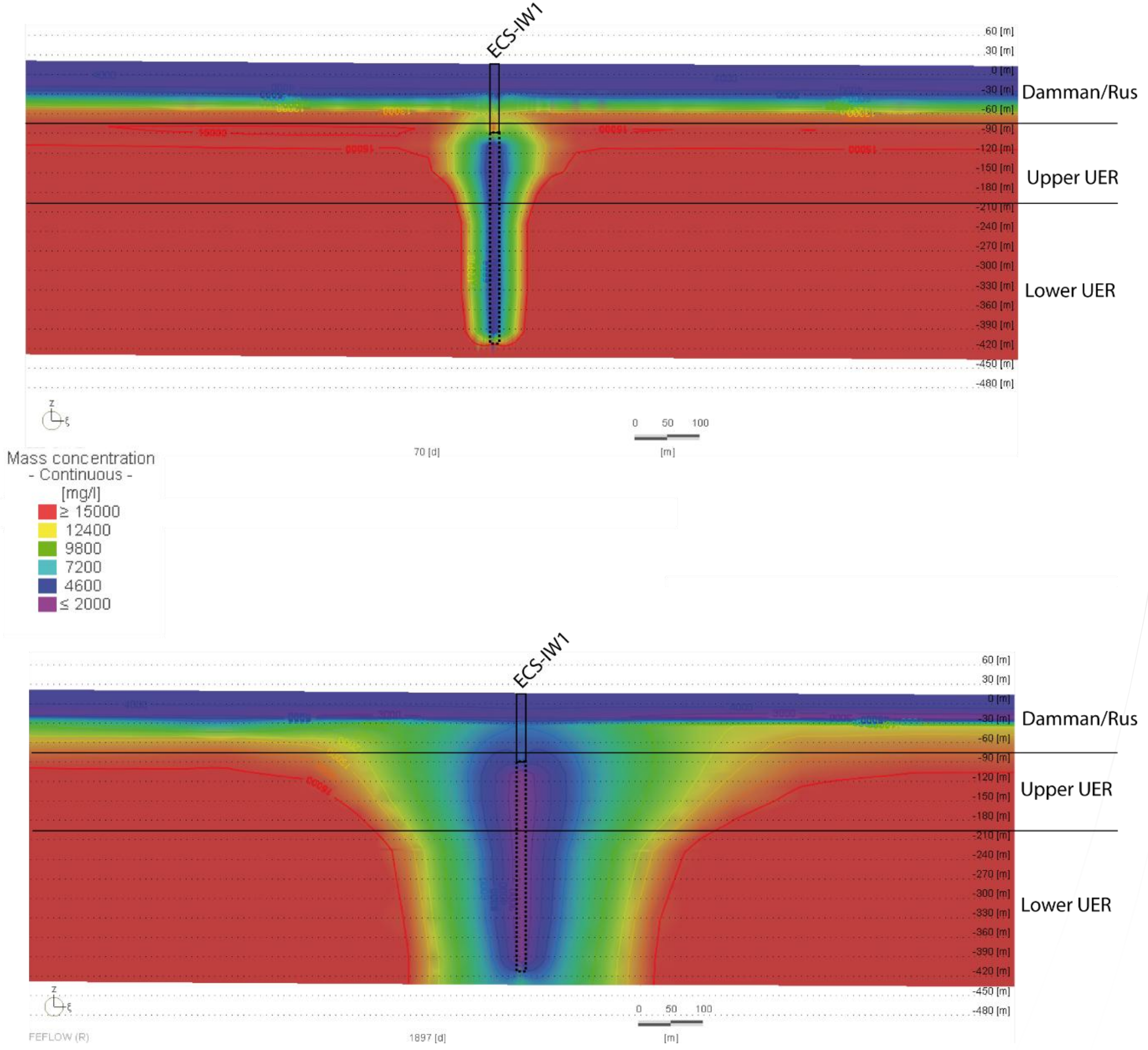
GeoBM

MODFLOW

CASE 27 TSE RECHARGE at ECS, Messaimeer Graveyard, Al Rayyan Stadium (Doha, Qatar) – 3D FLOW – MASS TRANSPORT (SALINITY) (2020-21)

Objectifs du problème: To calibrate a 3D flow-mass transport (salinity) model for different areas in Doha, for the study of the reinjection of treated sewage effluents (TSE) in the hypersaline aquifer.



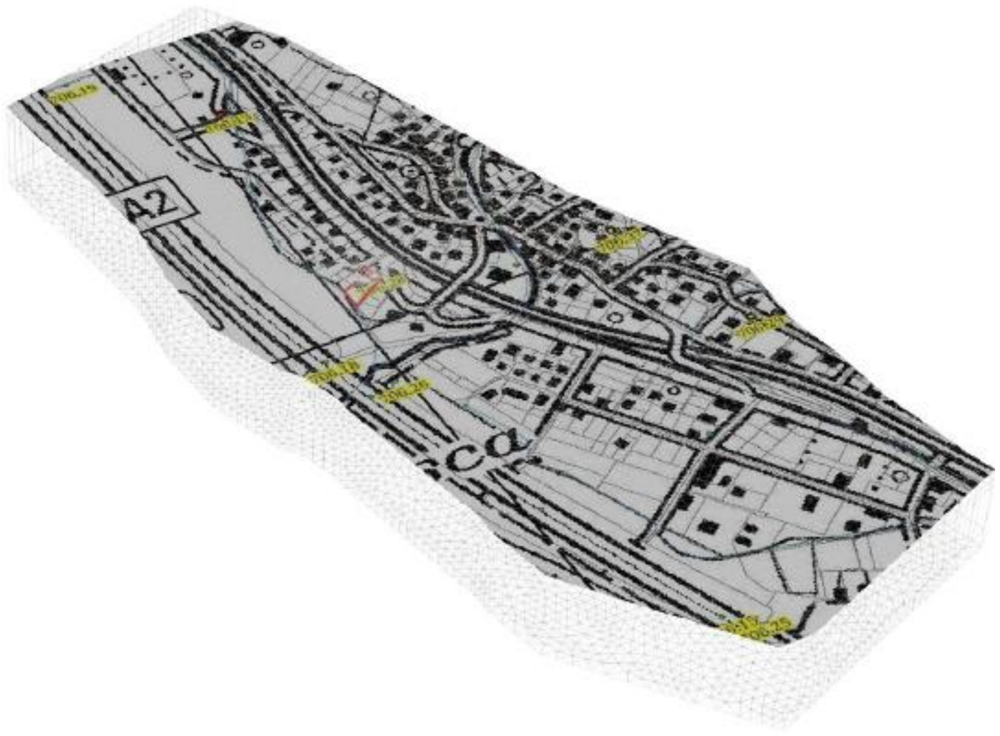


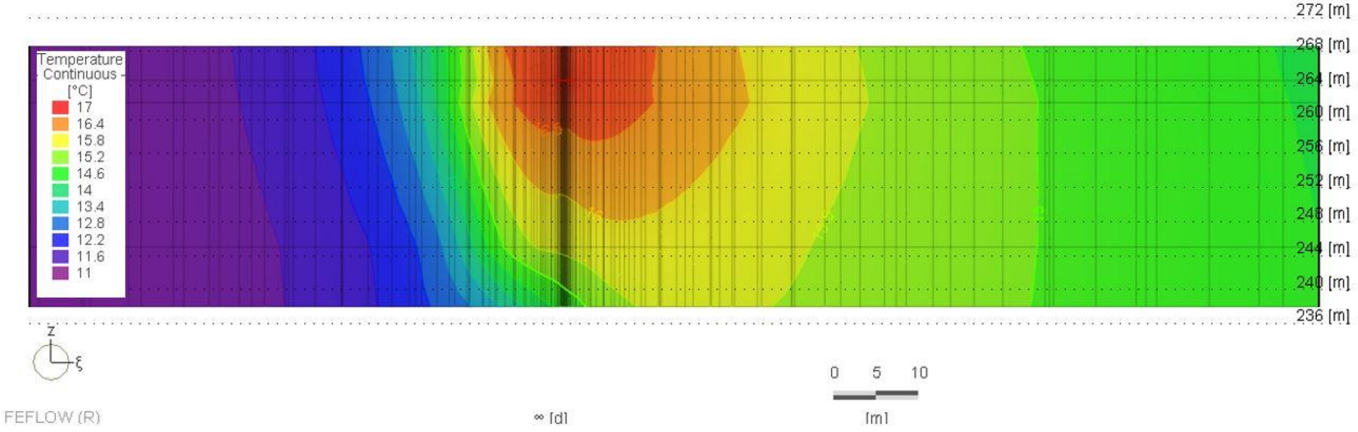
GeoBM

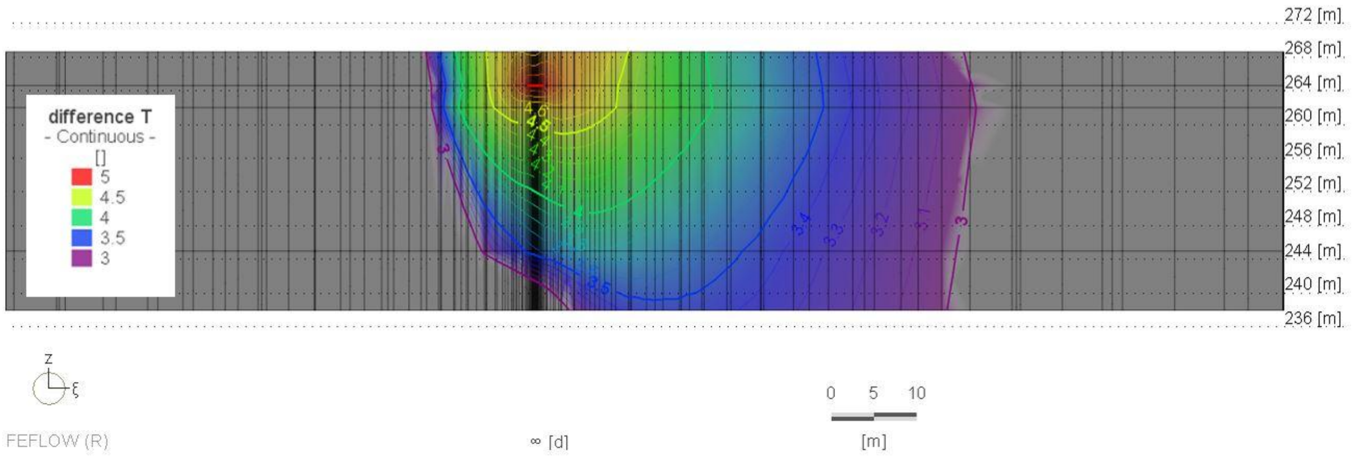
FEFLOW

CASE 28 OSOGNA HEAT PUMP (TI, CH) – 3D HYDRO-THERMAL (2017-2019)

Objectives: To calibrate a 3D hydro-thermal model to evaluate the extension (impact) of the thermal plume with time.



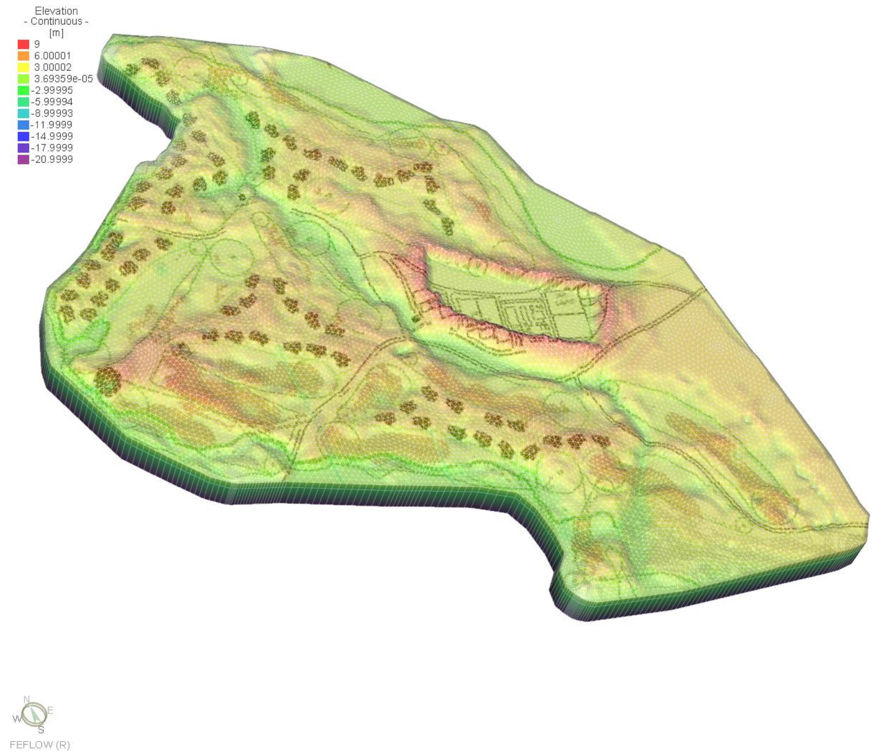


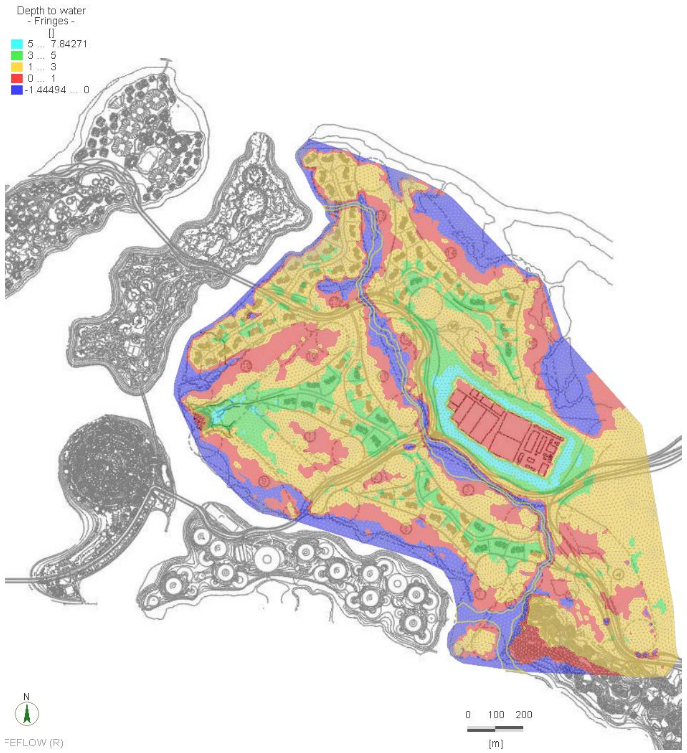


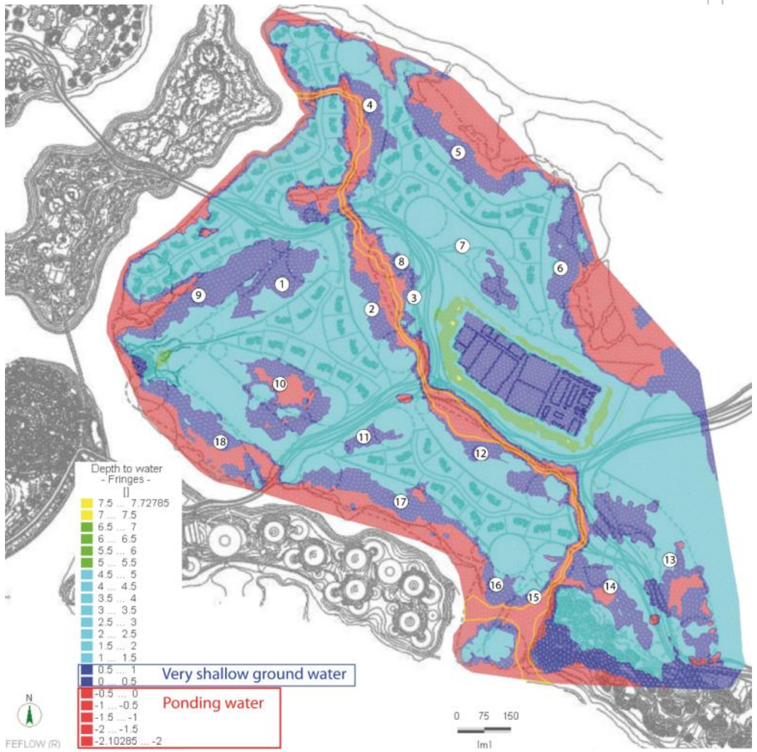
GeoBM

CASE 29 SHURAYRAH GOLF CLUBHOUSE, KSA– 3D FLOW (2021-2024)

- Objectives: A 3D groundwater model was developed for the future Shurayrah Golf Clubhouse (KSA) to simulate current conditions and assess groundwater-related risks across Shurayrah Island. The model was used to produce depth-to-groundwater maps for MHWS, the 2020 baseline, and 2070 projections. A +0.9 m design water level scenario was also evaluated and adopted for future drainage and recharge planning.



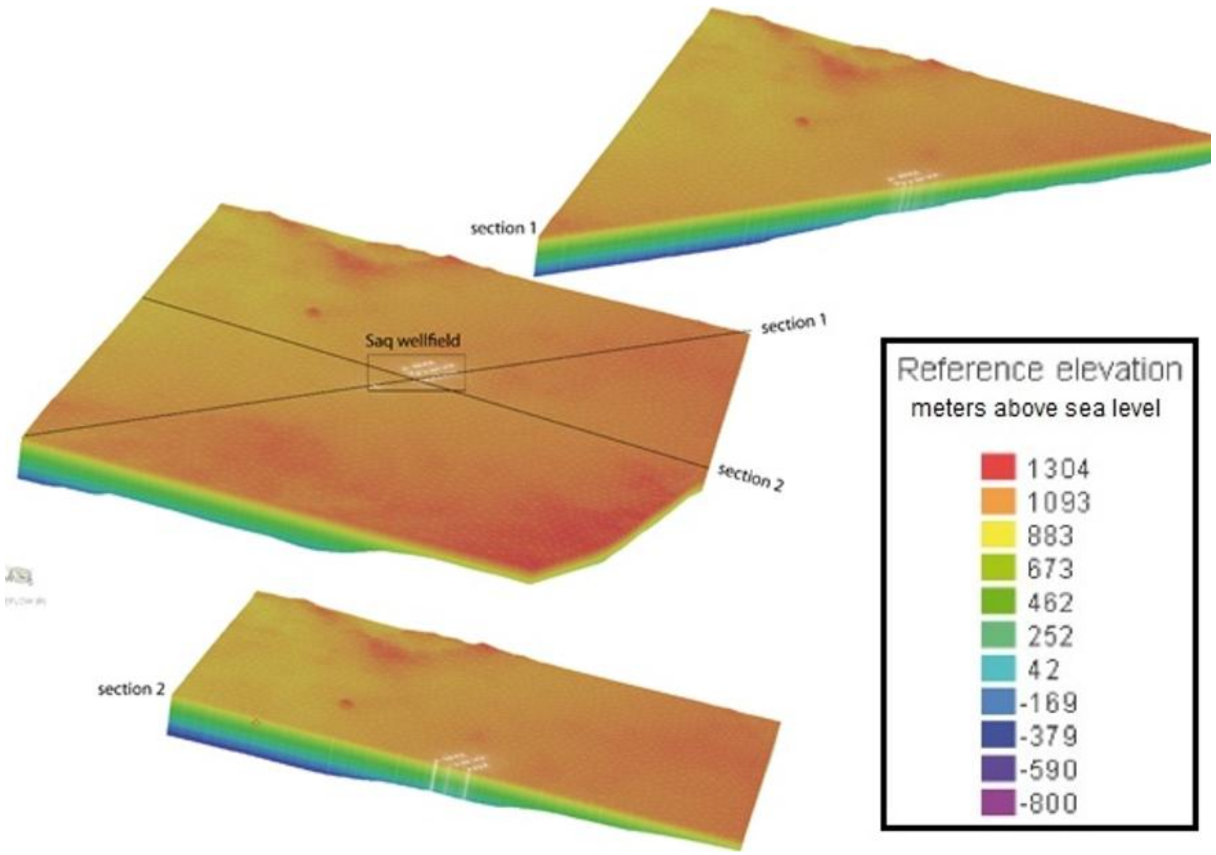


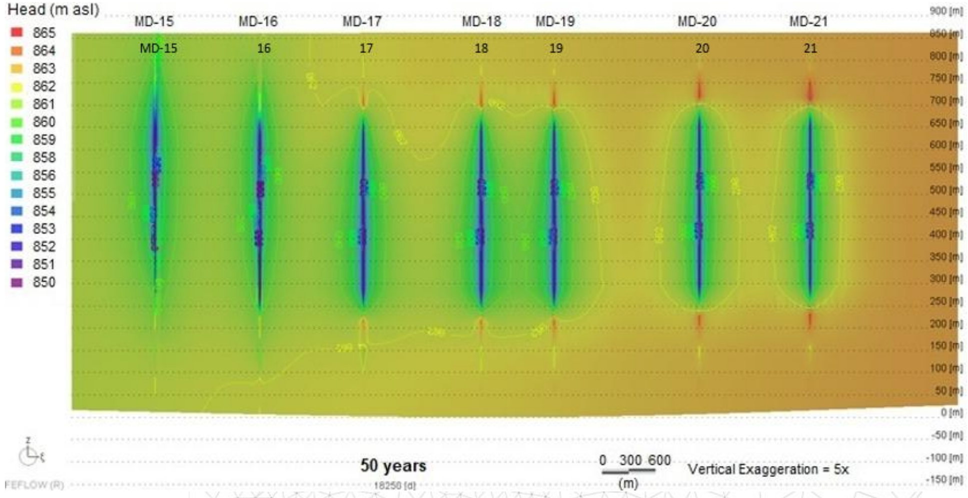


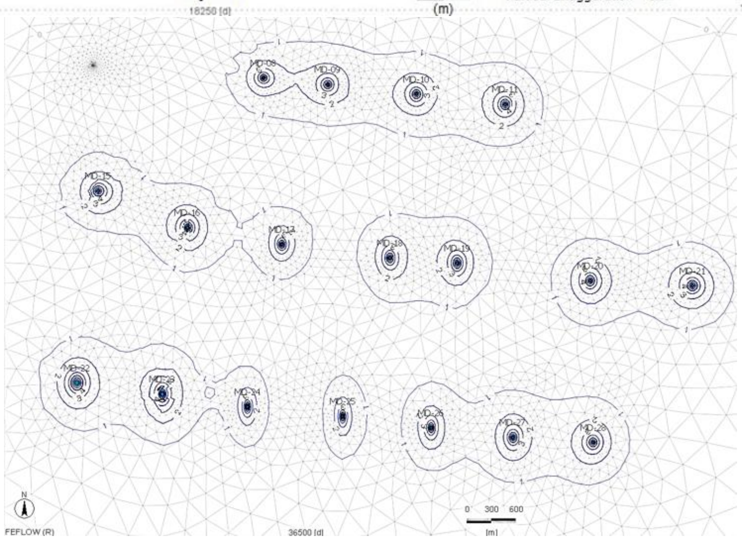
GeoBM Sagl

CASE 30 AQUIFER MANAGEMENT – THE GREAT SAQ WELL FIELD (KSA) – 3D FLOW – (2021-2022)

Objectives: A 3D hydrogeological model was developed to assess the long-term sustainability of water supply through water balance analysis, predict groundwater level drawdowns over 50- and 100-year periods, and evaluate model sensitivity to key parameters with inherent uncertainties.







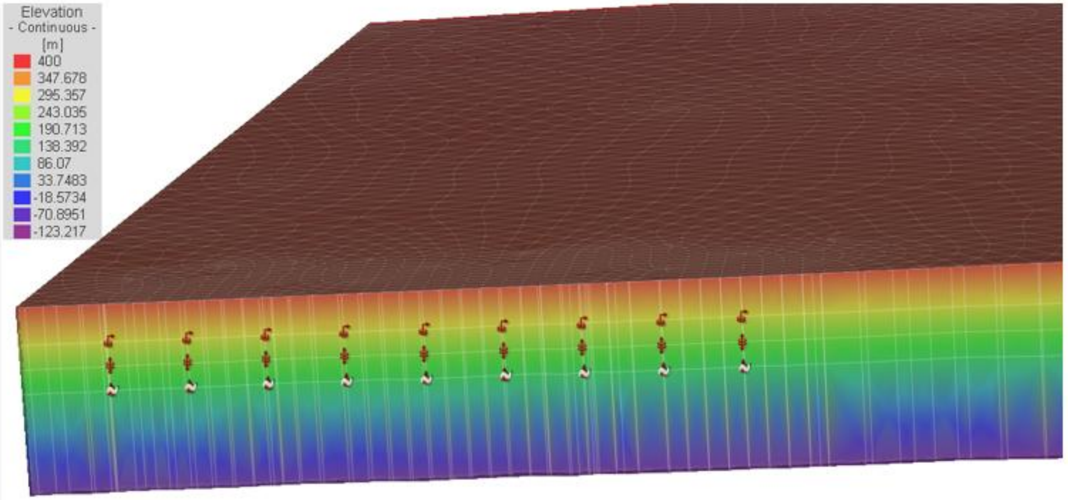
FEFLOW

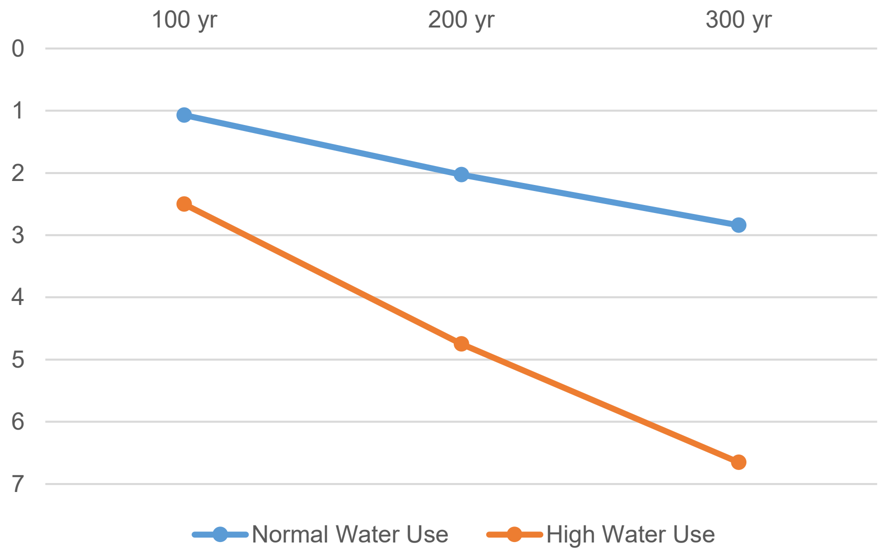
CASE 31 AQUIFER MANAGEMENT – 3D HYDRO- WILAYA EL MENIA, (ALGERIA) – (2022-2023)

Objectives: To calibrate a 3D hydro model to assess the quality and quantity of water available for commercial use

Normal Water Use Scenario

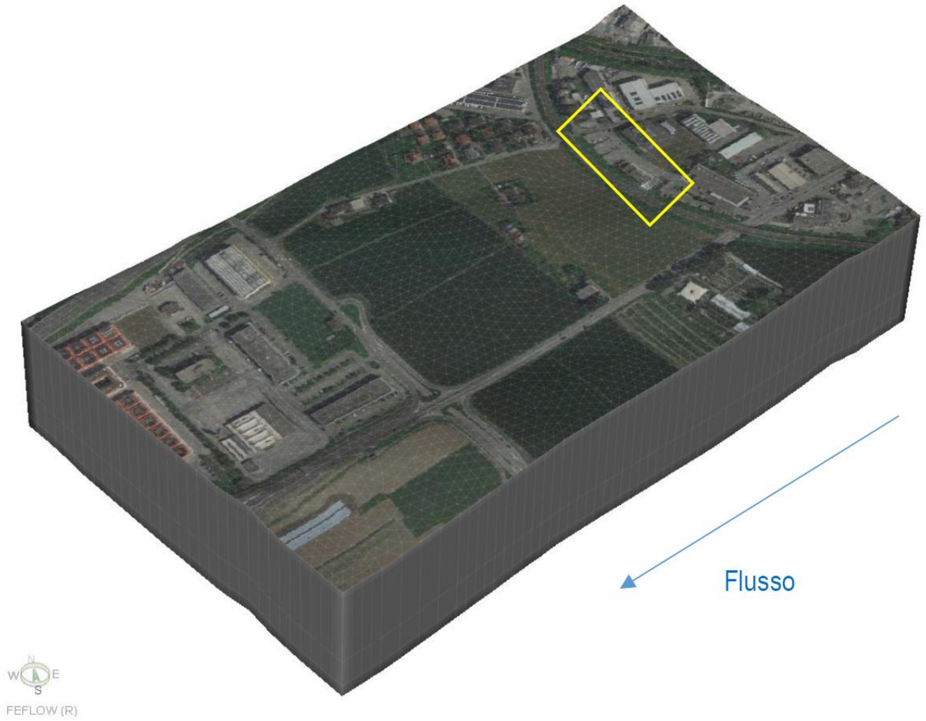
K	Ss	Drawdown at Farm Boundary (m)			Radius of Influence (km)		
		100 yr	200 yr	300 yr	100 yr	200 yr	300 yr
Normal	Low	1.07	2.03	2.84	4.9	6.3	7.3
Normal	Normal	0.48	1.08	1.58	3.6	5.2	6
Normal	High	0.33	0.76	1.15	3.42	4.26	5.26

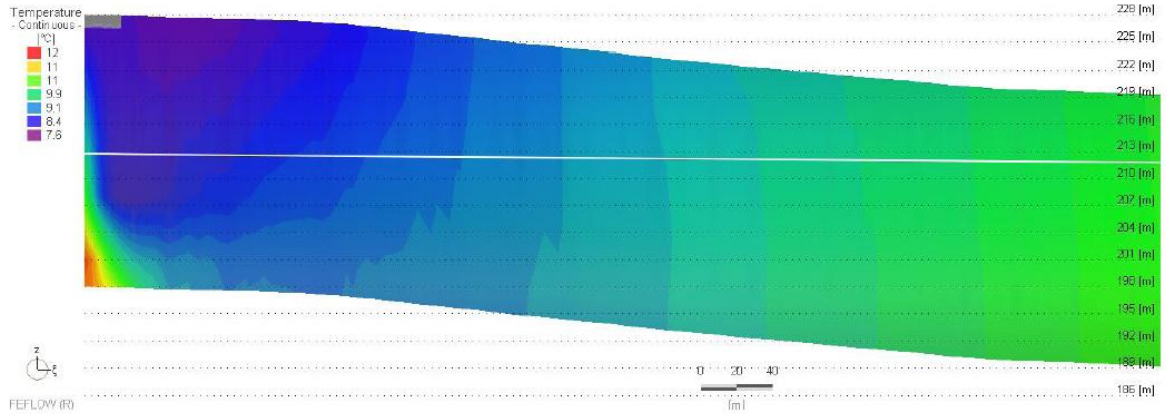


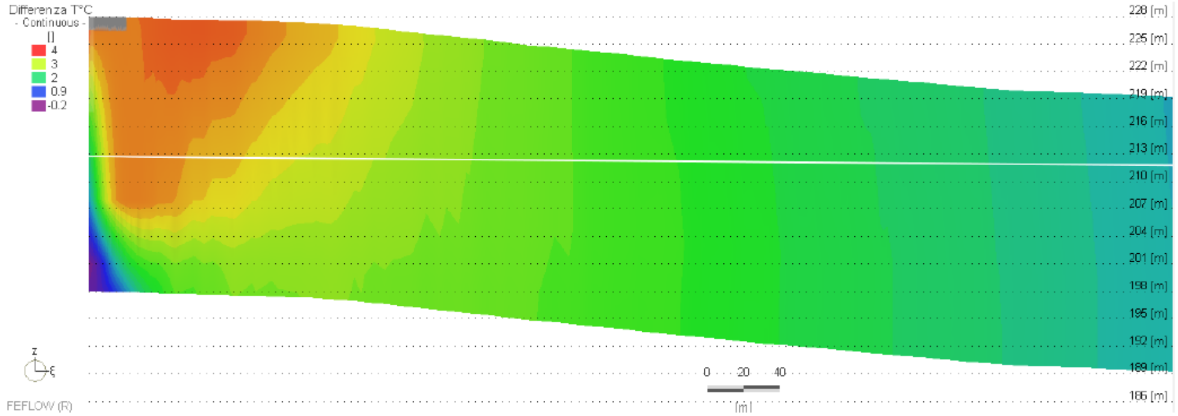


CASE 32 GIUBIASCO HEAT PUMP (TI, CH) – 3D HYDRO-THERMAL (2022)

Objectives: To calibrate a 3D hydro-thermal model to evaluate the extension (impact) of the thermal plume with time.



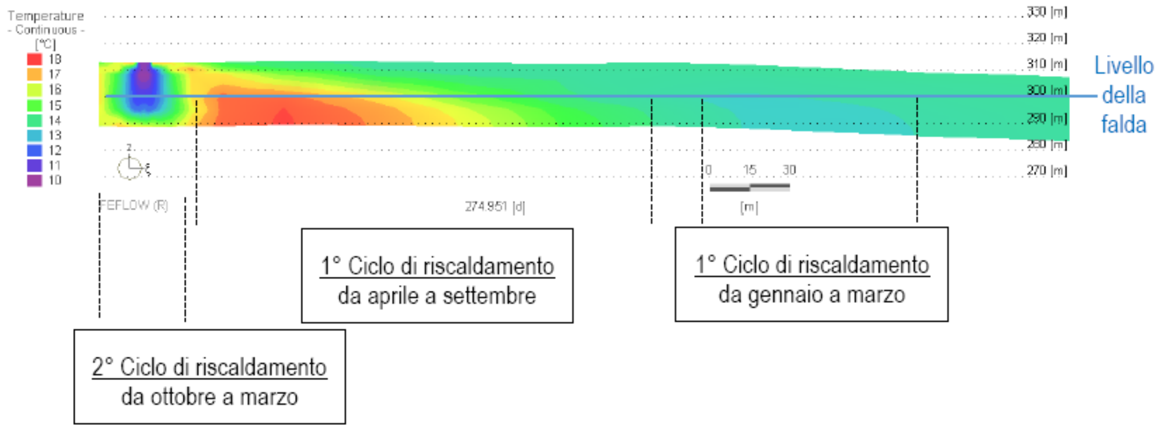




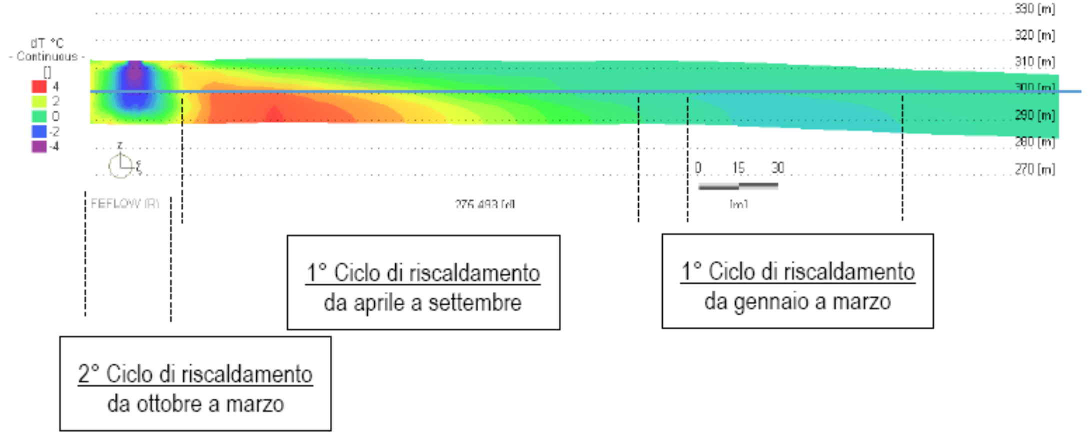
CASE 33 CADEMPINO HEAT PUMP (TI, CH) – 3D HYDRO-THERMAL (2023)

Objectives: To calibrate a 3D hydro-thermal model to evaluate the extension (impact) of the thermal plume with time.

A _ Temperatura °C.



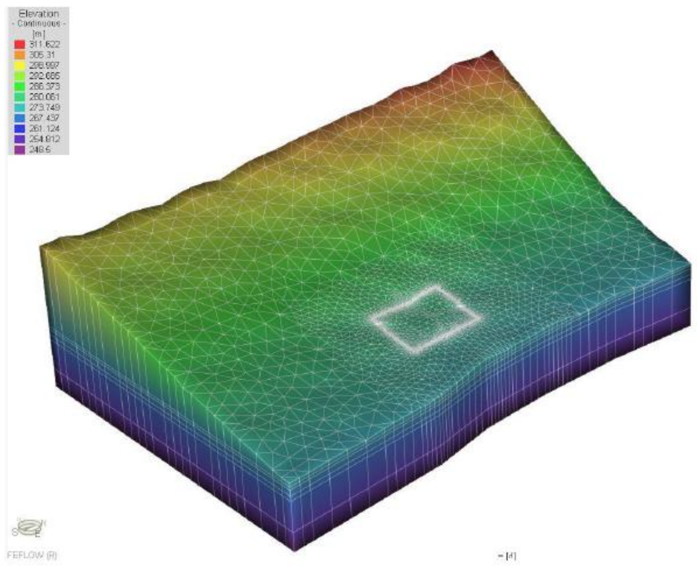
B _ Differenza di temperatura °C.

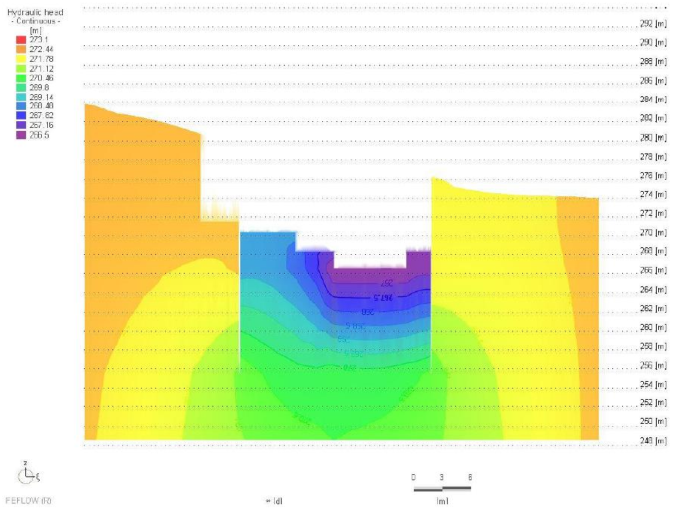


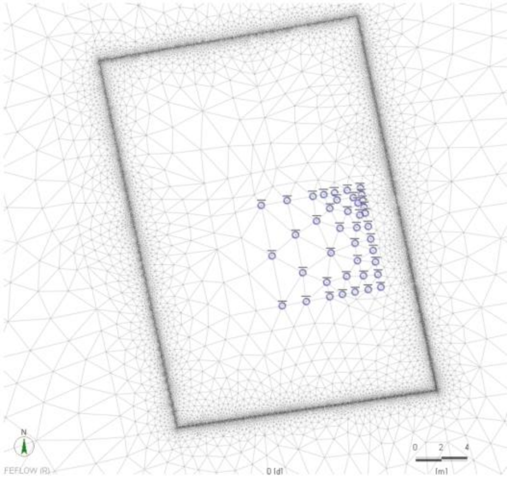
FEFLOW

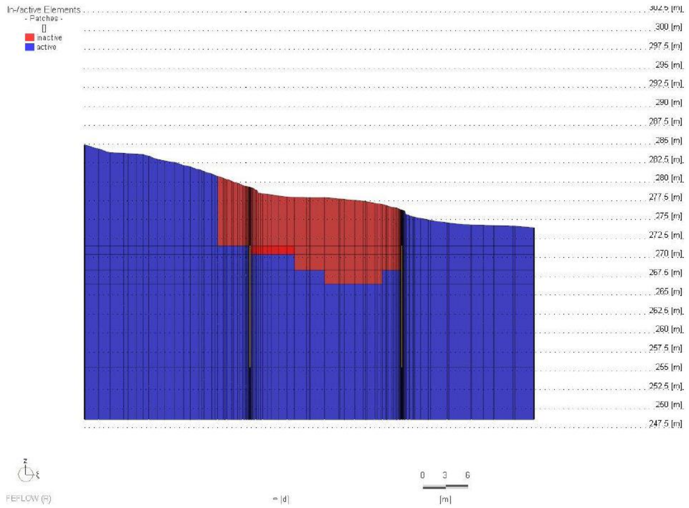
CASE 34 WATER TABLE DRAWDOWN – Stazione di pompaggio-ARM (TI, CH) – 3D FLOW (2023)

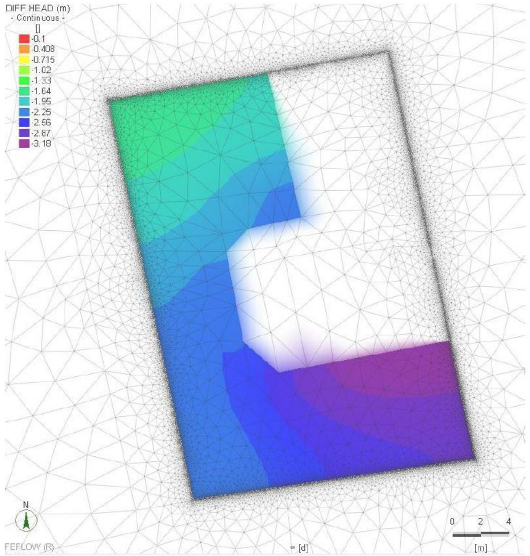
Objectives: To calibrate a 3D flow model for enabling works construction dewatering.







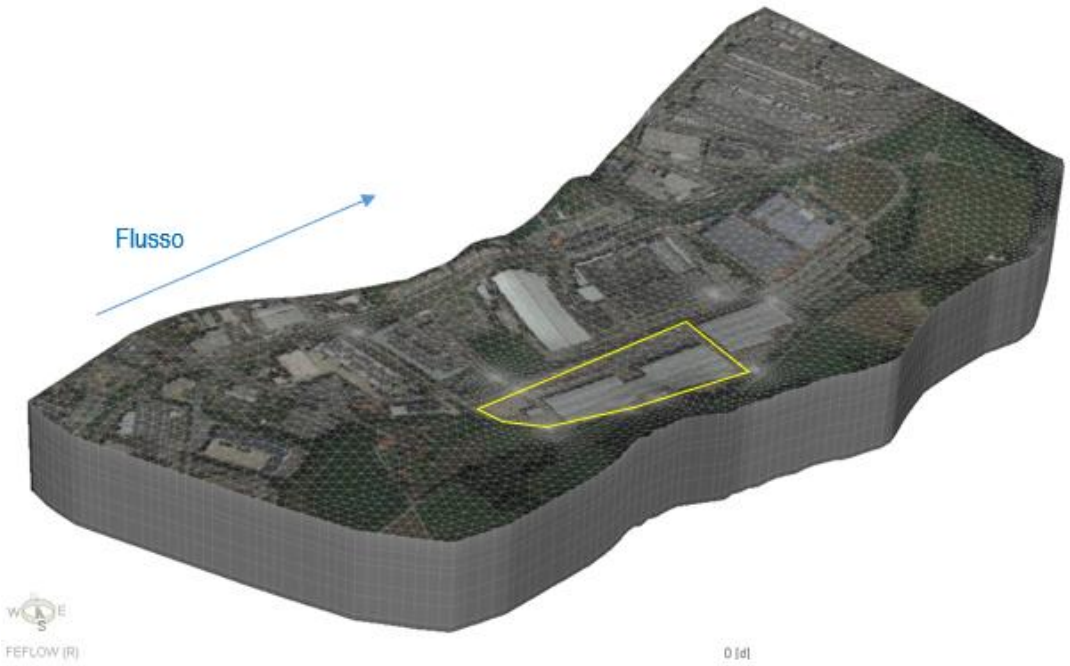


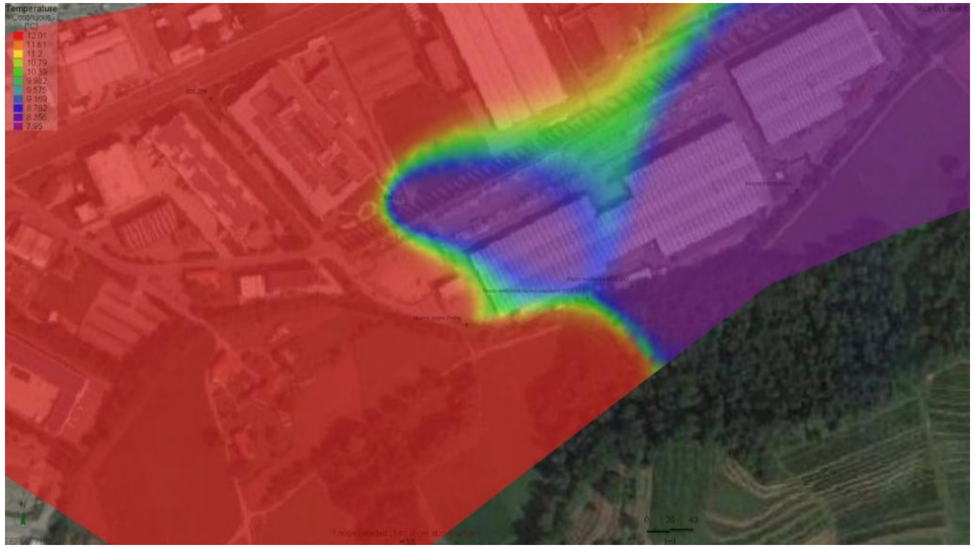


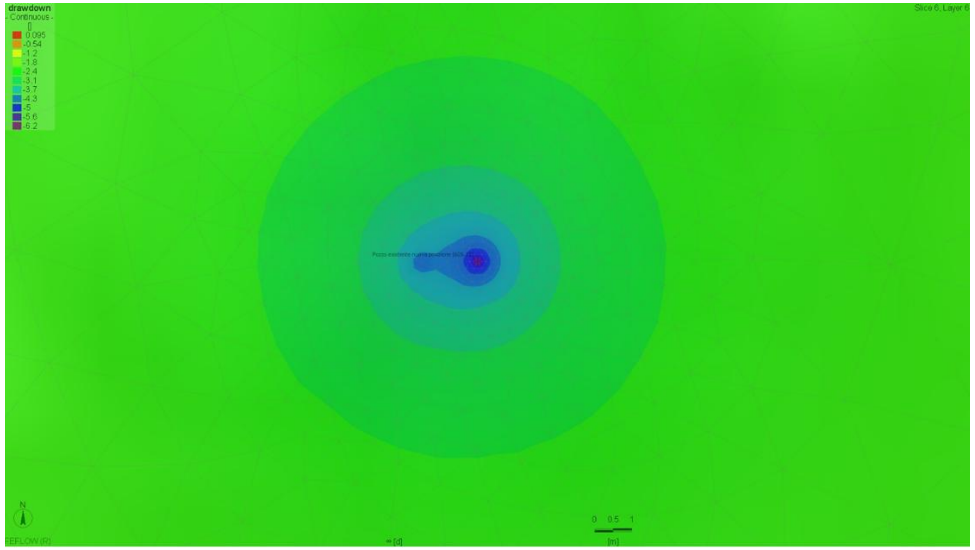
GeoBM

CASE 35 STABIO HEAT PUMP (TI, CH) – 3D HYDRO-THERMAL (2023)

Objectives: To calibrate a 3D hydro-thermal model to evaluate the extension (impact) of the thermal plume with time.



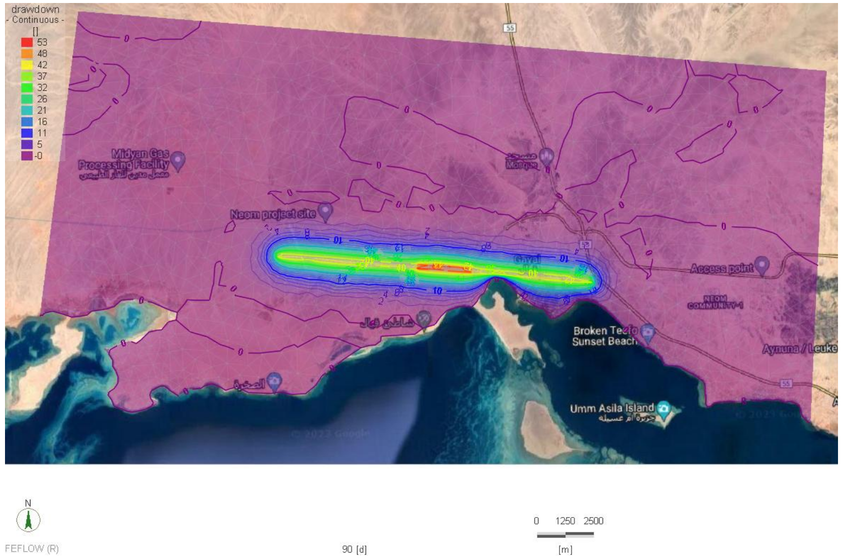


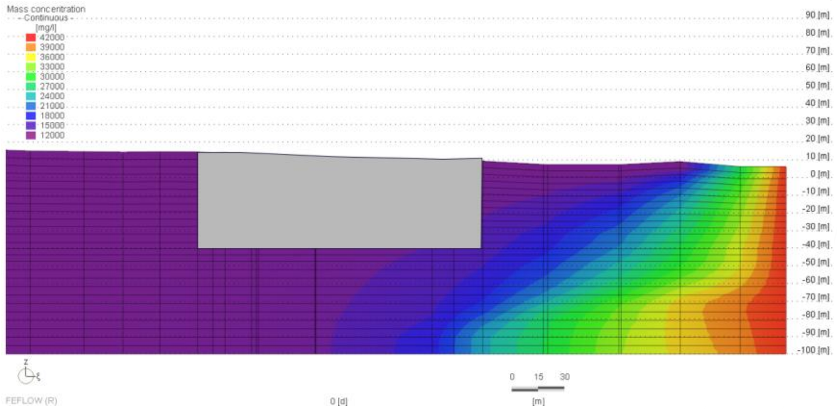


FEFLOW

CASE 36 FLOW and SALINITY MODEL – The Spine development at NEOM, on the Red Sea Coast of Saudi Arabia (KSA) – 3D FLOW – MASS TRANSPORT (SALINITY) (2022-23)

Objectives: 3D numerical groundwater modeling to assess the impact on groundwater levels and salinity for Lots 5 to 7 of The Line and The Spine developments at NEOM, along Saudi Arabia's Red Sea coast.



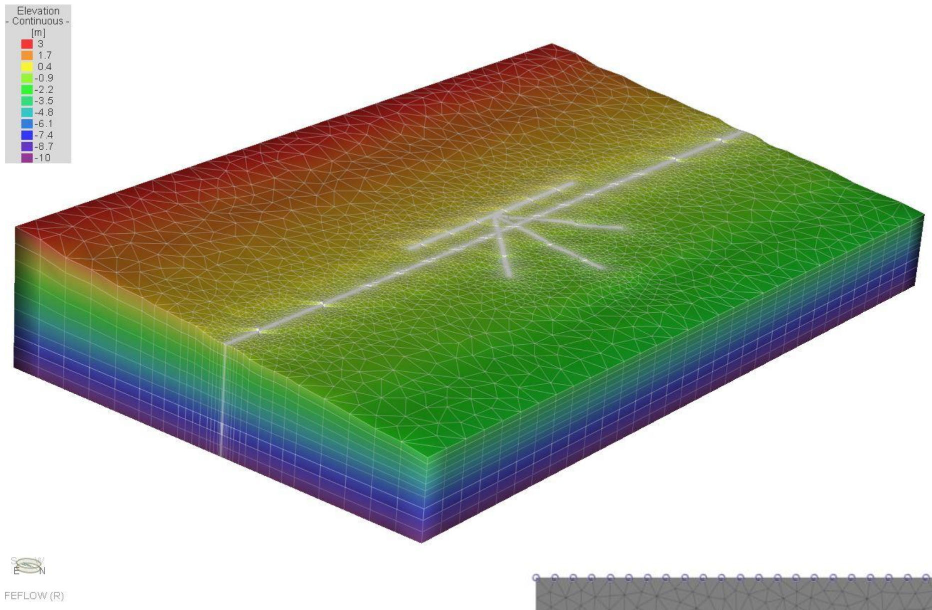


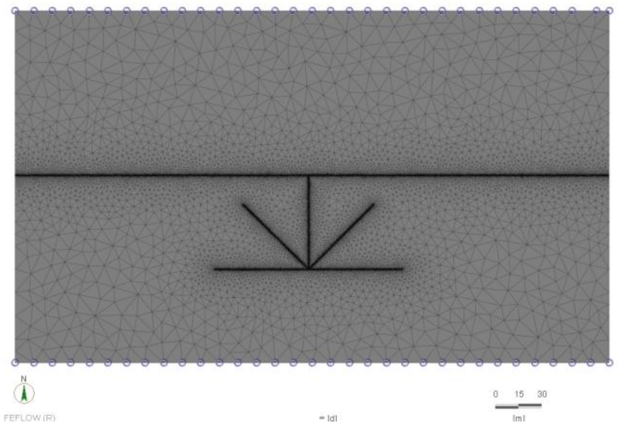
GeoBM

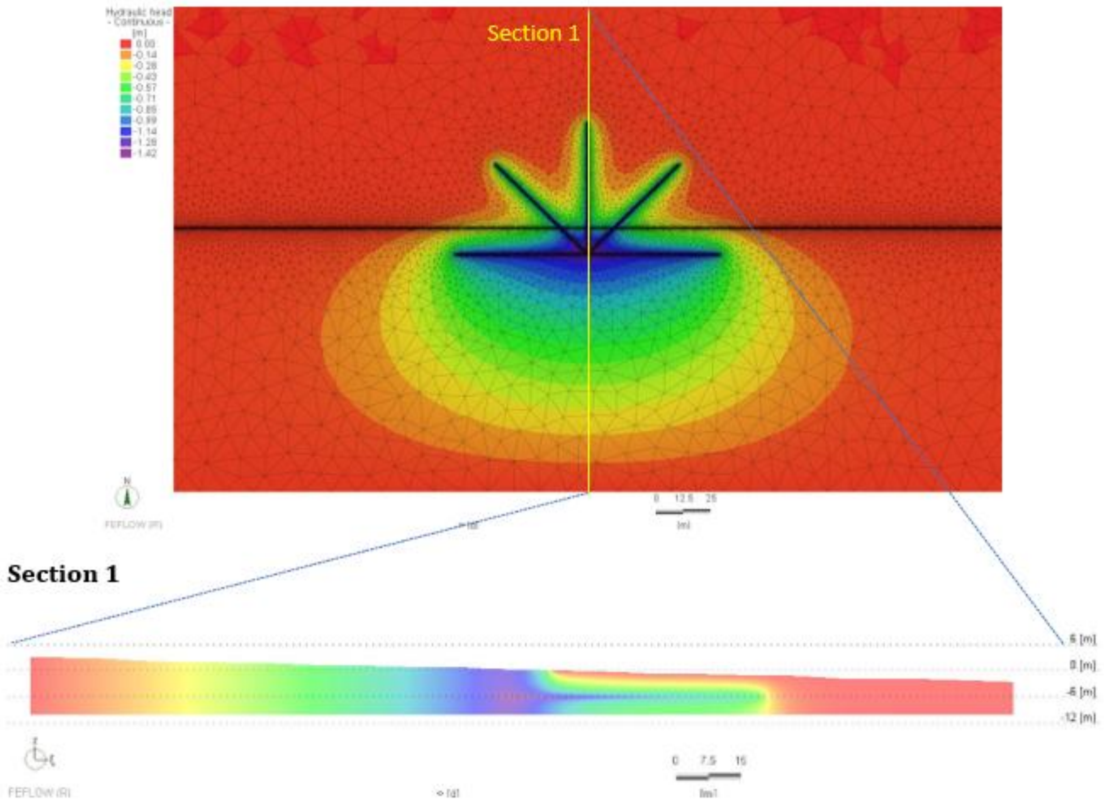
FEFLOW

CASE 37 BRUNEI BEACH WELL SYSTEM – BRUNEI – 3D FLOW (2023)

Objectives: To calibrate a 3D flow model to simulate two (2) beach well layouts and to determine which simulated layout would be able to provide mostly 350 m3/hr with an acceptable drawdown of maximum – 4 meters.



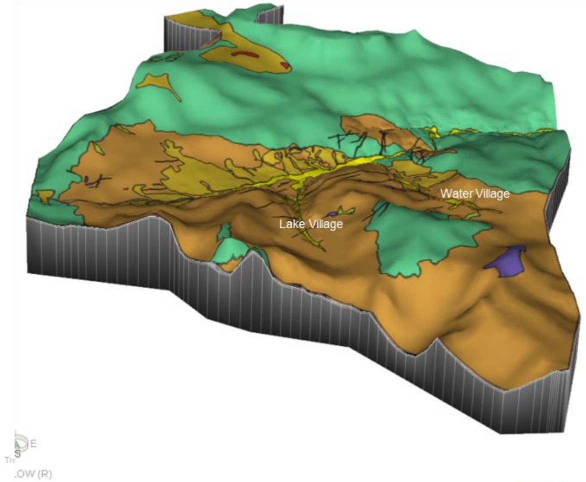


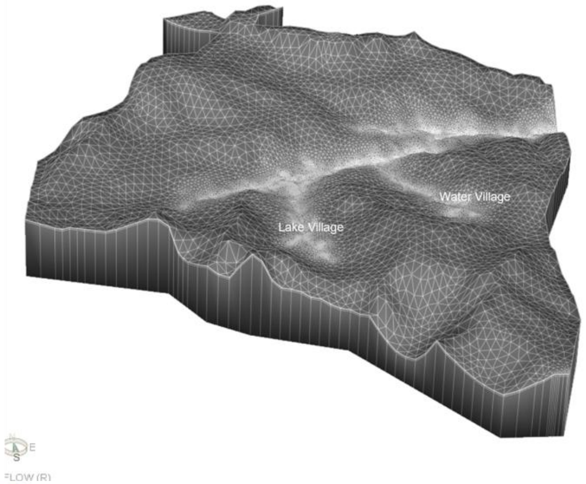


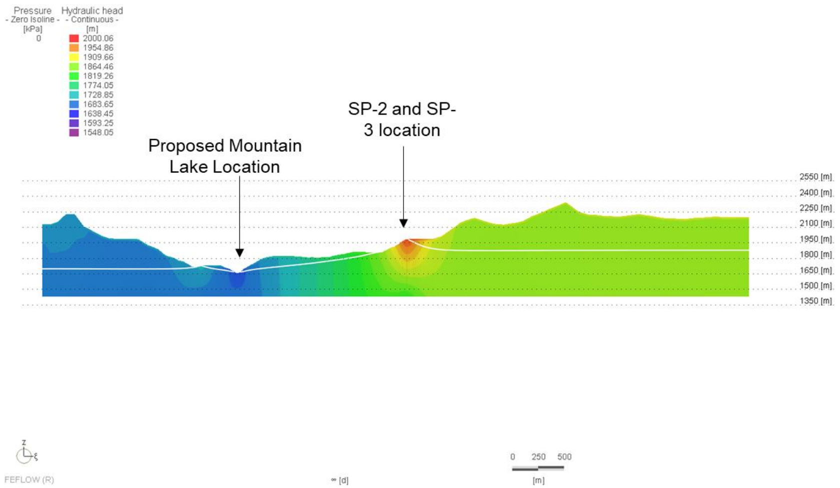
FEFLOW

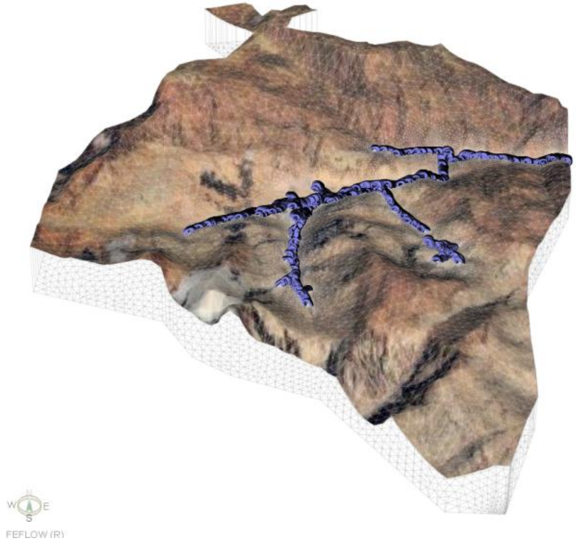
CASE 38 TROJENA CATCHMENT STUDY – KSA – 3D FLOW (2023-24)

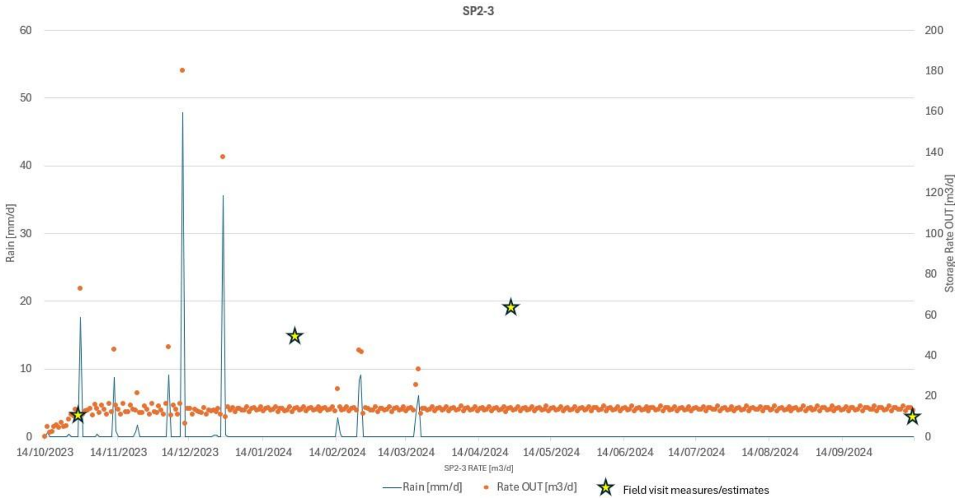
Objectives: A 3D conceptual groundwater model of the site was developed to establish baseline conditions and serve as a tool for understanding potential future changes in groundwater dynamics.







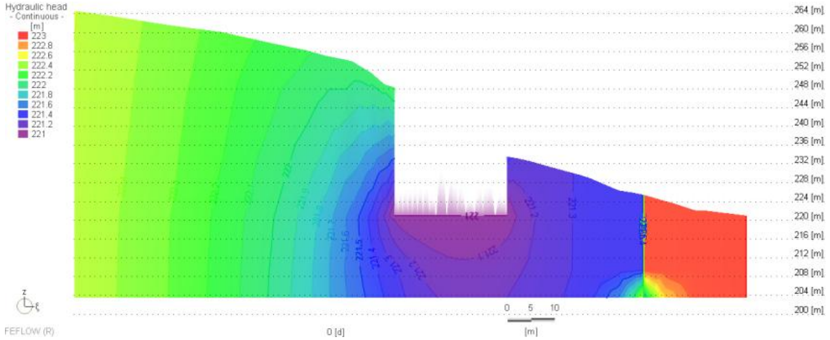


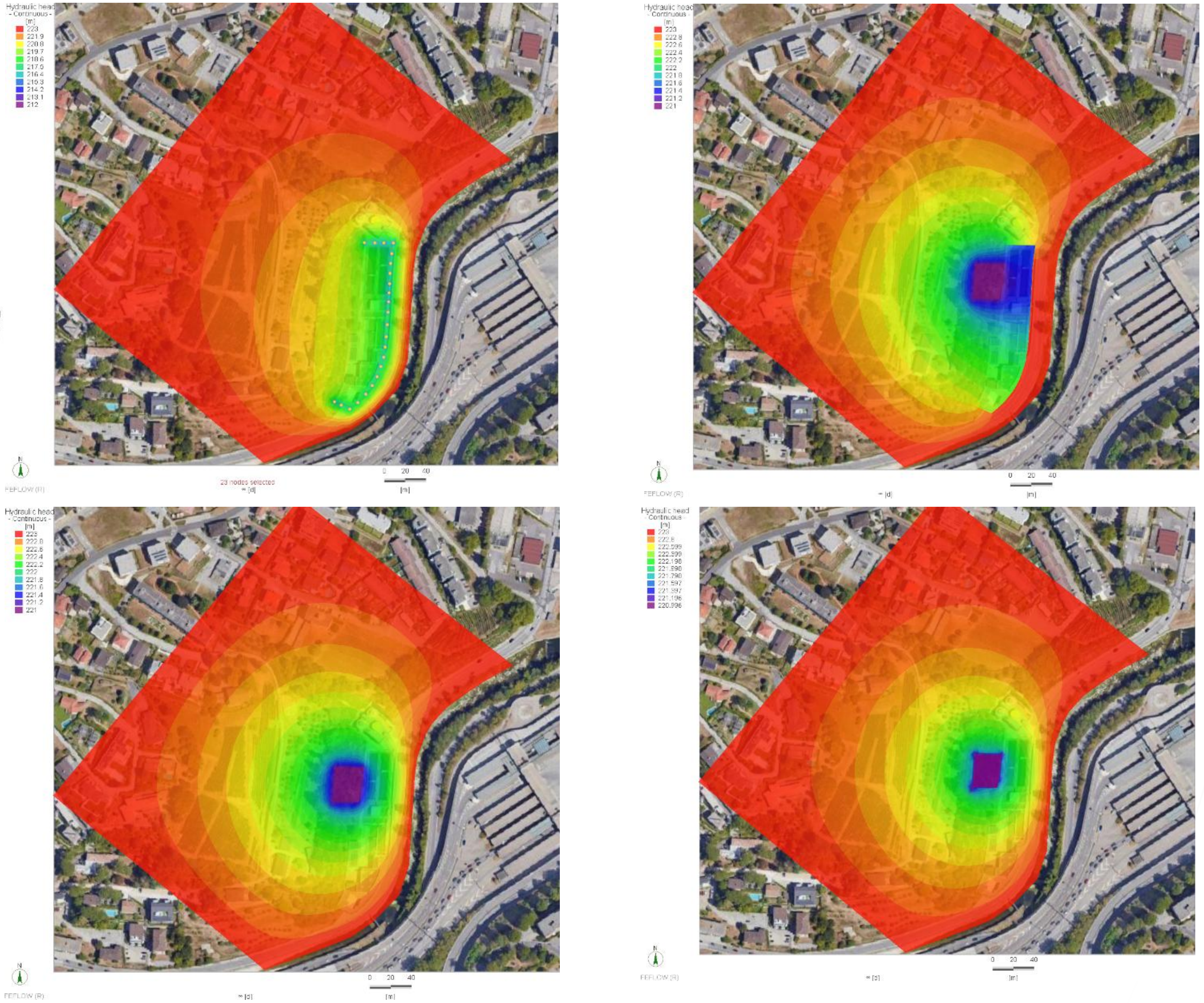


FEFLOW

CASE 39 WATER TABLE DRAWDOWN – SEAWAGE TREATMENT PLANT "IDA-VACALLO" (TI, CH) – 3D FLOW (2024)

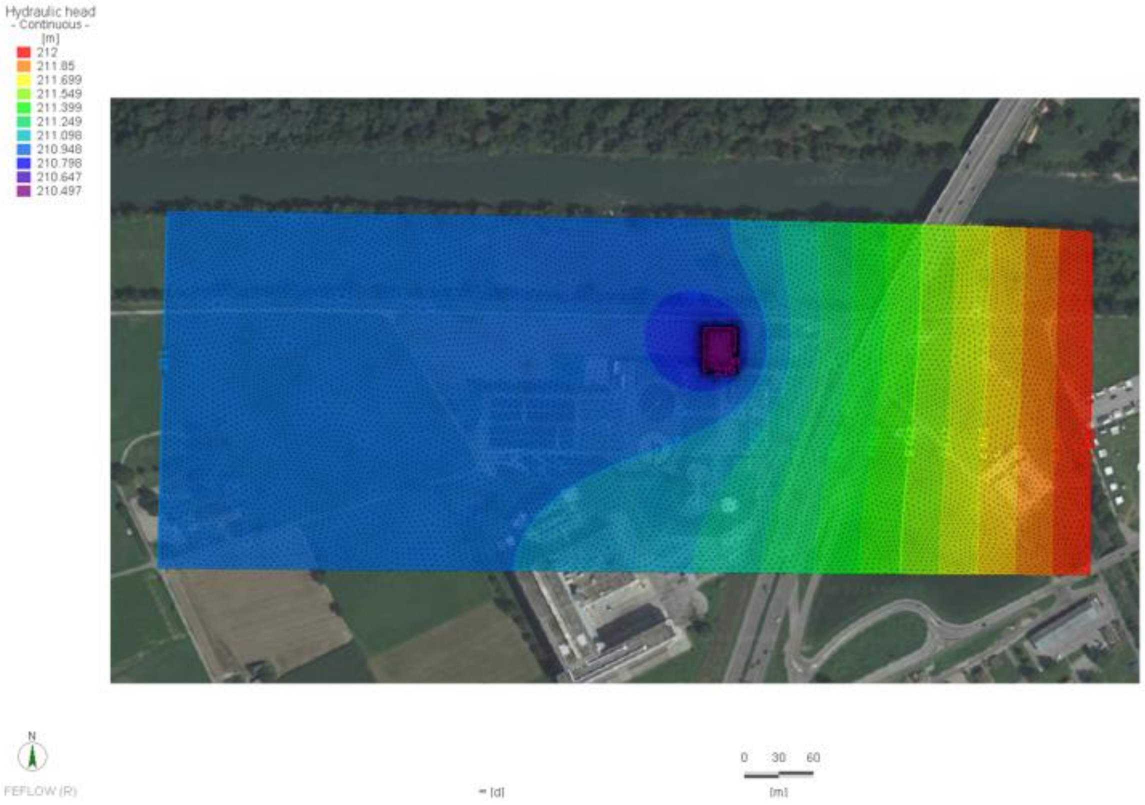
Objectives: To calibrate a 3D flow model to analyze of solutions for lowering groundwater levels in a 21x30m excavation area with a 3m variation. This includes estimating inflows into the excavation pit and proposing alternatives.

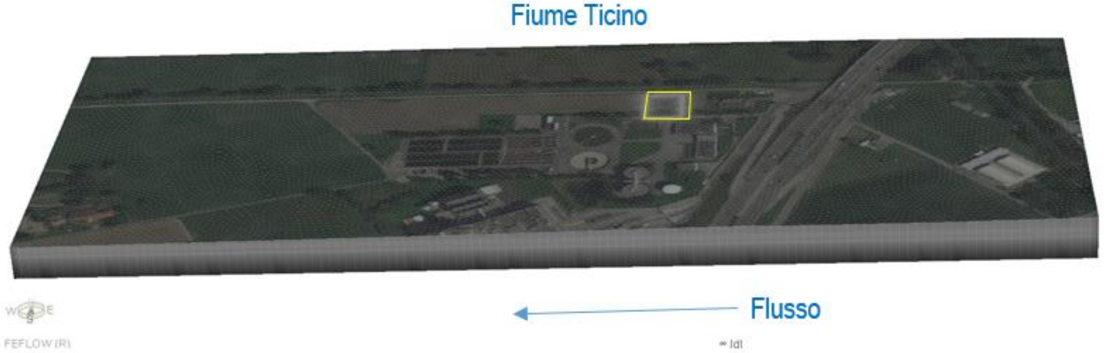


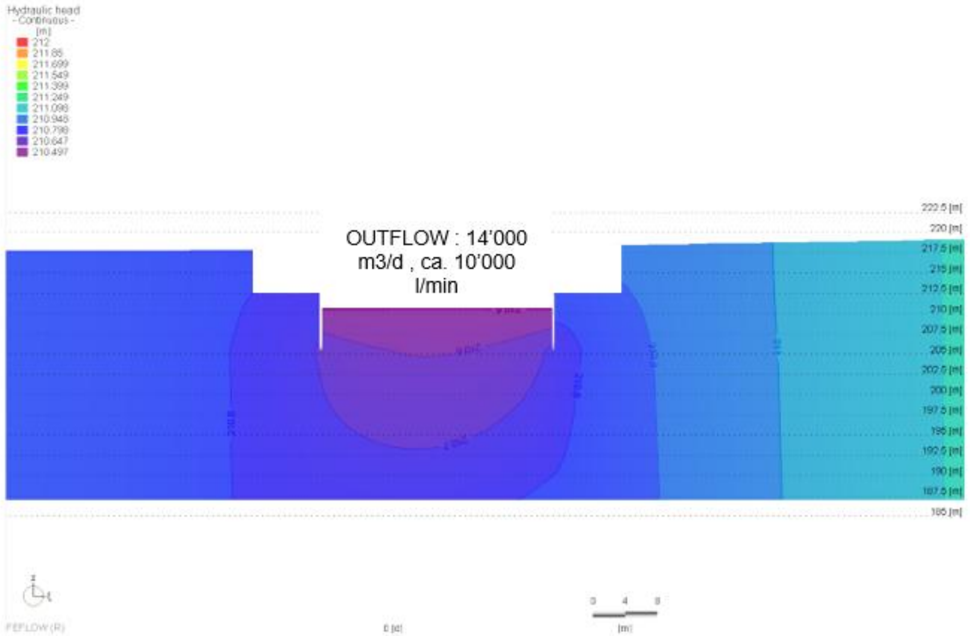


CASE 40 WATER TABLE DRAWDOWN – SEAWAGE TREATMENT PLANT "IDA-GIUBIASCO" (TI, CH) – 3D FLOW (2024)

Objectives: To calibrate a 3D flow model to analyze of solutions for lowering groundwater levels in a 21x30m excavation area with a 3m variation. This includes estimating inflows into the excavation pit and proposing alternatives.

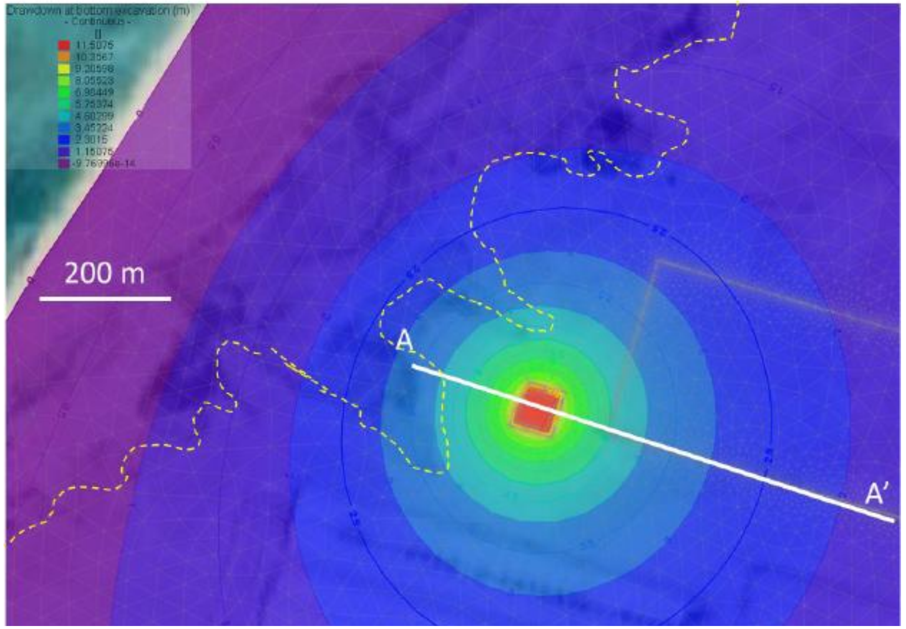


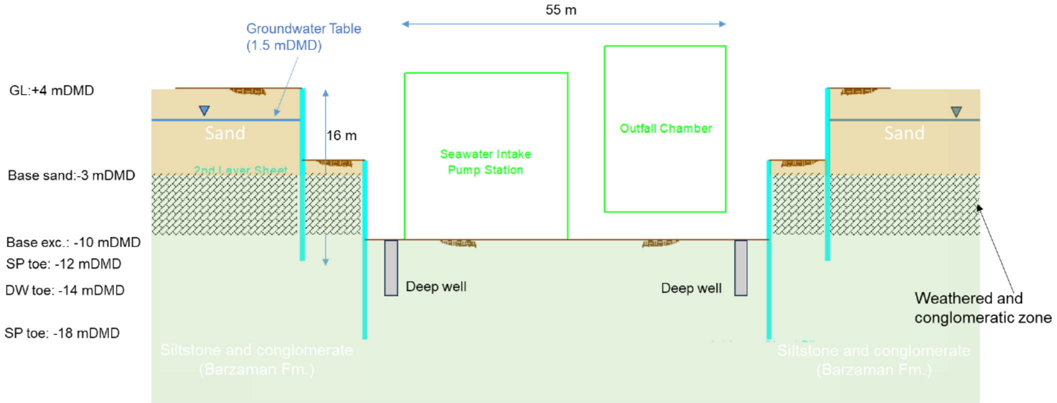


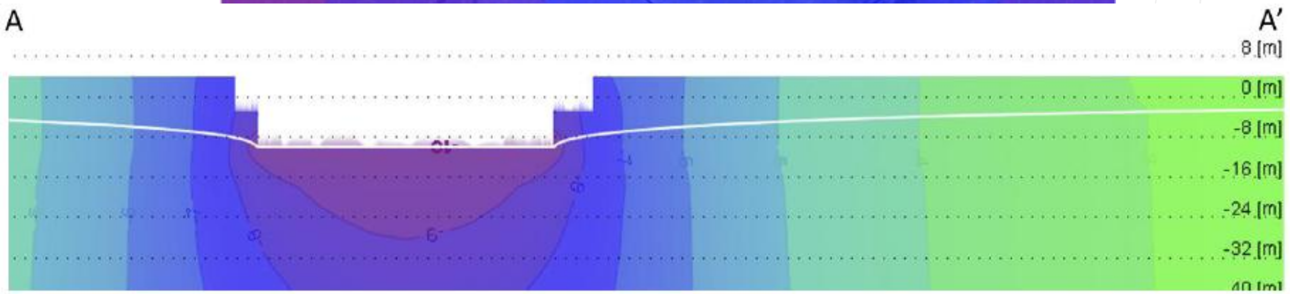


CASE 41 WATER TABLE DRAWDOWN – HASSYAN IWP - DUBAI (UAE) – 3D FLOW (2020)

Objectives: 3D flow model to assess the potential impact of construction dewatering on groundwater levels in nearby sensitive habitats.





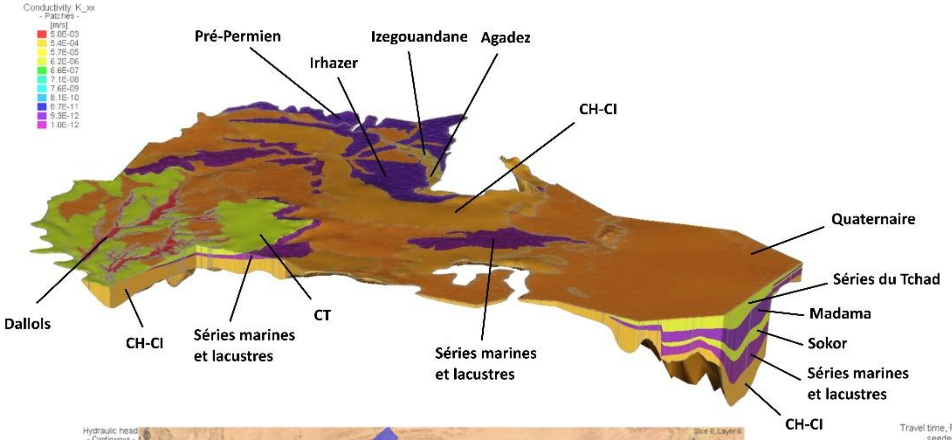


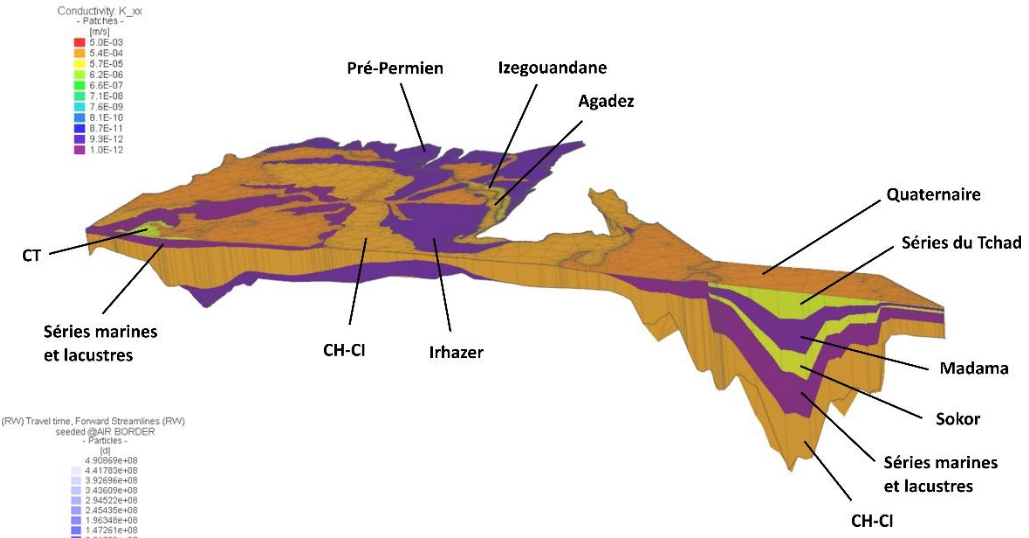
FEFLOW

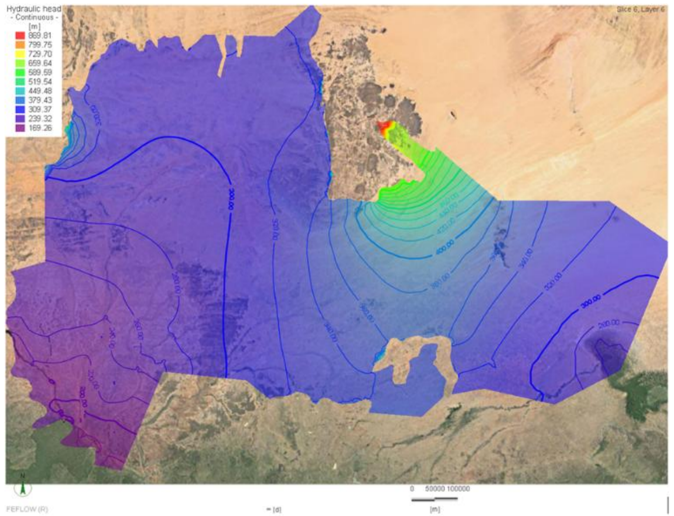
CASE 42 WATER Sustainability – NIGER – 3D FLOW (2023)

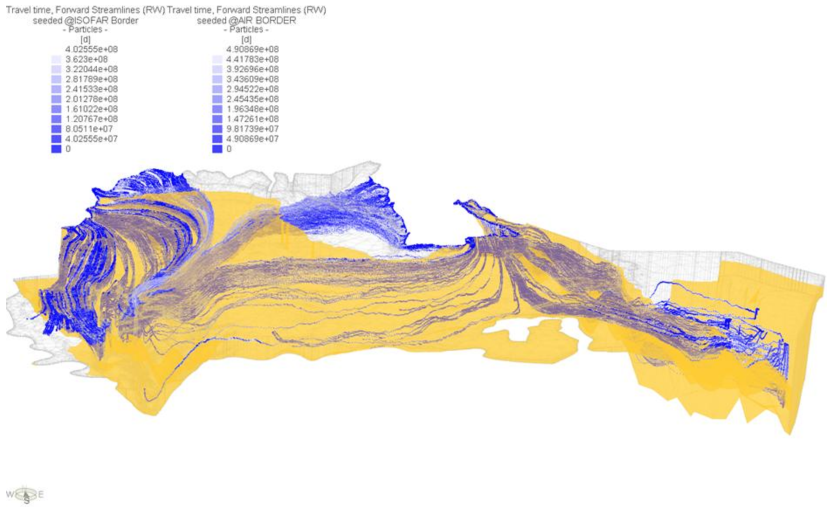
Objectives: 3D numerical model FEFLOW is designed to evaluate the groundwater balance on the scale of the entire two sedimentary basins East and West of Niger.

This involves integrating the geological structure of the country and the complex distribution of the different aquifers into a 3D digital mesh, and evaluating both recharge sources and discharge points, with emphasis on natural processes.





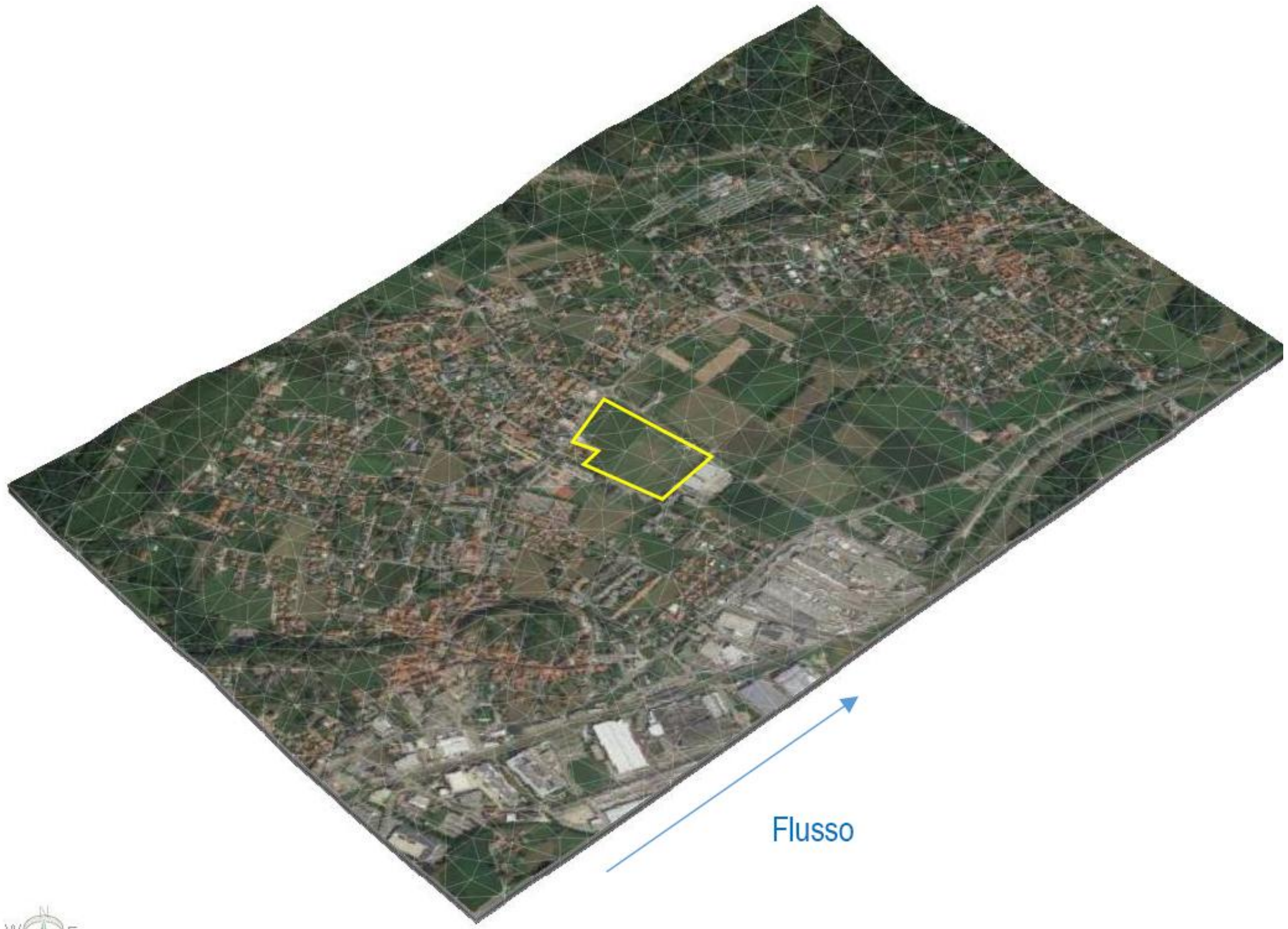




FEFLOW

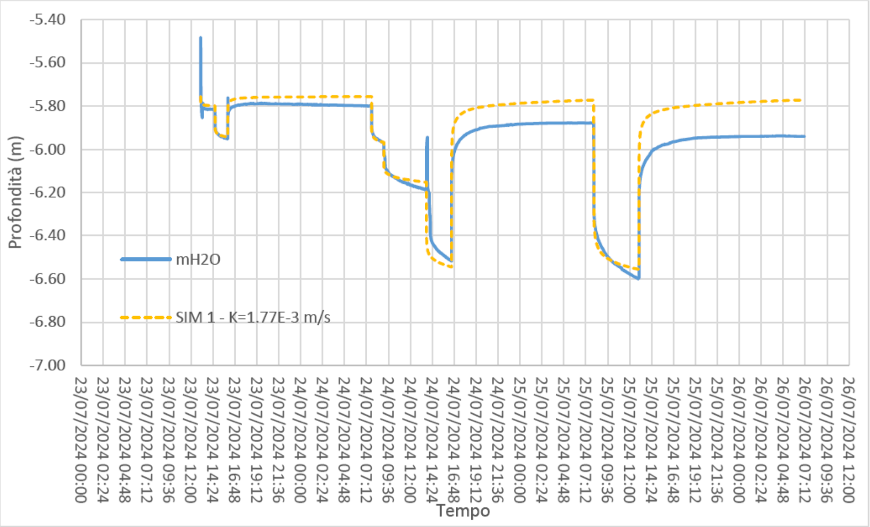
CASE 43 STABIO HEAT PUMP (TI, CH) – 3D HYDRO-THERMAL (2024-2025)

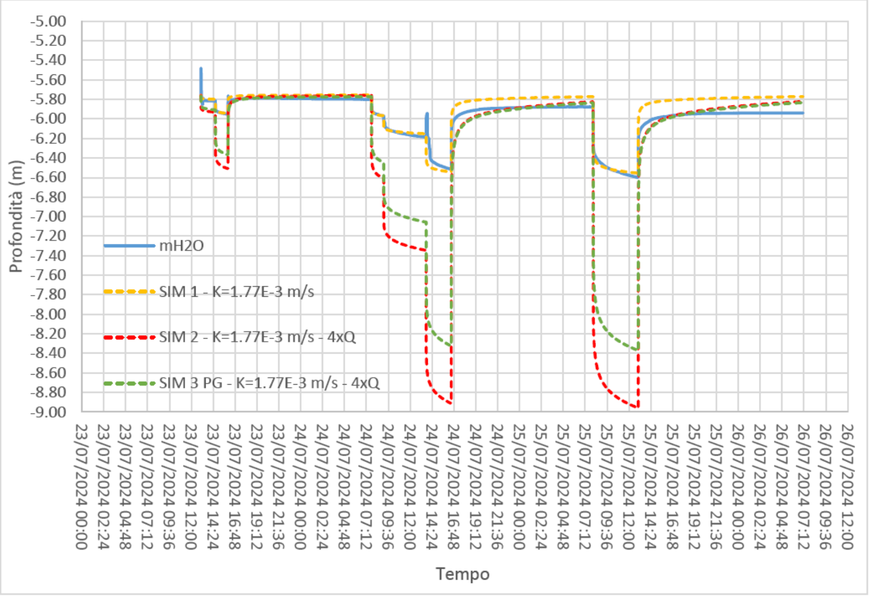
Objectives: To calibrate a 3D hydro-thermal model to evaluate the water sustainability and extension (impact) of the thermal plume with time.



W E S N

FEFLOW (R)



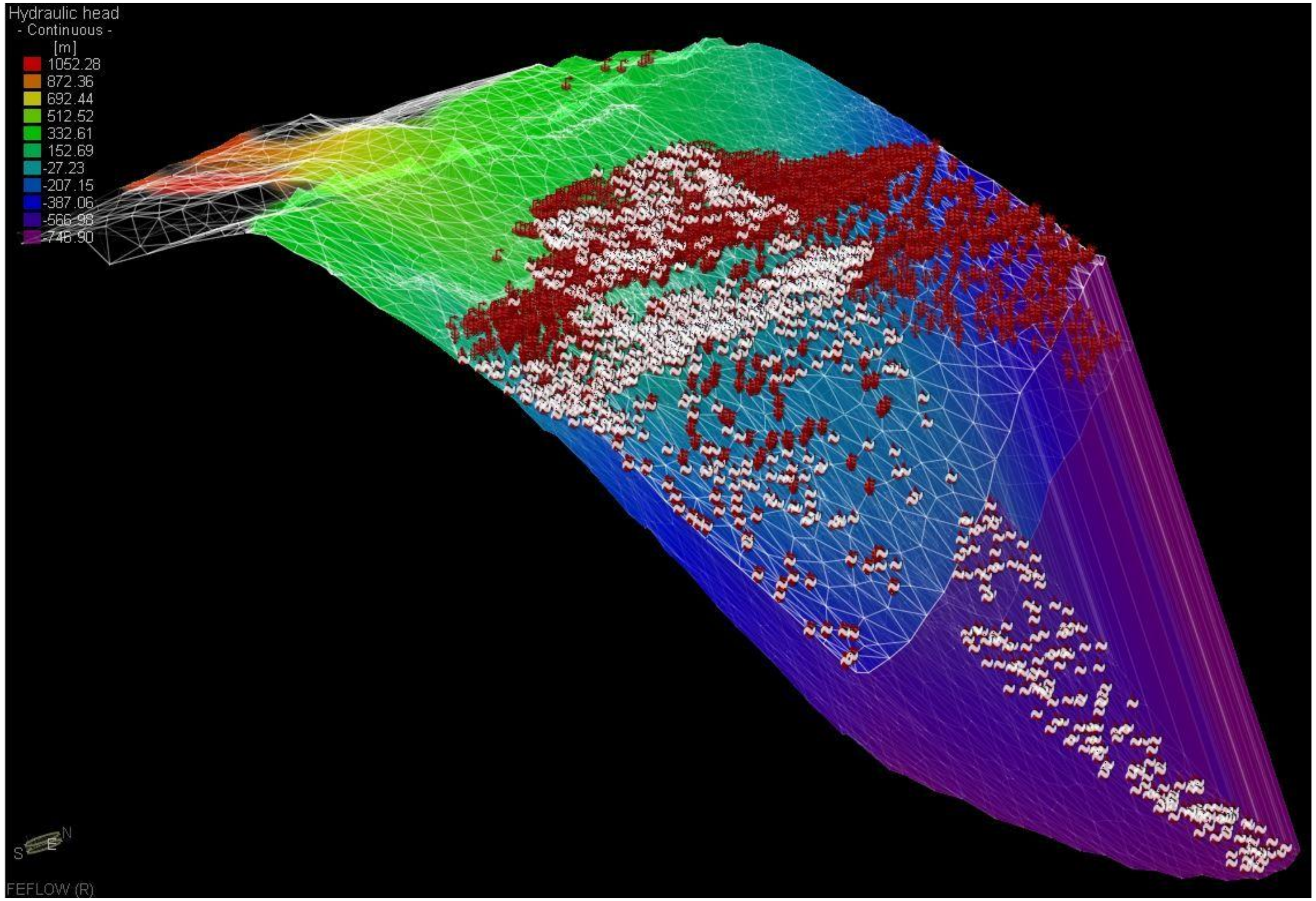


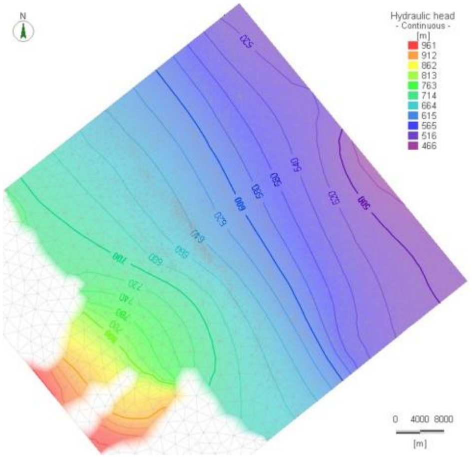
GeoBM Sagl

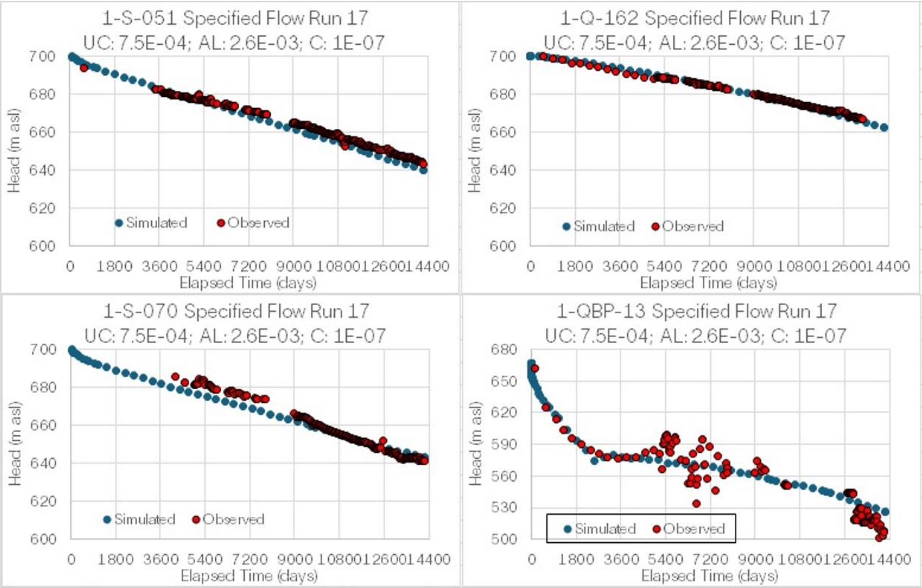
FEFLOW

CASE 44 AQUIFER MANAGEMENT – THE GREAT SAQ/DAWADMI WELL FIELD (KSA) – 3D FLOW – (2024)

Objectives: 3D hydrogeological model developed to assess water supply sustainability through water balance analysis, predict groundwater level drawdown over 50- and 100-year horizons, and evaluate model sensitivity to key uncertainties.



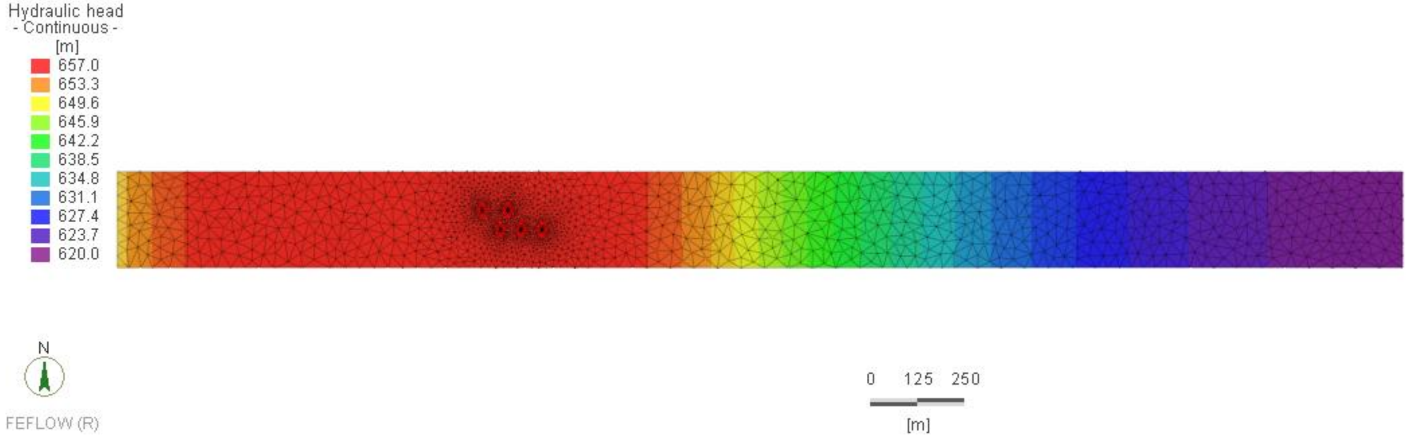


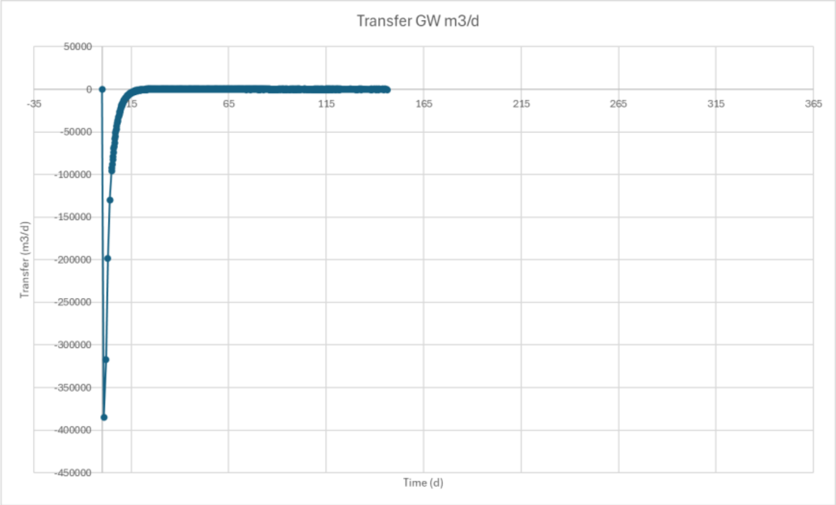


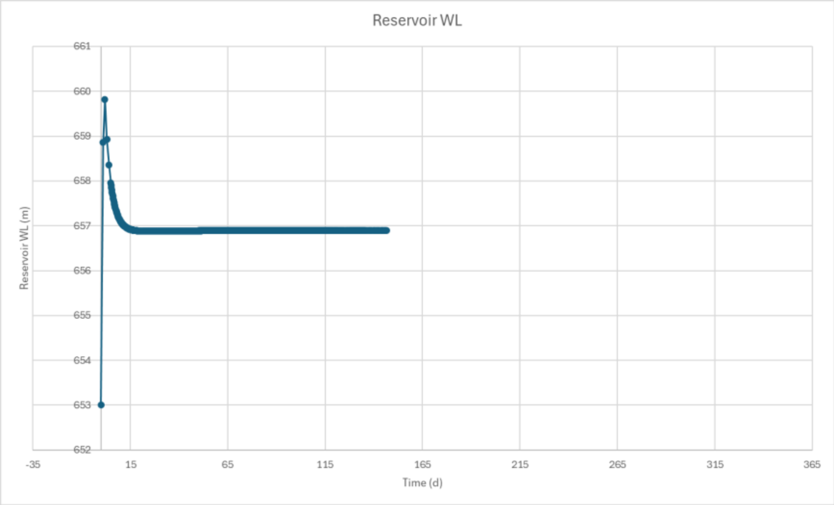
GeoBM

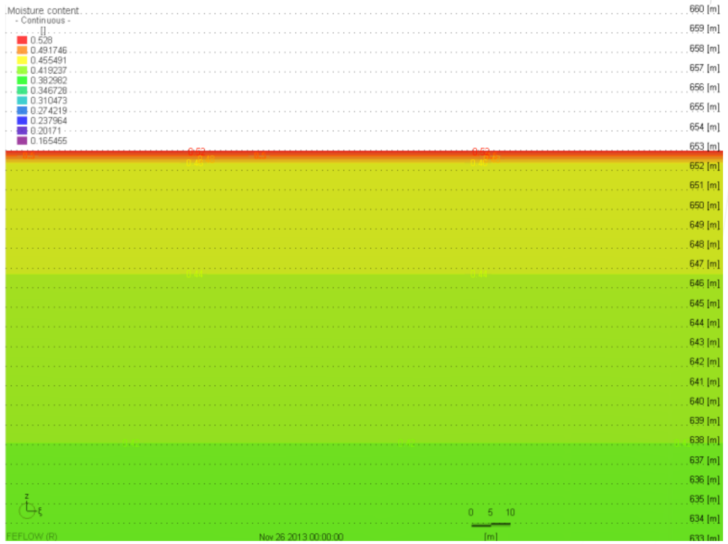
CASE 45 WADI AL ALB (KSA) FORCED RECHARGE – 3D FLOW (2024)

Objectives: 3D hydrogeological model developed to assess water supply sustainability through water balance analysis, predict groundwater level drawdown over 50- and 100-year horizons, and evaluate model sensitivity to key uncertainties.





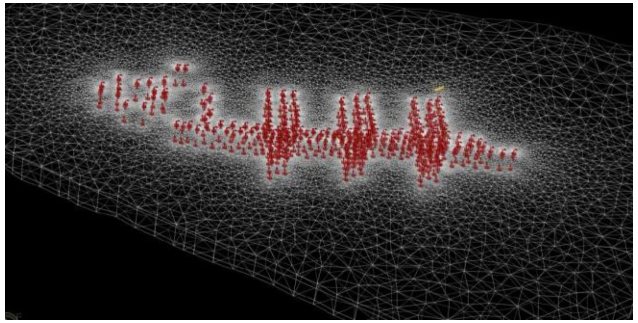


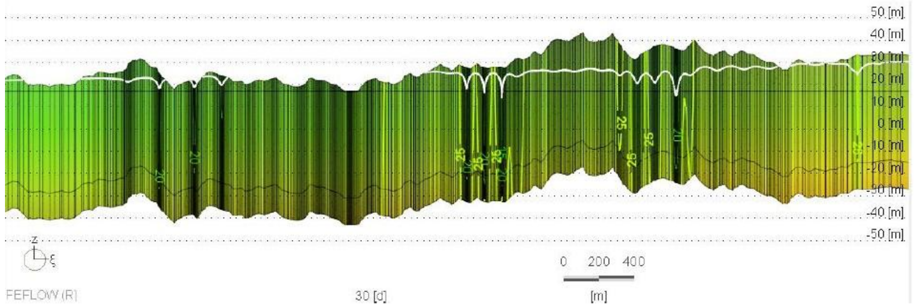


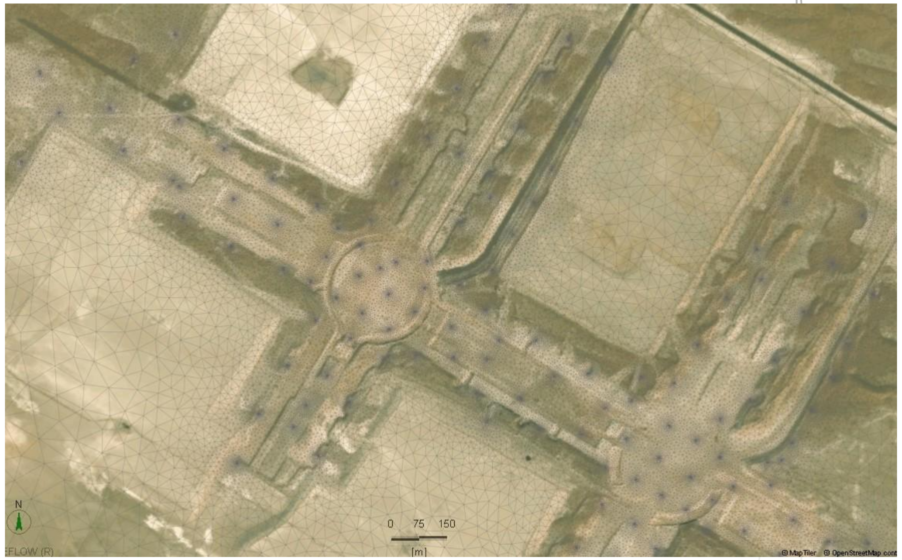
FEFLOW

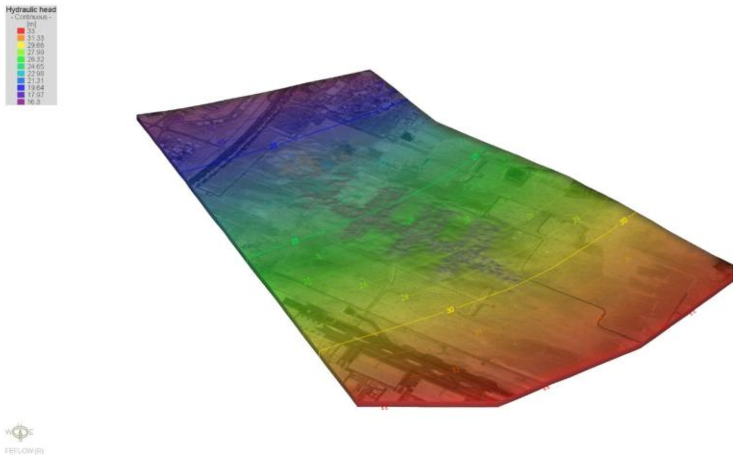
CASE 46 DUBAI "AL MAKTOUM INTERNATIONAL AIRPORT" DEWATERING – 3D FLOW (2024-2025)

Objectives: 3D flow model for the future Al Maktoum international airport (Dubai, UAE) to design the dewatering deep wells system to control the water table during the excavation and construction stages.



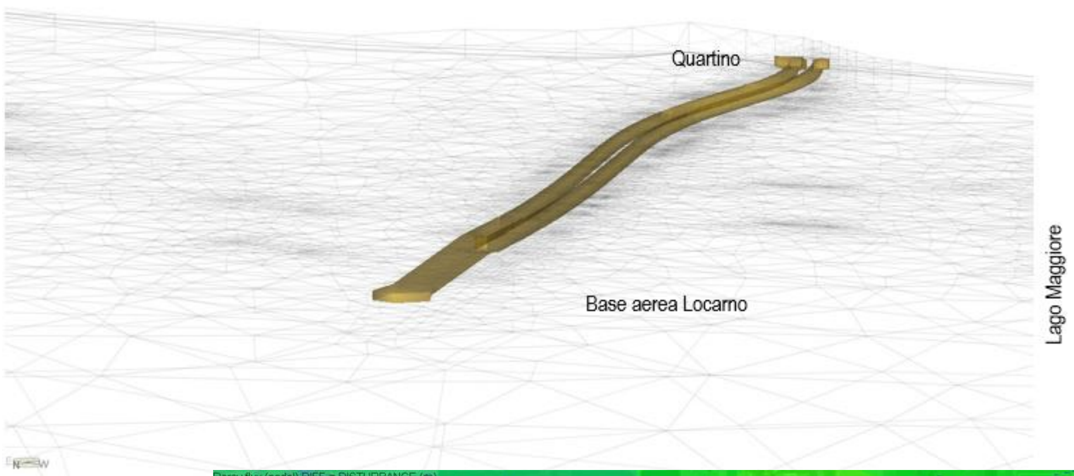


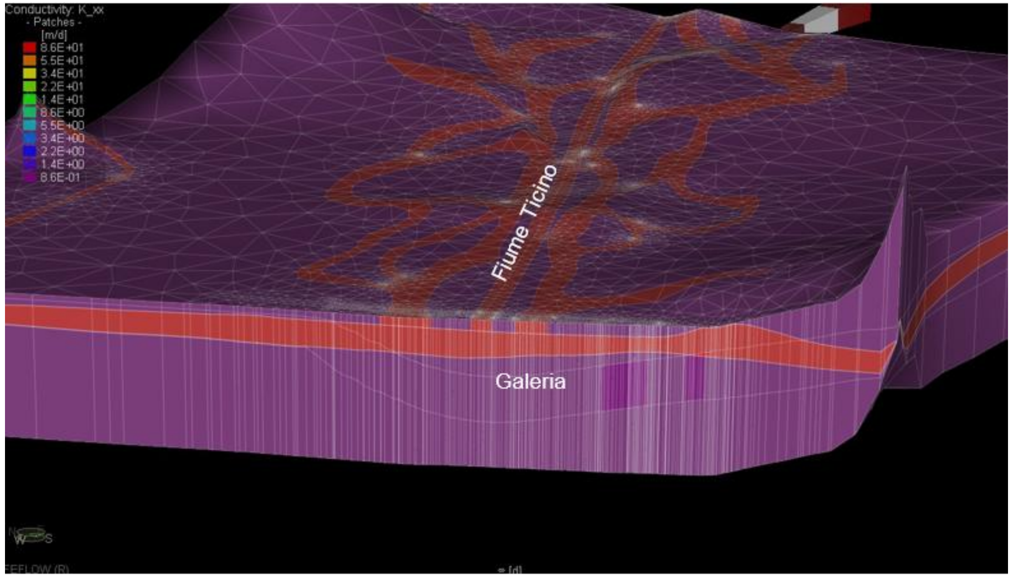


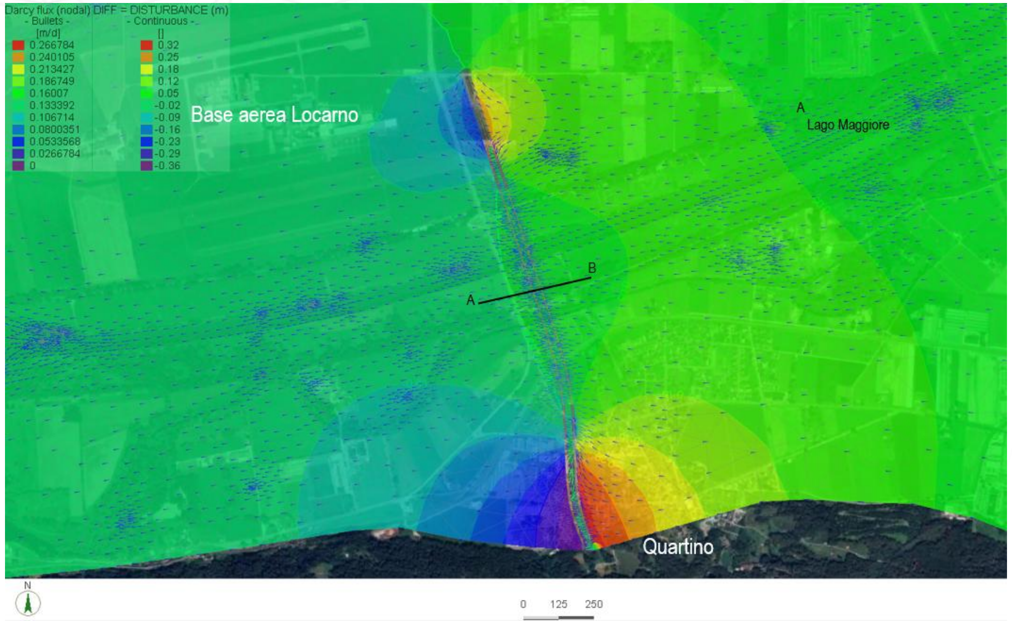


CASE 47 PROGETTO COBELLO – PIAN MAGADINO TUNNELING (TI, CH) – 3D FLOW (2025)

Objectives: To calibrate a 3D flow model to analyze the hydraulic impact of the future tunnel crossing the Magadino Plain, with particular focus on the effects on groundwater and the protected area of the Bolle di Magadino.







3D HETEROGENEOUS MEDIUM GENERATION with Hydro_Gen

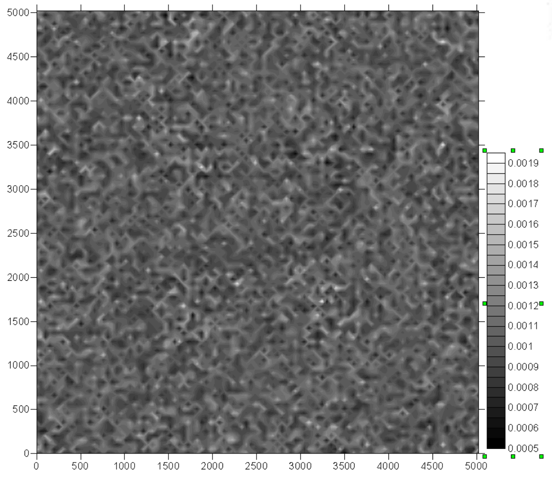
The approach is based on random spatial functions Y

The spatial distribution of the physical property (i.e. permeability k) is random and correlated in space

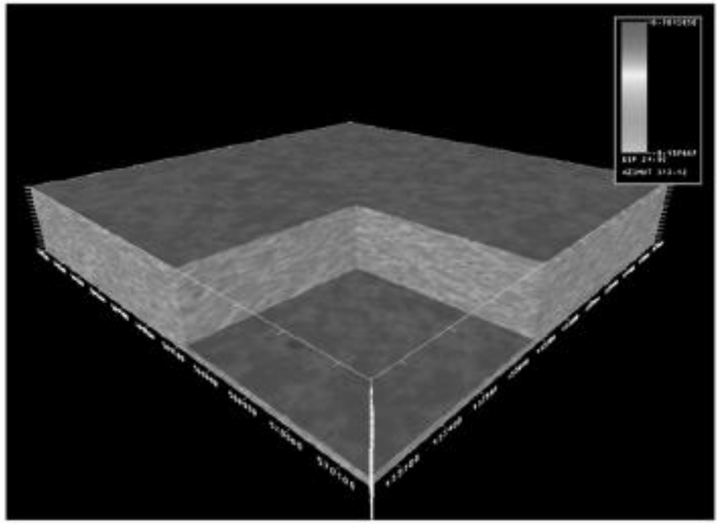
The permeability k varies spatially according to a stationary lognormal law (Freeze (1975) and Gelhar (1993)) where Y follows a normal distribution with mean μ and variance σ2.

I)

	x-coordinate	y-coordinate	altitude	K measured	LOG K	depth (m)	
						from	to
LF2	569675.20	133689.40	984.30	1.60E-05	-4.80	-12.00	-13.50
				8.70E-06	-5.06	-31.50	-34.50
				1.40E-04	-3.85	-68.50	-69.00
				2.30E-04	-3.64	-83.00	-83.50
LF3	569574.80	133434.90	946.67	5.50E-05	-4.26	-49.00	-50.00
P302	569659.60	133659.70	980.25	5.00E-05	-4.30	-56.00	-57.00
				5.00E-05	-4.30	-129.00	-140.00
I301	569623.60	133661.90	984.21	2.00E-05	-4.70	-34.00	-36.00
				6.00E-03	-2.22	-51.00	-53.00



II)



III)

Grid dimension (m)			Model dimension (m)			Statistical parameters			Correlation lengths		
dx	dy	dy	dimX	dimY	dimZ	Covariance type	Variance	Mean	λx (m)	λy (m)	λz (m)
10	10	10	1050	1050	-160	Exponential	1.08	-4.69	10	50	2