Transport Modeling of Wastewater in the Sana'a Aquifer

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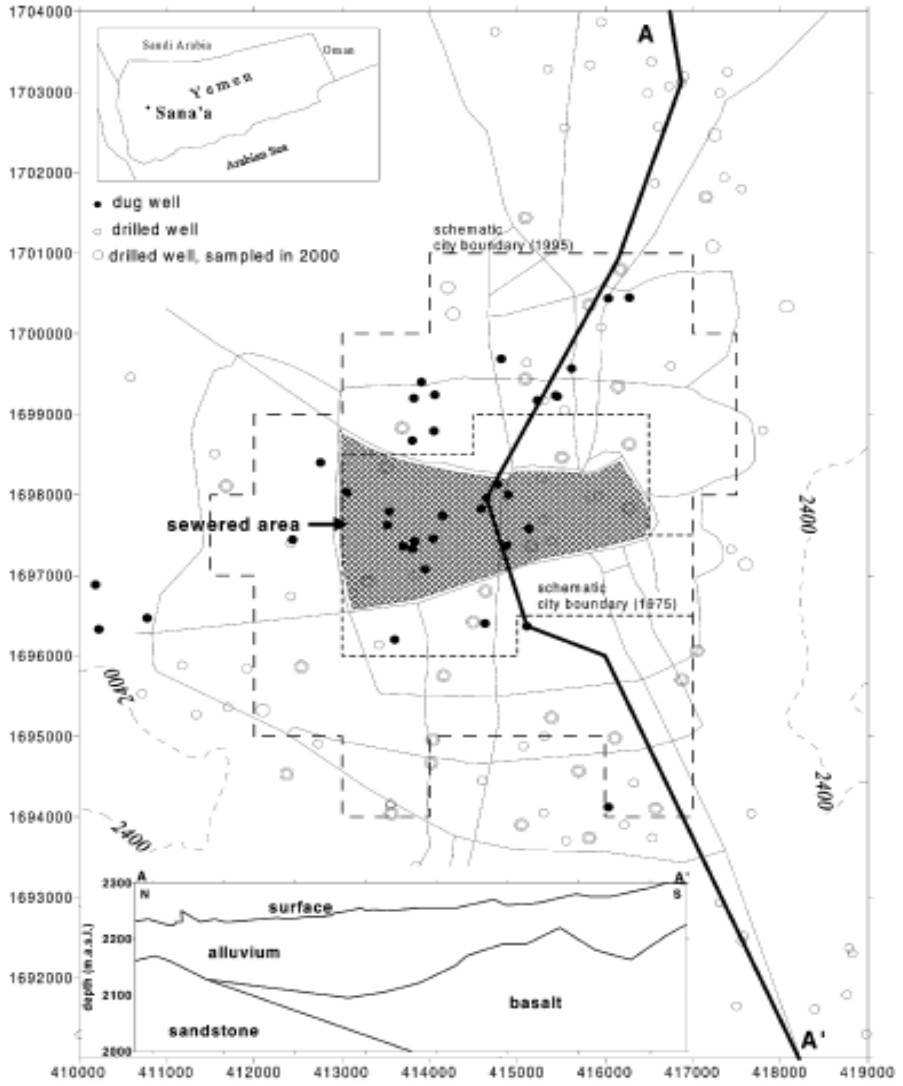
Introduction

- Sana'a Aquifer in Yemen

Background Information

- Sana'a Basin
  - Area = 3,200 km^2
  - 2,200 m above sea level
  - *Geological Formations:*
    - Quaternary Alluvium
      - Max thickness = 200 m
    - Tertiary Basalt
      - Thickness = 800 m (south)
    - Cretaceous Sandstone
      - Average thickness = 300 m



Background Information Continued

- Focus is on the unconsolidated alluvium
- Shallow water table approximate depth of 40 m (which is heavily exploited)
- Alluvium
  - Consists of mainly basaltic fragments
  - Also contains fractions of clay, silt, sand and pebble sized grains
- Wastewater infiltrates into this part of the aquifer

Concern

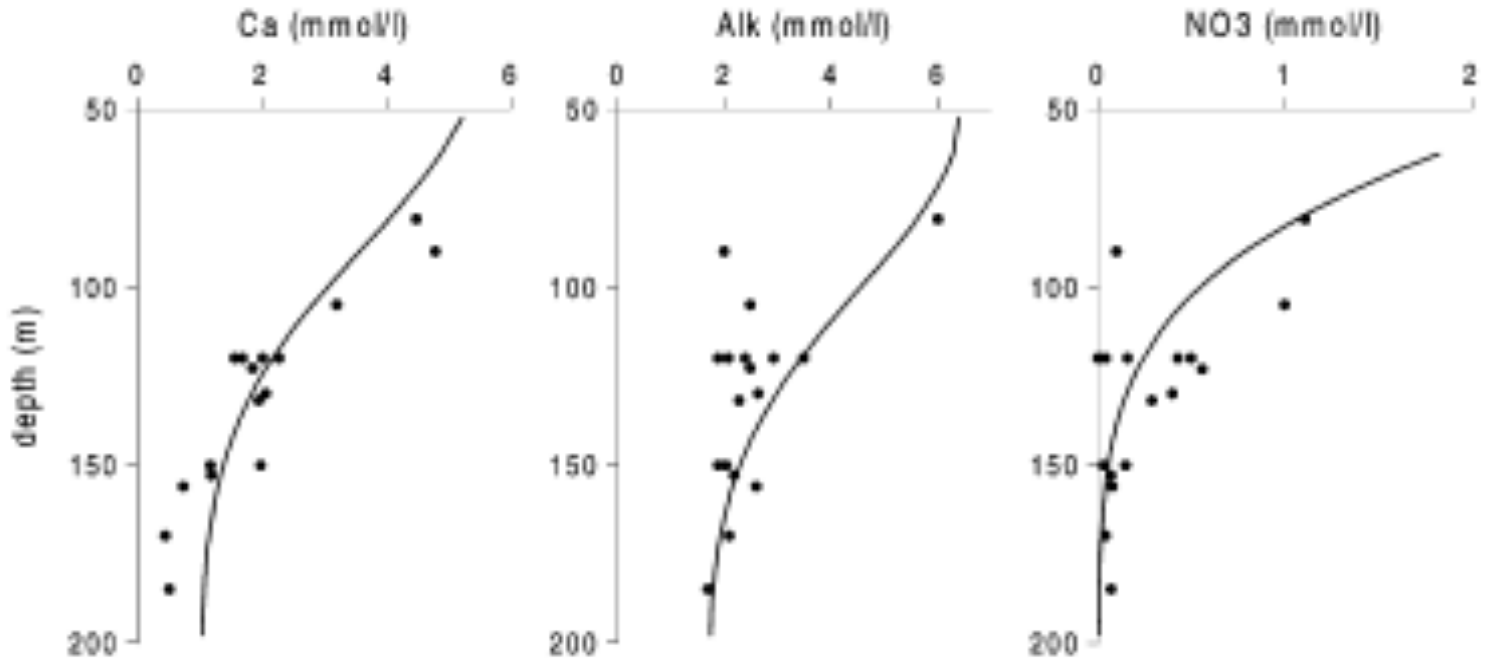
- Population growth
  - Average 6.1 percent annual growth from (1997-2001)
  - 1994 total population around 1,000,000 (2004 estimated population of 1.708 million)
- Wastewater
  - Disposal differs from the that of U.S.
    - Sana'a uses sewage ponds, cesspits and old water wells for disposal of solid and liquid wastewater

Original Study

- Element quantities at different depths
- Examined different wells
  - Dug wells (before 1970's) and bored wells (1960's and after)
- Valuation of oxidation, nitrification difference with time (samples were taken in 1995 and then in 2000)

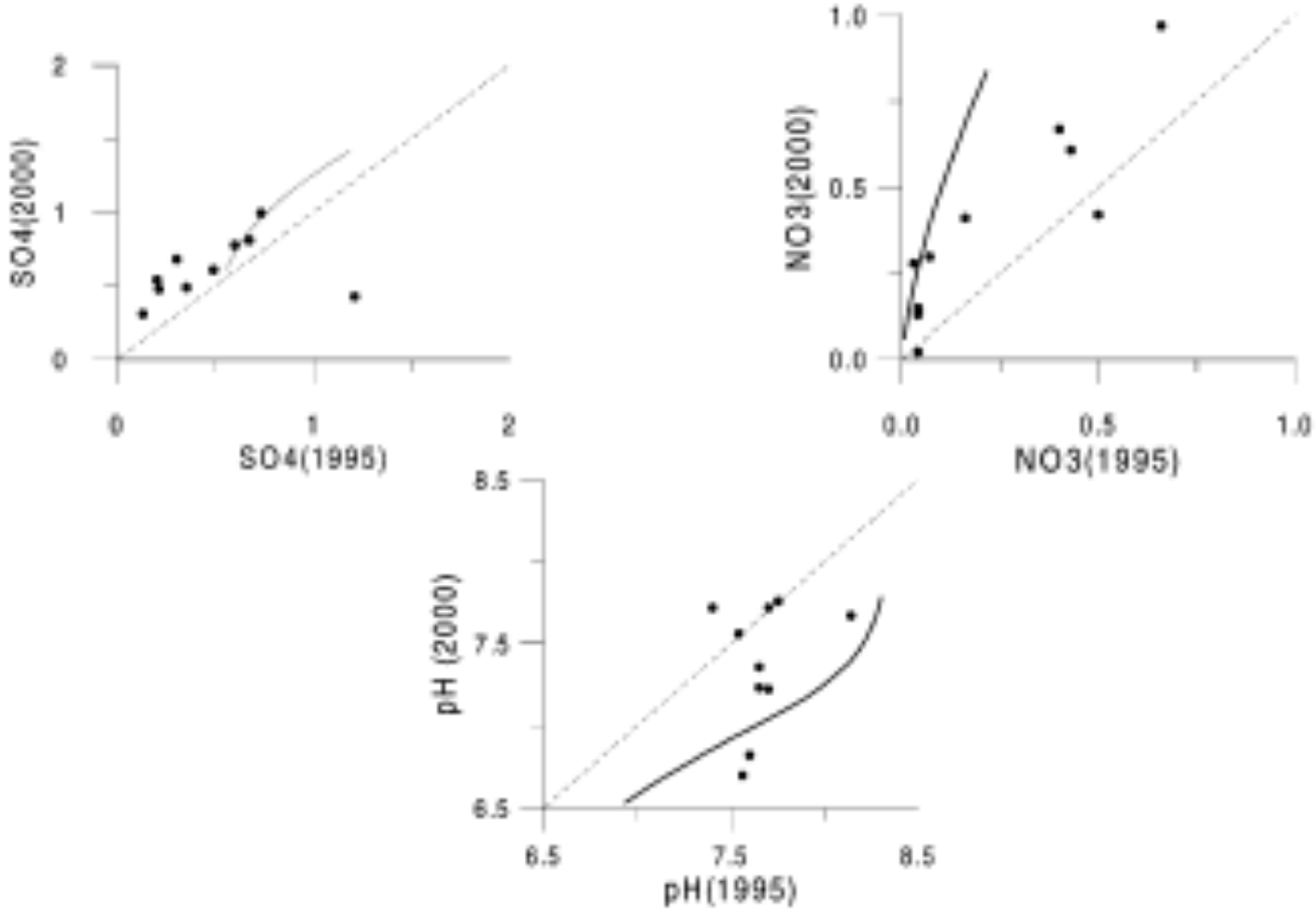
Original Study Continued

- Major cations and anions compared to depth
- Solid lines are model results from PHREEQC



Original Study Continued

- Comparison of 1995 to 2000 collected data



Transport Study

- Based off information given affects through the saturation zone given initial report was not shown.
- The purpose is see how the elements would react as they pass through the soil.
- Multiple wells showed contamination in initial study.

Transport Study

- Hypothesis:
  - Chlorine concentrations will go up as the system proceeds through the each step.
  - Calcium and potassium would increase concentrations.

PHREEQC Information

Wastewater Input

```
SOLUTION 0 Wastewater - Raw sewage
    temp      23
    pH        7.3
    pe        2
    redox     pe
    units     mmol/l
    density   1
    Alkalinity 15.7
    Ca        2.5
    Cl        10
    K         1.5
    Mg        1.5
    N(-3)     10
    Na        9.82
    S(6)      1.81
    water     1 # kg
```

Alluvium Water Input

```
SOLUTION 1-40 Initial Alluvium water
    temp      26
    pH        8.35
    pe        12
    redox     pe
    units     mmol/l
    density   1
    Alkalinity 1.65
    Ca        2.5
    Cl        1.52
    K         0.07
    Mg        0.3
    N(-3)     0
    Na        1.6
    S(6)      1.81
    water     1 # kg
```

Note: Information was given from research paper

Saturation Indices (SI)

Wastewater

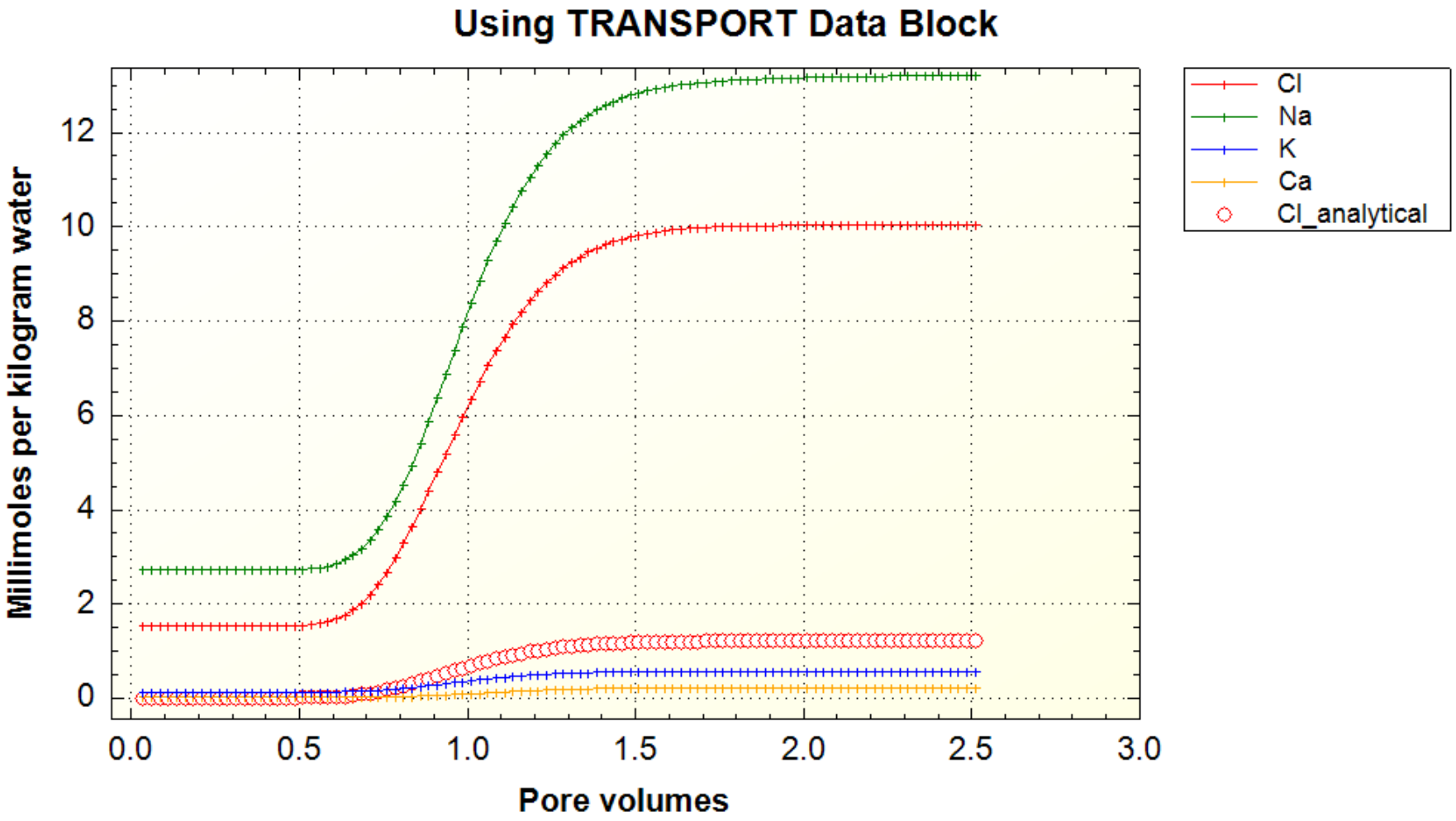
Phase	SI**	log IAP	log K(296 K, 1 atm)	
Anhydrite	-1.83	-6.08	-4.26	CaSO4
Aragonite	0.44	-7.89	-8.32	CaCO3
Calcite	0.58	-7.89	-8.47	CaCO3
CO2(g)	-1.39	-2.83	-1.44	CO2
Dolomite	1.05	-15.99	-17.04	CaMg(CO3)2
Gypsum	-1.50	-6.08	-4.58	CaSO4:2H2O
H2(g)	-18.65	-21.74	-3.10	H2
H2O(g)	-1.55	-0.00	1.55	H2O
Halite	-5.73	-4.16	1.57	NaCl
NH3(g)	-5.93	-4.09	1.84	NH3
O2(g)	-46.67	-49.55	-2.88	O2
Sylvite	-5.87	-4.98	0.89	KCl

Saturation Indices (SI)

Alluvium Water

Phase	SI**	log IAP	log K(299 K, 1 atm)	
Anhydrite	-1.55	-5.84	-4.29	CaSO4
Aragonite	0.67	-7.68	-8.34	CaCO3
Calcite	0.81	-7.68	-8.49	CaCO3
CO2(g)	-3.40	-4.87	-1.47	CO2
Dolomite	0.83	-16.29	-17.11	CaMg(CO3)2
Gypsum	-1.26	-5.84	-4.58	CaSO4:2H2O
H2(g)	-40.75	-43.85	-3.10	H2
H2O(g)	-1.48	-0.00	1.48	H2O
Halite	-7.28	-5.71	1.57	NaCl
O2(g)	-1.45	-4.35	-2.90	O2
Sylvite	-7.97	-7.07	0.90	KCl

Transport Model



Results

- Based of the transport graph, that all element concentrations increased.
- I noticed that the SI of wastewater and the alluvium, had a higher concentrations of dolomite than calcite.
- In the tests conducted within the paper indicate the calcite was dominate SI to precipitate out of solution at the levels.

Future Test Possibilities

- Obtain more samples from the future date and compare to previous tests to see if conditions have changed. This includes any industrial, or additional sewer treatment systems since first test.

Questions?

Reference

- Foppen, J.W.A. (2002), Impact of high-strength wastewater infiltration on groundwater quality and drinking water supply: the case of Sana'a Yemen. Journal of Hydrology. 263, 198-216.