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3D Geological modelling in Victoria: from the moho the aquifer

State Government
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AUSTRALIA

MELBOURNE
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3D Modelling in Victoria

- The program
  - Rediscover Victoria 3D
- The models
  - New outputs
- Adding value
  - Basin management
  - Data delivery

Rediscover Victoria 3D

- Accelerated development of a 3D geological map of Victoria
  - The project will develop a sophisticated, fully attributed 1:250000 scale three-dimensional model **linking** the onshore and offshore geology of the state.
- Regional 3D geological models
  - 1:1M and 1:250K scale models
  - Full crust – Moho to the sky
- Define large scale geometry
  - Architecture
  - Plumbing
- Fluid pathways
  - Most stakeholders
    - Gold, base metals, oil and gas, groundwater, geothermal, carbon sequestration

New Outputs

- Complete and available
  - Bendigo Zone 1:250000
  - Otway Basin framework study
  - Isostatic gravity and gravity worm datasets

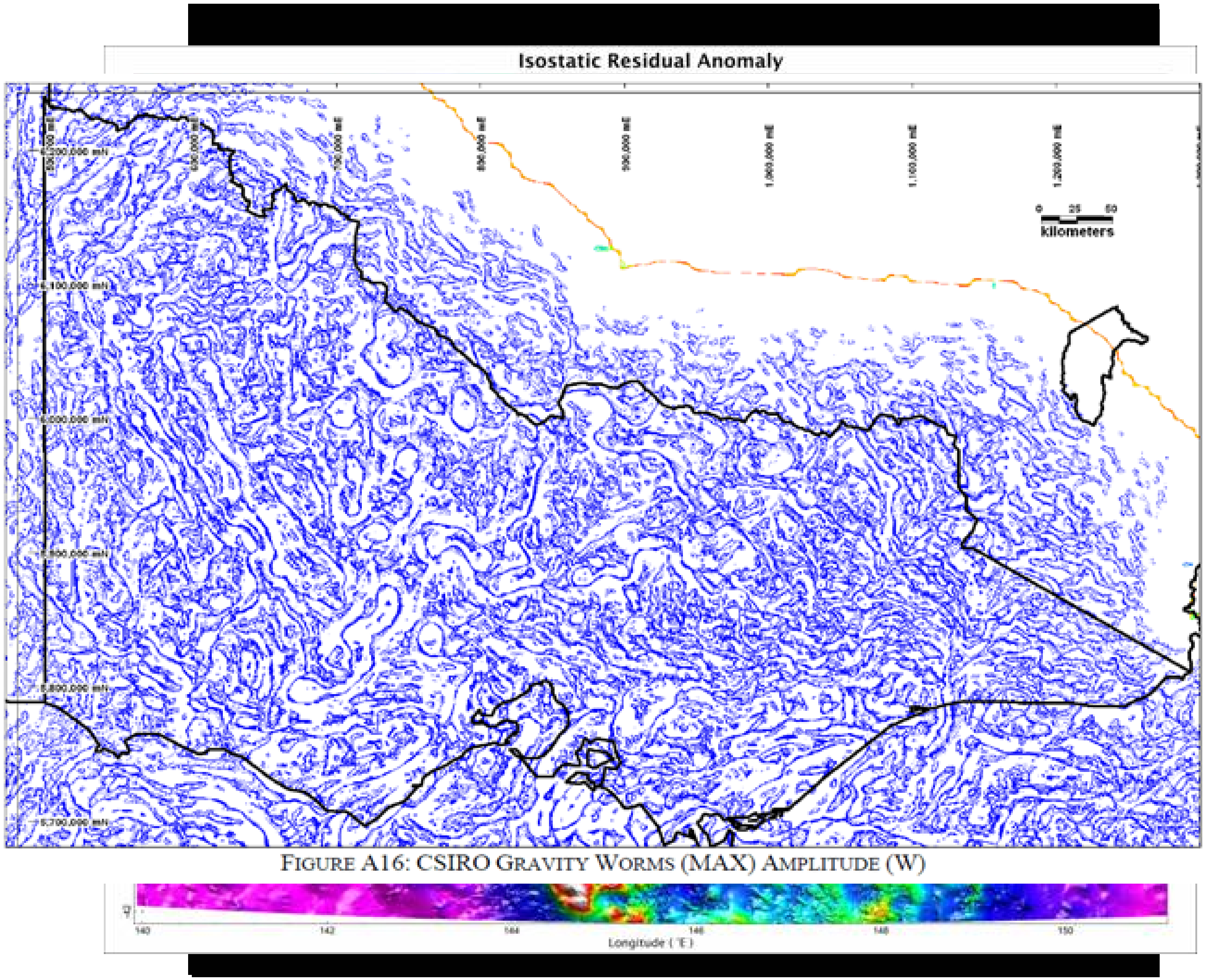
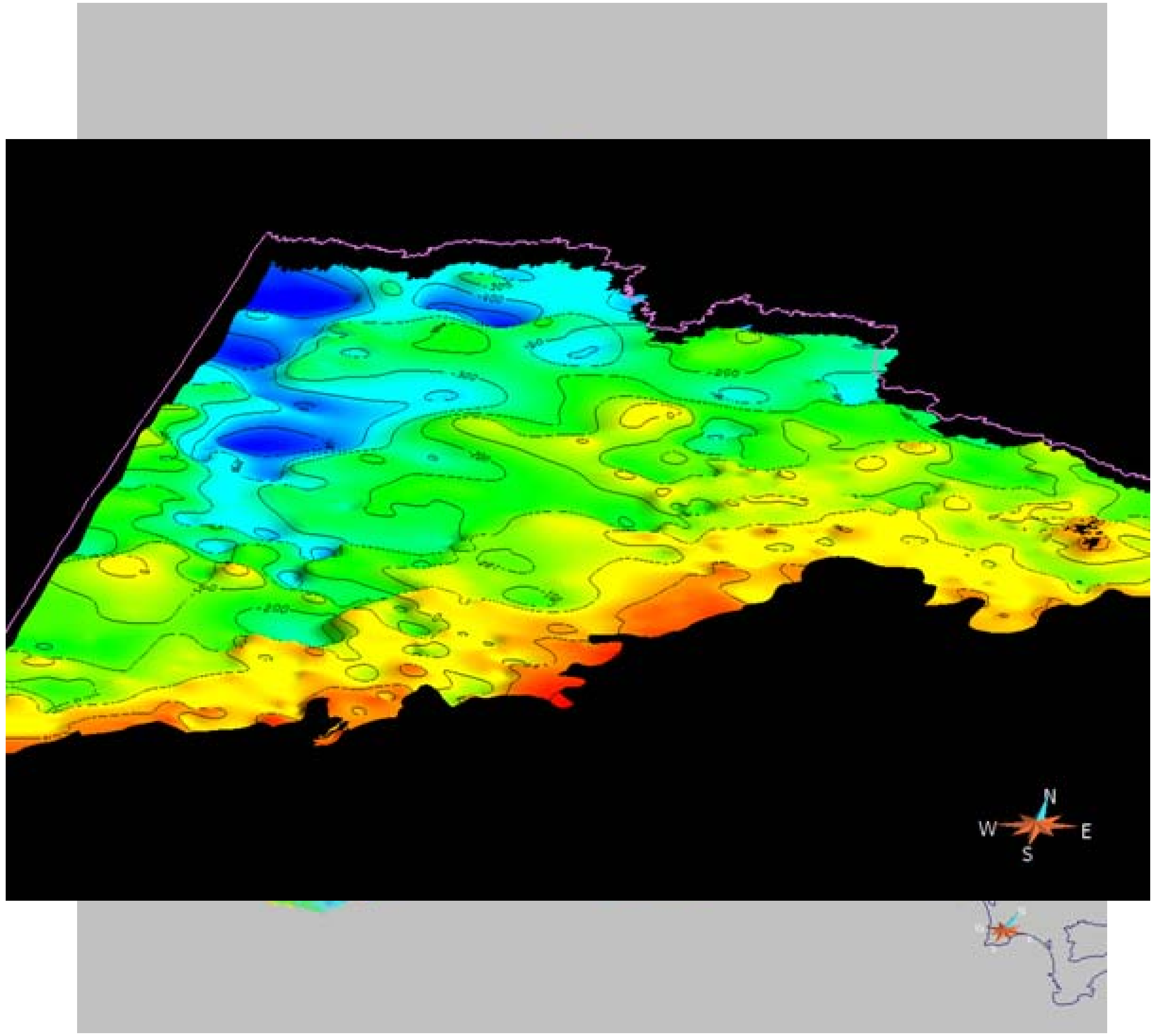


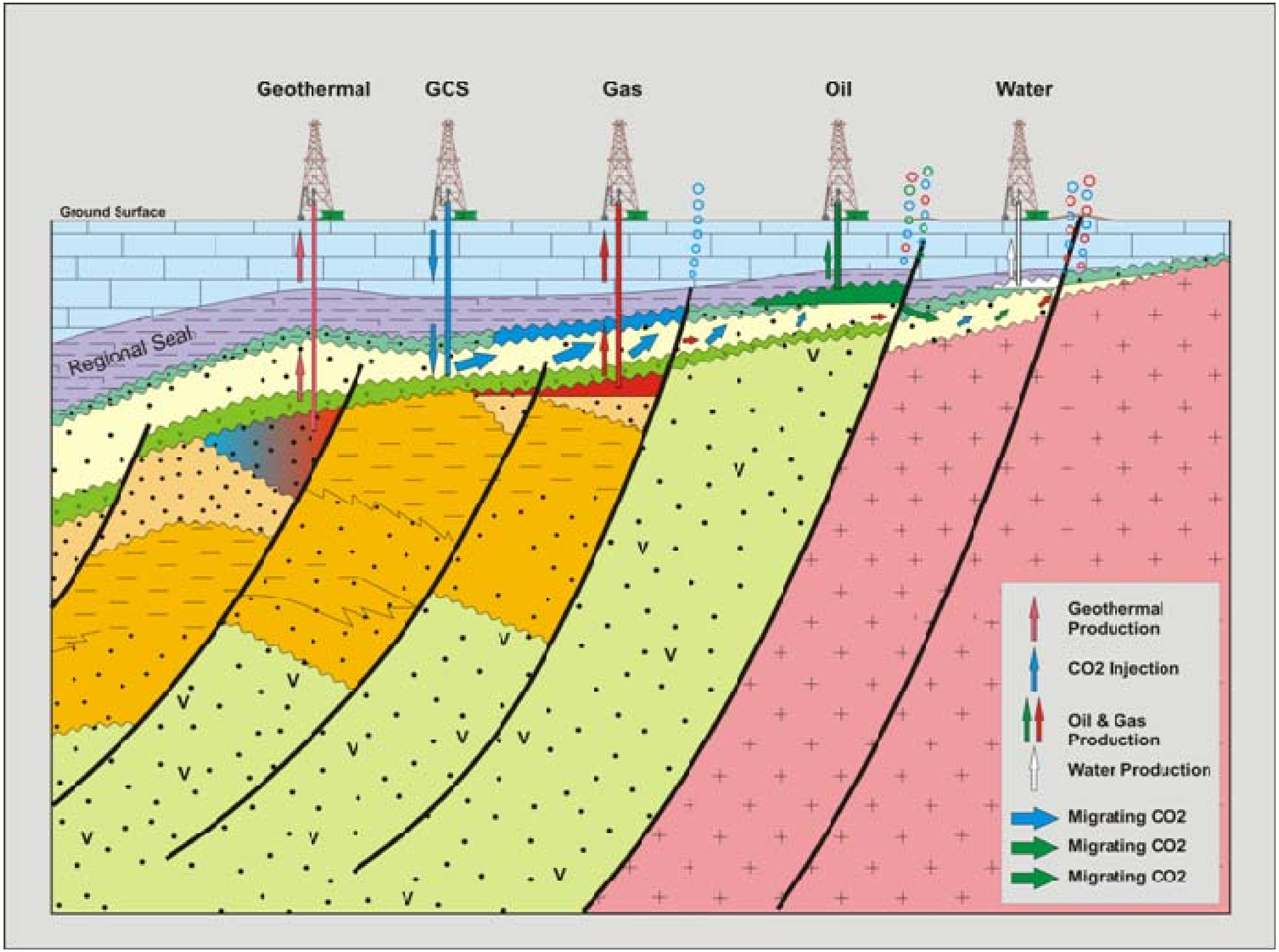
FIGURE A16: CSIRO GRAVITY WORMS (MAX) AMPLITUDE (W)

Outputs

- Western Victoria basement / basin integration
- Murray Basin depth to basement surface
- Gippsland basin potential field study



The pore-space as a resource

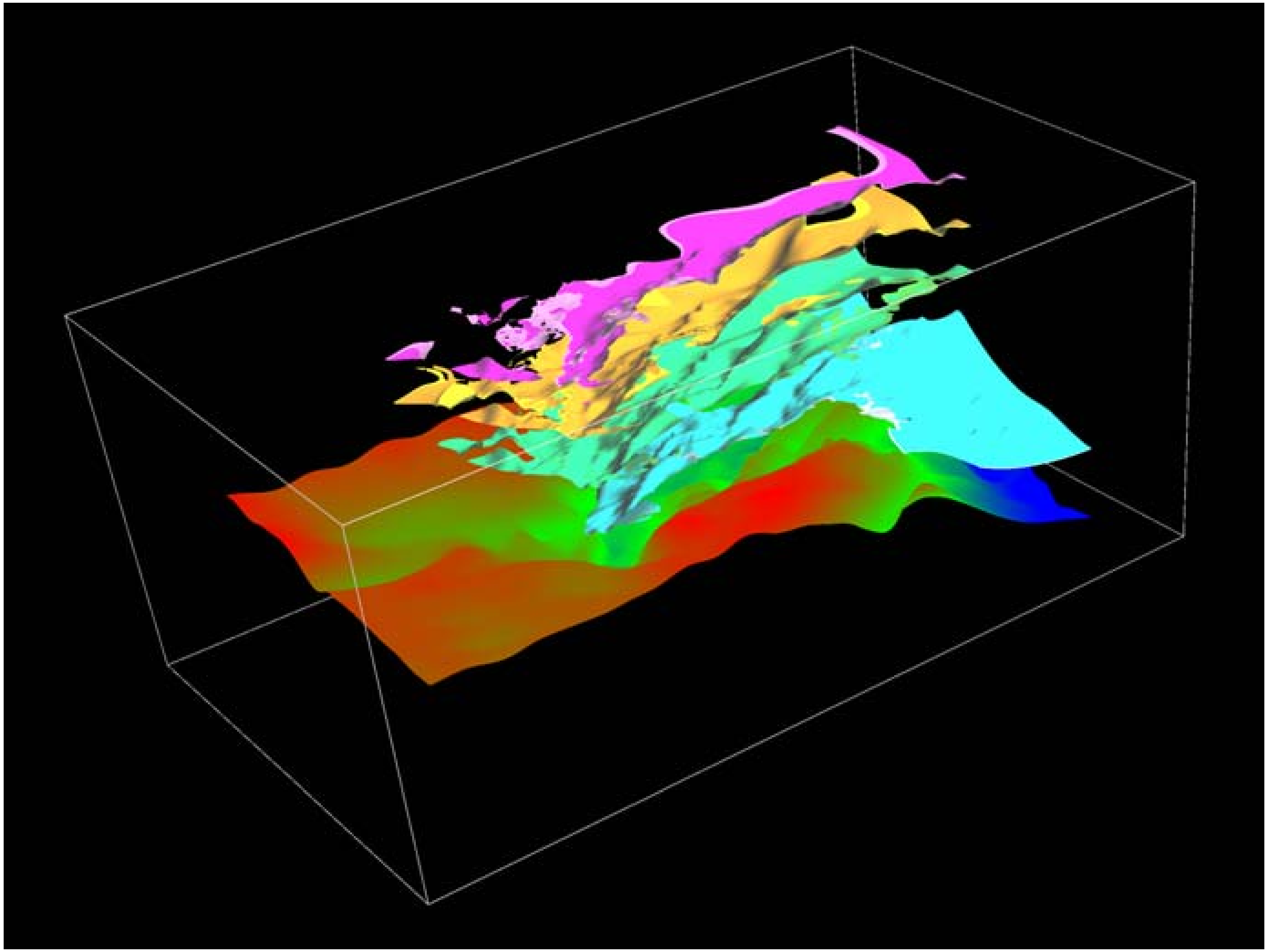


Applications for geothermal exploration

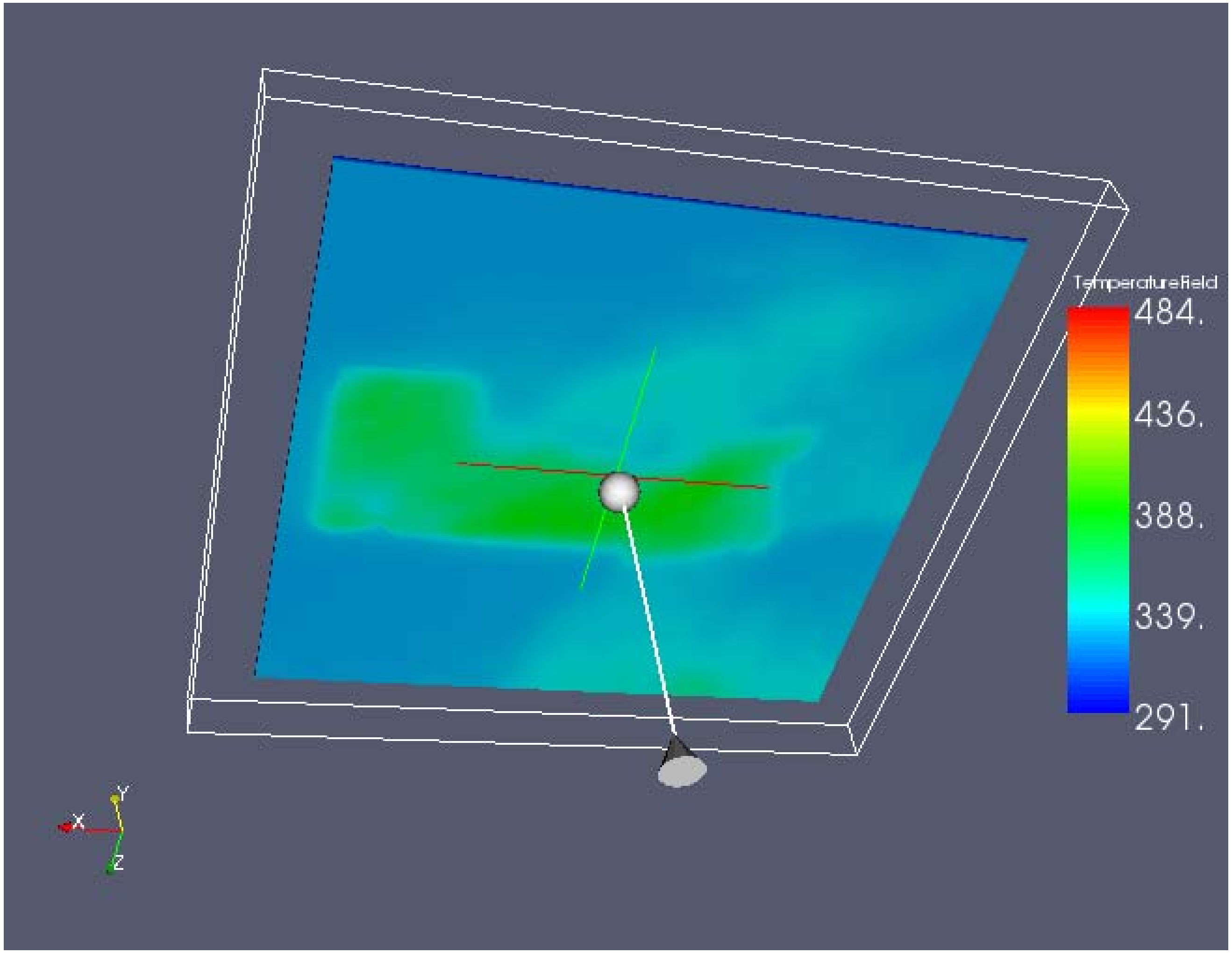
Exploded view of the Latrobe Valley coal seams

Modelling done by Chris Osborne, CCV

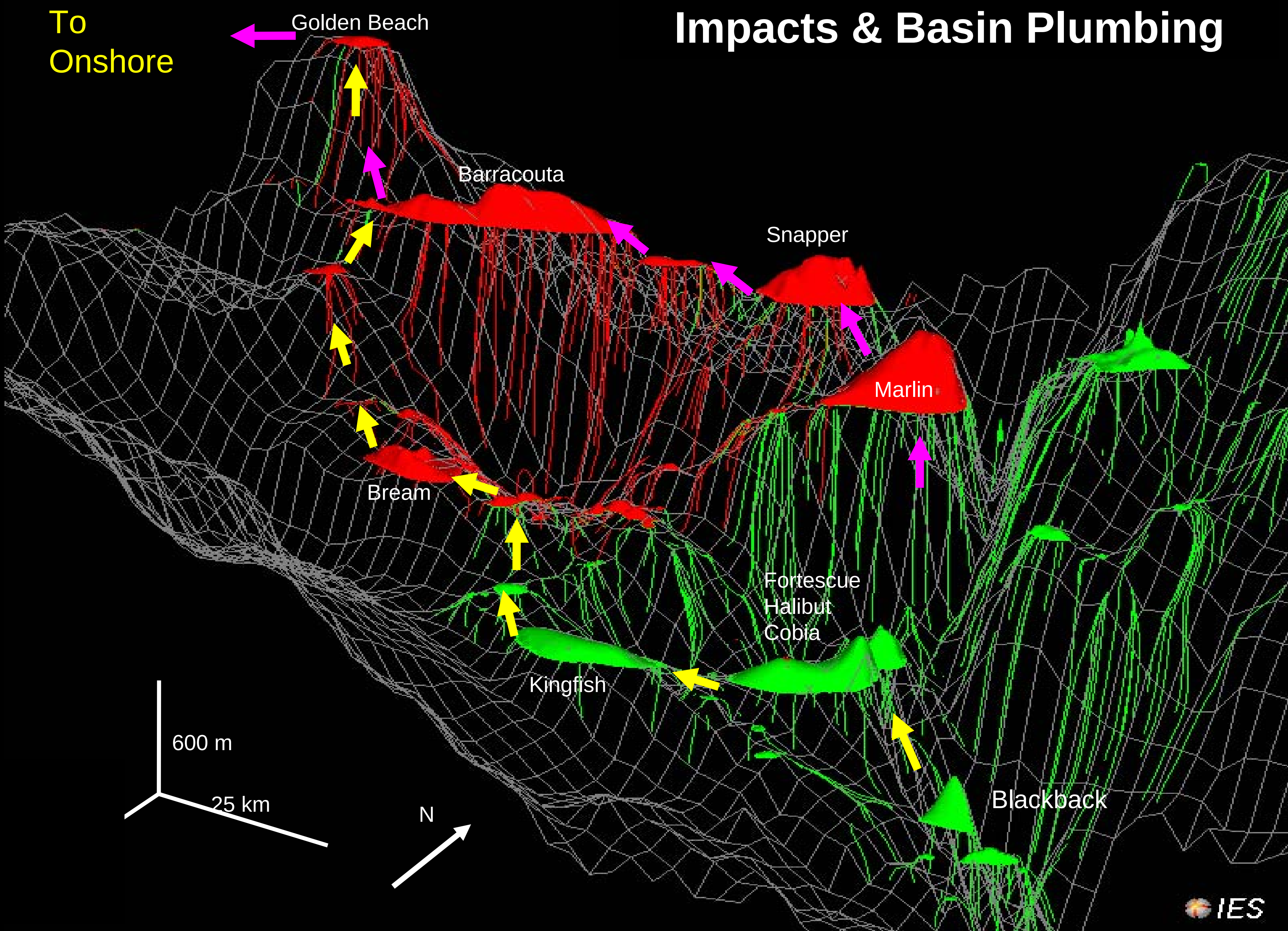
Value-add to this dataset by using it to model heatflow



Applications for geothermal exploration

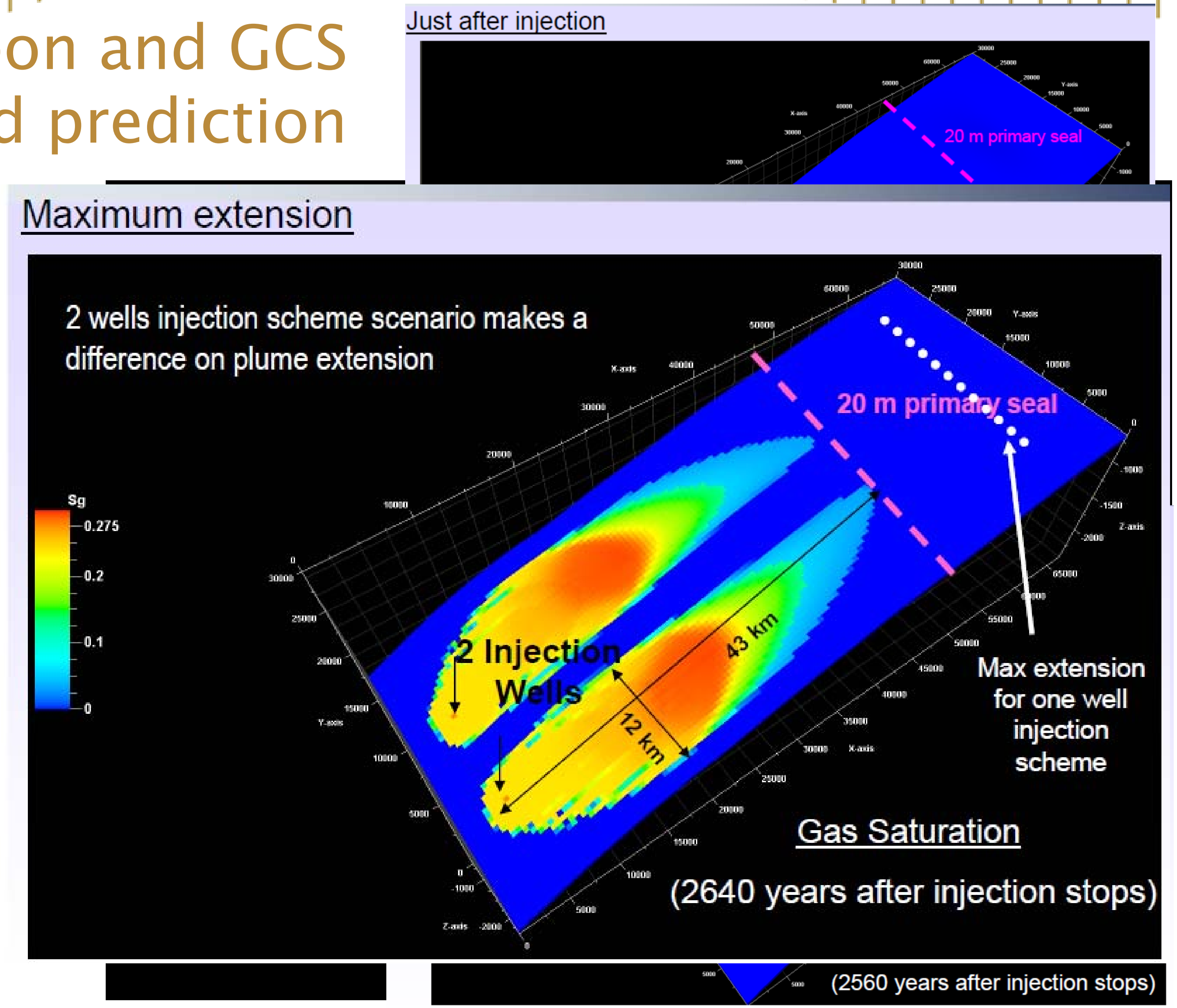


Impacts & Basin Plumbing



Hydrocarbon and GCS targeting and prediction

So where and how can we inject 200MT of CO2 into a basin?



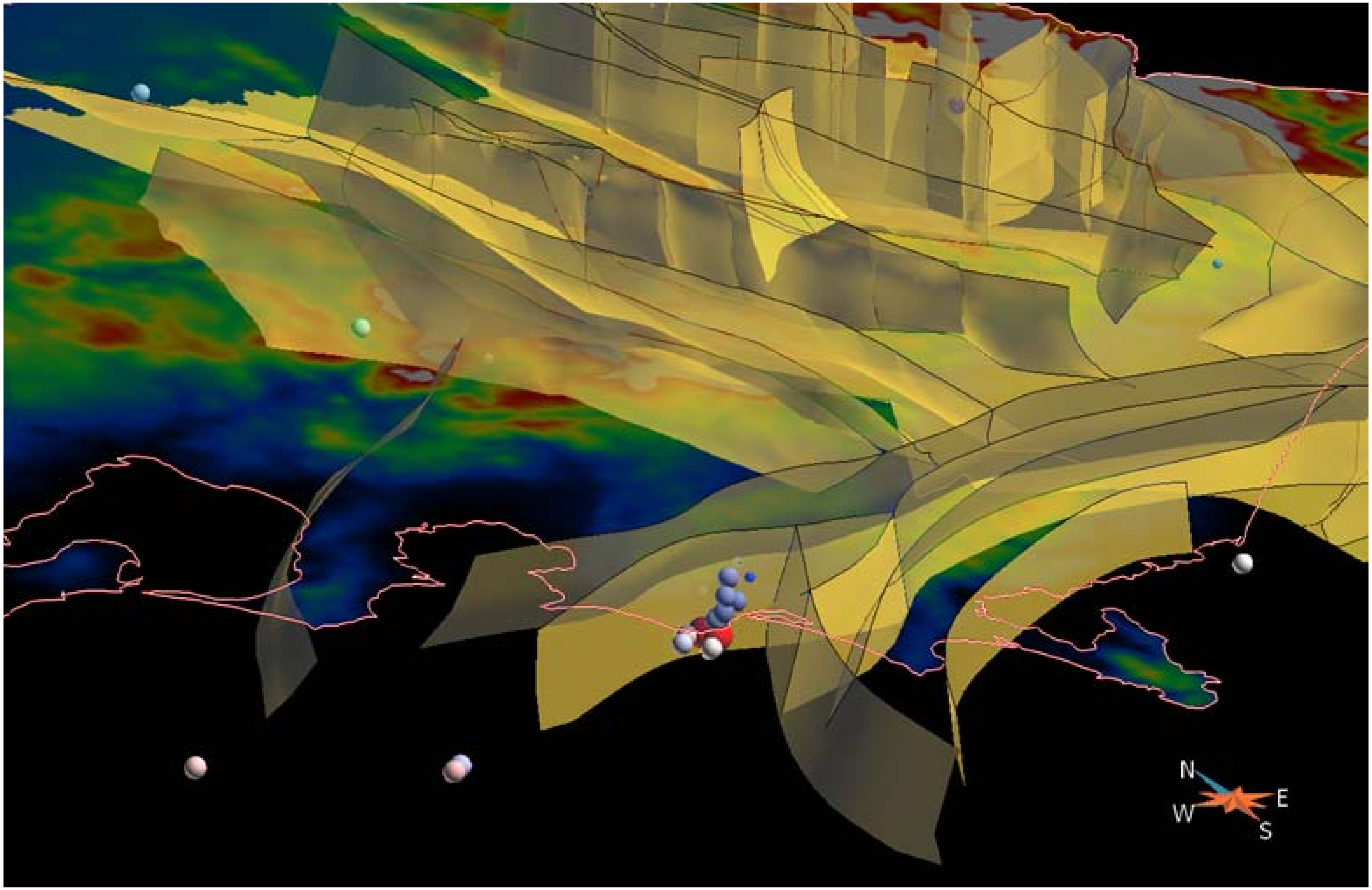
General research applications

Recent earthquake mapping

Stress field analysis

Model calibration

Earth system monitoring

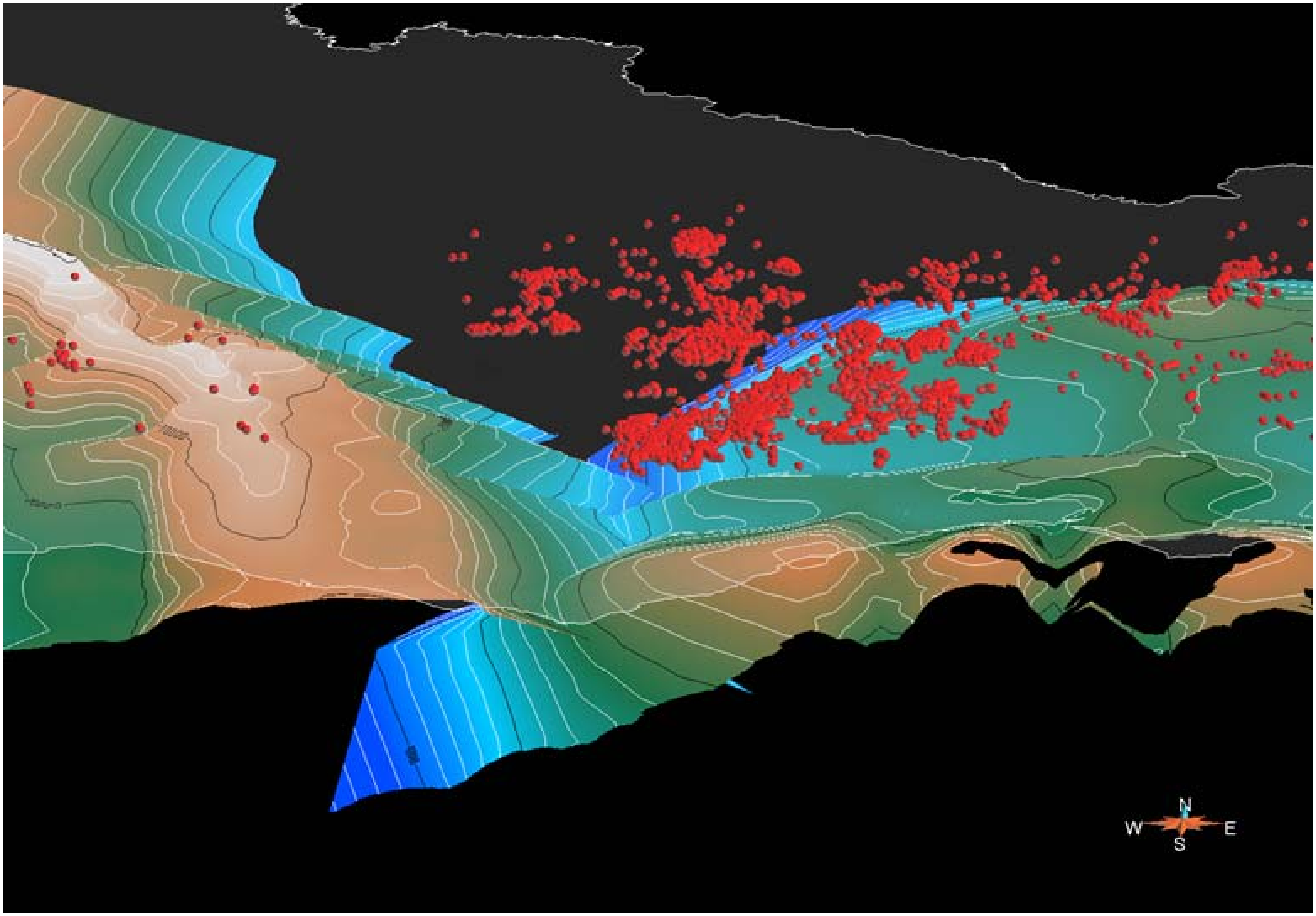


3D modelling and the mineral system

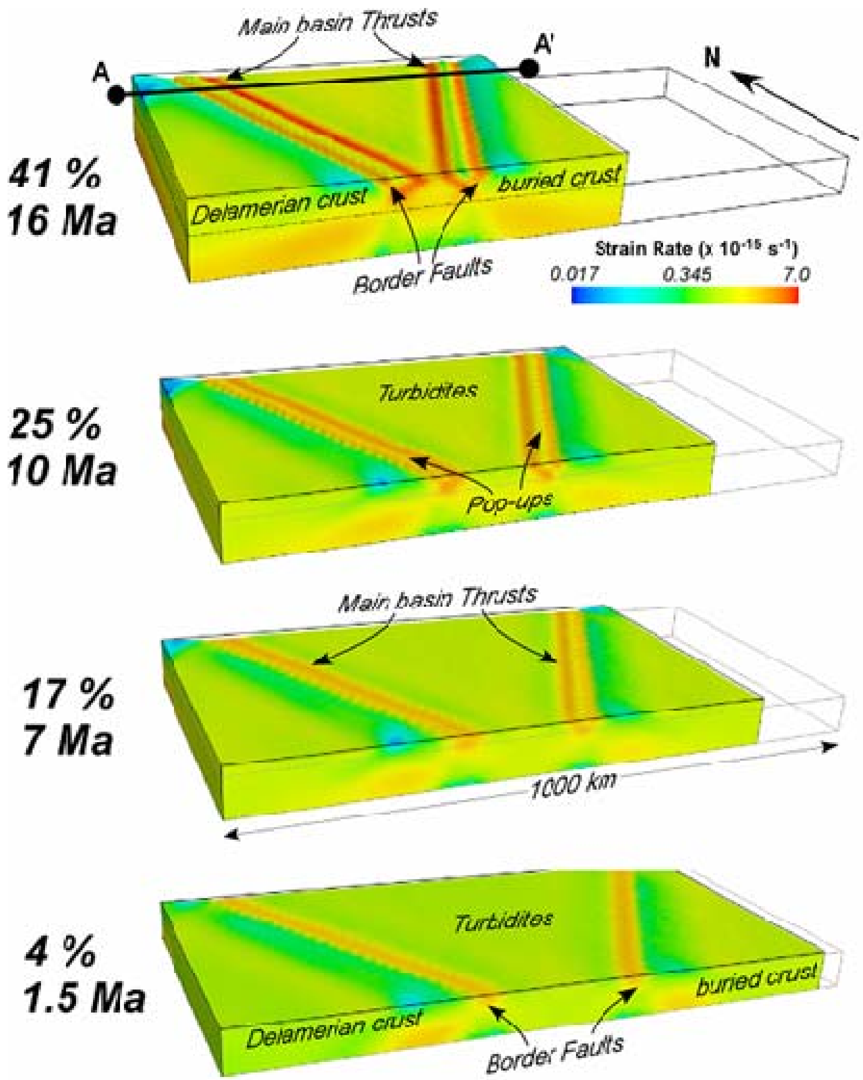
- Basement controls on mineralisation

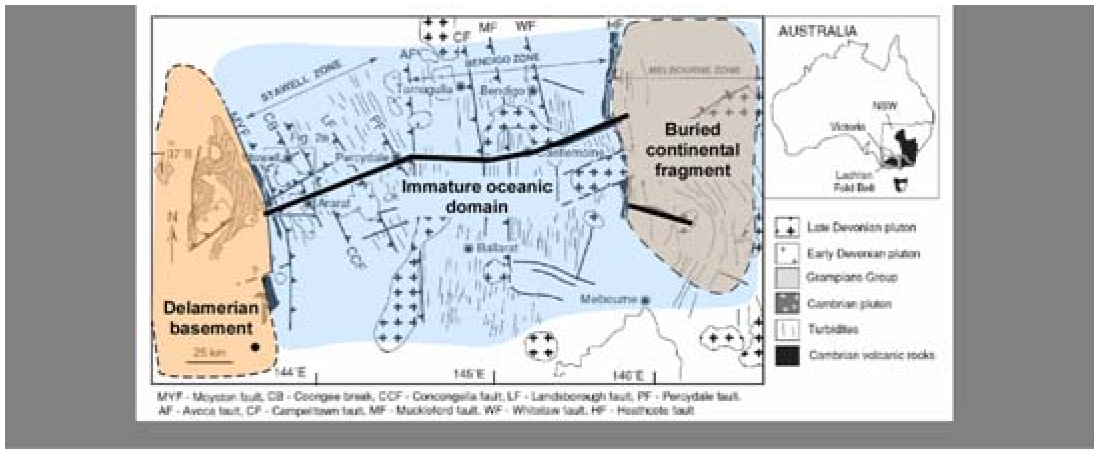
- We need to understand the *whole* mineral system

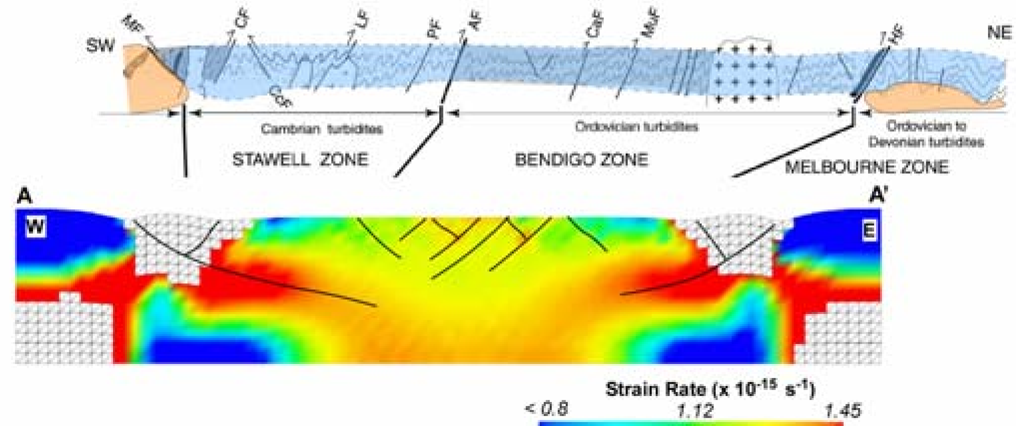
- including its tectonic evolution



3D modelling and the mineral system

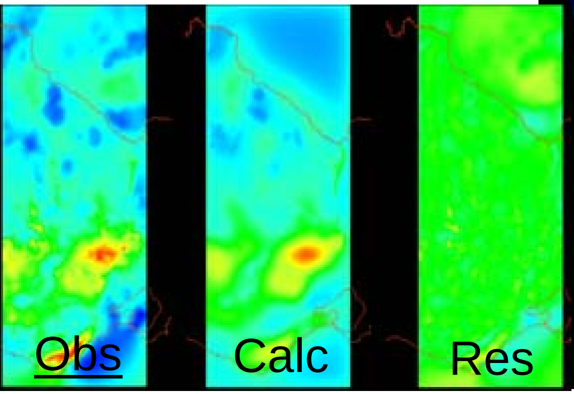


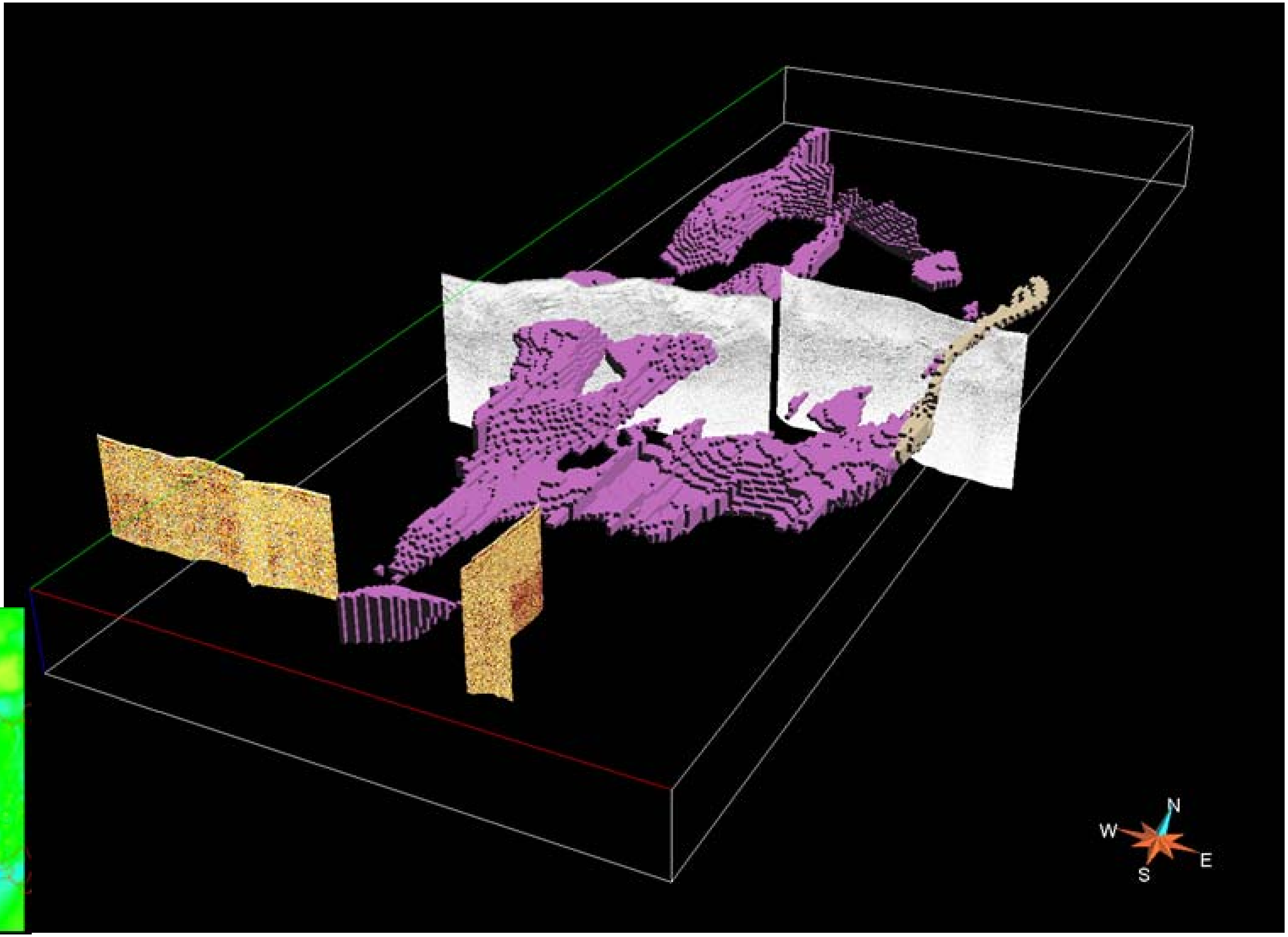




Source rock distribution analysis

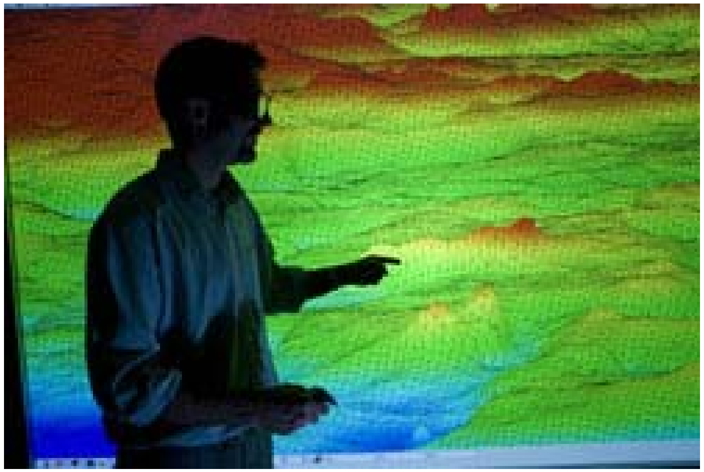
Allows explorers to refine their search area based on distribution of potential source rocks and fluid pathways





3D Data delivery

- 3D Model Manager System
  - Storage
  - Data management
  - Data delivery
    - Coordinate, datum and format conversion
  - Visualisation capability

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F4 Street Furniture
F3 Manipulate
F2 Perimeters
F1 Solid Revolve
(4) Camera is now immersive
(3) Camera is now eyeball
(2) Display captured
(1) Camera is now immersive
Cu1
Hd2
G3
Controls
F5 Create Building
F6 Texture Paint
F7 Carving
F8 -

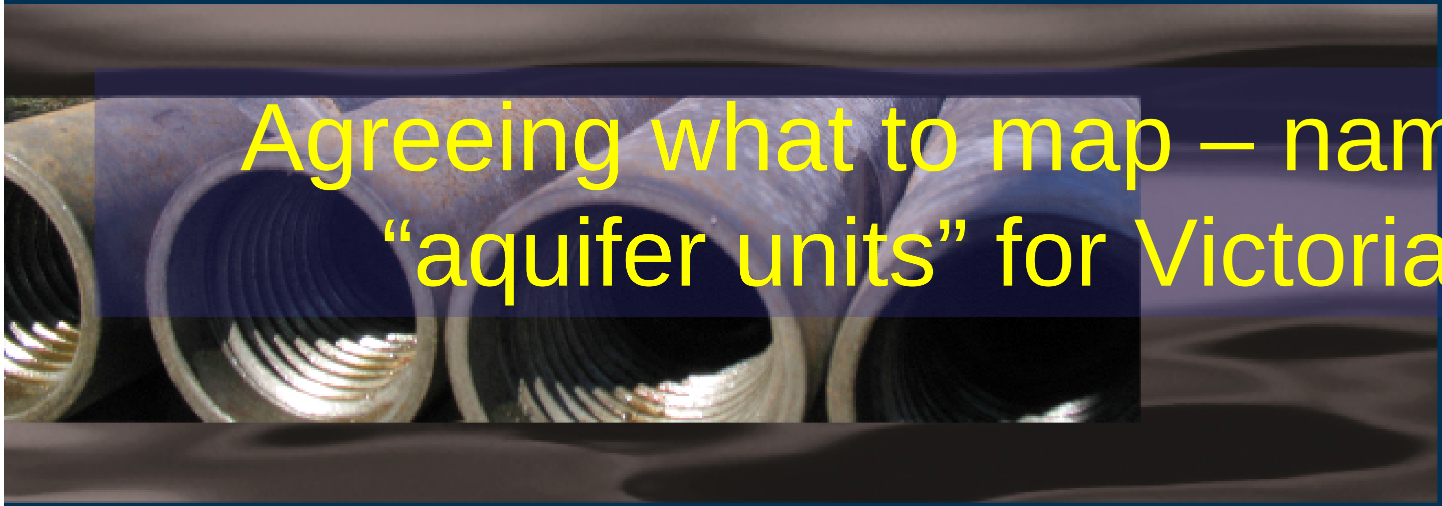
Conclusions

- We are providing next-generation fully attributed, high resolution 3D geological models
  - of the whole state
  - of the whole crust
  - for all commodities
  - to which Government, industry and research groups can add-value
- And its FREE!

www.3dvictoria.dpi.vic.gov.au

Department of
Sustainability and
Environment

Groundwater Management and Water Licensing



Agreeing what to map – naming "aquifer units" for Victoria

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Agreeing what to map – naming "aquifer units" for Victoria

- Chris McAuley
  - Department of Sustainability and Environment Manager, Groundwater Allocation and Planning

- Acknowledgements
  - Southern Rural Water Corporation
  - SKM
  - Workshop participants

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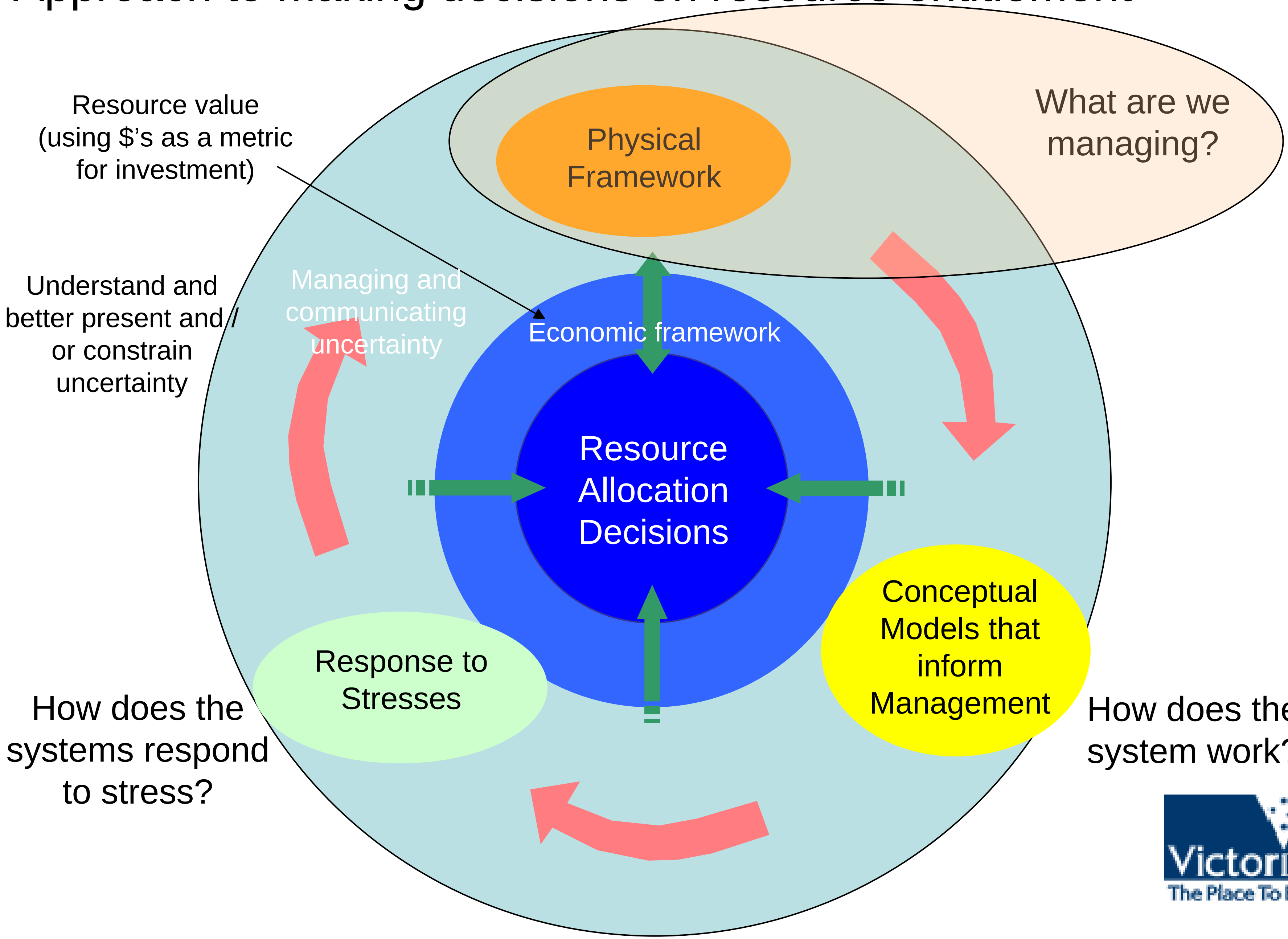
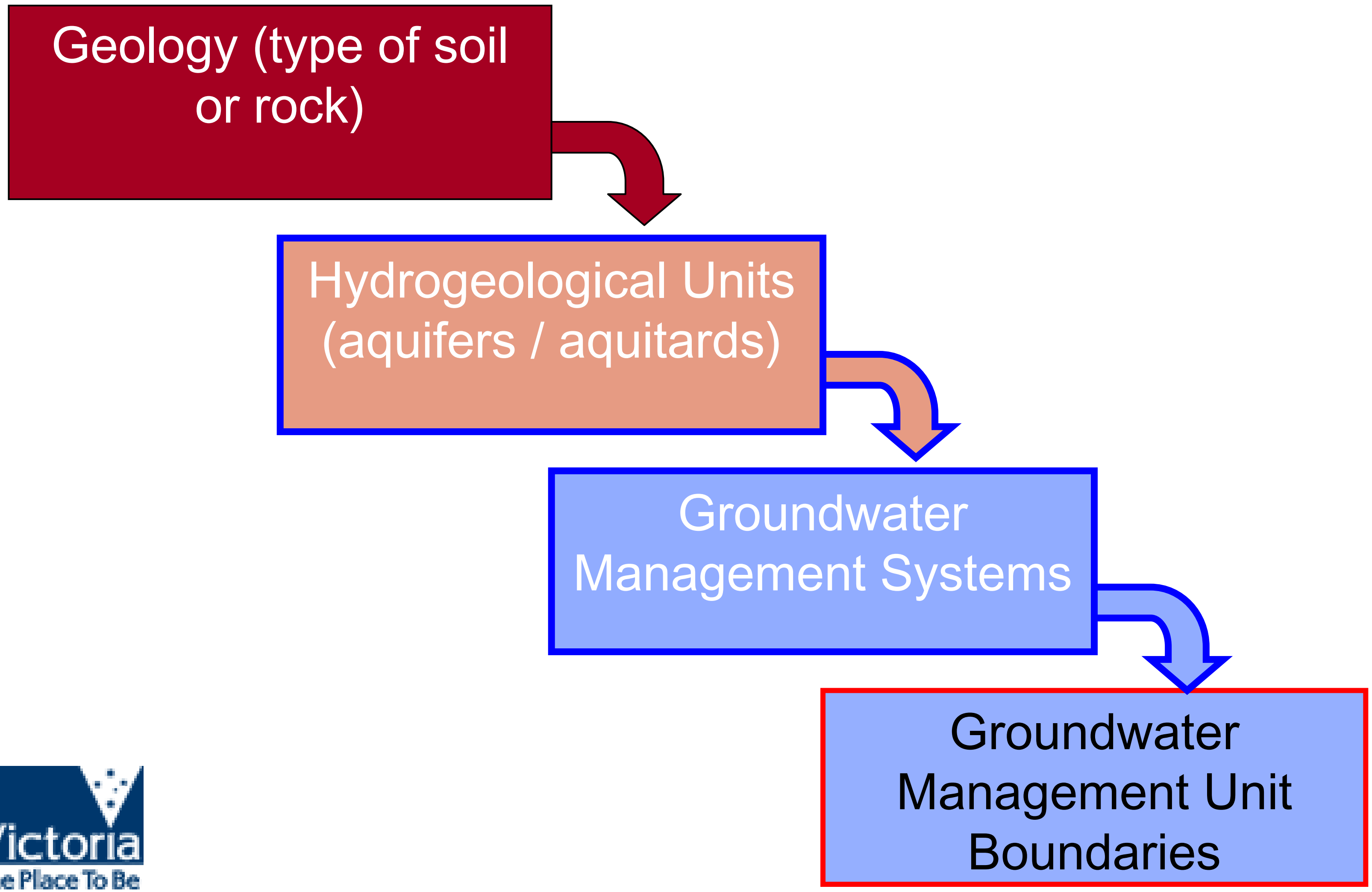
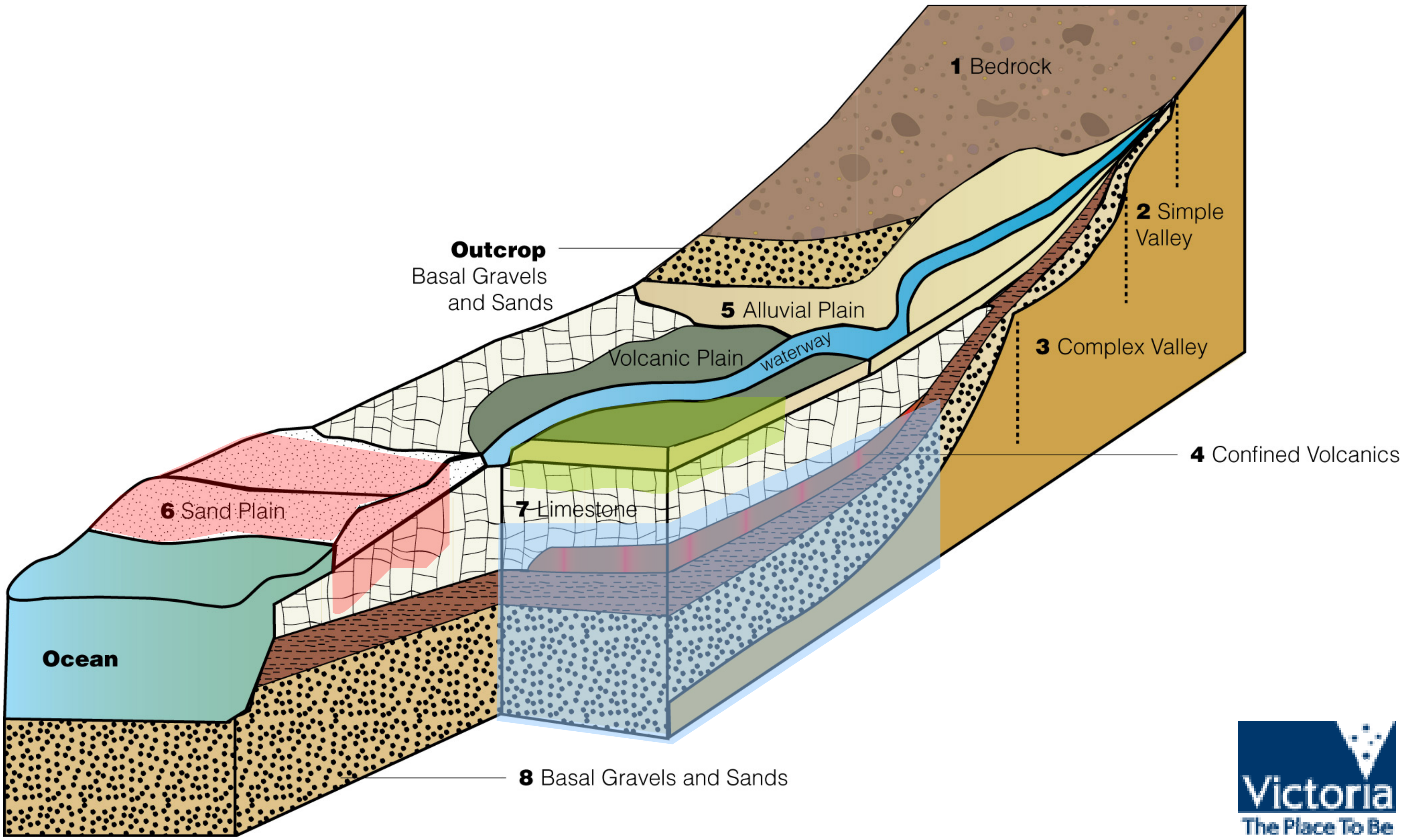
Approach to making decisions on resource entitlement



Developing management units



Groundwater Management Systems



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Initial framework

Consultative Group

(pre-eminent hydrogeologists)

Workshop

Consultative Group

(pre-eminent hydrogeologists)

Incorporate feedback

Decision maker

Finalise

Development approach summary

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Implications and benefits

- A consistent naming framework for aquifers enables consistency between projects within Victoria.
- It provides a consistent framework for any 3D mapping that may be undertaken.
- It provides the building blocks for defining groundwater management systems and groundwater management unit boundaries.

- The challenge is that as you “scale up” the system to encompass more areas, there is a likely need to expand the aquifer definitions. This may provide a challenge for a National program.

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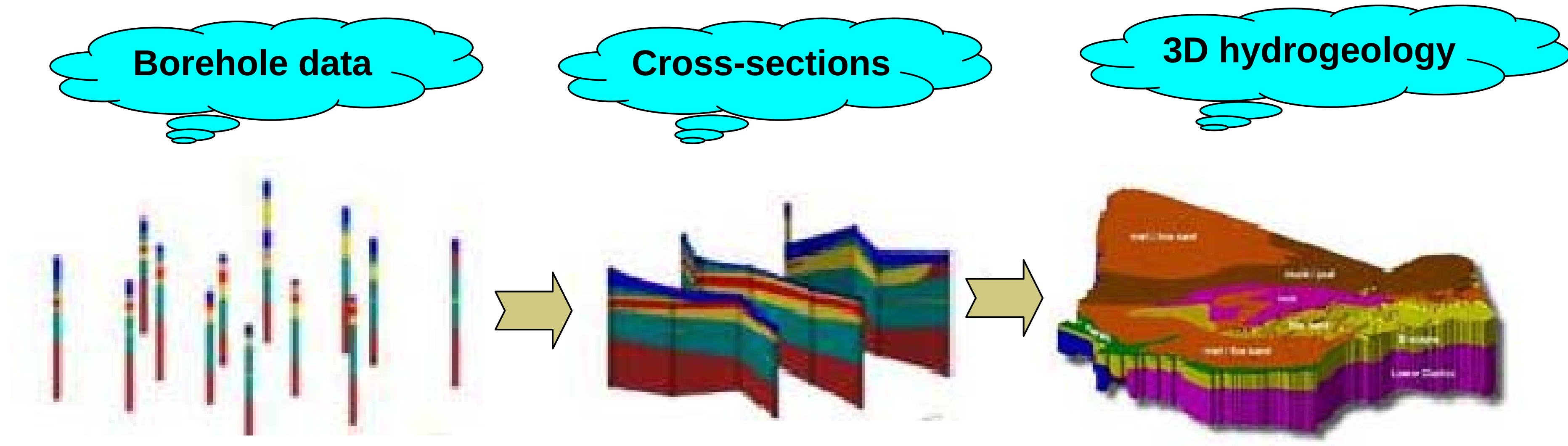

Implications of 20 years of conceptual and numerical modelling on 3D hydrogeology developments

Xiang Cheng, Bruce Gill and Mark Reid

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future farming systems research

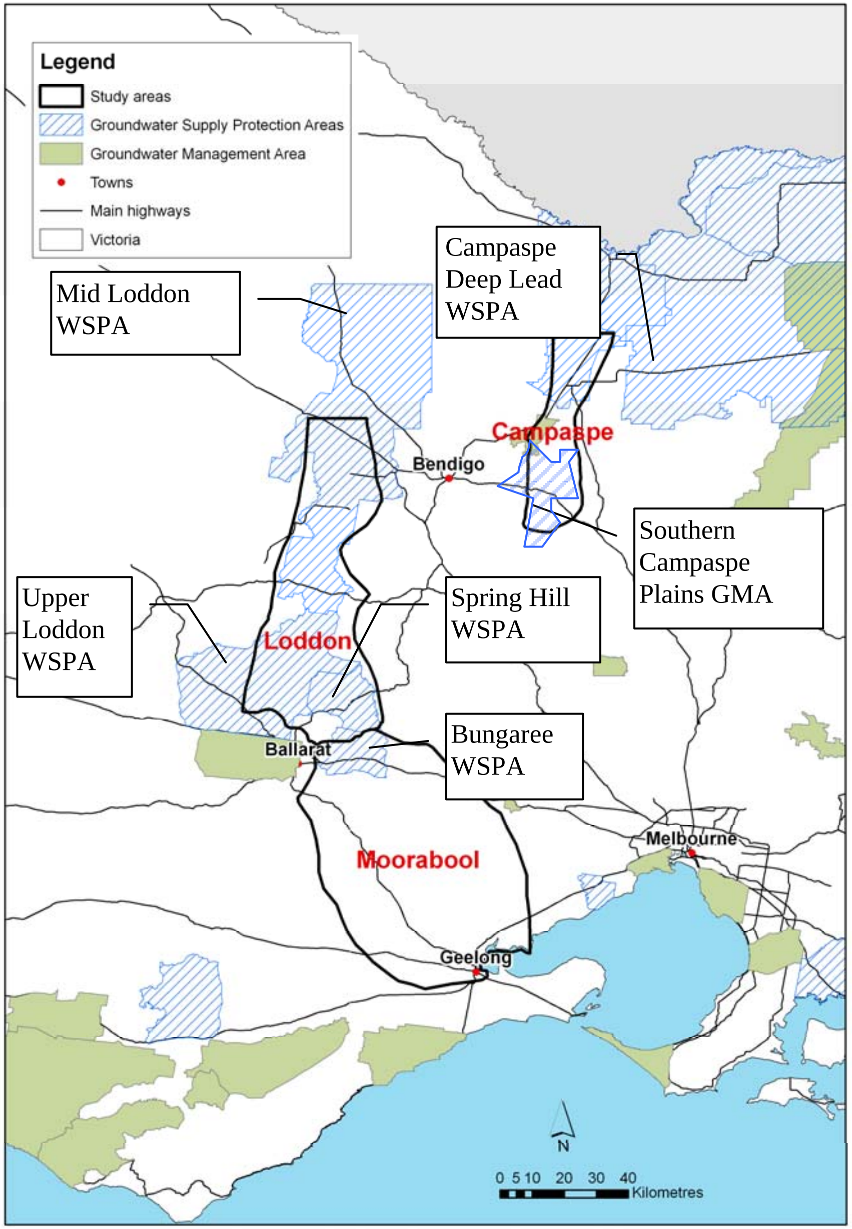
Outline

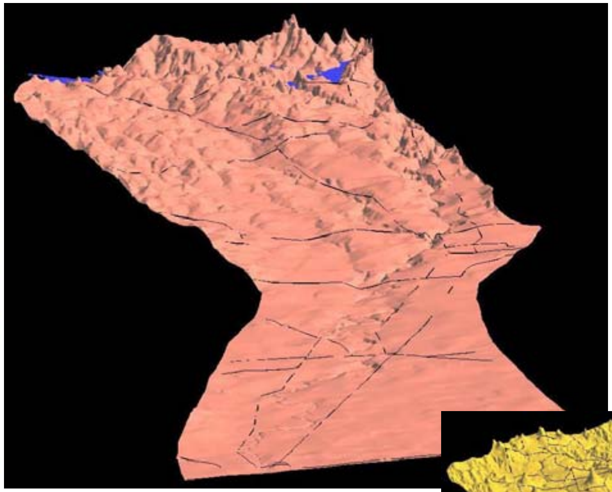
- Background of the DPI 3D hydrogeological mapping and visualisation project
- The purposes of this GW modelling review
- Statewide Audit of Permissible Annual Volumes
- The GW modelling work in the study areas
- Key findings of the Audit and modelling review
- Discussion

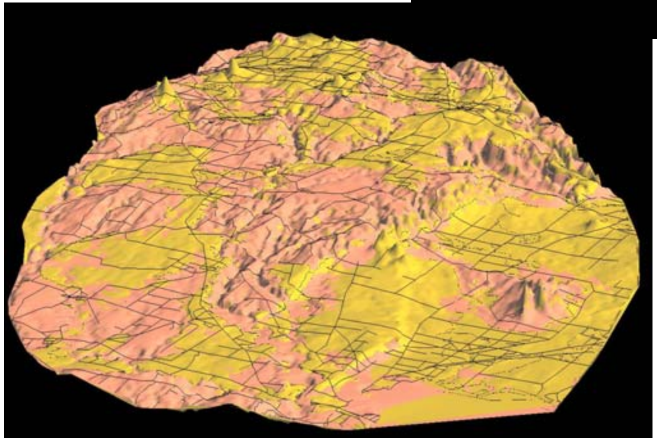
Background of the DPI 3D project

- Why we conduct this study
  - Constraints in groundwater investigation and management
  - Larger mining data sets
  - New 3D technologies from oil and minerals industries
- Key objectives
  - To integrate all available data sets using new 3D tools and methods
  - To improve groundwater resource delineation and management
- Background of the study areas

The study areas







The purposes of this review

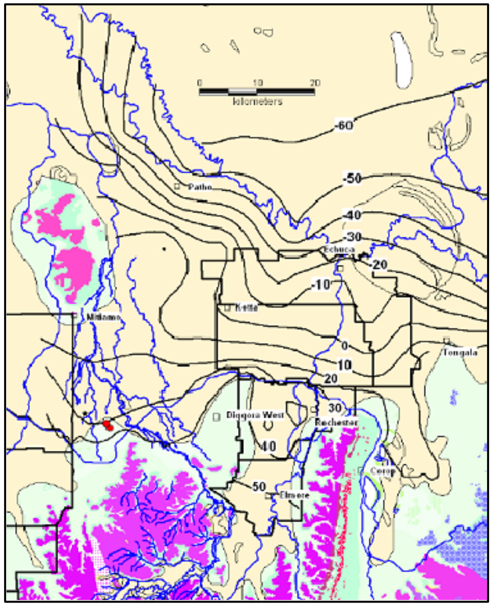
- To build an understanding of the existing PAV estimation methods
- To document key findings from GW modelling work
- To explore the potential for 3D technologies to evaluate and improve future GW models
- To inform development of products from the 3D visualisation and mapping process

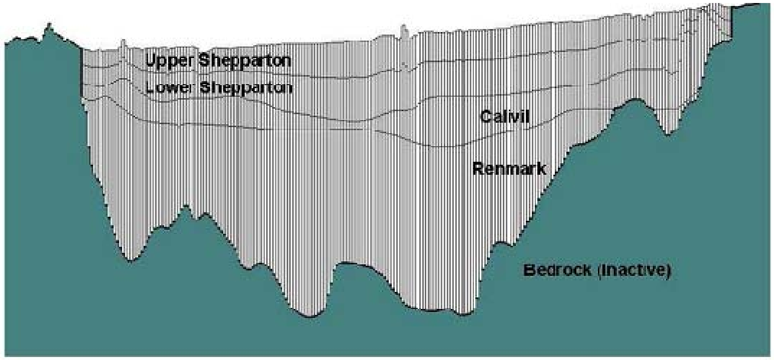
Statewide Audit of PAV

- Examined 35 PAV reports in Victoria
  - Hydrogeological framework
  - GMA boundaries and area
  - Monitoring data (e.g. water level and quality)
  - PAV methodology
  - Interaction with surface water
  - Throughflow calculation
  - Storage calculation
- 31 PAV estimates were evaluated as unreasonable

GW modelling work (Campaspe)

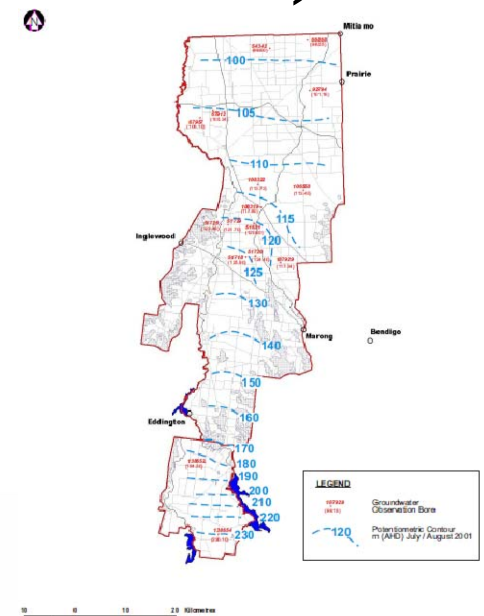
- At least 12 GW modelling studies over 20 yrs, e.g.
  - The Riverine Plain GW model (Nolan 1991; GHD 1992)
  - The Campaspe GW model (Chiew 1991)
  - The MDB Sustainable Yields Project ‘Southern Riverine Plains GW Model’ (Goode & Barnett 2008)
- Primarily for GW resource and salinity investigation
- Different scales
- Different boundaries
- Different approaches
- Many model inputs and outputs

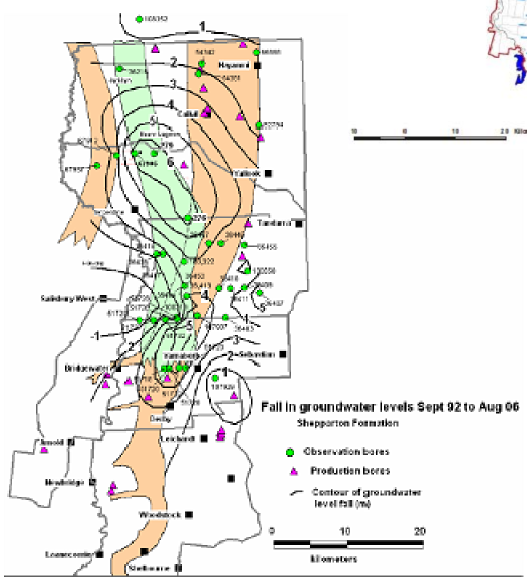




GW modelling work (Upper Loddon)

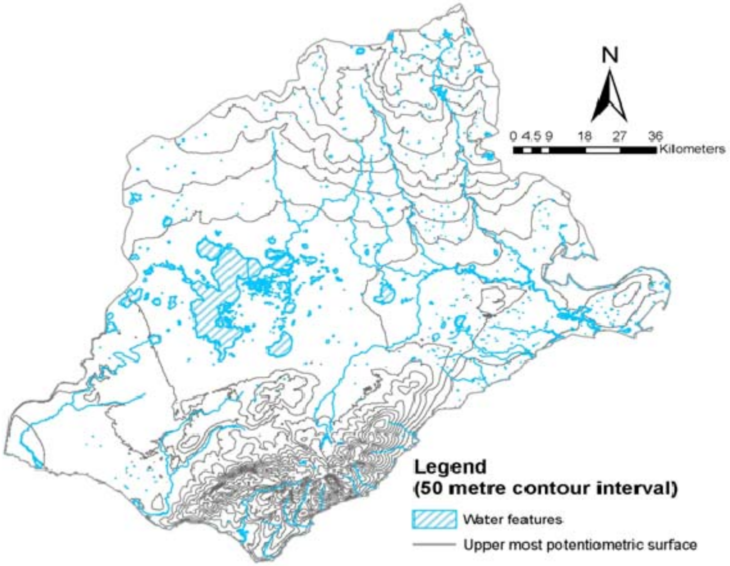
- Five GW modelling studies reviewed, including:
  - Three regional models covering both Campaspe and Loddon
  - Mid Loddon WSPA Groundwater Model (URS 2003; 2006)
  - GW occurrence and Process in the Mid-Loddon WSPA (Macumber 2007)

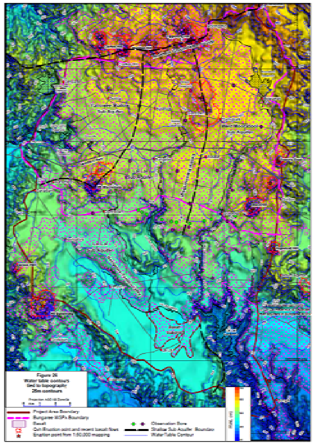




GW modelling work (Moorabool)

- At least 10 modelling studies, including:
  - Several student projects
  - The DSE Corangamite ‘ecoMarkets’ project (Hocking 2007)
  - GW assessment of the Bungaree WSPA (URS 2002)
  - Geology and GFSs in Moorabool (Evans 2006)
  - The Victorian Volcanic Plains study (Cox et al 2007)





Key findings

- A large amount of data was collected, processed and generated
- Model development repeatedly started from ‘scratch’
- Conceptualisation mostly limited to the use of geological maps and GW monitoring bore data
- Heavily relied on traditional methods for model development and communicating outputs
- Very difficult to make direct comparisons between models
- A good hydrogeological framework is essential
- Inadequate post model data management

Discussion

3D hydrogeology methods can provide:

- The best way to process and manage a large amount of hydrogeoological data
- More transparent and repeatable products for development of hydrogeological framework
- A means to deal with boundaries problems (e.g. CMA, GMA, mapping boundaries)

End of show

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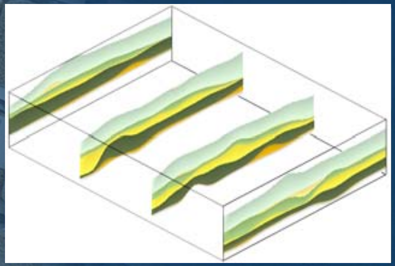
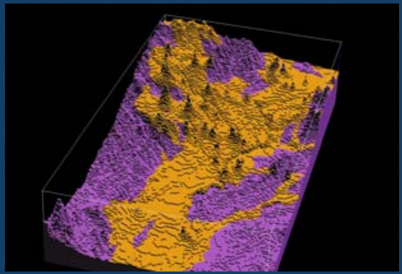
Visualisation of data layers





the key to increasing the integrity of geological based groundwater models

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Contributors

Don Cherry

Dr Jon Fawcett

Bruce Gill

Future Farming Systems Research Division

Department of Primary Industries

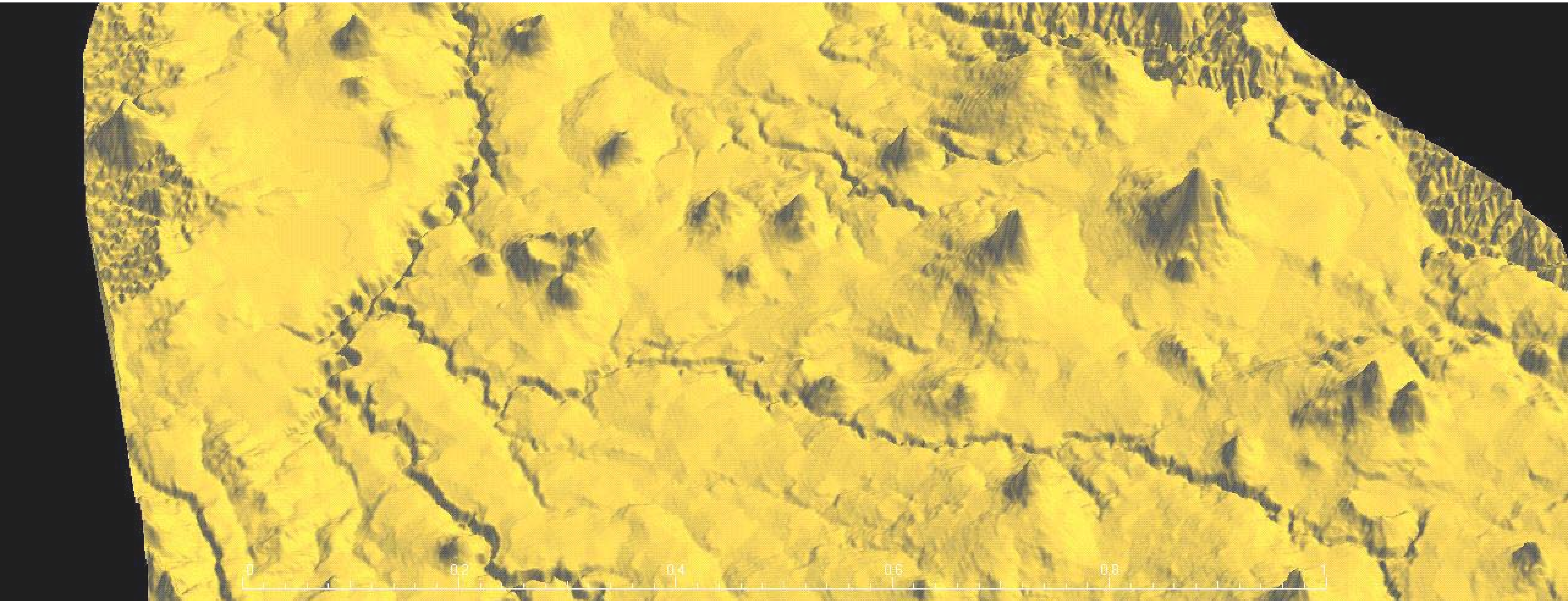
Victoria

The study

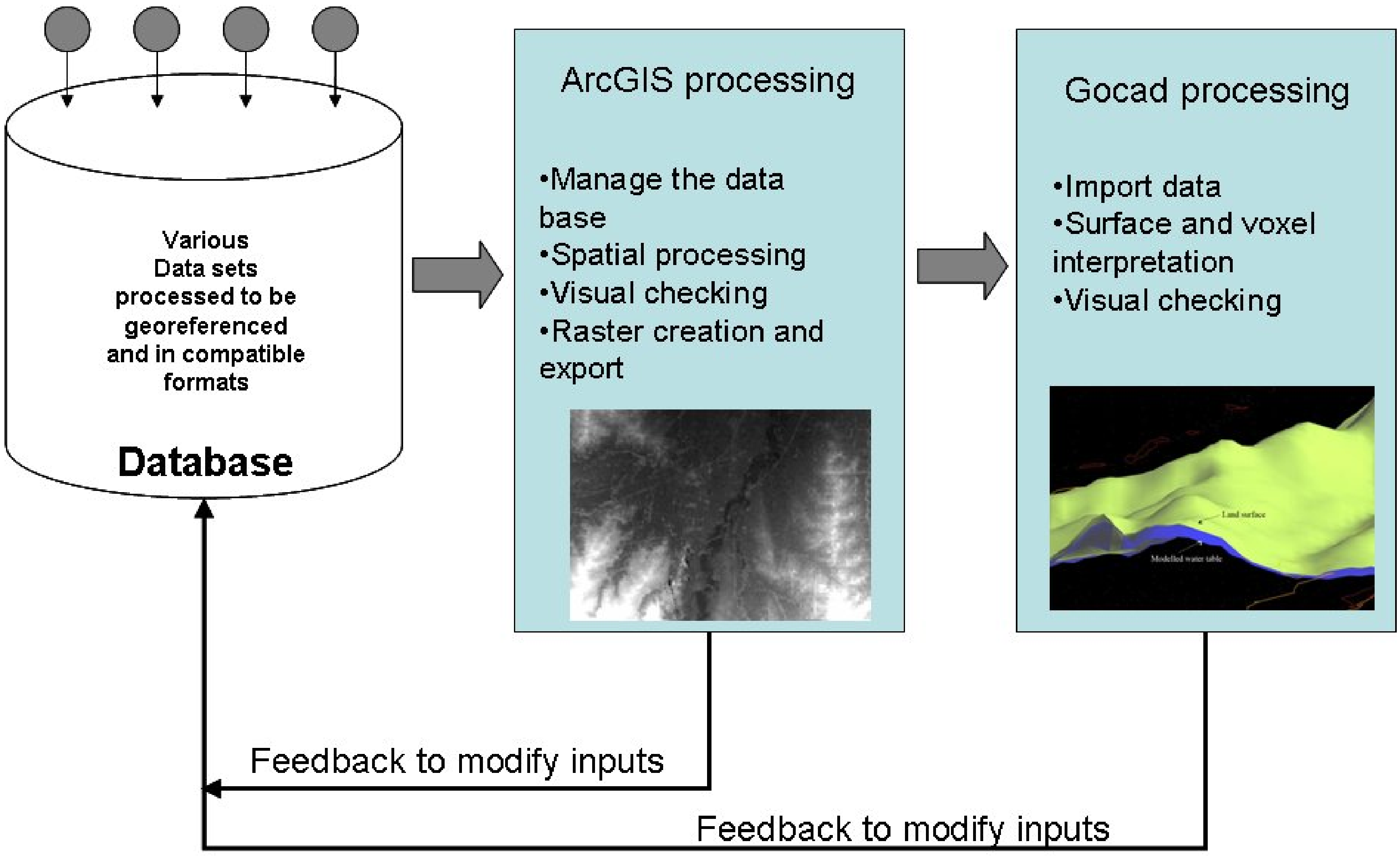
- 3yr project funded by NWC & VWT
- Taking the geological interpretation of multi-dimensional data from drill holes, pre-digital maps and sections to a new era of interactive 3D visualisation and interpretation
- Pick up methods used widely in minerals and oil industries
- Emulate work underway in North America & Europe
- Improve understanding of groundwater resources so we can better manage them

Data Issues

- Multiple databases (MS, web-based, custom etc)
- Multiple formats (relational, spreadsheets etc)
- Missing information (logs, coordinates)
- Incorrect information (translation errors etc)
- Poor or varying interpretation

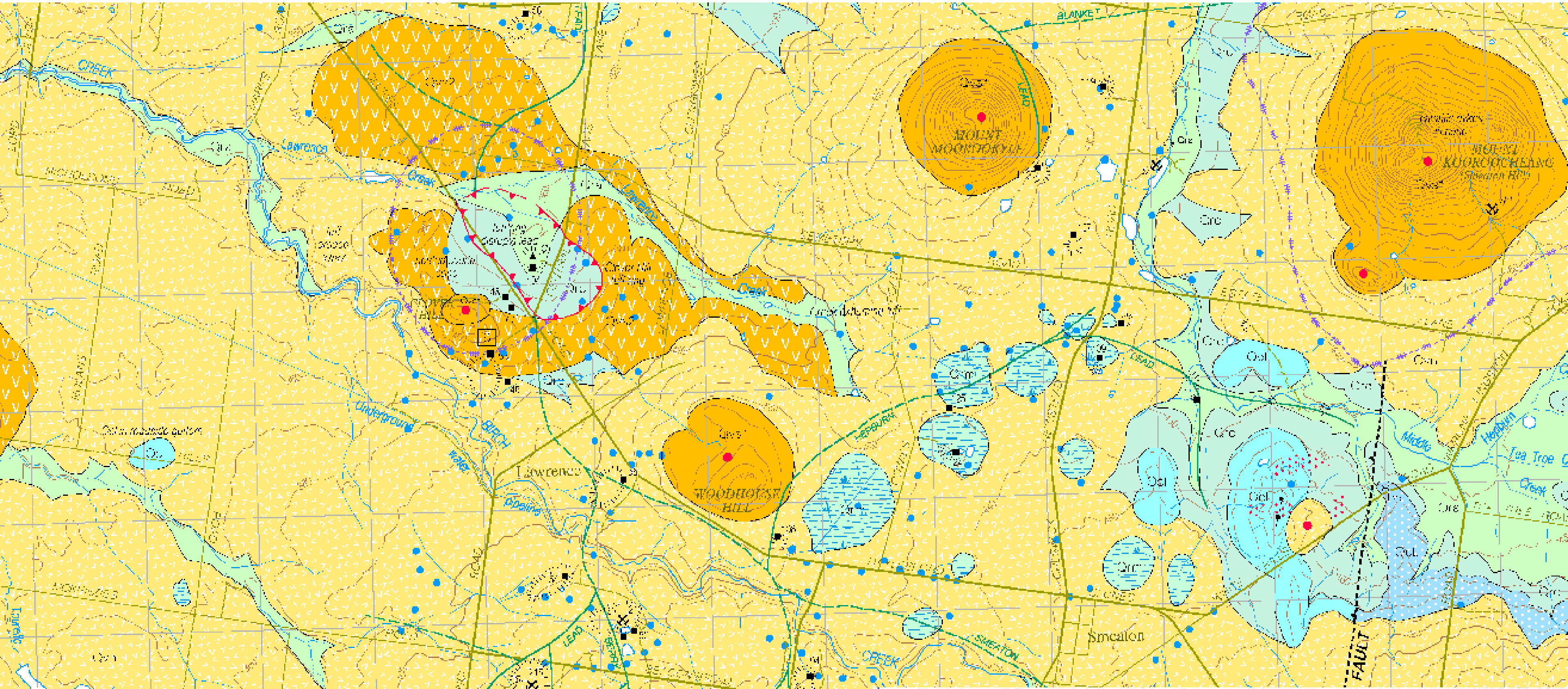


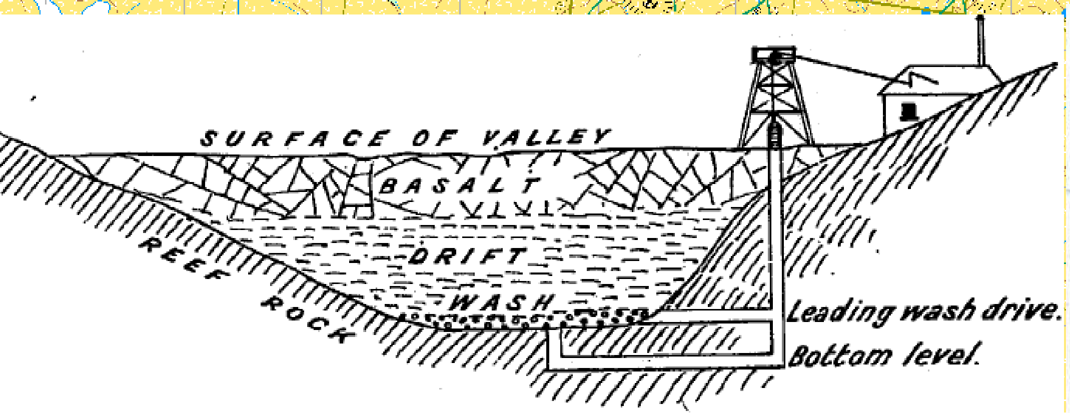
Methods

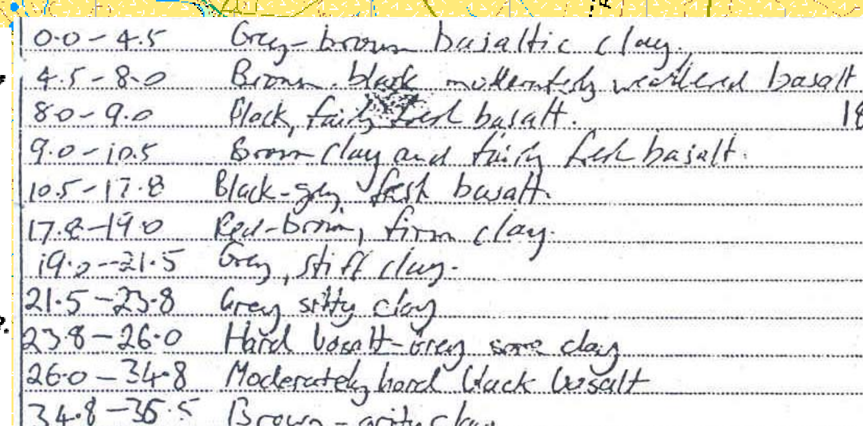


Various
Data sets
processed to be
georeferenced
and in compatible
formats
Database
ArcGIS processing
•Manage the data base
•Spatial processing
•Visual checking
•Raster creation and export
Gocad processing
•Import data
•Surface and voxel interpretation
•Visual checking
Feedback to modify inputs
Feedback to modify inputs

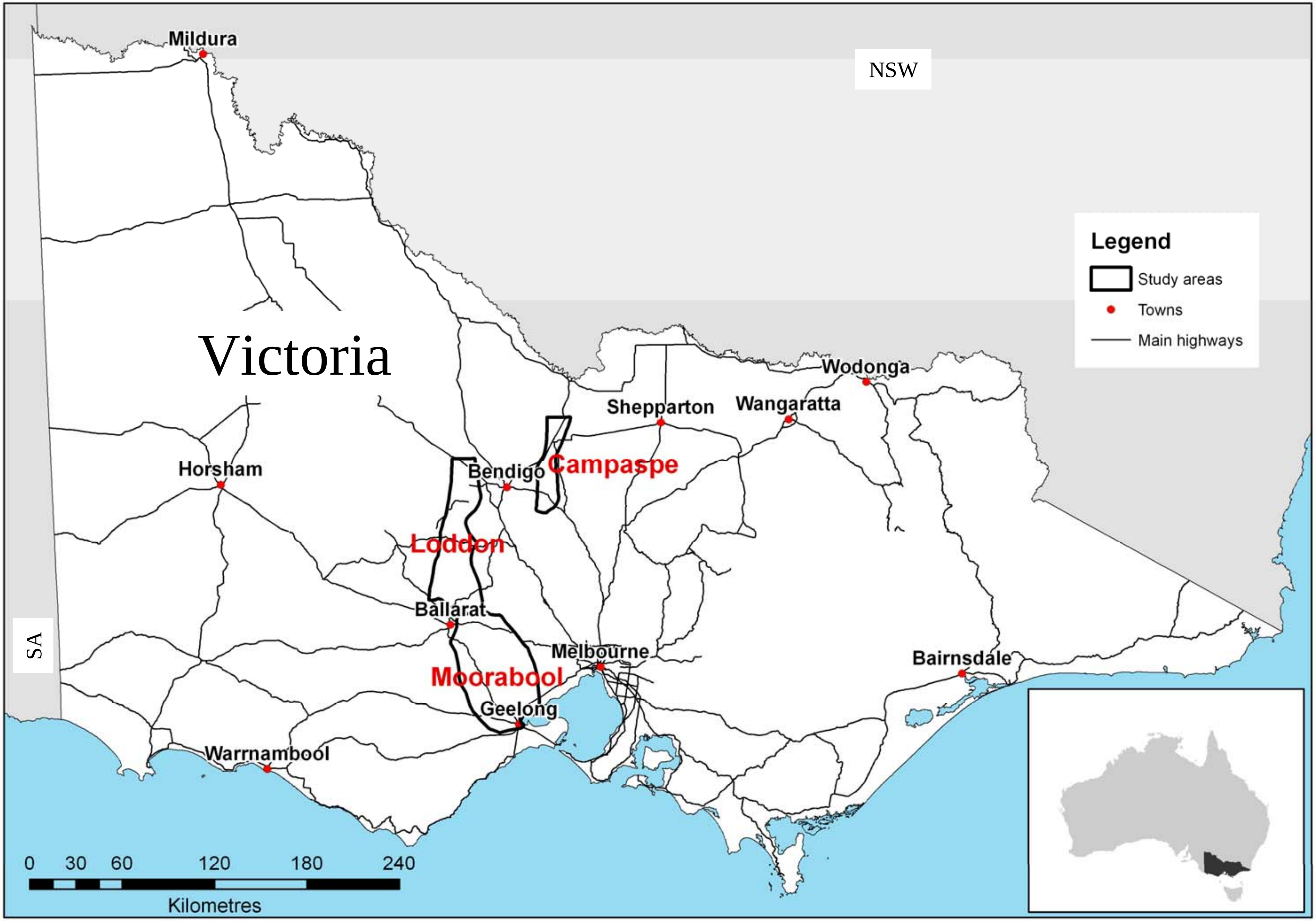
Maps – Sections – Bore logs







0.0 – 4.5	Grey-brown basaltic clay.
4.5 – 8.0	Brown-black moderately weathered basalt
8.0 – 9.0	Black, fairly fresh basalt.
9.0 – 10.5	Brown clay and fairly fresh basalt.
10.5 – 17.8	Black-grey fresh basalt.
17.8 – 19.0	Red-brown, firm clay.
19.0 – 21.5	Grey, stiff clay.
21.5 – 23.8	Grey silty clay
23.8 – 26.0	Hard basalt-grey some clay
26.0 – 34.8	Moderately hard black basalt
34.8 – 35.5	Brown – gritty clay


Mildura
NSW
Legend
Study areas
Towns
Main highways
Victoria
Wodonga
Shepparton
Wangaratta
Horsham
Bendigo
Campaspe
Loddon
Ballarat
Melbourne
Bairnsdale
Moorabool
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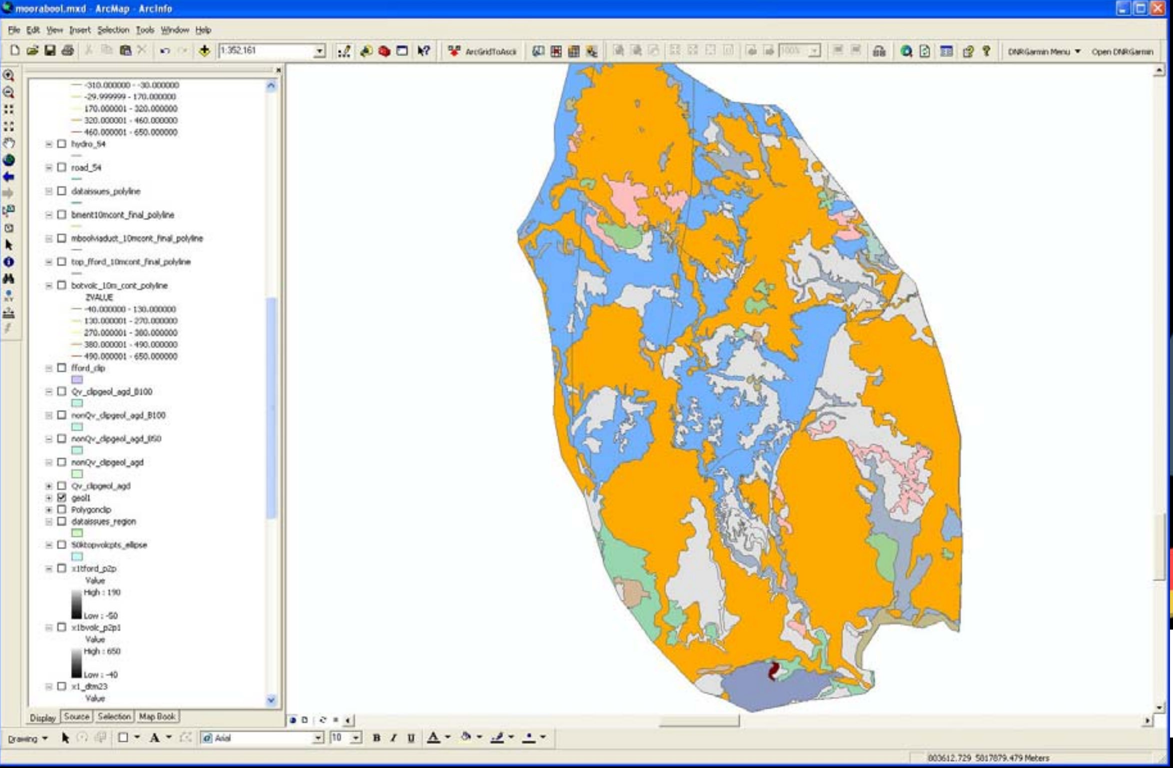
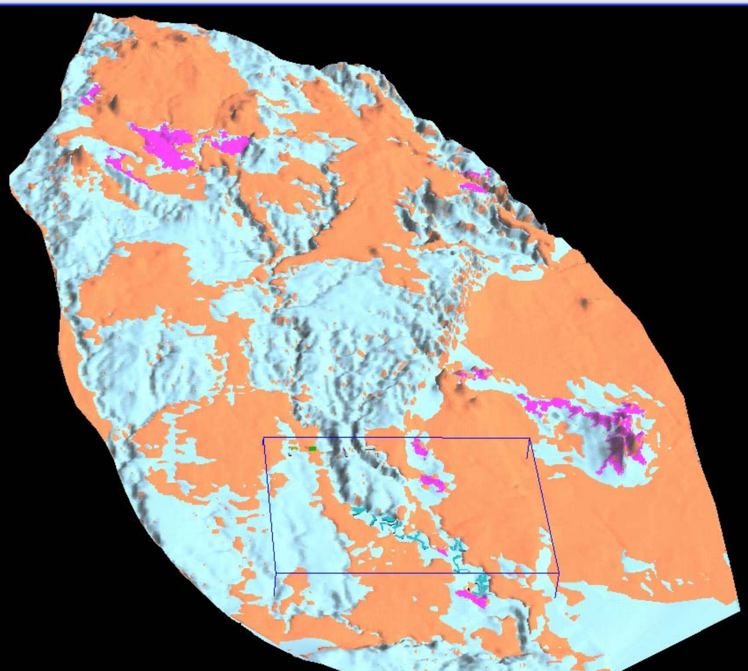
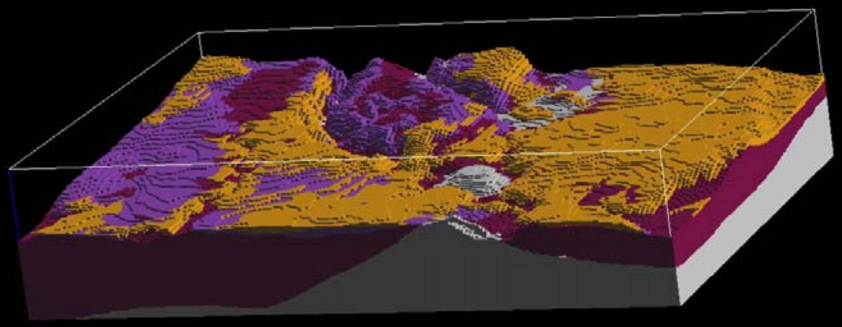
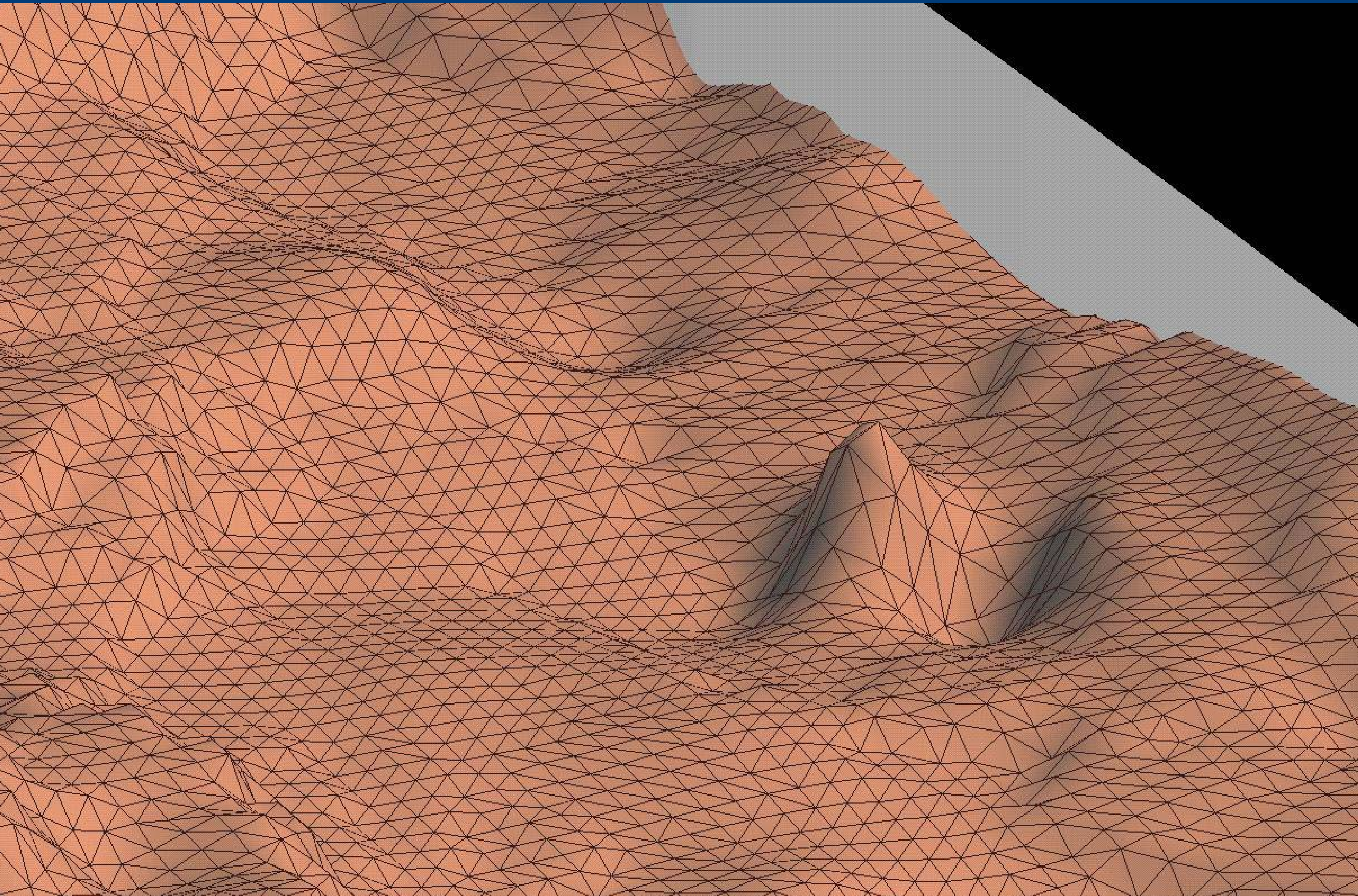


Sample views

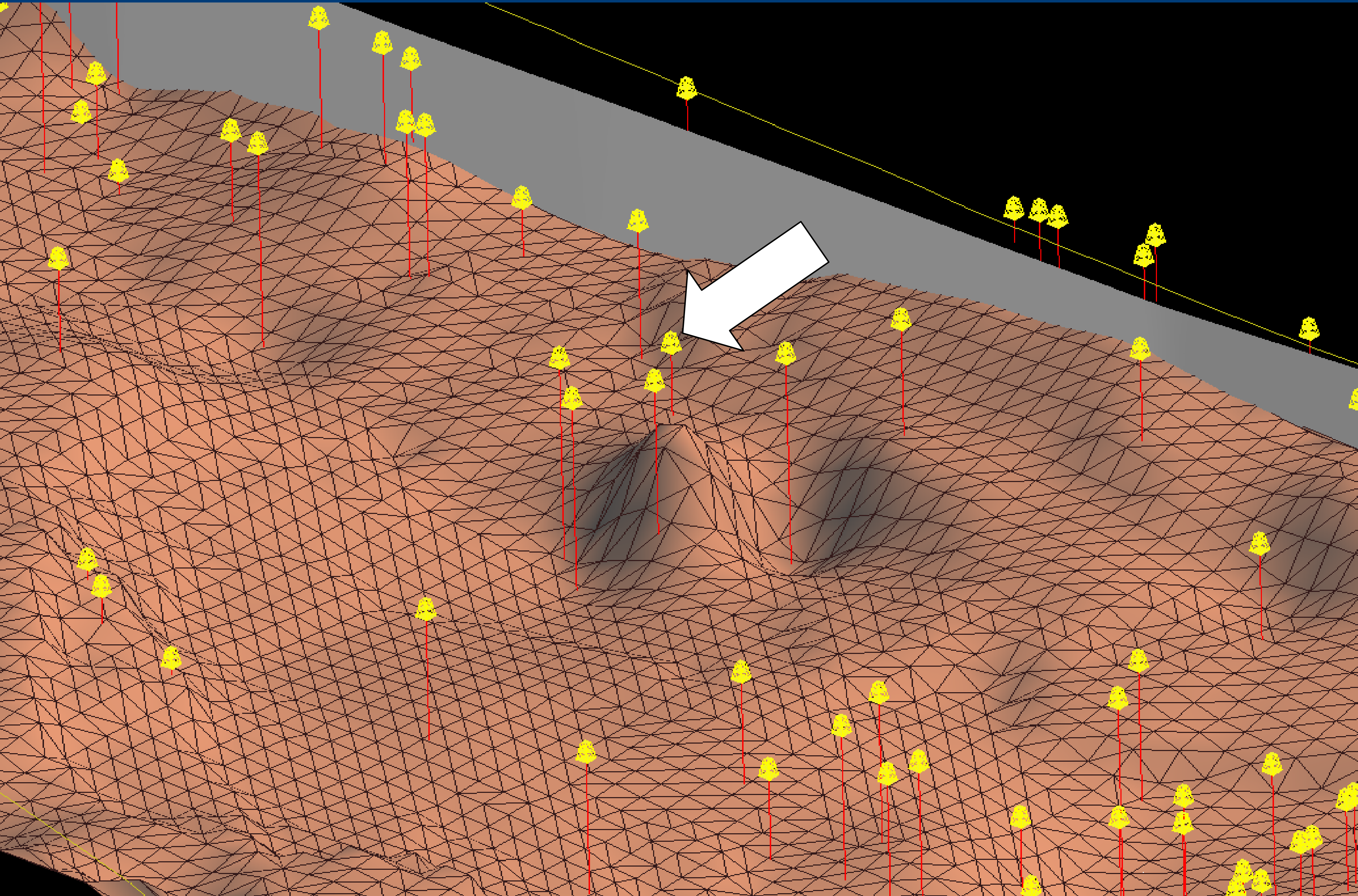


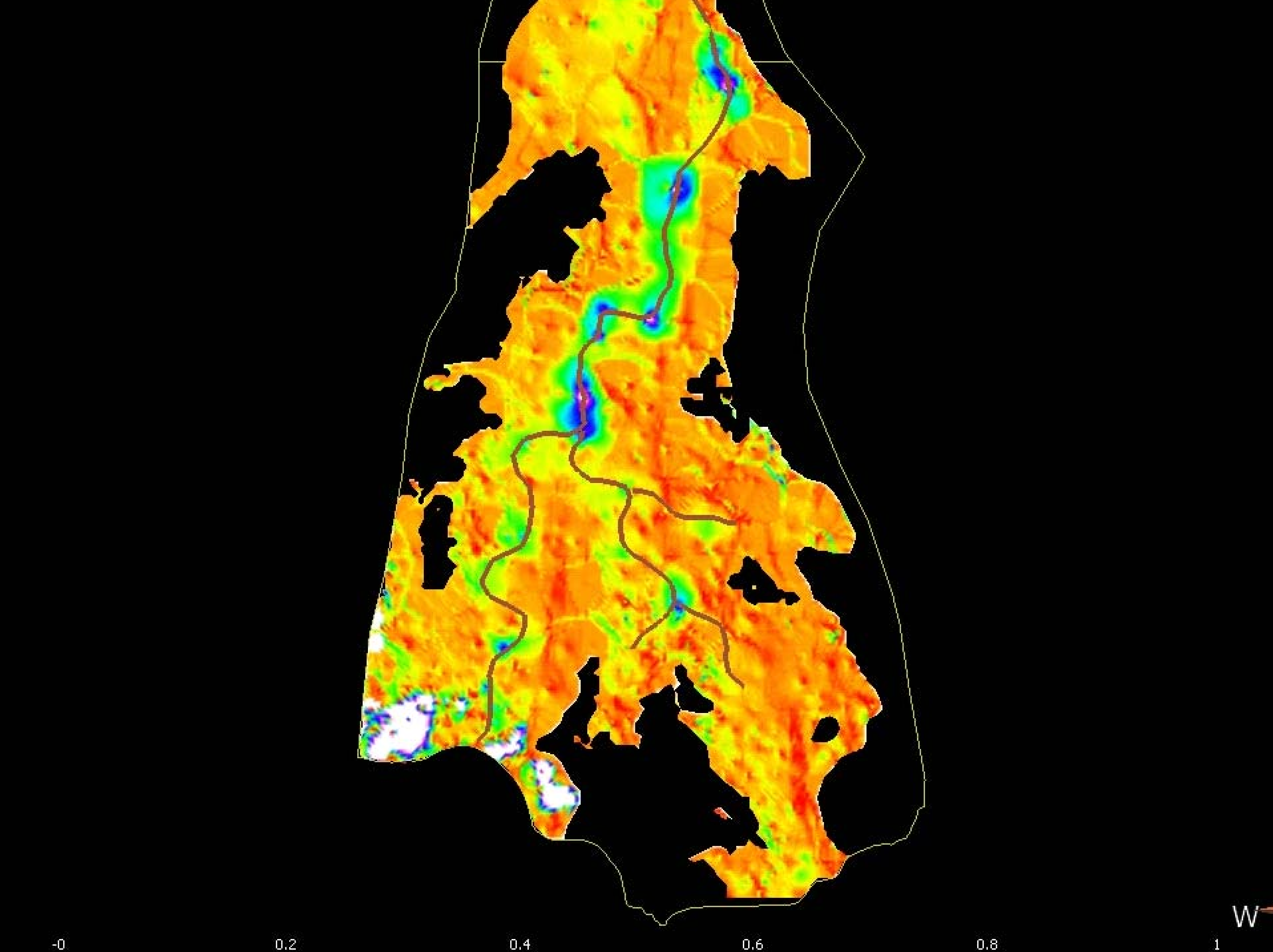


Visual check – error discovery



Identify spurious borehole

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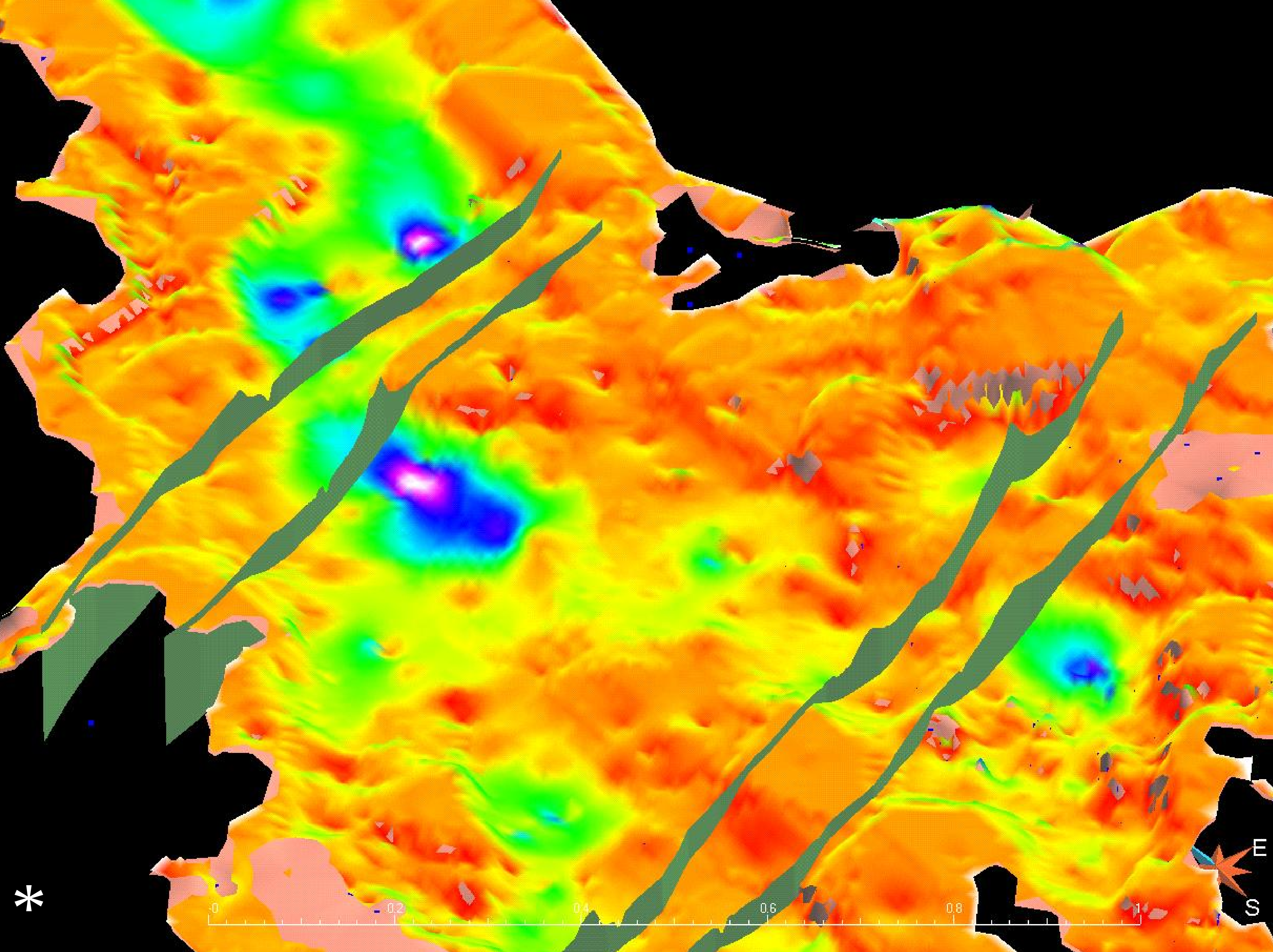
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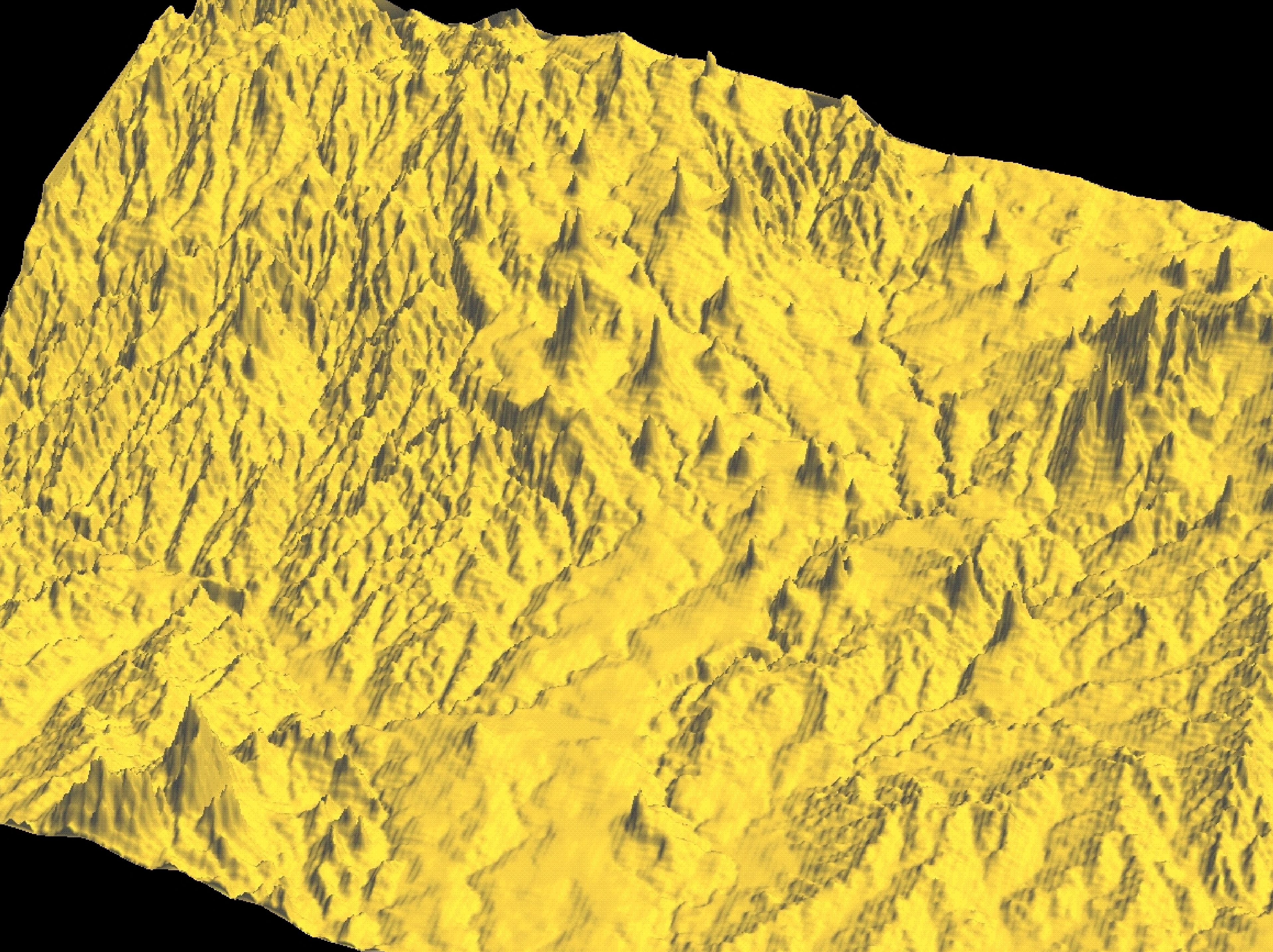
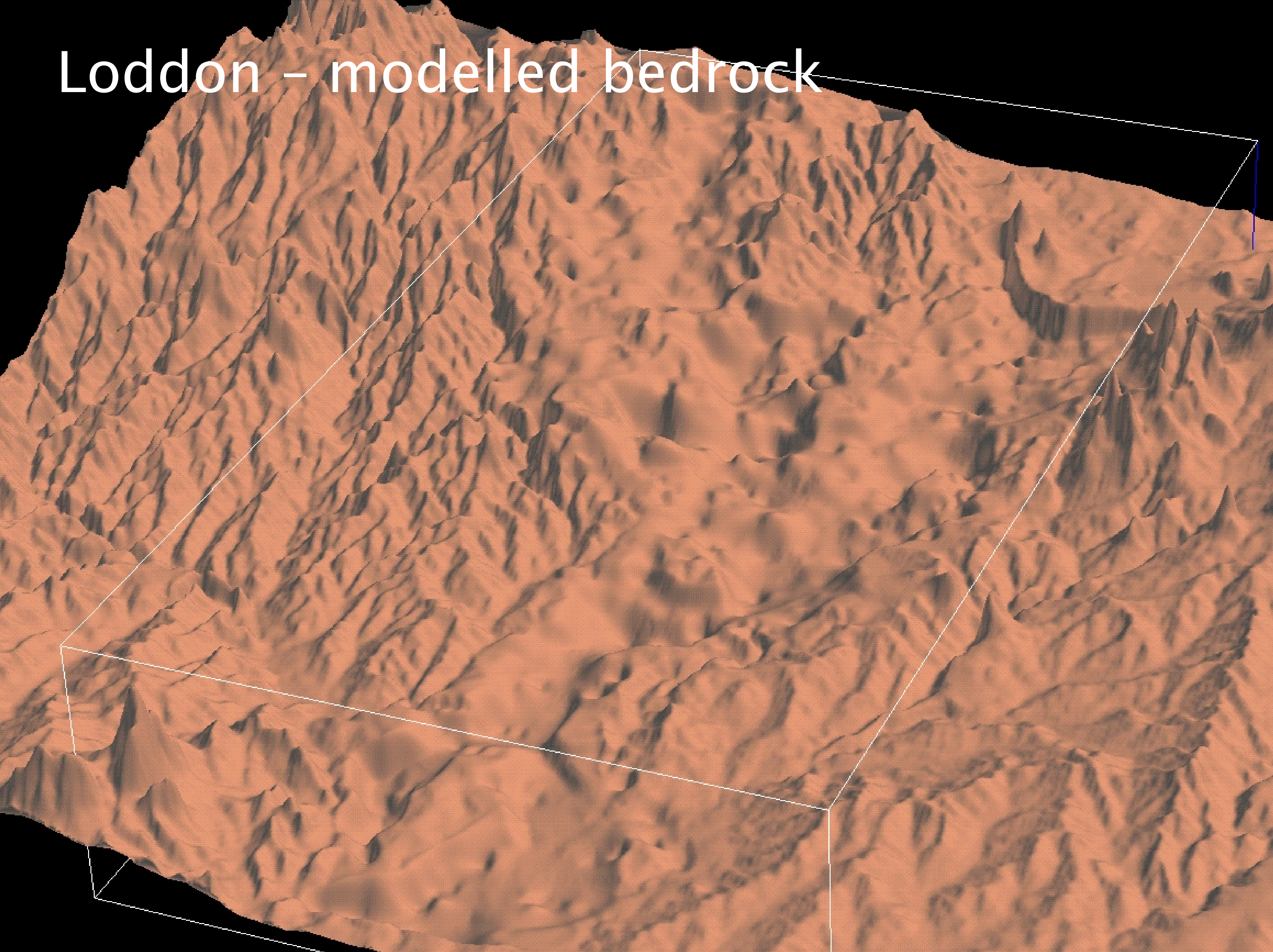
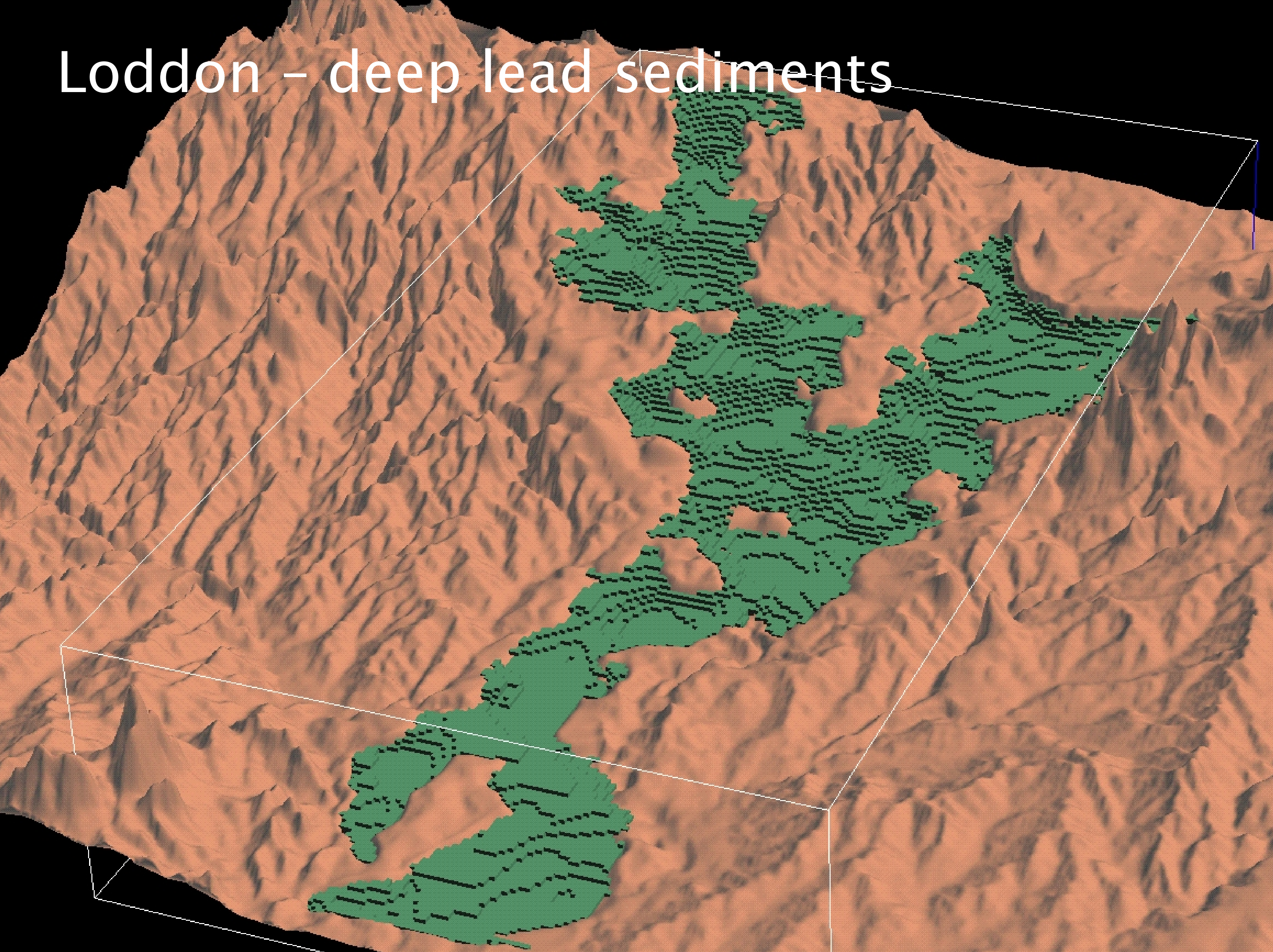
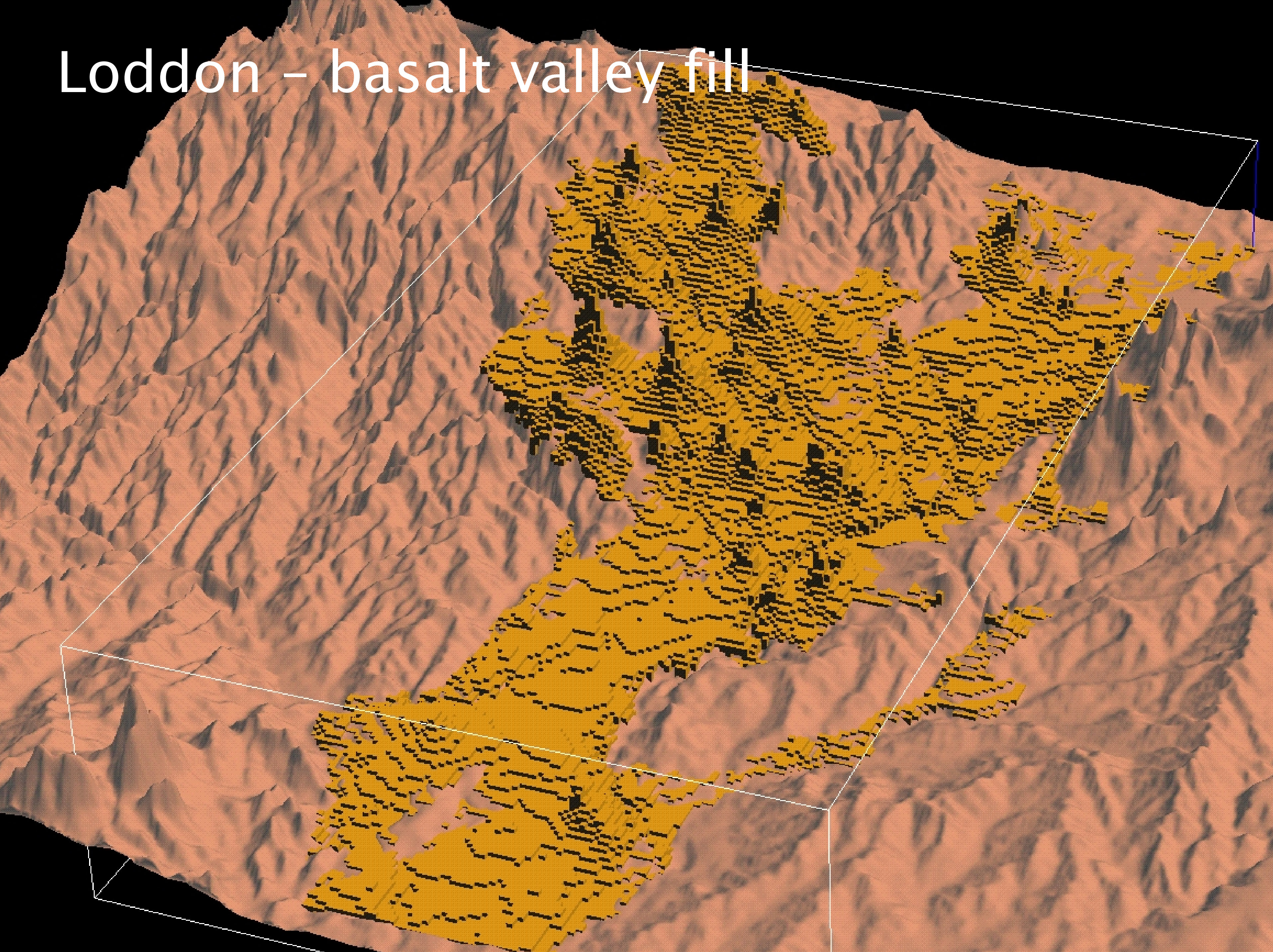


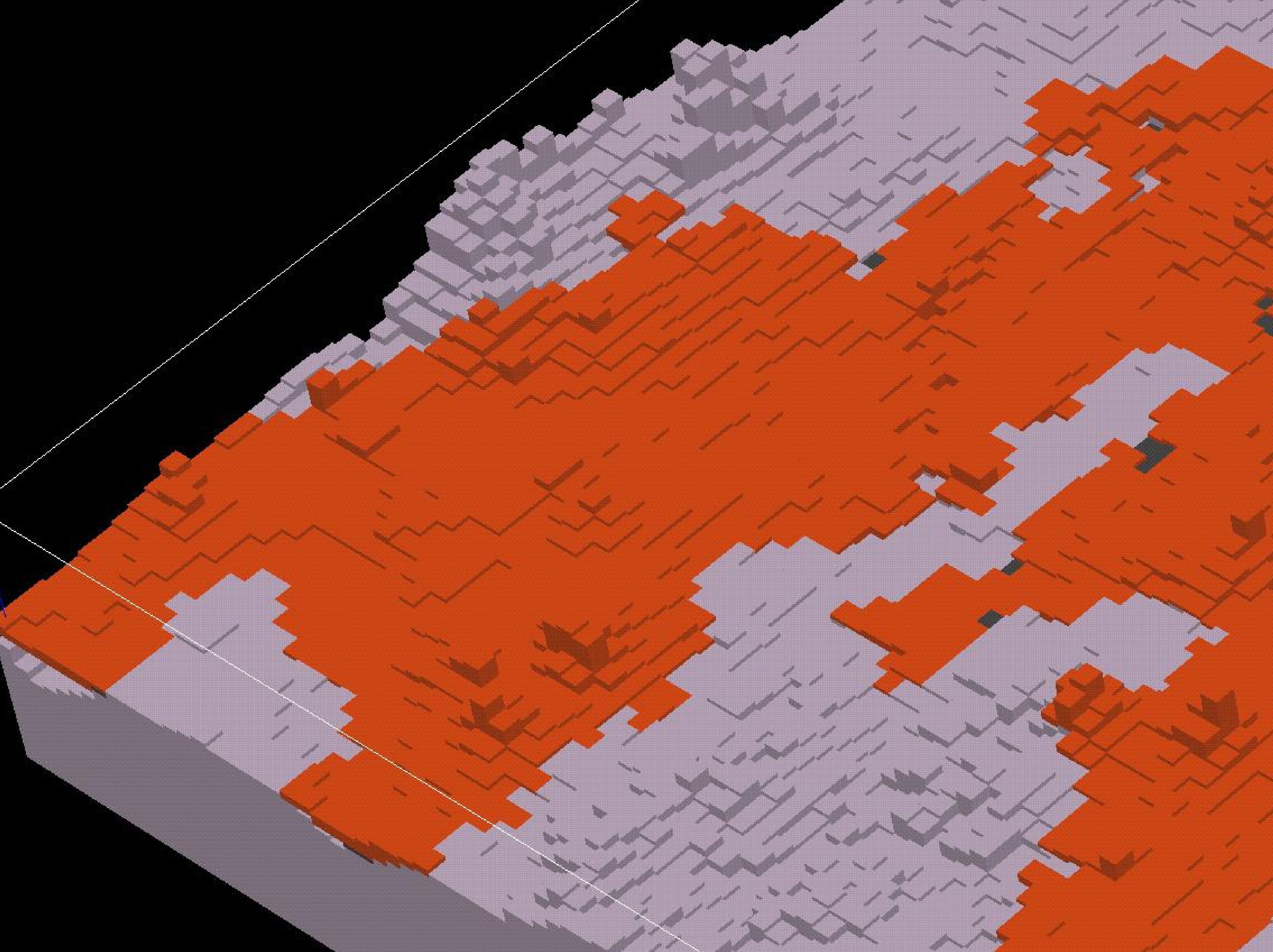

Loddon – modelled bedrock

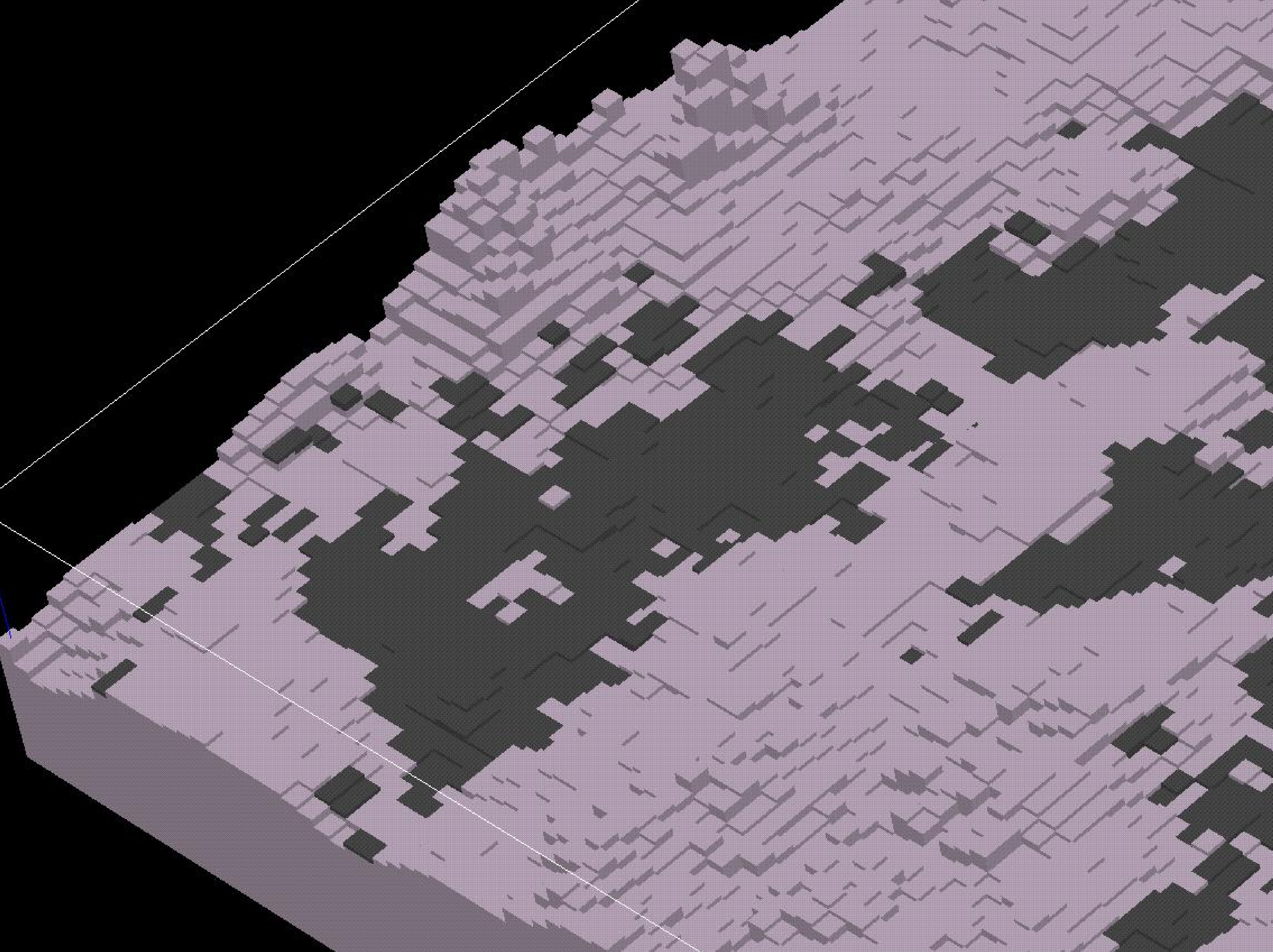
Loddon - deep lead sediments

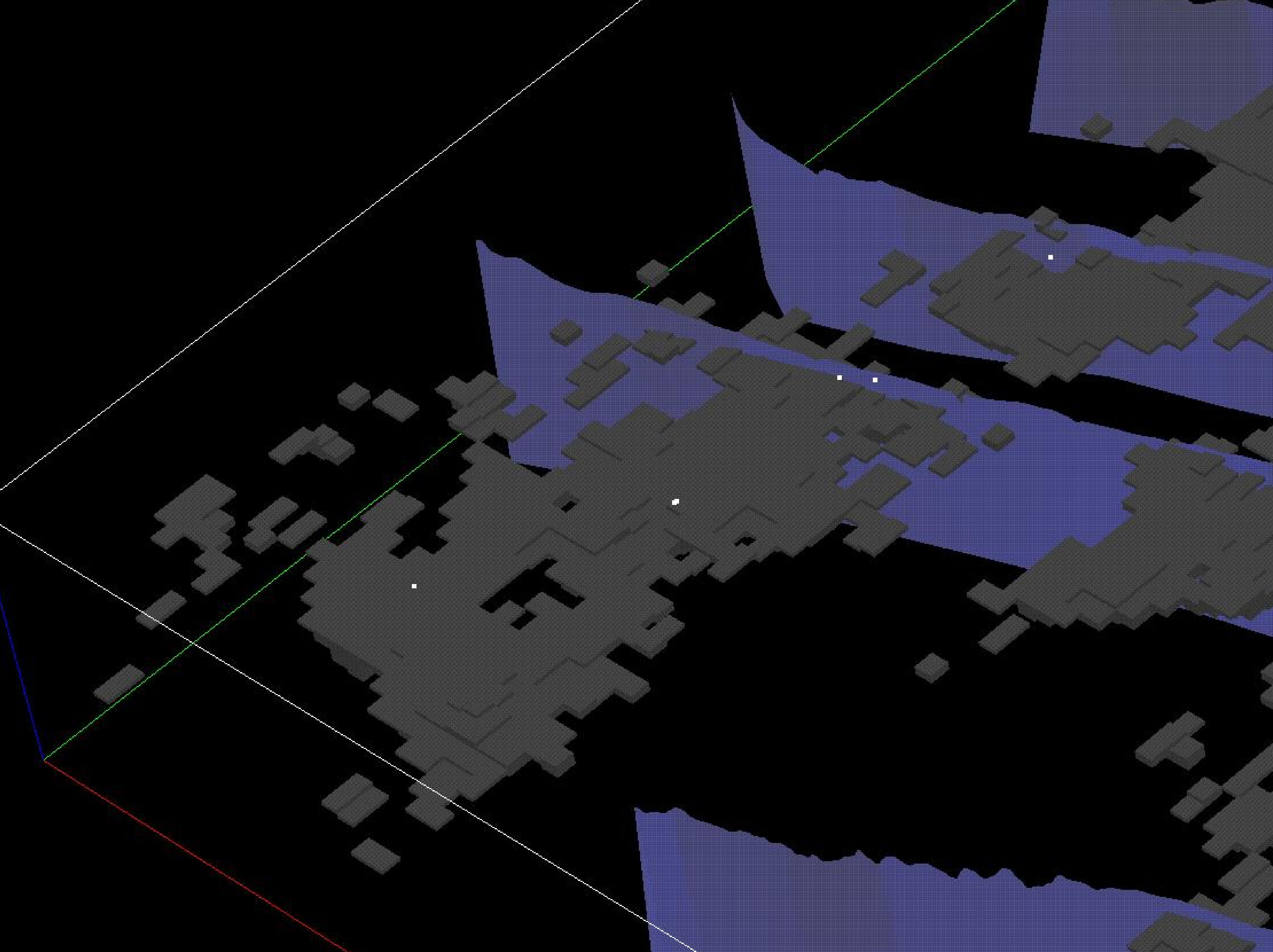


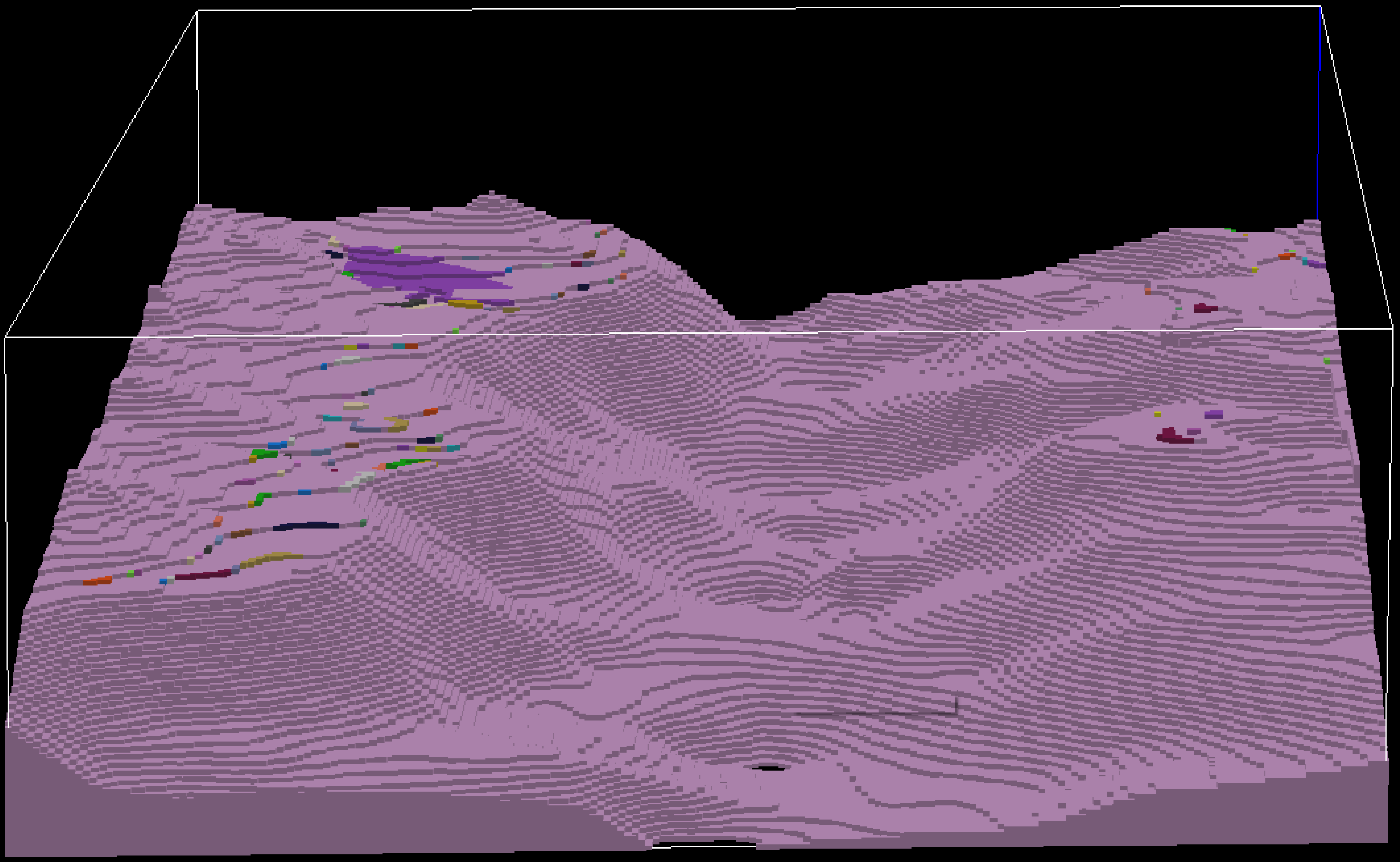
Loddon - basalt valley fill

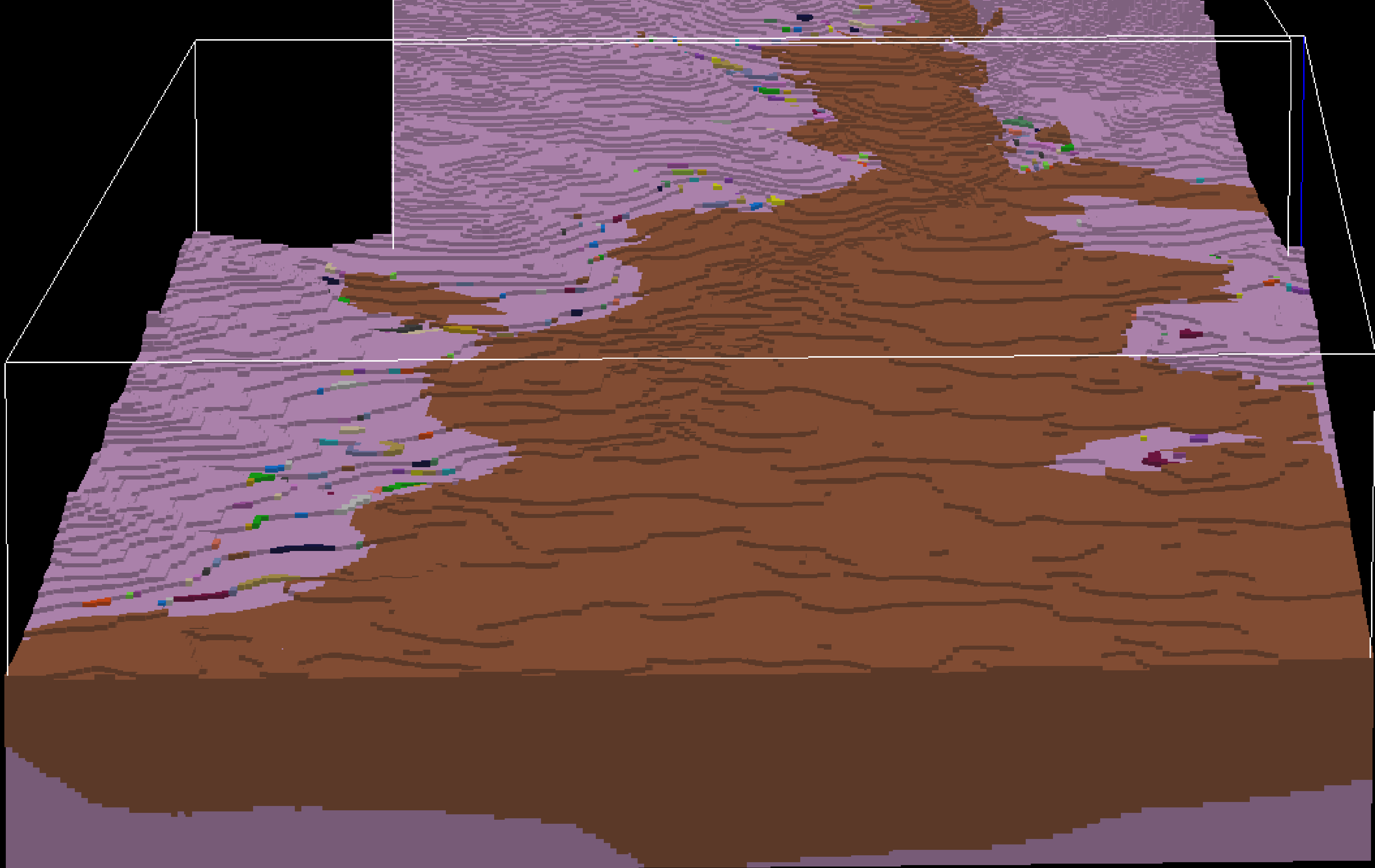


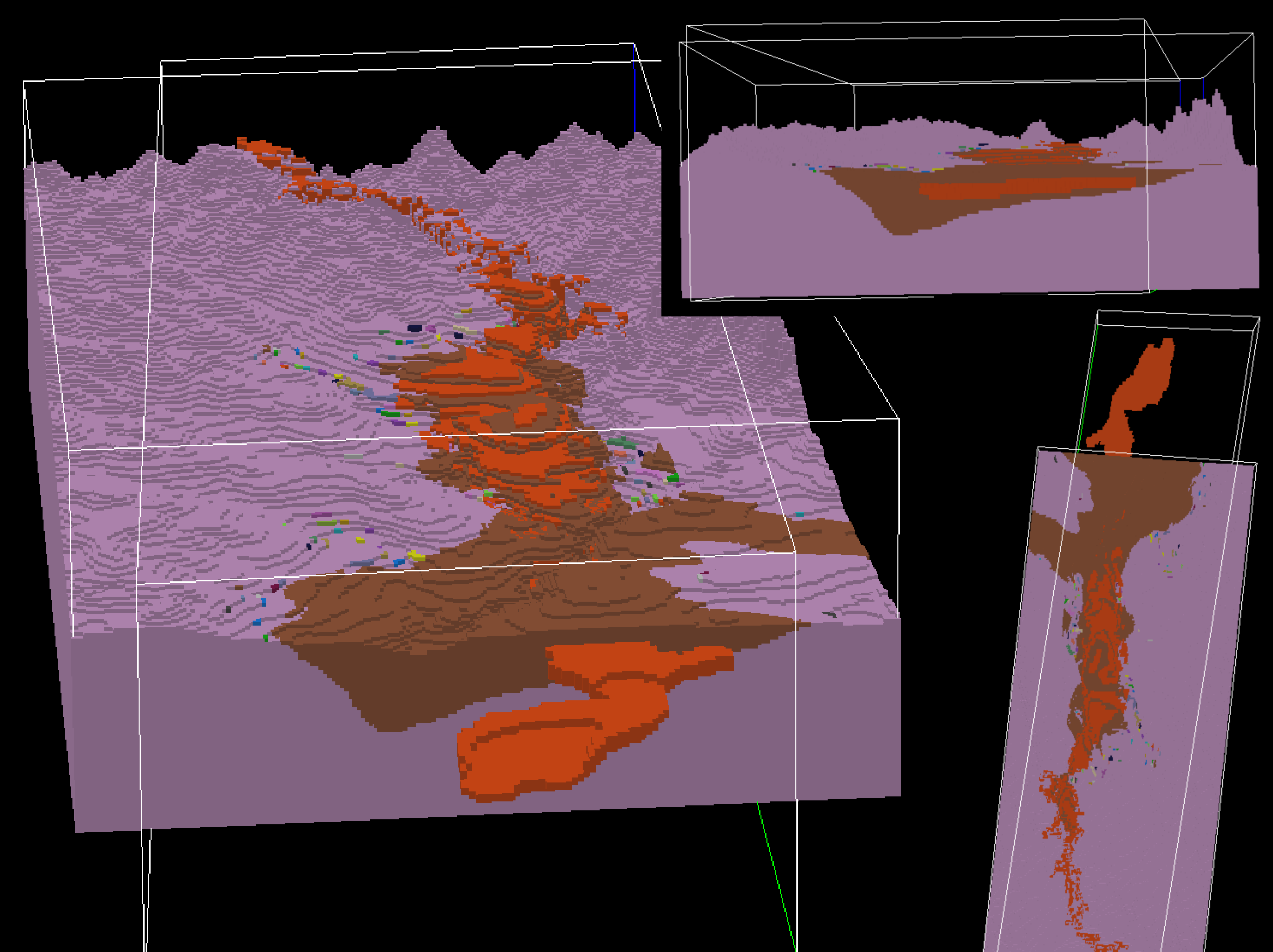












Concluding comments

Early success in identifying errors, aquifer geometries and alignment of interpretations with other studies.

3D geological modelling is an essential step in the process of understanding the geological and hydrogeological features of an aquifer. Feed into groundwater management models.

•Does the modelled data fit the known geological interpretation?
•Does it look right?

Visual checks of modelled data uses the analytical power of the human eye to instantly recognise errors or anomalies.

How many times have you stopped to straighten a picture on a wall?

References and further reading

Thank you

Illinois State Geological Survey

http://www.isgs.uiuc.edu/research/3DWorkshop/index.shtml

British Geological Survey

http://www.bgs.ac.uk/science/3Dmodelling/lithoframe1M.html

Victorian Resources Online – Geographic visualisation videos

http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/gis_data_display_video_clips

Evans, T.J. (2006) Geology and groundwater flow systems in the West Moorabool River catchment and their relation to river salinity. Unpubl Masters Thesis, UniTech Sydney.

Role of 3D visual conceptualisation of groundwater system models as a management support tool

First Australian 3D Hydrogeology Workshop
31 August and Tuesday 1 September, 2009

Malcolm Cox , Joseph Young, Allan James ,
Amy Hawke and Andrew Todd

Queensland University of Technology

Background

Common lack of understanding how a groundwater system functions

Water users commonly *cannot* “see” their bore/s in the context of a system at a catchment scale

Many rural myths and misconceptions

Decade of drought → resource impacts
→ incentive to manage

Role of Agencies

Most local and state agencies act responsibly

- highly aware of water resource issues
- adopted some level of management
- some network of observation bores

Problems

- often water level measurements are irregular (time and space)

- data on groundwater extraction is mostly very limited

- agencies typically establish a valuable database
  often do not utilise it effectively
  data turnaround usually slow

Groundwater Models

Many agencies have produced simulation models (FDM and FEM) at least for major groundwater systems

Simulation models are important, but often limited by poor conceptual hydrogeological models

Numerical simulation models are usually unavailable to most stakeholders

When models are available → in hard copy report

Numerical models usually *not understood* or *trusted* by stakeholders

Visualisation

Increasingly used in sciences
in geosciences, especially for subsurface systems

Usually the response to 3D visualisation and animation is highly positive (community, users **and** managers)

→ *understanding* and enhances cooperation between regulatory agencies and water users

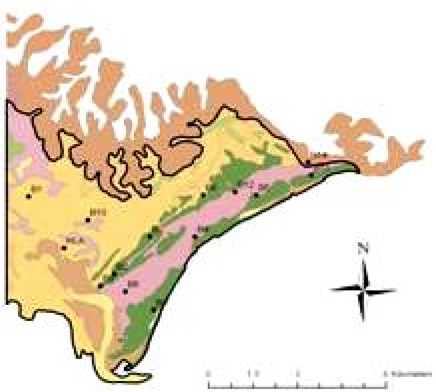
Our Aims

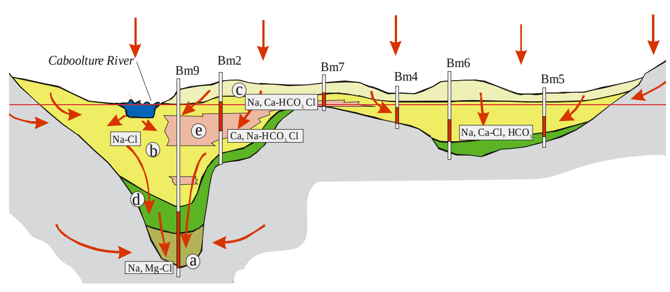
visualisation model of hydrogeological “framework”

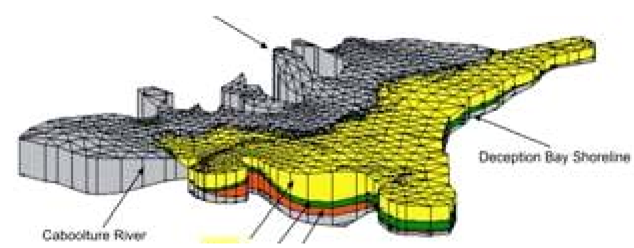
does not require expensive licences

relatively easy to learn to operate

“take-home” CD with documentation for most desktop PC’s







Groundwater Visualisation System (GVS)

product → flexible software package for most groundwater systems

- display 2D and 2.5D images
- multiple layers of selected surface data
- 3D visualisation of a conceptual models
- display animation of lines, surfaces or other time-series data
- display drillholes in space with downhole data
- enable variable viewing (zoom, rotation)
- enable interrogation such as cross-section slicing and dragging
- switching on and off of images, opacity variation
- internal solid geometry (hydrogeology)
- linked database
- imbedded bore hydrographs and rainfall data

Important: ability to integrate multiple data sets

Applications

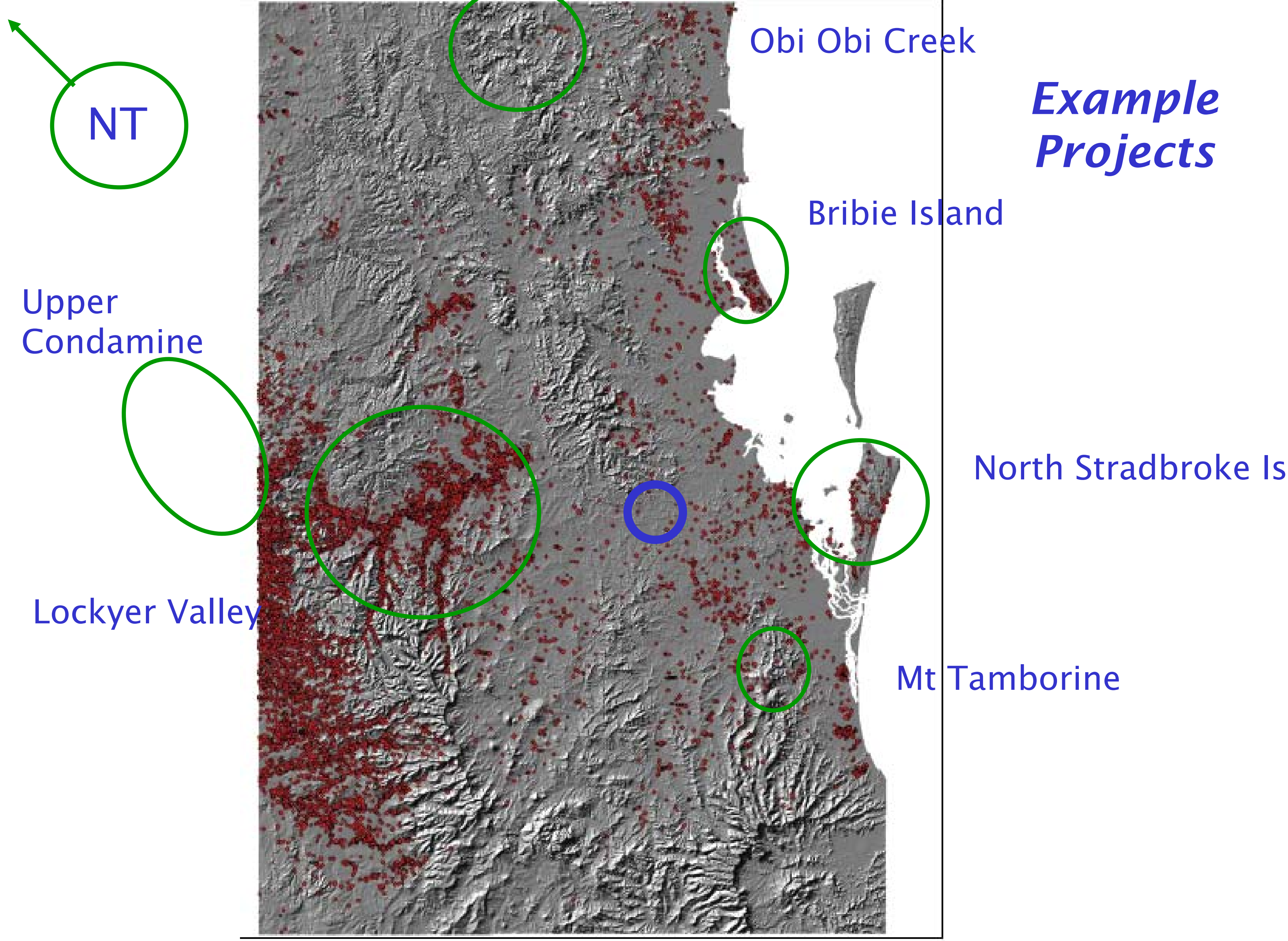
QUT projects develop 3D *vis models* for various cases
available data integrated → hydrogeological framework

- Landcare/catchment groups concerned about water quality &
- resource integrity
- Irrigated catchments with intensive extraction (deltaic or alluvial sediments): sugarcane, cotton, mixed crops
- support management of unregulated use in expanding rural subdivisions
- manage urban supply in sand aquifers (+ sand mining)
- testing recharge processes

Meetings with stakeholders and agencies

For many of these projects a numerical simulation model exists
→ the *vis models* are seen as independent

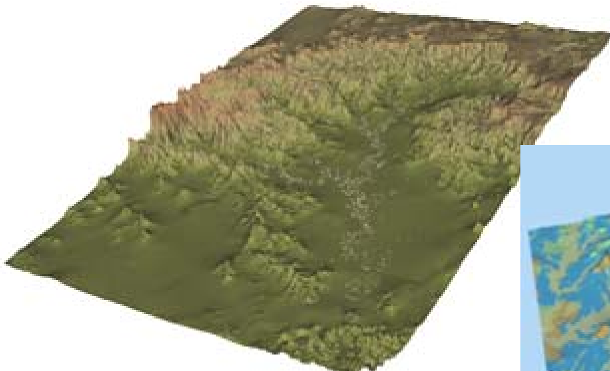
Example Projects

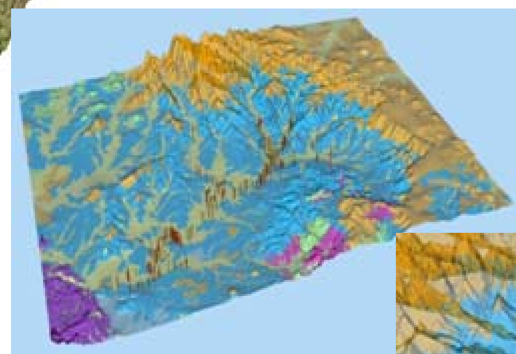


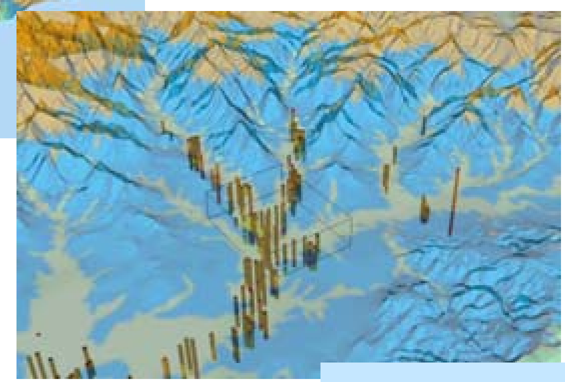
Lockyer Valley

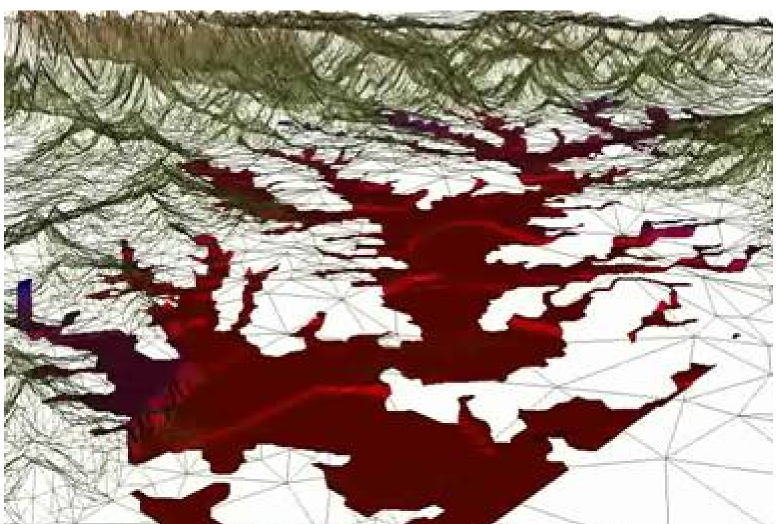
initially tested 3D method and visualisation/animation

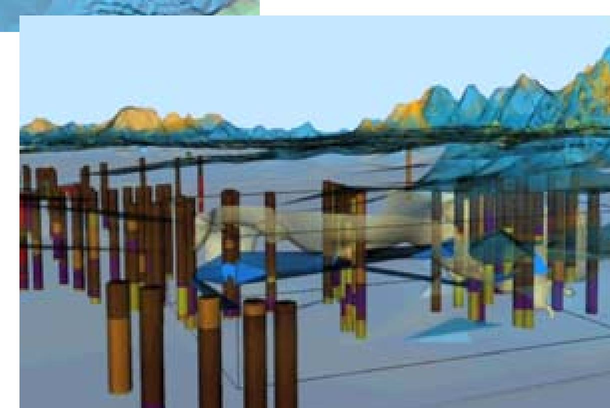
new project for whole catchment: alluvium model and water level animation



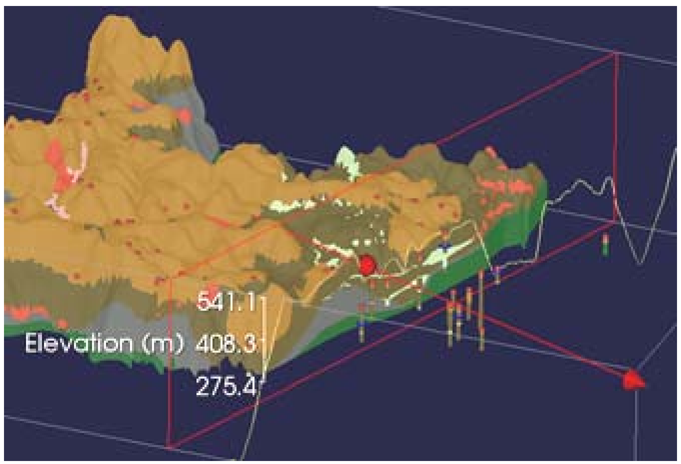


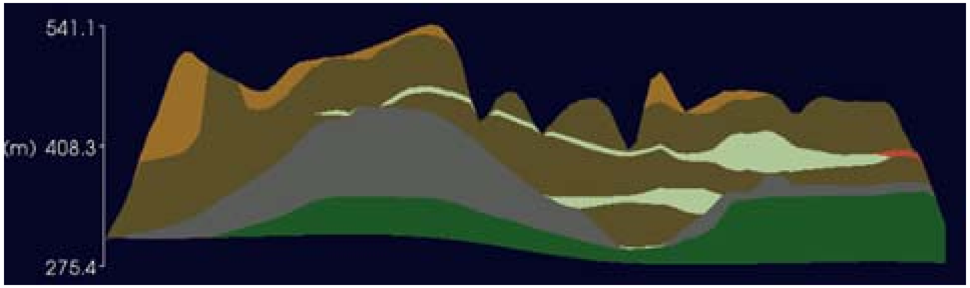


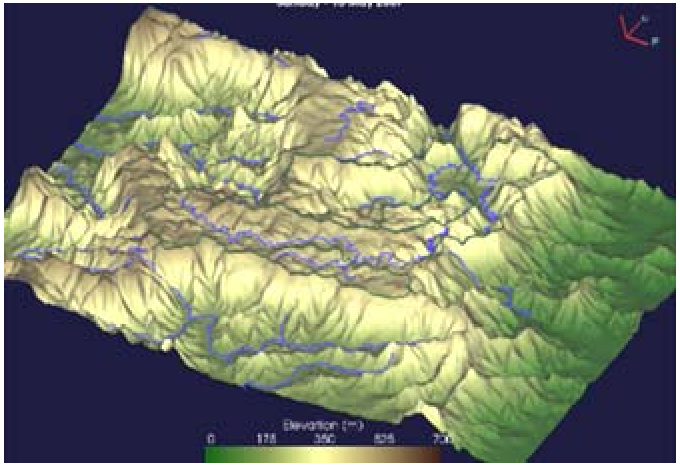




Obi Obi Creek catchment (Maleny)
Landcare group
Interest in groundwater system
Links to surface waters, reservoir and water quality

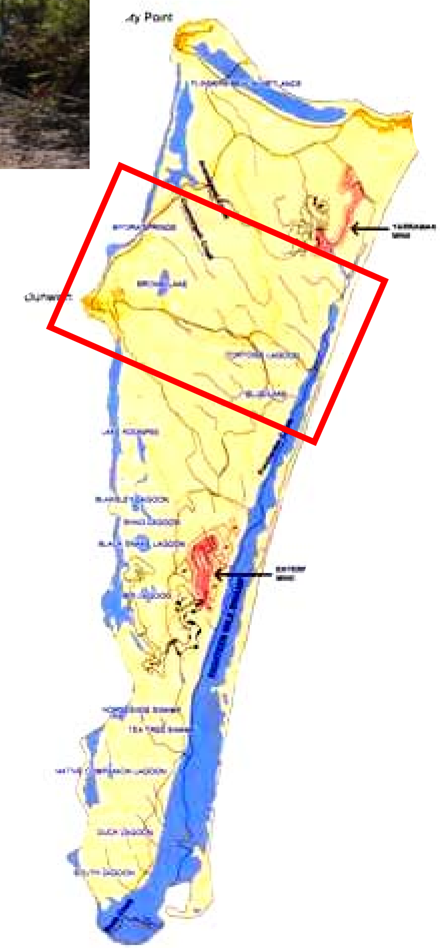


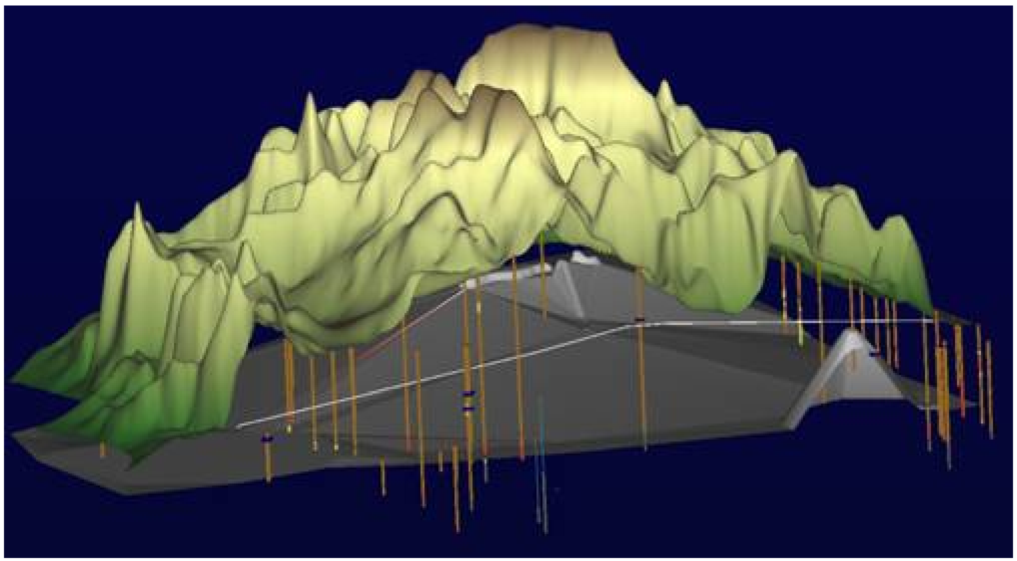




North Stradbroke Is

develop GVS, test water level animation
Ideas for whole island model
DERM has Modflow model

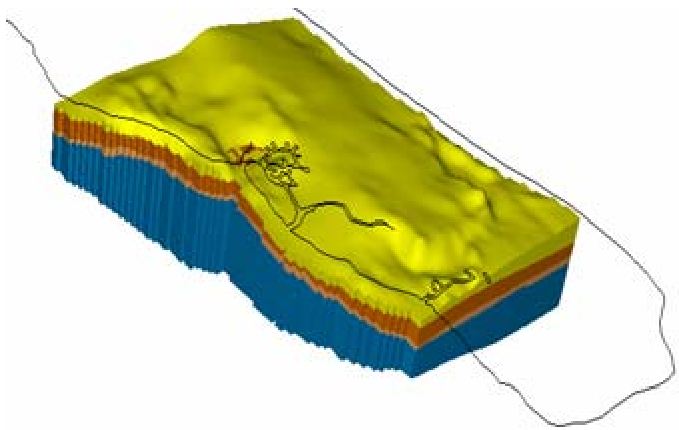


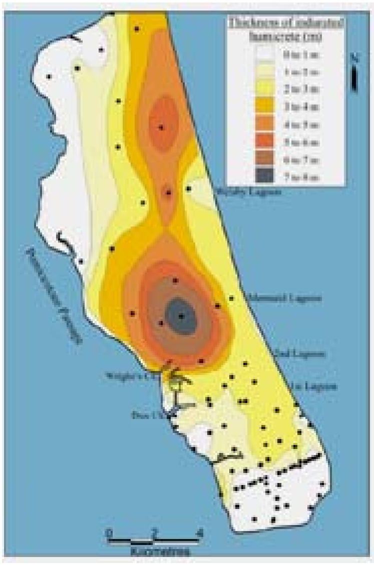


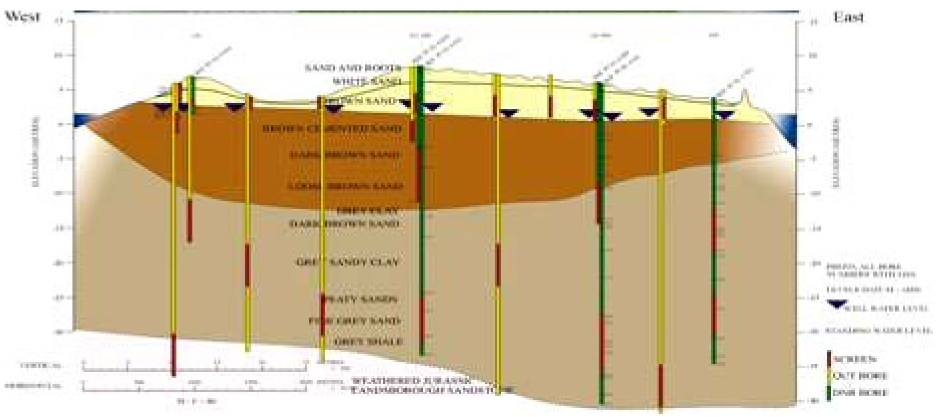
Bribie Island

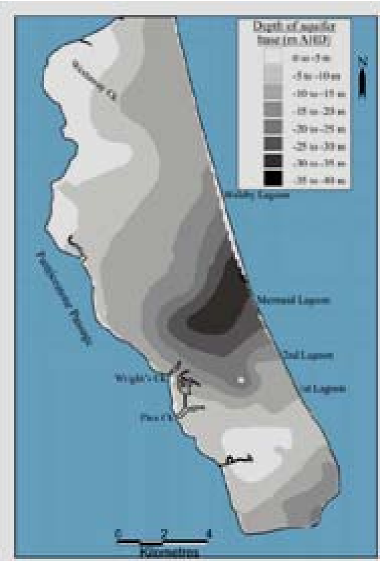
community pressure re new bore field: concerns

DERM has Modflow model; doing a new one



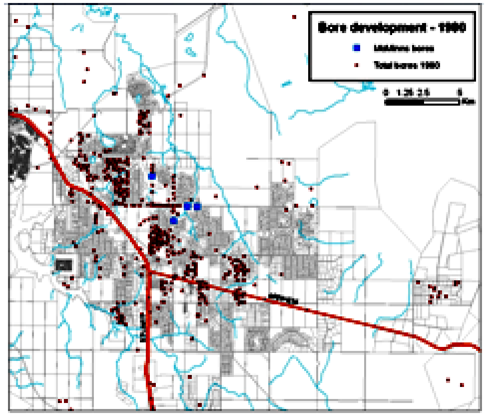


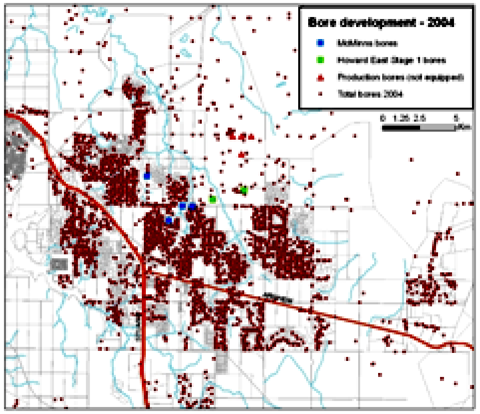


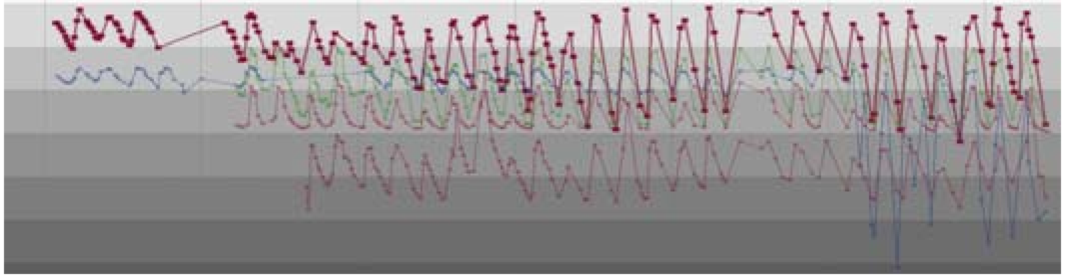


Howard East: NT

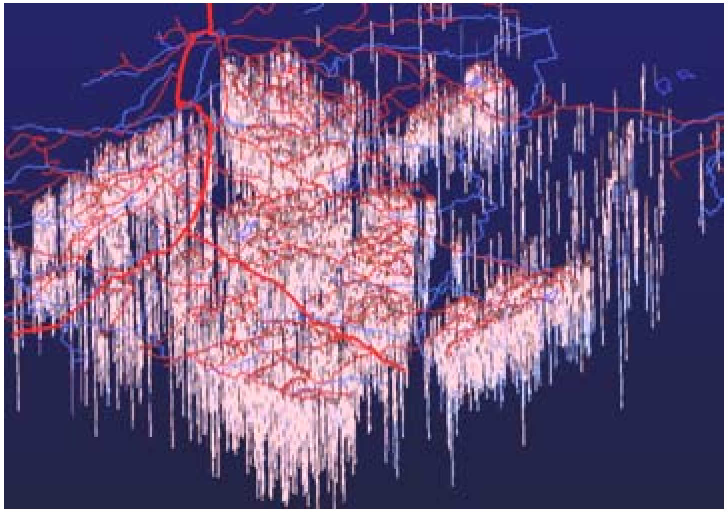
uncontrolled g/water use in rural developments
NRETAS has Modflow & Feflow models





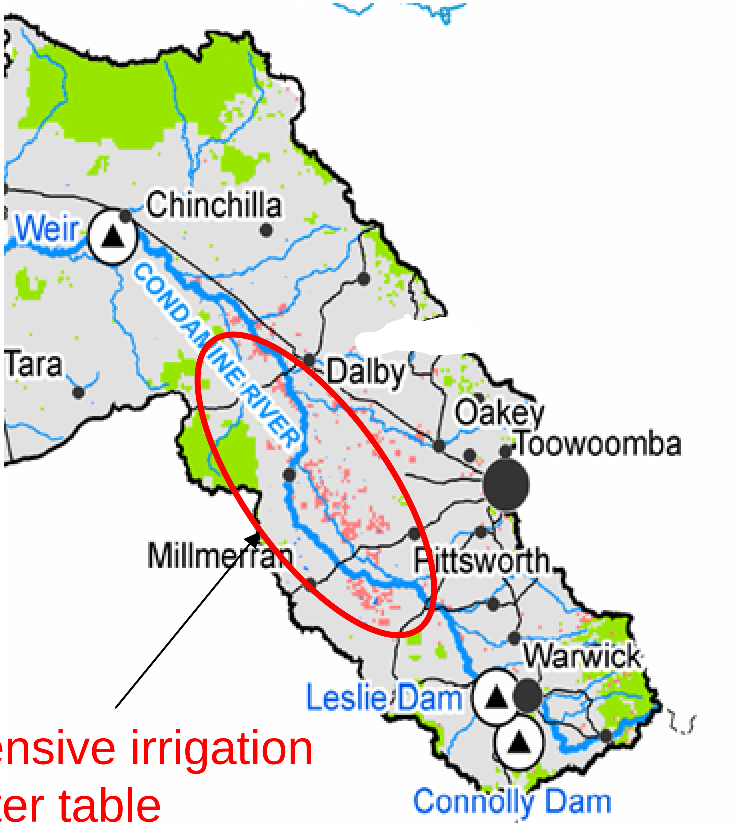


1970 2005



Upper Condamine

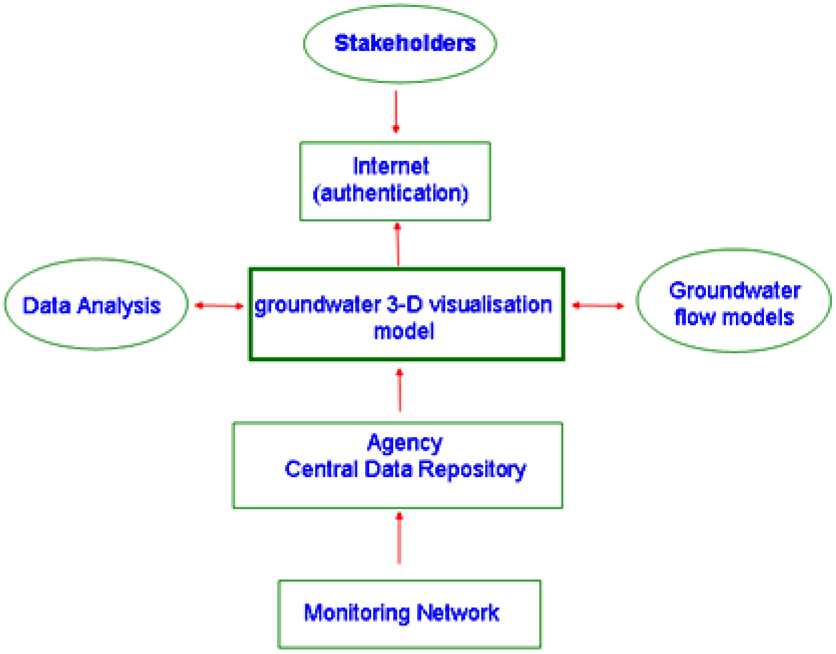
intensive irrigation for cotton
400+ monitoring bores
deep alluvium, layered aquifers, unknown links
recharge not fully understood (?very old water)
3D vis model in parallel with new Modflow model



intensive irrigation
water table
drawdown > 5 m

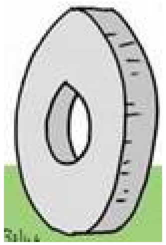
Where to?

* features of GVS developed and refined with each project
* potential for externally generated models (e.g. g/water flow simulations) to be imported
* introduce water chemistry data and maps
* looking at regional models (link with GoCad)
* long term aim develop remote capability
  flexible access
  remote interrogation of GVS model



Common Questions

Are we re-inventing the wheel?

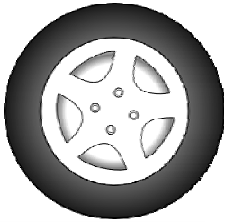


Future funding?

Is this research?

Being done by software powerhouses?

Continuing need and market?



Thank you

Australian Government

Geoscience Australia

Using open standards to deliver digital geoscience information for 3D modelling

GeoSciML and OGC data standards

Ollie Raymond
Geoscience Australia

Interoperability Working Group
IUGS Commission for the Management and Application of Geoscience Information (CGI)

GEOSCIENCE AUSTRALIA

Committee for the Management and Application of Geoscience Information

Interoperability Working Group

Australia

USA

Canada

UK

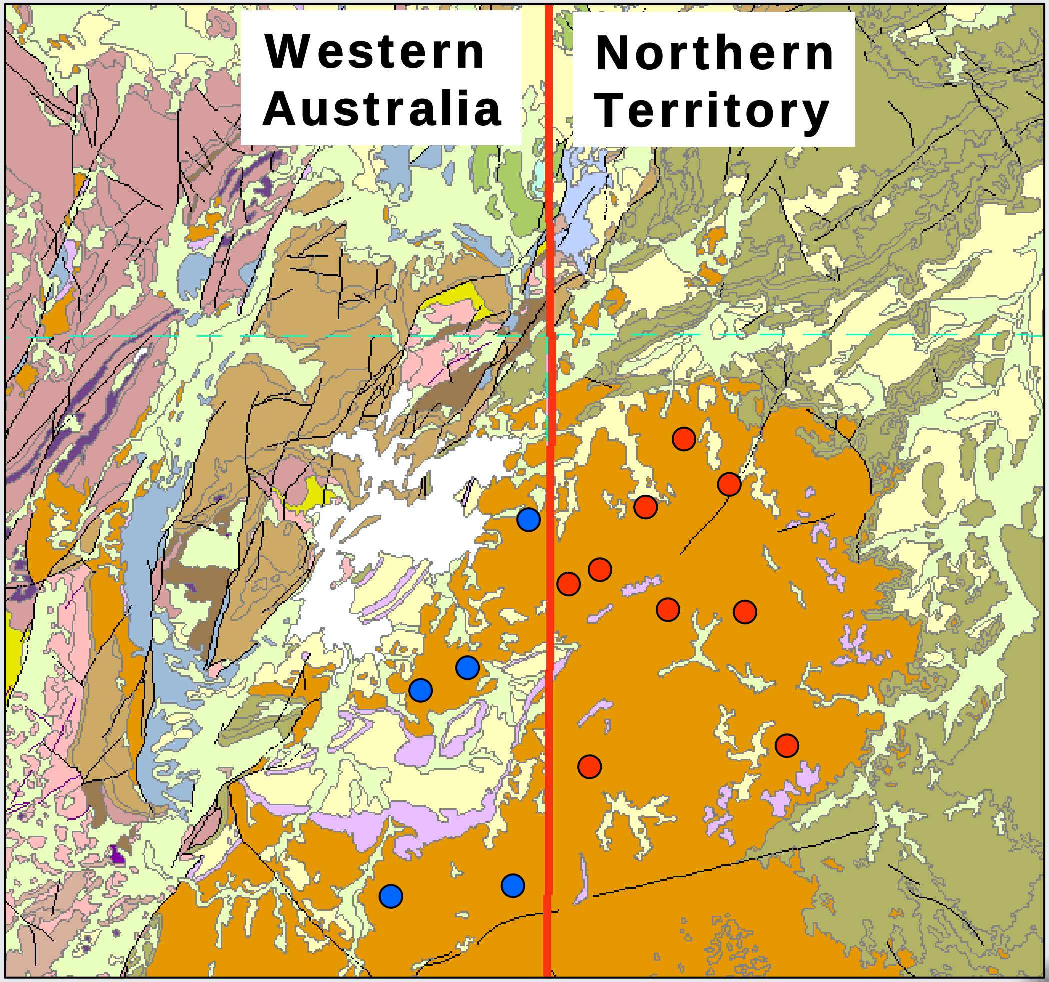
France

Sweden

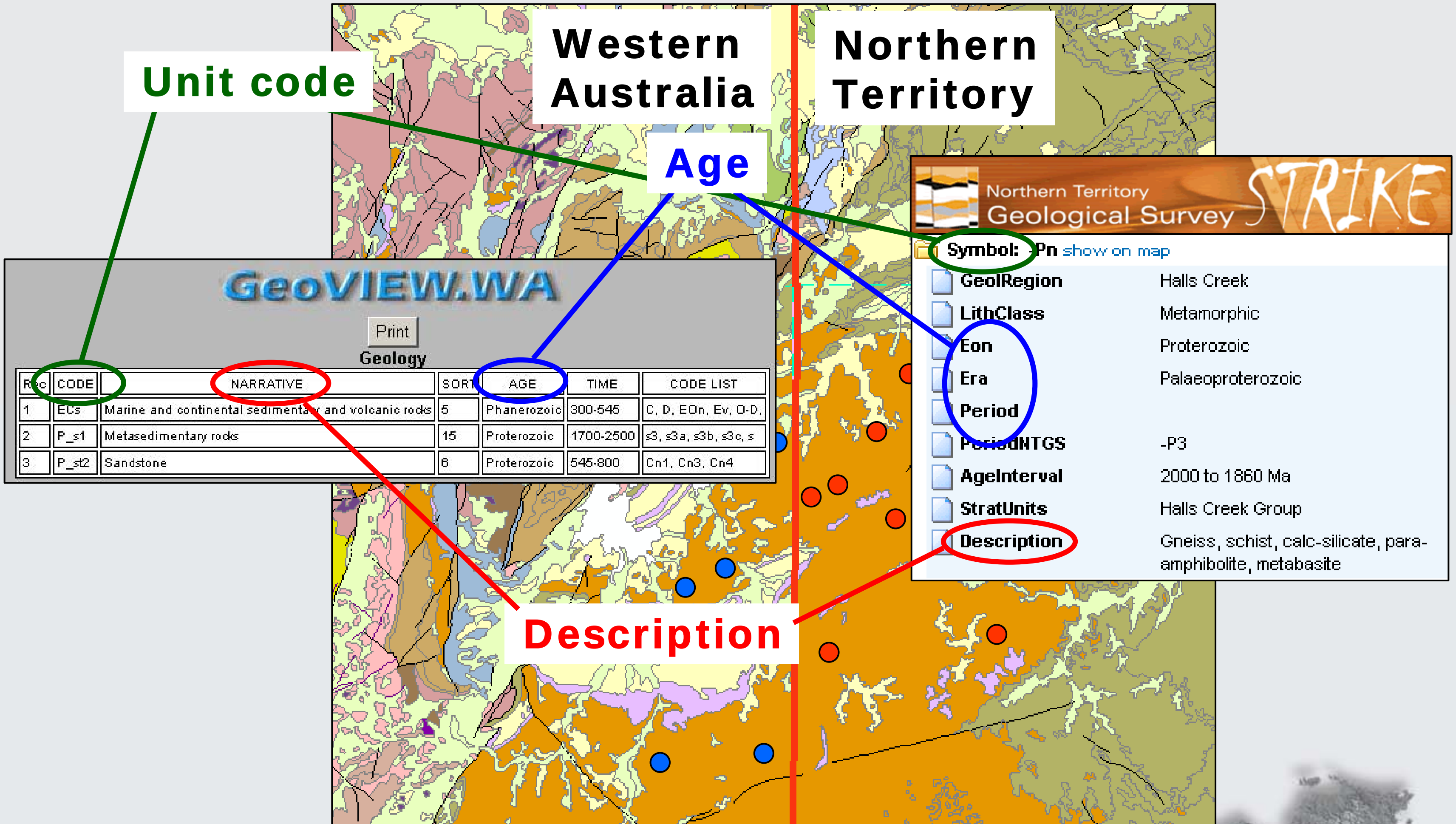
Japan

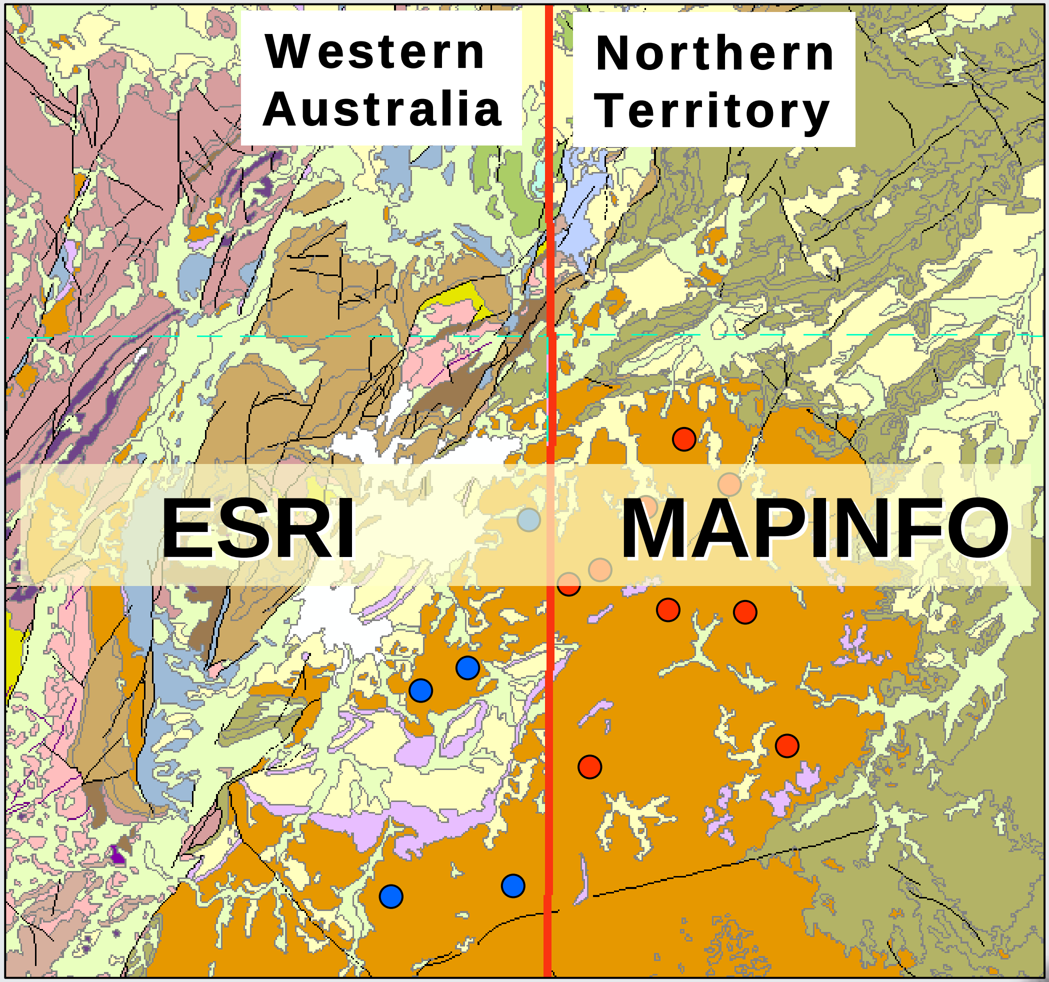
Italy

Dealing with data from distributed sources...



Don’t you hate it when…




Western Australia
Northern Territory
ESRI
MAPINFO

You need an agreed data transfer standard....

Open Geospatial Consortium (OGC)

provides a framework for developing open, internationally agreed, data transfer standards

(eg; GeoSciML and O&M)

and standard protocols to broadcast that data via the internet (ie; WMS, WFS, WCS)

What are GeoSciML and O&M? (Part 1)

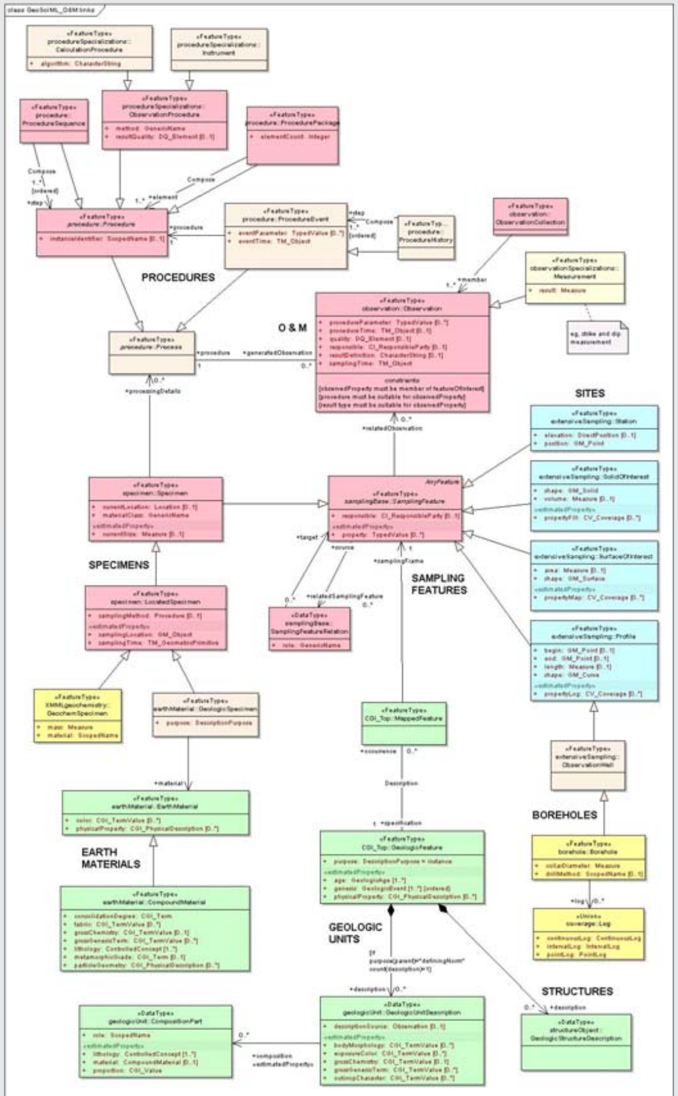
- **O**bservations and **M**easurements Markup Language
  - for describing sampling features (eg; boreholes)
  - for describing observations related to sampling features
- **GeoSci**ence **M**arkup **L**anguage
  - for describing geological features

What are GeoSciML and O&M? (Part 2)

Data Model

- a logical data structure
  - tells users what data goes where
- a complex model (hierarchical, relational)
- scientifically robust, developed by the scientific community
- internationally agreed
- what terminology may be used (vocabularies)

What are GeoSciML and O&M? (Part 3)



GeoSciML

- geological units
- geological structures
- earth materials
- rock properties
- relations between geological features
- mapped features (2D, 3D)
- vocabularies
- metadata

O&M

- sampling sites, specimens
- borehole collars and paths
- locations (2D, 3D)
- survey metadata
- borehole logs
- relations between observations and sampling media
- time series measurements
- metadata

What are GeoSciML and O&M? (Part 4)

XML encoding

- the markup language used to deliver the data model to the internet


```xml
<?xml version="1.0" encoding="UTF-8" ?>
<!--  Example of encoding a BGS borehole using the MappedInterval approach   -->
- <wfs:FeatureCollection xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://www.opengis.net/wfs
   http://schemas.opengis.net/wfs/1.1.0/wfs.xsd urn:cgi:xmlns:CGI:GeoSciML:2.0
   http://www.geosciml.org/geosciml/2.0/xsd/geosciml.xsd" xmlns:gml="http://www.opengis.net/gml"
   xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:wfs="http://www.opengis.net/wfs" xmlns:gsml="urn:cgi:xmlns:CGI:GeoSciML:2.0">
 - <gml:featureMember>
  - <gsml:Borehole xmlns="urn:cgi:xmlns:CGI:GeoSciML:2.0" gml:id="bh.TR34SWBJ90" xmlns:om="http://www.opengis.net/om/1.0"
      xmlns:sa="http://www.opengis.net/sampling/1.0" xmlns:cv="http://www.opengis.net/cv/0.2.1">
      <gml:name codeSpace="http://www.cgi-iugs.org/uri">urn:cgi:feature:BGS:SOBI:TR34SW/BJ/90/.</gml:name>
      <gml:name>ELMS VALE</gml:name>
      <sa:sampledFeature xlink:role="urn:cgi:featureType:CGI:GeoSciML:2.0:GeologicUnit" xlink:href="urn:ogc:def:nil:OGC:unknown" />
    - <sa:shape>
      - <gml:LineString gml:id="bh.TR34SWBJ90.shape" srsName="urn:ogc:def:crs:EPSG:6.15:7405" srsDimension="3">
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          <gml:pos>630400 0141150 74.5</gml:pos>
        </gml:LineString>
      </sa:shape>
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    - <gsml:collarLocation>
      - <gsml:BoreholeCollar>
        - <gsml:location>
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            </gml:Point>
          </gsml:location>
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```

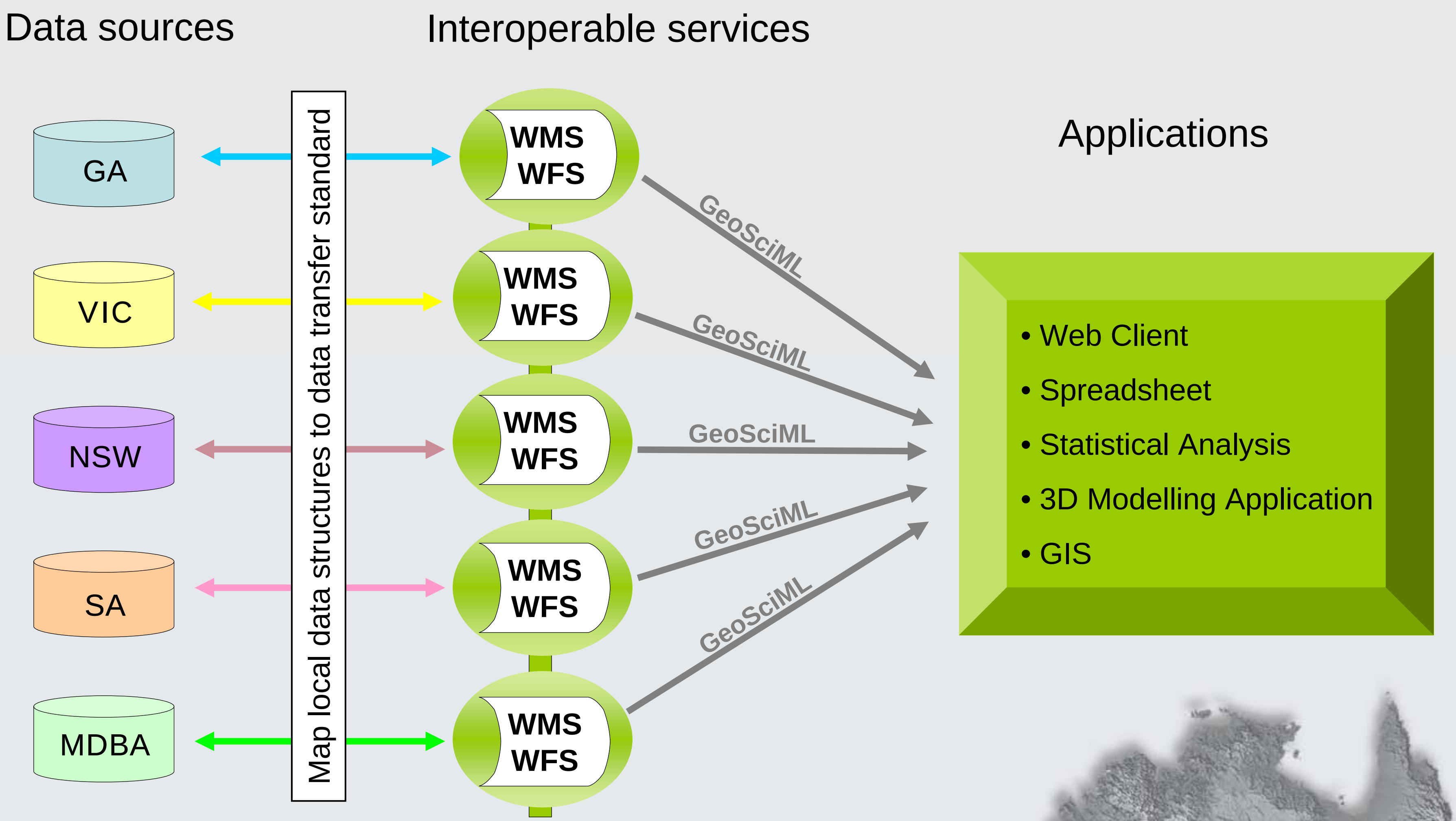
What are GeoSciML and O&M? (Part 4)

XML encoding

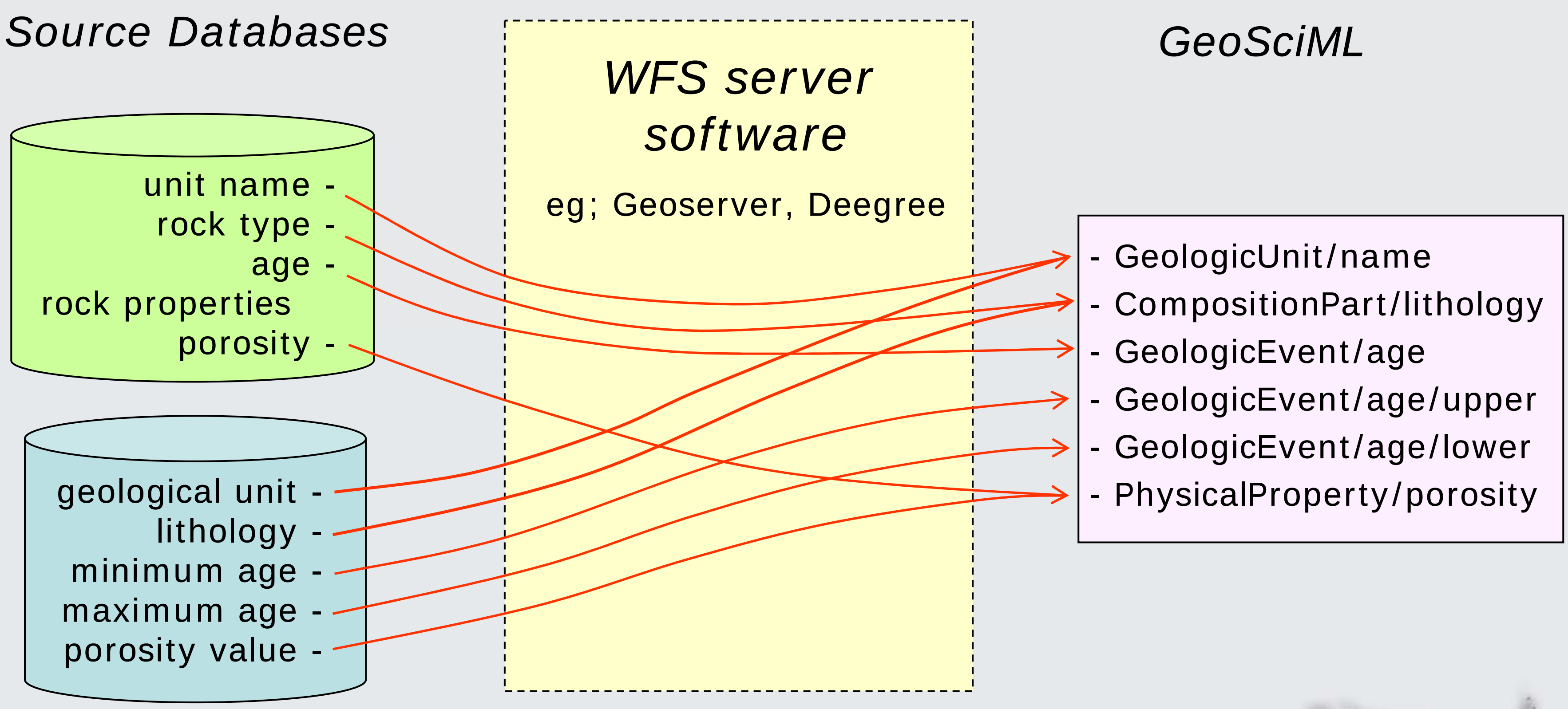
- the markup language used to deliver the data model to the internet
- built on established OGC standards such as WFS (Web Feature Service) and GML (Geographic Markup Language)
- open source
- software independent
- machine readable

Web Services Data Delivery Model

Service Oriented Architecture (SOA)



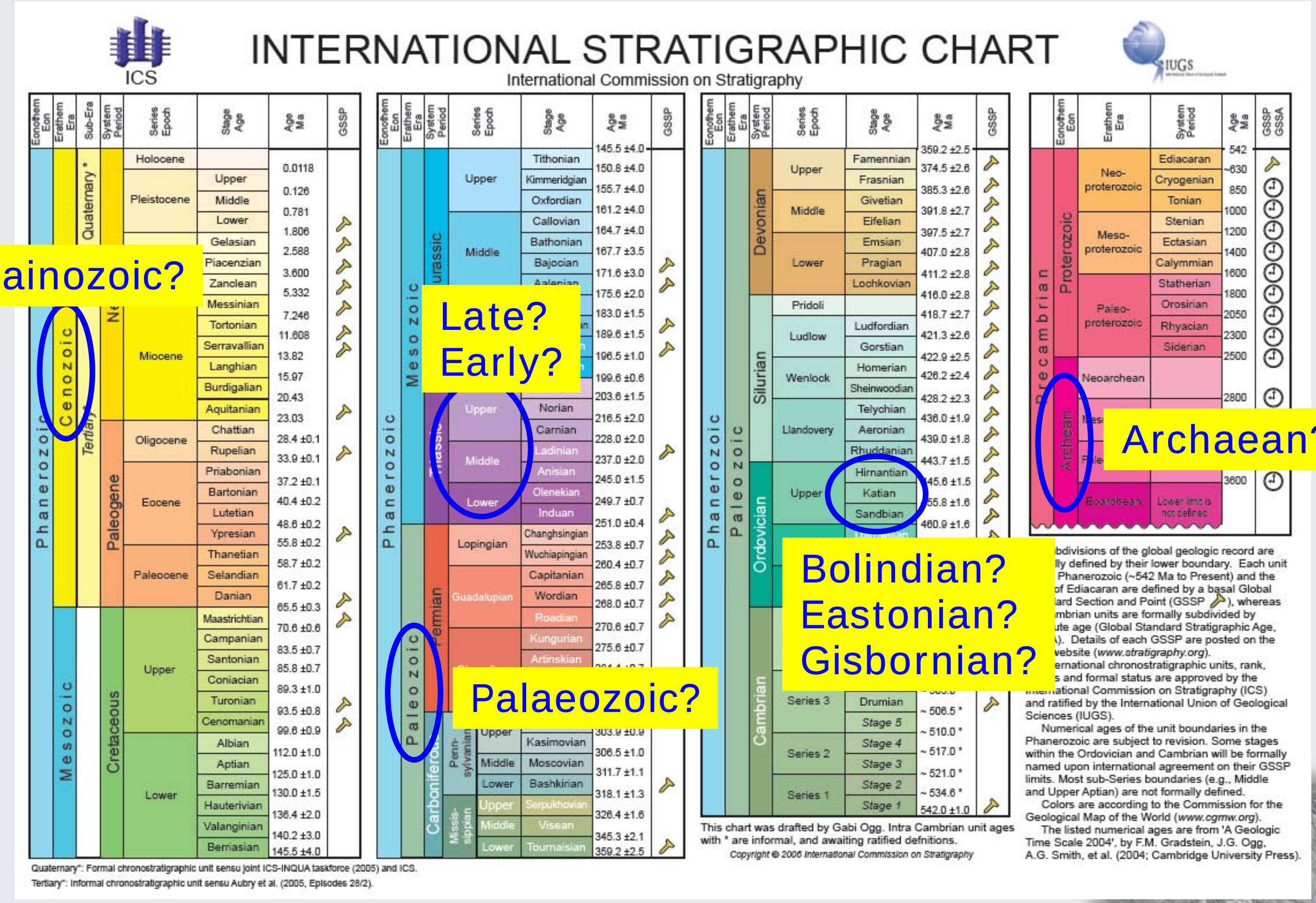
Mapping local databases to GeoSciML



- typically, no alterations to local data stores are necessary

Using agreed vocabularies eg; age

- resolves issues of spelling, language, synonymy, hierarchy



Groundwater data transfer standards?

WaterML
- for surface water data
- international collaboration (predominantly USA)

- GroundWaterML
  - developed in Canada for Canadian data
  - potential for collaboration to make it a global standard

Ground**W**ater **M**arkup **L**anguage - GWML

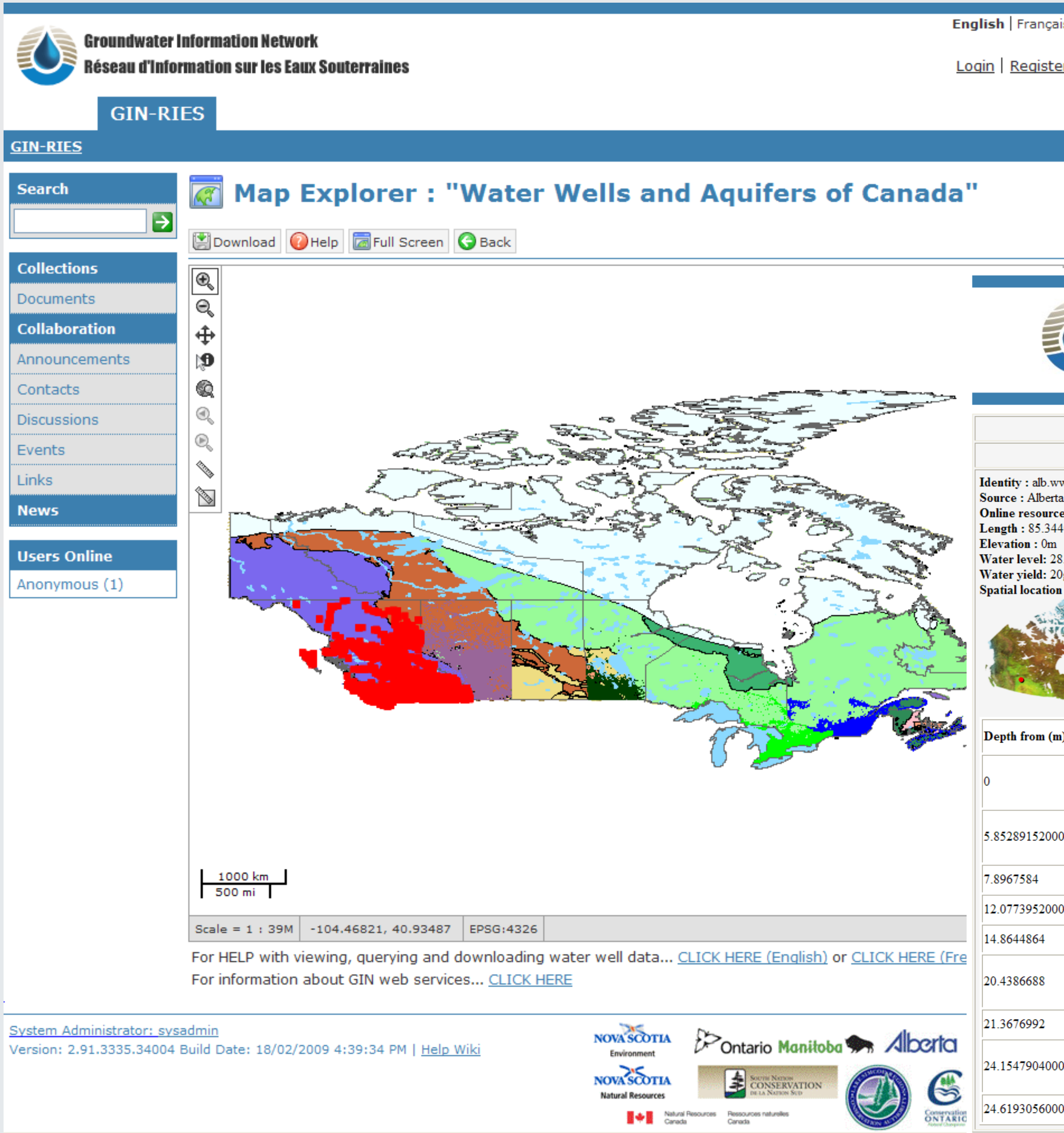
- an exchange standard built on GeoSciML and O&M
- developed by the Geological Survey of Canada for their Groundwater Information Network (GIN).
- the model covers description of hydrogeological units, using groundwater properties and geological properties
- also covers water quality and quantity and groundwater exploitation artifacts (eg; wells)

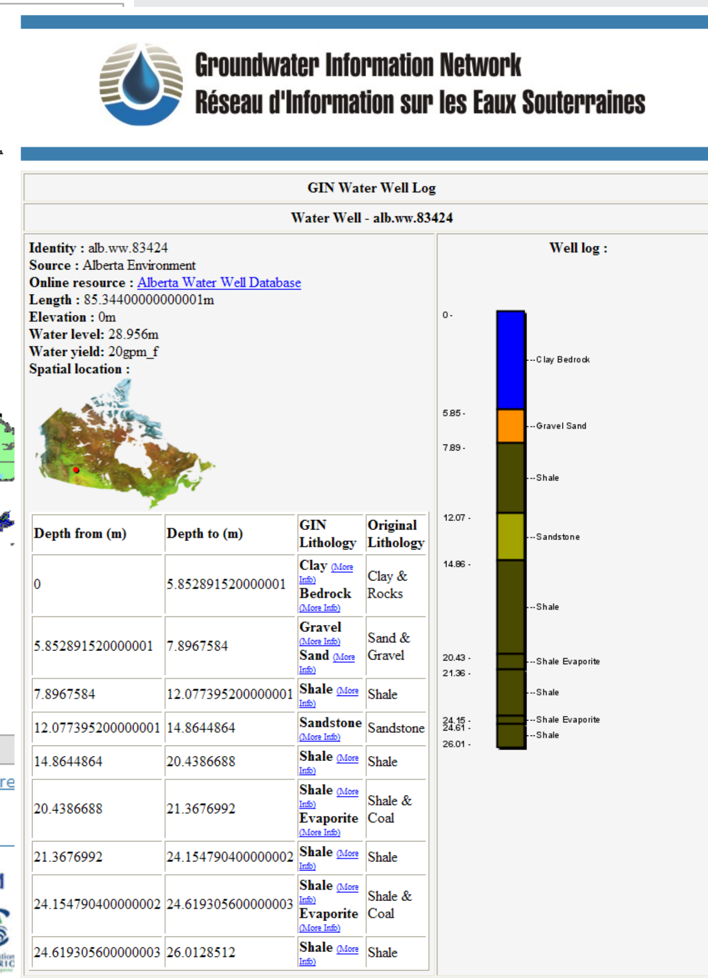
http://gw-info.net/

70 different groundwater-related feature types including

- aquifers, aqicludes, aquitards
  - including rock type attributes, porosity etc from GeoSciML
- water quantity, reservoirs
- water flow systems, levels, budgets
- borehole components
  - extension of O&M
  - eg; casing, screens, pumping, seals
- monitoring and testing
- water composition, quality, salinity
  - eg; suspended, dissolved and colloidal content
- relations between hydrogeological objects

Canadian Groundwater Information Network





GIN Water Well Log

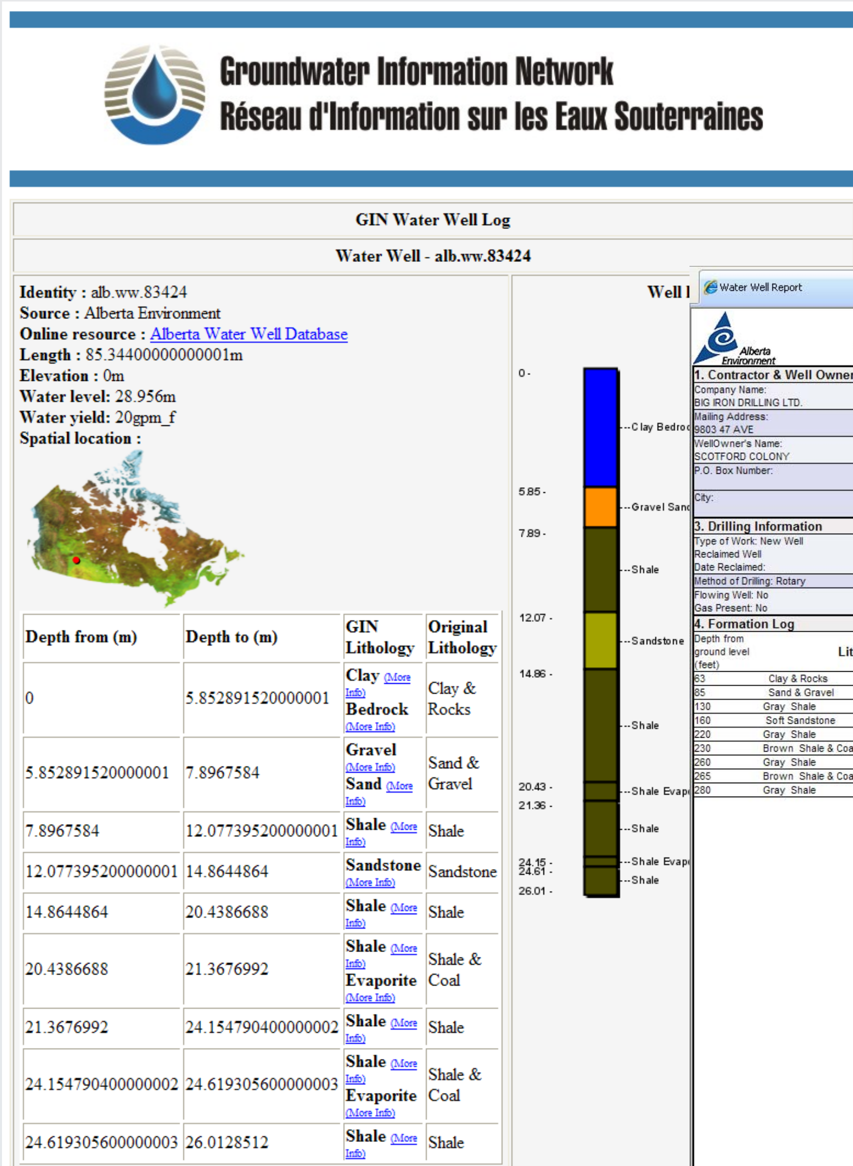
Water Well - alb.ww.83424

Identity : alb.ww.83424
Source : Alberta Environment
Online resource : Alberta Water Well Database
Length : 85.34400000000001m
Elevation : 0m
Water level: 28.956m
Water yield: 20gpm_f
Spatial location :

Well log :

Depth from (m)	Depth to (m)	GIN Lithology	Original Lithology
0	5.852891520000001	Clay (More Info) Bedrock (More Info)	Clay & Rocks
5.852891520000001	7.8967584	Gravel (More Info) Sand (More Info)	Sand & Gravel
7.8967584	12.077395200000001	Shale (More Info)	Shale
12.077395200000001	14.8644864	Sandstone (More Info)	Sandstone
14.8644864	20.4386688	Shale (More Info)	Shale
20.4386688	21.3676992	Shale (More Info) Evaporite (More Info)	Shale & Coal
21.3676992	24.154790400000002	Shale (More Info)	Shale
24.154790400000002	24.619305600000003	Shale (More Info) Evaporite (More Info)	Shale & Coal
24.619305600000003	26.0128512	Shale (More Info)	Shale

Canadian Groundwater Information Network



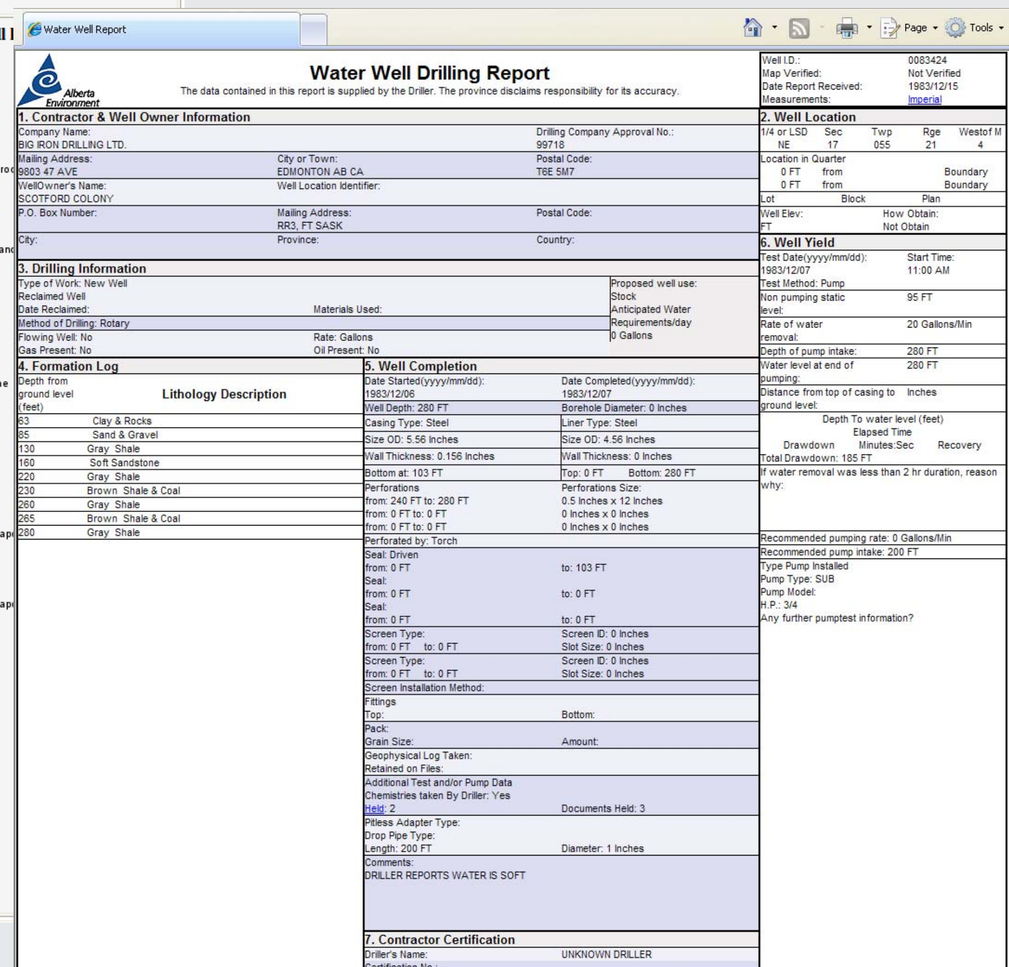
Groundwater Information Network
Réseau d'Information sur les Eaux Souterraines

GIN Water Well Log

Water Well - alb.ww.83424

Identity : alb.ww.83424
Source : Alberta Environment
Online resource : Alberta Water Well Database
Length : 85.34400000000001m
Elevation : 0m
Water level: 28.956m
Water yield: 20gpm_f
Spatial location :

Depth from (m)	Depth to (m)	GIN Lithology	Original Lithology
0	5.852891520000001	Clay (More Info) Bedrock (More Info)	Clay & Rocks
5.852891520000001	7.8967584	Gravel (More Info) Sand (More Info)	Sand & Gravel
7.8967584	12.077395200000001	Shale (More Info)	Shale
12.077395200000001	14.8644864	Sandstone (More Info)	Sandstone
14.8644864	20.4386688	Shale (More Info)	Shale
20.4386688	21.3676992	Shale (More Info) Evaporite (More Info)	Shale & Coal
21.3676992	24.154790400000002	Shale (More Info)	Shale
24.154790400000002	24.619305600000003	Shale (More Info) Evaporite (More Info)	Shale & Coal
24.619305600000003	26.0128512	Shale (More Info)	Shale



Water Well Report

Water Well Drilling Report

The data contained in this report is supplied by the Driller. The province disclaims responsibility for its accuracy.

Well I.D.: 0083424
Map Verified: Not Verified
Date Report Received: 1983/12/15
Measurements: Imperial

1. Contractor & Well Owner Information
Company Name: BIG IRON DRILLING LTD.
Drilling Company Approval No.: 99718
Mailing Address: 9803 47 AVE
City or Town: EDMONTON AB CA
Postal Code: T6E 5M7
WellOwner's Name: SCOTFORD COLONY
Well Location Identifier:
P.O. Box Number:
Mailing Address: RR3, FT SASK
Postal Code:
City:
Province:
Country:

2. Well Location
1/4 or LSD: NE; Sec: 17; Twp: 055; Rge: 21; Westof M: 4
Location in Quarter
0 FT from Boundary
0 FT from Boundary
Lot / Block / Plan
Well Elev: FT; How Obtain: Not Obtain

3. Drilling Information
Type of Work: New Well
Reclaimed Well
Date Reclaimed:
Materials Used:
Method of Drilling: Rotary
Flowing Well: No
Rate: Gallons
Gas Present: No
Oil Present: No
Proposed well use: Stock
Anticipated Water Requirements/day: 0 Gallons

4. Formation Log

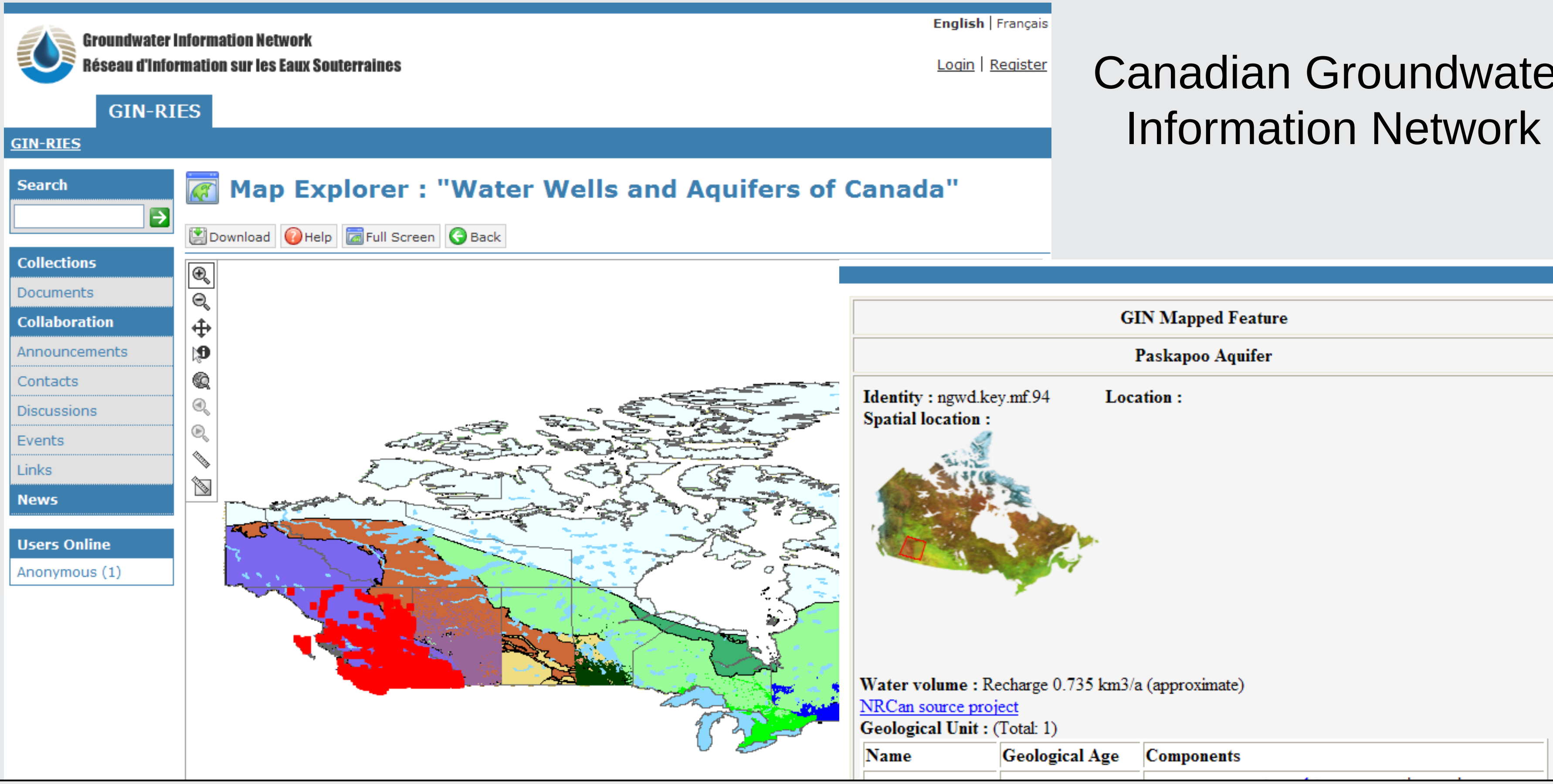
Depth from ground level (feet)	Lithology Description
63	Clay & Rocks
85	Sand & Gravel
130	Gray Shale
160	Soft Sandstone
220	Gray Shale
230	Brown Shale & Coal
260	Gray Shale
265	Brown Shale & Coal
280	Gray Shale

5. Well Completion
Date Started(yyyy/mm/dd): 1983/12/06
Date Completed(yyyy/mm/dd): 1983/12/07
Well Depth: 280 FT
Borehole Diameter: 0 Inches
Casing Type: Steel
Liner Type: Steel
Size OD: 5.56 Inches
Size OD: 4.56 Inches
Wall Thickness: 0.156 Inches
Wall Thickness: 0 Inches
Bottom at: 103 FT
Top: 0 FT Bottom: 280 FT
Perforations
from: 240 FT to: 280 FT
from: 0 FT to: 0 FT
from: 0 FT to: 0 FT
Perforations Size:
0.5 Inches x 12 Inches
0 Inches x 0 Inches
0 Inches x 0 Inches
Perforated by: Torch
Seal: Driven
from: 0 FT to: 103 FT
Seal:
from: 0 FT to: 0 FT
Seal:
from: 0 FT to: 0 FT
Screen Type:
from: 0 FT to: 0 FT
Screen ID: 0 Inches
Slot Size: 0 Inches
Screen Type:
from: 0 FT to: 0 FT
Screen ID: 0 Inches
Slot Size: 0 Inches
Screen Installation Method:
Fittings
Top:
Bottom:
Pack:
Grain Size:
Amount:
Geophysical Log Taken:
Retained on Files:
Additional Test and/or Pump Data
Chemistries taken By Driller: Yes
Held: 2
Documents Held: 3
Pitless Adapter Type:
Drop Pipe Type:
Length: 200 FT
Diameter: 1 Inches
Comments:
DRILLER REPORTS WATER IS SOFT

6. Well Yield
Test Date(yyyy/mm/dd): 1983/12/07
Start Time: 11:00 AM
Test Method: Pump
Non pumping static level: 95 FT
Rate of water removal: 20 Gallons/Min
Depth of pump intake: 280 FT
Water level at end of pumping: 280 FT
Distance from top of casing to ground level: Inches
Depth To water level (feet)
Drawdown / Elapsed Time Minutes:Sec / Recovery
Total Drawdown: 185 FT
If water removal was less than 2 hr duration, reason why:
Recommended pumping rate: 0 Gallons/Min
Recommended pump intake: 200 FT
Type Pump Installed
Pump Type: SUB
Pump Model:
H.P.: 3/4
Any further pumptest information?

7. Contractor Certification
Driller's Name: UNKNOWN DRILLER
Certification No.:

Canadian Groundwater Information Network

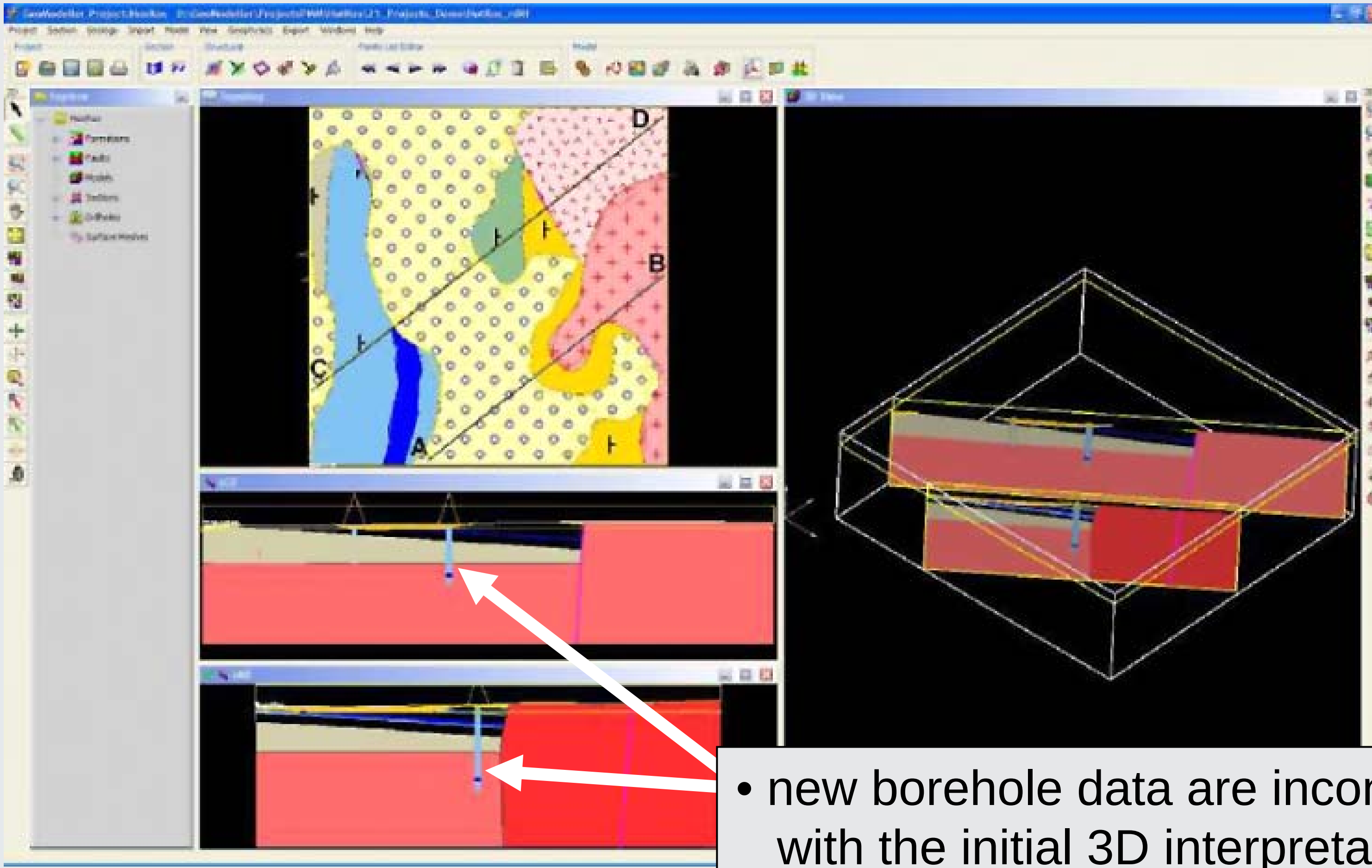


- 3D applications using GWML data are available to registered users

An example of borehole data in 3D modelling

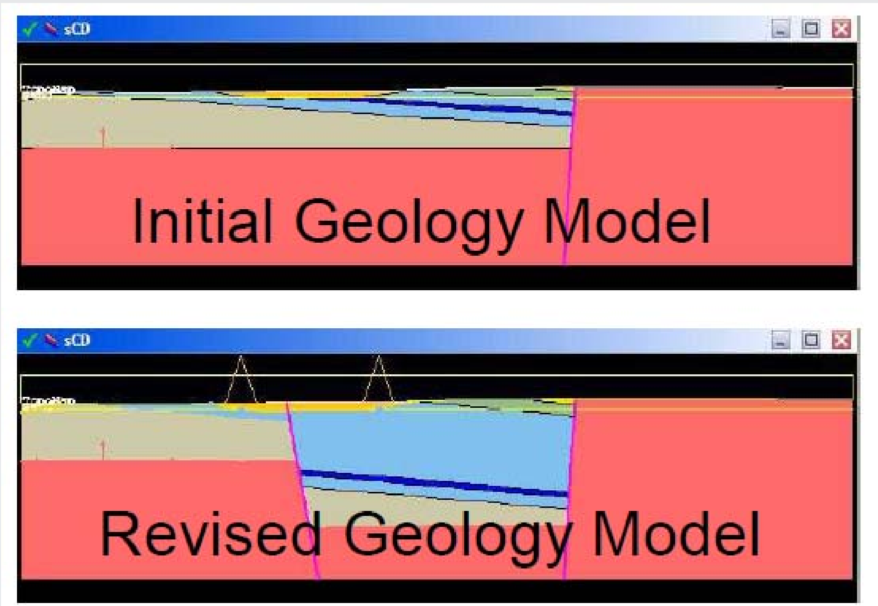
- import O&M/GeoSciML borehole data into GeoModeller

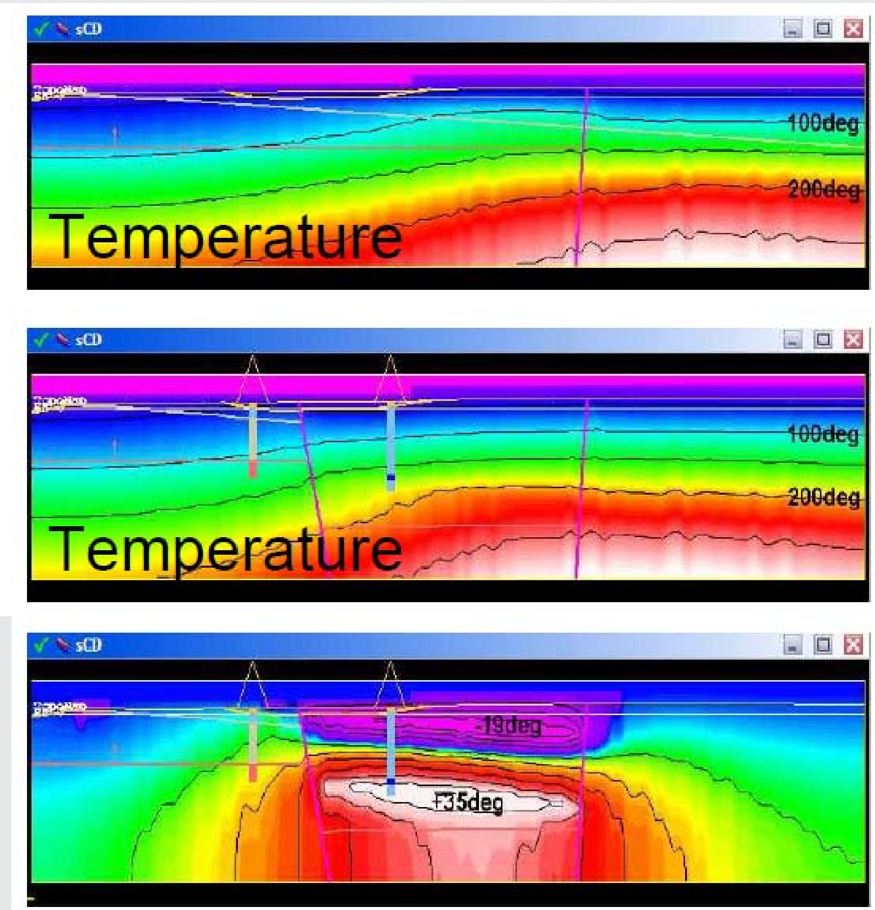
GeoModeller borehole example



- new borehole data are inconsistent with the initial 3D interpretation
- a thicker sedimentary pile is indicated

GeoModeller borehole example





The revised geological model results in a significantly different temperature model

In summary,

- Established international data transfer standards such as O&M and GeoSciML provide a mechanism for sharing interoperable geoscience data from distributed data sources

- Data transfer standards in the groundwater domain are less mature, but have been developed and used overseas for delivering and manipulating data in 3D

Questions?

AN ORGANISATION FOR A NATIONAL
EARTH SCIENCE INFRASTRUCTURE PROGRAM

AuScope and its role in the looming geoscience digital deluge

Bruce Simons

AuScope Grid

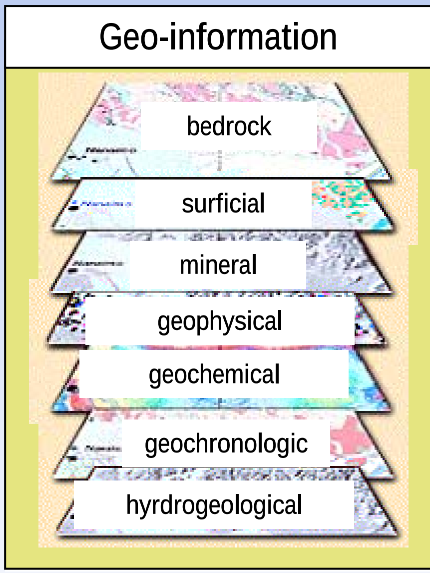
Department of Primary Industries

Outline

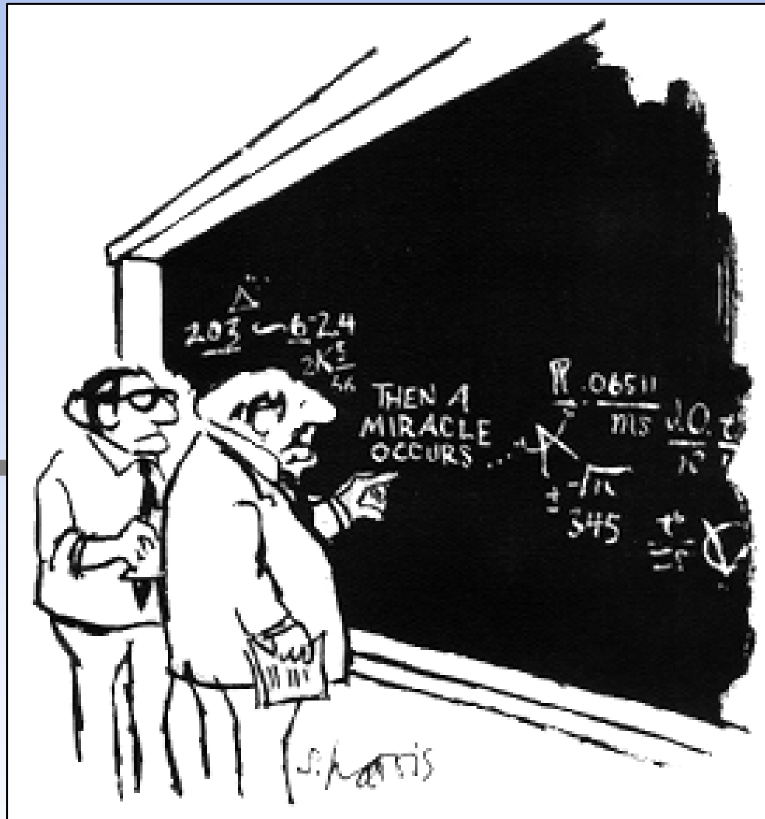
- Why build an Earth Science Information Network?
- What is AuScope?
- What is an Information Network?
- Building an Earth Science Information Network
- The AuScope Earth Science Information Network

AuScope

Decisions, decisions…?



knowledge base



"I think you should be more explicit here in step two."

?

Commonwealth

State

Local

Regional

Industry

Research

decision makers

AuScope

With acknowledgement to Boyan Brodaric, Natural Resources Canada

Don’t you hate it when……………………..

- You have to keep and maintain versions of someone else’s data, and you don’t know if it’s correct or outdated?
- You know there’s useful information out there, but you cannot find it?
- You waste valuable time downloading and converting datasets?
- You can see the data you want on a web map but you can’t download the real data for analysis?

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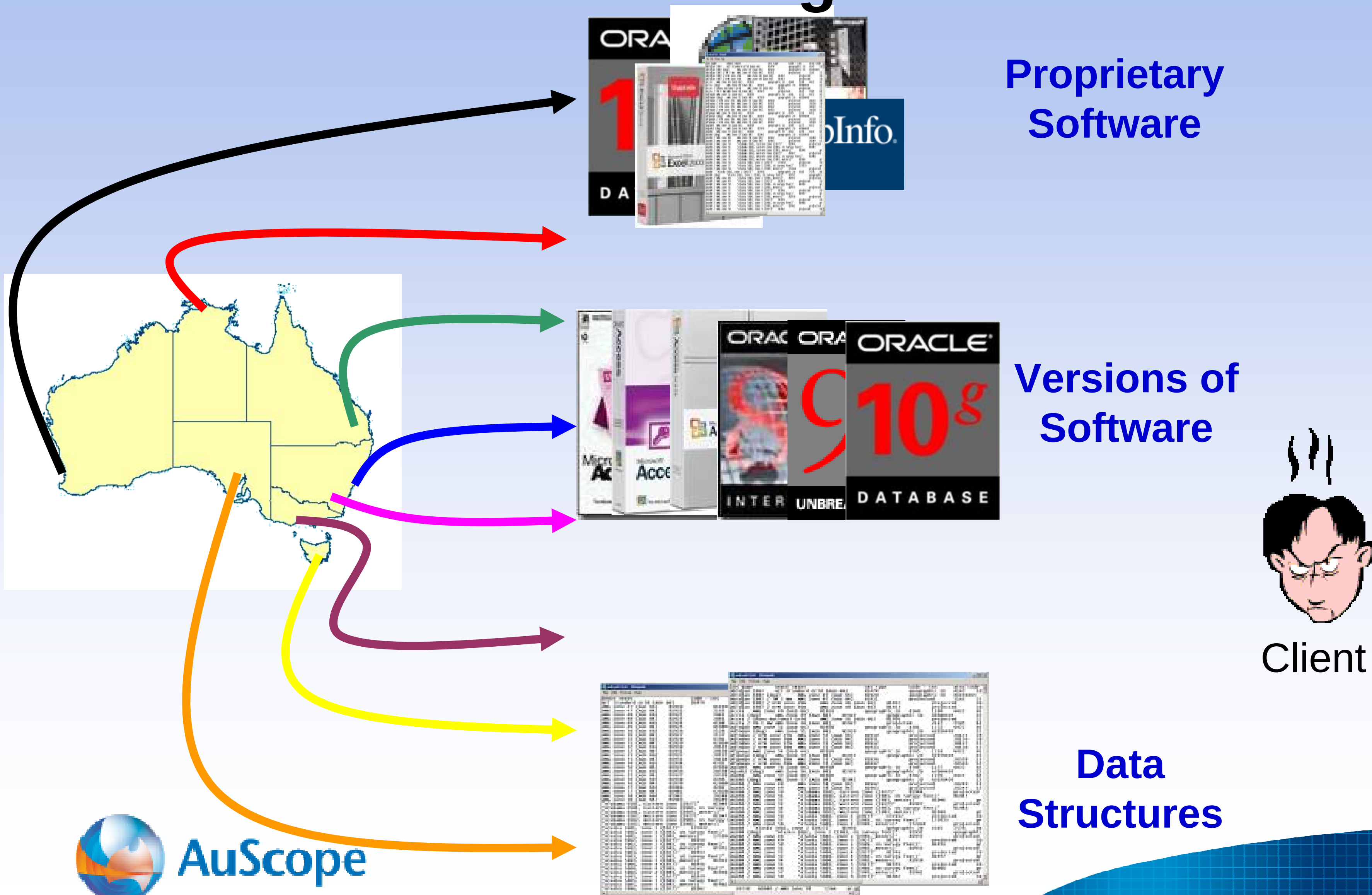
Part of our problem…data access is not standardised across organisations



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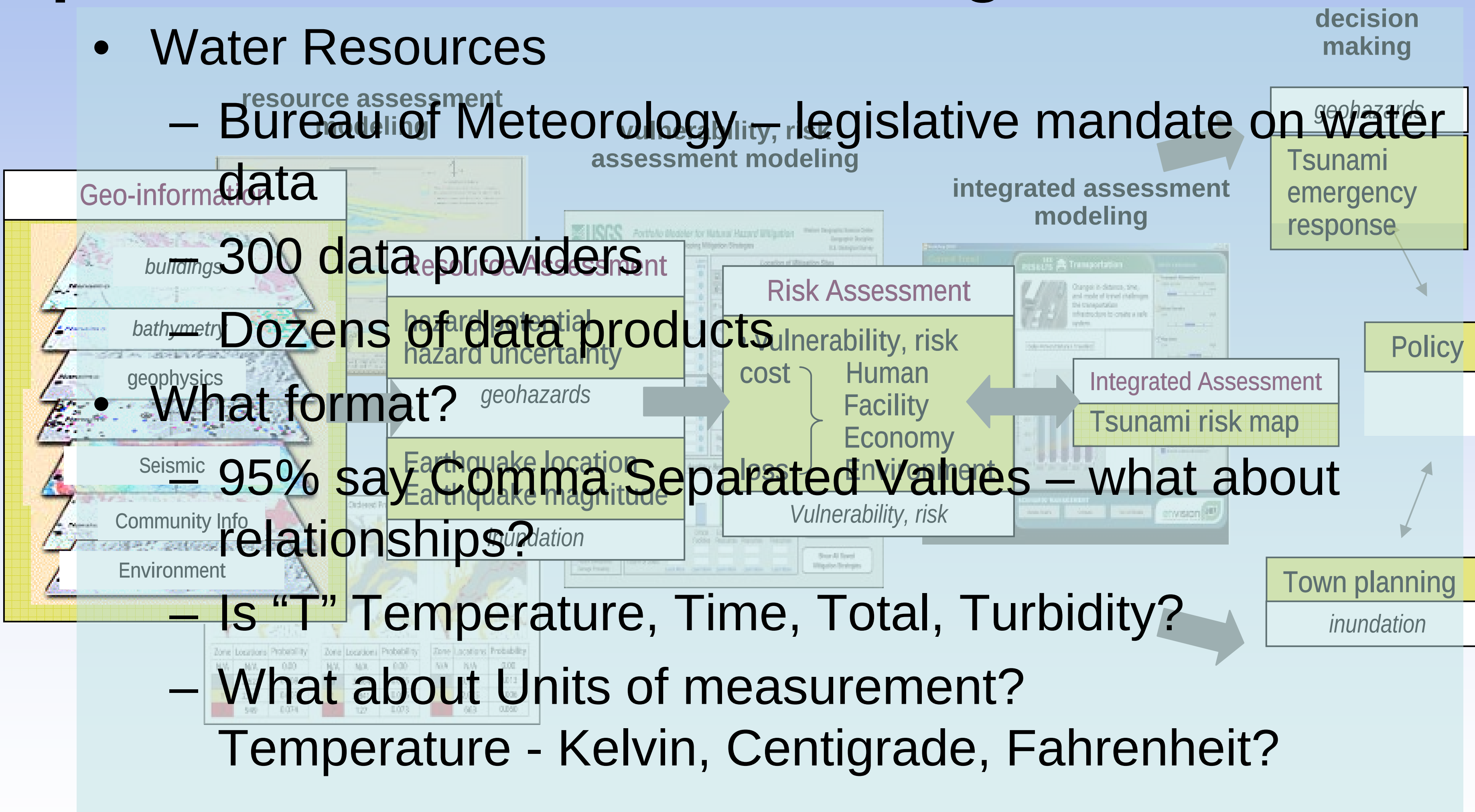
The problem runs deeper…information is part of a workflow across organisations

- Water Resources
  - Bureau of Meteorology – legislative mandate on water data
  - 300 data providers
  - Dozens of data products
- What format?
  - 95% say Comma Separated Values – what about relationships?
  - Is "T" Temperature, Time, Total, Turbidity?
  - What about Units of measurement? Temperature - Kelvin, Centigrade, Fahrenheit?



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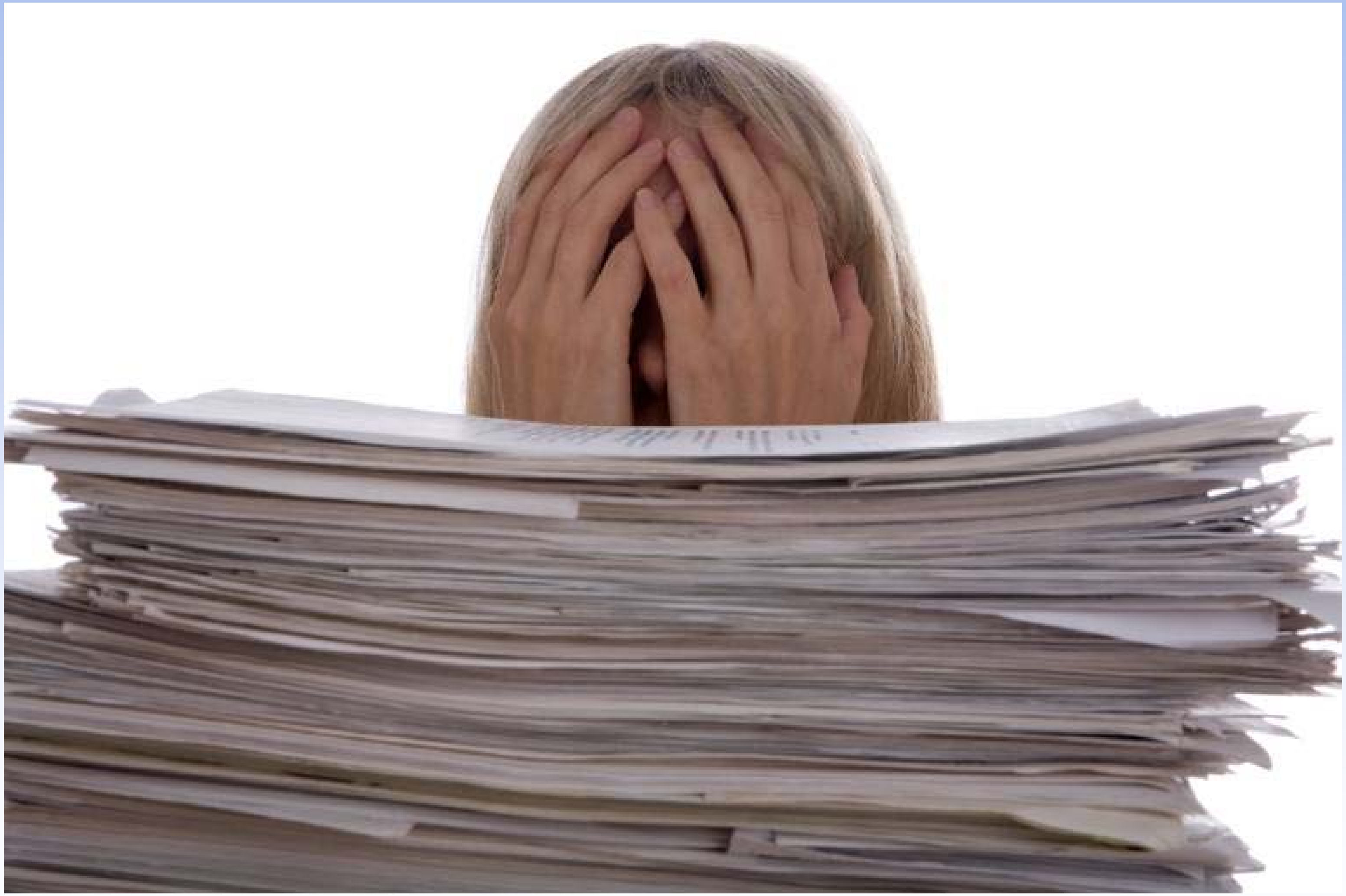
It’s all to hard



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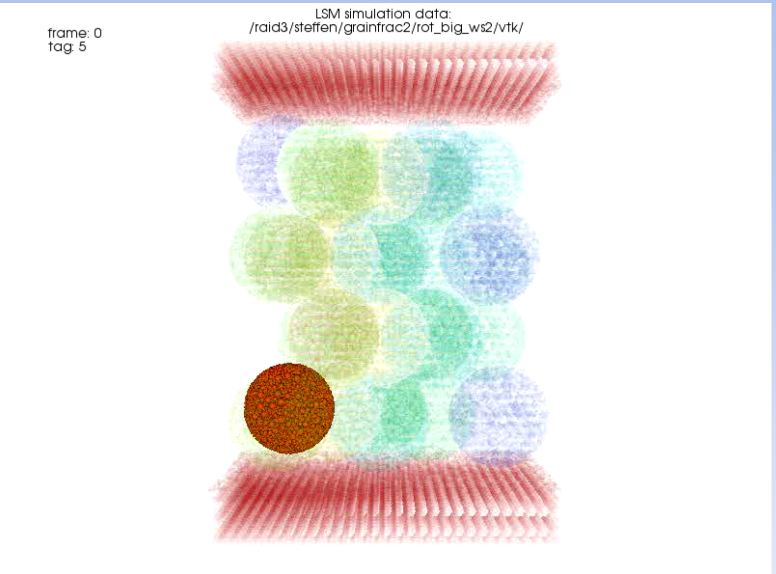
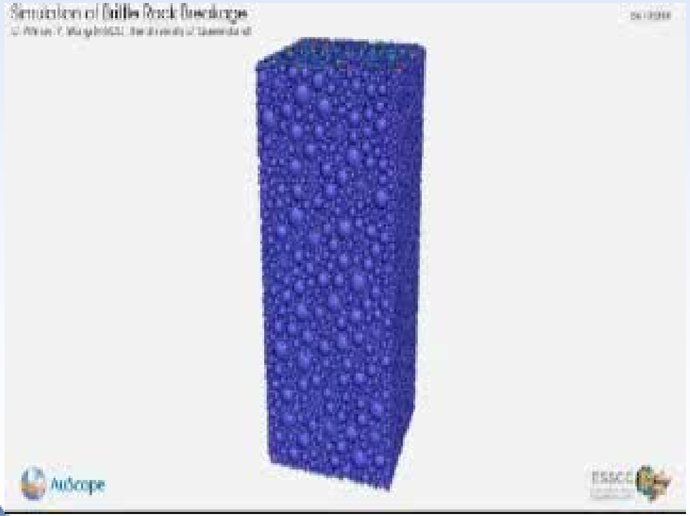
What is AuScope?

Earth Science *Research Community*

Integration of observations, models, simulation, analysis, workflows





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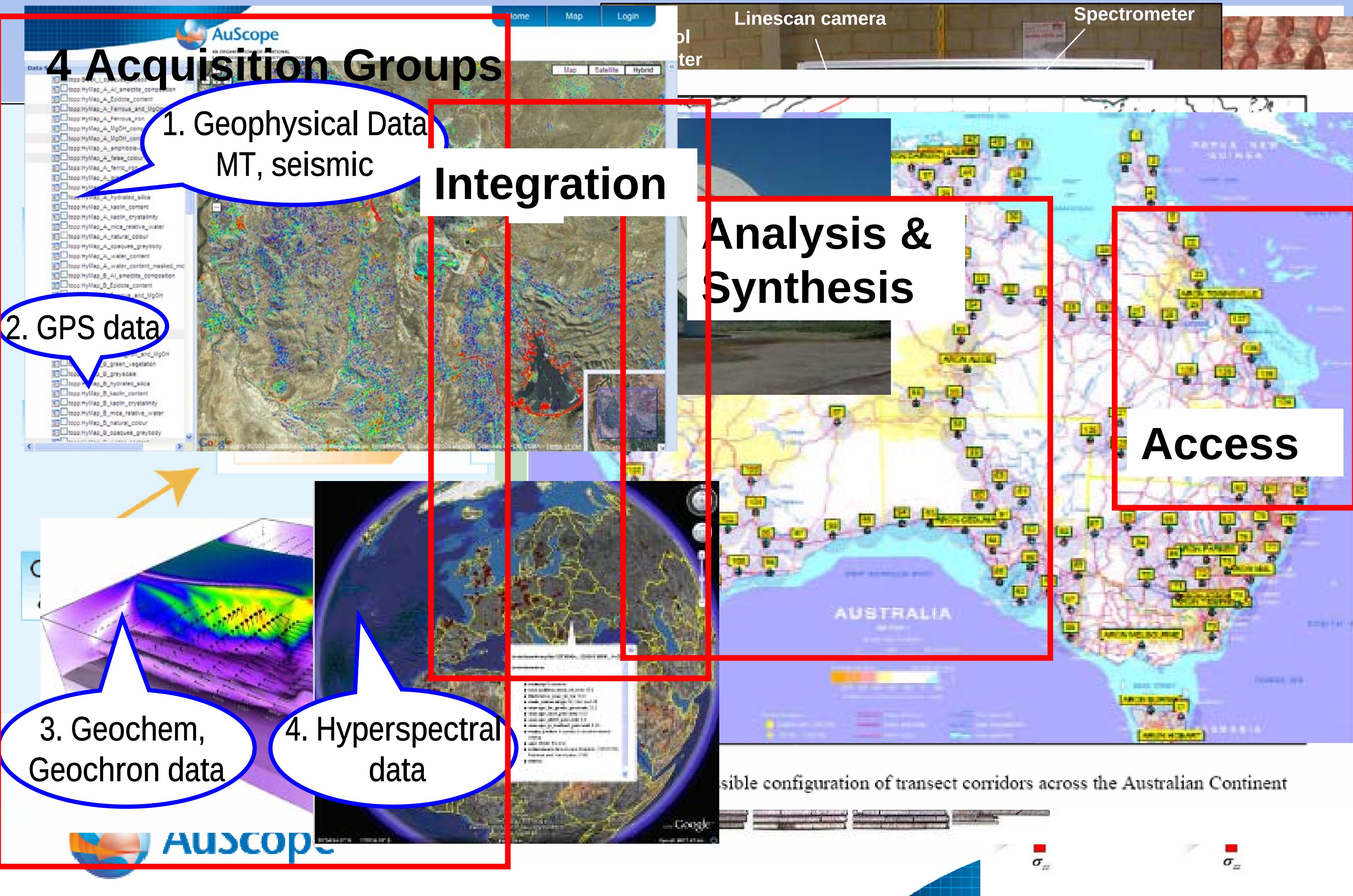
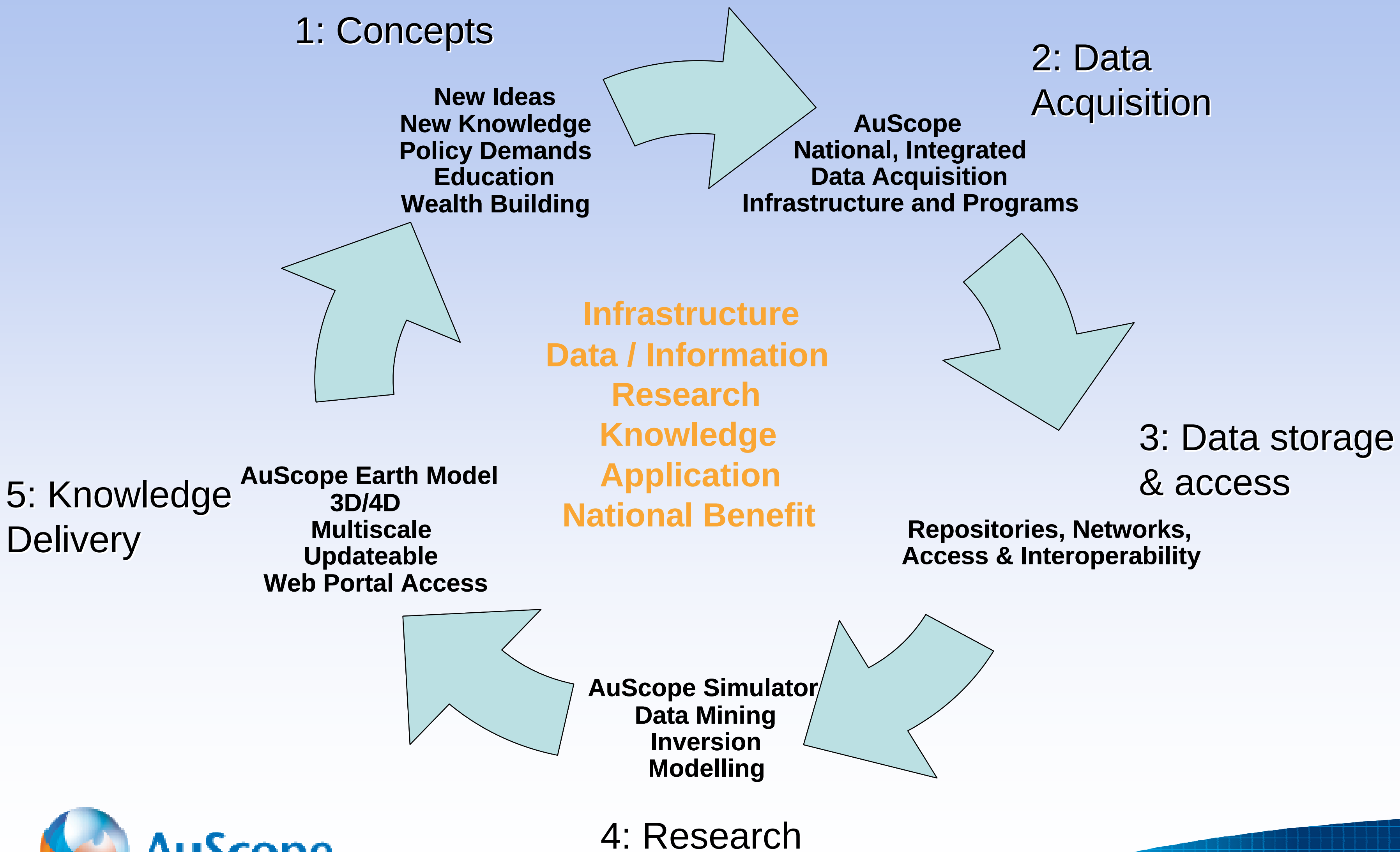
National Collaborative Research Infrastructure Strategy

- NCRIS – a new Australian Government Initiative
- Australian Government: ~$500M for FY06-FY11
- 11 Capability Areas + one Systemic ICT Infrastructure
- NCRIS Principles
  - "Major infrastructure …should serve the research and innovation system broadly, not just the host / funded institutions
  - "...seek to enable the fuller participation of Australian researchers in the international research system"
- ~~Test Beds~~ ~~Prototypes~~ 

AuScope Infrastructure *System*



Coherent Accessible Infrastructure



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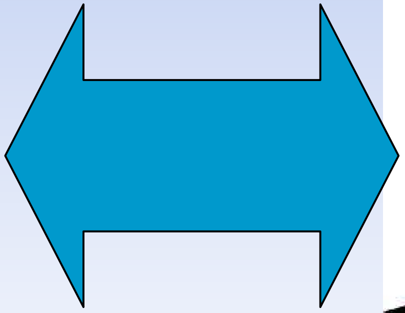
What is an Information Network?

Data sharing, applications, discovery and access

What hat do you wear? Consumer, Provider or both!

Consumer

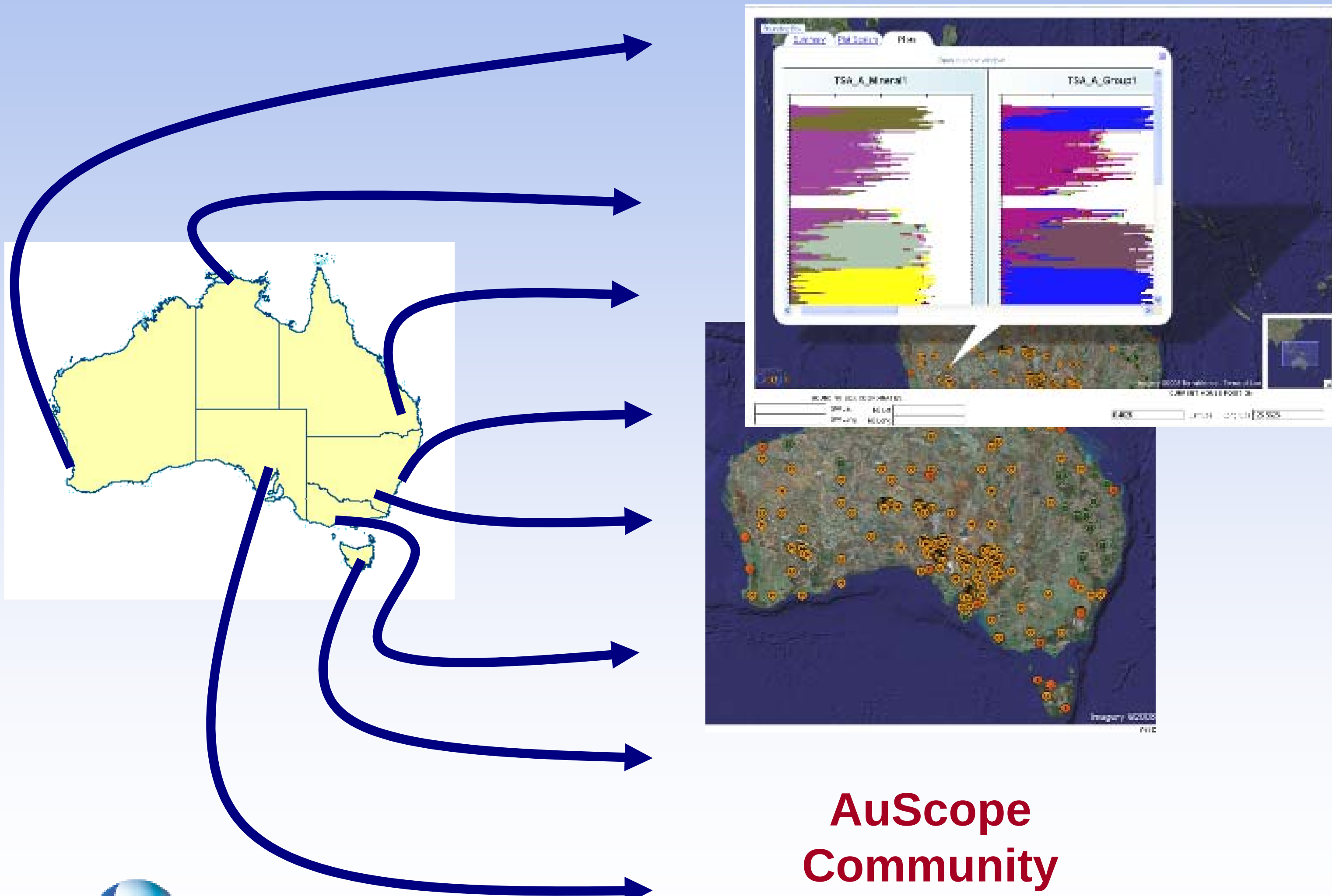
Standardise Information models
Standardise the Query interface



Provider

Do *not* change my internal operations dramatically *(including databases)*
Should not second guess the *consumers* workflow

A solution: Open standards based earth science information infrastructure



Client

AuScope Community Agreements

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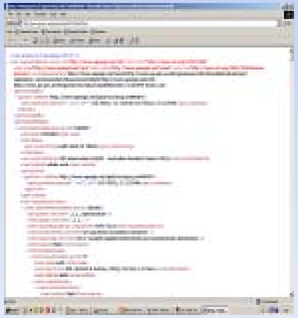
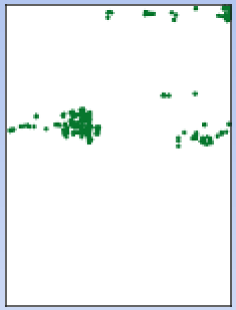
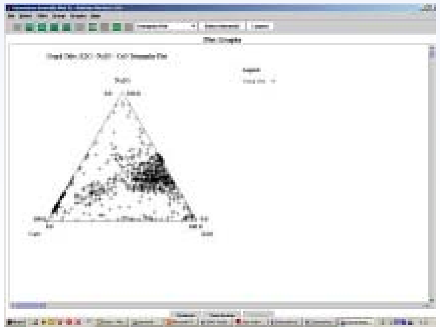
Applications:
It's not about you…it's about them.





Rendered into a map layer AND queried by a user or….

… formatted into a report or ….



… read and used by any enabled application

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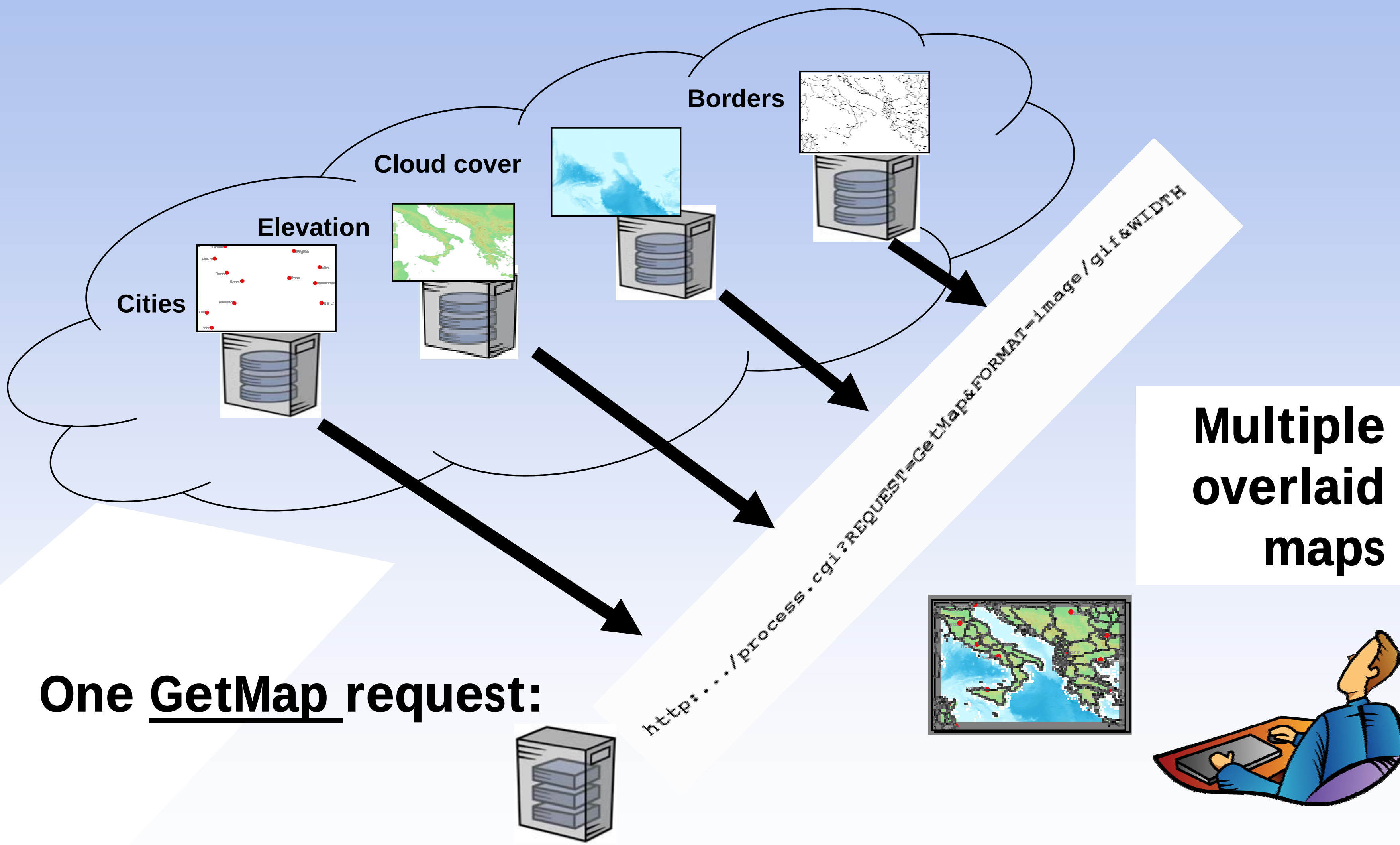
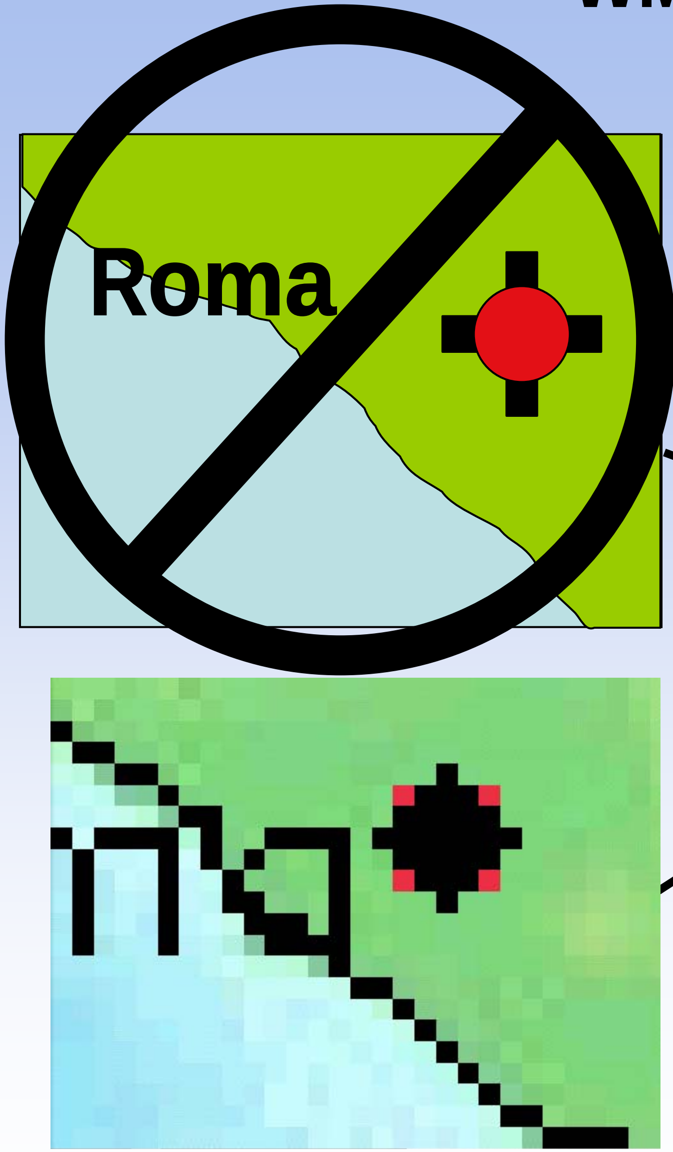
Slides courtesy Stuart Girvan – Geoscience Australia

Web Map Service (WMS) can access multiple maps

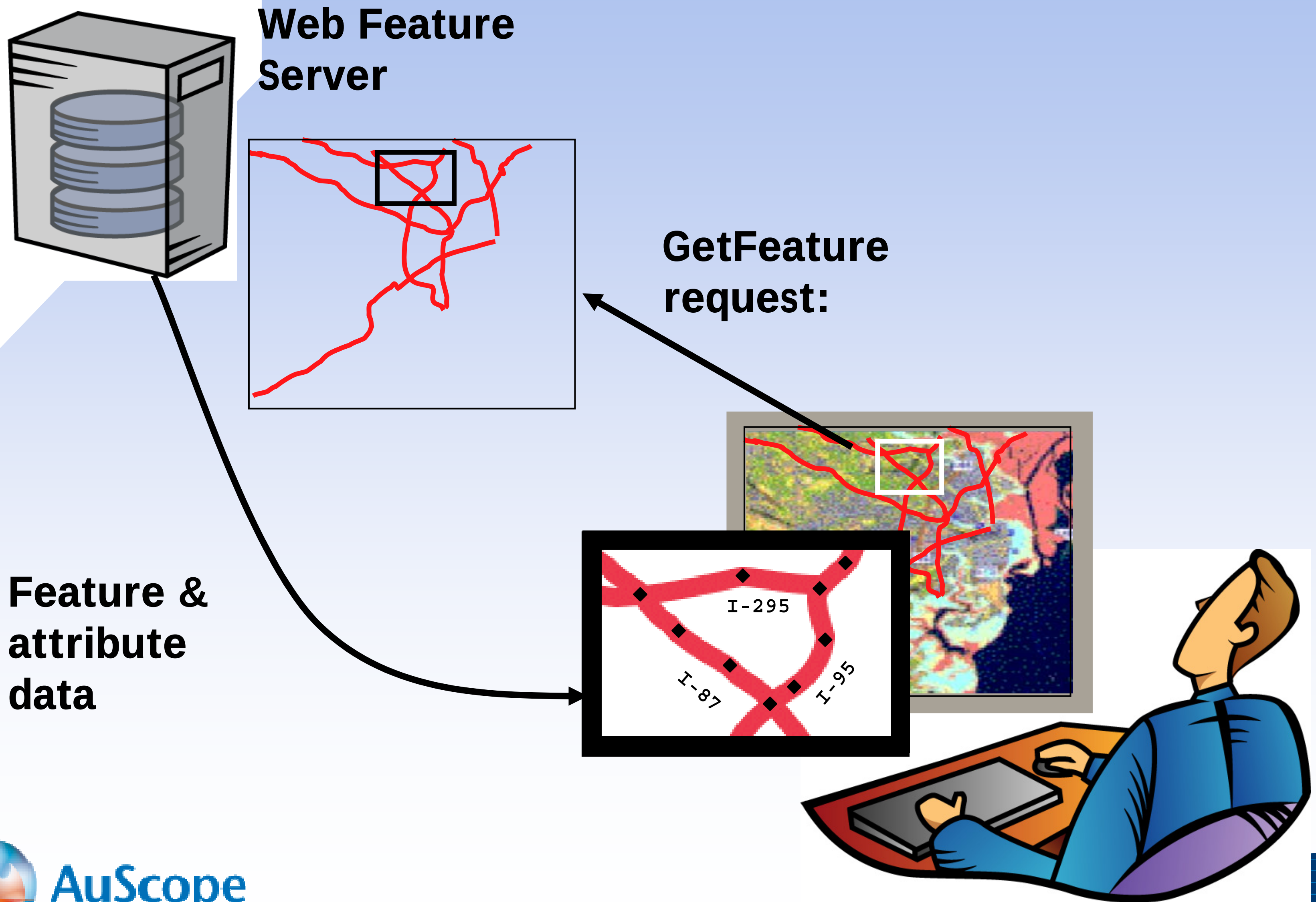


WMS can’t “give data away.”



WMS <u>GetMap</u> returns a server’s “dumb” JPEG, GIF or PNG representation of the data on the server. It does NOT return the actual data, only a bitmap of the data.

Web Feature Service (WFS) returns data.



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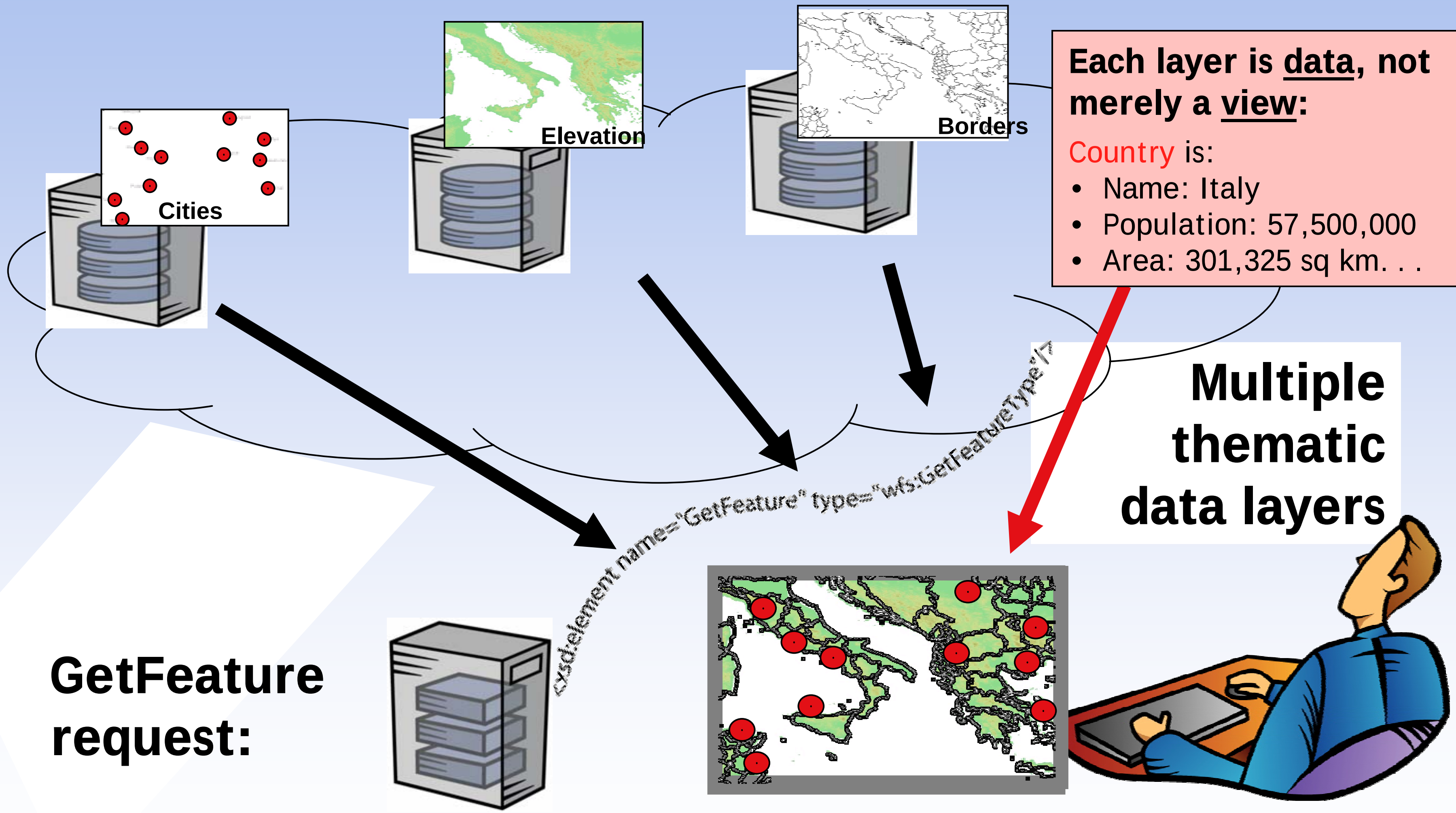
Web Feature Service (WFS) gets <u>operable</u> feature data from multiple servers

Each layer is <u>data</u>, not merely a <u>view</u>:

Country is:
- Name: Italy
- Population: 57,500,000
- Area: 301,325 sq km. . .



Multiple thematic data layers

GetFeature request:

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Building an Earth Science Information Network

…locally for access nationally and globally

…to provide access to authoritative, high quality, data and information

…to enable reuse and repurposing of data and information

…to integrate with other national and state network initiatives

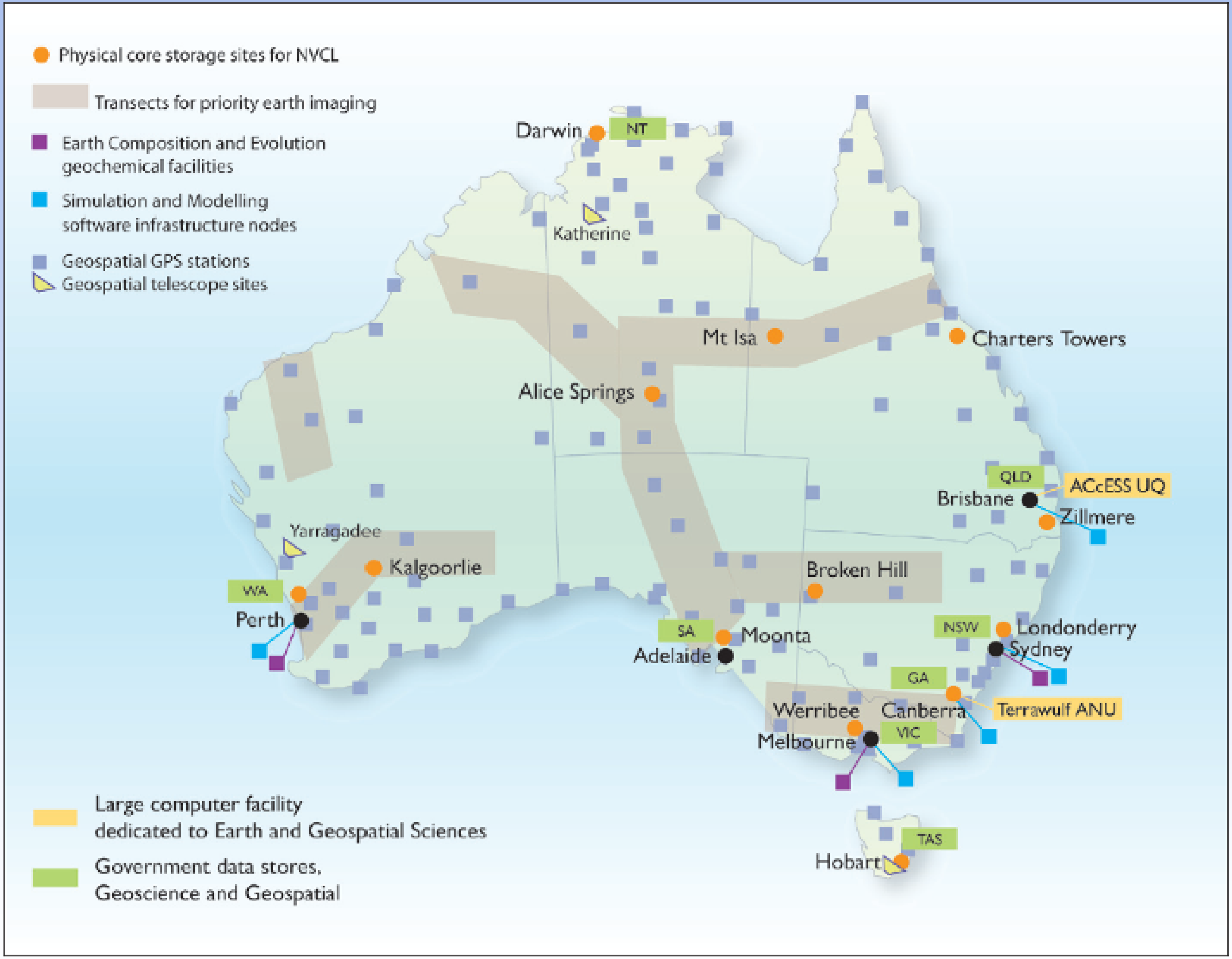
1st Step: Standardise the Information Models

- Not a storage problem…
  - Exchange
- Semantics and structure
  - GeoSciML, OGC
- Tool support
  - Creation and validation

Geography Markup Language

Workflow
FullMoon XML Processor
Exchange Layer
URN Resolver Service
openRDF.org
Sesame
deegree
GeoServer
With Application Schemas
GeoNetwork opensource
Resources
Standard Vocabularies
Government Department Data
AuScope service catalog
AuScope

The AuScope Earth Science Information Network



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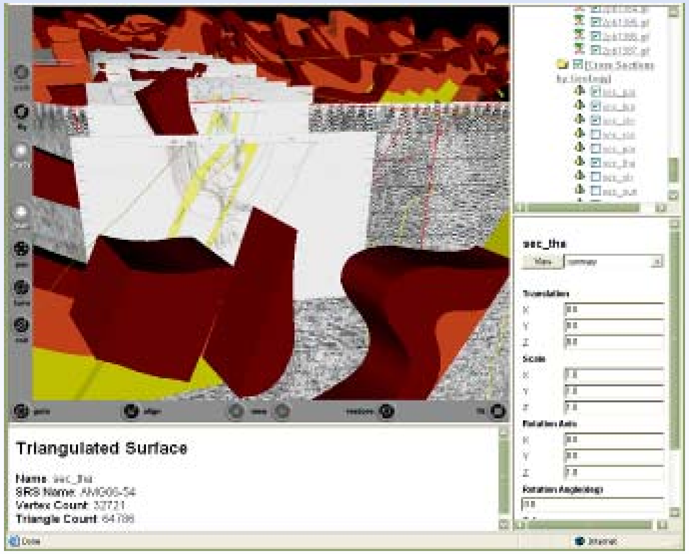
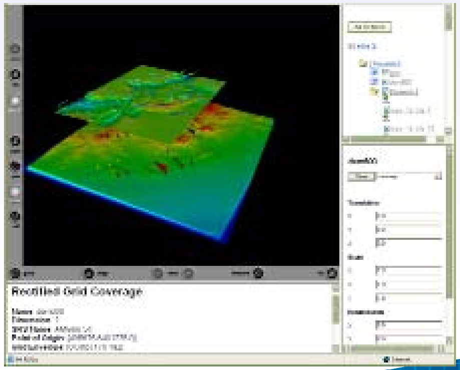
Benefits for…

- Providers
  - All providers get to retain their back end database structures
  - (Potential to have) consumers and independent 3rd parties develop their own portals and applications



- Users
  - Accelerate time to results
  - Enable collaboration and promote operational flexibility
  - Increase productivity
  - Leverage existing capital investments
  - Increased access to data and collaboration
  - Infrastructure optimisation



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Funding

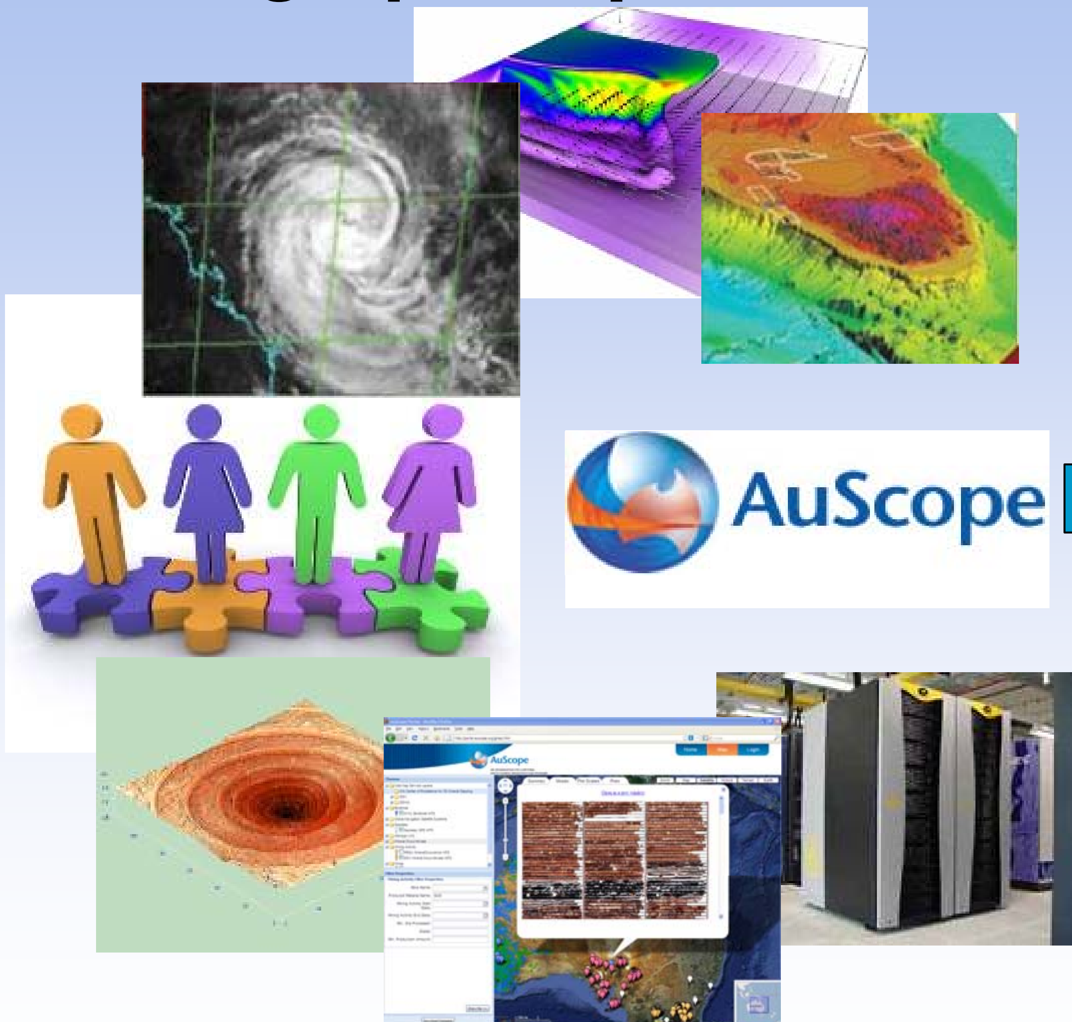
- NCRIS Funding to 2011 – fully committed
- Australian Spatial Research Digital Commons
- Education Initiative Funding
- AuScope 2

Future work

- 3D
- Simulation & Modelling Workflows
- Other Domains:
  - Groundwater (NCGRT)
  - Water (BOM)
  - Geothermal
  - ?

AuScope

Bringing the science community together using open spatial standards



AuScope

GVS

Groundwater Visualisation System

A software framework for developing low-end, scalable and robust software for 3D visualisation and animation of groundwater conceptual models

Allan James, Amy Hawke, Malcolm Cox, Joe Young, Andrew Todd

31 August, 2009

Queensland University of Technology

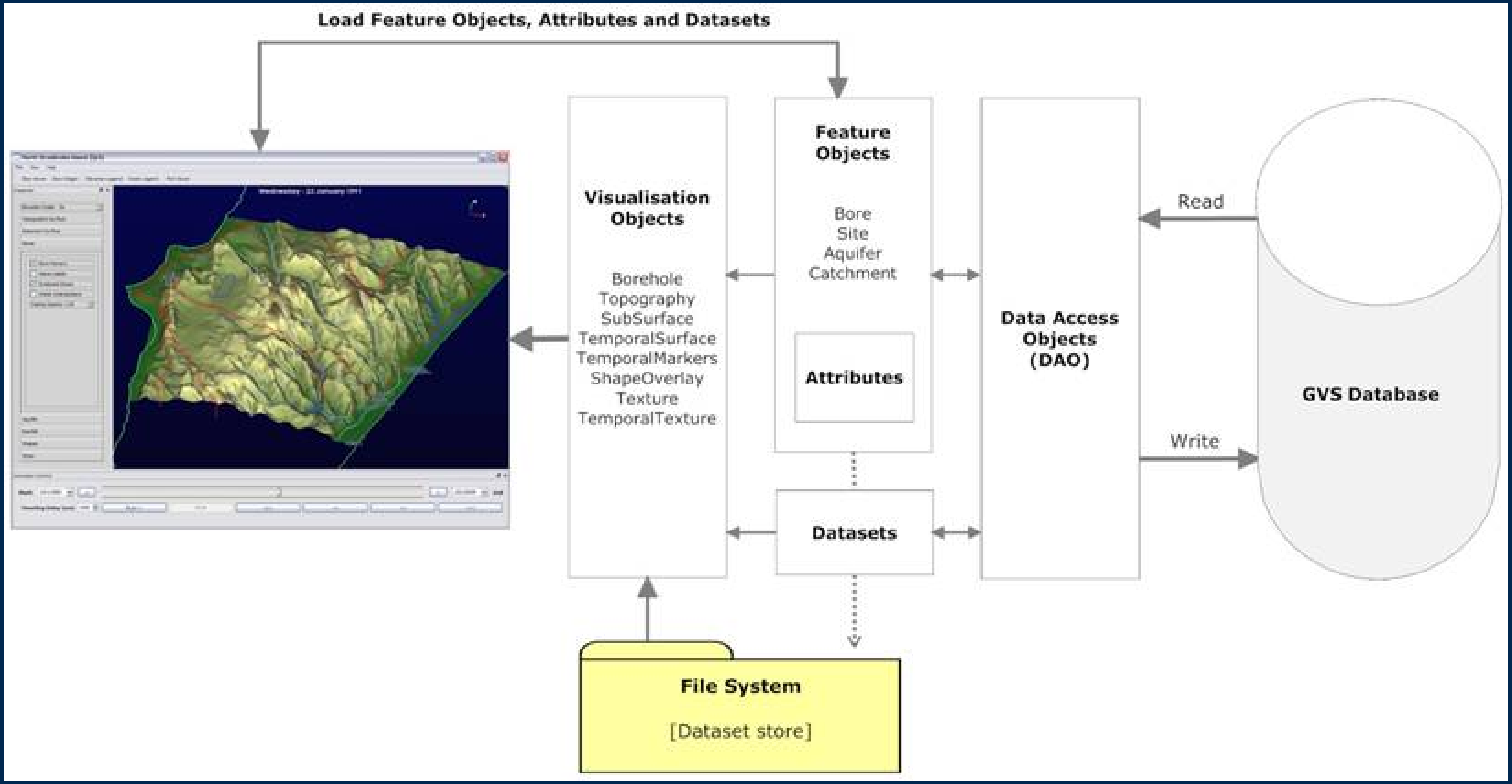
Initial Objectives

- Develop an extensible framework for integrating data from various sources to produce interactive 3D visualisations of conceptual groundwater models
- Provide a simple yet robust data model and database for the organisation and storage of groundwater-related data and a c++ code library for access to the data
- Provide support for animation of associated time-series data
- Develop effective methods for displaying and interacting with the data within a 3D visualisation scene
- Enable stand-alone models to be packaged along with the software and documentation to form a deliverable product output that can be used by stakeholders and community

GVS - Overview

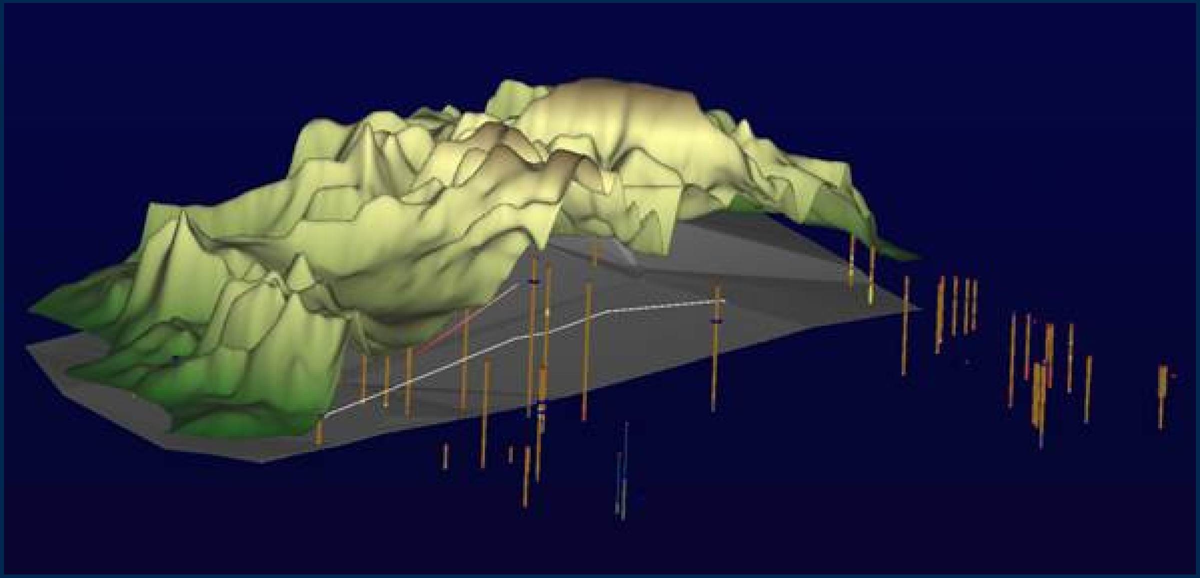
Four primary components:

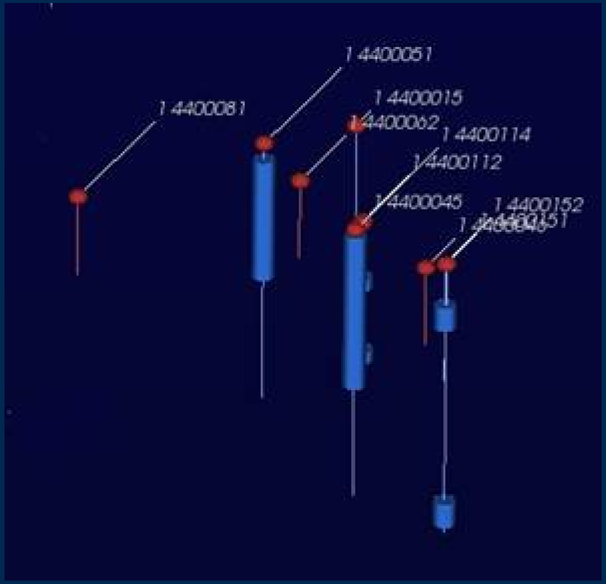
- Features, Attributes, Datasets and Visualisation objects



GVS – Feature Objects

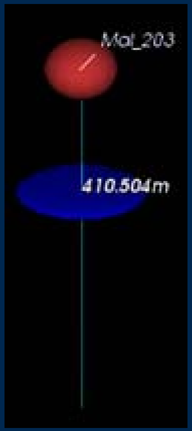
- Representation of physical or real-world objects related to groundwater
- currently four feature types supported in the system
    - Catchment, Aquifer, Bore (w/ logs), Site
- features, attributes and datasets (descriptor) are stored in the database
    - attribute data and datasets linked to relevant features
    - able to save/load via Data Access Objects (DAO)

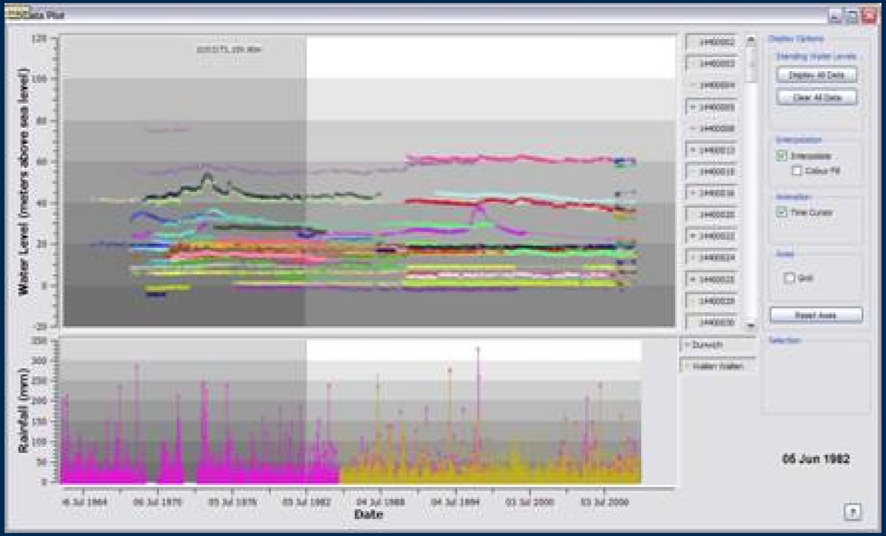


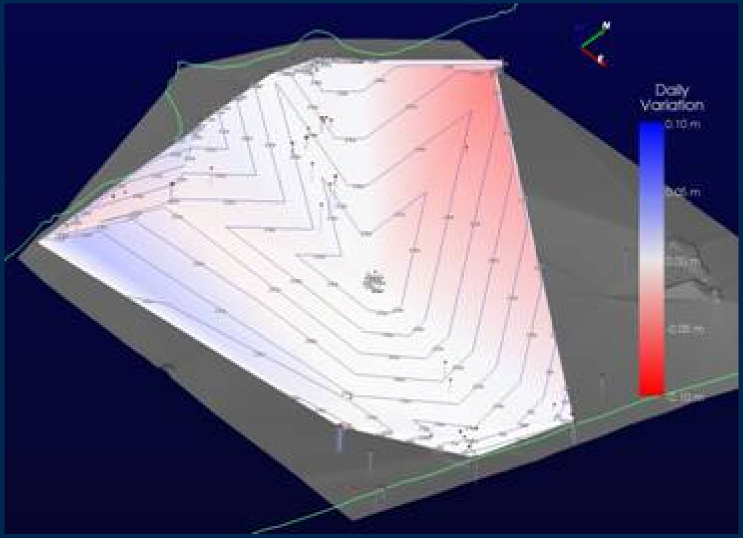


GVS - Attributes

- Attributes refer to general data values including time-series
- attribute data linked to relevant feature objects
    - SWL time-series attribute linked to bores
    - other attributes (*rainfall, stream flow, water quality, chemistry* …)
- time-series attributes can be plotted to produce graphs
- enables animation capabilities



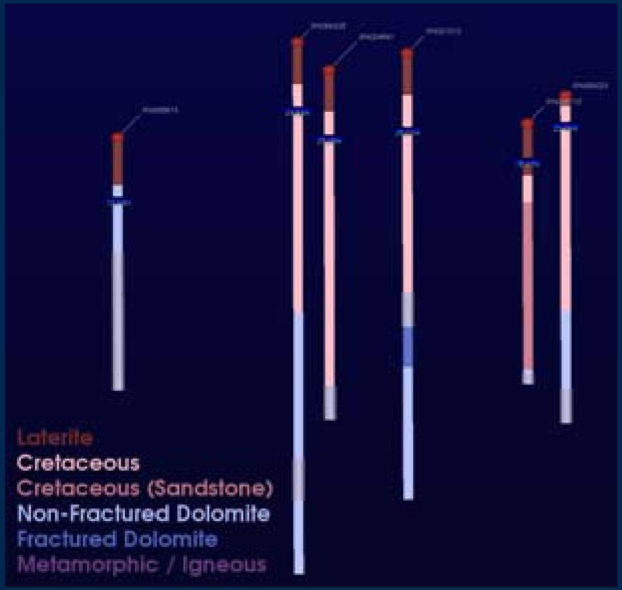


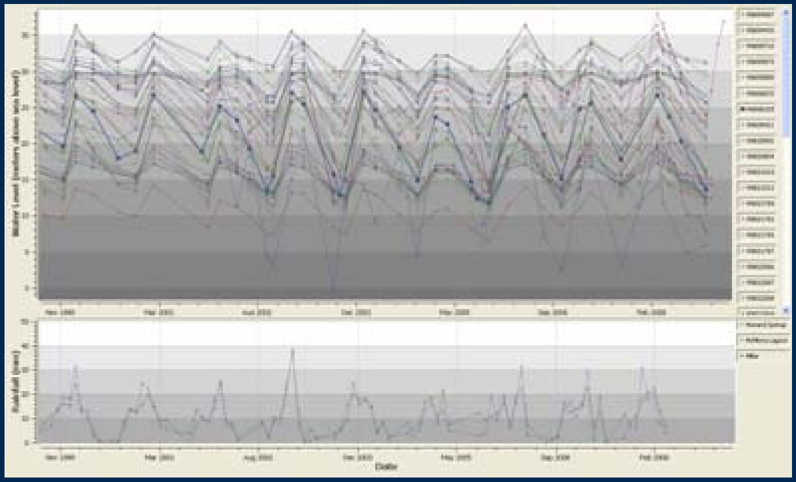


GVS – Feature objects and attributes

Bore

- geological logs (lithology)
- casing construction (screens)
- water intersections
    - estimated yield (pump test)
- SWL time-series attribute
- other bore attributes (*extraction, hydraulic conductivity, …*)
- import data from g/w database extracts
- topographic surface queried for bore elevations
- bore depth determined from logs





GVS – Feature objects and attributes

Site

- locations of observed / measured variables
  - *including time-series data*
- rainfall, stream flow, extraction, chemistry, ….

Aquifer

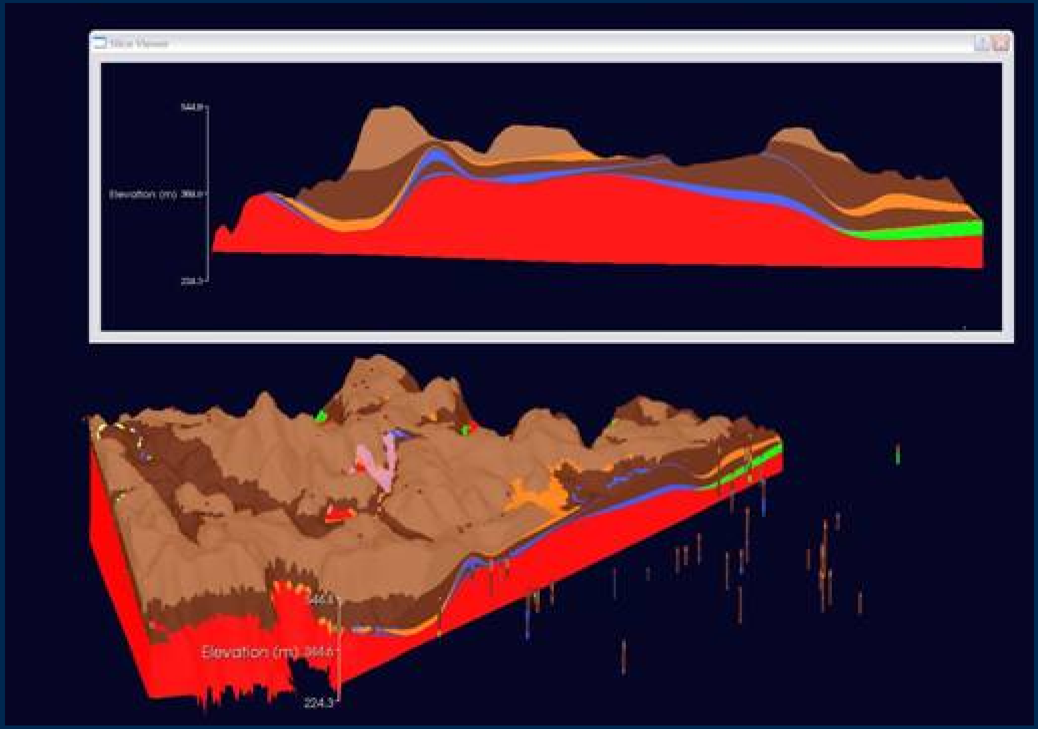
- identified water-bearing subsurface units and useful properties
- bore logs can reference an intersected aquifer
  - *i.e. which aquifer does this screen intersect?*
- expert interpretation required - needs further work

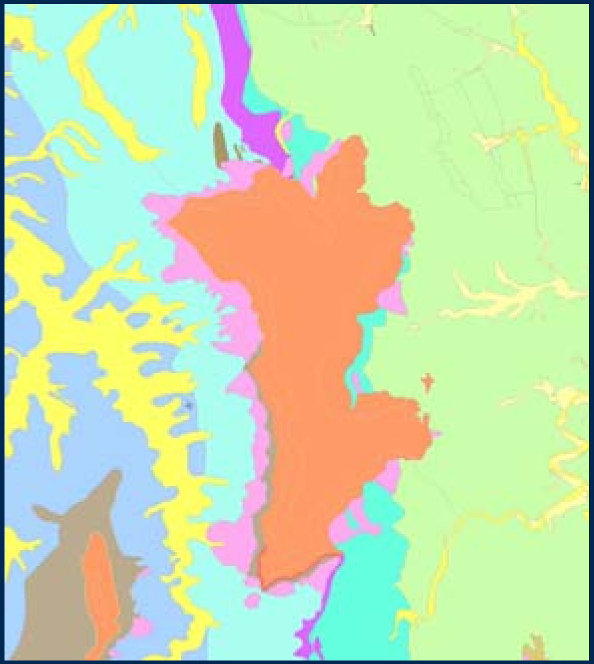
Catchment

- represents a water catchment or basin
- can also be used to define a specific project area
- catchments can reference a ‘parent’ catchment to form a hierarchy

GVS - Datasets

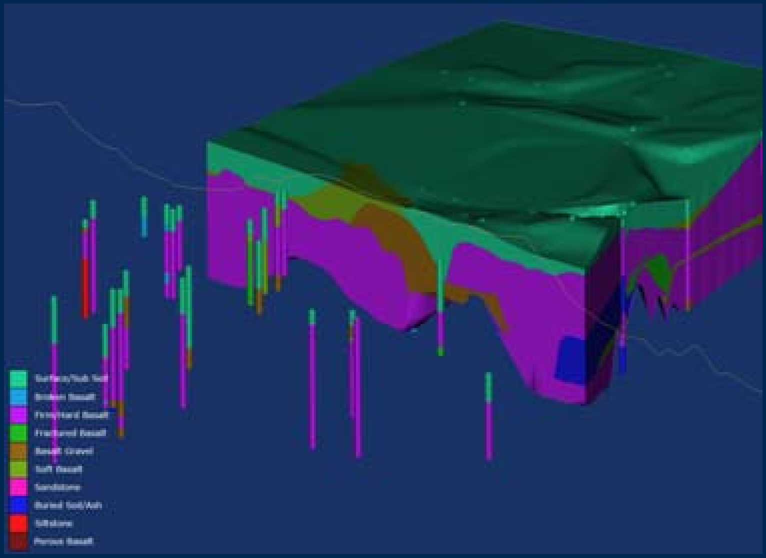
- incorporate file-based data (meshes, DEMs, images overlays, shapefiles, etc..)
- dataset descriptor (stored in DB) points to actual data file location
- capability for time-series datasets

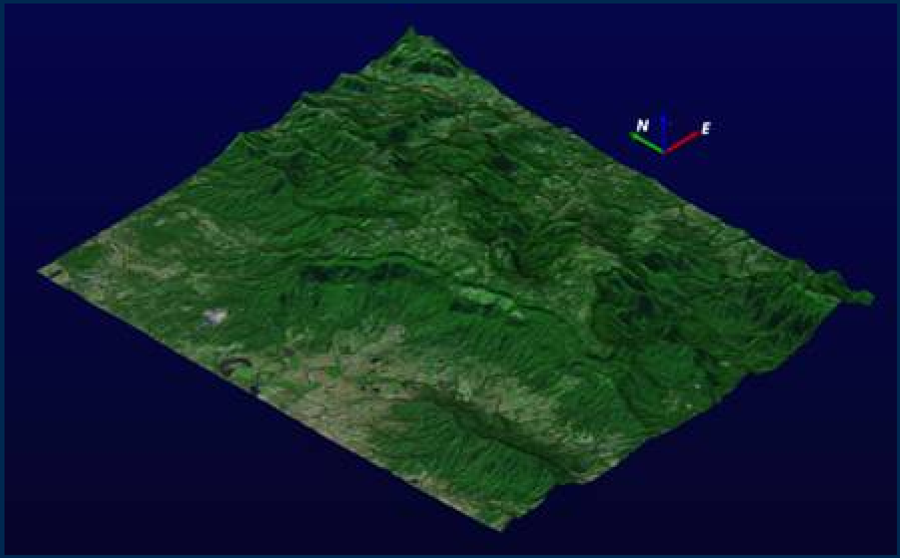




GVS – Dataset examples

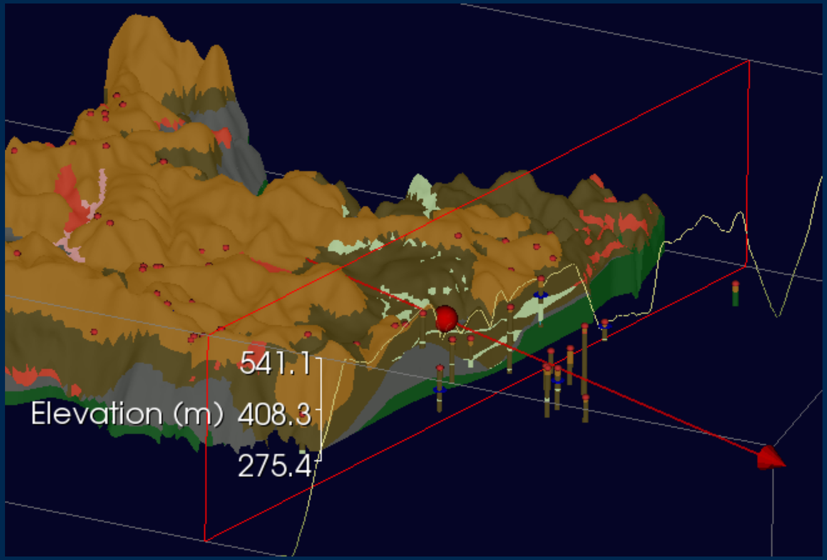
- DEM / Lidar / Heightmaps
- Image layers (*aerial, soil maps, geology, land use etc…*)
- Shapefiles (ESRI)
    - boundaries, water bodies, sites, streams, lakes, roads etc..
- 3D geometry – “solid” subsurface

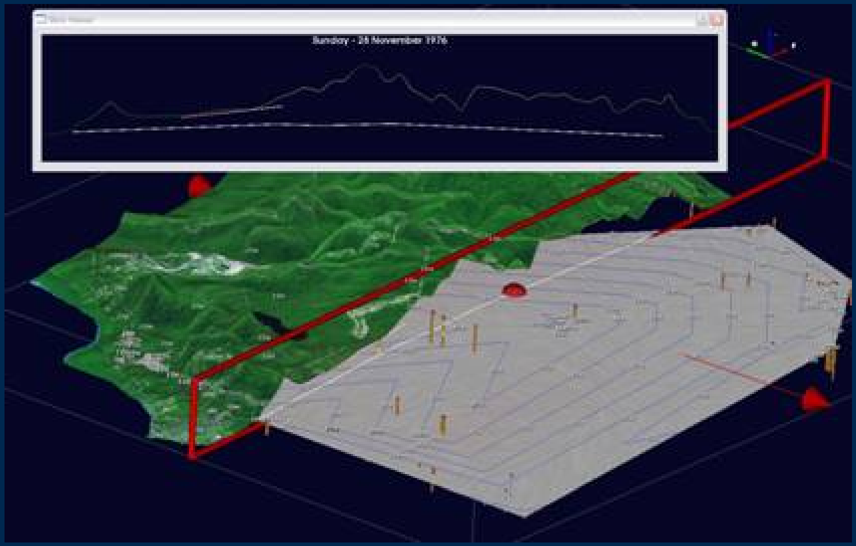




GVS – Visualisation objects

- linked to features, attributes and datasets to create an interactive visual representation
- 3D scene “actors” built from data – geometry
- support animation, elevation scaling, slicing using interactive slice plane

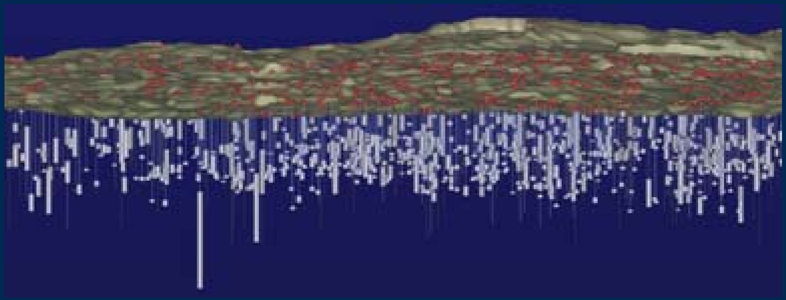


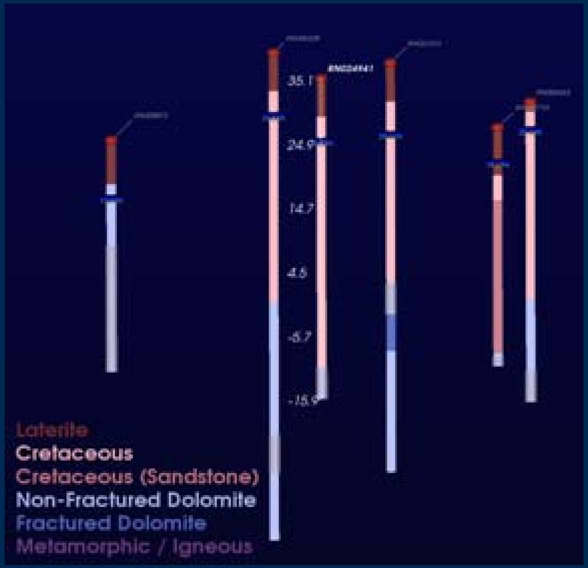


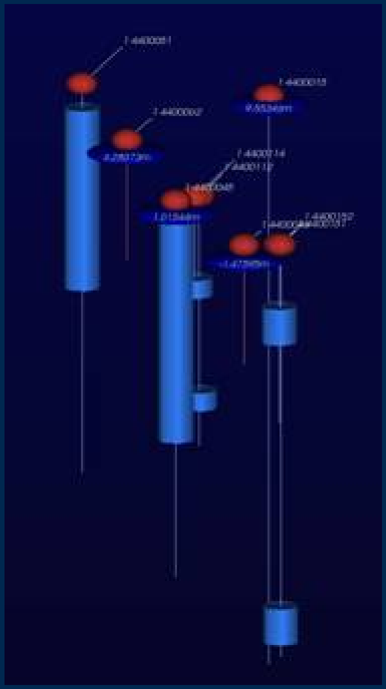
GVS – Visualisation objects

Boreholes

- visualisation object built from bore feature
- label and sphere marker shows bore ID and location
- vertical line showing bore depth
- coloured cylinders for geology, casing (screens) and water intersection intervals



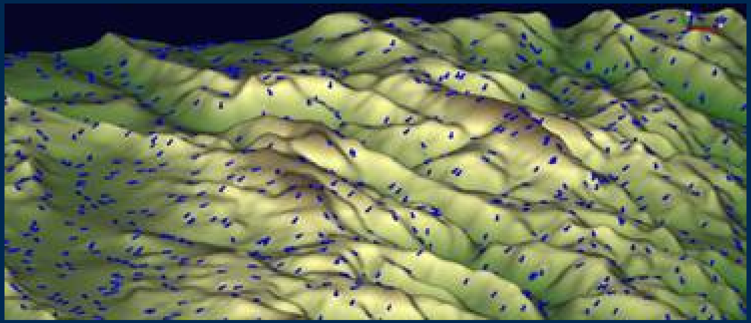


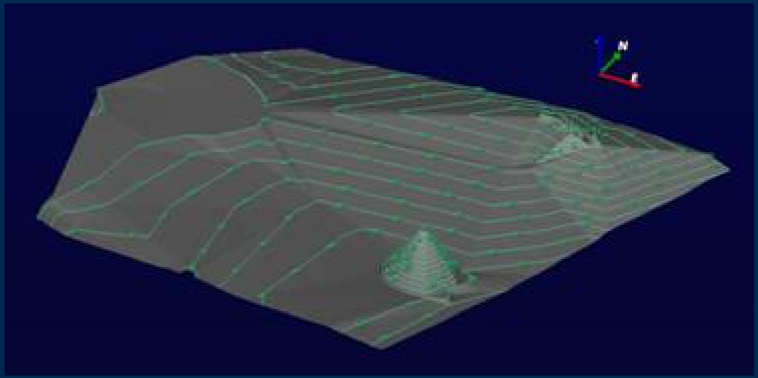


GVS – Visualisation objects

Surfaces (i.e. topography, basement)

- stored as datasets (height image / VTK)
- elevation contours
- surface flow direction arrows

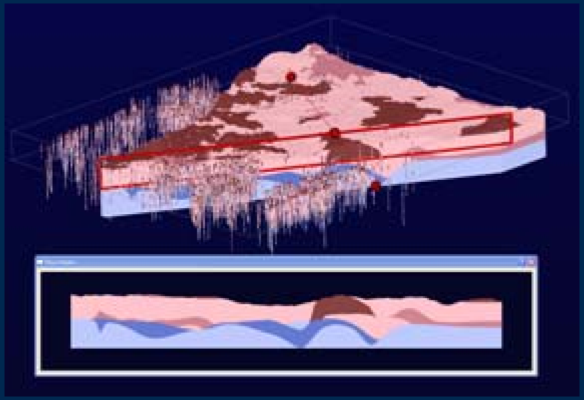


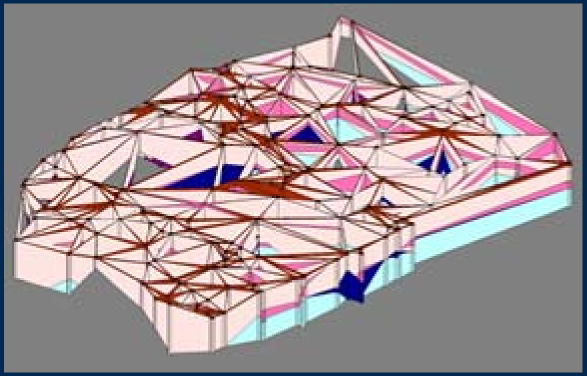


GVS – Visualisation objects

Subsurface meshes

- represents internal hydrogeology
- use of external software for interpolation (GMS, GoCad)
- requires expert interpretation
- stored as a dataset in a flexible data format – VTK

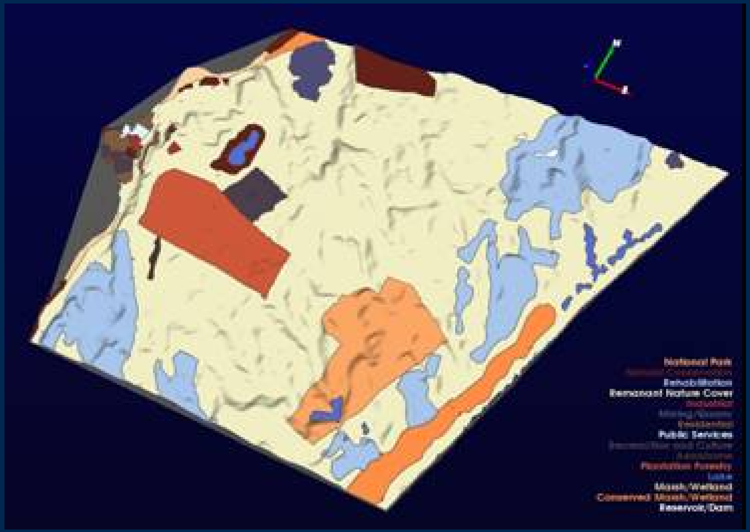




GVS – Visualisation objects

Static and temporal textures

- textures draped over topography
- support for time-series textures



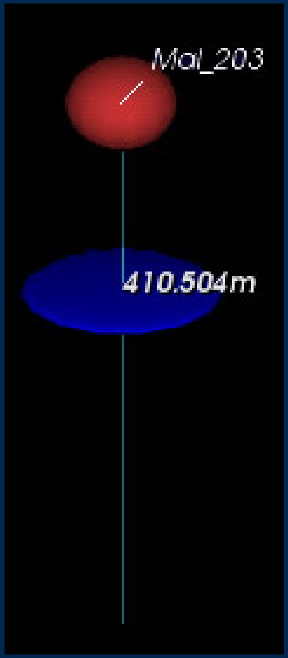
Shape overlays

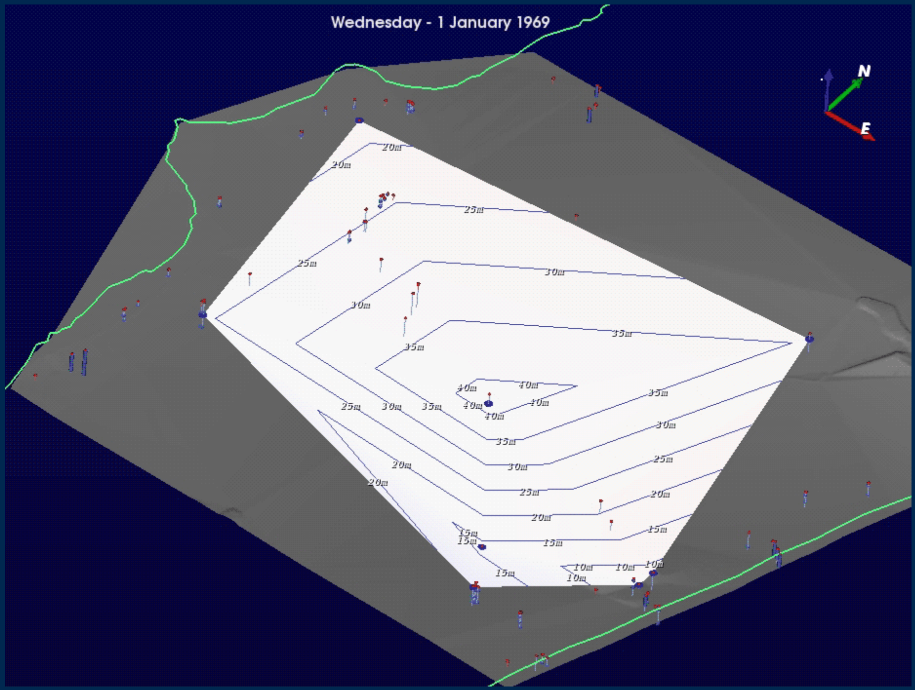
- ESRI shape files – draped over topographic surface

GVS – Visualisation objects

Temporal markers and surfaces

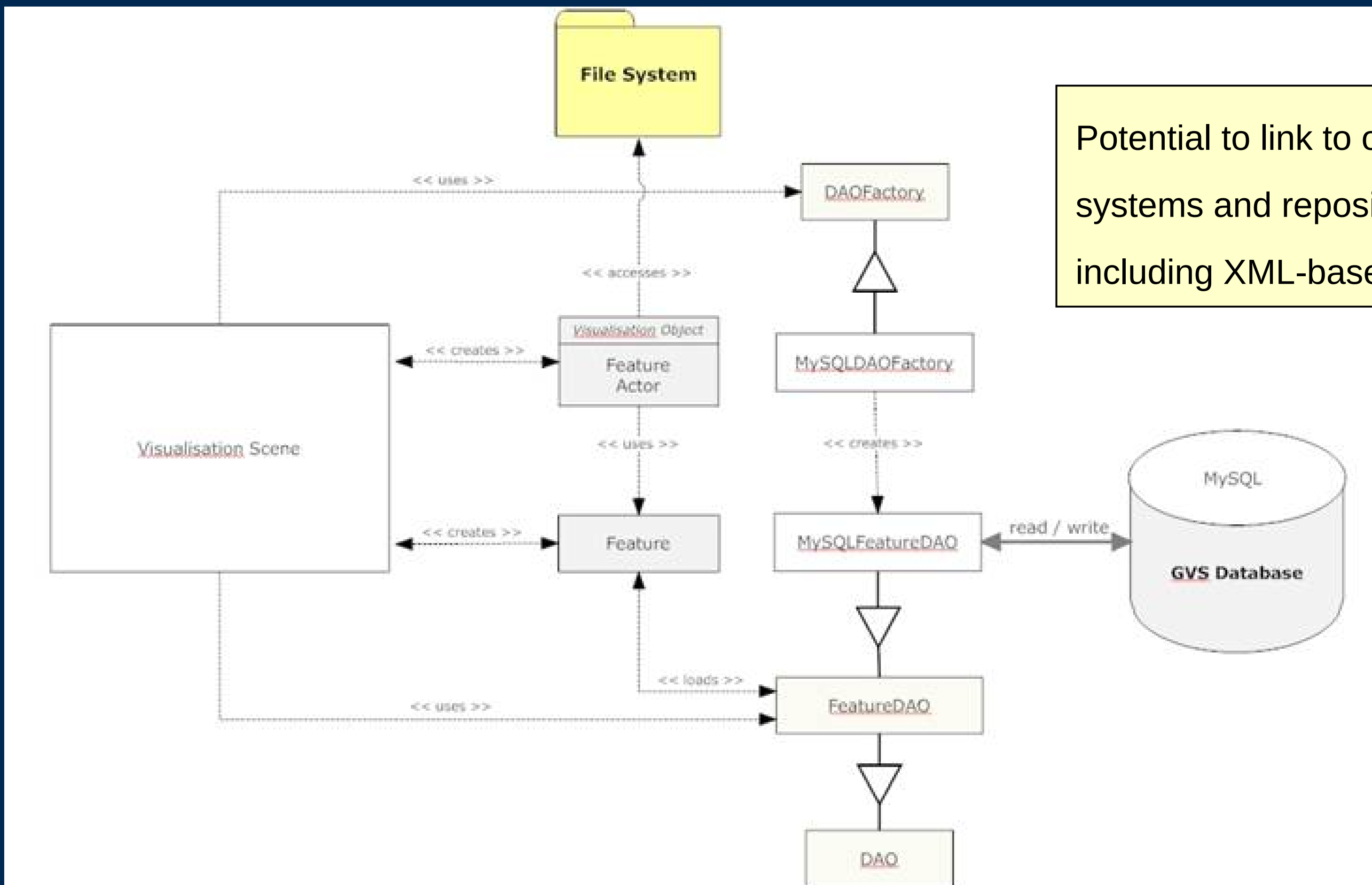
- spatial attribute markers (i.e. water level, rainfall)
- surfaces can represent animated water table built from SWL attribute data
- contours
- flow direction





Database and data access

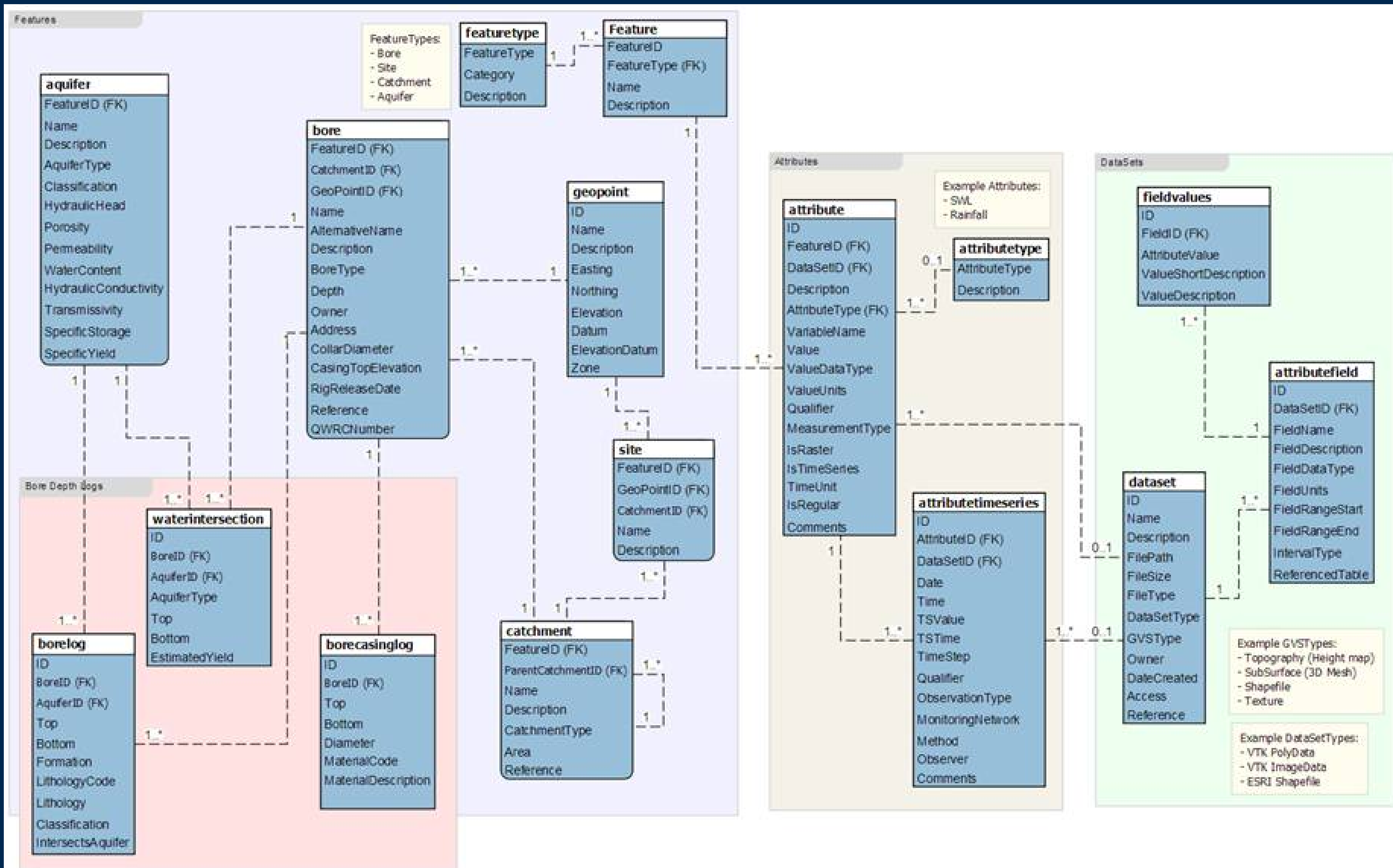
• *Data Access Object (DAO)* software design pattern implemented to enable support for additional data sources



Potential to link to other database systems and repositories ….

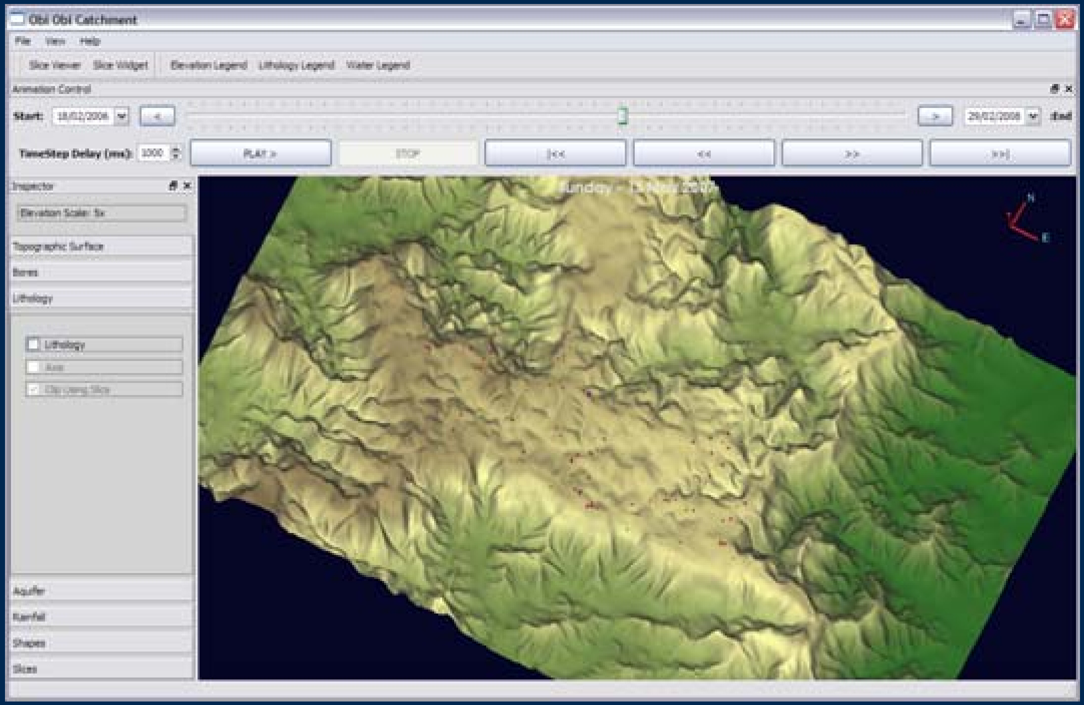
including XML-based data sources

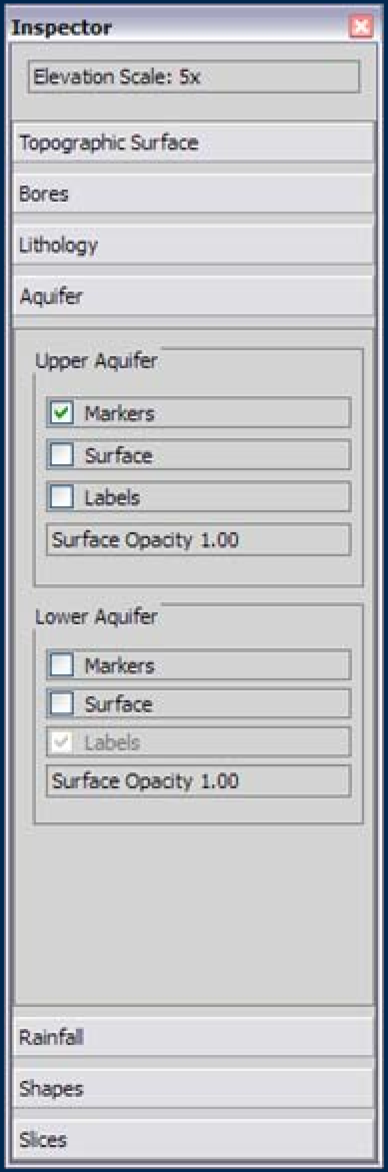
GVS Database Schema



Tools developed using GVS

- Stand-alone desktop tool
- User-friendly graphical interface (Qt)
- Dockable panels
- Toggle feature visibilities / opacities
- Elevation scaling





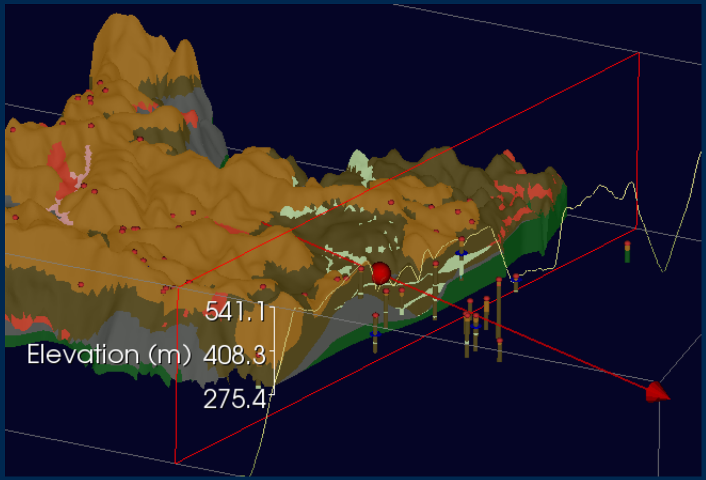
• 3D Interaction -

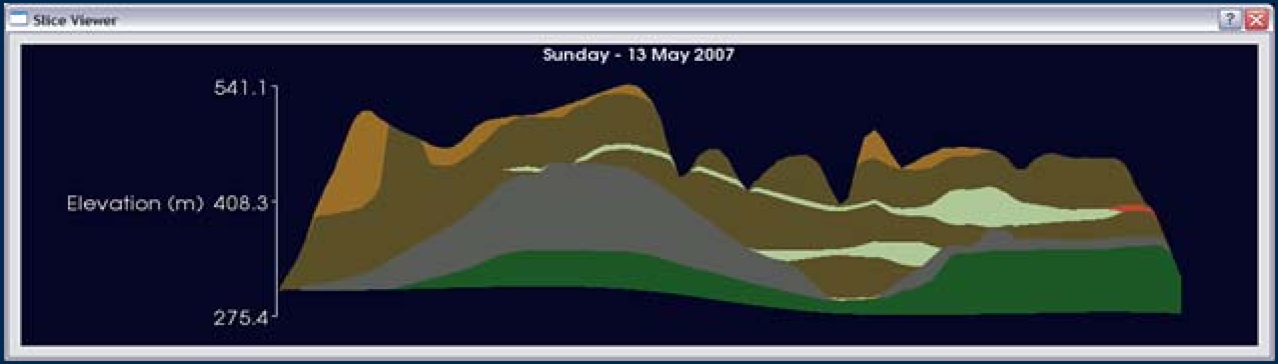
Pan / Rotate / Zoom

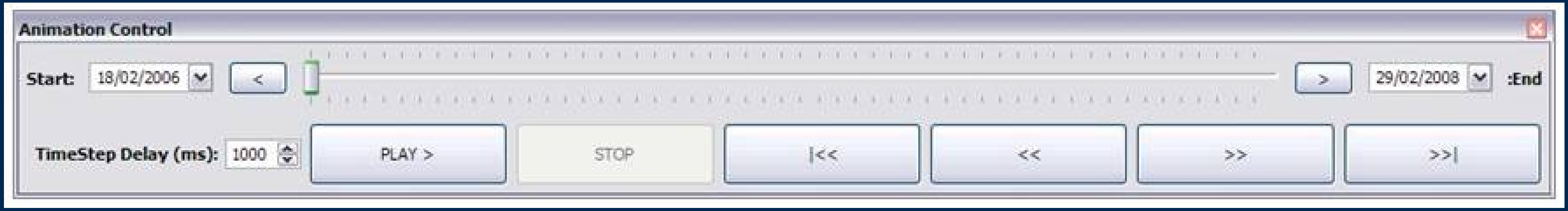
• Interactive slicing with

2D slice viewer window

• Animation of time-series attribute data

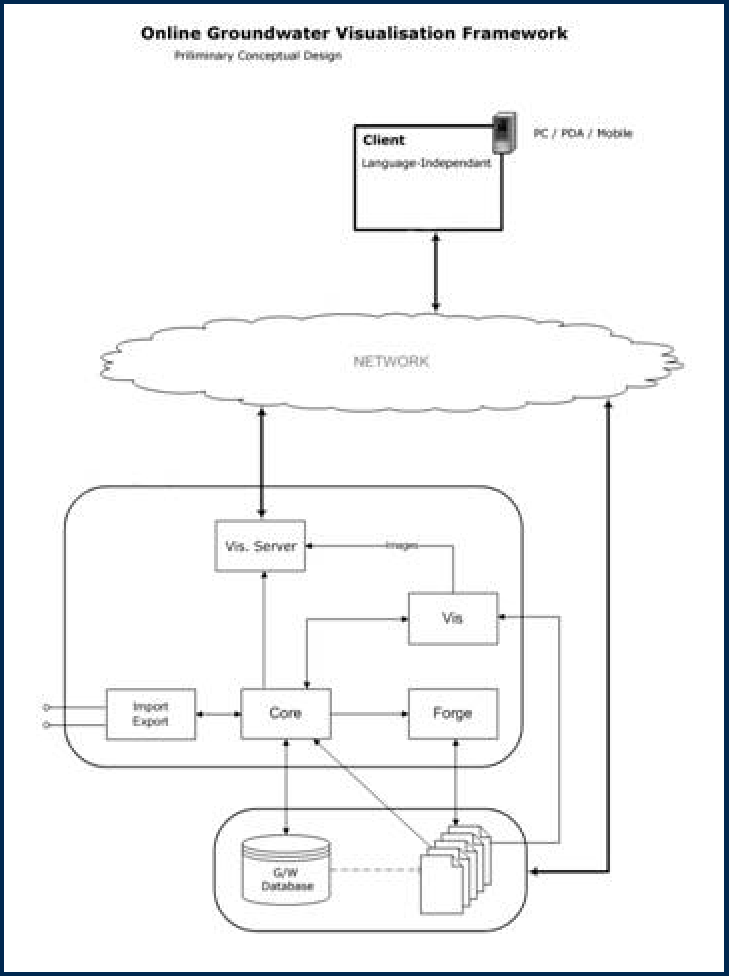






Future development

- Database / repository refinement
- Remote access capability
    - Shared interrogation of models
- Import external models, including simulations



GVS is still a work-in-progress …

Thank You!

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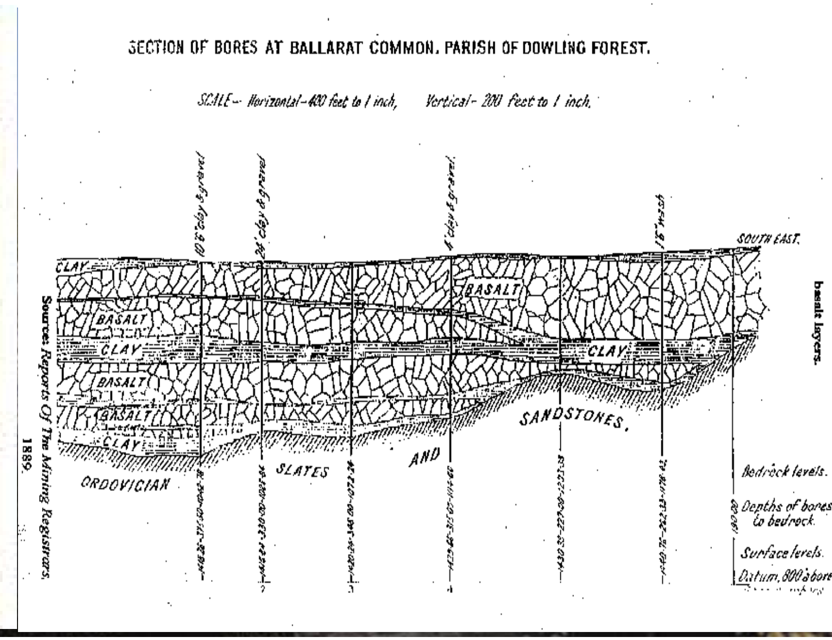
PRIMARY INDUSTRIES



Hydrogeological conceptualisation, the first stage in 3D model development

John Fawcett, Don Cherry, Bruce Gill and Mark Reid

Key Points- Conversation

- Interrogation of hydrogeological data sets in development of the 3D models

- How accurate is good enough (purpose – resource question)

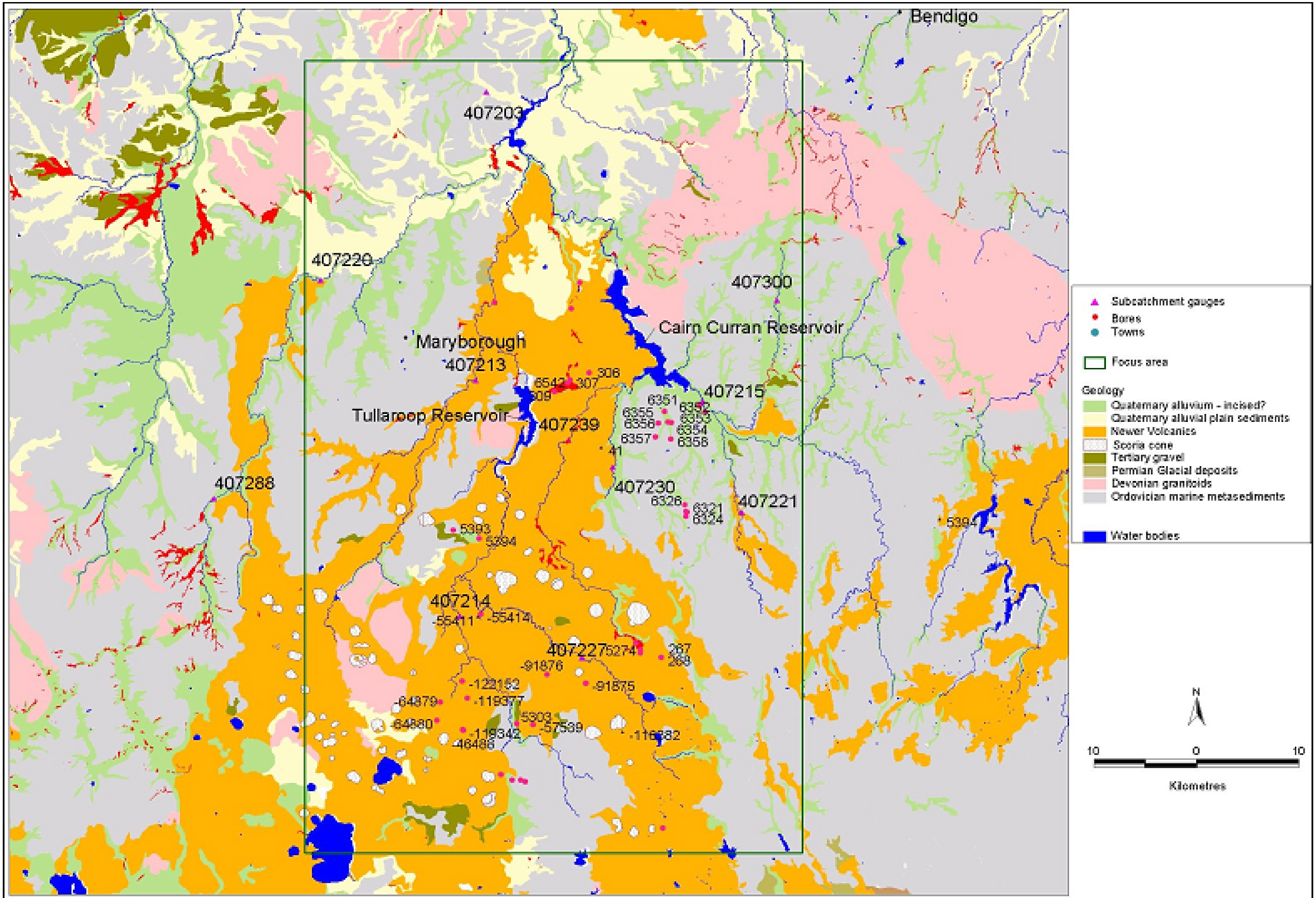
- Good groundwater models and or 3D models

  ----Good hydrogeological conceptualisation before model development

  ----Always a degree of extrapolation between data points

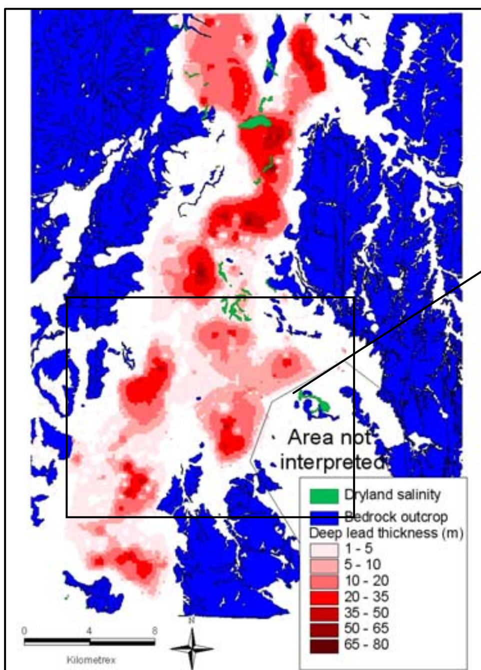
- Cliff Ollier Quote –

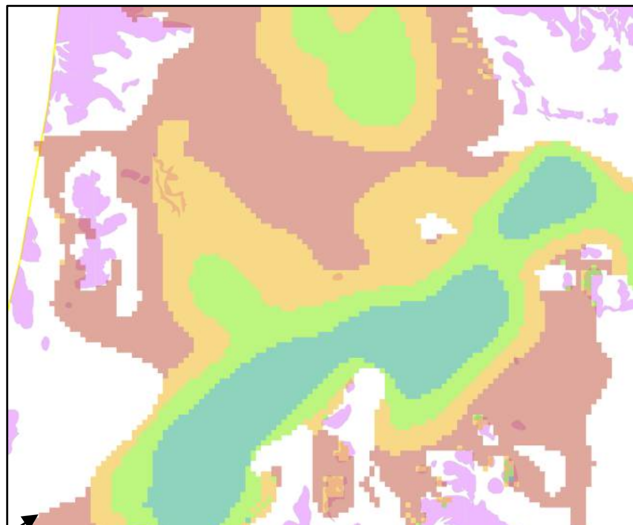
  WE DO THE BEST WE CAN TO MAP THE <u>PARTIALLY UNDERSTOOD</u> INTO POTENTIALLY HELPFUL MAPS

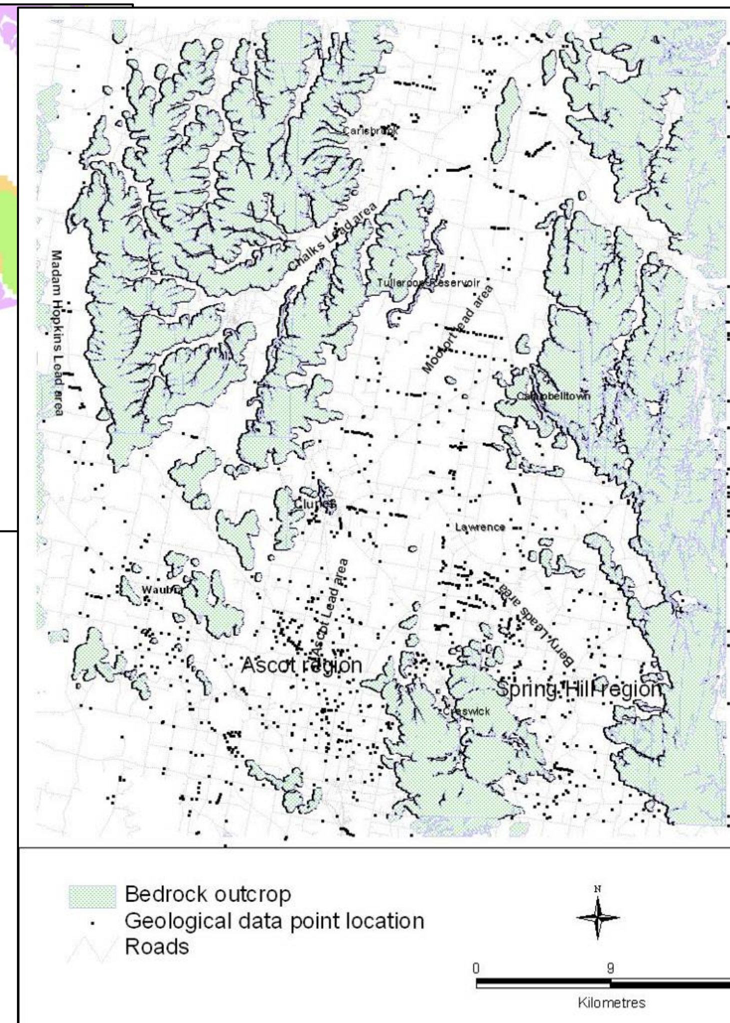

Bendigo
407203
407220
407300
Cairn Curran Reservoir
Maryborough
407213
6542
306
307
309
407215
Tullaroop Reservoir
407239
407288
407230
407221
5393
5394
407214
407227
Subcatchment gauges
Bores
Towns
Focus area
Geology
Quaternary alluvium - incised?
Quaternary alluvial plain sediments
Newer Volcanics
Scoria cone
Tertiary gravel
Permian Glacial deposits
Devonian granitoids
Ordovician marine metasediments
Water bodies
N
10
0
10
Kilometres

Two interpretations of Deep Lead sediments

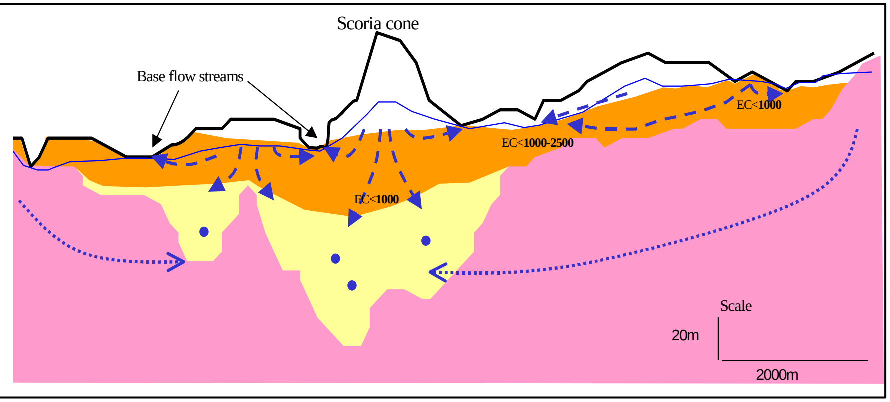
based on same data - one contains higher level geological interpretation

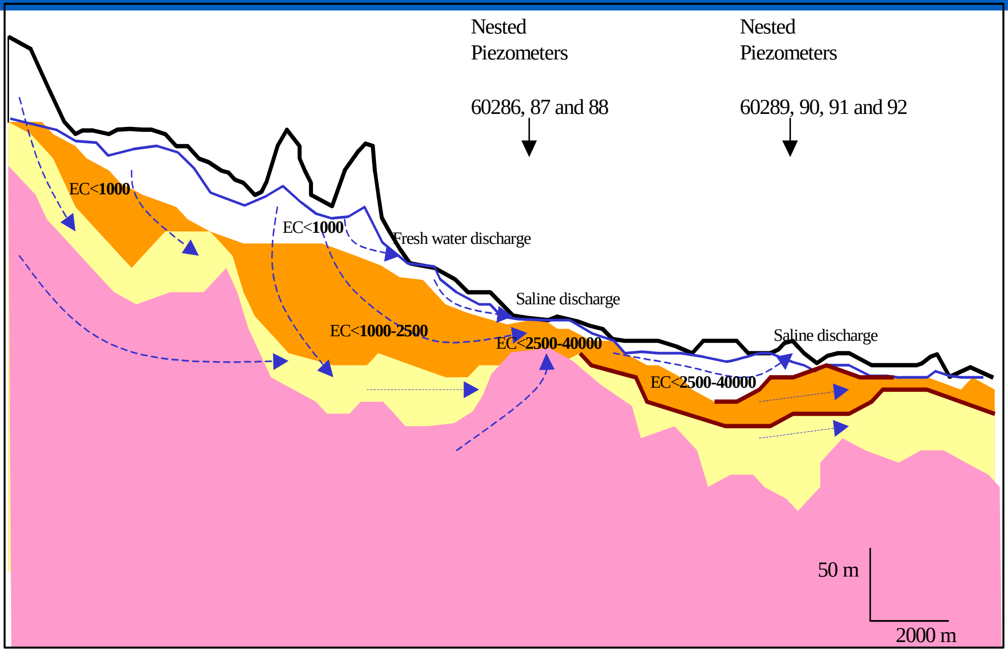


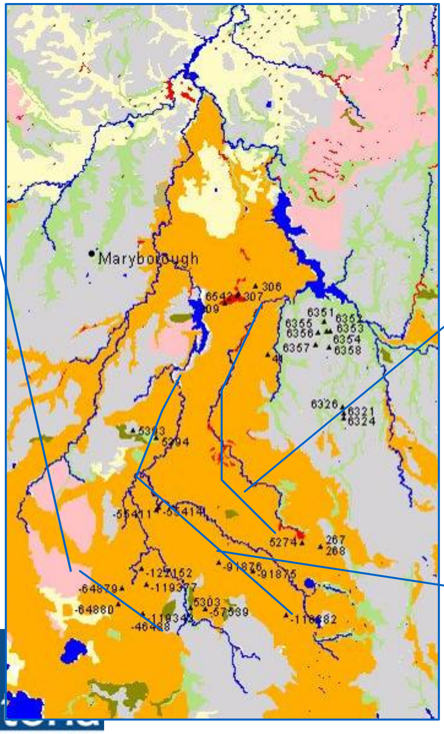


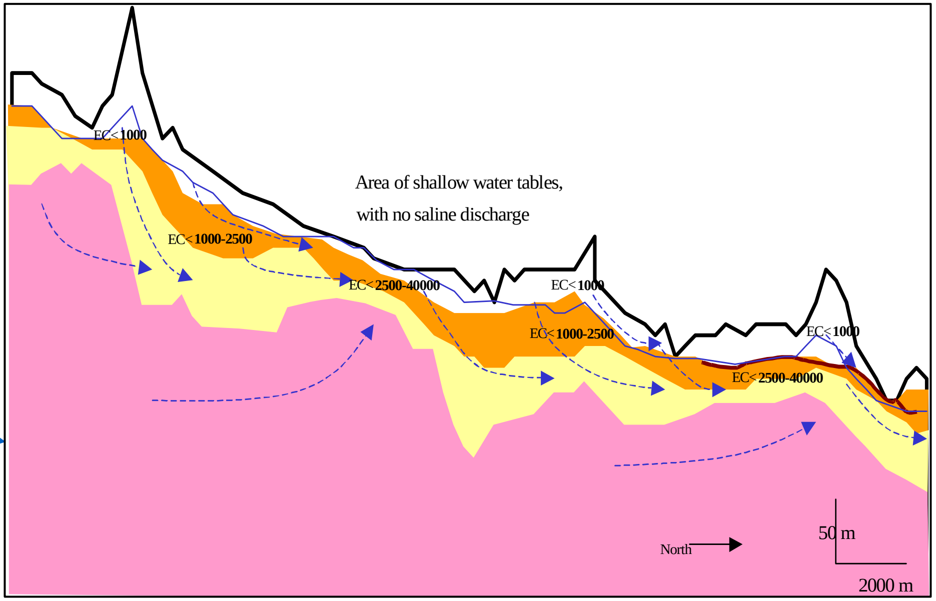


Conceptual Hydrogeological Model









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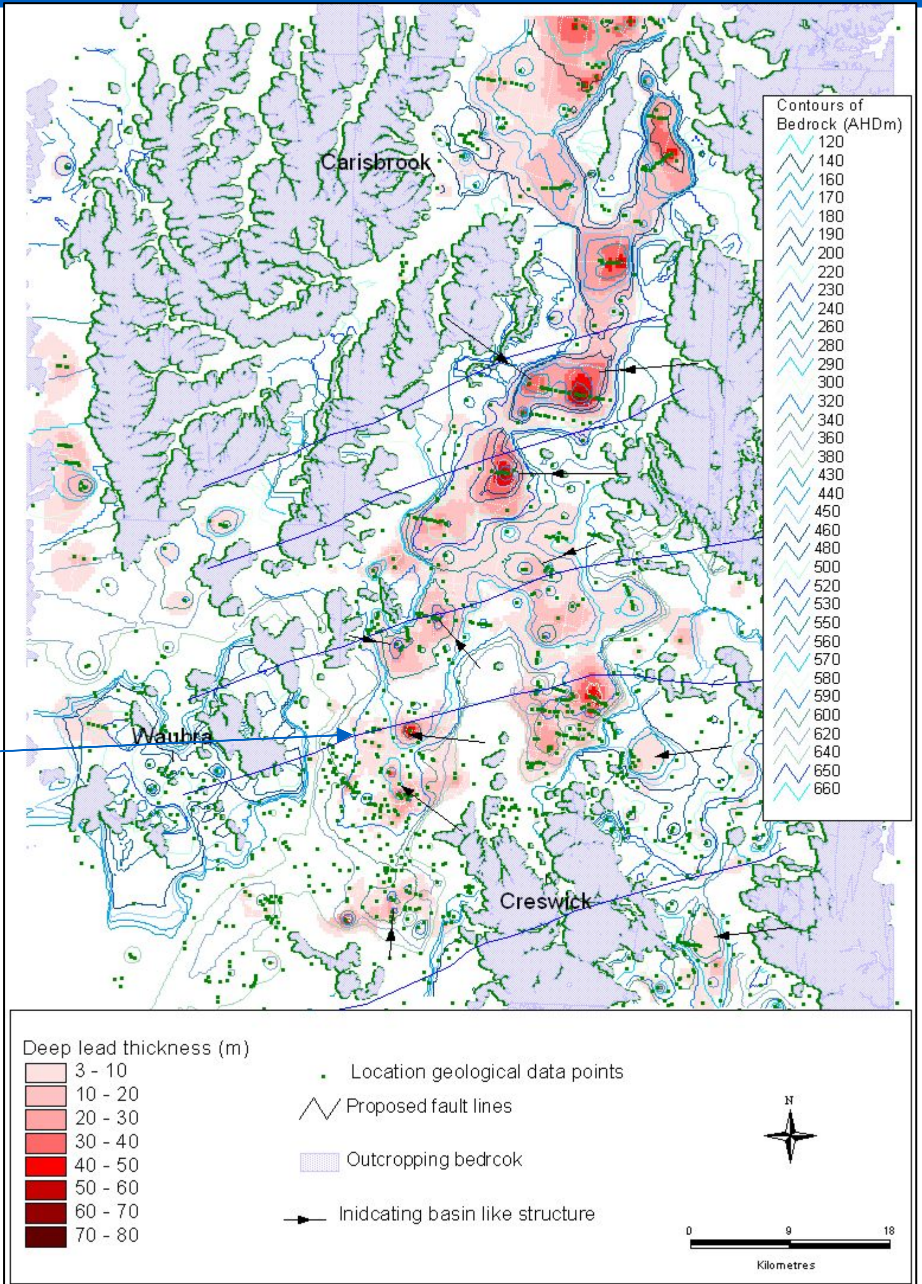
Distribution of Aquifer structurally controlled ?

Large Scale Faults
No Data



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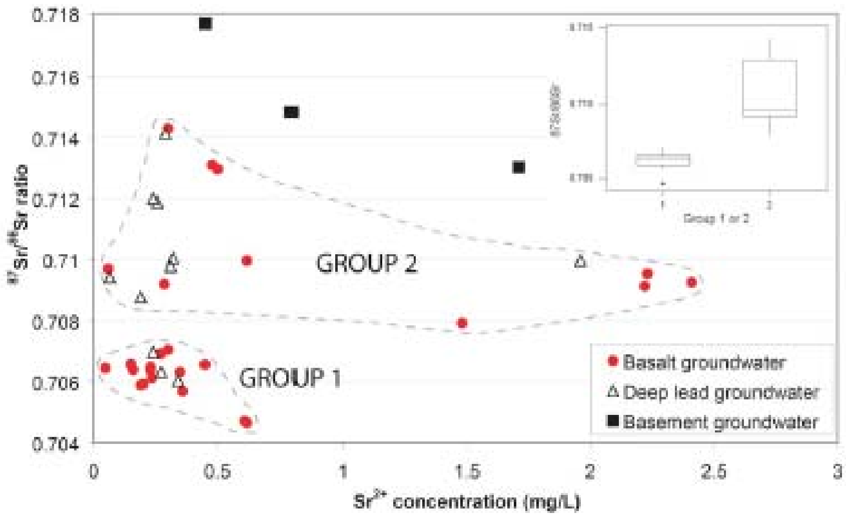
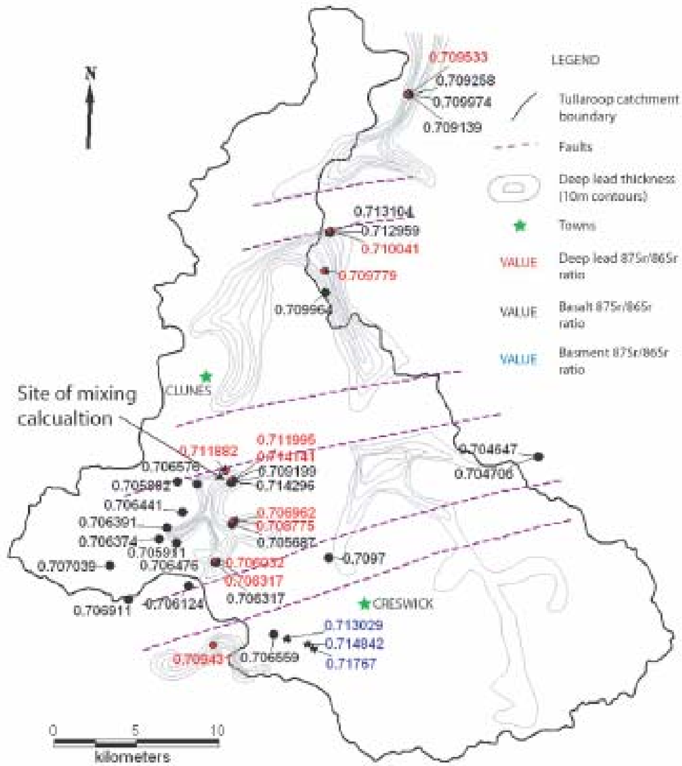
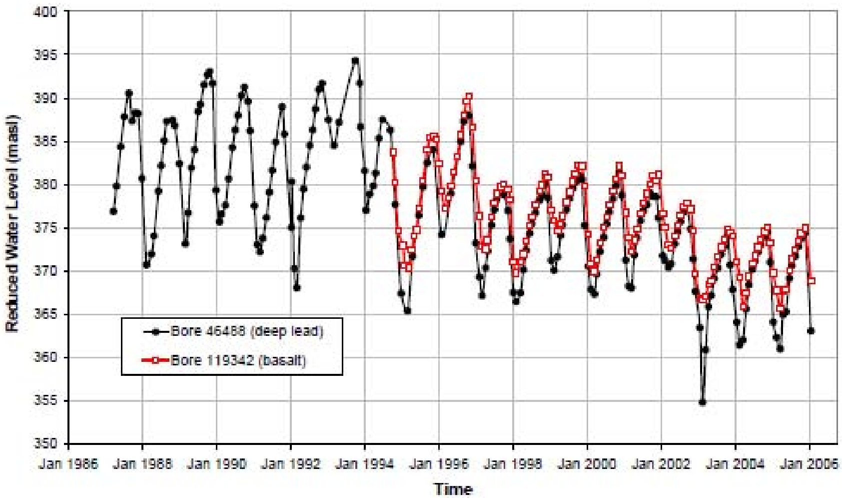
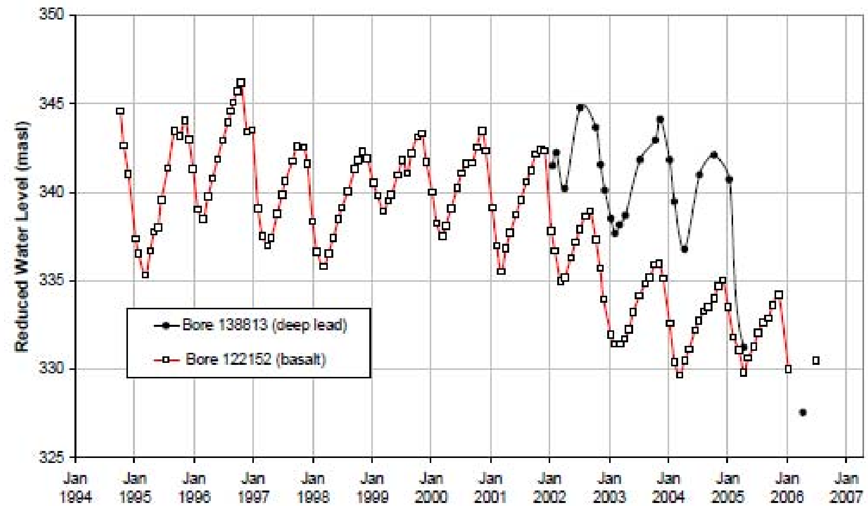
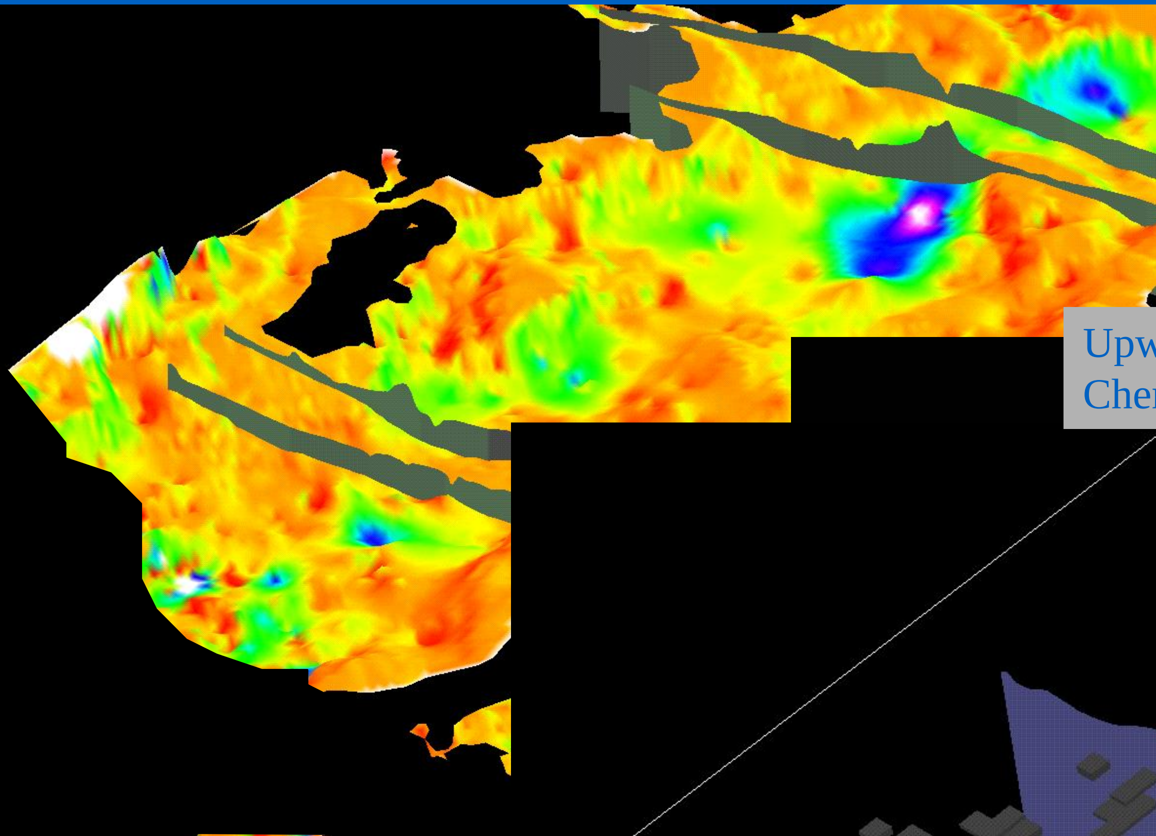
Additional data sets

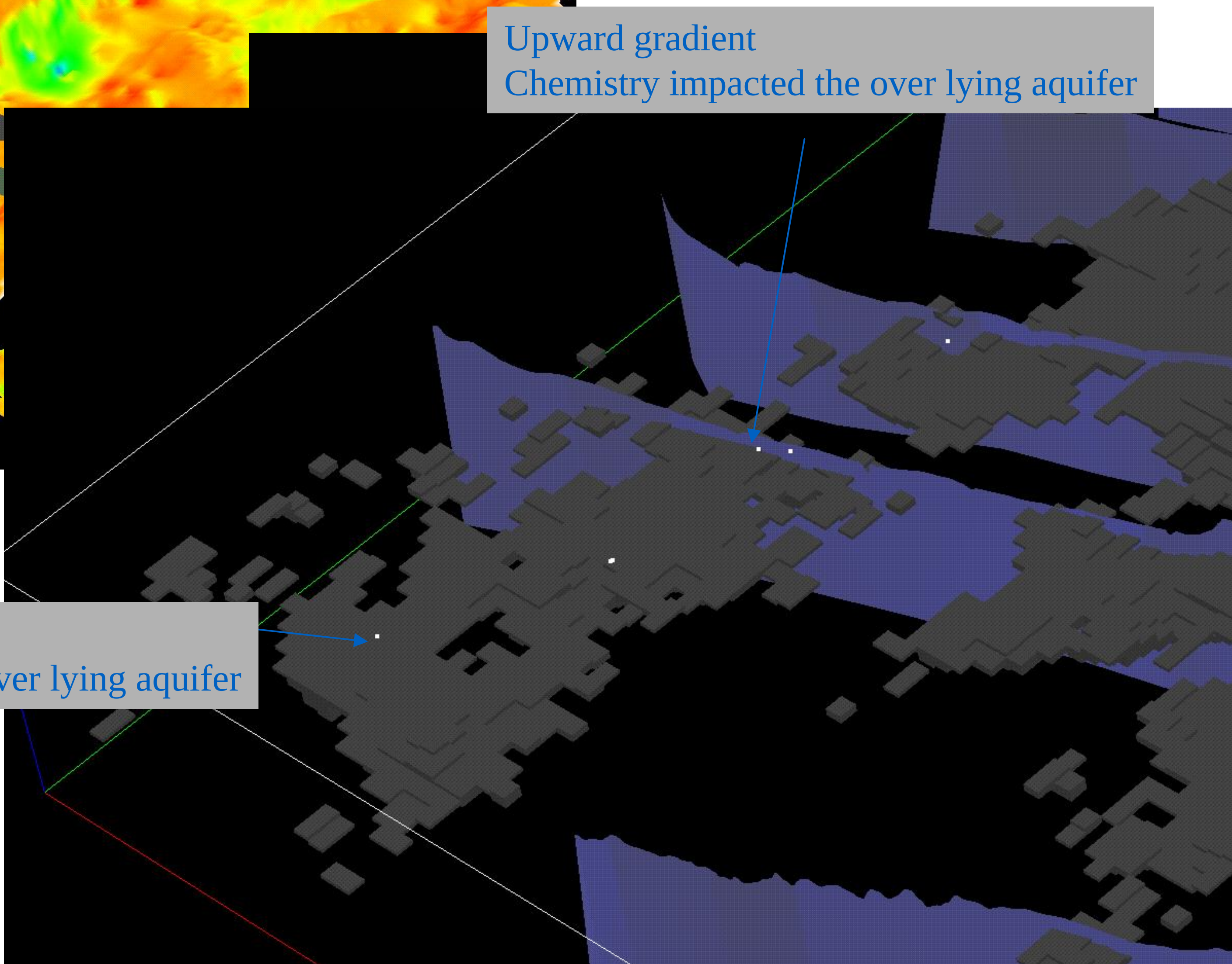






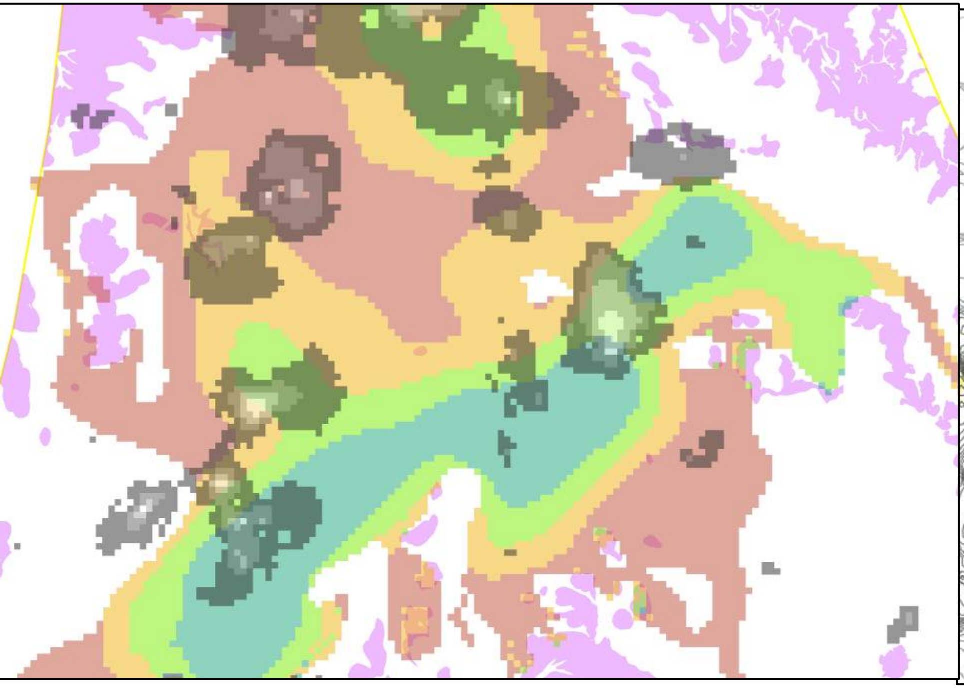


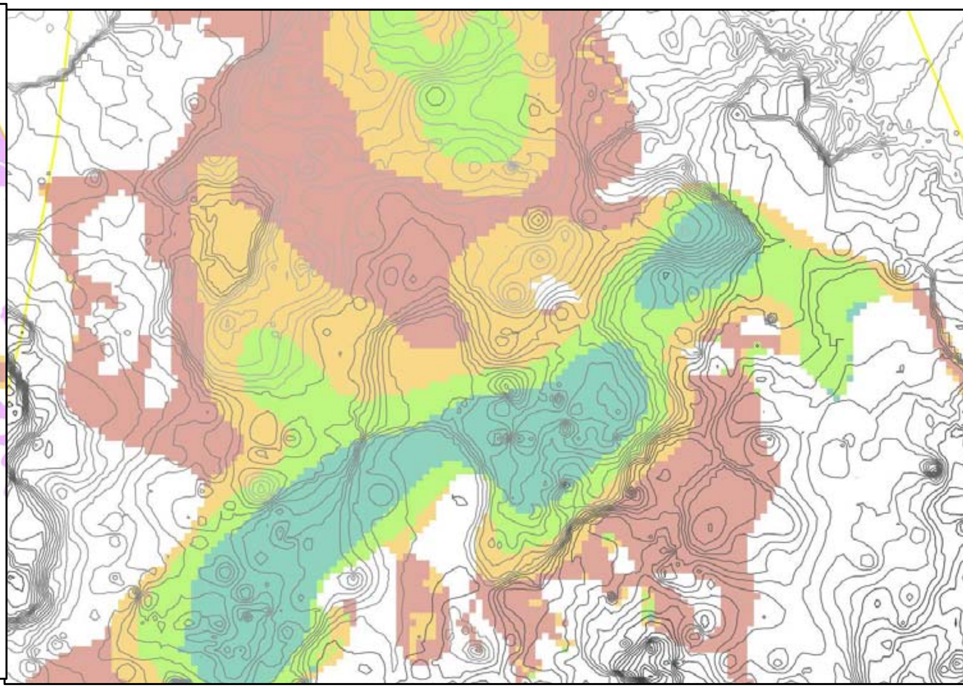



Upward gradient
Chemistry impacted the over lying aquifer
Downward gradient
Chemistry impacted by over lying aquifer

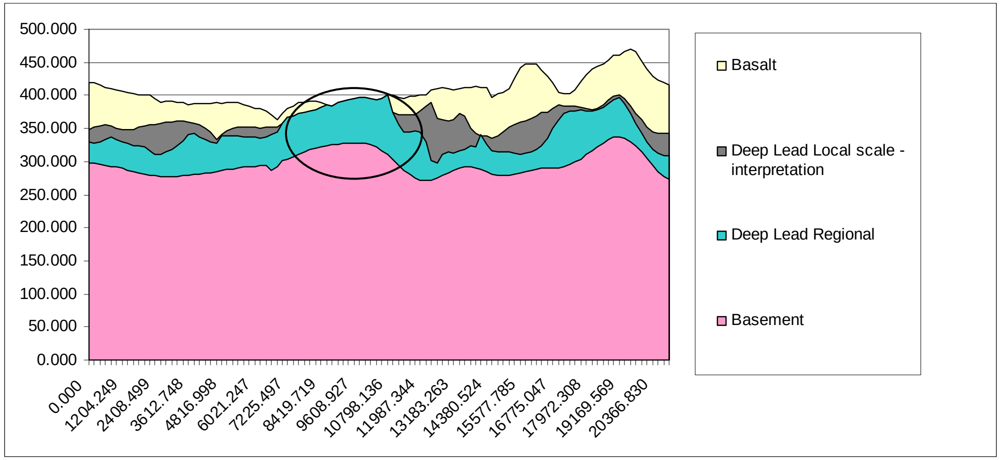
Compare some Results

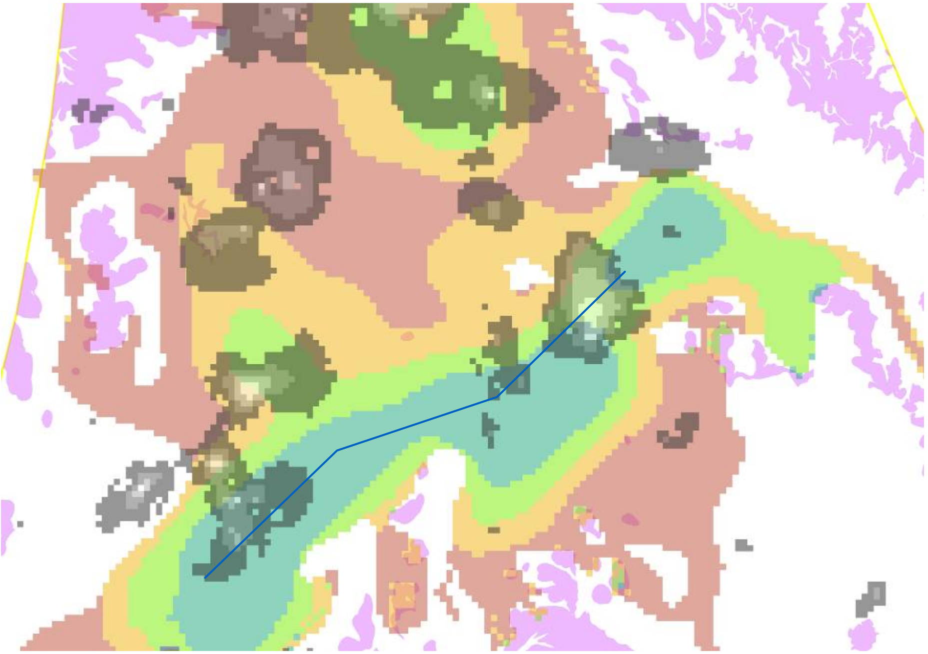
2 interpretations of the Loddon deep lead – more developed interpretation (grey shapes on left) from all available data in 3D





Compare some Results





Learning Process

- Understanding the hydrogeological system
  - Develop sound conceptual hydrogeological models
- Individual assessment of bore data
  - Do I leave or remove
  - What other information exists to interpret a bores geology
  - What other information exists to interpret aquifer dimension
- How do other data sets improve our confidence in model layers
  - e.g. Faults and groundwater chemistry
  - Allows for data points other than bore data

Referrences

- Fawcett J, Cherry D and Reid M (2006) Hydrogeological units of the Upper Loddon and Spring Hill Groundwater Management units. Department of Primary Industries, Victoria.

- Holdgate, G.R., M.W. Wallace, S.J. Gallagher, R.B.Witten, B.Stats and B.E.Wagstaff, (2006), Cenozoic fault control on 'deep lead' palaeoriver system, Central Highlands, Victoria. Australian Journal of Earth Sciences.

- Hagerty S (2007) Groundwater – Surface Water interaction in the Tullaroop catchment, Central Victoria. Latrobe University, Department of Environmental Sciences, faculty of Science, Technology and Engineering, Bundoora, Victoria (Honours Thesis Unpubl).

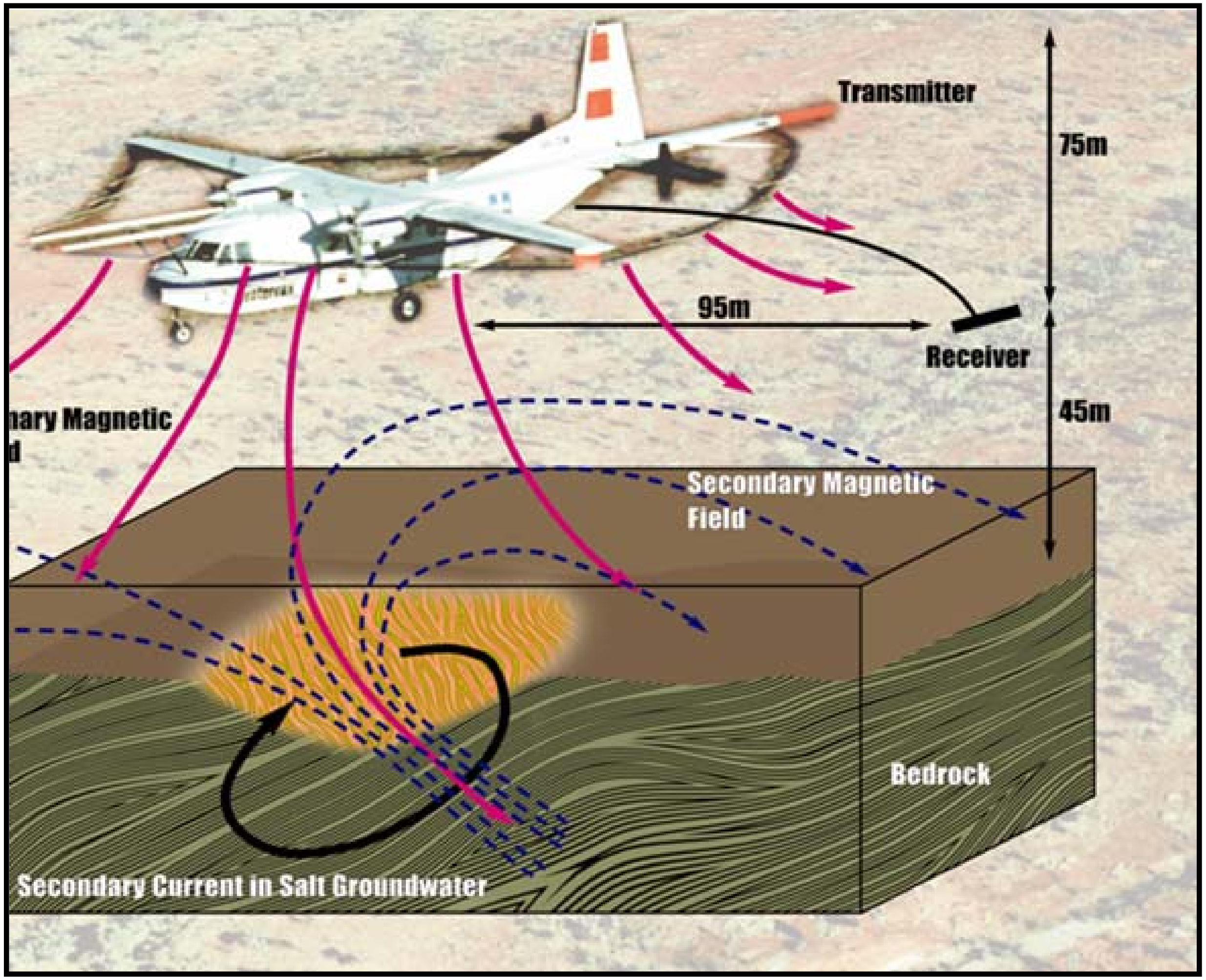
Mapping Groundwater
Airborne Electromagnetic Surveying

1st Australian 3D Hydrogeology Workshop

Scott Macaulay

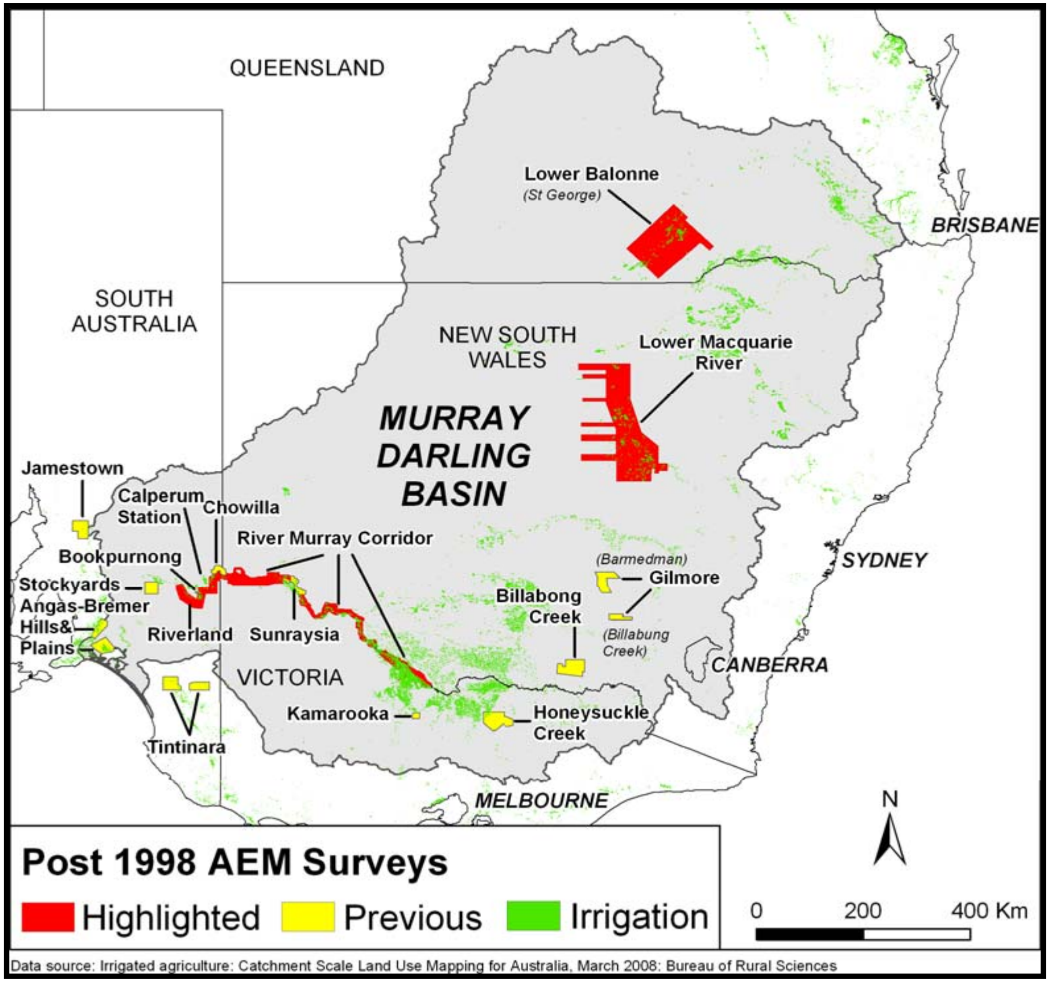
31 August – 1 September 2009

Airborne electromagnetic surveying

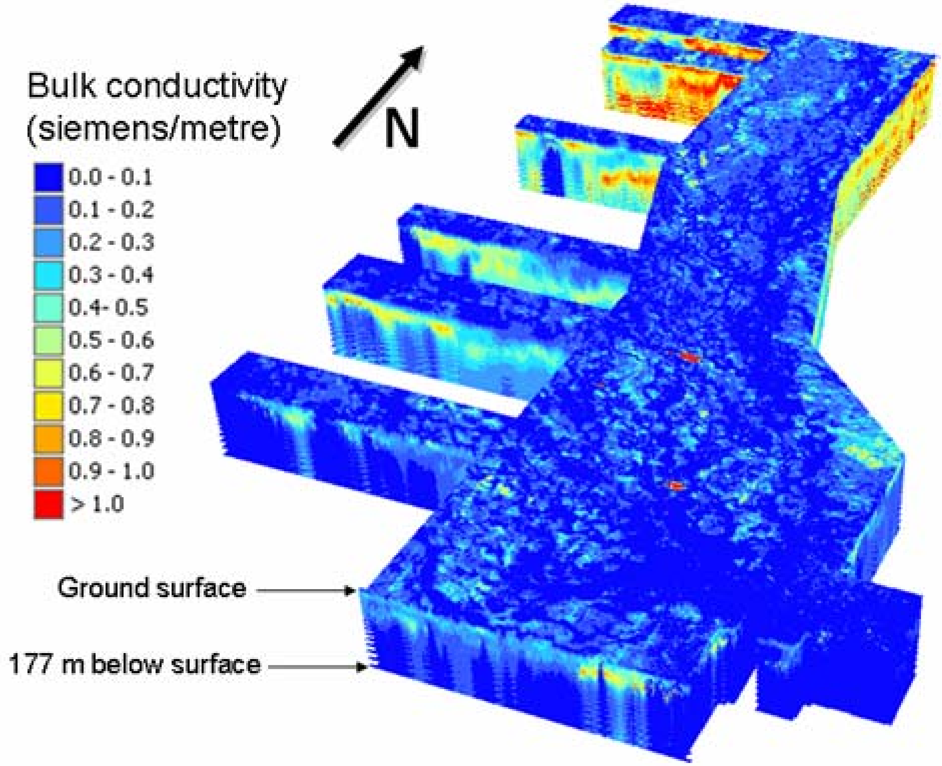


Australian Government
Bureau of Rural Sciences

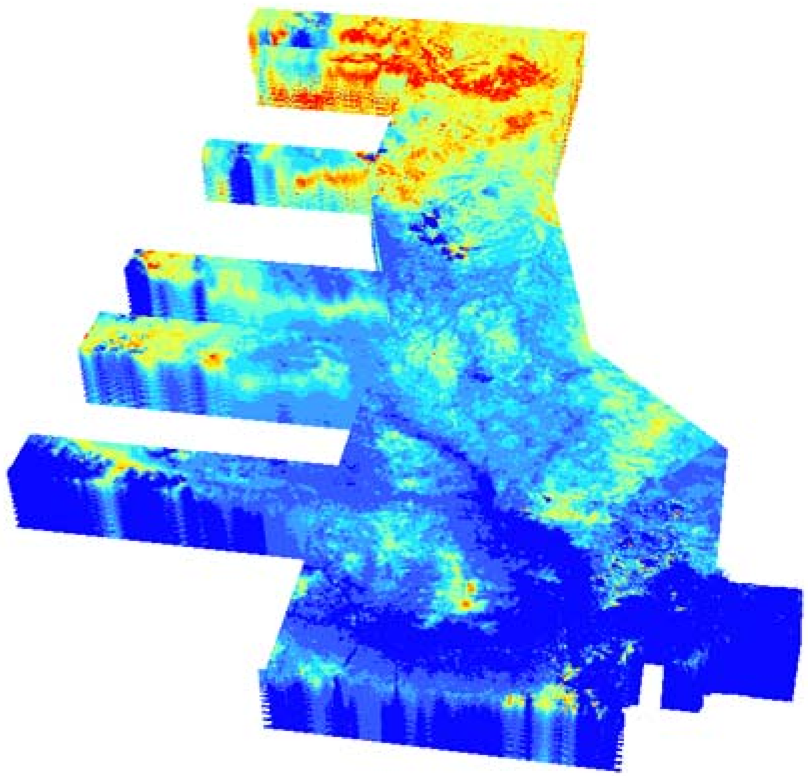
Airborne electromagnetic surveying



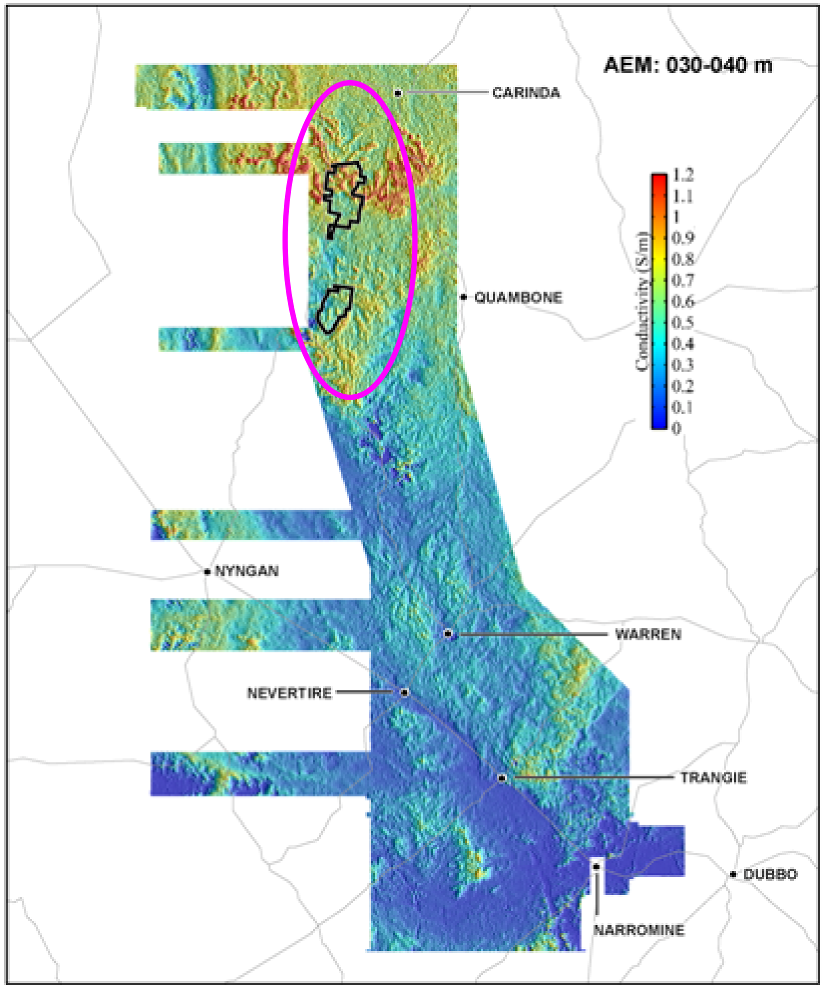
Three-dimensional AEM dataset for the Lower Macquarie River Valley

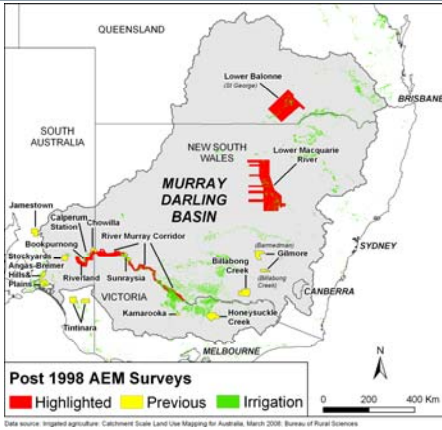


Three-dimensional AEM dataset for the Lower Macquarie River Valley

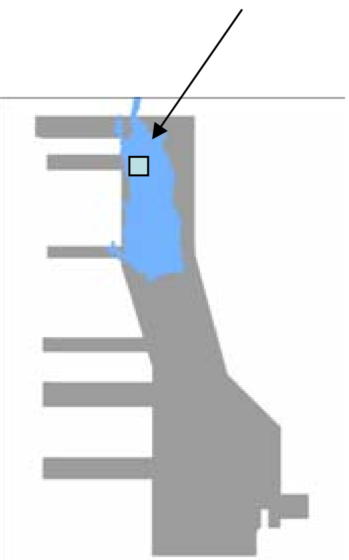


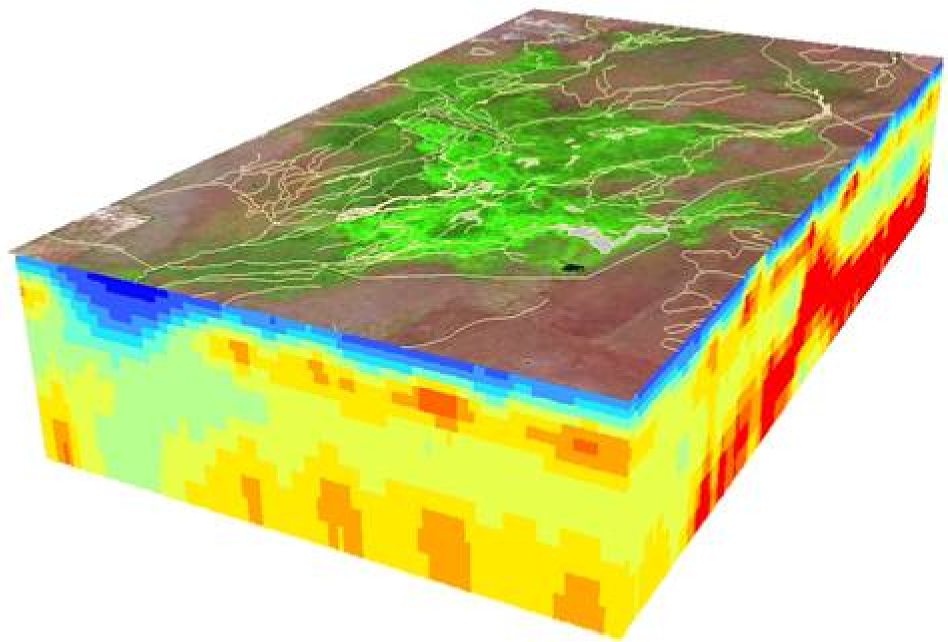
Airborne electromagnetic surveying



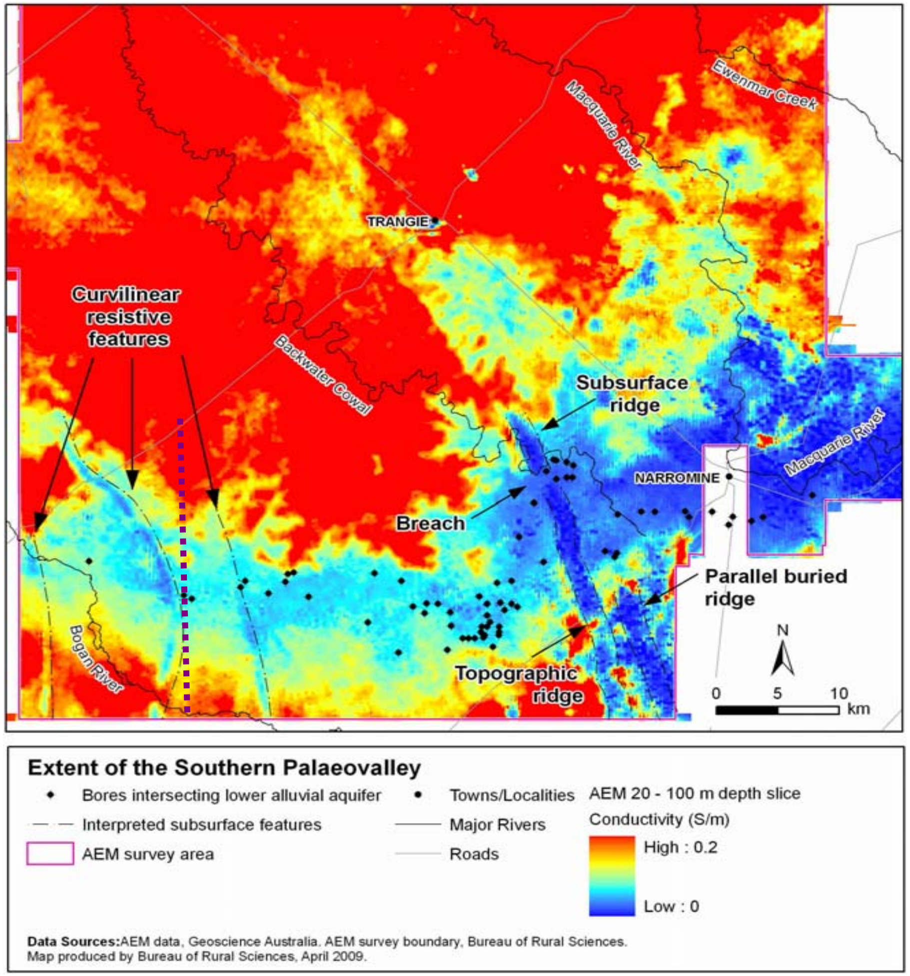


Macquarie Marshes





Southern Palaeovalley



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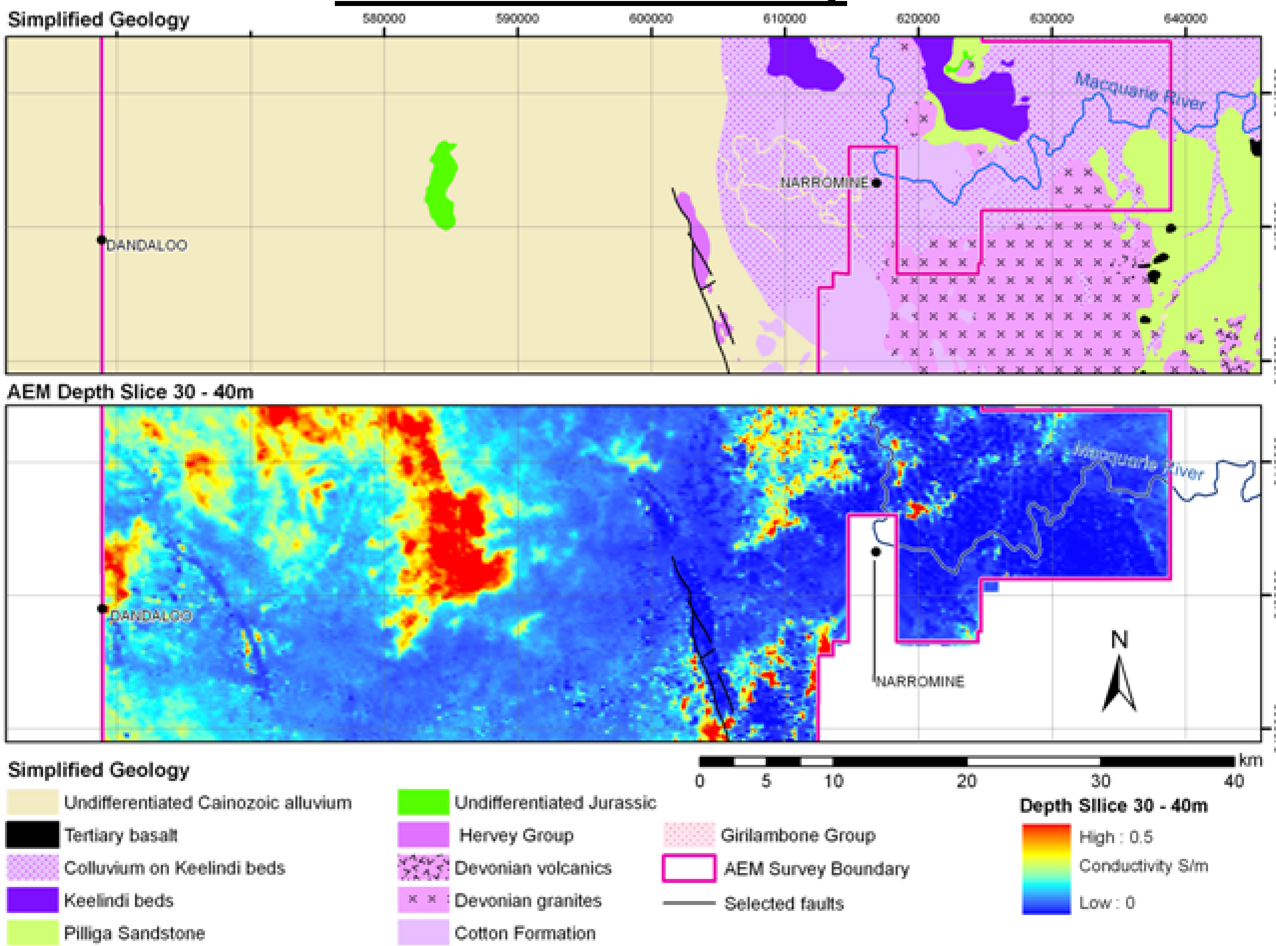
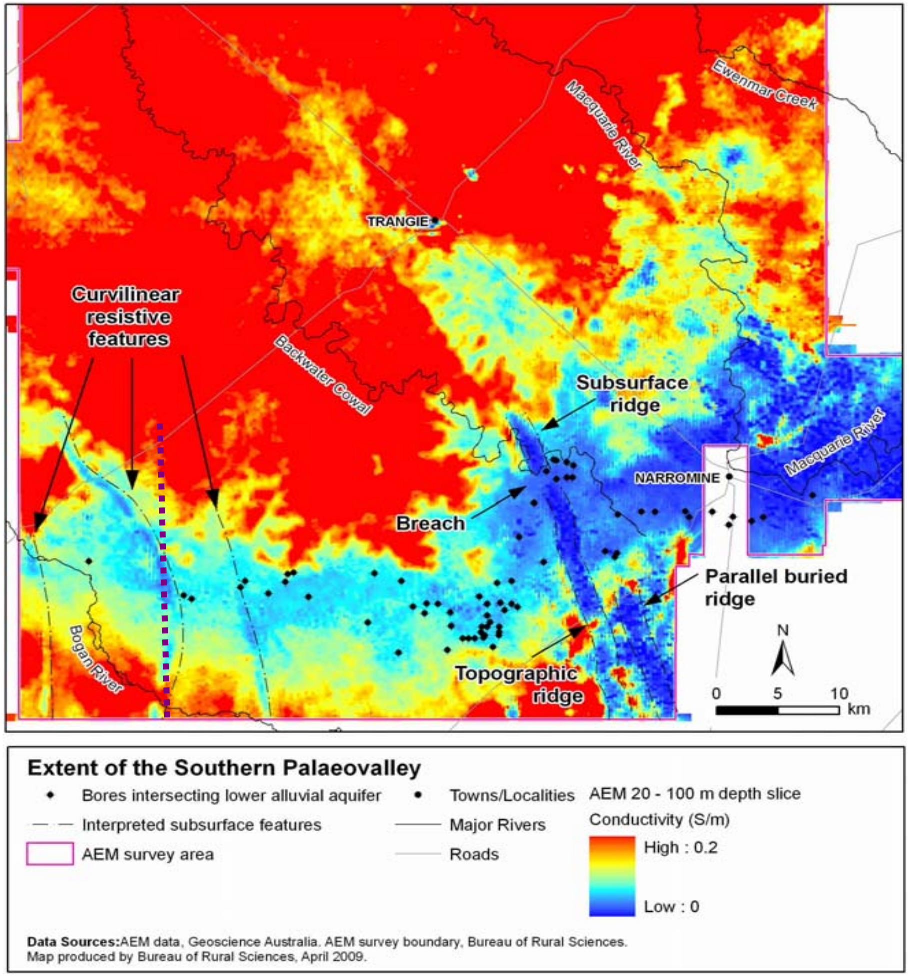
Southern Palaeovalley



Data Sources: Geology data: simplified from NSW 1:250 000 Statewide Geology, Narromine sheet, NSW DPI, 2003. AEM Survey Boundary: Bureau of Rural Sciences. AEM data: Geoscience Australia. Map produced by Bureau of Rural Sciences, June 2009.

Southern Palaeovalley



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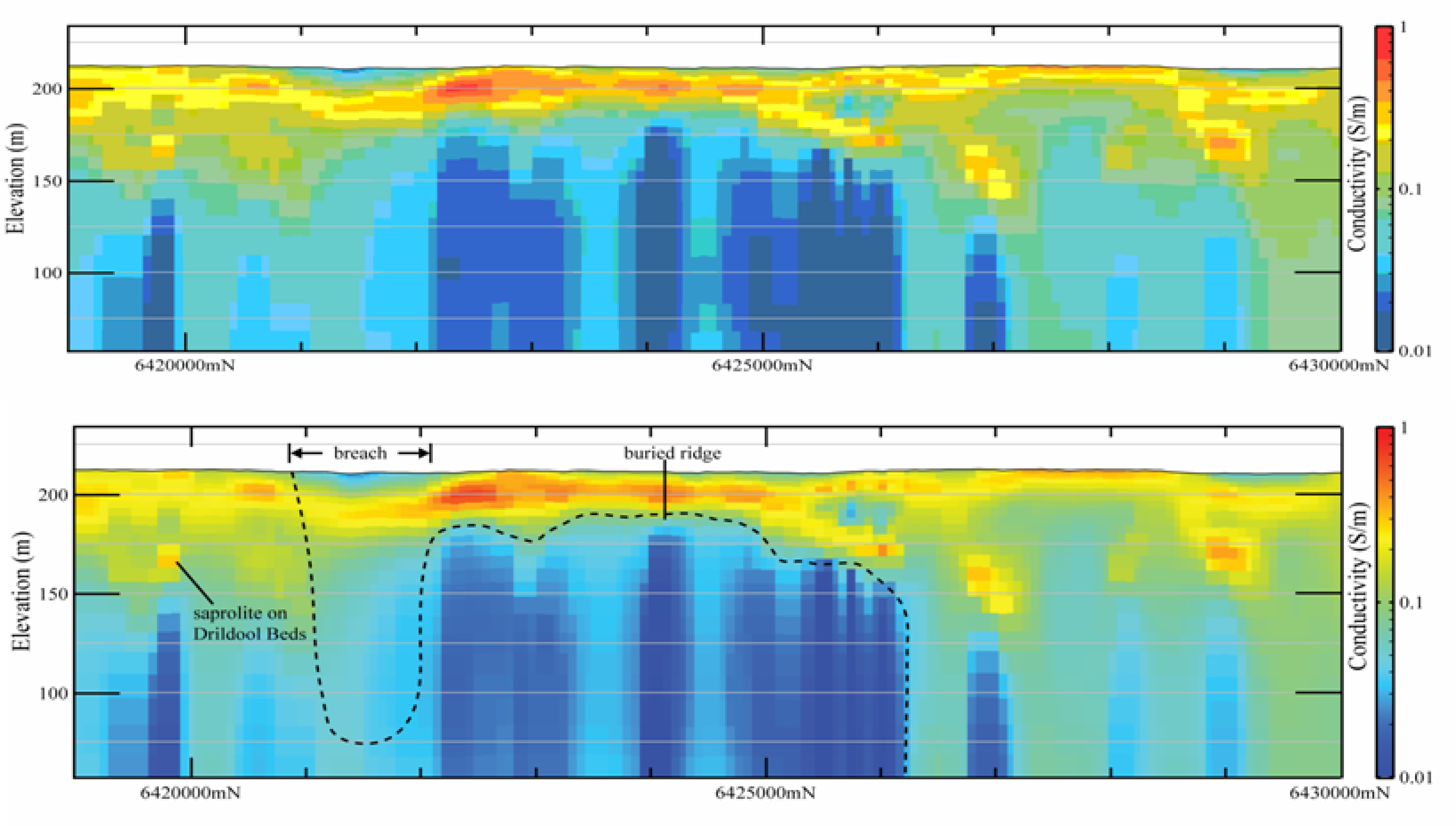

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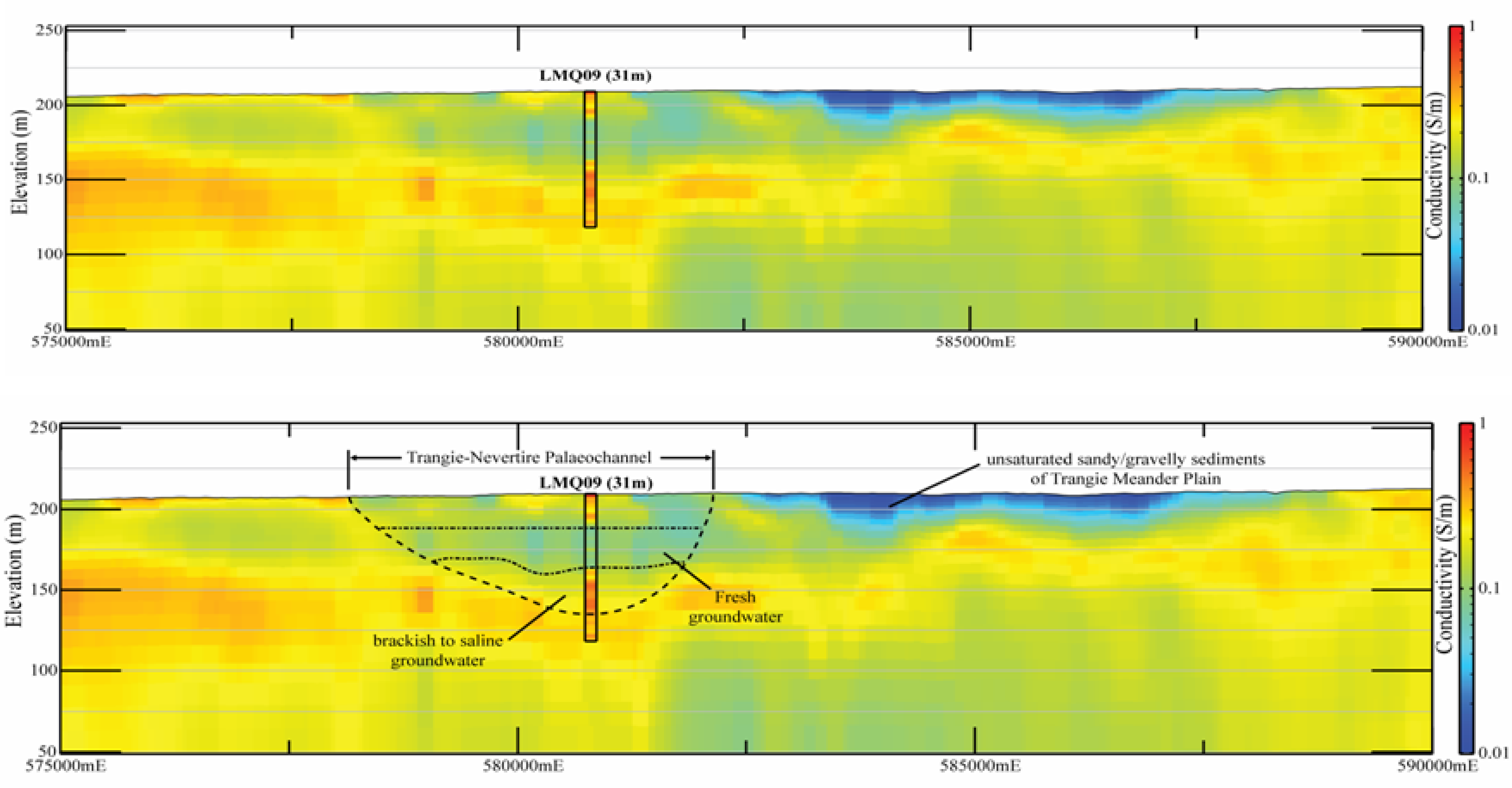
Trangie – Nevertire Palaeochannel



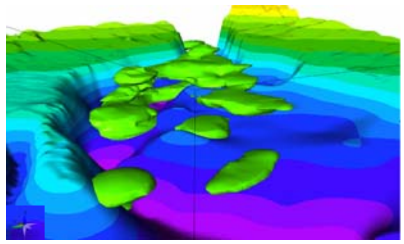
Thank-you

…. and Questions?

For further information please contact:
Scott Macaulay
scott.macaulay@brs.gov.au
Ph: 02 6272 4883

3D Hydrograph Analysis for Constraining the Construction of Hydrogeological Models

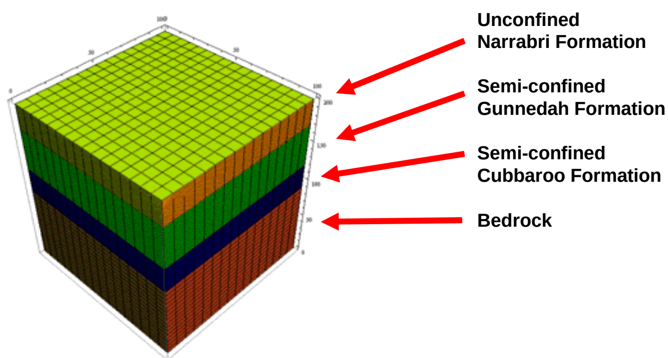
31 August 2009



Palaeochannels in the Lower Namoi Catchment

A/Prof B. Kelly, Dr B. Giambastiani, Dr W. Timms, and C. The[1]
University of New South Wales
Connected Waters Initiative
National Centre for Groundwater Research and Training
Australian Bureau of Meterology

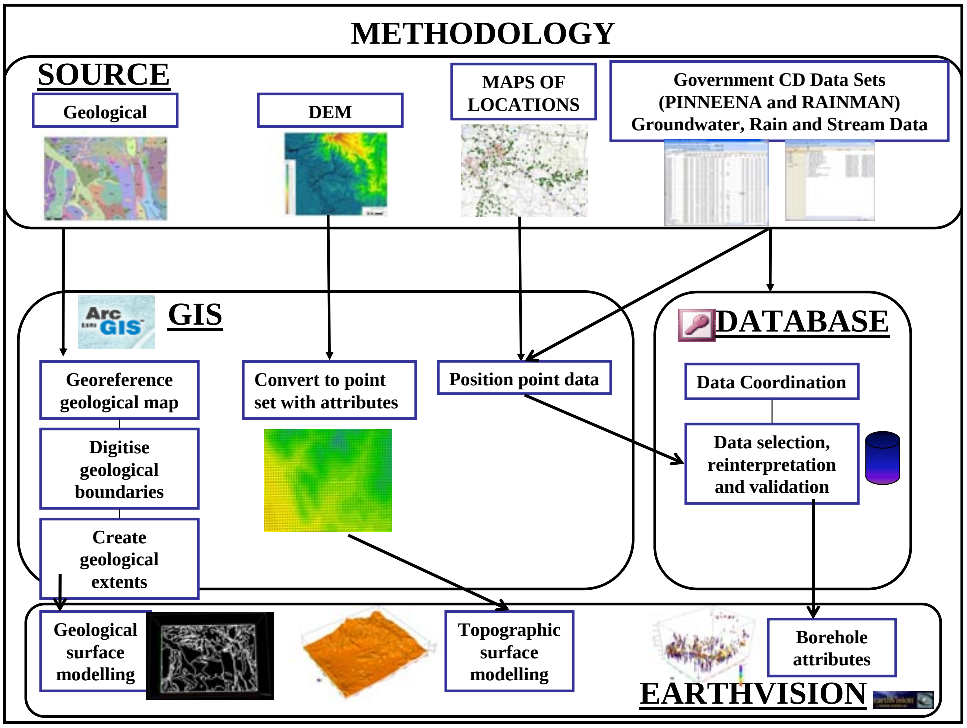
MODFLOW

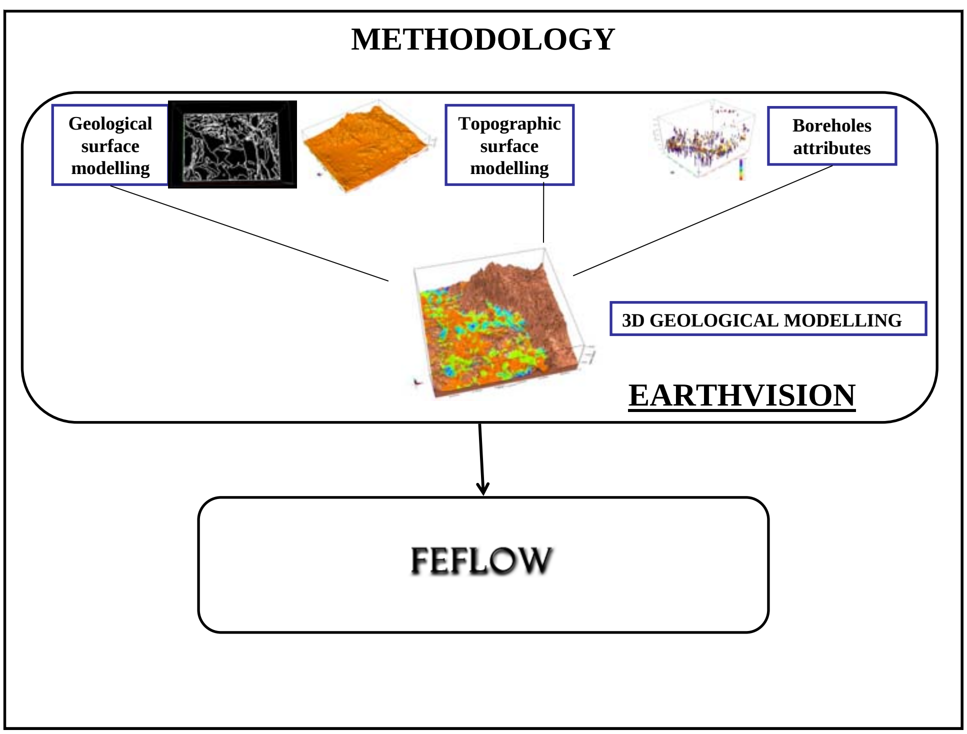


Current MODFLOW models used to represent aquifers throughout the Murray-Darling Basin are simple layer cake representations.

Accurate modelling of the movement and interaction of different water quality zones requires conceptual models that capture the complexity of the aquifer geometry and facies distribution. In particular the meandering pathways of hydraulic connectivity need to be mapped and represented in detail.

3D hydrograph analysis can give us insights into the pathways of hydraulic connection.


METHODOLOGY
SOURCE
Geological
DEM
MAPS OF LOCATIONS
Government CD Data Sets (PINNEENA and RAINMAN) Groundwater, Rain and Stream Data
GIS
Georeference geological map
Digitise geological boundaries
Create geological extents
Convert to point set with attributes
Position point data
DATABASE
Data Coordination
Data selection, reinterpretation and validation
Geological surface modelling
Topographic surface modelling
Borehole attributes
EARTHVISION

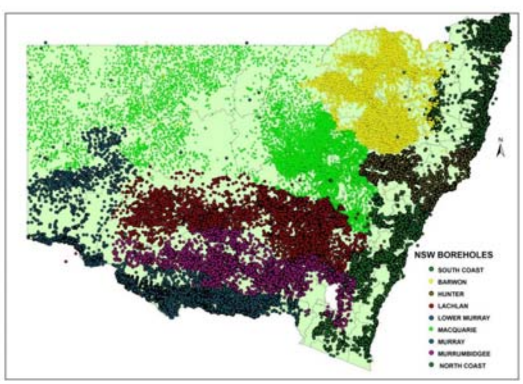

METHODOLOGY
Geological surface modelling
Topographic surface modelling
Boreholes attributes
3D GEOLOGICAL MODELLING
EARTHVISION
FEFLOW

Better Conceptual Model

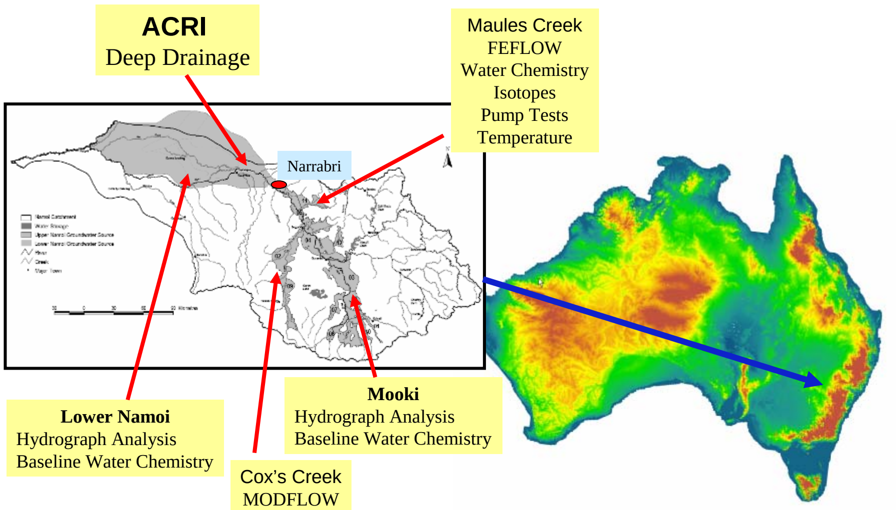
- Using the NSW government borehole records there are two ways you can examine the structure of aquifers.
- Interpolate between the borehole lithology logs using geostatistical and categorical gridding methods.
- Borehole hydrograph analysis (the subject of this presentation).

Bores in New South Wales

- In NSW there are thousands of bore details recorded in the DWE Pinneena Groundwater CD.
  http://waterinfo.nsw.gov.au/pinneena/gw.shtml (accessed August 2008)
- These bores can be used to define the shape of the bedrock surface, sedimentary sequences, and water level trends with time.



Namoi Catchment



Python Scripts

- Python scripts/programs are used to:
  - Clean the data
  - Plot every groundwater monitoring record for the Namoi Catchment
  - Query the data

To be replaced by Mathematica scripts

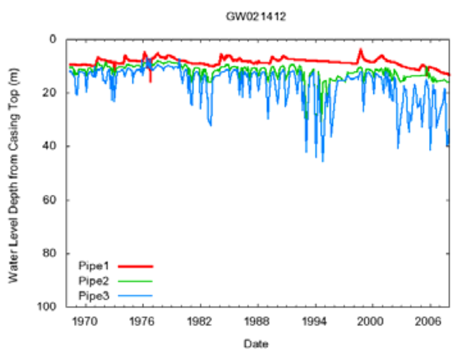
Borehole Hydrographs

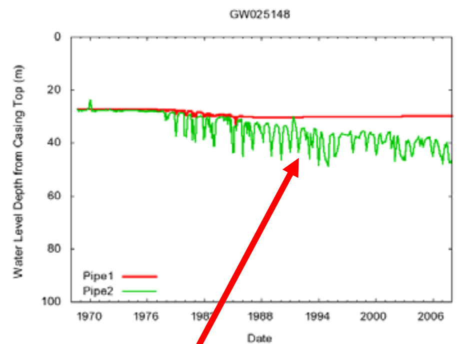
No Flood Recharge

Upper Slight Decline

Lower Aquifer Being Mined

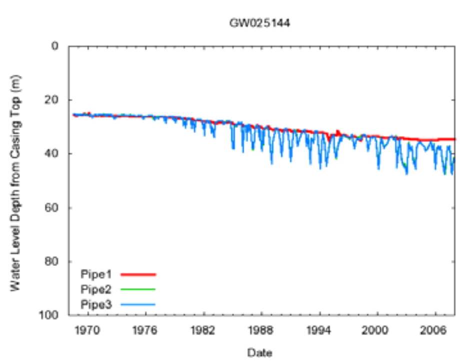
Flood Recharge
Indicated by the sudden rises in the red line

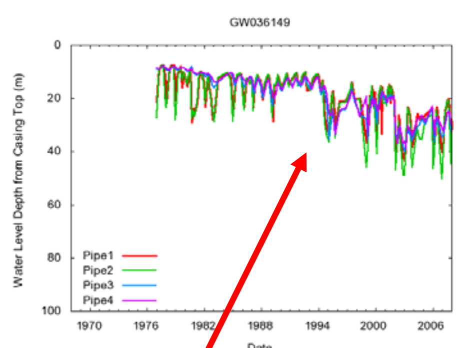




Low Aquifer Connectivity

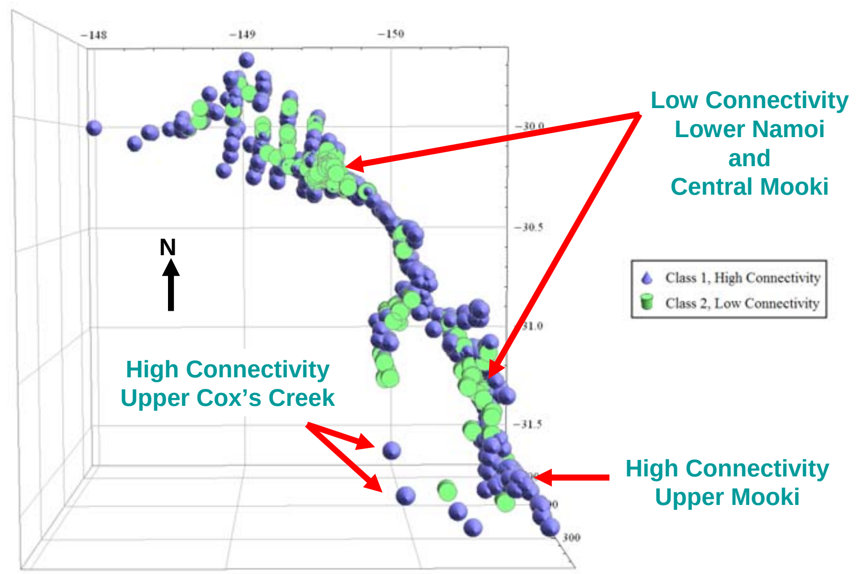
Borehole Hydrographs
Examples of Aquifer Mining



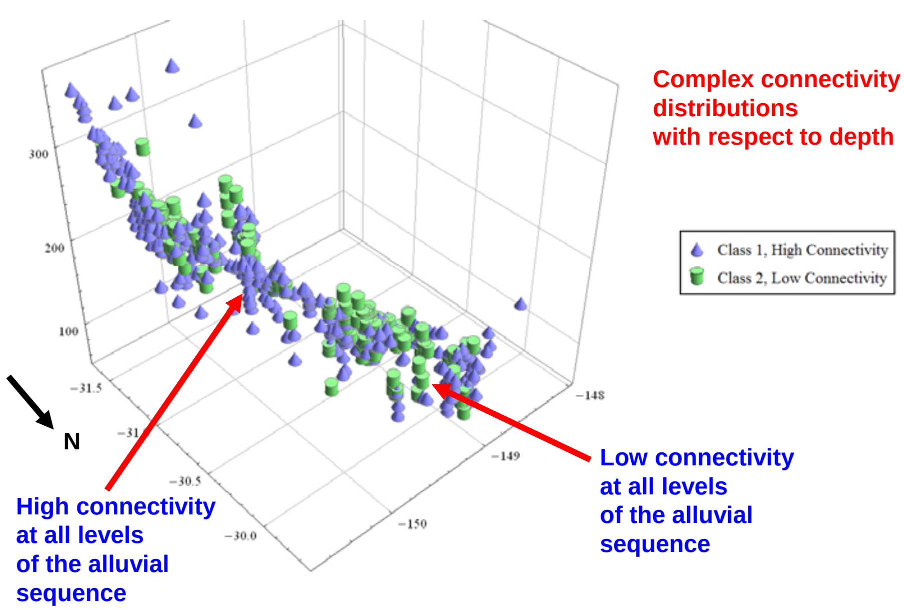


High Aquifer Connectivity

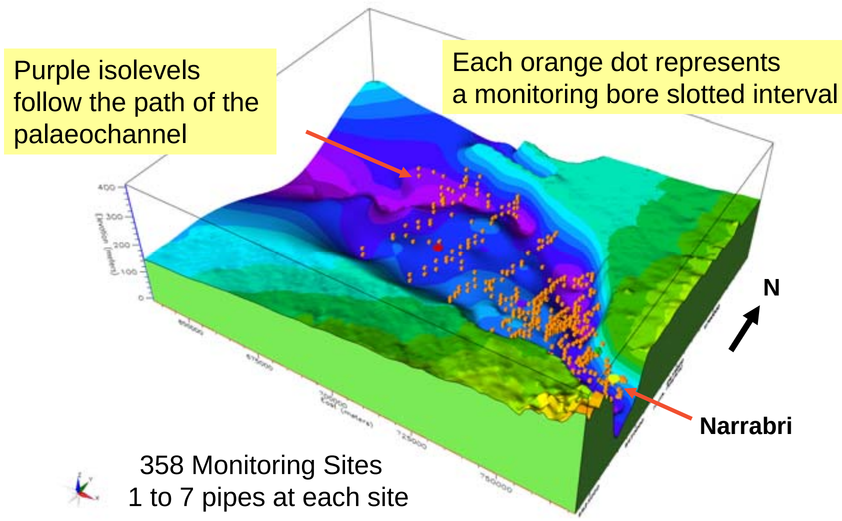
Namoi 2003 Aquifer Connectivity



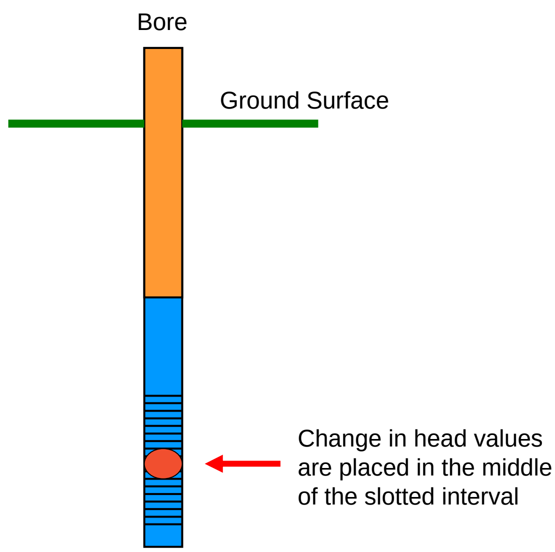
Namoi 2003 Aquifer Connectivity



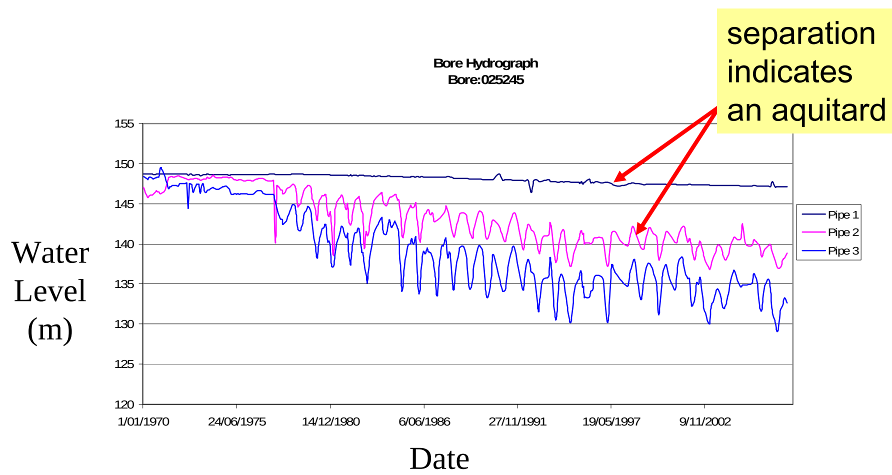
Lower Namoi
State Government Monitoring Bores



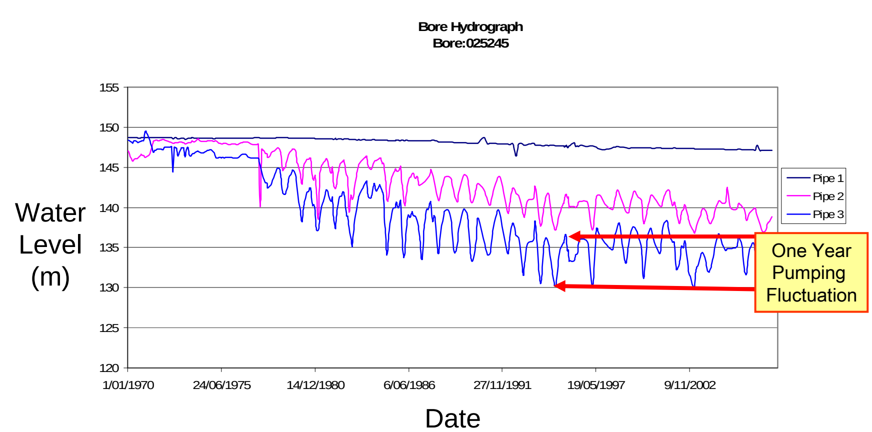
Data Plotting Position



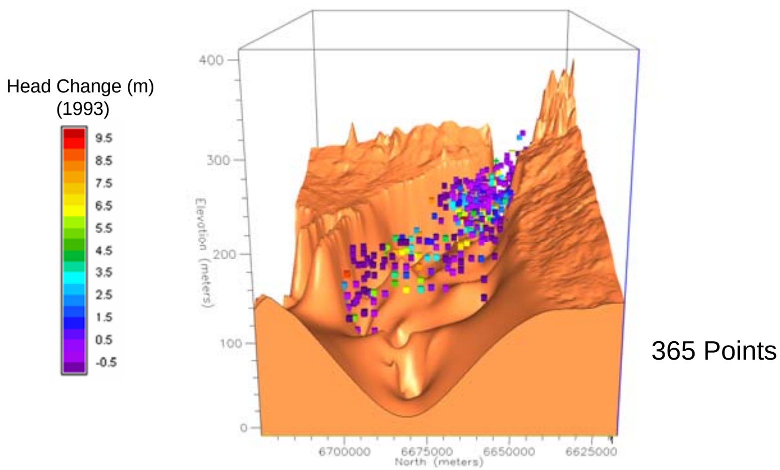
Using Pumping Stress to Map Connectivity



Mapping Hydraulic Connections Using One year groundwater head fluctuation

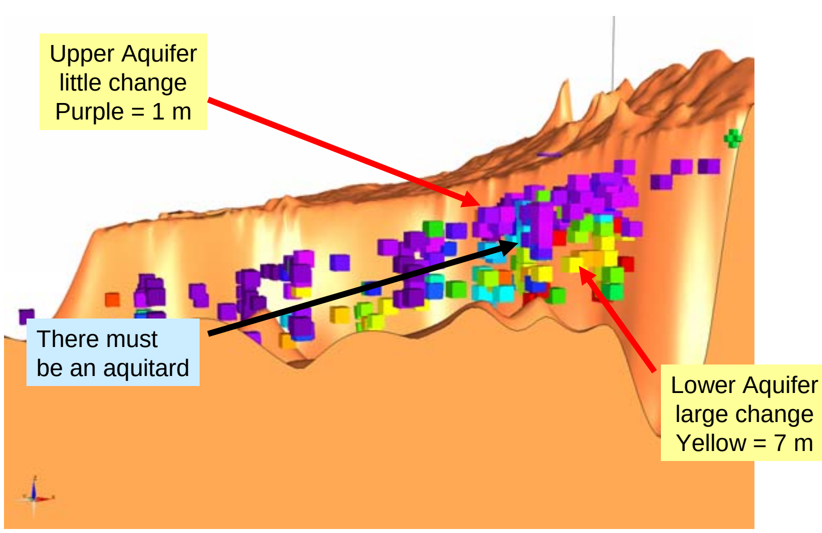


One Year Groundwater Head Fluctuation 1993



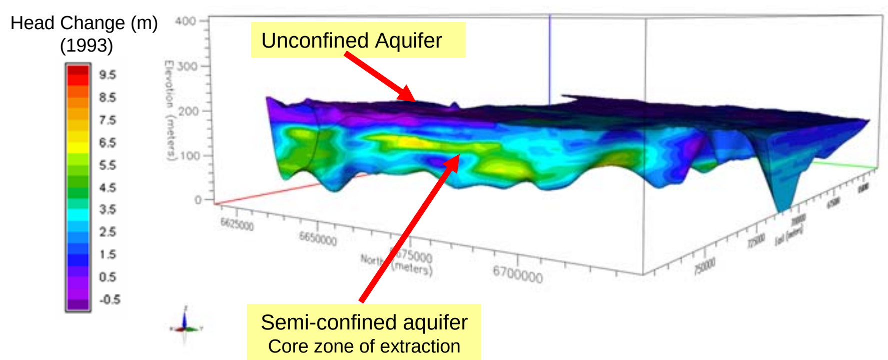
Change in head values plotted at the mid-point of the slotted interval

One Year Groundwater Head Fluctuation 1993

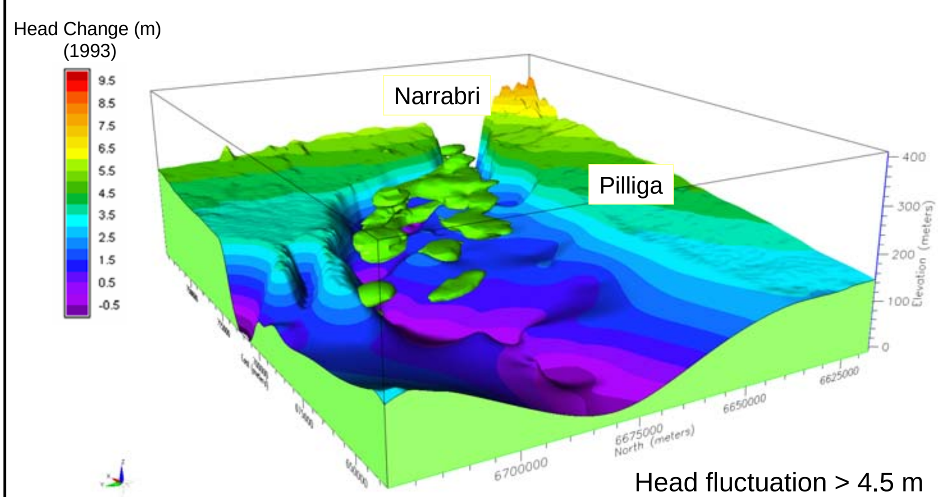


One Year Groundwater Head Fluctuation 1993

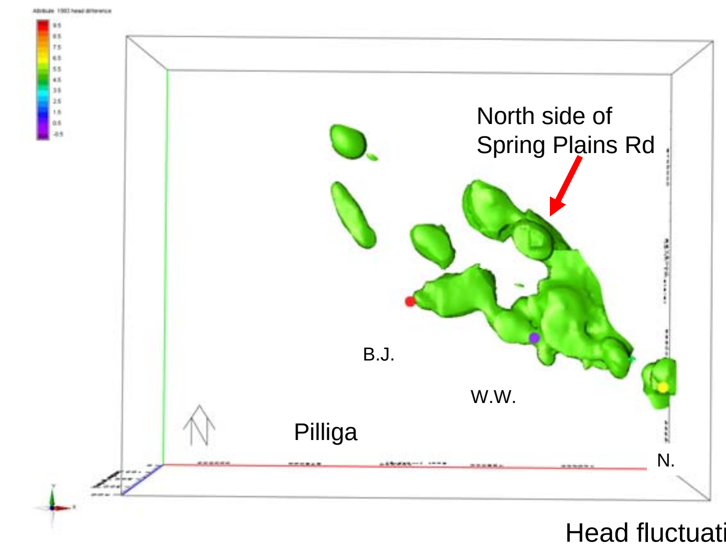
Data gridded using ordinary kriging



Cut Away of One Year Head Fluctuation

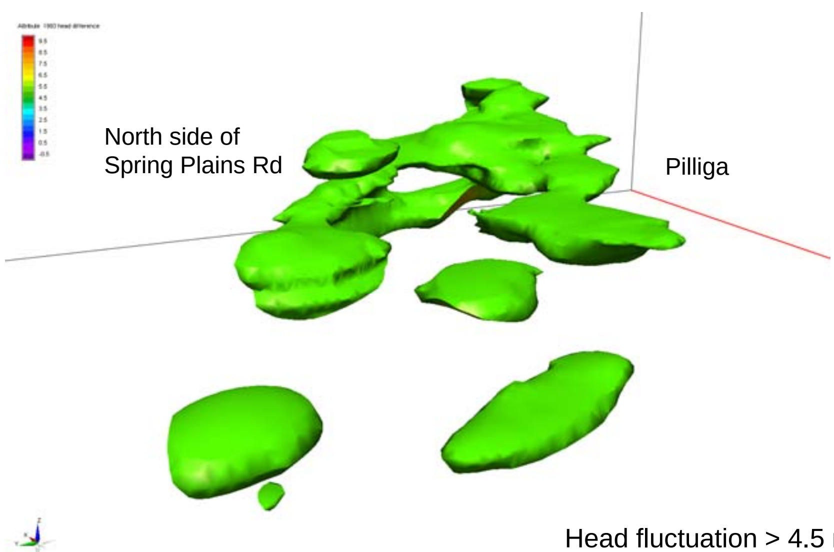


Head Fluctuation Follows the Palaeochannels



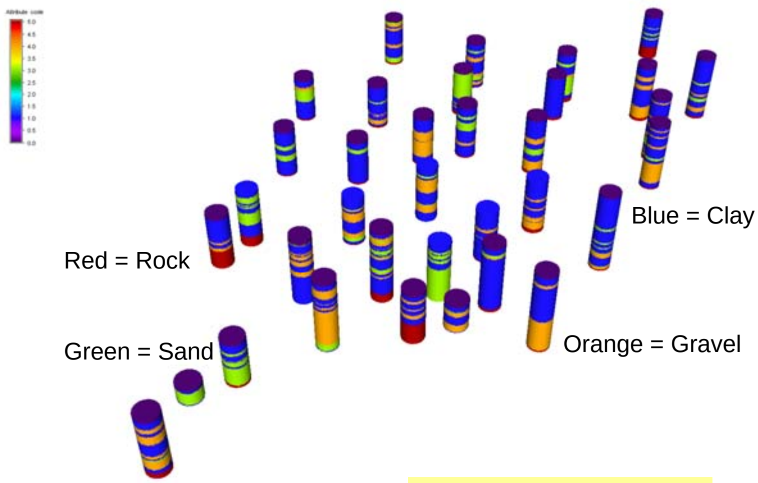
Head fluctuation > 4.5 m

Northern Palaeochannel Divided into Upper and Lower



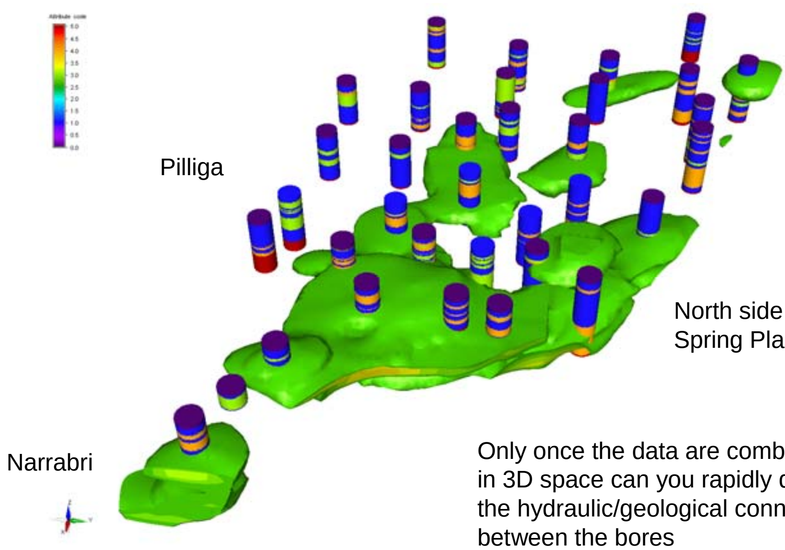
Head fluctuation > 4.5 m

Driller Logs Lower Namoi



Focus your attention on the orange gravels

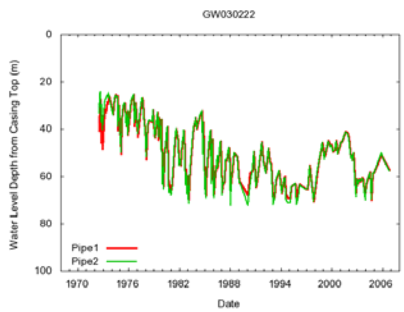
One Year Fluctuation Head Change > 4 m

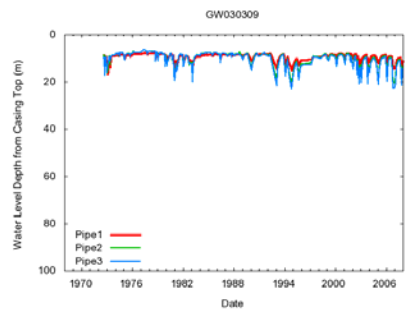


Only once the data are combined in 3D space can you rapidly determine the hydraulic/geological connections between the bores

Temporal Groundwater Head Variability

How does the connectivity interpretation match with the change in head (borehole water level) in the irrigation districts over time?

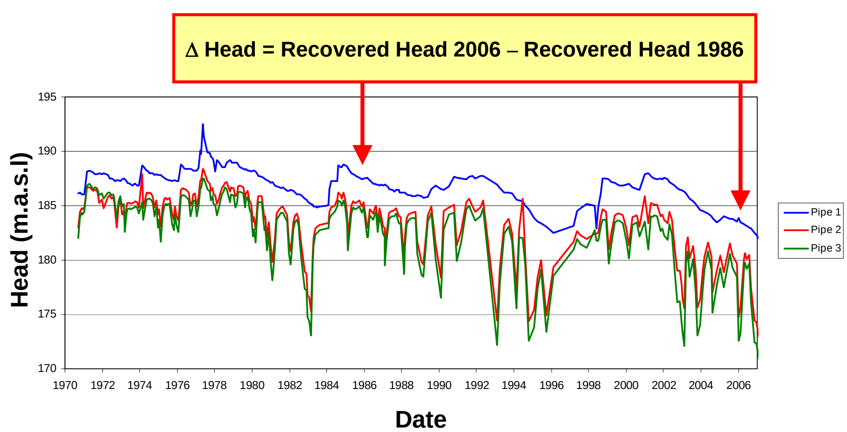




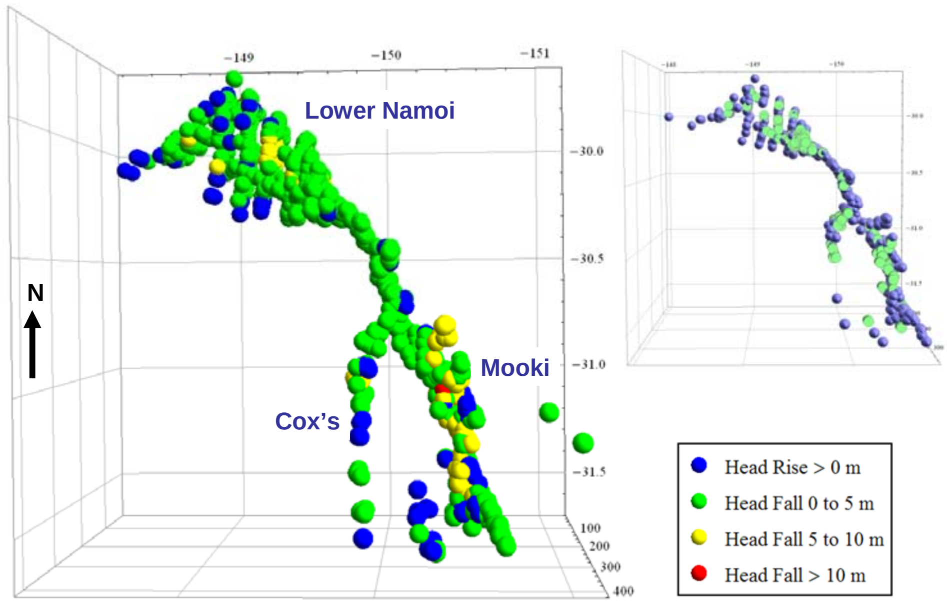
High connectivity
Large change in head

High connectivity
No change in head

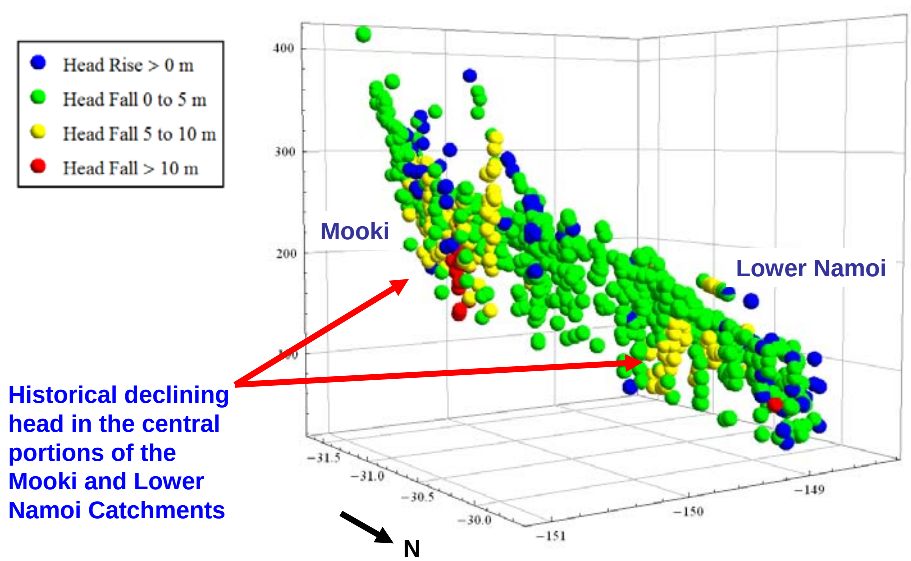
Temporal Change in Groundwater Head 1986 to 2006



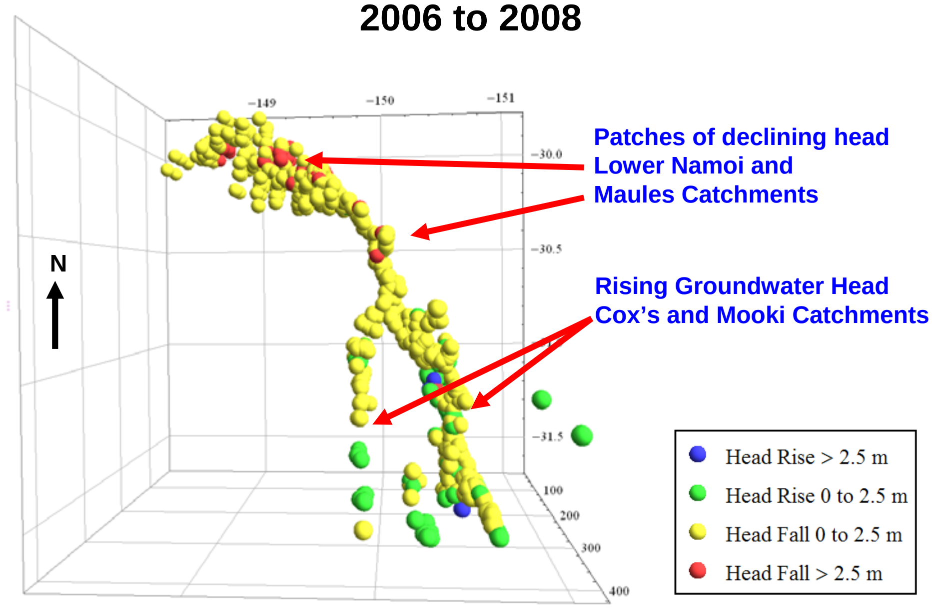
3D Spatial and Temporal Change in Head 1986 to 2006



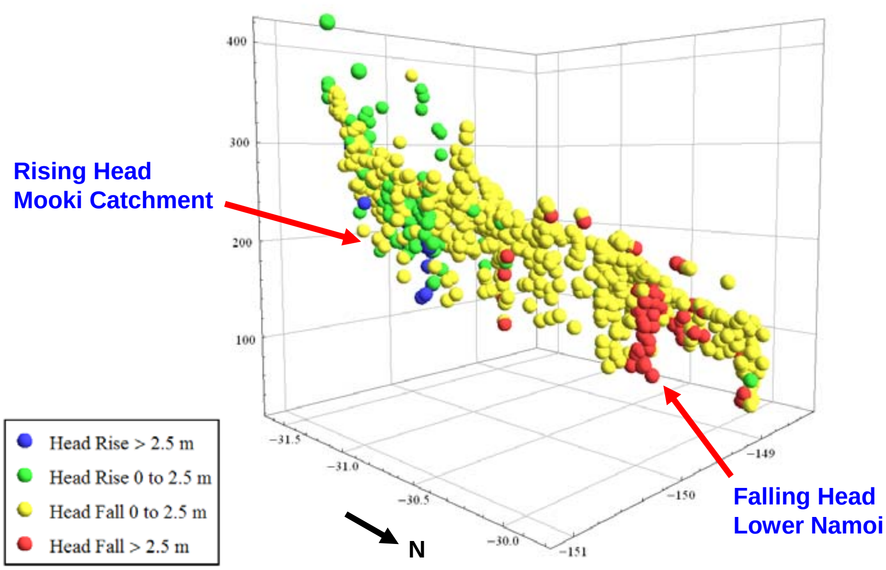
3D Spatial and Temporal Change in Head 1986 to 2006



3D Spatial and Temporal Change in Head
2006 to 2008



3D Spatial and Temporal Change in Head
2006 to 2008



Final Thoughts

- 3D spatial analysis of borehole hydrographs yields insights that enhance our conceptualisation of complex aquifer systems.
- Assigning hydrographs to aquifers based on simple conceptual models can result in poor interpretations. Let the data speak.
- The complexity that is revealed is not captured in existing MODFLOW models used to guide water management. How do we incorporate the complexity shown into future groundwater models?
- Much research and management within the MDB is focused on stream and aquifer connectivity. It is the lack of connectivity that is causing some major problems. Time for Managed Aquifer Recharge ?

Australian Government

Geoscience Australia

Eromanga 3D map: Killing several birds with one model

Alison Kirkby & Simon van der Wielen

With contributions from: ***Evgeniy Bastrakov, Andy Barnicoat, Allison Britt, Andrew Cross, Terry Mernagh, Malcolm Nicoll, Richard Chopping, Anthony Schofield, Roger Skirrow***.

Talk Outline

- Background
- Methodology of how the model was built
- Results

Locality Map

Study Area

NW Corner: -150,000 mE;

-1,250,000 mN.

SE Corner: 1,700,000 mE;

-3,800,000 mN.

Eromanga Basin:

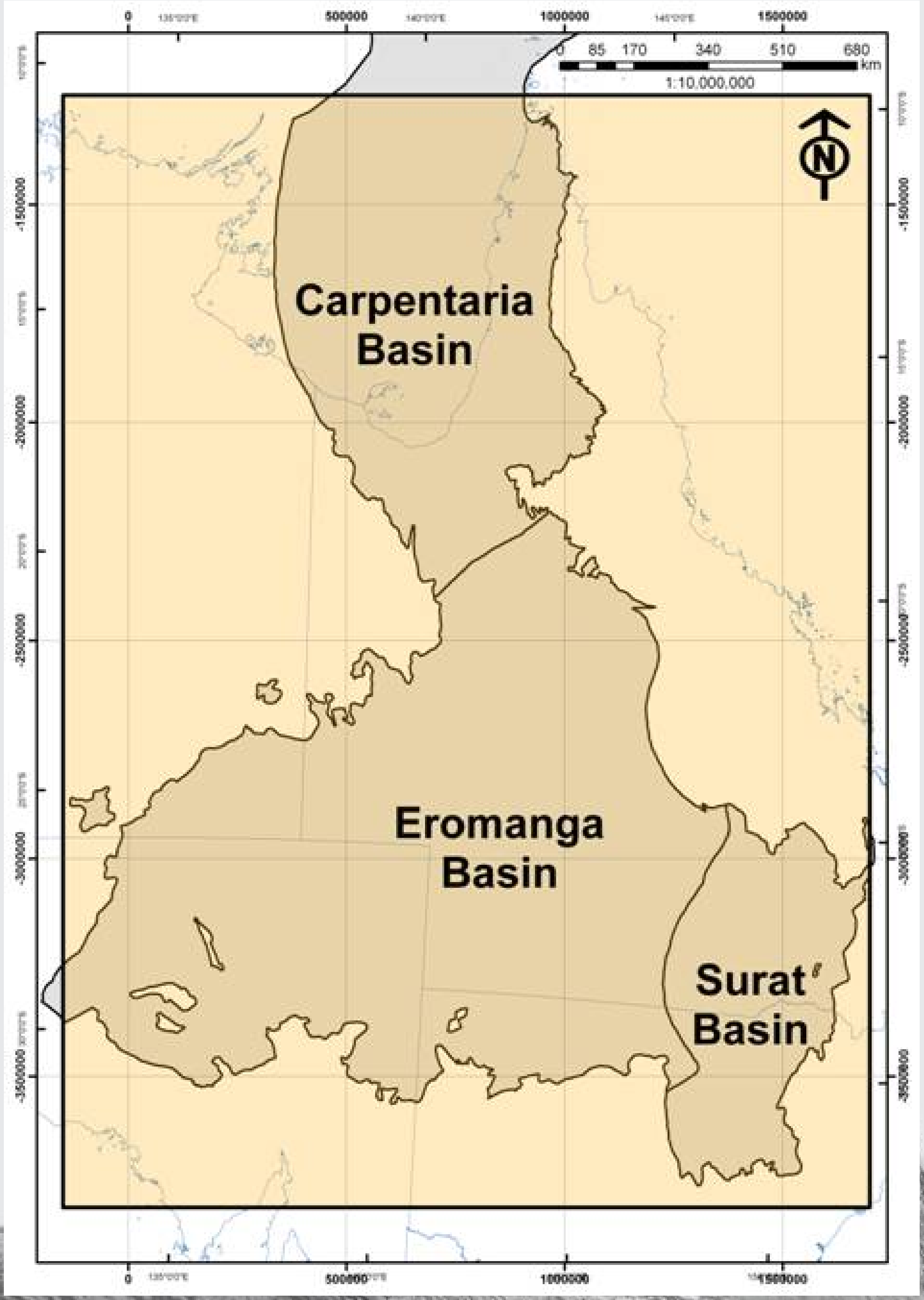
1,224,506 km²

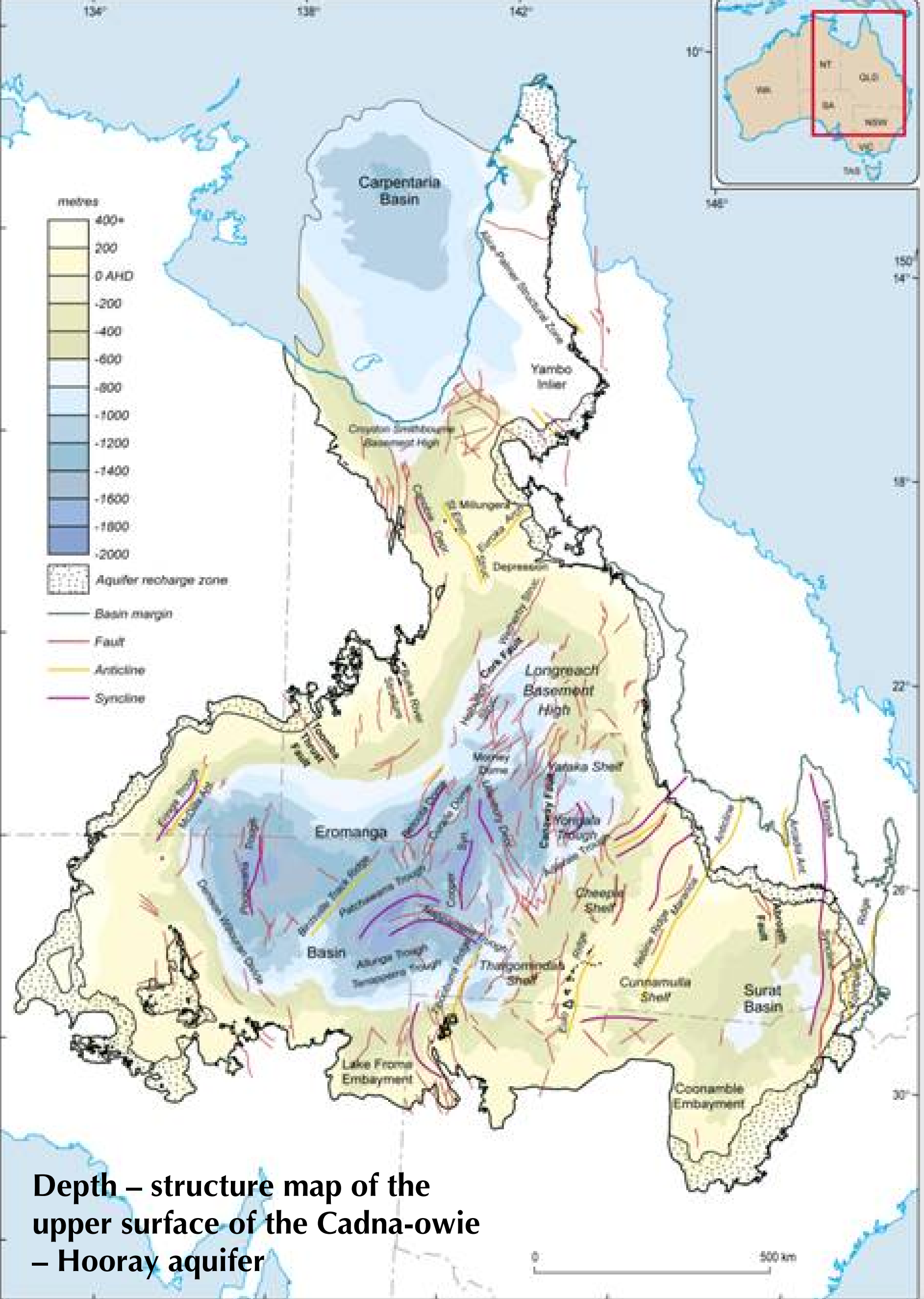
Surat Basin:

257,460 km²

Carpentaria Basin:

696,090 km²





Depth – structure map of the upper surface of the Cadna-owie – Hooray aquifer

Structure

- Main structural trend is NNE
- Four major depocentres
  - Central Eromanga
  - Surat
  - Carpentaria
  - Poolowanna Trough

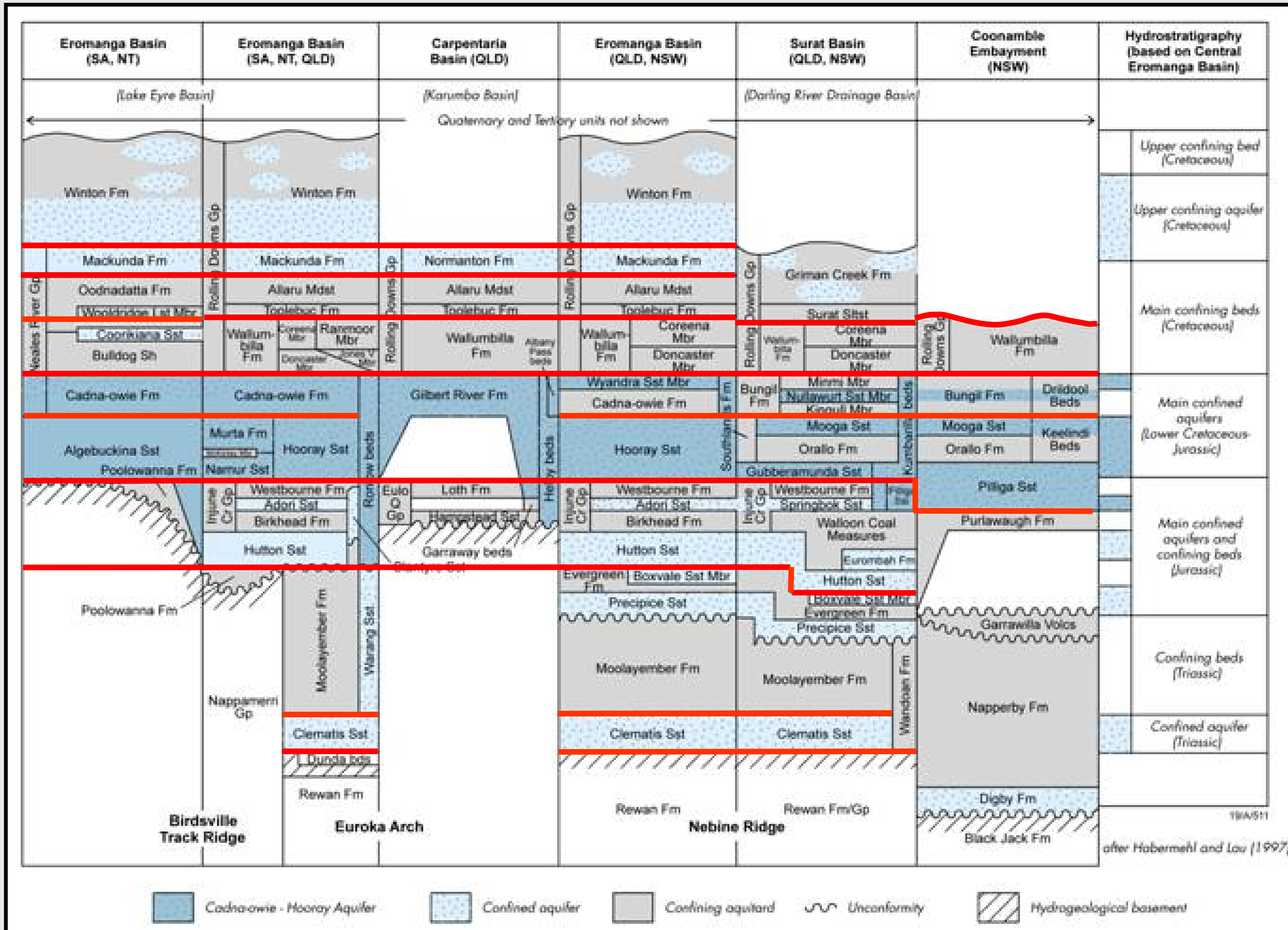
Stratigraphic Framework

00_DEM (Topography)

01_Ksrw (Winton)
02_Ksrm (Mackunda)
03_Klro (Toolebuc)
04_Ksr (Rolling Downs)
05_Ksco (Cadna-owie)
06_Jsyh (Hooray)
07_Jsbh (Hutton)

08_Rsmo (Moolayember)
09_Rsl (Clematis)

10_Basement



Radke et al., 2000

The Approach…

1. Integrate existing datasets into a 3D environment (in this case gOcad).

2. Use existing datasets to build a 3D map of the Eromanga Basin

3. Populate map with data including pH, temperature, groundwater chemistry, etc

1. Data Model

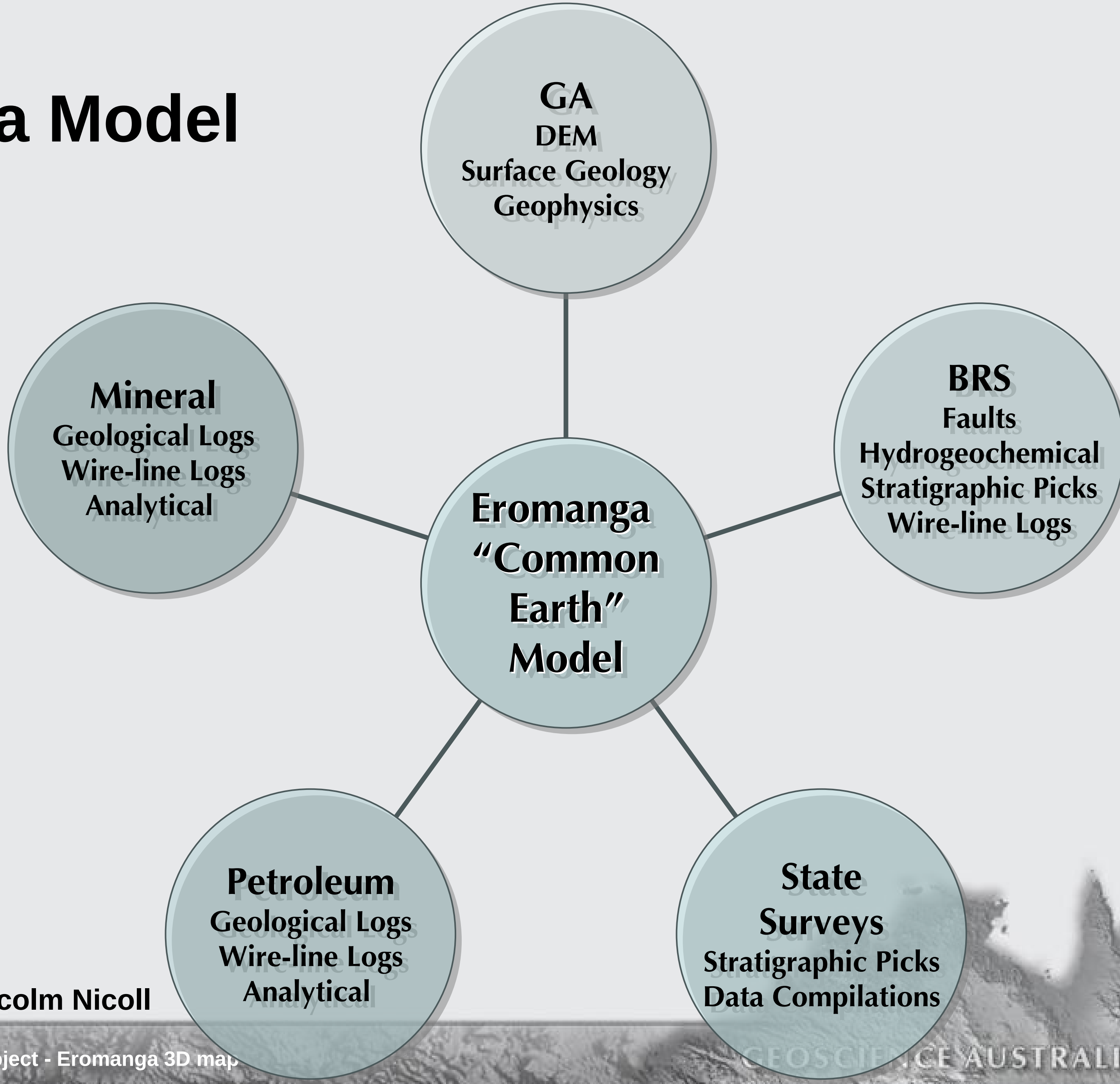


Figure courtesy of Malcolm Nicoll

1. Data Model

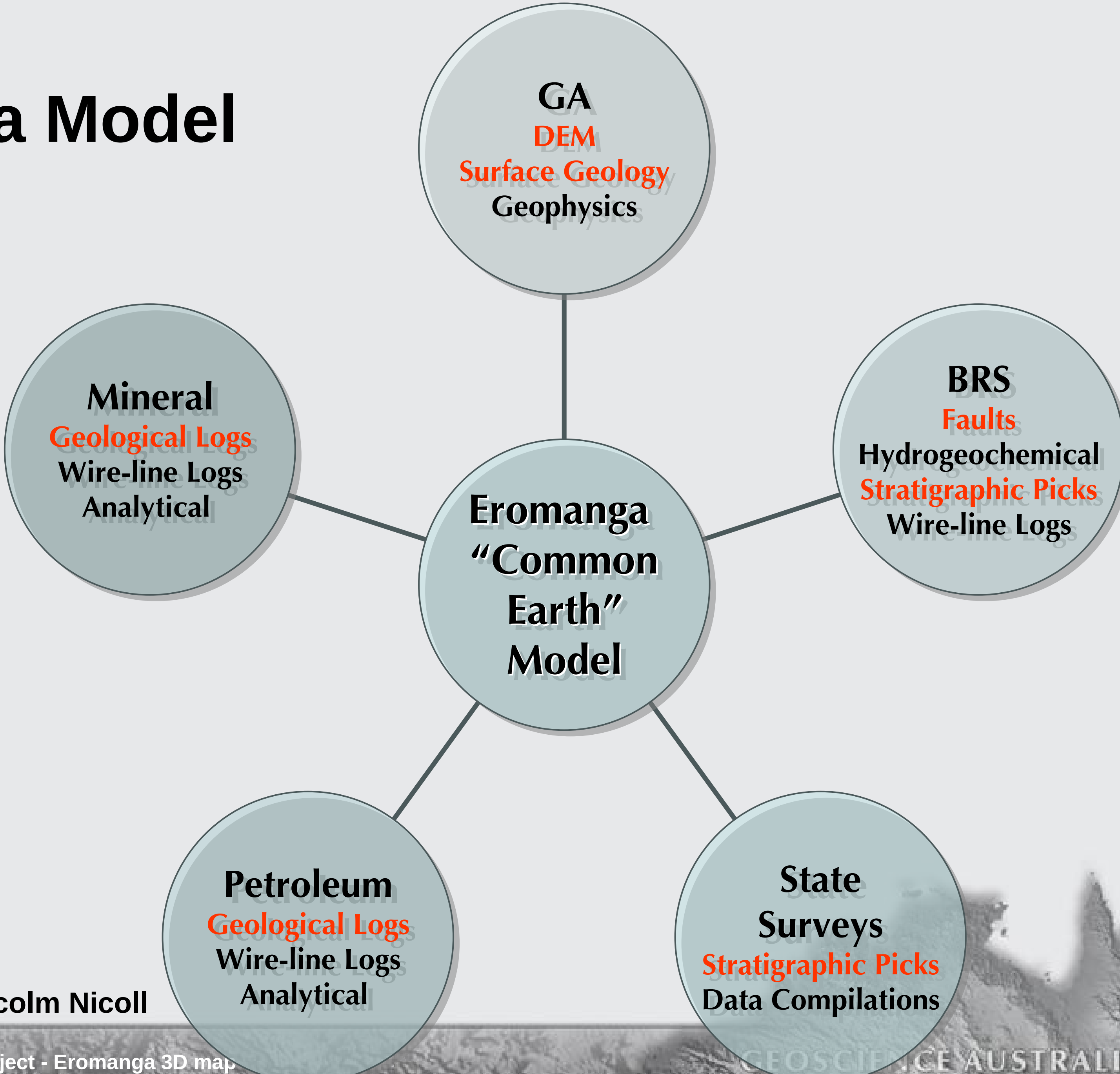
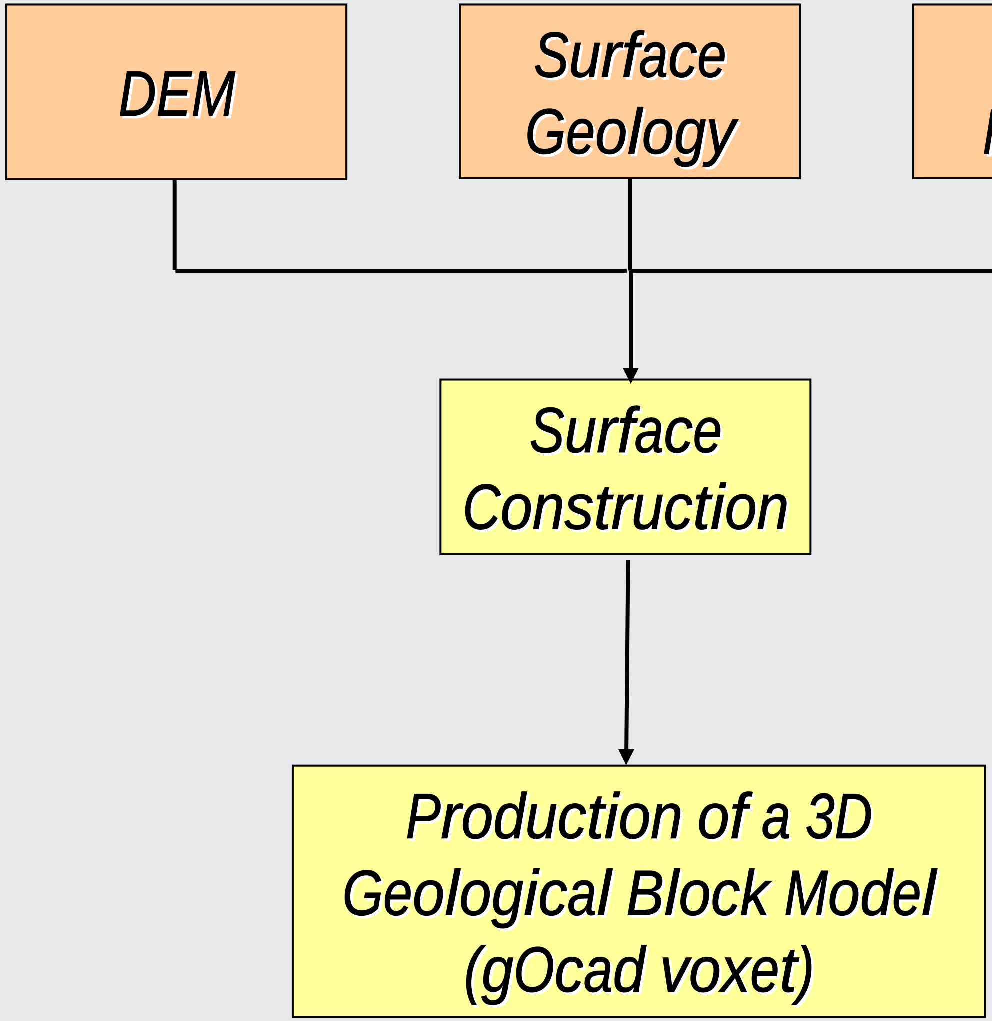


Figure courtesy of Malcolm Nicoll

Eromanga Basin Construction - datasets

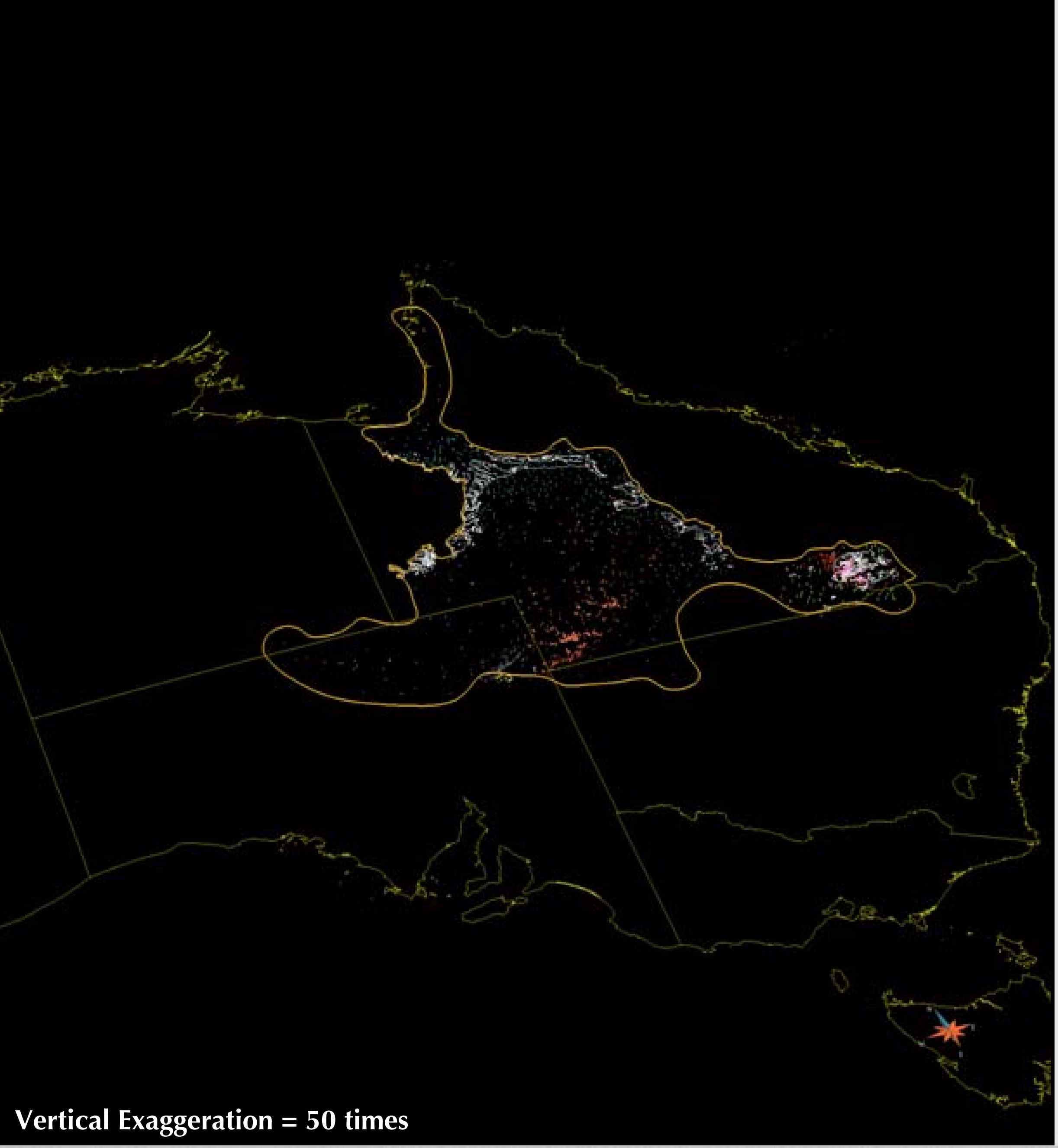
- 1:1 Million Geology
- DEM
- Faults simplified from BRS database (assumed to be vertical)
- Drilling markers
  - State surveys
  - Bureau of Rural Sciences
  - Geoscience Australia

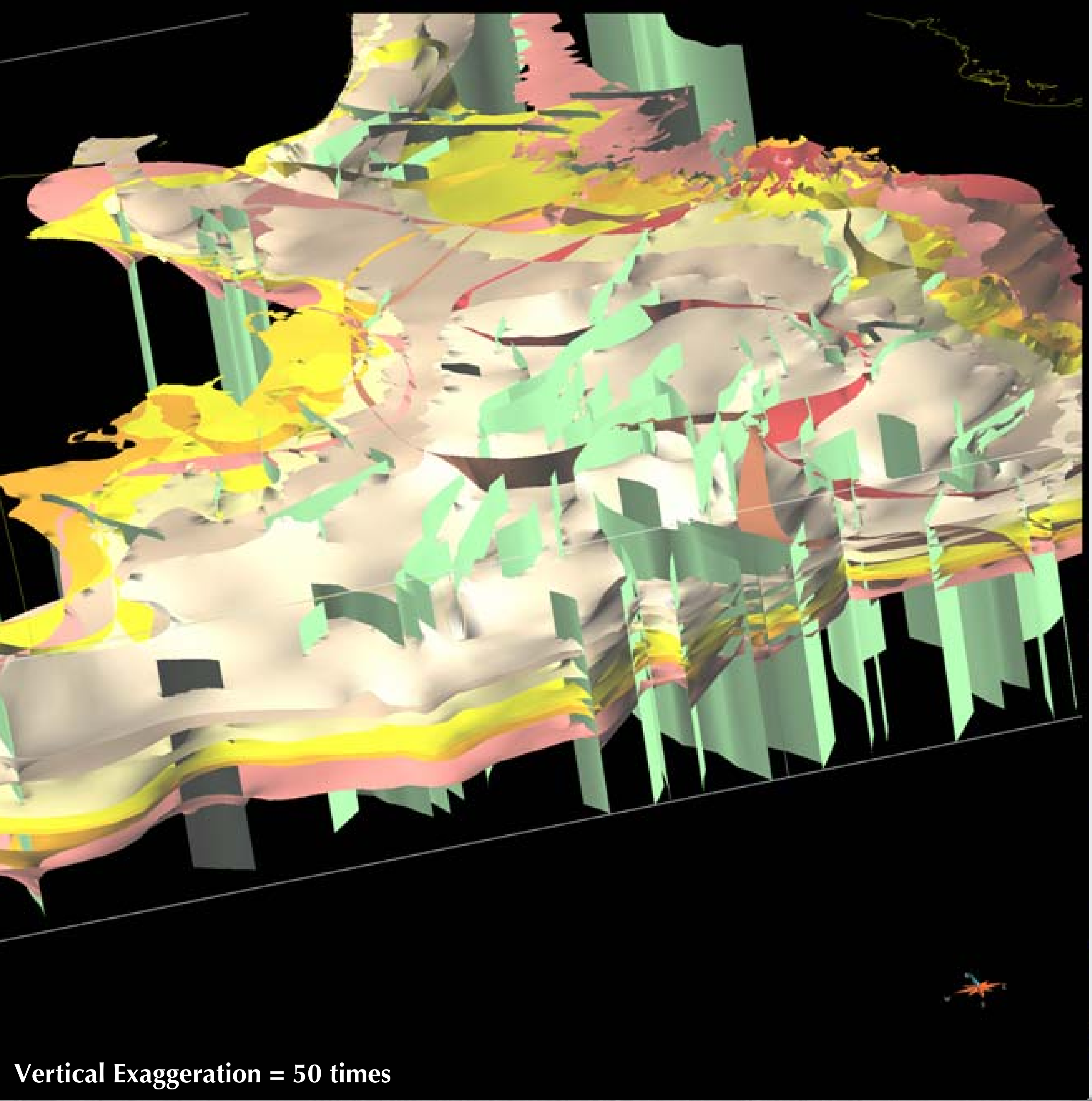
2. Geological model construction



Surface Construction

1: Create surface outline





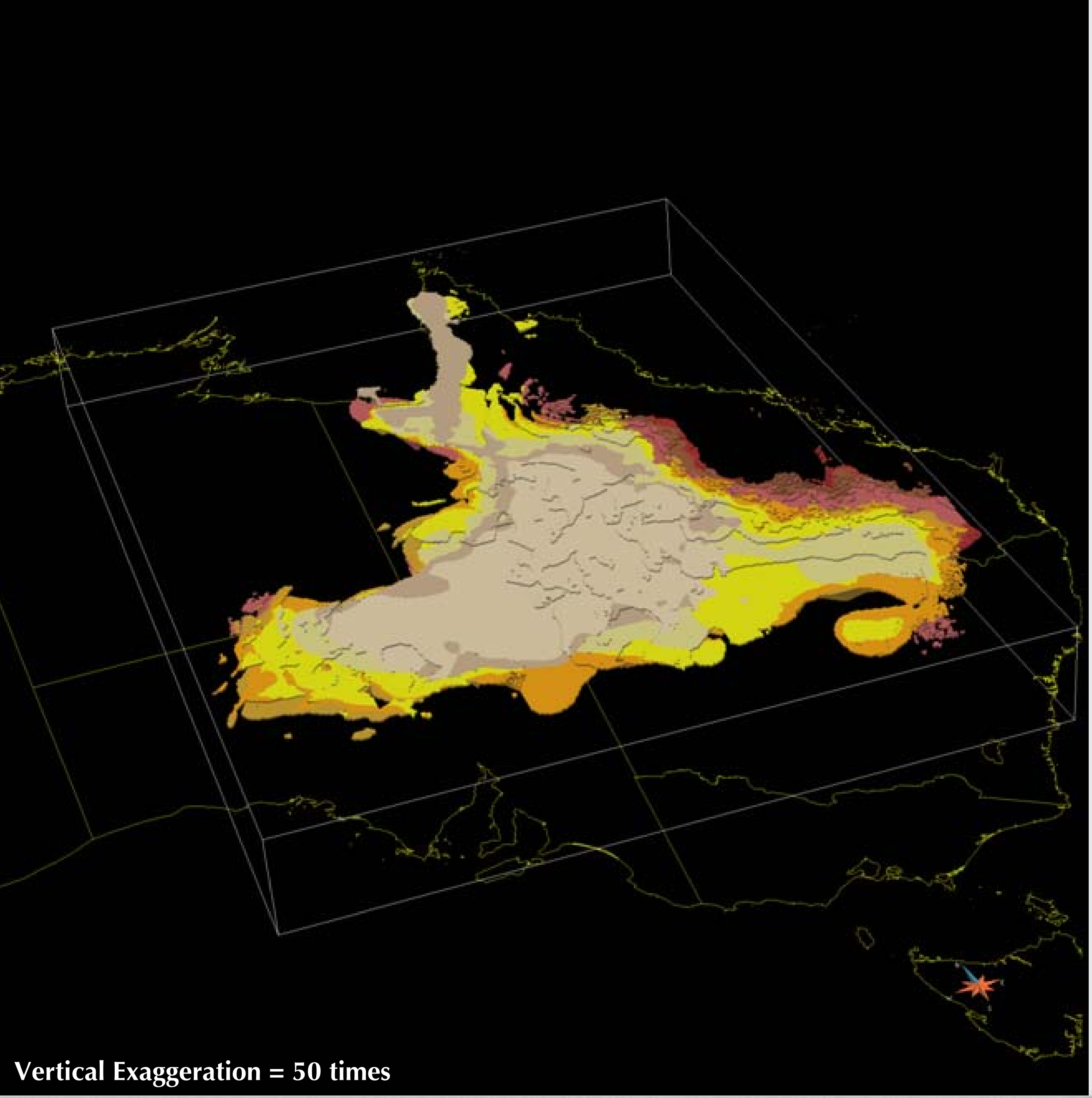
Surface Construction

2: Create surfaces from outline and drill markers

3: Generate cross sections from surfaces and mapped faults

4: Cut surfaces with faults

Production of a 3D Geological Block Model (gOcad voxet)



01_Ksrw (Winton)

02_Ksrm (Mackunda)

03_Klro (Toolebuc)

04_Ksr (Rolling Downs)

05_Ksco (Cadna-owie)

06_Jsyh (Hooray)

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08_Rsmo (Moolayember)

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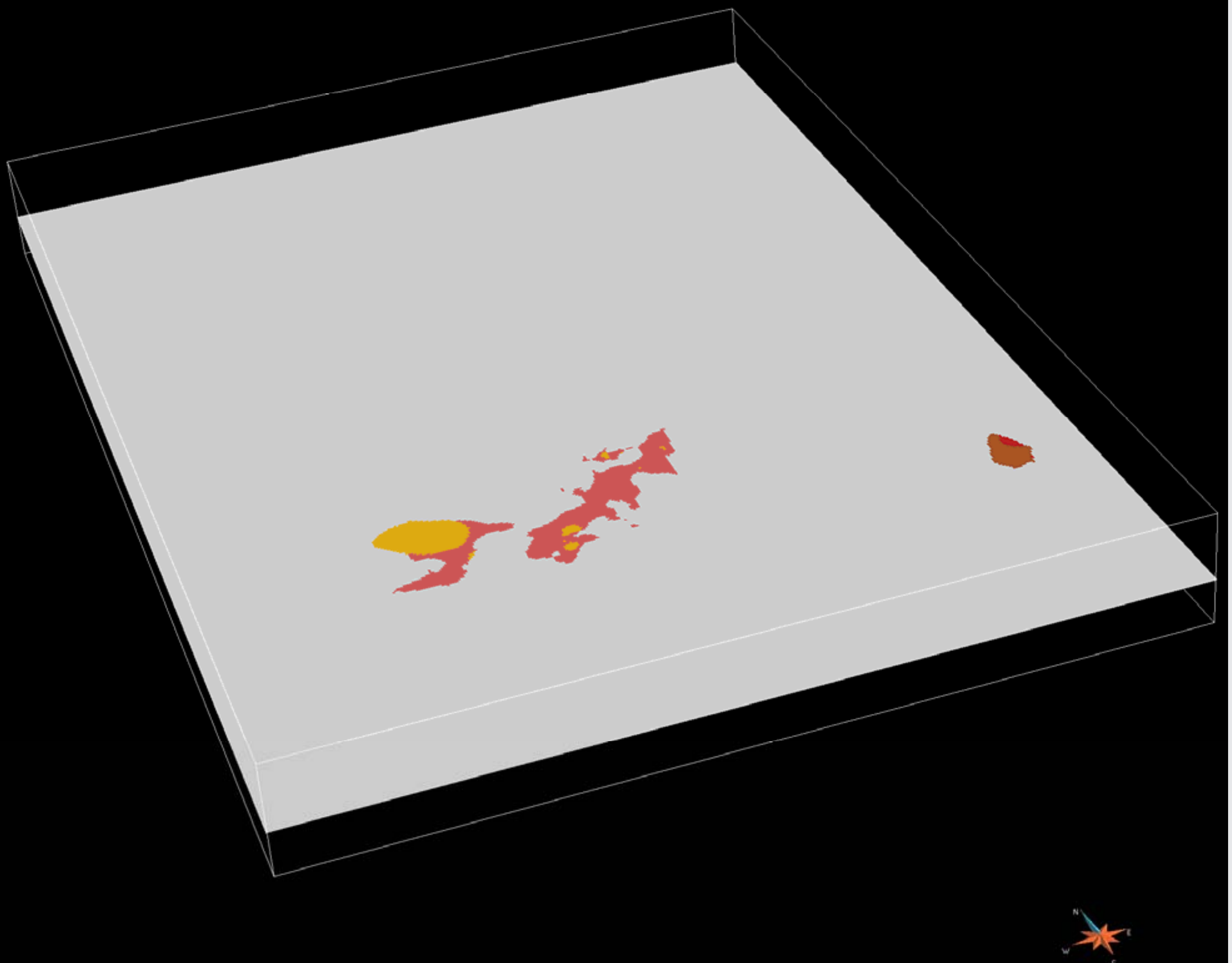
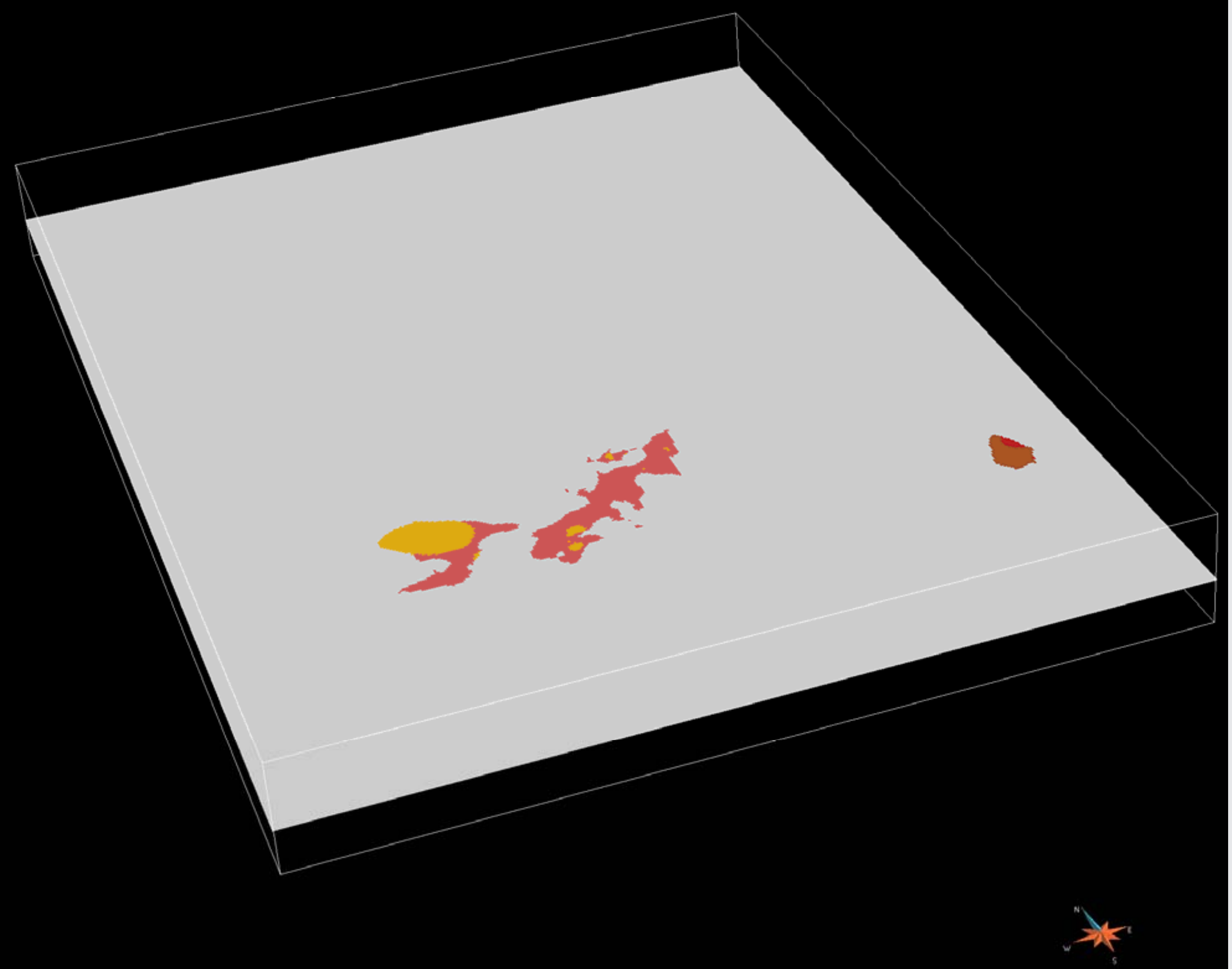
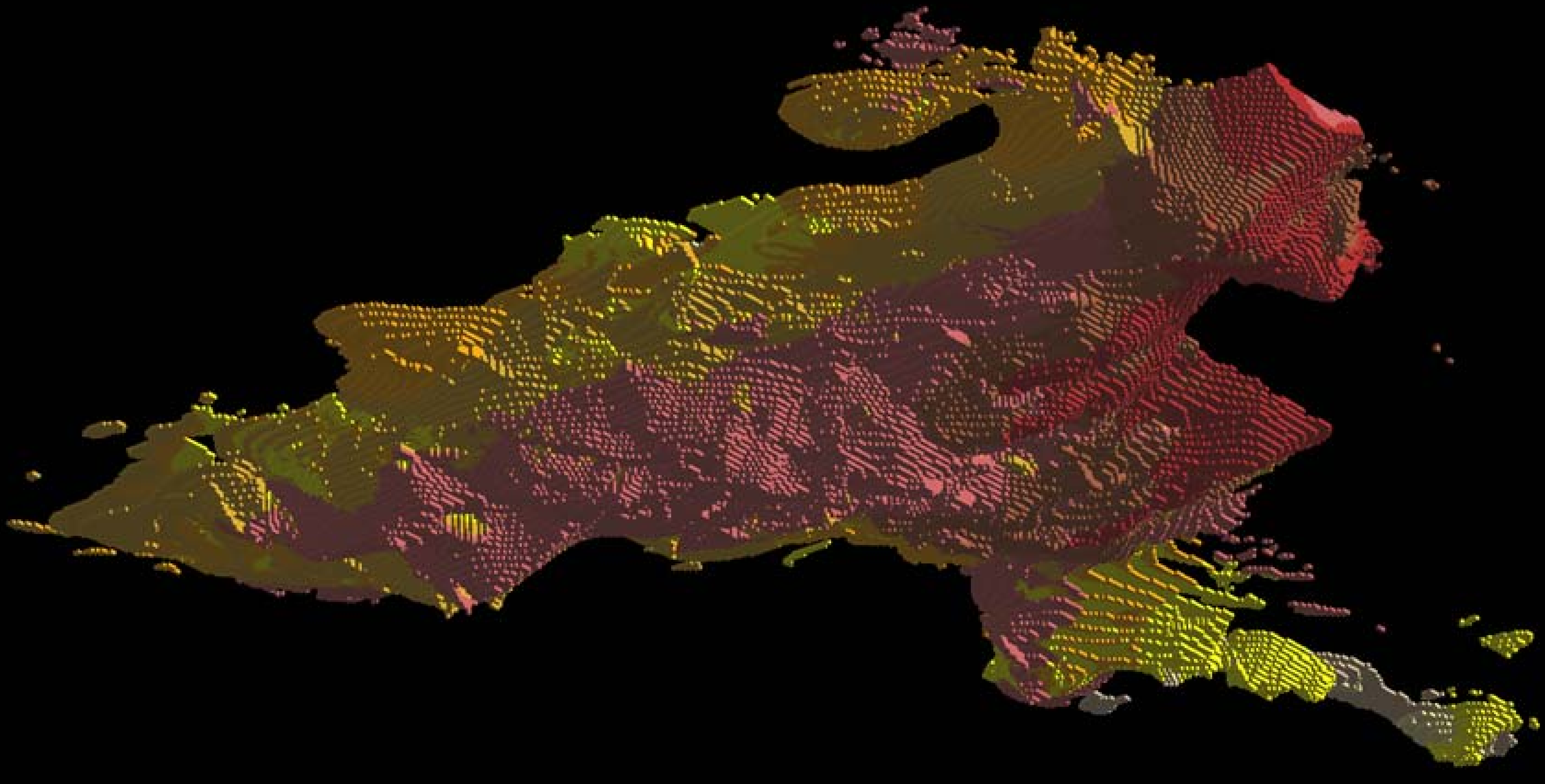


Vertical Exaggeration = 50 times

Production of a 3D Geological Block Model (gOcad voxet)

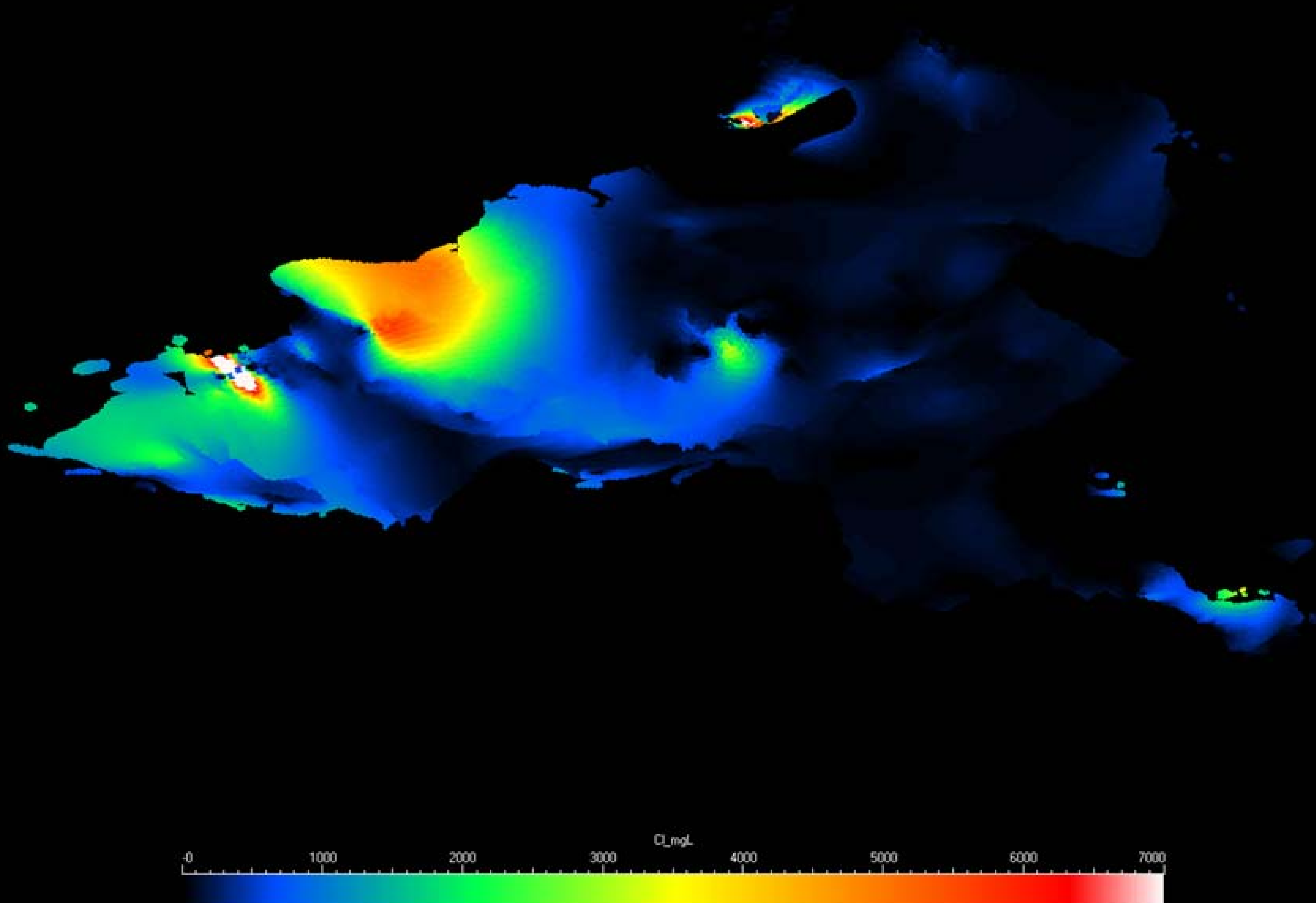


Vertical Exaggeration = 50 times

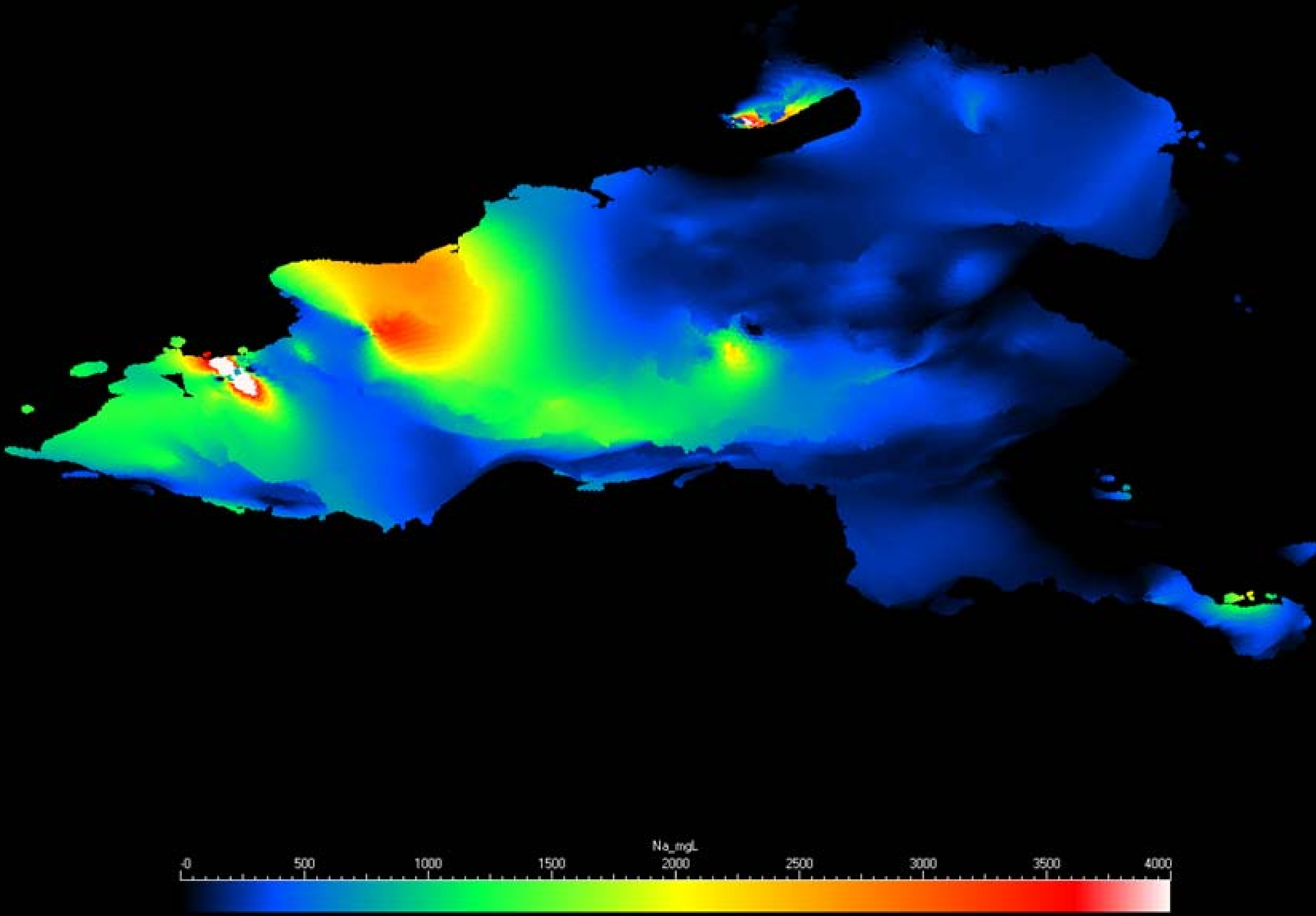


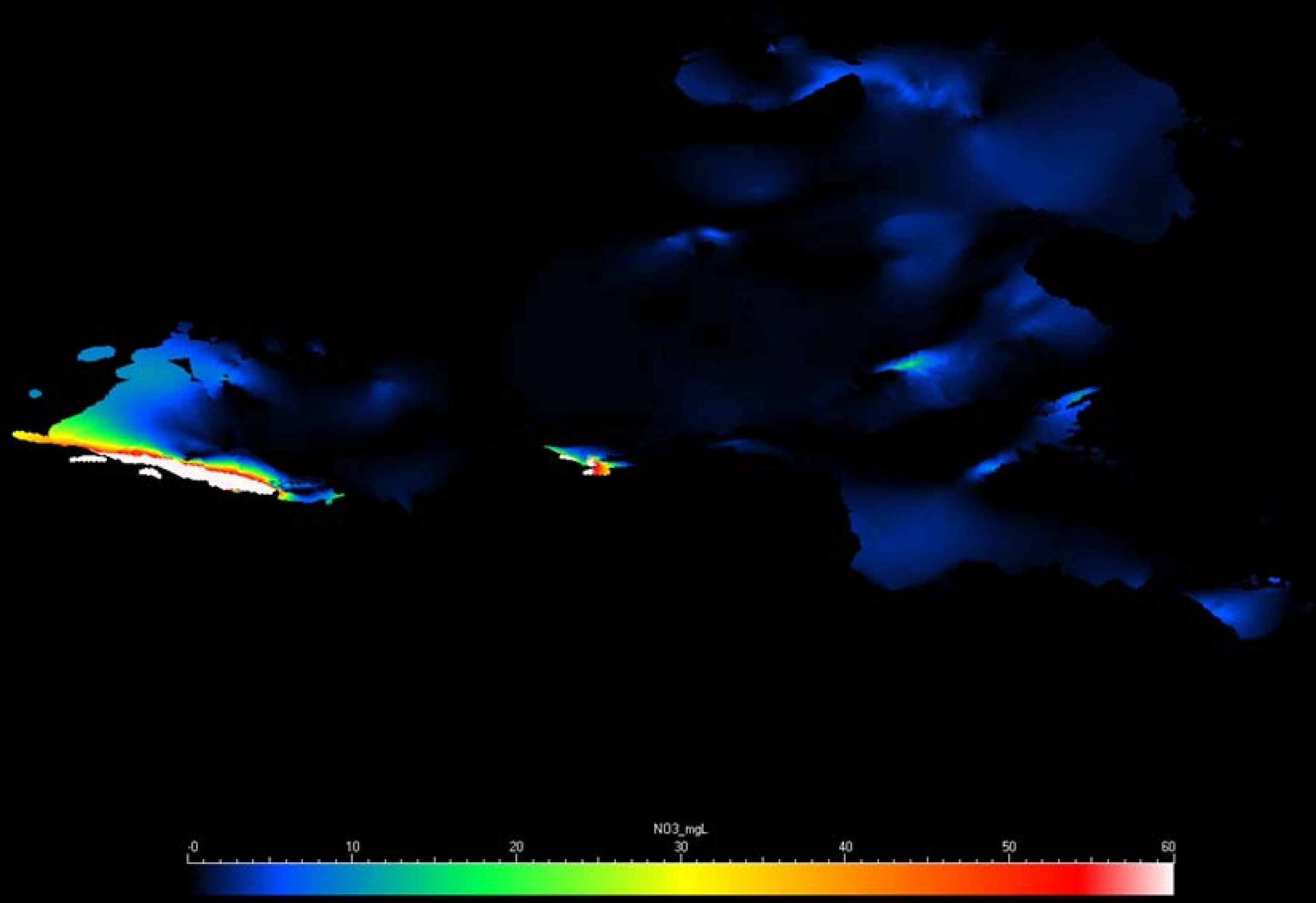
3. Hydrological data

- Over 30 different chemical and other properties have been incorporated in this model
- Following slides show some examples
- Data distribution: variable

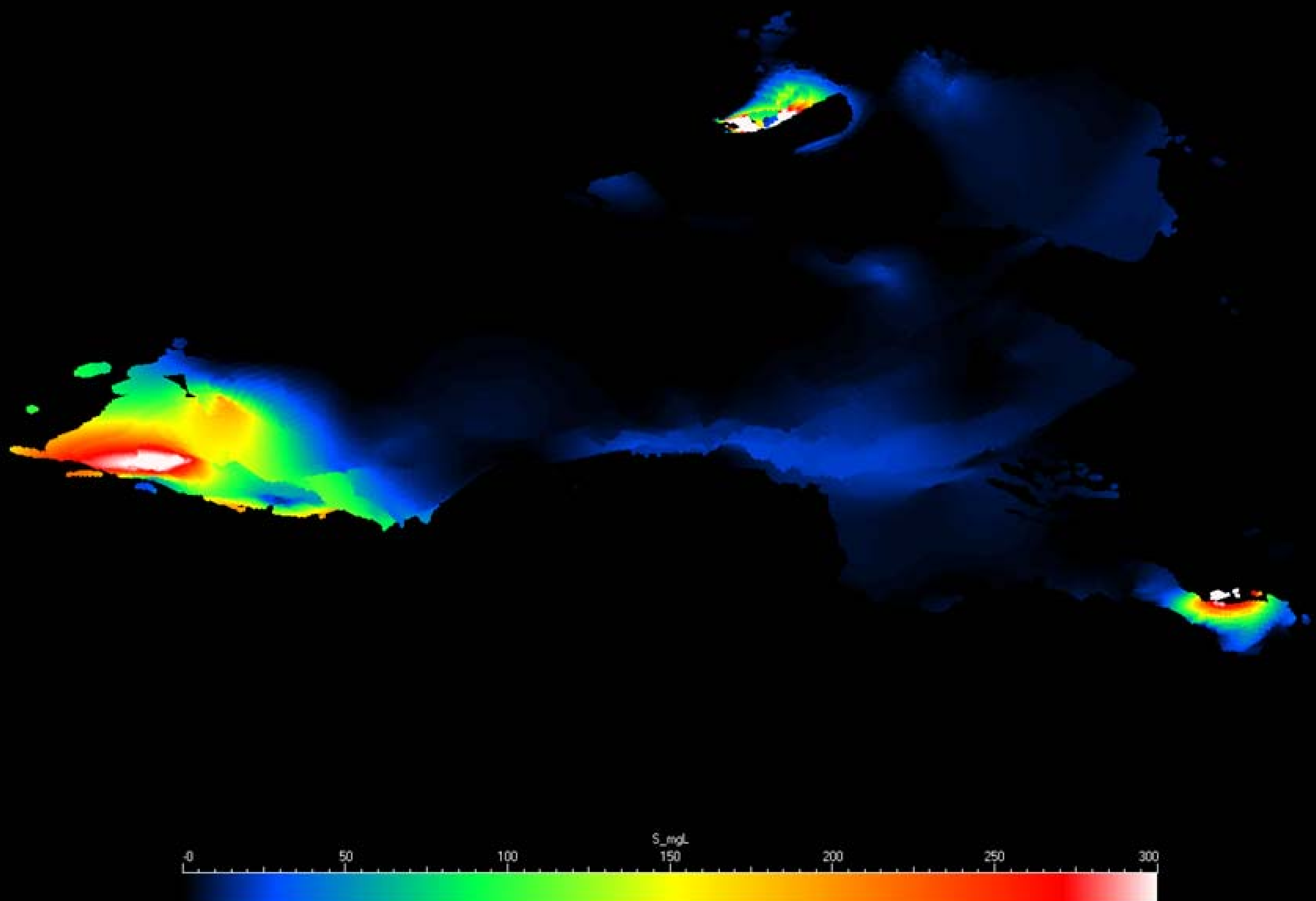


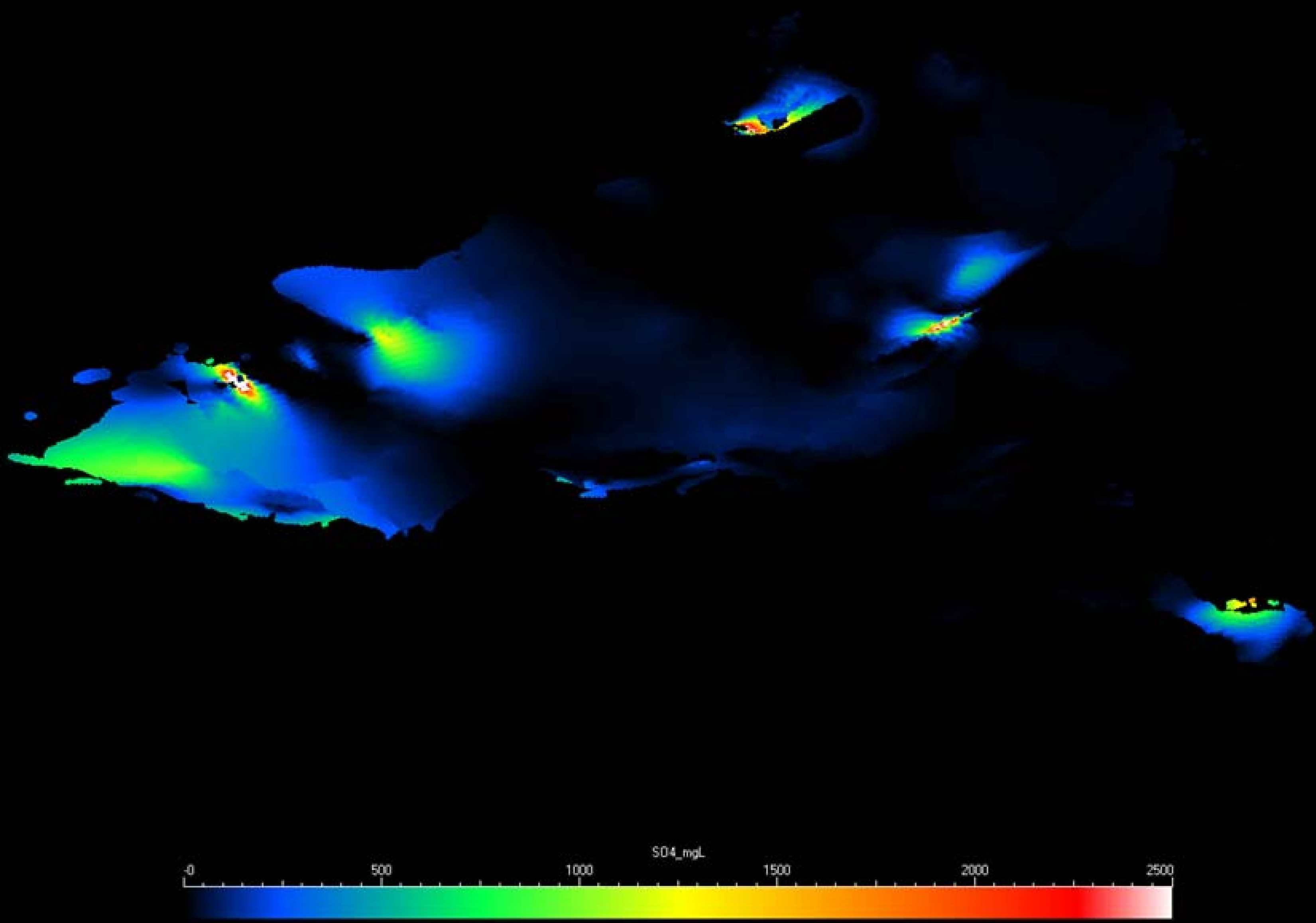
Cl_mgL
-0
1000
2000
3000
4000
5000
6000
7000


Na_mgL
-0
500
1000
1500
2000
2500
3000
3500
4000

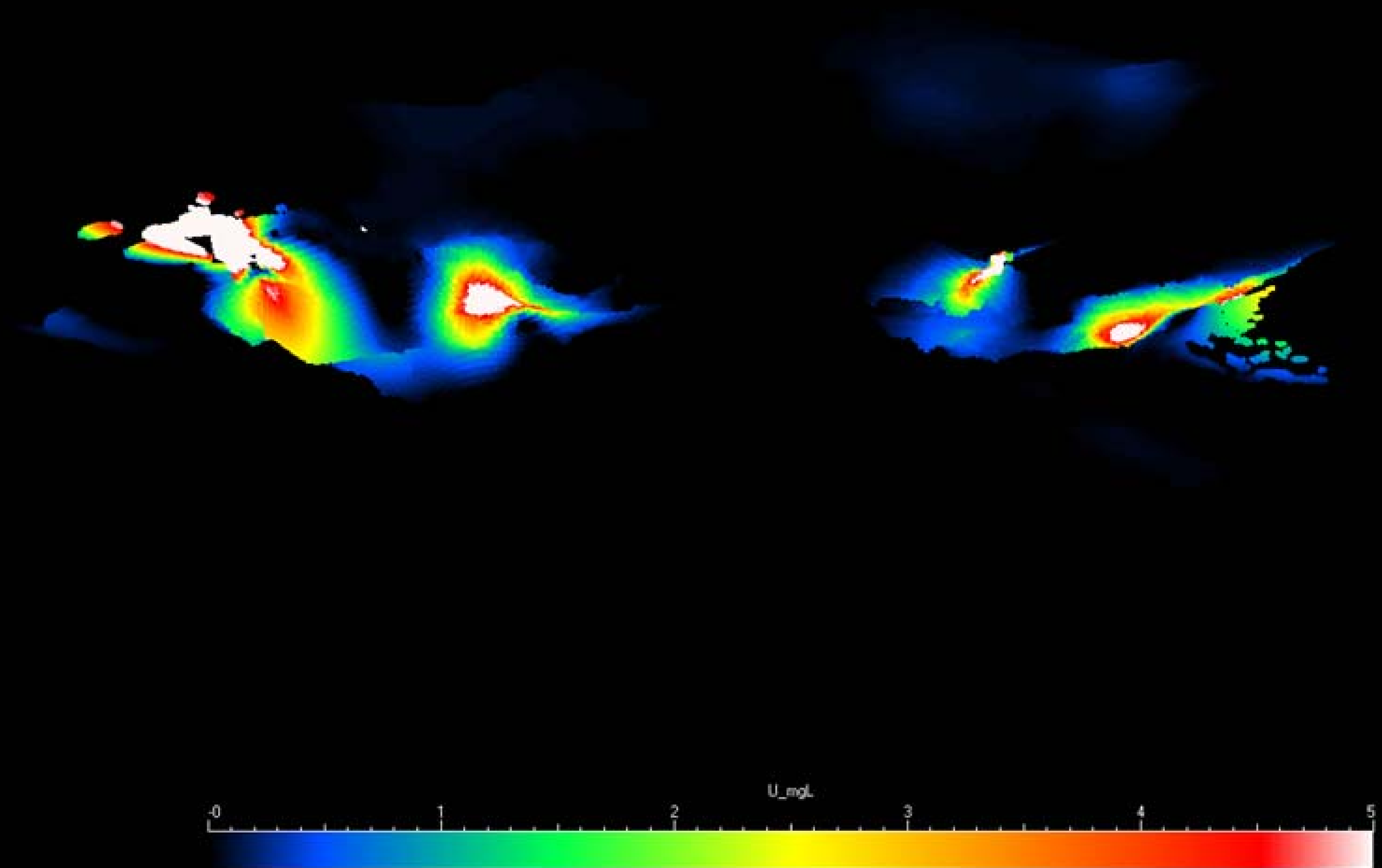


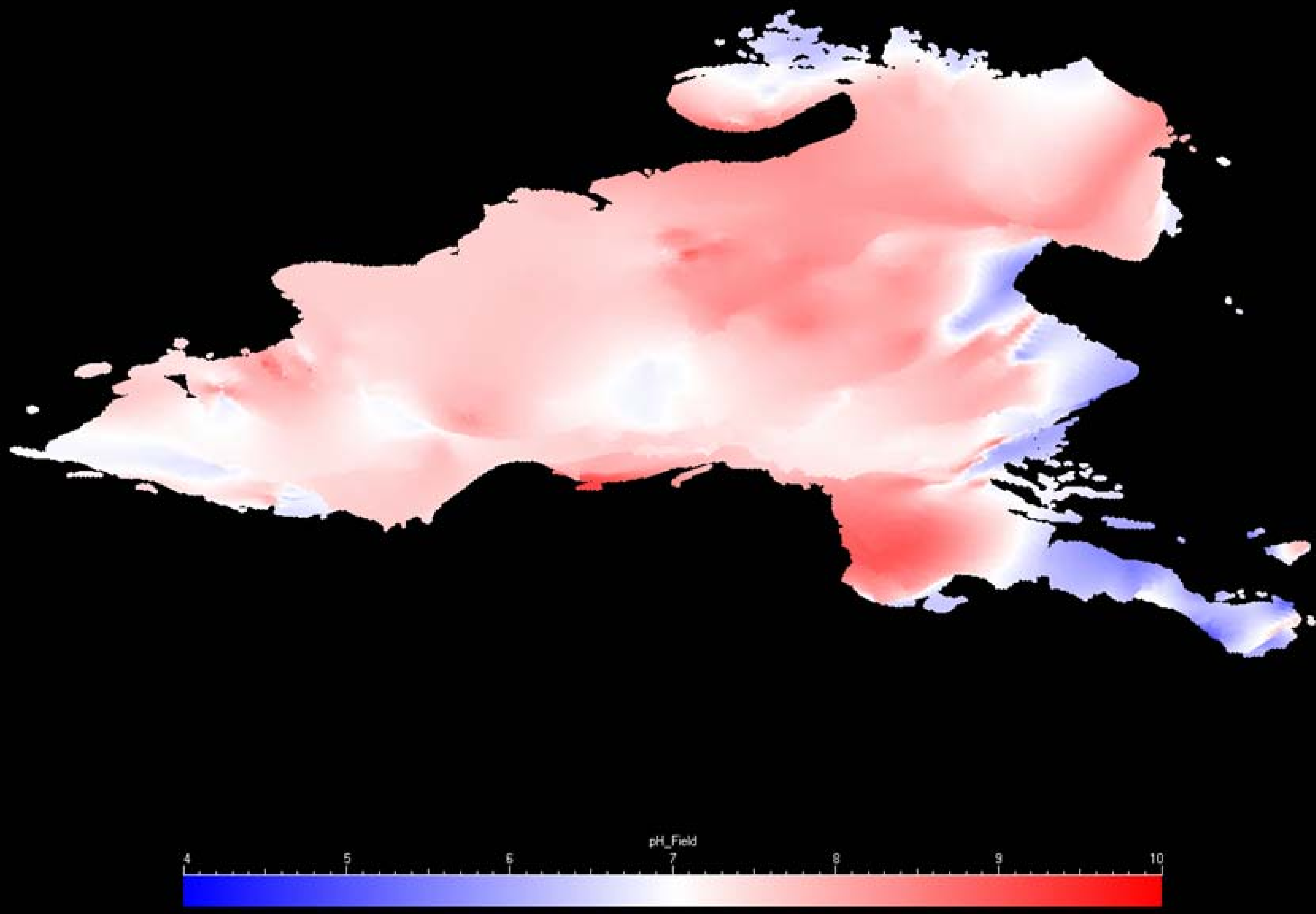
NO3_mgL
-0
10
20
30
40
50
60

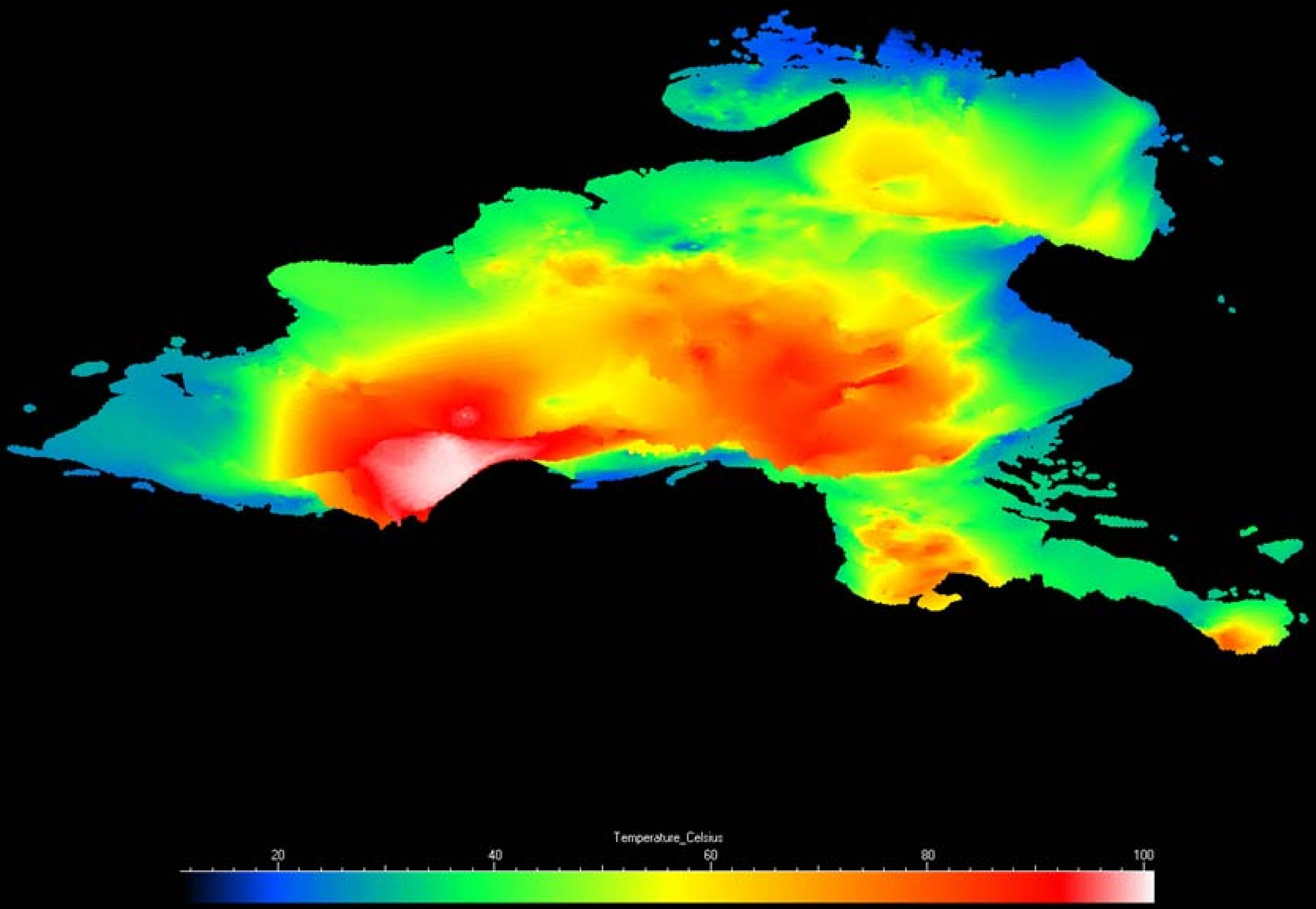

S_mgL
-0
50
100
150
200
250
300

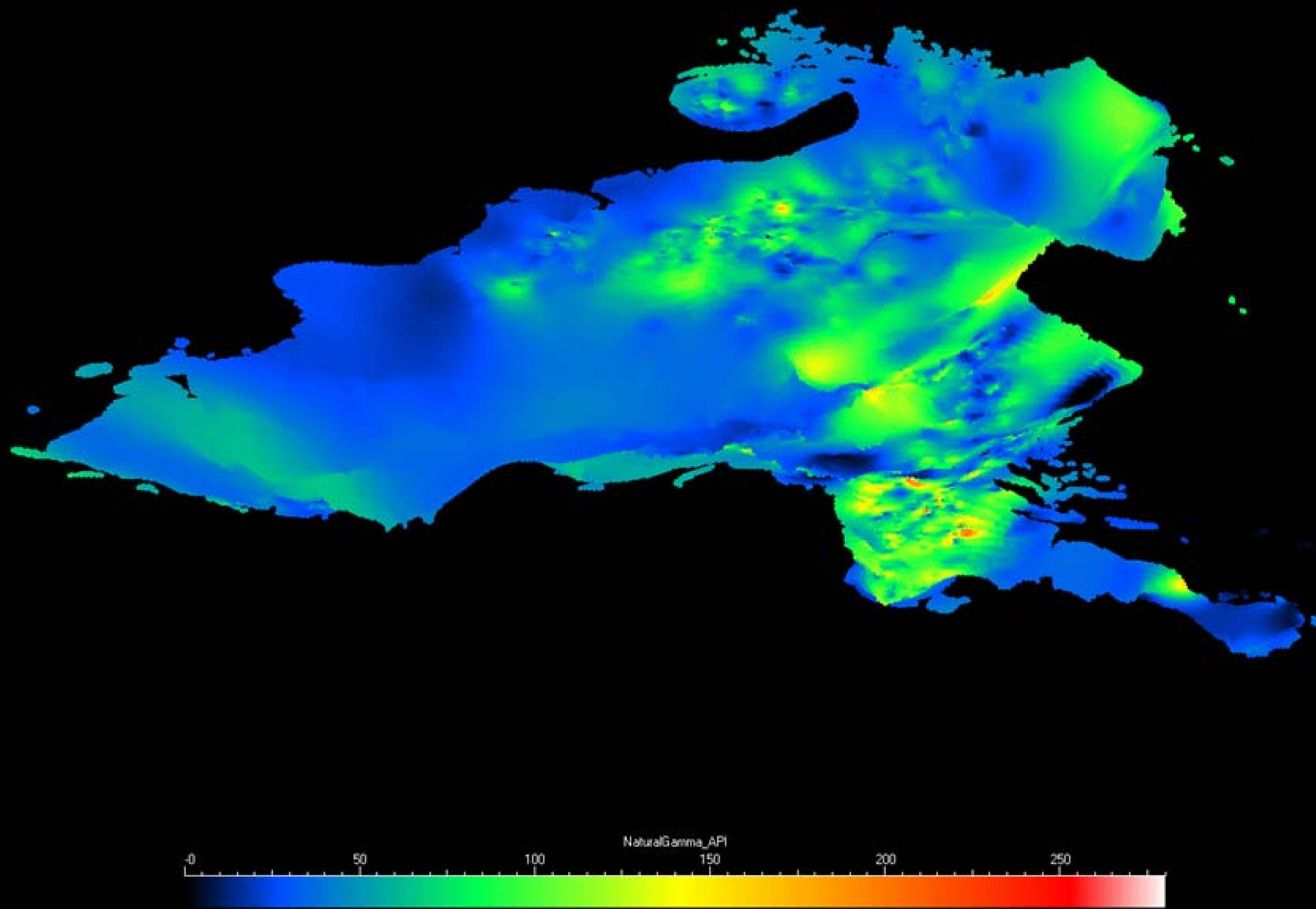


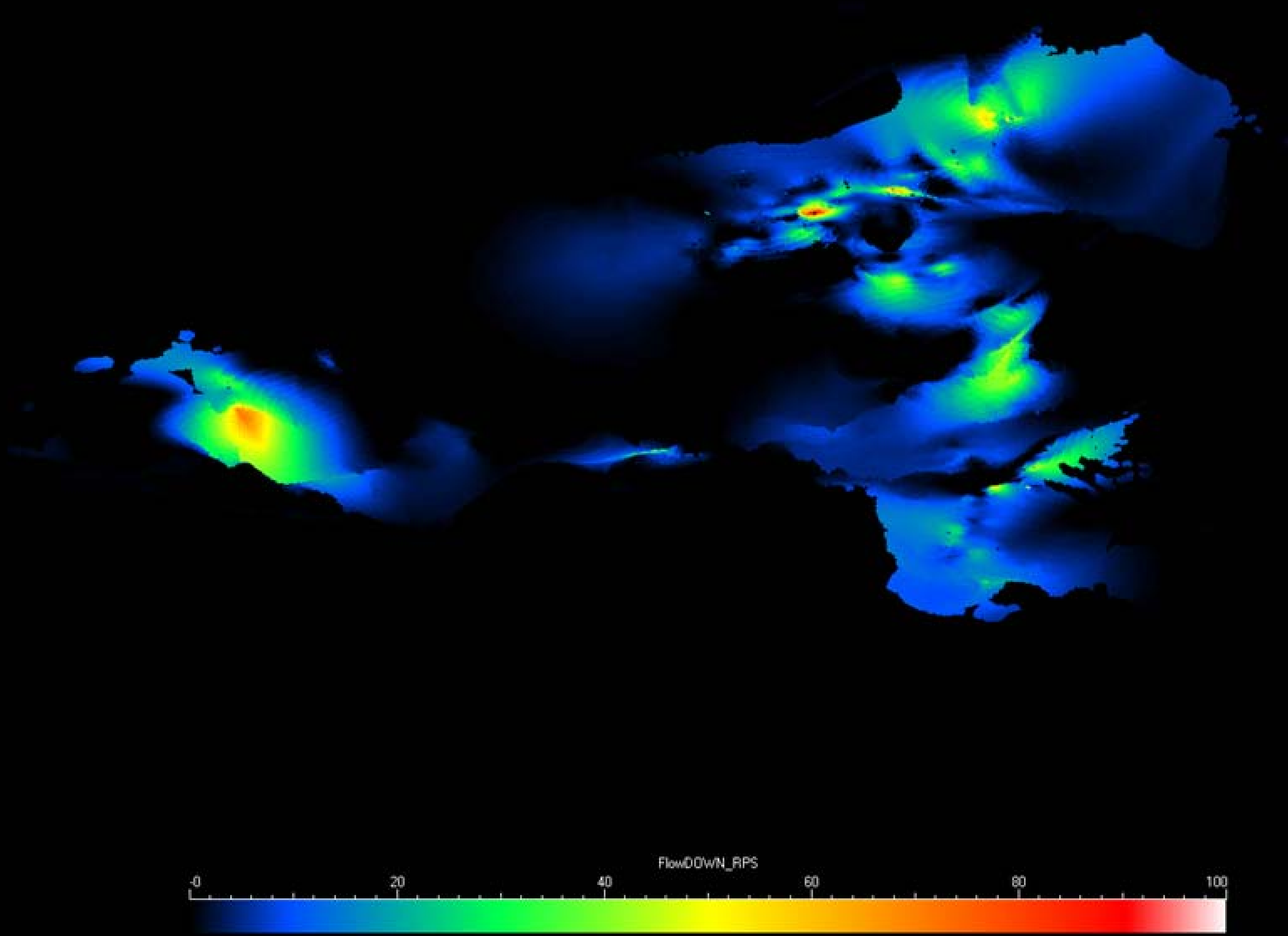
SO4_mgL
-0
500
1000
1500
2000
2500


U_mgL
-0
1
2
3
4
5


pH_Field
4
5
6
7
8
9
10

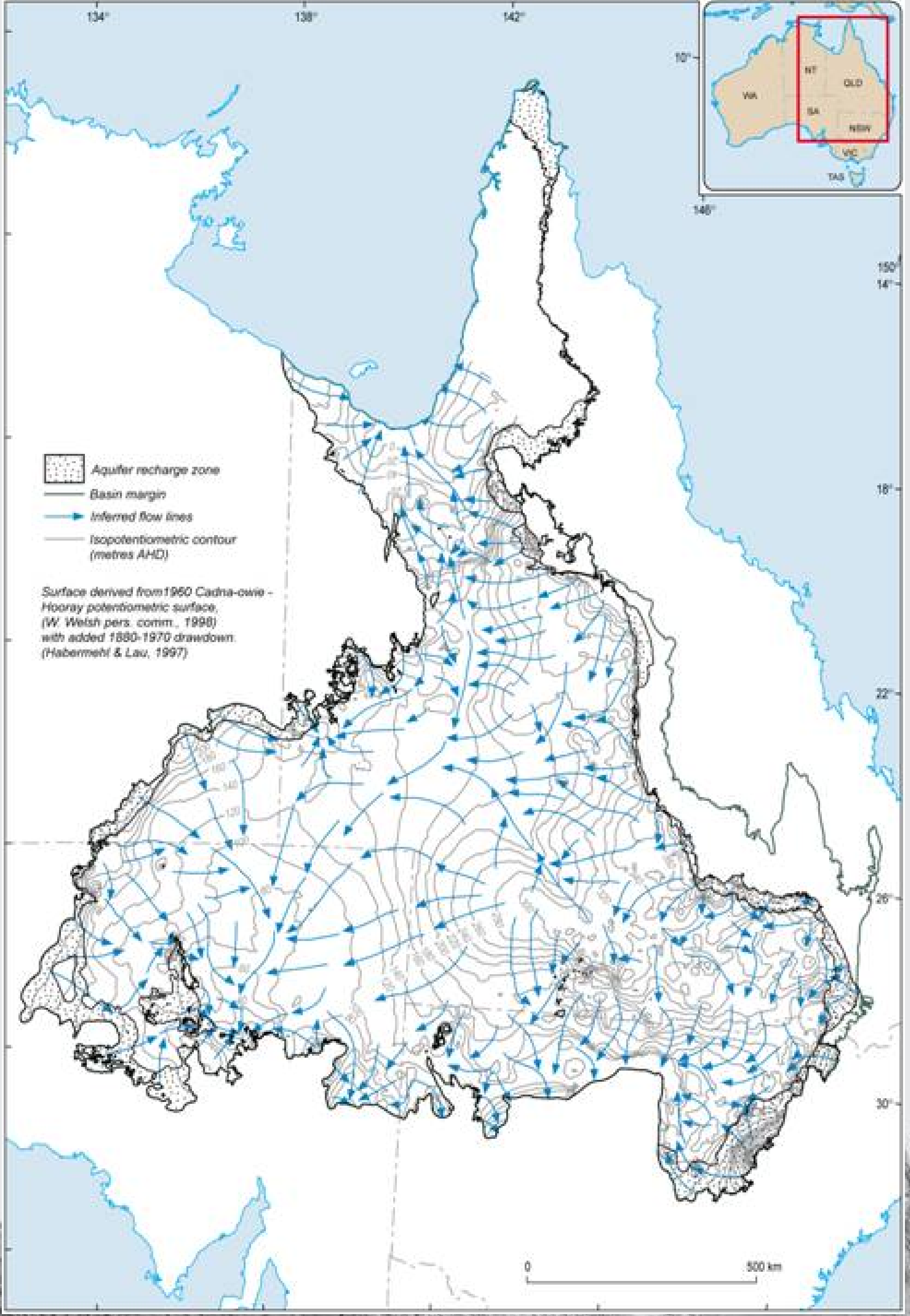

Temperature_Celsius
20
40
60
80
100


NaturalGamma_API
-0
50
100
150
200
250



FlowDOWN_RPS
-0
20
40
60
80
100

Fluid Flow Direction



3D Hydrogeology Workshop

Approach to developing a 3D conceptual hydrogeology model in a dual aquifer system with multiple bore logs, Howard East, Darwin, using in-house software (GVS)

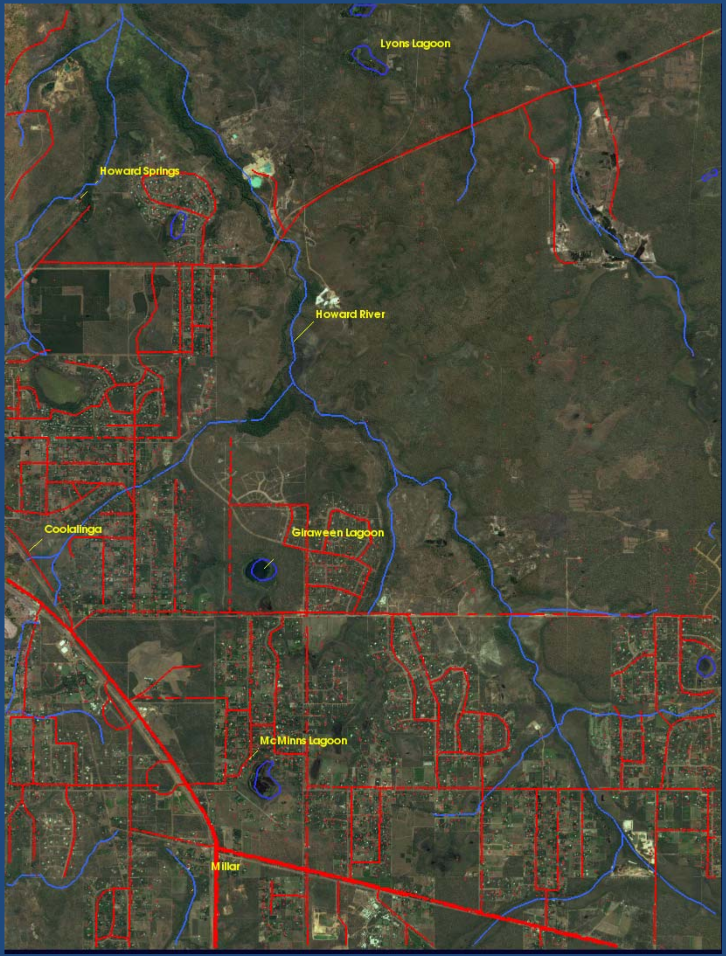
Amy Hawke, Allan James, Malcolm Cox, Joseph Young

Queensland University of Technology

Howard East

- South East of Darwin
- Rapid growth over last 40 years
- Monitoring network exists
  - In greater region NRETAS have 85 monitoring bores
  - Over 4000 private bores
- Need for stakeholders to better understand groundwater before potential regulation

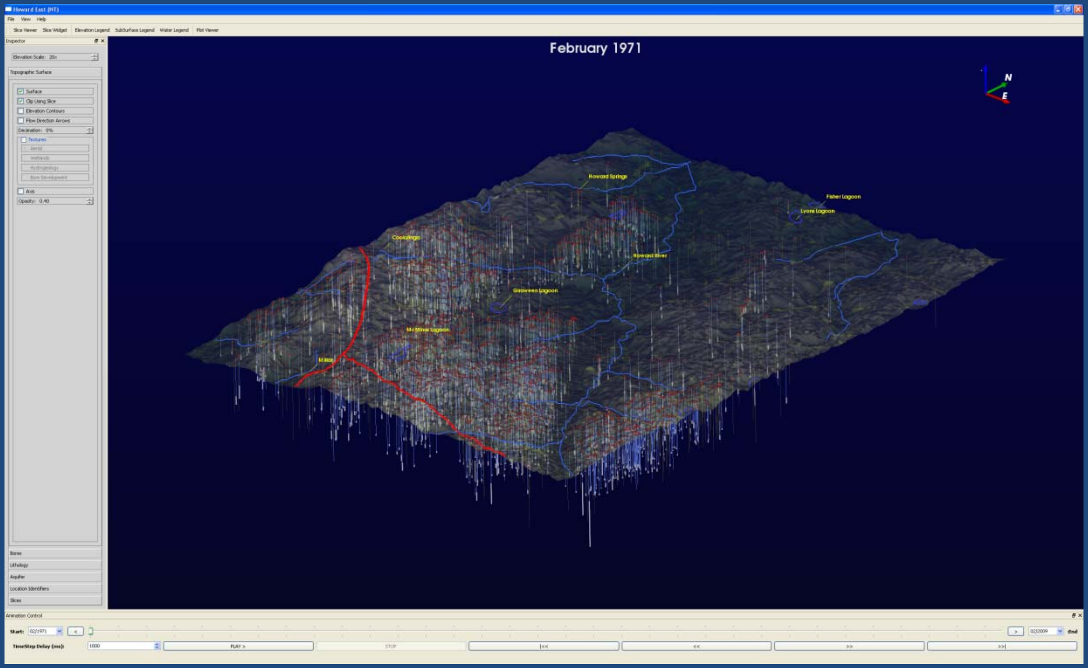
Hydrogeological background



- Howard River flows through domain
- Aquifer materials
  - Shallow laterite
  - Cretaceous sedimentary formations
  - Transition zone, sand-rich weathered material
  - Dolomite

Objectives

- To provide a visualisation tool to the community that will aid understanding of groundwater resources
- To support informed decisions in the management of the system



Data

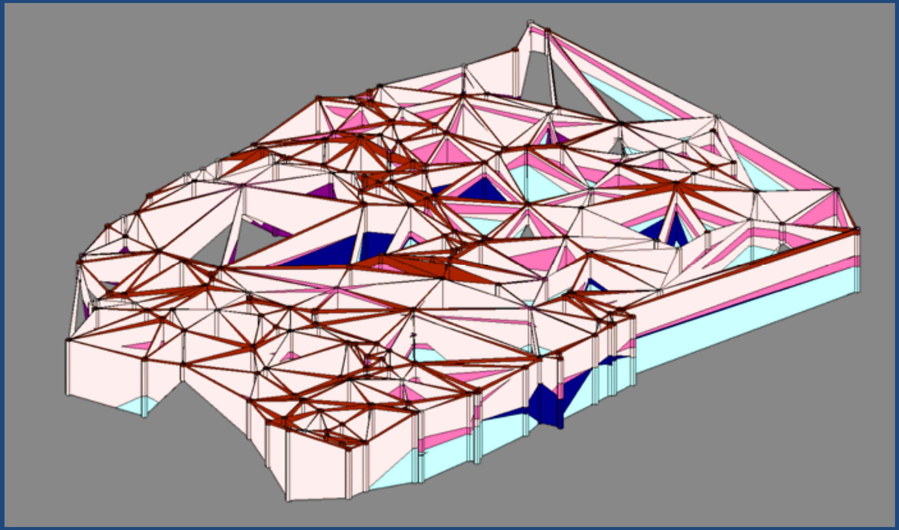
- bore data
  - NRETAS (NT Gov), Power & Water
  - Locations, depths, casings, drill logs, monitoring levels
- ESRI Shape files
  - Geoscience Australia
  - Roads, watercourses, lagoons
- Surface Layers
  - NRETAS, Google maps
  - Hydrogeological map, wetland areas, aerial image
- DEM (90m)
  - International Centre for Tropical Agriculture

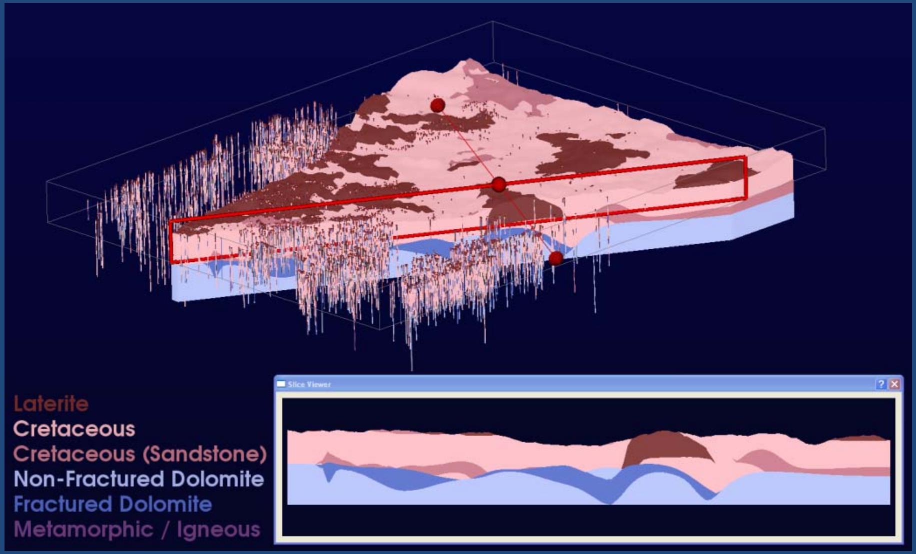
Outputs

- CD containing
  - GVS software of Howard East model
  - MySQL database install
  - Install and software documentation

3D Geological Mesh

- Over 22 000 log entries
- 15 discrete categories
- Reduced to a final 6 geological units

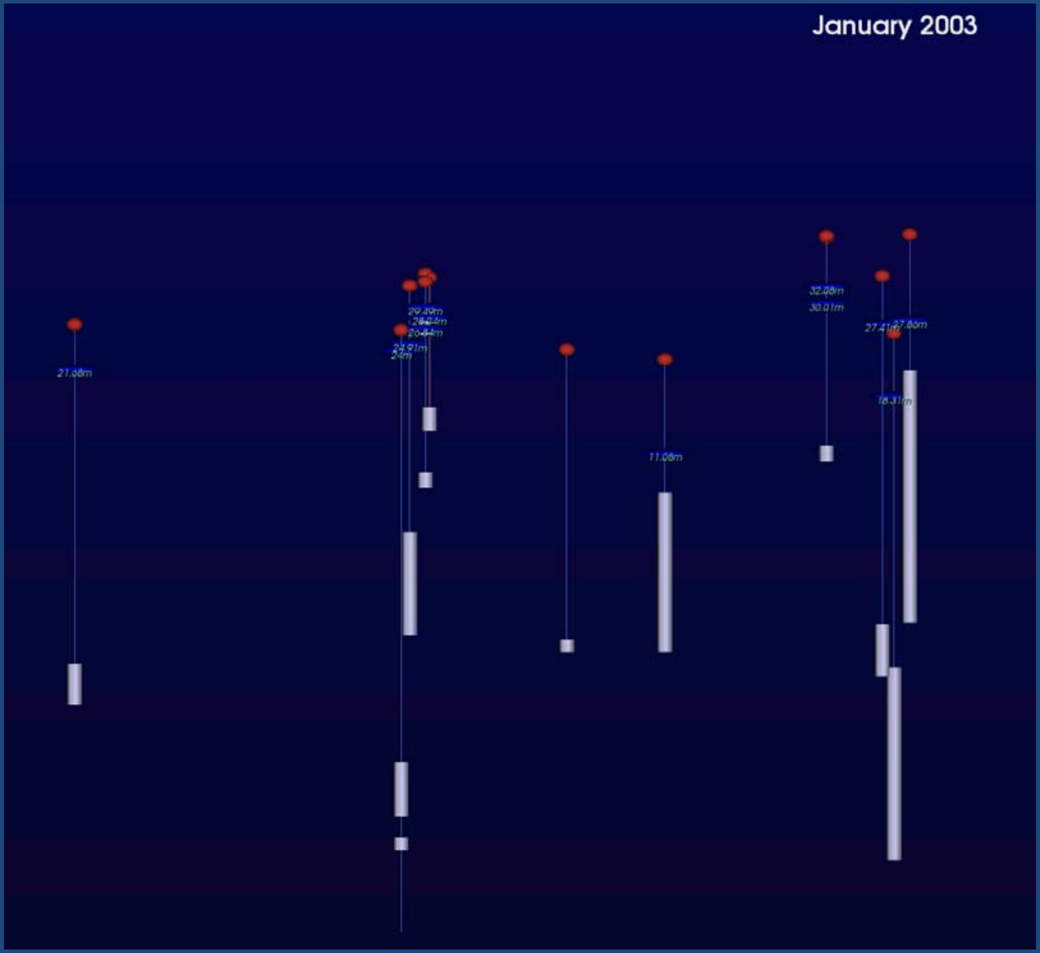




- Various interpolation techniques trialled
- Final Mesh – natural neighbour interpolation on 200 optimal logs

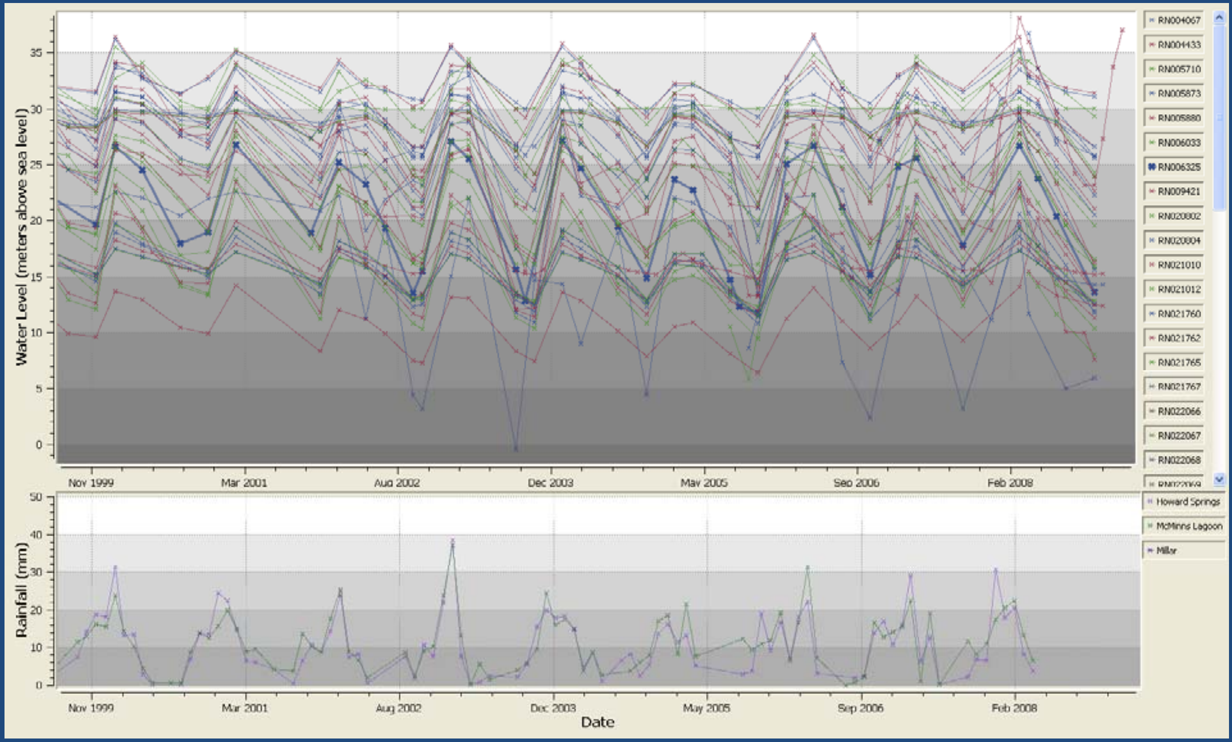
Water Levels

- Screen zones reflect aquifer locations
- Markers indicate water levels and are animated over time



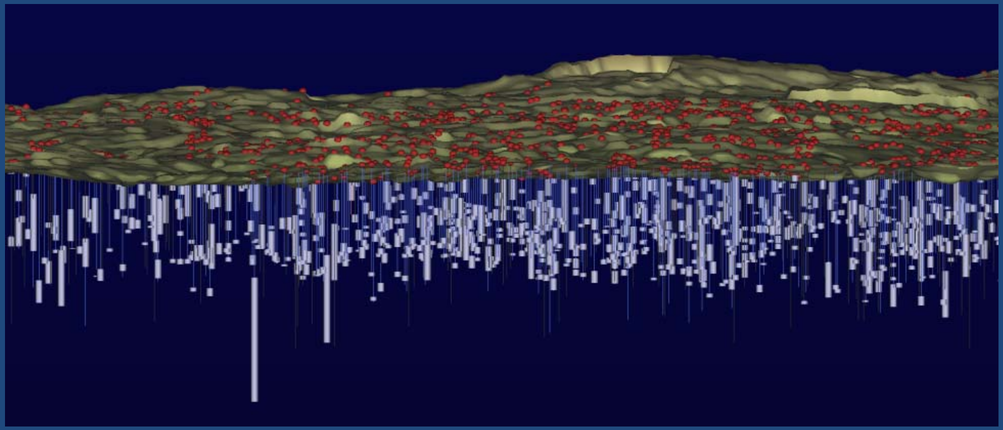
Hydrograph Plots

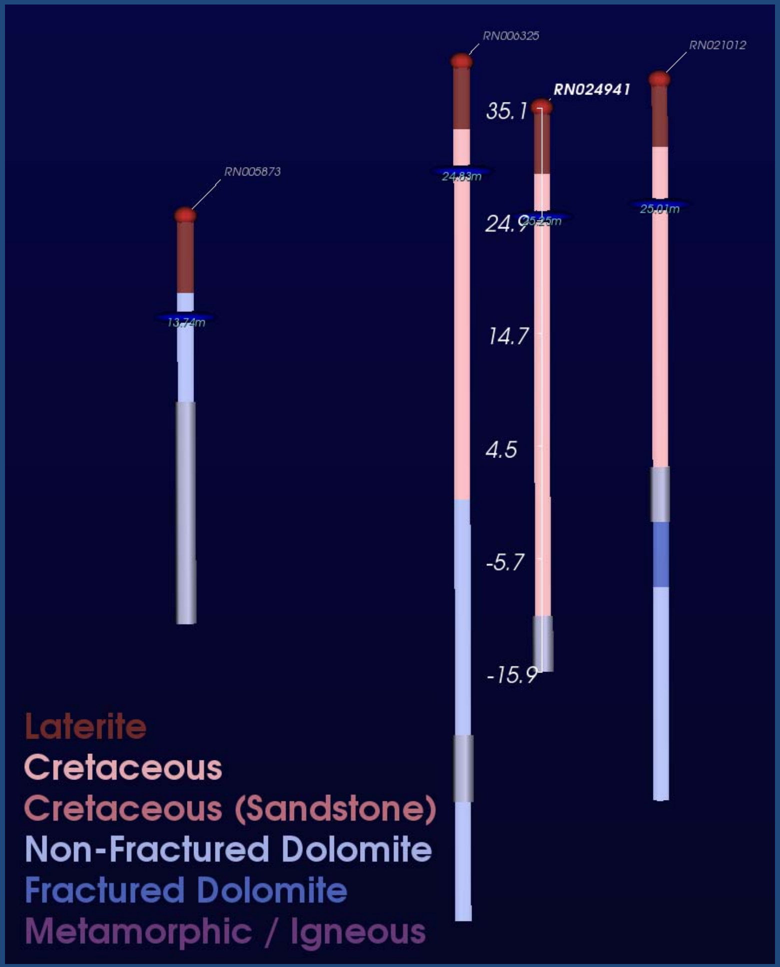
- Interactive hydrograph plots with local rainfall
- Reference bore back to 3D scene
- Water levels displayed relative to Sea Level Datum
- Show seasonal variation



Benefits

- Community able to see function of entire system.
- Users can interrogate the model to view points of particular interest to them





Acknowledgements

- QUT – Institute for Sustainable Resources
- TRaCK
  - Sharna Nolan, Poh-Ling Tan
- NRETAS
  - Des Yin Foo, Chris Wicks, Steve Tickell
- Power & Water
  - David George
- Local Hydrologist
  - Peter Jolly

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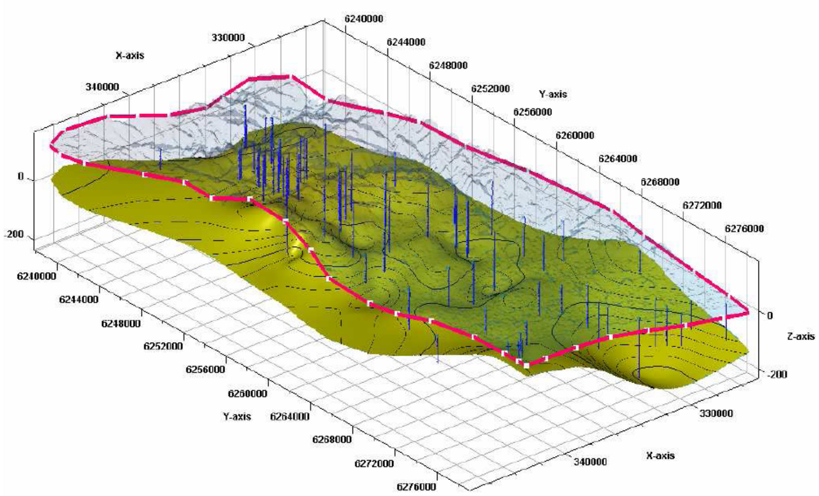
3D Hydrogeology in Western Australia

aquifer mapping, regional models and stratigraphic analysis



David Schafer

Jon-Philippe Pigois

Outline

- aquifer mapping for resource management
- major groundwater resource models
- stratigraphic analysis using PETREL
- shallow seismic visualisations

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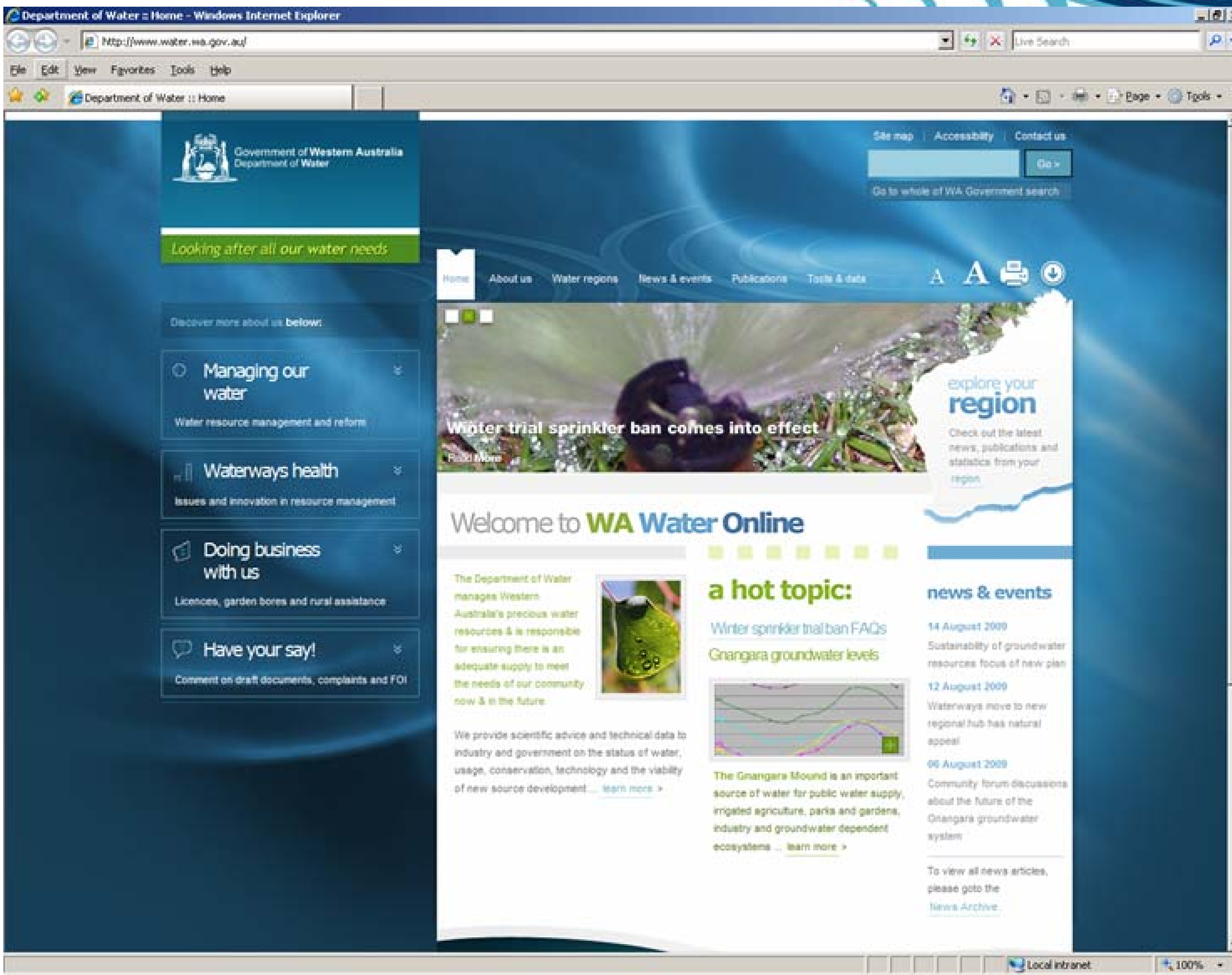
www.water.wa.gov.au



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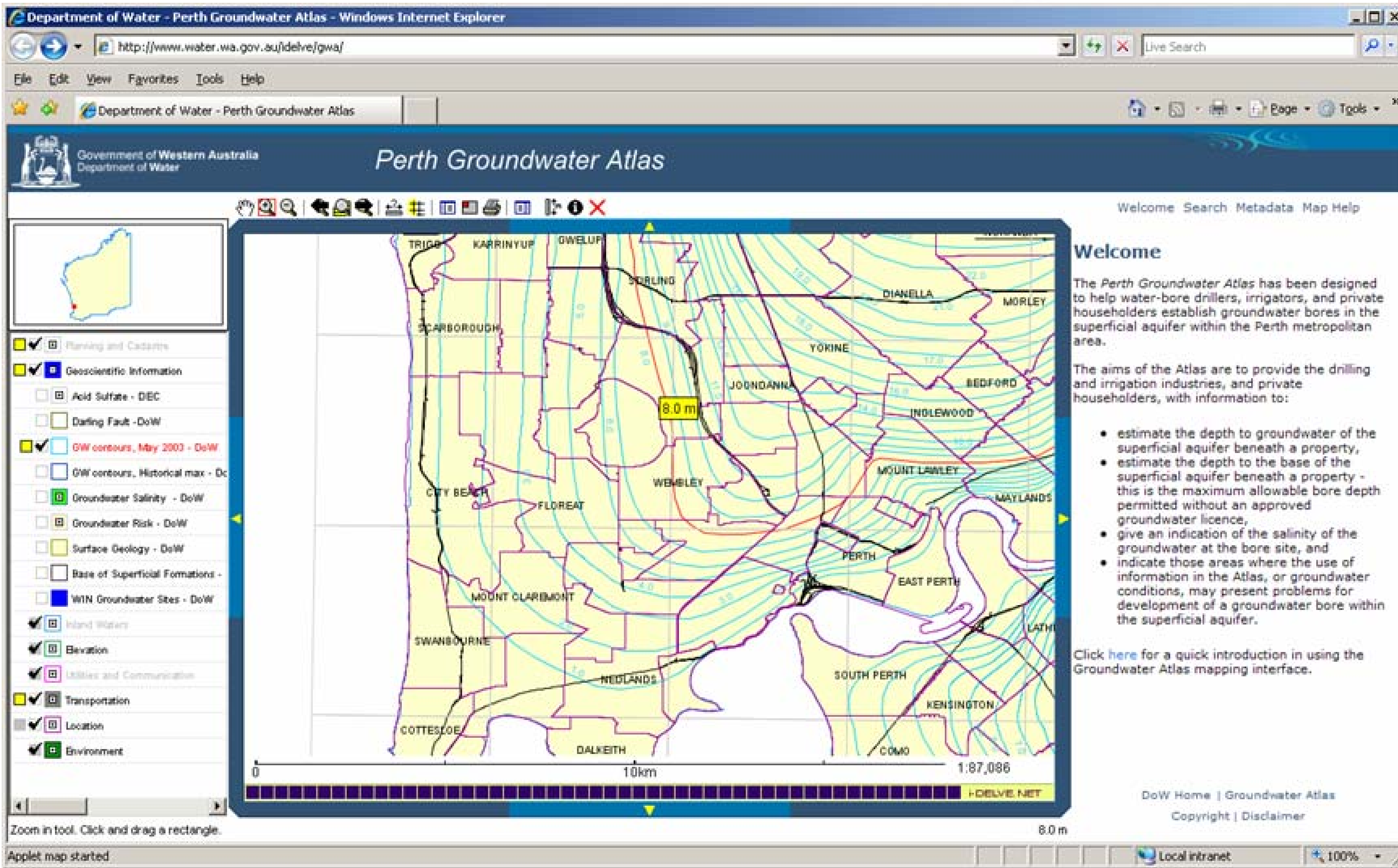
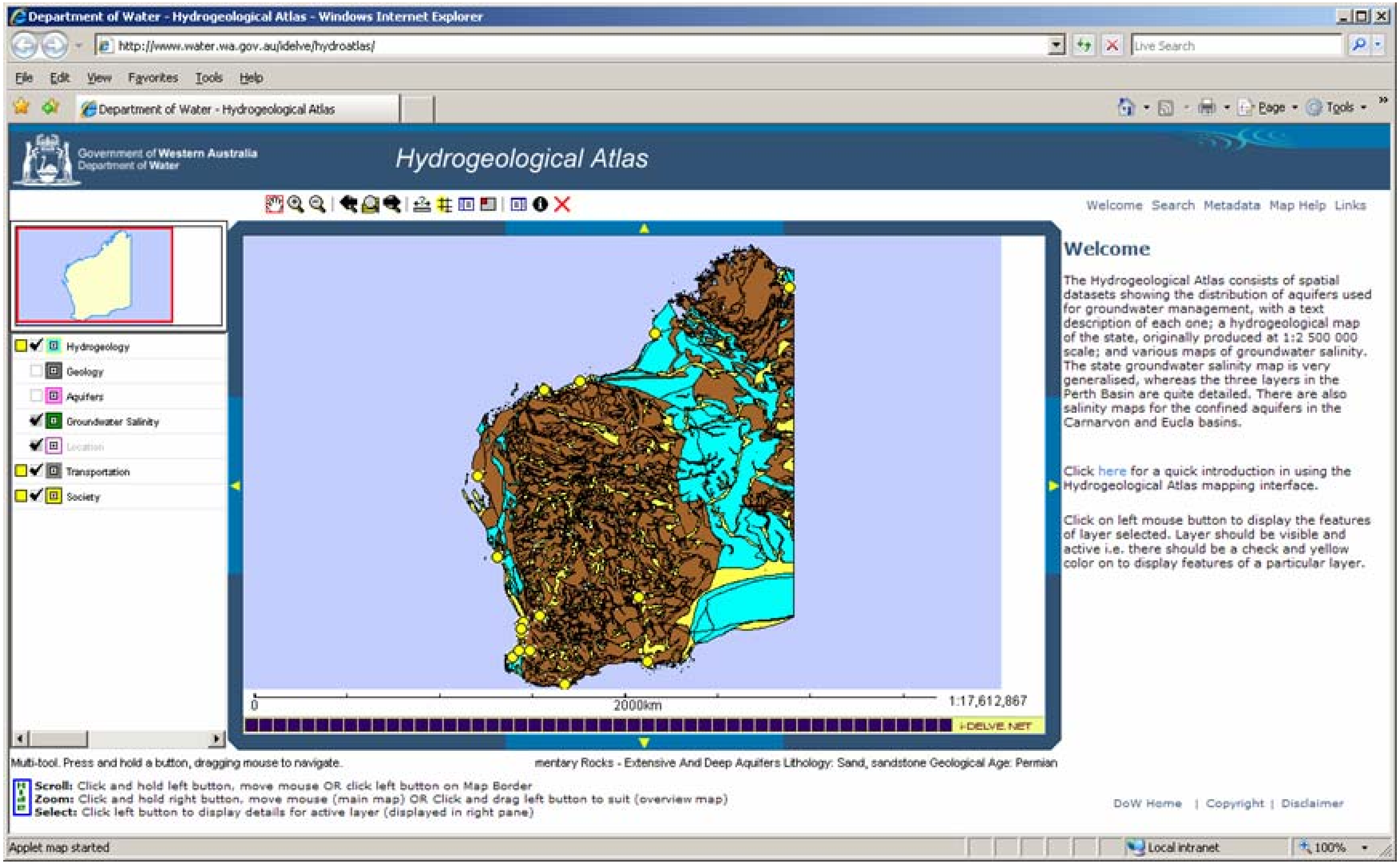
Perth groundwater Atlas



Hydrogeological Atlas webpage



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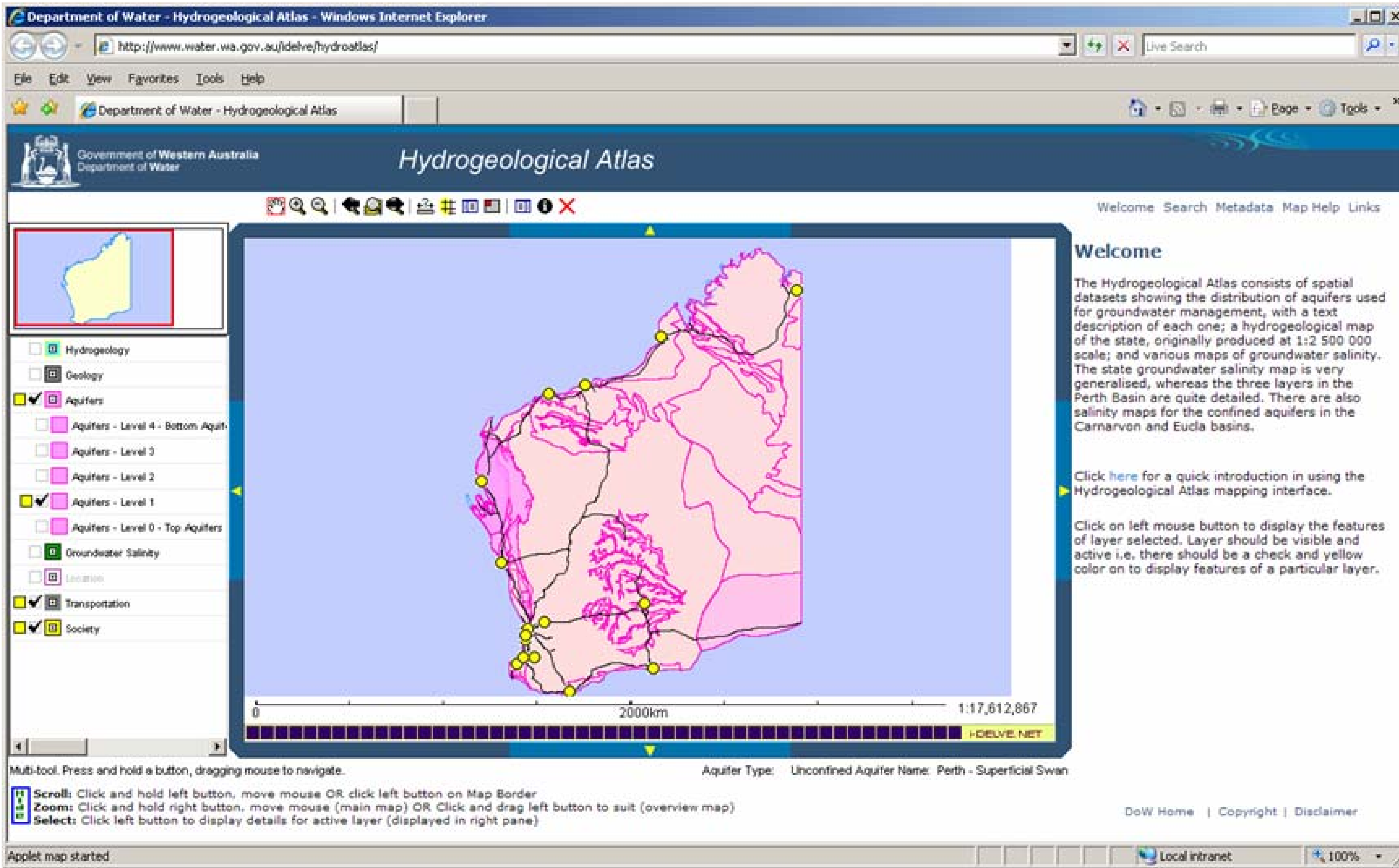
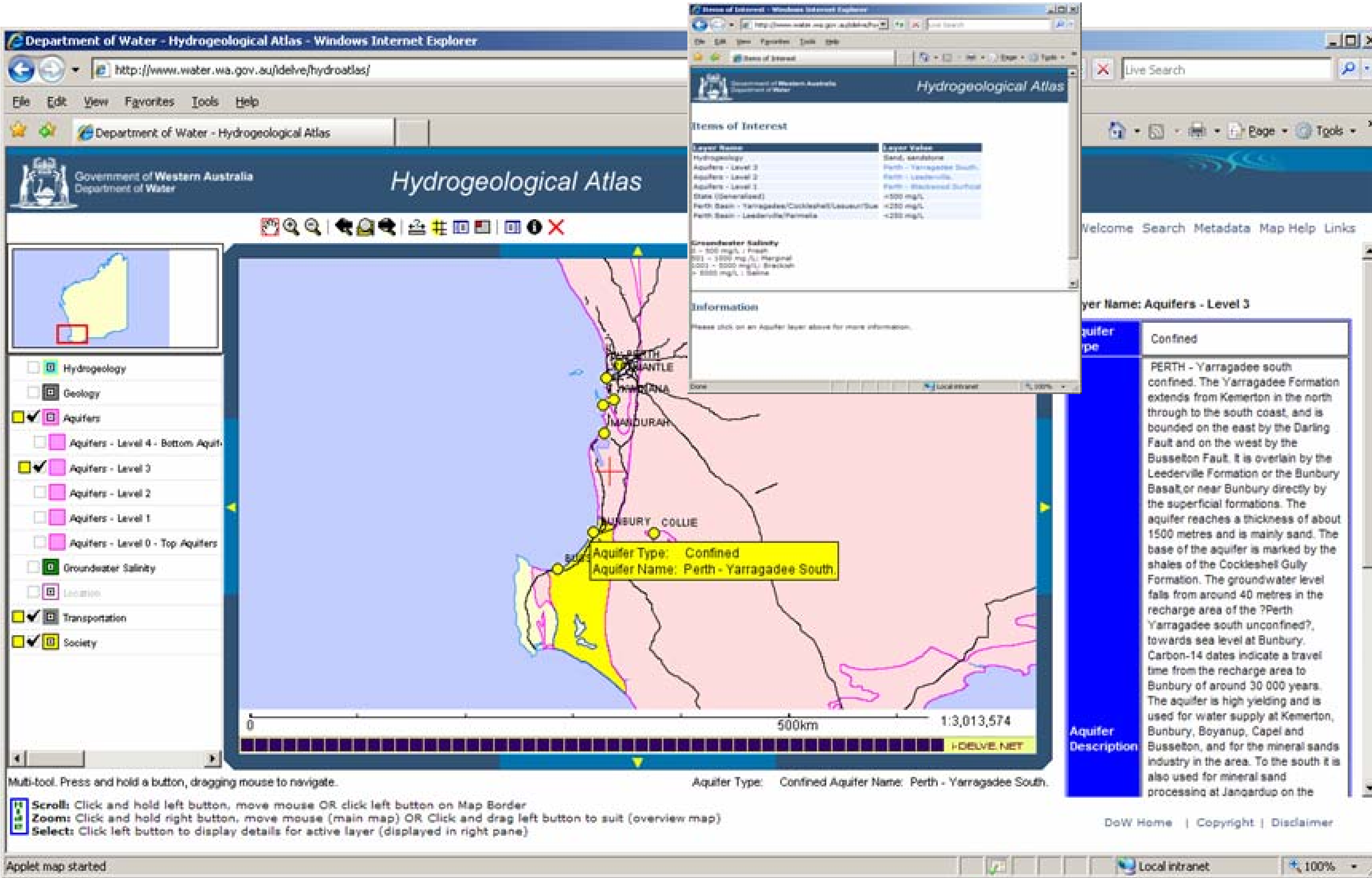
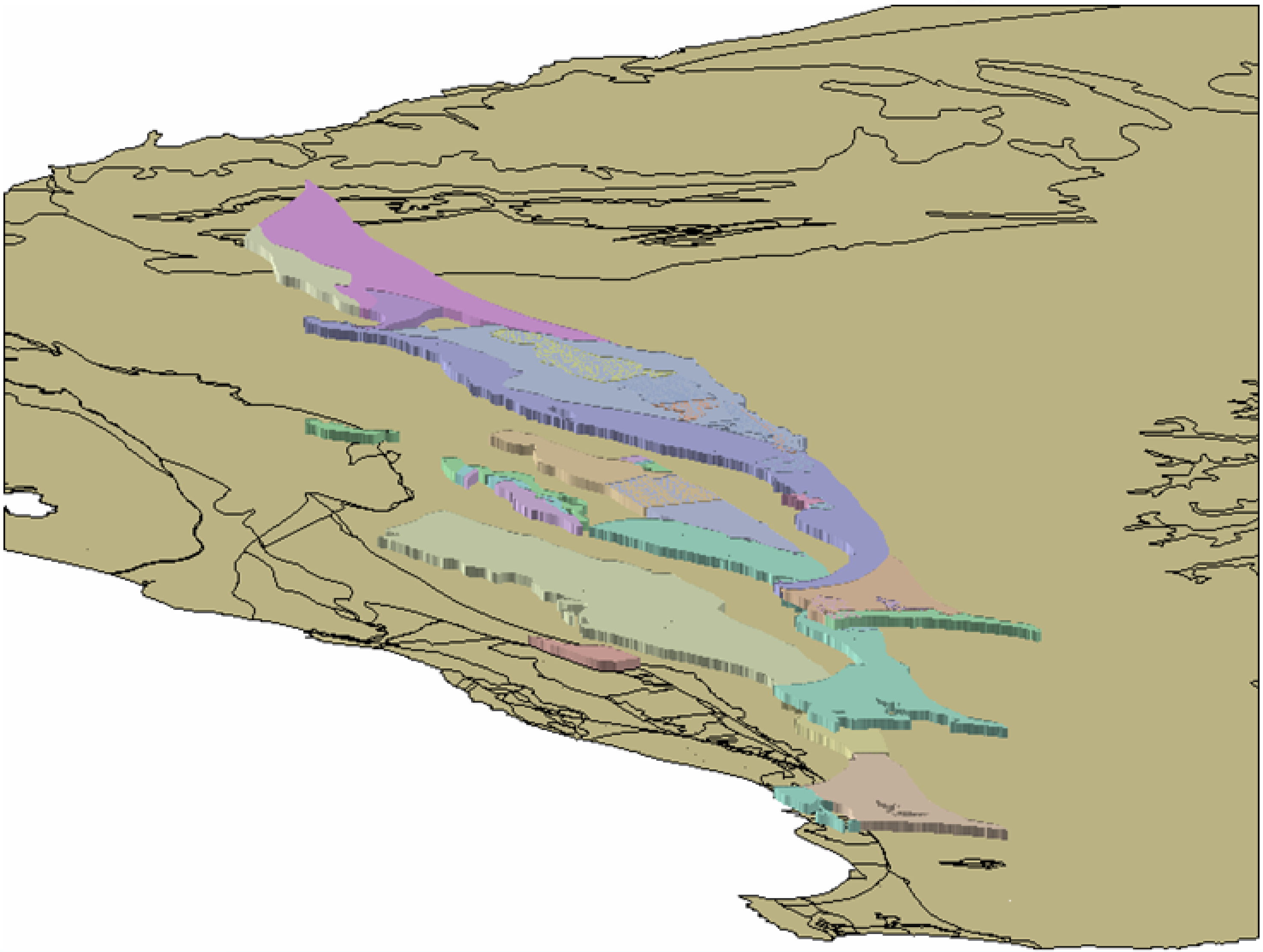
Aquifers



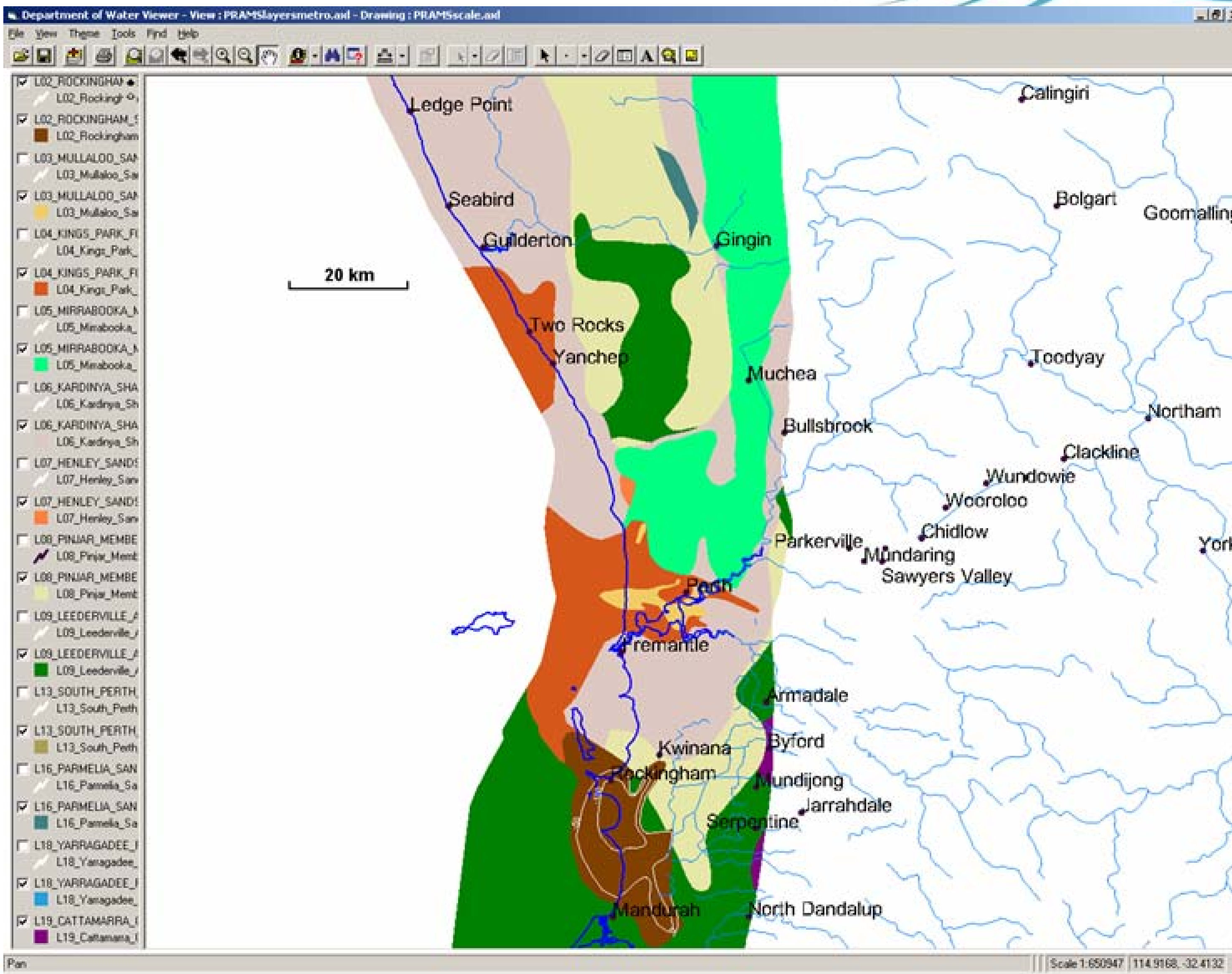
Aquifer information



DWAID Aquifer shapes



GISViewer – PRAMS layers



PETREL surfaces

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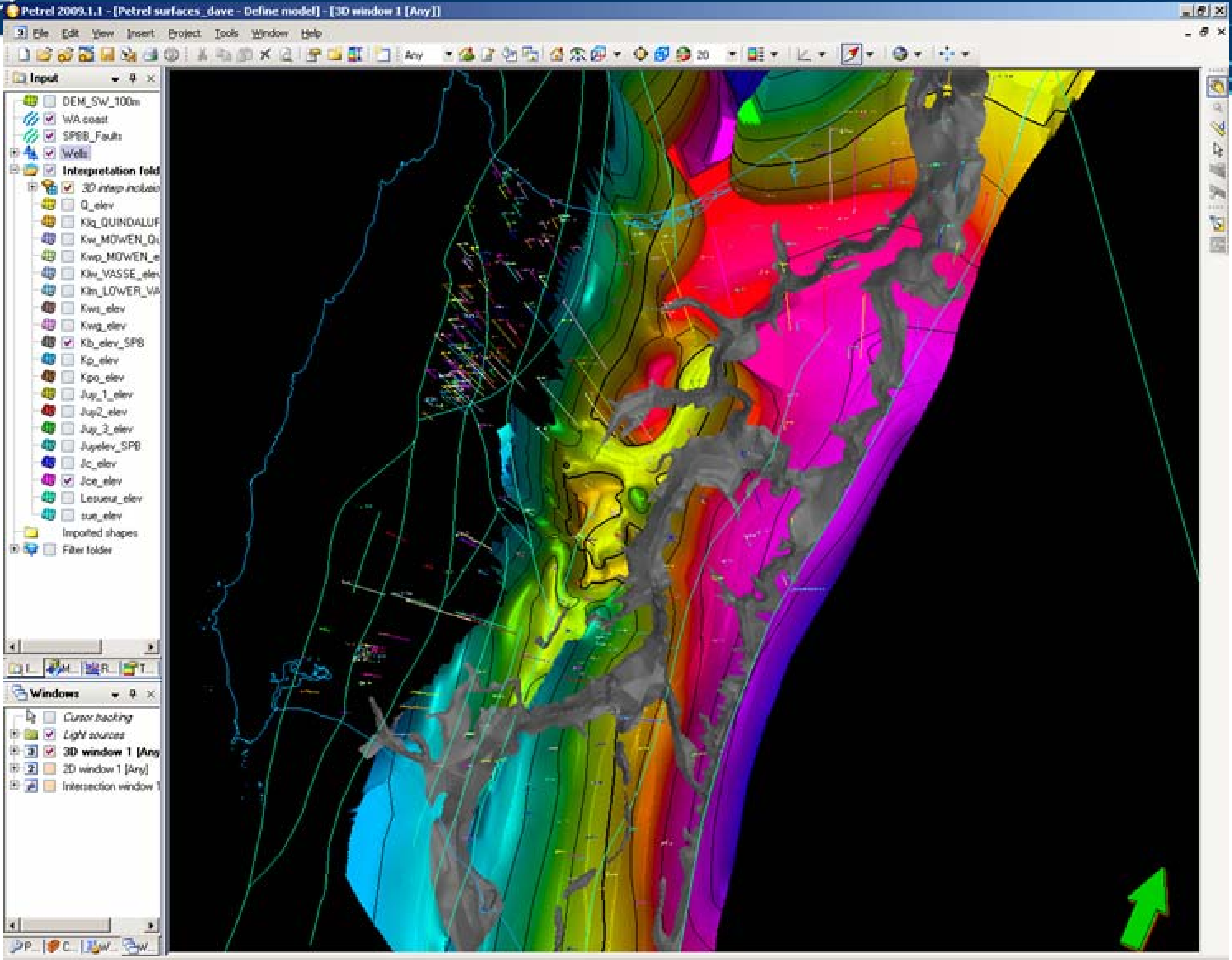


Can transfer surfaces between PETREL and ARCMap

Groundwater models

Major regional models

SWAMS - South West regional aquifer modelling system

PRAMS - Perth regional aquifer modelling system

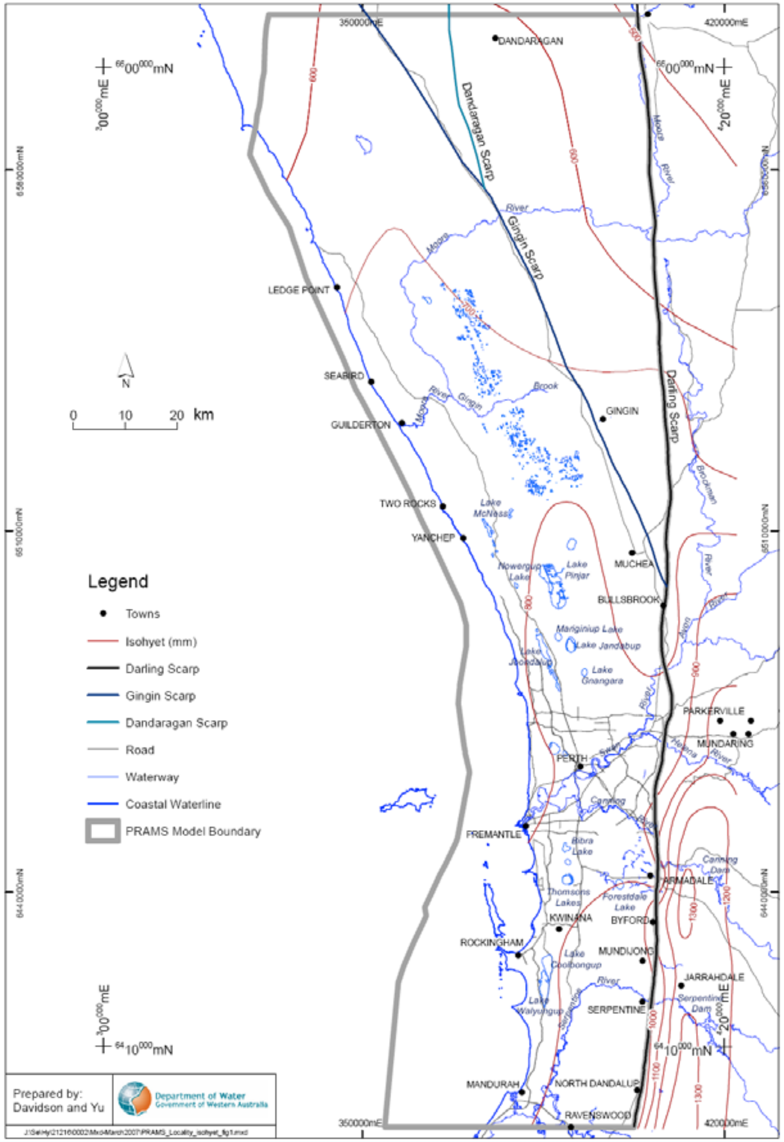
PHRAMS - Peel Harvey regional aquifer modelling system *(under development)*

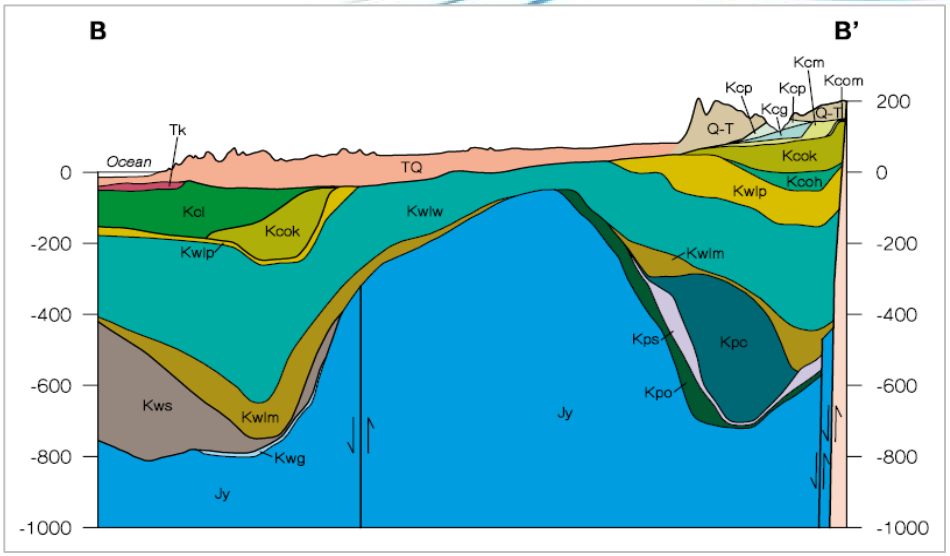
Sub-regional models

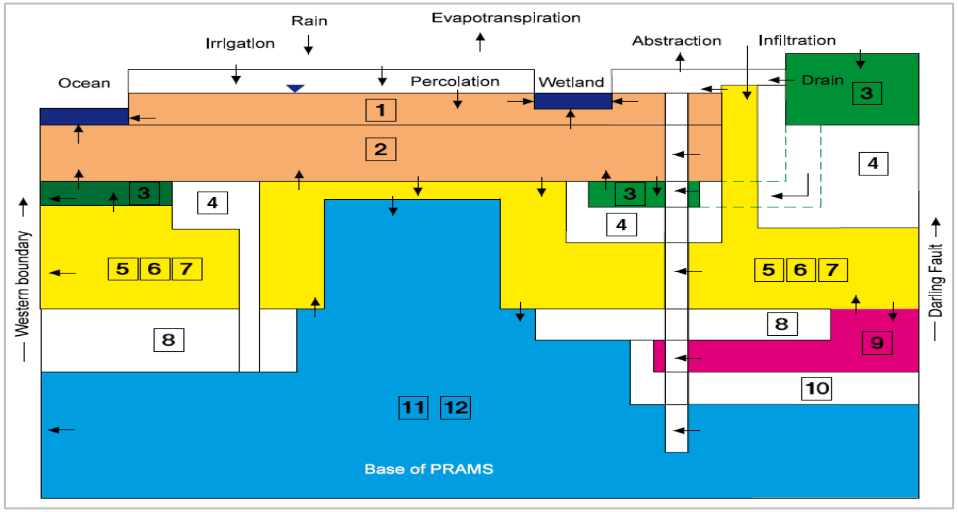
Collie basin
Carnarvon-Gascoyne River alluvial
Scott Coastal
Cowaramup
Yanchep
Kemberton

Millstream
Mariginiup
Swan-Caversham
Byford
Blackwood
Karnup/Baldivis/Keralup

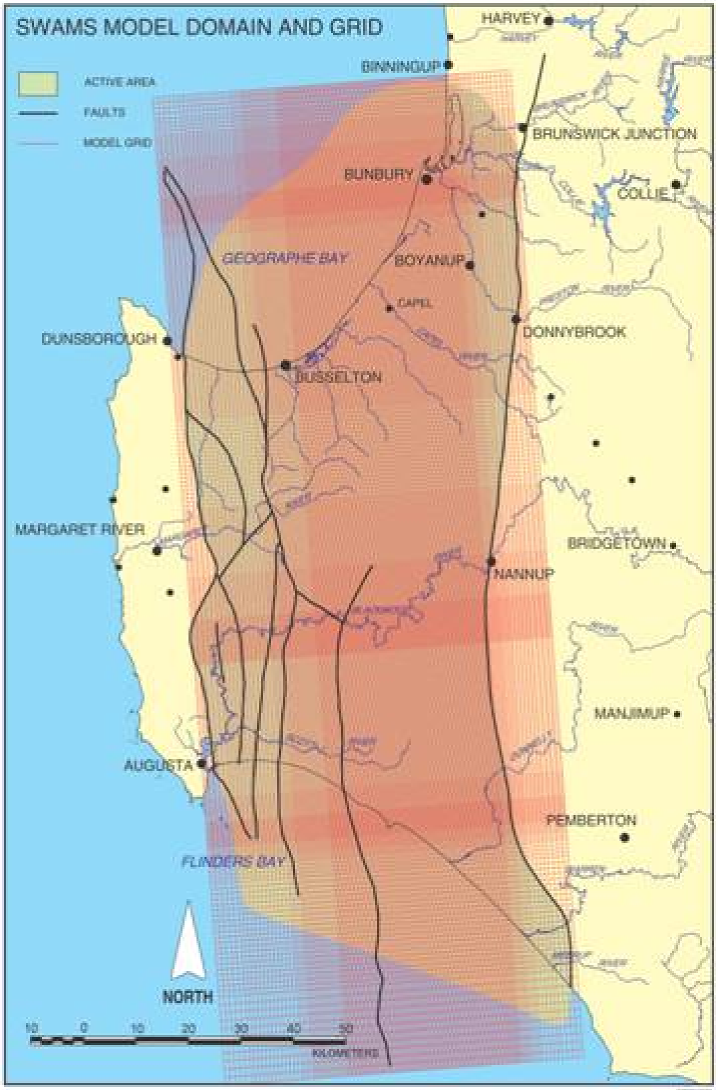
Groundwater models: PRAMS

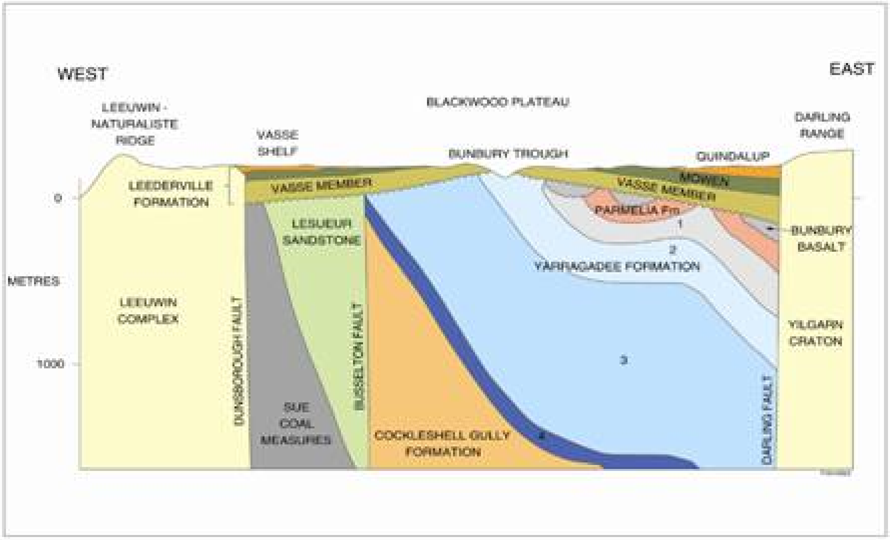


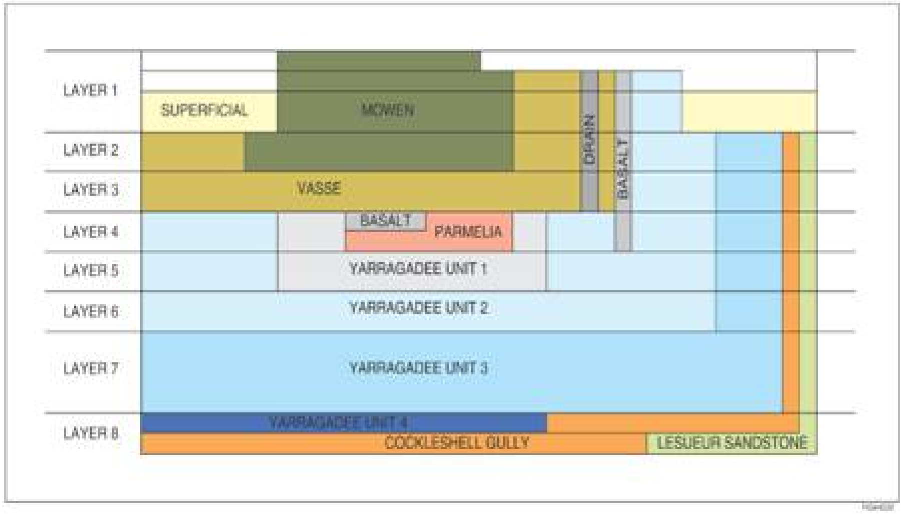




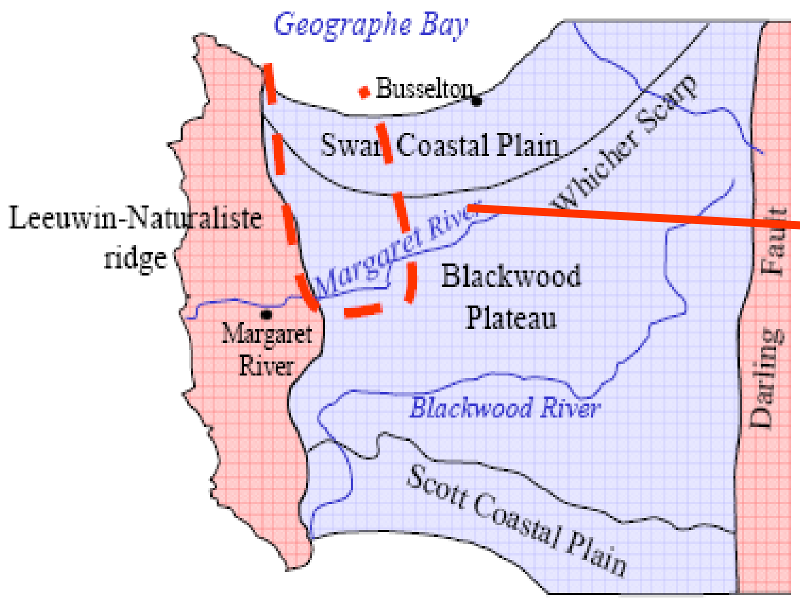
Groundwater models: SWAMS



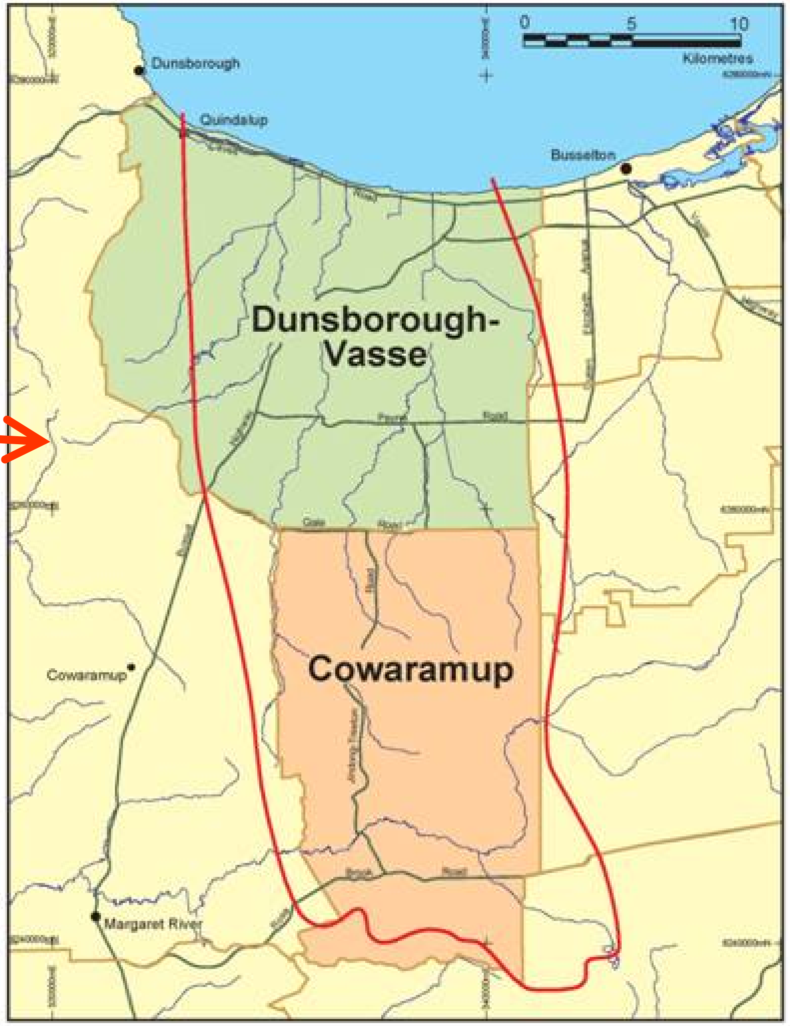




Study area

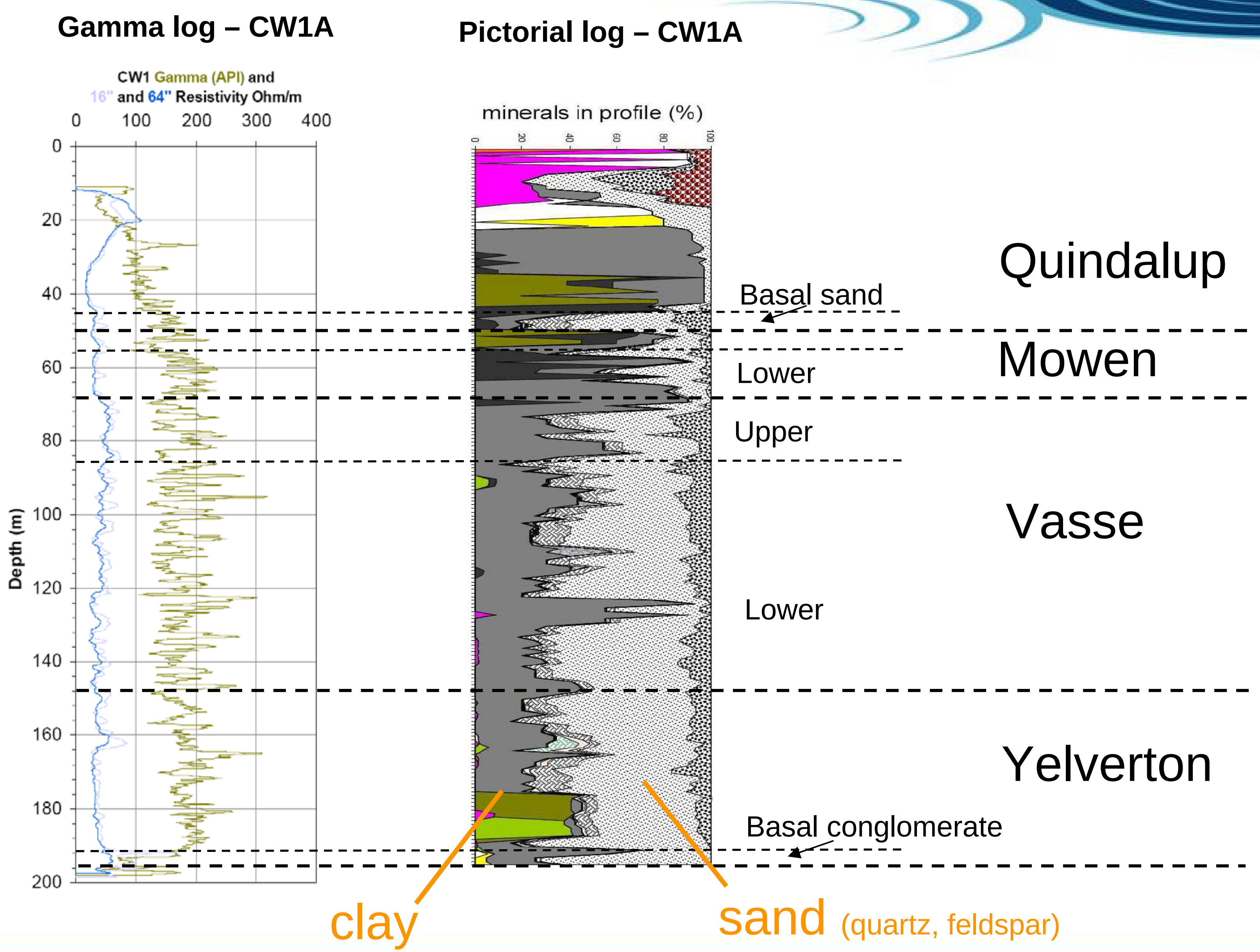


Geographe Bay
Busselton
Swan Coastal Plain
Whicher Scarp
Leeuwin-Naturaliste ridge
Margaret River
Margaret River
Blackwood Plateau
Blackwood River
Scott Coastal Plain
Darling Fault



0 5 10
Kilometres
Dunsborough
Quindalup
Busselton
Dunsborough-Vasse
Cowaramup
Cowaramup
Margaret River

Stratigraphic interpretation



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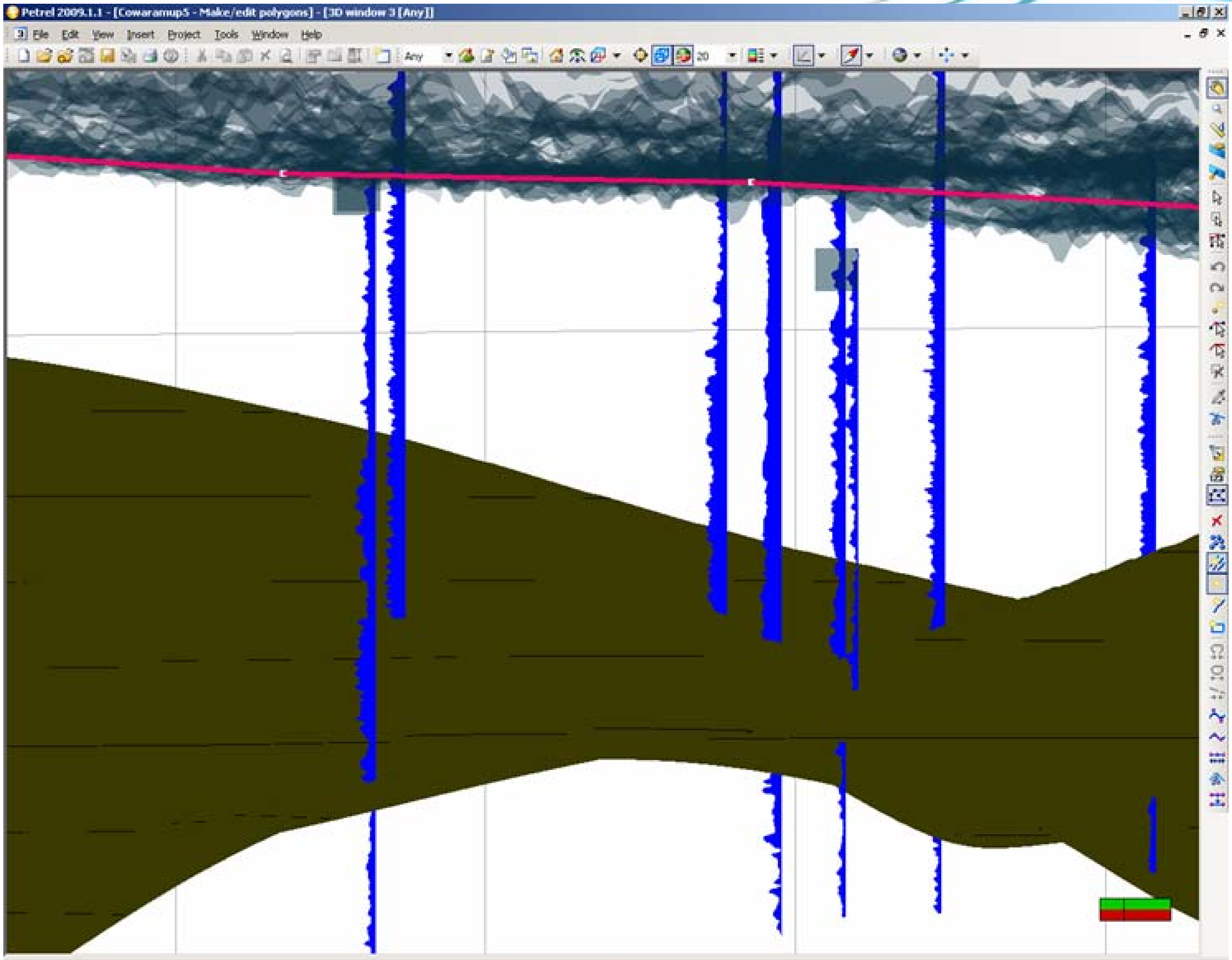
Formation layer picks



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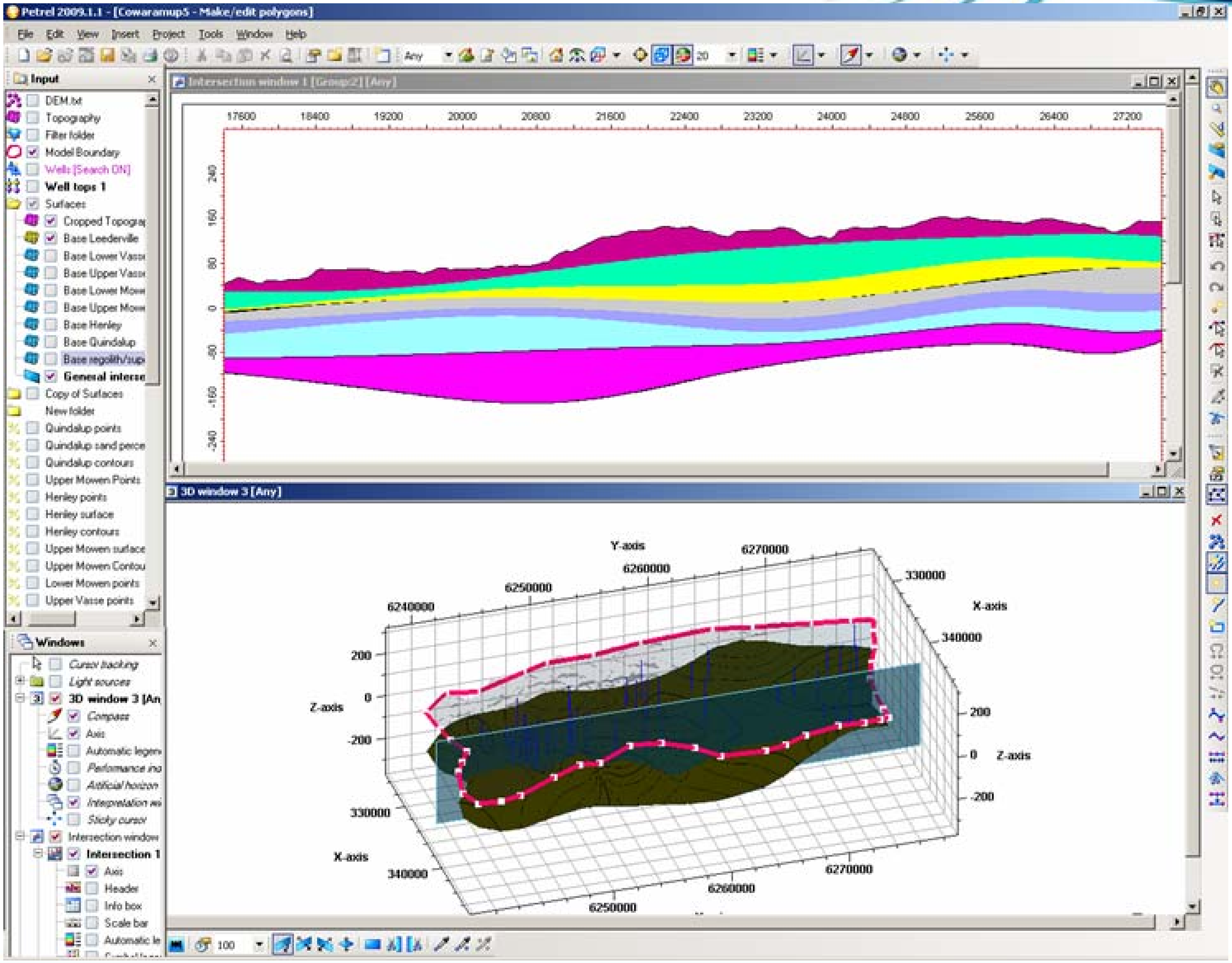
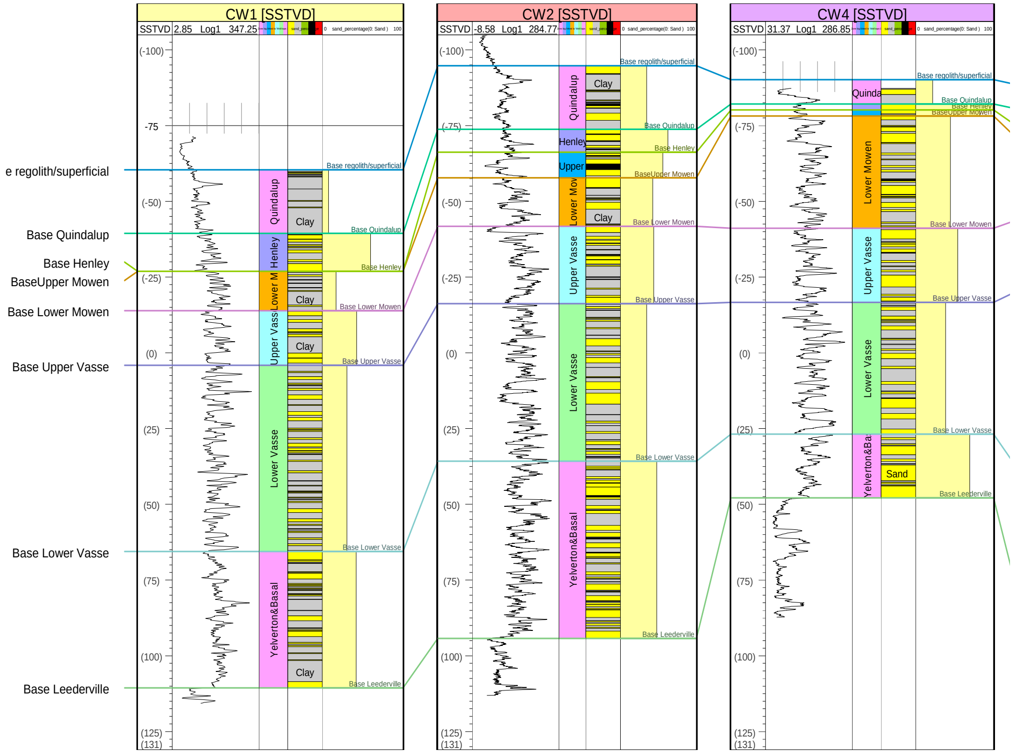
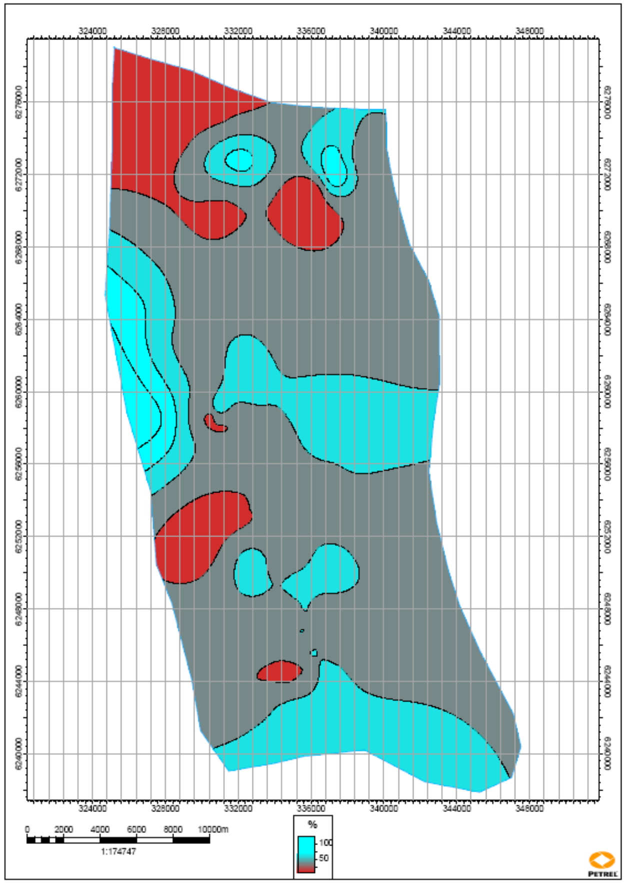
Cross-sections



Data Analysis - PETREL



Stratigraphy



Sand percentage maps

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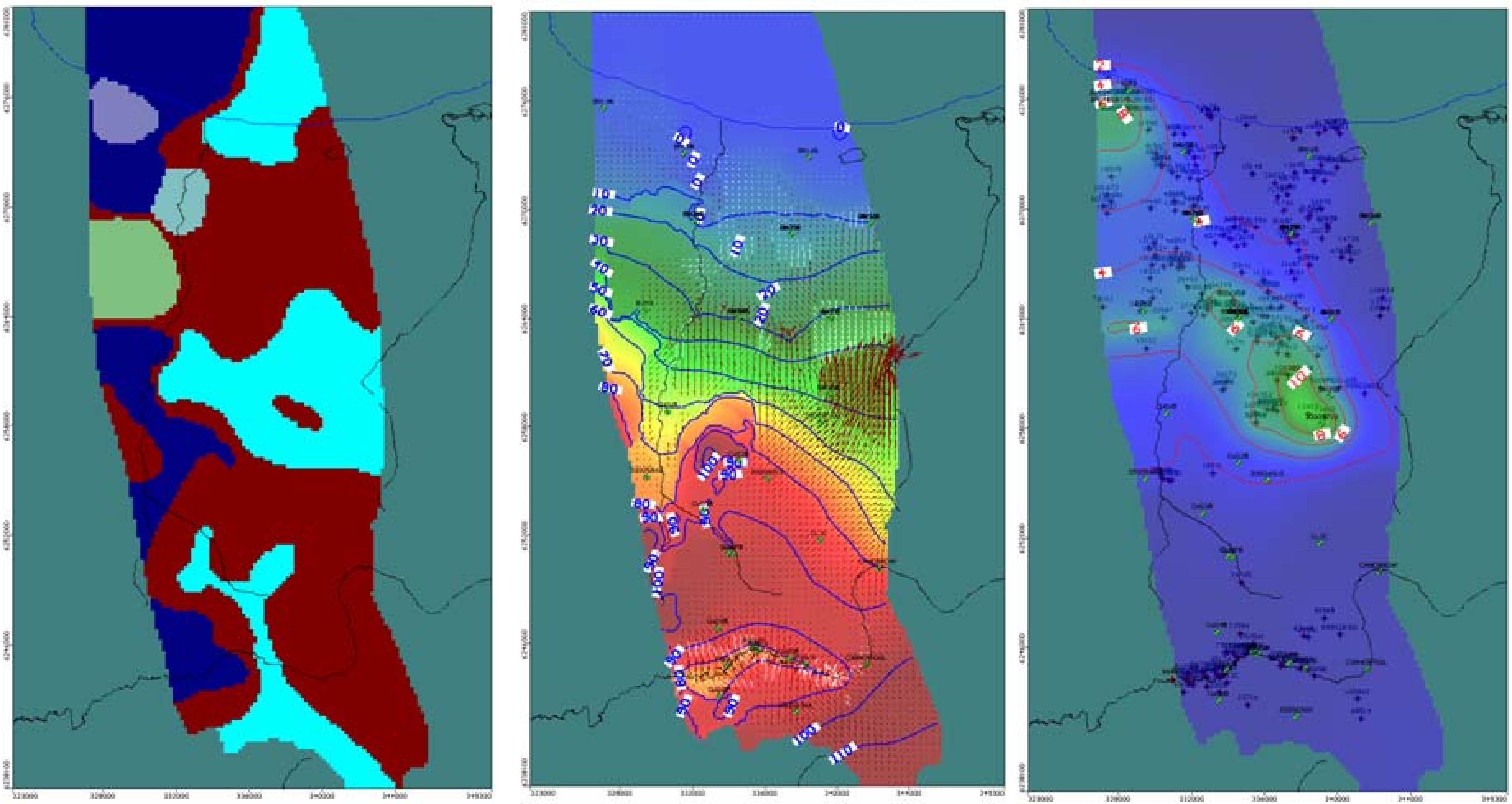
Groundwater model



Conductivity zones | Model flow | Modelled drawdown

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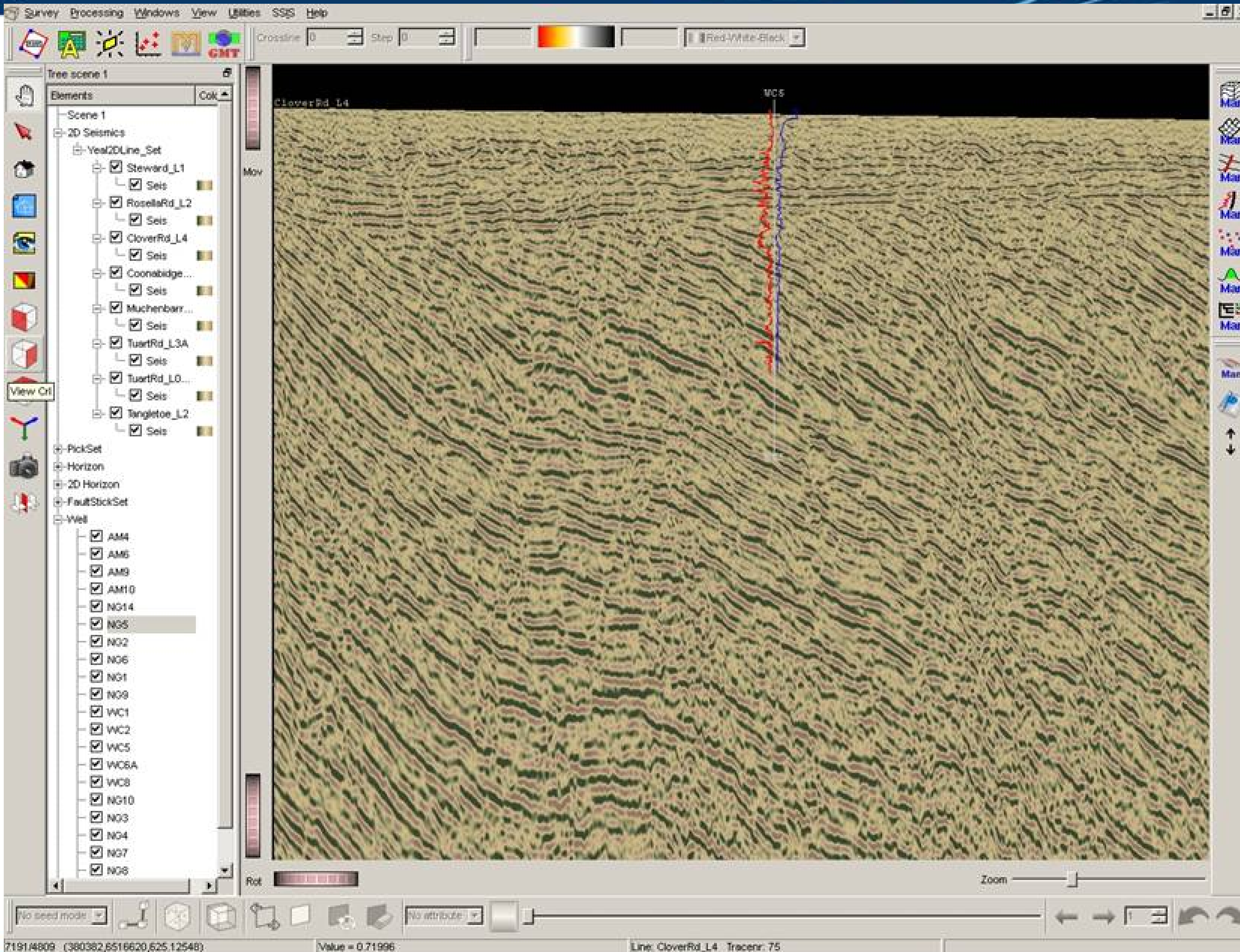
Seismic



THREE DIMENSIONAL TEMPORAL ANALYSIS OF SURFACE AND GROUND WATER INTERACTIONS

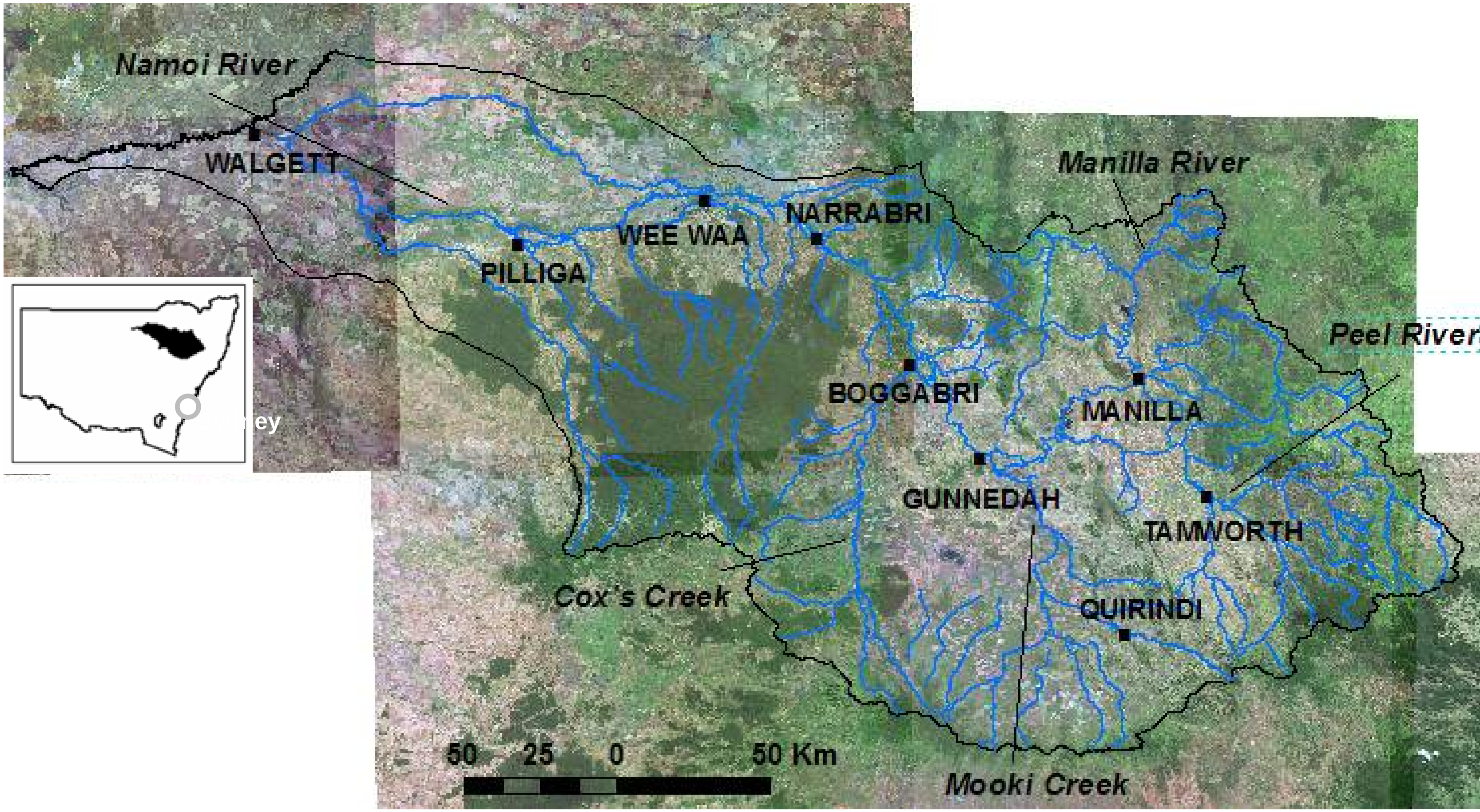
Giambastiani B.M.S
Kelly B.F.J.
McCallum A.
The C.

Australian Government
National Water Commission
Cotton Catchment Communities CRC
UNSW CONNECTED WATERS
Water Research Laboratory
Namoi CMA CATCHMENT MANAGEMENT AUTHORITY

MAIN PURPOSES

- **Examining the temporal visual correlation between groundwater extraction, streamflow, rainfall and groundwater head;**
- **Mapping in 3D the change in groundwater head due to flood events in order to show hydraulic connections and the pathways of recharge;**
- **Providing catchment authorities with a visual communication tool for community meetings about water management;**

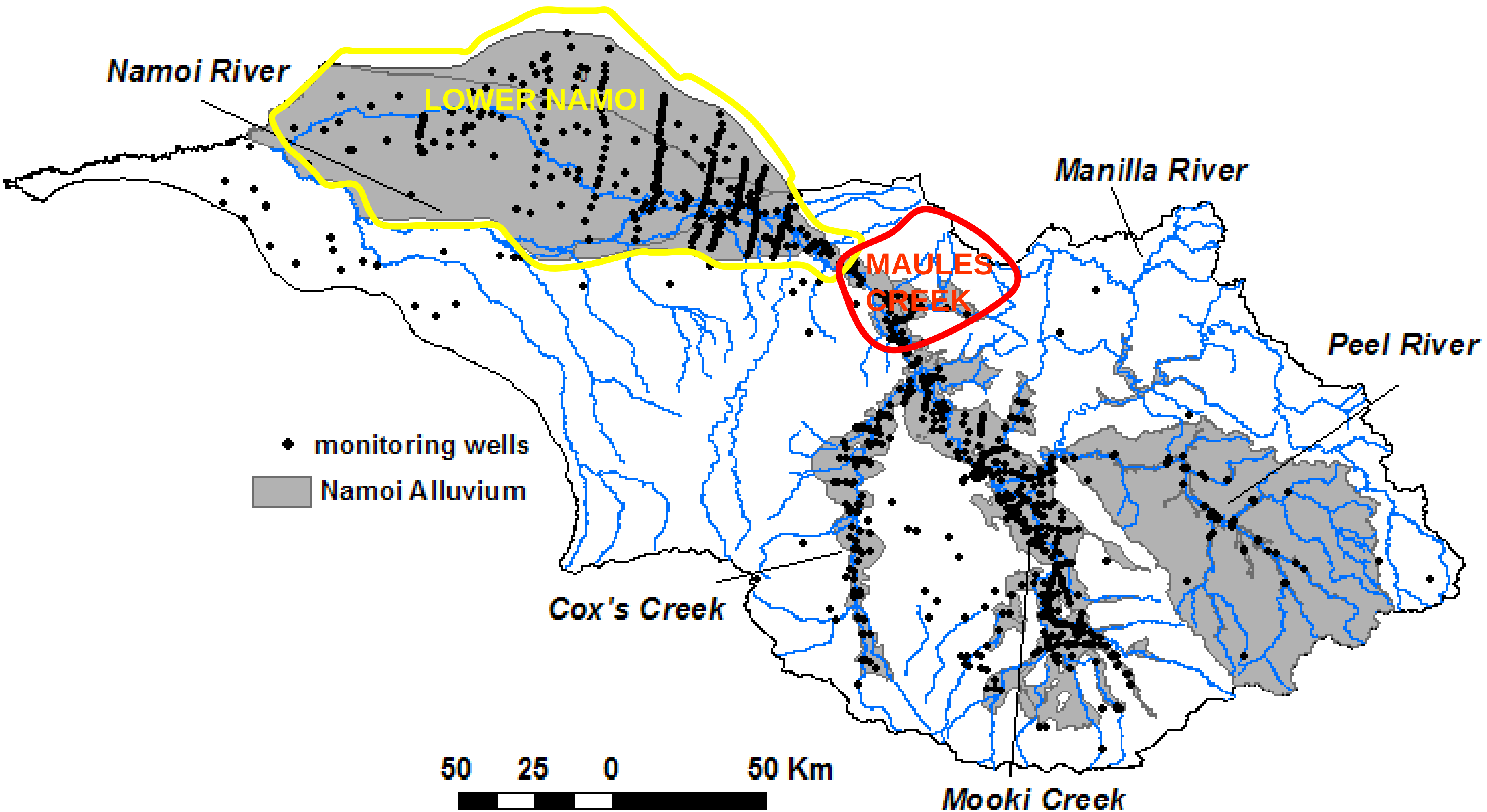
STUDY AREA: THE NAMOI CATCHMENT



- **groundwater extraction = 15.2% of the total annual groundwater use from the MDB (14820 users)**
- **diverted surface water and extracted groundwater for irrigating crops, mining, stock and domestic purposes (CSIRO, 2007)**

STUDY AREA: NAMOI CATCHMENT

- More than 550 groundwater monitoring boreholes (NSGW, 2007)
- From 1 to 7 pipes at each borehole location
- Water levels recorded 4 or more time a year



DATA SOURCES

- **Rainfall data**
  - **Australian Government Bureau of Meteorology**
  - **http://www.bom.gov.au/**

- **Streamflow data**
  - **NSW Government Historic data DVD "PINNEENA" for Continuous Monitoring**
  - **http://www.waterinfo.nsw.gov.au/pinneena/cm.shtml**

- **Groundwater head measurements:**
  - **NSW Government Historic data CD "PINNEENA" for Groundwater Works**
  - **http://www.waterinfo.nsw.gov.au/pinneena/gw.shtml**

- **Groundwater usage:**
  - **1996 to 2008 data supplied by the NSW Department of Water and Energy**
  - **1984 to 1995 data from:**

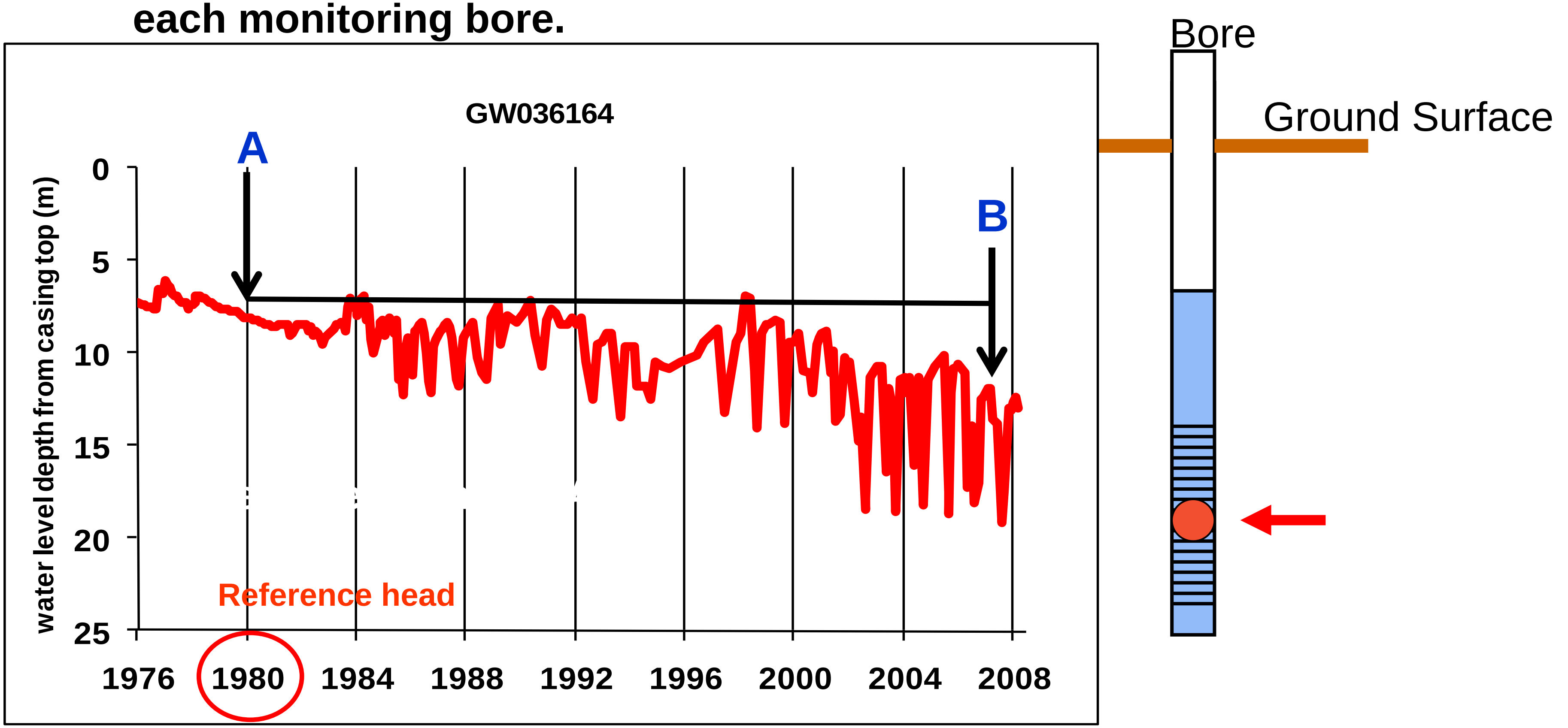
    Upper Namoi Valley Groundwater Status Report 2004, Department of Infrastructure, Planning and Natural Resources, draft 22 June 2006.

METHOD

HYDROGRAPH DATA ANALYSIS

1) **Relative change in head (from 1980 to 2007): comparing the yearly recovered values of each year to the recovered value recorded in 1980**

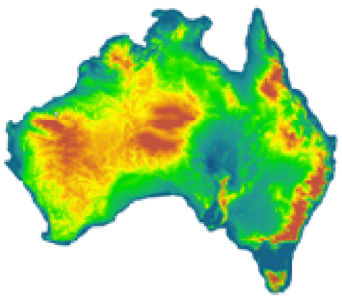
2) **Plotting position in 3D at the mid-point of the slotted interval for each monitoring bore.**



METHOD

3D STRUCTURAL MODEL

Define topography and aquifer limits



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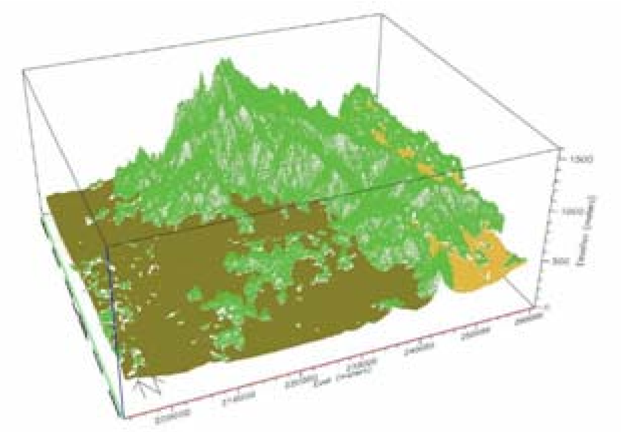

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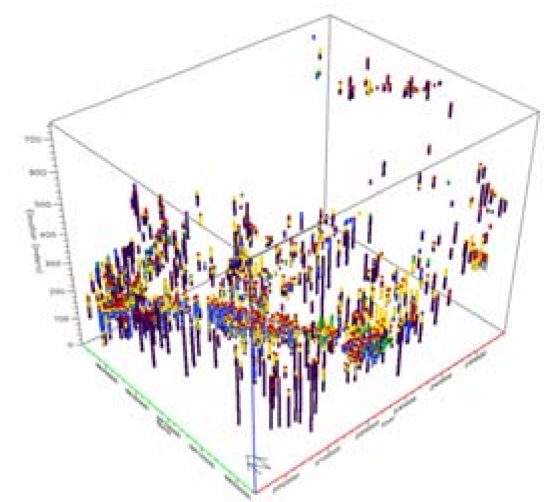
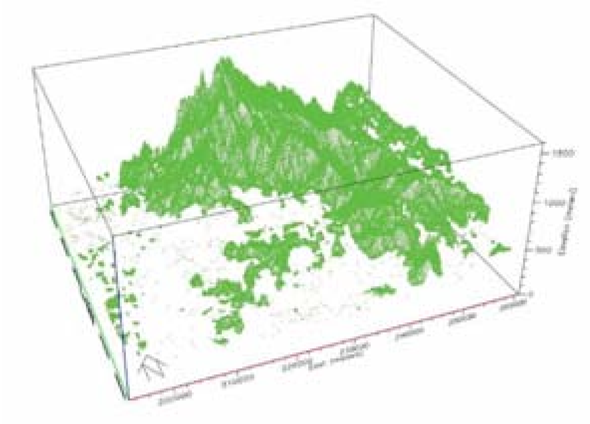


DEM in ArcGIS

Sort DEM: Rock and Sediment (Slope Analysis Tool)

Find bedrock top elevations from lithological logs

+



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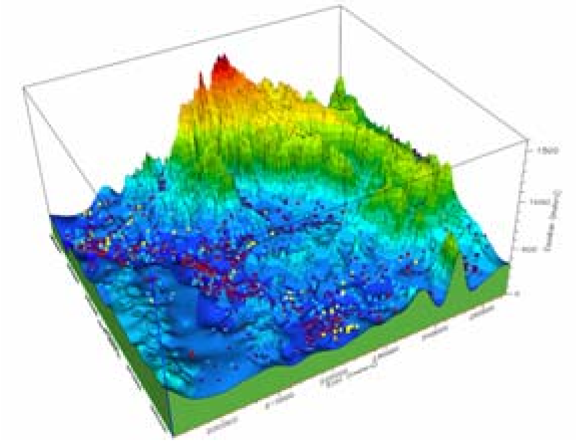
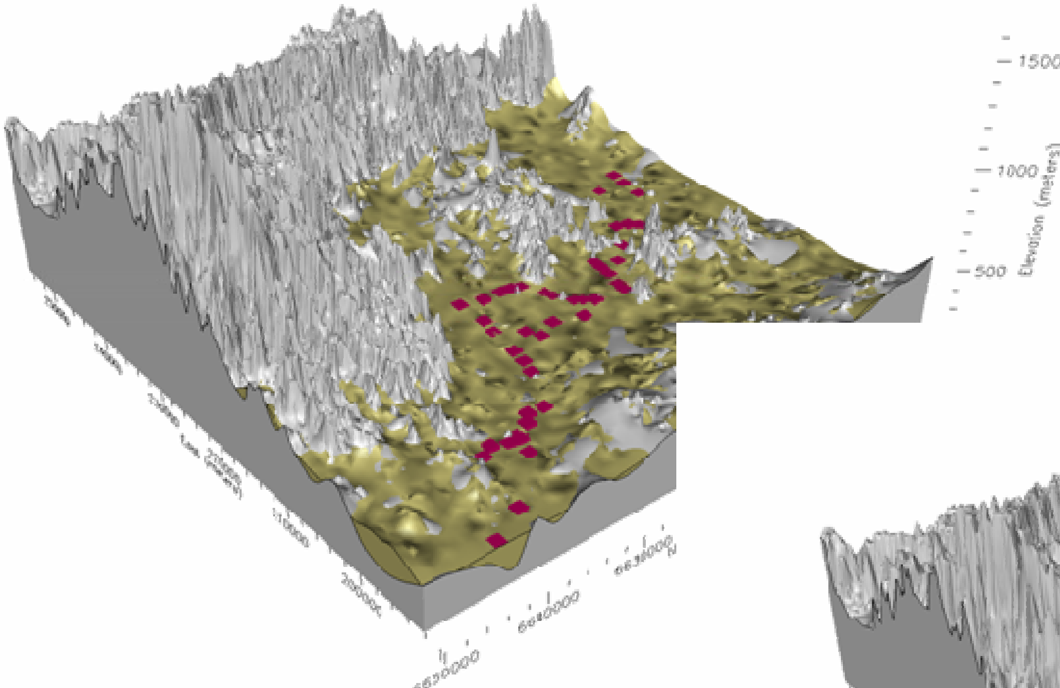
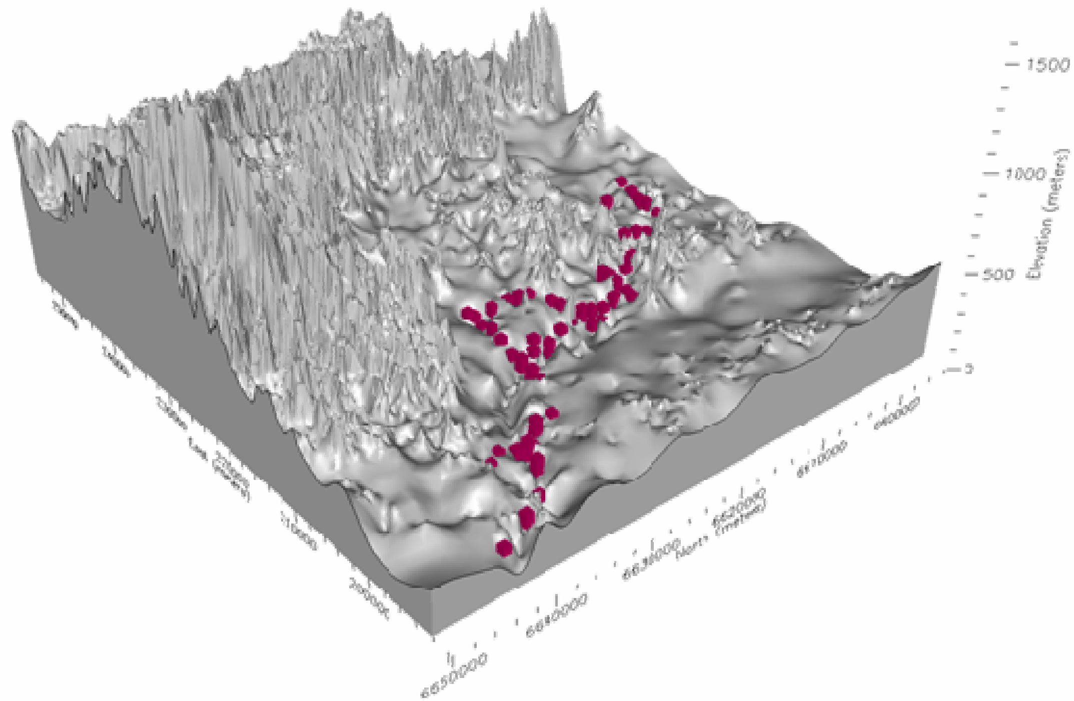


Combine rock outcrop and borehole rock data

Contour/Grid the bedrock

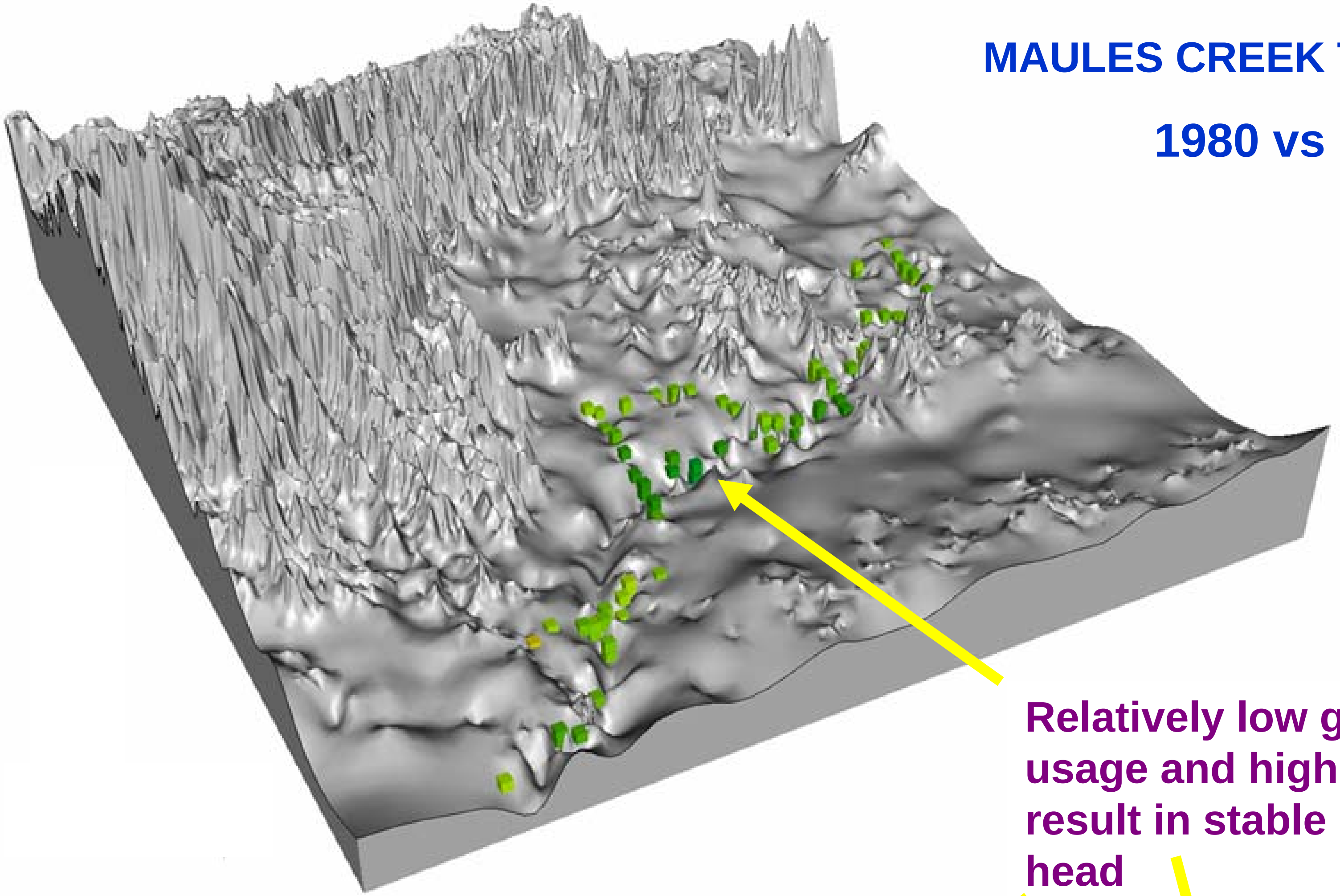
MAULES CREEK 3D GEOLOGICAL MODEL

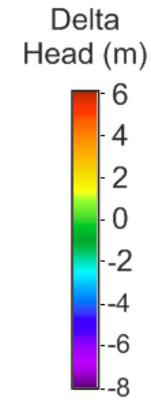




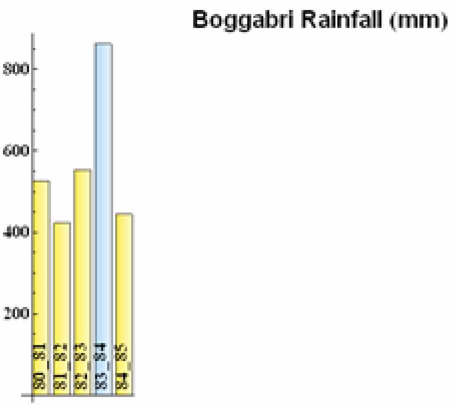
MAULES CREEK TIME-LAPSE

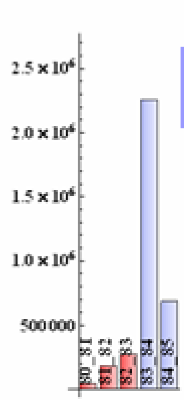
1980 vs 1985



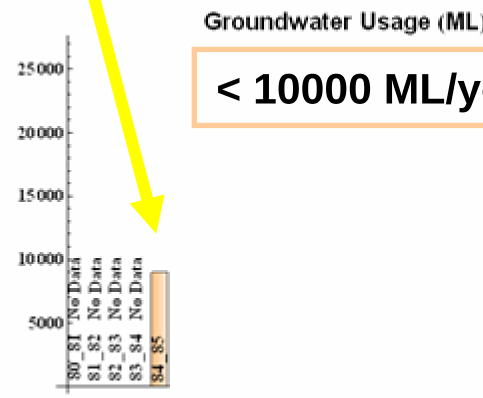


Relatively low groundwater usage and high streamflow result in stable groundwater head





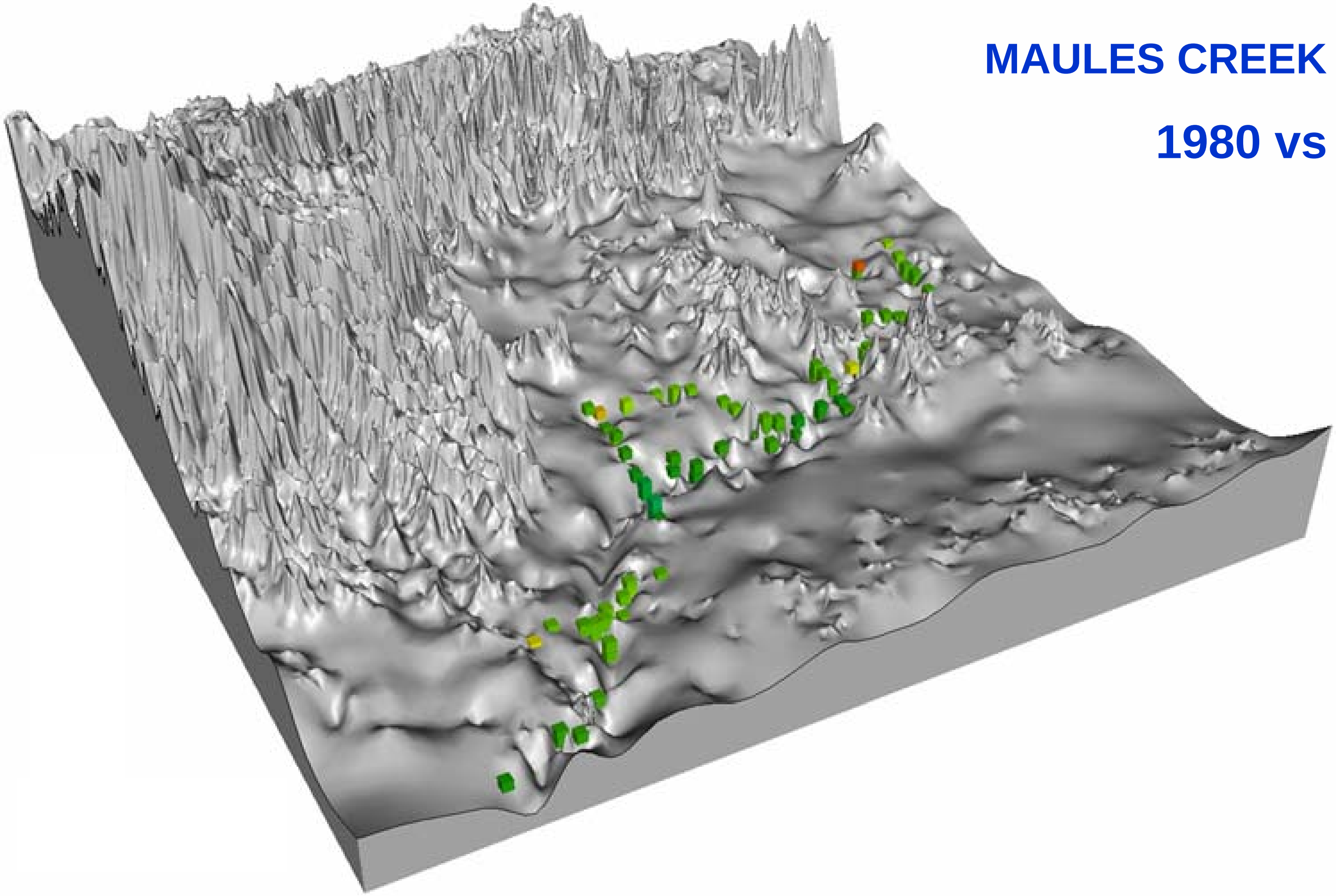
> 343 ML/year

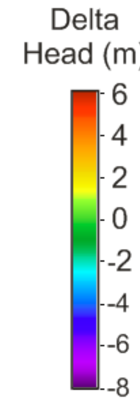


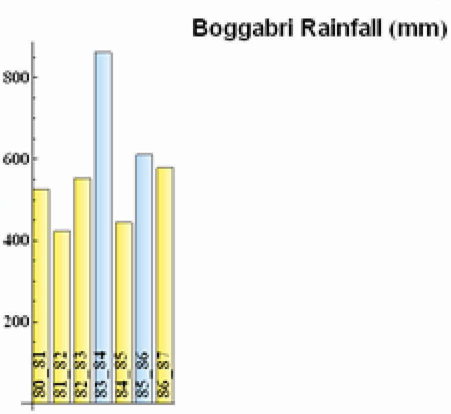
< 10000 ML/year

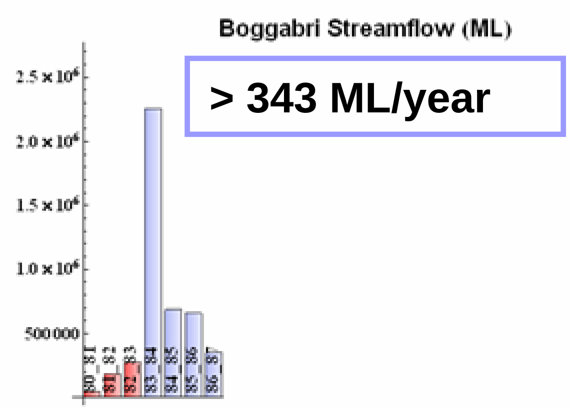
MAULES CREEK TIME-LAPSE

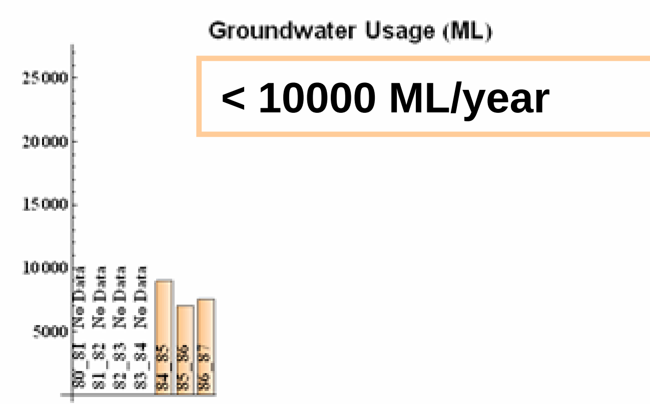
1980 vs 1987





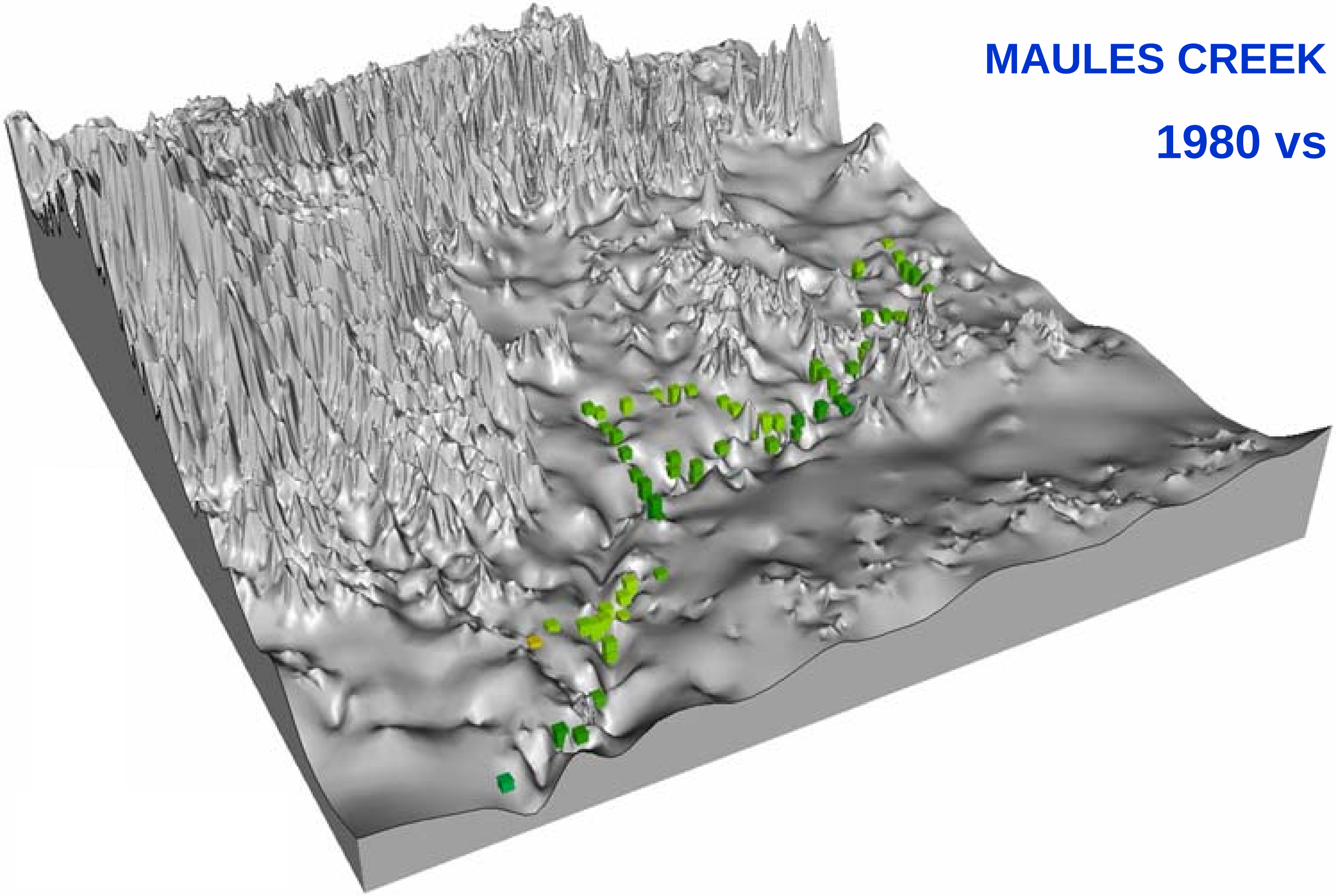


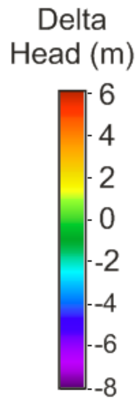


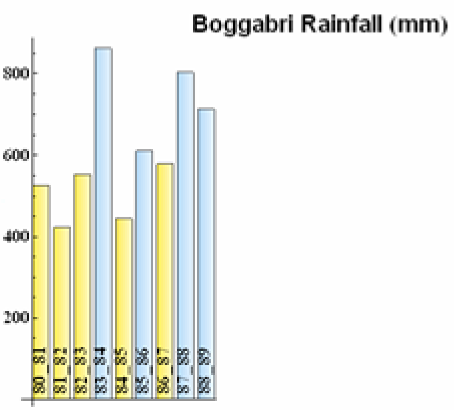


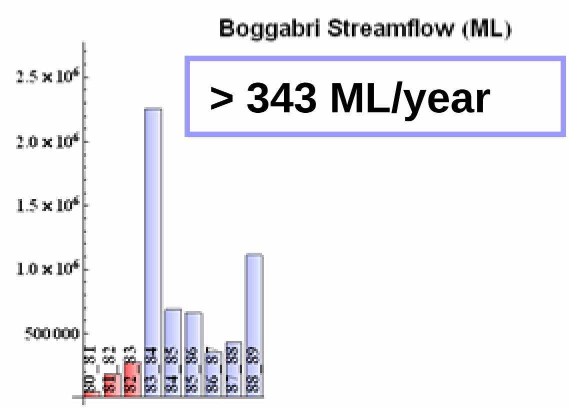
MAULES CREEK TIME-LAPSE

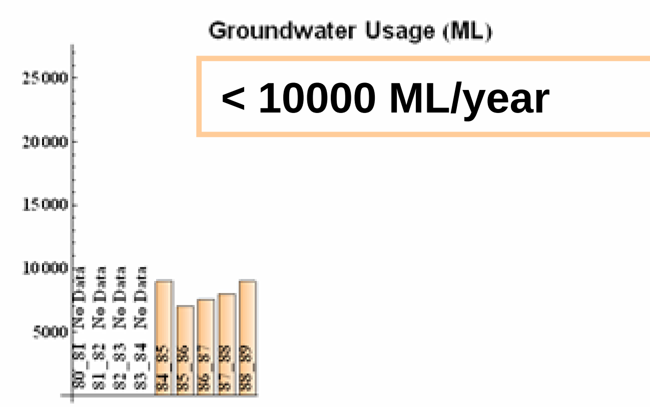
1980 vs 1989





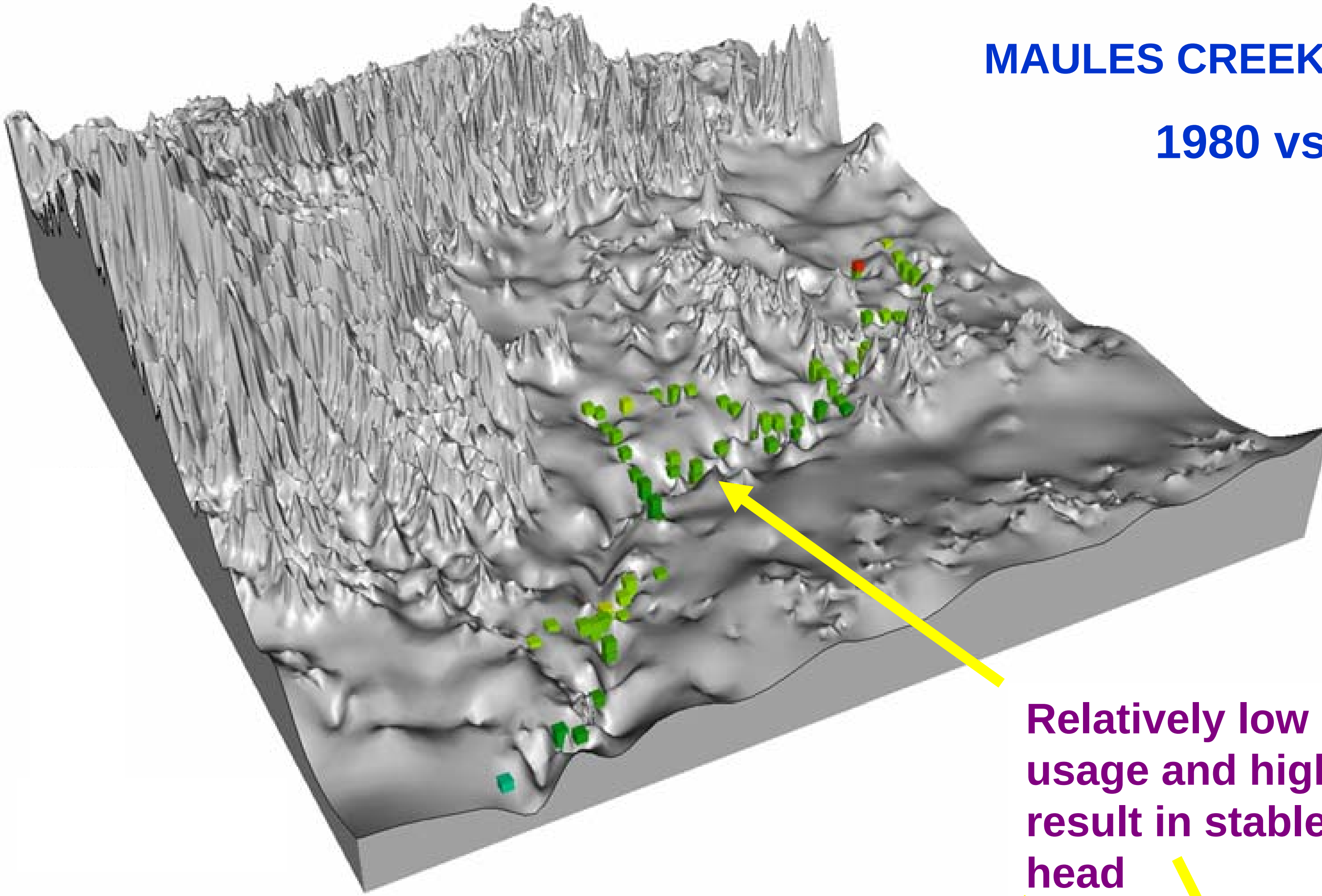


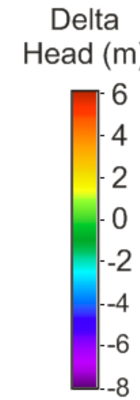




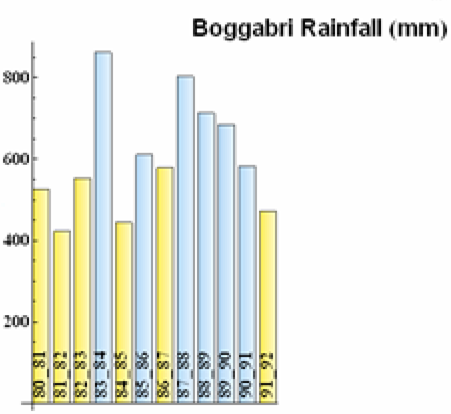
MAULES CREEK TIME-LAPSE

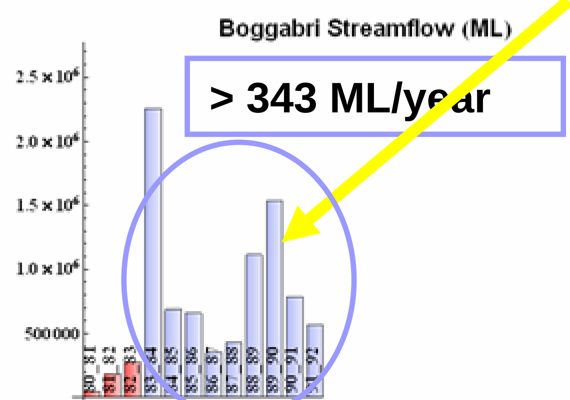
1980 vs 1992

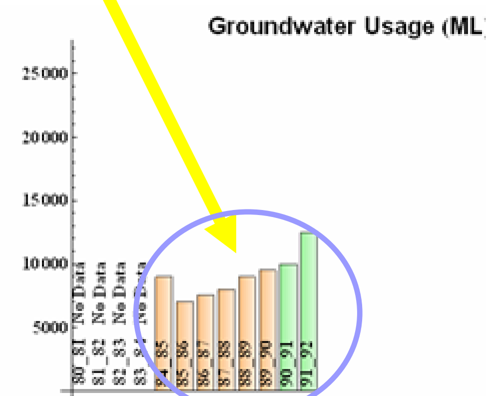


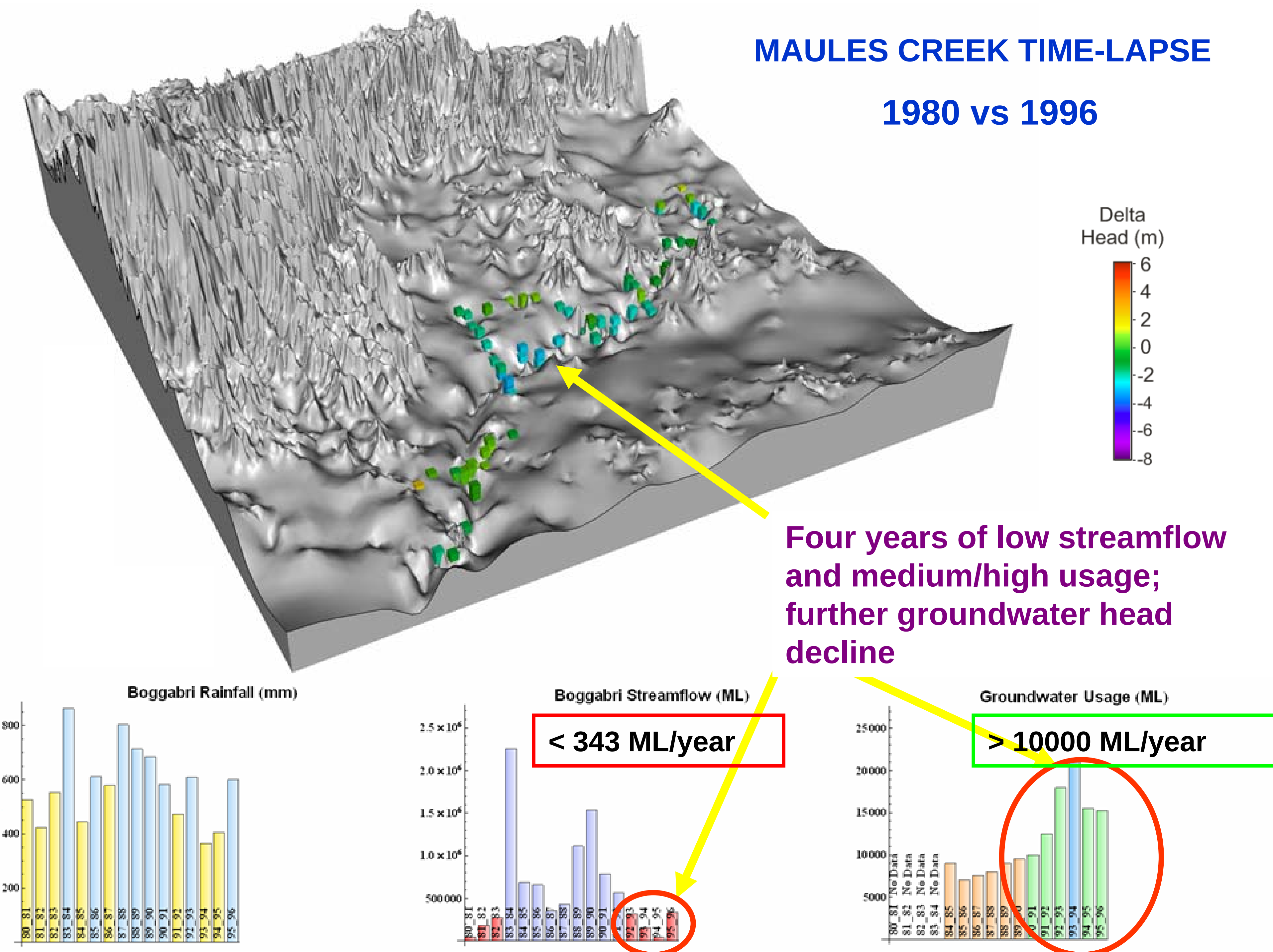


Relatively low groundwater usage and high streamflow result in stable groundwater head





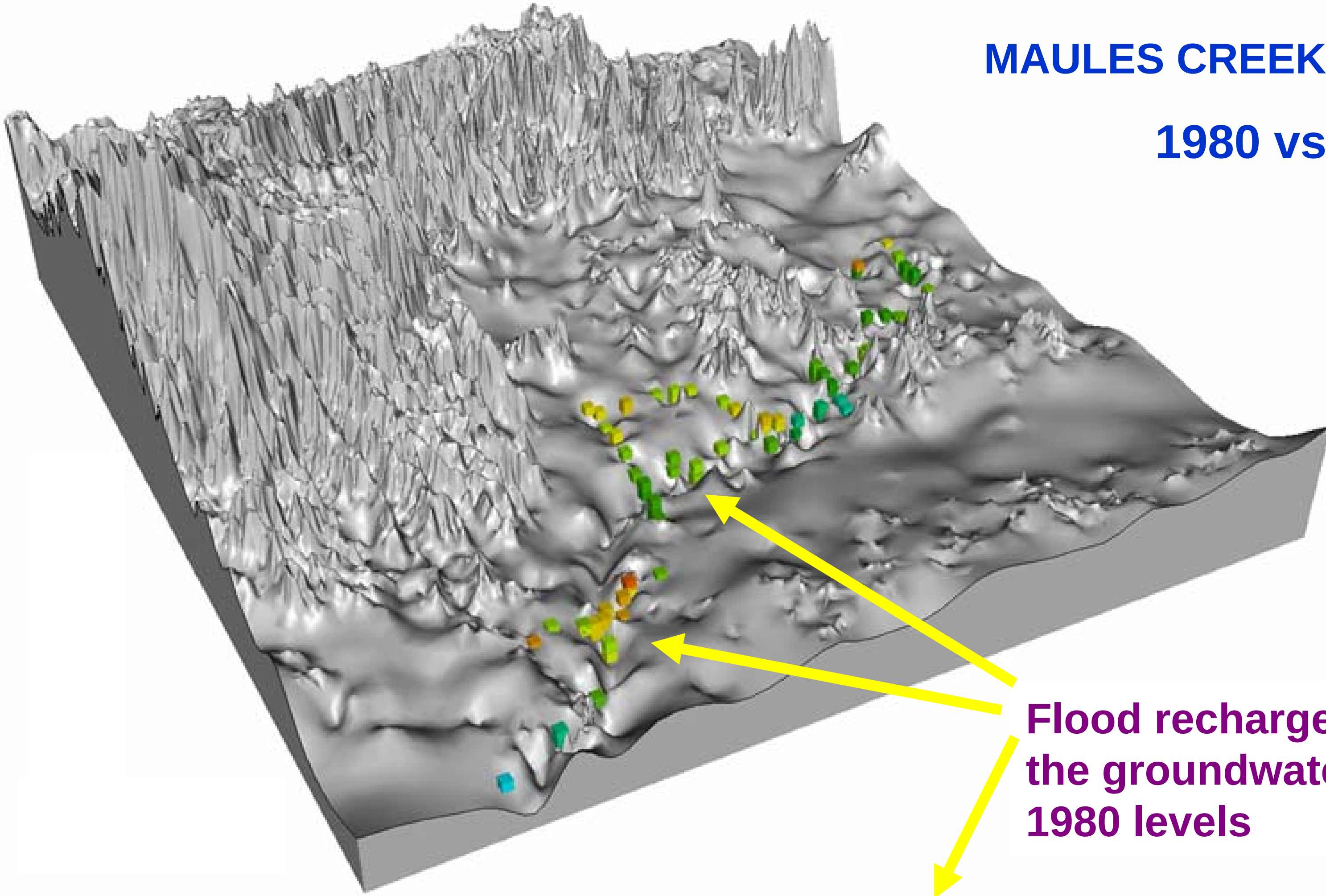


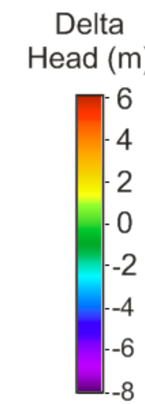


MAULES CREEK TIME-LAPSE
1980 vs 1996
Delta Head (m)
6
4
2
0
-2
-4
-6
-8
Four years of low streamflow and medium/high usage; further groundwater head decline
Boggabri Rainfall (mm)
800
600
400
200
80_81 81_82 82_83 83_84 84_85 85_86 86_87 87_88 88_89 89_90 90_91 91_92 92_93 93_94 94_95 95_96
Boggabri Streamflow (ML)
< 343 ML/year
2.5×10^6
2.0×10^6
1.5×10^6
1.0×10^6
500 000
Groundwater Usage (ML)
> 10000 ML/year
25 000
20 000
15 000
10 000
5000
No Data

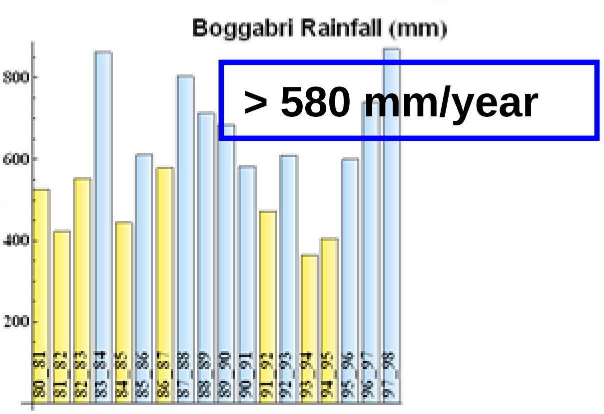
MAULES CREEK TIME-LAPSE

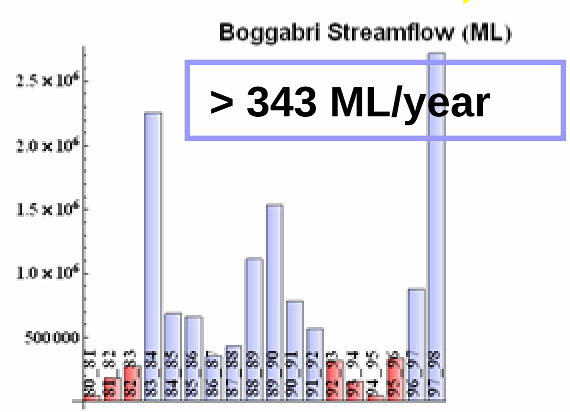
1980 vs 1998

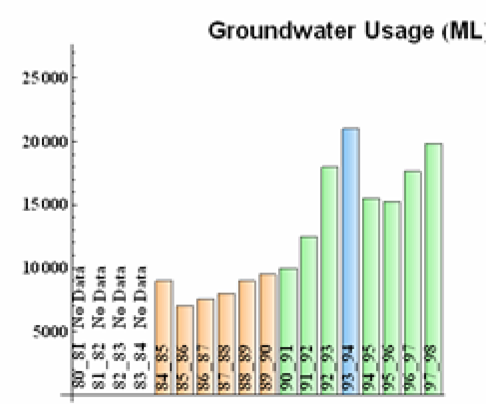




Flood recharge increases the groundwater head above 1980 levels

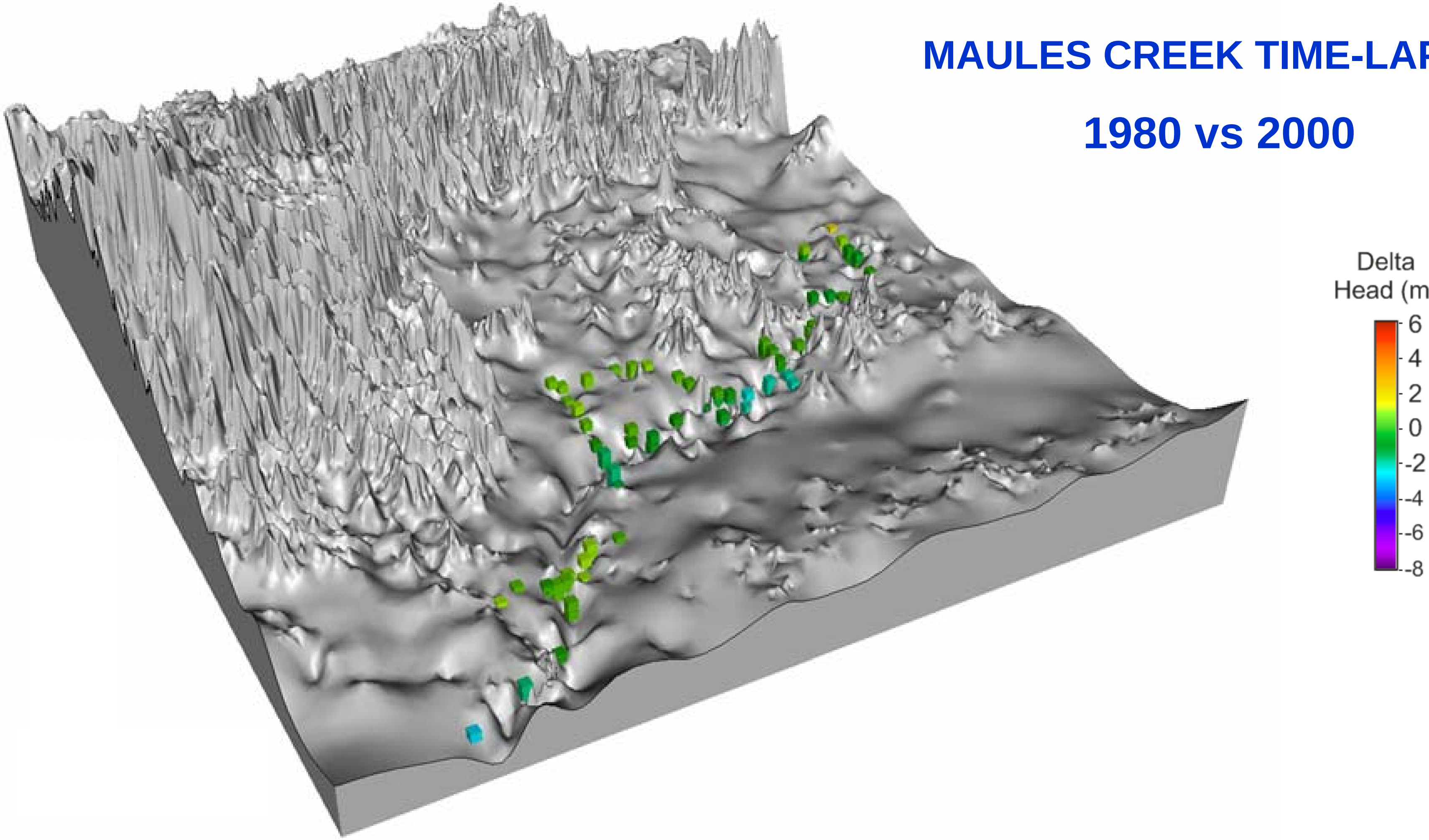


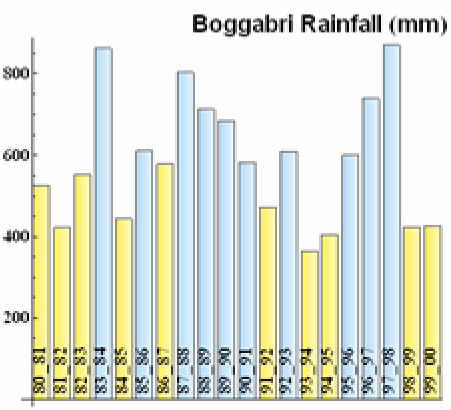


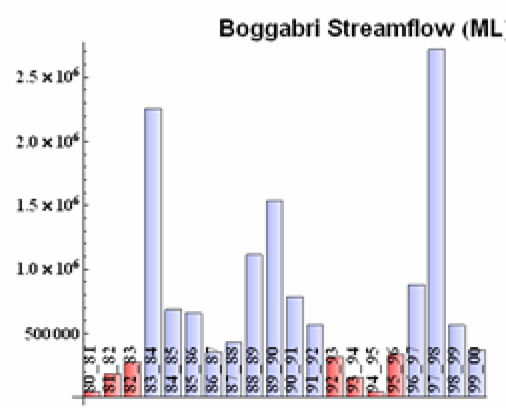


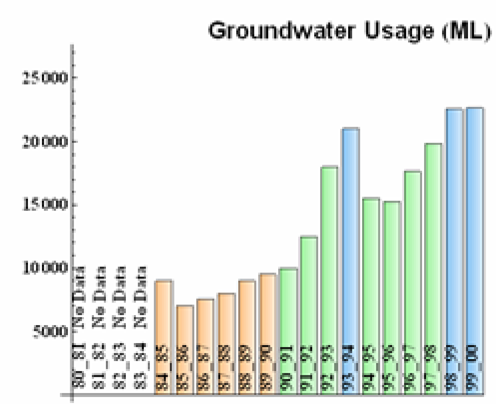
MAULES CREEK TIME-LAPSE

1980 vs 2000



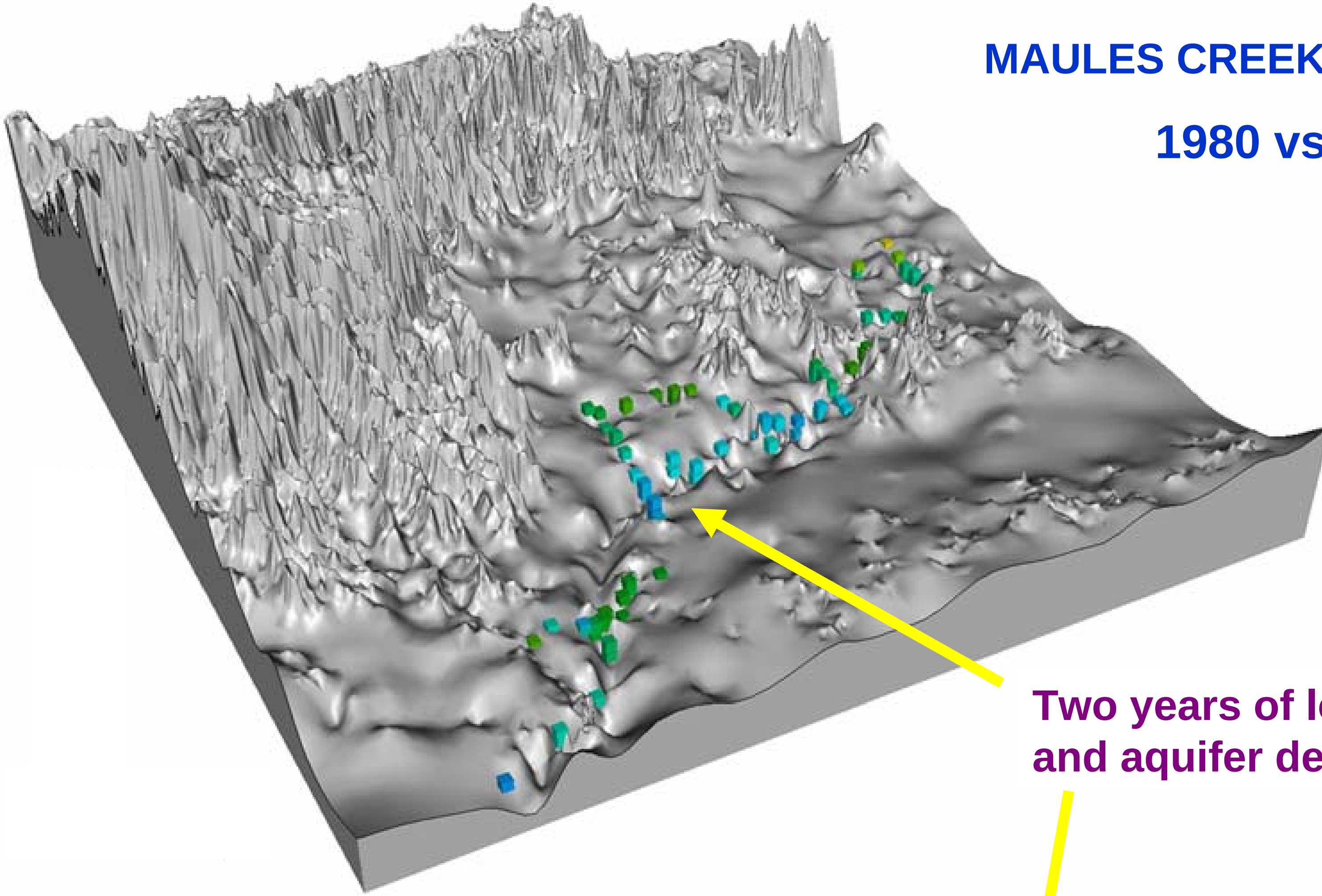


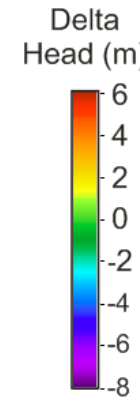




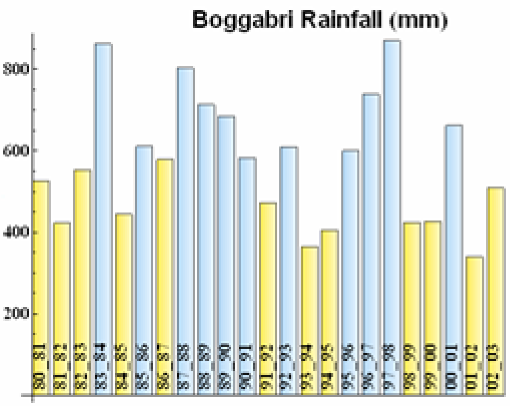
MAULES CREEK TIME-LAPSE

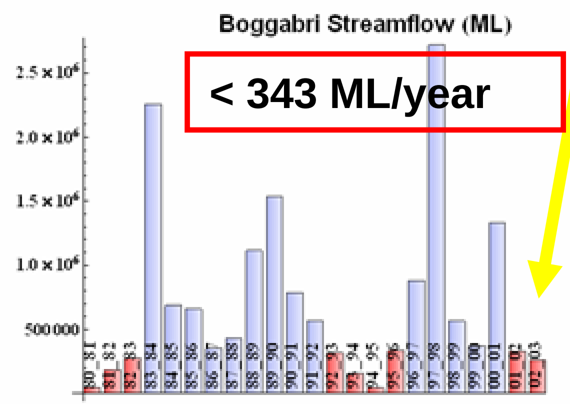
1980 vs 2003

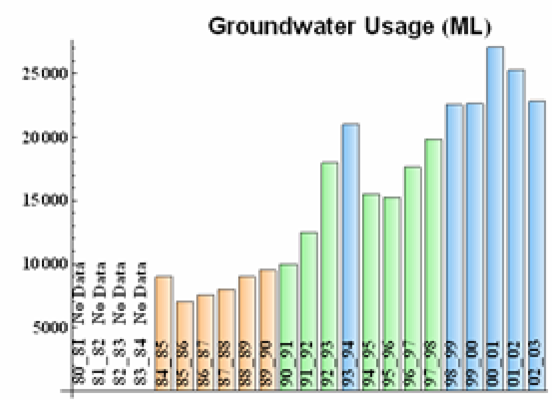




Two years of low streamflow and aquifer decline

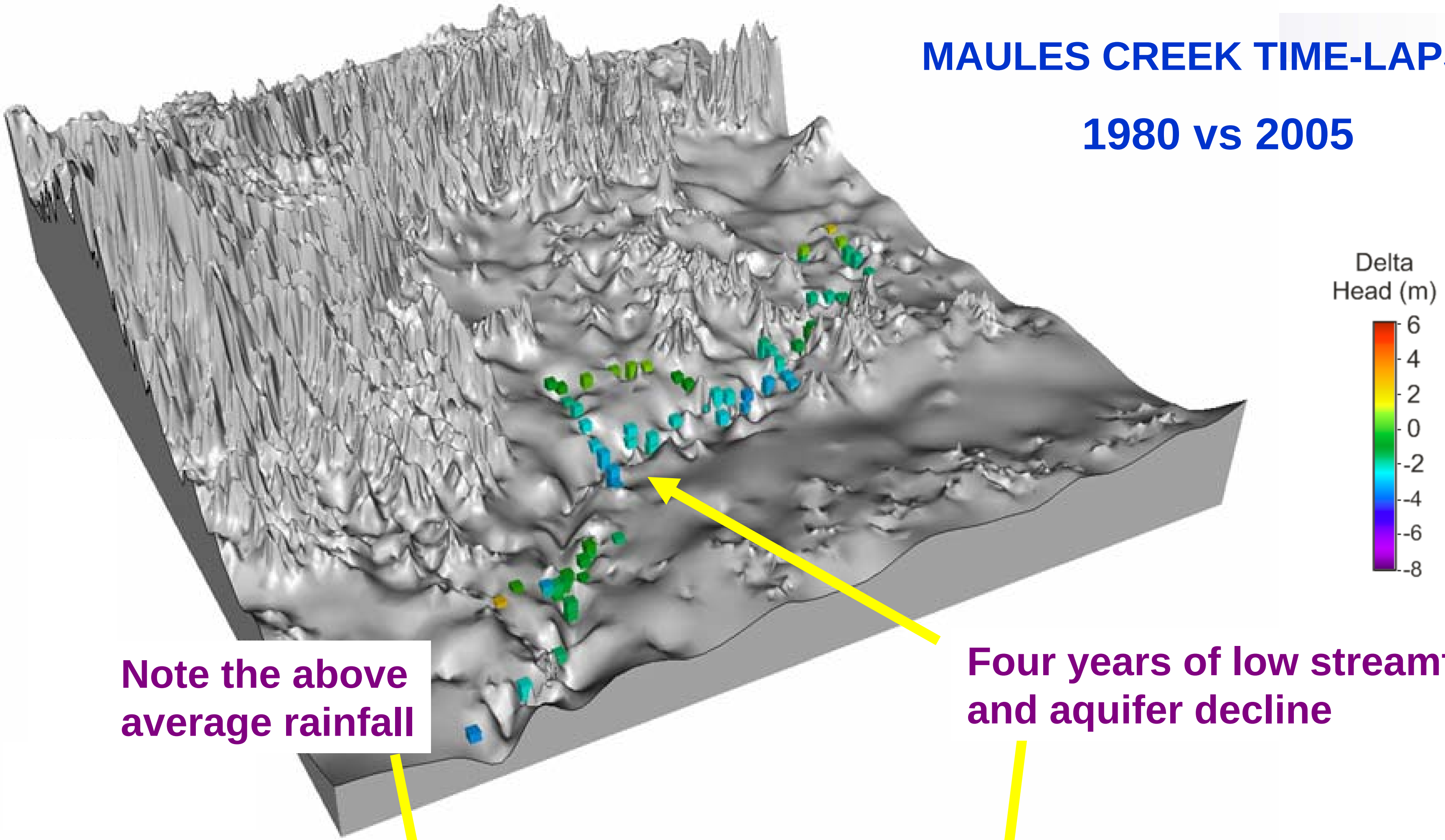






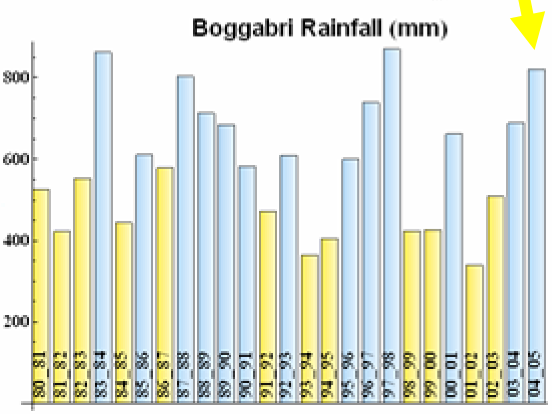
MAULES CREEK TIME-LAPSE

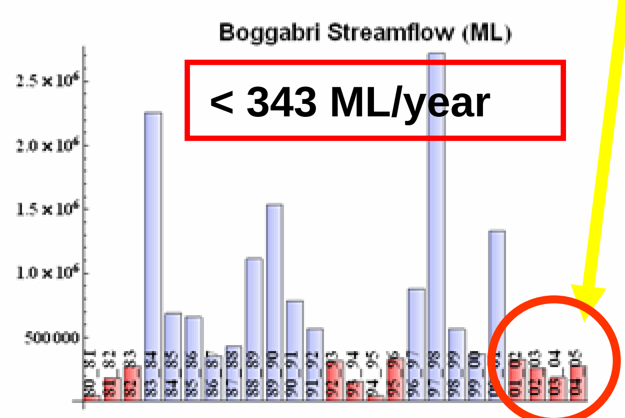
1980 vs 2005

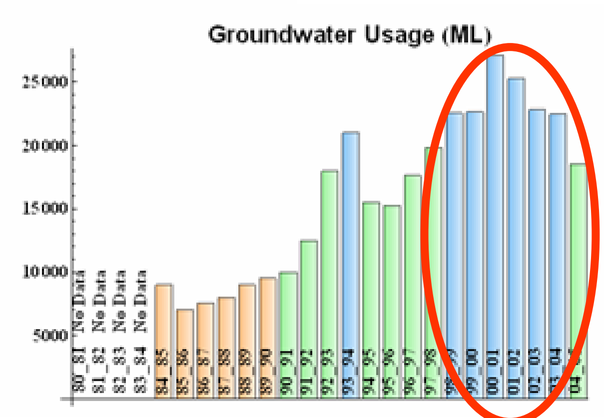


Note the above average rainfall

Four years of low streamflow and aquifer decline

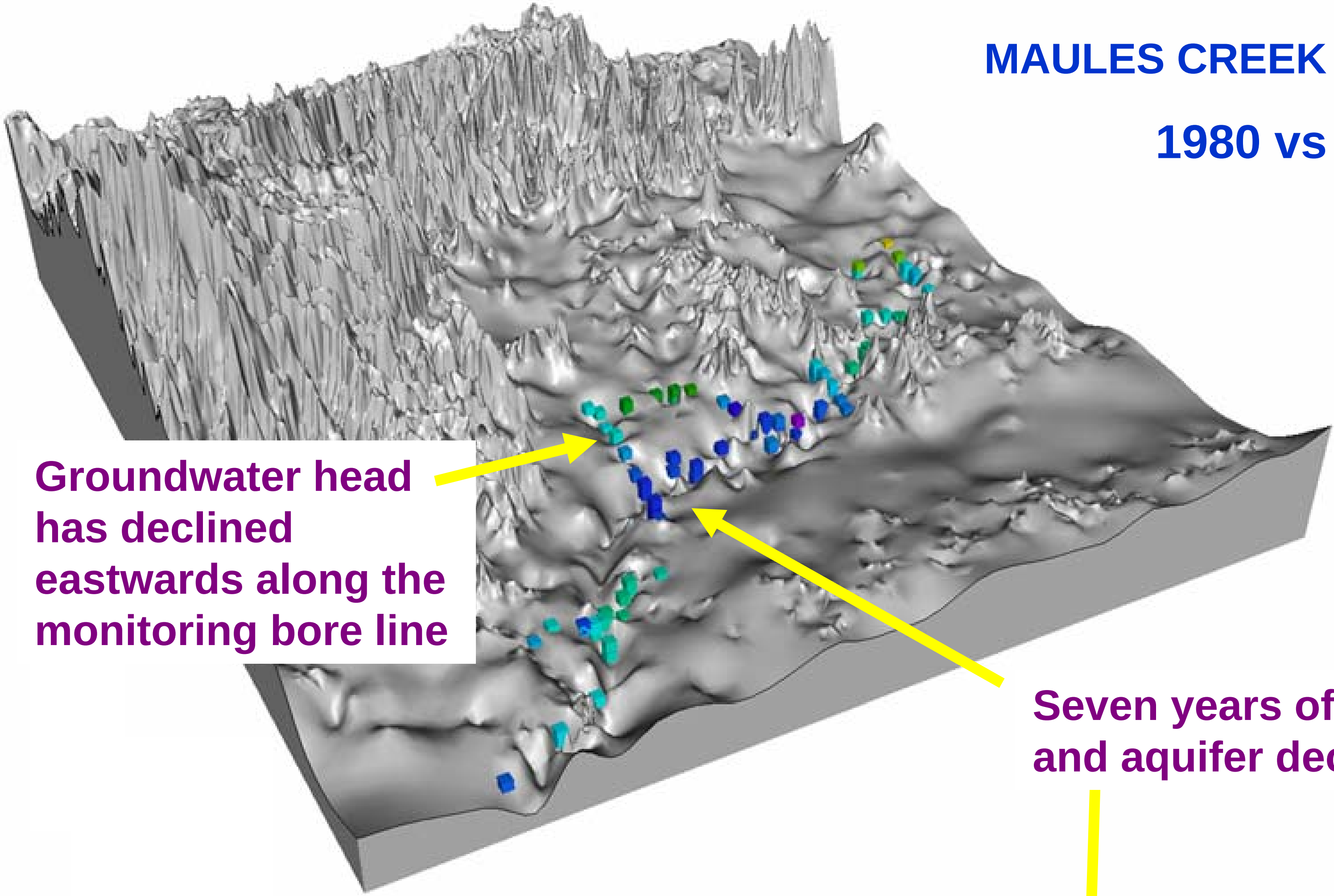


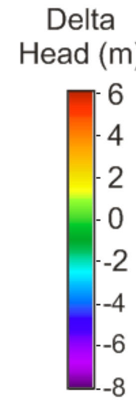




MAULES CREEK TIME-LAPSE

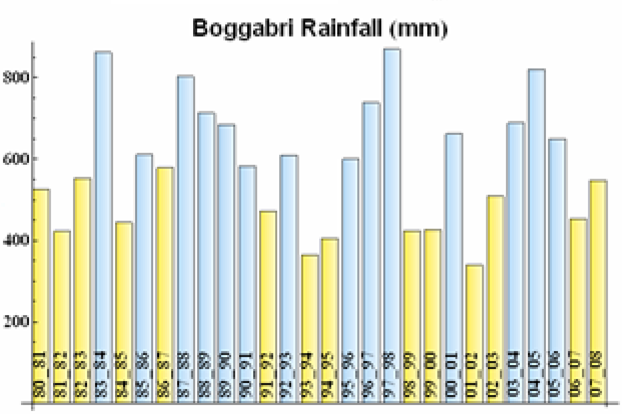
1980 vs 2008

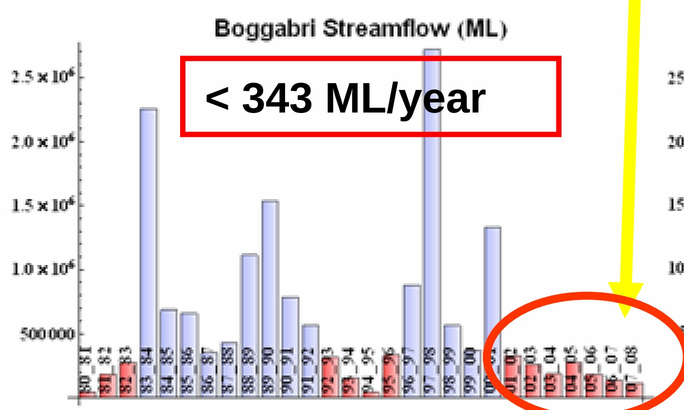


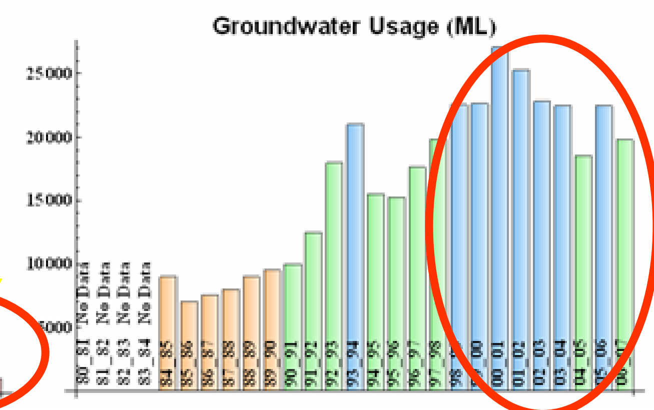


Groundwater head has declined eastwards along the monitoring bore line

Seven years of low streamflow and aquifer decline



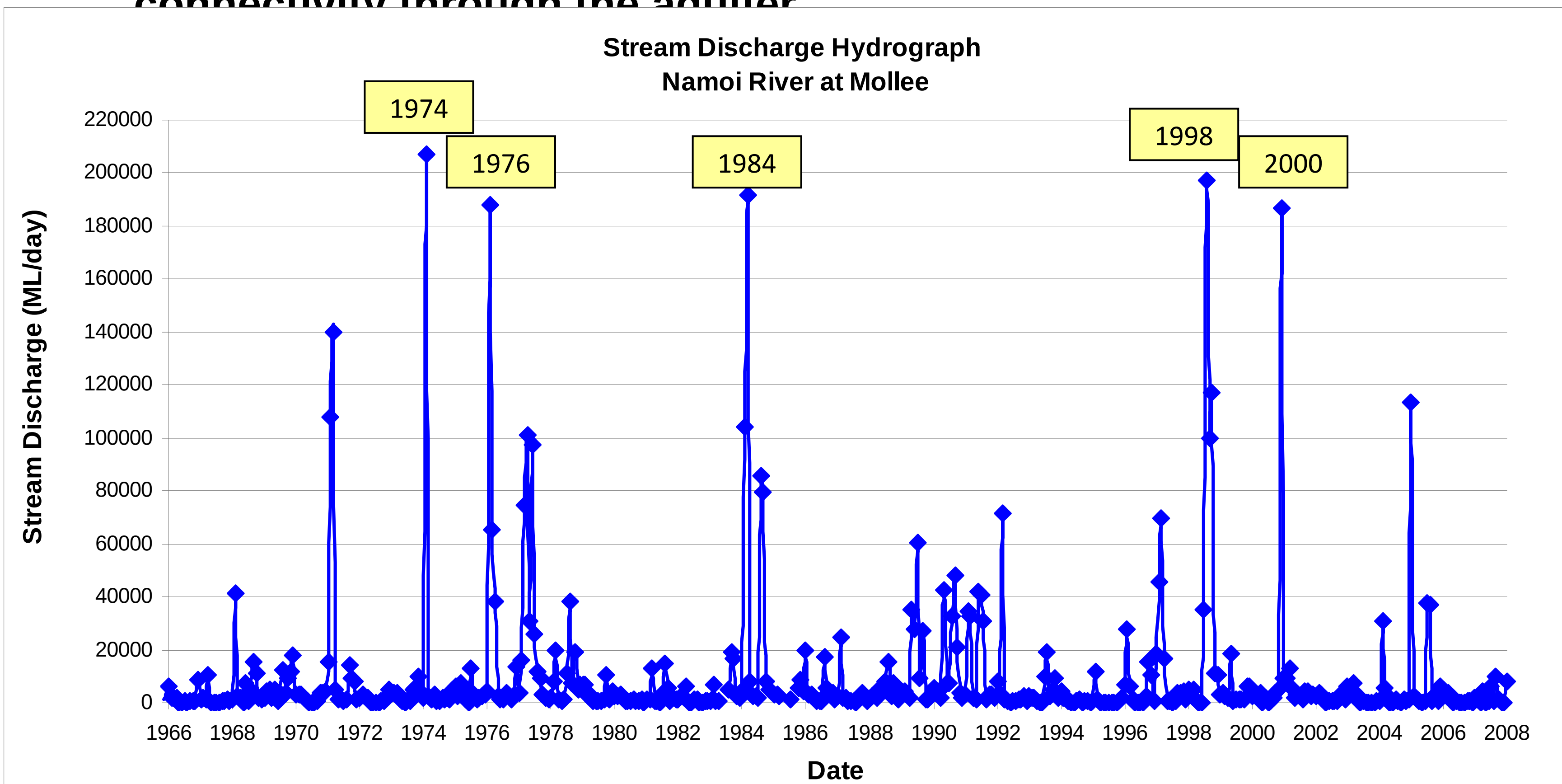




METHOD

STREAMFLOW DATA and RAINFALL DATA

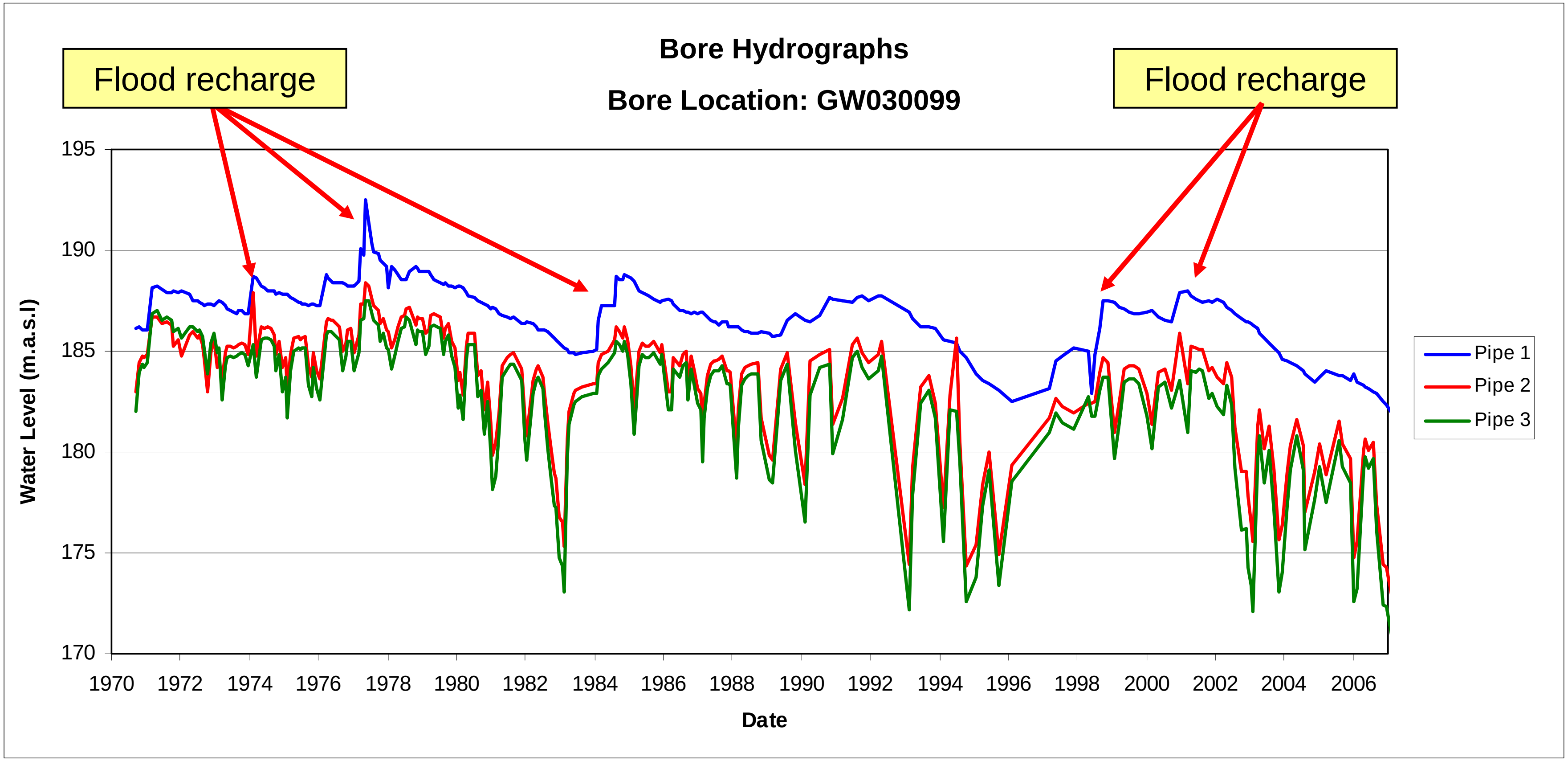
Groundwater head change due to flooding events for mapping hydraulic connectivity through the aquifer



5 High Magnitude Floods examined

METHOD

REFERENCE BORE SHOWING FLOODS

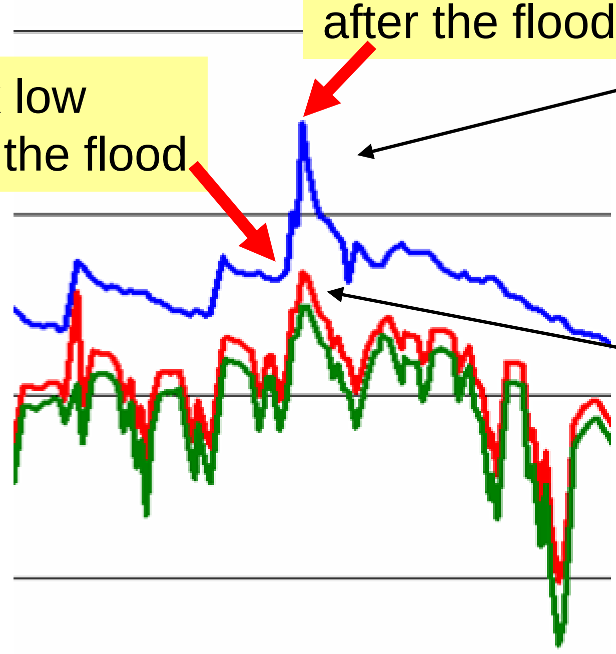


METHOD

HYDROGRAPH DATA ANALYSIS

2) Pick high
after the flood

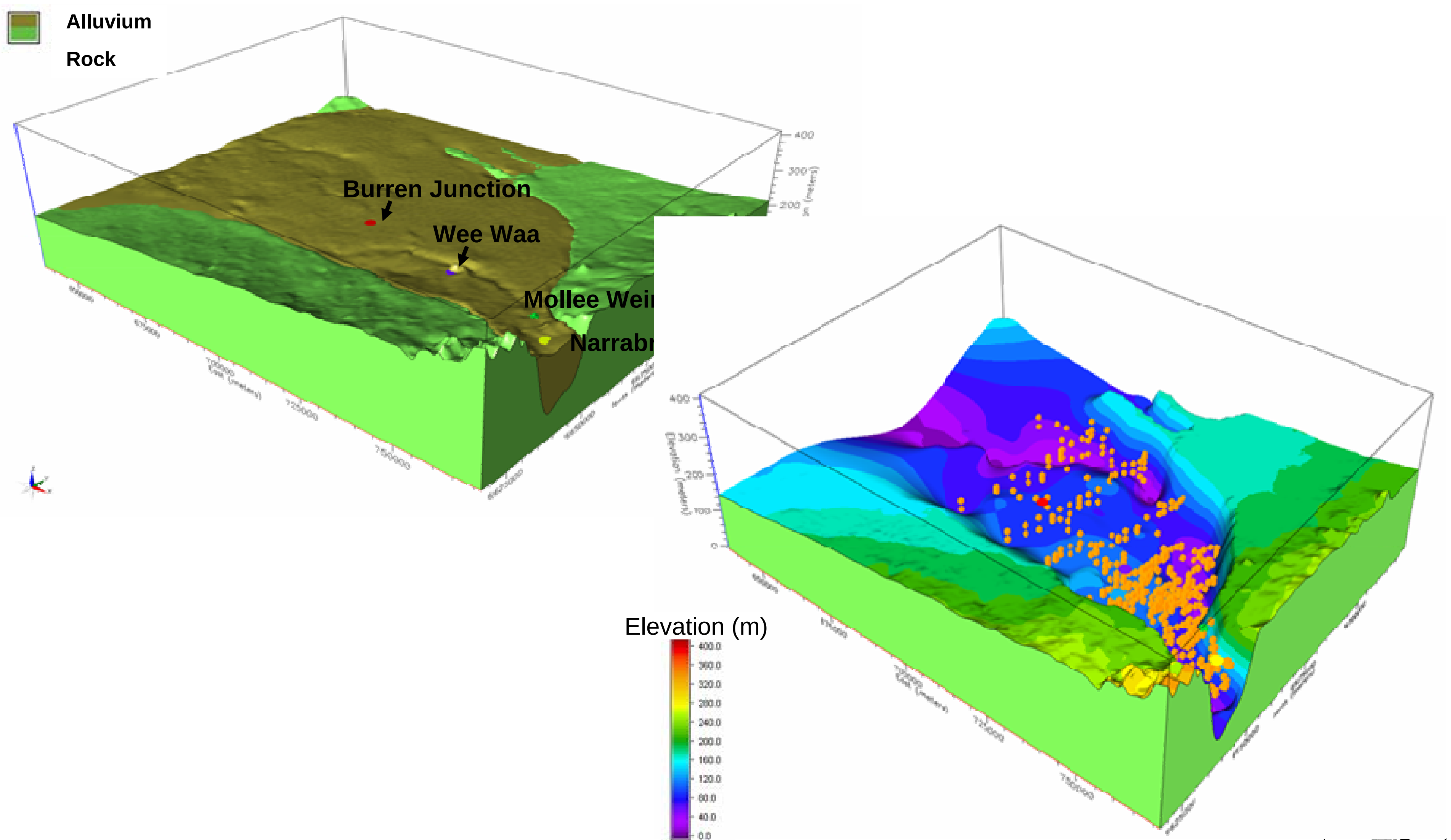
1) Pick low
before the flood

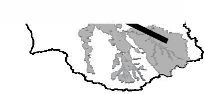


We had to use a
2 month window
either side of the
flood to get enough
data.

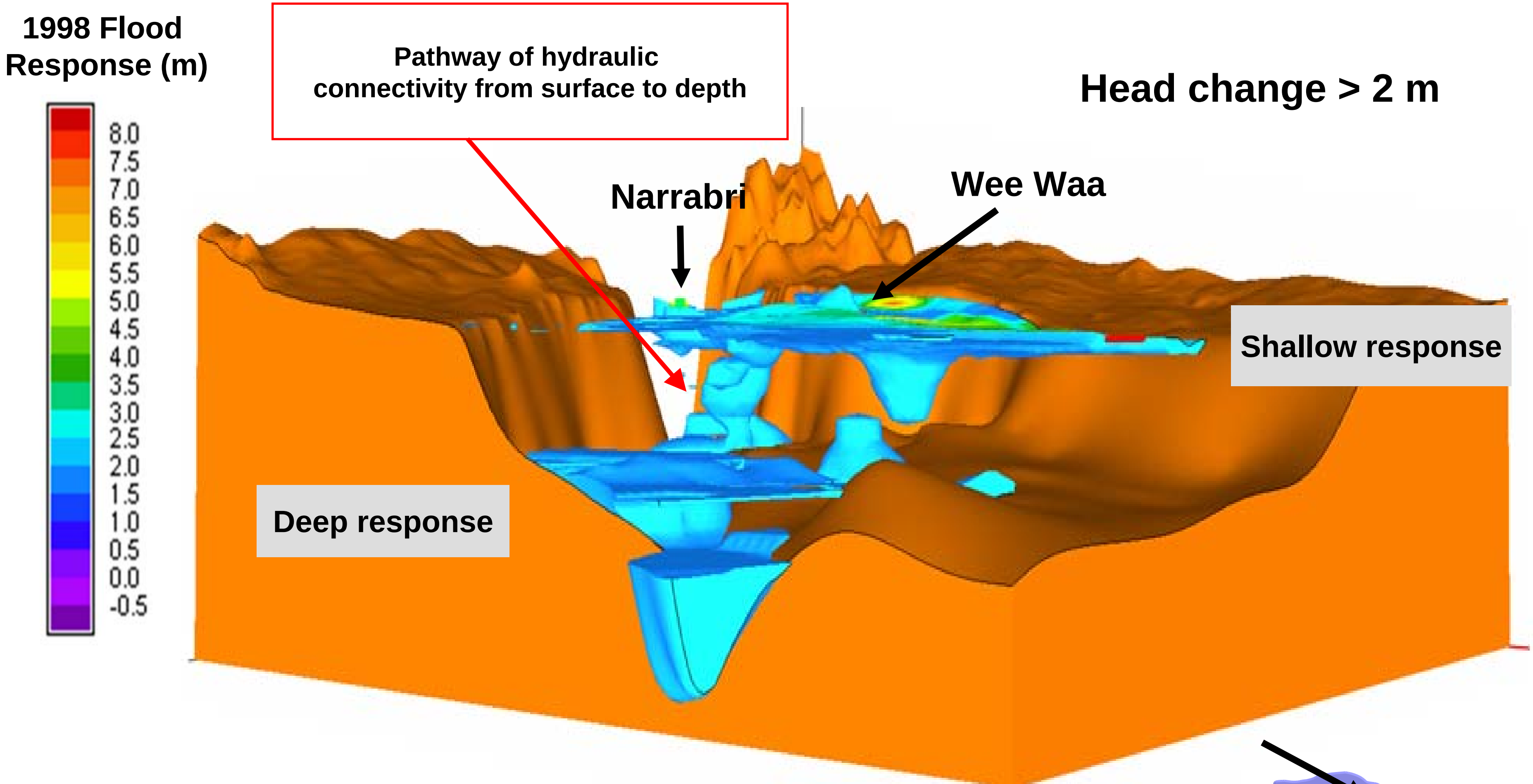
3) Grid the flood rise data = High – Low
(3D ordinary Kriging - EarthVision)

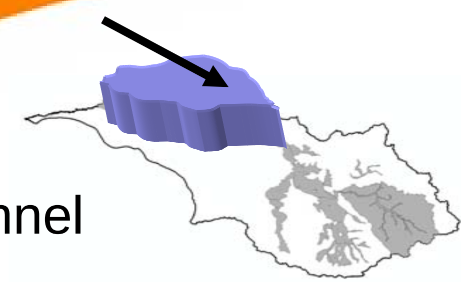
LOWER NAMOI CATCHMENT 3D GEOLOGICAL MODEL





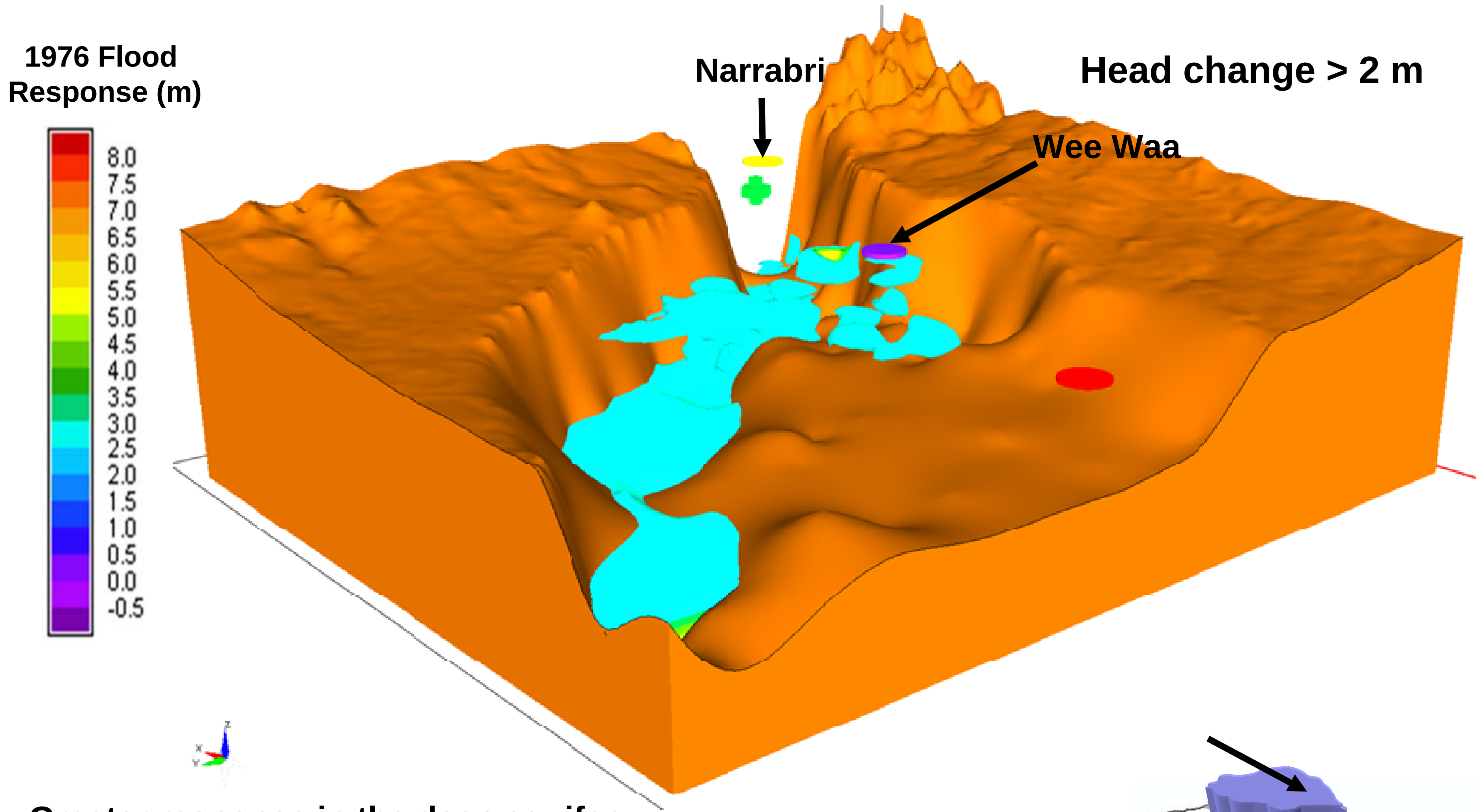
RESULTS – WINTER FLOOD 1998

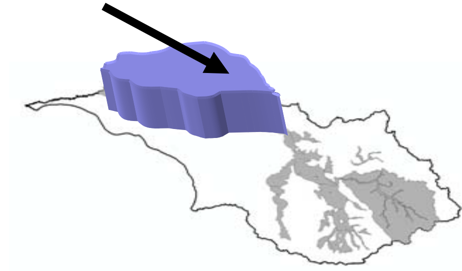




Large head change in both shallow and deep aquifer
Weak connection between shallow aquifer and palaeochannel

RESULTS – SUMMER FLOOD 1976





Greater response in the deep aquifer.

CONCLUSION

- Advantage of the method = no assumptions are required about assigning screens of boreholes to a specific aquifer;

- 3D analysis of the long and short term change in head is able to show the impact of irrigation

- In Maules Creek catchment groundwater head is correlated to streamflow. Surface and ground water in this region needs to be managed as a connected resource

- Mapping 3D head change throughout the aquifer due to flood recharge is able to identify primary recharge zones and hydraulic connectivity.

  In Lower Namoi catchment the deep aquifer is poorly connected to the Namoi River.

- This methodology could be useful for monitoring the impact of Water Sharing Plans

- Good tool to improve conceptualisation of the hydrogeology for all stakeholders involved in water allocation and use

THANK YOU …

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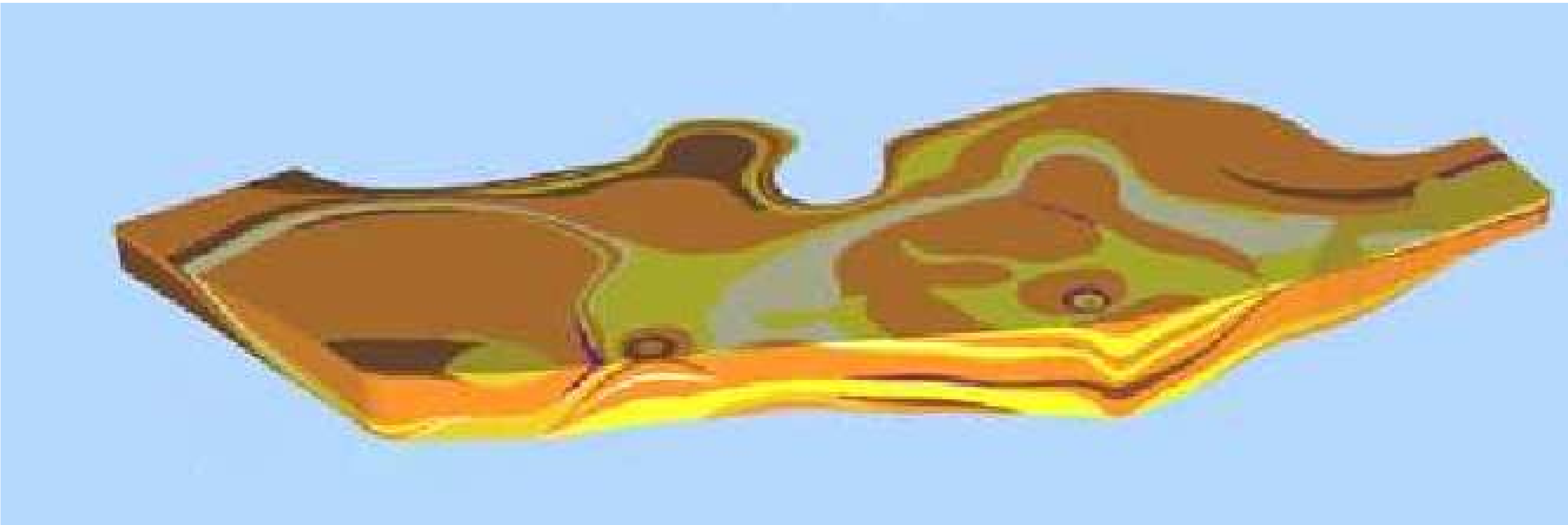
b.giambastiani@unsw.edu.au

www.connectedwaters.unsw.edu.au

http://www.connectedwaters.unsw.edu.au/resources/video/video_maules.html

www.wrl.unsw.edu.au

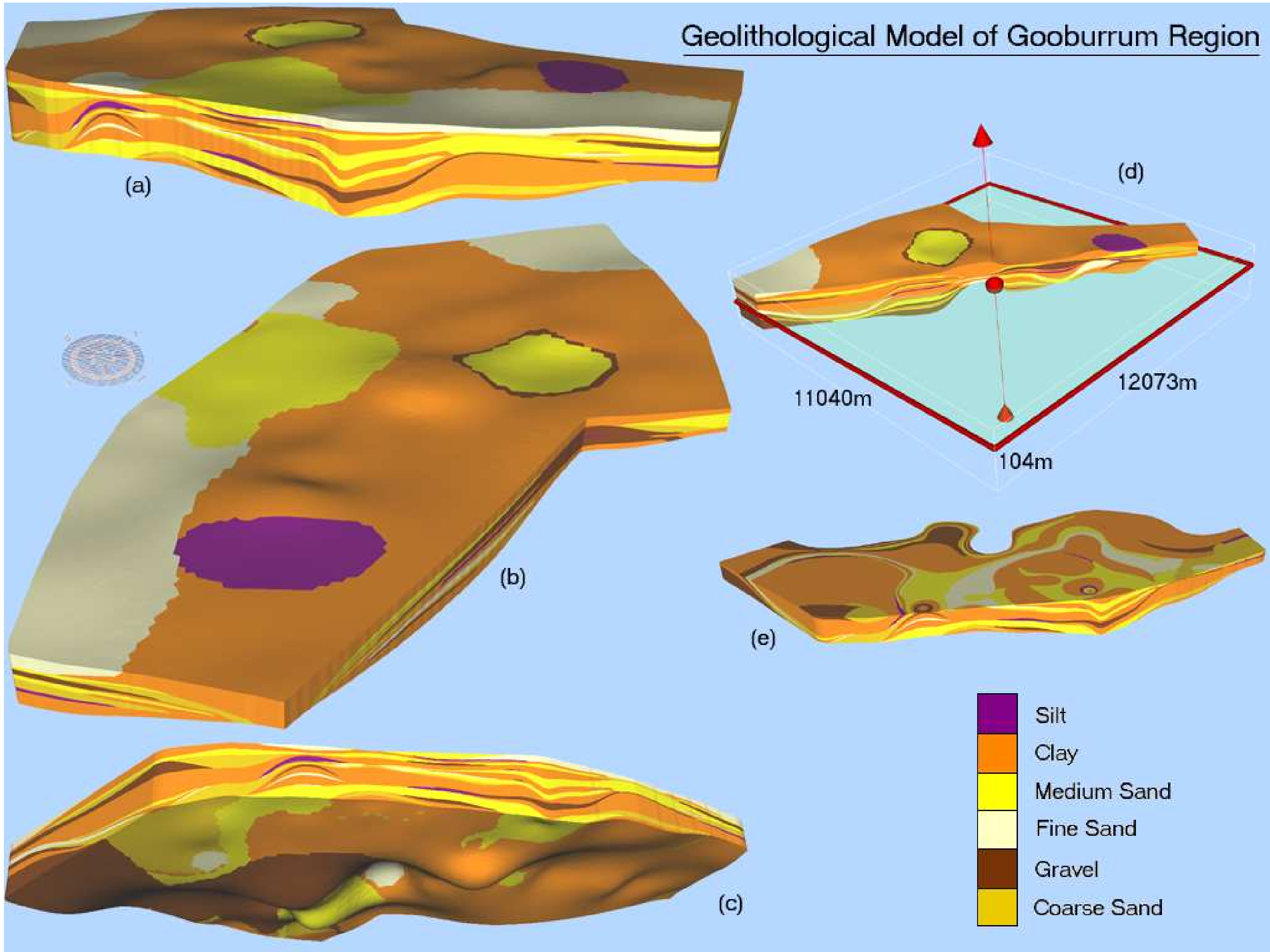
Software for 3D simulation of variable-density flow and transport in coastal groundwater systems



Ben Cumming[1], Ian Turner[1], Tim Moroney[1], Mal Cox[2]

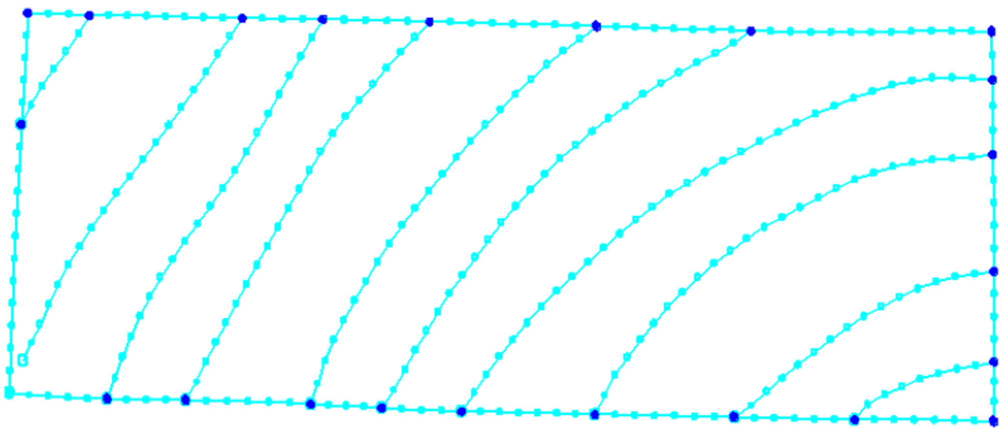
[1]QUT School of Mathematical Sciences

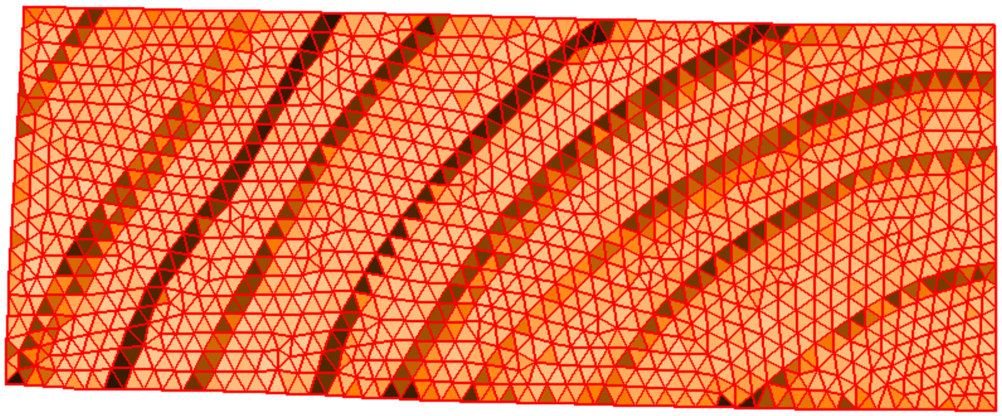
[2]QUT School of Natural Resources


Geolithological Model of Gooburrum Region
(a)
(b)
(c)
(d)
11040m
12073m
104m
(e)
Silt
Clay
Medium Sand
Fine Sand
Gravel
Coarse Sand

QUT School of Mathematical Sciences has a strong interest in flow in porous media

- Fractional dispersion processes for groundwater.
- Multiphase simulation of wood drying in kilns.
- Bagasse in sugar cane industry.
- Regional-scale groundwater modelling.

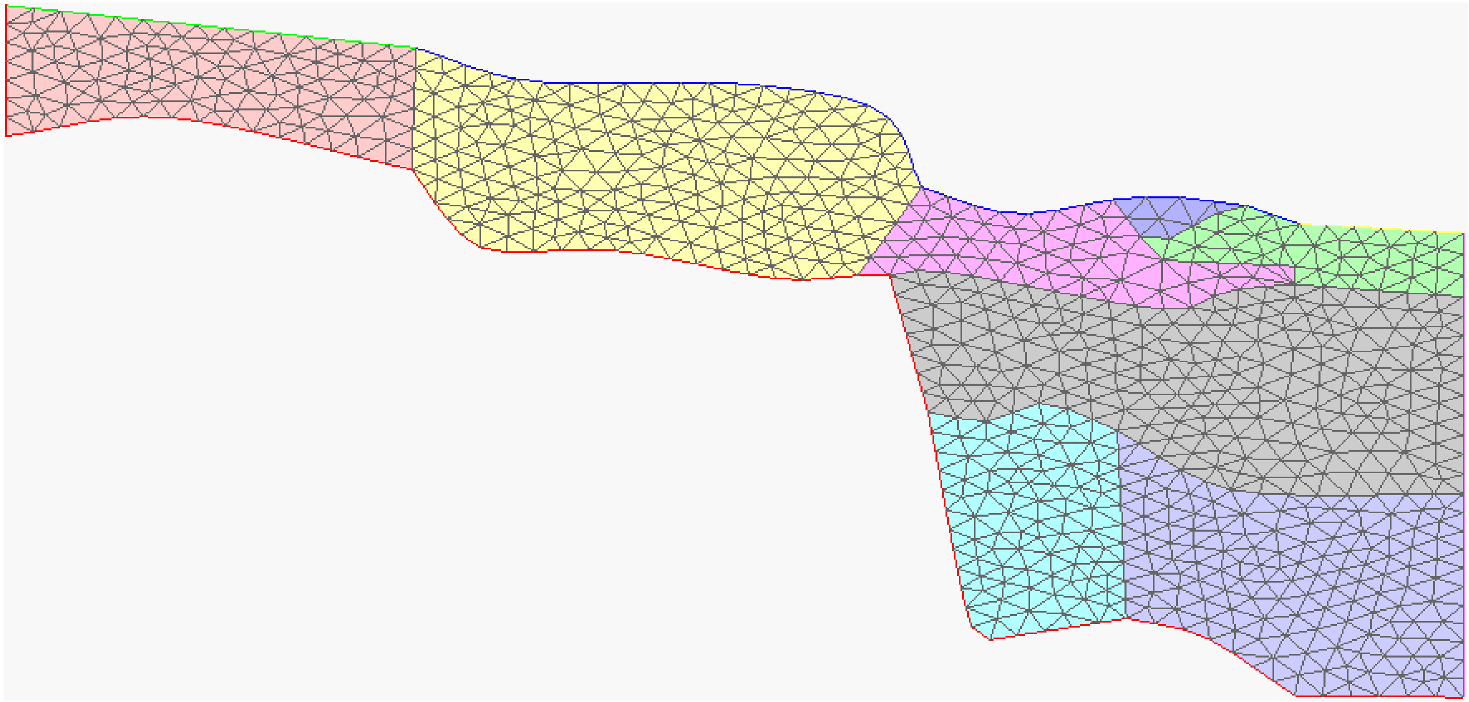


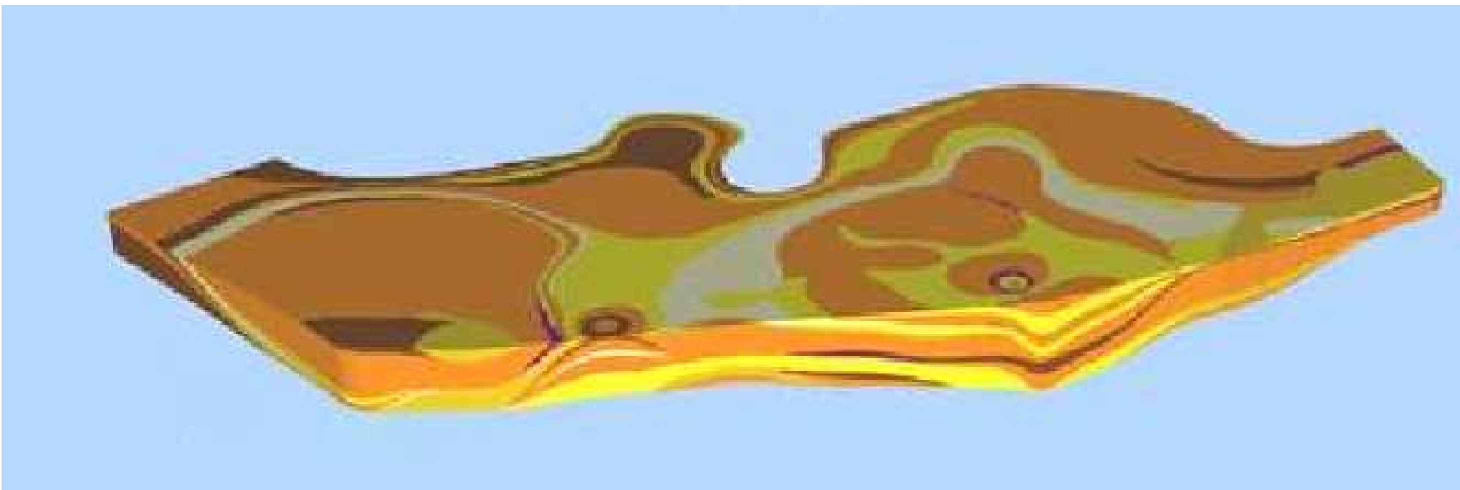


My PhD project is to ***develop software for simulation*** of flow in porous media.

- Tools for other researchers and modellers to have access to state of the finite volume methods.
- Is accessible and affordable. Licensed under a permissive open source licence.
- Provides a platform that can be extended easily in the future.
- Can be used as a collaborative tool.

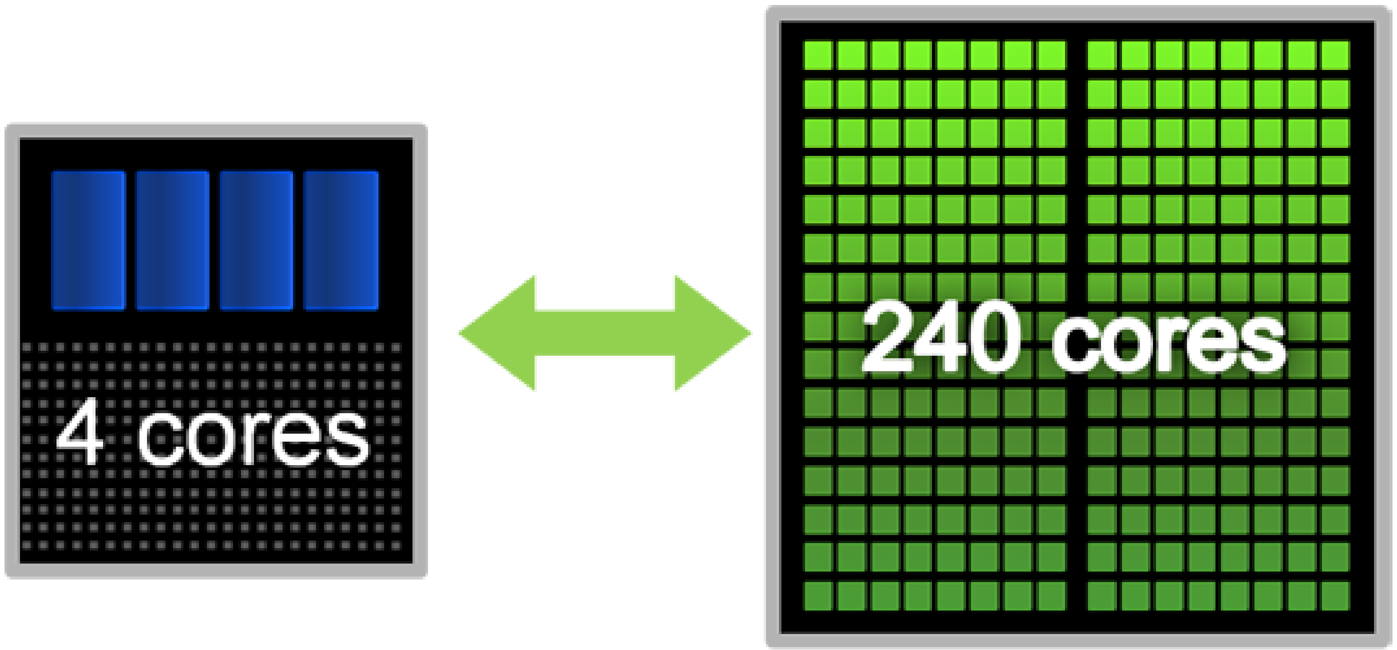
We want to use unstructured and heterogeneous domains for our models.



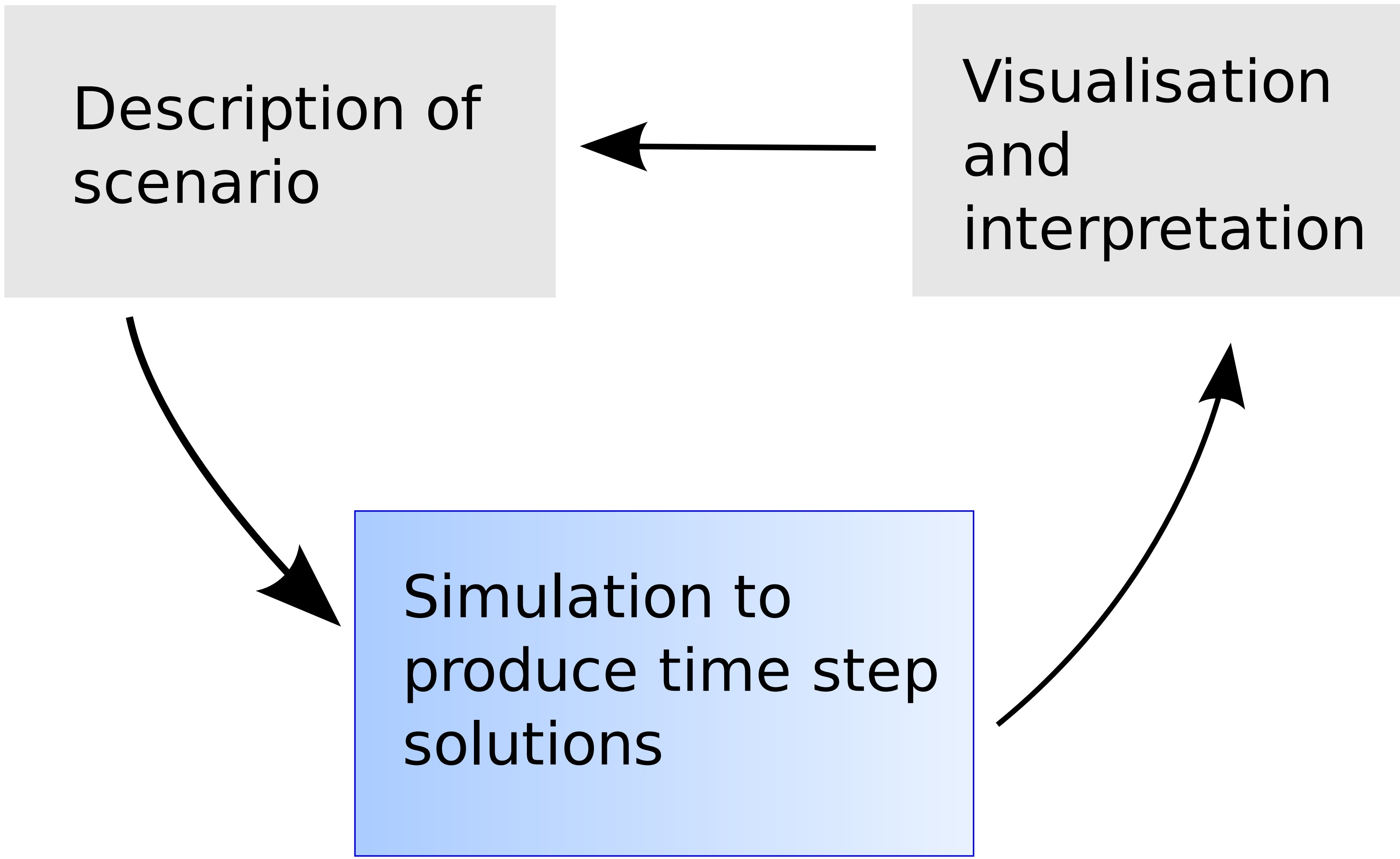


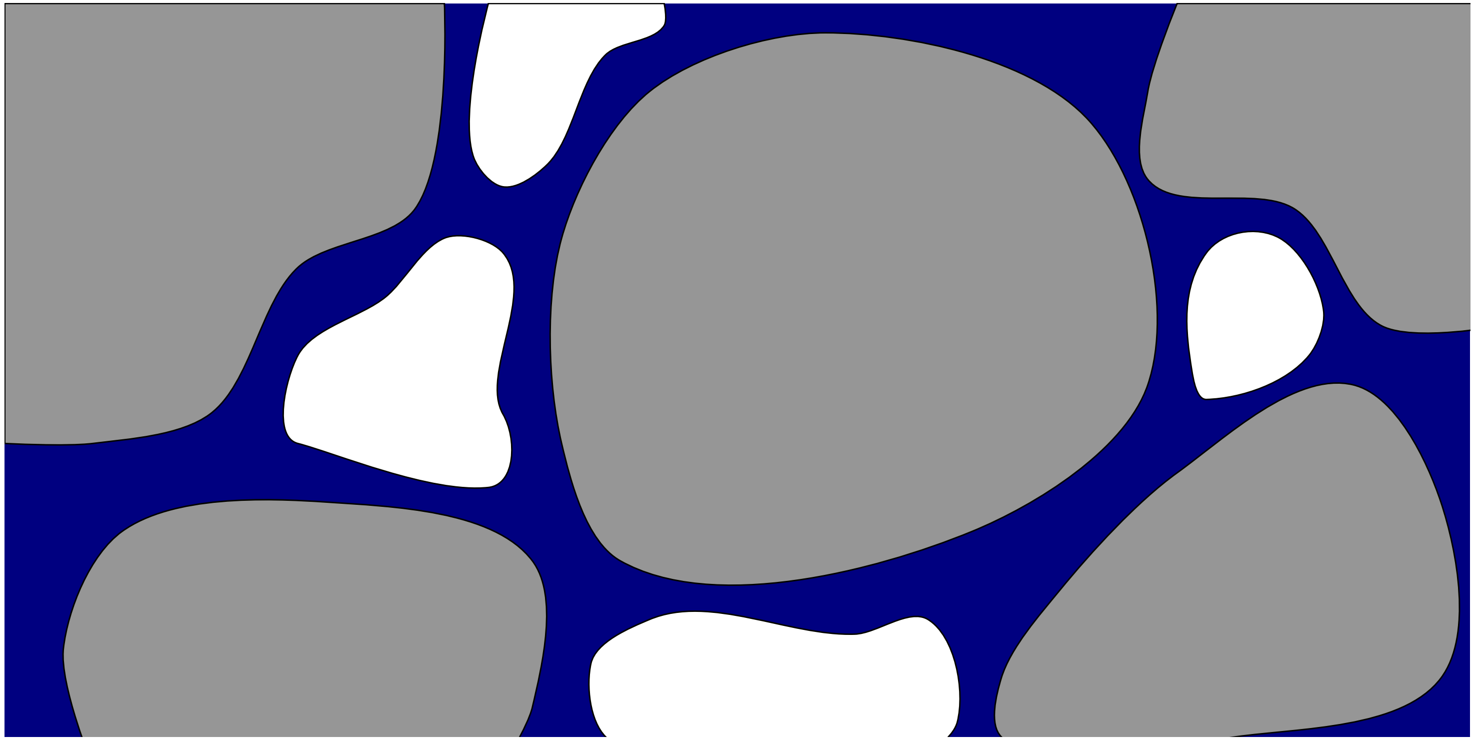
We want to take advantage of different opportunities for parallel processing

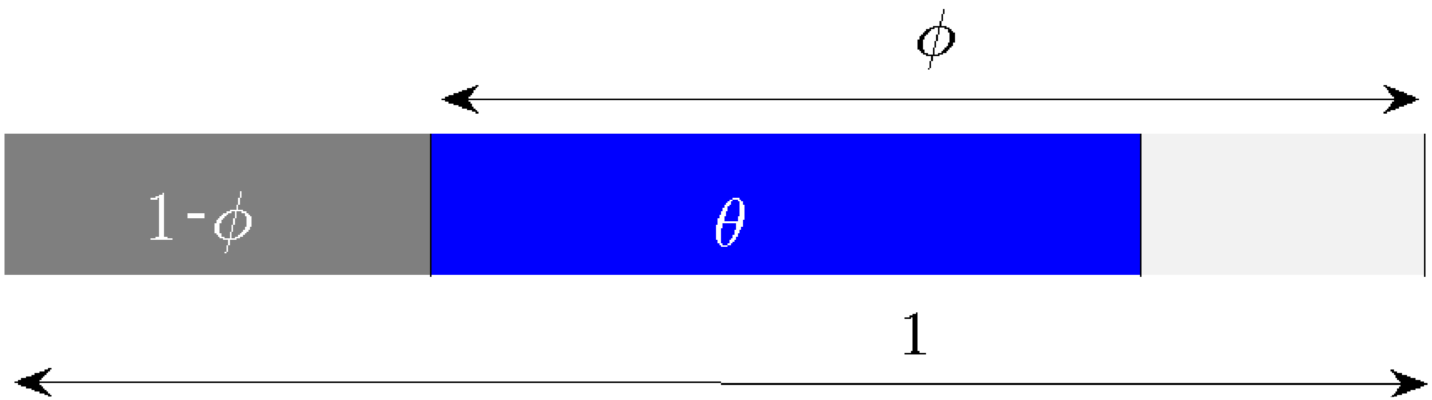
- Multicore CPUs using OpenMP.
- Clusters using MPI.
- Heterogeneous computing using many-core GPUs in graphics cards or custom hardware.



www.nvidia.com


Description of scenario
Visualisation and interpretation
Simulation to produce time step solutions




ϕ
1-ϕ
θ
1

The process is governed by two ***mass balance*** equations:

Fluid Mass: $$\frac{\partial(\rho\theta)}{\partial t} = \overbrace{-\boldsymbol{\nabla} \cdot \rho \boldsymbol{q}}^{\text{advection}},$$

Salt Mass: $$\frac{\partial(c\theta)}{\partial t} = \underbrace{-\boldsymbol{\nabla} \cdot c\boldsymbol{q}}_{\text{advection}} + \underbrace{\boldsymbol{\nabla} \cdot \theta \boldsymbol{D} \boldsymbol{\nabla} c}_{\text{dispersion}}.$$

where:

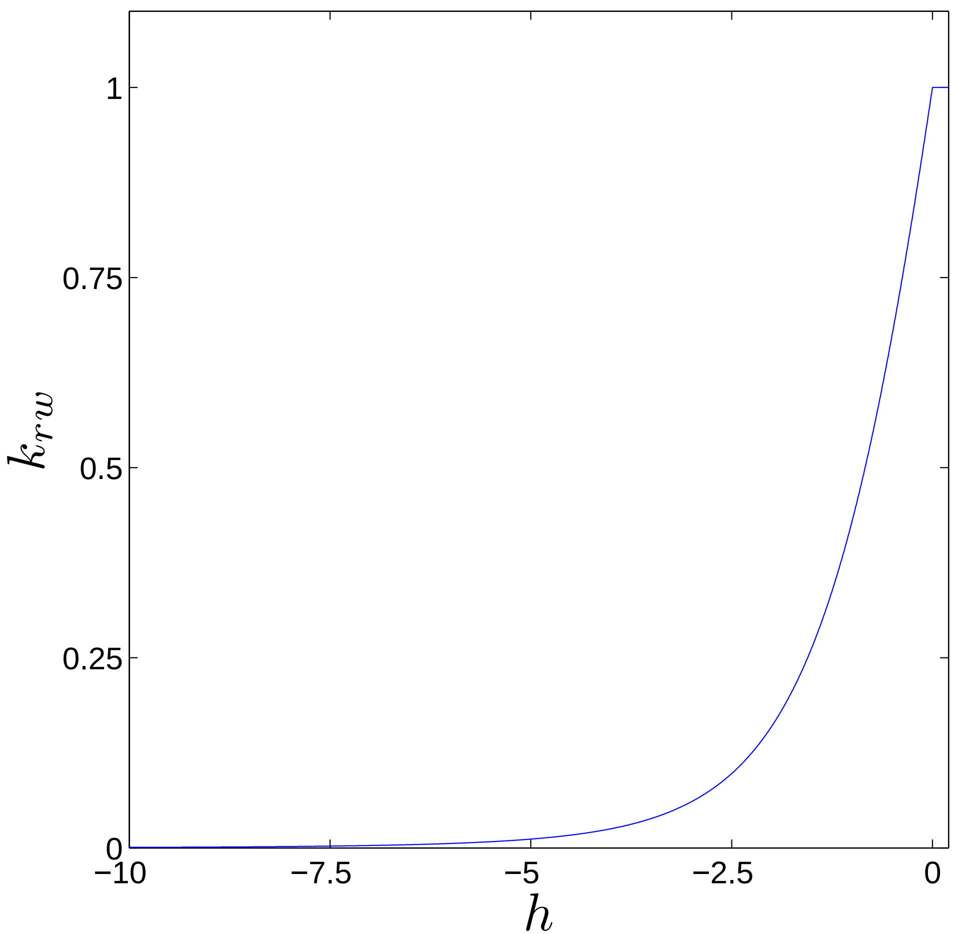
- ρ =density
- c =concentration
- $\boldsymbol{D}$ =coefficient of dispersion.

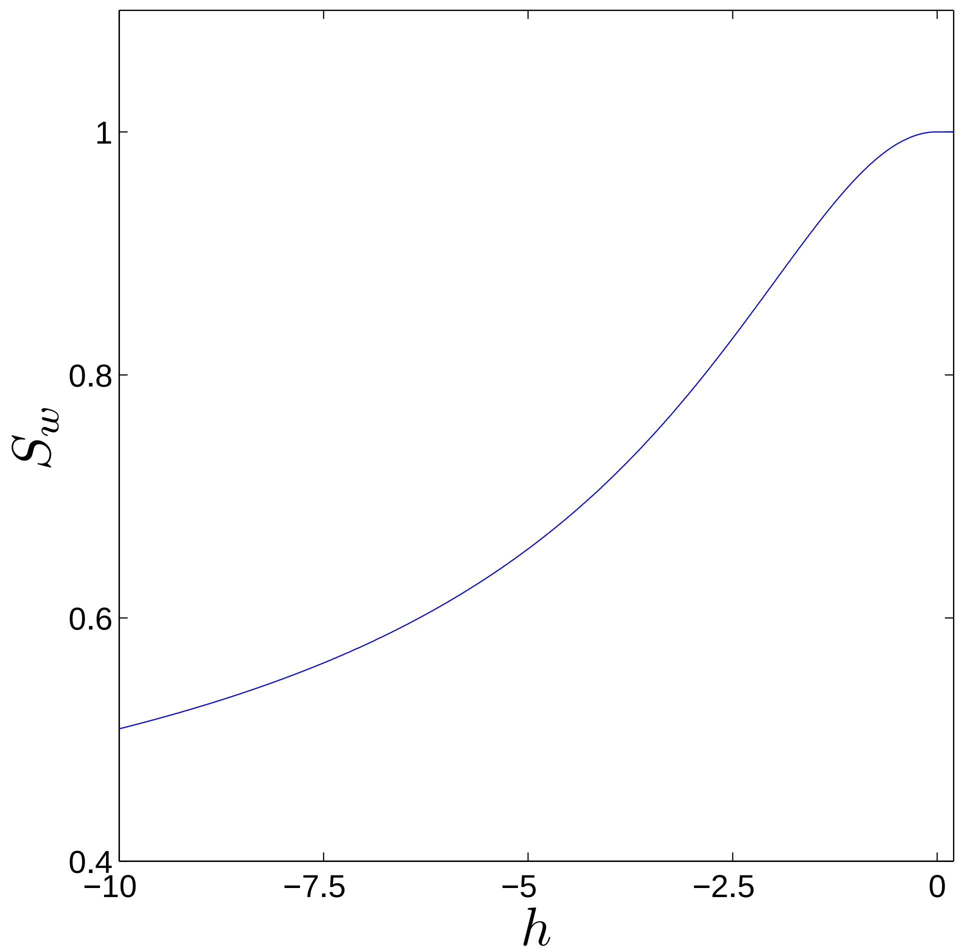
The ***Darcy flux*** describes the flow driven by the gradient of pressure and buoyancy:

$$\boldsymbol{q} = -\frac{k_s k_{rw}}{\mu}\left(\boldsymbol{\nabla} p + \rho g \boldsymbol{\nabla} z\right).$$

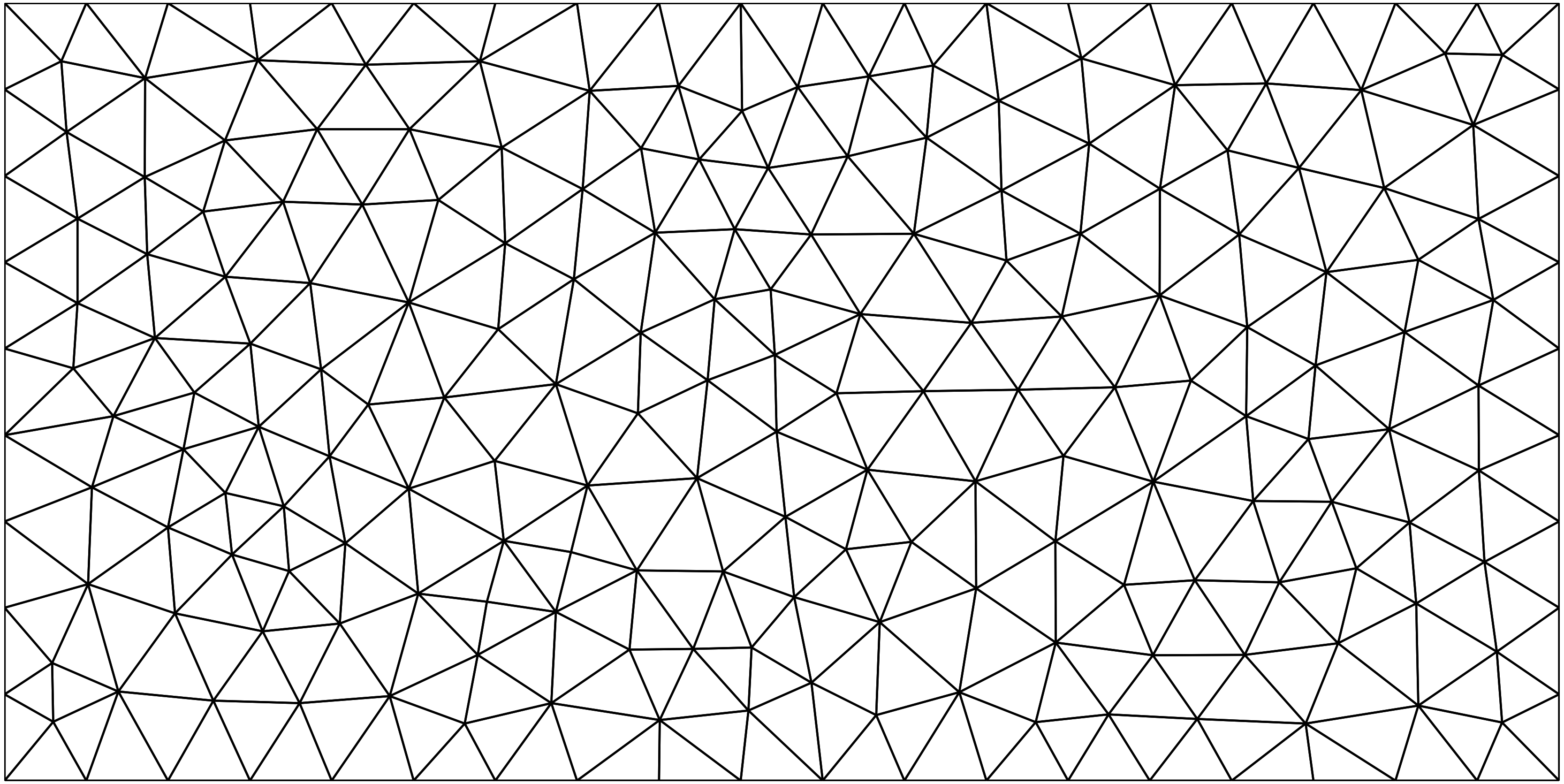
where:

- k_s =absolute permeability
- k_{rw} =relative permeability
- g =gravitational acceleration
- μ =viscosity

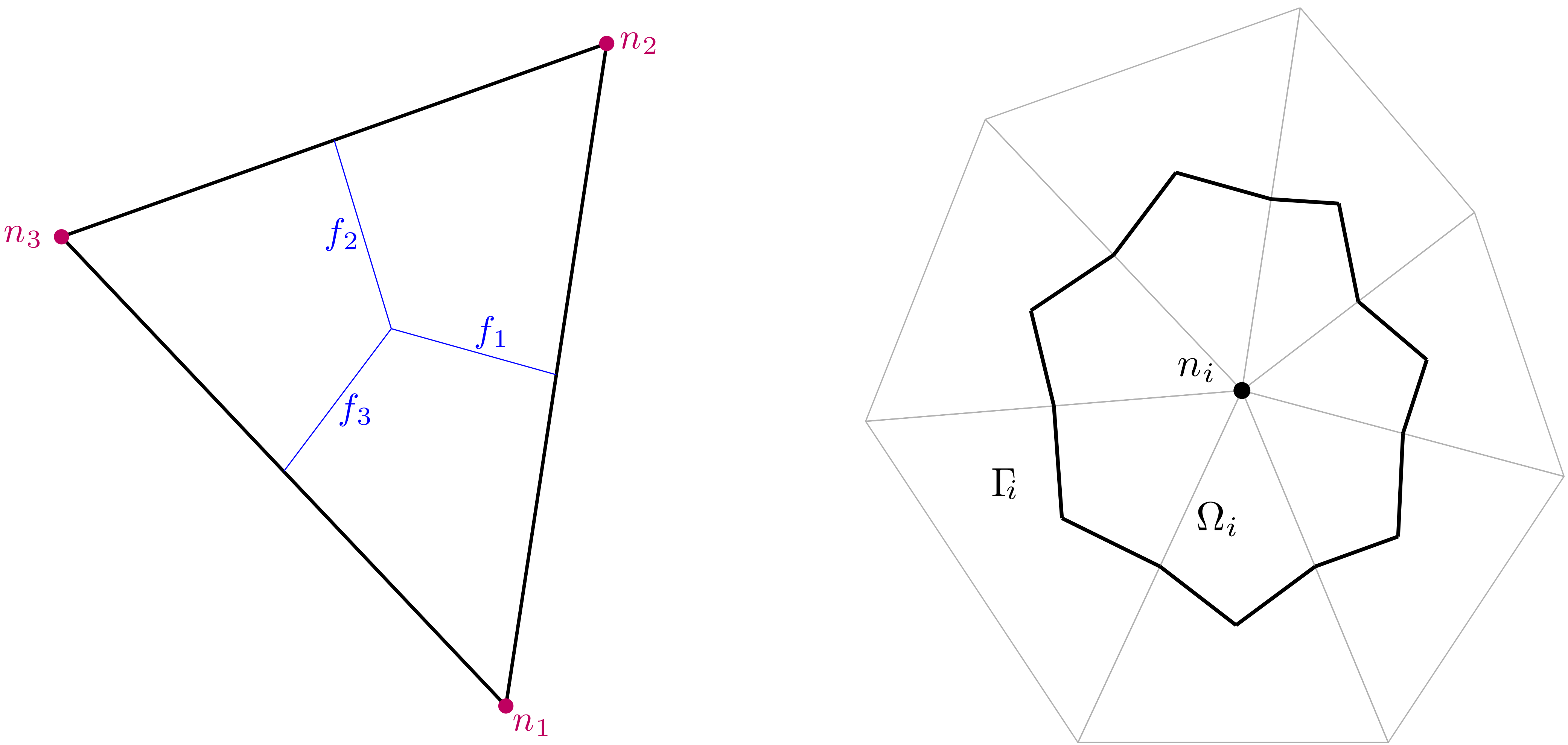




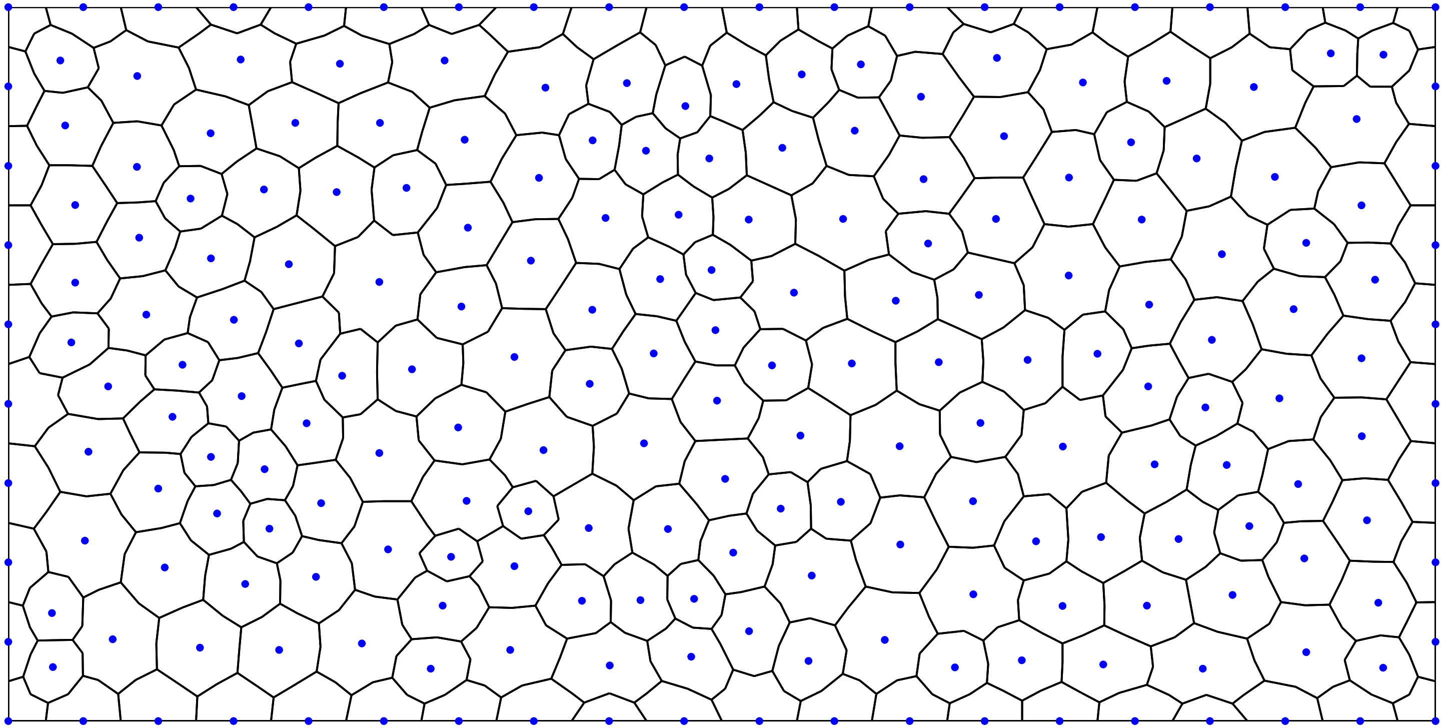
Closure laws that relate auxiliary variables such as density, porosity, moisture content and relative permeability (ρ, ϕ, θ and k_{rw} respectively) to the primary variables are defined.



Start with a polyhedral tesselation, called a ***finite element*** mesh...

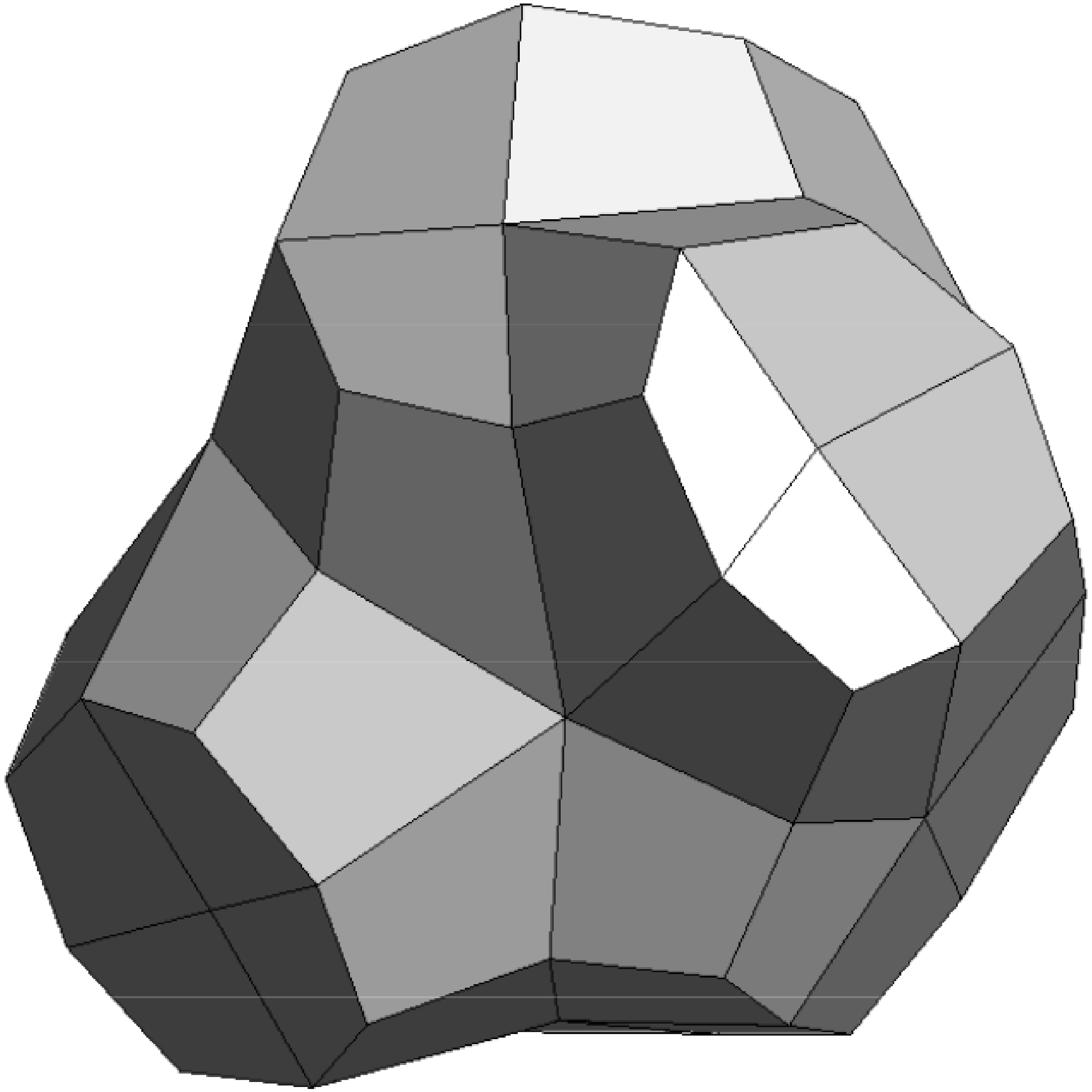


form a ***control volume*** around each node by joining the midpoints of each edge...



which forms the ***control volume-finite element (CVFE)*** mesh.

- The finite volume formulation is over each control volume.
- The underlying triangular finite element mesh is used for interpolation.



The same method is used in three dimensions, however the geometry of the individual control volumes is harder to get one's head around!

The mass balance equation is integrated over each CV:

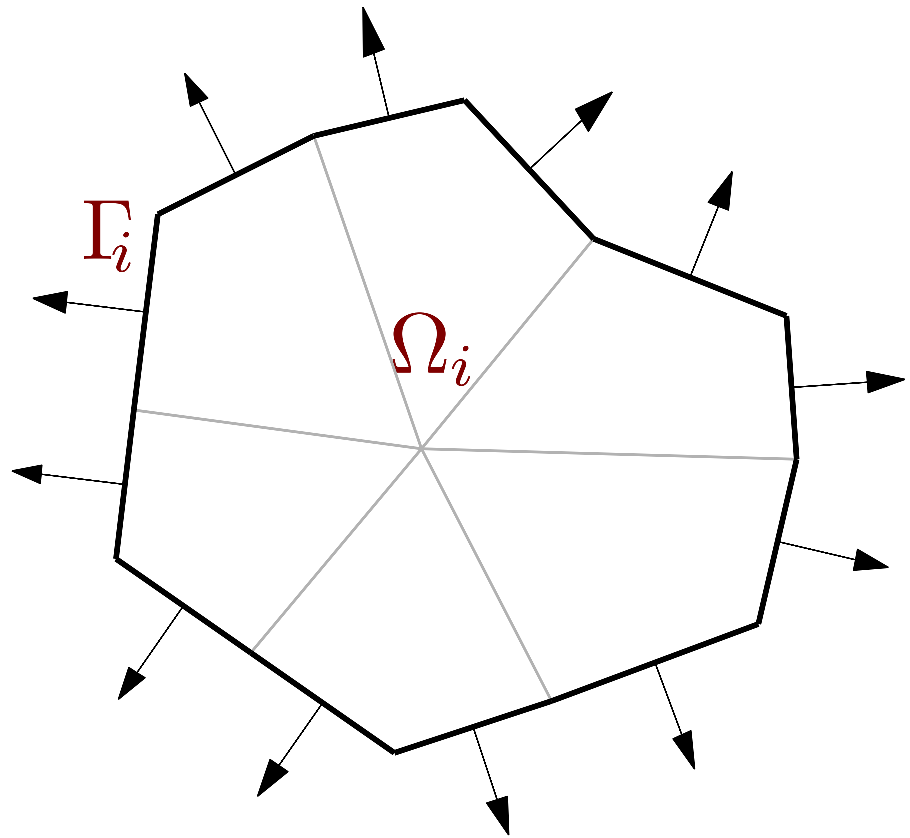
$$\int_{\Omega_i} \frac{\partial(\rho\theta)}{\partial t}\, dV = -\int_{\Gamma_i} \rho \boldsymbol{q} \cdot \boldsymbol{n}\, d\sigma,$$

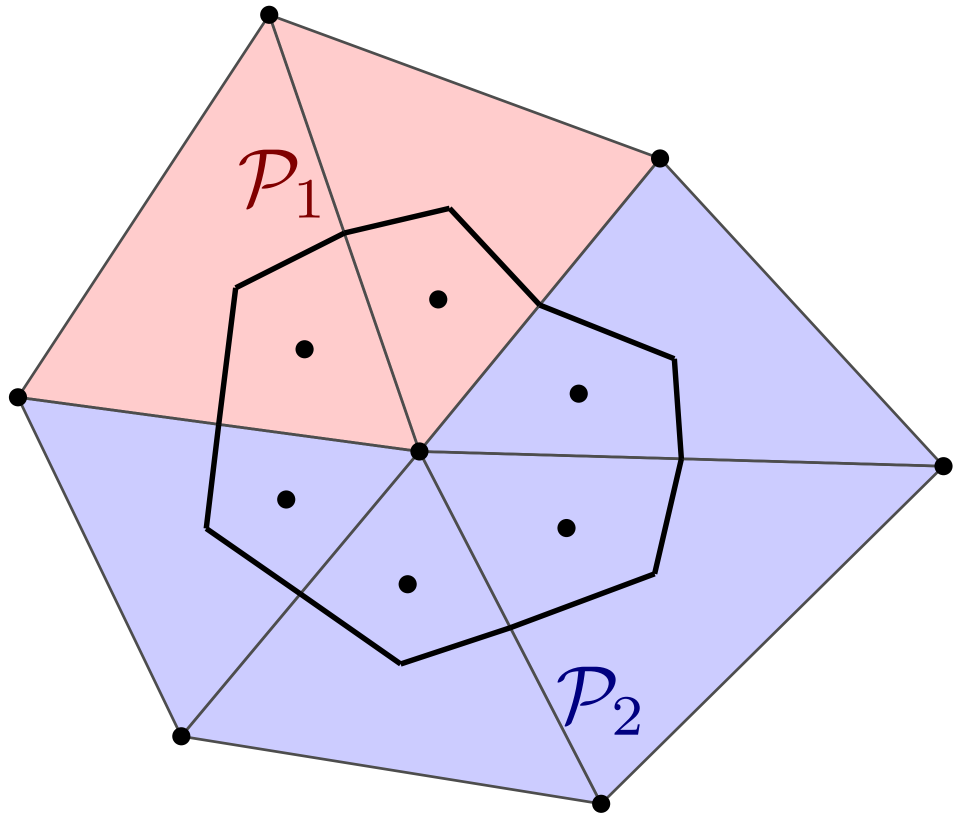
which we write in the discrete form:

$$\frac{dM_i}{dt} = -\sum_{j\in\Gamma_i} A_j \rho_j \boldsymbol{q}_j \cdot \boldsymbol{n}_j.$$

Which is equivalent to

$$\begin{bmatrix}\text{rate of change}\\ \text{of mass in } \Omega_i\end{bmatrix} = -\begin{bmatrix}\text{flux of mass}\\ \text{surface over } \Gamma_i\end{bmatrix}$$





p and c are continuous variables. M is a discrete variable defined for each control volume:

$$\begin{aligned} M_i &= \frac{1}{\Delta_i} \int_{\Omega_i} \rho\theta \, dV \\ &\approx \frac{1}{\Delta_i} \sum_{k=1}^{n_{SCV}} \Delta_{i,k} \rho_{i,k} \theta_{i,k} \\ &= V_{m,i}(\boldsymbol{p}). \end{aligned}$$

Material properties can be discontinuous at the node.

For the control volume Ω_i we have two ***differential equations***:

$$\text{fluid:} \qquad M_i' = -Q_{m,i}(\boldsymbol{h}, \boldsymbol{c}),$$

$$\text{salt:} \qquad C_i' = -Q_{c,i}(\boldsymbol{h}, \boldsymbol{c}),$$

and two ***algebraic equations***:

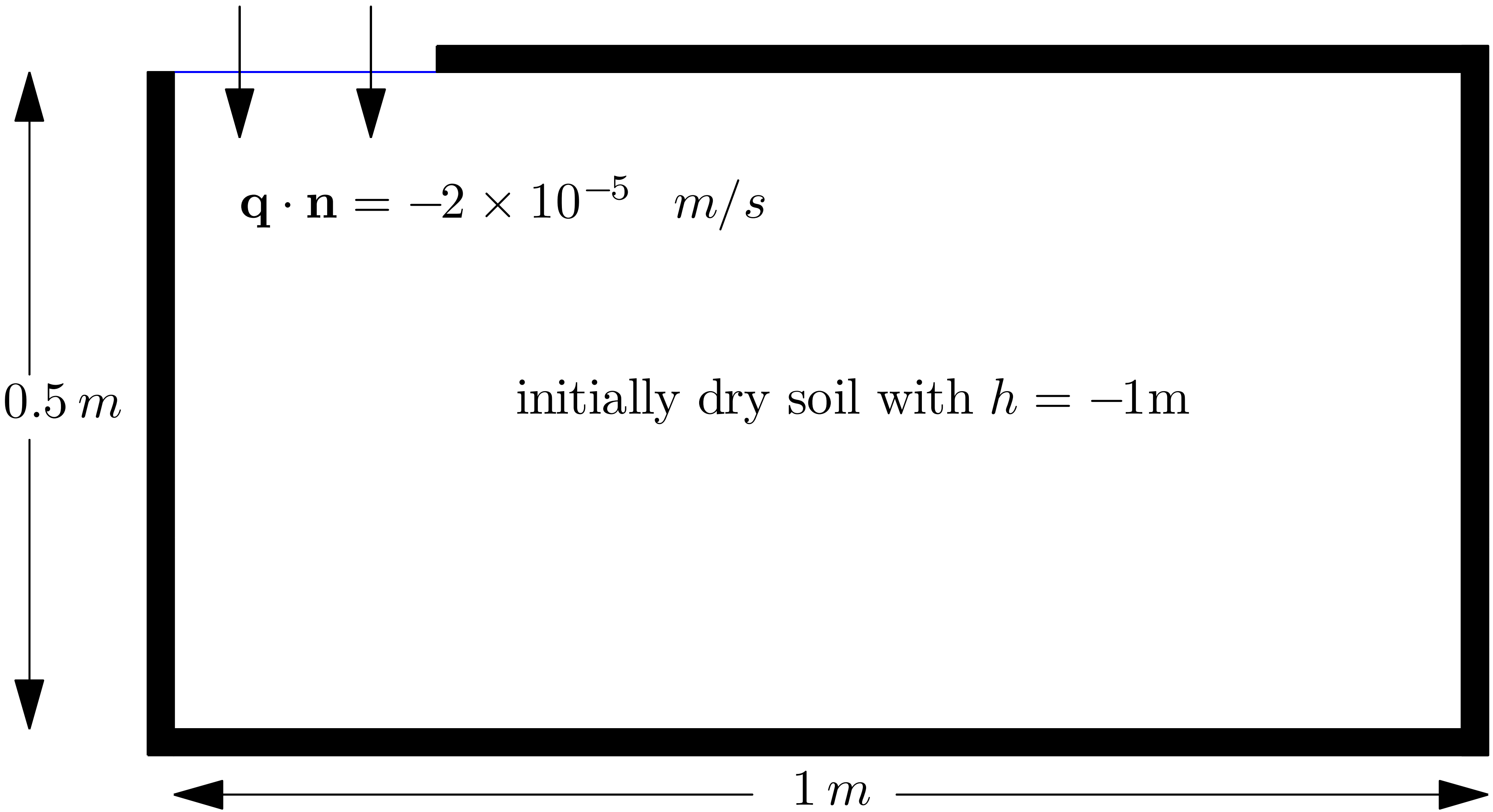
$$\text{fluid:} \qquad M_i = V_{m,i}(\boldsymbol{p}, \boldsymbol{c}),$$

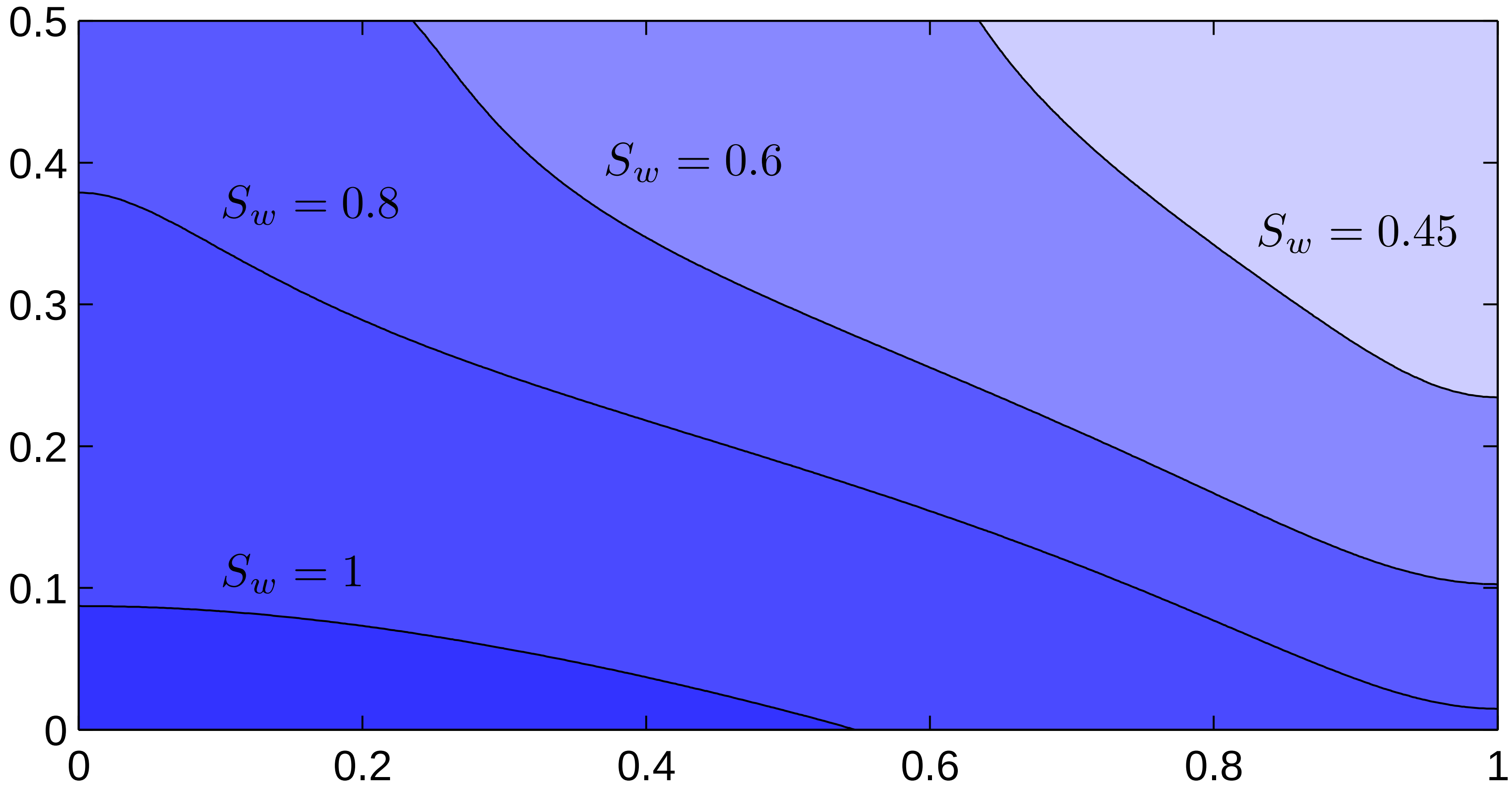
$$\text{salt:} \qquad C_i = V_{c,i}(\boldsymbol{p}, \boldsymbol{c}),$$

and four ***variables***:

algebraic	differential
pressure p_i	fluid mass M_i
concentration c_i	salt mass C_i

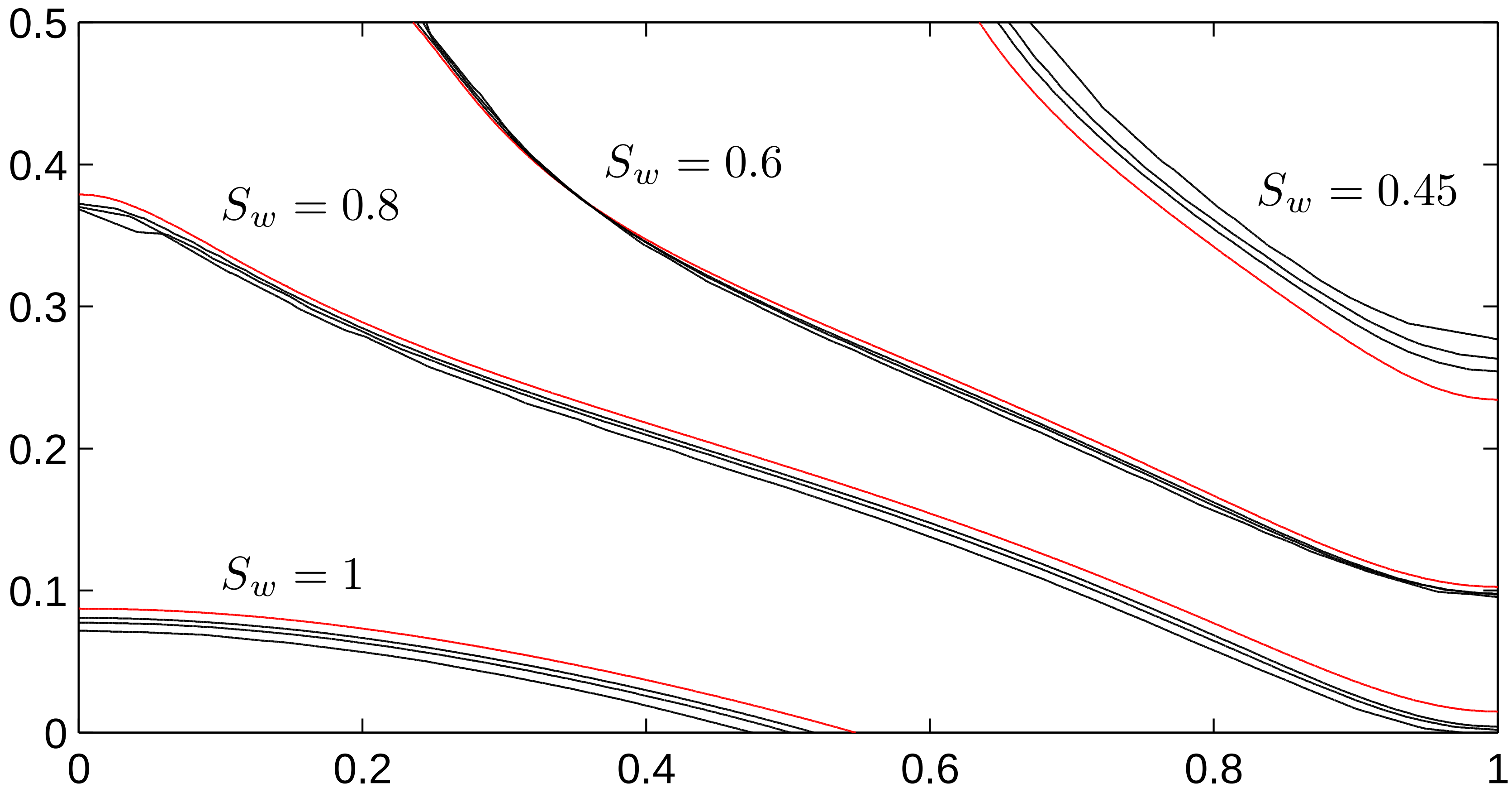
- The discrete equations are a system of semi-explicit ***differential algebraic equations (DAEs)***.
- The temporal derivative at timestep $n+1$ is approximated using a ***backwards differentiation formula***.
- This gives rise to a nonlinear system of equations to be solved using ***Jacobian-free Newton-Krylov method***.
- The vast majority (%80-%90) of computational time is spent on interpolation from nodal values to CV faces and quadrature points.
- This is a trivially paralleliseable operation!


$\mathbf{q} \cdot \mathbf{n} = -2 \times 10^{-5} \quad m/s$
initially dry soil with $h = -1$m
$0.5\,m$
$1\,m$



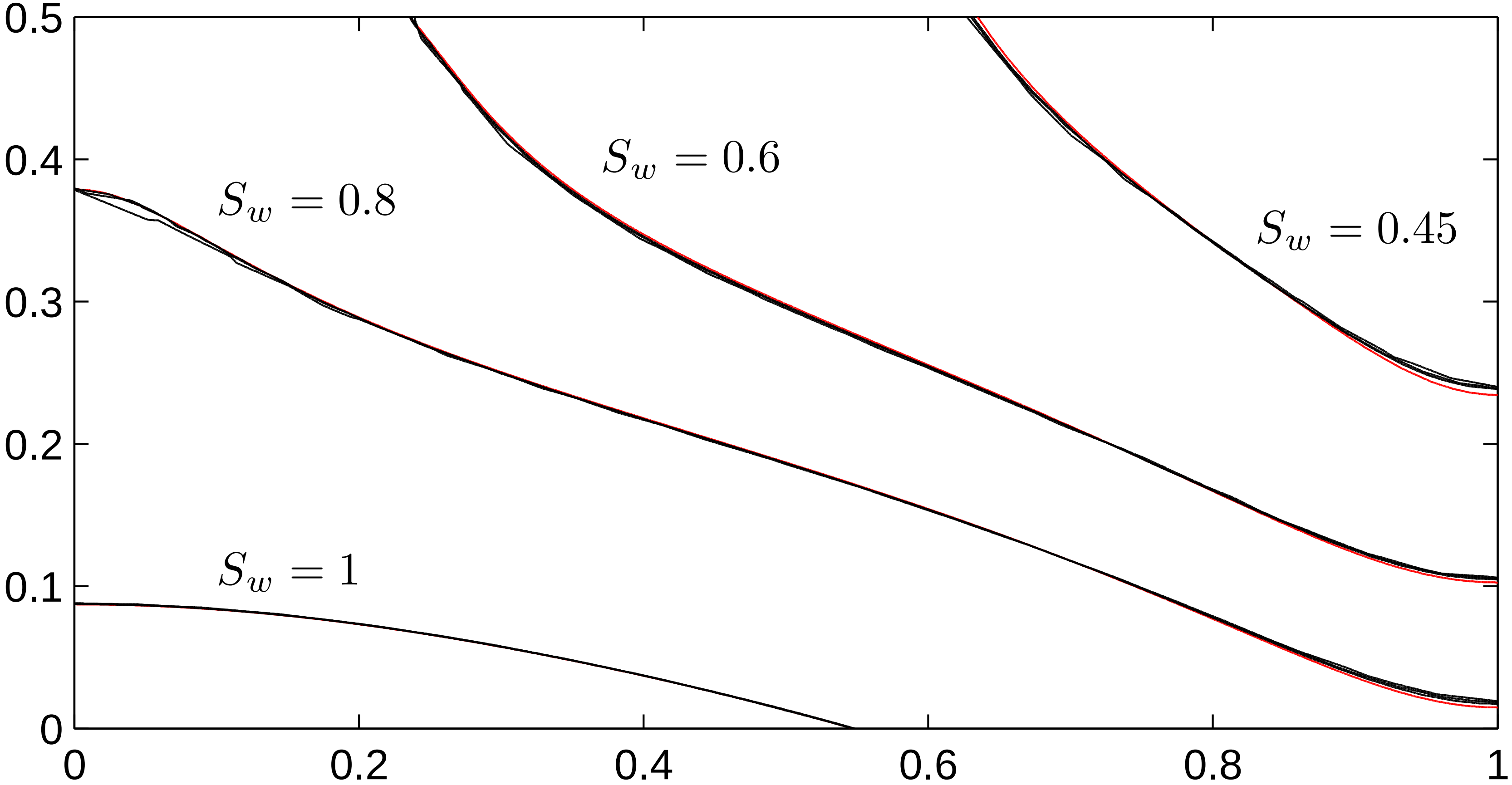
Saturation profiles at $t = 4\,\mathrm{hours}$ *on a high-resolution, 5151-node, quadrilateral mesh.*

Mesh convergence with Upwind Weighting

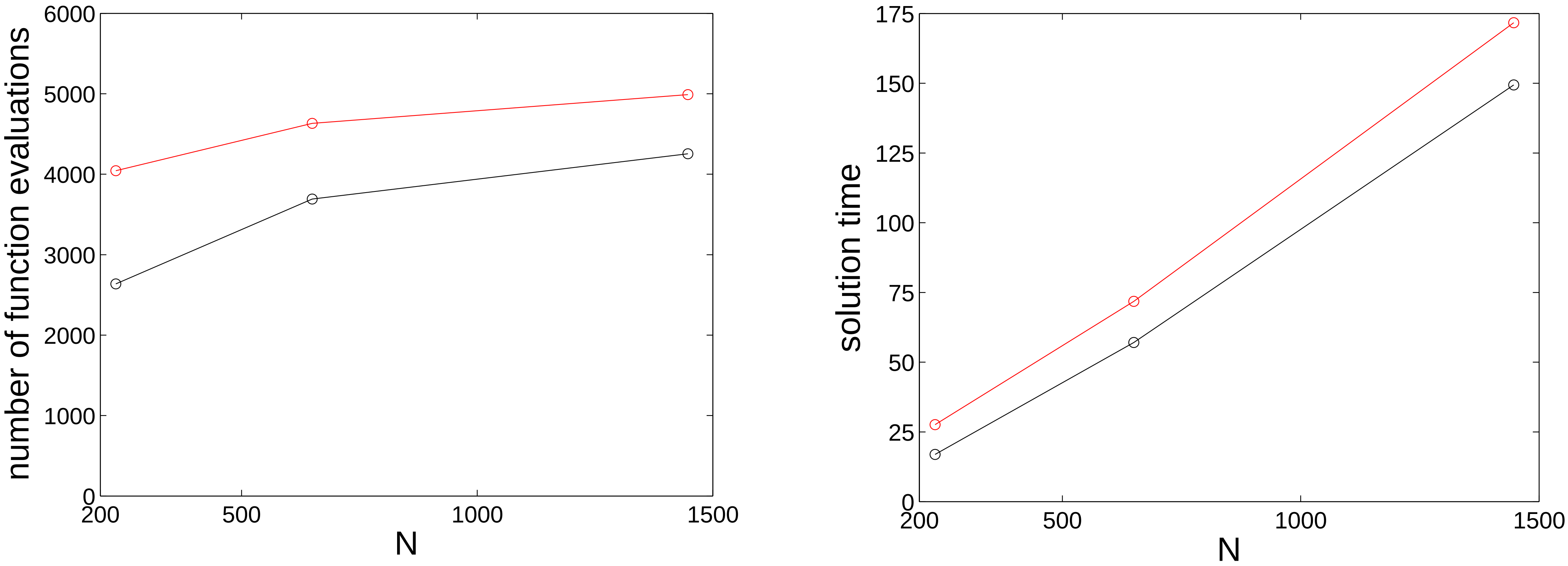


Triangle meshes with 233, 650 and 1447 nodes.

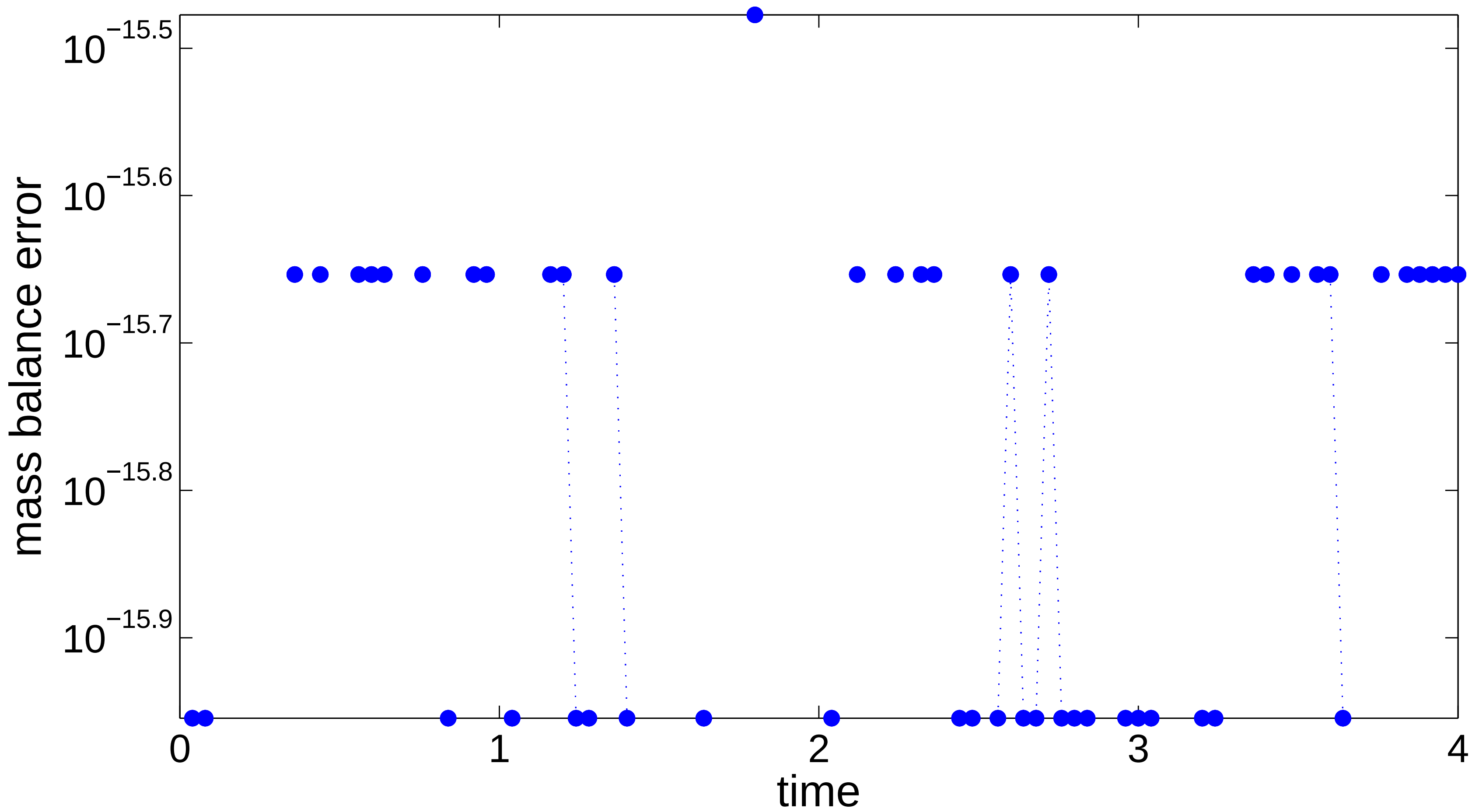
Mesh Convergence with Van Leer Flux Limiting



Triangle meshes with 233, 650 and 1447 nodes.

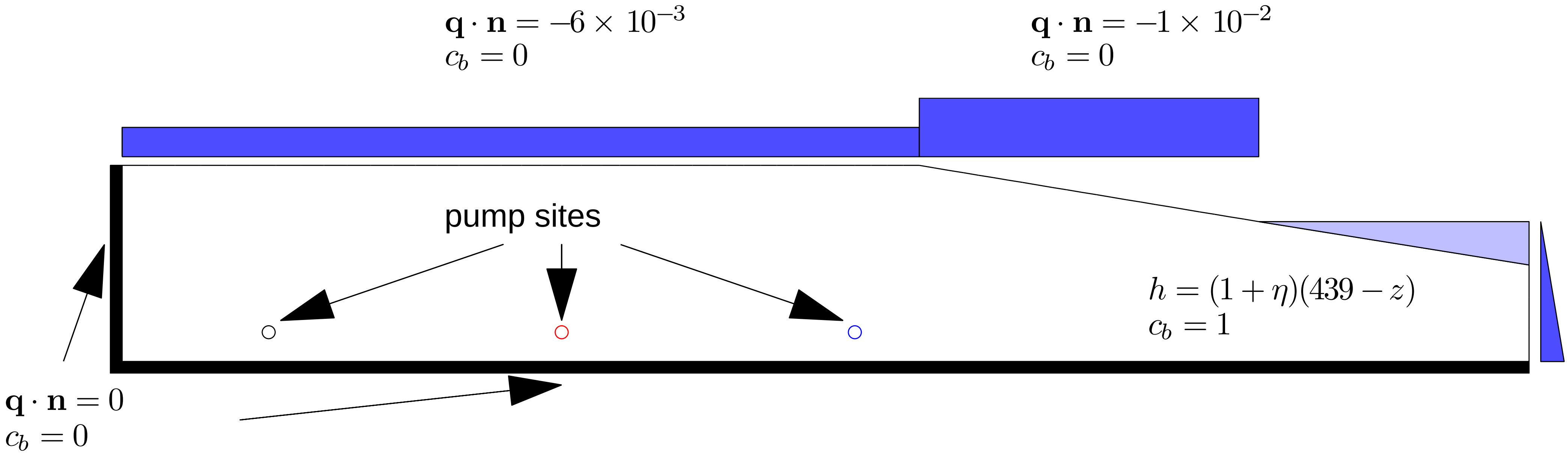


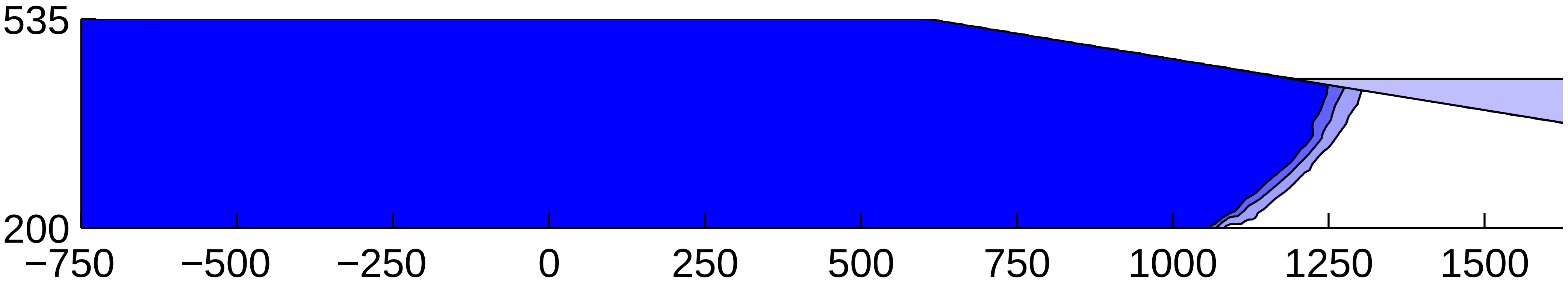
- Flux limiting (red) requires more function evaluations than the upwind solution (black) on the same mesh.
- However, the 650-node solution with flux limiting was more accurate than the 1447-node solution with upwinding, and required less compute time.

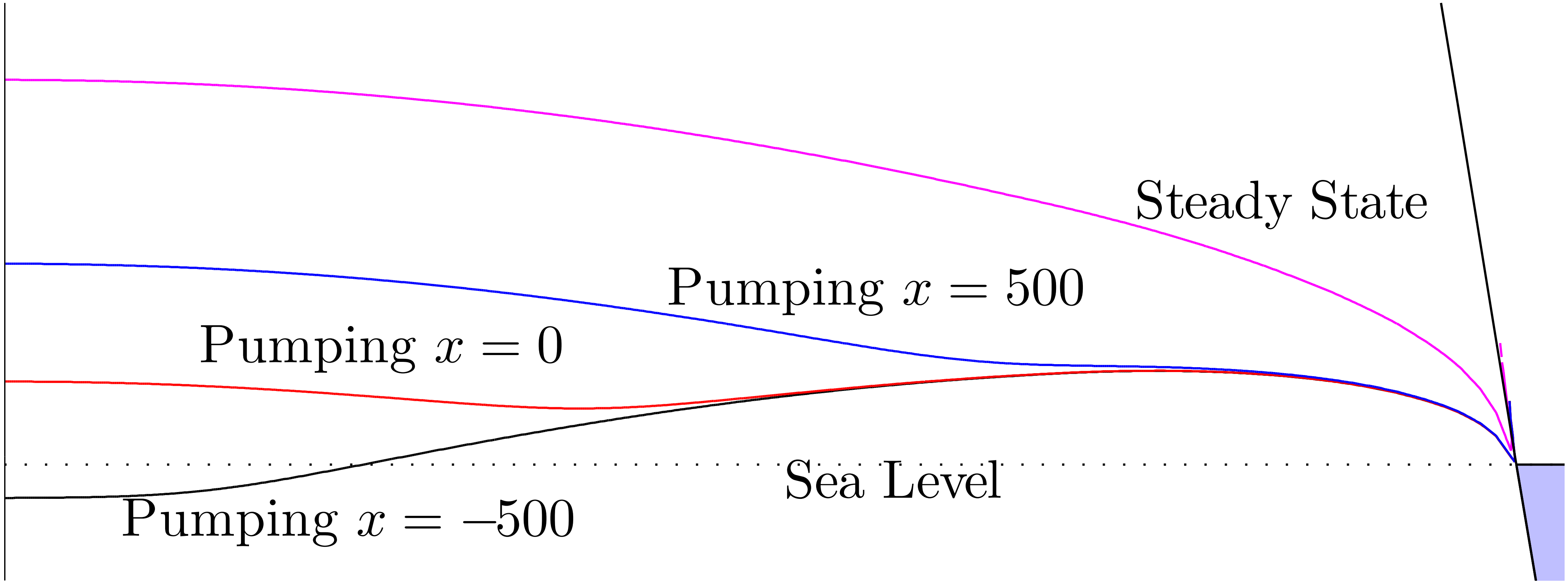


- The mass balance error is of the order of machine precision!

Saltwater infiltration in an unconfined aquifer[ZVL04]:

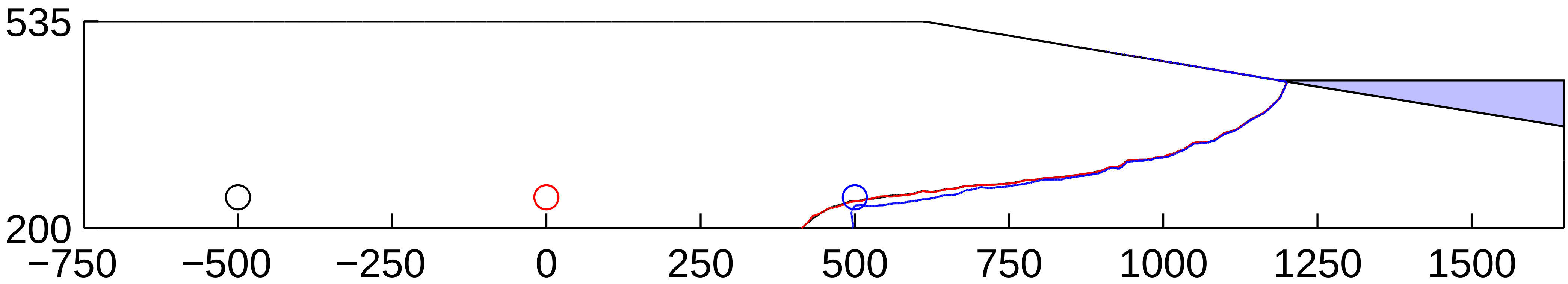


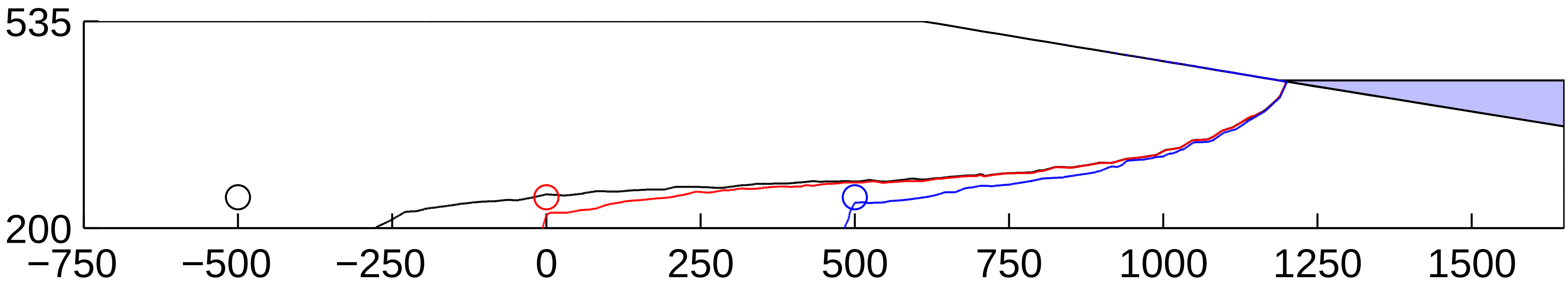




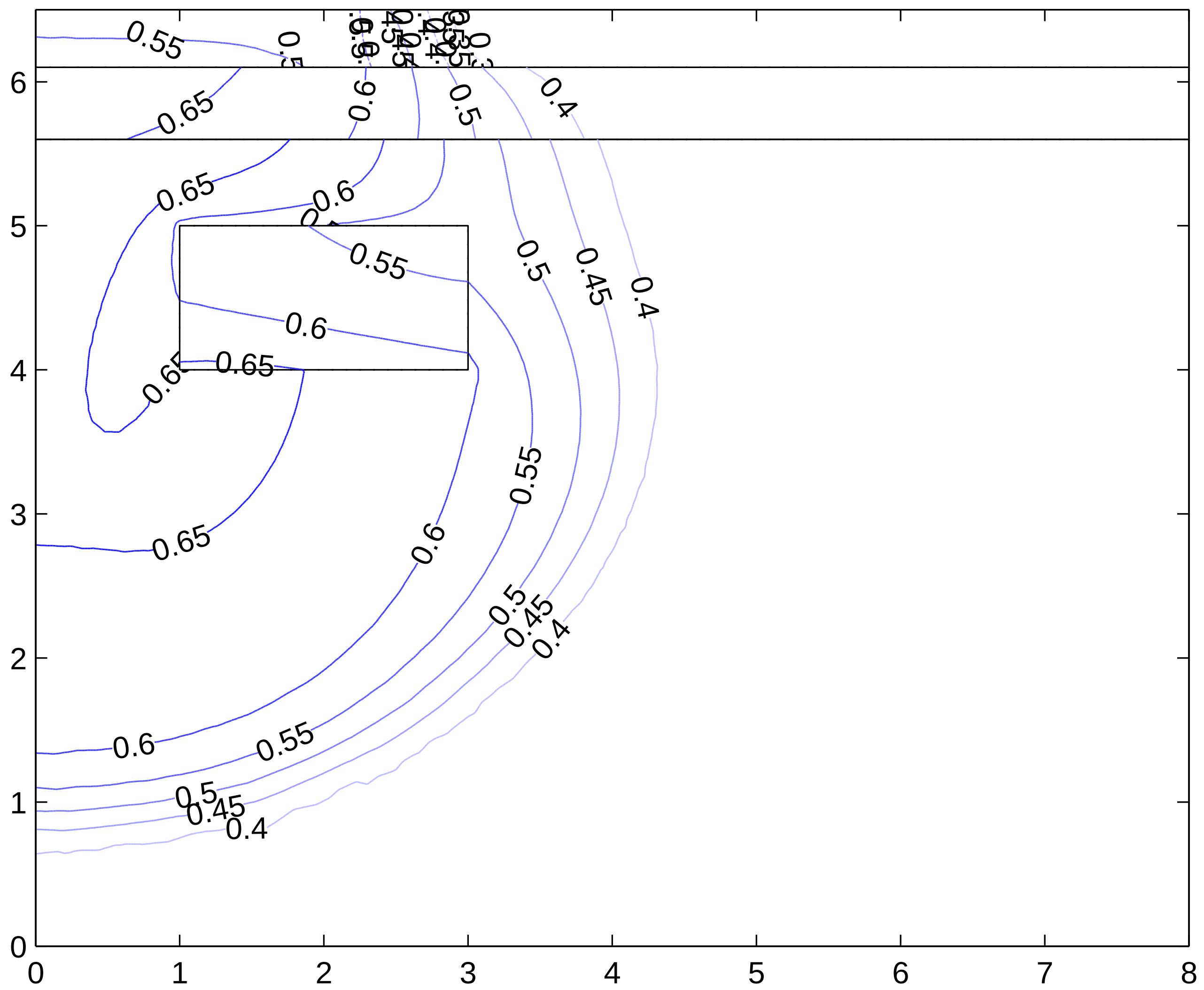
The effect of pumping at different locations on the water table level.

The c=0.2 isochlors for t=4 and t=10 hours

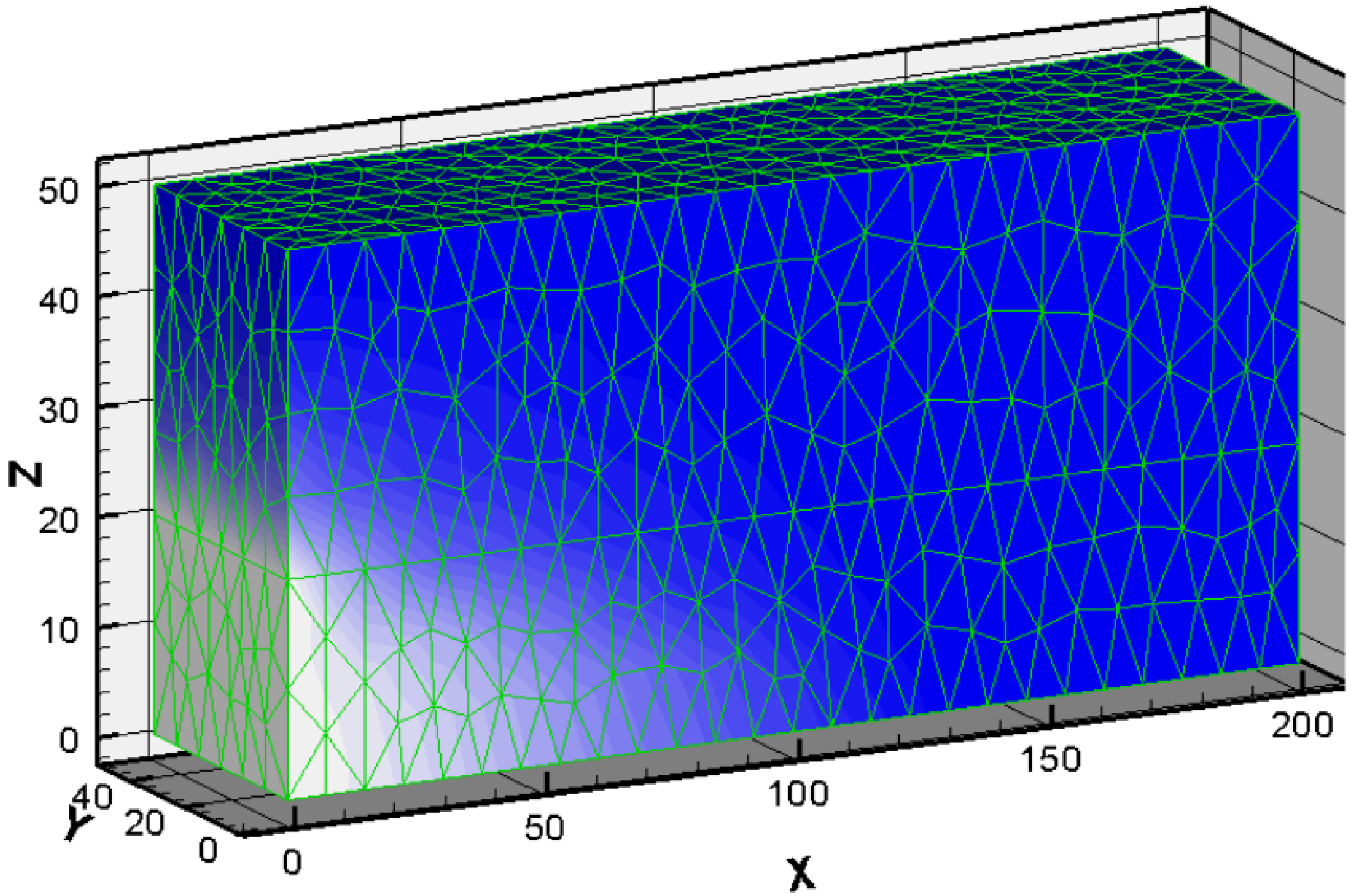




Unsaturated infiltration into a heterogeneous aquifer[FWP95]:



- Improving the accuracy of flux calculations for “shallow” aquifers.
- Implementing the methods in three dimensions.



References

[FWP95] PA Forsyth, YS Wu, and K Pruess. Robust numerical methods for saturated–unsaturated flow with dry initial conditions in heterogeneous media. *Advances in Water Resources*, 18:25–38, 1995.

[MT06] TJ Moroney and IW Turner. A finite volume method based on radial basis functions for two-dimensional nonlinear diffusion equations. *Applied Mathematical Modelling*, 30(10):1118–1133, October 2006.

[ZVL04] Q Zhang, RE Volker, and DA Lockington. Numerical investigation of seawater intrusion at Gooburrum, Bundaberg, Queensland, Australia. *Hydrogeology Journal*, 12(6):674–687, December 2004.

Southern Victoria Hydrogeological Mapping

SKM SINCLAIR KNIGHT MERZ | achieve outstanding client success

Andrew Harrison, Sinclair Knight Merz

Southern Rural Water
Managing Water. Serving Communities.

Background

- Southern Victoria – complex hydrogeology with deep basins
- Current hydrogeological mapping of Southern Victoria:
  - Static hard copy
  - Significant cross-boundary issues
  - Tops of aquifers only
- Need for a dynamic digital 3D aquifer framework allowing:
  - Resource characterisation
  - New interpretations to be included as new information comes to hand
  - Bores to be assigned to aquifers in 3D space (and associated use and water levels)
  - Easy communication of complex technical data

Objectives

> To develop an aquifer framework for Southern Victoria

> To provide a digital framework for the storage and analysis of bore data

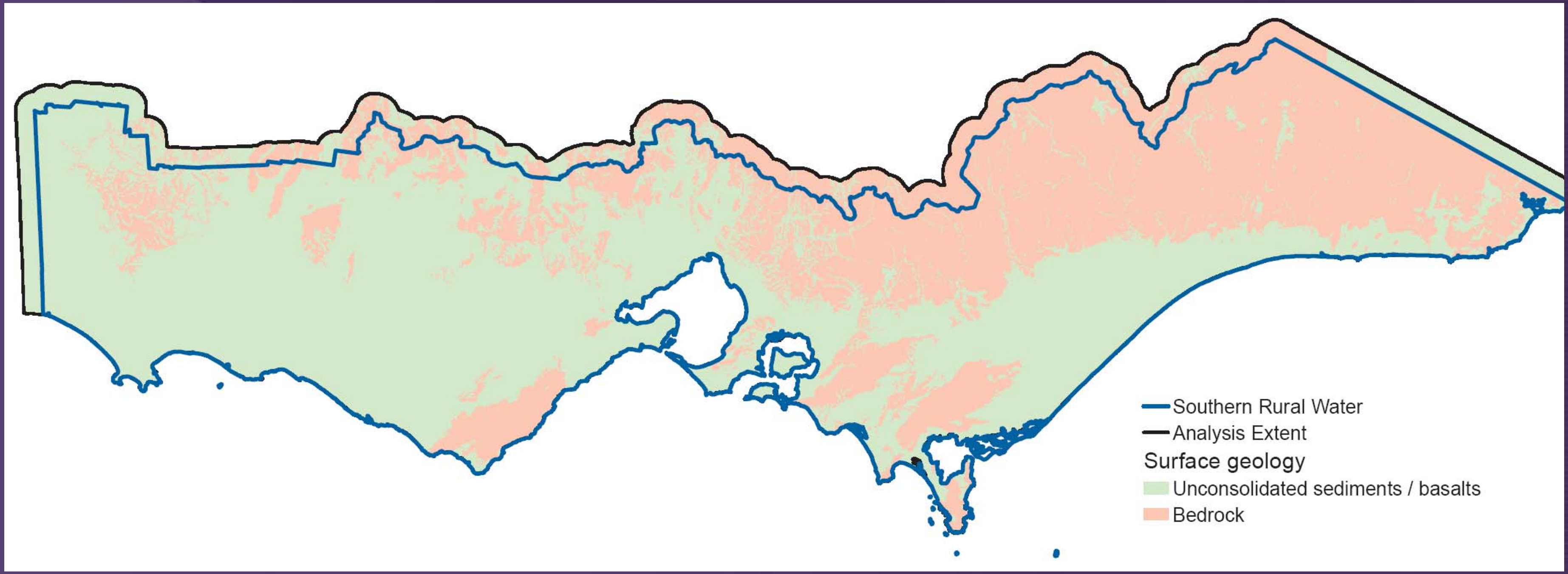
> To develop 3D surfaces of tops and bases of each aquifer

> To map salinity, potentiometry and yield of aquifers as continous digital products across the area

> Project conducted for Southern Rural Water

> Delivered through a partnership between SKM and GHD

Extent of mapping area



Aquifer Framework

> How to categorise complex geology into logical aquifers and aquitards

> Workshops:
- Eastern Victoria
- Western Victoria

3 Tiers of Classification

Geological Units (470) (eg Rivernook Member)	**Hydrogeological Units (102)** (eg Dilwyn Formation)	**Aquifers (9)** (eg LowerTertiary Aquifer)
G1	HGU 101	
G2		Aquifer 100
G3	HGU 102	
G4		
G5	HGU 201	
G6		Aquifer 200
G7	HGU 202	
G8		
G9	HGU 301	
G10		Aquifer 300
G11	HGU 302	
G12		

Aquifer Classification

Aquifer Name	Aquifer Code	Aquifer Number	Hydrogeological Units Present			
			Otway Basin	Port Philip and Westernport Basin	Tarwin Basin	Gippsland Basin
Quaternary Aquifer	**QA**	**100**	▪ Various Quaternary Deposits ▪ Newer Volcanics	▪ Various Quaternary Deposits	▪ Various Quaternary Deposits	▪ Various Quaternary Deposits ▪ Haunted Hill Formation ▪ Eagle Point Sand ▪ Curlip Gravel ▪ Jahrramond Formation ▪ Boisdale Formation (Nuntin Clay)
Upper Tertiary Aquitard	**UTD**	**200**	ABSENT	ABSENT		
Upper Tertiary Aquifer	**UTA**	**300**	▪ Moorabool Viaduct Fm ▪ Hanson Plain Sand ▪ Dorodong Sand ▪ Grange Burn Sand	▪ Moorabool Viaduct Fm ▪ Brighton Group ▪ Baxter Sandstone	ABSENT	▪ Boisdale Formation – Wurruk Sand
Upper Mid-Tertiary Aquifer	**UMTA**	**400**	▪ HG: Port Campbell Limestone ▪ HG: Portland Limestone ▪ TG: Fyansford Formation ▪ TG: Batesford Limestone ▪ MG: Upper Gambier Limestone ▪ HG: Bochara Limestone ▪ MG: Duddo Limestone • MG: Winnambool Fm	▪ Fyansford Fm ▪ Sherwood Marl ▪ Newport Fm	ABSENT	▪ Balook Formation ▪ Jemmy's Point Formation ▪ Lake Wellington Formation ▪ Lakes Entrance Formation ▪ Tambo River Fm ▪ Wuk Wuk Marl) ▪ Gippsland Limestone ▪ LVG: Yallourn Formation ▪ Yarragon Fm ▪ LVG: Morwell M1-2 aquifers ▪ LVG: M2C aquifer ▪ Seaspray Sands ▪ Alberton Formation
Upper Mid-Tertiary Aquitard	**UMTD**	**500**	▪ MG: Geera Clay ▪ HG: Gellibrand Marl	▪ Gellibrand Marl ▪ Newport Silt ▪ TG: Jan Juc Formation ▪ TG: Pt Addis Limestone ▪ TG: Peubla Clay ▪ TG: Zeally Limestone ▪ Maude Fm (incl Maude Limestone and Maude Basalt) ▪ Pintadeen Basalt (P2)	ABSENT	ABSENT

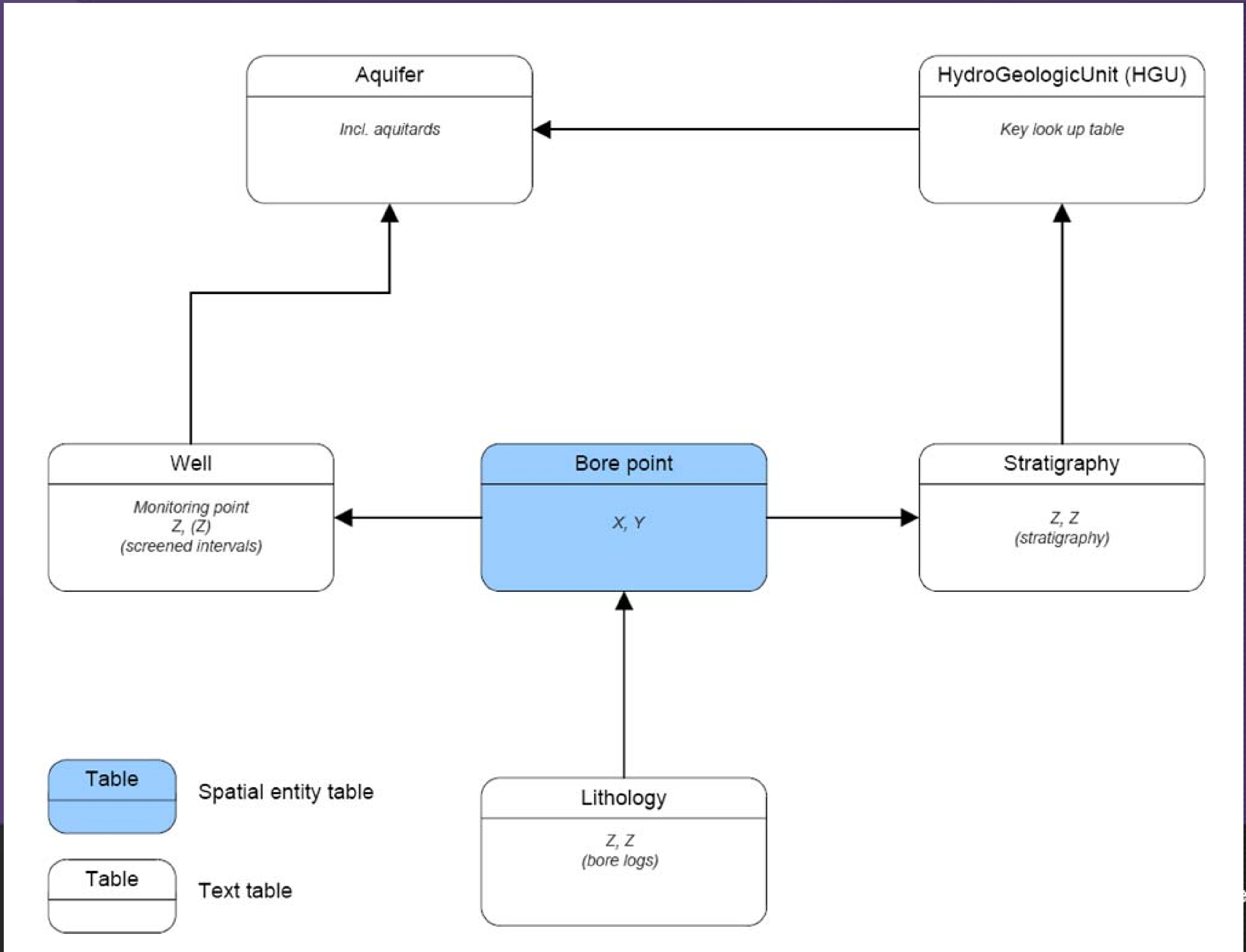
Aquifer classification cont.

Aquifer Name	Aquifer Code	Aquifer Number	Hydrogeological Units Present			
			Otway Basin	Port Philip and Westernport Basin	Tarwin Basin	Gippsland Basin
Lower Mid-Tertiary Aquitard	**LMTD**	**700**	■ NG: Lower Gambier Limestone ■ NG: Older Volcanics (P2) ■ NG: Wangoom Sand ■ NG: Narrawaturk Marl ■ Demons Bluff Group ■ NG: Upper Mepunga Fm	■ Demons Bluff Group (Boonah Fm Salt Creek Fm, Anglesea Fm, Addicot Fm, Angahook Fm)	ABSENT	ABSENT
Lower Tertiary Aquifer	**LTA**	**800**	■ NG: Lower Mepunga Fm ■ WG: Dilwyn Fm (Dartmoor Fm) ■ WG equivalent: Eastern View Fm ■ WG: Yaugher Volcanics ■ WG: Pember Mudstone ■ WG: Pebble Point Fm ■ SG: Timboon Sand	■ Werribee Fm/ Maddingley Coal Seam ■ Older Volcanics (P1) ■ Yaloak Fm ■ Mornington Volcanics	■ Thorpdale Volcanics ■ Childers Fm	■ Thorpdale Volcanics ■ Childers Fm ■ M2C aquifer (under Hazelwood and in northern basin margin) ■ Traralgon Fm ■ Carrajung Volcanics
Pre-Canoizoic Basement	**BSE**	**900**	■ SG: Paaratte Fm ■ SG: Waarre Fm ■ SG: Flaxman Fm ■ SG: Belfast Mudstone ■ OG: Eumeralla Fm ■ OG: Casterton Formation, ■ OG: Crayfish subgroup ■ All Palaeozoic Basement Rocks	■ All Palaeozoic Basement Rocks	■ KS: Strzelecki Group ■ All Palaeozoic Basement Rocks	■ KS: Strzelecki Group ■ All Palaeozoic Basement Rocks

Database

- Based on “ArcHydro” concept
- A consistent format for the storage of bore construction, lithology, stratigraphy, salinity and water level data (not time series)
- Allows interpretation of bore logs and tracks interpretation changes
- SQL format allowing simultaneous multi-users
- Is compatible with Microsoft Access and ESRI ArcGIS

Database schema



ent success

AQUIFER

Column Name	Data Type	Length	Allow Nulls
AQ_ID	int	4	
AQ_CODE	int	4	
AQ_NAME	varchar	50	✓
AQ_ABBREV	varchar	10	✓
CR_DATE	datetime	8	✓
RET_DATE	datetime	8	✓

HYDROGEOLOGICALUNIT

Column Name	Data Type	Length	Allow Nulls
HGU_ID	int	4	
HGU_NAME	varchar	100	✓
HGU_CODE	int	4	
AQ_ID	int	4	✓
AQ_CODE	int	4	✓
CR_DATE	datetime	8	✓
RET_DATE	datetime	8	✓

BOREPOINT

Column Name	Data Type	Length	Allow Nulls
BPOINT_ID	int	4	
BORE_ID	varchar	20	
BORE_SRC	varchar	100	✓
COMPL_DATE	datetime	8	✓
EASTING	int	4	✓
NORTHING	int	4	✓
DATUM	varchar	20	✓
PROJECTION	varchar	20	✓
BORE_DEPTH	decimal	9	✓
RLNS	decimal	9	✓
RLNS_DEM	decimal	9	✓
RLNS_SRC	varchar	100	✓
MAP_SHEET	varchar	20	✓
LATITUDE	decimal	9	✓
LONGITUDE	decimal	9	✓
SFCE_HGU	int	4	✓
BORE_FLAG	int	4	✓
CR_DATE	datetime	8	✓
RET_DATE	datetime	8	✓

STRATIGRAPHY

Column Name	Data Type	Length	Allow Nulls
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BPOINT_ID	int	4	✓
BORE_ID	varchar	20	✓
DEPTH_FROM	decimal	9	✓
DEPTH_TO	decimal	9	✓
HGU_ID	int	4	✓
HGU_CODE	int	4	✓
STR_DESCR	varchar	100	✓
STR_SRC	varchar	100	✓
STR_CMNT	varchar	250	✓
STR_FLAG	int	4	✓
SCENARIO	int	4	✓
AUTHOR	varchar	100	✓
AUTHOR_COM	varchar	100	✓
RET_BY	varchar	100	✓
RET_BY_COM	varchar	100	✓
CR_DATE	datetime	8	✓
RET_DATE	datetime	8	✓

WELL

Column Name	Data Type	Length	Allow Nulls
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BPOINT_ID	int	4	✓
BORE_ID	varchar	20	✓
WELL_SRC	varchar	100	✓
SCRN_FROM	decimal	9	✓
SCRN_TO	decimal	9	✓
AQ_ID	int	4	✓
AQ_CODE	int	4	✓
EC	int	4	✓
EC_DATE	datetime	8	✓
EC_SRC	varchar	100	✓
TDS	decimal	9	✓
TDS_DATE	datetime	8	✓
TDS_SRC	varchar	100	✓
WL	decimal	9	✓
RWL	decimal	9	✓
WL_DATE	datetime	8	✓
WL_SRC	varchar	100	✓
WL_FLAG	int	4	✓
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EC_FLAG	int	4	✓
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RET_DATE	datetime	8	✓

LITHOLOGY

Column Name	Data Type	Length	Allow Nulls
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DEPTH_FROM	decimal	9	✓
DEPTH_TO	decimal	9	✓
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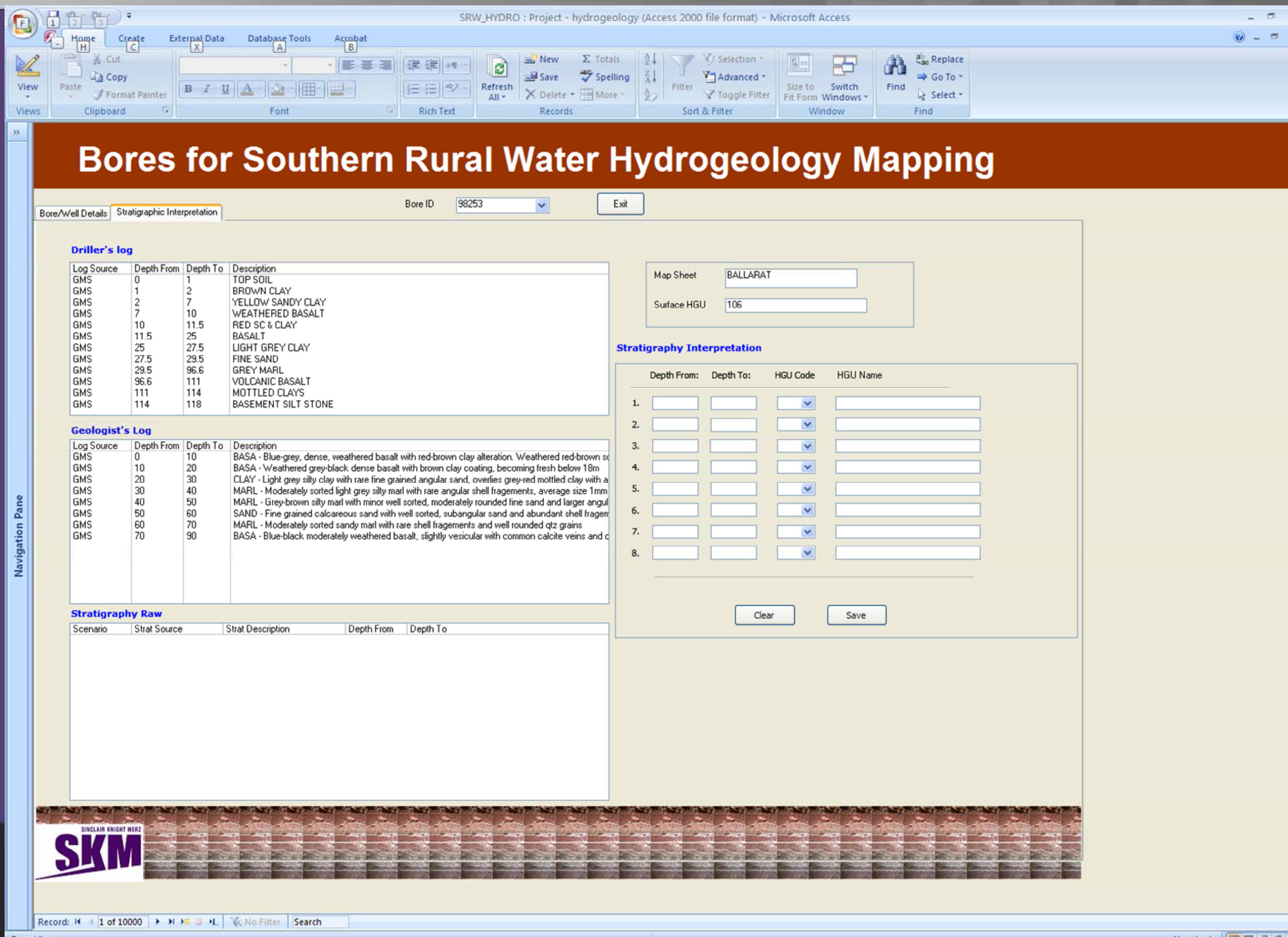
LOG_TYPE	varchar	100	✓
DESCR	varchar	250	✓
BPOINT_ID	int	4	✓
BORE_ID	varchar	20	✓
CR_DATE	datetime	8	✓
RET_DATE	datetime	8	✓

STRATIGRAPHY_RAW

Column Name	Data Type	Length	Allow Nulls
STR_RAW_ID	int	4	
BPOINT_ID	int	4	✓
BORE_ID	varchar	20	✓
DEPTH_FROM	decimal	9	✓
DEPTH_TO	decimal	9	✓
STR_DESCR	varchar	100	✓
STR_SRC	varchar	100	✓
SCENARIO	int	4	✓
CR_DATE	datetime	8	✓
RET_DATE	datetime	8	✓

User Friendly Interface



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Data sources

- Statewide Groundwater Database (GMS) – 70,000 bores
- DPI Mining bore hole database (GEDIS) – 33,000 bore logs
- DPI salinity bore database – 1,500 bores
- Corangamite CMA – 200 bores
- Melb Univ PhD thesis (Angela Bush) – 200 log interpretations

Products

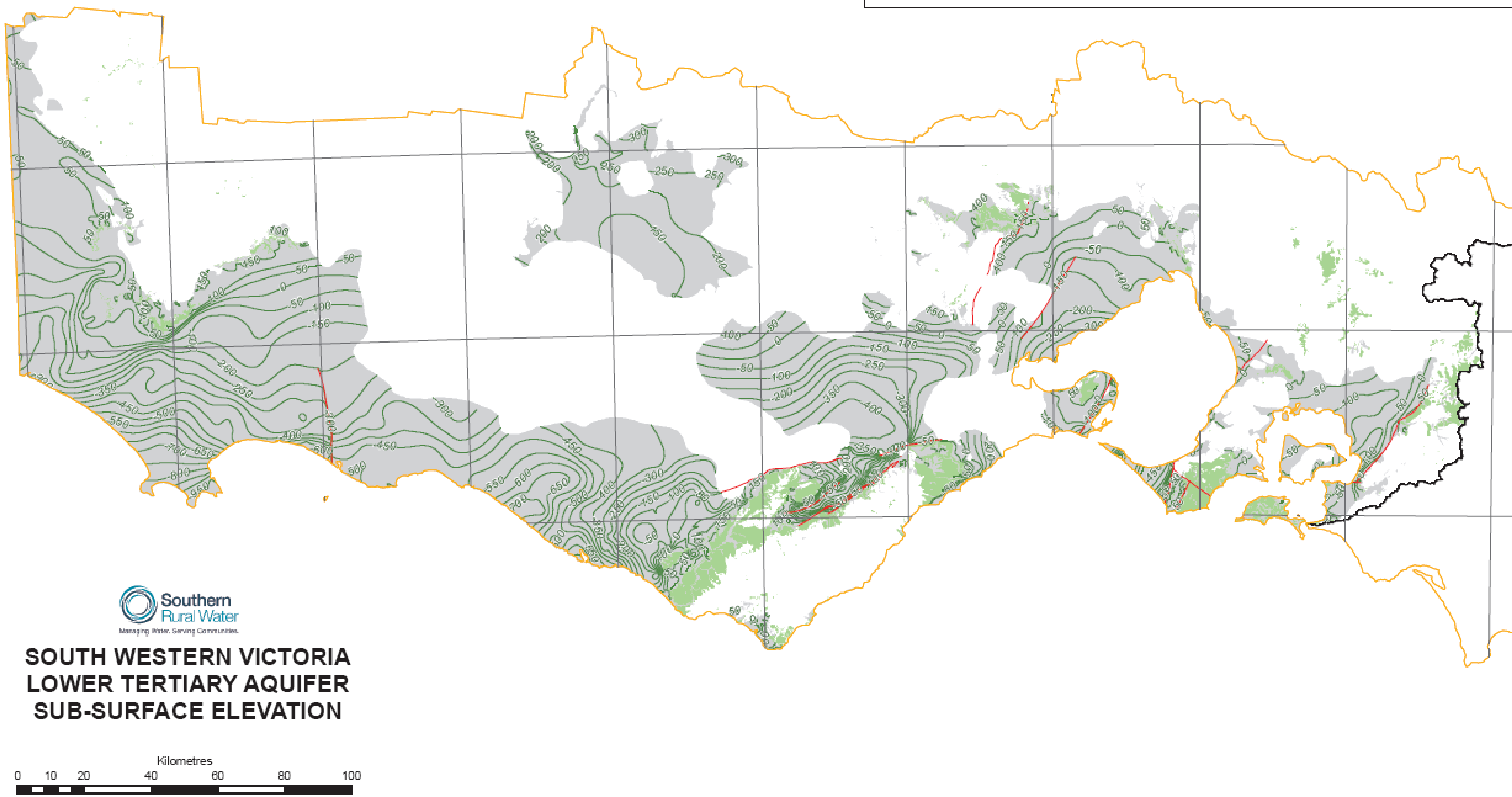
3D gridded GIS surfaces of:

> tops and bases of each aquifer
> recent groundwater potentiometry (levels)
> groundwater salinity
> aquifer yield

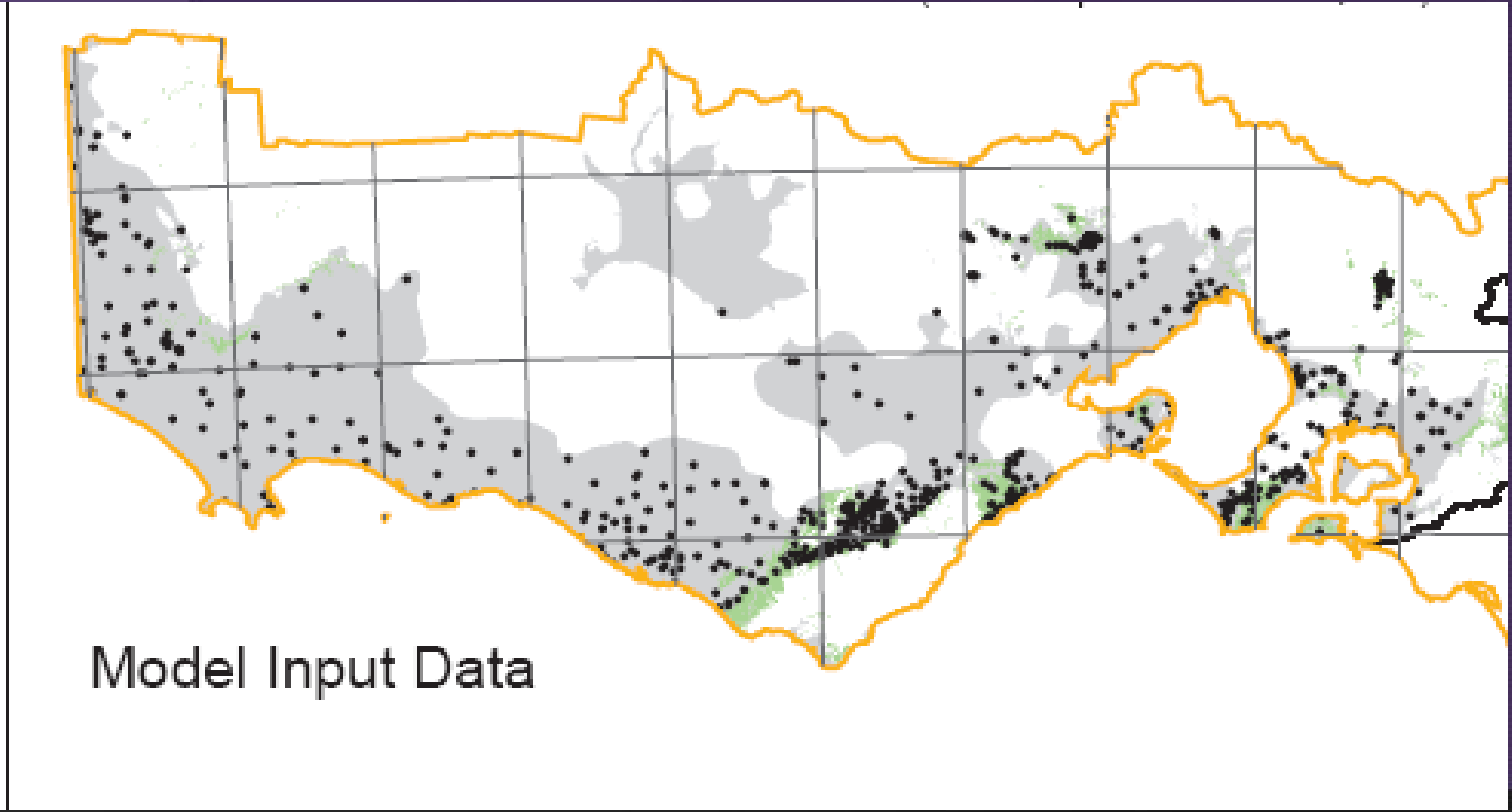
Plus:

> Representative cross-sections

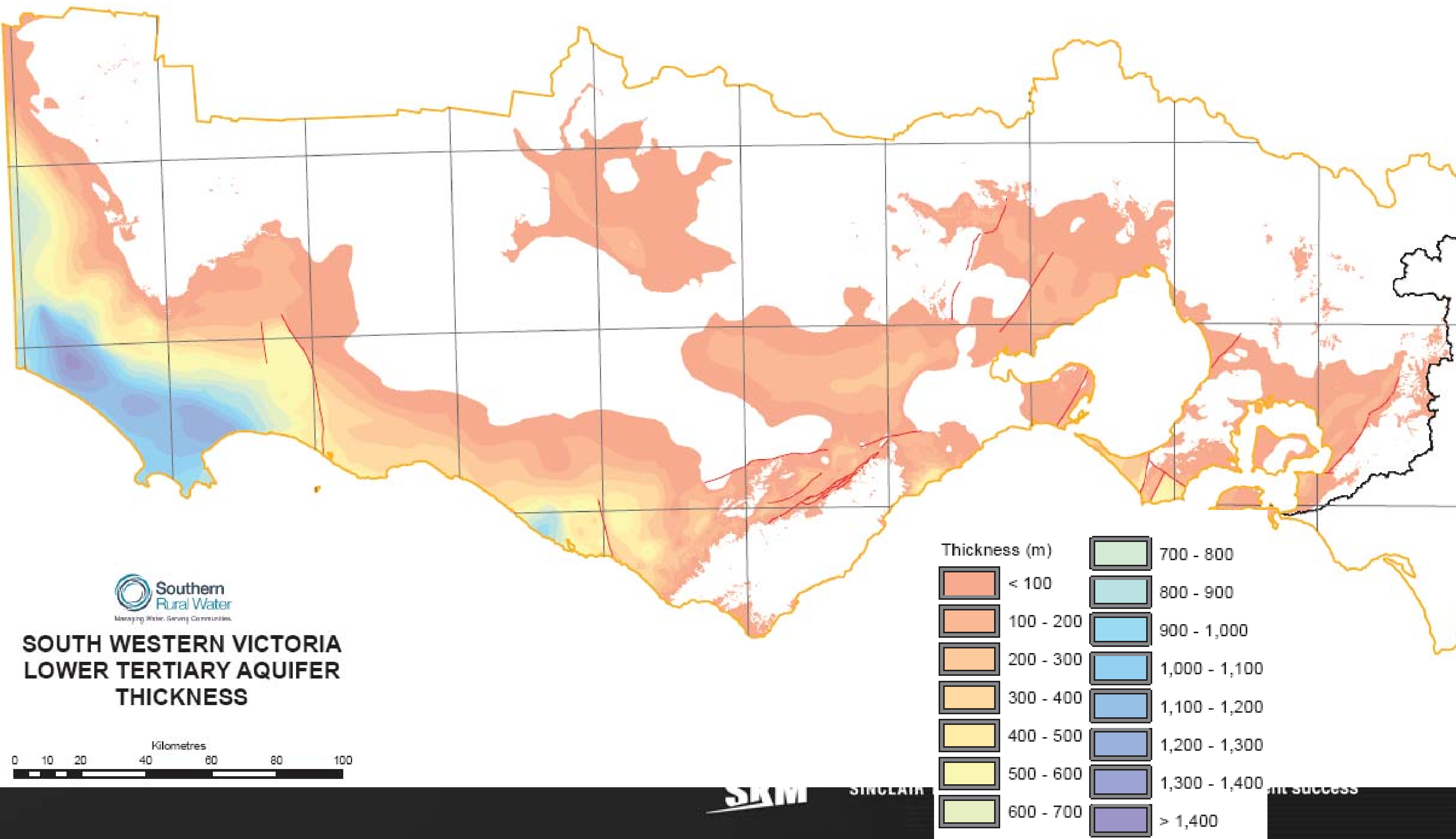
Aquifer surfaces



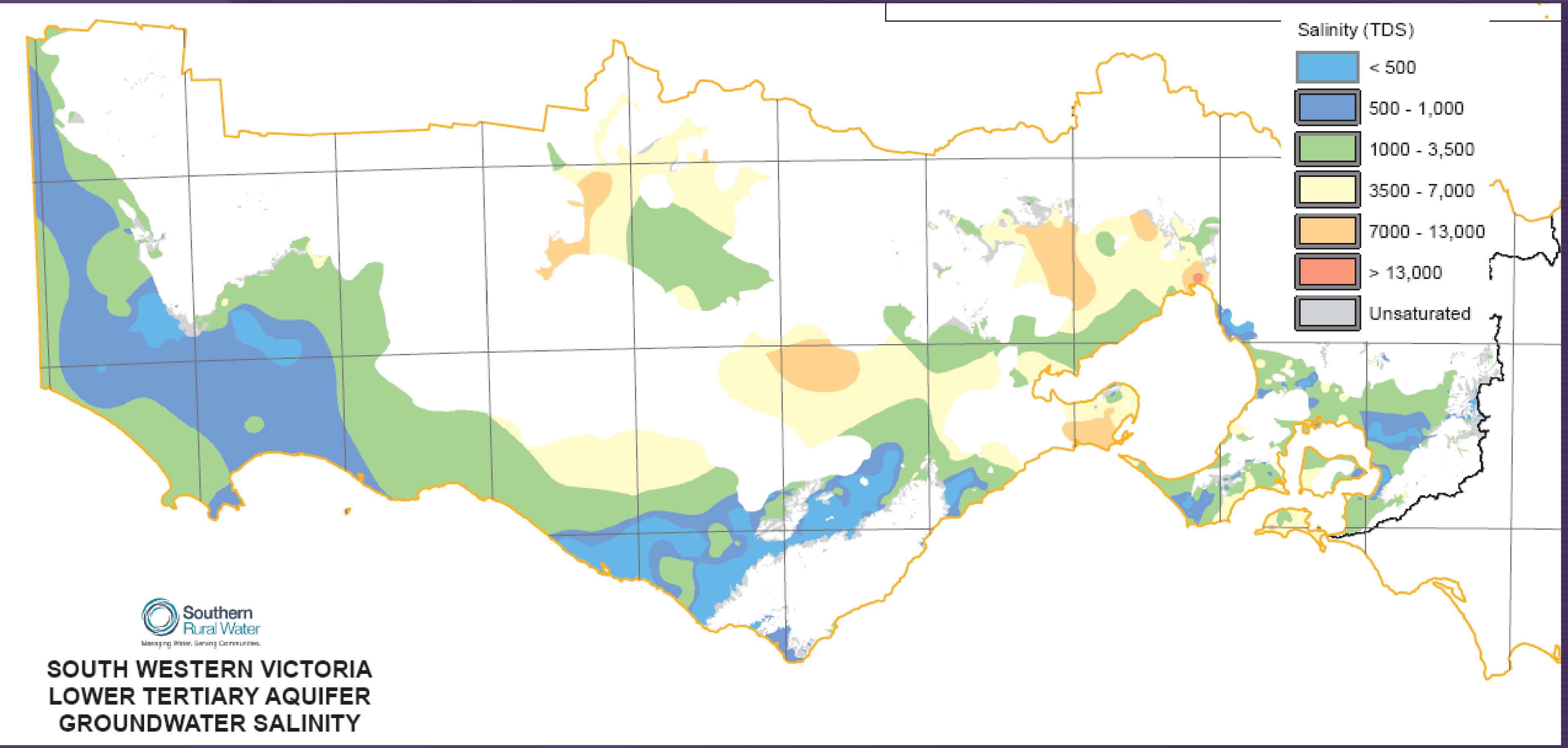
Representation of intepretation uncertainty



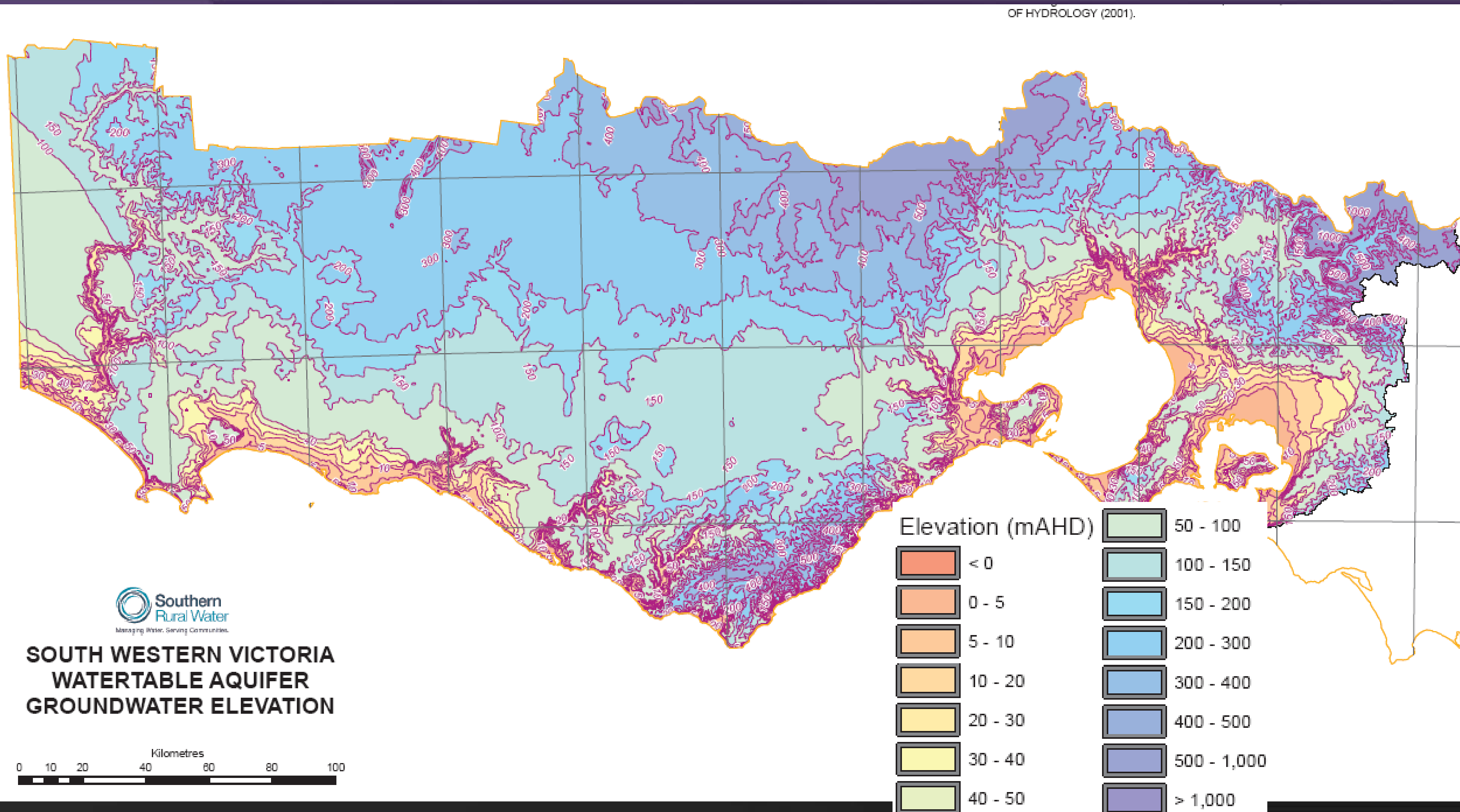
Aquifer Thickness



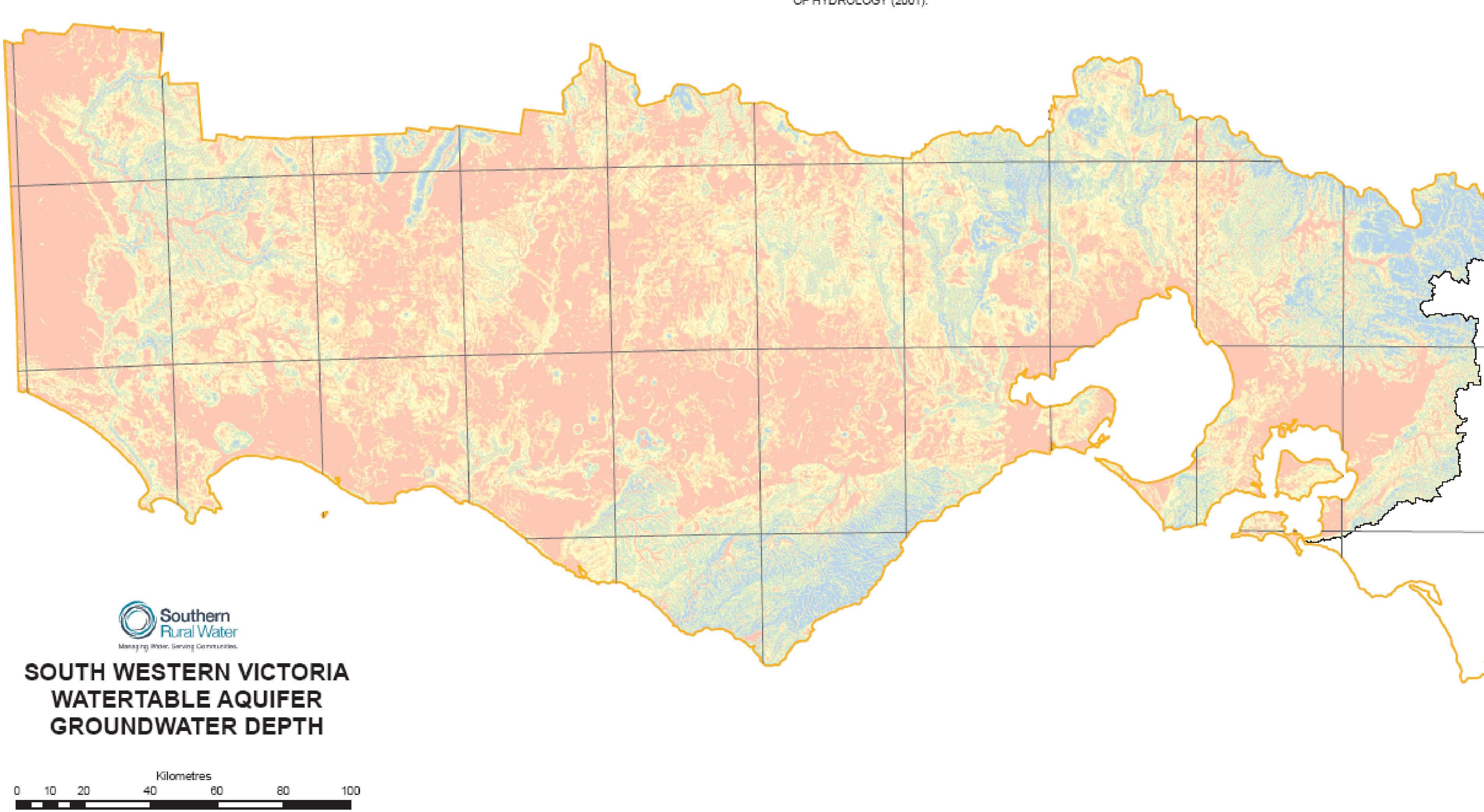
Groundwater salinity



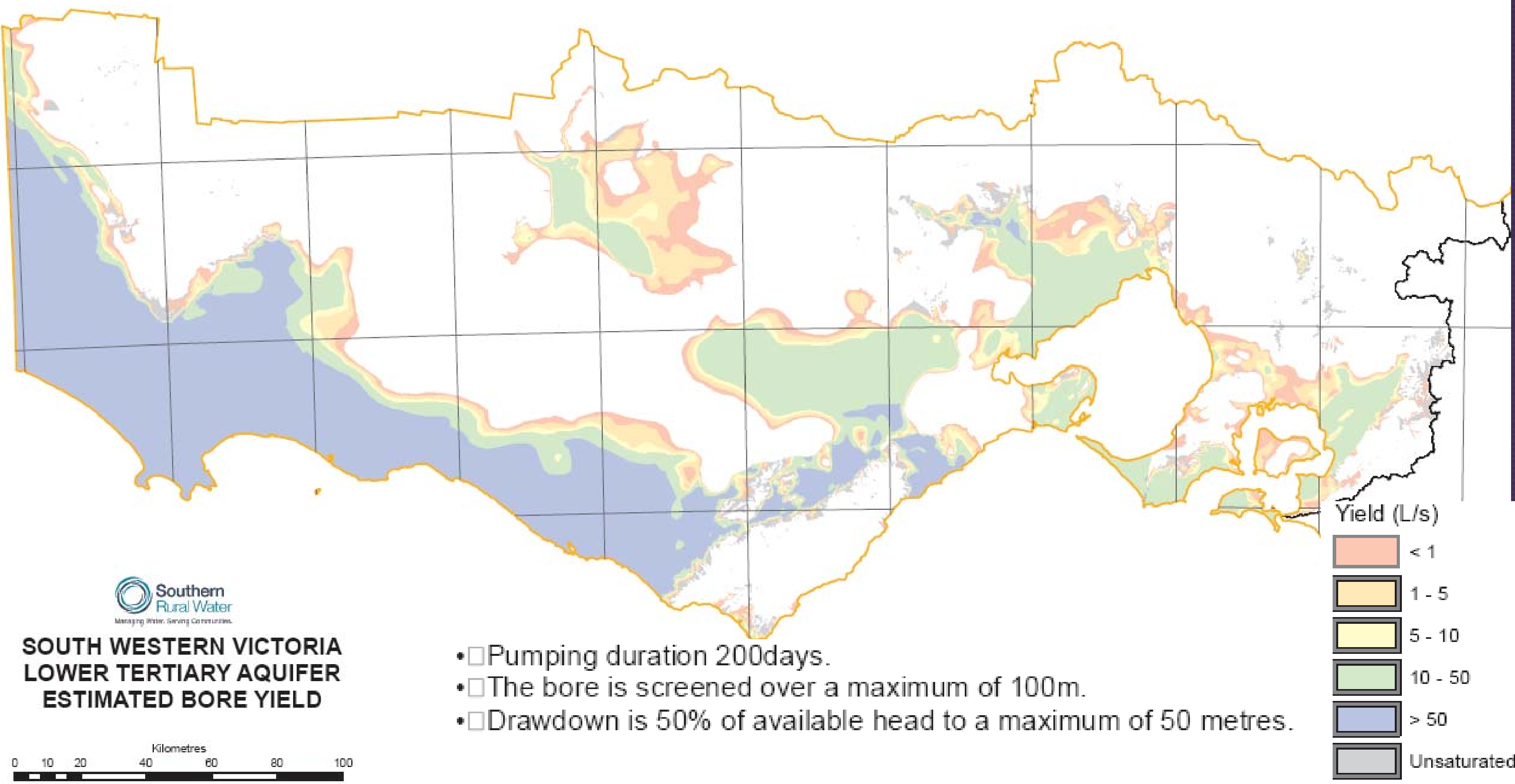
Potentiometry



Water table depth

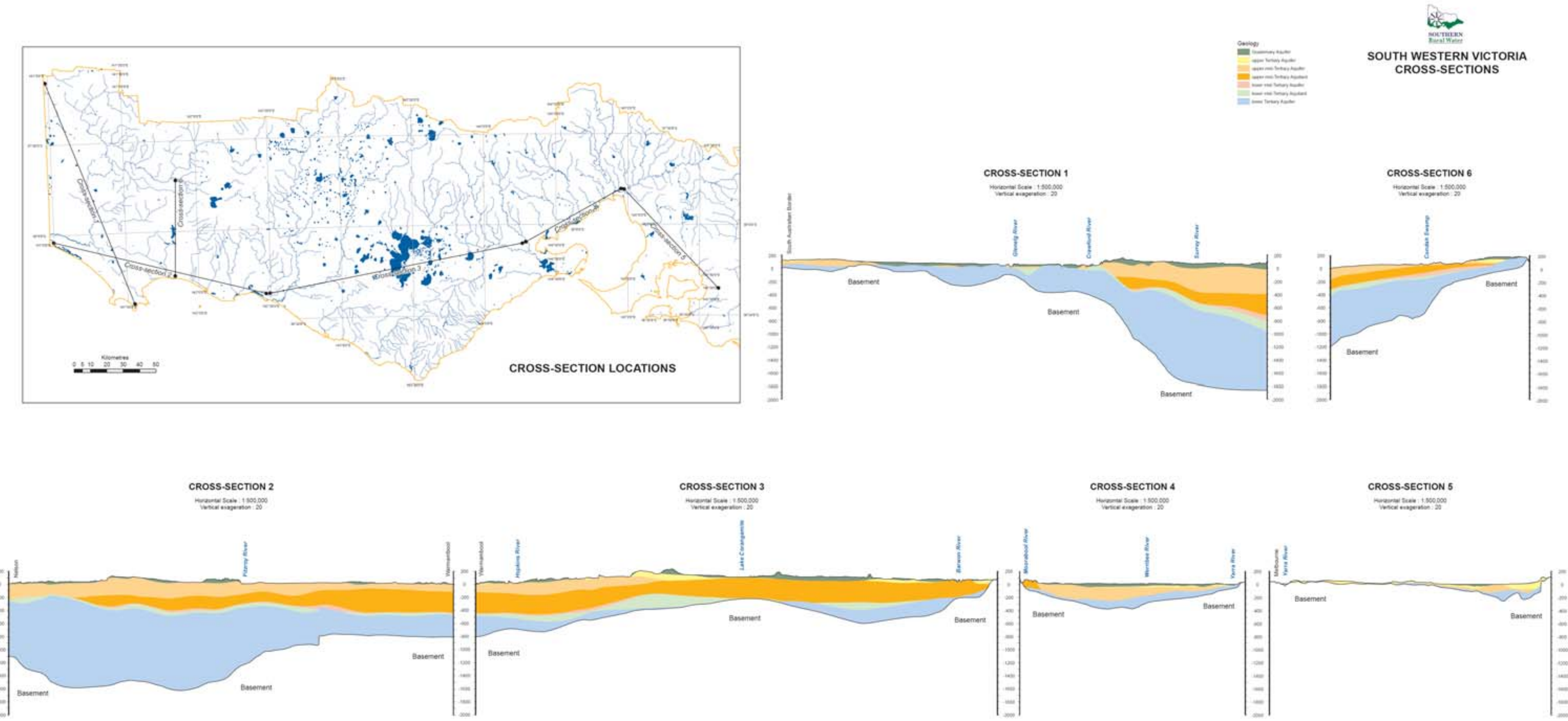


Estimated Bore Yield



- Pumping duration 200days.
- The bore is screened over a maximum of 100m.
- Drawdown is 50% of available head to a maximum of 50 metres.

Cross-sections



Conclusions

> A consistent framework for the definition of aquifers across Southern Victoria

> A consistent format for the storage of bore construction, lithology, stratigraphy, salinity and water level data (not time series)

> Used to conceptualise aquifer geometry and behaviour

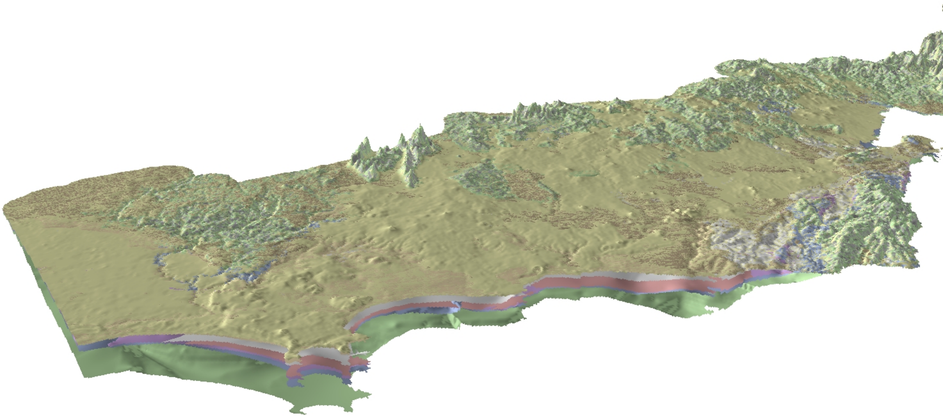
> Ability to be up-dated with versioning control

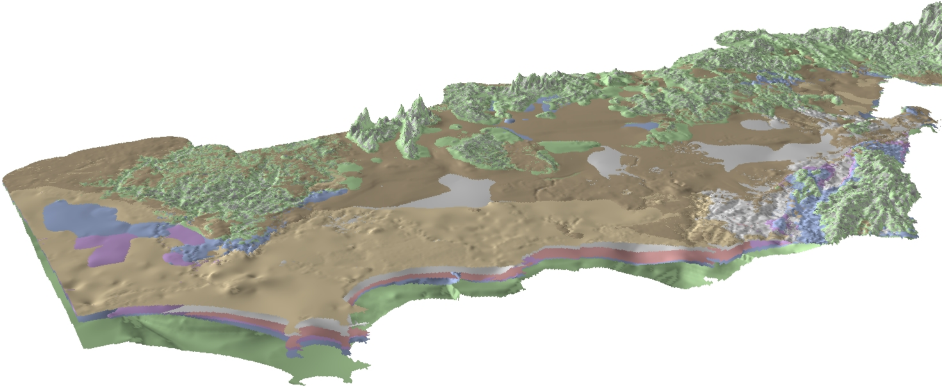
> Allows bore usage and licence information to be assigned to aquifers

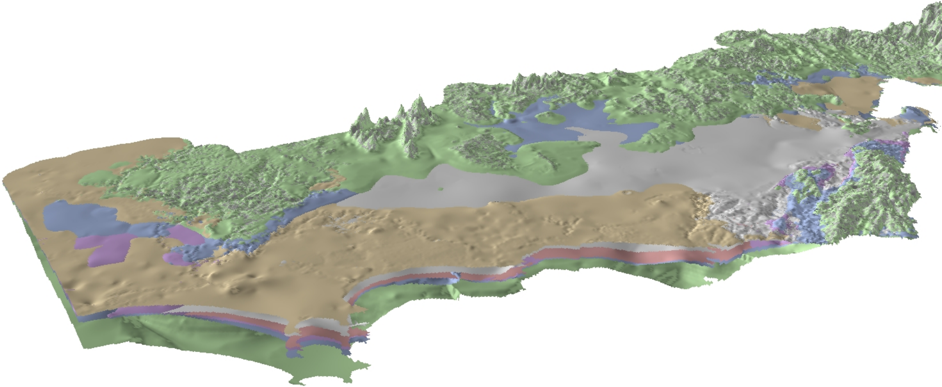
> GMU definition

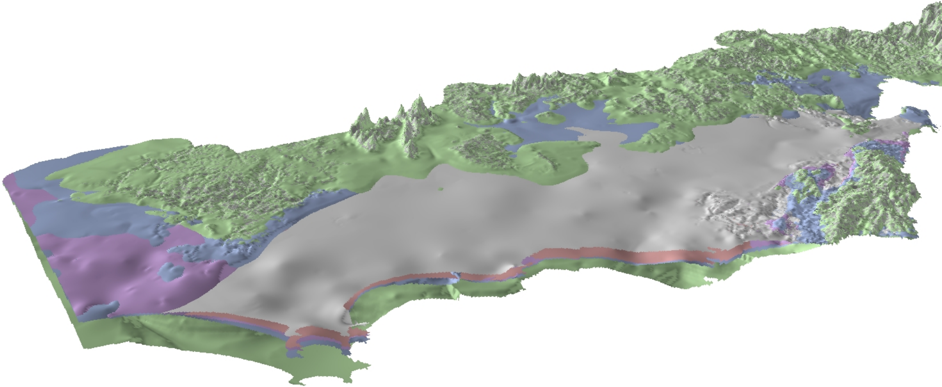
Conclusions cont.

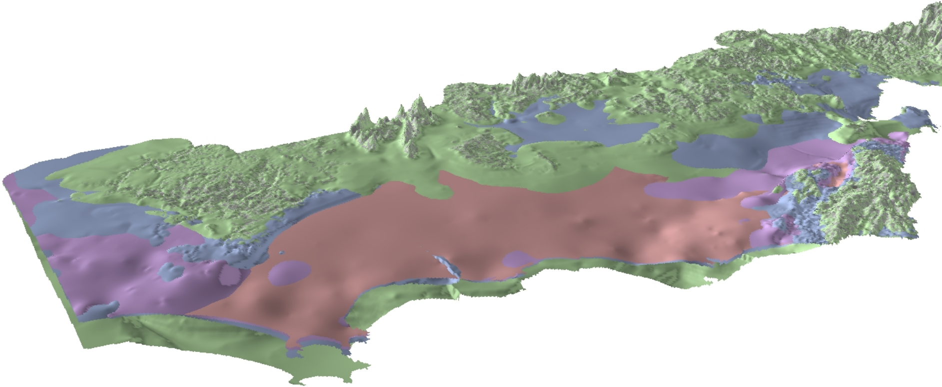
- Could be linked to surface water flow and quality, rainfall, evaporation and recharge information.
- NWC study - nationally consistent groundwater information systems

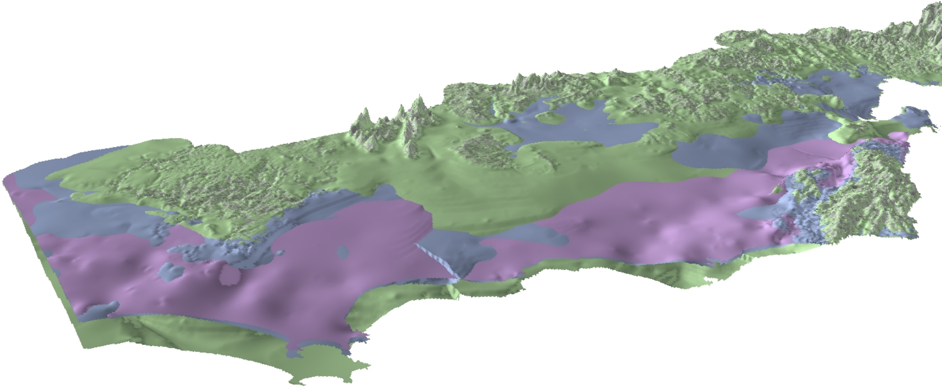


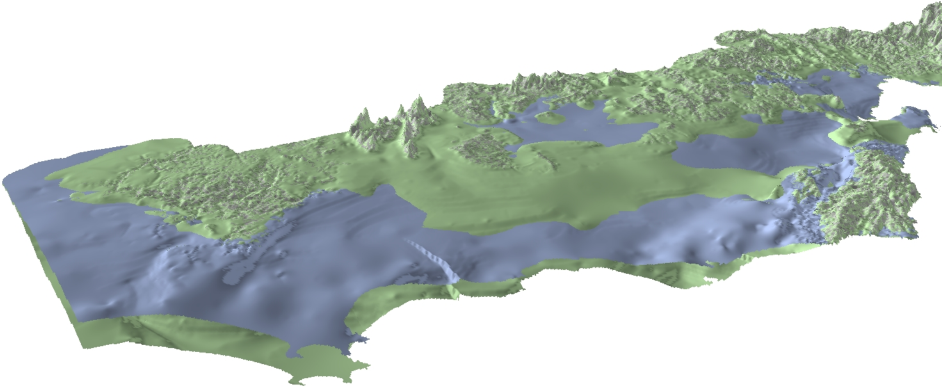


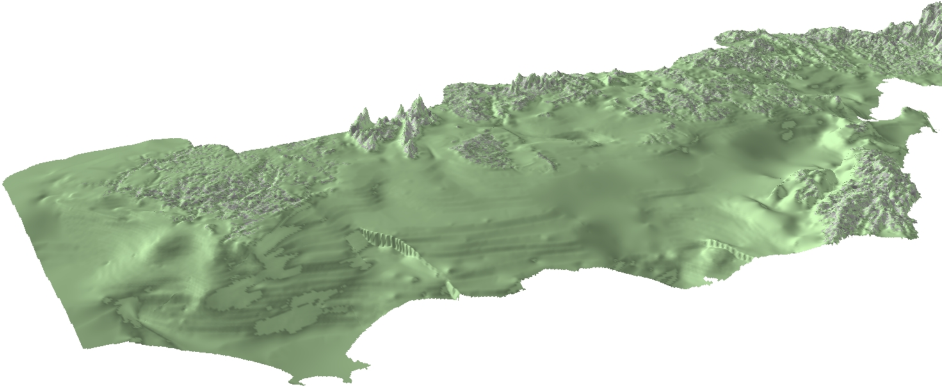












HYDROGEOLOGICAL MAPPING

Terry Flynn

3D Hydrogeology Workshop

Canberra September 2009

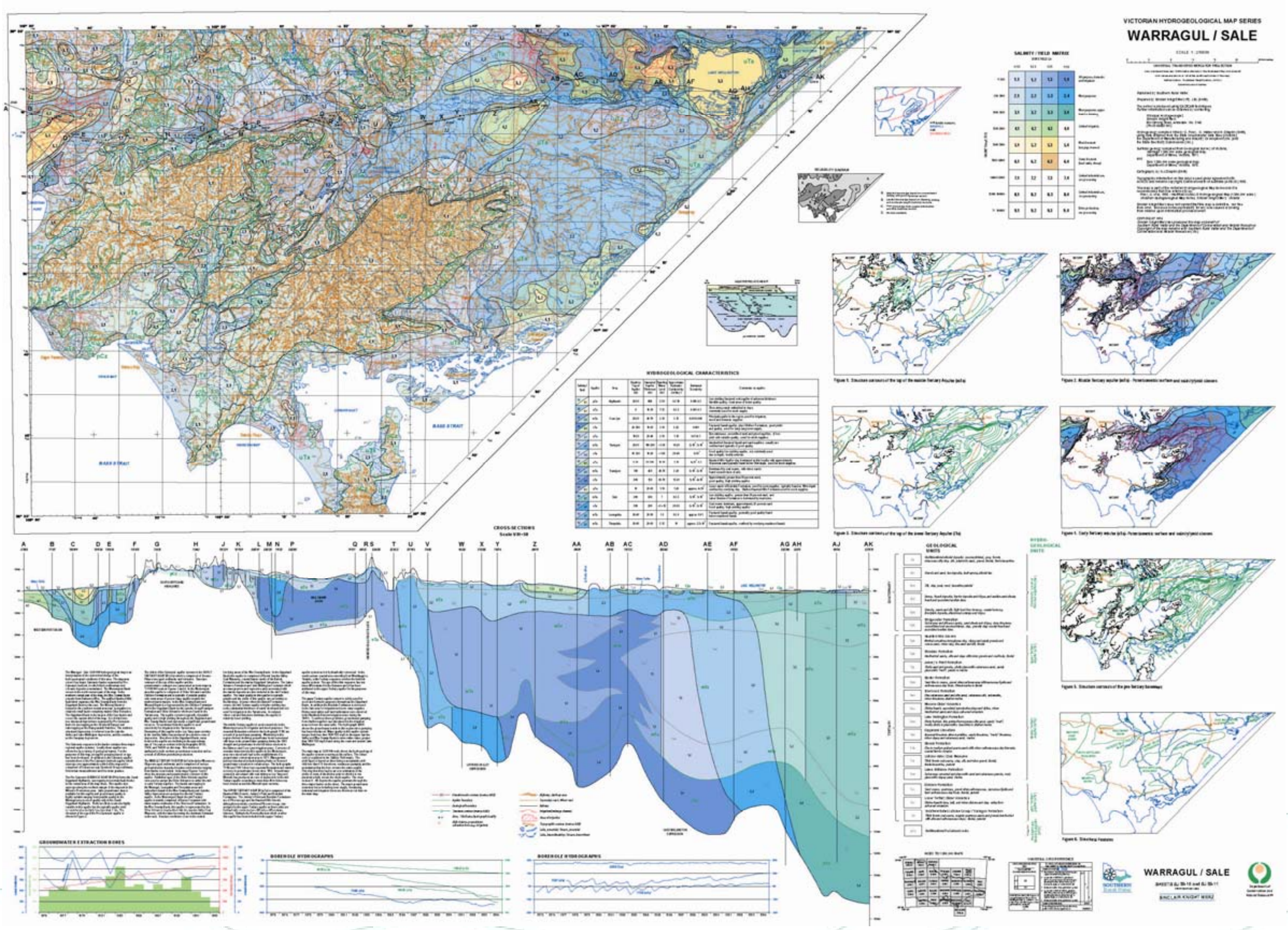
INTRODUCTION

- SRW manages licensing in southern Vic
- Our stakeholders are state government, CMAs, other agencies, licence holders and community
- Have a responsibility to comply with government regulation (Water Act) in decision making
- Licensees have an obligation to adhere to Water Act
- The rules that implement the regulation are evolving and often open to interpretation and dispute

BACKGROUND

- Dealing with a dynamic system (climate, land use, water development)
- Lots of pieces of information (bore data, groundwater levels, water quality, rainfall, usage, anecdotal)
- Many views (retain natural environment, priority of access, market based)
- We are often third dog in the argument
- We need an informed discussion
- We need to protect our business

HYDROGEOLOGICAL MAPS – pictures and stories



3D MAPPING FEATURES

- Information geo-referenced
- Identifies information in 3d
- Maps are renewable
- Can be analysed with other information (eg GIS)
- Numbering system that relates geology, Groundwater Management Units, Hydrogeological Units etc, trading zones
- Can add time series eg licence info, usage, hydrographs
- All groundwater projects in our region can relate

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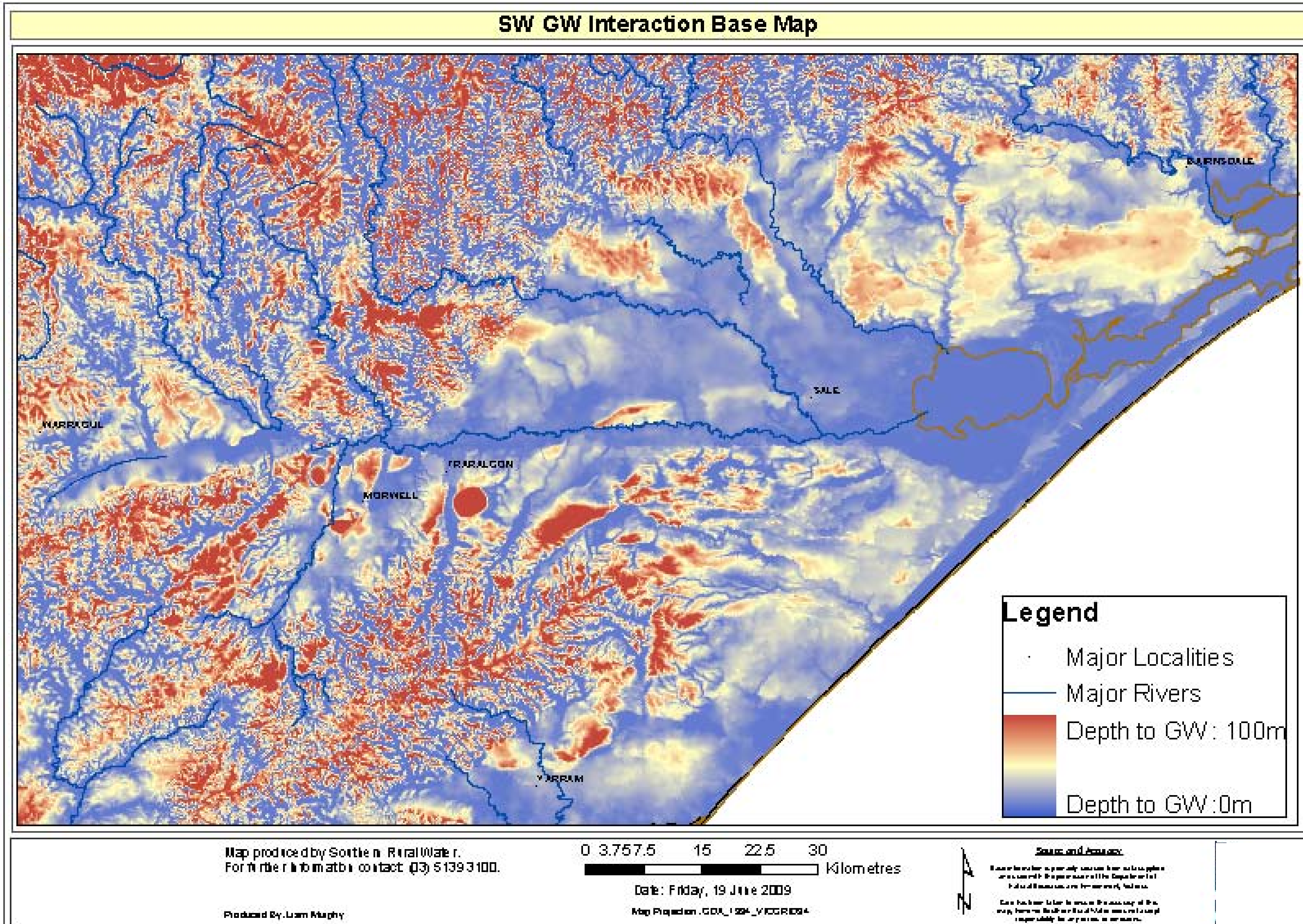
GROUNDWATER MAPS



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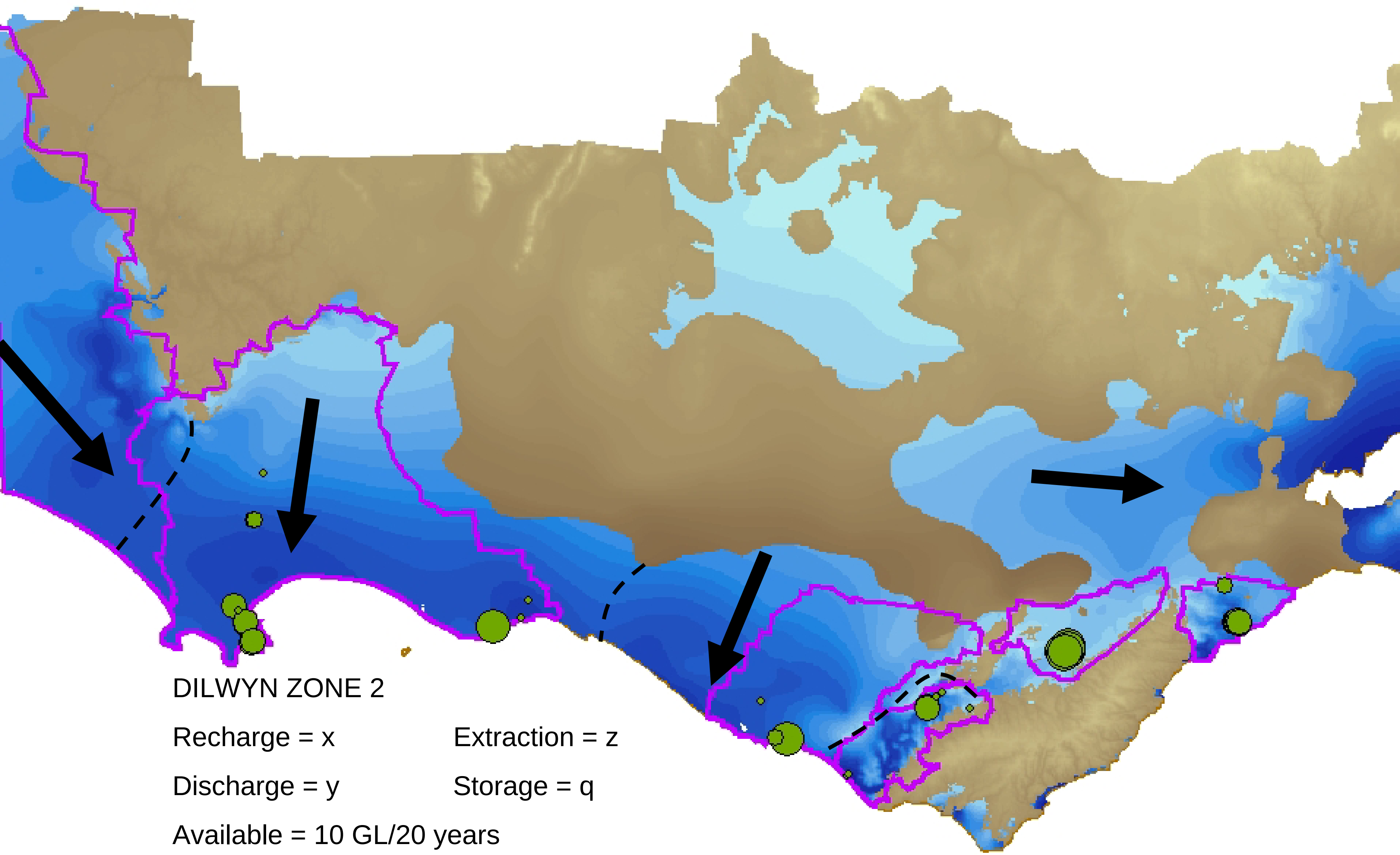
CONCEPTUALISATION



DILWYN ZONE 2

Recharge = x

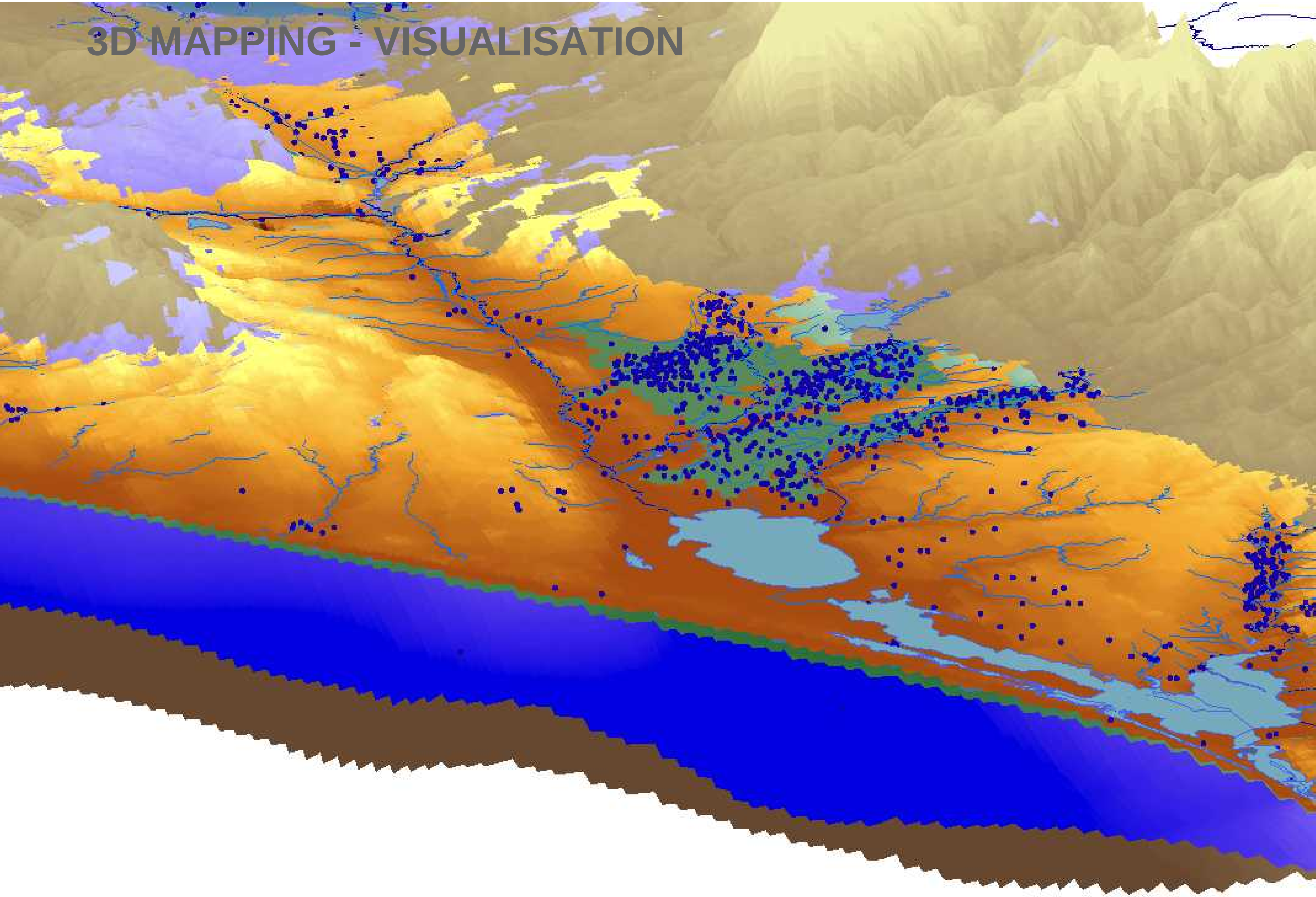
Extraction = z

Discharge = y

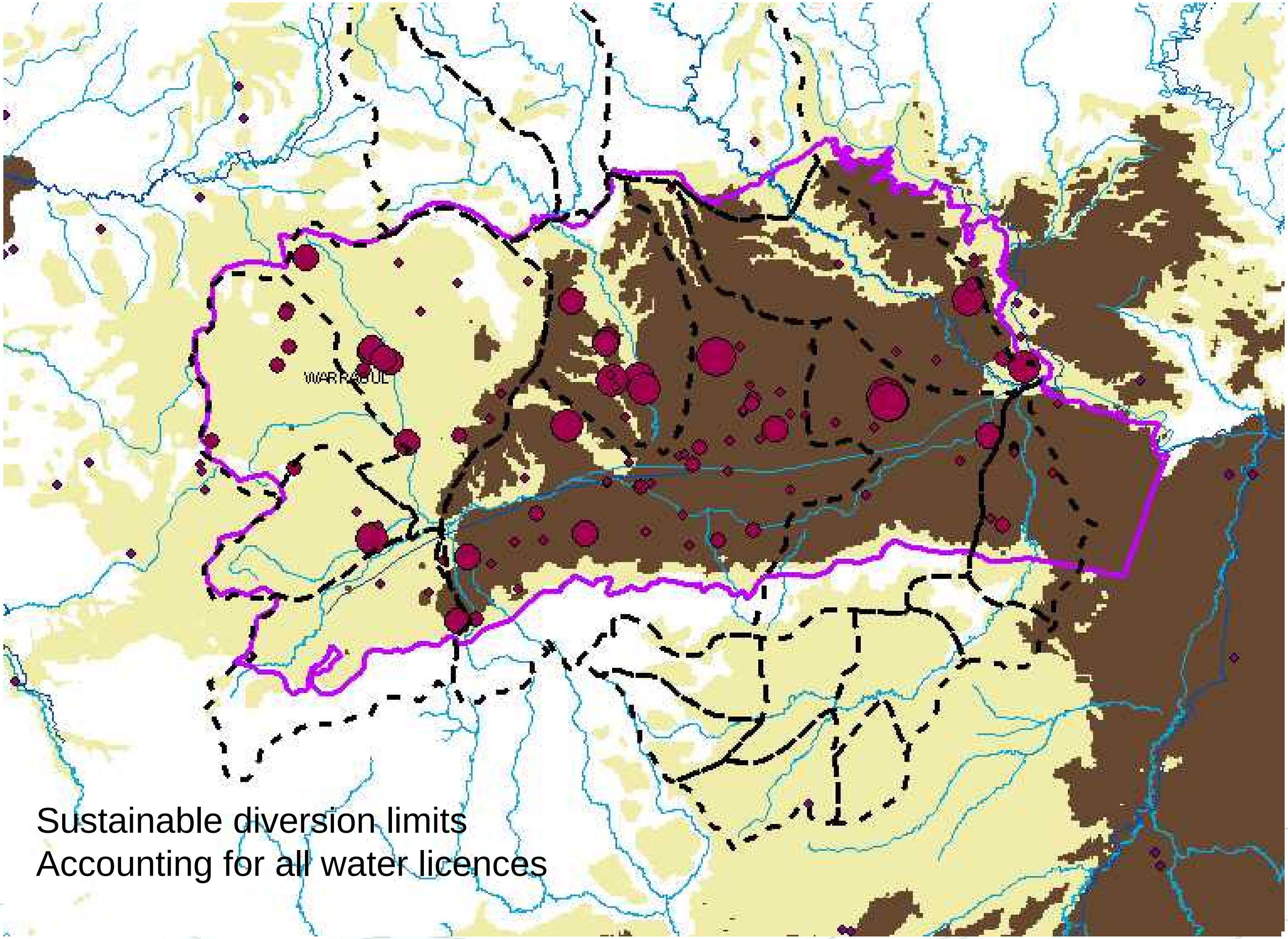
Storage = q

Available = 10 GL/20 years

3D MAPPING - VISUALISATION



EXAMPLE Moe GMA – Latrobe River catchment



Sustainable diversion limits
Accounting for all water licences

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WHERE TO – SOUTHERN GROUNDWATER FUTURES

- Hydrogeological Mapping
- Groundwater Atlas
- Groundwater Strategy

WHERE TO – GROUNDWATER ATLAS

How will the Atlas be used?

The Atlas development will;

- Analyse our system and express it as information.
- Provide information to our stakeholders and licence holders.

The outcomes will be that;

- We will better understand our system
- Stakeholders and licence holders will better understand our system
- An informed discussion about how to improve our management.

WHERE TO – PARALLEL INITIATIVES / OUR STRATEGY

Sustainable Water Strategies – *SWS enables regional implementation*

Local management rules, dairy licences, private rights

Water Register project – *Align licence data with mapping system*

eg capture bore locations via GPS, bore screen-depth, licensed volume in each aquifer and actual water extraction.

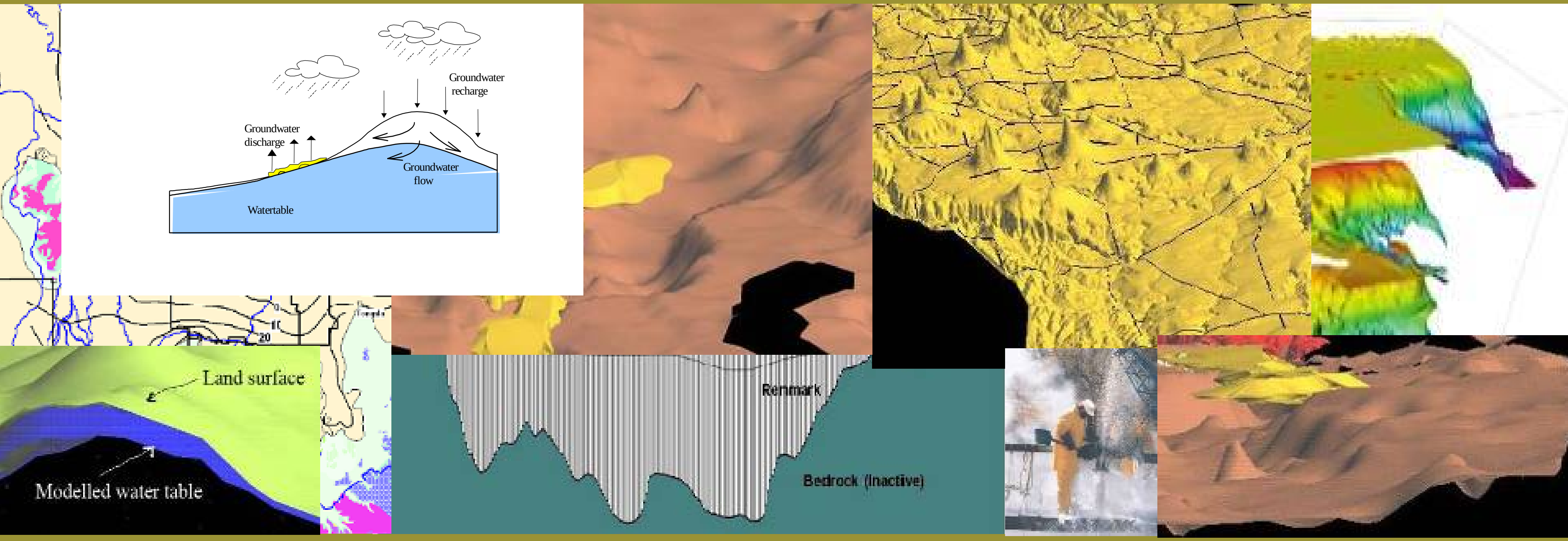
National Water Commission/BoM - *extend the mapping concept nationally.*

a prototype project with the BoM (subject to NWC and BoM funding) to use SRW's 3D database as a proof-of-concept for other Australian jurisdictions. The project will further develop time-series support and visualization.

CONCLUSION

Hydrogeological mapping

- Allows us to better manage to aquifers and connected systems.
- Provides an opportunity to quickly analyse hydrogeology.
- Dramatically improves the presentation of groundwater information.
- The process of developing the maps creates a new understanding of groundwater and organisation of data.
- Is a new platform for storing, interpreting and reporting data.
- Establishes SRW as a credible manager of groundwater.



3D Hydrogeology for engaging groundwater users and managers

Bruce Gill

1st Australian 3D Hydrogeology Workshop, 31 Aug -1 Sept 2009
Geoscience Australia, Canberra

Victoria The Place To Be
DEPARTMENT OF PRIMARY INDUSTRIES | future farming systems research

Talk Outline

- Study description
- Groundwater Resource Management principles
- Study area descriptions
- Survey Planning
- 3D technology implications
- Conclusions

Background of the PhD

- Department of Primary Industries Victoria 3D hydrogeology technologies project
- PhD running in parallel with DPI study, but exploring the ‘human interactions with the technology’ side
- Latrobe University, Melbourne
- Supervisors: Associate professor Dr John Webb and Dr Peter Sale
- Key interactions with Goulburn-Murray Rural Water Authority and groundwater users in 2 study areas
- Commenced August last year

Research Question

- That 3D hydrogeology mapping, resource assessment methods and visualisations can lead to improved groundwater resource management outcomes.
- How?
  - Understand current gw management needs and processes and best management practices
  - Understand gw users and managers needs
  - Survey user and manager to measure current understandings and perceptions of the gw resource
  - Record responses and reactions to 3D hydrogeology outputs in respect to the research question.

Groundwater Resource Management BMP's

- Gw is often the only available supply
- Gw usage almost always privately funded (except town water-supply)
- History of regulation
  - Handled differently in different countries/states
  - Governments always required to act when the resource comes under pressure
  - Quite different from surface water resource scarcity response, due to private nature of gw economics.
  - Tragedy of the commons applies to gw

Groundwater Resource Management BMP's (cont.)

The 'Holy Grail' of 'sustainable yield'

- Numerous references citing the history of this
- Numerous definitions, e.g:
  - Safe yield – 'The limit to the quantity of water which can be withdrawn regularly and permanently without dangerous depletion of the storage reserve' (Lee, 1915)
  - 'Development and use of groundwater at a rate that is renewable' (Mann, 1961), to
  - Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity' (ASCE, 1998)

Groundwater Resource Management BMP’s (cont.)

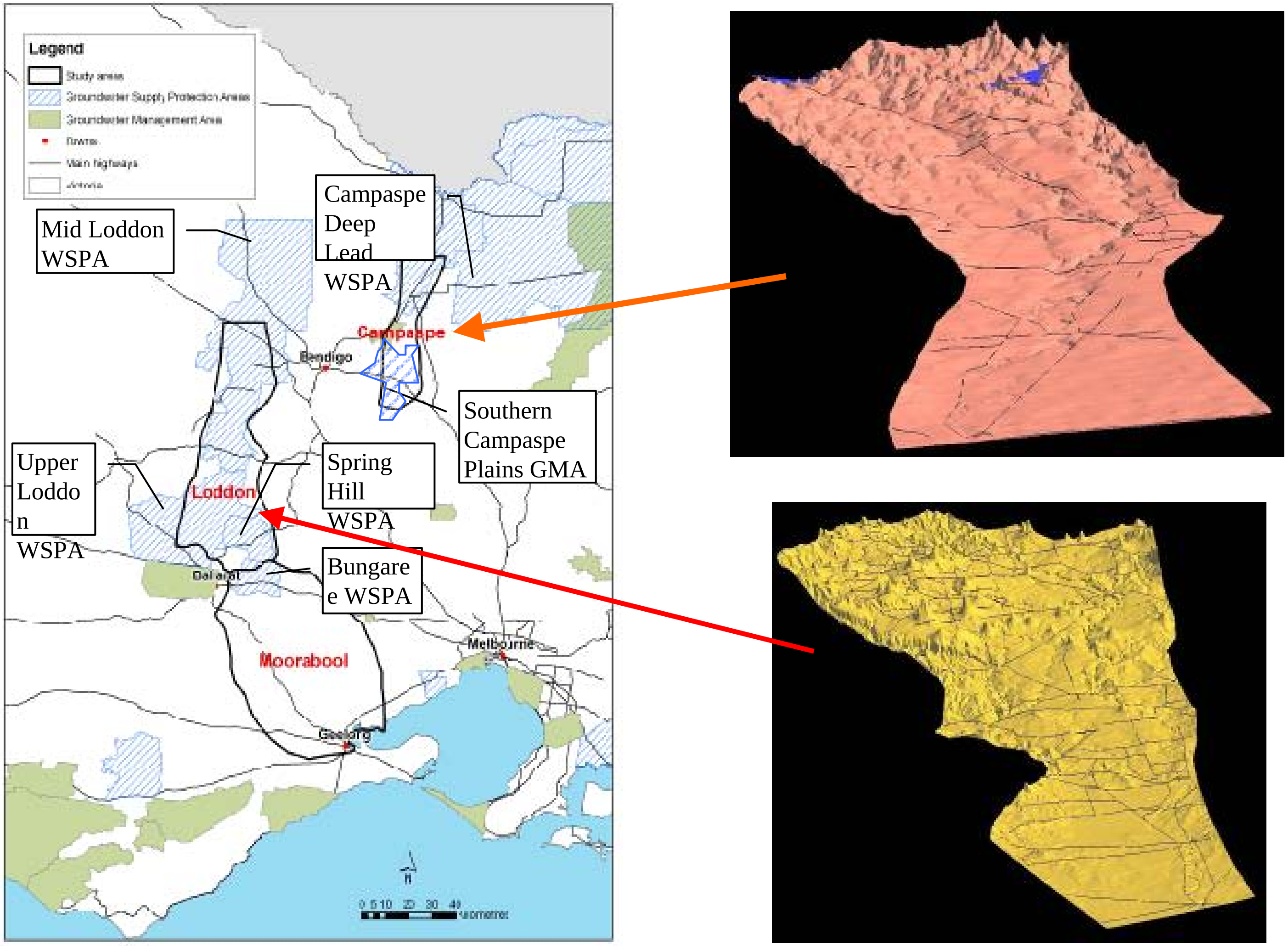
The ‘Holy Grail’ of ‘sustainable yield’ (cont.)

- Maimone (2004) proposes :
- “the idea that there is a single, correct number representing sustainable yield must be abandoned’, and
- ‘it may not be possible to completely address the full complexity of the concept of sustainability in many situations, however, much is gained by an organised approach to developing a working definition, coupled with an **adaptive management approach**’

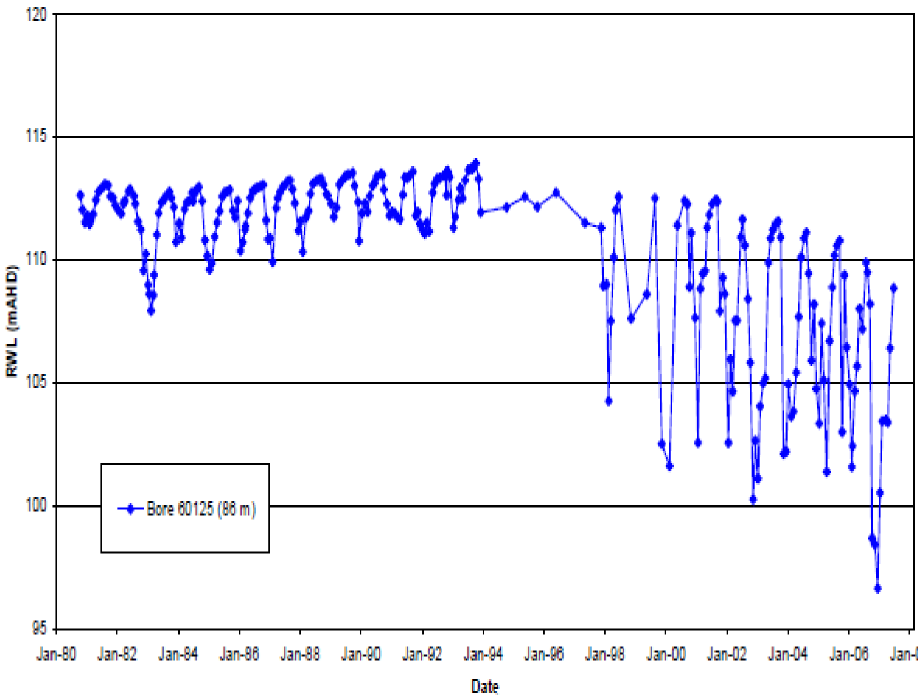
This seems to be where most jurisdictions have headed, eg:

- Kansas (Sophocleous, 2000)
- Spain (Lopez-Gunn et al, 2006)
- Victoria (DNRE, 1998) – PAV assessments established a ‘working definition’ that started a process.

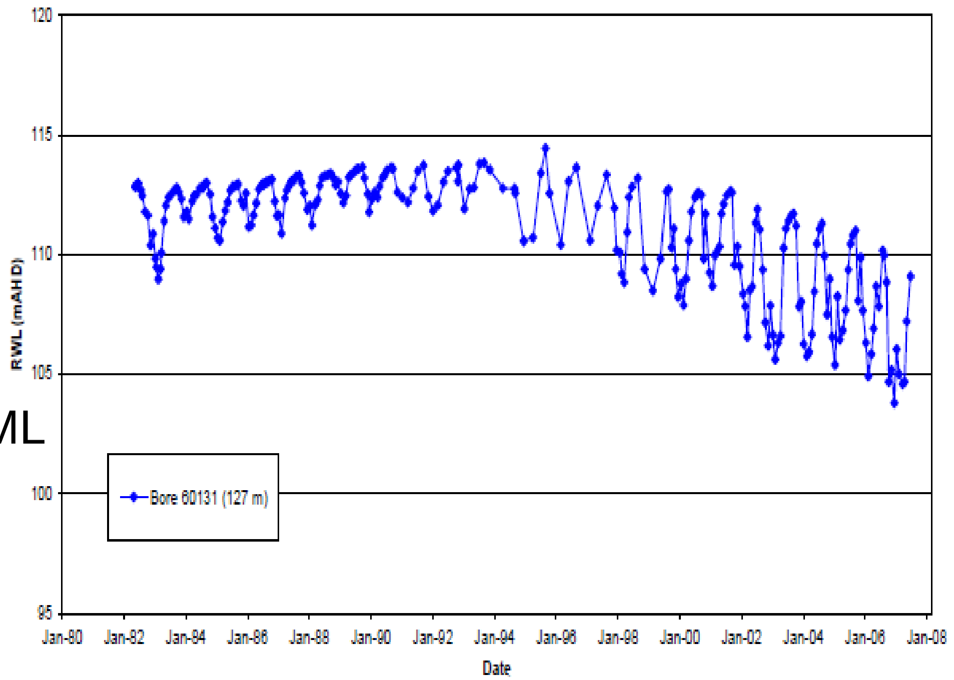
Study area background



Study area background (cont.)



Groundwater declines in the Campaspe Management Area



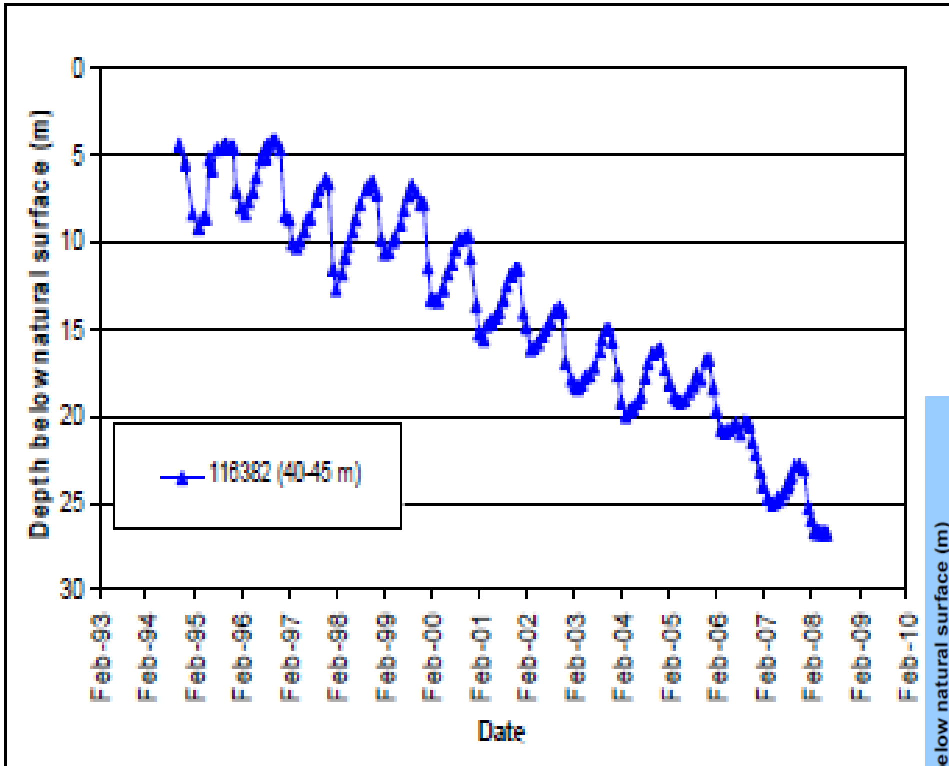
Permissible Consumptive Volume: 47,252ML

Licensed allocation: 46,267 ML

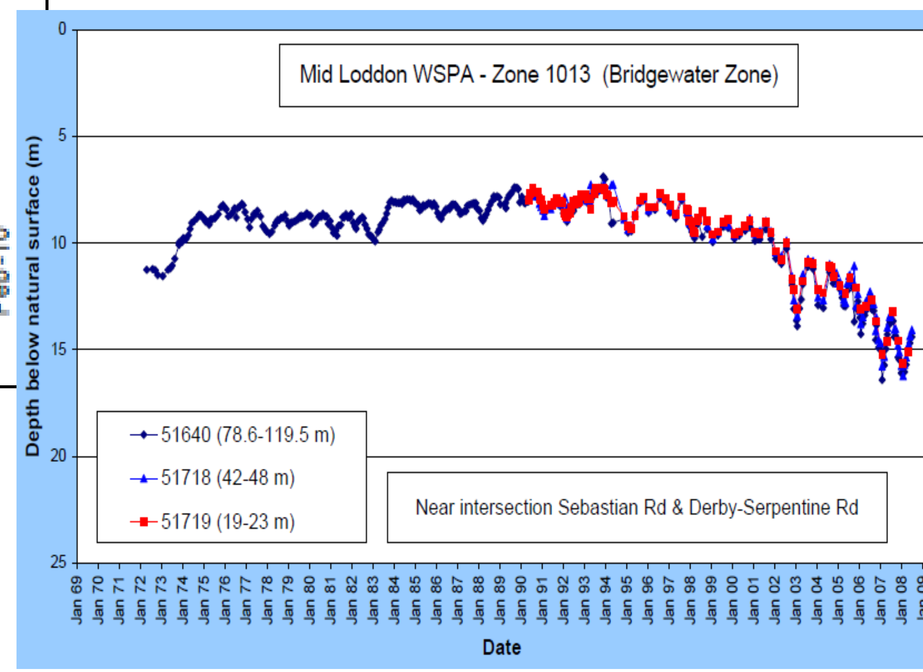
Metered usage (2007) 34,762ML,

(50%in 2008 due to declines)

Study area background (cont.)



Groundwater declines in the Upper Loddon (Spring Hill) Management Area



Where might 3D hydrogeology fit in?

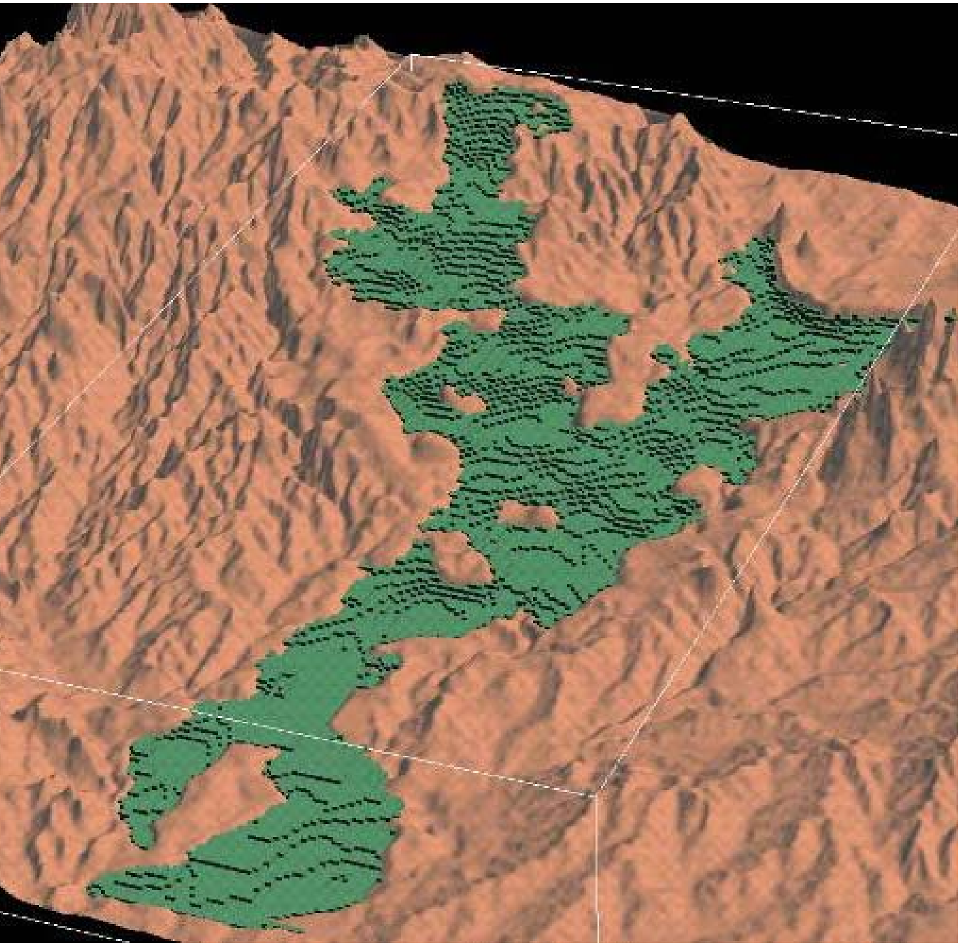
Lopez-Gunn & Cortina (2006) highlight that the more successful implementations of gw management plans in Spain have been where there is cooperation between users and the responsible authority.

A key factor in establishing this is a shared understanding of the resource

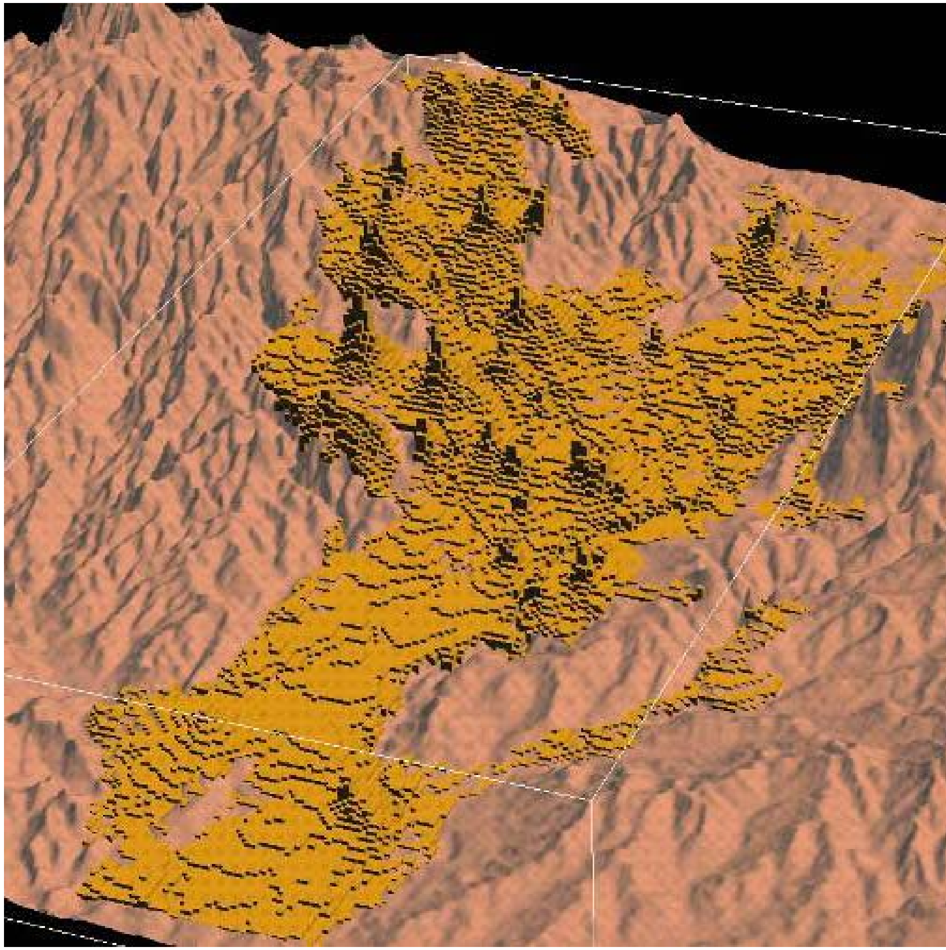
Traditional analogue renditions of the subsurface are clearly limited for a lay audience

What sort of visualisations will be more valuable?

How can issues of reliability, uncertainty, probability be handled to gain acceptance of such constructs?



Upper Loddon Deep Lead



Upper Loddon Volcanics

Survey Methodology

- Likely to be a wide range of gw understanding, from wire wagglers to learned operators and decision makers
- Social Research Methods need to be understood, e.g. Research theory, objectivity, quantitative vs. qualitative.
- This work, in relation to gw resource understanding and management needs, seeking to:
  - Understand human behaviour and action
  - Find possible solutions to social issues
  - Empower and liberate people (with knowledge)
  - Make predictions (what products might fill the needs best)
  - Test the value of some visualisations

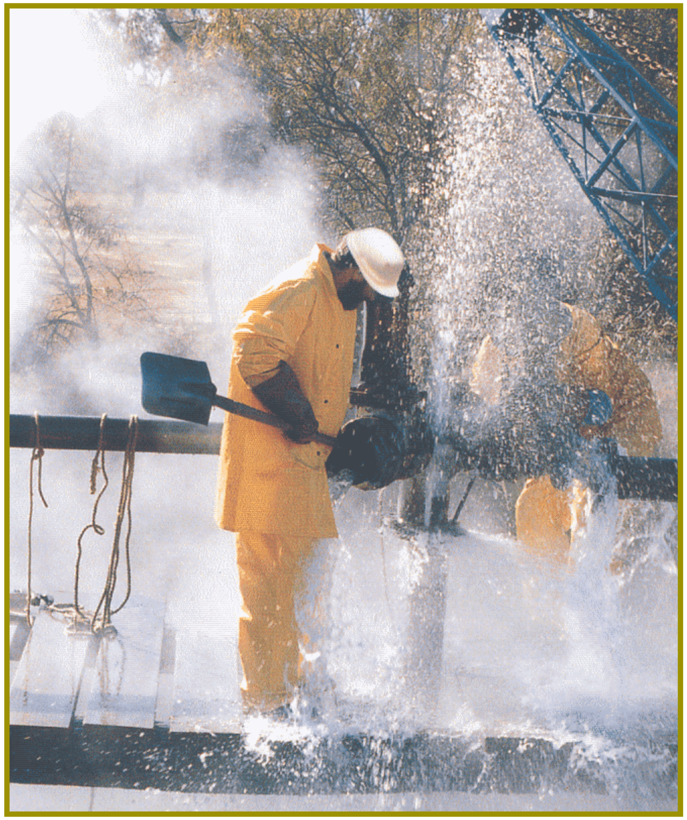
Conclusions

- Early days so far
- A risk that 3D products could be viewed in the same way as numerical models – Mysterious Black Boxes
- Need to be careful not to over-sell the potential of 3D methods
- Hence the importance of testing products and outputs with real stakeholders
- Very interested to see what other people are finding

b1

b1 What do you have in mind for this point here?
bg20, 24/08/2009

Any Questions?



Community Engagement for Development and Application of 3D Visualisation Models
- *a 'two edged sword'*

First Australian 3D Hydrogeology Workshop
31 August – 1 September, 2009

Andrew Todd, Malcolm Cox, Allan James
Queensland University of Technology.

Institute for Sustainable Resources

Ultimate Objective ?

➢ **We have appropriate management practise for water resource sustainability.**

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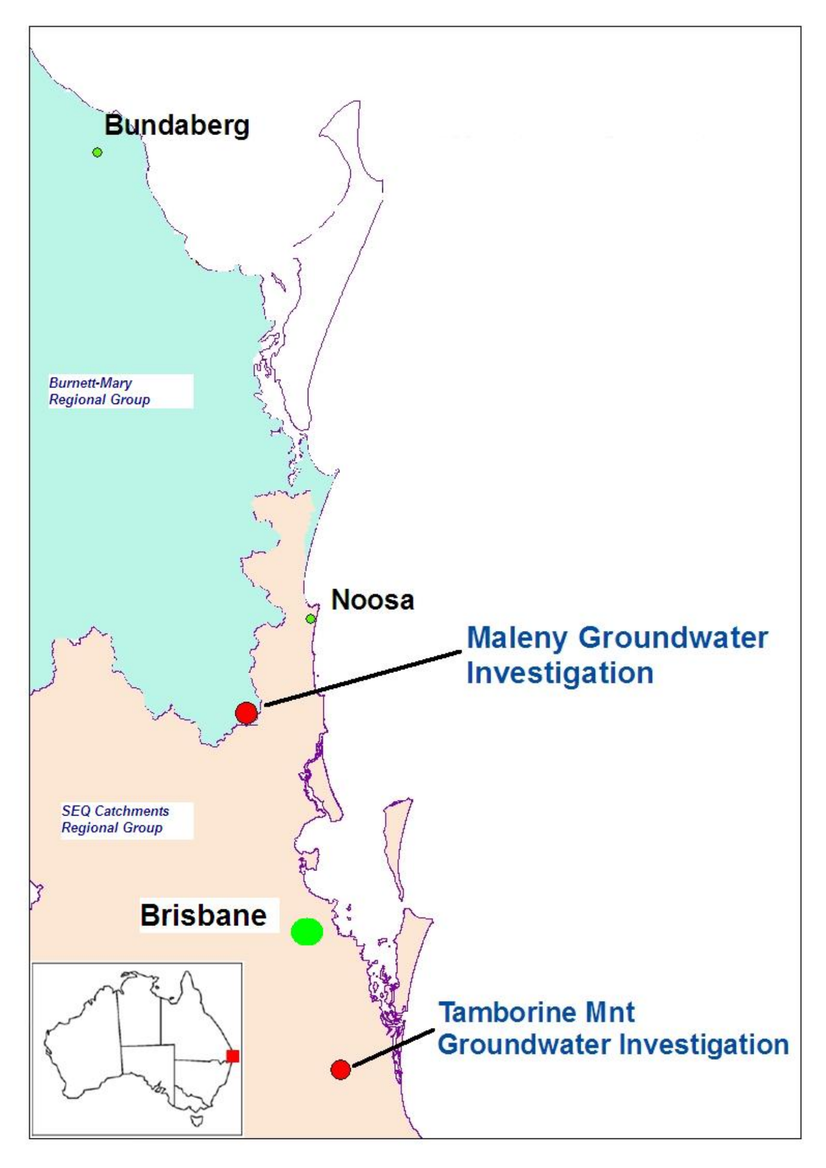
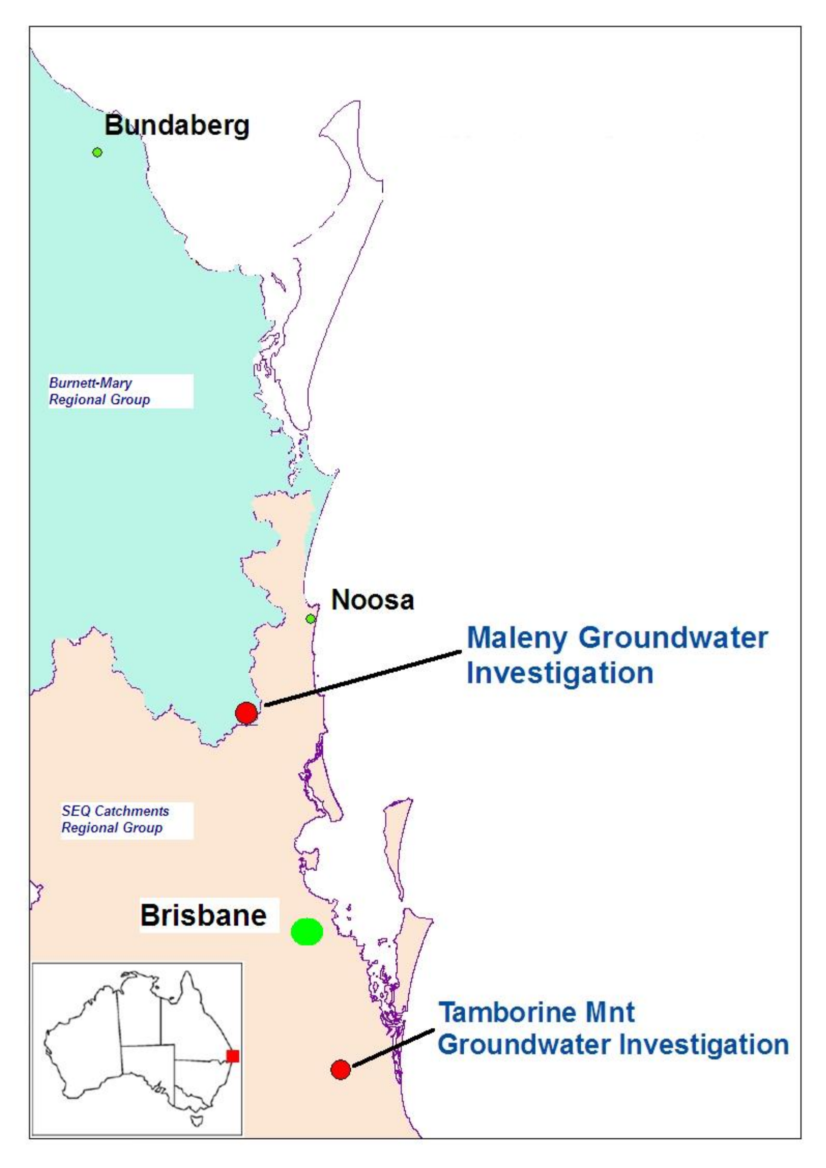
➢**We have appropriate management practise for water resource sustainability.**

Land-holders are the “end of the line” for implementing sustainable water and land use management practise.

Projects Background

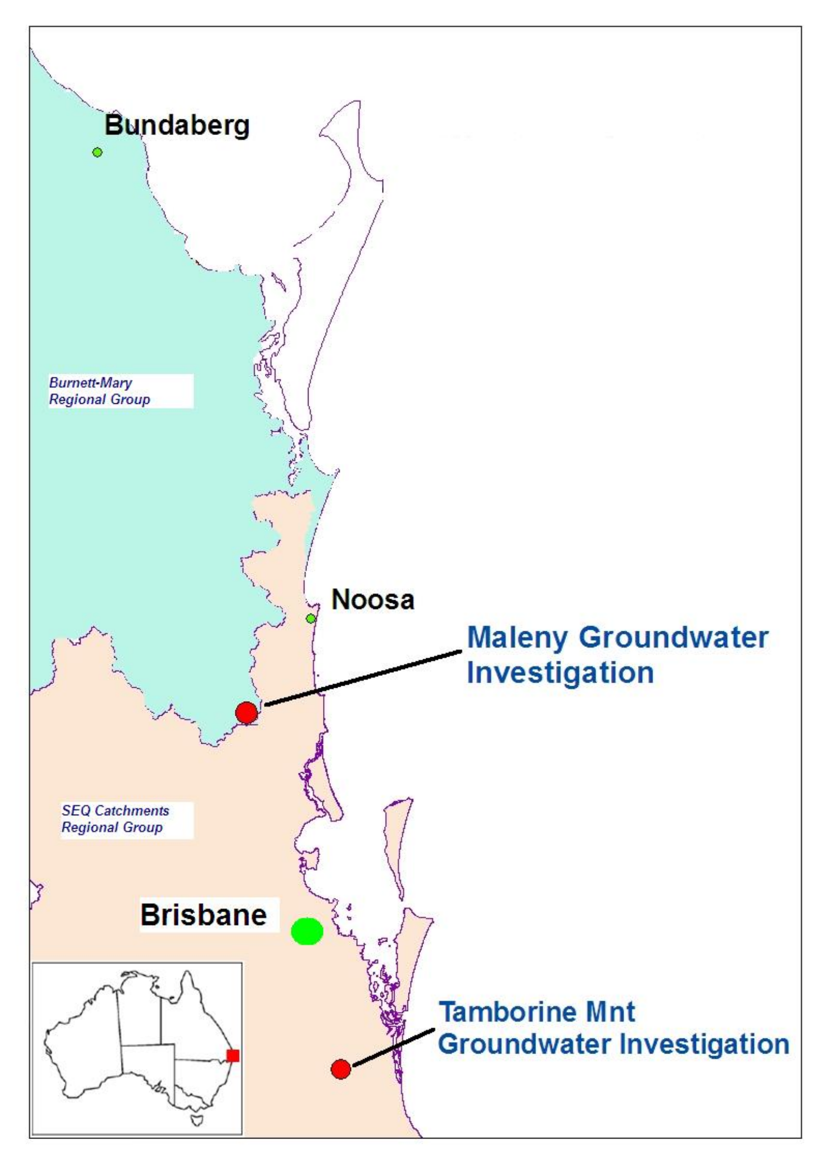


Projects Background



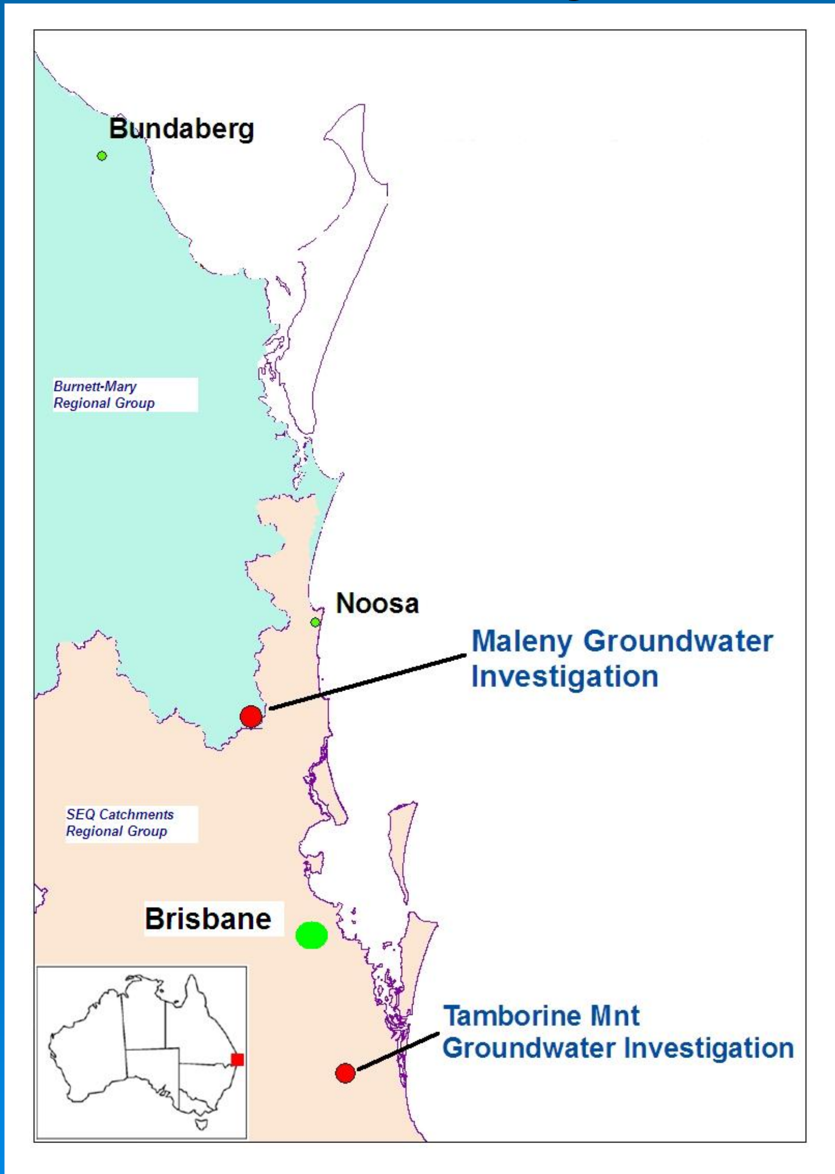
- **Australian Govt. Funding**

Projects Background



- Australian Govt. Funding
- Facilitated by regional Catchment group – SEQ Catchments Ltd

Projects Background



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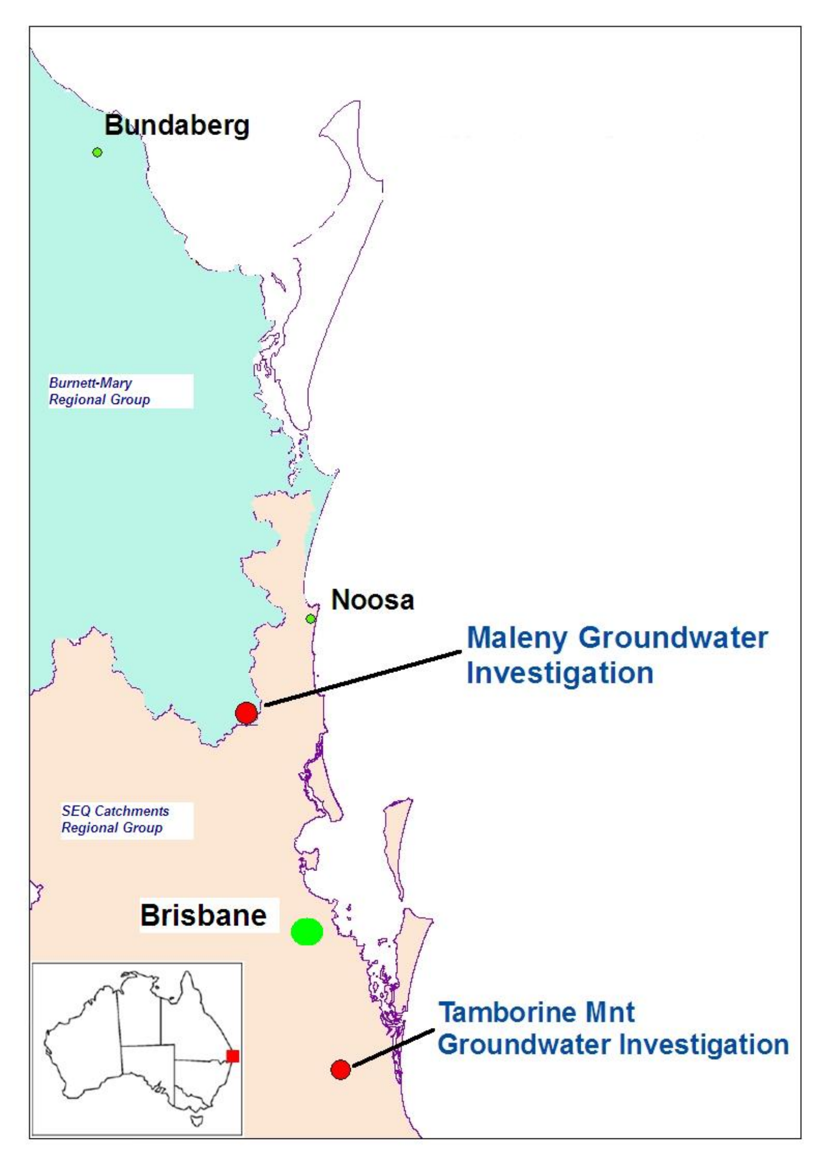
- **Initiated by community groundwater concerns**

Projects Background



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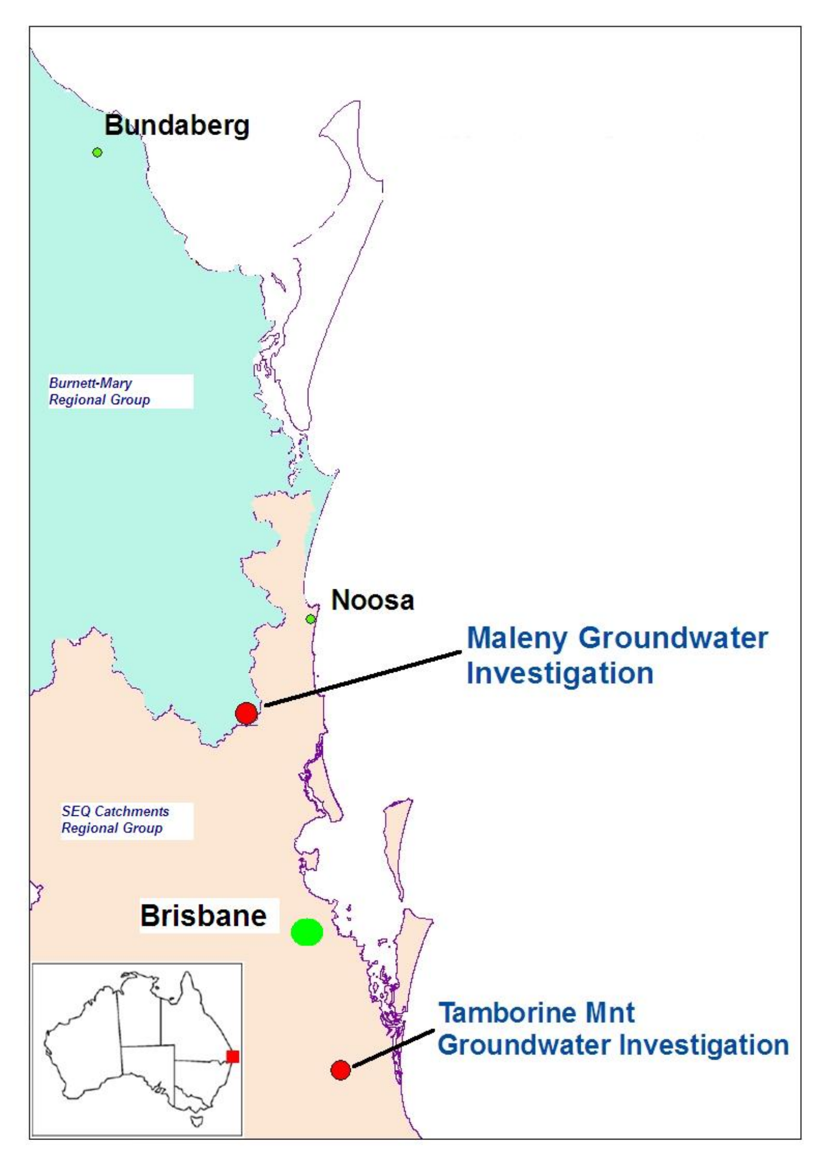
- 1st project implemented by SEQ Catchments Ltd
- 2nd project implemented by QUT

Projects Background



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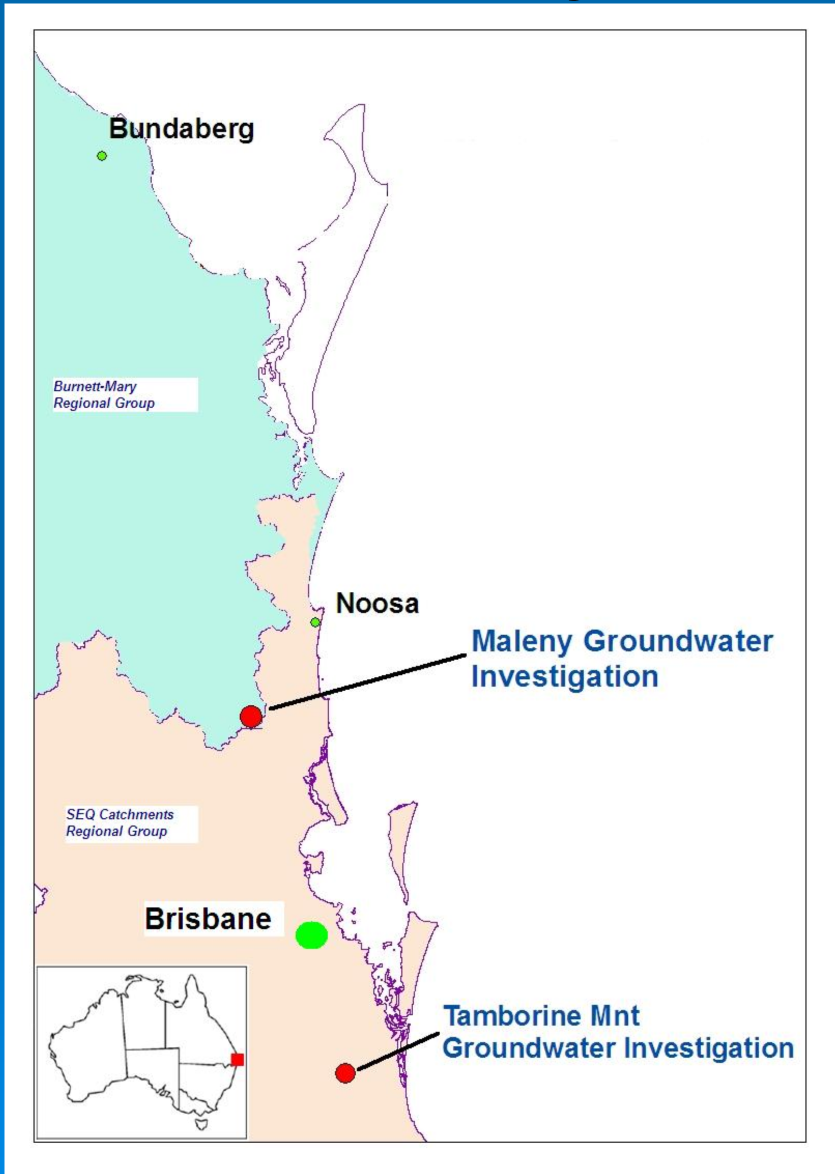
- Initiated by community groundwater concerns.
- 1st project implemented by SEQ Catchments Ltd
- 2nd project implemented by QUT
- **3D Visualisation models developed by QUT**

Projects Background



Management Context:

- DERM has regulatory responsibility
- Undeclared and essentially unregulated
- Rapidly growing peri-urban population
- Mainly stock / domestic, but some commercial extraction
- Groundwater dependent ecosystems

Groundwater Investigation Objectives ?

➢**Provide a conceptual model for use in deciding appropriate management practises for sustainability.**

Need:

➢**To understand how local groundwater systems work;**

➢**Understand impacts of current land and water use**

Groundwater Investigation Objectives ?

➢**Provide a conceptual model for use in deciding appropriate management practises for sustainability**

Need:

➢**To understand how local groundwater systems work;**

➢**Understand impacts of current land and water use**

- ➢**Need data (SWL, rainfall, geology and water quality)**
- ➢**Need to communicate new understandings to land holders and the wider community.**

Typical SEQ Groundwater Investigation Problems

- Lack of local hydrogeological information (compiled);

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Typical SEQ Groundwater Investigation Problems

- **Lack of local hydrogeological information (compiled);**
- **Lack of groundwater monitoring sites (or funding to install them);**
- **Generally poor community awareness and/or understanding of groundwater in the water cycle and land/water use impacts;**
- **Land holder suspicion of authorities;**
- **The Qld Dept Environment & Resource Management (DERM) are under-resourced to look at areas with low regional priority.**

Investigation Approach

Independently engage local community and regional stakeholders to:

- **compile existing information and local knowledge;**
- **monitor existing private bores (SWL & water quality);**
- **Involve community, establish trust and develop opportunities for communication.**
- **Develop a 3D Visualisation model as a communication tool**

Investigation Approach

(Groundwater Investigation Group concept)

Form Collaborative Arrangements (GIG) :

Identify local issues
Establish partnerships
Develop monitoring plan
Establish networks

Resource information collection (2 years +):

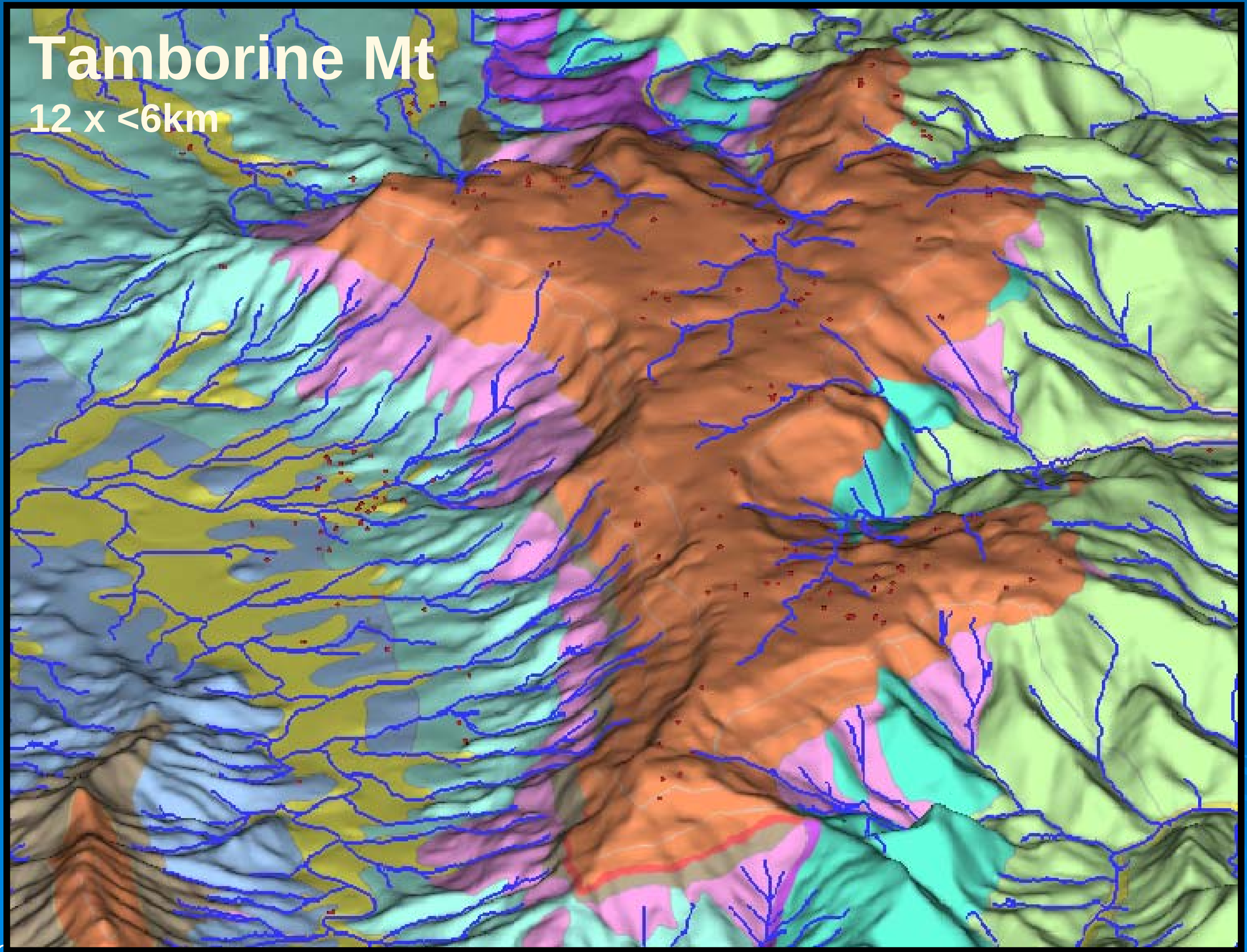
Geology
Fortnightly / daily water levels
Daily rainfall
Monthly quality

Resource Condition Assessment:

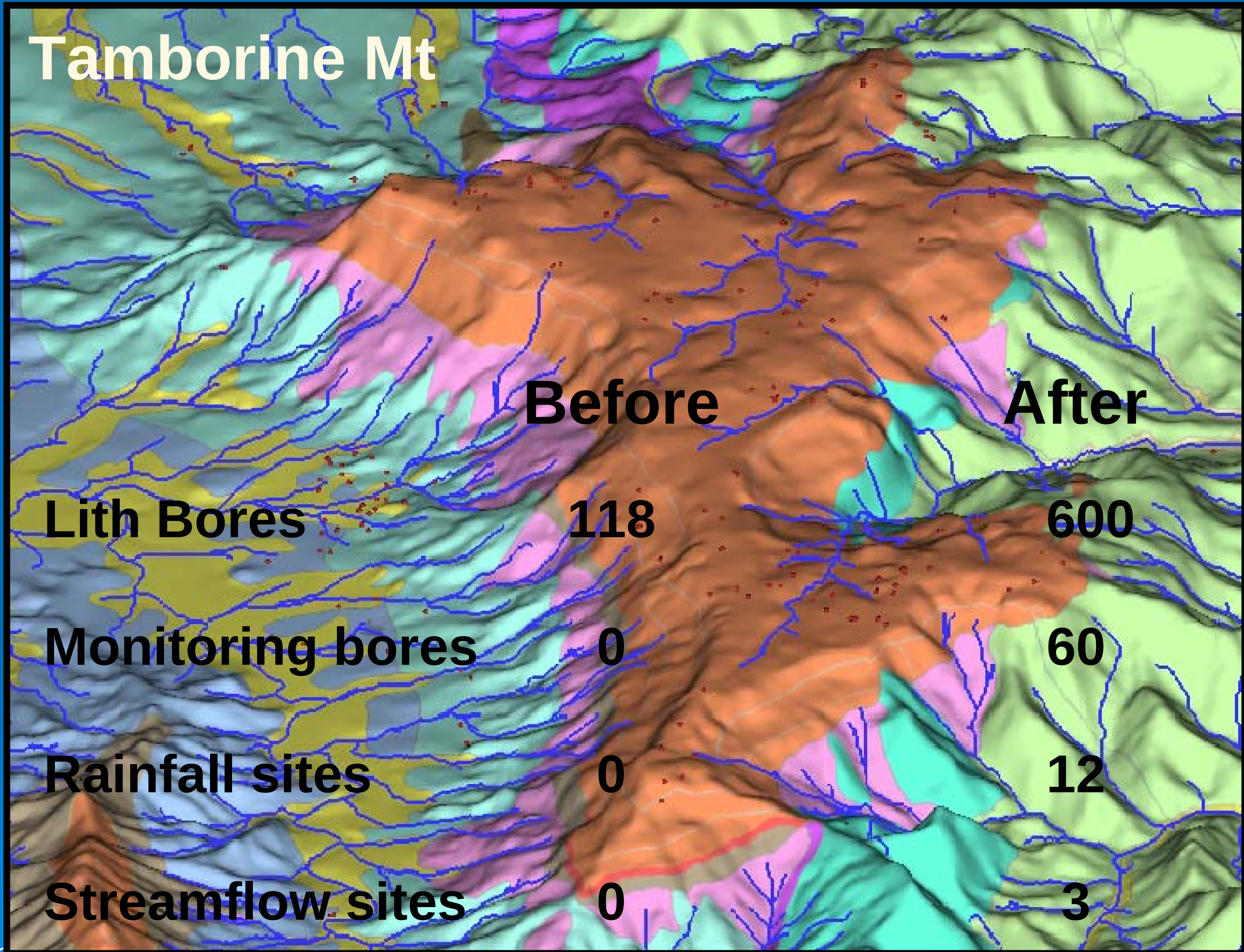
Data management
Data analysis & mapping
Reporting
3D Visualisation

Community Involvement and Feedback

Geological Context



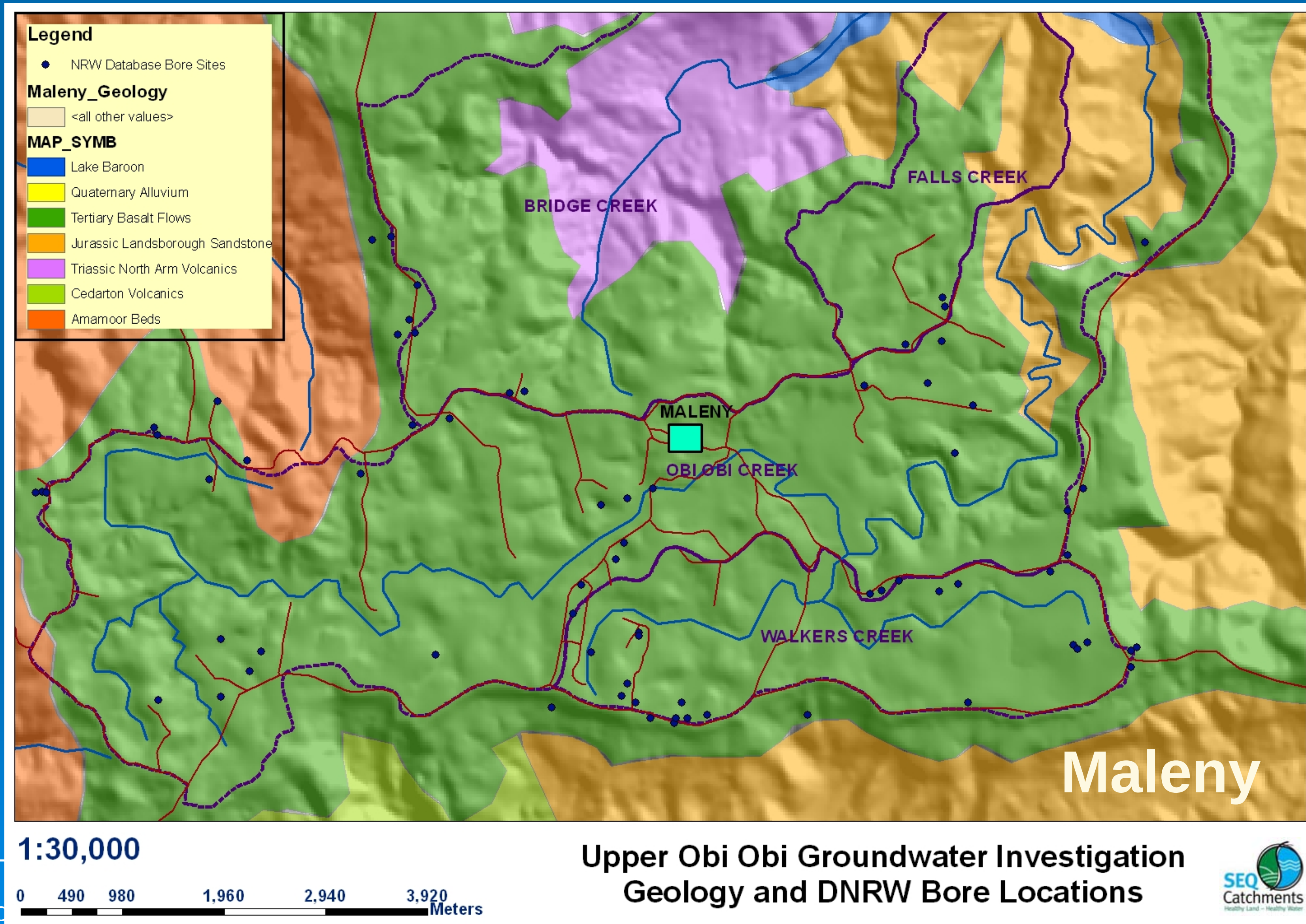
Engagement Results



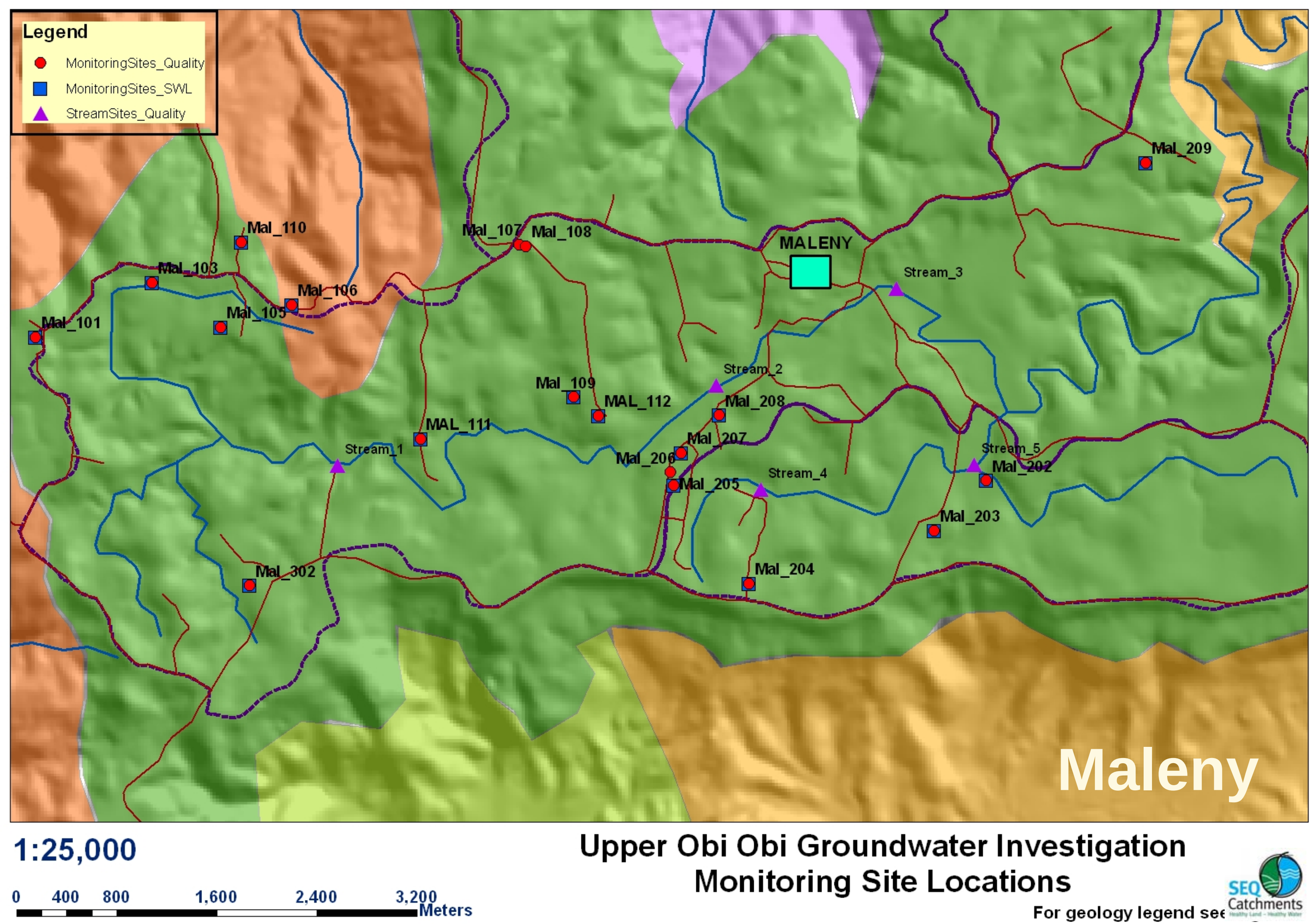
Tamborine Mt

	Before	After
Lith Bores	118	600
Monitoring bores	0	60
Rainfall sites	0	12
Streamflow sites	0	3

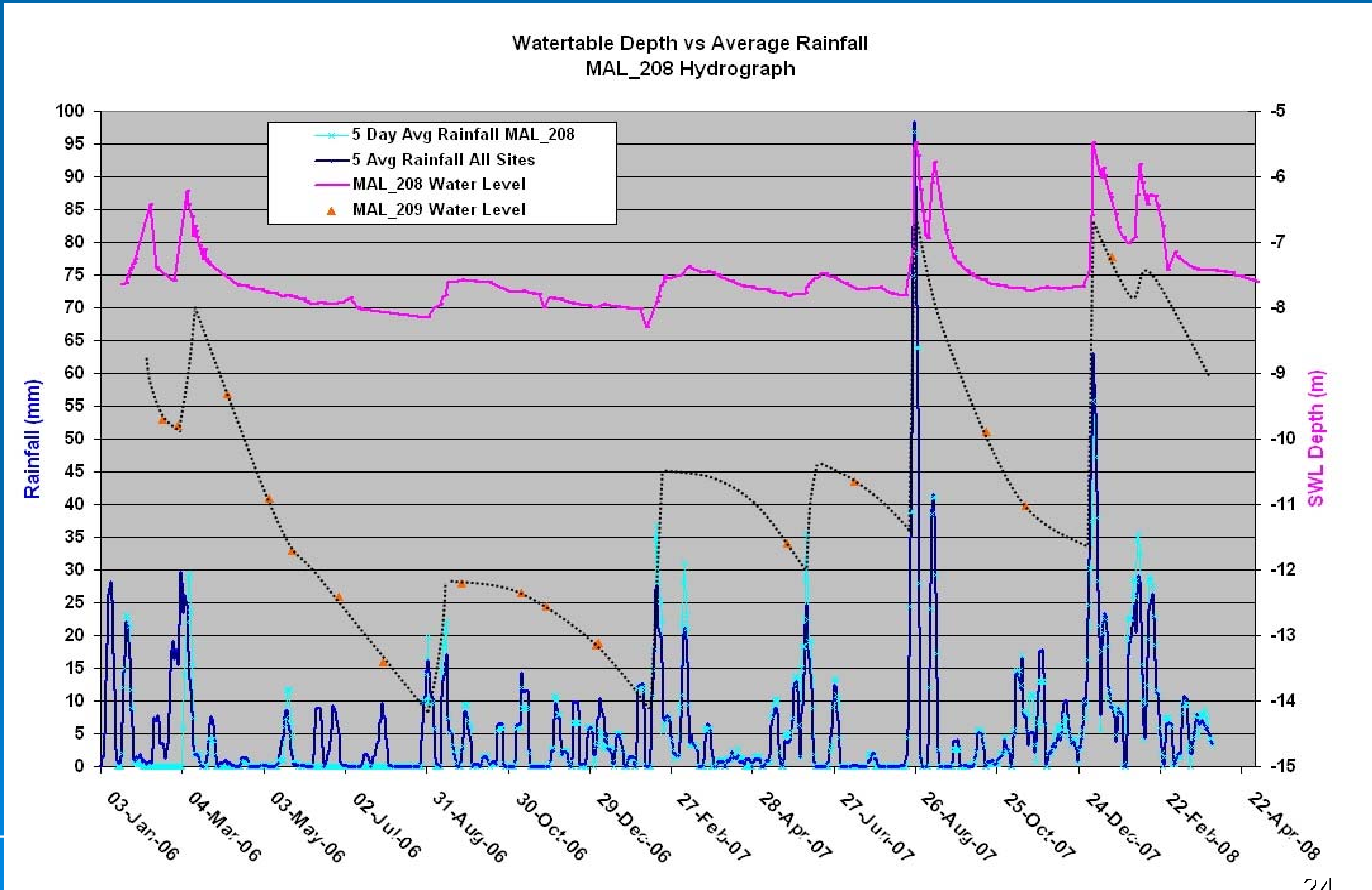
Engagement Results



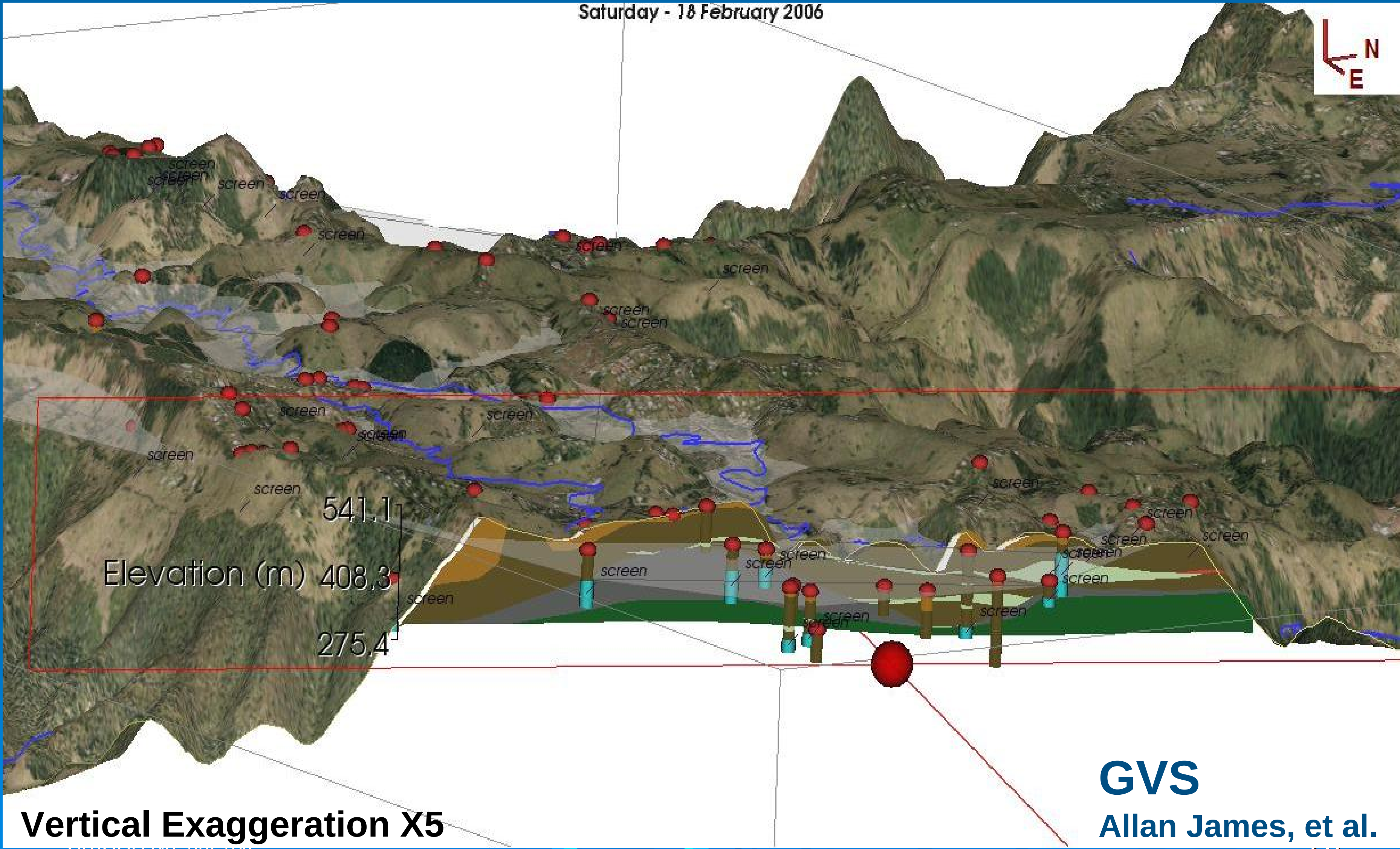
Engagement Results



Investigation Results



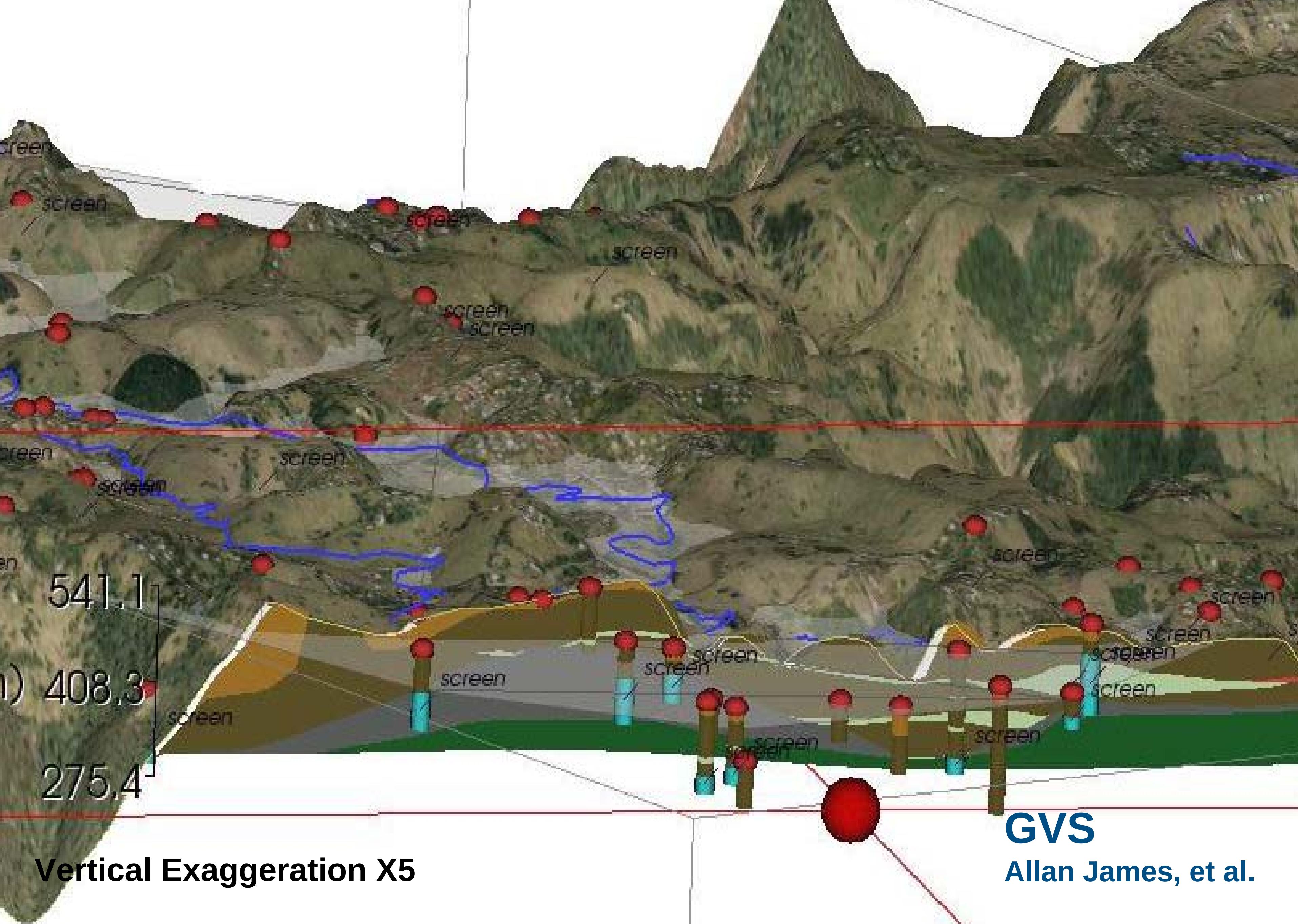
Investigation Results



Vertical Exaggeration X5

GVS

Allan James, et al.


541.1
408.3
275.4
screen
Vertical Exaggeration X5
GVS
Allan James, et al.

Investigation Results

Data Limitations

- not all production bores offered can be accessed for SWL monitoring – manageable using various techniques
- SWL monitoring is affected by pump use - manageable
- Bore construction may mean that several aquifers flow into a bore, implying water quality will be unrepresentative of either.
- Sub-surface lithology is usually dependent on using driller's logs - manageable

Implications

Community engagement benefits:

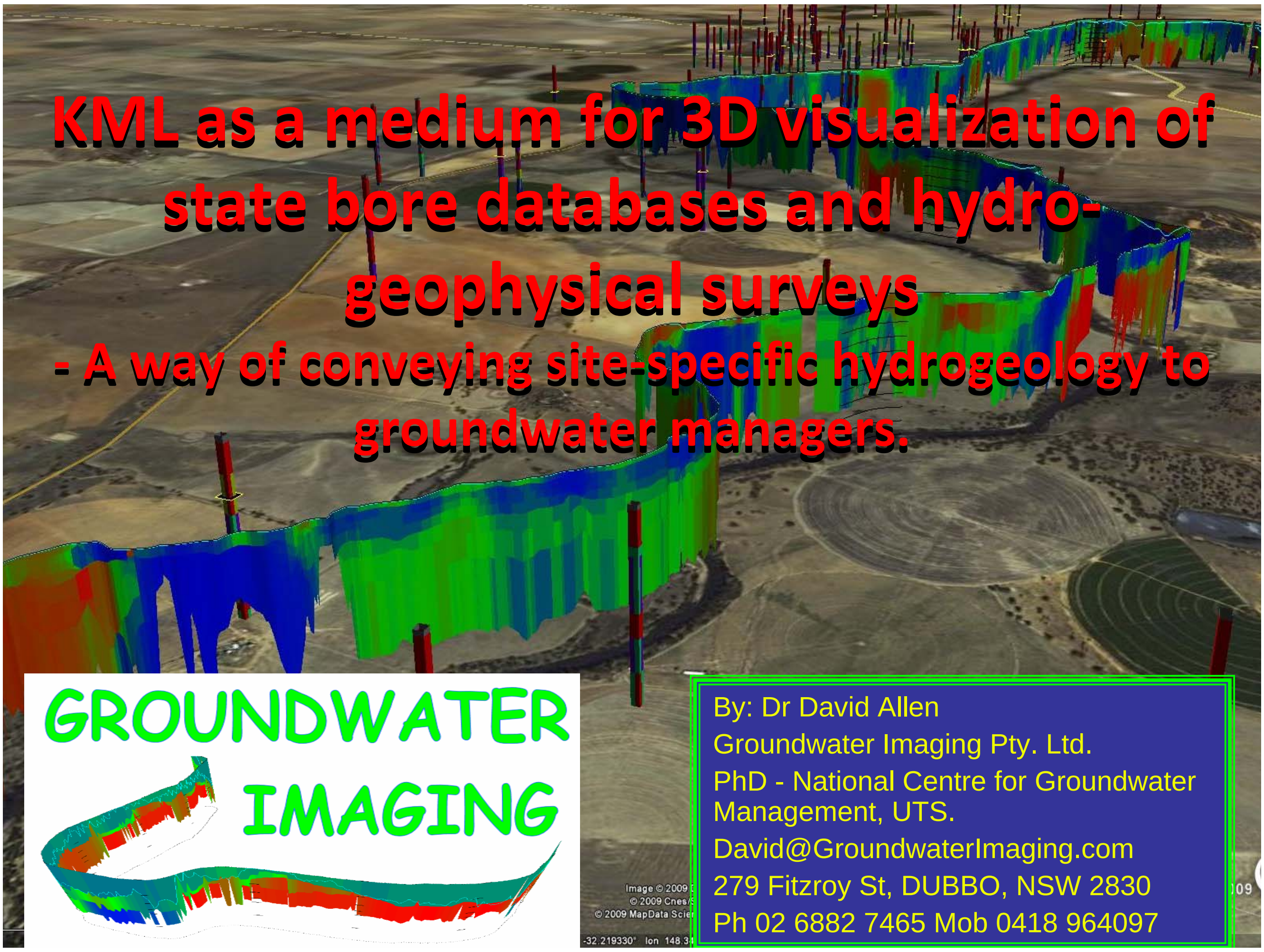
- Low cost source of data

- Community participation and ownership of investigation results encourages acceptance / ownership of recommendations and likelihood of behavioural change;

- 3D Visualisation provides an excellent tool for communication (as well as a data assessment tool).

KML as a medium for 3D visualization of state bore databases and hydro-geophysical surveys

- A way of conveying site-specific hydrogeology to groundwater managers.



GROUNDWATER IMAGING

By: Dr David Allen
Groundwater Imaging Pty. Ltd.
PhD - National Centre for Groundwater Management, UTS.
David@GroundwaterImaging.com
279 Fitzroy St, DUBBO, NSW 2830
Ph 02 6882 7465 Mob 0418 964097

Talk outline

- What is KML
- Why KML in hydrogeology
- Introductory example
- Lithological Log graphics
- Drillers log regularization
- Hydro-geophysical graphics
- Limitations of KML
- Future direction
- The example revisited.

What is KML

Keyhole Markup Language (**KML**) is an XML-based language schema for expressing geographic annotation and visualization on existing or future Web-based, two-dimensional maps and three-dimensional Earth browsers. KML was developed for use with Google Earth, which was originally named Keyhole Earth Viewer. KML is an international standard of the Open Geospatial Consortium.

KML files are very often distributed in **KMZ** files, which are zipped files with a .kmz extension.

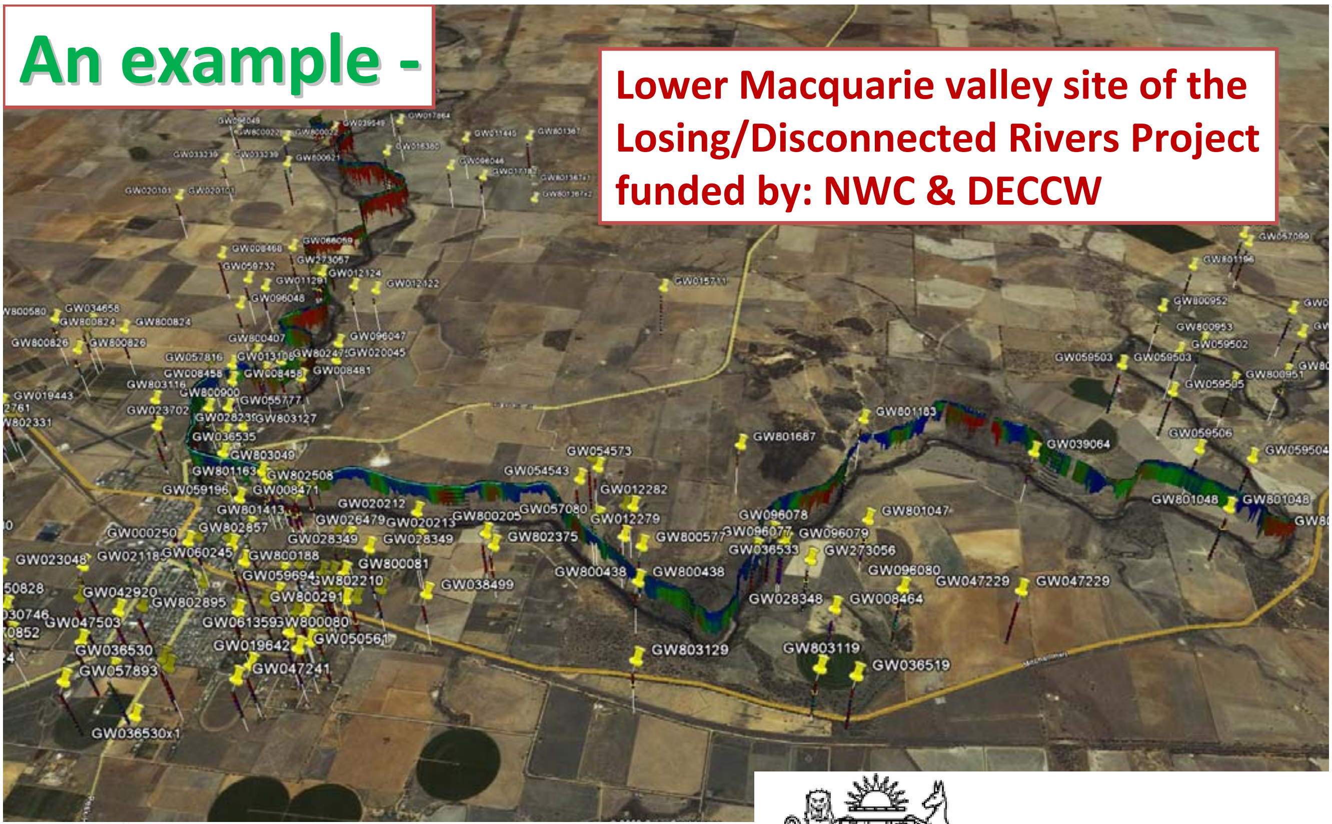
Source:Wikpedia

Why use KML in hydrogeology

- Status Quo – there has to be a better way – DWE employees have been found to be wading through piles of bore log summaries and handwriting pertinent bore details on maps – they need better visualization tools.
- In order to interpret and market hydro-geophysical services I needed to be able to present, in 3D, my data along with bore lithology logs and surface features.
- Farmers do not have a way to quickly synthesize existing bore data prior to siting new bores.

An example -

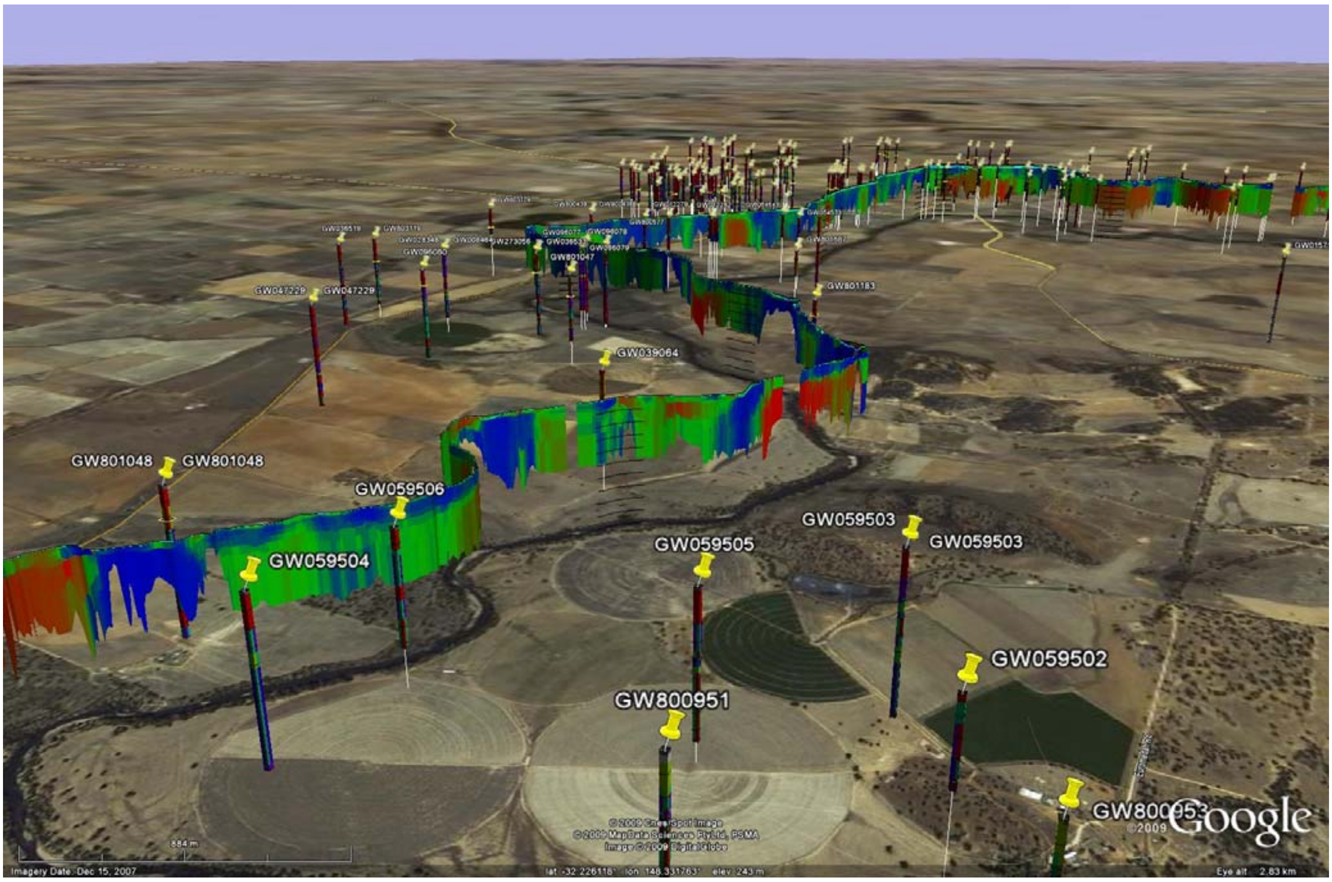
Lower Macquarie valley site of the Losing/Disconnected Rivers Project funded by: NWC & DECCW



Australian Government
National Water Commission

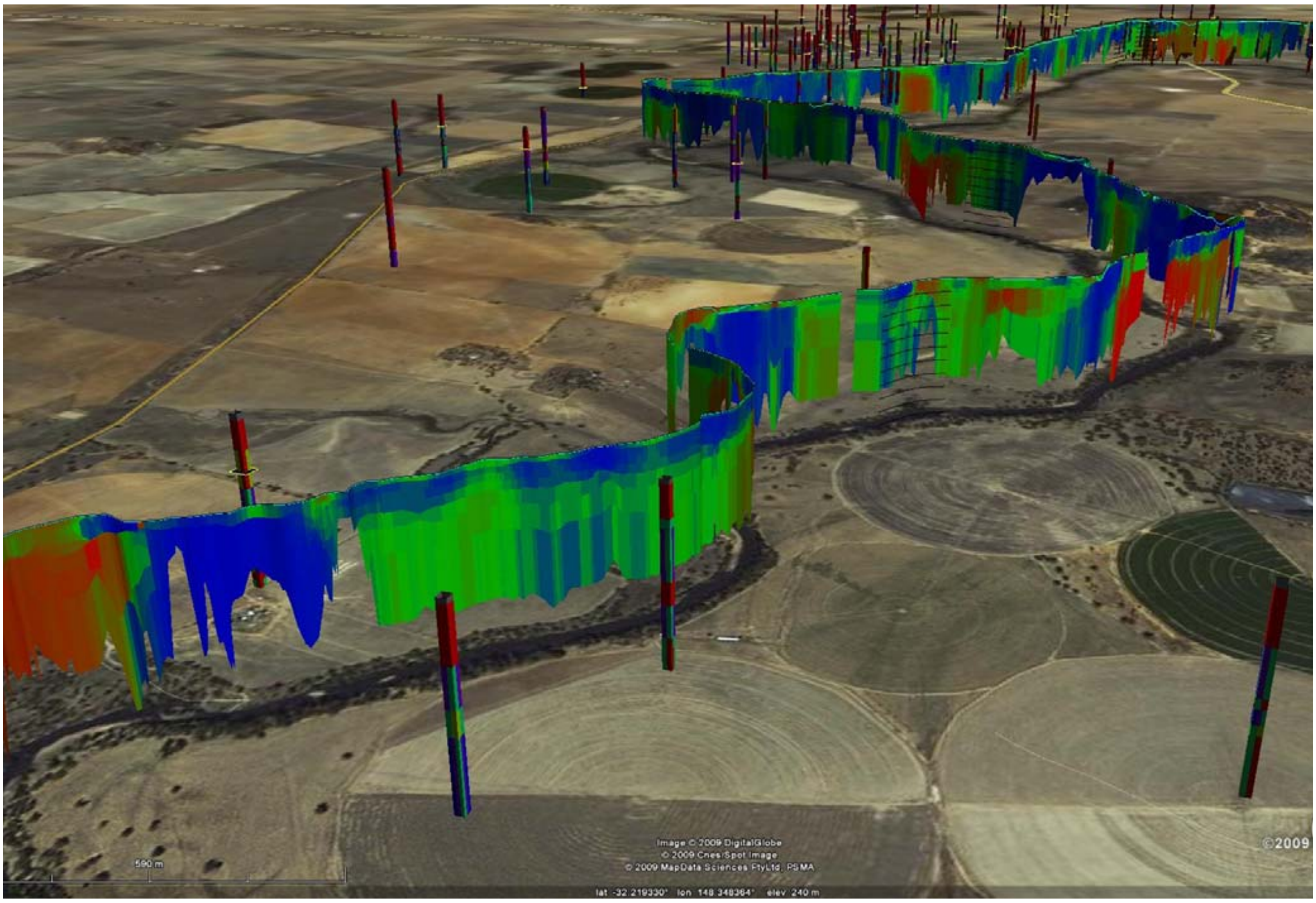
NSW Government
Department of Water & Energy

Subsurface data may be presented, raised a fixed distance above the ground in Google Earth. Depth ticks help the viewer determine depth below ground.

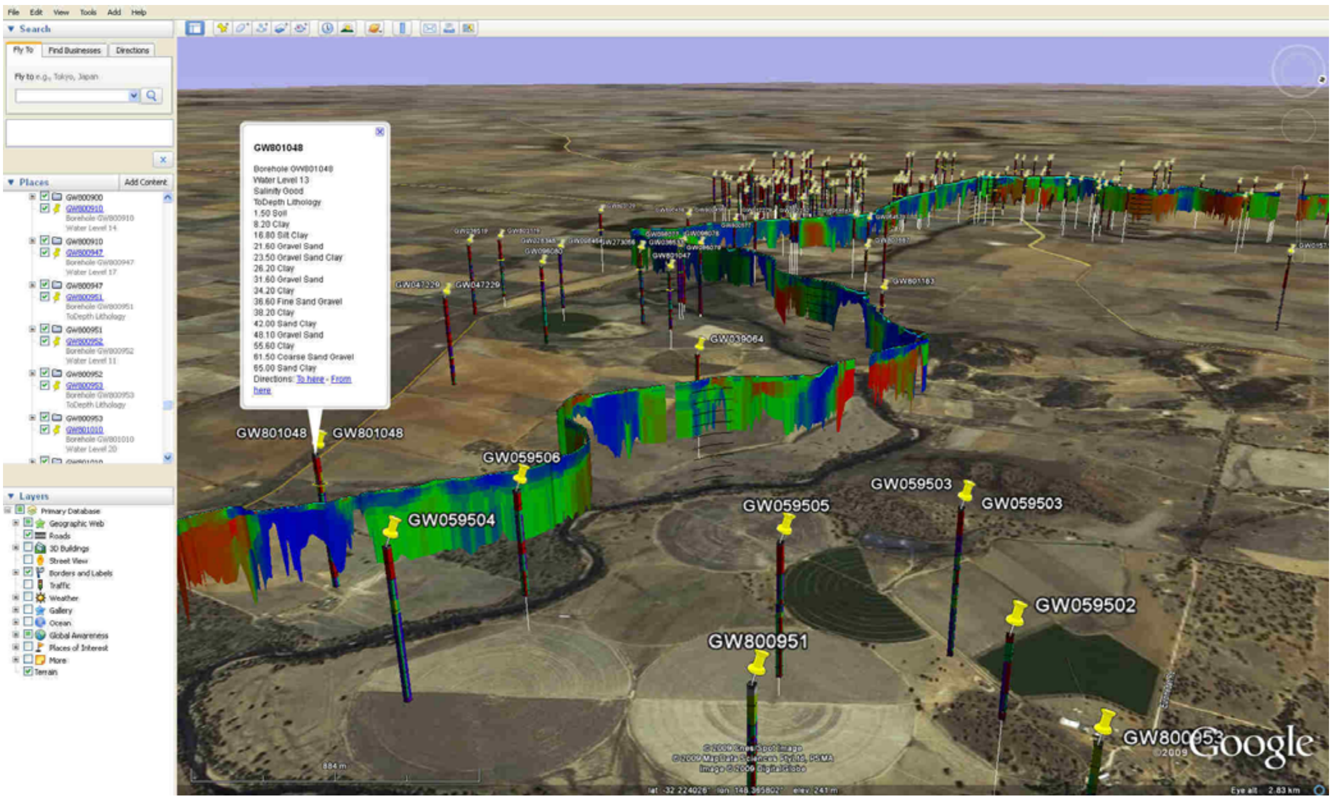


Macquarie River - Turkey Farm Reserve to Brummagen Creek Resistivity Curtain Diagram
Depth Scale Linear - ticks at 0, 4, 8, 12, 16, 20, 24, 28, 32, 36, and 40 metres

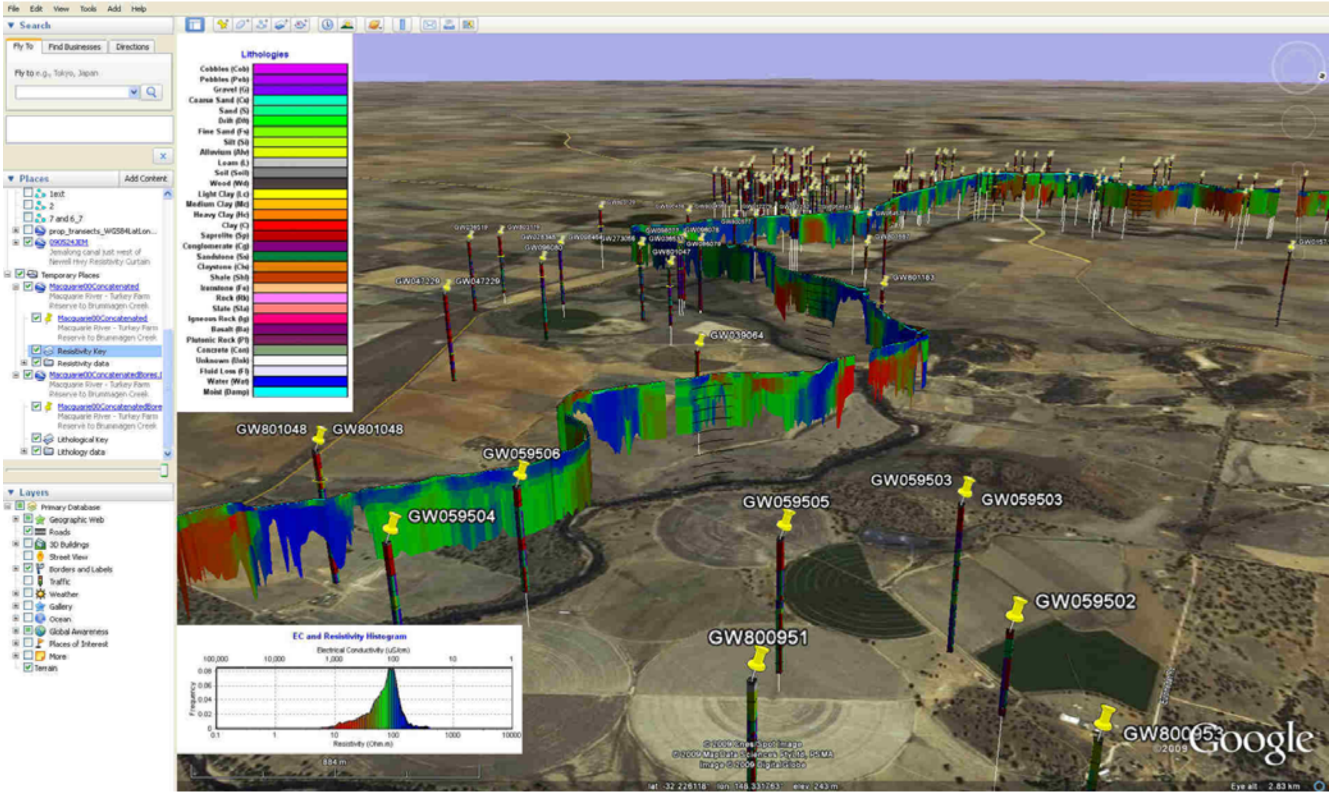
Data source : NSW DWE funded by NWC



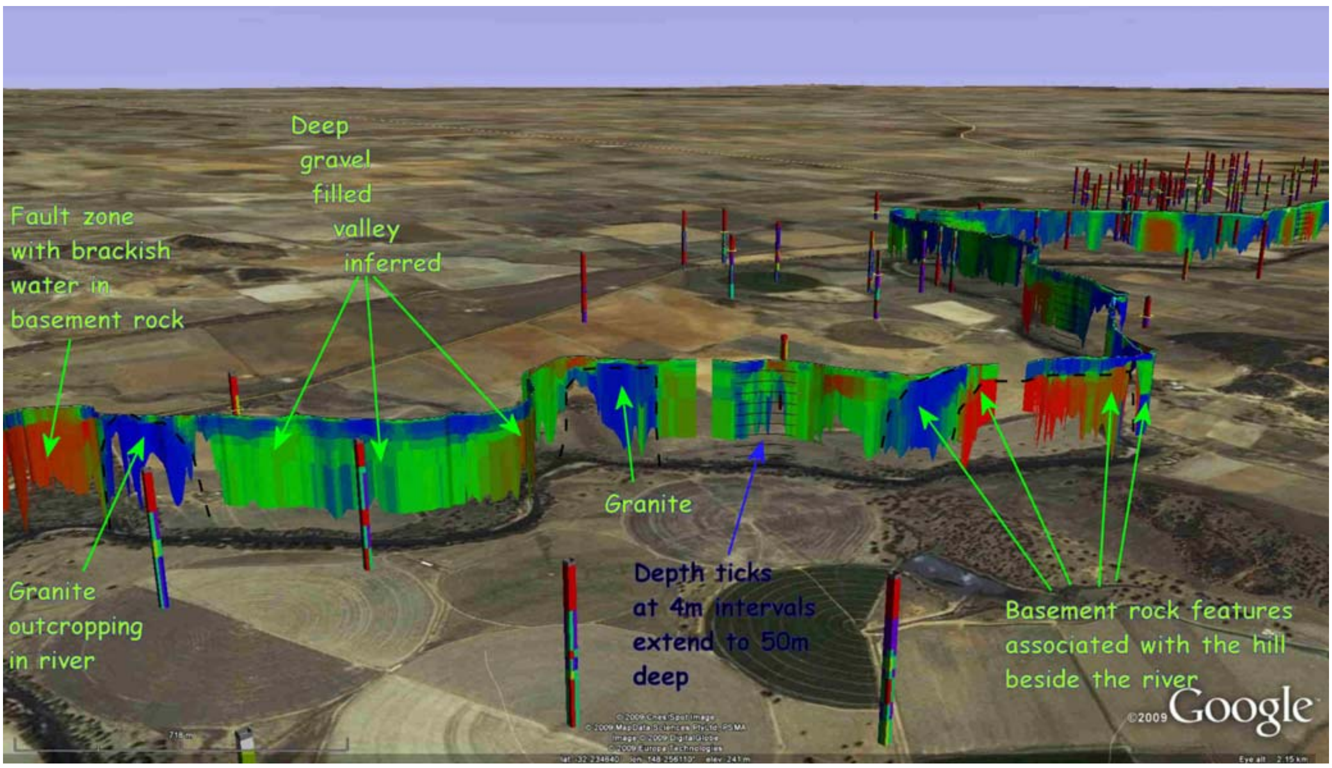
Clickable icons reveal bore details without cluttering the display



Lithological and Geophysical Keys can be packaged with the KML and added as screen overlays displayed by selection within the Google Earth places menu.



Complex hydrogeology can practically be interpreted only once all relevant information is presented together in 3D.



The complete lithological key – for each site, a subset of this key is presented.

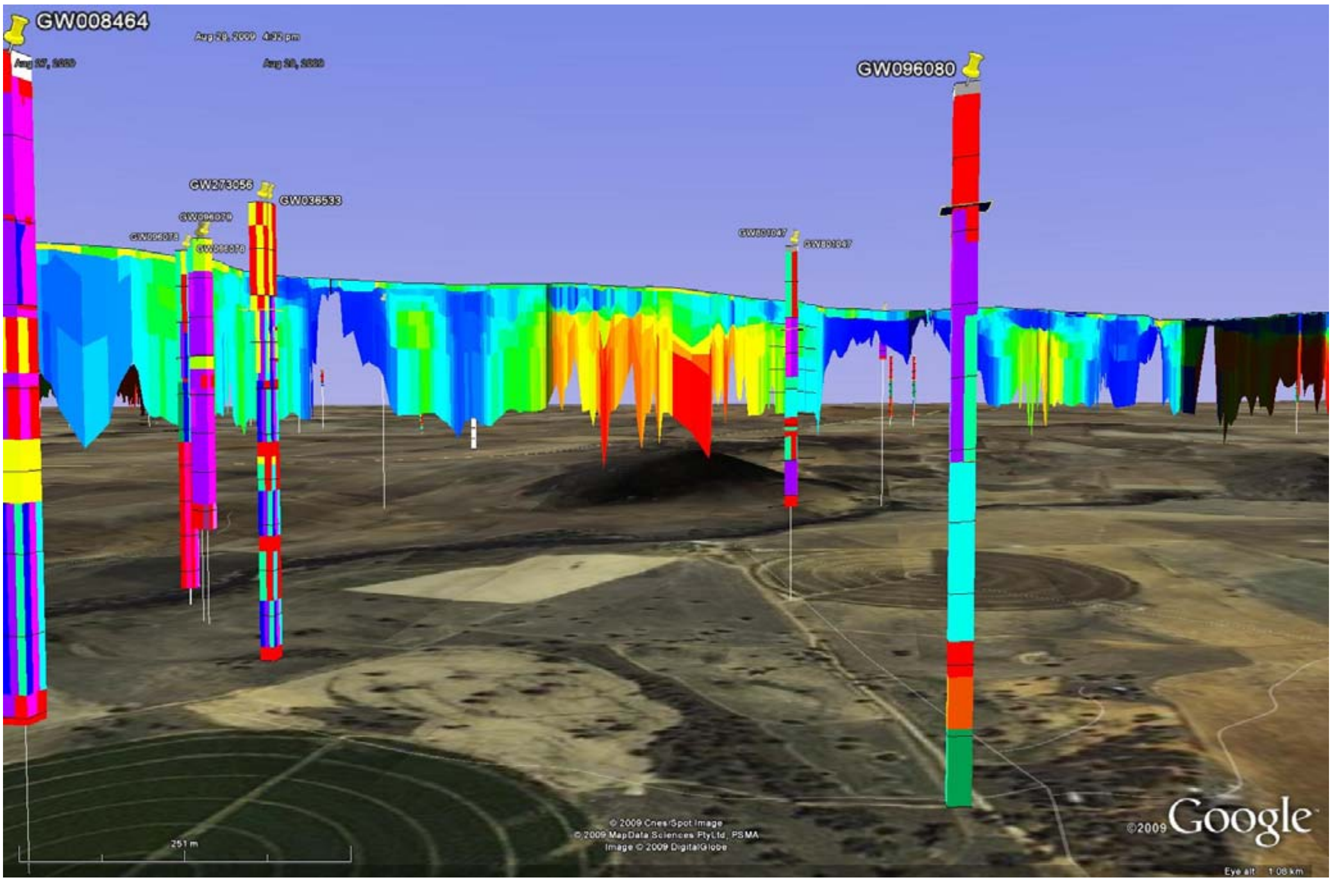
Sediment Description	Code	Color
Boulders	Bou	
Cobbles	Cob	
Pebbles	Peb	
Gravel	G	
Coarse Sand	Cs	
Sand	S	
Drift	Dft	
Fine Sand	Fs	
Silt	Si	
Alluvium	Alv	
Loam	L	
Soil	Soil	
Humus	Hu	
Wood	Wd	
Peat	Pt	
Lignite	Li	
Coal	Cb	
Fireclay	Fc	
Light Clay	Lc	
Medium Clay	Mc	
Heavy Clay	Hc	
Clay	C	
Saprolite	Sp	

Sediment Description	Code	Color
Laterite	Lat	
Bauxite	Bau	
Conglomerate	Cg	
Rudite	Rud	
Breccia	Bre	
Sandstone	Ss	
Sandrock	Sr	
Arenite	Ar	
Arkose	Ark	
Greywacke	Gyw	
Siltstone	Sis	
Claystone	Cls	
Shale	Shl	
Argillite	Arg	
Marl	Marl	
Limestone	Lim	
Calcareous	Ca	
Chalk	Chk	
Dolomite	Dol	
Calcrete	Cal	
Silcrete	Sil	
Ironstone	Fe	
Chert	Ch	

Sediment Description	Code	Color
Evaporite	Ev	
Rock	Rk	
Metamorphic Rock	Met	
Slate	Sla	
Schist	Sch	
Gneiss	Gns	
Quartzite	Qzt	
Soapstone	Soap	
Serpentinite	Serp	
Igneous Rock	Ig	
Volcanic Rock	Vo	
Basalt	Ba	
Gabbro	Gab	
Pyroclastic Rocks	Py	
Tuff	Tuff	
Ignimbrite	Igb	
Rhyolite	Rhy	
Plutonic Rock	Pl	
Gypsum	Gy	
Pyrite	Pyt	
Mica	Mica	
Quartz	Q	
Maghemite	Mh	

Sediment Description	Code	Color
Concrete	Con	
Rubble	Rb	
Overburden	Ovb	
Fill	Fill	
Void	Void	
Unknown	Unk	
Fluid Loss	Fl	
Water	Wat	
Moist	Damp	

Lithological Log Graphics – close up Google Earth lighting parameters have been adjusted



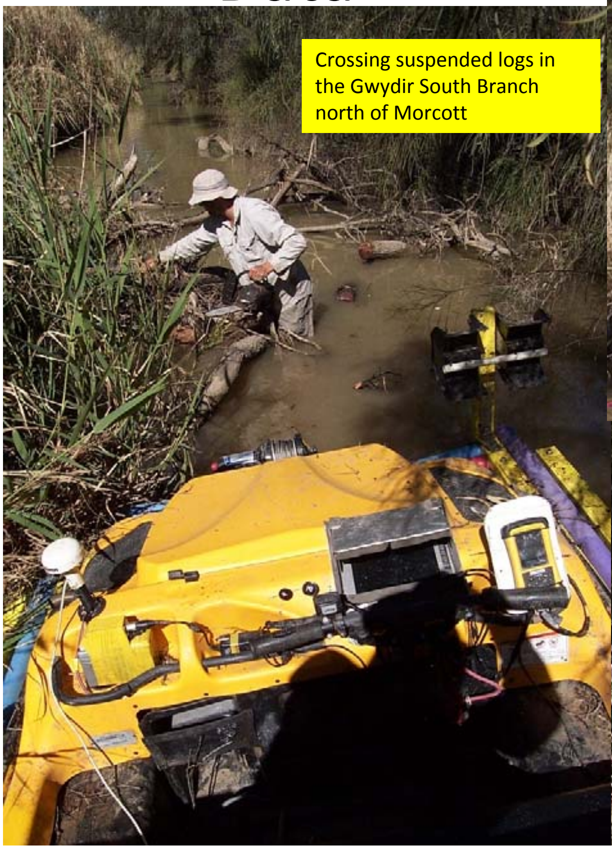
Drillers log regularization

- Due to the almost infinite number of combinations of sedimentary descriptions that are used in Australian drillers logs, logs are best regularized into compound descriptors – two or more colours are displayed on the logs.
- My regularization interrogates drillers logs using a database of one and two word descriptors and lists of synonyms. Two word matches tare stripped out first, then remaining one word matches.
- For visual clarity, I colour similar sediment types with similar colours.

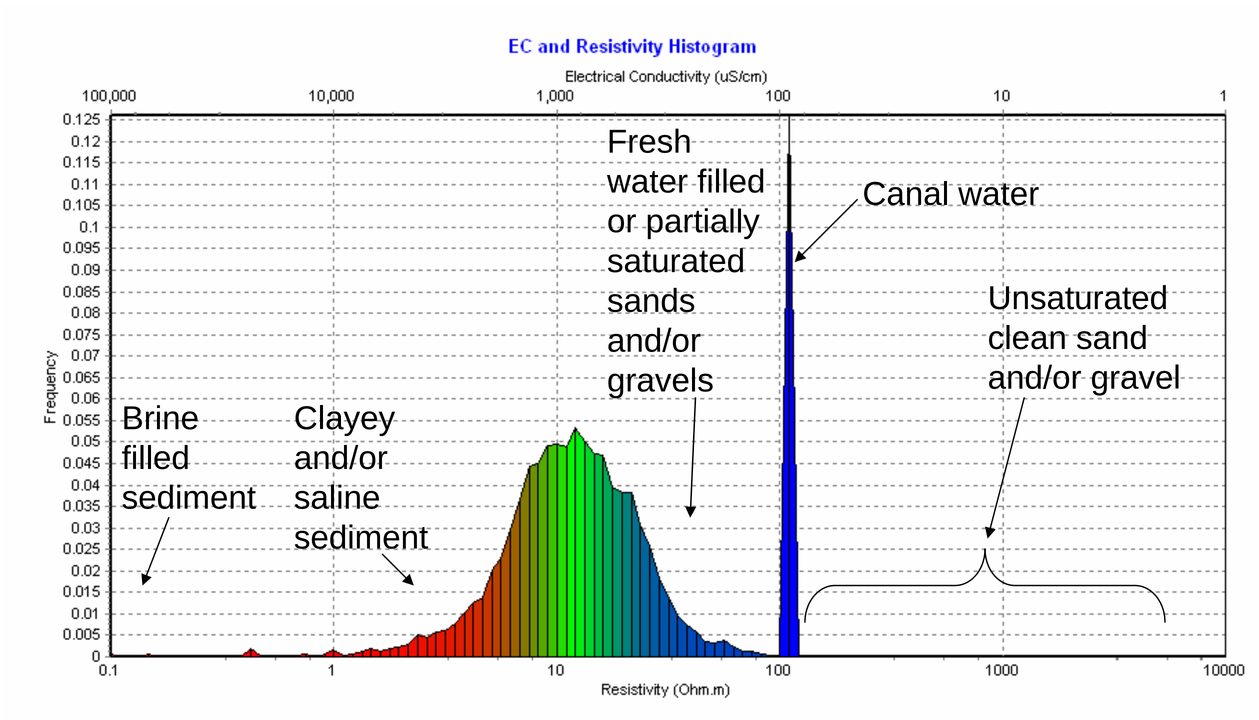
Sample Lithological codes, descriptors and synonyms

```
const
  initNumSedTypes:Integer = 78;
  initsedCode:Array[1..78] of String = (
  'Bou','Cob','Peb','G','Cs',
  'S','Dft','Fs','Si','Alv',
  'L','Soil','Hu','Wd','Pt',
  'Li','Cb','Fc','Lc','Mc',
  'Hc','C','Sp','Lat','Bau',
  'Cg','Rud','Bre','Ss','Sr',
  'Ar','Ark','Gyw','Sis','Cls',
  'Shl','Arg','Marl','Lim','Ca',
  'Chk','Dol','Cal','Sil','Fe',
  'Ch','Ev','Rk','Met','Sla',
  'Sch','Gns','Qzt','Soap','Serp','Ig',
  'Vo','Ba','Gab','Py','Tuff',
  'Igb','Rhy','Pl','Gy','Pyt',
  'Mica','Q','Mh','Con','Rb',
  'Ovb','Fill','Void','Unk','Fl',
  'Wat','Damp');
  initsedDesc:Array[1..78] of String = (
  'Boulders','Cobbles','Pebbles','Gravel','Coarse Sand',
  'Sand','Drift','Fine Sand','Silt','Alluvium',
  'Loam','Soil','Humus','Wood','Peat',
  'Lignite','Coal','Fireclay','Light Clay','Medium Clay',
  'Heavy Clay','Clay','Saprolite','Laterite','Bauxite',
  'Conglomerate','Rudite','Breccia','Sandstone','Sandrock',
  'Arenite','Arkose','Greywacke','Siltstone','Claystone',
  'Shale','Argillite','Marl','Limestone','Calcareous',
  'Chalk','Dolomite','Calcrete','Silcrete','Ironstone',
  'Chert','Evaporite','Rock','Metamorphic Rock','Slate',
  'Schist','Gneiss','Quartzite','Soapstone','Serpentinite','Igneous Rock',
  'Volcanic Rock','Basalt','Gabbro','Pyroclastic Rocks','Tuff',
  'Ignimbrite','Rhyolite','Plutonic Rock','Gypsum','Pyrite',
  'Mica','Quartz','Maghemite','Concrete','Rubble',
  'Overburden','Fill','Void','Unknown','Fluid Loss',
  'Water','Moist');
  initSedSynonyms:Array[1..78] of String = (
  '','Stoney,Stones,Stone,"rock floaters",floaters,Float','Pebbly','Gravely,Gravelly,"Gravel Wash","Coarse Drift",G','"Course Sand",CS,sand-coarse',
  'Sandy,Gritty,S,sand-medium,"sand med."','','FS,sand-fine','Silty,SI','Alluvial',
  'Loamy,Loamey,L','Topsoil,Dirt','','Organic','',
  'Lignitic,Ligneous','"Coal Seams",Coaly,Coaley','','LC','MC',
  'HC,"Stiff Clay","Pipe Clay","Swelling Clay","tight clay"','Clayey,Mud,Muddy,Pug,Puggy,Clayed,claybound,clay bound,clays','Weathered,Decomposed,Rotten,Saprock,decom','','',
  '"Cemented Gravel"','Rudaceous','','Sst,Arenite','"Coffee Rock"',
  'Arenaceous','"Feldspathic Sandstone",Arkoses,Feldspathic','Grauwacke,Greywack,Graywacke','','Mudstone',
  'Shaley,Shaly,Shally','Argillaceous','Calcareous Mudstone','Limstone','',
  'Chalky','Dolostone','','','Limonitic,Goethitic',
  'Jasper,Jaspilite','Evapourite','Bedrock','Metamorphic','Slatey,Slaty',
  '','','','','Serpentine','Igneous',
```

Geophysical Data



A typical Electrical conductivity key – actually a histogram presenting relative abundances of EC values within a dataset.



What KML is not good for

- Although KML is great for final presentation, Google Earth on its own is not a working environment for data management.
- KML examples presented are good for site-specific investigation but statewide presentation presents greater challenges.

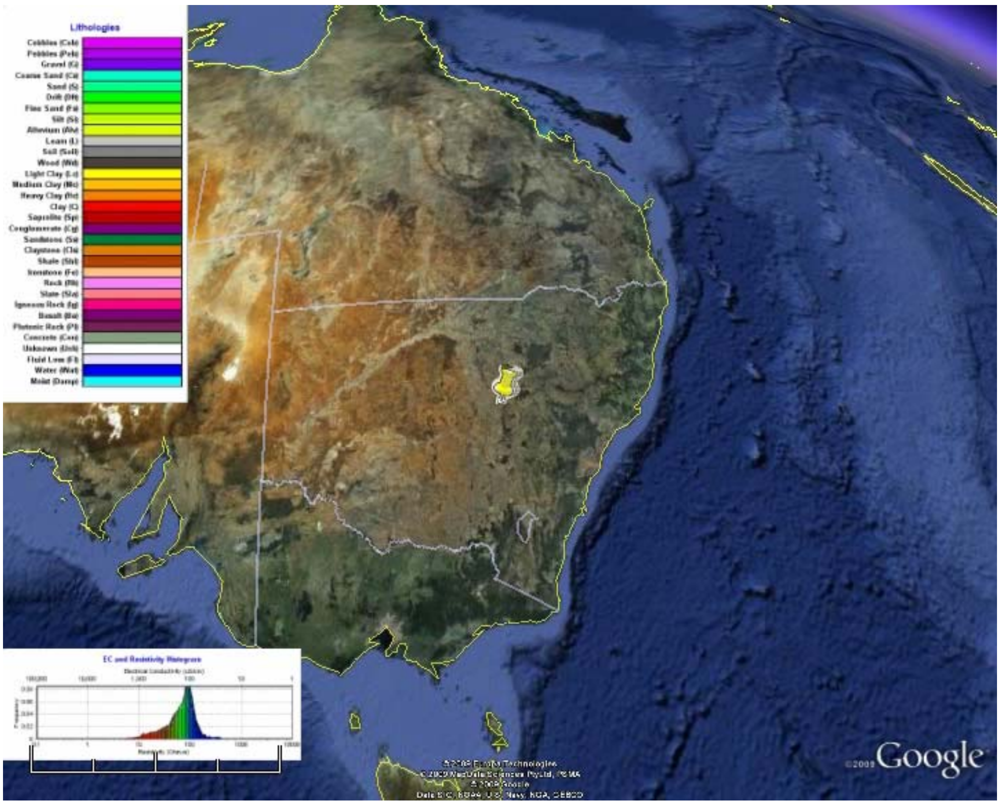
Proposed enhancement

- As well as NSW bore data, Victorian and Queensland bore data serving has been found to be feasible;
- Textured bore logs could be created with Collada .dae files;
- Direct connection with state databases could be made with relevant co-operation;
- For refined presentation, site specific 2nd pass bore log regularization could simplify graphics;
- Other bore information such as yields, screen locations and drillers log sediment colours could be added to graphics and balloon text.

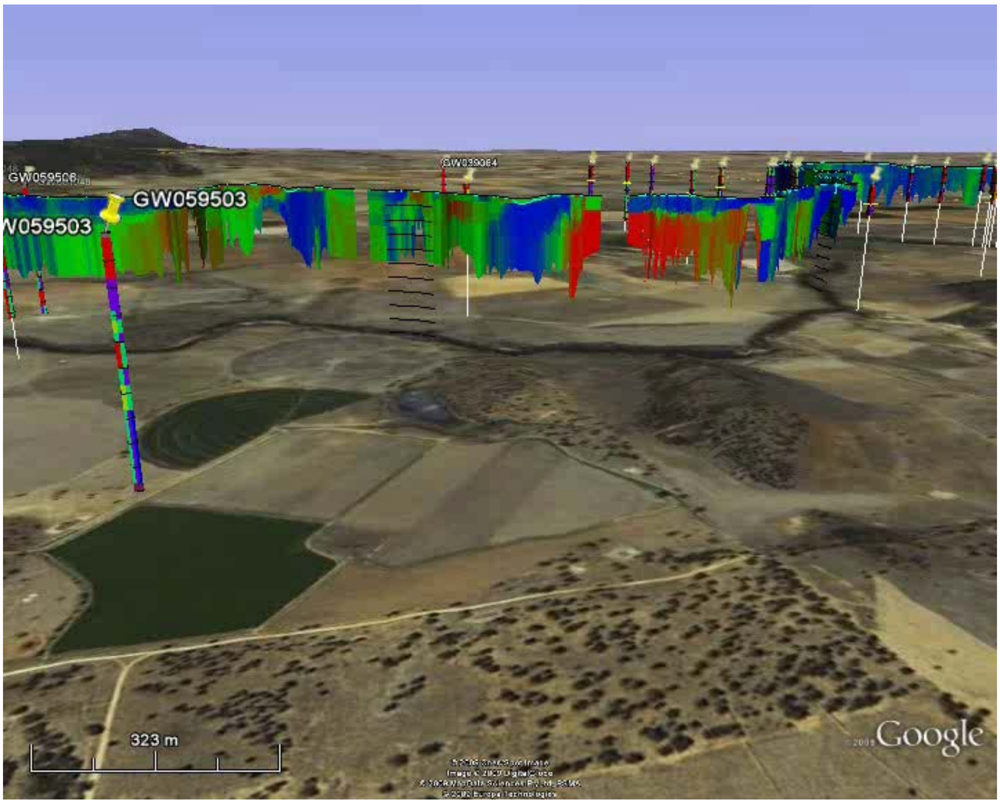
What next

- Groundwater Imaging P/L plans to continue development and marketing of this type of visualization product in between conduct of geophysical surveys.
- Should further government assistance and co-operation be negotiated, a more effective development and deployment may be achieved.
- All state bore databases and numerous geophysical datasets could be served.

The Macquarie example - movie 1 – a Google Tour



The Macquarie example - movie 2 – moving with the mouse and transparency



Converting geophysical imagery to groundwater conceptual models

- within a 3D viewer, pseudo-bore lithologs can be placed along geophysical transects and semi-manually assigned lithologies commensurate with those of surrounding bores and the geophysical imagery.
- The pseudo-bore lithologies can be converted into groundwater conceptual models within products such as Aquaveo GMS or ArcHydro Groundwater and Subsurface analyst tools.

Google Earth hints

- The transparency slider can temporarily clear features to reveal what is behind
- Individual bores or other items can be deselected in the key.
- A considerable amount of data can be imported but the example presented is near the limit of maximum practical size considering performance.
- ArcGIS Explorer and other programs can also read the KML.