ENGSCI 263: Resource Consent Project [Contamination in the Onehunga Aquifer]

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Why? - Problem Summary

<u>Problem Statement</u>

We wish to investigate the effect of extraction from the Onehunga Aquifer on the pressure and copper concentration, to provide a recommendation to the Auckland Regional Council regarding the outcome of Watercare's consent application.

<u>Potential High-Level Stakeholders</u>

1. Watercare:

   Would like consent to double their maximum take from the Onehunga Aquifer.

2. Auckland Regional Council:

   Would like the best outcomes for local communities, considering many factors including both the sustainability of the aquifer and the recent drought.

3. New Zealand Government:

   Require that the Auckland Regional Council considers the change in quality of groundwater resources, in accordance with the National Policy Statement for Freshwater Management.

4. Ngāti Whātua:

   Oppose the consent, in favour of prioritising ecosystem restoration and sustainable harvesting of mahinga kai.

<u>Possible Outcomes</u>

The possible courses of action following the resource consent hearing are to:

- Increase the resource consent, to a maximum allowable take of 40 million litres per day
- Do not change the current maximum allowable take (of 20 million litres per day)
- Reduce the resource consent, to a recommended safe level
- Impose an indefinite moratorium on the aquifer usage

How? - Addressing the Problem via Modelling

Our model aims to capture and quantify the effect of different extraction rates on the pressure and dissolved copper in the Onehunga Aquifer over time. In particular, this will be achieved by quantifying the flows in and out of the aquifer and applying various physical principles.

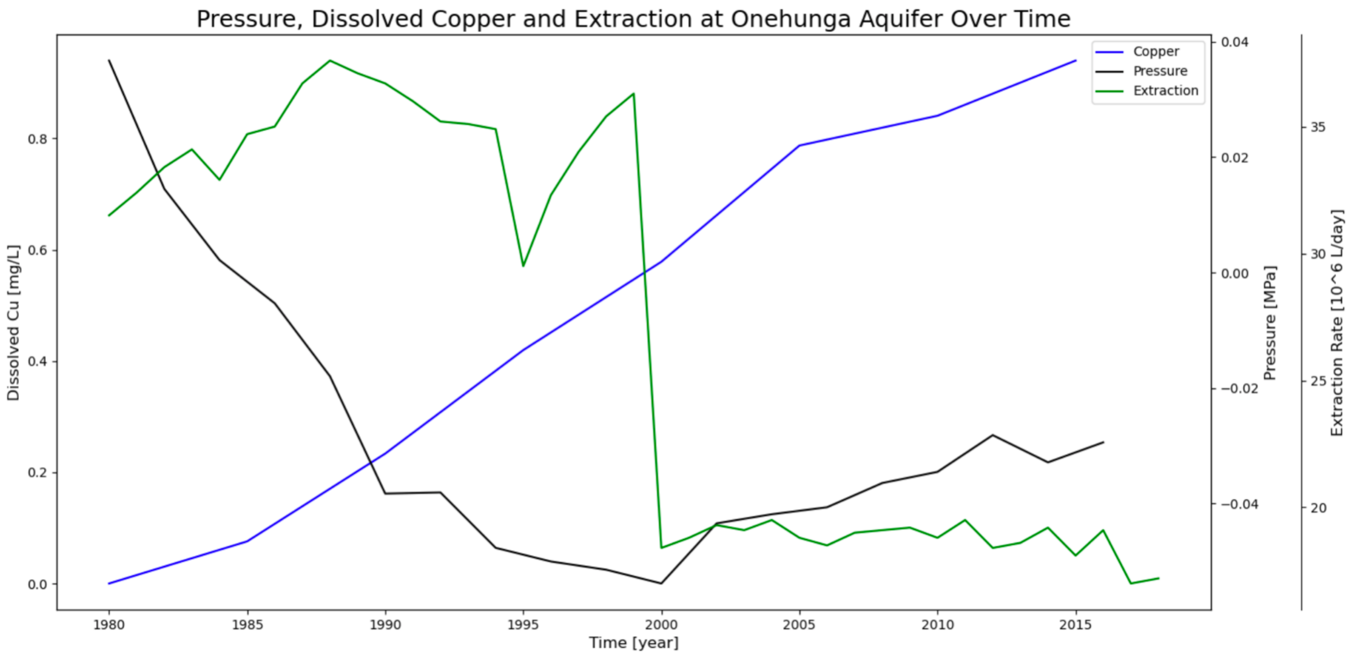
We expect to be able to quantify how the pressure and copper concentration will change in the (near) future, for each possible outcome of the resource consent application. Furthermore, we wish to estimate when the level of dissolved copper will exceed the World Health Organisation's (2004, p.17) guideline value of 2 mg/L (if at all), and when the pressure and copper concentration stabilise (if at all), under each outcome.

This insight will help the Auckland Regional Council understand the consequences of each outcome, in regards to the sustainability and health of the Onehunga Aquifer, hence we will include it in our recommendation.

Given? - Data and Relevant Research

Data Visualisation

The following figure illustrates the historical data collected at the Onehunga Aquifer.

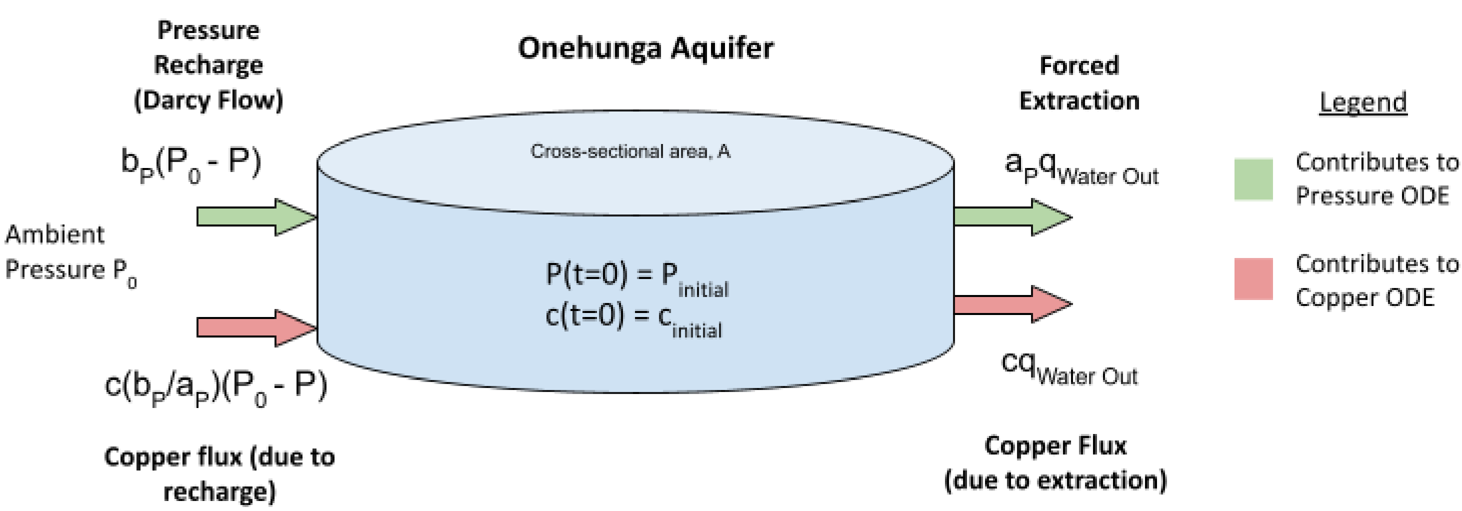


Data Description

All historical data is from 1980 onwards, and was collected every year (until 2018), every two years (until 2016) and every fifth year (until 2015) for the extraction rate, pressure and copper concentration, respectively.
There is a clear increasing, linear trend in the copper concentration throughout the entire time domain.
Until 2000, the pressure appeared to decrease at a non-linear rate, but it has since increased at a fairly constant rate. Of note, the extraction rate was significantly decreased (roughly halved) in the year 2000, due to a new restriction of 20 million litres per day (introduced in an attempt to restore the aquifer's pressure).

Assume? - Conceptual Model Design

Conceptual Model Sketch



Conceptual Model Justification

We will utilise the conservation of mass and the conservation of chemical species in our model, which correspond to the constitutive laws of Darcy's law and Fick's law; these will form the foundation of our pressure and concentration differential equations, respectively. Our model will be a lumped parameter model where the properties of the aquifer (namely pressure and copper concentration) are assumed to be roughly uniform in space, hence a single value of each property is assumed to represent the average value in the domain.

Regarding flows crossing the system boundary, parameters, and boundary conditions, we also assume:

- The domain is cylindrical with a constant cross-sectional area
- Constant rainfall; although it fluctuates, the regional averages are fairly constant (Bowden et al, 2002)
- Constant ambient pressure and copper concentration
- Uniform, isothermal conditions: the aquifer temperature does not vary significantly in time or space (NGWA, 1999), hence this assumption is valid. Furthermore, this simplifies the use of temperature-dependent properties such as dynamic viscosity (Pestov, 2000) (e.g. in Darcy's law).
- All 'unforced' water (and hence copper) flow into the system is governed by Darcy's law. This is valid assuming the rock properties surrounding the domain (ie permeability and porosity) are uniform and constant, and that the dynamic viscosity is constant.
- No leakage occurs. That is, fluid only crosses the system boundary via the extraction pump, or due to the pressure gradient according to Darcy's law. Furthermore, we assume there are no significant water sources that lead to the aquifer, such as rivers, and no water is pumped in.

Formulate? - Differential Equations of Interest

Pressure ODE

$$\frac{dP}{dt} = -a_P q_{Water\ Out} - b_P(P - P_0) \quad \text{P(t=0)} = P_{initial}$$

$where$:

t = Time since the start of time domain (s)

$a_P = \frac{g}{A\phi}$

$b_P = \frac{g}{A\phi}\frac{k\rho A_{rchrg}}{\mu L}$

g= Acceleration due to gravity (m/s^2)

A =Cross-sectional area of the aquifer (m^2)

ϕ =Porosity of the aquifer (volume fraction, dimensionless)

k = Permeability of the aquifer (m^2)

ρ =Density of water (kg/m^3)

A_{rchrg} = Surface area of the domain over which recharge occurs (m^2)

T = Aquifer temperature (°C)

μ = Dynamic viscosity of water, at temperature T (Pa.s)

L =Distance over which recharge occurs (m)

$q_{Water\ Out}$ =Mass flow rate of water being extracted (kg/s)

P = Pressure of fluid in aquifer at time t (Pa)
P_0 =Ambient pressure (Pa)

Copper Concentration ODE

$$m\frac{dc}{dt} = cq_{Water\ Out} + c\frac{b_P}{a_P}(P - P_0) \qquad \text{c(t=0)} = c_{initial}$$

$where$:
m =Total mass of water in the domain (kg)
c =Concentration of copper in aquifer (mass fraction, dimensionless)

References

NGWA (1999). Dissolved Mineral Sources and Significance. Retrieved from https://www.ngwa.org/what-is-groundwater/About-groundwater/dissolved-mineral-sources-and-significance

Pestov, I. (2000). Numerical techniques for simulating groundwater flow in the presence of temperature gradients. https://doi.org/10.21914/anziamj.v42i0.638

World Health Organisation (2004). Copper in Drinking-water, 17.

Bowden, D. & Crowcroft,G (2002). Auckland Water Resource Quantity Statement 2002. Retrieved from http://www.aucklandcity.govt.nz/council/documents/technicalpublications/TP%20171%20-%20Auckland%20Water%20Quantity%20Statement%202002%20part%201.pdf