Joanne Kerr

From: PANDEY Sanjeev
Sent: Friday, 6 August 2021 1:40 PM
To: 'Noel Merrick'; CTPI 4@optusnet.com.au'; Ransley Tim; 'Phil Hayes'; Adrian Werner; Phil Hayes; CTPI 49-Sch4 @gmail.com
Cc: FLOOK Steven; SCHONING Gerhard
Subject: RE: Technical Advisory Panel
Attachments: TAPMinutes_Subsidence.docx; 20210723_TAP_Subsidence_to-Circulate.pdf; Merrick_MDBGWshop_Bendigo_2004_Presentation.pdf; Merrick_MDBGWshop_Bendigo_2004_Final.pdf

Follow Up Flag: Follow up
Flag Status: Flagged

Dear TAP members

Attached are minutes of subsidence meeting. Please let me know if we have captured all the key elements from the meeting? Attached are also PowerPoint that we presented and two documents that Noel mentioned during the meeting and later provided to us – Thanks Noel!

Regards
Sanjeev

-----Original Appointment-----
From: MENEGUZZO Krysten **On Behalf Of** PANDEY Sanjeev
Sent: Wednesday, 7 July 2021 3:33 PM
To: PANDEY Sanjeev; 'Noel Merrick'; CTPI 4@optusnet.com.au'; 'Tim.Ransley@ga.gov.au'; 'Phil Hayes'; Adrian Werner; FLOOK Steven; SCHONING Gerhard; MARSHALL Hugh; GALLAGHER Mark; ZHANG Wendy; ERASMUS Dean
Cc: CTPI 49-Sch4 @gmail.com; BUI XUAN HY Anna; Phil Hayes
Subject: Technical Advisory Panel
When: Friday, 23 July 2021 1:00 PM-3:00 PM (UTC+10:00) Brisbane.
Where: <<1 William Street (1WS) - 4 Floor - Meet 4.02>>

Good afternoon TAP Members

This is a placeholder for the first TAP meeting.

This session will be on subsidence.

Kind Regards

Krysten Meneguzzo
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Department of Regional Development, Manufacturing and Water
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Part-time (Monday – Thursday)

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Technical Advisory Panel (TAP) for the Surat CMA

MINUTES for MEETING No. 13 (Subsidence)

Thursday 23 July 2021

Teams Meeting

Attendees

Panel members: Noel Merrick (HydroSimulations), Adrian Werner (Flinders University), Phil Hayes (University of Queensland), Randall Cox

OGIA participants: Sanjeev Pandey (SP) (Chair), Gerhard Schöning (GS), Steven Flook (SF), Anna Bui Xuan Hy (AB), Wendy Zhang (WZ), Dean Erasmus (DE)

Apologies

Tim Ransley

Agenda Items

1. Context and what is driving OGIA's research into subsidence – *SP*
2. Analysis of monitoring data (InSAR) to identify CSG induced subsidence – approach and interim findings – *SF, GS, DE, WZ*
3. Modelling and predictions of subsidence – approach and interim findings – *GS, AB*
4. Developing methods for baselining– general approach and work in progress – *SF, DE, SP*

Deliberations

No material was provided ahead of the meeting. For each agenda item, a presentation was made (attached) by OGIA team members. This was followed by discussion, points of clarification and TAP members' deliberations to make recommendations.

Item 1 – Context

TAP members **noted** the context and structure of OGIA's subsidence-related research into three themes that emerged from OGIA's stakeholder engagement (*Attachment 1*):

- Analysis of monitoring data
- Predictions; and
- Establishing baseline.

Item 2 – Analysis of monitoring data

TAP members

- **noted** the information presented (*Attachment 1*)
- **endorsed** the overall approach to analysis of InSAR data
- **commented** that the machine learning approach applied is still preliminary and the applicability of the method is yet to be demonstrated

Item 3 – Modelling and predictions

TAP members:

- **noted** the information presented (*Attachment 1*)

- **noted and agreed:**
    - the concept of using predictions to estimate change of slope and direction of slope instead of absolute elevation changes; and
    - challenges associated with using ground movement data to validate/calibrate the model
- **endorsed:**
    - the overall approach to modelling and modelling methods; and
    - that the modelling is fit for purpose
- **noted** that OGIA is planning to further refine modelling and collaborate with UQ in the post-UWIR period to test various hypothesis; and
- **suggested**
    - considering "land settlement" modelling in the Namoi Valley (*Attachment* 2).
    - considering compaction estimate from the model to estimate storage parameters for groundwater flow modelling

Item 4 – Establishing baseline methods

TAP members:

- **noted** the information presented (*Attachment 1*)
- **endorsed:**
    - the overall approach in establishing baseline method; and
    - that in the context of ground movement, baseline is not a snapshot in time, but rather a trend over a reasonable period of time
- **suggested** that OGIA consider using a reference point/area outside those affected by CSG operations, for ongoing comparison.

General

TAP members acknowledged and complimented the quality and amount of work undertaken by OGIA on subsidence, particularly in a short timeframe.

Technical advisory panel meeting

Subsidence – Friday 23 July 2021

Sanjeev Pandey, Steven Flook, Gerhard Schoning, Anna Bui, Dean Erasmus, Wendy Zao

Office of Groundwater Impact Assessment

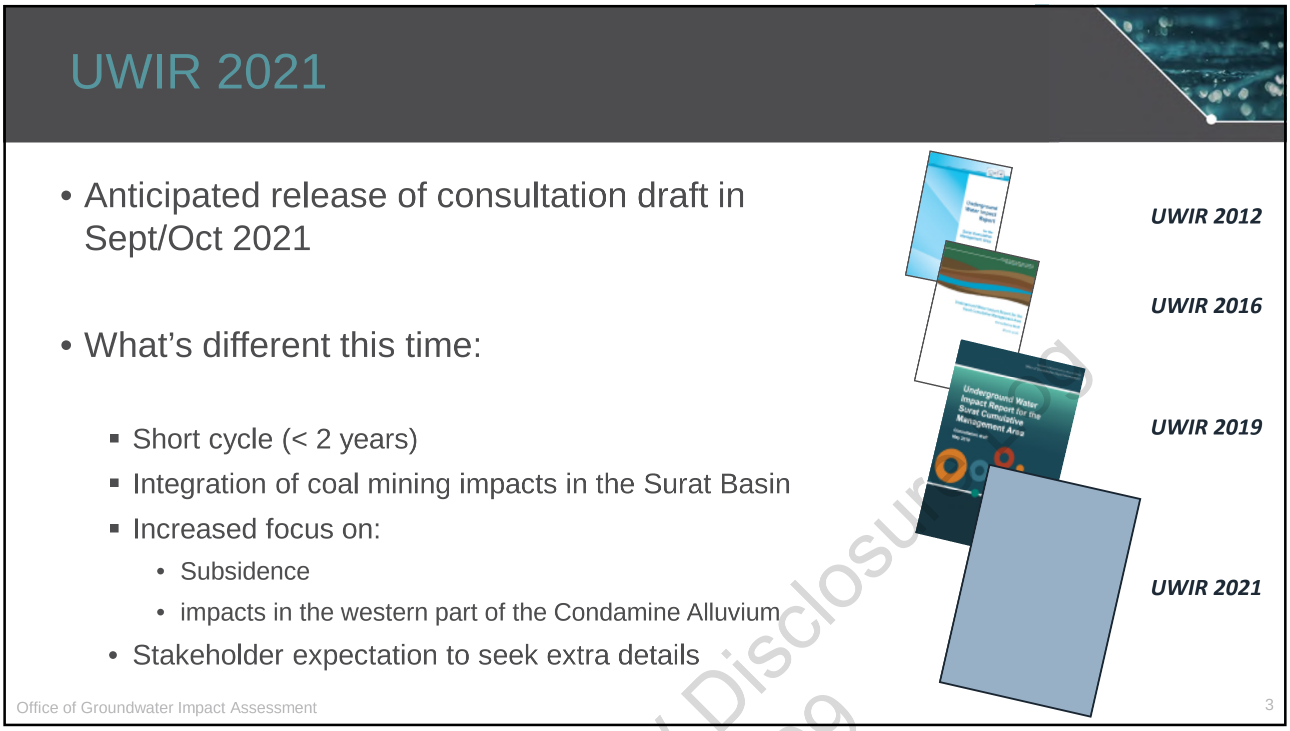
Queensland Government

1

Context

Office of Groundwater Impact Assessment

2



UWIR 2021

- Anticipated release of consultation draft in Sept/Oct 2021
- What's different this time:
  - Short cycle (< 2 years)
  - Integration of coal mining impacts in the Surat Basin
  - Increased focus on:
    - Subsidence
    - impacts in the western part of the Condamine Alluvium
  - Stakeholder expectation to seek extra details

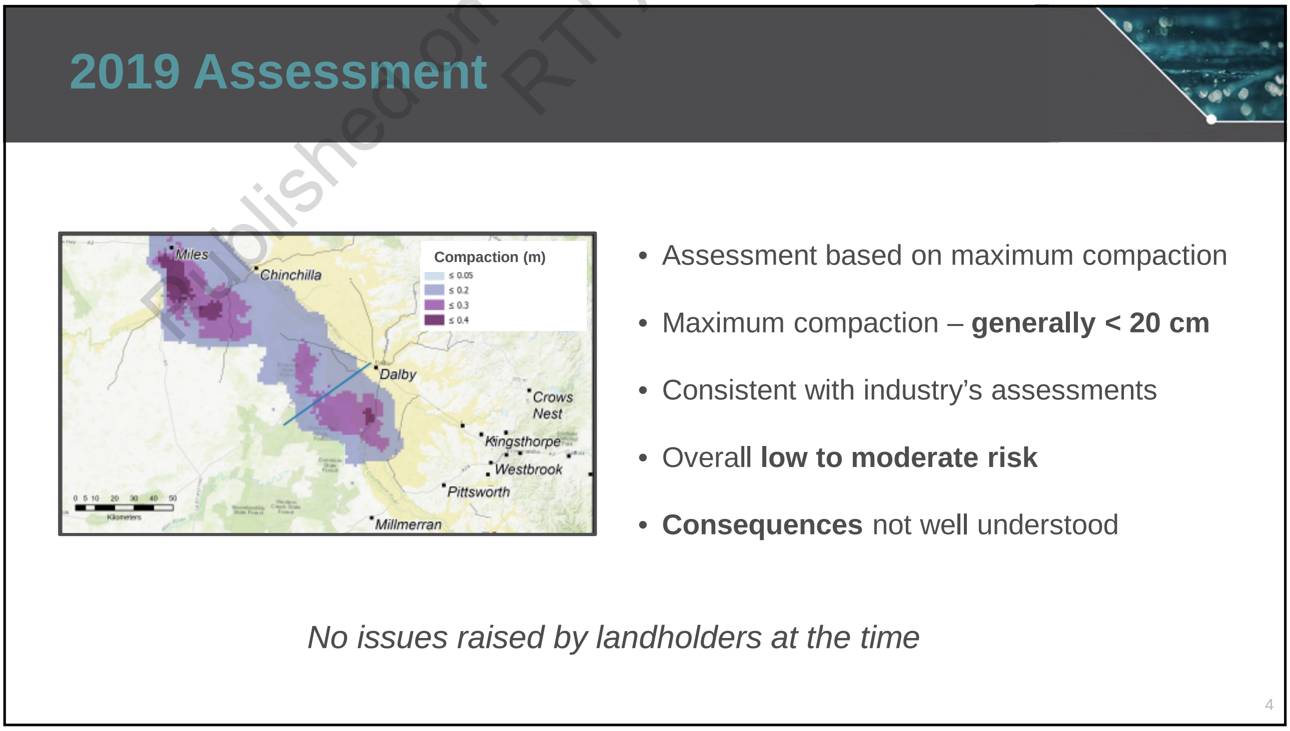
UWIR 2012

UWIR 2016

UWIR 2019

UWIR 2021

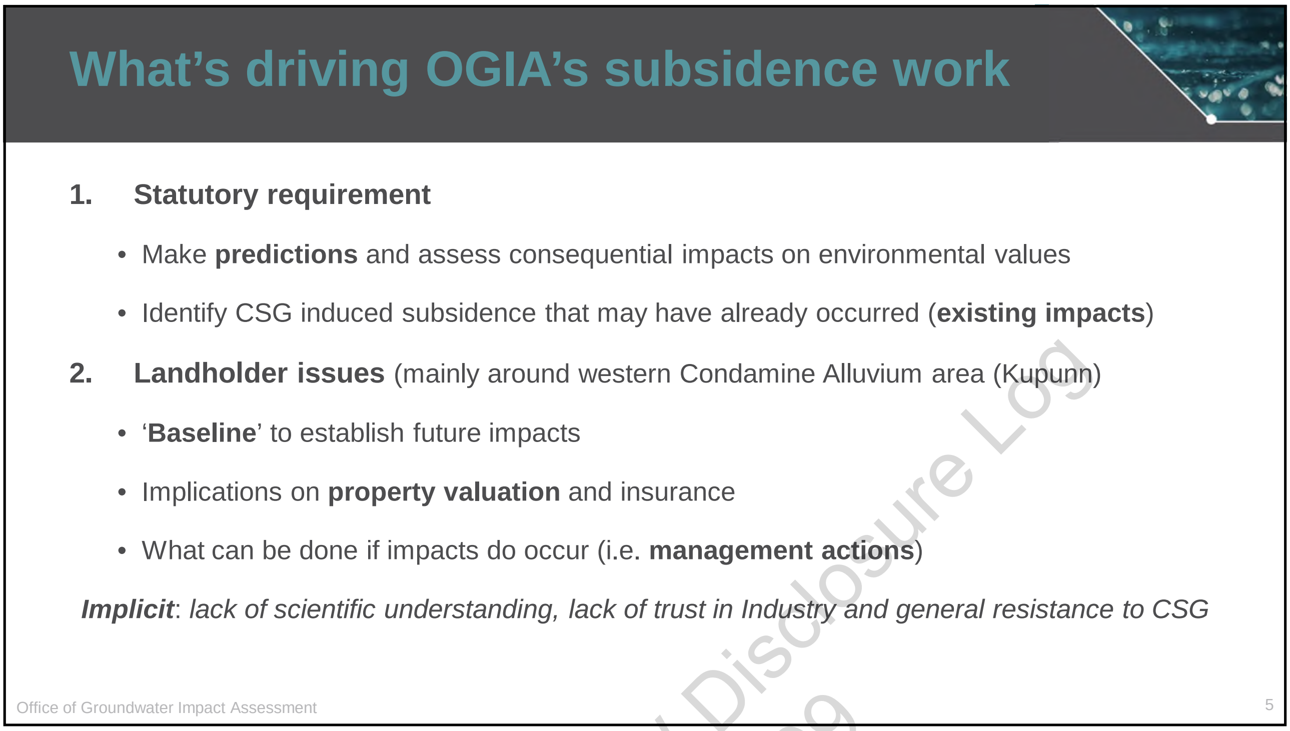
Office of Groundwater Impact Assessment



2019 Assessment

- Assessment based on maximum compaction
- Maximum compaction – **generally < 20 cm**
- Consistent with industry's assessments
- Overall **low to moderate risk**
- **Consequences** not well understood

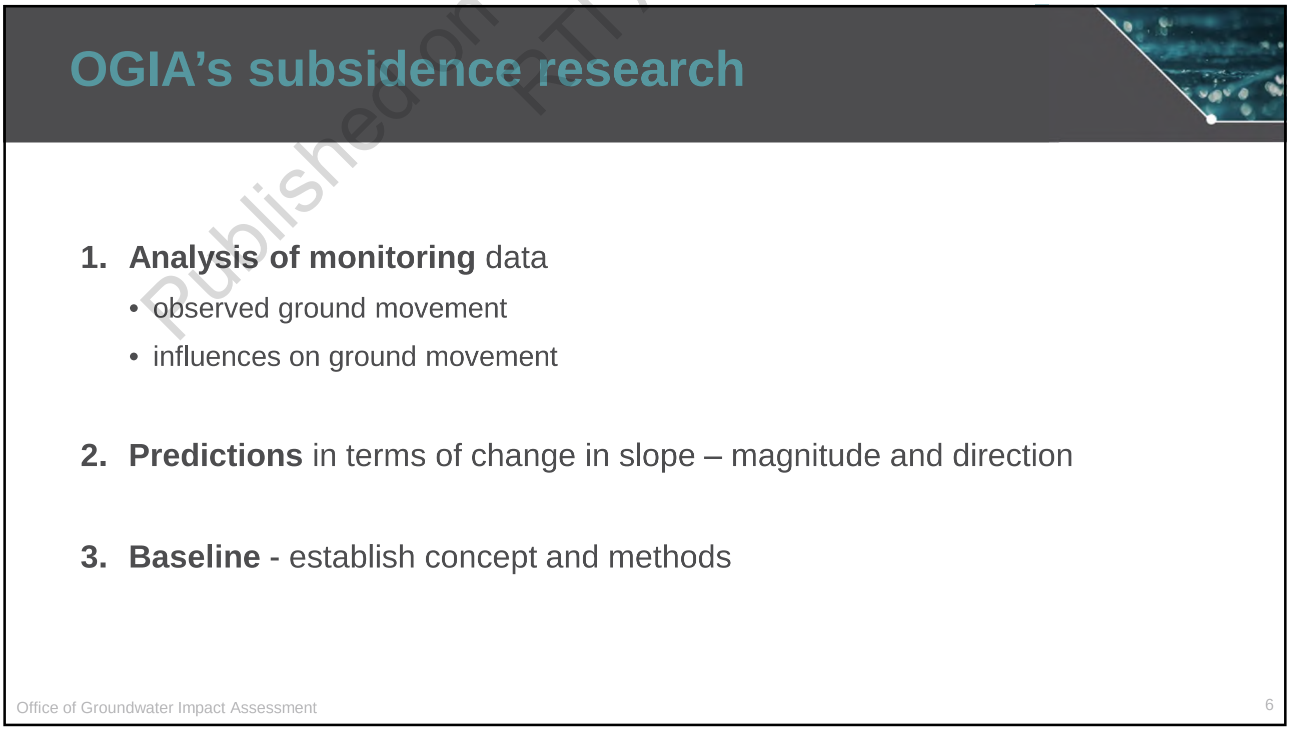
No issues raised by landholders at the time



What’s driving OGIA’s subsidence work

1. **Statutory requirement**
   - Make **predictions** and assess consequential impacts on environmental values
   - Identify CSG induced subsidence that may have already occurred (**existing impacts**)
2. **Landholder issues** (mainly around western Condamine Alluvium area (Kupunn)
   - ‘**Baseline**’ to establish future impacts
   - Implications on **property valuation** and insurance
   - What can be done if impacts do occur (i.e. **management actions**)

Implicit: *lack of scientific understanding, lack of trust in Industry and general resistance to CSG*



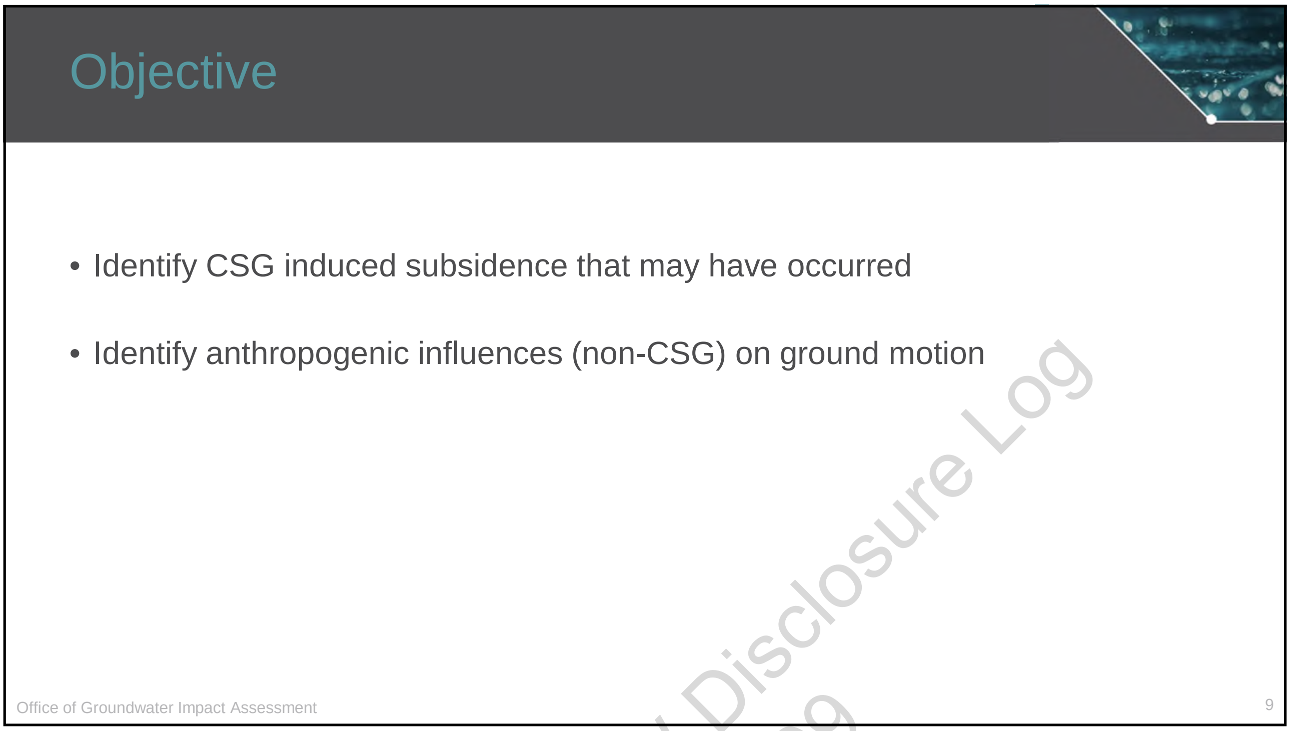
OGIA’s subsidence research

1. **Analysis of monitoring** data
   - observed ground movement
   - influences on ground movement
2. **Predictions** in terms of change in slope – magnitude and direction
3. **Baseline** - establish concept and methods

What are we seeking from the TAP members

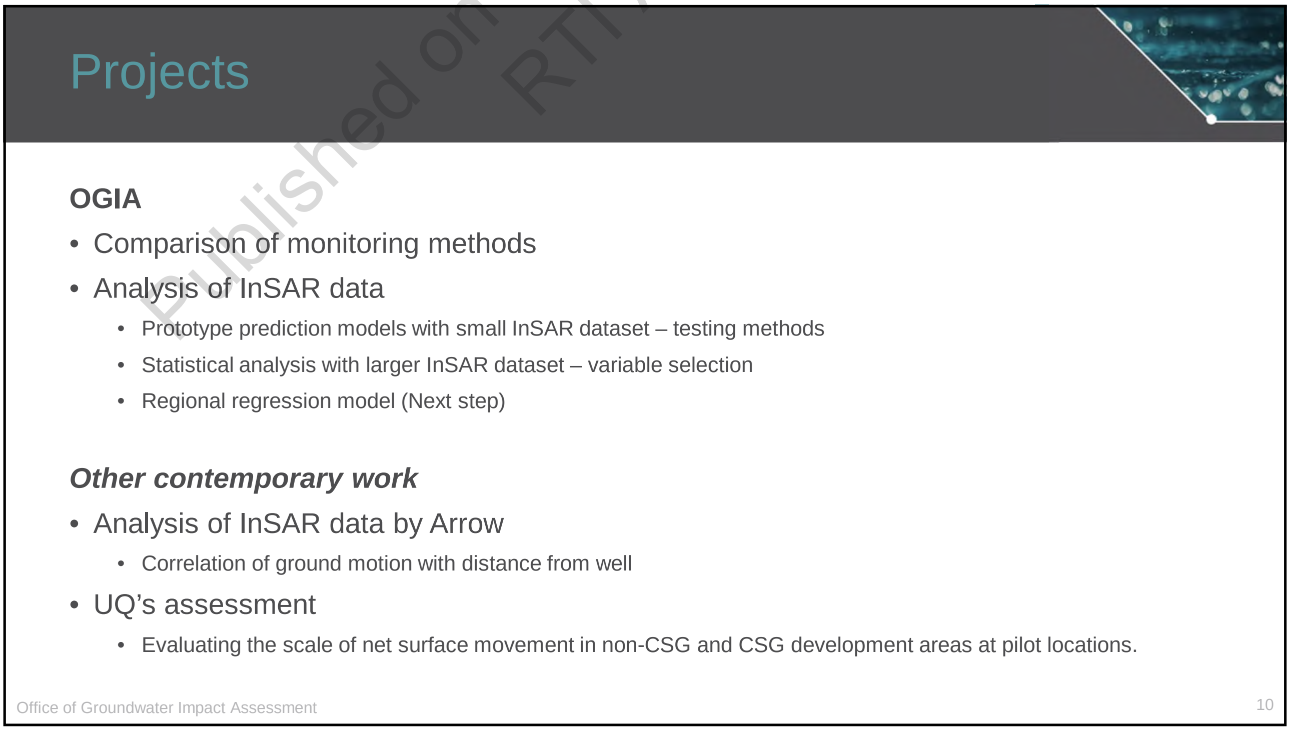
- Note the information presented and work in progress
- Endorsement and guidance on
  - approach to 'unpacking' InSAR data for existing CSG impacts
  - whether the assessment and modelling approach is fit for purpose
  - the concept of 'baseline'
  - approach to establish baselining method
- Sharing contemporary research by others on subsidence that OGIA may needs to be aware of

Interpretation of monitoring data



Objective

- Identify CSG induced subsidence that may have occurred
- Identify anthropogenic influences (non-CSG) on ground motion



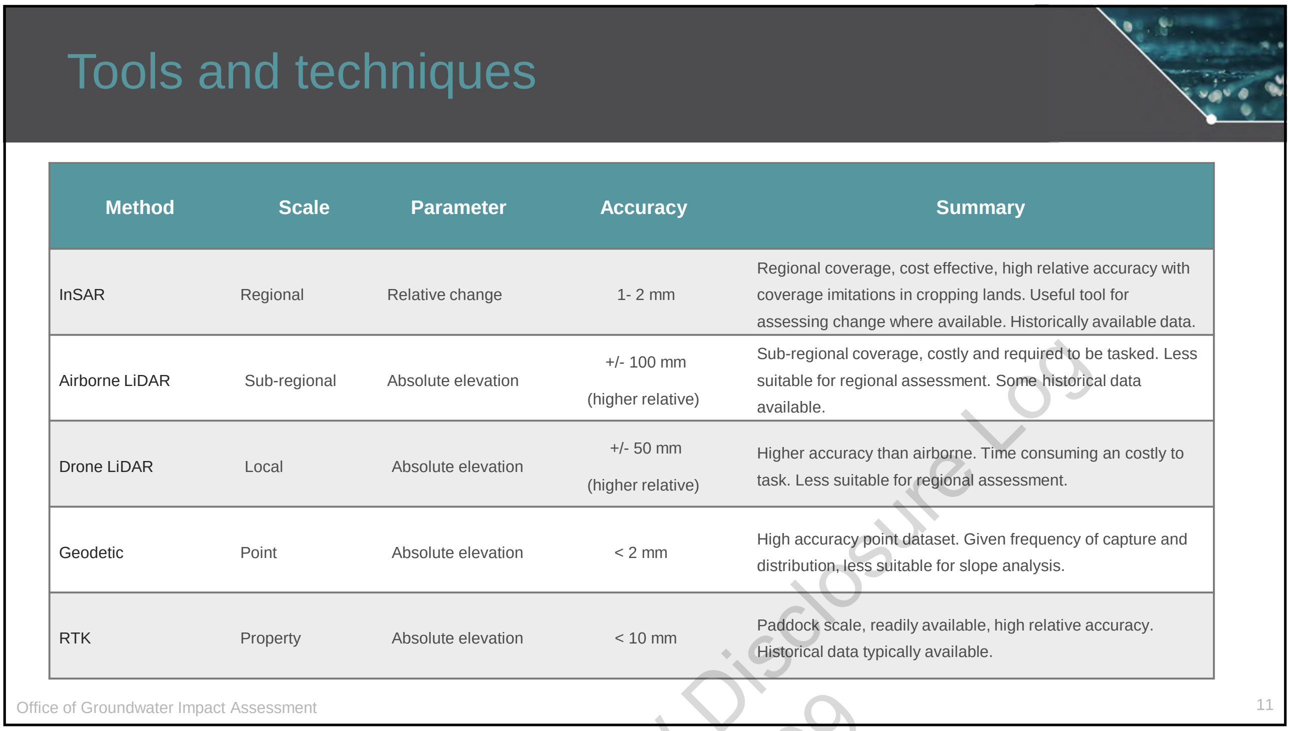
Projects

OGIA

- Comparison of monitoring methods
- Analysis of InSAR data
  - Prototype prediction models with small InSAR dataset – testing methods
  - Statistical analysis with larger InSAR dataset – variable selection
  - Regional regression model (Next step)

Other contemporary work

- Analysis of InSAR data by Arrow
  - Correlation of ground motion with distance from well
- UQ's assessment
  - Evaluating the scale of net surface movement in non-CSG and CSG development areas at pilot locations.



Tools and techniques

Method	Scale	Parameter	Accuracy	Summary
InSAR	Regional	Relative change	1- 2 mm	Regional coverage, cost effective, high relative accuracy with coverage imitations in cropping lands. Useful tool for assessing change where available. Historically available data.
Airborne LiDAR	Sub-regional	Absolute elevation	+/- 100 mm (higher relative)	Sub-regional coverage, costly and required to be tasked. Less suitable for regional assessment. Some historical data available.
Drone LiDAR	Local	Absolute elevation	+/- 50 mm (higher relative)	Higher accuracy than airborne. Time consuming an costly to task. Less suitable for regional assessment.
Geodetic	Point	Absolute elevation	< 2 mm	High accuracy point dataset. Given frequency of capture and distribution, less suitable for slope analysis.
RTK	Property	Absolute elevation	< 10 mm	Paddock scale, readily available, high relative accuracy. Historical data typically available.

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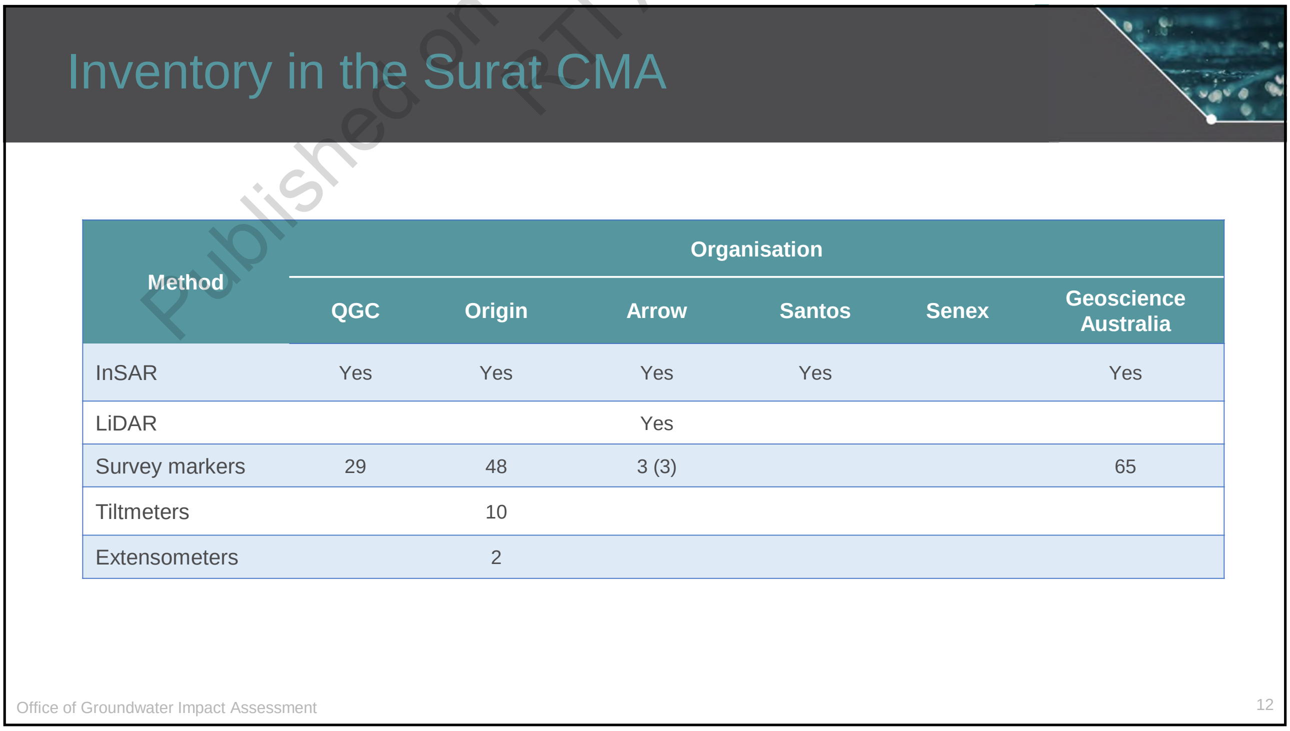


Inventory in the Surat CMA

Method	Organisation					
	QGC	Origin	Arrow	Santos	Senex	Geoscience Australia
InSAR	Yes	Yes	Yes	Yes		Yes
LiDAR			Yes			
Survey markers	29	48	3 (3)			65
Tiltmeters		10				
Extensometers		2				

12

Prototype prediction models: Data summary

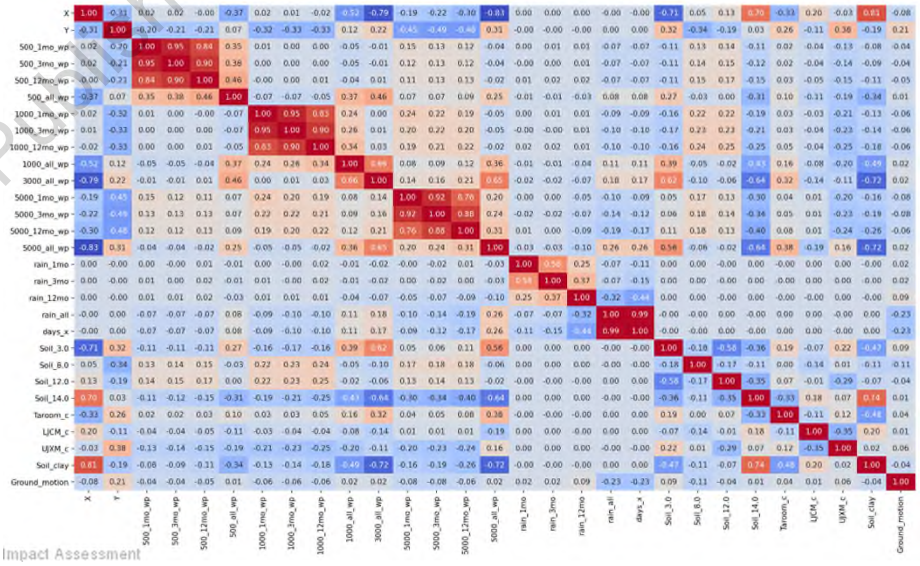
InSAR dataset from Arrow Energy

25,824 observation points

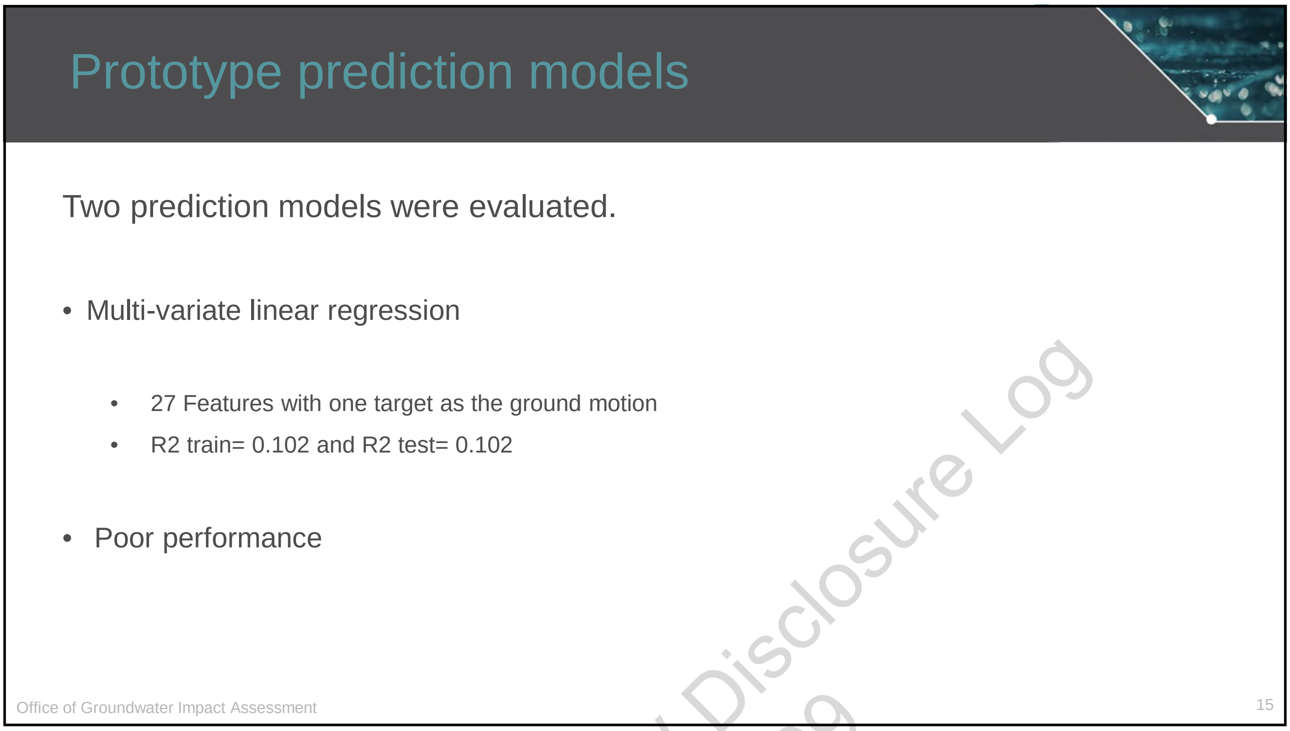
August 2015 to June 2020 (12 day intervals).

CSG water production volumes, rainfall, soil types and coal proportion.

Prototype prediction models: Covariance matrix



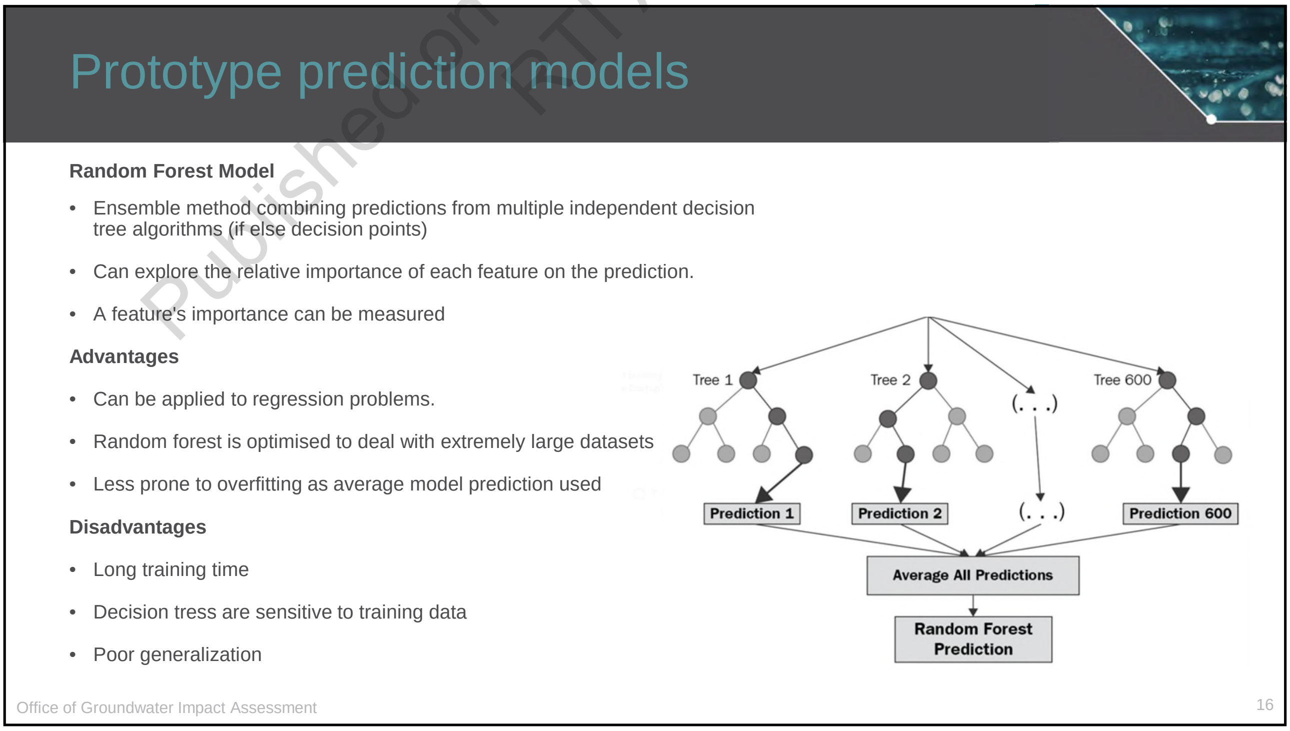
	X	Y	500_1mo_wp	500_3mo_wp	500_12mo_wp	500_all_wp	1000_1mo_wp	1000_3mo_wp	1000_12mo_wp	1000_all_wp	3000_all_wp	5000_1mo_wp	5000_3mo_wp	5000_12mo_wp	5000_all_wp	rain_1mo	rain_3mo	rain_12mo	rain_all	days_x	Soil_3.0	Soil_8.0	Soil_12.0	Soil_14.0	Taroom_c	LJCM_c	UJXM_c	Soil_clay	Ground_motion
X	1.00	-0.31	0.02	0.02	-0.00	-0.37	0.02	0.01	-0.02	-0.52	-0.79	-0.19	-0.22	-0.30	-0.83	0.00	0.00	0.00	-0.00	-0.00	-0.71	0.05	0.13	0.70	-0.33	0.20	-0.03	0.81	-0.08
Y	-0.31	1.00	-0.20	-0.21	-0.21	0.07	-0.32	-0.33	-0.33	0.12	0.22	-0.45	-0.49	-0.46	0.31	-0.00	-0.00	-0.00	0.00	0.00	0.32	-0.34	-0.19	0.03	0.26	-0.11	0.38	-0.19	0.21
500_1mo_wp	0.02	-0.20	1.00	0.95	0.84	0.35	0.01	0.00	0.00	-0.05	-0.01	0.15	0.13	0.12	-0.04	0.00	0.01	0.01	-0.07	-0.07	-0.11	0.13	0.14	-0.11	0.02	-0.04	-0.13	-0.08	-0.04
500_3mo_wp	0.02	-0.21	0.95	1.00	0.90	0.38	0.00	0.00	0.00	-0.05	-0.01	0.12	0.13	0.12	-0.04	-0.00	0.00	0.01	-0.07	-0.07	-0.11	0.14	0.15	-0.12	0.02	-0.04	-0.14	-0.09	-0.04
500_12mo_wp	-0.00	-0.21	0.84	0.90	1.00	0.46	-0.00	0.00	0.01	-0.04	0.01	0.11	0.13	0.13	-0.02	0.01	0.02	0.02	-0.07	-0.07	-0.11	0.15	0.17	-0.15	0.03	-0.05	-0.15	-0.11	-0.05
500_all_wp	-0.37	0.07	0.35	0.38	0.46	1.00	-0.07	-0.07	-0.05	0.37	0.46	0.07	0.07	0.09	0.25	-0.01	-0.01	-0.03	0.08	0.08	0.27	-0.03	0.00	-0.31	0.10	-0.11	-0.19	-0.34	0.01
1000_1mo_wp	0.02	-0.32	0.01	0.00	-0.00	-0.07	1.00	0.95	0.83	0.24	0.00	0.24	0.22	0.19	-0.05	0.00	0.01	0.01	-0.09	-0.09	-0.16	0.22	0.22	-0.19	0.03	-0.03	-0.21	-0.13	-0.06
1000_3mo_wp	0.01	-0.33	0.00	0.00	0.00	-0.07	0.95	1.00	0.90	0.26	0.01	0.20	0.22	0.20	-0.05	-0.00	-0.00	0.01	-0.10	-0.10	-0.17	0.23	0.23	-0.21	0.03	-0.04	-0.23	-0.14	-0.06
1000_12mo_wp	-0.02	-0.33	0.00	0.00	0.01	-0.05	0.83	0.90	1.00	0.34	0.03	0.19	0.21	0.22	-0.02	0.02	0.02	0.01	-0.10	-0.10	-0.16	0.24	0.25	-0.25	0.05	-0.04	-0.25	-0.18	-0.06
1000_all_wp	-0.52	0.12	-0.05	-0.05	-0.04	0.37	0.24	0.26	0.34	1.00	0.66	0.08	0.09	0.12	0.36	-0.01	-0.01	-0.04	0.11	0.11	0.39	-0.05	-0.02	-0.43	0.16	-0.08	-0.20	-0.49	0.02
3000_all_wp	-0.79	0.22	-0.01	-0.01	0.01	0.46	0.00	0.01	0.03	0.66	1.00	0.14	0.16	0.21	0.65	-0.02	-0.02	-0.07	0.18	0.17	0.62	-0.10	-0.06	-0.64	0.32	-0.14	-0.11	-0.72	0.02
5000_1mo_wp	-0.19	-0.45	0.15	0.12	0.11	0.07	0.24	0.20	0.19	0.08	0.14	1.00	0.92	0.76	0.20	0.00	0.00	-0.05	-0.10	-0.09	0.05	0.17	0.13	-0.30	0.04	0.01	-0.20	-0.16	-0.08
5000_3mo_wp	-0.22	-0.49	0.13	0.13	0.13	0.07	0.22	0.22	0.21	0.09	0.16	0.92	1.00	0.88	0.24	-0.02	-0.02	-0.07	-0.14	-0.12	0.06	0.18	0.14	-0.34	0.05	0.01	-0.23	-0.19	-0.08
5000_12mo_wp	-0.30	-0.48	0.12	0.12	0.13	0.09	0.19	0.20	0.22	0.12	0.21	0.76	0.88	1.00	0.31	0.01	0.00	-0.09	-0.19	-0.17	0.11	0.18	0.13	-0.40	0.08	0.01	-0.24	-0.26	-0.06
5000_all_wp	-0.83	0.31	-0.04	-0.04	-0.02	0.25	-0.05	-0.05	-0.02	0.36	0.65	0.20	0.24	0.31	1.00	-0.03	-0.03	-0.10	0.26	0.26	0.56	-0.06	-0.02	-0.64	0.38	-0.19	0.16	-0.72	0.02
rain_1mo	0.00	-0.00	0.00	-0.00	0.01	-0.01	0.00	-0.00	0.02	-0.01	-0.02	-0.00	-0.02	0.01	-0.03	1.00	0.58	0.25	-0.07	-0.11	0.00	0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	0.02
rain_3mo	0.00	-0.00	0.01	0.00	0.02	-0.01	0.01	-0.00	0.02	-0.01	-0.02	0.00	-0.02	0.00	-0.03	0.58	1.00	0.37	-0.07	-0.15	0.00	0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	0.02
rain_12mo	0.00	-0.00	0.01	0.01	0.02	-0.03	0.01	0.01	0.01	-0.04	-0.07	-0.05	-0.07	-0.09	-0.10	0.25	0.37	1.00	-0.32	-0.44	0.00	0.00	-0.00	0.00	-0.00	-0.00	0.00	-0.00	0.09
rain_all	-0.00	0.00	-0.07	-0.07	-0.07	0.08	-0.09	-0.10	-0.10	0.11	0.18	-0.10	-0.14	-0.19	0.26	-0.07	-0.07	-0.32	1.00	0.99	-0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	-0.23
days_x	-0.00	0.00	-0.07	-0.07	-0.07	0.08	-0.09	-0.10	-0.10	0.11	0.17	-0.09	-0.12	-0.17	0.26	-0.11	-0.15	-0.44	0.99	1.00	-0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	-0.23
Soil_3.0	-0.71	0.32	-0.11	-0.11	-0.11	0.27	-0.16	-0.17	-0.16	0.39	0.62	0.05	0.06	0.11	0.56	0.00	0.00	0.00	-0.00	-0.00	1.00	-0.18	-0.56	-0.36	0.19	-0.07	0.22	-0.47	0.09
Soil_8.0	0.05	-0.34	0.13	0.14	0.15	-0.03	0.22	0.23	0.24	-0.05	-0.10	0.17	0.18	0.18	-0.06	0.00	0.00	0.00	-0.00	-0.00	-0.18	1.00	-0.17	-0.11	0.00	-0.14	0.01	-0.11	-0.11
Soil_12.0	0.13	-0.19	0.14	0.15	0.17	0.00	0.22	0.23	0.25	-0.02	-0.06	0.13	0.14	0.13	-0.02	-0.00	-0.00	-0.00	0.00	0.00	-0.56	-0.17	1.00	-0.35	0.07	-0.01	-0.29	-0.07	-0.04
Soil_14.0	0.70	0.03	-0.11	-0.12	-0.15	-0.31	-0.19	-0.21	-0.25	-0.43	-0.64	-0.30	-0.34	-0.40	-0.64	0.00	0.00	0.00	-0.00	-0.00	-0.36	-0.11	-0.35	1.00	-0.33	0.18	0.07	0.74	0.01
Taroom_c	-0.33	0.26	0.02	0.02	0.03	0.10	0.03	0.03	0.05	0.16	0.32	0.04	0.05	0.08	0.38	-0.00	-0.00	-0.00	0.00	0.00	0.19	0.00	0.07	-0.33	1.00	-0.11	0.12	-0.48	0.04
LJCM_c	0.20	-0.11	-0.04	-0.04	-0.05	-0.11	-0.03	-0.04	-0.04	-0.08	-0.14	0.01	0.01	0.01	-0.19	0.00	0.00	-0.00	0.00	0.00	-0.07	-0.14	-0.01	0.18	-0.11	1.00	-0.35	0.20	0.01
UJXM_c	-0.03	0.38	-0.13	-0.14	-0.15	-0.19	-0.21	-0.23	-0.25	-0.20	-0.11	-0.20	-0.23	-0.24	0.16	0.00	0.00	0.00	-0.00	-0.00	0.22	0.01	-0.29	0.07	0.12	-0.35	1.00	0.02	0.06
Soil_clay	0.81	-0.19	-0.08	-0.09	-0.11	-0.34	-0.13	-0.14	-0.18	-0.49	-0.72	-0.16	-0.19	-0.26	-0.72	-0.00	-0.00	-0.00	0.00	0.00	-0.47	-0.11	-0.07	0.74	-0.48	0.20	0.02	1.00	-0.04
Ground_motion	-0.08	0.21	-0.04	-0.04	-0.05	0.01	-0.06	-0.06	-0.06	0.02	0.02	-0.08	-0.08	-0.06	0.02	0.02	0.02	0.09	-0.23	-0.23	0.09	-0.11	-0.04	0.01	0.04	0.01	0.06	-0.04	1.00



Prototype prediction models

Two prediction models were evaluated.

- Multi-variate linear regression
    - 27 Features with one target as the ground motion
    - R2 train= 0.102 and R2 test= 0.102
- Poor performance



Prototype prediction models

Random Forest Model

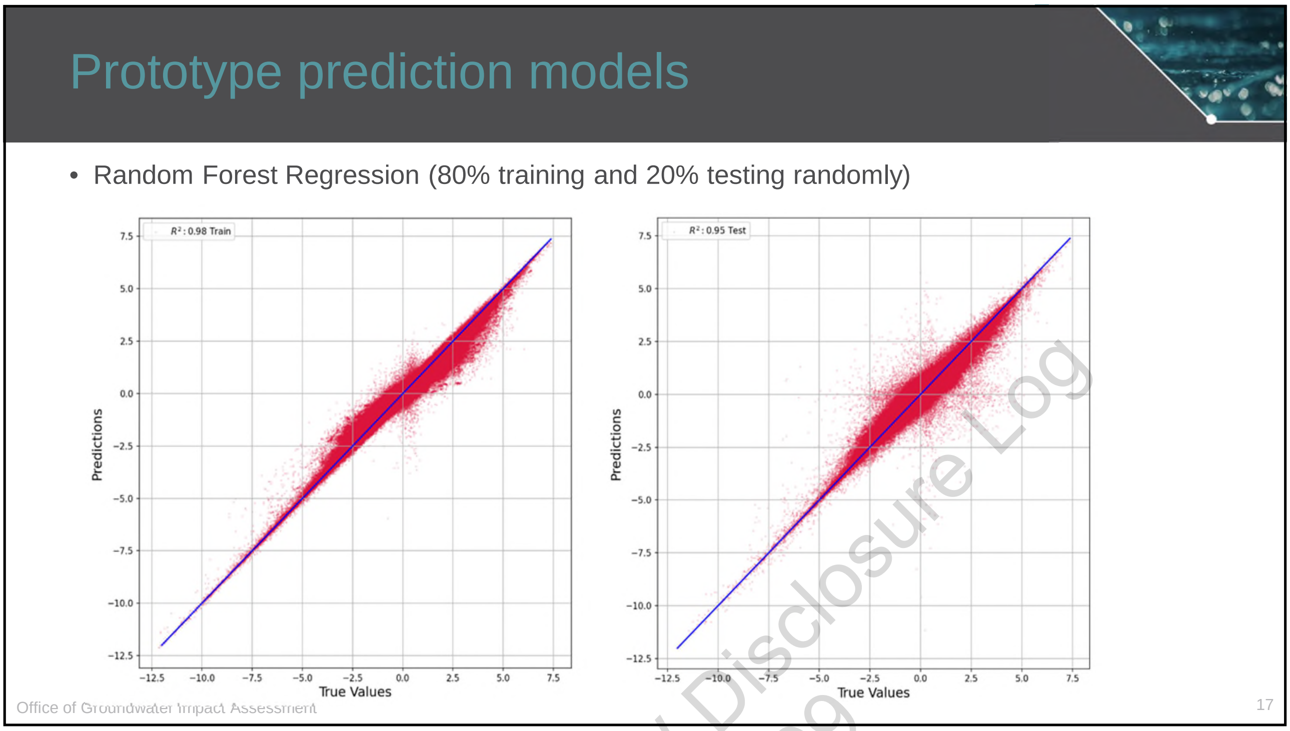
- Ensemble method combining predictions from multiple independent decision tree algorithms (if else decision points)
- Can explore the relative importance of each feature on the prediction.
- A feature's importance can be measured

Advantages

- Can be applied to regression problems.
- Random forest is optimised to deal with extremely large datasets
- Less prone to overfitting as average model prediction used

Disadvantages

- Long training time
- Decision tress are sensitive to training data
- Poor generalization



Prototype prediction models

- Random Forest Regression (80% training and 20% testing randomly)

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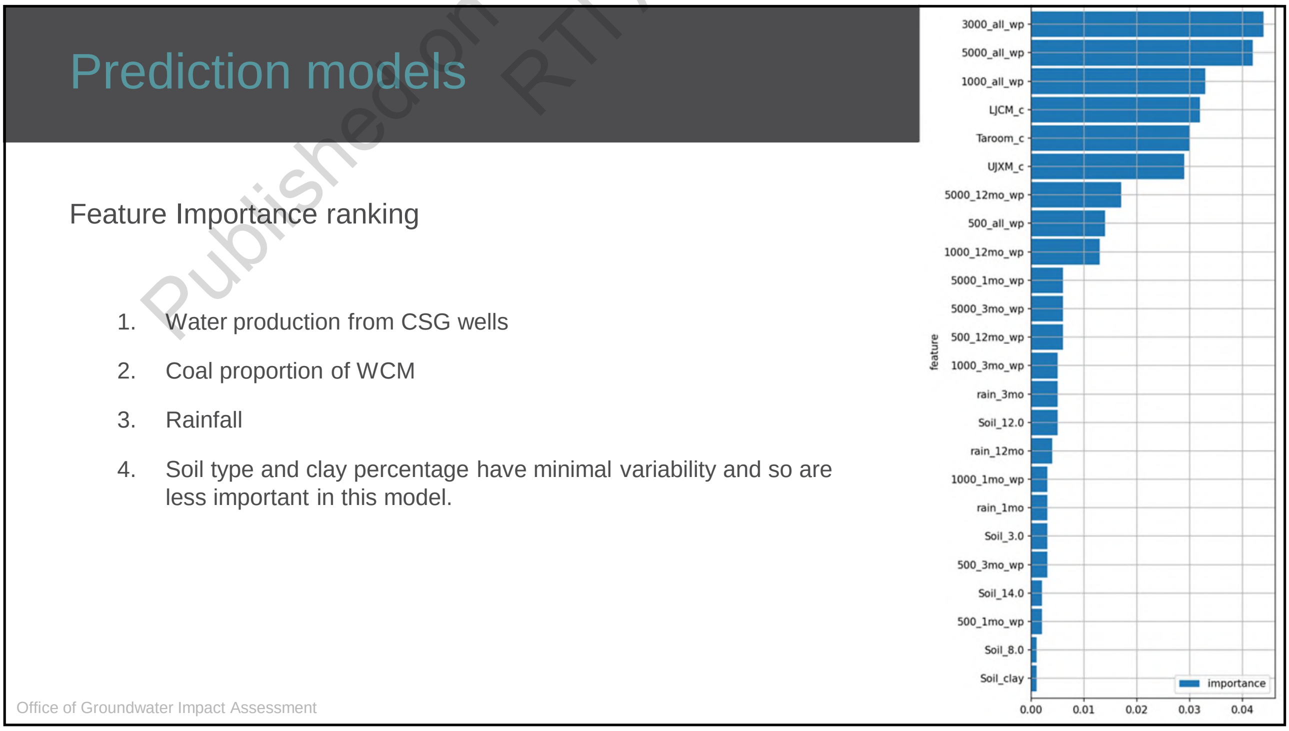

Prediction models

Feature Importance ranking

1. Water production from CSG wells
2. Coal proportion of WCM
3. Rainfall
4. Soil type and clay percentage have minimal variability and so are less important in this model.

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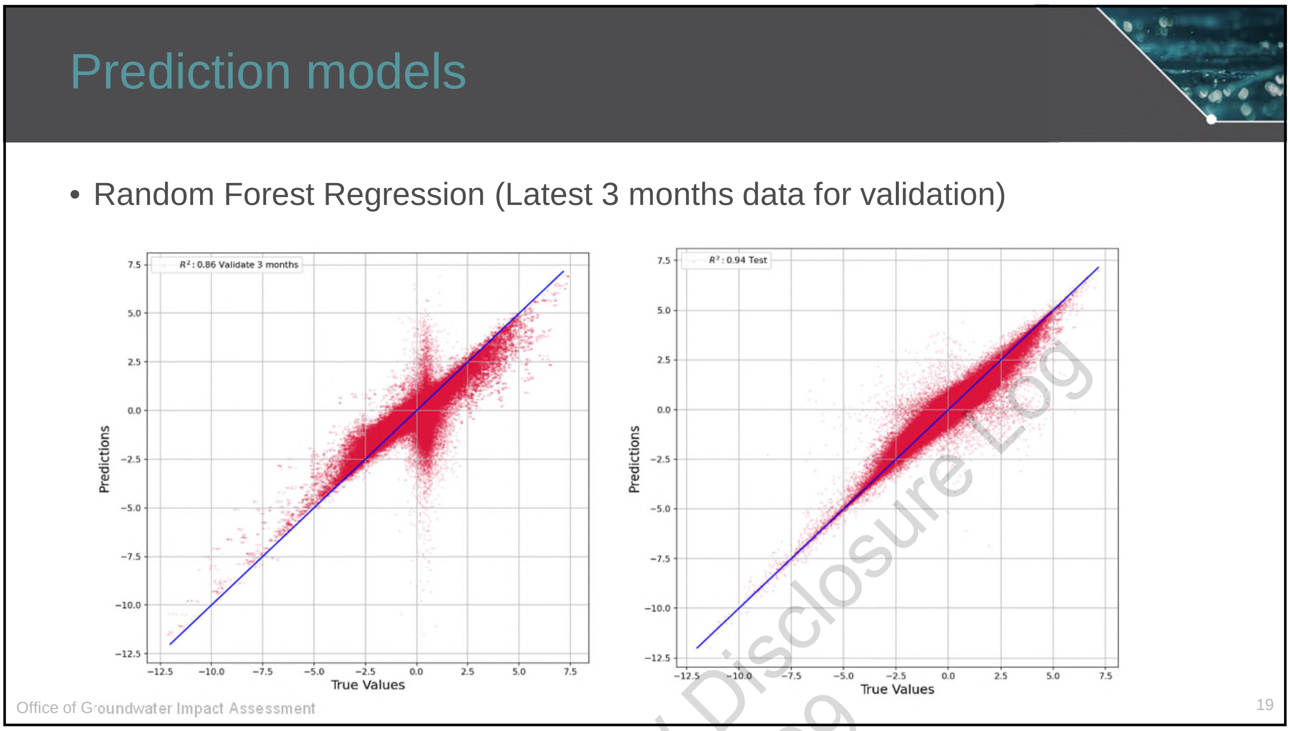
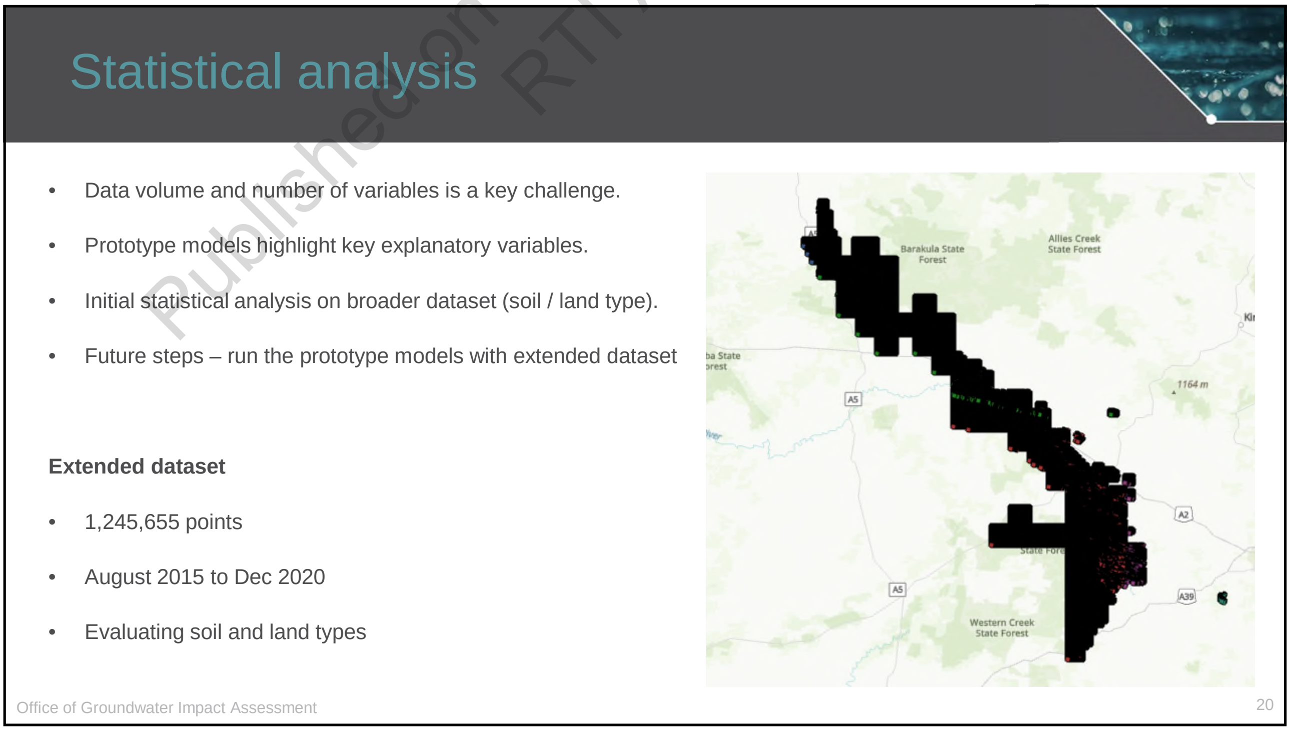


Prediction models

- Random Forest Regression (Latest 3 months data for validation)



Statistical analysis

- Data volume and number of variables is a key challenge.
- Prototype models highlight key explanatory variables.
- Initial statistical analysis on broader dataset (soil / land type).
- Future steps – run the prototype models with extended dataset

Extended dataset

- 1,245,655 points
- August 2015 to Dec 2020
- Evaluating soil and land types

Statistical analysis

Statistical analyses of cumulative ground motion on different soil types

Soil type	Points	mean	std	min	25%	50%	75%	max
Chromosols	89790	-8.1	16.9	-202.8	-14.0	-5.8	1.0	54.0
Dermosols	273040	-5.6	11.5	-181.5	-11.4	-4.6	1.1	105.7
Ferrosols	15457	-5.9	14.2	-78.9	-13.9	-4.9	3.0	94.2
Kandosols	12021	-6.6	14.2	-152.2	-13.1	-4.9	1.9	53.0
Kurosols	138432	-6.4	13.9	-201.8	-12.0	-4.6	1.4	109.7
Rudosols	296	-9.0	12.5	-42.3	-15.1	-7.9	-1.7	25.9
Sodosols	405041	-4.6	18.7	-188.7	-13.0	-4.1	3.9	192.1
Tenosols	6396	-3.3	13.3	-91.1	-10.6	-2.3	5.0	42.9
Vertosols	305183	2.1	30.5	-182.4	-14.3	-2.0	12.5	226.2

Statistical analysis

Statistical analyses of cumulative ground motion on different land types

Land type	count	mean	std	min	25%	50%	75%	max
Conservation and Natural Environments	9032	-10.3	16.4	-143.5	-18.0	-9.0	-1.3	177.6
Production from Relatively Natural Environments	563468	-6.8	15.7	-183.8	-14.2	-5.1	2.6	158.5
Production from Dryland Agriculture and Plantations	114353	18.5	41.2	-183.6	-9.7	12.3	45.5	226.2
Production from Irrigated Agriculture and Plantations	17662	4.9	38.0	-150.9	-19.0	2.5	27.3	167.6
Intensive Uses	32303	-8.8	28.4	-202.8	-15.5	-3.6	5.7	94.2
Water	3114	-13.2	27.5	-180.9	-24.3	-8.7	3.5	92.2

Agriculture and plantations seem have high positive value of ground motion, and it may due to larger amount of water supply (natural rainfall or provided).

Next Steps

- Taking the CSG influence area into account in the statistical analysis. CSG well production might be the dominant factor in that area
- Using random forest on larger dataset to study the feature importance and validating with the statistical analysis.
- Determine how to treat categorised data in regression modelling. For e.g land-use

Geomechanical modelling

Objectives

- **Predictions** of:
    - CSG induced changes in slope, and direction of slope in and around the Condamine Alluvium
- Test different influencing factors and their implications **(hypothesis testing),** e.g.
    - CSG vs non-CGS
    - Heterogeneity
    - Scale
- As a **communication** and educational tool for landholders

Projects

OGIA

- 3-D Geomechanical modelling for the Condamine area (completed)
- Application of 1-D modelling across the Surat CMA (completed)
- Influence of coal seam discontinuity on subsidence estimation (post UWIR)
- Investigate effects of coal sorption-induced shrinkage (Masoudian et al, 2019) – with UQ (Post UWIR)

Other contemporary work

- *Ongoing UQ projects*

Method

Construction of a 3D numerical geomechanical model to estimate subsidence resulting from CGG groundwater extraction – collaboration with Schlumberger geomechanical team.

Key data

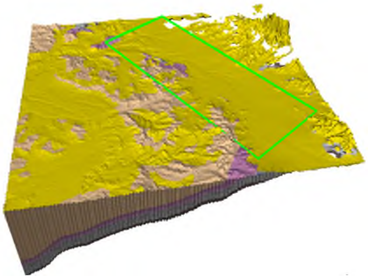
- 41 wells with geophysical suites, derived lithology and geomechanical properties
- Regional groundwater model, derived pore pressure data per layers
- Geological model

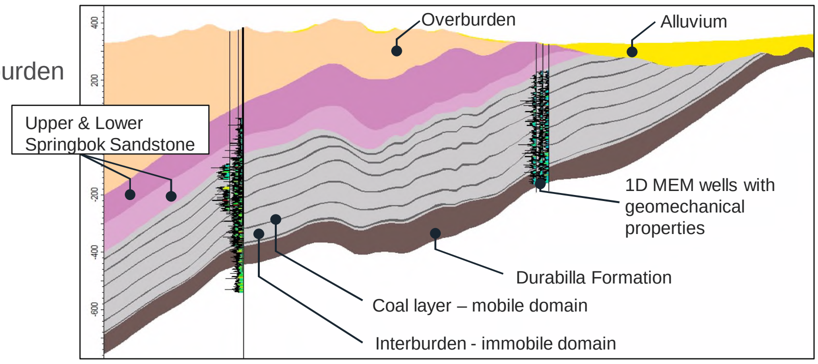
Key steps

- Step 1: Data compilation - define elastic and strength properties of material from wells
- Step 2: Build a series of 1D Mechanical Earth Model (MEM) in Techlog (SLB)
- Step 3: Build a 3D geomechanical model using Petrel / Delfi
- Step 4: Model simulation using Visage

3D Geological Model

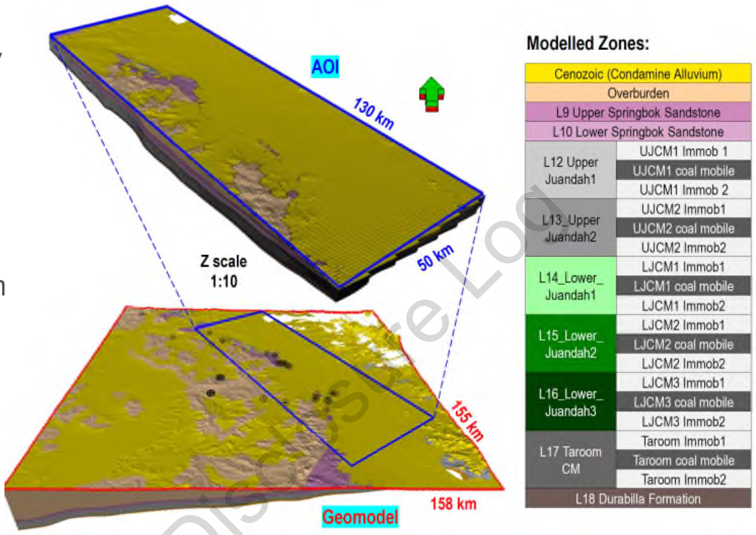
- OGIA regional model
- petroleum wells
- 5 units and their subdivisions
- 750m resolution
- separate layers for coal and interburden
- Coal layers lumped per sub-unit





Model Grid

- Coal layers modelled conceptually based on isochore maps
- Refined vertical layering to avoid convergence issues
- Sensitivity to scale tested @250 m 500 m and 750 m

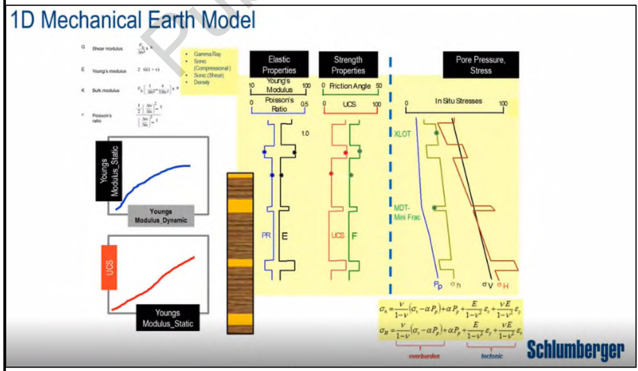


Modelled Zones:

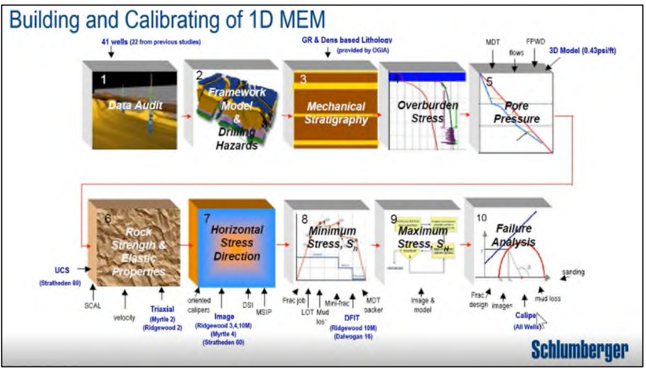
Cenozoic (Condamine Alluvium)	
Overburden	
L9 Upper Springbok Sandstone	
L10 Lower Springbok Sandstone	
L12 Upper Juandah1	UJCM1 Immob 1
	UJCM1 coal mobile
	UJCM1 Immob 2
L13_Upper Juandah2	UJCM2 Immob1
	UJCM2 coal mobile
	UJCM2 Immob2
L14_Lower_ Juandah1	LJCM1 Immob1
	LJCM1 coal mobile
	LJCM1 Immob2
L15_Lower_ Juandah2	LJCM2 Immob1
	LJCM2 coal mobile
	LJCM2 Immob2
L16_Lower_ Juandah3	LJCM3 Immob1
	LJCM3 coal mobile
	LJCM3 Immob2
L17 Taroom CM	Taroom Immob1
	Taroom coal mobile
	Taroom Immob2
L18 Durabilla Formation	

1D Mechanical Earth Model (MEM)

1D MEM model constructed by SLB Geomechanical Team, using 41 wells available

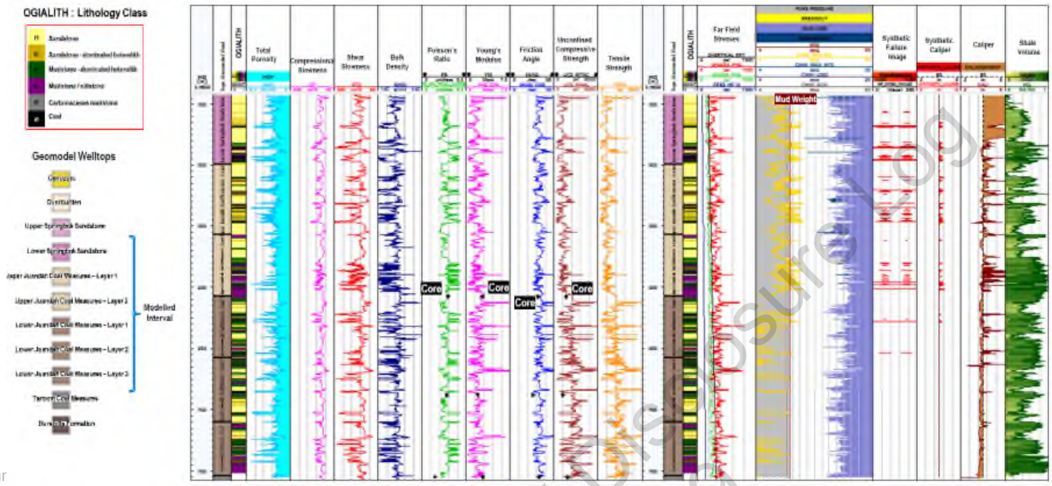


$$\sigma_h = \frac{\nu}{1-\nu}(\sigma_v - \alpha P_p) + \alpha P_p + \frac{E}{1-\nu^2}\varepsilon_x + \frac{\nu E}{1-\nu^2}\varepsilon_y$$
$$\sigma_H = \frac{\nu}{1-\nu}(\sigma_v - \alpha P_p) + \alpha P_p + \frac{E}{1-\nu^2}\varepsilon_y + \frac{\nu E}{1-\nu^2}\varepsilon_x$$



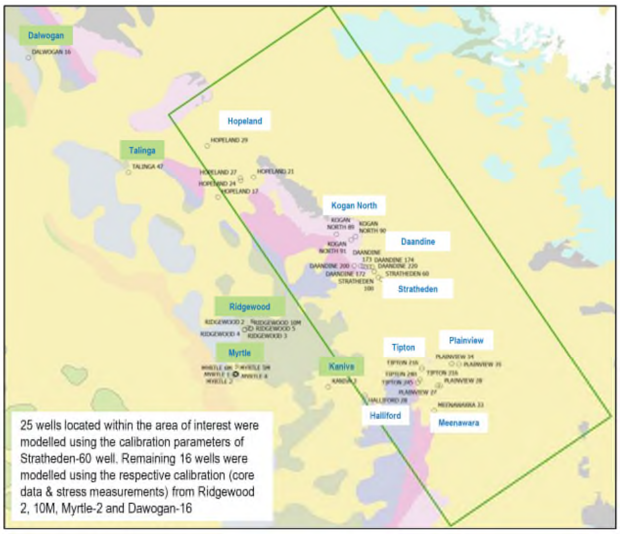
1D MEM

For each well, static logs for Young Modulus, Poisson Ration, Friction Angle and UCS were created. This inform on geomechanical properties for each geological units.



1D MEM

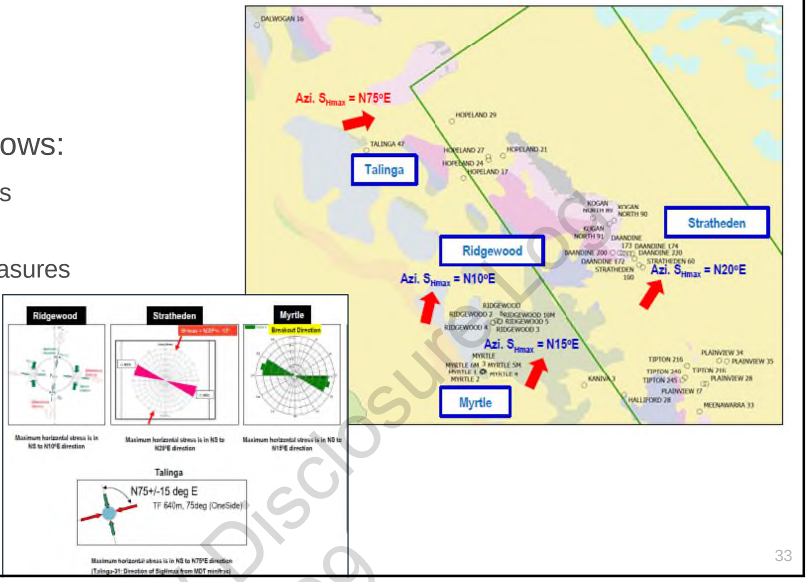
- 41 wells modelled
  - 25 in the AOI / 16 outside



25 wells located within the area of interest were modelled using the calibration parameters of Stratheden-60 well. Remaining 16 wells were modelled using the respective calibration (core data & stress measurements) from Ridgewood 2, 10M, Myrtle-2 and Dawogan-16

1D MEM

- 41 wells modelled
  - 25 in the AOI / 16 outside
- Stress regime generally follows:
  - Thrust regime in shallower units (above the upper Springbok)
  - Strike-Slip in Walloon Coal Measures
  - Stress direction roughly N-NE



Maximum horizontal stress is in NS to N10°E direction

Maximum horizontal stress is in NS to N20°E direction

Maximum horizontal stress is in NS to N15°E direction

Maximum horizontal stress is in NS to N75°E direction (Talinga-31: Direction of SigHmax from MDT minifrac)

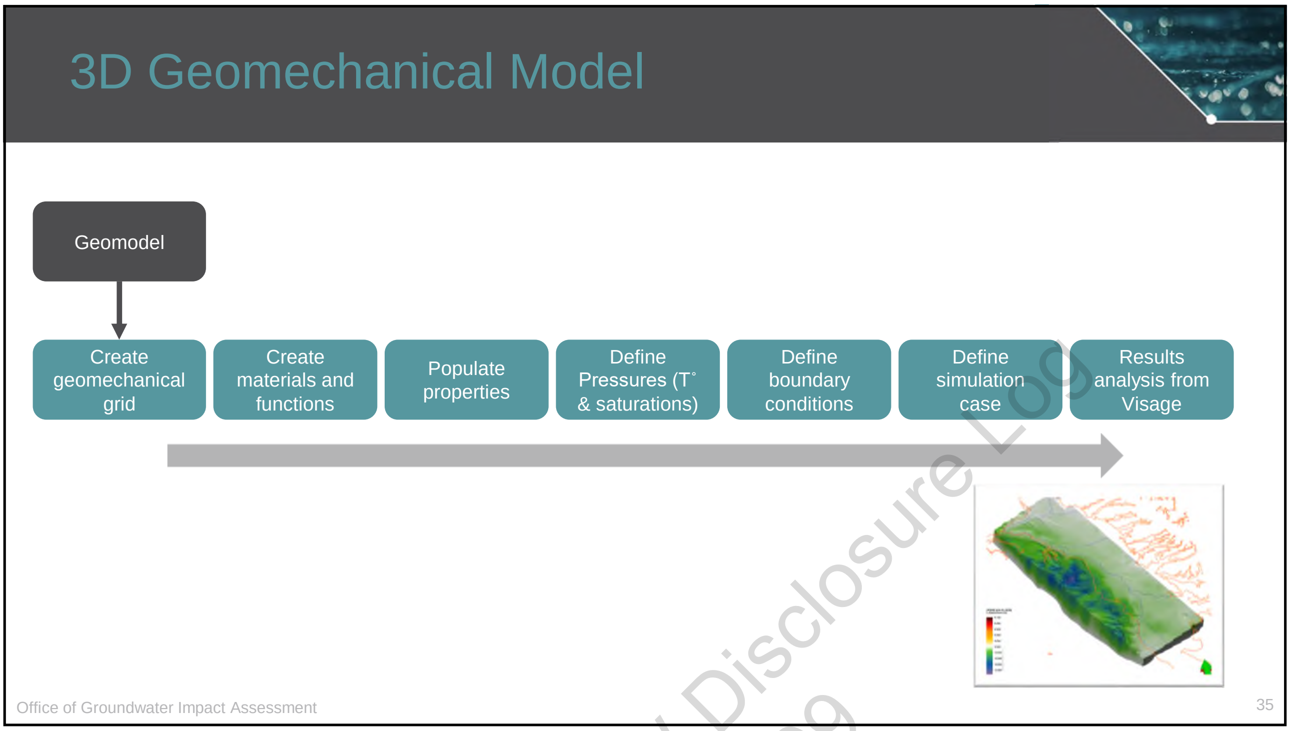
Cenozoic (Condamine alluvium) geomechanical properties

Properties	Alluvium properties adopted for this study	Reference 1	Reference 2	Reference 3
Young's modulus	0.002 – 0.04 Mpsi (Mean 0.02)	0.003 – 0.02 Mpsi 20 – 140 MPa	n/a	0.002 – 0.04 MPsi 15 – 280 Mpa
Poisson's ratio	0.28 – 0.38 (Mean 0.33)	n/a	n/a	0.28 – 0.38
Unconfined Compressive Strength	20 – 200 psi (Mean 100psi)	18 – 155 psi 126 – 1063 kPa	17 – 200 psi 123 - 1386 kPa	n/a
Friction Angle	25 – 35 deg (Mean 30 deg)	n/a	n/a	27 – 47 deg

Reference 1:
Foundation Investigation Jingi Jingi Creek Bridge
Department of Transport and Main Roads, Queensland Government
Report R3543, December 2014

Reference 2:
Braemar Creel Bridge Foundation Investigation
Department of Transport and Main Roads, Queensland Government
Report R3510, November 2012

Reference 3:
The addition of geotechnical properties to a geological classification of coarse-grained alluvium in a pediment zone
Fakher,A. et al.
Quarterly Journal of Engineering Geology and Hydrogeology(2007),40(2):163
http://dx.doi.org/10.1144/1470-9236/06-029



3D Geomechanical Model

Geomodel

Create geomechanical grid

Create materials and functions

Populate properties

Define Pressures (T˚ & saturations)

Define boundary conditions

Define simulation case

Results analysis from Visage

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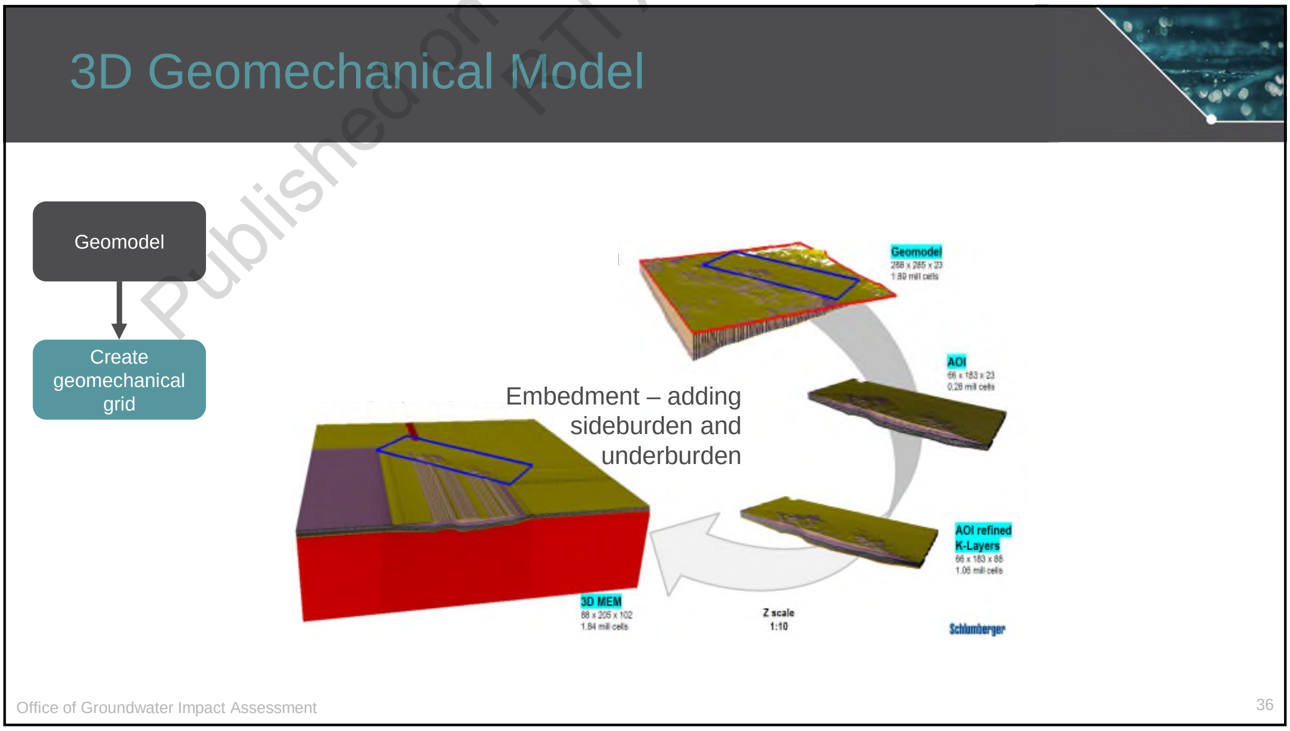

3D Geomechanical Model

Geomodel

Create geomechanical grid

Embedment – adding sideburden and underburden

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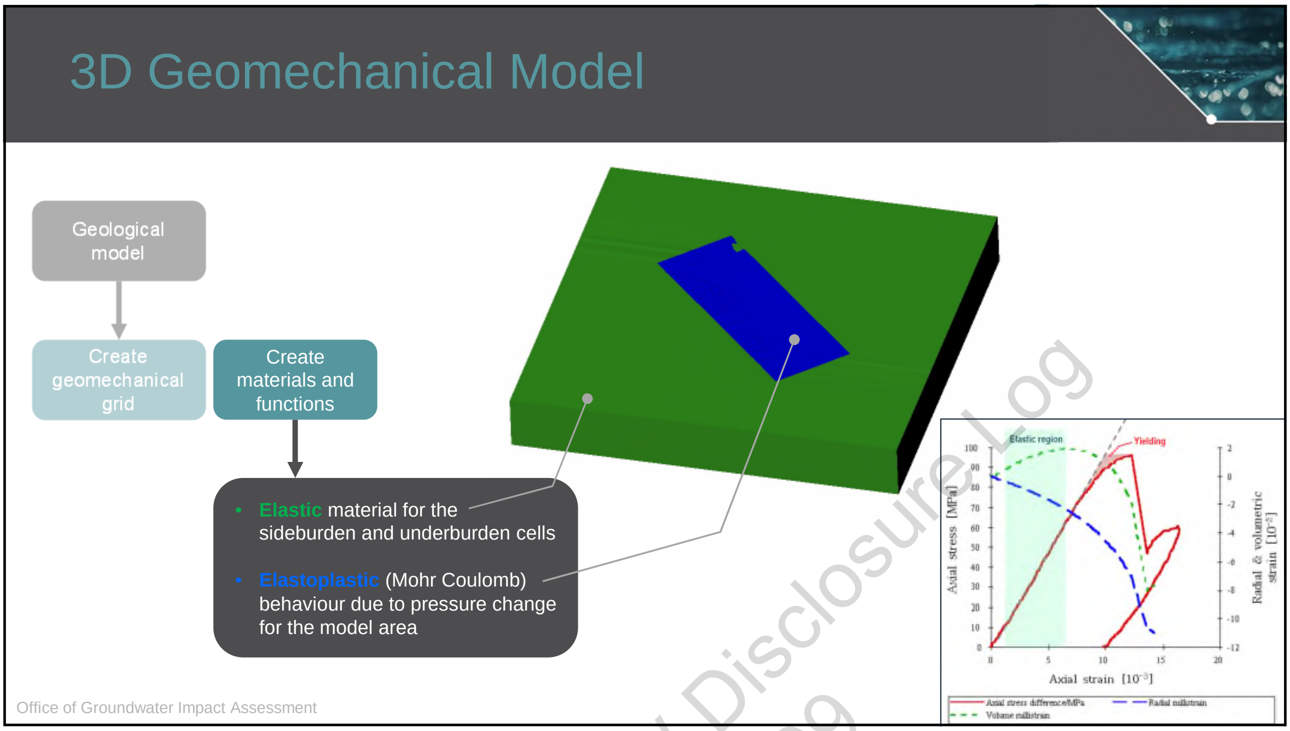


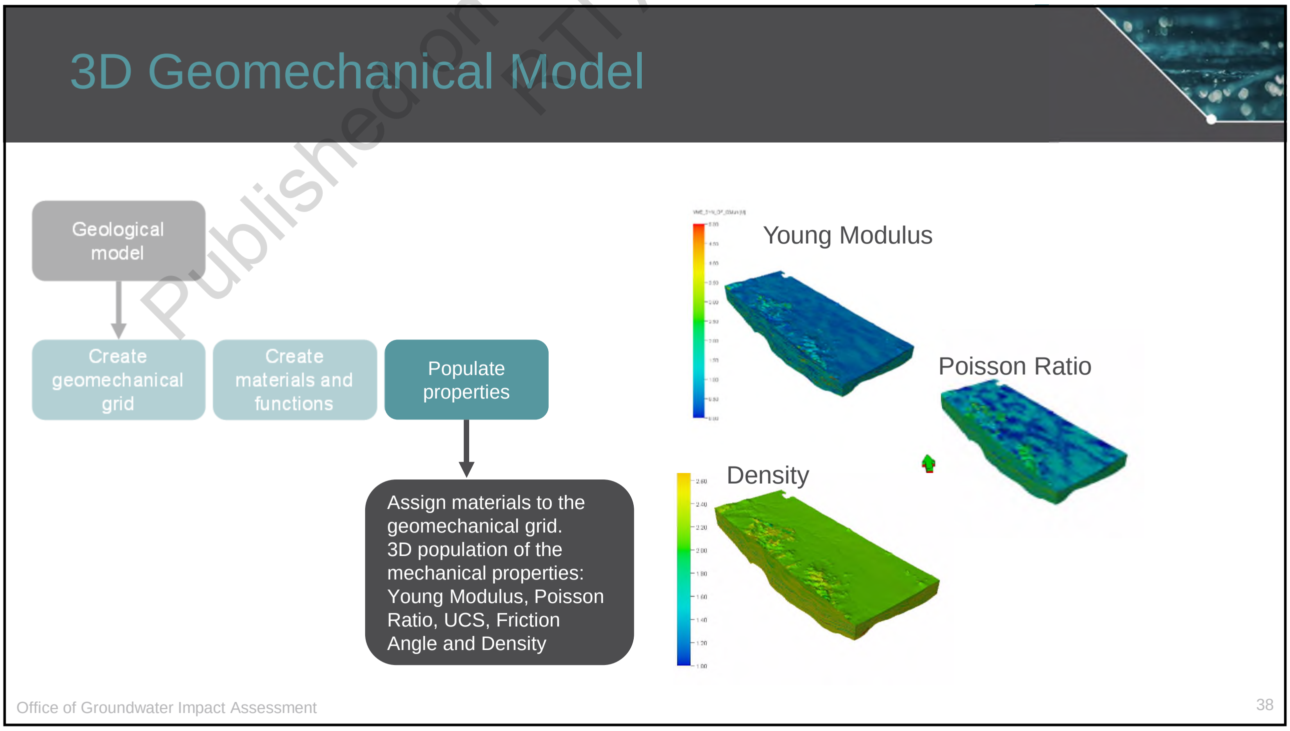
3D Geomechanical Model

Geological model

Create geomechanical grid

Create materials and functions

- **Elastic** material for the sideburden and underburden cells
- **Elastoplastic** (Mohr Coulomb) behaviour due to pressure change for the model area



3D Geomechanical Model

Geological model

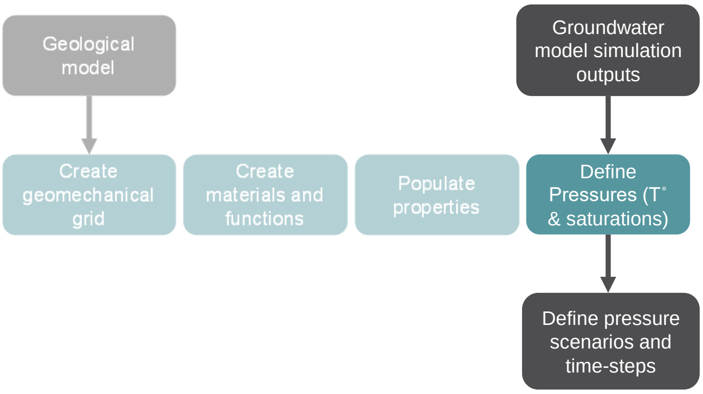
Create geomechanical grid

Create materials and functions

Populate properties

Assign materials to the geomechanical grid.
3D population of the mechanical properties: Young Modulus, Poisson Ratio, UCS, Friction Angle and Density

3D Geomechanical Model: Pressure


Geological model

Create geomechanical grid

Create materials and functions

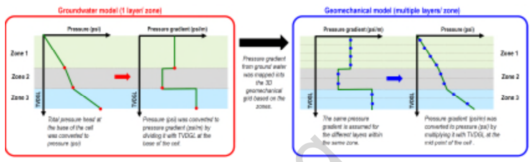
Populate properties

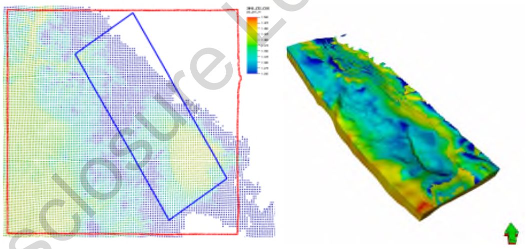
Groundwater model simulation outputs

Define Pressures (T˚ & saturations)

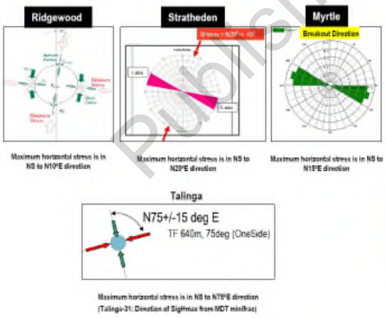
Define pressure scenarios and time-steps

Pressure Data Resampling to Geomechanical Model





3D Geomechanical Model

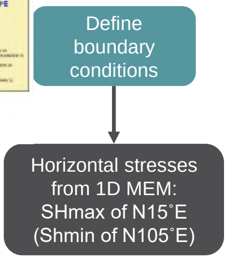


Maximum horizontal stress is in NS to N10°E direction

Maximum horizontal stress is in NS to N20°E direction

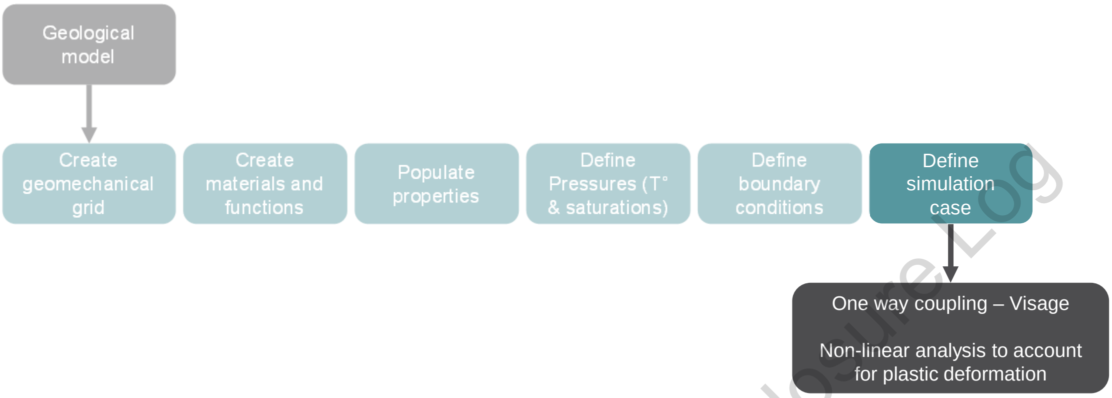
Maximum horizontal stress is in NS to N15°E direction

Maximum horizontal stress is in NS to N75°E direction (Talinga-31: Direction of SigHmax from MDT minifrac)


Define boundary conditions

Horizontal stresses from 1D MEM: SHmax of N15˚E (Shmin of N105˚E)

3D Geomechanical Model



Geological model

Create geomechanical grid

Create materials and functions

Populate properties

Define Pressures (T° & saturations)

Define boundary conditions

Define simulation case

One way coupling – Visage

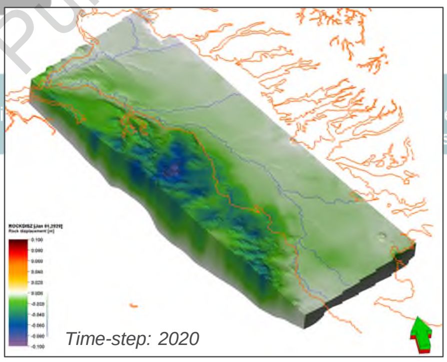
Non-linear analysis to account for plastic deformation

3D Geomechanical Model

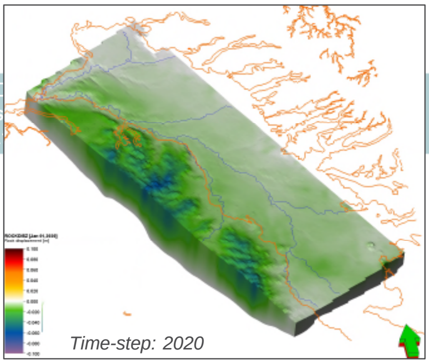
Geological model

Create geomechani grid

Results analysis from Visage



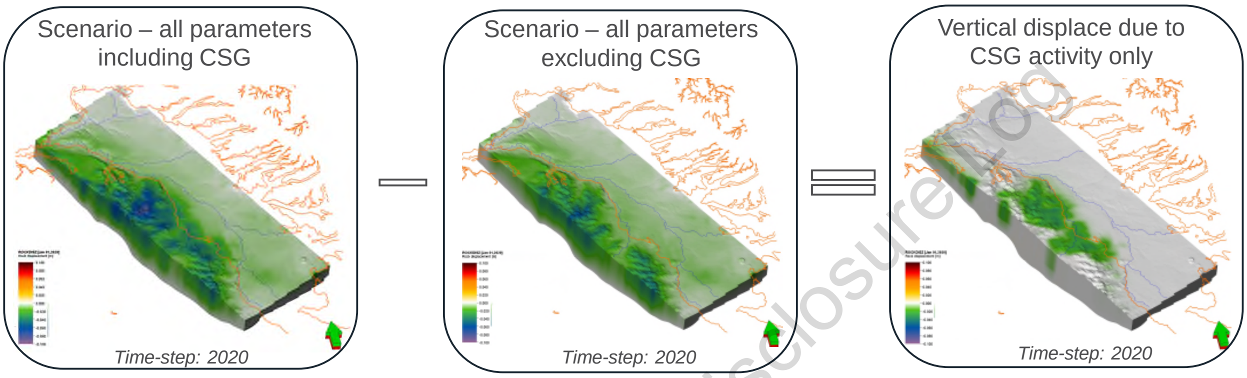
Scenario – all parameters including CSG



Scenario – all parameters excluding CSG

Preliminary results-Vertical displacement

- Model run at 13 timesteps from 1995 to 2109
- Validation currently underway in the historic period using InSAR data.


Scenario – all parameters including CSG

Time-step: 2020

Scenario – all parameters excluding CSG

Time-step: 2020

Vertical displace due to CSG activity only

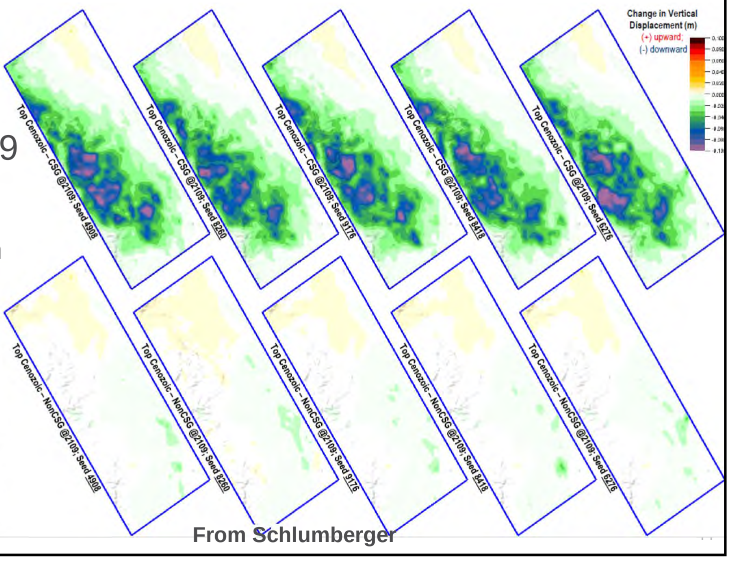
Time-step: 2020

Preliminary results-Subsidence

Sensitivity runs

The maximum subsidence at 2109

- **Scenario with CSG: 0.13 to 0.15 m**
- **Scenario without CSG: 0.02 to 0.04 m**



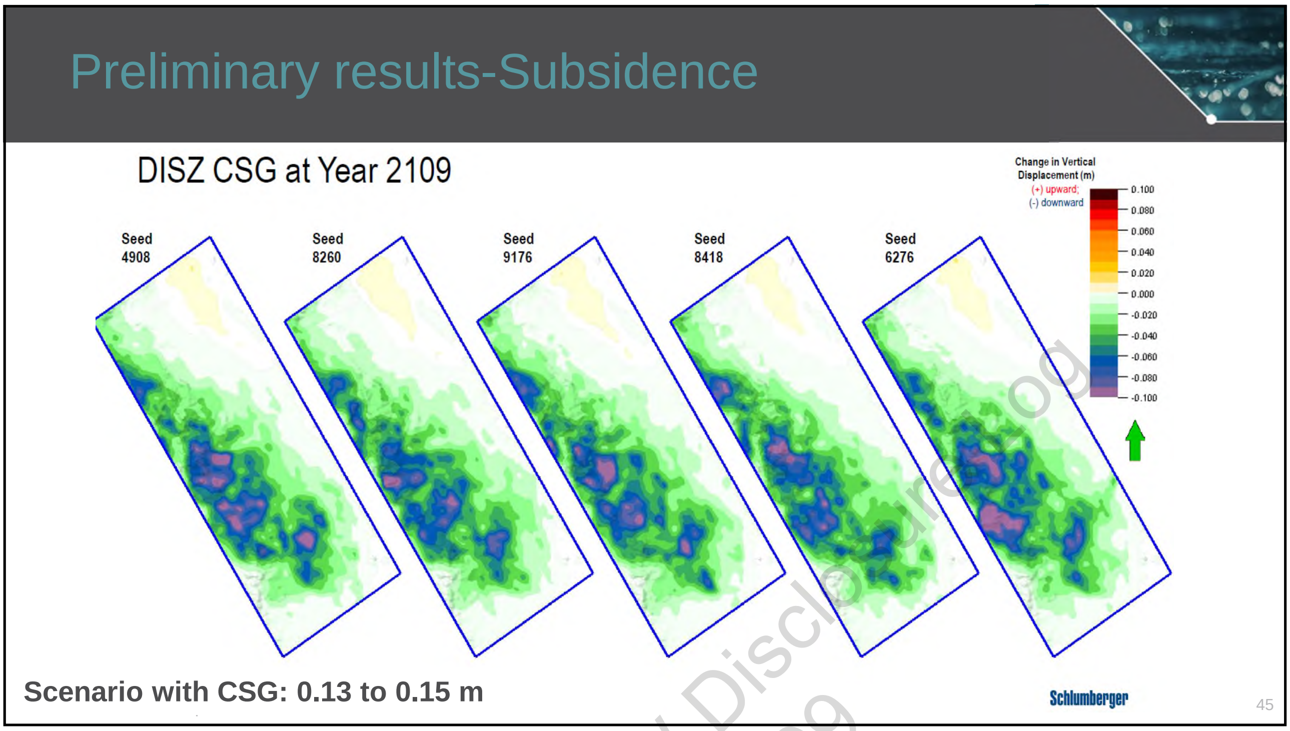
DISZ Top Cenozoic (GL) for CSG @ 2109

SEED	MIN	MAX	MEAN	STD
4908	-0.127	0.011	-0.023	0.024
8260	-0.151	0.008	-0.022	0.022
9176	-0.130	0.010	-0.023	0.023
8418	-0.135	0.005	-0.022	0.022
6276	-0.150	0.011	-0.023	0.024

DISZ Top Cenozoic (GL) for NonCSG @ 2109

SEED	MIN	MAX	MEAN	STD
4908	-0.028	0.011	-0.002	0.003
8260	-0.021	0.008	-0.002	0.003
9176	-0.026	0.011	-0.002	0.003
8418	-0.035	0.006	-0.002	0.003
6276	-0.036	0.012	-0.002	0.003

From Schlumberger

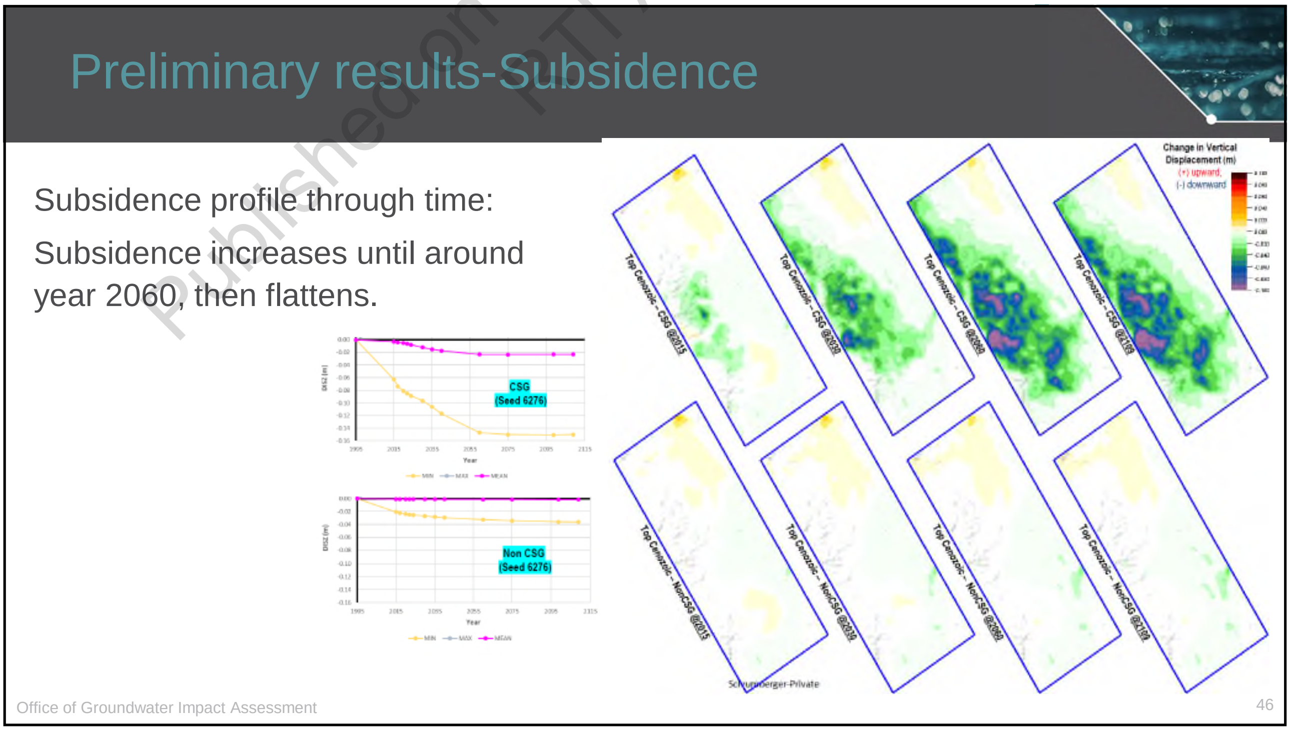


Preliminary results-Subsidence

DISZ CSG at Year 2109

Scenario with CSG: 0.13 to 0.15 m

Schlumberger



Preliminary results-Subsidence

Subsidence profile through time:

Subsidence increases until around year 2060, then flattens.

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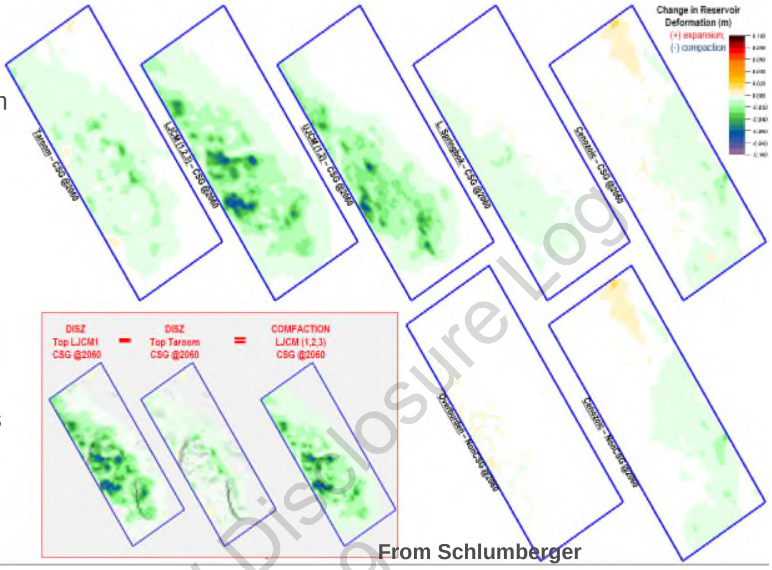
Preliminary results-Compaction

The **compaction** per zone can be calculated by subtracting the vertical displacement from the top to the bottom of formation.

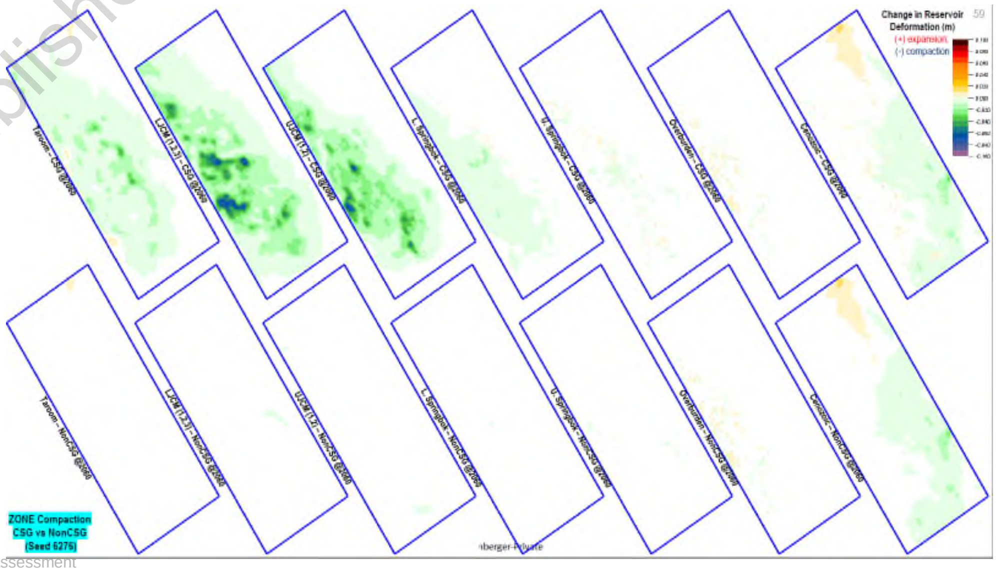
- The majority of subsidence in the **CSG case** is due to the **compaction** in the **Lower Juandah Coal Measures**
- The majority of subsidence in the **Non-CSG case** is due to the compaction in the **Cenozoic**.
- There is negligible overburden stress arching from zones above CMs.



From Schlumberger

Preliminary results

Compaction per zone



Preliminary results - summary

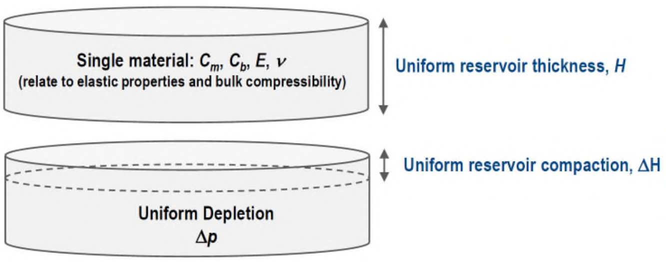
- The maximum subsidence at the end of the simulation (YR 2109) is predicted to be **0.13 to 0.15m for scenario with CSG** and **0.02 to 0.04m for scenario without CSG**
- The maximum subsidence **NET impact from CSG dewatering** at the end of the simulation (YR 2109) is predicted to be **0.13 to 0.15 m**
- Subsidence keeps increasing with time and stabilised in year 2060/2075.
- The majority of subsidence is due to the **compaction** in the **Lower Juandah Coal Measures**
- Minimal bridging effect is observed due to the large area of depressurisation

Validation of compaction estimates

- 1D analytical model applied using the same parameter fields as 3D geomechanical mode and the following equation:

$$\Delta H = \frac{(1-2v)(1+v)}{E(1-v)} H\Delta P$$ (Settari 2002 & Fjaer 1992)

Where H = thickness
E is Youngs Modulous
v is Possoins ratio
P is pressure

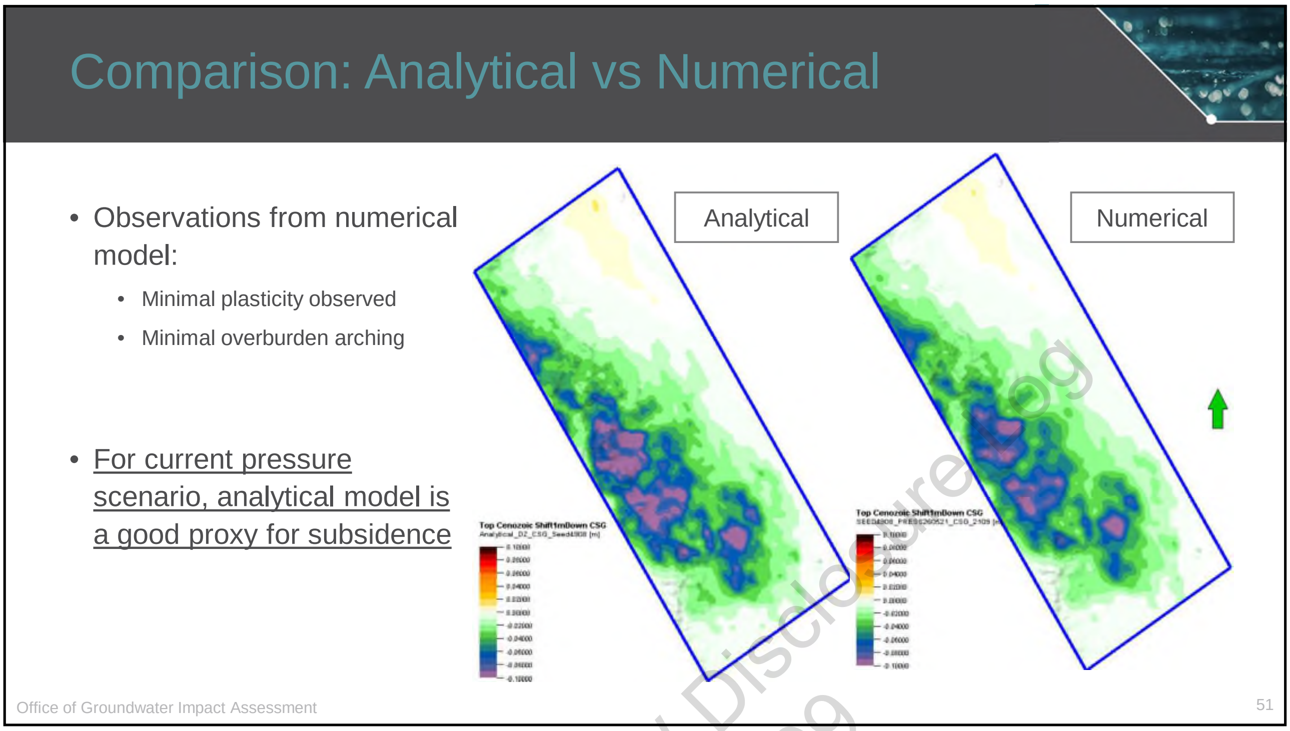


Assumptions

- Homogeneous, linear elastic reservoir material
- Uniform pressure depletion

Advantages:

- Fast and can be run many times to produce stochastic results



Comparison: Analytical vs Numerical

- Observations from numerical model:
  - Minimal plasticity observed
  - Minimal overburden arching

- <u>For current pressure scenario, analytical model is a good proxy for subsidence</u>

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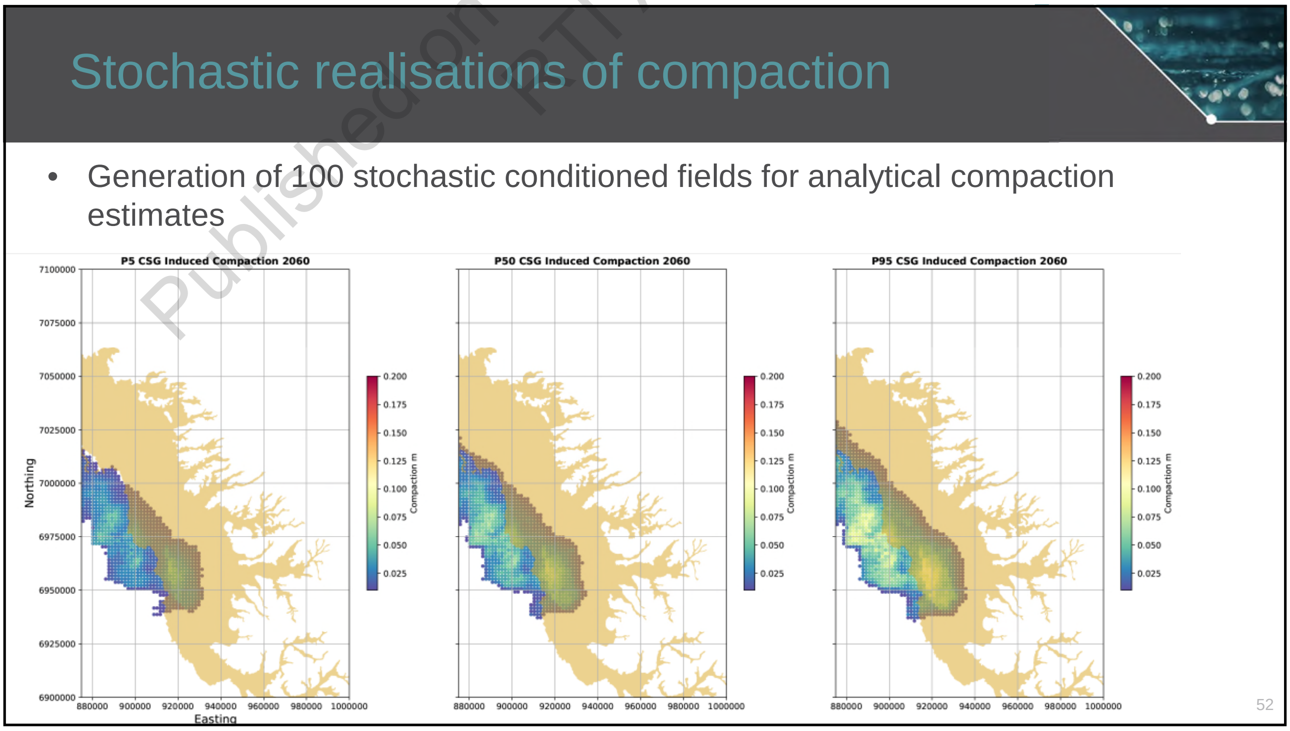


Stochastic realisations of compaction

- Generation of 100 stochastic conditioned fields for analytical compaction estimates

What’s next

UWIR2021

- Running the final result using UWIR 2021 pressure scenario
- Run stochastic compaction estimates for regional areas
- Looking at slope & flow direction changes at surface

Post UWIR2021

- Influence of coal seam discontinuity on subsidence estimation
- Investigate effects of coal sorption-induced shrinkage (Masoudian et al, 2019) – with UQ

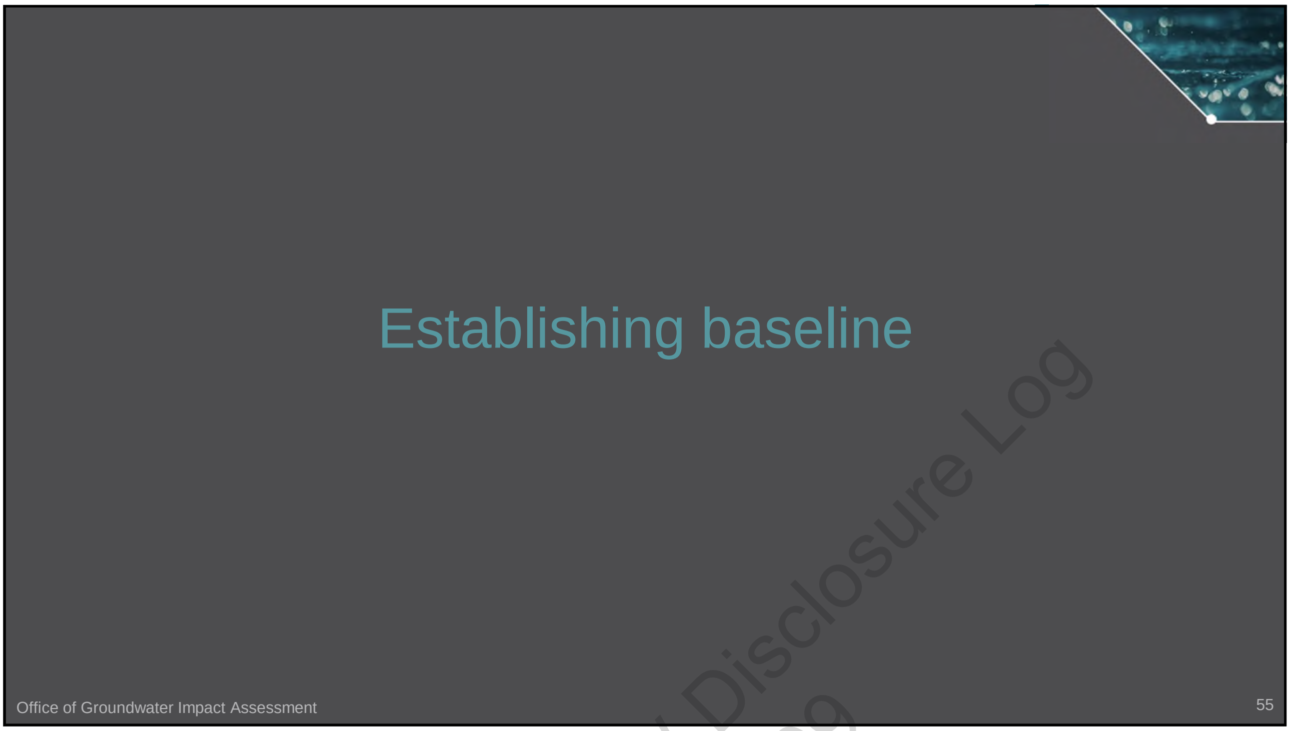
Projects

OGIA

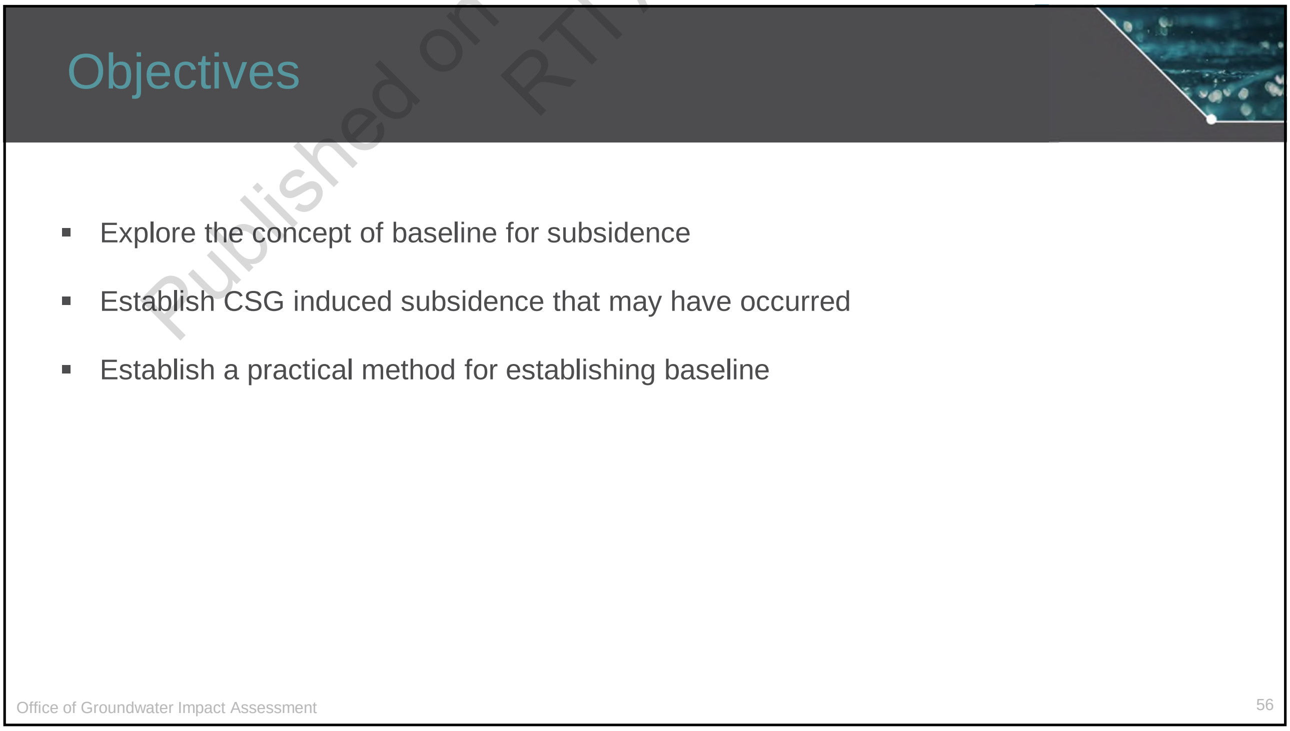
- 3-D Geomechanical modelling for the Condamine area (completed)
- Application of 1-D modelling across the Surat CMA (completed)
- Influence of coal seam discontinuity on subsidence estimation (post UWIR)
- Investigate effects of coal sorption-induced shrinkage (Masoudian et al, 2019) – with UQ (Pots UWIR)

Other contemporary work

- *Ongoing UQ projects*

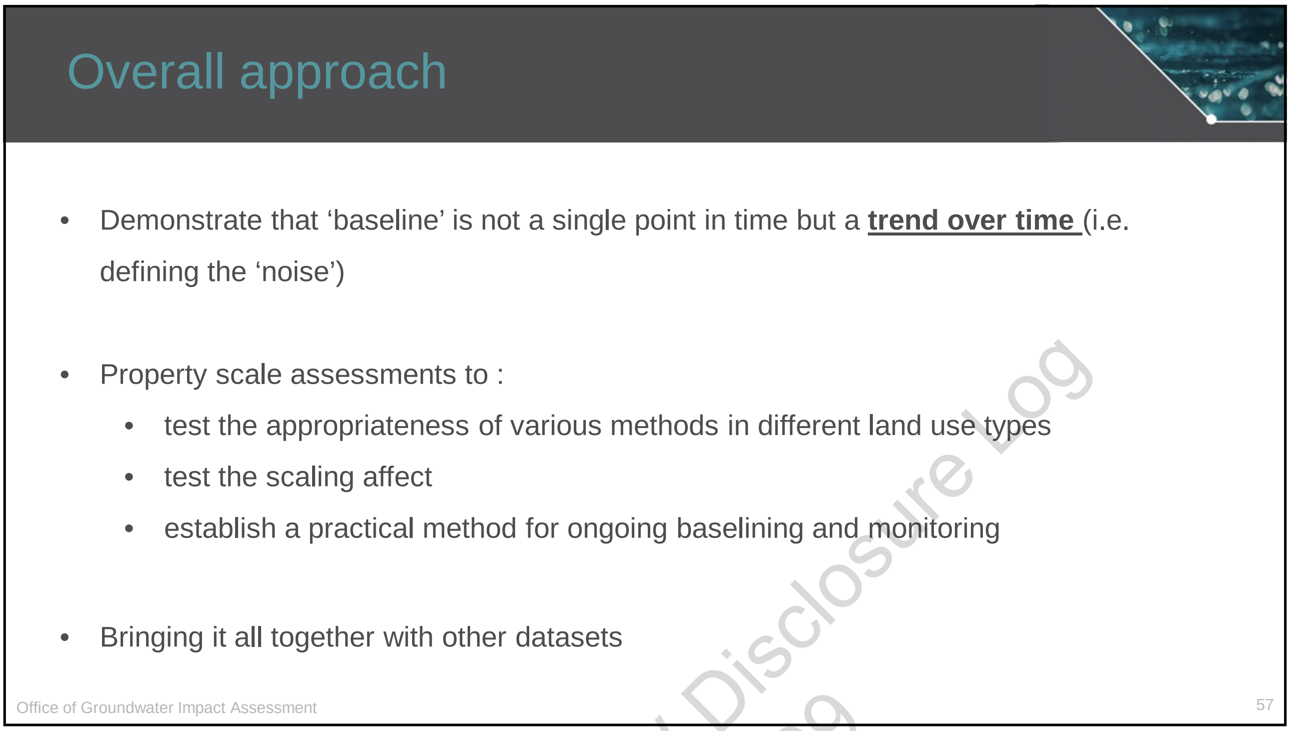


Establishing baseline



Objectives

- Explore the concept of baseline for subsidence
- Establish CSG induced subsidence that may have occurred
- Establish a practical method for establishing baseline

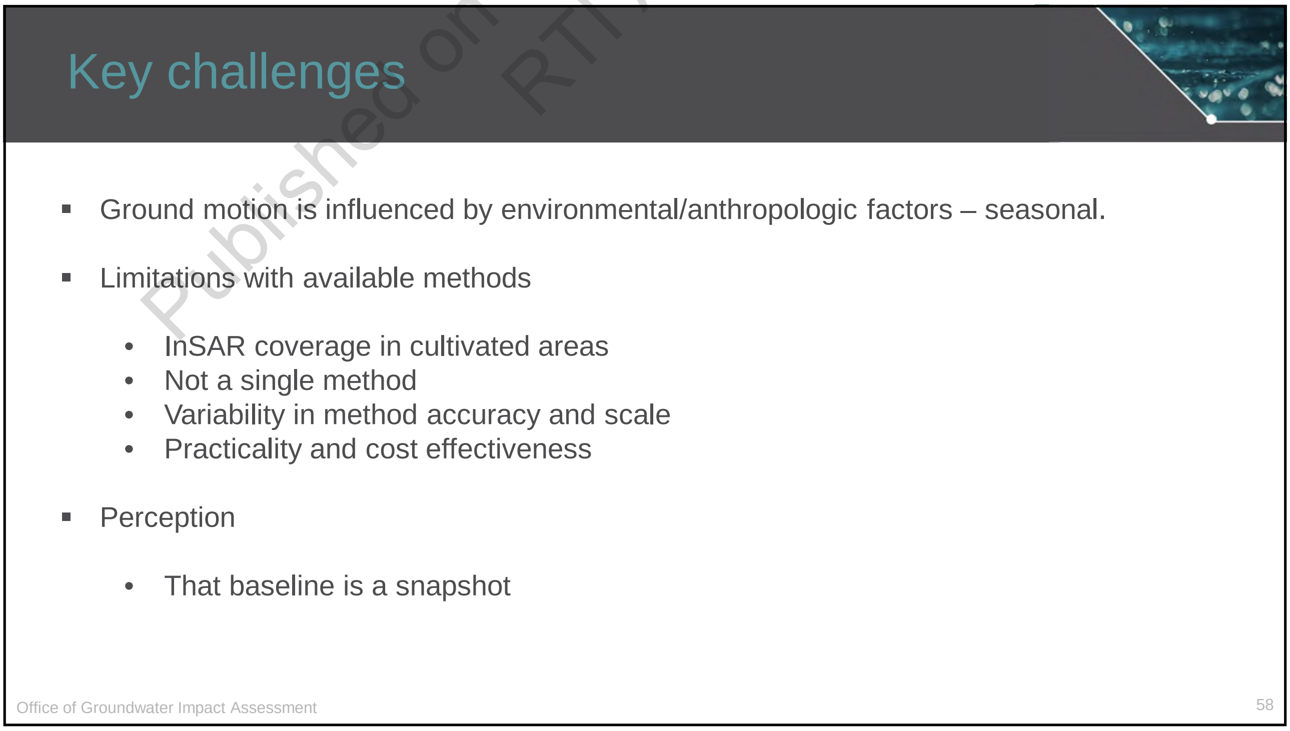


Overall approach

- Demonstrate that ‘baseline’ is not a single point in time but a **trend over time** (i.e. defining the ‘noise’)

- Property scale assessments to :
  - test the appropriateness of various methods in different land use types
  - test the scaling affect
  - establish a practical method for ongoing baselining and monitoring

- Bringing it all together with other datasets



Key challenges

- Ground motion is influenced by environmental/anthropologic factors – seasonal.
- Limitations with available methods
  - InSAR coverage in cultivated areas
  - Not a single method
  - Variability in method accuracy and scale
  - Practicality and cost effectiveness
- Perception
  - That baseline is a snapshot

Current progress

Two projects underway

1. Property scale survey
    - test the appropriateness of methods various methods
2. Time-series analysis of RTK data
    - what is the background variability at a paddock scale

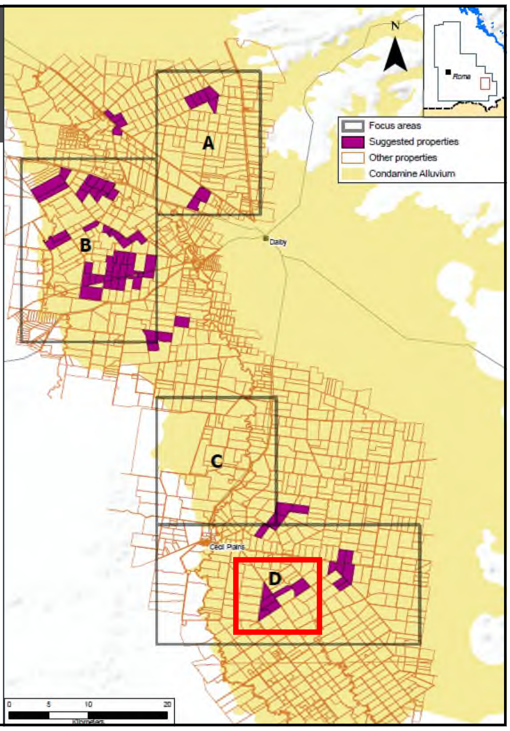
Paddock scale pilot

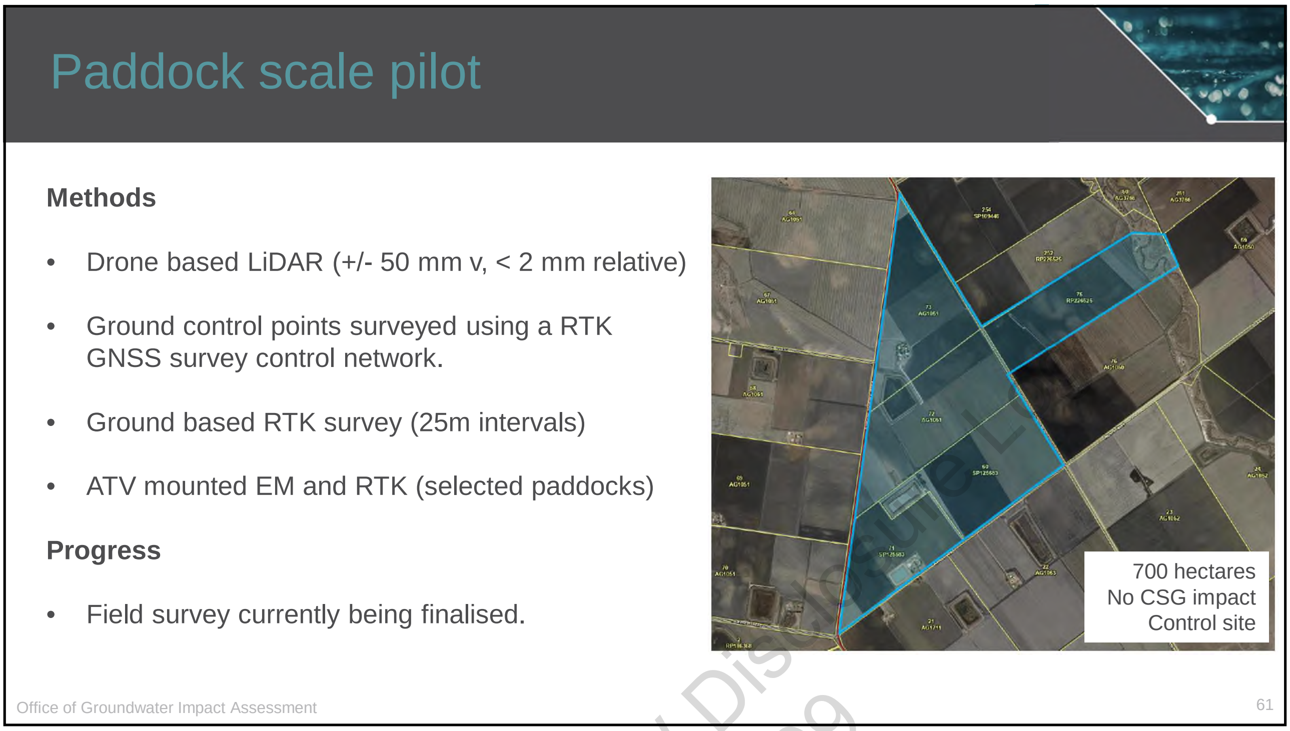
Background - community concerns

- Limitations of monitoring tools – scale, repeatability and suitability for cropping lands, etc.
- Preference for traditional land survey for paddock scale baseline of slope and aspect

Objectives

- Test different methods – how different are the results?
- How do the results differ to lower resolution products?
- Can we upscale to a more readily available product?





Paddock scale pilot

Methods

- Drone based LiDAR (+/- 50 mm v, < 2 mm relative)
- Ground control points surveyed using a RTK GNSS survey control network.
- Ground based RTK survey (25m intervals)
- ATV mounted EM and RTK (selected paddocks)

Progress

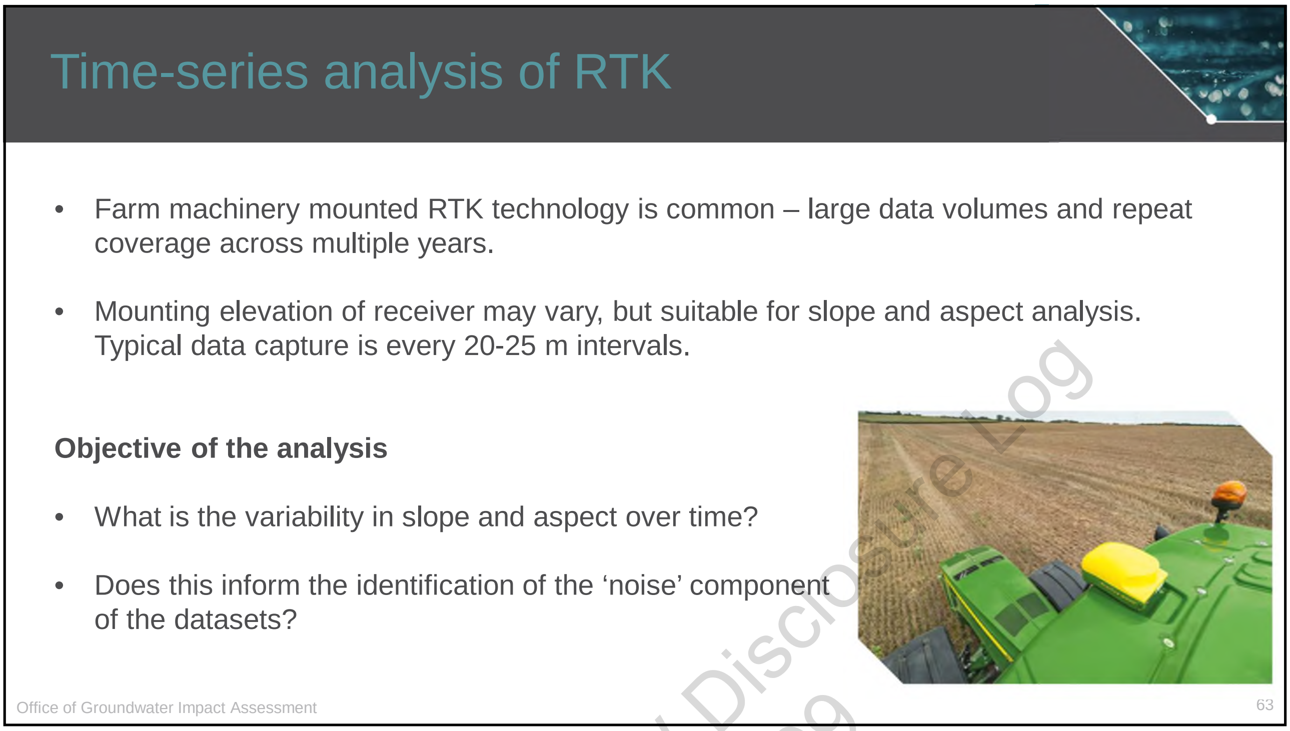
- Field survey currently being finalised.

700 hectares
No CSG impact
Control site

Paddock scale pilot

Next steps

- Compare and evaluate derived slope and aspect DEM products
  - LiDAR / Ground survey / ATV RTK / 1 second DEM
- Consider the most appropriate method for ongoing baseline
- Potential expansion of method to other areas



Time-series analysis of RTK

- Farm machinery mounted RTK technology is common – large data volumes and repeat coverage across multiple years.
- Mounting elevation of receiver may vary, but suitable for slope and aspect analysis. Typical data capture is every 20-25 m intervals.

Objective of the analysis

- What is the variability in slope and aspect over time?
- Does this inform the identification of the 'noise' component of the datasets?

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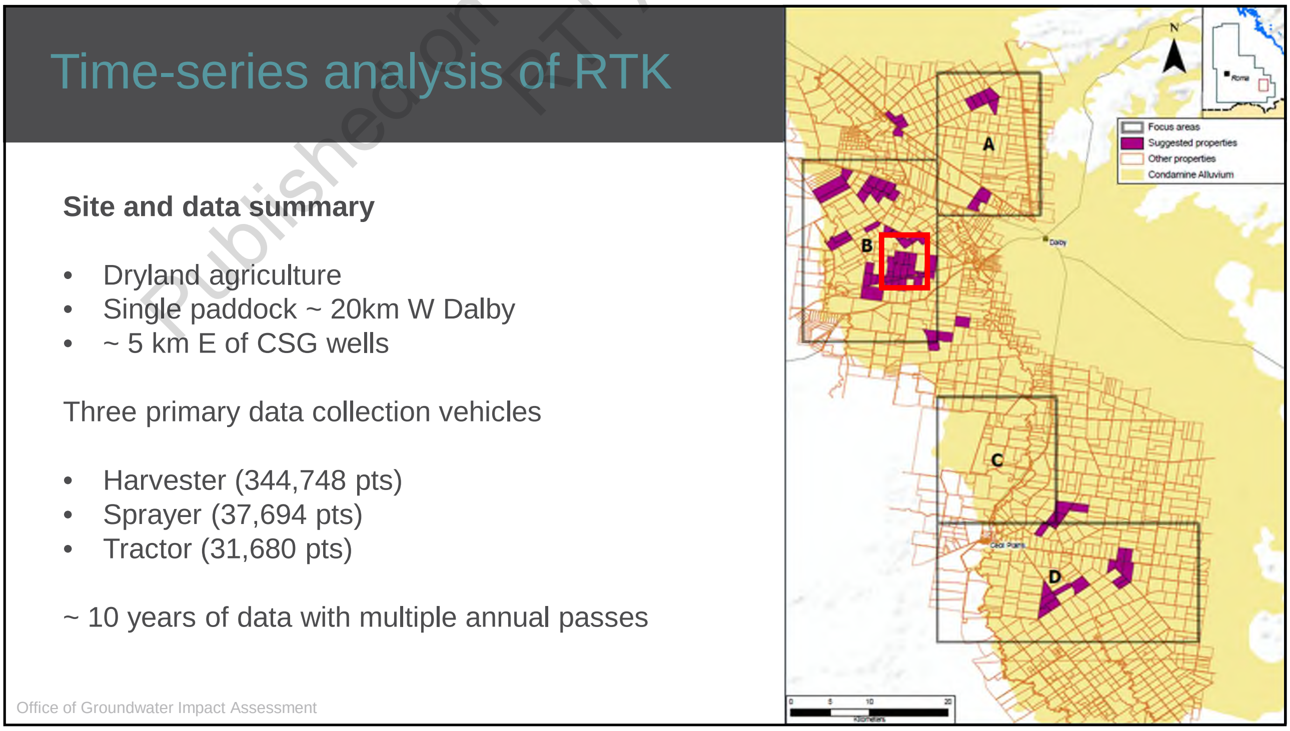

Time-series analysis of RTK

Site and data summary

- Dryland agriculture
- Single paddock ~ 20km W Dalby
- ~ 5 km E of CSG wells

Three primary data collection vehicles

- Harvester (344,748 pts)
- Sprayer (37,694 pts)
- Tractor (31,680 pts)

~ 10 years of data with multiple annual passes

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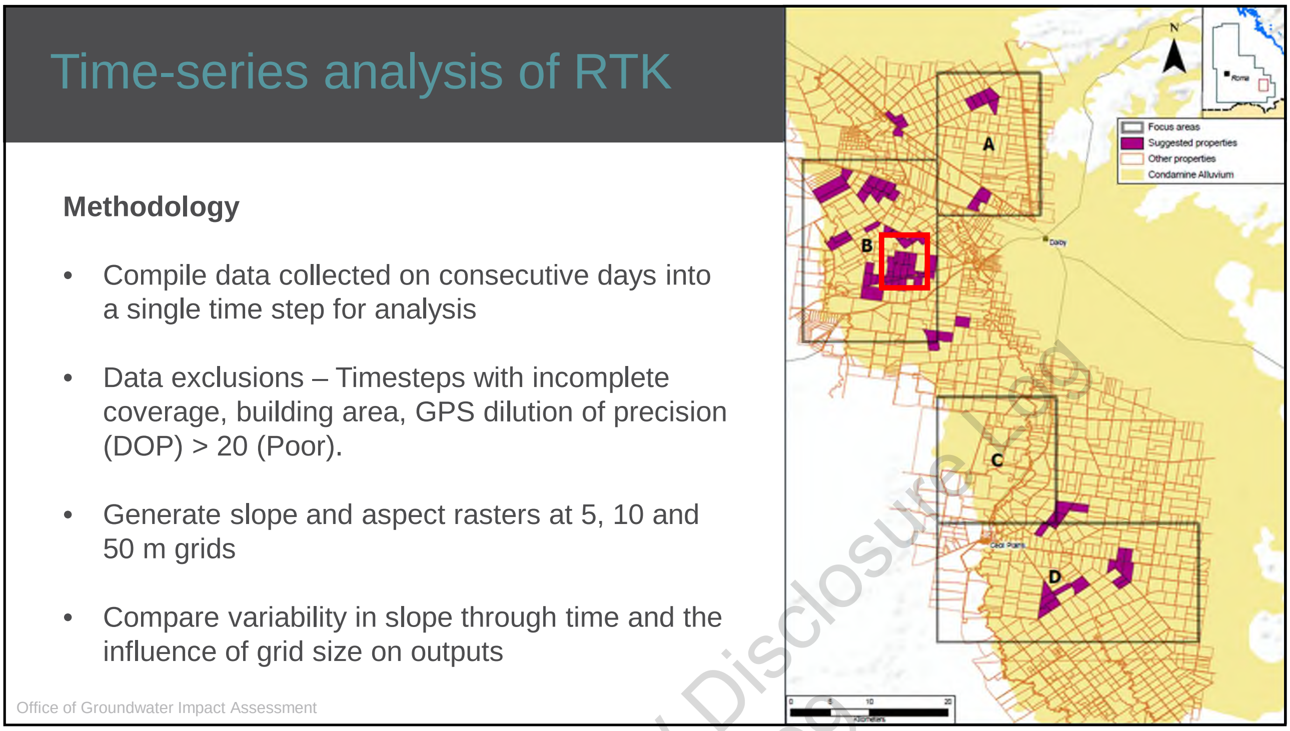
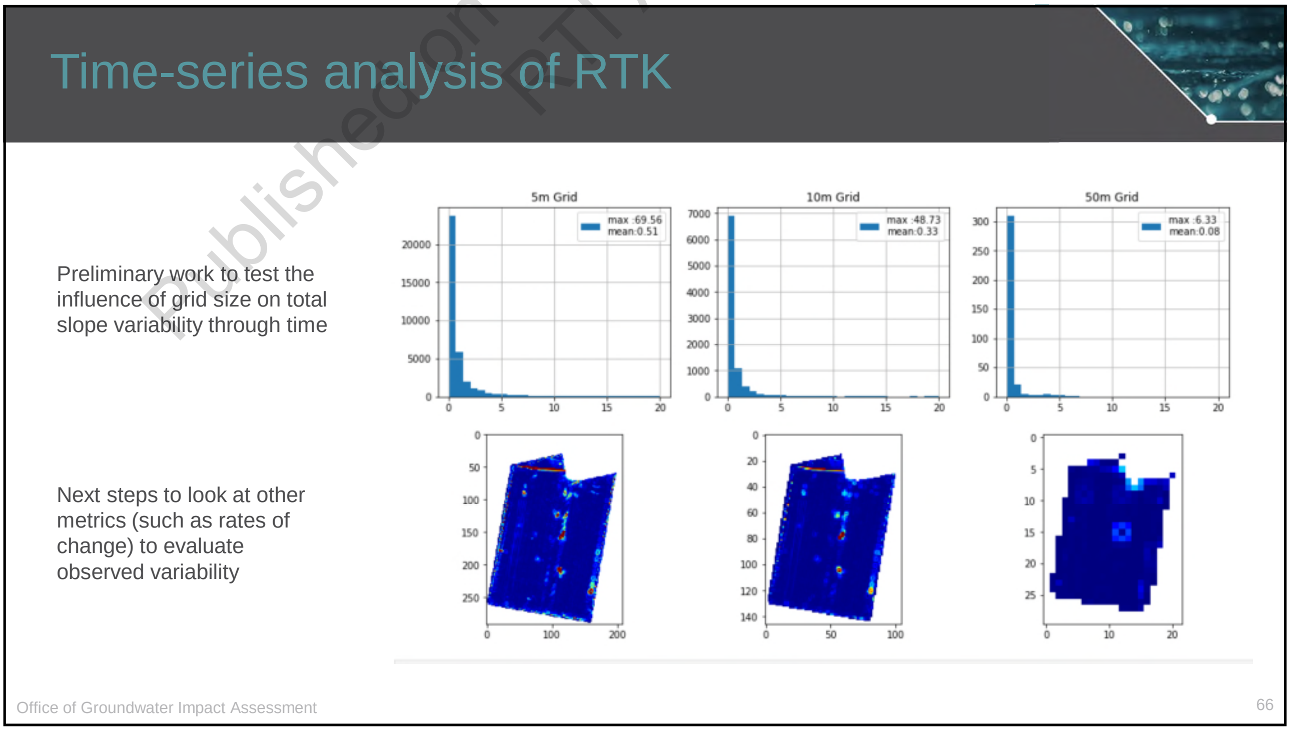


Time-series analysis of RTK

Methodology

- Compile data collected on consecutive days into a single time step for analysis
- Data exclusions – Timesteps with incomplete coverage, building area, GPS dilution of precision (DOP) > 20 (Poor).
- Generate slope and aspect rasters at 5, 10 and 50 m grids
- Compare variability in slope through time and the influence of grid size on outputs



Time-series analysis of RTK

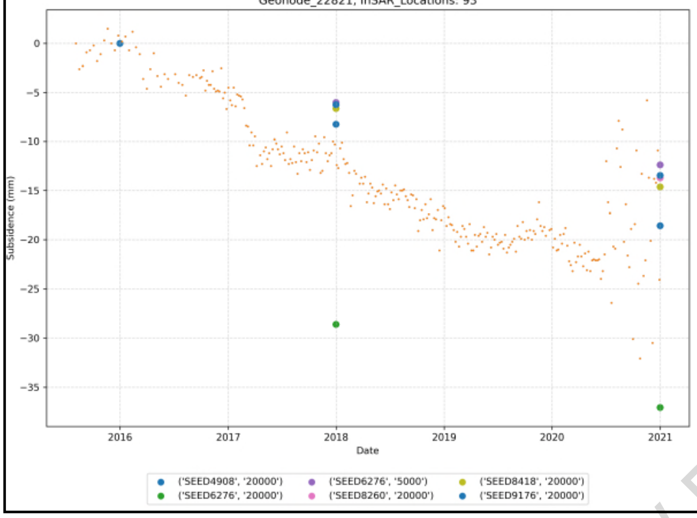
Preliminary work to test the influence of grid size on total slope variability through time

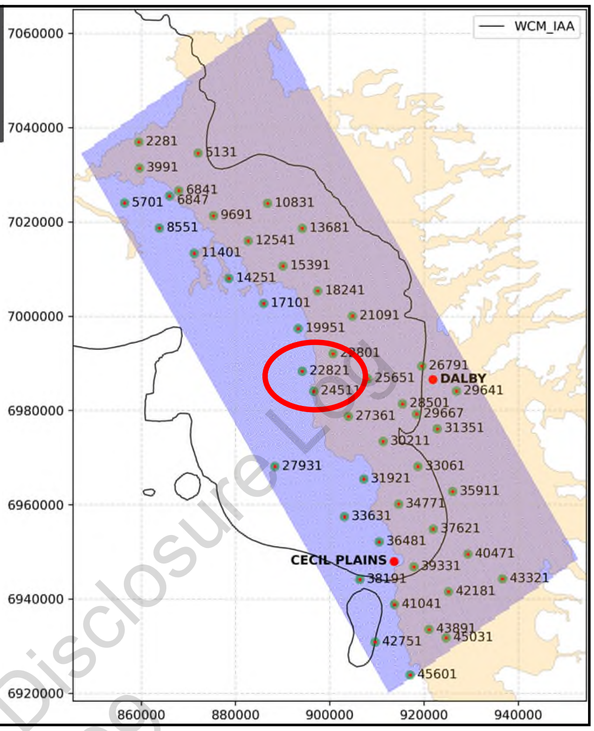
Next steps to look at other metrics (such as rates of change) to evaluate observed variability

GM Vs InSAR

Example A – CSG impact area, off the main Condamine Alluvium.

Geonode_22821, InSAR_Locations: 93





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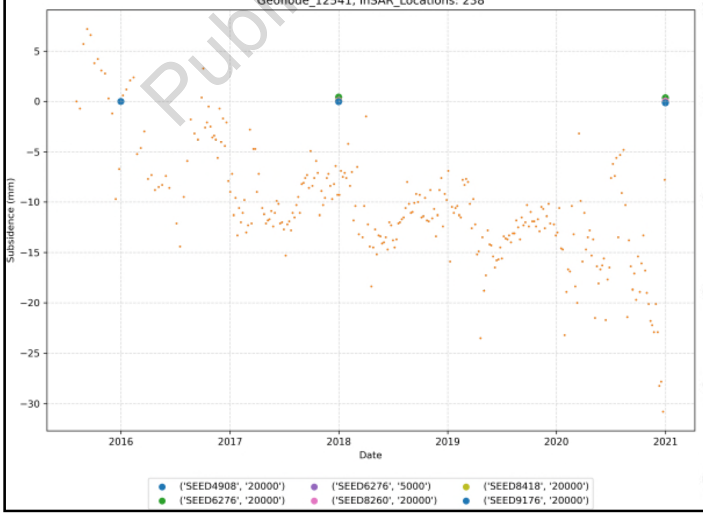
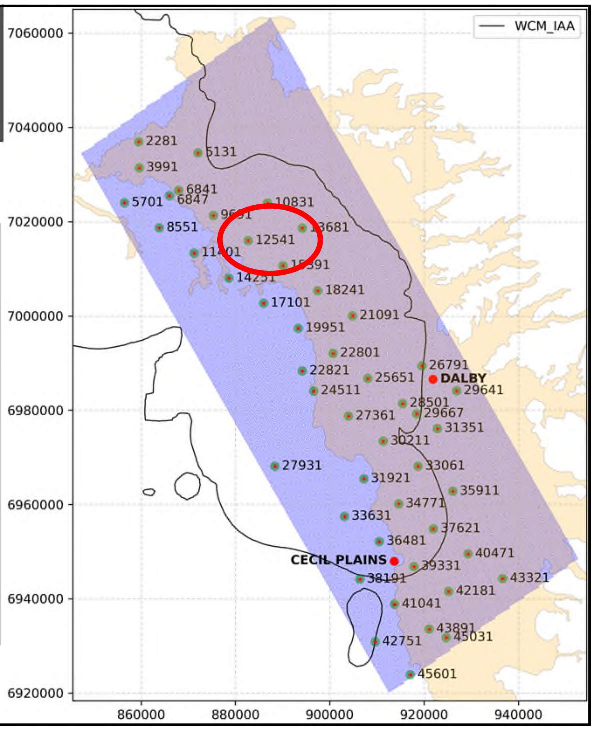
GM Vs InSAR

Example B – CSG impact area within Condamine Alluvium.

Geonode_12541, InSAR_Locations: 238





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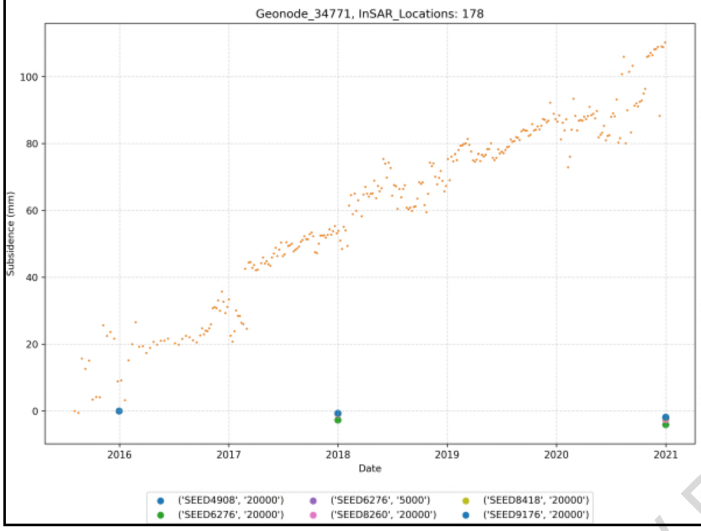
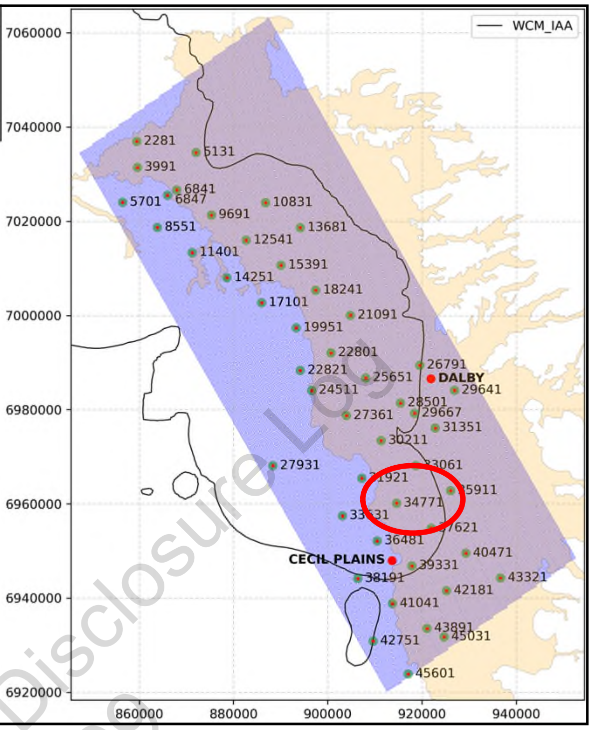
GM Vs InSAR

Example C – CSG impact area within Condamine Alluvium.





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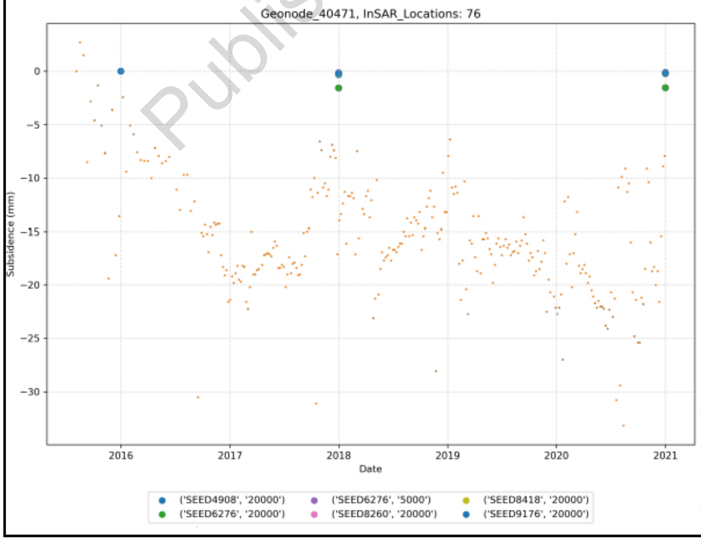
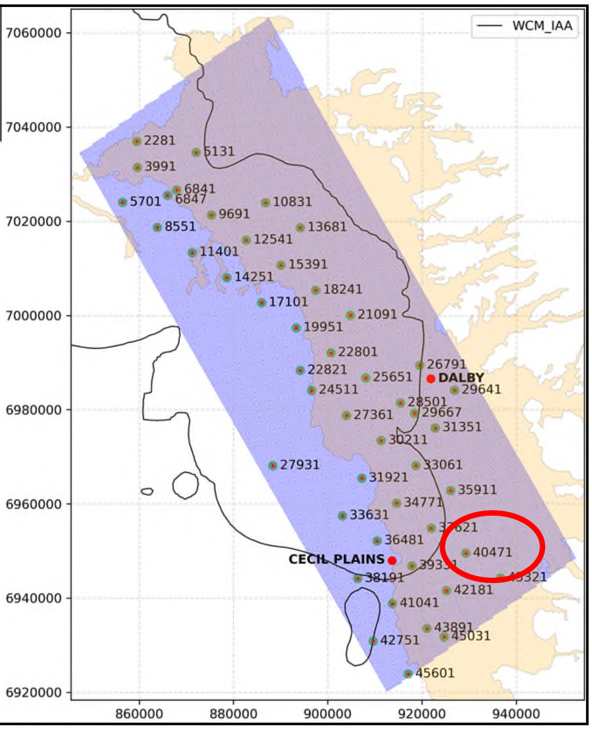
GM Vs InSAR

Example D – Outside CSG impact area, w Condamine Alluvium.





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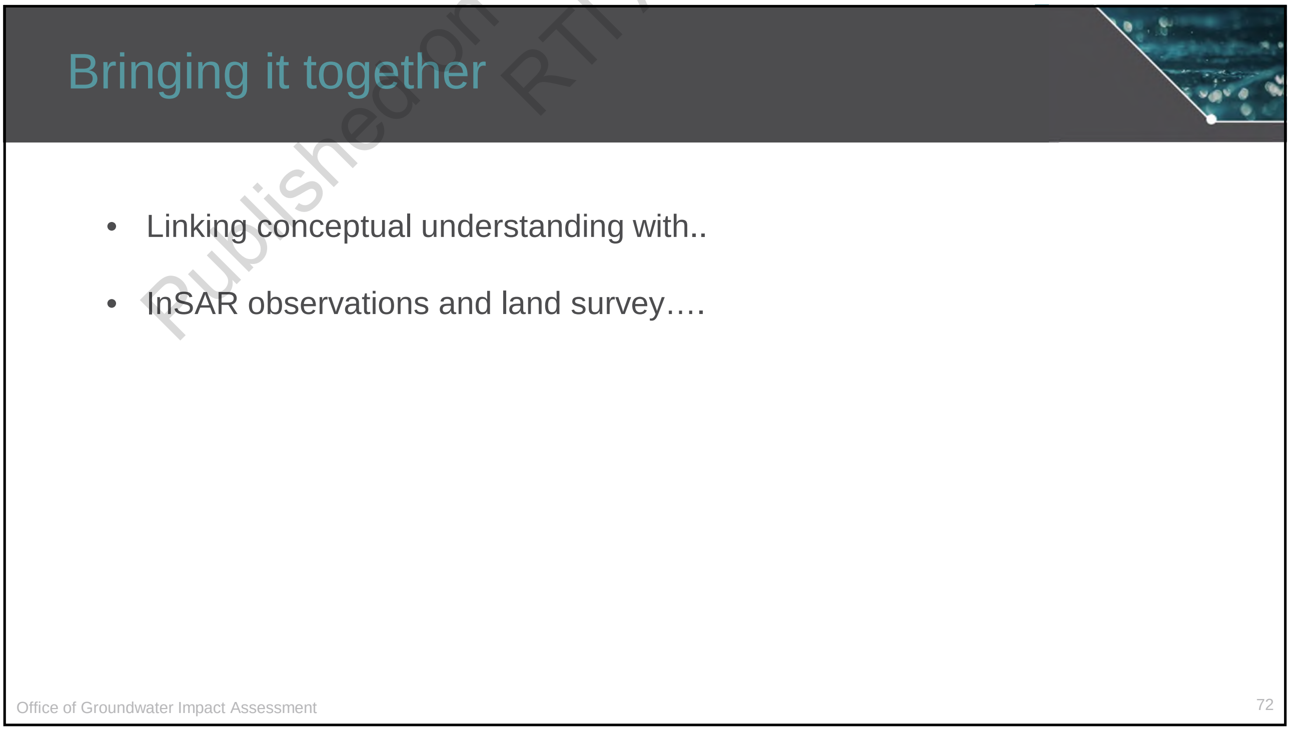
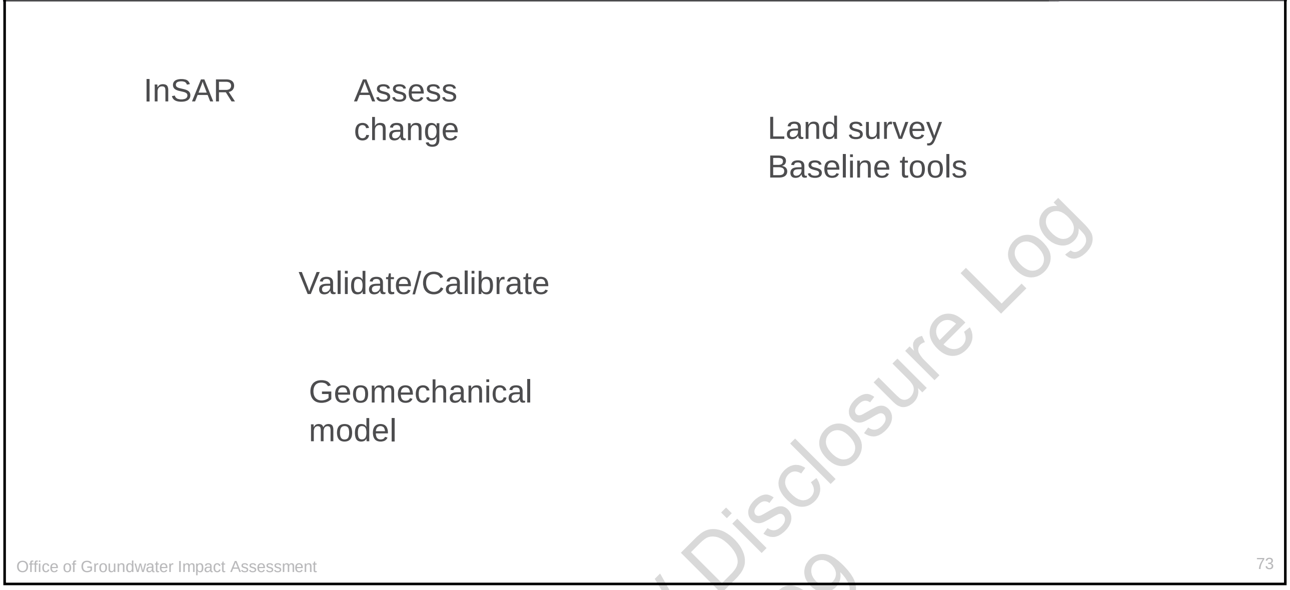
Wrap up



Bringing it together

- Linking conceptual understanding with..
- InSAR observations and land survey….

Bringing it together



InSAR

Assess change

Land survey
Baseline tools

Validate/Calibrate

Geomechanical model

What's driving OGIA's subsidence work

1. **Statutory requirement**
   - Make **predictions** and assess consequential impacts on environmental values
   - Identify CSG induced subsidence that may have already occurred (**existing impacts**)
2. **Landholder issues** (mainly around western Condamine Alluvium area (Kupunn)
   - '**Baseline**' to establish future impacts
   - Implications on **property valuation** and insurance
   - What can be done if impacts do occur (i.e. **management actions**)

***Implicit**: lack of scientific understanding, lack of trust in Industry and general resistance to CSG*

End

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Queensland Government

LAND SETTLEMENT DUE TO GROUNDWATER PUMPING IN THE LOWER NAMOI VALLEY OF NSW

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ABSTRACT

A 10-year water sharing plan (WSP) has been developed for the Lower Namoi aquifer that stretches from Narrabri to Cryon in northern NSW. Under the Water Management Act 2000 (WMA), WSPs are being put in place to define the water sharing arrangements between the environment and water users, and between different categories of water users. The plans are designed to provide for healthier rivers and groundwater systems and dependent ecosystems. They provide water users with clarity and certainty about their water access rights.

As part of the WSP, local water level response management is being trialled. Factors considered are land subsidence, groundwater quality, priority groundwater dependent ecosystems and social issues such as bore interference.

In 1974 a series of benchmarks was established from which land subsidence could be monitored. These were supplemented by a more intensive network installed in 1981. Survey levelling of these sites was carried out in 1982, 1987, 1988 and 1990. Subsidence of between 0.08 and 0.21 metres was recorded for the 10-year period 1981 to 1990.

Since that time the volume of groundwater pumping has continued to increase and water levels have continued to fall. A 3-layer regional MODFLOW groundwater flow model for the period 1980 to 1998 has been calibrated, verified, subjected to post audit, and externally reviewed. The model has been used to simulate subsidence, to see if MODFLOW is sufficient for this purpose, and to see if satisfactory calibration is possible with plausible storage and compressibility parameters. Reasonable calibration has been achieved. Subsidence studies overseas have shown that residual compaction can lag far behind water level fluctuations. It is demonstrated here that residual compaction is unlikely for the Lower Namoi aquifer system.

This initial effort at simulating subsidence will guide the approach taken in other valleys in New South Wales, and the lessons learned will be used in the hierarchy of water level response management tools that are to be applied as a secondary consideration to water sharing plans.

INTRODUCTION

The Water Management Act (2000) requires the preparation of water sharing plans (WSPs) for New South Wales aquifer systems, with a tenure of 10 years. WSPs are being put in place to define the water sharing arrangements between the environment and water users, and between different categories of water users. The plans are designed to provide for healthier rivers and groundwater systems and dependent ecosystems. They provide water users with clarity and certainty about their water access rights.

As part of the implementation of the WSP local water level response management is being trialled, in order to protect the local sustainability of the aquifer system. This approach is complementary to sustainable yield management. Local impact management (based on water level response) will be implemented if there is unacceptable hydraulic interference between neighbouring bores, if water quality is in danger of being degraded, if priority groundwater dependent ecosystems require protection, or if excessive pumping is likely to cause permanent compaction of sediments and subsequent land subsidence.

Measurable subsidence has occurred in the Lower Namoi Valley aquifer that stretches from Narrabri to Cryon in northern NSW. This valley hosts the most developed groundwater system in the State, with more than 30 years of irrigated agriculture. Significant quantities of groundwater (along with surface water) are used to irrigate summer crops, predominantly cotton. The aquifer system is highly over-committed and steps are in place to reduce groundwater allocations over the life of the WSP for this valley. In 1974 a series of benchmarks was established from which land subsidence could be monitored. These were supplemented by a more intensive network installed in 1981. Survey levelling of these sites was carried out in 1982, 1987, 1988 and 1990. Subsidence of between 0.08 and 0.21 metres was recorded for the 10-year period 1981 to 1990 (Ross and Jeffery, 1991).

One of the concerns is that the excessive pumping of groundwater in past decades might induce residual compaction. That is to say, that even if water levels can be stabilised, the subsidence might continue for a long time. This lag has been reported for many aquifers overseas.

LAND SUBSIDENCE AND AQUIFER-SYSTEM COMPACTION

Land subsidence is the gradual settling or sudden sinking of the Earth’s surface owing to subsurface movement of earth materials. One of the principal causes of land subsidence is the gradual compaction of susceptible aquifer systems that can accompany groundwater level declines caused by groundwater pumping . Detrimental effects of land subsidence include the loss of aquifer storage, increased flooding, cracks and fissures at land surface, damage to man-made structures, and intangible economic costs.

Compaction of the aquifer system occurs when the hydraulic head or fluid pressure in compressible, fine-grained sediments declines, releasing pore water in the compressible sediments from storage. (Fluid pressure has units of stress and is equal to hydraulic head times the specific weight of water.) For a constant total stress on the aquifer system, the associated decrease in fluid pressure is accompanied by an equivalent increase in the effective or intergranular stress on the granular matrix or skeleton of the aquifer system, resulting in aquifer-system compaction. The magnitude of the compaction is governed by the compressibility of the sediments, which varies by an order of magnitude or more depending on whether the intergranular stress changes are in the elastic or inelastic range of stress for the compacting sediments. Elastic compaction is compaction that occurs when the skeletal structure of the sediments is not permanently rearranged: it can be reversed by an associated rise in hydraulic head. Inelastic compaction is compaction that occurs when there is a permanent rearrangement of the skeletal structure of the sedimentary matrix; it cannot be reversed by a rise in hydraulic head, and, therefore, results in a permanent lowering of land surface and a loss of groundwater storage capacity. The point to which hydraulic heads must decline to cause inelastic compaction in the compressible sediments is termed the preconsolidation head.

In the context of an aquifer system, the past maximum stress, or preconsolidation stress, can generally be represented by the previous lowest groundwater level. For stress less than preconsolidation stress—that is, groundwater level higher than previous lowest groundwater level (preconsolidation stress), the aquifer system deforms elastically, and the deformation is recoverable. For stress beyond preconsolidation stress—groundwater level lower than previous lowest groundwater level, the pore structure of the system's susceptible fine-grained sediments may undergo a significant rearrangement, resulting in permanent reduction of the pore volume and vertical displacement of the land surface, or land subsidence.

Land subsidence due to groundwater pumping is well documented. There are reports of subsidence of about 9 m in Mexico City and the San Joaquin Valley of California, 7 m in Wairakei New Zealand, and 5 m in Tokyo (Poland 1984). Groundwater-induced subsidence is contributing to the slow demise of Venice in Italy.

Specific Storage

Water released from storage in an artesian aquifer, under the condition of a decreasing head, is from two mechanisms: the compression of the aquifer skeleton caused by an increase in effective stress, and expansion of water caused by decrease in pore pressure.

The specific storage (S_s), is defined as the volume of water released from or added to the unit volume of the aquifer material when the hydraulic head changes a unit amount. It is generally expressed as:

$$S_s = \rho_w g (\alpha + n\beta_w)$$

where S_s is specific storage of the aquifer material [L^{-1}], ρ_w is density of water [M/L^3], g is gravitational acceleration [L/T^2], α is compressibility of the aquifer material [LT^2/M], β_w is compressibility of the water [LT^2/M], and n is porosity of the aquifer material.

The term $\alpha\rho_w g$, is the component of the specific storage due to the compression of the aquifer material, caused by unit change in the pressure head, and is controlled by the compressibility of the soil matrix (α). This component is termed the skeletal component of the specific storage (S_{sk}). The term $\rho_w g\, n\beta_w$ is the component of the specific storage caused by the expansion of the water when the pressure head is lowered by a unit amount, and is controlled by compressibility of water β_w, and is denoted as S_{sw}.

The skeletal component of the specific storage addresses the storage change of the aquifer system due to the compression of the soil matrix. Skeletal compressibility of the fine-grained aquitards and coarse-grained aquifers typically differ by several orders of magnitude; therefore, it is useful to define them separately.

The skeletal specific storage of the aquitard, S'_{sk}, is defined for two ranges of stress (σ), elastic and inelastic:

$$S'_{sk} = \begin{cases} S'_{ske} = \alpha'_{ke}\rho_w g, & \sigma' < \sigma'_{(\max)} \\ S'_{skv} = \alpha'_{kv}\rho_w g, & \sigma' > \sigma'_{(\max)} \end{cases}$$

The subscripts *e* and *v* refer to elastic and inelastic properties, respectively. For a change in effective stress, the aquitard deforms elastically when the effective stress remains less than the previous maximum effective stress, σ'_{max}. When the effective stress exceeds σ'_{max}, the aquitard deforms inelastically.

For coarse-grained sediments typically found within aquifers, inelastic skeletal compressibility is negligible; therefore, skeletal specific storage of an aquifer (coarse-grained sediments), S_{sk}, is adequately represented by the fully recoverable, elastic component of the skeletal specific storage, S_{ske}:

$$S_{sk} = S_{ske} = \alpha_{ke}\rho_w g$$

where α_{ke} is elastic compressibility of the aquifer (coarse-grained) material.

The component of specific storage that addresses the expansion of water is composed of two parts; the expansion of the water in the aquifer, S_{sw}, and the expansion of the water in the aquitards, S'_{sw}. Thus, elastic specific storage of the whole aquifer system, S_s, can be expressed as:

$S_s = S_{ske} + S'_{ske} + S_{sw} + S'_{sw}$

As only aquitards compact inelastically, and the fact that S_{skv} is much greater than S'_{sw}, the aquitard inelastic skeletal specific storage, S_{skv}, can adequately represent the inelastic specific storage of the whole aquifer system:

$$S_{sv} = S'_{skv} = \alpha'_{skv}\rho_w g$$

where S_{sv} is inelastic specific storage of the aquifer system.

Riley (1998) concluded that, in a typical aquifer system consisting of unconsolidated to partially consolidated late Cainozoic sediment, the inelastic specific storage generally is 20 to more than 100 times larger than elastic specific storage. Water that drains during a permanent compaction event is lost forever and cannot be recharged.

Storage Coefficient

The product of the skeletal specific storage values of the aquitards, or aquifer, and aggregate thickness of the aquitards, $\Sigma b'$, or aquifer, Σb, define skeletal storage coefficient of the aquitards (S_k'), and the aquifers (S_k), respectively:

$$S'_k = \begin{cases} S'_{ke} = S'_{ske}\left(\Sigma b'\right), & \sigma' < \sigma'_{\max} \\ S'_{kv} = S'_{skv}\left(\Sigma b'\right), & \sigma' > \sigma'_{\max} \end{cases}$$

$$S_k = S_{ke} = S_{ske}\left(\Sigma b\right)$$

where S_{ke} is elastic skeletal storage coefficient of aquifers, S_{ke}' is elastic skeletal storage coefficient of the aquitards, and S_{kv}' is inelastic skeletal storage coefficient.

A separate equation relates the fluid compressibility of water to the component of the aquifer storage attributed to pore water, S_w:

$$S_w = S'_{sw}\left(\Sigma b'\right) + S_{sw}\left(\Sigma b\right) = \beta\rho_w g\left[n'\left(\Sigma b'\right) + n\left(\Sigma b\right)\right]$$

where n' and n are porosities, and S'_{sw} and S_{sw} are the specific storage components for water, of the aquitards and aquifers, respectively.

The aquifer system elastic storage coefficient, S, is defined as the sum of the skeletal storage coefficients of the aquitards and aquifers, plus the storage attributed to water compressibility:

$$S = S'_k + S_k + S_w$$

For a compacting aquifer system, the aquitard inelastic skeletal storage coefficient, S'_{kv}, is much greater than S_w, and the inelastic storage coefficient of the aquifer system, S_v, is approximately equal to the aquitard inelastic skeletal storage coefficient:

$$S_v \approx S'_{kv}$$

In a confined aquifer system subjected to large scale overdraft, the volume of water derived from irreversible aquitard compaction typically ranges from 10 to 30 percent of the total groundwater pumped (Riley, 1969).

Effective Stress

The change in water level is a measure of the change in applied stress. At an arbitrary depth plane, the weight of the overlying sediments and water is called the total stress or geostatic pressure. This comprises two components: the effective stress, borne by the solid component of the medium; and the pore water stress, borne by the water.

When groundwater head varies in a confined aquifer, the stress shifts from one component to the other in order to maintain constant geostatic pressure. Assuming the overlying water table remains constant, a decline in head results in an increase of equal amount in effective stress (Poland and Davis, 1969):

$$\Delta\sigma' = -\rho_w g\Delta h$$

where Δh is the change in head [L], negative for decrease and positive for increase.

In an unconfined aquifer, the geostatic pressure will vary as the water table goes up and down. Therefore, a change in effective stress from a given head change generally is different in confined and unconfined aquifers. The resulting change in effective stress in an unconfined aquifer can be expressed as (Poland and Davis, 1969):

$$\Delta\sigma' = -\rho_w g\left(1 - n + n_w\right)\Delta wt$$

where n is porosity [dimensionless]; n_w is moisture content above the water table as a function of total volume [dimensionless]; and Δwt is the change in water table height, positive for raising and negative for lowering of the water table [L].

As the term $(1-n+n_w)$ is less than unity, the change in effective stress is less for an unconfined aquifer than for a confined aquifer.

Compaction

Previous studies (Riley 1969) have indicated that elastic compaction or expansion of sediments is proportional or nearly proportional to the change in effective stress. The elastic compression of the fine-grained sediments (interbeds) in an aquifer is given approximately by:

$$\Delta b = -\Delta h S'_{ske} b_0$$

where Δb is change in thickness [L], positive for compaction and negative for expansion; S'_{ske} is the skeletal component of the elastic specific storage of the interbed [L^{-1}]; and b_0 is the thickness of the interbed [L].

The same assumption can be made when simulating the inelastic compaction of the interbeds—that is, the inelastic compaction or expansion of the sediment is proportional to the change in effective stress:

$$\Delta b^* = -\Delta h S'_{skv} b_0$$

where Δb^* is inelastic compaction [L]; and S'_{skv} is the skeletal component of the inelastic specific storage of the interbed [L^{-1}]. Laboratory studies suggest a better linear relation with the logarithm of the head change (Leake and Prudic, 1991).

MODFLOW IMPLEMENTATION

Leake and Prudic (1991) added the Interbed Storage (IBS) package to the standard MODFLOW code developed by McDonald and Harbaugh (1988). This package requires specification of the following parameters on a cell-by-cell basis within a model layer that contains fine-grained interbeds:

- ☐ Elastic storage coefficient;
- ☐ Inelastic storage coefficient;
- ☐ Initial preconsolidation head;
- ☐ Initial compaction.

It is the user’s responsibility to aggregate interbed thicknesses spatially, and multiply by estimates for specific storage. Given the lack of data on inelastic values, the user is likely to compute externally the inelastic storage coefficient as a multiple of the elastic storage coefficient. The term 'interbed', where subsidence in aquifers occurs in response to groundwater abstraction, is assumed to be:

- ☐ Of significantly lower hydraulic conductivity than the surrounding sediments;
- ☐ Of insufficient lateral extent to be considered a confining bed that separates adjacent aquifers; and
- ☐ Of relatively small thickness in comparison to lateral extent.

Compaction (Δb or Δb^*) is computed in each cell in each layer at the end of a time step, by multiplying the head change by the appropriate storage coefficient. If the current head is higher than the preconsolidation head, then the elastic value is used. If the current head is lower than the preconsolidation head, then the inelastic value is used and the preconsolidation head is set at the new head value. Land subsidence is computed at a cell by summing the compaction simulated in each of the model layers, and is reported for the model cell at the uppermost layer.

Limitations

The IBS package is limited by the following assumptions:

- ☐ Storage values are assumed constant in time;
- ☐ Changes in geostatic pressure for an unconfined aquifer are ignored – this will overestimate compaction;
- ☐ Aquitard heads are assumed to equilibrate within the time step; that is, aquitards are assumed to drain sufficiently at this time scale in order to dissipate excess pore pressure – this could overestimate compaction at early time and underestimate compaction at late time;
- ☐ Inelastic compaction is assumed to be proportional to head change – this will cause an overestimate of compaction.

The modeller must be careful about the choice of time step, as the IBS package assumes that interbed drainage occurs during this time. In addition, if the aggregate interbed storage coefficient (elastic or inelastic) is commensurate with the previously calibrated aquifer storage coefficient, then hydrographic calibration will be upset as simulated water level fluctuations will reduce. The aquifer storage coefficient will have to be reduced by the magnitude of the interbed storage coefficient. However, the latter could fluctuate from elastic to inelastic values during simulation.

LOWER NAMOI VALLEY APPLICATION

The Lower Namoi Valley is an alluviated valley with an area of 5100 km^2 in the semi-arid area of Northern New South Wales, 500 km north-west of Sydney. The valley contains a sequence of non-marine alluvial deposits of Tertiary and Quaternary age, which range in thickness to 120 m as discussed by Williams et al. (1989). The study area is characterised by a narrow palaeochannel, 3 to 10 km in width, passing to the north-west through Narrabri, flanked by a buried basement ridge on its western side and shallow basement with colluvial cover on its eastern side. The channel then trends westerly and subsequently south-westerly towards Cryon (about 30 km west of Burren Junction). It is infilled with fluviatile sediments of the Cubbaroo Formation, up to 60 m thick. The sediments consist of subrounded to rounded sand and gravel with interbedded clay and minor carbonaceous stringers. Sand and gravel zones in the Gunnedah and Cubbaroo Formations provide the main production aquifers. Yields up to 250 L/s are obtained from the Gunnedah Formation at depths of 60-90 m, and from the Cubbaroo Formation at 80-120 m depth as described by Hamilton et al. (1988).

Since its initial development more than 20 years ago, a 3-layer regional MODFLOW groundwater flow model has been calibrated, verified, subjected to post audit, and externally reviewed (Merrick, 2001). The model has been used recently to simulate subsidence, to see if MODFLOW is sufficient for this purpose, and to see if satisfactory calibration is possible with plausible storage and compressibility parameters. The Lower Namoi MODFLOW model has 30 rows and 50 columns of 2500 m cells. The model has been calibrated with monthly stress periods from 1980 to 1998. The model layer associations are:

- ❑ Layer 1 – Narrabri Formation;
- ❑ Layer 2 – Gunnedah Formation;
- ❑ Layer 3 – Cubbaroo Formation.

Simulation Parameters

Only Layers 1 and 2 have been simulated for aquifer compaction, as most pumping is from the Gunnedah Formation and Layer 3 has limited spatial extent. The preconsolidation head has been set at 1980 observed groundwater levels, to coincide with a period of drought and high abstraction at the start of the simulation.

The total thickness of the aquitards in Layers 1 and 2 was estimated from the percentage of the fine-grained sediments in these layers that was determined from descriptions of the aquifer material noted in drillers' bore logs. Figures 1 and 2 show the clay thickness contour maps for each layer. Separate maps were produced for lithologies described as clay/sand and clay/gravel mixtures.

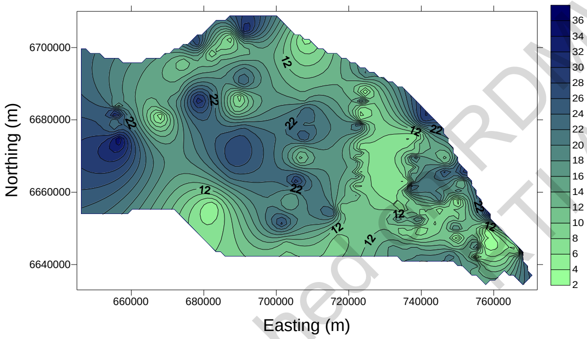

Figure 1. Layer 1 clay thickness (m)

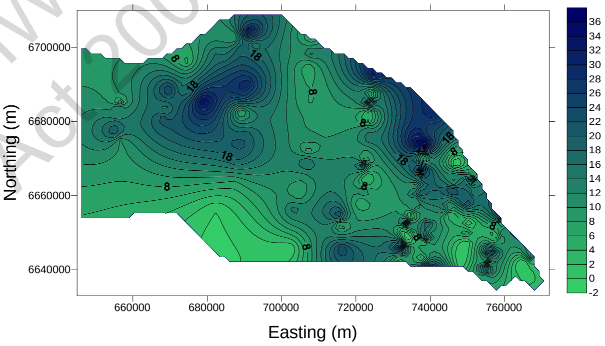

Figure 2. Layer 2 clay thickness (m)

Initial compressibility estimates for each lithology were taken from Domenico and Schwartz (1998), reproduced here as Table 1. The initial skeletal specific storage values for clay, clay/sand, and clay/gravel were estimated as 9.8x10^{-4} m^{-1}, 5.5x10^{-4} m^{-1}, and 4.9x10^{-4} m^{-1}, respectively, and were subsequently varied during calibration.. The inelastic skeletal specific storage was initially taken to be 100 times the elastic skeletal specific storage. These skeletal specific storage values multiplied by the aggregate thickness of each sediment type, were then entered into the IBS package within the PMWIN interface to MODFLOW.

Table 1. Compressibility values (m^2/N)

Clay	$10^{-6} \sim 10^{-8}$
Sand	$10^{-7} \sim 10^{-9}$
Gravel	$10^{-8} \sim 10^{-10}$

Simulation Results

The best combination of parameters was found to be:

- ❑ Elastic skeletal specific storage 2.1x10^{-6} m^{-1};
- ❑ Inelastic multiplier 75 (specific storage 1.6x10^{-4} m^{-1}).

The elastic value is consistent with the low end compressibilities in Table 1. The simulated distribution of land subsidence at 1998 is shown in Figure 3, where the maximum simulated subsidence is less than 0.5 m.

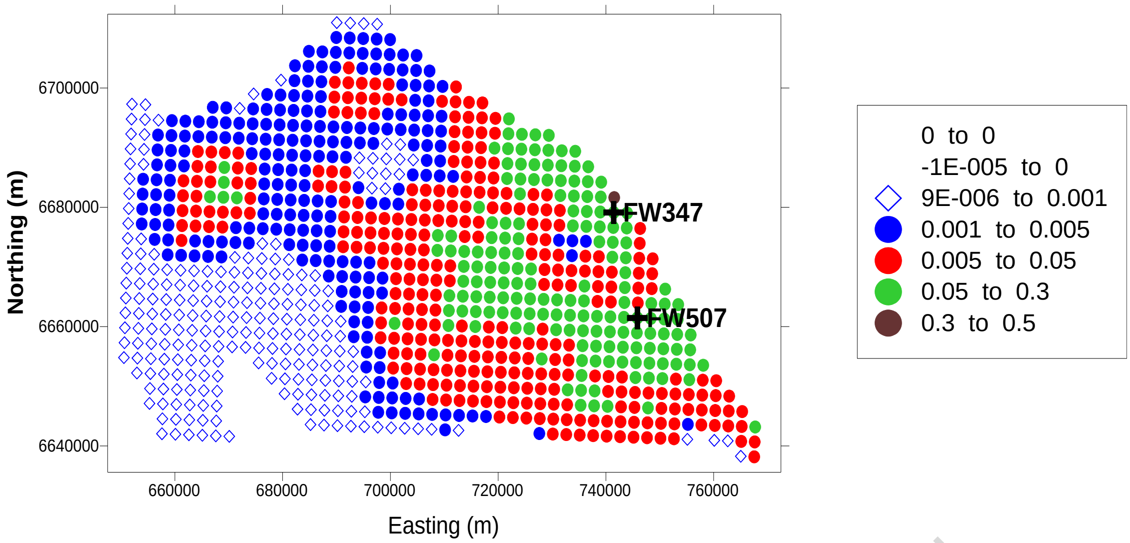

Figure 3. Simulated distribution of land subsidence (m)

The simulated pattern agrees qualitatively with the observed distribution of subsidence at the last measurement event in 1990. Quantitative agreement is best evaluated at representative benchmarks FW347 and FW507 (Figure 3). Time series plots of simulated and observed subsidence are presented in Figures 4 and 5. The paucity of measurement points means that the expected sequence of compaction and uplift events are not adequately captured by the field datasets. Corresponding water level fluctuations are shown in Figures 6 and 7. At FW347, the maximum observed compaction is 0.16 m, for a water level decline of 40 m. At FW507, the maximum observed compaction is less (0.06 m), for a correspondingly lower water level fluctuation (14 m).

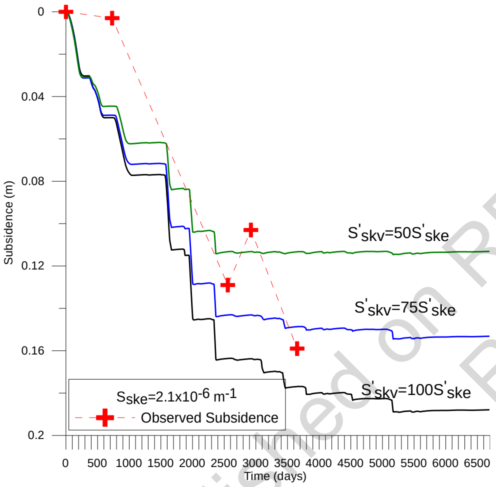

Figure 4. Evolution of subsidence at benchmark FW347

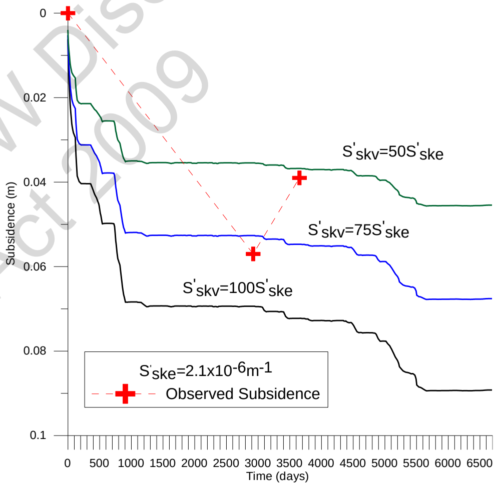

Figure 5. Evolution of subsidence at benchmark FW507

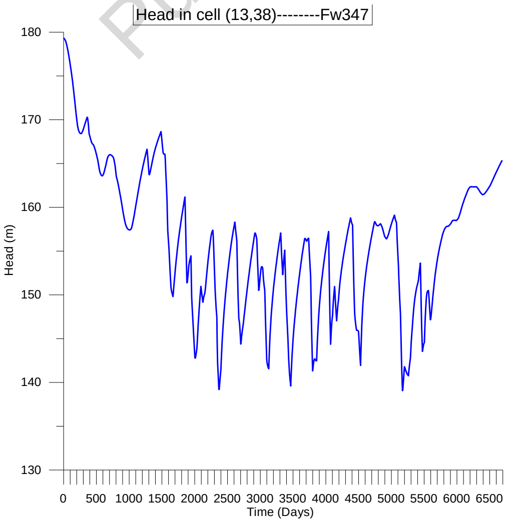

Figure 6. Simulated water level fluctuations at benchmark FW347 (mAHD)

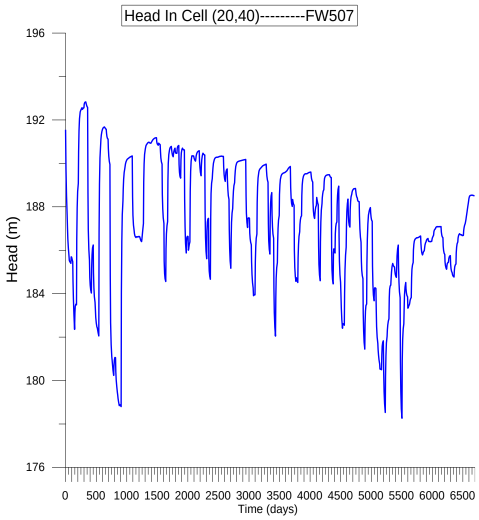

Figure 7. Simulated water level fluctuations at benchmark FW507 (mAHD)

RESIDUAL COMPACTION

Residual compaction can occur long after water levels have stabilised, due to the slow-draining nature of fine-grained sediments. A measure of the time scale for drainage from an aquitard that drains through both upper and lower boundaries is given by the aquitard time constant (Riley, 1969), which can be expressed as:

$$\tau = \frac{S'b'}{4K'}$$

where S' is the storage coefficient of the aquitard, thickness b', with hydraulic conductivity K'. The time constant is the time by which 93 percent of excess pore pressure has dissipated (Leake and Prudic, 1991). For an aquitard that drains only through the upper or lower boundary, the time constant is 4τ.

As a check on the usefulness of this indicator, independent analytical modelling was done with the dual aquifer model embedded in HotSpots software (Merrick and Merrick, 2002). The code was modified to produce highly-sampled head profiles across an aquitard of specified thickness. Figures 8 and 9 show the head profiles for typical Lower Namoi parameters for aquitards of 1 m and 10 m thickness, respectively, for times varying from 2.4 hours to 1 year. A single bore pumps 10 ML/d from the lower aquifer at a distance of 10 m from the monitoring point. As the aquitard is draining only through the bottom boundary in this example, the corresponding time constants (4τ) are 1 d and 10 d, for specific storage values of 1 x 10^{-3} m^{-1} and 1 x 10^{-4} m^{-1}.

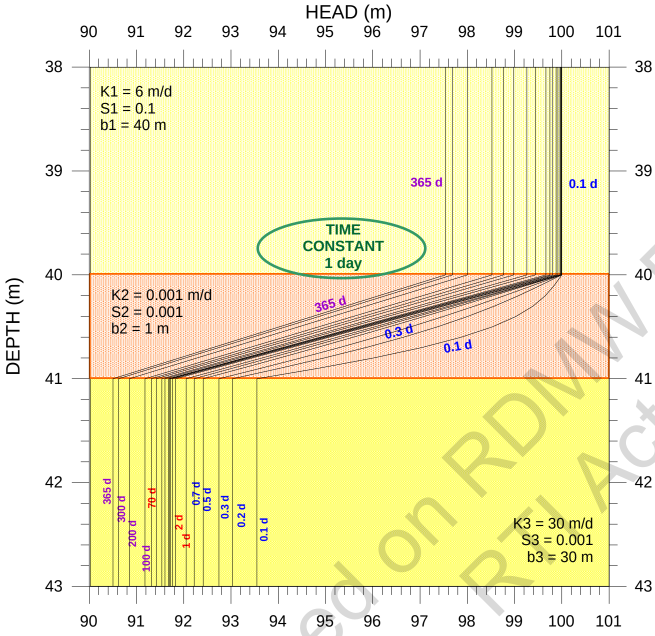

Figure 8. Simulated transient head profiles across a 1 metre thick aquitard

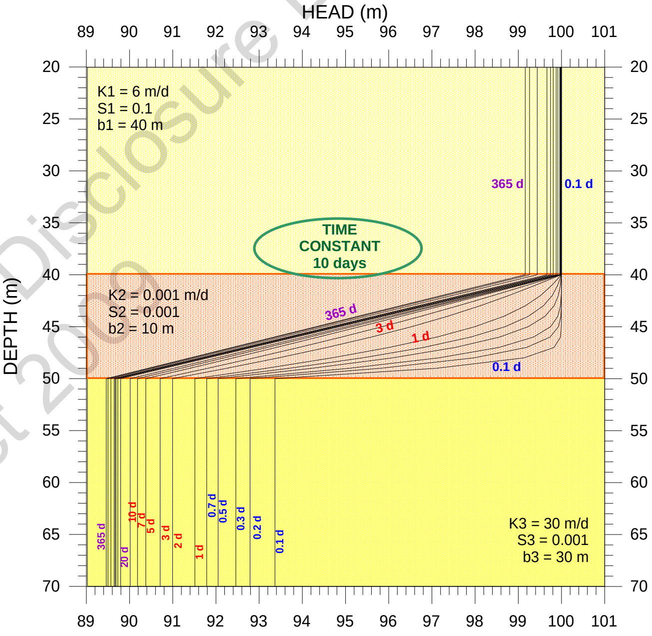

Figure 9. Simulated transient head profiles across a 10 metre thick aquitard

The time constant is a reliable indicator of the time at which equilibrium is almost established in the aquitard, which occurs when the head decline in the aquitard becomes linear. Equilibrium occurs much faster in a thin aquitard. In a thick aquitard, there is insignificant head loss in the upper aquifer until a substantial thickness of the aquitard starts to drain.

For the Lower Namoi aquifer, the calibrated inelastic specific storage (1.6x10^{-4} m^{-1}) is similar to the case shown in Figure 9. The aggregate aquitard thickness, however, can be much greater than 10 m, as shown in Figure 2. But it is the maximum thickness of a single aquitard that will determine the time lag, as multiple thin interbeds will drain rapidly. It is likely that subsidence in the Lower Namoi Valley will occur within the same season as the causative pumping. Long-term residual compaction is unlikely.

CONCLUSION

The Interbed Storage Package within MODFLOW is a simple but adequate algorithm for simulating and predicting layer compaction and land subsidence in a regional aquifer system, provided that individual fine-grained interbeds are relatively thin (say, less than 10 metres). The module requires very little data, as textbook compressibility ranges should be adequate to constrain parameter estimates during calibration. However, it is essential that the spatial distribution of fine-grained sediments be well known. It appears that drillers' logs will be adequate for this purpose. A history of survey levelling is necessary for reliable calibration. The modeller must be careful to choose a time step size that is compatible with the aquitard drainage time scale, and should also be aware of the other limitations of this approach.

In places where a MODFLOW model has not been developed, or a quick assessment is needed, it would be possible to add a subsidence module to HotSpots software. This could show the transient head profiles across a representative aquitard, so that the risk of residual compaction can be assessed. A similar compaction algorithm to that employed in the Interbed Storage Package would account for elastic compaction and rebound, and inelastic compaction, for simple or complex water level fluctuations.

For the Lower Namoi Valley, it is concluded that subsidence has occurred contemporaneously with water level fluctuations, and there is little risk of residual compaction in the future.

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LAND SETTLEMENT DUE TO GROUNDWATER PUMPING IN THE LOWER NAMOI VALLEY OF NSW

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National Centre for Groundwater Management, University of Technology, Sydney
Mike Williams, Don Mampitiya, Fabienne d'Hautefeuille
& Peter Sinclair
Department of Infrastructure, Planning and Natural Resources

9th Murray-Darling Basin Groundwater Workshop: 17-19 February 2004, Bendigo

NSW CONCERNS

- Responsibilities under the Water Management Act (2000)
- Water Sharing Plans (10 year tenure)
- **Local impact management** (= groundwater level response management) in parallel with Sustainable Yield management
  - *If neighbouring bores interfere (drawdown)*
  - *If water quality will degrade*
  - *If GDEs are threatened*
  - ***If subsidence is likely***

Is Groundwater-Induced Subsidence Worth Worrying About?

- 9 metre drop in Mexico City
- 9 metre drop in California (San Joaquin Valley)
- 7 metre drop in Wairakei, NZ
- 5 metre drop in Tokyo
- 3 metre drop in Po Valley, Italy
- 35 cm drop in London
- 14 cm drop in Venice

- Loss of aquifer storage
- Increased flooding
- Ground cracks
- Structural damage
- Repair costs
- Higher relative sea level rise (coastal areas)

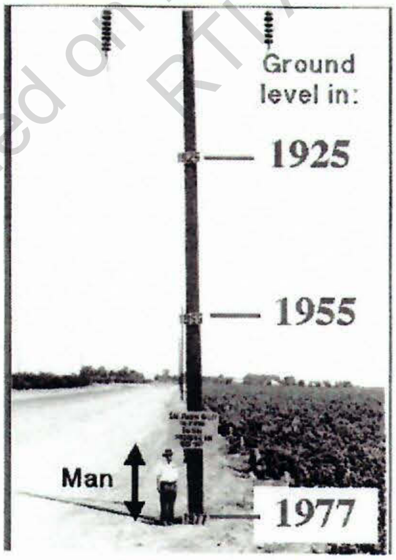
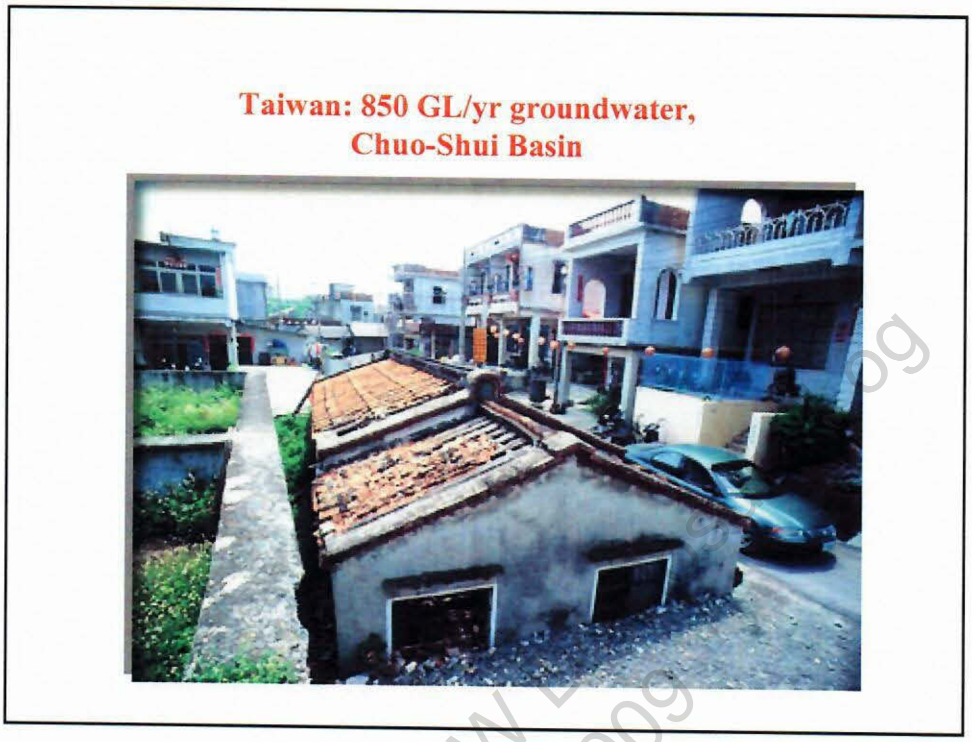
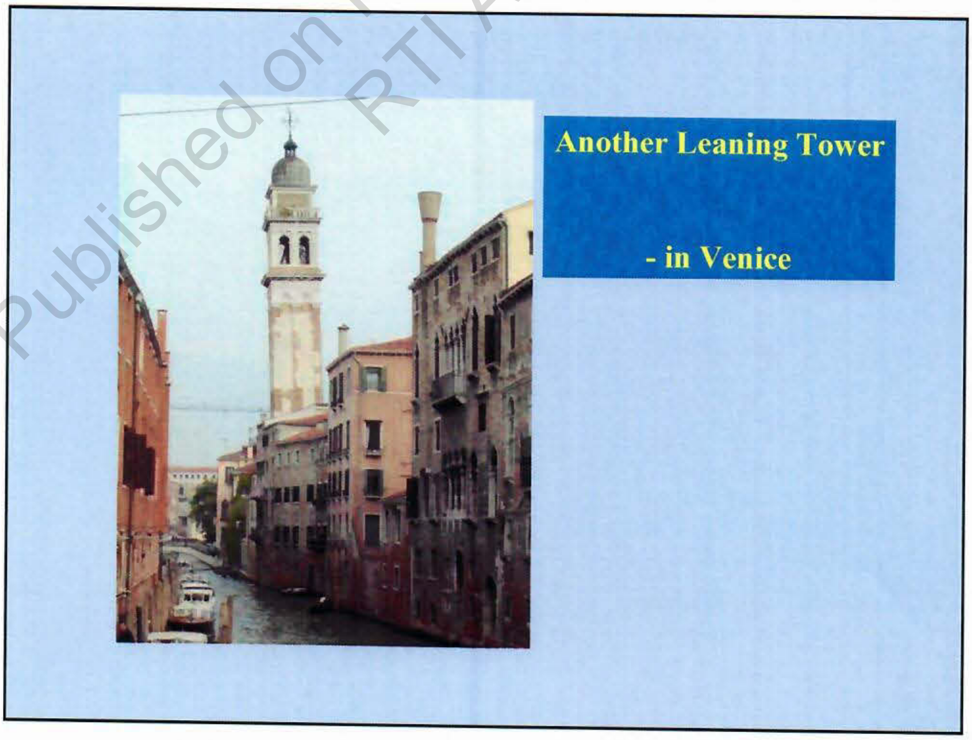


Photo 1. Significant land subsidence due to aquitard compaction at depth 260-660m in San Joaquin Valley, CA. Dr. Poland (1972) in the photo, the pioneer of studying landsubsice in USA, led the group of investigation at USGS

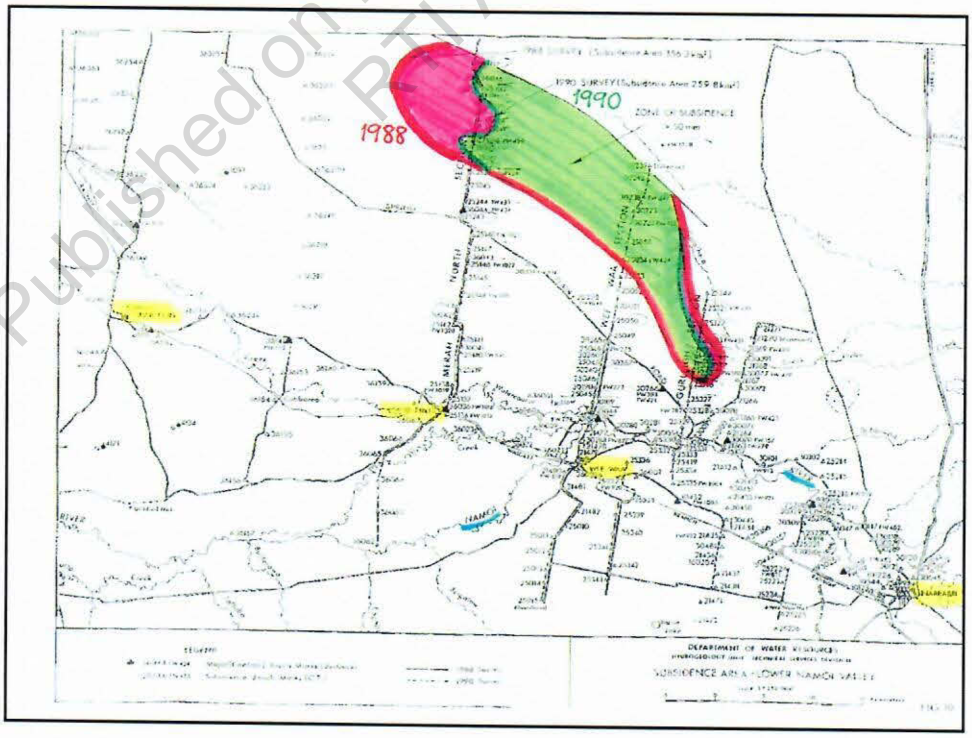

Taiwan: 850 GL/yr groundwater,
Chuo-Shui Basin

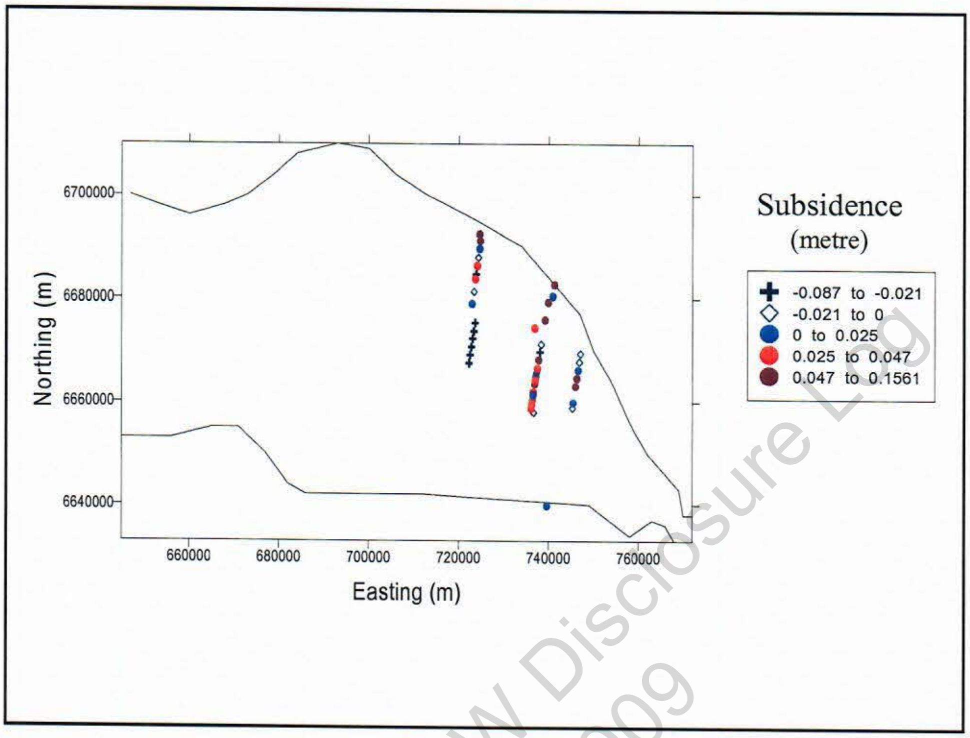

Another Leaning Tower

- in Venice

LOWER NAMOI VALLEY

- 1974 Benchmarks
- More intensive network 1981
- Survey levelling in 1982, 1987, 1988, 1990
- Observed **subsidence**:
  - Maximum 21 cm from 1981 to 1990
- Highly over-committed resource
- Sustainable Yield about 90 GL/year
- **Concern**: has subsidence "been and gone", or is more still to come? (residual compaction)



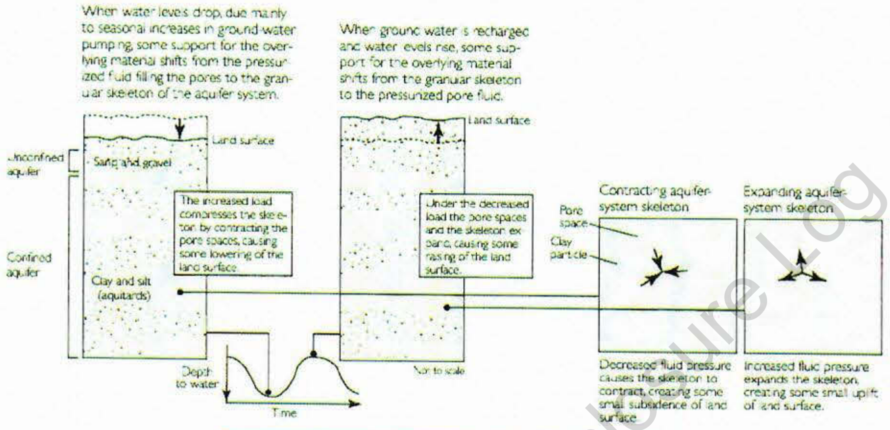


PHYSICAL PROCESS

- The weight of overlying sediments is shared by the aquifer skeleton and the groundwater
- Fluctuating groundwater level shifts the relative support provided by the grains and by the water
- For mild stresses, the process is **elastic**
  - (compression = expansion)
- For severe stresses, the process can be **inelastic**
  - (compression > expansion)
- Irreversible compaction in fine-grained interbeds, confining units, aquitards
  - Water is released from storage in clays/silts
  - One-time mining of groundwater

Source: USGS Circ.1182

ELASTIC



When water levels drop, due mainly to seasonal increases in ground-water pumping, some support for the overlying material shifts from the pressurized fluid filling the pores to the granular skeleton of the aquifer system.

When ground water is recharged and water levels rise, some support for the overlying material shifts from the granular skeleton to the pressurized pore fluid.

The increased load compresses the skeleton by contracting the pore spaces, causing some lowering of the land surface.

Under the decreased load the pore spaces and the skeleton expand, causing some raising of the land surface.

Decreased fluid pressure causes the skeleton to contract, creating some small subsidence of land surface.

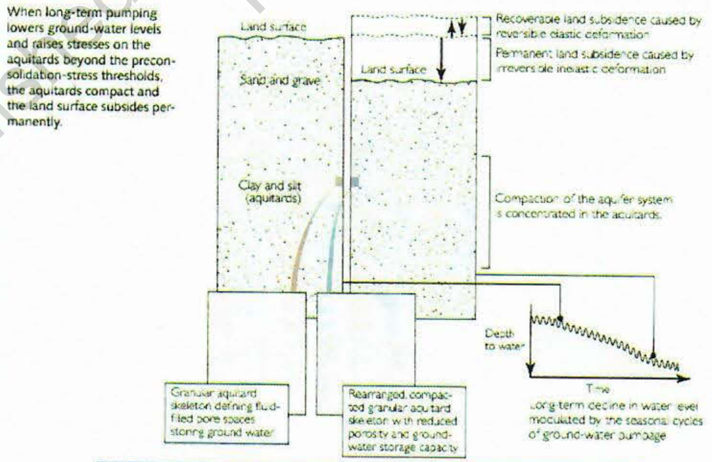
Increased fluid pressure expands the skeleton, creating some small uplift of land surface.

Stress < Preconsolidation stress

GWL higher than lowest GWL

Source: USGS Circ.1182

INELASTIC



When long-term pumping lowers ground-water levels and raises stresses on the aquitards beyond the preconsolidation-stress thresholds, the aquitards compact and the land surface subsides permanently.

Recoverable land subsidence caused by reversible elastic deformation

Permanent land subsidence caused by irreversible inelastic deformation

Compaction of the aquifer system is concentrated in the aquitards.

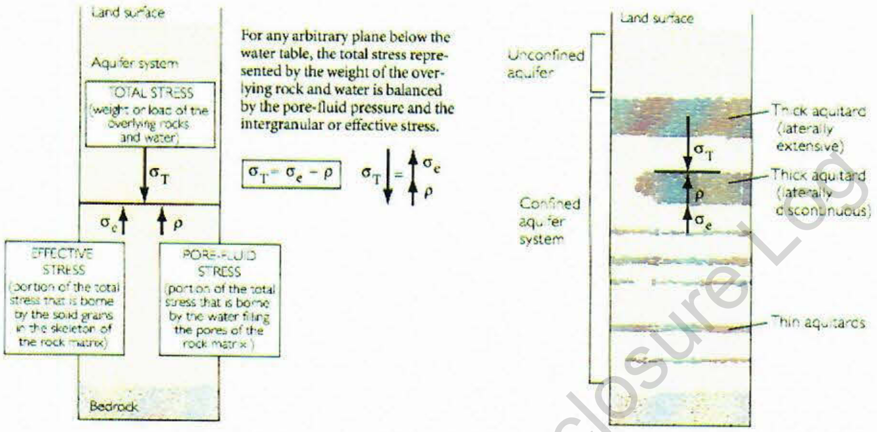
Granular aquitard skeleton defining fluid-filled pore spaces storing ground water

Rearranged, compacted granular aquitard skeleton with reduced porosity and ground-water storage capacity

Long-term decline in water level modulated by the seasonal cycles of ground-water pumpage

Stress > Preconsolidation stress

GWL lower than previous lowest GWL



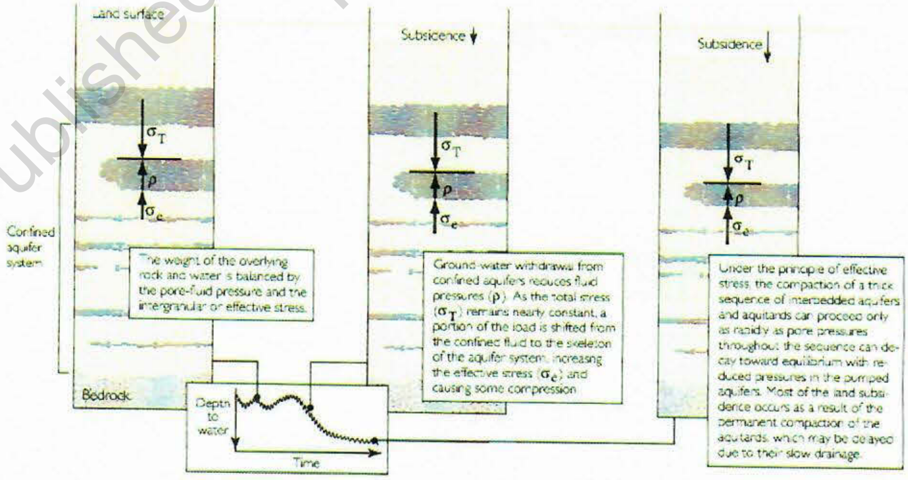
TOTAL STRESS (weight or load of the overlying rocks and water)

EFFECTIVE STRESS (portion of the total stress that is borne by the solid grains in the skeleton of the rock matrix)

PORE-FLUID STRESS (portion of the total stress that is borne by the water filling the pores of the rock matrix)

For any arbitrary plane below the water table, the total stress represented by the weight of the overlying rock and water is balanced by the pore-fluid pressure and the intergranular or effective stress.

$$\boxed{\sigma_T = \sigma_e - \rho}$$



The weight of the overlying rock and water is balanced by the pore-fluid pressure and the intergranular or effective stress.

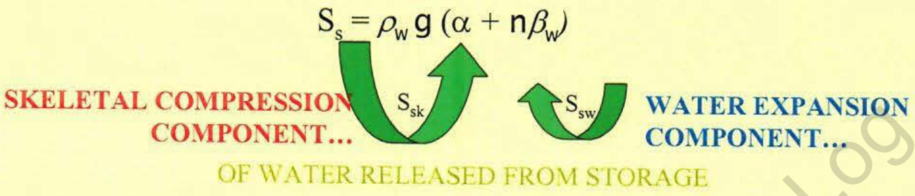
Ground-water withdrawal from confined aquifers reduces fluid pressures (ρ). As the total stress (σ_T) remains nearly constant, a portion of the load is shifted from the confined fluid to the skeleton of the aquifer system, increasing the effective stress (σ_e) and causing some compression.

Under the principle of effective stress, the compaction of a thick sequence of interbedded aquifers and aquitards can proceed only as rapidly as pore pressures throughout the sequence can decay toward equilibrium with reduced pressures in the pumped aquifers. Most of the land subsidence occurs as a result of the permanent compaction of the aquitards, which may be delayed due to their slow drainage.

7

R

SPECIFIC STORAGE



$$S_s = \rho_w g\,(\alpha + n\beta_w)$$

SKELETAL COMPRESSION COMPONENT…

WATER EXPANSION COMPONENT…

OF WATER RELEASED FROM STORAGE

S_s is specific storage of the aquifer material [L^{-1}],
ρ_w is density of water [M/L^3],
g is gravitational acceleration [L/T^2],
α is compressibility of the aquifer material [LT^2/M],
β_w is compressibility of the water [LT^2/M],
n is porosity of the aquifer material

SKELETAL SPECIFIC STORAGE

$$S'_{sk} = \begin{cases} S'_{ske} = \alpha'_{ke}\rho_w g, & \sigma' < \sigma'(\max) \\ S'_{skv} = \alpha'_{kv}\rho_w g, & \sigma' > \sigma'(\max) \end{cases}$$

Typically, the inelastic compressibility is 20 to 100 times the elastic value

STORAGE COEFFICIENT

$$S_k' = \begin{cases} S_{ke}' = S_{ske}'\left(\Sigma b'\right), & \sigma' < \sigma_{\max}' \\ S_{kv}' = S_{skv}'\left(\Sigma b'\right), & \sigma' > \sigma_{\max}' \end{cases}$$

$$S_k = S_{ke} = S_{ske}\left(\Sigma b\right)$$

TOTAL $S = S_k' + S_k + S_w$

COMPACTION

ELASTIC $\Delta b = -\Delta h S_{ske}' b_0$

INELASTIC $\Delta b^* = -\Delta h S_{skv}' b_0$ (approx.)

MODFLOW
INTERBED STORAGE (IBS) PACKAGE

Specify for each cell in each layer:

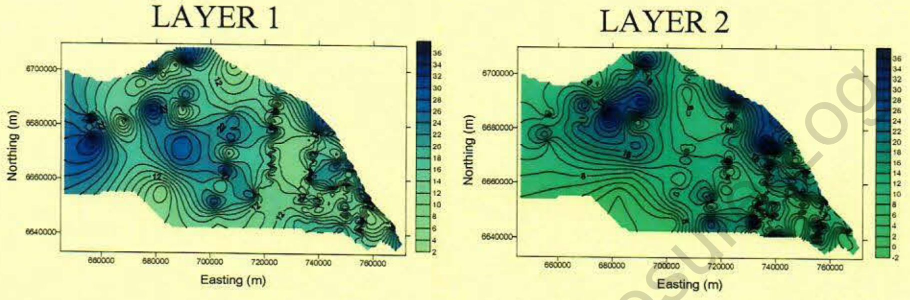
- ☐ Elastic storage coefficient;
- ☐ Inelastic storage coefficient;
- ☐ Initial preconsolidation head;
- ☐ Initial compaction.

This requires the user to aggregate interbed thicknesses spatially, and multiply by estimates of specific storage

MODFLOW
LIMITATIONS

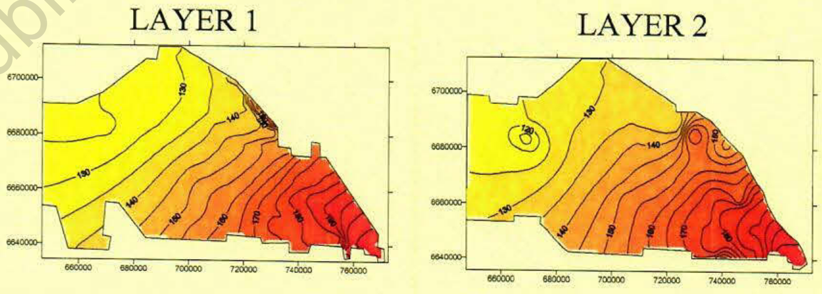
- ☐ Storage values are assumed constant in time;
- ☐ Aquitard heads are assumed to equilibrate within the **time step**; that is, aquitards are assumed to drain sufficiently at this time scale in order to dissipate excess pore pressure – this could overestimate compaction at early time and underestimate compaction at late time;
- ☐ Inelastic compaction is assumed to be proportional to head change – this will cause an overestimate of compaction;
- ☐ Changes in geostatic pressure for an unconfined aquifer are ignored – this will overestimate compaction.

LOWER NAMOI MODEL
CLAY THICKNESS



Calculated from drillers' bore logs

LOWER NAMOI MODEL
PRECONSOLIDATION HEAD



Set at 1980 observed levels

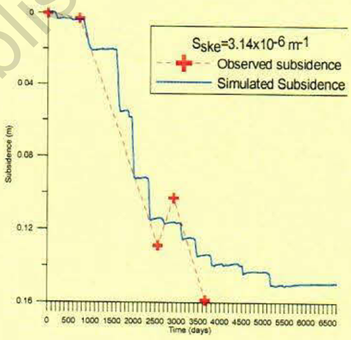
LOWER NAMOI MODEL
BEST PARAMETERS

- ☐ Elastic skeletal specific storage 3.1×10^{-6} m^{-1};
- ☐ Inelastic multiplier 100 (specific storage 3.1×10^{-4} m^{-1}).

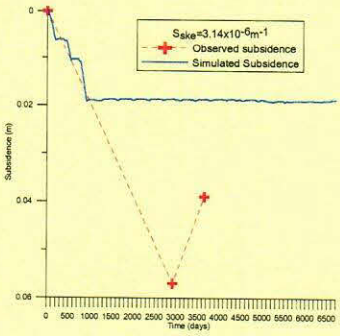
Compare values in Pope & Burbey (2004) in Virginia:

- ☐ Elastic skeletal specific storage $(4.5 \text{ to } 6.0)\times10^{-6}$ m^{-1};
- ☐ Inelastic multiplier 3 to 25
- ☐ Specific storage $(0.15 \text{ to } 1.5)\times10^{-4}$ m^{-1}

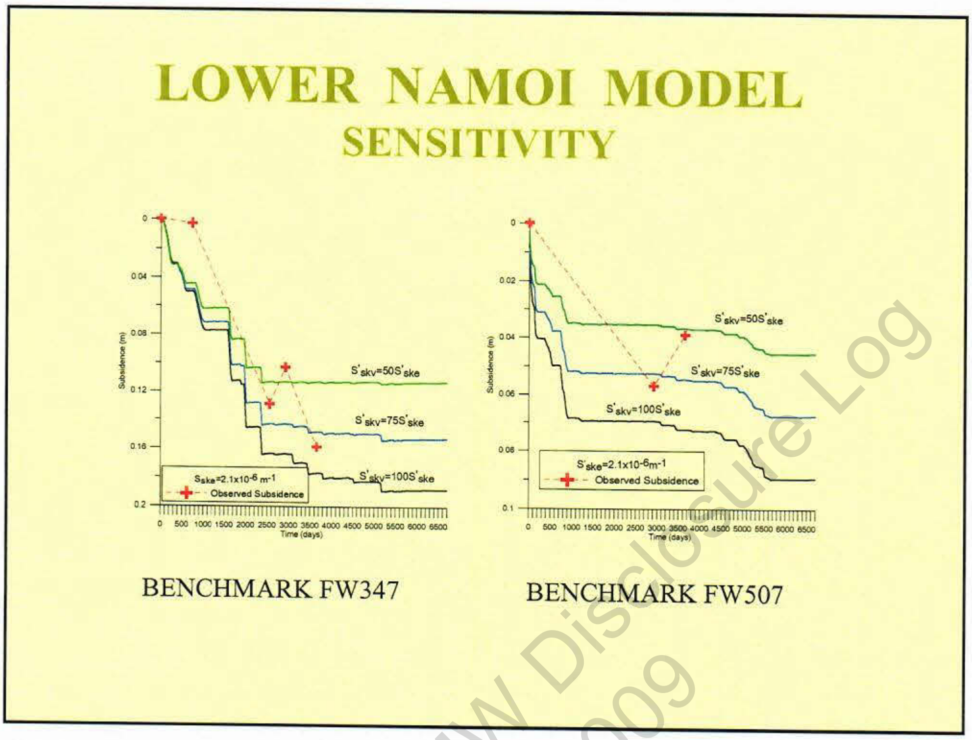
LOWER NAMOI MODEL
CALIBRATION



BENCHMARK FW347



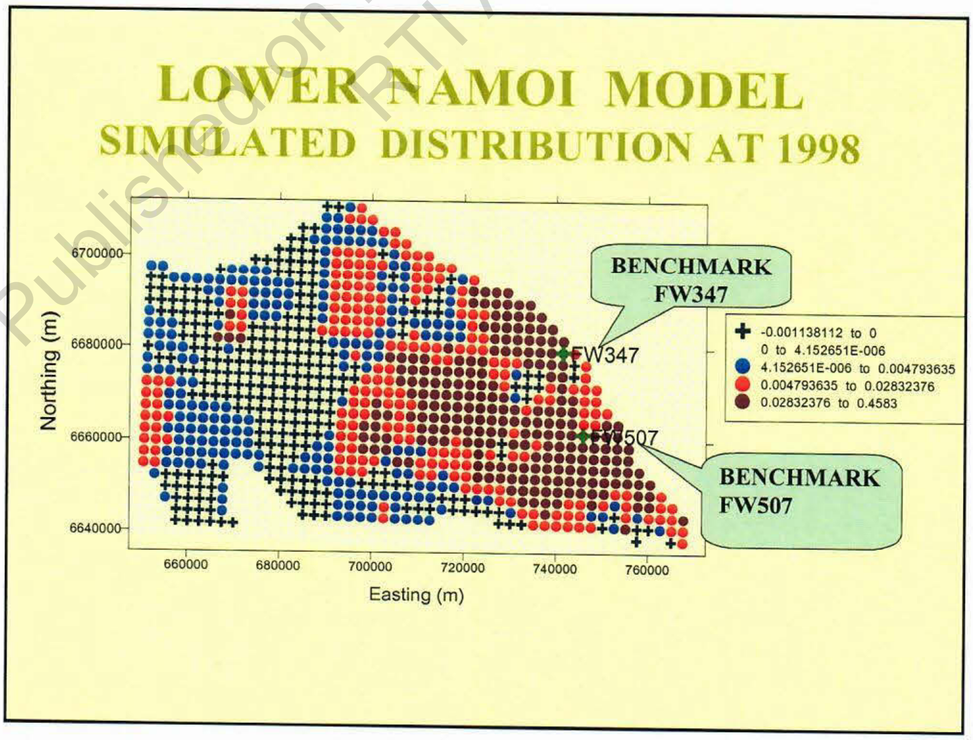
BENCHMARK FW507



LOWER NAMOI MODEL
SENSITIVITY

BENCHMARK FW347

BENCHMARK FW507



LOWER NAMOI MODEL
SIMULATED DISTRIBUTION AT 1998

- ✚ -0.001138112 to 0
- 0 to 4.152651E-006
- ● 4.152651E-006 to 0.004793635
- ● 0.004793635 to 0.02832376
- ● 0.02832376 to 0.4583

RESIDUAL COMPACTION

DUE TO SLOW-DRAINING FINE-GRAINED SEDIMENTS

TIME CONSTANT

$$\tau = \frac{S'\,b'}{4\,K'}$$

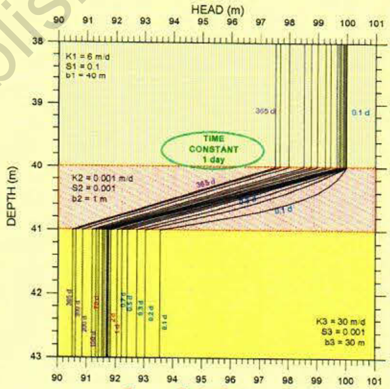
Time by which 93% of excess pore pressure has dissipated

Drainage is slow if interbed:

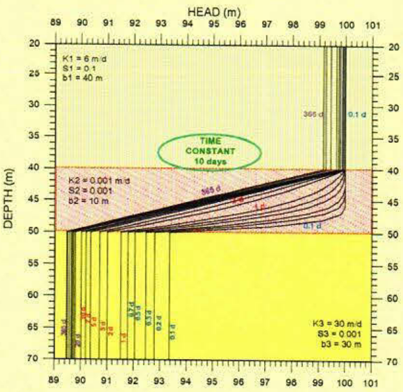
- is thick
- has high storage
- has low permeability

ANALYTICAL MODEL

TYPICAL LOWER NAMOI PARAMETERS



1m thick aquitard



10m thick aquitard

CONCLUSION

- IBS is a simple but adequate algorithm
- Very few data requirements
- Start with textbook compressibility ranges, then calibrate
- Driller's logs probably adequate for distribution of interbed aggregate thickness
- Modeller must choose time step guided by time constant
- Residual compaction is unlikely in the Lower Namoi Valley
- Need much more field evidence

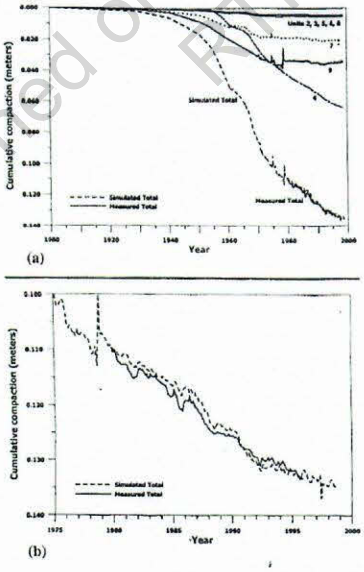


Figure 11. Simulated and measured aquifer-system compaction at Franklin from (a) 1900–1995, and (b) 1980–1995, the period of extensometer record.

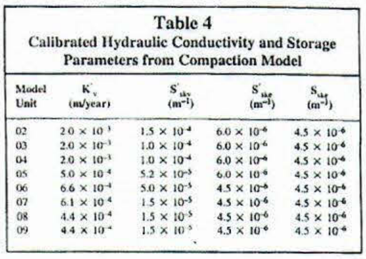


Table 4
Calibrated Hydraulic Conductivity and Storage Parameters from Compaction Model

Model Unit	K'_v (m/year)	S'_{skv} (m^{-1})	S'_{ske} (m^{-1})	S_{ske} (m^{-1})
02	2.0×10^{-3}	1.5×10^{-4}	6.0×10^{-6}	4.5×10^{-6}
03	2.0×10^{-3}	1.0×10^{-4}	6.0×10^{-6}	4.5×10^{-6}
04	2.0×10^{-3}	1.0×10^{-4}	6.0×10^{-6}	4.5×10^{-6}
05	5.0×10^{-4}	5.2×10^{-5}	6.0×10^{-6}	4.5×10^{-6}
06	6.6×10^{-4}	5.0×10^{-5}	4.5×10^{-6}	4.5×10^{-6}
07	6.1×10^{-4}	1.5×10^{-5}	4.5×10^{-6}	4.5×10^{-6}
08	4.4×10^{-4}	1.5×10^{-5}	4.5×10^{-6}	4.5×10^{-6}
09	4.4×10^{-4}	1.5×10^{-5}	4.5×10^{-6}	4.5×10^{-6}

Source: Pope & Burbey, 2004

Technical Advisory Panel (TAP) for the Surat CMA

MINUTES for MEETING No. 13 (Subsidence)

Thursday 23 July 2021

Teams Meeting

Attendees

Panel members: Noel Merrick (HydroSimulations), Adrian Werner (Flinders University), Phil Hayes (University of Queensland), Randall Cox

OGIA participants: Sanjeev Pandey (SP) (Chair), Gerhard Schöning (GS), Steven Flook (SF), Anna Bui Xuan Hy (AB), Wendy Zhang (WZ), Dean Erasmus (DE)

Apologies

Tim Ransley

Agenda Items

1. Context and what is driving OGIA's research into subsidence – *SP*
2. Analysis of monitoring data (InSAR) to identify CSG induced subsidence – approach and interim findings – *SF, GS, DE, WZ*
3. Modelling and predictions of subsidence – approach and interim findings – *GS, AB*
4. Developing methods for baselining– general approach and work in progress – *SF, DE, SP*

Deliberations

No material was provided ahead of the meeting. For each agenda item, a presentation was made (attached) by OGIA team members. This was followed by discussion, points of clarification and TAP members' deliberations to make recommendations.

Item 1 – Context

TAP members **noted** the context and structure of OGIA's subsidence-related research into three themes that emerged from OGIA's stakeholder engagement (*Attachment 1*):

- Analysis of monitoring data
- Predictions; and
- Establishing baseline.

Item 2 – Analysis of monitoring data

TAP members

- **noted** the information presented (*Attachment 1*)
- **endorsed** the overall approach to analysis of InSAR data
- **commented** that the machine learning approach applied is still preliminary and the applicability of the method is yet to be demonstrated

Item 3 – Modelling and predictions

TAP members:

- **noted** the information presented (*Attachment 1*)

- **noted and agreed:**
    - the concept of using predictions to estimate change of slope and direction of slope instead of absolute elevation changes; and
    - challenges associated with using ground movement data to validate/calibrate the model
- **endorsed:**
    - the overall approach to modelling and modelling methods; and
    - that the modelling is fit for purpose
- **noted** that OGIA is planning to further refine modelling and collaborate with UQ in the post-UWIR period to test various hypothesis; and
- **suggested**
    - considering "land settlement" modelling in the Namoi Valley (*Attachment* 2).
    - considering compaction estimate from the model to estimate storage parameters for groundwater flow modelling

Item 4 – Establishing baseline methods

TAP members:

- **noted** the information presented (*Attachment 1*)
- **endorsed:**
    - the overall approach in establishing baseline method; and
    - that in the context of ground movement, baseline is not a snapshot in time, but rather a trend over a reasonable period of time
- **suggested** that OGIA consider using a reference point/area outside those affected by CSG operations, for ongoing comparison.

General

TAP members acknowledged and complimented the quality and amount of work undertaken by OGIA on subsidence, particularly in a short timeframe.

Joanne Kerr

From: CTPI 49-Sch4@ozemail.com.au>
Sent: Saturday, 7 August 2021 6:36 AM
To: SCHONING Gerhard
Subject: Re: Next gen modelling

Follow Up Flag: Follow up
Flag Status: Flagged

Hello Gerhard

Actually, I had a good feeling about that meeting too. The TAP could hardly have been more effusive in their praise of all that was done - and who wouldn't be, after all? It is impressive stuff.

Yes, lets talk as soon as is good for you. I need to "listen" - I feel out of the loop. Anything we do now needs to make as much use of available data and latest conceptualisations as possible. I feel unaware of these. So if there is anything I should read, send it to me.

Best wishes

CTPI 49

On 6/08/2021 5:50 pm, SCHONING Gerhard wrote:

> H CTPI 49-S
>
> Thanks very much for your time today. I think your presentation was actually a great way to end the current cycle of work a and set a tone for what's coming . Keen to set up that chat with Tao next week if you have time
> , let me know if any day in particular will work for you.
>
> Enjoy your weekend ,
> Gerhard
>
> Get Outlook for Android
>
>

--
Watermark Numerical Computing
49 Ardoyne Rd
Corinda 4075
Australia
+61 7 3379 1664

Joanne Kerr

From: PANDEY Sanjeev
Sent: Monday, 9 August 2021 10:42 AM
To: Adrian Werner
Cc: FLOOK Steven; SCHONING Gerhard; BUI XUAN HY Anna
Subject: RE: Technical Advisory Panel

Follow Up Flag: Follow up
Flag Status: Flagged

Thanks Adrian. Much appreciated.

From: Adrian Werner <adrian.werner@flinders.edu.au>
Sent: Monday, 9 August 2021 9:37 AM
To: PANDEY Sanjeev
Subject: RE: Technical Advisory Panel

I support the minutes as written. OGIA continues to lead the way in hydrogeological modelling of large systems in Australia – the presentations indicate a seamless extension from groundwater impacts to subsidence.

From: PANDEY Sanjeev <Sanjeev.Pandey@rdmw.qld.gov.au>
Sent: Friday, 6 August 2021 1:10 PM
To: 'Noel Merrick' <CTPI 49-Sch4 @hydroalgorithmics.com CTPI 49- @optusnet.com.au' CTPI 49 @optusnet.com.au>; Ransley Tim <Tim.Ransley@ga.gov.au>; 'Phil Hayes' <phil.hayes@uq.edu.au>; Adrian Werner <adrian.werner@flinders.edu.au>; Phil Hayes <philip.hayes@uq.edu.au>; CTPI 49-Sch4 @gmail.com
Cc: FLOOK Steven <Steven.Flook@rdmw.qld.gov.au>; SCHONING Gerhard <Gerhard.Schoning@rdmw.qld.gov.au>
Subject: RE: Technical Advisory Panel

Dear TAP members

Attached are minutes of subsidence meeting. Please let me know if we have captured all the key elements from the meeting? Attached are also PowerPoint that we presented and two documents that Noel mentioned during the meeting and later provided to us – Thanks Noel!

Regards
Sanjeev

-----Original Appointment-----
From: MENEGUZZO Krysten **On Behalf Of** PANDEY Sanjeev
Sent: Wednesday, 7 July 2021 3:33 PM
To: PANDEY Sanjeev; 'Noel Merrick'; CTPI 49 @optusnet.com.au'; 'Tim.Ransley@ga.gov.au'; 'Phil Hayes'; Adrian Werner; FLOOK Steven; SCHONING Gerhard; MARSHALL Hugh; GALLAGHER Mark; ZHANG Wendy; ERASMUS Dean
Cc: CTPI 49-Sch4 @gmail.com; BUI XUAN HY Anna; Phil Hayes
Subject: Technical Advisory Panel
When: Friday, 23 July 2021 1:00 PM-3:00 PM (UTC+10:00) Brisbane.
Where: <<1 William Street (1WS) - 4 Floor - Meet 4.02>>

Good afternoon TAP Members

This is a placeholder for the first TAP meeting.

This session will be on subsidence.

Kind Regards

Krysten Meneguzzo
Project Officer
Office of Groundwater Impact Assessment
Department of Regional Development, Manufacturing and Water
07 3199 7321 | krysten.meneguzzo@rdmw.qld.gov.au
Level 5, 1 William St, Brisbane QLD 4000
PO Box 15216, City East QLD 4002
business.qld.gov.au/ogia

Part-time (Monday – Thursday)

Microsoft Teams meeting

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teams@itp.onpexip.com
Video Conference ID: 132 229 899 4
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Joanne Kerr

From: Randall Cox CTPI 49@optusnet.com.au>
Sent: Monday, 23 August 2021 12:36 PM
To: PANDEY Sanjeev; 'Noel Merrick'; Ransley Tim; 'Phil Hayes'; 'Adrian Werner'; 'Phil Hayes'; CTPI 49-Sch4 @gmail.com
Cc: FLOOK Steven; SCHONING Gerhard
Subject: RE: Technical Advisory Panel

Follow Up Flag: Follow up
Flag Status: Flagged

Hi Sanjeev,

Fine by me.

For your records, might be worth naming the attachments as attachment 1 and attachment 2 to align with the text in the minutes

Regards,

Randall

From: PANDEY Sanjeev <Sanjeev.Pandey@rdmw.qld.gov.au>
Sent: Friday, 6 August 2021 1:40 PM
To: CTPI 49-Sch4 @hydroalgorithmics.com>; CTPI 4@optusnet.com.au' CTPI 4@optusnet.com.au>; Ransley Tim <Tim.Ransley@ga.gov.au>; 'Phil Hayes' <phil.hayes@uq.edu.au>; Adrian Werner <adrian.werner@flinders.edu.au>; Phil Hayes <philip.hayes@uq.edu.au>; CTPI 49-Sch4 @gmail.com
Cc: FLOOK Steven <Steven.Flook@rdmw.qld.gov.au>; SCHONING Gerhard <Gerhard.Schoning@rdmw.qld.gov.au>
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