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Geothermal Reservoir Modelling: Uses and Limitations

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NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

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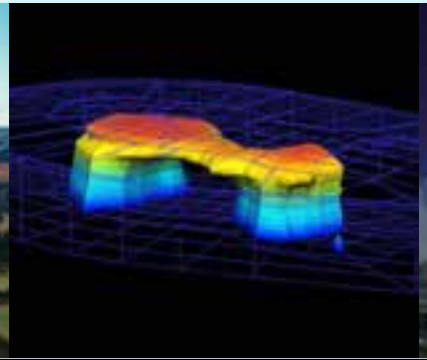

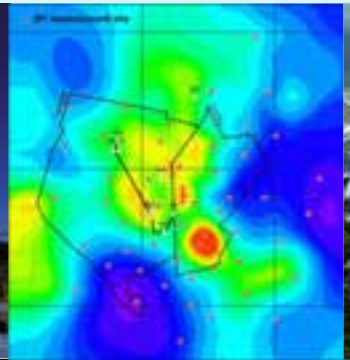


Outline

- Introduction to modelling
- Geothermal modelling process
- Modelling uses
- Limitations

Introduction to modelling

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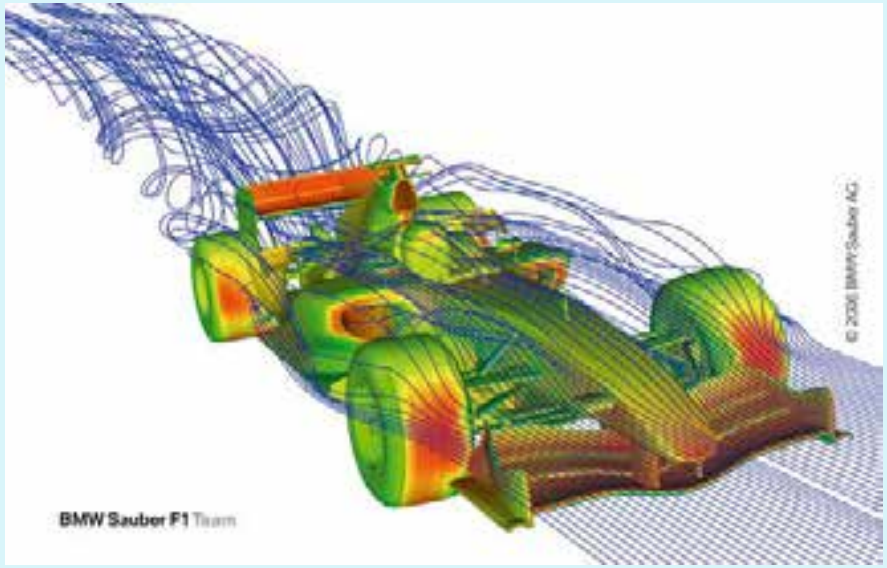
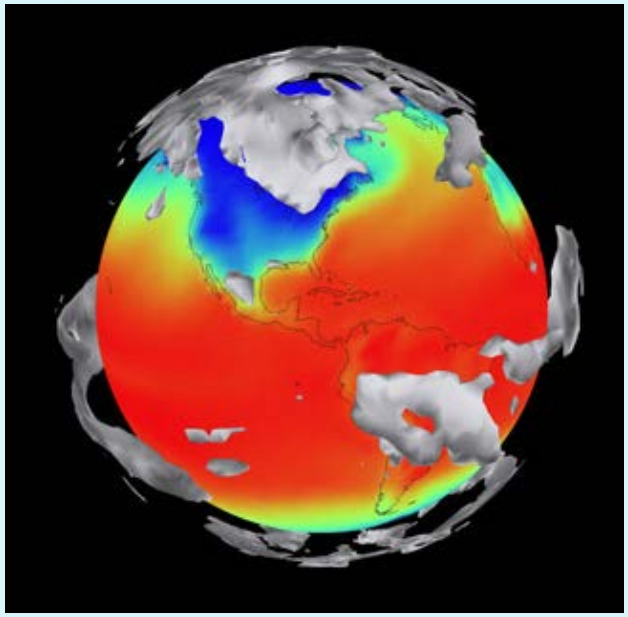
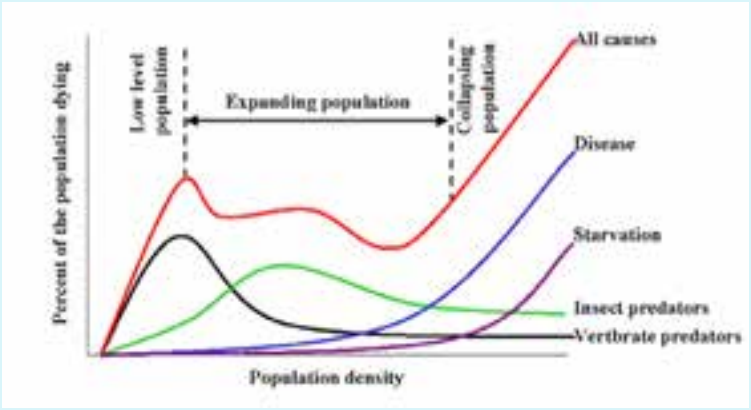
- Modelling is used everywhere



Formula 1



Climate



Populations

Physiology

Why make models?

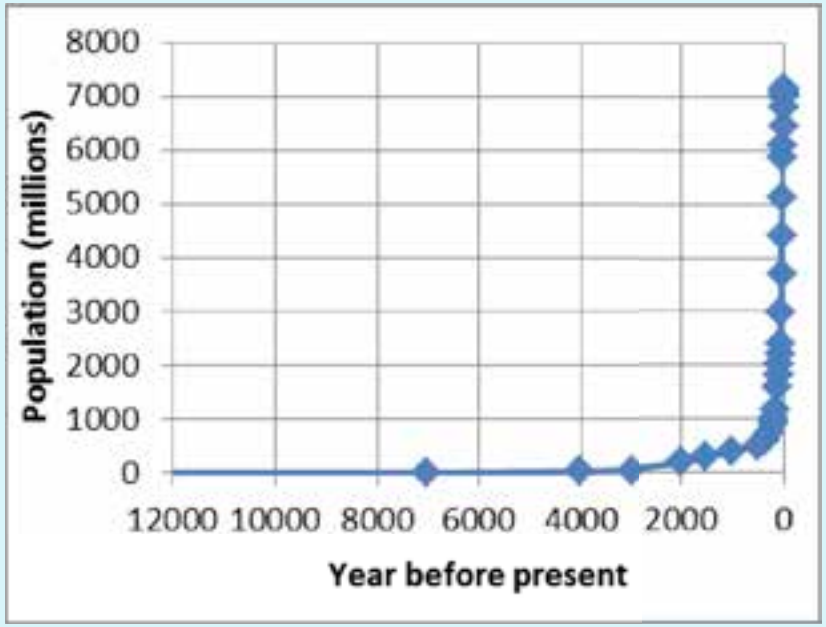
- To help understand the what is happening or has happened
- Sometimes we can't measure what happened:
  - Things are too small or happen to fast
  - You can't reach what you want to measure – eg deep underground
  - Measuring data can affect the results – eg pressure sensors on planes
  - You can't always put things inside people!

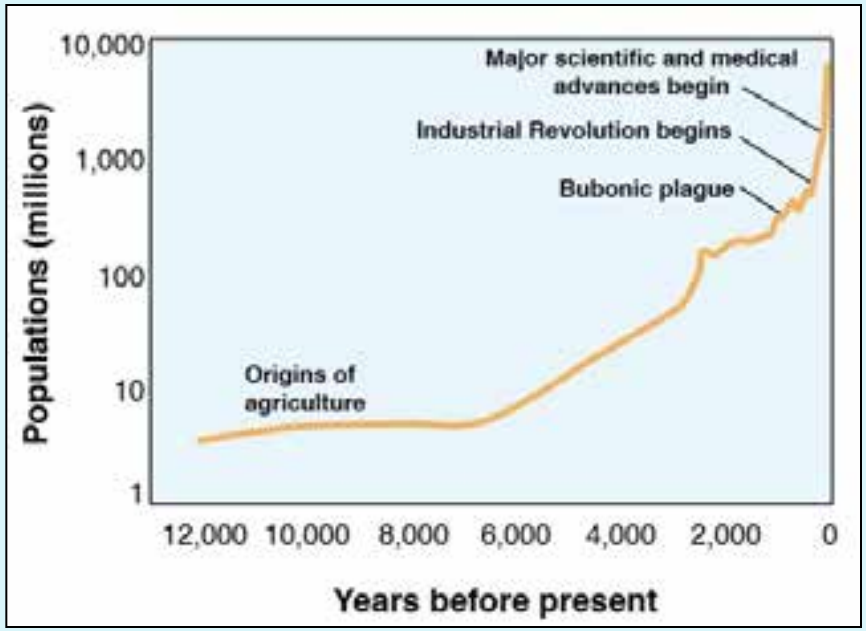
Why make models?

- To make predictions about what will happen in the future
  - Important for planning – eg budgets
  - Can save a lot of money – eg design costs
  - Can save a lot of time
  - Build confidence in decisions – not just from model results but also modelling process

A simple example

- World population growth





- Follows an exponential law
- Different rates for different periods

A simple example

- For our model we'll use an **Exponential Law**

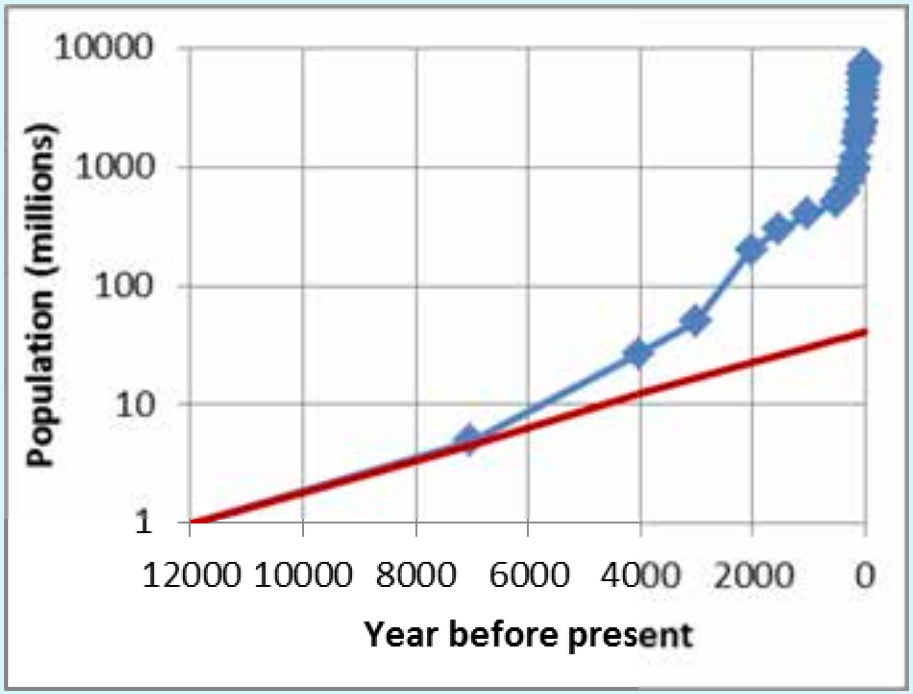
$$P = e^{Rt}$$

- We'll use four different rates for four different periods:
  1. Pre-Agriculture
  2. Pre-Industrial
  3. Post-Industrial
  4. Modern

A simple example

- 1st attempt:

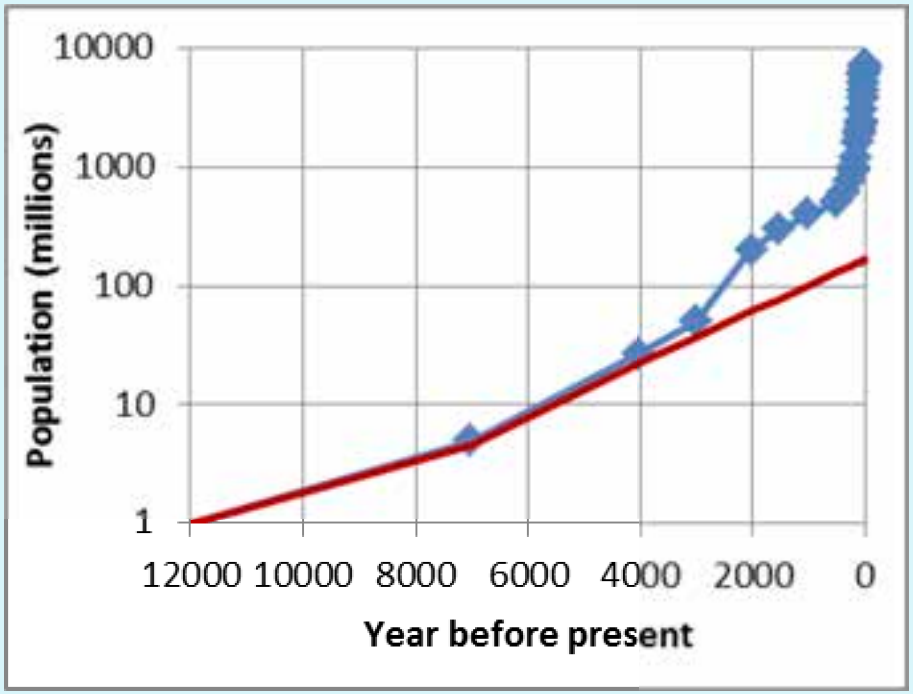
Period	*R* value
Pre-Agriculture	0.0003
Pre-Industrial	0.0003
Post- Industrial	0.0003
Modern	0.0003



A simple example

- 2nd attempt:

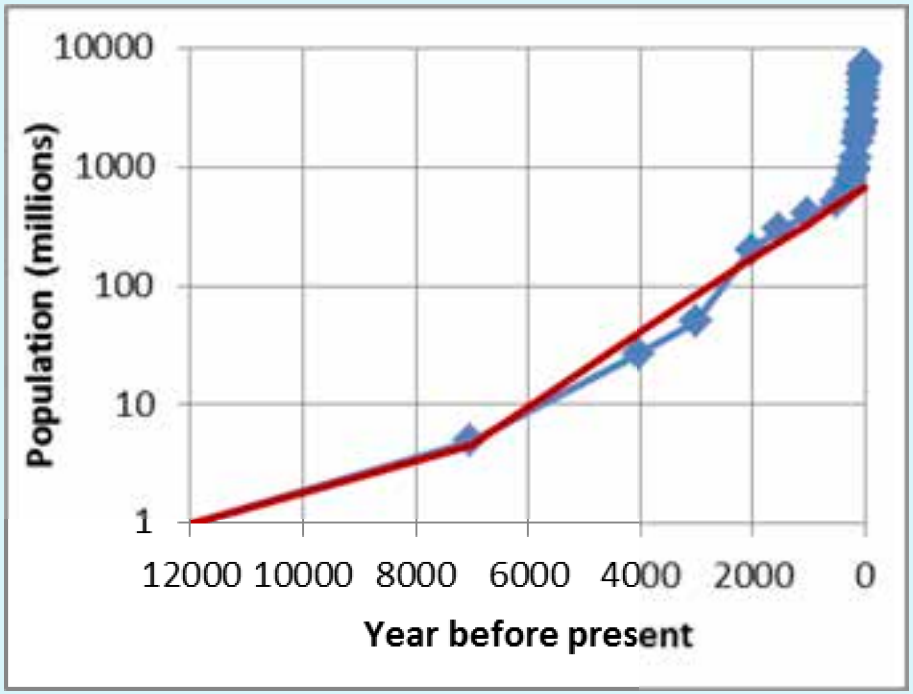
Period	*R* value
Pre-Agriculture	0.0003
Pre-Industrial	0.0005
Post- Industrial	0.0005
Modern	0.0005



A simple example

- 3rd attempt:

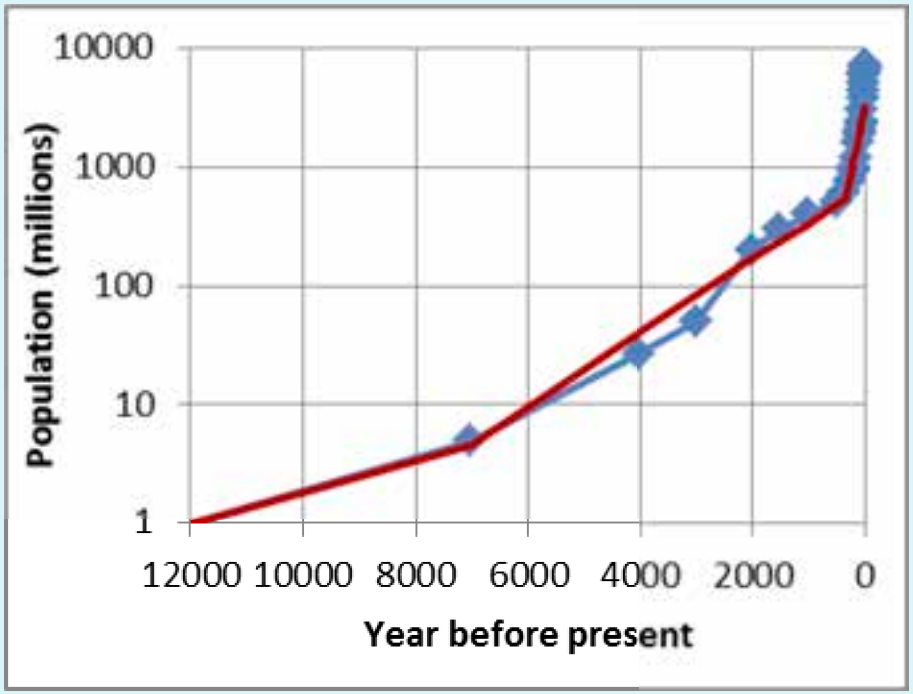
Period	*R* value
Pre-Agriculture	0.0003
Pre-Industrial	0.0007
Post- Industrial	0.0007
Modern	0.0007



A simple example

- 4th attempt:

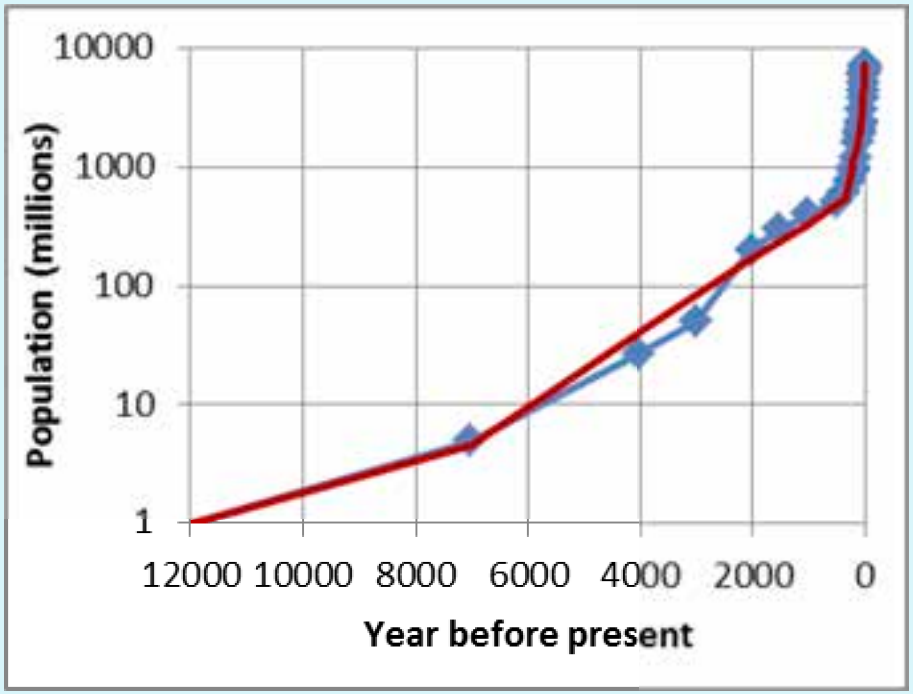
Period	*R* value
Pre-Agriculture	0.0003
Pre-Industrial	0.0007
Post- Industrial	0.005
Modern	0.005



A simple example

- 5th attempt:

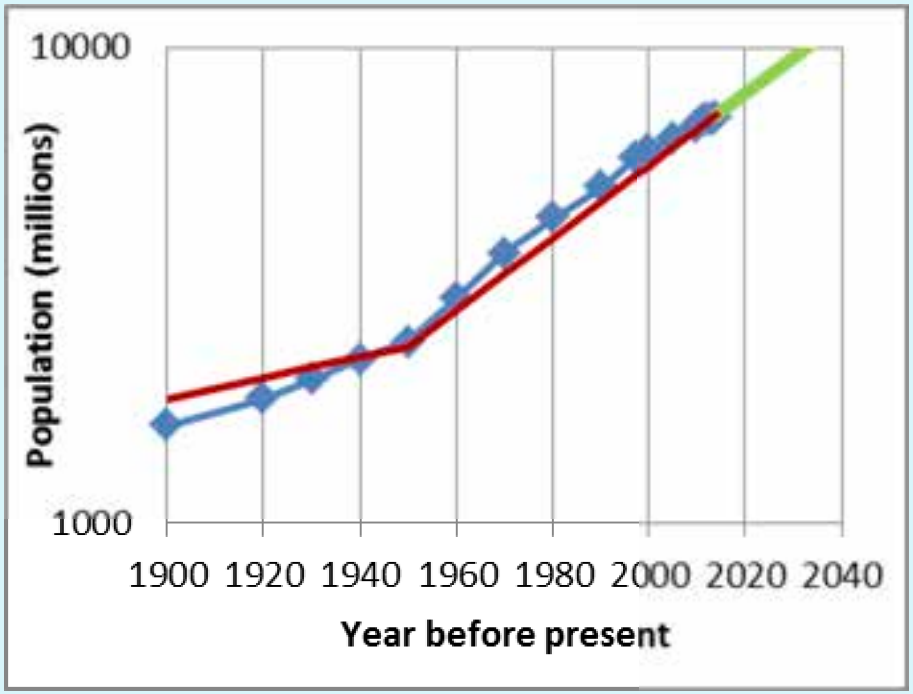
Period	*R* value
Pre-Agriculture	0.0003
Pre-Industrial	0.0007
Post- Industrial	0.005
Modern	0.0175



This process is called model calibration

A simple example

- Our calibrated model matches historic data
- Now we can use it predict the future



Geothermal models

- Geothermal models are like our example
- They are based on laws and calibrated using real data
- There a many different types of geothermal models ranging in complexity
- Stored heat calculations are very simple "models" that follow the **Conservation of Heat Law:**

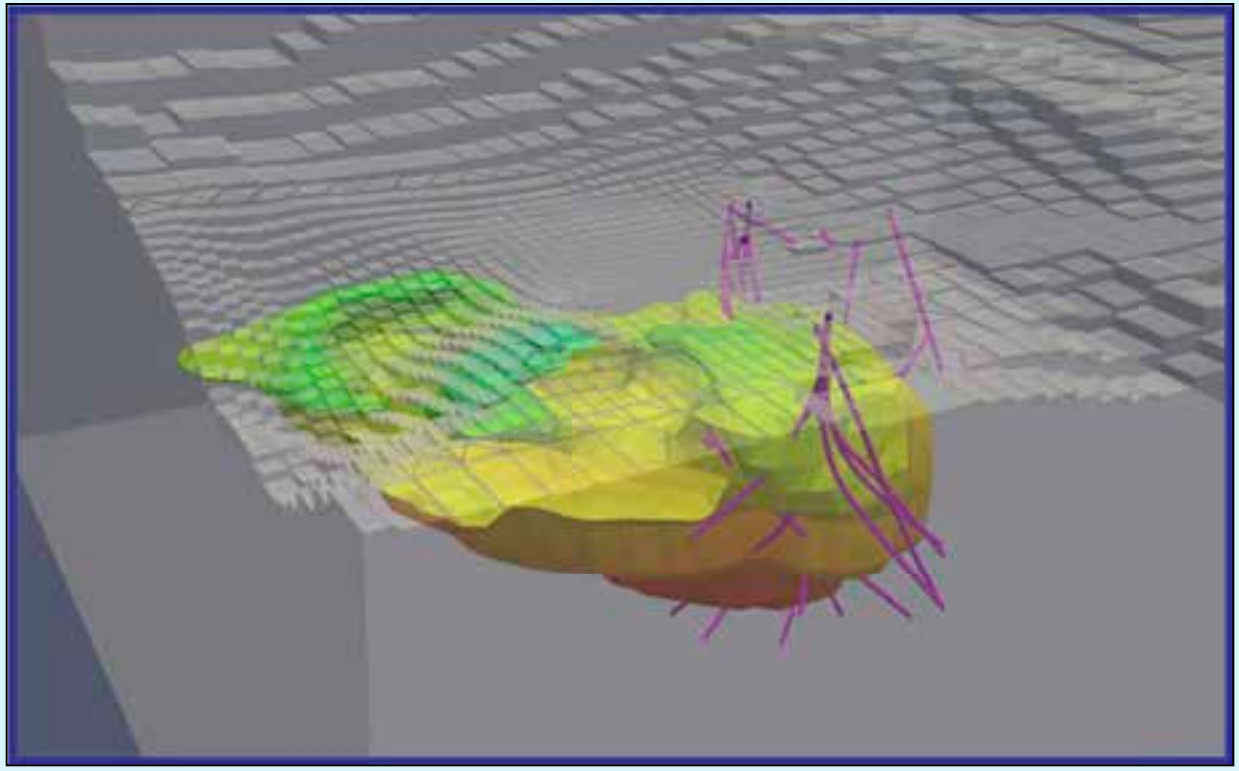
Useable Heat	=	Total Heat	–	Unusable Heat
(energy you take out)		(energy in the ground)		(energy that stays in the ground)

Geothermal models

- Geothermal reservoir models are much more complicated and follow several laws:
- **Conservation of Mass**
  - "What goes in must come out"
- **Conservation of Heat**
  - "Energy cannot be created or destroyed"
- **Darcy's Law**
  - Define how hot water and steam move underground

Geothermal models

- Before talking about model uses and limitations it is helpful to understand how geothermal models are made



Geothermal modelling process

1. Gather and analyse data
2. Create a “conceptual model” of the geothermal system
3. Build an calibrate “natural state” model
4. Use the natural state model to make a production model and calibrate with production history data
5. Run future scenarios using the production model

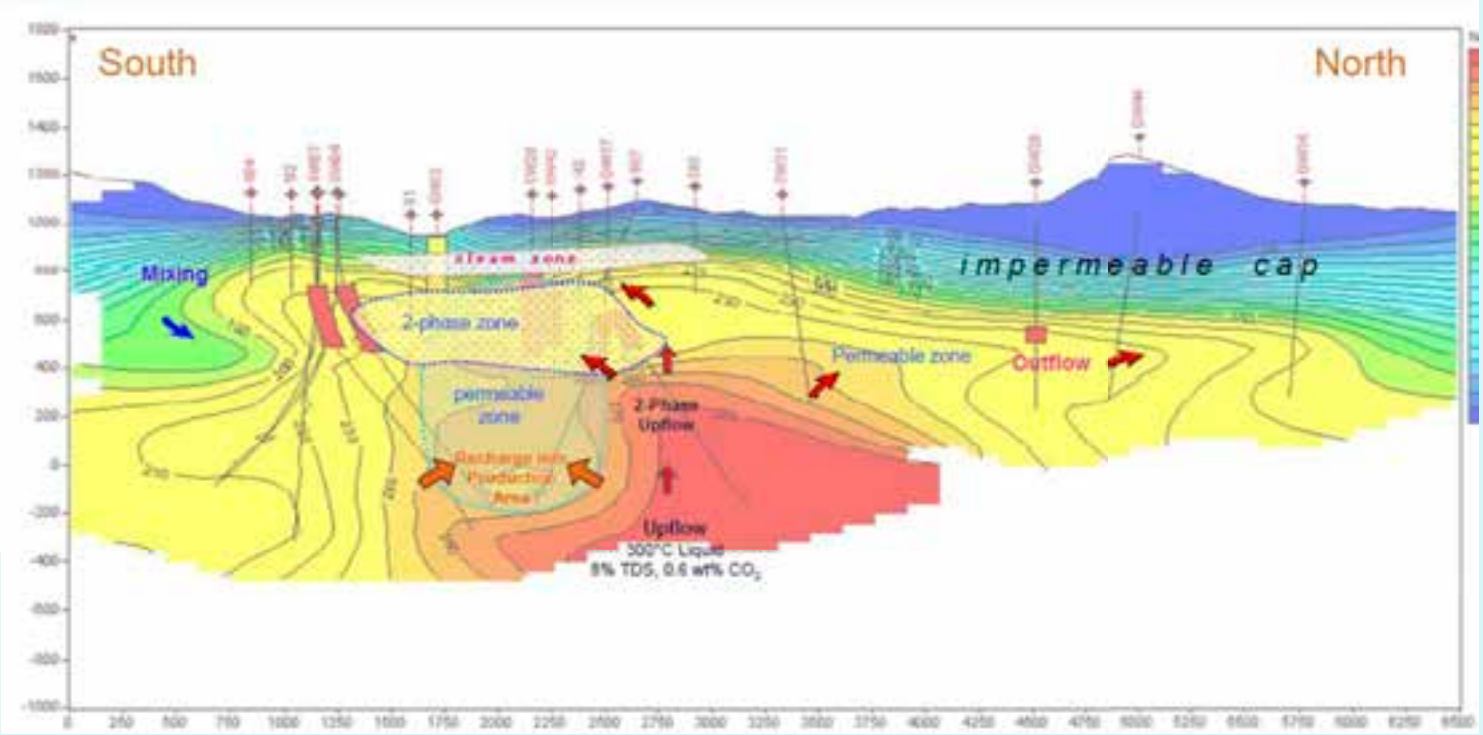
- Steps 3 to 5 are iterative

Gather and analyse data

- Gather as much data as possible
- From a wide variety of sources:
  - Geosciences
  - Environmental sciences
  - Engineering
  - Hydrological
- **Data collected before production occurs is very important!**
- **Some things are impossible to predict before wells are drilled**

Conceptual model

- Combines and distils all the available data
- Provides a “conceptual” idea about how the geothermal system behaves



Natural state model

- A reservoir model of the system before any production occurred
- Model calibrated using pre-production data:
  - Exploration well data
  - Surface features (geysers, hot pools, springs etc)
  - Completion test data from the first production wells

Production model

- Reservoir model follows the production history for the system
- Transient data are used to calibrate the model
  - Pressure decline
  - Enthalpy changes
  - etc

Future scenarios

- Once a model has been calibrated using production data it can be used to predict the future
- The more **good** data used for calibration the more accurate the predictions
- Scenarios are set up that define expected future production, well locations, reinjection strategies etc
- How scenarios are created depends on what the model is to be used for

Modelling uses

- Geothermal reservoir models are mainly used to predict the following:
  - How long a system can be economically exploited
  - What schedule of new wells are required to maintain production
  - How a system will respond to different rates of production
  - How to best re-inject fluid into a system
  - How the natural geothermal features will react to the systems exploitations
  - What other environmental effects may occur

Modelling uses

- Which of these are important to a developer?
  - How long a system can be economically exploited
  - What schedule of new wells are required to maintain production
  - How a system will respond to different rates of production
  - How to best re-inject fluid into a system
  - How the natural geothermal features will react to the systems exploitations
  - What other environmental effects may occur

Modelling uses

- Which of these are important to a policy maker?
  - How long a system can be economically exploited
  - What schedule of new wells are required to maintain production
  - How a system will respond to different rates of production
  - How to best re-inject fluid into a system
  - How the natural geothermal features will react to the systems exploitations
  - What other environmental effects may occur

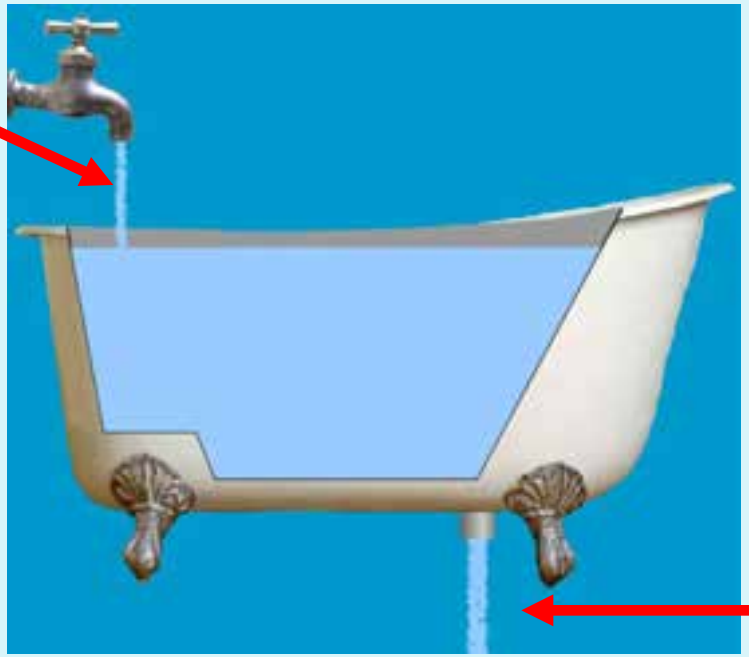
Modelling uses

- Reservoir models are also used for research
  - How do geothermal systems form and why?
  - How do geothermal system interact?
  - What are the fundamental processes that occur in geothermal systems?
  - etc

How long a system can be economically exploited

- In most cases the amount of energy taken out of a geothermal system by production is more than the natural recharge

Natural recharge



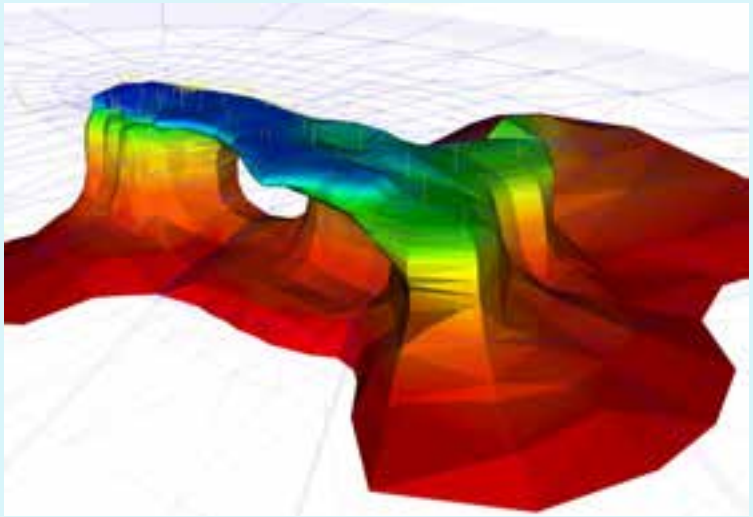
Energy taken out

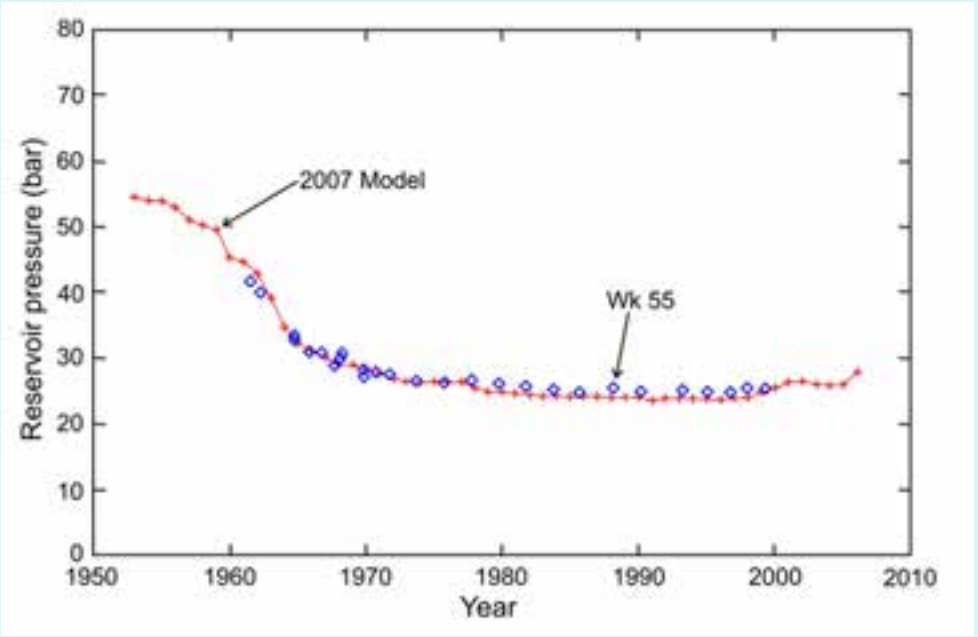
How long a system can be economically exploited

- At some point it will become uneconomic to continue exploitation and the production will have to stop while the pressure recovers in the system
- This may be in 25 years, 35, 50 or even 100
- Stored heat calculations give simple estimates useful only as a first guess
- Reservoir models are much more accurate and take into account many other factors

How long a system can be economically exploited

- Brief History of Wairakei:
  - Started operation in late 1958
  - Pressures dropped quite soon
  - Pressure decline of 25bar by 1965
  - Panic!
  - Send for the modellers!



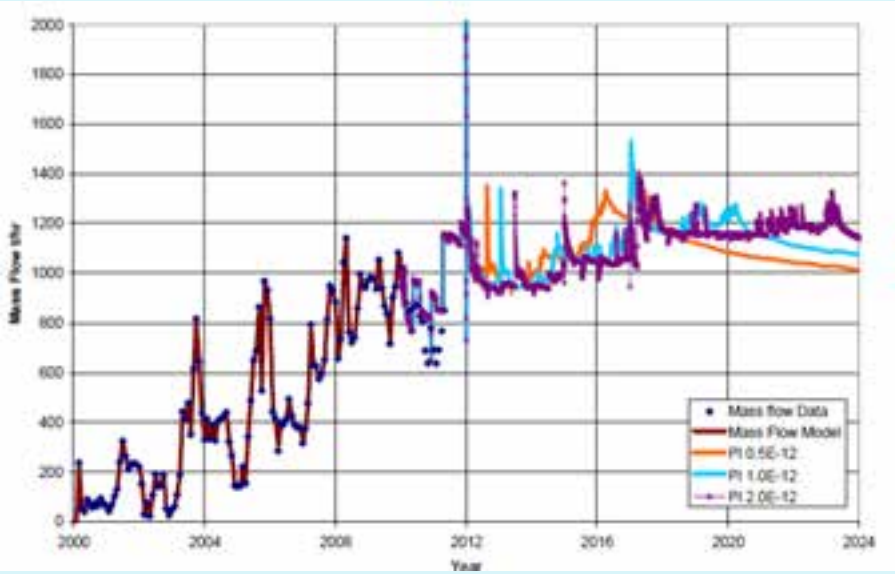


How long a system can be economically exploited

- In New Zealand regulators require reservoir models to be used as part of the permitting process
- In many other countries it may become a requirement for companies listed on the stock exchange

What schedule of new wells are required to maintain production

- As pressure declines locally, wells will produce less.
- Reservoir models are used to predict when new wells must be brought online to maintain power production



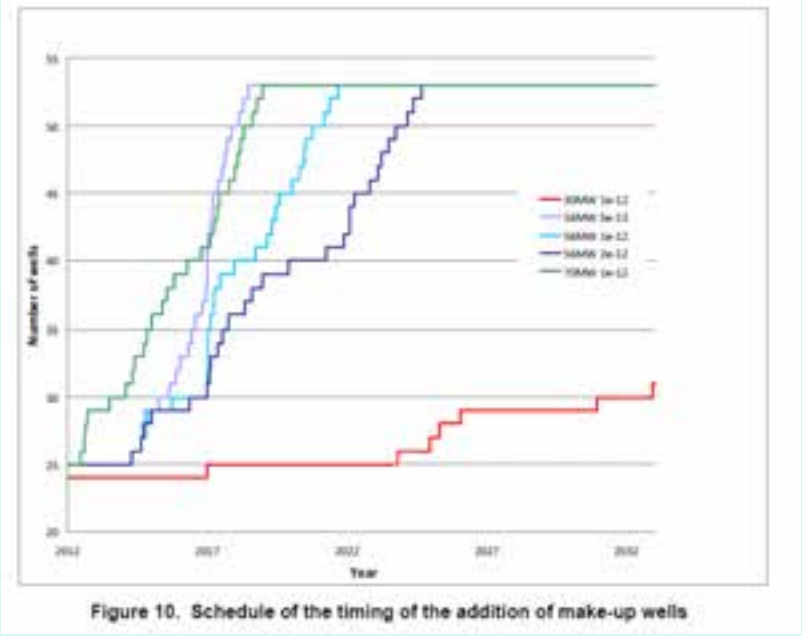


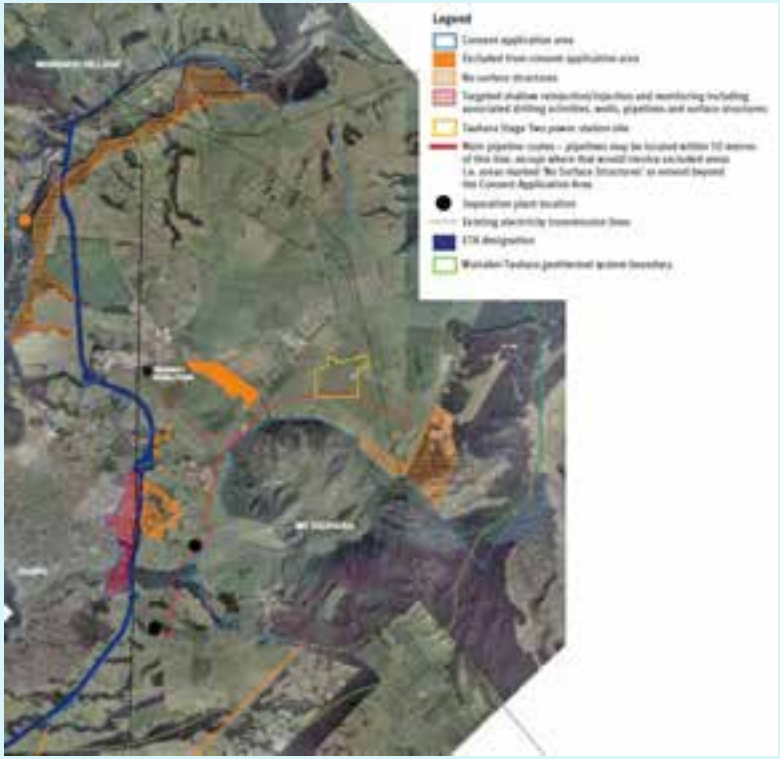
Figure 10. Schedule of the timing of the addition of make-up wells

What schedule of new wells are required to maintain production

- Reservoir models can also be used to plan extra capacity needed for regular maintenance

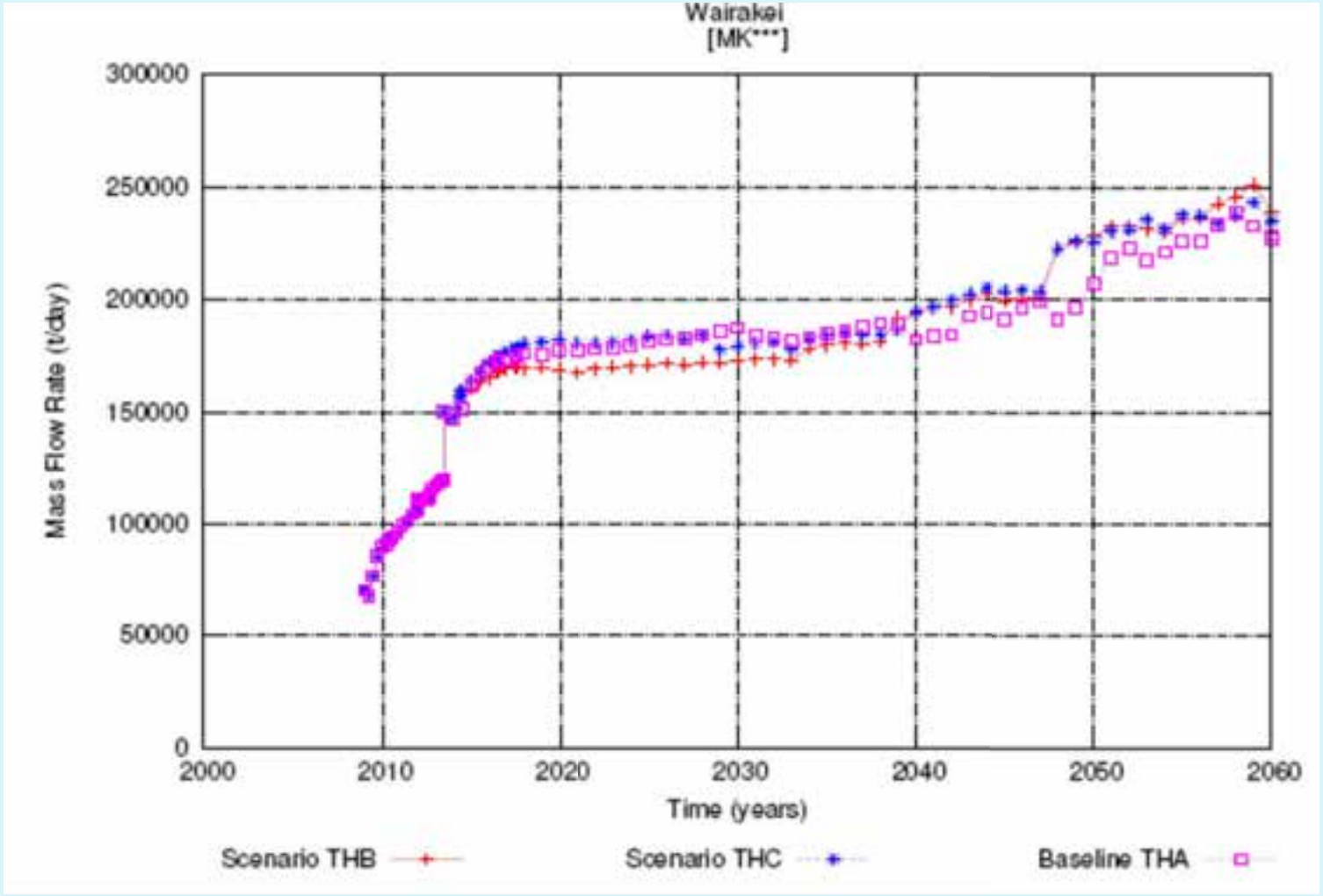
How a system will respond to different rates of production

- Different rates of production affect how quickly pressure in a system declines
- This also affects the schedule of new wells to be drilled
- Different pressure decline rates will affect the environment differently

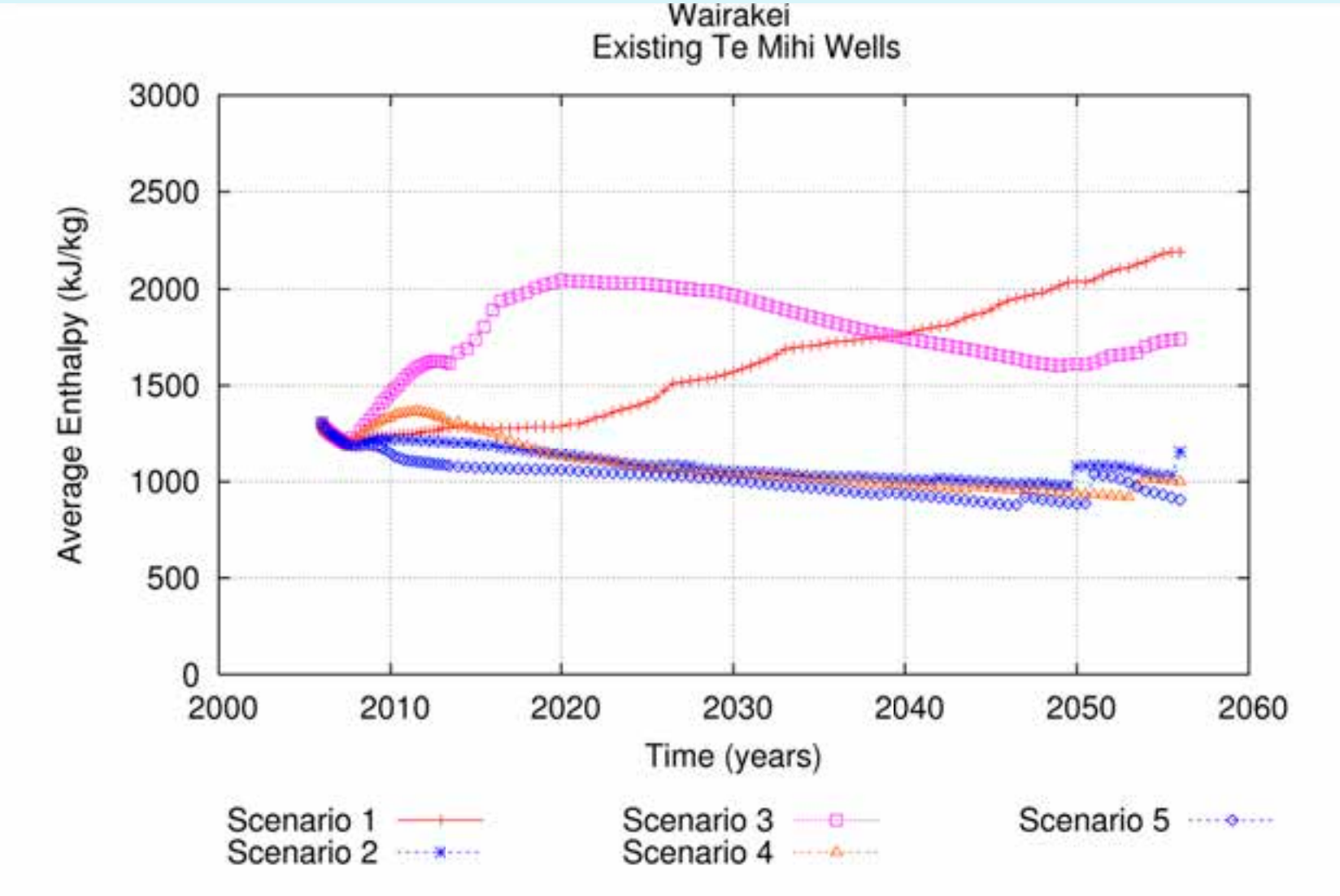


Tauhara expansion (source: Contact)

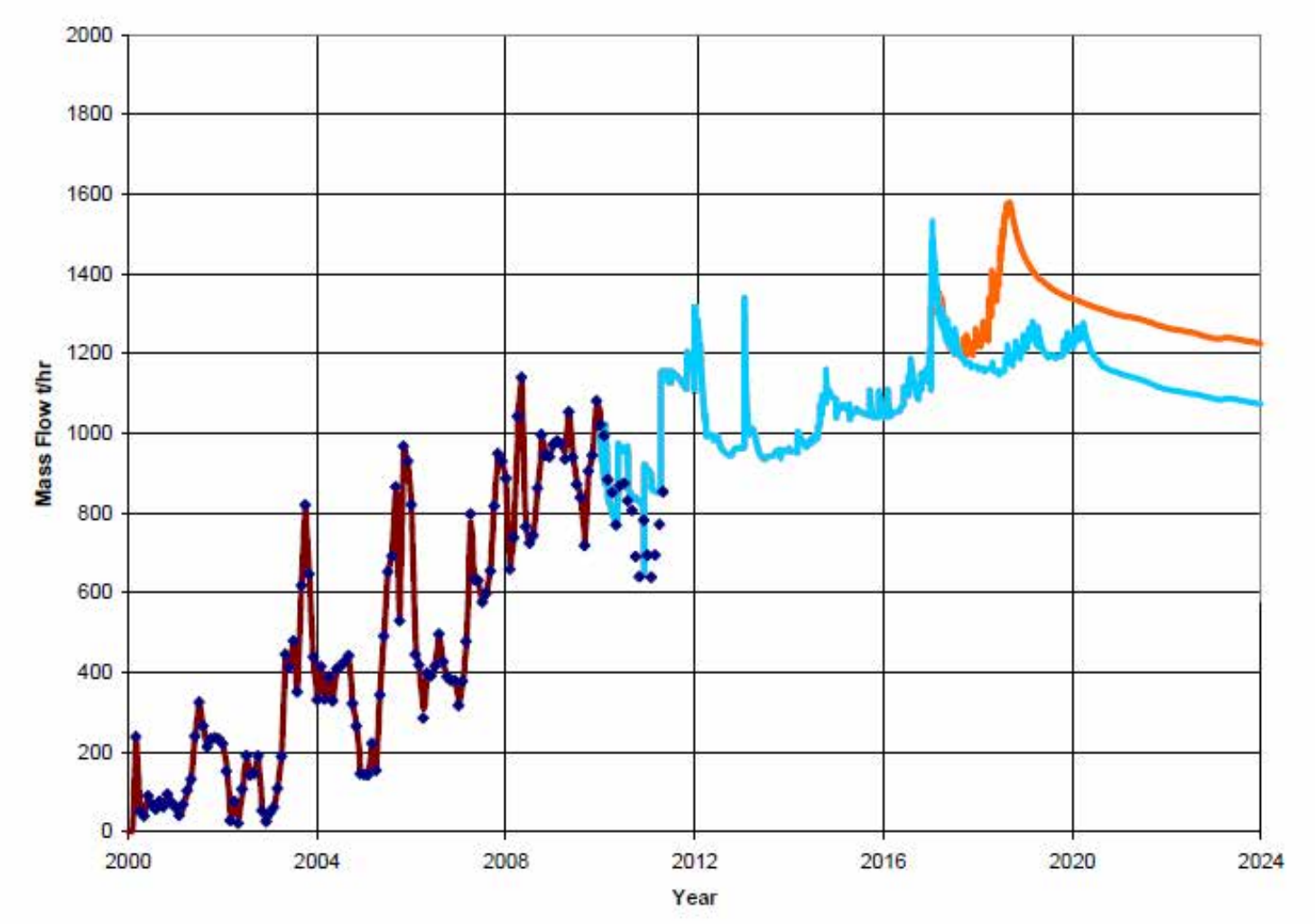
How a system will respond to different rates of production



How a system will respond to different rates of production



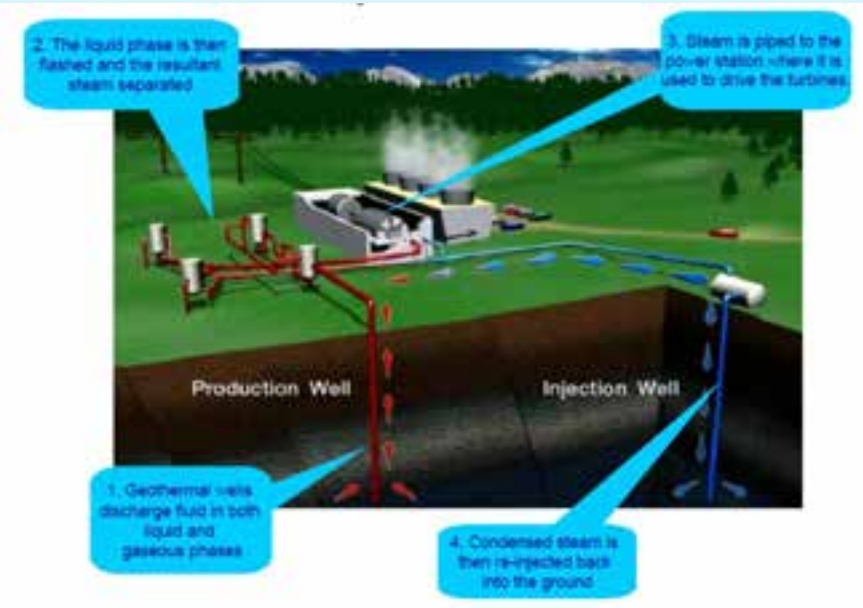
How a system will respond to different rates of production



How to best re-inject fluid into a system

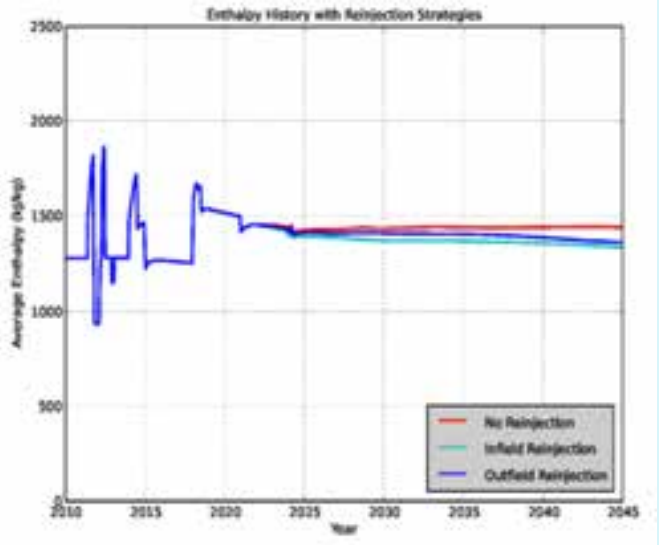
- Re-injection is carried out for two main reasons:

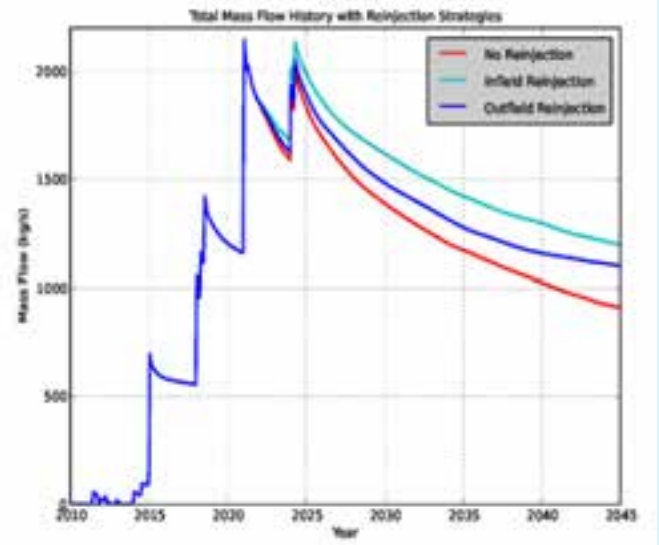
1. To slow down that rate the pressure in the system declines (pressure support)
2. To safely dispose of extracted fluid



How to best re-inject fluid into a system

- For pressure support reservoir models are used for the following:
  - Indicate where best to re-inject
  - How much to re-inject
  - At what temperature
- The objective is to support production while avoiding thermal breakthrough

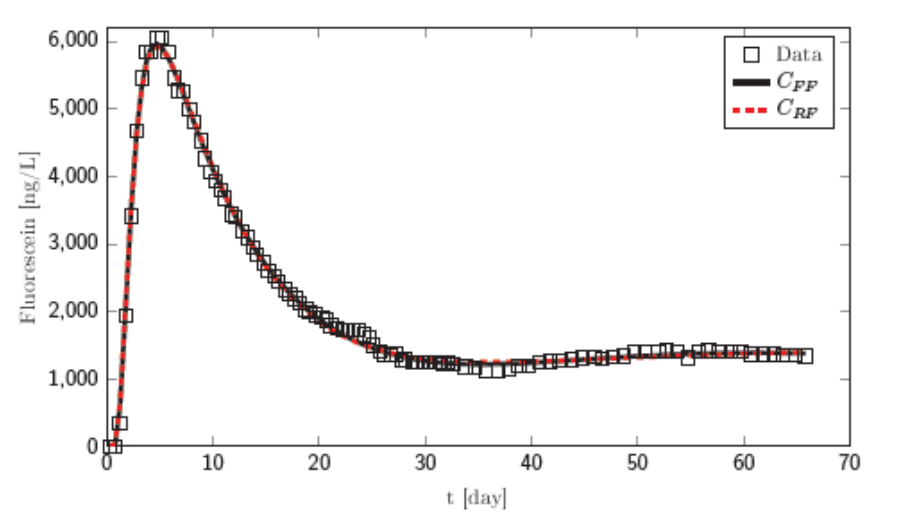


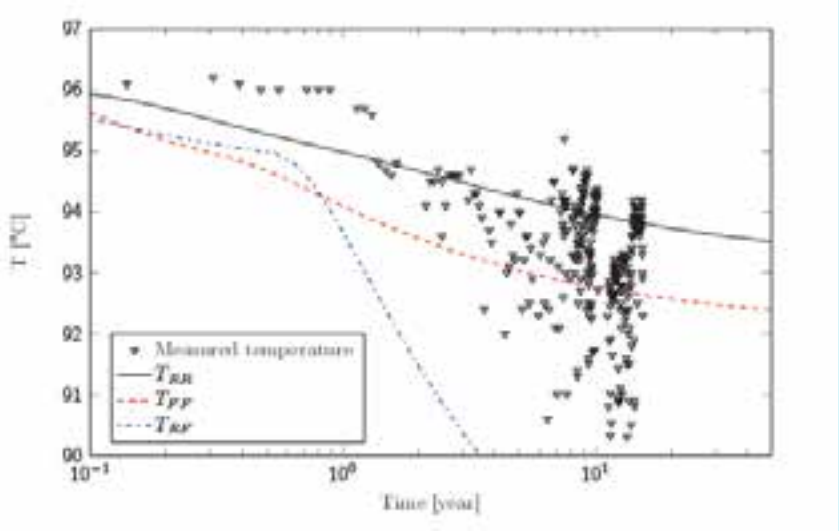


(source: Kipyego 2013)

How to best re-inject fluid into a system

- For fluid disposal the objective is to determine where large quantities of fluid can be injected without affecting production or the environment
- Can simulate tracer tests for calibration



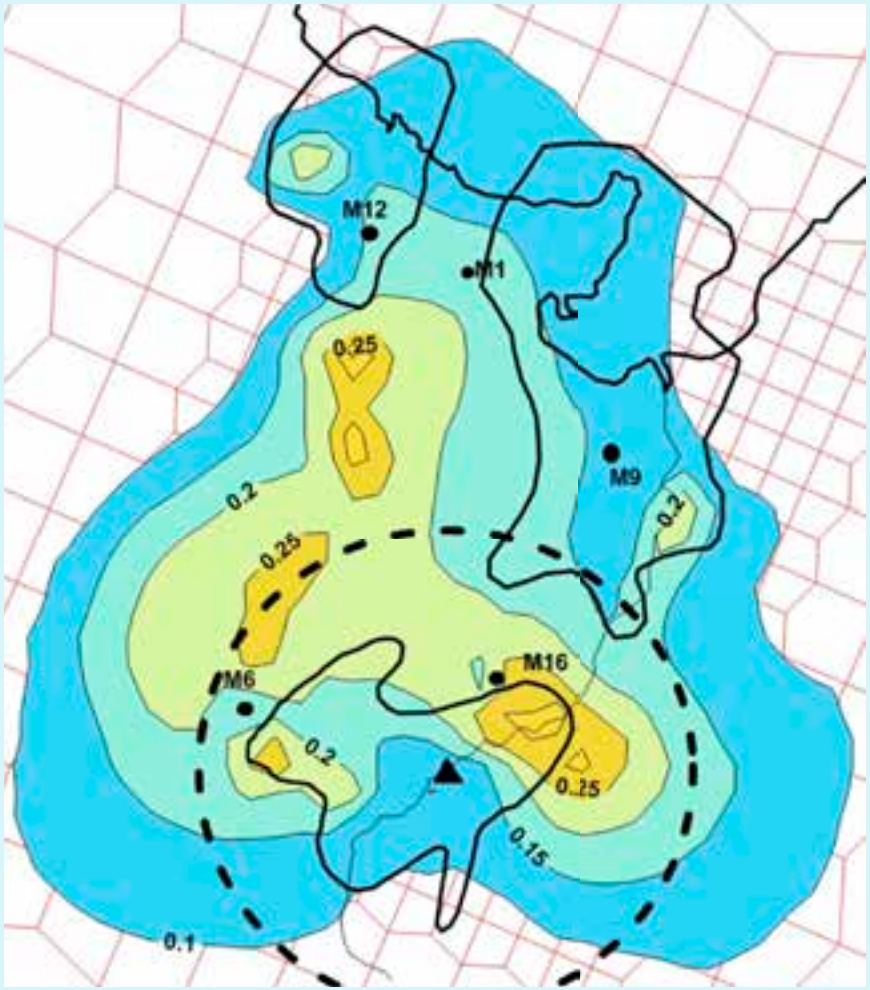


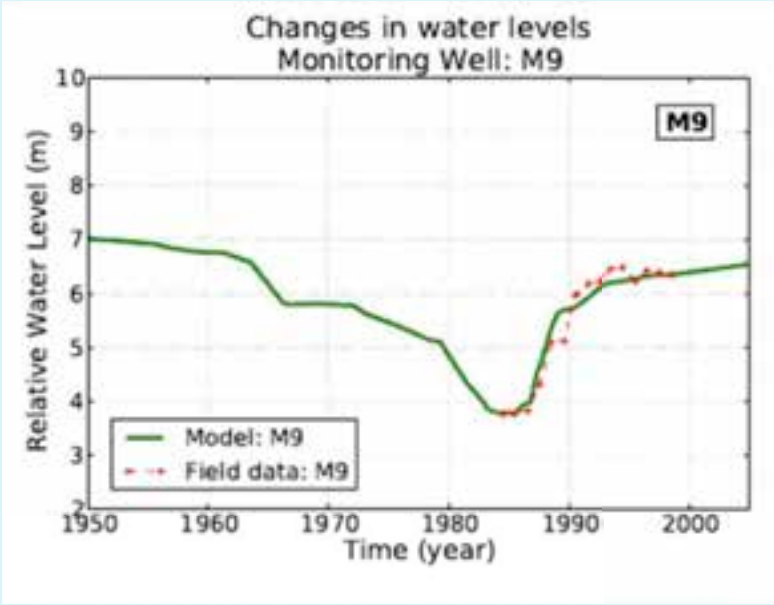
Tracer simulations (source: Bjarkason 2014)

How the natural geothermal features will react to the systems exploitation

- Depending on the connection between them, surface features can be affected by production
- In Rotorua in New Zealand a borehole closure programme was implemented in 1980 to protect important natural features

How the natural geothermal features will react to the systems exploitation



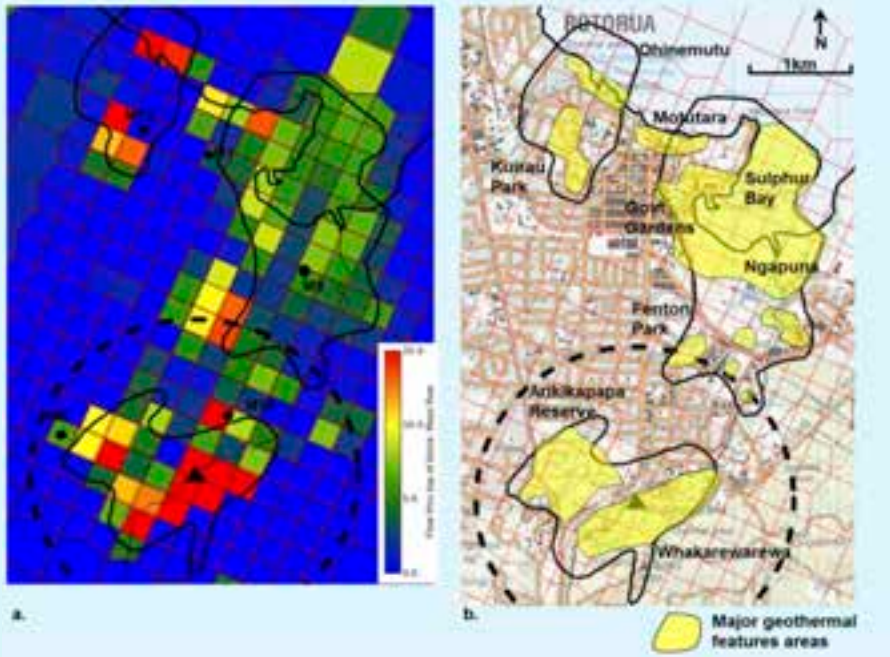


(source: Ratouis 2014)

How the natural geothermal features will react to the systems exploitation

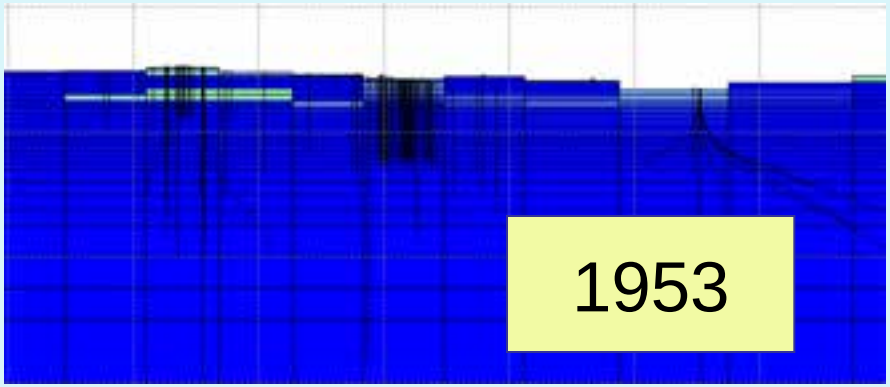
- There is renewed interest in more exploitation of the Rotorua system
- Our reservoir model will be used to assess the likely impact of any future increase on protected surface features

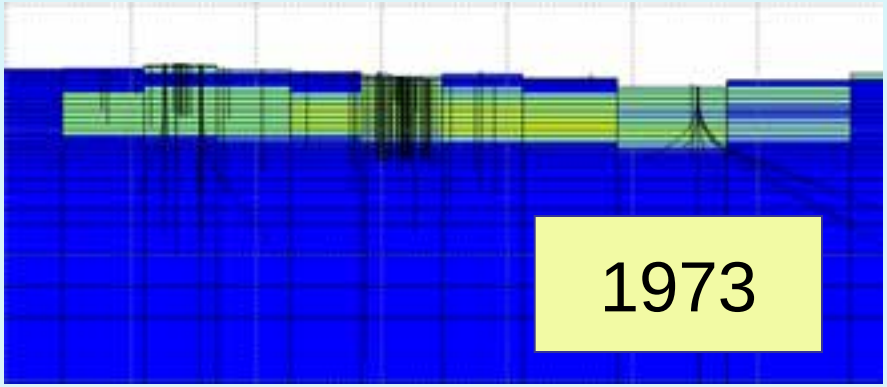
(source: Ratouis 2014)

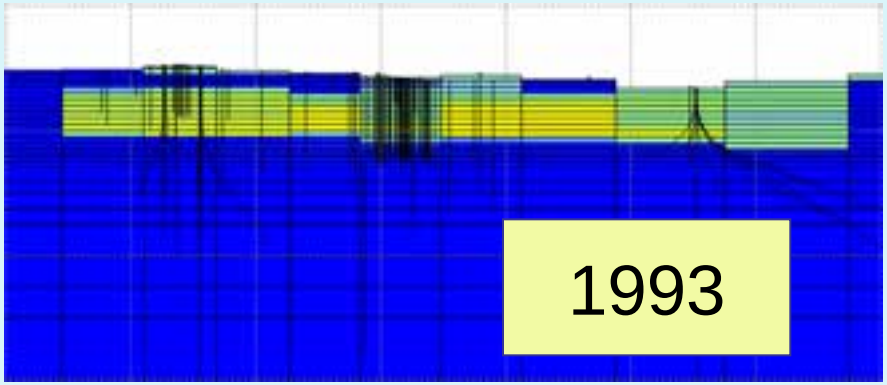


How the natural geothermal features will react to the systems exploitation

- In some cases production creates new surface features!
- Models can help predict this







What other environmental effects may occur

- Many environmental effects are controlled by the pressure and temperature in the geothermal system
- Reservoir models predict these and so can be used to predict environmental effects
- A common environmental effect is **subsidence**

Ohaaki Marae

What other environmental effects may occur

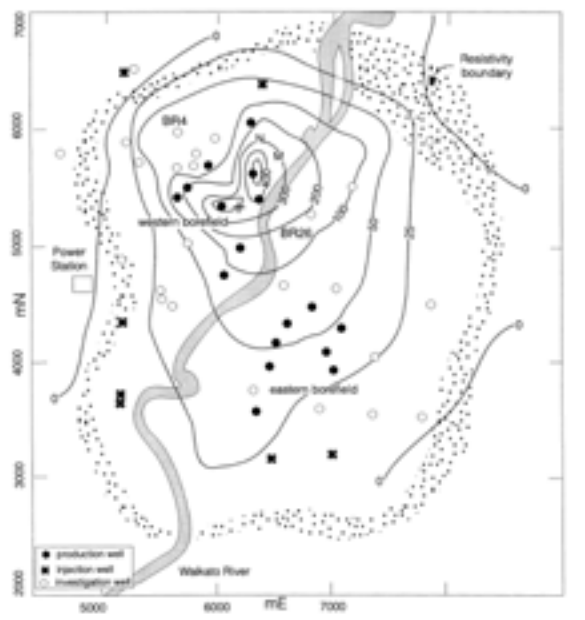
- Subsidence of nearly 10m affecting cultural meeting house

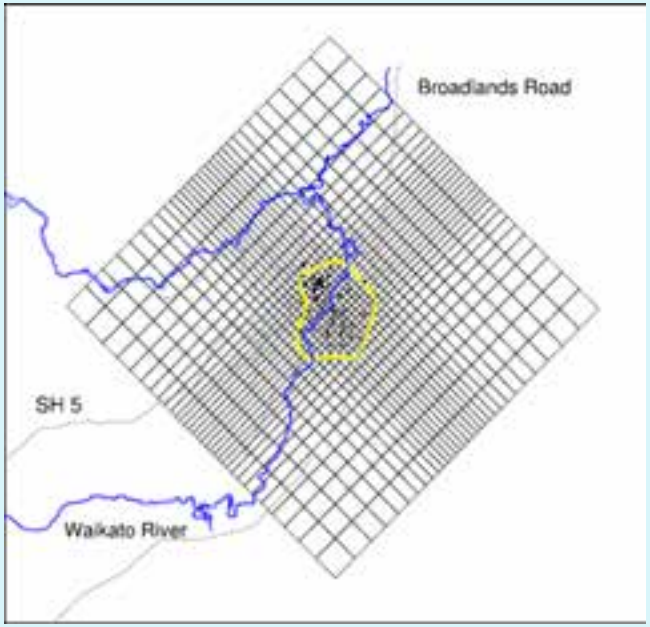
1978

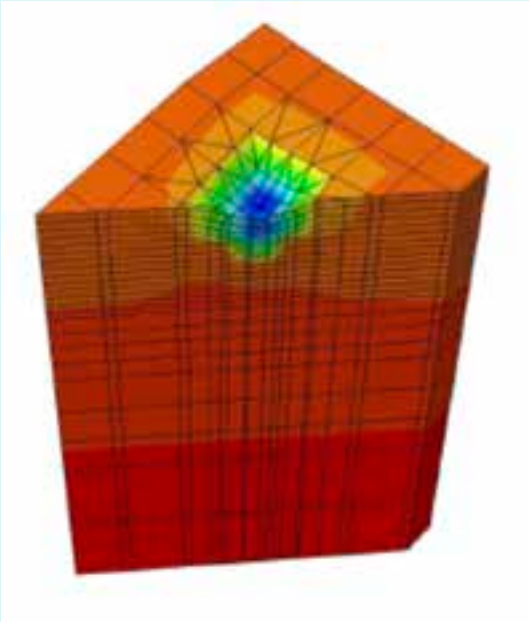
Today

What other environmental effects may occur

- Ohaaki reservoir model







Subsidence rate per year (source: Allis)

What other environmental effects may occur

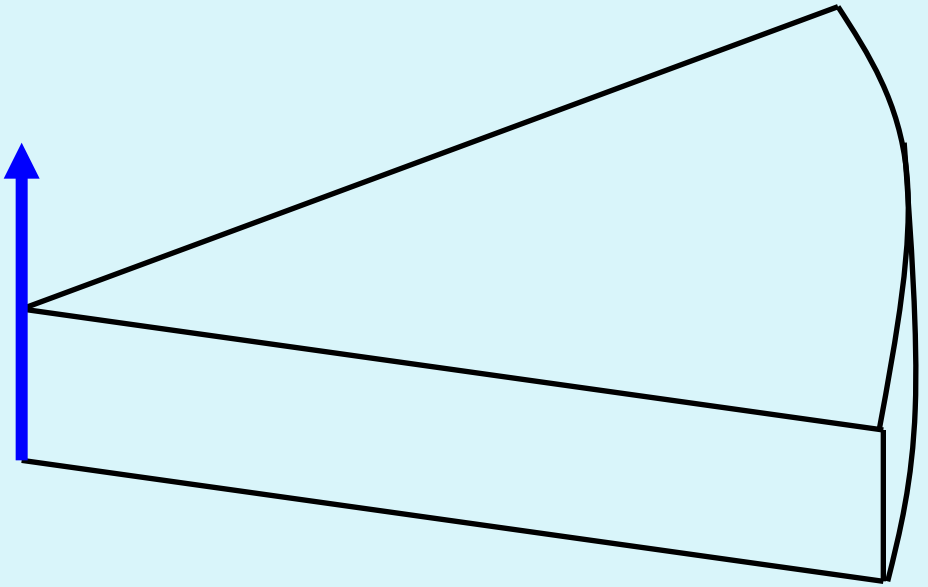
- Subsidence can also have an impact on the power plant

Expanding gap filled twice already

Modelling uses

- Small models of individual wells

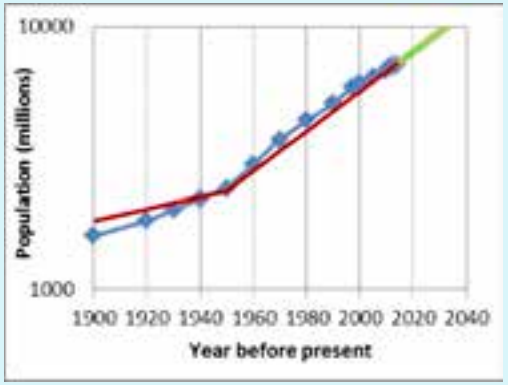
Production or injection



- Analyse well performance
- Estimate well properties

Limitations of Modelling

- Do you think our estimate of global population will be correct?



- **No!**
- **"All models are <u>wrong</u>…"**
- **"… but good models are <u>useful</u>"**
- Every model has assumptions that limit what it should be used for and what it can tell us.
- It is important to understand what reservoir models can **<u>not</u>** tell us

Drilling Success

- Reservoir models can **not**:
  - Predict probability of drilling success
  - Tell you exactly where to drill a well
  - Predict exactly where good permeability exist
  - Predict problems with casing, cementing etc
  - Predict well performance before drilling

- Reservoir models calibrated with good data **can**:
  - Tell you where hot, high enthalpy fluid is most likely to be
  - Predict where good **average** permeability exist
  - Predict future well performance following initial testing

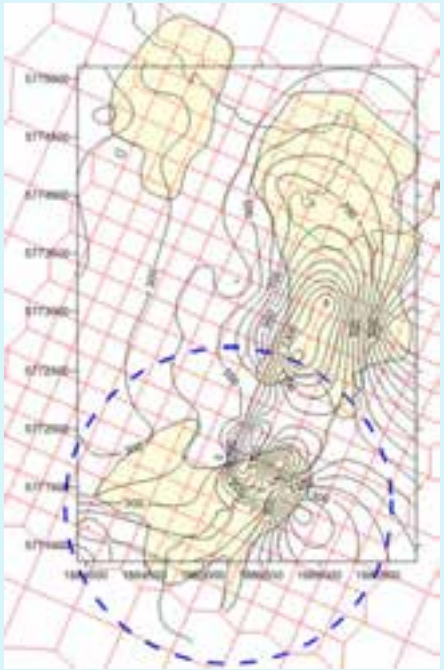
Operations

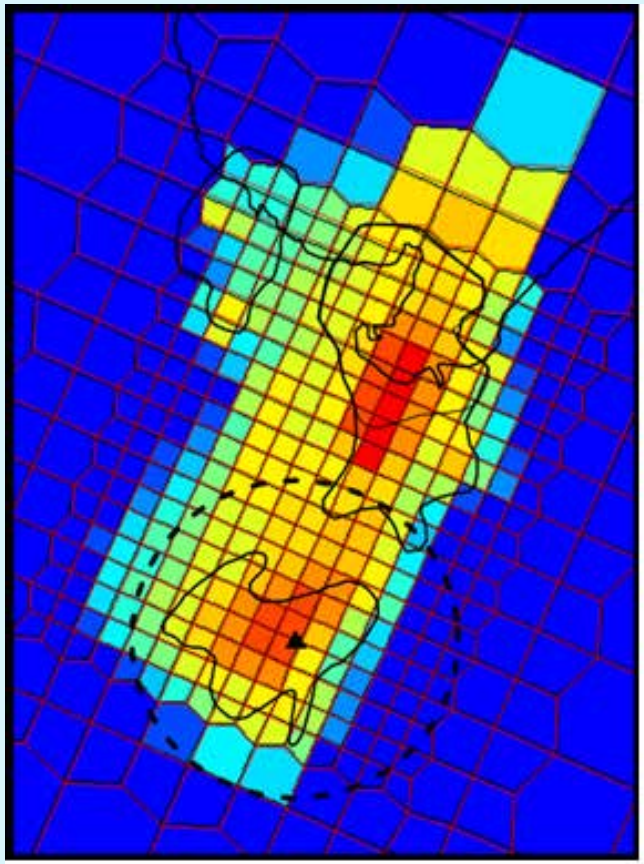
- Reservoir models can **not**:
  - Predict operational problems
  - Predict mechanical failures
  - Predict human error
  - Predict economic decisions
- Reservoir models can help:
  - Plan contingency in resource availability
  - Predict the effects of unexpected, long-term changes in production

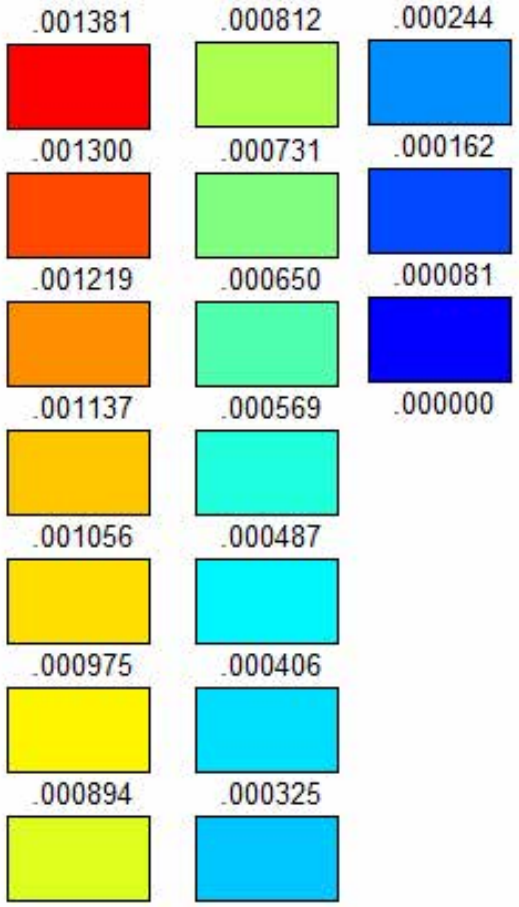
Chemistry

- Standard reservoir models can **not**:
  - Predict where scaling will occur and how quickly
  - Predict which wells will be affected by high NCG content
- If you want predictions like these you must:
  - Gather accurate data about chemistry in the system
  - Include chemistry in the reservoir model – this can make models much more complicated
  - Calibrate the model using the chemistry data
  - For scaling the results from the reservoir model must often be used in another smaller model of the components in question

Chemistry







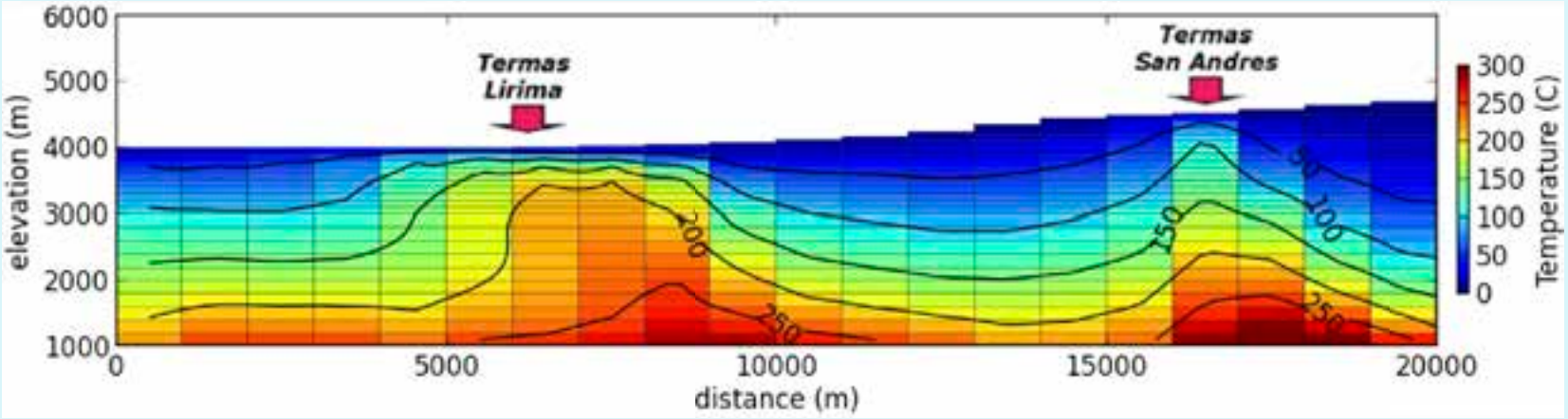
Measured and modelled chloride concentrations (sources: Stewart, Setiadi)

Calibration Data

- **It is very important for all aspects of a geothermal development that you gather <u>good data regularly</u> (or require good data to be gathered)**
- Models without much data for calibration or poor quality data are of limited use
- Natural state data is important – if you don't know where you started its hard to know where you will arrive!

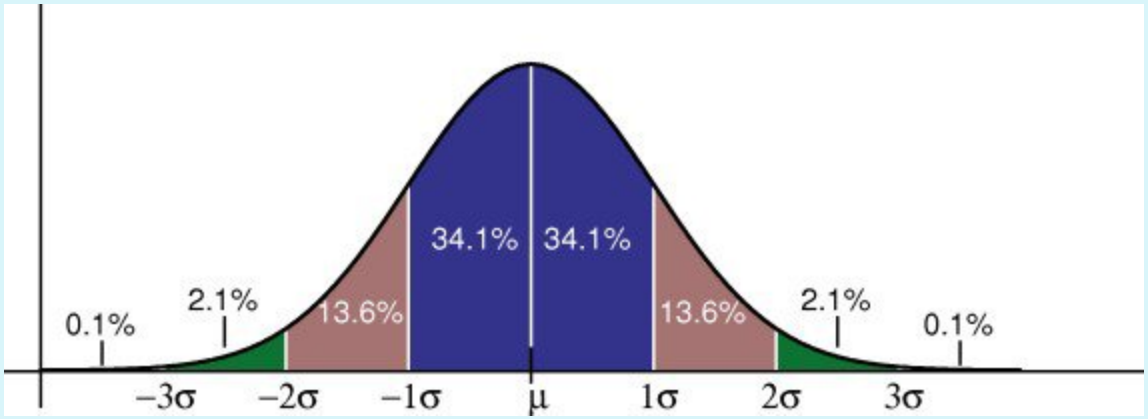
Preliminary models

- Preliminary models can be made early in the process with a small amount of data
- They are more accurate than stored heat calculations but are still only indicative
- Can be used as a basis for more advanced models



Statistics

- Standard reservoir models are not statistical models
- They can be used as part of Monte Carlo simulations but this is computationally expensive
- Including uncertainty quantification in reservoir models is one of our important areas of current research



Thank you

- Thank you to IRENA
- Questions?