Groundwater Modeling of a Deep Coastal Aquifer System in Tanzania Guided by Hydrocarbon Exploration Data

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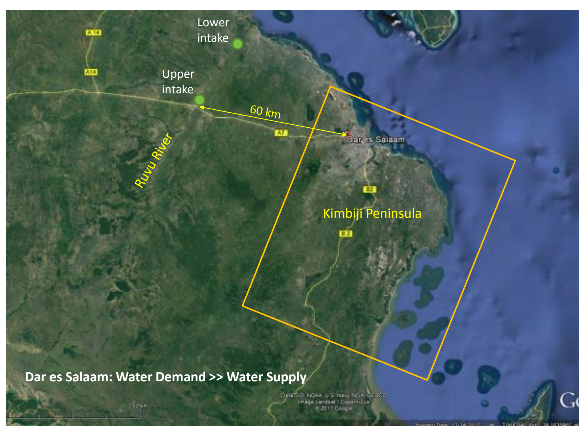
Presentation overview

- Use of oil/gas exploration data in a groundwater context;
- Numerical groundwater modelling in support of regional aquifer development planning
- Conclusions/observations from deep groundwater exploration a deep coastal aquifer setting

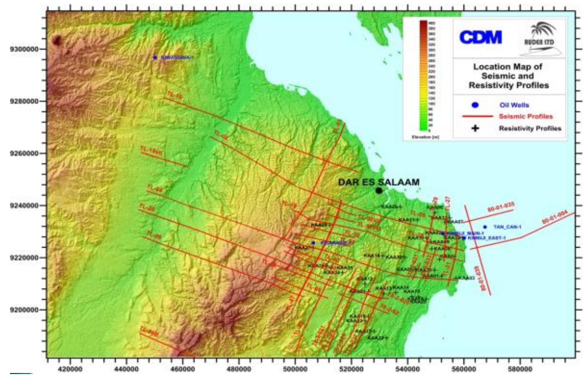
Kimbiji Aquifer Assessment Objective

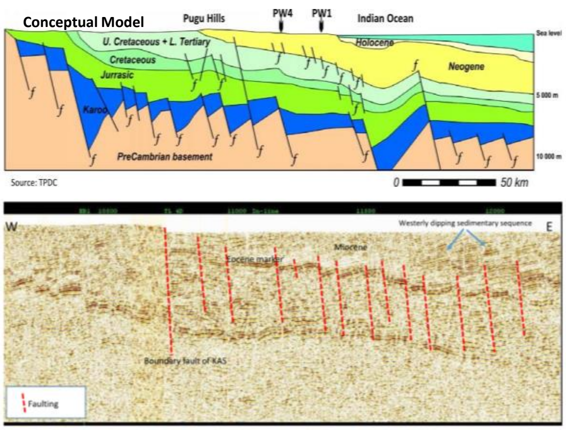
"to undertake an in-depth integrated qualitative and quantitative analysis of the Kimbiji aquifer for supporting its sustainable development and management"

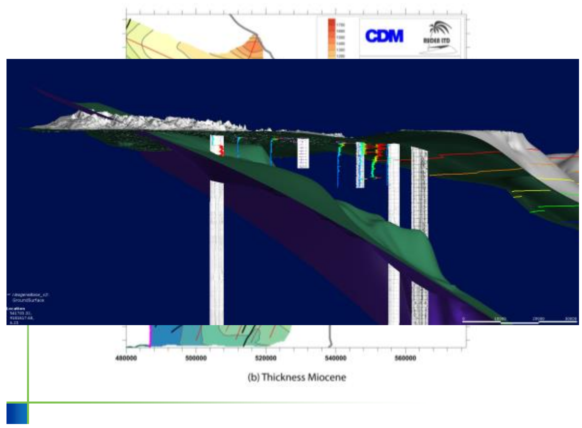
Location

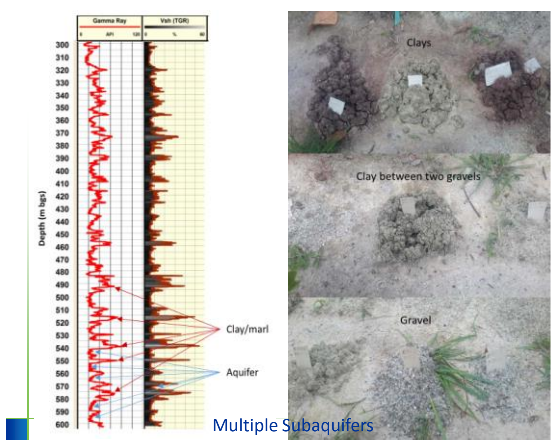


Processed 1,140 km of Seismic Survey Data; Reviewed Borehole Logs and Completion Reports









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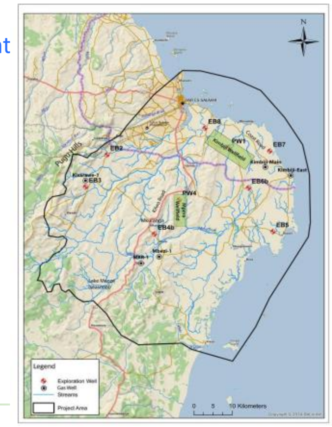
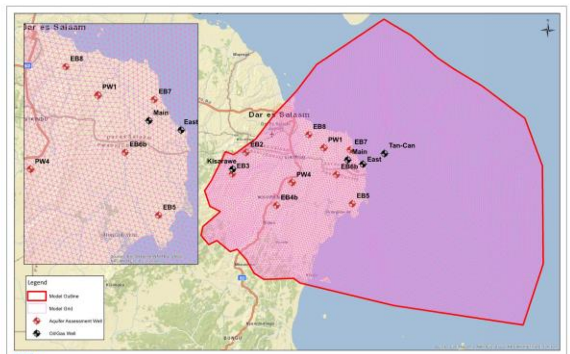
Wellfield Development



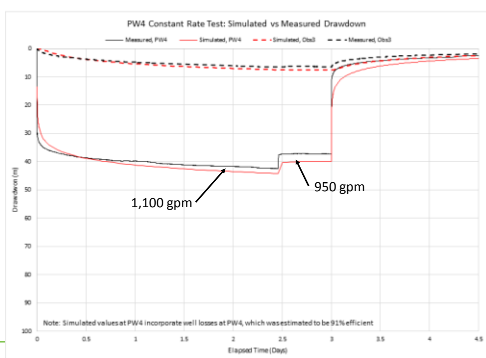
Numerical Groundwater Model

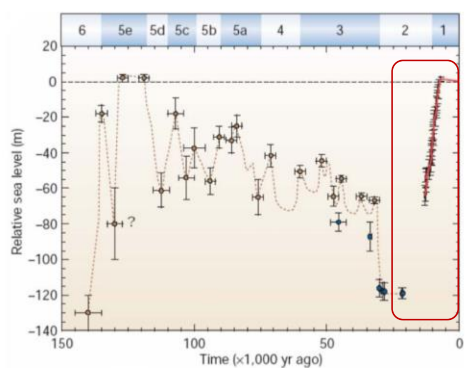
- Fully 3-Dimensional
- Finite element
- Recharge varied spatially based on rainfall, evapotranspiration, and land cover
- Simulates freshwater-saline water interaction
- Calibrated to static heads (including artesian heads) and drawdowns (during aquifer performance tests)
- Extensively documented and independently reviewed
- Calibrated model was applied as an investigation tool to support:
  - Hydrogeological characterisation
  - Scientific questioning and guidance
  - Aquifer development planning
  - Strategic environmental assessment



Modeling Code : DYNSYSTEM (www.dynsystem.com)

Model Calibration - Example





Nicholson, S.E. (1996), A review of climate dynamics and climate variability in eastern Africa, in The Limnology, Climatology and Paleoclimatology of the East African Lakes, edited by T. C. Johnson and E. O.Odada, pp. 25–56, Gordon and Breach, Amsterdam.

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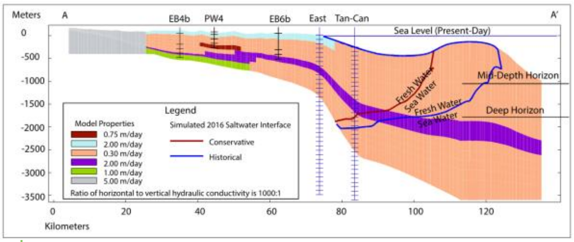
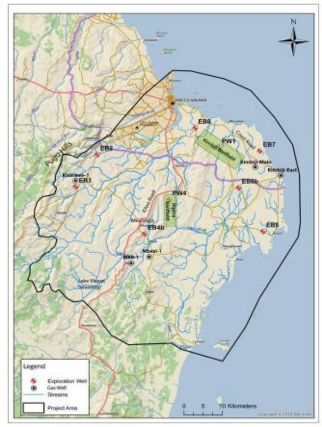
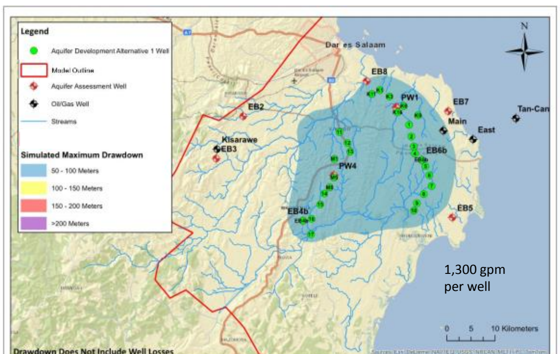
Saline Groundwater Position



Wellfield Development



Extended Wellfield – max. drawdown @ 100 years



Simulated Maximum Drawdown, Aquifer Development Alternative 1, 200,000 m3/day

Extended Wellfield – drawdown at water table @ 100 years

Simulated Water Table Drawdown, Aquifer Development Alternative 1, 200,000 m3/day

Conclusions

- Benefits and challenges: bridging the oil and water sectors
- Oil/water – "deep/shallow"
- Hydrogeological discoveries are yet to be made
- 3D numerical model was invaluable (at relatively low cost):
  - Framing of questions and focusing recommendations
  - Explaining how the system works to client and funders (also helped explain concepts of wellhead protection)
- Sharp interface modeling is appropriate for regional-scale models

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Thanks! Any Questions?

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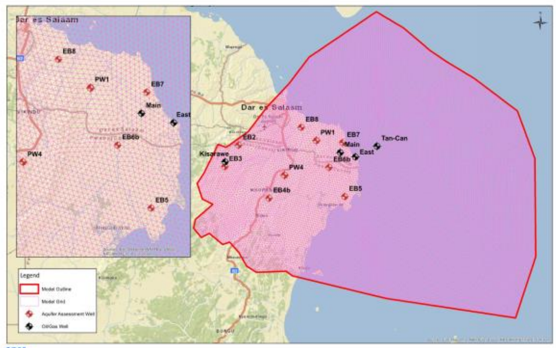
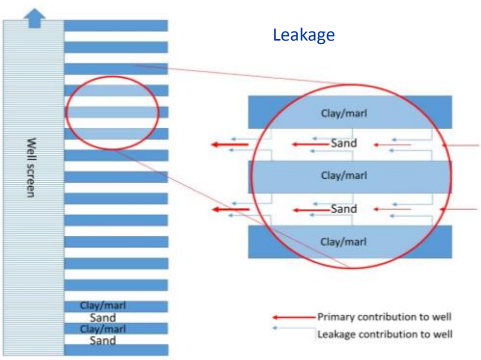
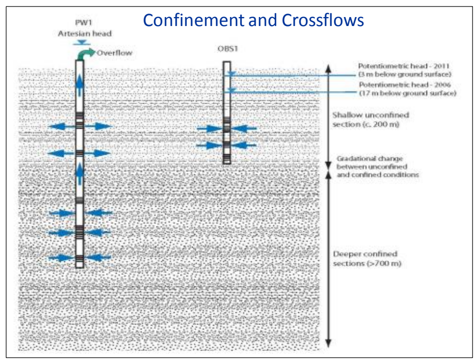


Numerical Model Domain





Historical Case:

- The model was run in steady-state, using present-day recharge and upwards fluxes at the model base, and a sea level that is 125 meters below current conditions to establish an equilibrium saline water interface position from which historical simulations could be started.
- With the steady-state saline water interface position in place as a starting condition, the model was run in transient mode, using 100-year time steps, for 19,000 years, varying the sea level based on estimates made by Woodroffe and Horton (2005).
- As the sea level rose, the simulated saline water interface position moved closer to the shoreline until a present-day, historically-based interface position was established.

Conservative Case:

- The model was run in steady-state, using present-day recharge and upwards fluxes as well as the current sea level elevation.
- This produced a saline water interface position that is significantly closer to the shore and represents a conservative estimate of these conditions.

Notes

A groundwater model is calibrated to data and observations. For the KAA project, the groundwater model was calibrated to:

- Average seasonal average conditions, based on average annual recharge (as described in the CMR) to represent "steady-state" (static) conditions; and
- Transient (time-varying) conditions, guided by the aquifer performance tests which were carried out in each of the completed exploration wells.

Notes

Table 1 - Summary of Well and Test Data

Well Name	X[1]	Y[1]	Ground Surface	Piezometric Head	Estimated Transmissivity Range	Representative Transmissivity	Screen Length[3]	Estimated Hydraulic Conductivity	Estimated Well Efficiency
	(m)	(m)	(m asl)[4]	(m asl)	(m^2/d)	(m^2/d)	(m)	(m/d)	(%)
EB2	511887	9232464	97.8	85.9	1 - 3	1	216	0.005	76%
EB3	506332	9223812	128.0	102.7	69 - 287	185	172	1.076	76%
EB4b	524175	9211033	57.9	>57.9[2]	148 - 490	243	288	0.844	59%
EB5	554884	9211671	21.9	>21.9[2]	26 - 115	86	177	0.486	49%
EB6b	548547	9223514	50.3	40.9	56 - 495	276	211	1.308	52%
EB7	554067	9233474	42.1	23.7	18 - 91	63	319	0.197	49%
EB8	537279	9239670	23.9	11.7	62 - 105	85	256	0.332	82%
PW1	543383	9234361	27.0	>27.0[2]	187 - 425	216	296	0.730	71%
PW4	530582	9220323	82.0	57.3	223 - 344	252	288	0.875	91%

(1) Coordinates are in UTM Zone 37S Meters

(2) Well is artesian

(3) Distance between the top of the shallowest screen interval and the bottom of the deepest screen interval

(4) meters above sea level

Table 3 - Hydraulic Property Data Sets

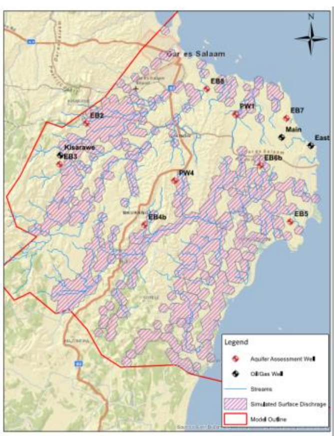
Data Set Number	Represents	Location	Horizontal Hydraulic Conductivity	Vertical Hydraulic Conductivity
			(m/d)	(m/d)
1	Bulk of aquifer system	Kimbiji aquifer system	0.3	0.0003
2	More permeable materials in the uplands area	Small are in uplands to west/southwest	5	0.050
3	Higher permeability layer	KAS, mid to lower depths	2	0.002
4	Higher permeability layer	KAS, mid to lower depths	1	0.001
5	Higher permeability layer	KAS, mid to lower depths	0.75	0.001
6	Shallow aquifer properties	Uppermost later of KAS	2	0.002
7	Paleogene (rock)	Small area in the vicinity of Pugu Hills, near EB2	0.007	0.007
8	Made ground (fill)	Dar es Salaam	3	0.300

Table 4 - Model Calibration

Well Name	Measured Head	Simulated Head	Delta (Simulated – Measured)	Estimated Transmissivity	Estimated Transmissivity Range	Transmissivity in Model[2]
	(m)	(m)	(m)	(m^2/d)	(m^2/d)	(m^2/d)
EB2	85.9	86.7	0.8	1	1 - 3	1
EB3	102.7	101.9	-0.8	185	69 - 287	119
EB4b	>57.9[1]	73.6[1]	-	243	148 - 490	263
EB5	>21.9[1]	26.7[1]	-	86	26 - 115	54
EB6b	40.9	40.4	-0.5	276	56 - 495	133
EB7	23.7	24.0	0.4	63	18 - 91	94
EB8	11.7	12.1	0.4	85	62 - 105	62
PW1	>27.0[1]	27.3[1]	-	216	187 - 425	253
PW4	57.3	59.8	2.5	252	223 - 344	164

(1) Well is artesian

(2) Transmissivity calculated by summing the products of screen length and horizontal hydraulic conductivity at each well location



Notes

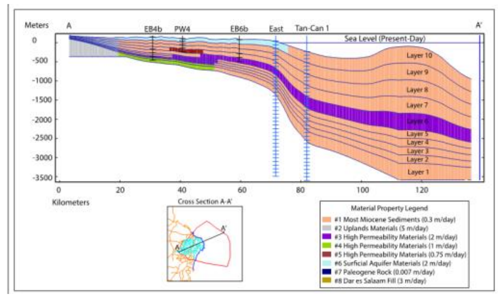


Figure 9: Rainfall and Surface Water Gauging Stations

3 ipy
from 42
ipy

Table 4: Estimated Recharge, 1969-2010

Month	Rainfall	Recharge	Average Recharge
	(mm)	(mm)	%
January	70.05	0.00	0.0%
February	55.41	0.00	0.0%
March	140.39	0.00	0.0%
April	253.34	53.75	21.2%
May	179.63	25.23	14.0%
June	40.02	0.00	0.0%
July	22.63	0.00	0.0%
August	22.88	0.00	0.0%
September	22.49	0.00	0.0%
October	62.12	0.00	0.0%
November	114.49	0.00	0.0%
December	108.12	0.00	0.0%
Annual	1091.59	78.98	7.2%

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