Mongolia CBM Resources

Hydrogeology and Water

Ulaanbaatar, Mongolia
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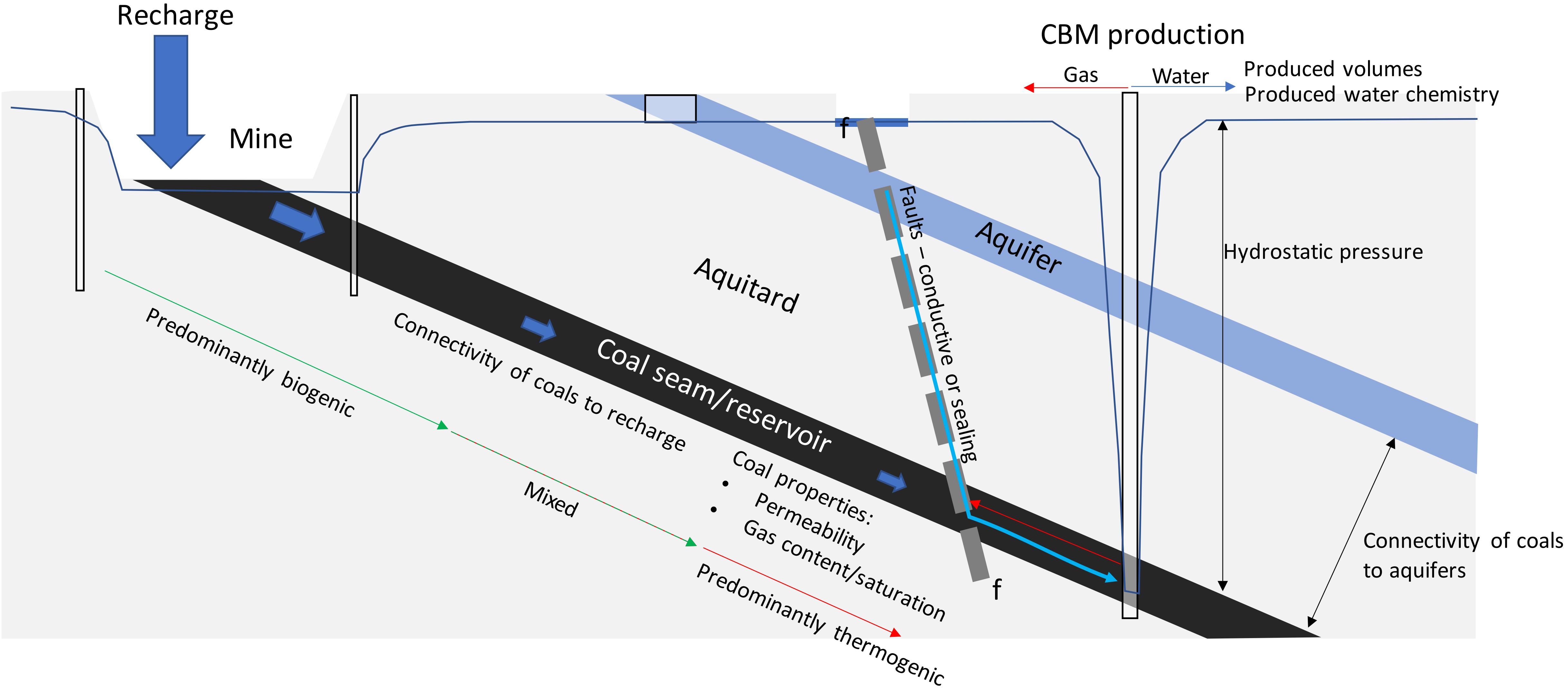
Outline

- ❖ Hydrogeological concepts and CBM
- ❖ Case study – Southern Bowen Basin, Australia
- ❖ CBM and Water Production
- ❖ Mongolian Examples
- ❖ Questions throughout

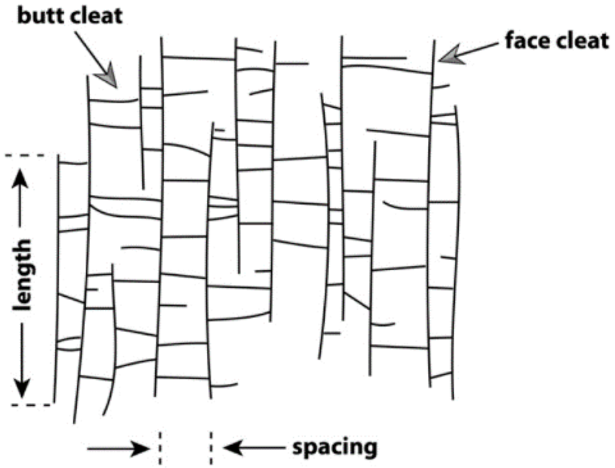
Hydrogeological concepts and CBM

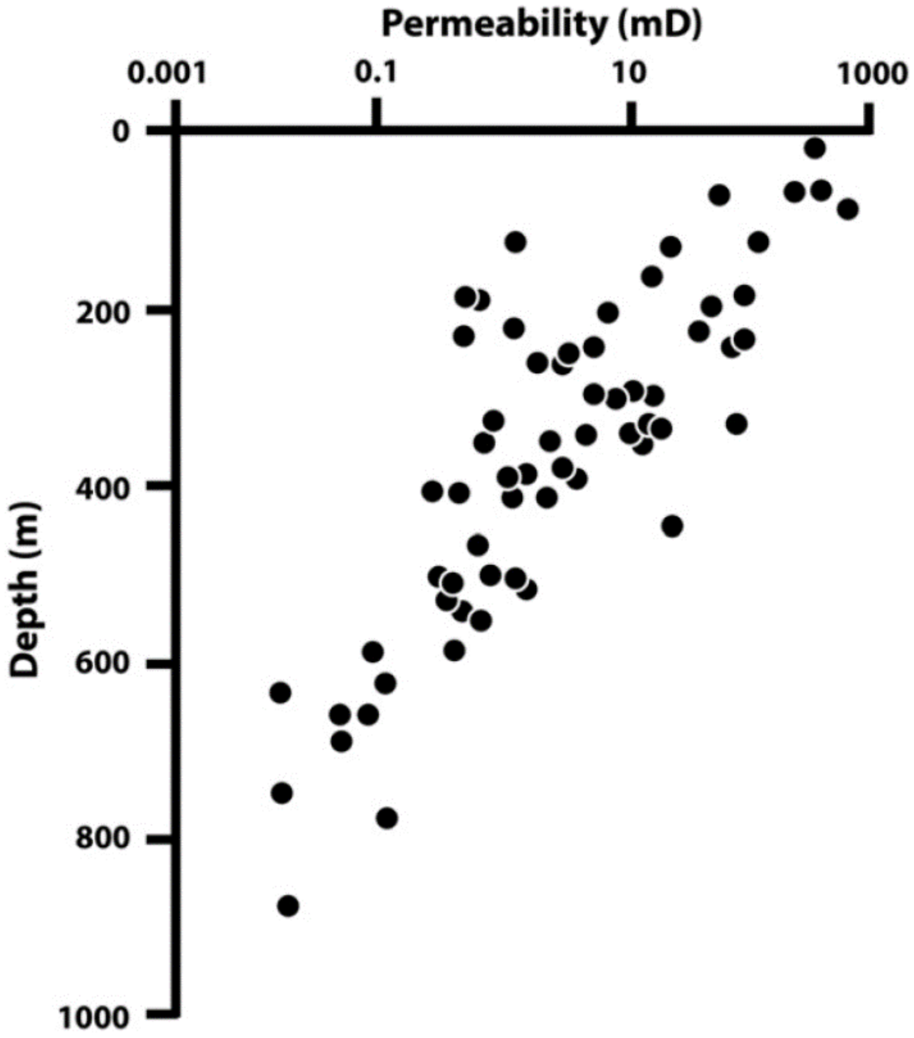
Key hydrogeological concepts



Coal Properties – Permeability

- Arguably the most important reservoir property for CBM production
  - Too low and the water and gas can't flow to the well
  - Too high and too much water needs to be produced
- Primarily driven by the natural fracture (cleat) network
  - Coalification process
  - Tectonic setting
- Permeability often reduces with depth
- Permeability can reduce during production (stress-dependent permeability)





Moore, T.A. (2012) Coalbed methane: A review. International Journal of Coal Geology 101 (2012) 36-81.

Coal Properties – Gas Content and saturation

- Without sufficient gas saturation (>=70%) gas flow unlikely to be economic
- Adsorption isotherm = amount of gas a coal can hold for a given pressure
- Most coals are unsaturated
- In an unsaturated coal, the reservoir pressure needs to be reduced to establish gas flow
    - Achieved by pumping water
- Saturation can be affected by hydrogeology

https://aplng.com.au/wp-content/uploads/2021/07/Natural_gas_and_water_bores.pdf

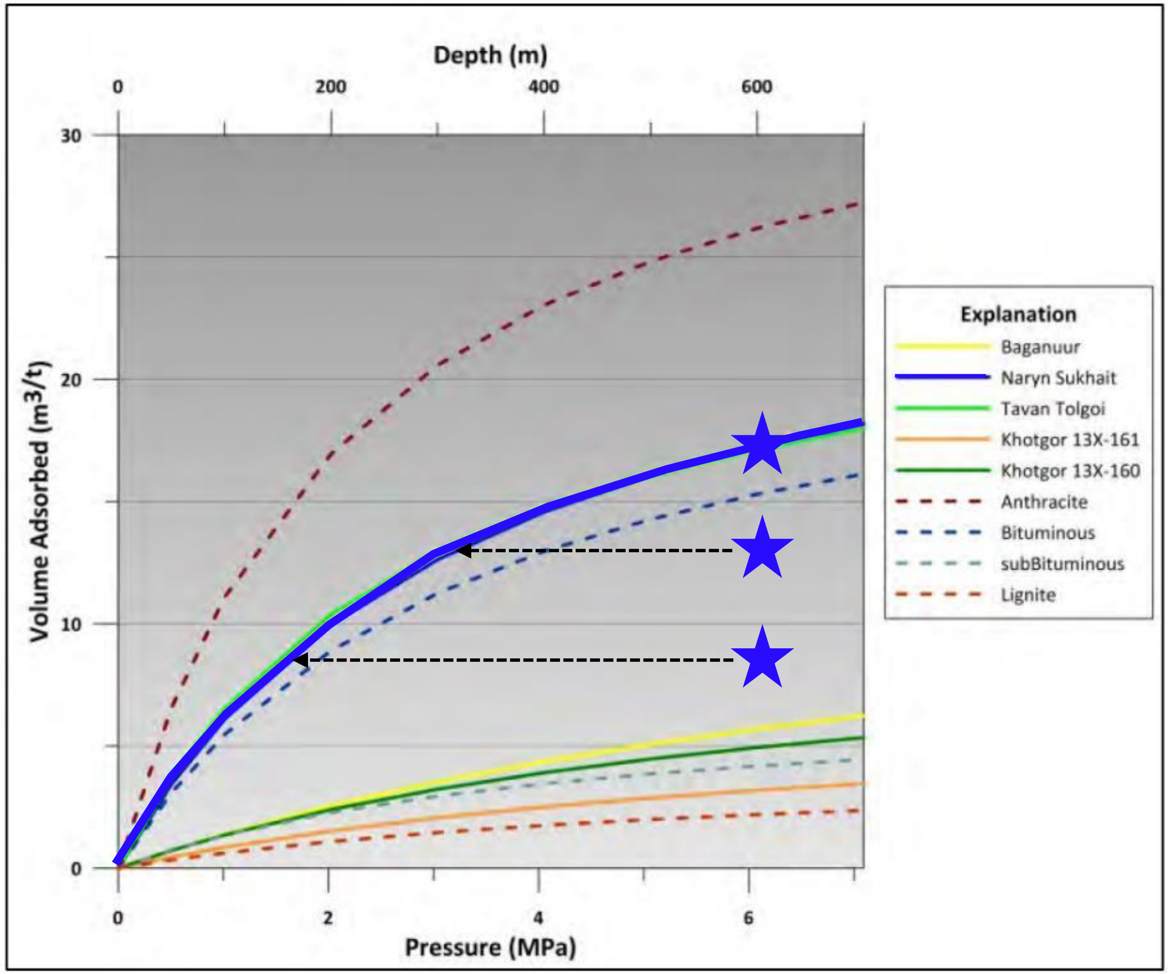


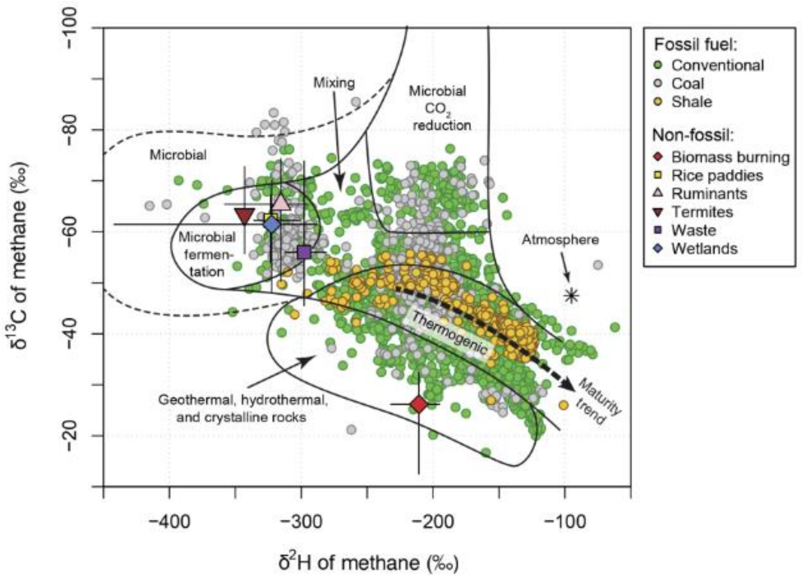
Figure 7: Adsorption Isotherm Type Curves by Rank and Mongolian Coal Deposits

After MNEC (2014) Coal Mine Methane (CMM) Resource Assessment and Emission Inventory Development in Mongolia

Hydrogeology and gas content

- CBM can be generated by two primary pathways
  - Thermogenic – generation during coalification through heat and pressure
  - Biogenic – generated by microbial action, via different metabolic pathways

    Isotopic composition can be used to assess pathway
- Biogenic gas requires recharge
  - Usually present in areas closer to outcrop
  - May be preserved from the time of burial

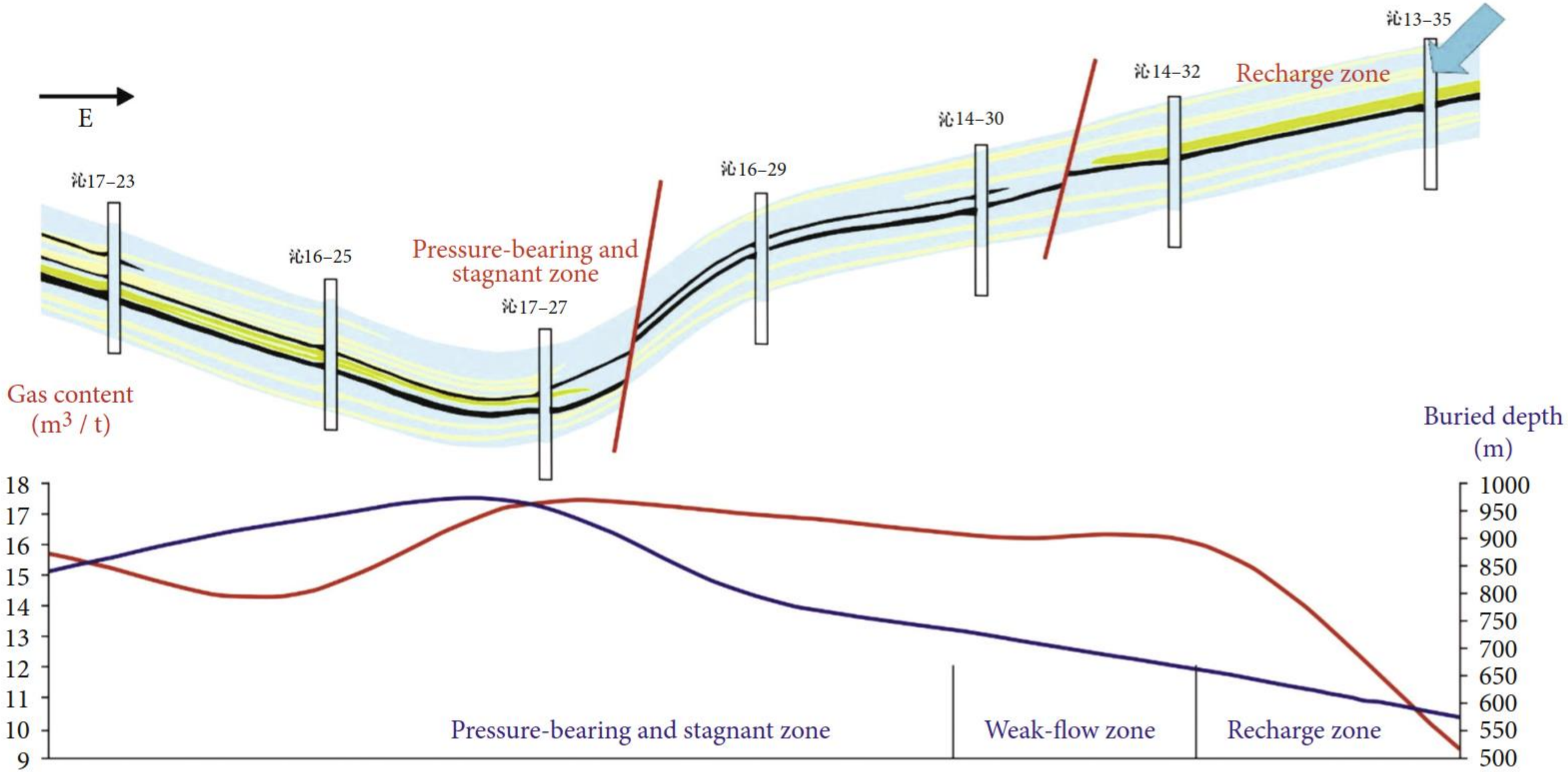


Sherwood et al (2017) Global Inventory of Gas Geochemistry Data from Fossil Fuel, Microbial and Burning Sources. Earth Syst. Sci. Data, 9, 639–656, 2017

Domains from Whiticar, M.J. (1999) Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane. Chemical Geology 161 No. 1-3 p219-314

- In an active flow system:
  - biogenic gas generated near a recharge source can be transported and trapped down dip to increase gas content
  - Gas can be flushed out of the coals and into an adjacent formation. This will reduce gas content in coals, but if a suitable conventional trap exists, the gas may accumulate elsewhere

Example of hydrodynamics and gas content

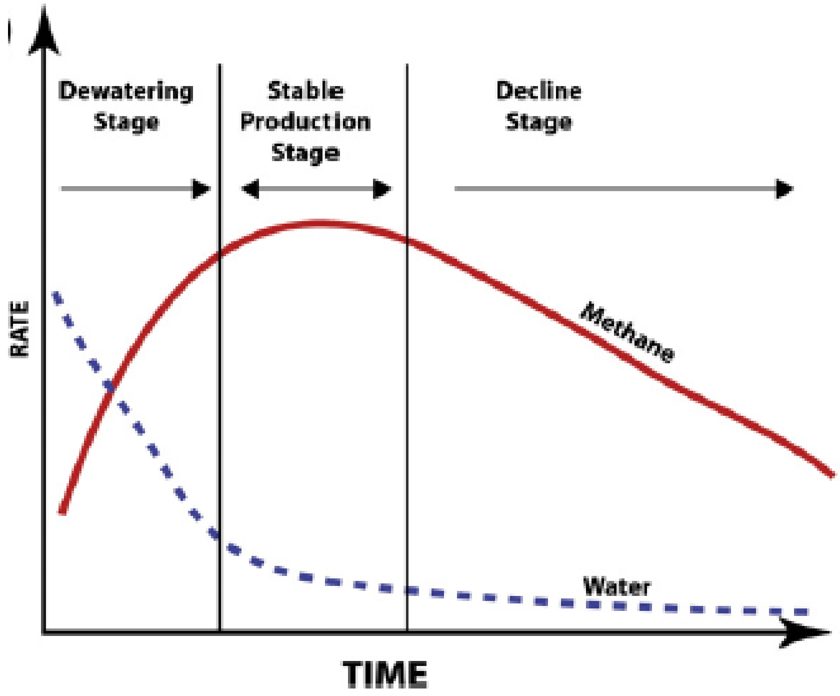


Wang et al (2021) Review of the Hydrogeological Controls on Coalbed Methane(CBM) and Development Trends. Geofluids Volume 2021, Article ID 8298579, 14 pages

Aquifer Geometry (1)

- Most reservoir engineers think of the coals as a sealed reservoir
- All formations have permeability
  - there will be some leakage into the coal as the pressure is reduced (Darcy's Law)
- Connection between the coal and an aquifer may:
  - Be due to direct juxtaposition of the coal with an aquifer or via a conductive fault
  - Result in the flushing of gas due to hydrodynamic flow leading to lower gas content
  - Inhibit production due to the inability to sufficiently depressurise
  - Cause the project to be uneconomical because of too much water production

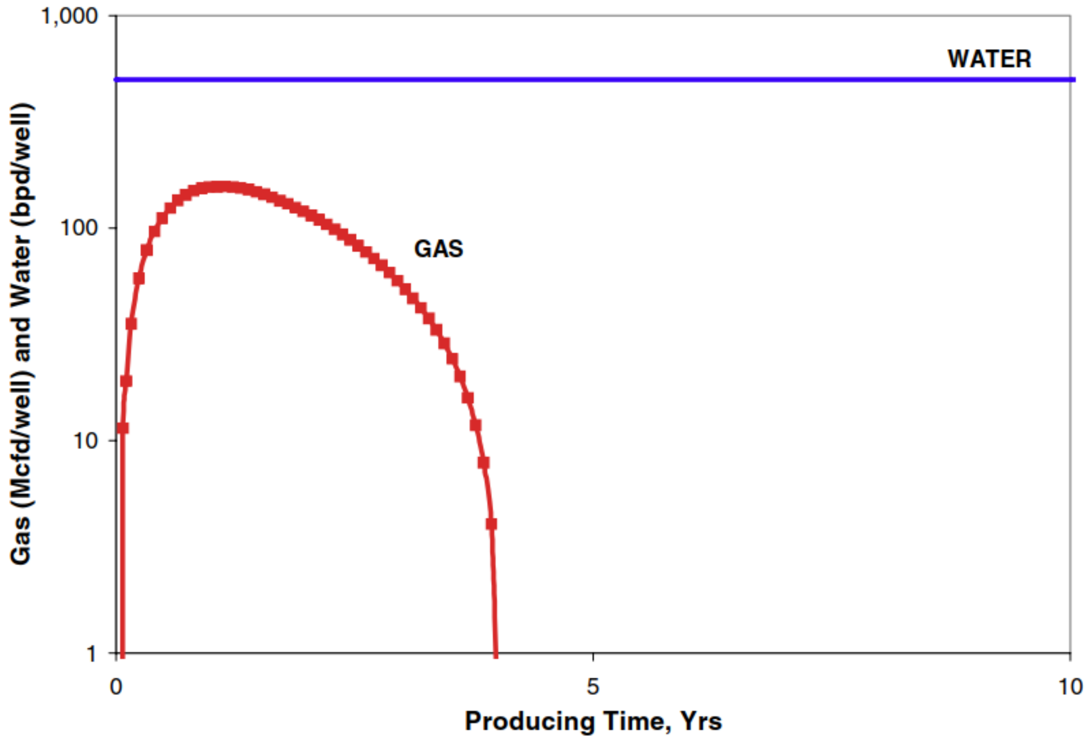
Idealised CBM production curves



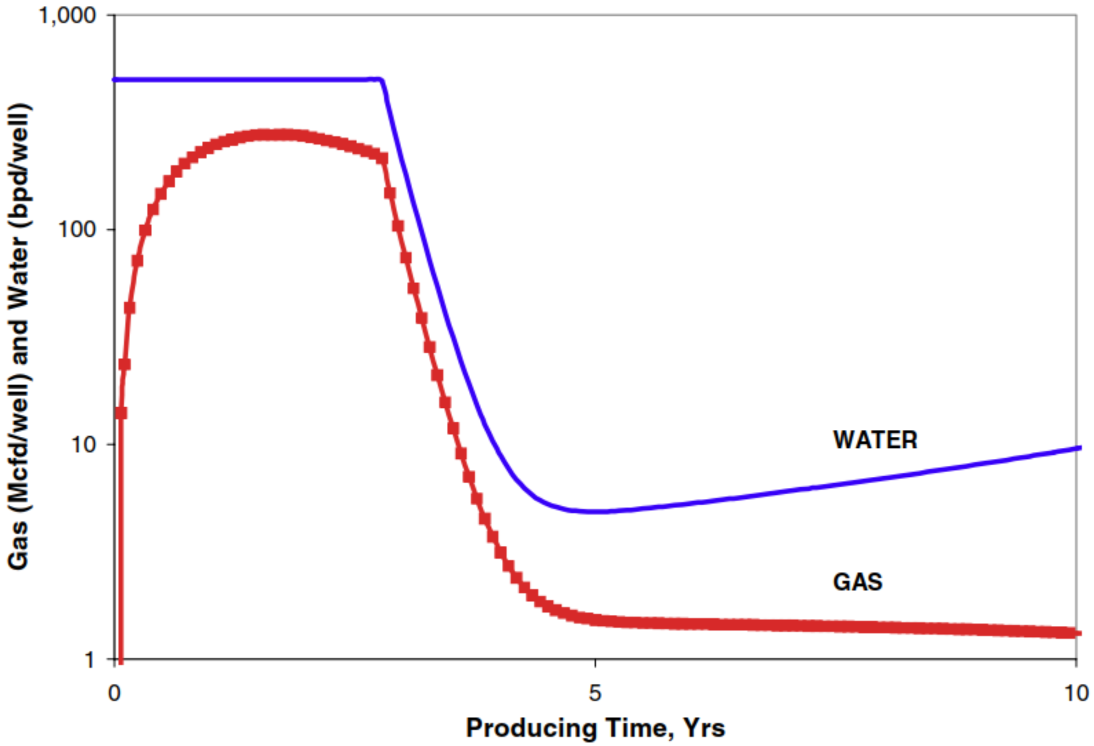
Moore, T.A. (2012) Coalbed methane: A review. International Journal of Coal Geology 101 (2012) 36-81.

Aquifer geometry (2) – effect on water production

Large amount of leakage



Lesser amount of leakage



Onsager, P.R. and Cox, D.O. (2000) Aquifer Controls on Coalbed Methane Development in the Powder River Basin, Wyoming. Society of Petroleum Engineers, SPE63090.

Aquifer Geometry - Faults

- Faulting may compartmentalise the reservoir
  - Closely space faults may reduce the effective reserve area of each well
  - May limit dewatering required
- Faults may provide conduit between the reservoir and an aquifer

Water chemistry

- CBM waters are generally Na-HCO3-Cl type
- SO4 may inhibit the production of biogenic methane
- General increase in salinity down flow path, and transition to NaCl
- May help identify areas where gas contents are higher
- Important for water management

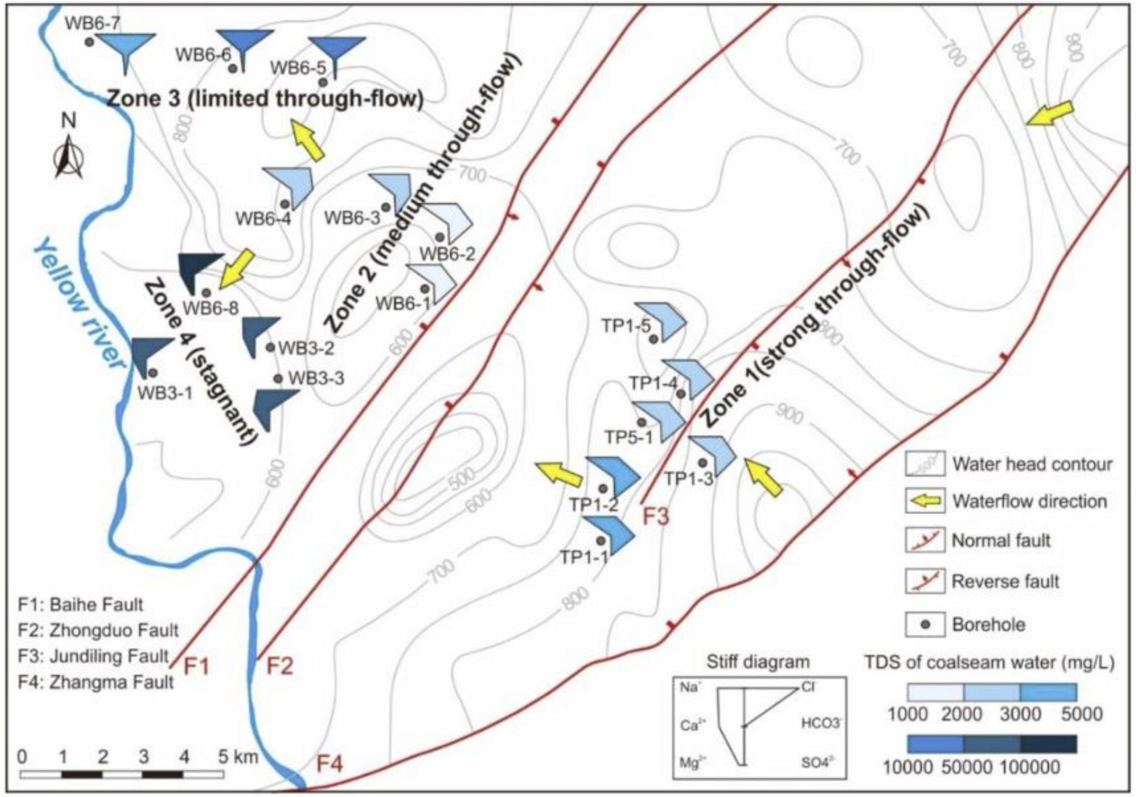


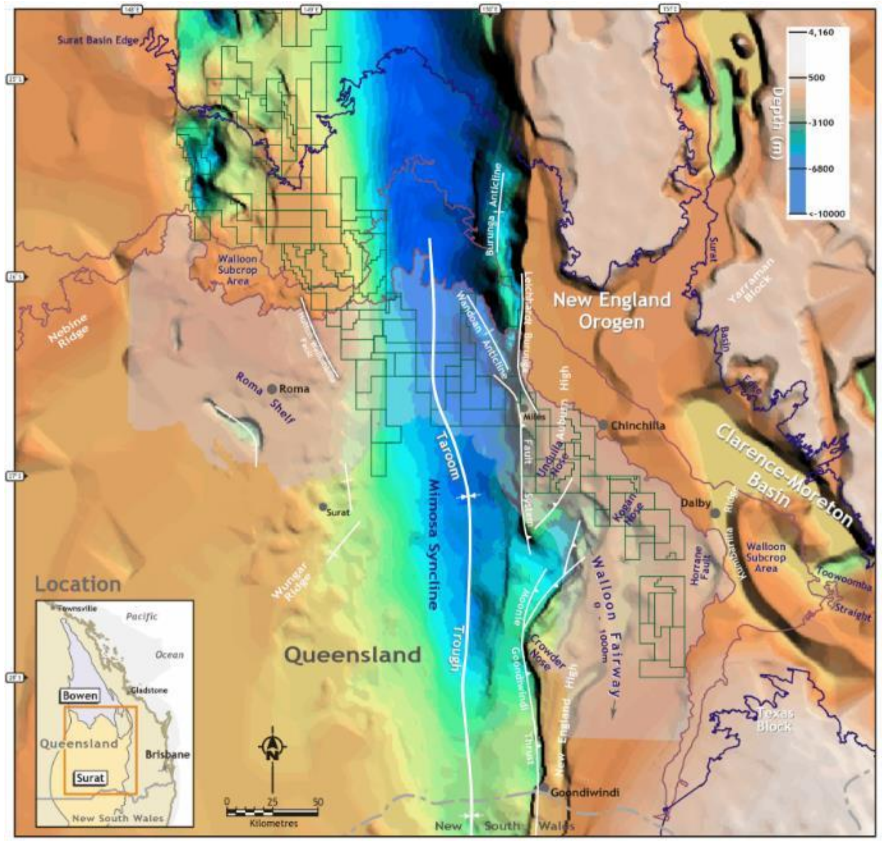
Fig. 9. Hydrodynamic zoning of groundwater in No.2 coal seam of the Yanchuannan CBM block.

Zhang et al (2020) Structure- and hydrology-controlled isotopic coupling and heterogeneity of coalbed gases and co-produced water in the Yanchuannan block, southeastern Ordos Basin. International Journal of Coal Geology 232 (2020) 103626

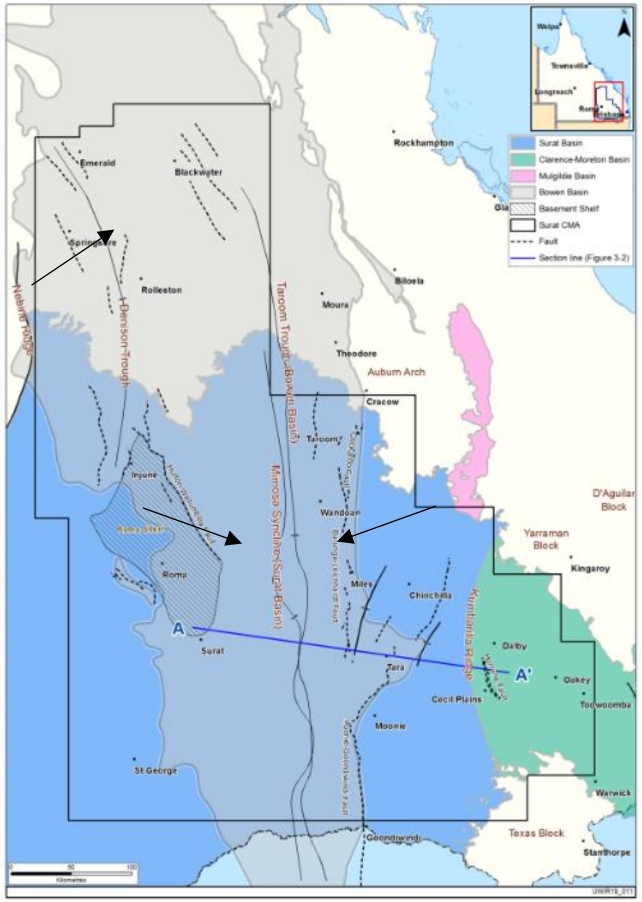
Case Study

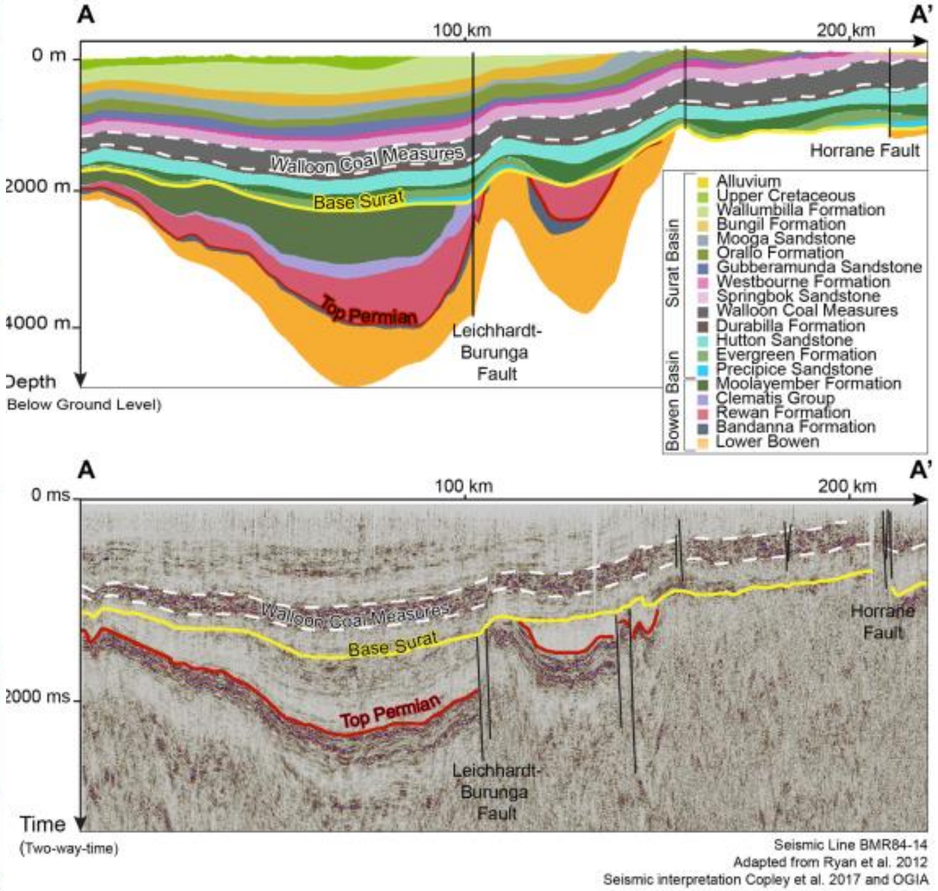
Surat Basin and southern Bowen Basin, Queensland, Australia

Geological Setting



https://aplng.com.au/wp-content/uploads/2022/03/2020-2021-Groundwater-Assessment-Report.pdf





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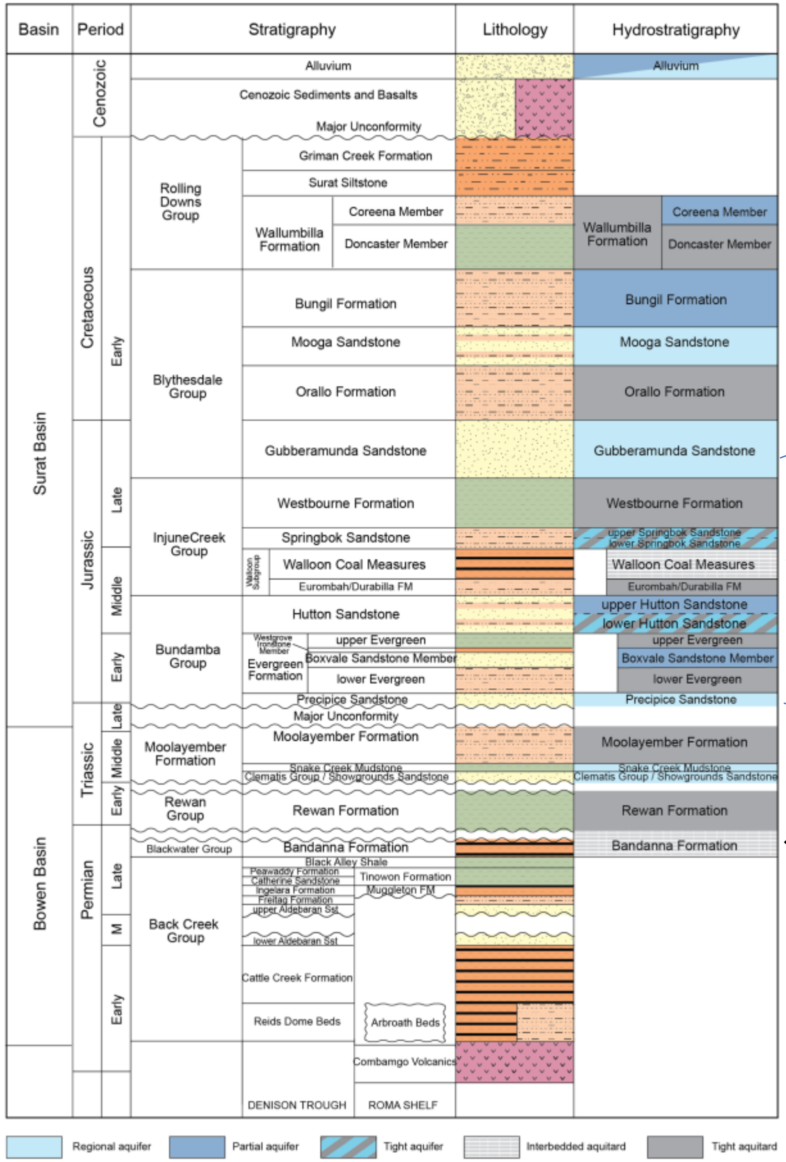
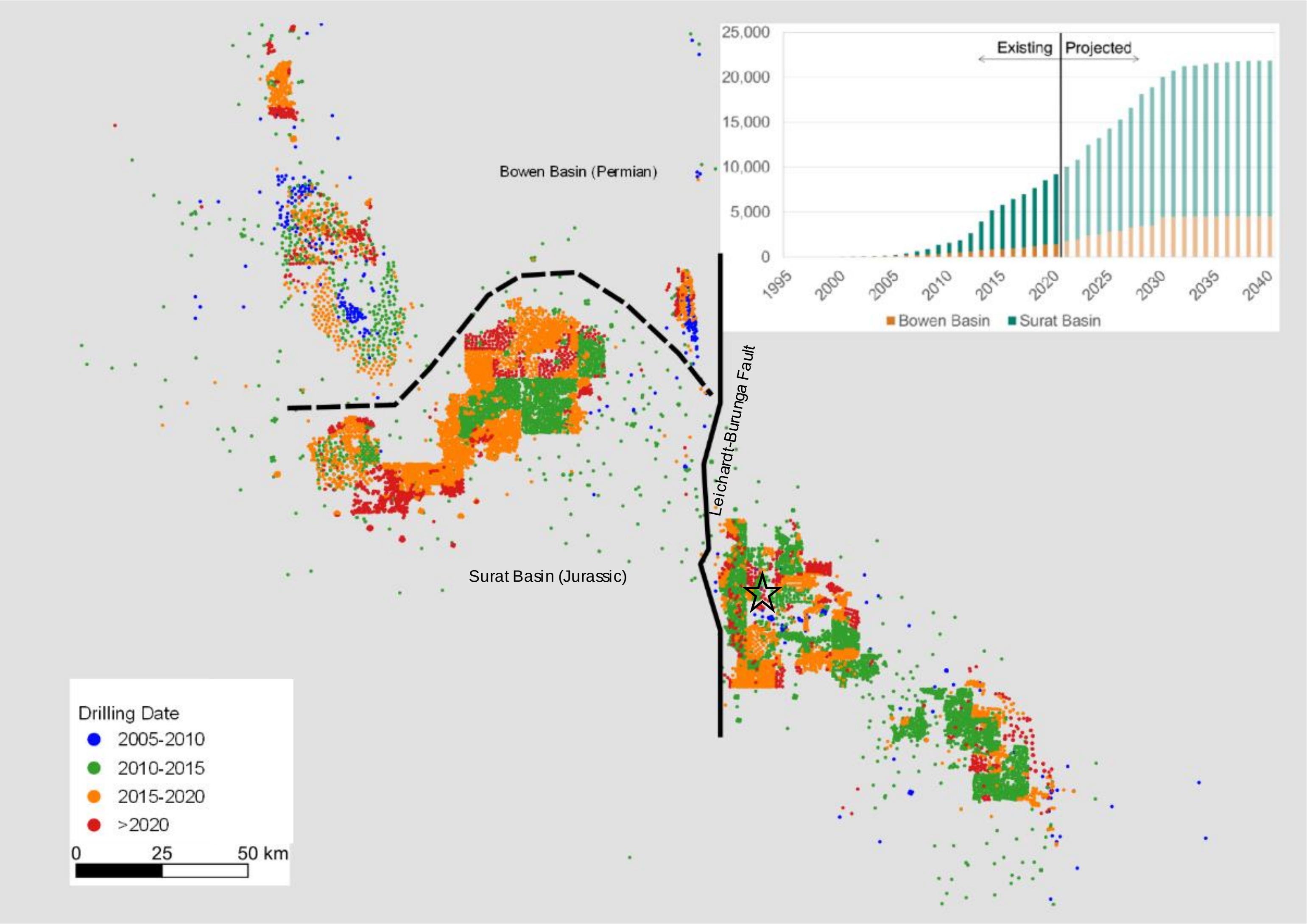
Hydrogeological setting



CBM Development



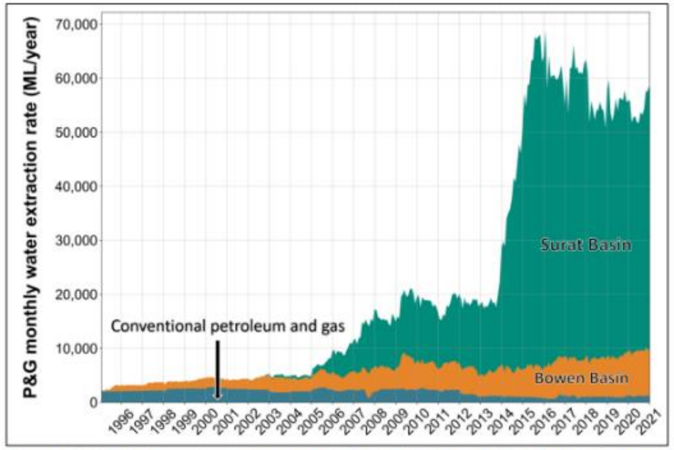


Figure 2-7: Historical associated water extraction by the P&G tenure holders in the Surat CMA

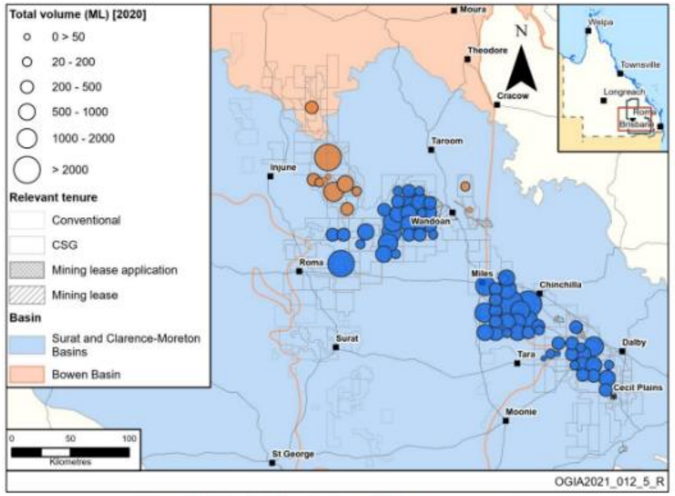


Figure 2-8: Spatial distribution of CSG water extraction

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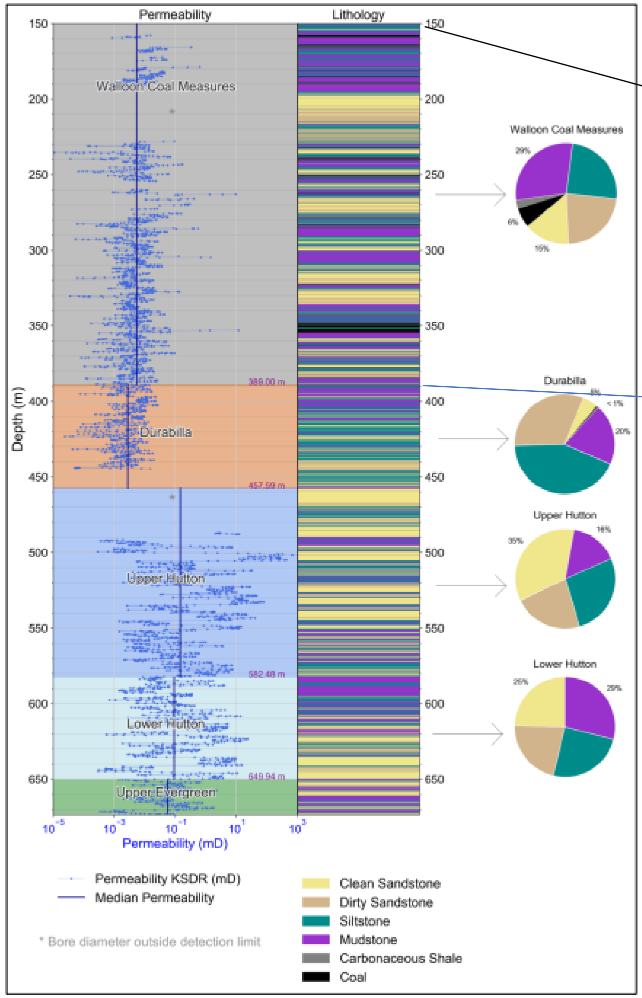
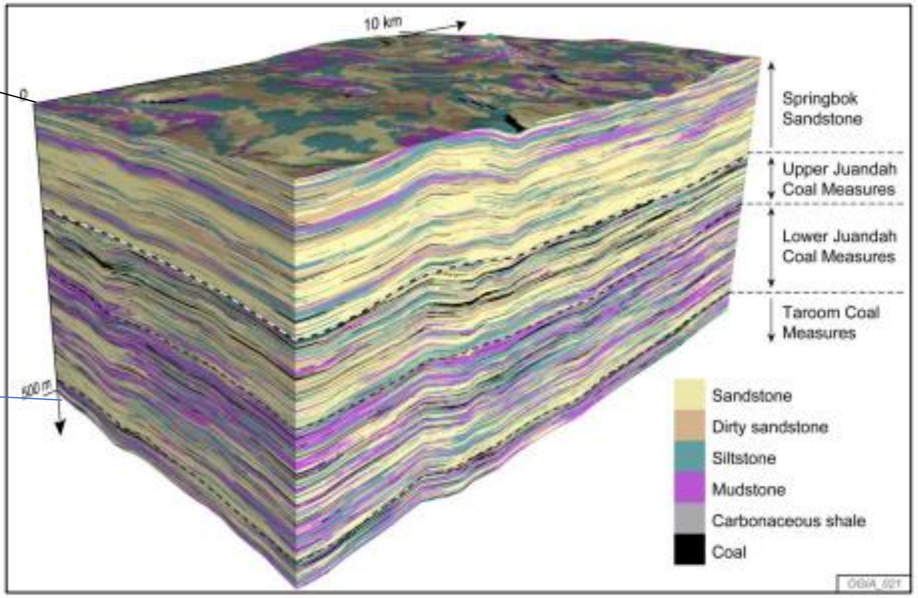
Lithology and permeability





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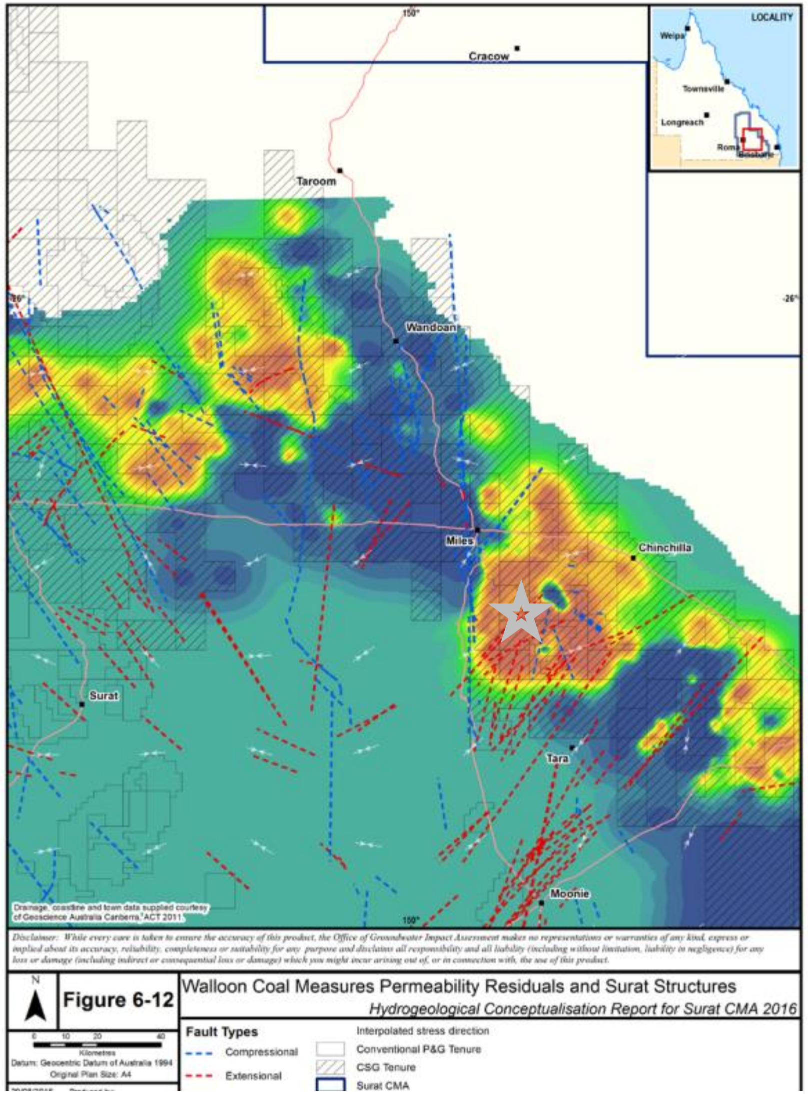

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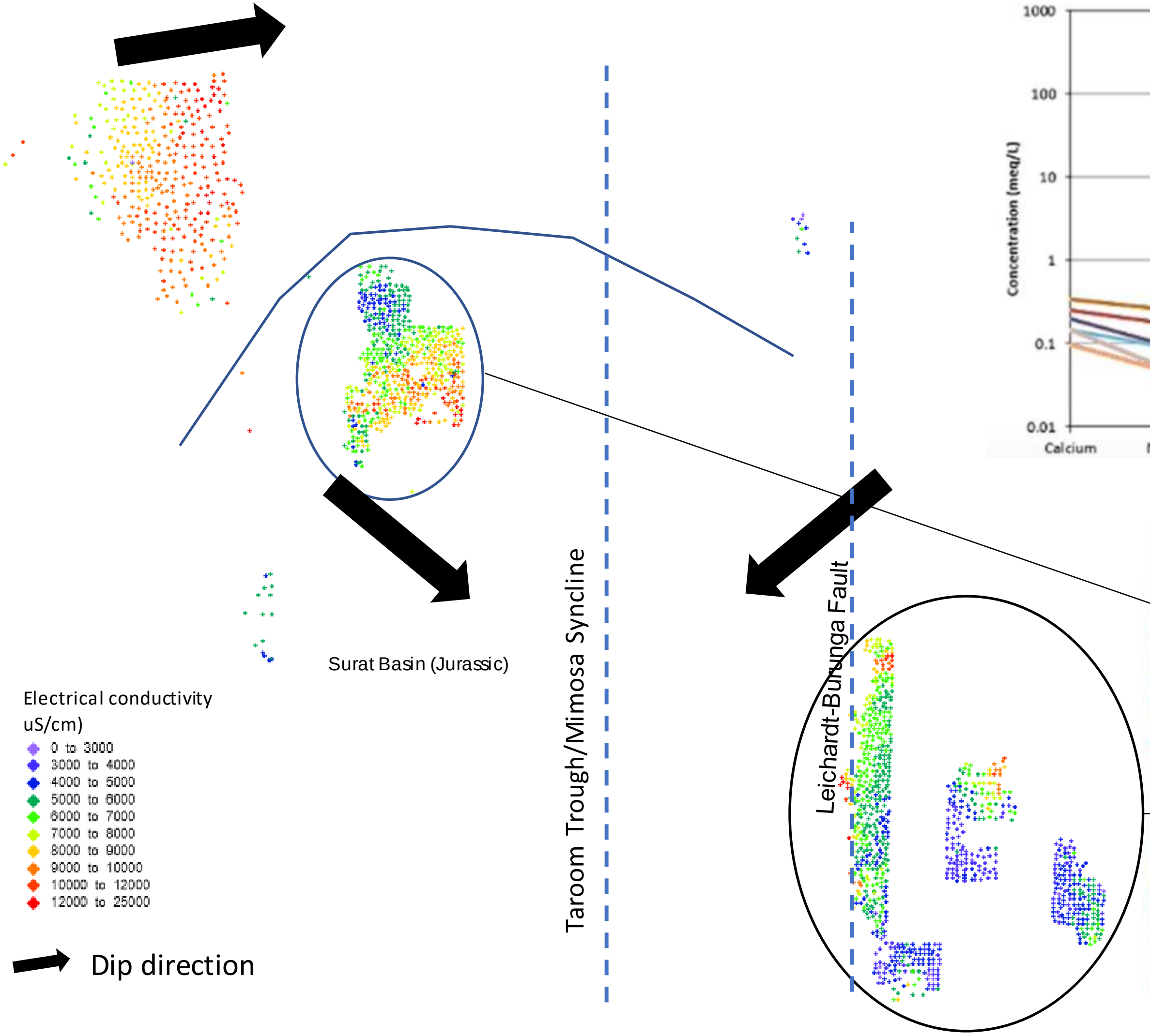
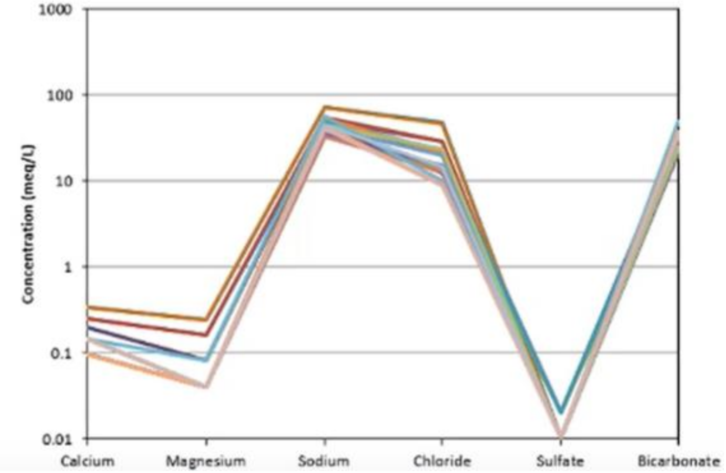
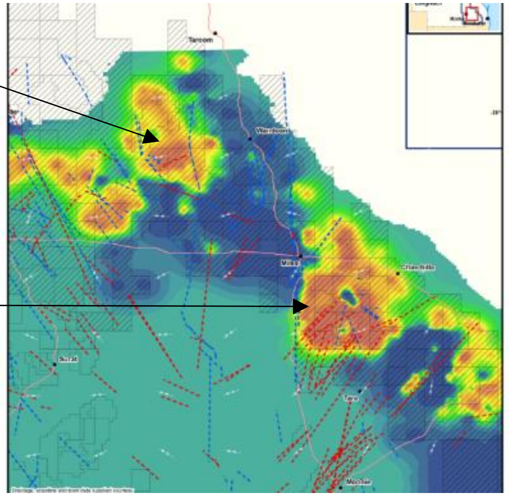
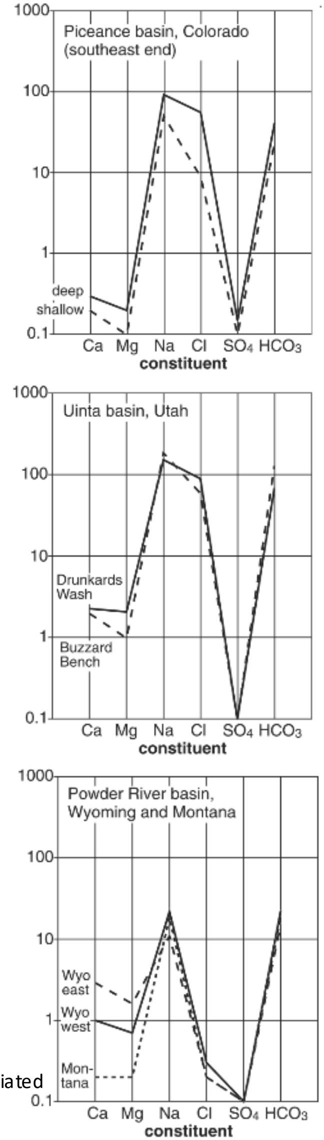
Water quality

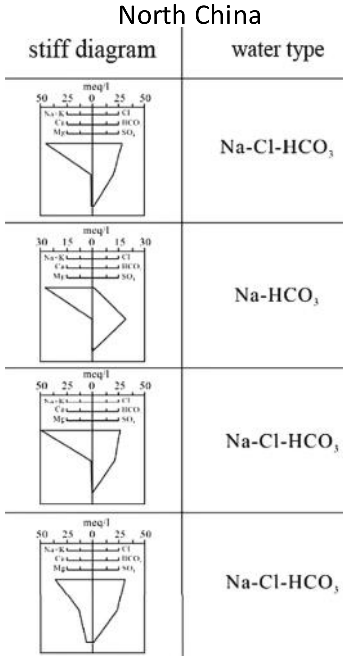








W. Van Voast (2003) Geochemical signature of formation waters associated with coalbed methane. AAPG Bulletin, v. 87, no. 4, pp. 667 – 676



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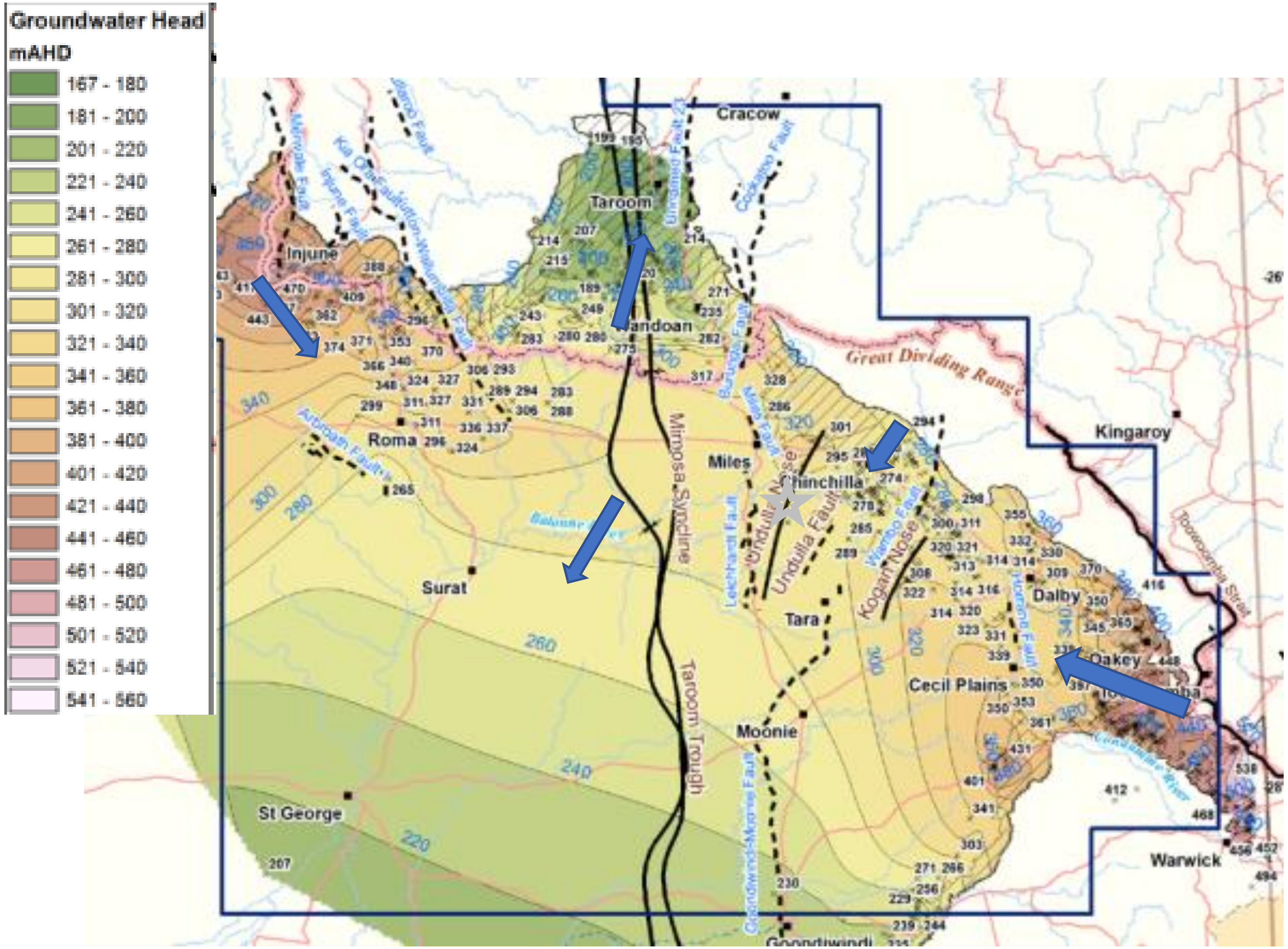
Groundwater flow



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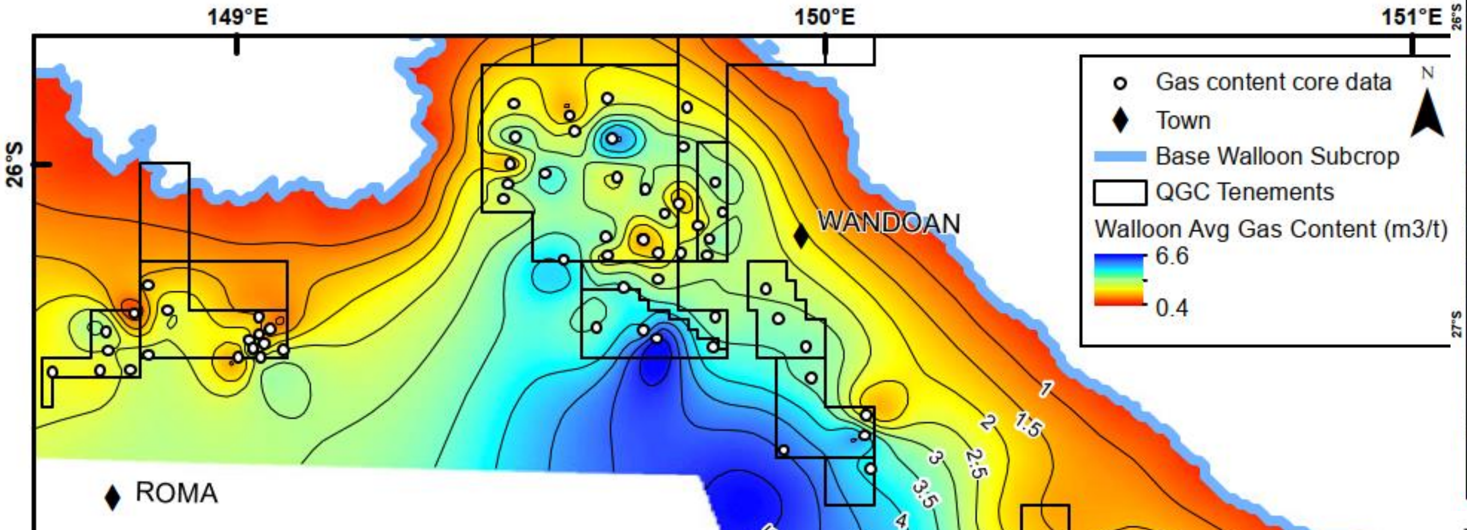
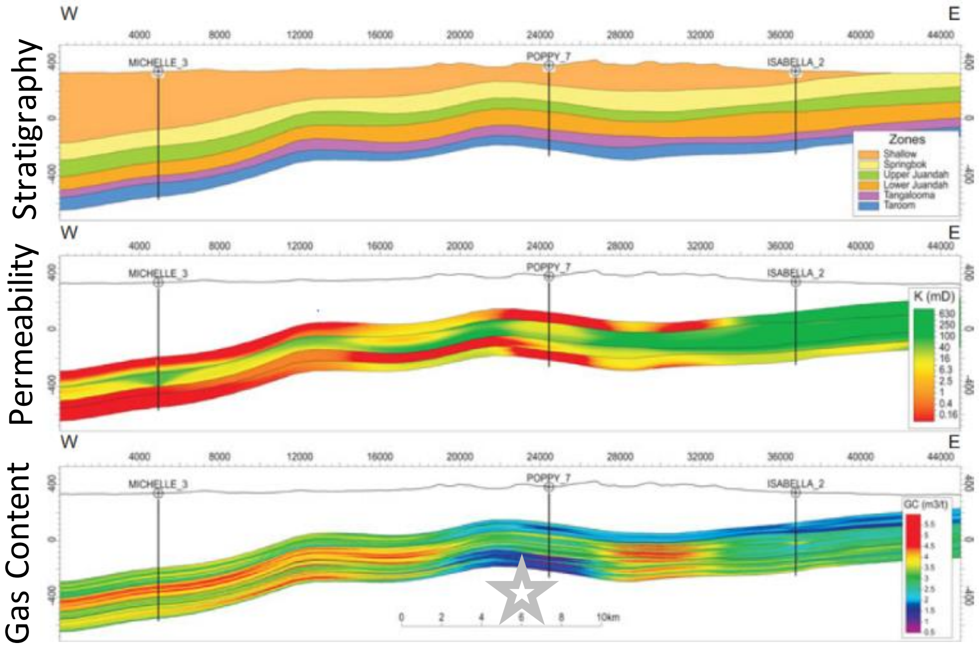
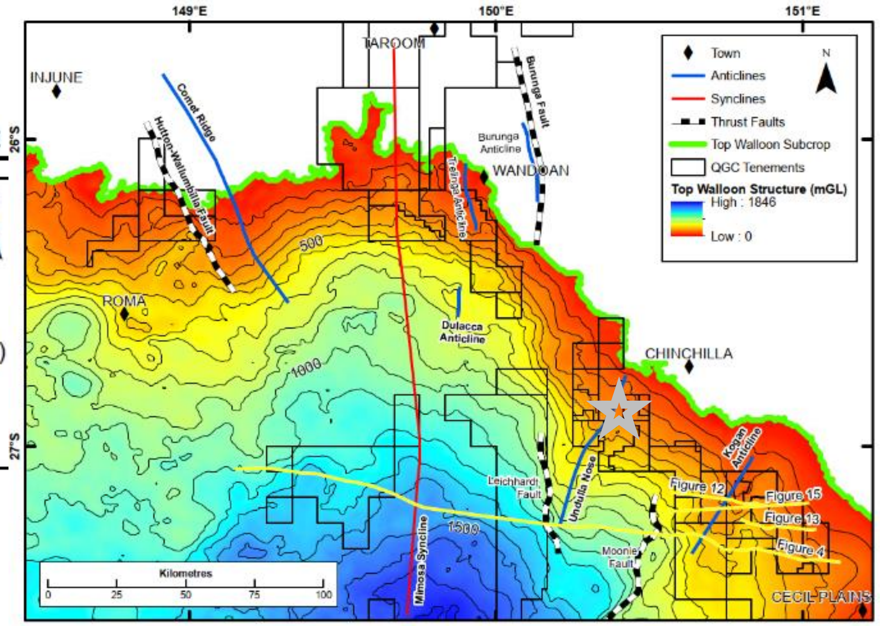
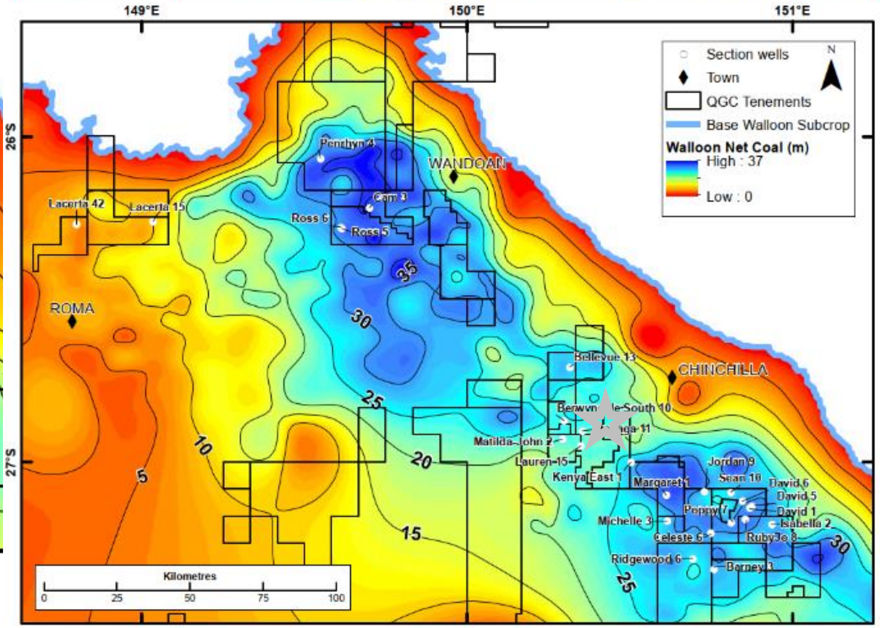
Gas Content



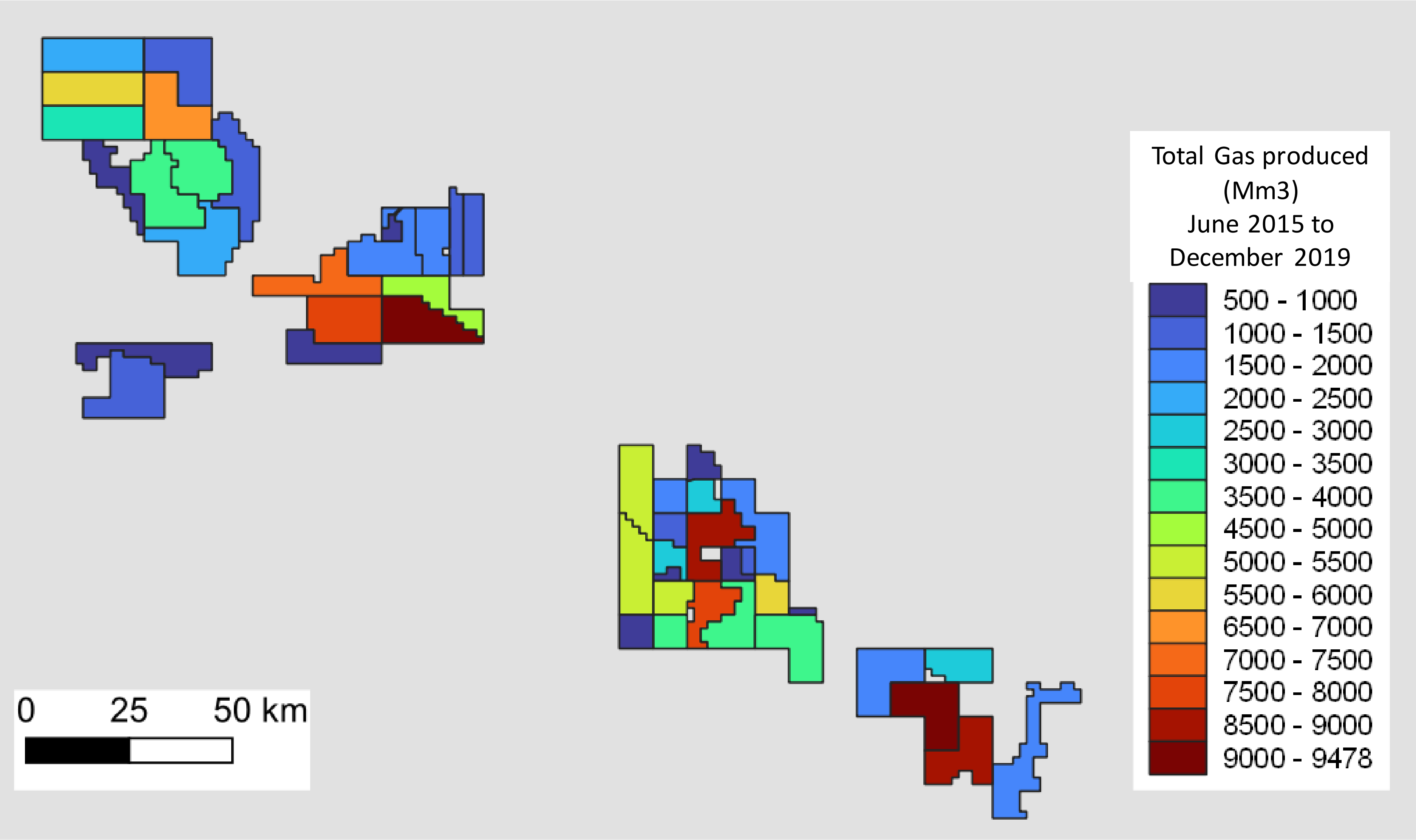






Ryan et al (2012) The Walloon Coal Seam Gas Play, Surat Basin, Queensland. APPEA Journal 2012

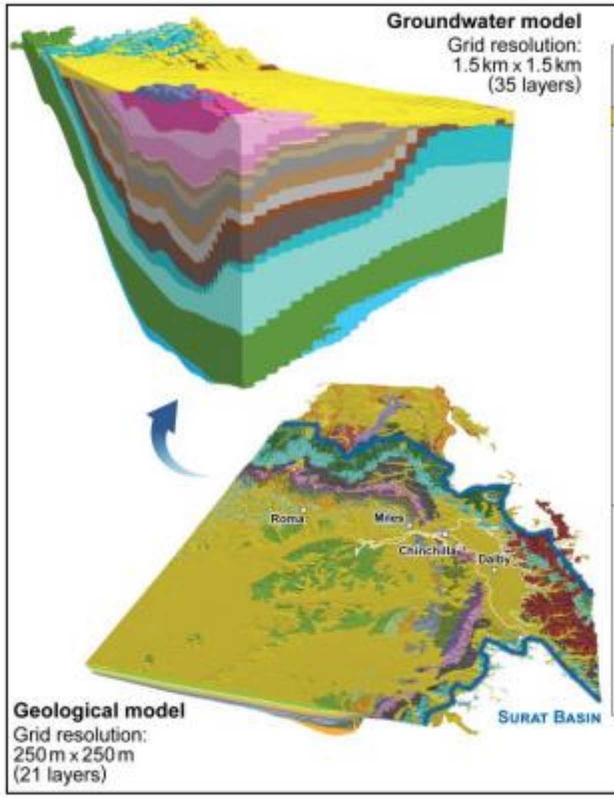
Gas production



Water Regulation

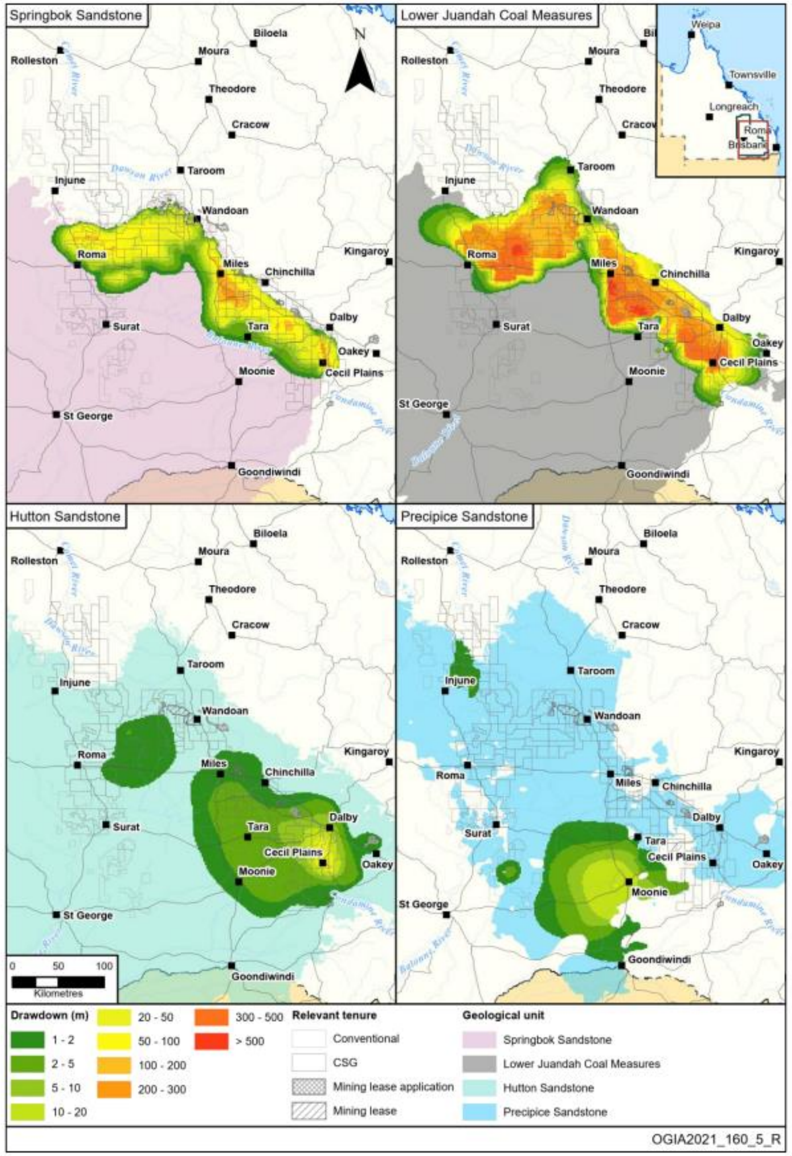
- Tenure holder right to extract water under the Queensland Petroleum and Gas Act (PaG)
- PaG imparts obligations under the Queensland Water Act
  - Underground Water Impact Assessment (UWIR)
  - Baseline assessment of water bores
  - Make good of water bores
- Where multiple tenure holders within a defined area, a Cumulative Management Area (CMA) is declared
- An “independent” government agency is responsible for the preparation of the UWIR
- The agency is funded by an industry levy

Groundwater modelling

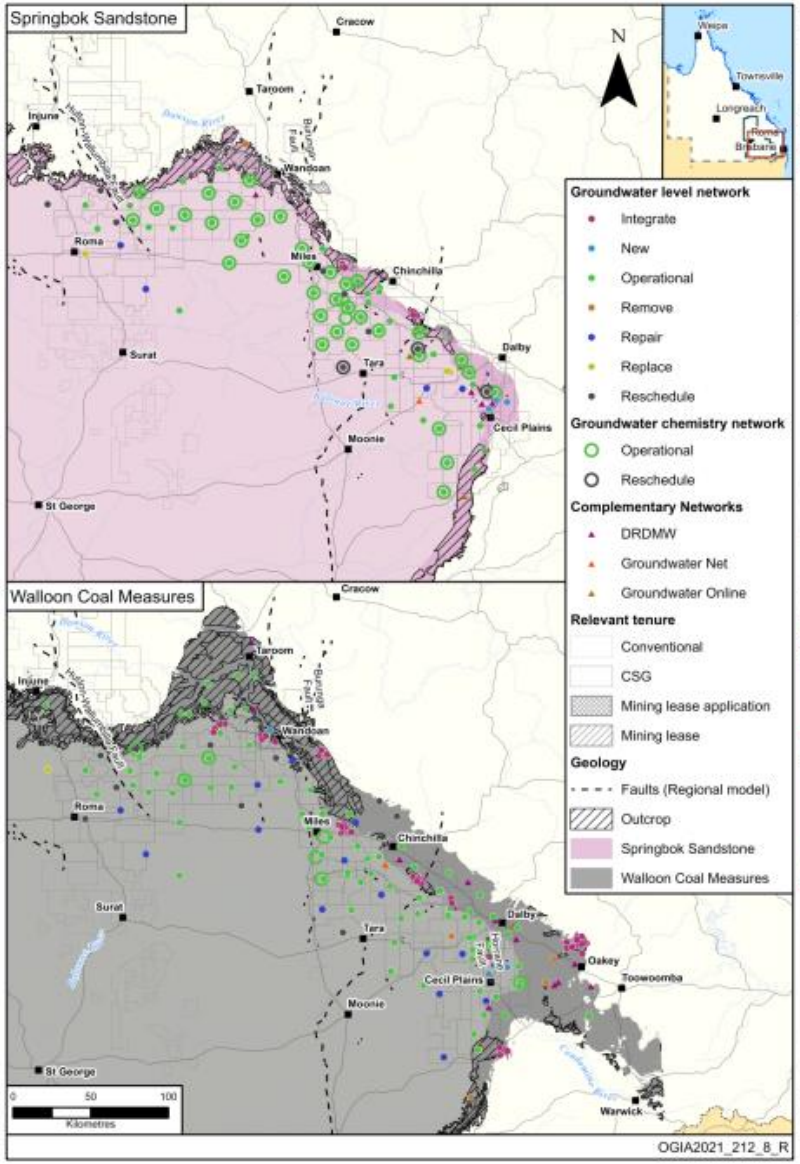


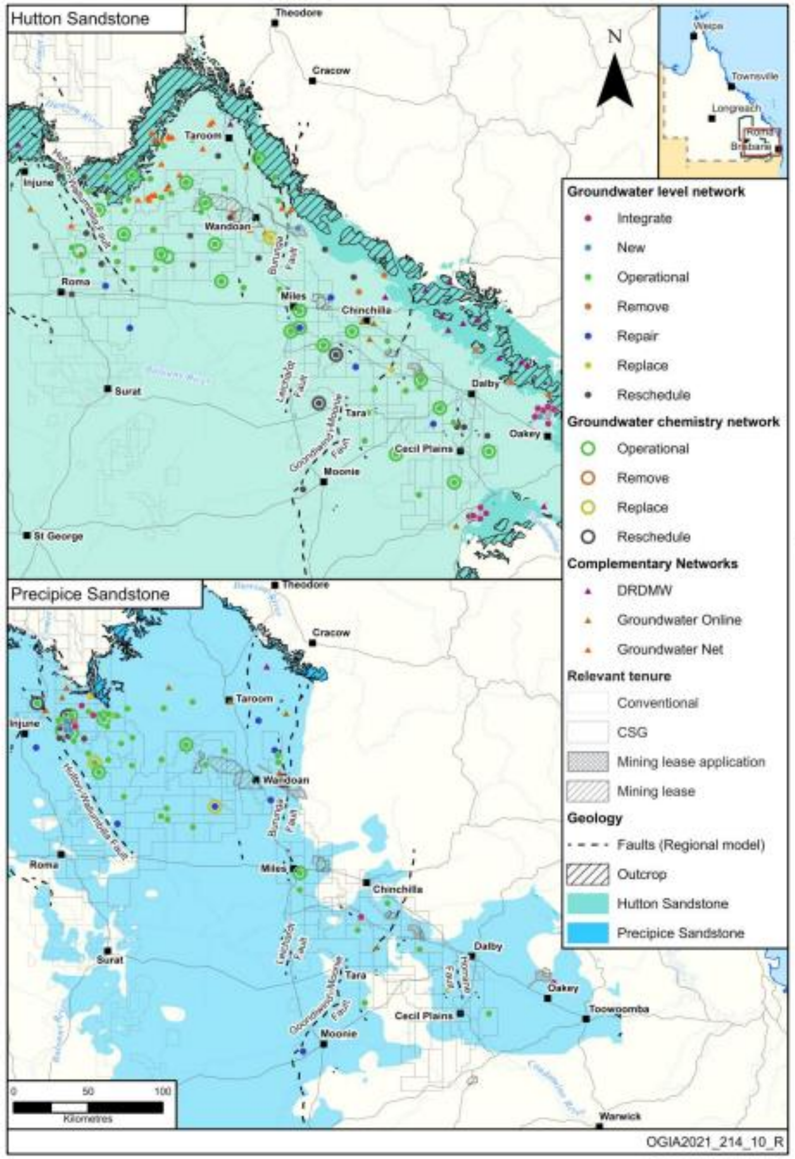
Basin	Hydrostratigraphic units: Geological model	Hydrostratigraphic units: Groundwater model	Model layer: Geo*	Model layer: GW*
	Cenozoic - Alluvium and Volcanics		1	1
Surat & Clarence-Moreton basins	Upper Cretaceous		2	2
	Wallumbilla Formation		3	3
	Bungil Formation		4	4
	Mooga Sandstone		5	5
	Orallo Formation		6	6
	Gubberamunda Sandstone		7	7
	Westbourne Formation		8	8
	Springbok Sandstone	Upper Springbok Sandstone	9	9
		Lower Springbok Sandstone		10
	Walloon Coal Measures	Non-productive zone	10	11
		Upper Juandah Coal Measures		12-13
		Lower Juandah Coal Measures		14-16
		Taroom Coal Measures		17
	Durabilla Formation		11	18
	Hutton Sandstone	Upper Hutton Sandstone	12	19
		Lower Hutton Sandstone		20
	Upper Evergreen Formation		13	21
	Boxvale Sandstone		14	22
	Lower Evergreen Formation		15	23
	Precipice Sandstone		16	24
Bowen Basin	Moolayember Formation		17	25
	Clematis Sandstone		18	26
	Rewan Group		19	27
	Bandanna Formation	Non-productive zone	20	28
		Upper Bandanna Formation		29
		Lower Bandanna Formation		30
	Bowen Basin	Undivided upper Bowen Basin	21	31
		Non-productive zone		32
		Upper Cattle Creek Formation		33
		Lower Cattle Creek Formation		34
		Undivided lower Bowen Basin		35

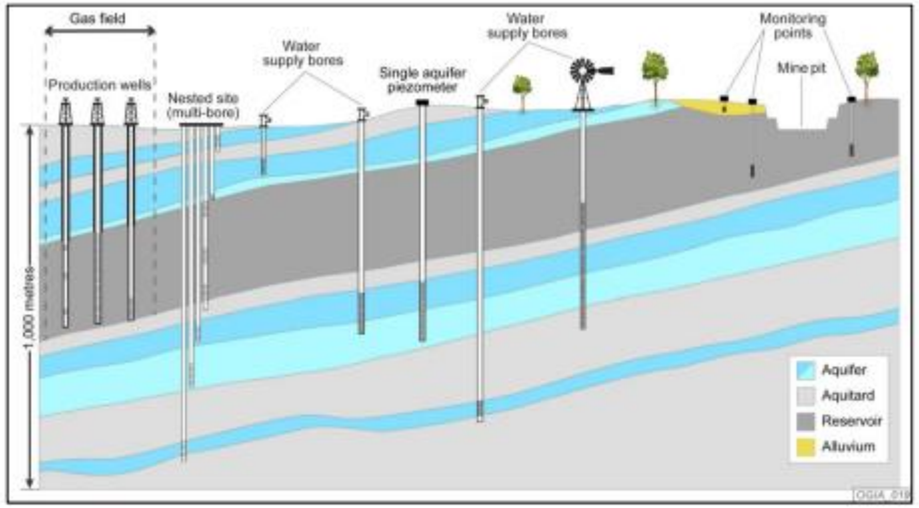
*Geo: Geological model *GW: Groundwater model

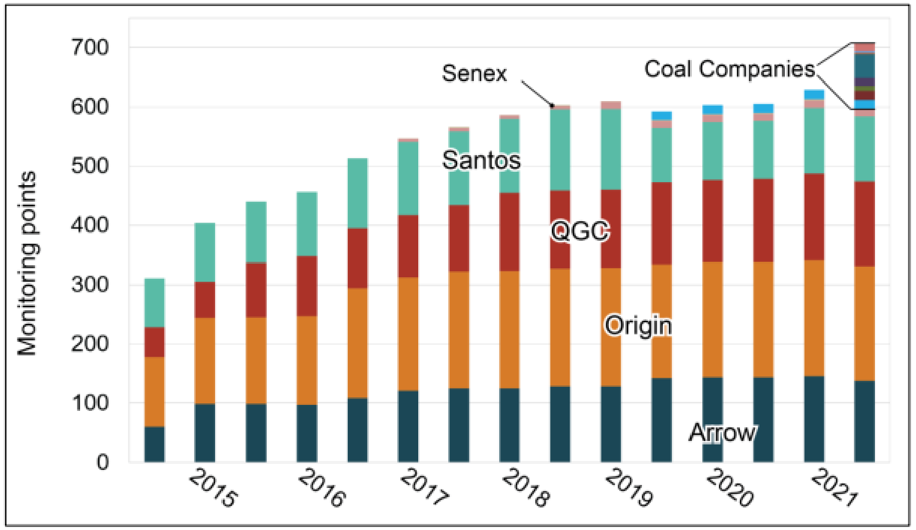


Groundwater Monitoring





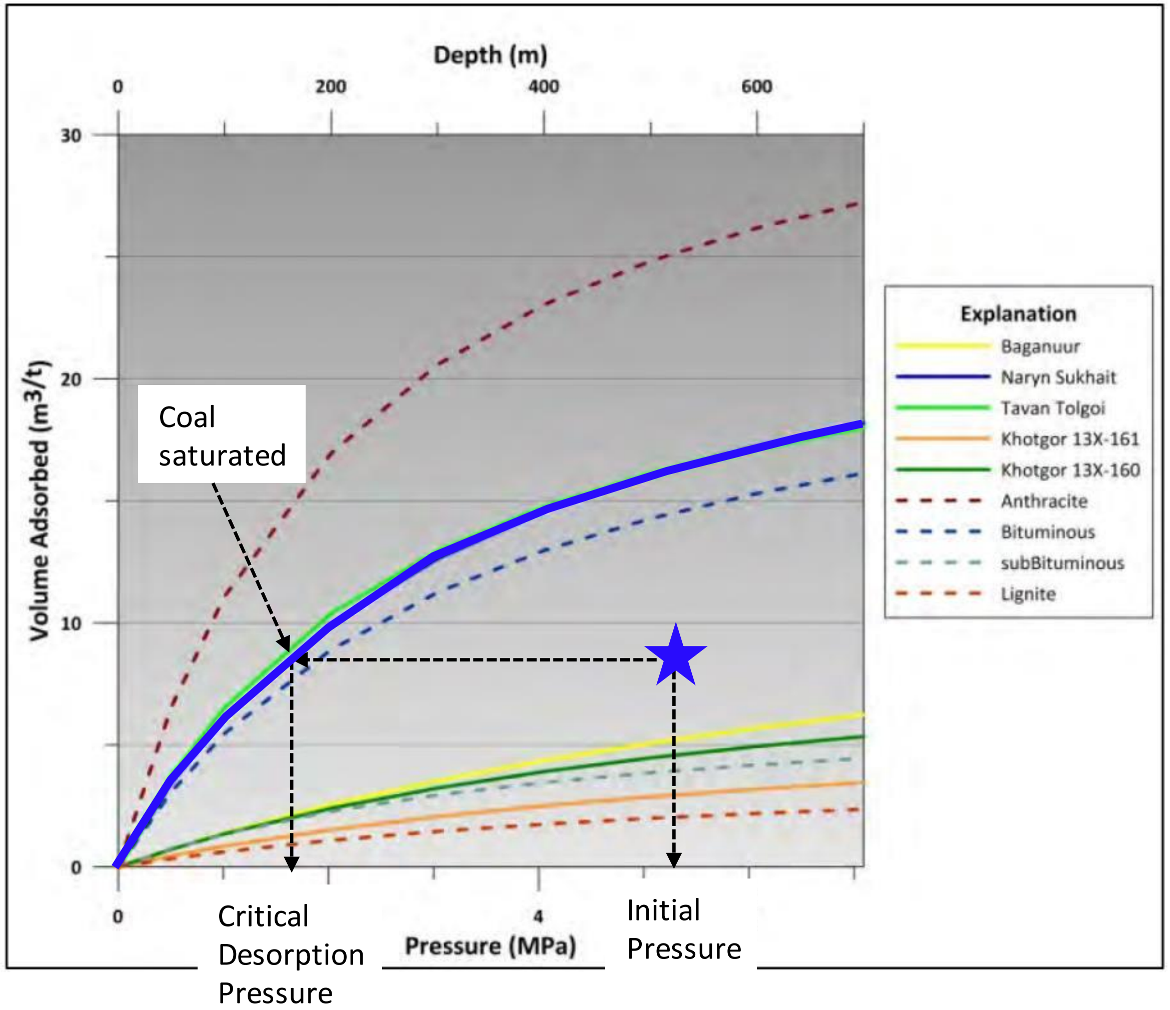




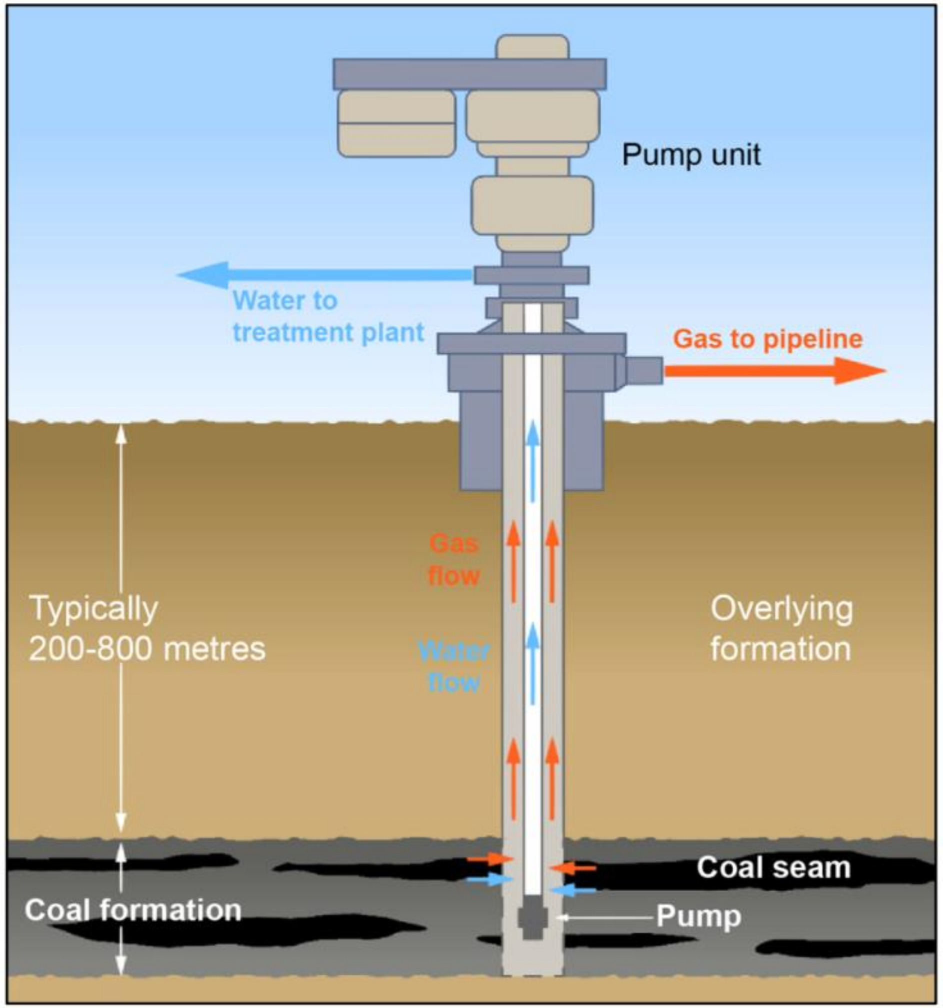
Water production and management

Why water production?

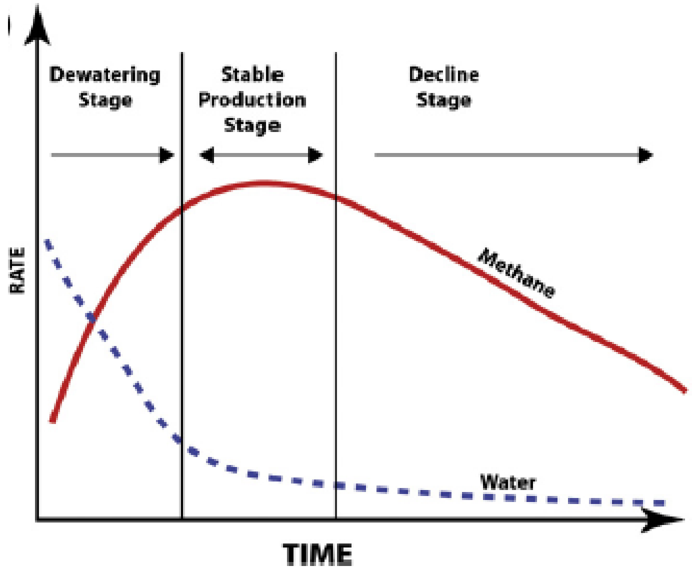
- Most coals are unsaturated
- To allow gas flow the reservoir pressure must be reduced to saturate the coal
- Pressure reduction is achieved by pumping groundwater
- Most CBM reservoirs require depressurisation to produce gas
- Volumes of produced water primarily related to permeability

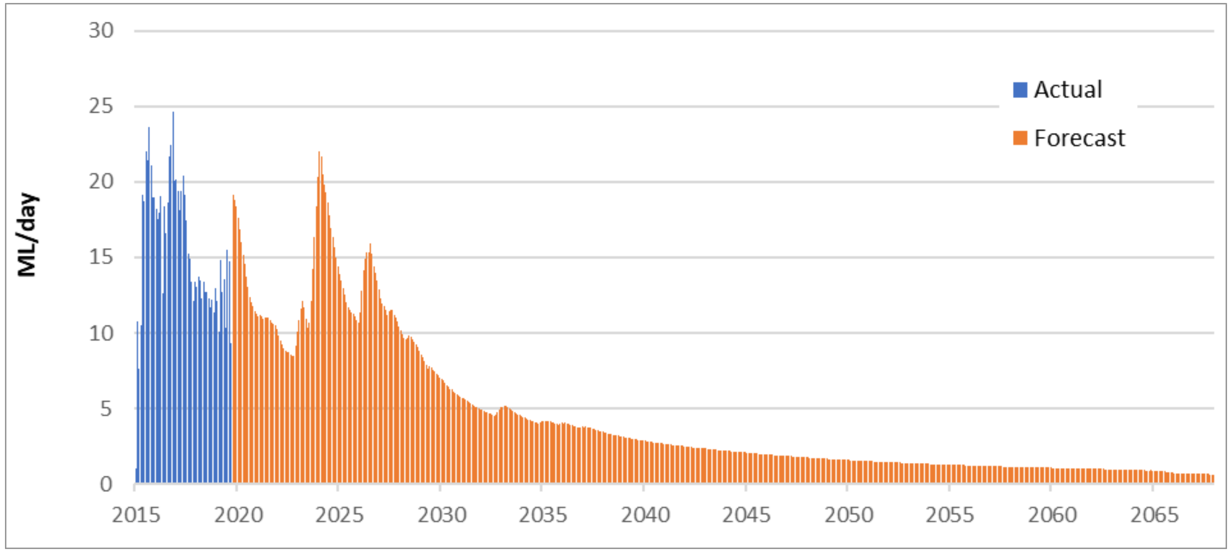


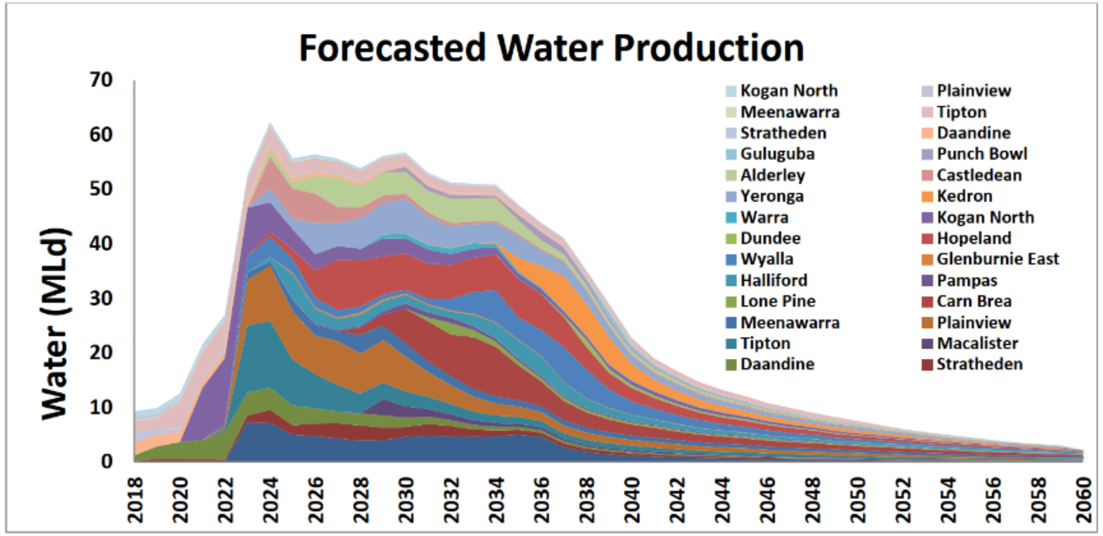
CBM pumps and wellheads

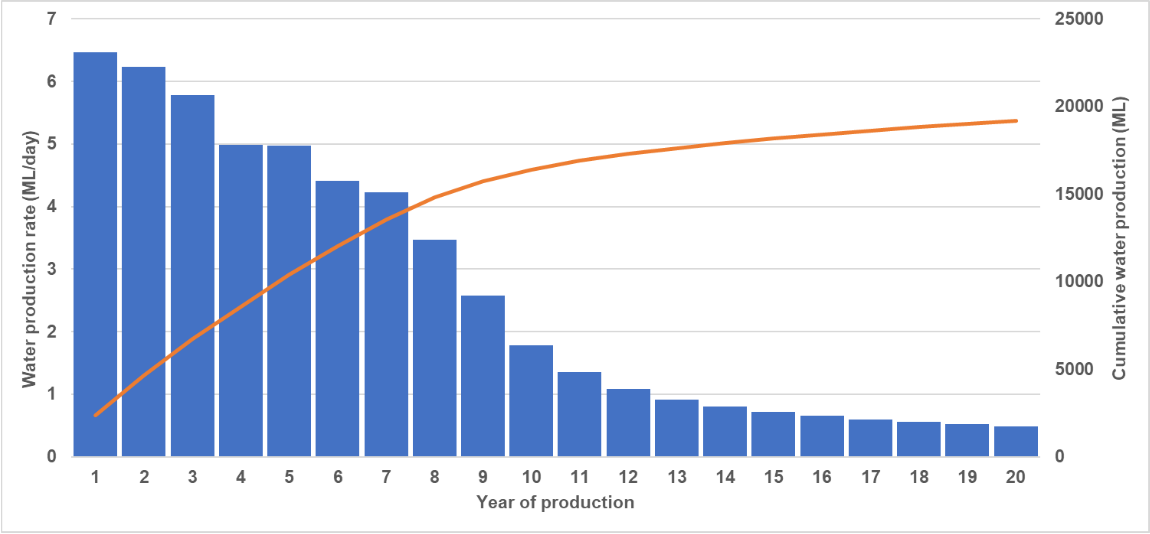


Water production forecasts

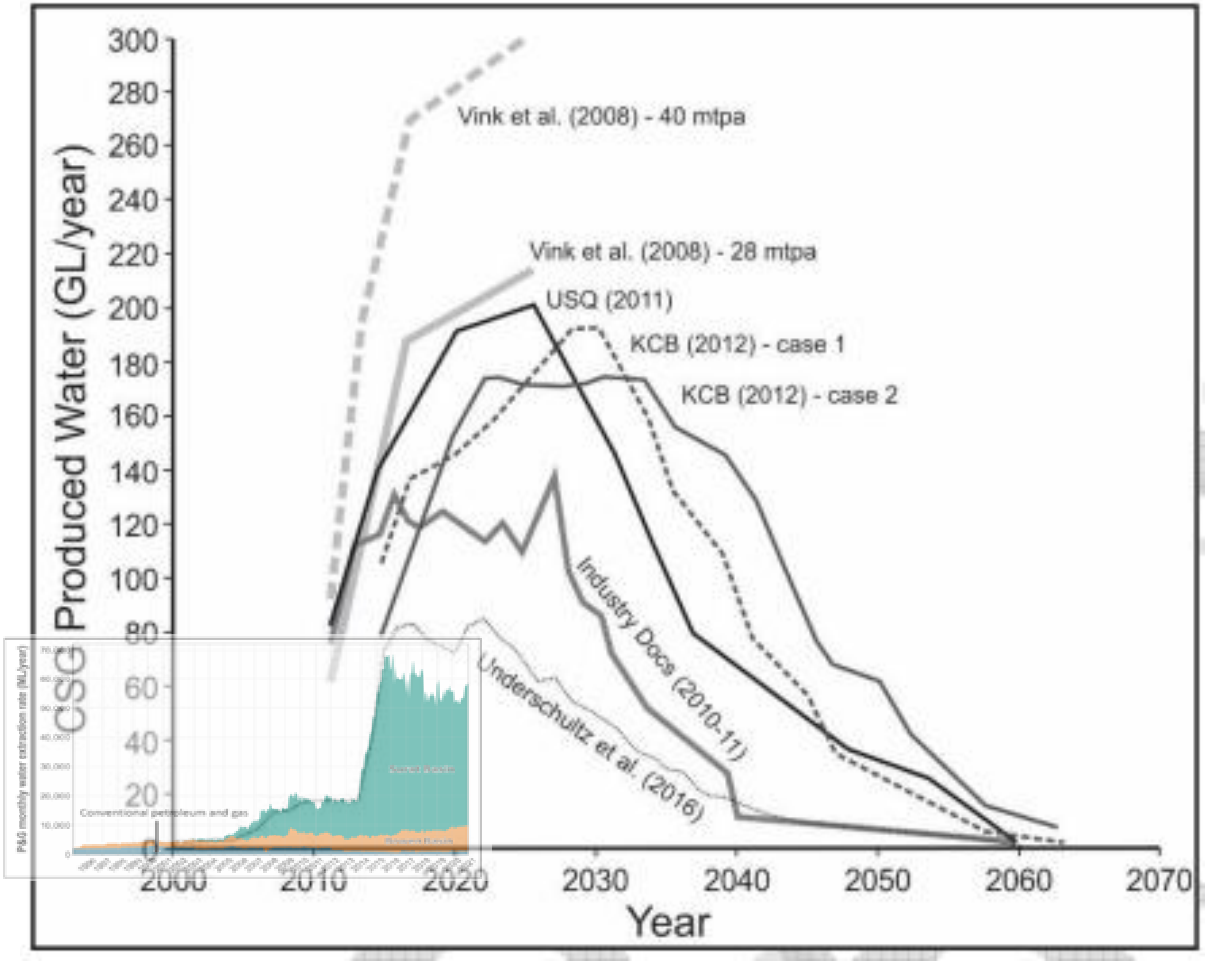








Comparison of actual vs forecast



After J.R. Underschultz, S. Vink, A. Garnett (2018) Coal seam gas associated water production in Queensland: Actual vs predicted. Journal of Natural Gas Science and Engineering

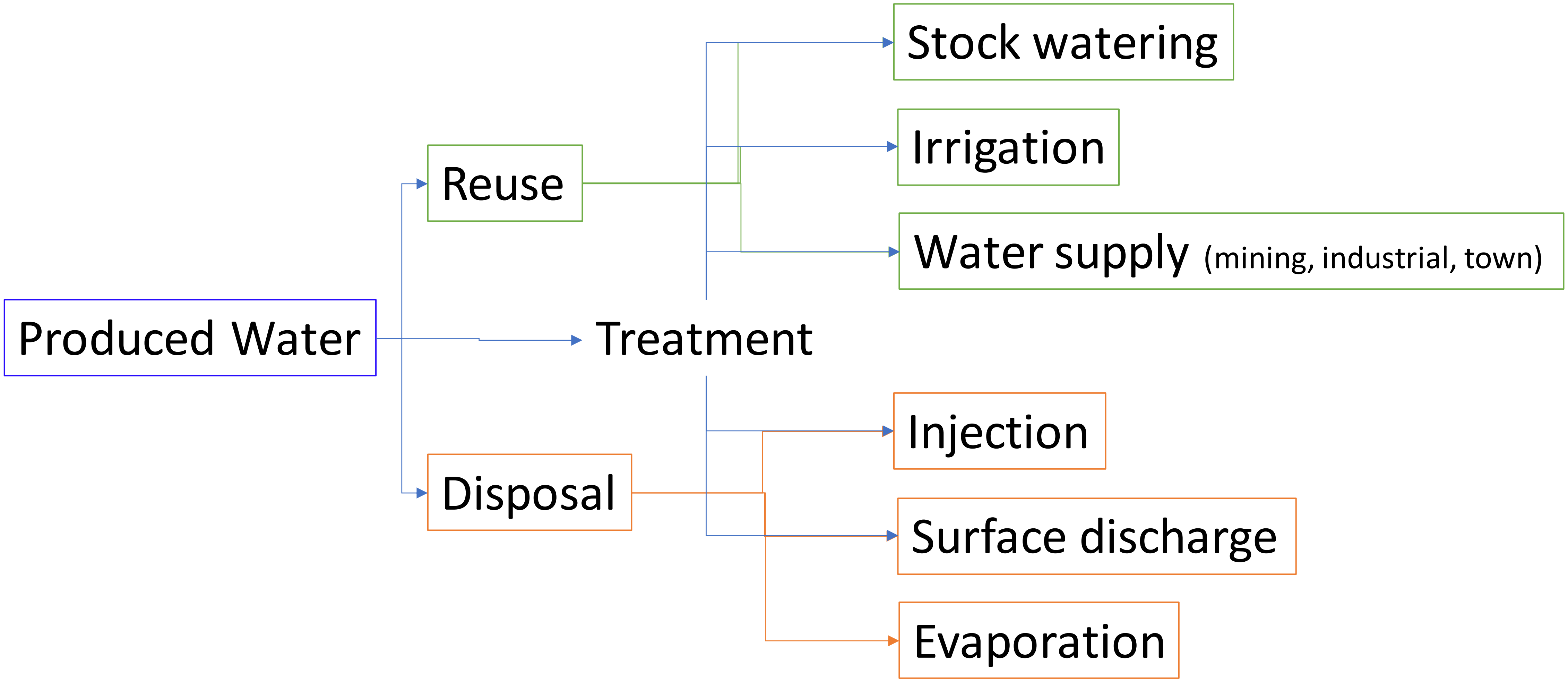
Management option drivers

- Water quality (primarily salinity)
- Volumes
- Ecosystem impacts
- Regulations
- Community acceptance
- Cost

Irrigation with untreated water from a CSG production pilot

http://galilee-energy.com.au/wp/wp-content/uploads/2022/01/20212210_Annual_Report2021.pdf

Water management options



Cost

Cost

- Discharge with no treatment
- Evaporation in constructed ponds
- Injection with no treatment
- Reuse with no treatment
- Discharge with treatment
- Treatment and reuse (e.g irrigation)
- Injection with treatment

Social/environmental acceptability

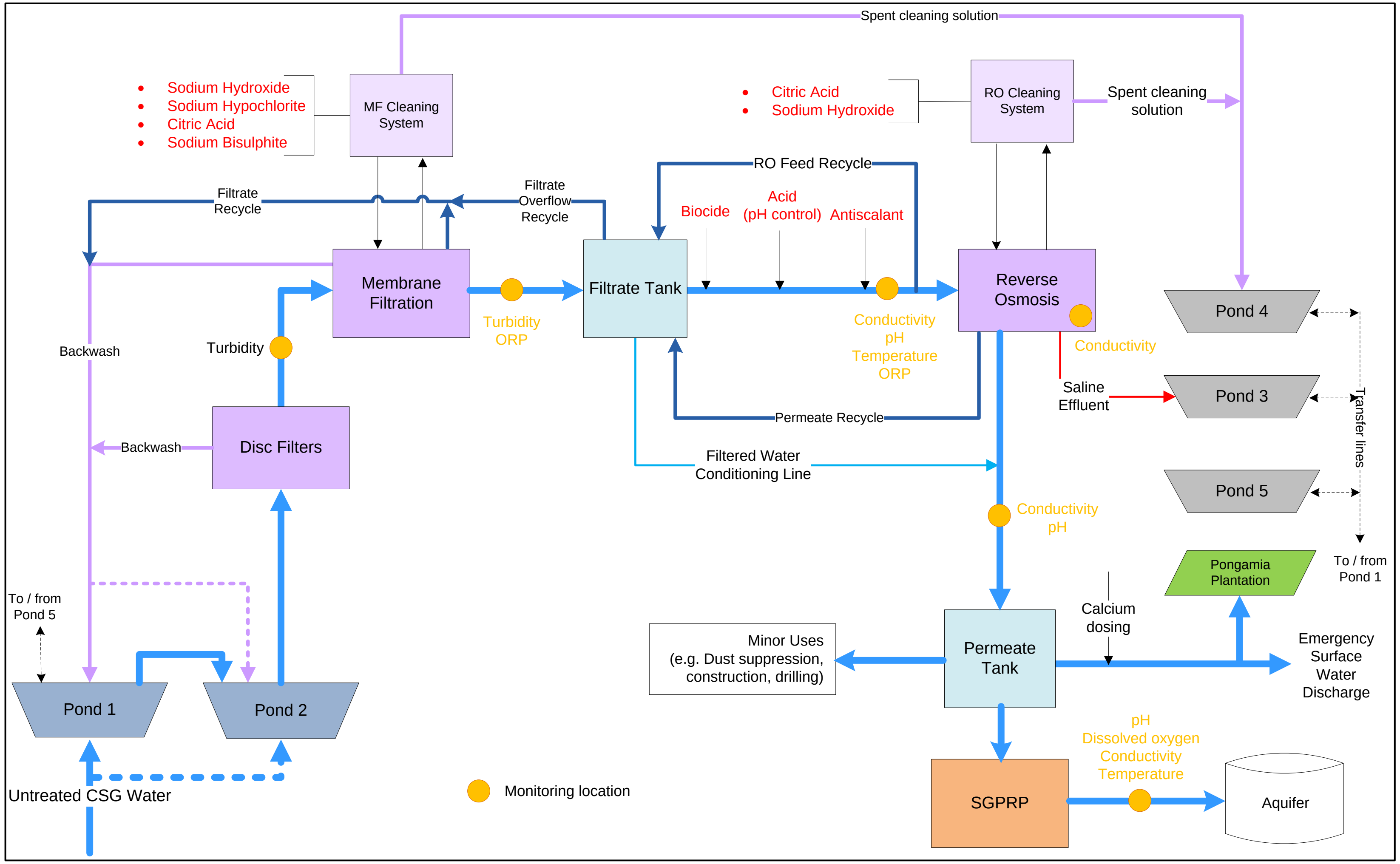
Water management costs

Water Disposal and Management Option	Economically Recoverable CBM(Bcf)	Reduced CBM Recovery Compared to Using Surface Discharge(Bcf)	%
1. Surface Discharge	17,070	-	**0**
2. Impoundments	15,680	1,390	**9**
3. Shallow Reinjection	14,910	2,160	**13**
4. Partial RO Treatment (w/Trucking of Residual)			
$ @ 500 mg/l TDS Discharge Limit	12,460	4,610	**27**
$ @ 1,000 mg/l TDS Discharge Limit	14,960	2,110	**12**
5. Ion Exchange			
$ @ 500 mg/l TDS Discharge Limit	14,090	2,980	**17.5**
$ @ 1,000 mg/l TDS Discharge Limit	15,940	1,130	**7**

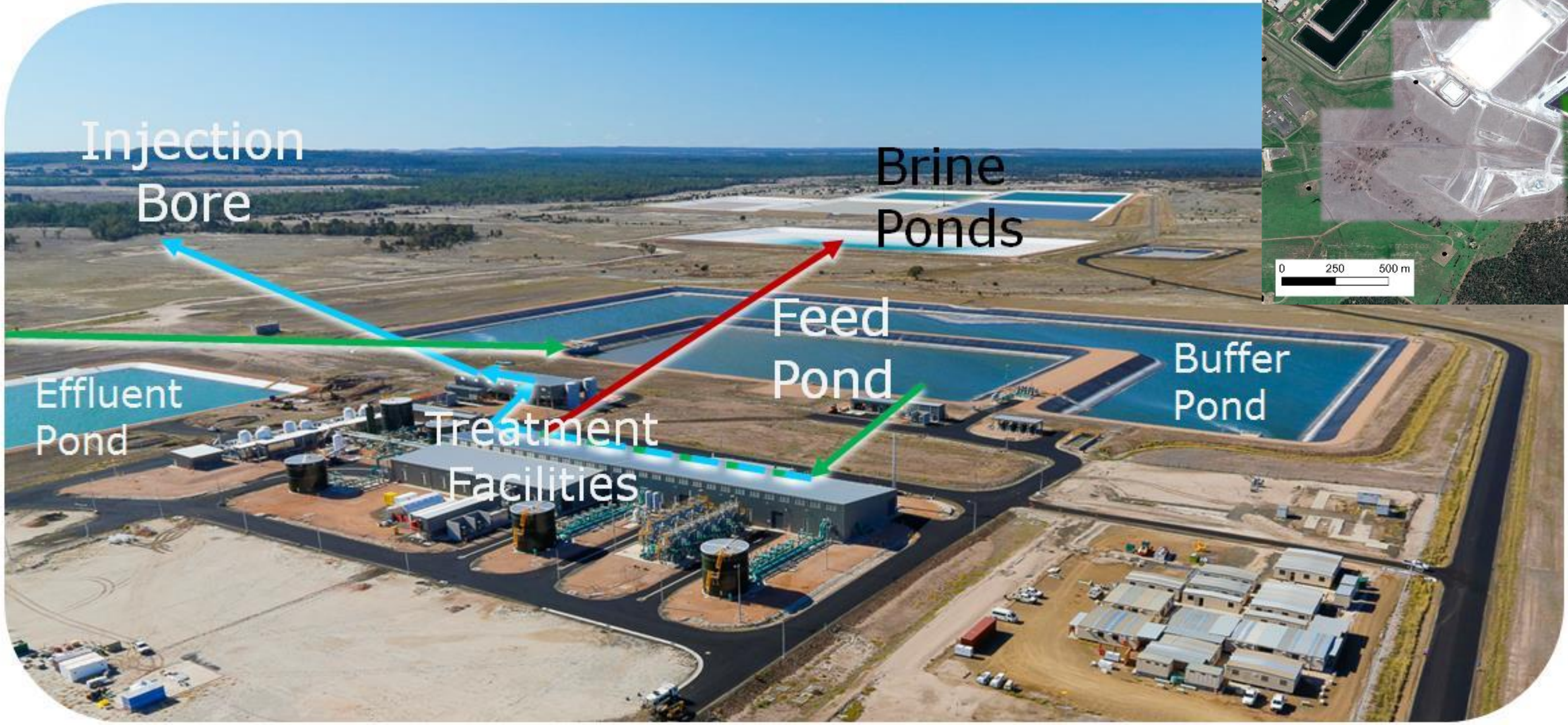
*The above volume of economically recoverable CBM in the Powder River Basin is in addition to the approximately 1,530 Bcf of CBM produced and 2,360 Bcf proven through 2004.

After: Advanced Resources International (2006) The Economics of Powder River Basin Coalbed Methane Development
http://adv-res.com/pdf/The%20Economics%20of%20Powder%20River%20Basin%20Coalbed%20Methane%20Development.pdf

Water treatment and management process flow diagram



Water treatment plant



Raw CSG
Treated CSG
RO Reject (brine)

Surface discharge

Photo courtesy of T. Moore

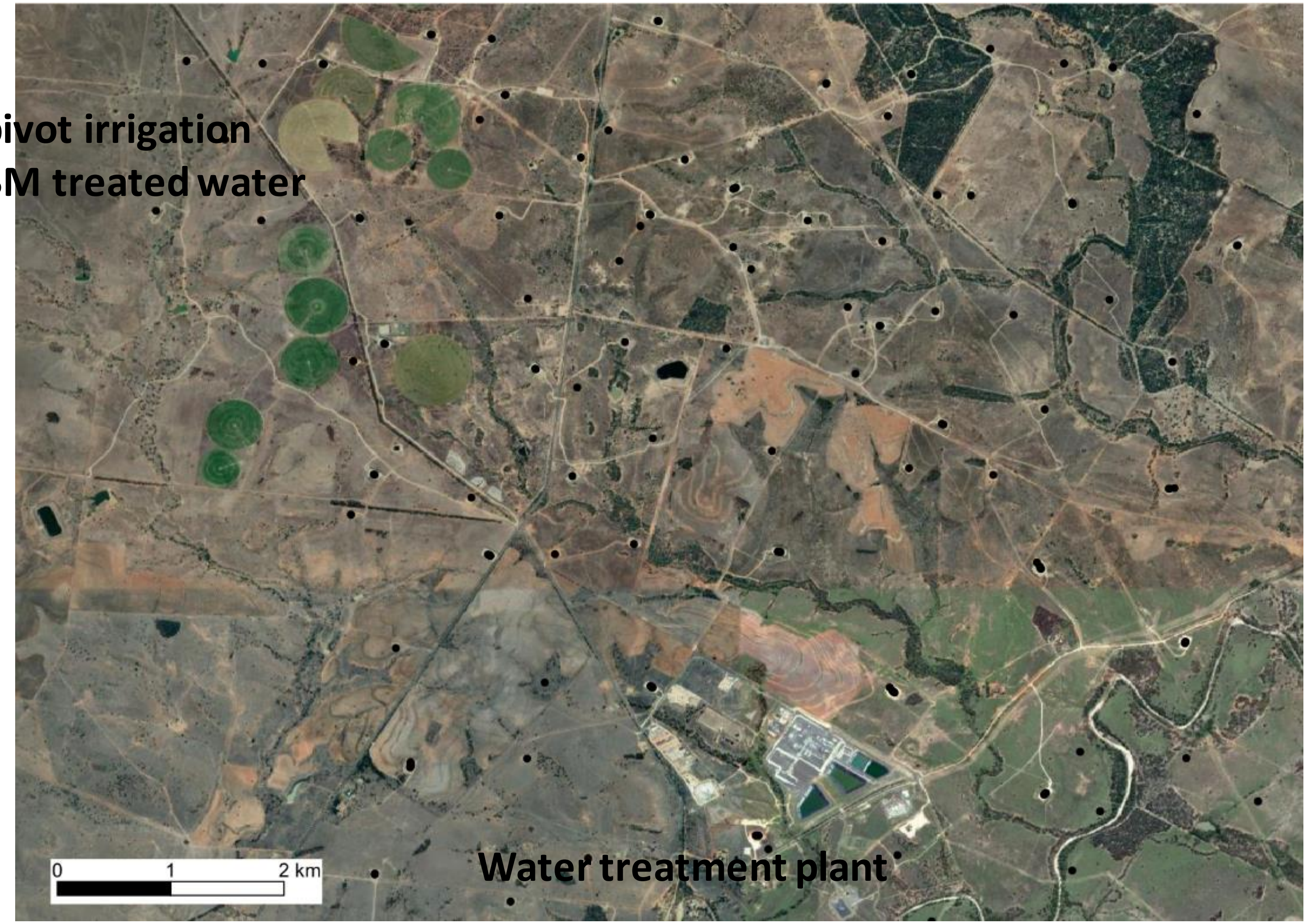
Livestock watering

- Water quality must be suitable
- Produced water volumes often too large

Photo courtesy of T. Moore

Irrigation

Centre pivot irrigation
using CBM treated water

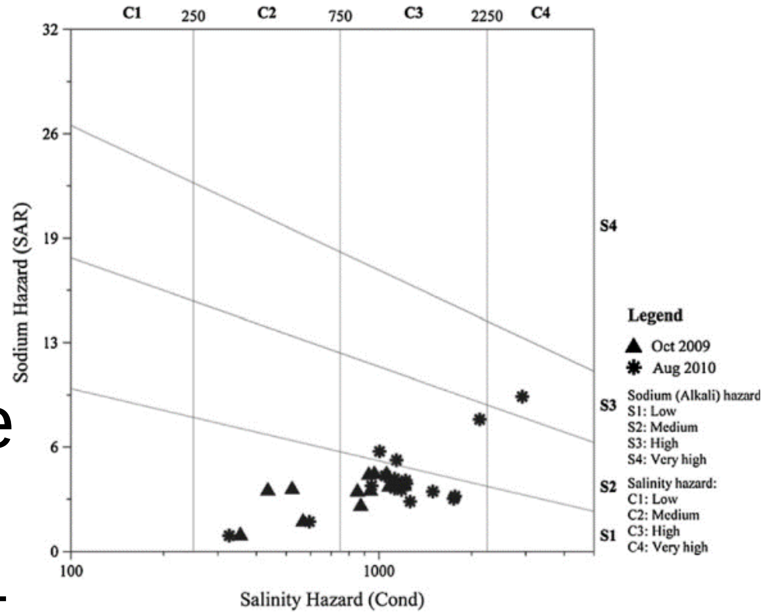


Centre pivot irrigation of sorghum
using CBM water (untreated)

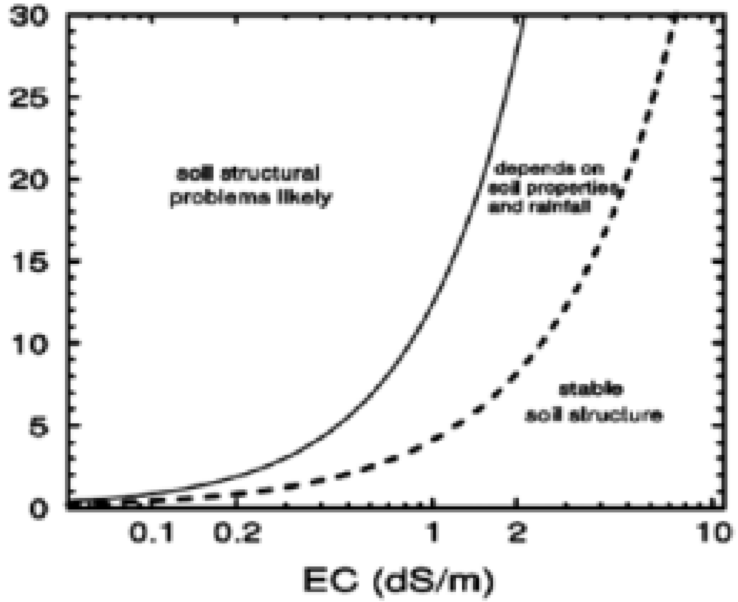
Irrigation water quality

- CBM waters usually have naturally high SAR
- Treatment through reverse osmosis will increase SAR
- Soil suitability must be assessed
- Chemical amendment of water may be required

$$\mathrm{SAR} = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$



Battogtokh et al (2012) Environmental reconnaissance of the Shivee-Ovoo coalmine area, Mongolia Environ Earth Sci (2012) 67:1927–1938



Raine and Bennett: The soil specific nature of threshold electrolyte concentration analysis. https://eprints.usq.edu.au/22151/9/Bennett_Raine_SSA2012_PV.pdf

Injection Target Wishlist

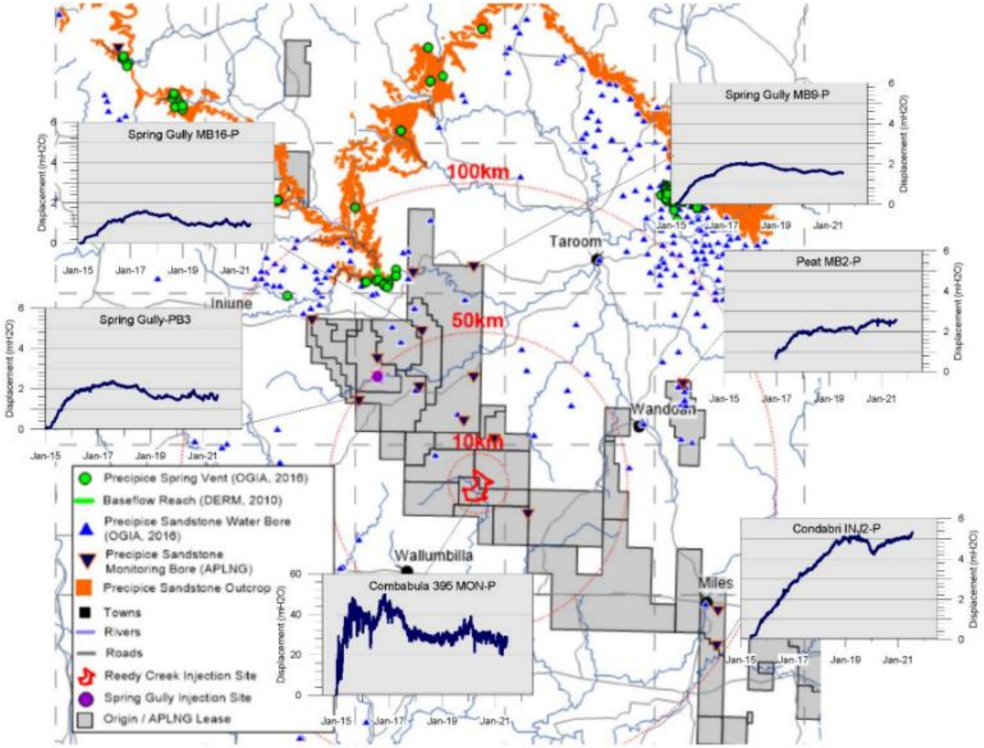
- Target aquifer confined by aquitards above and below
- Regionally extensive aquifer
- High primary permeability enhanced by fracturing
- Deep water level
- Quartz rich mineralogy
- Poor water quality (high TDS)
- Stratigraphically above CBM reservoir
- No significant exploration drilling
- Few local groundwater users
- No springs nearby
- No faults

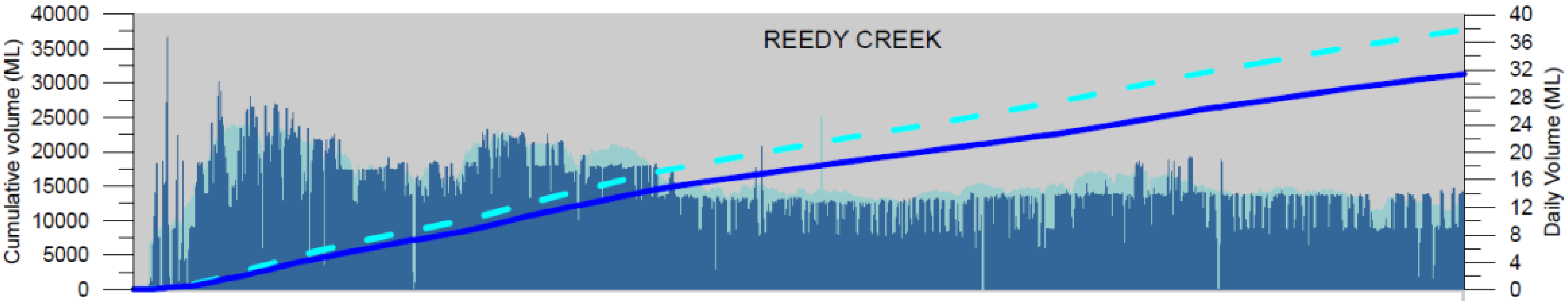
Injection assessment data requirements

Parameter	During drilling	DST/MDT	Wireline Geophysics	Test Pumping	Laboratory Testing
Stratigraphy/lithology	🟢		🟢		
Transmissivity (permeability)		🟠	🟠	🟢	🟠
Storage co-efficient			🟠	🟢	
Porosity			🟢		🟢
Boundaries/aquifer volume				🟢	
Water level/pressure		🟠		🟢	
Aquifer temperature		🟢	🟠	🟢	
Aquitard integrity			🟠	🟠	🟠
Water chemistry		🟠	🔴	🟢	🟢
Mineralogy			🟠		🟢
Geochemistry					🟢
Fracture pressure	🟢		🟠		🟢
Well losses				🟠	

Injection – Surat Basin

Stratigraphy		Hydrogeological Significance	Stratigraphy encountered at RC-INJ2-P		
			Drilled From	Drilled To	Thickness (m)
Wallumbilla Formation		Aquitard			
Bungil Formation		Aquifer			
Mooga Sandstone		Aquifer			
Orallo Formation		Aquitard			
Gubberamunda Sandstone		Aquifer			
Westbourne Formation*		Aquitard	222.2	357.9	135.7
Springbok Sandstone		Variable and generally minor aquifer, basal third generally aquitard	357.9	449.2	91.3
Walloon Coal Measures	Walloon Sub-Group/JCM	Minor coal and sandstone and mudstone aquitards	449.2	600.7	151.5
	Tangalooma Sandstone		600.7	602.5	1.9
	Taroom Coal Measures		602.5	799.9	197.4
Eurombah Formation		Aquitard	799.9	829.7	29.8
Hutton Sandstone		Aquifer	829.7	1,134.5	304.8
Upper Evergreen Formation		Aquitard	1,134.5	1,179.5	45.0
Boxvale Sandstone Member		Aquifer	1,179.5	1,202.2	22.8
Lower Evergreen Formation		Aquitard	1,202.2	1,277.5	75.2
Precipice Sandstone		Aquifer	1,277.5	1,312.8	35.4
Precipice Braided Stream Facies		Aquifer	1,312.8	1,334.0	21.2
Moolayember Formation		Aquitard	1,334.0	1377.7	43.7+





Injection bores and treatment plants

Injection Well - Powder River Basin

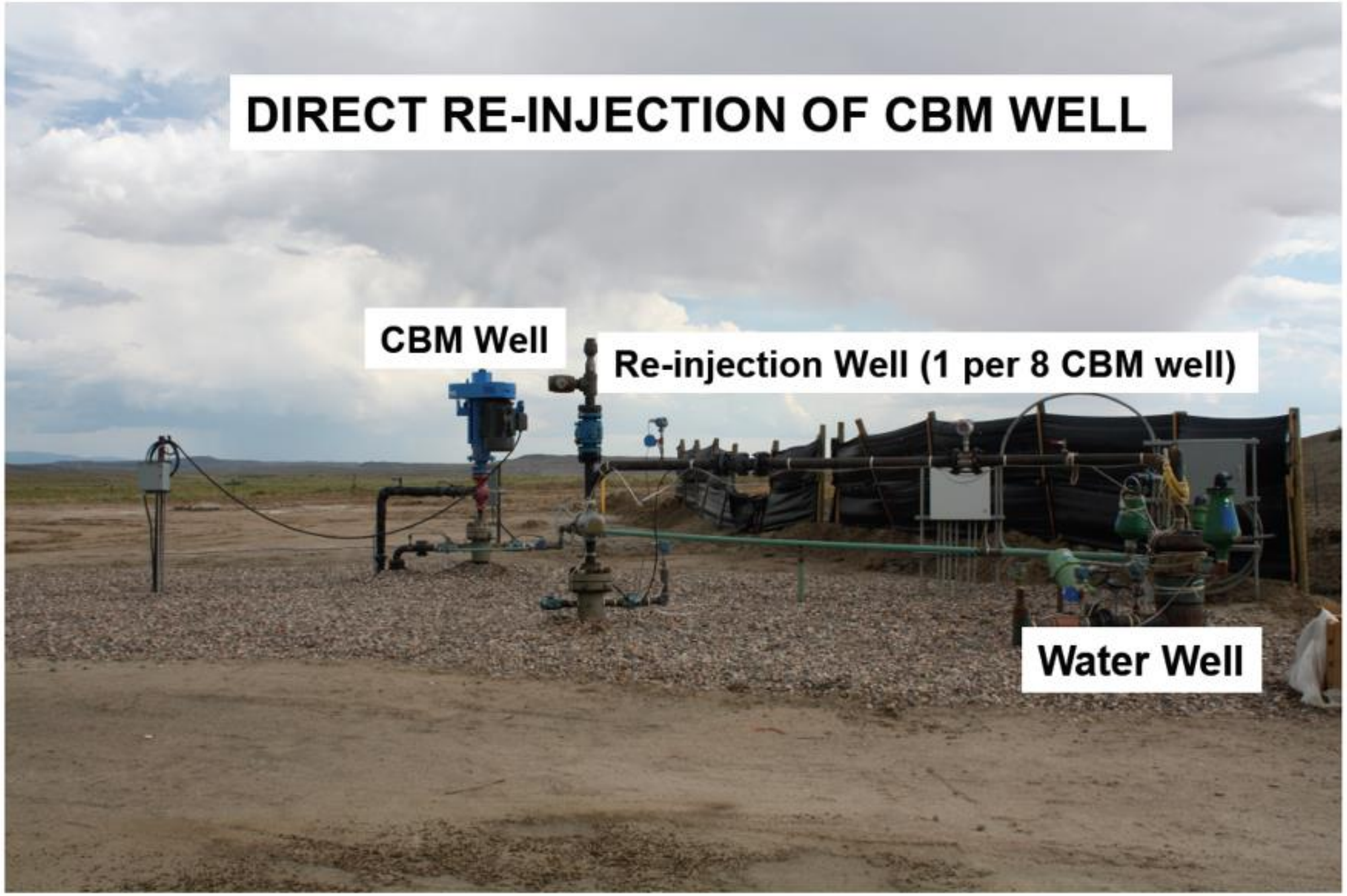
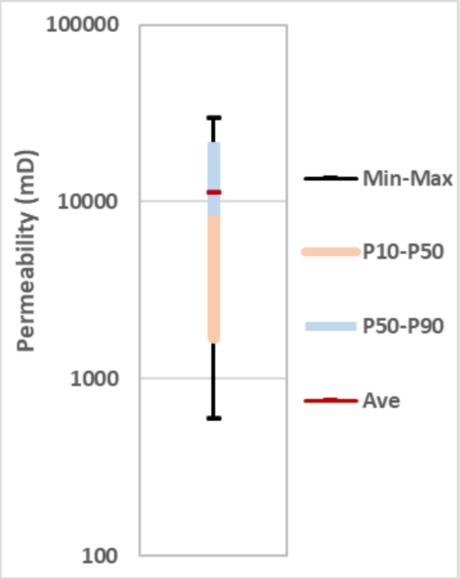


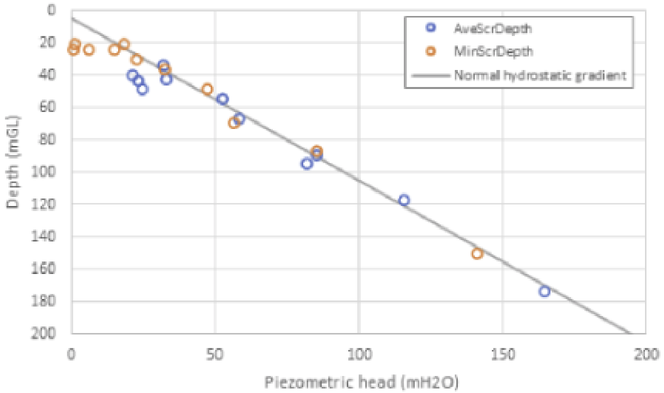
Photo courtesy of T. Moore

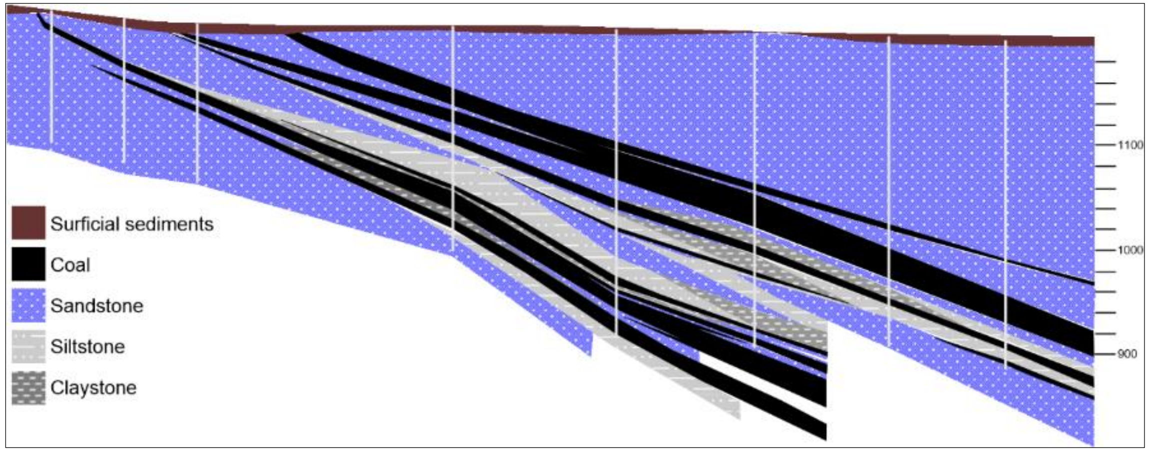
Mongolian Examples

Shivee-Ovoo

- Data only available for shallow areas around mine
- Appears to be sandstone (aquifers) interspersed and overlying coals
- Hydraulic connection
- Extremely high permeabilities measured in pumping tests, but likely to be related to sandstones
- Coal permeability (~500mD)

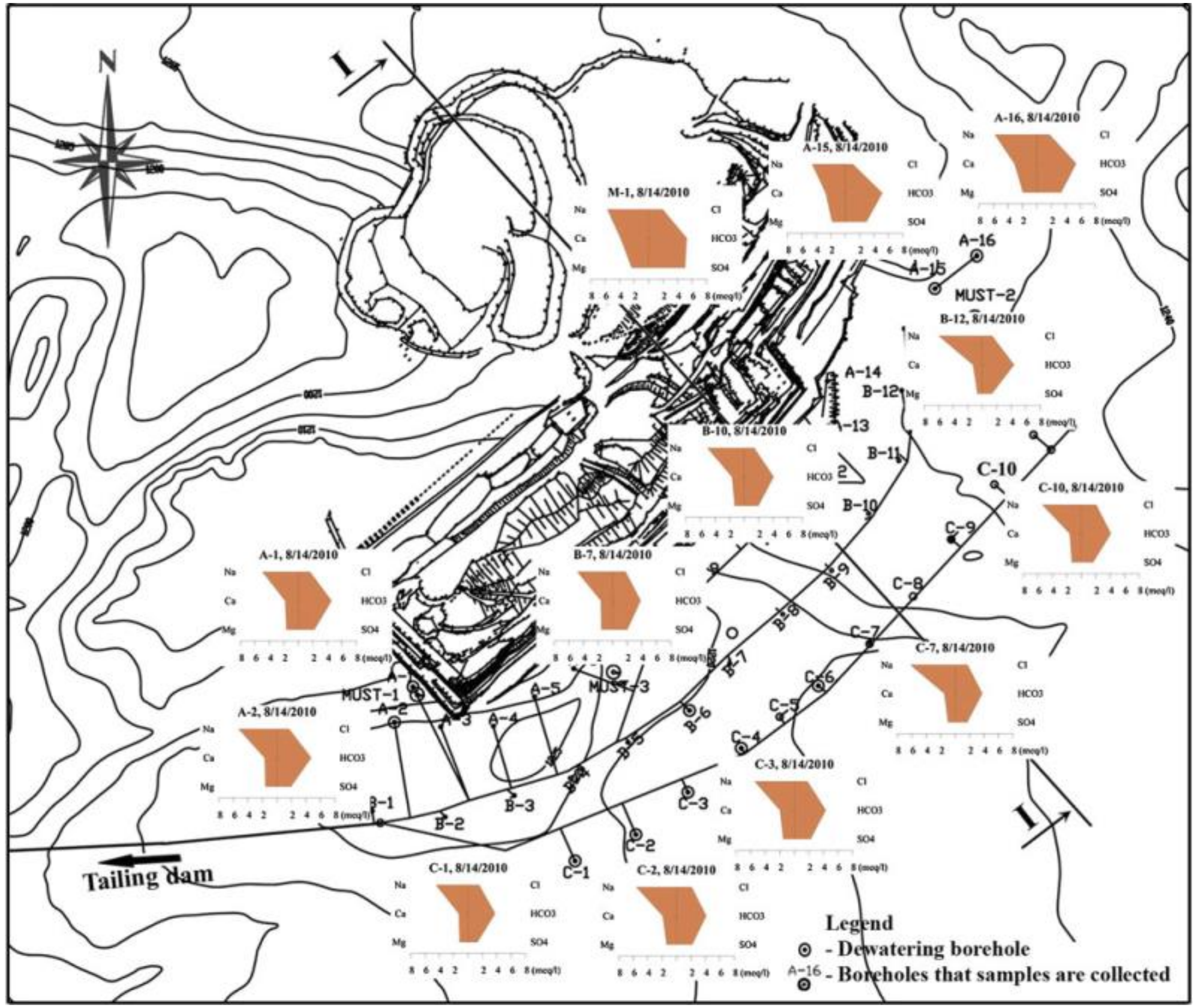






Shivee-Ovoo Water Quality

- Data only available for shallow areas
- Groundwater quality relatively fresh (400 - 2,900 mg/L TDS)
  - Conducive to most reuse options
- Presence of sulphate (SO4) may inhibit biogenic methane generation



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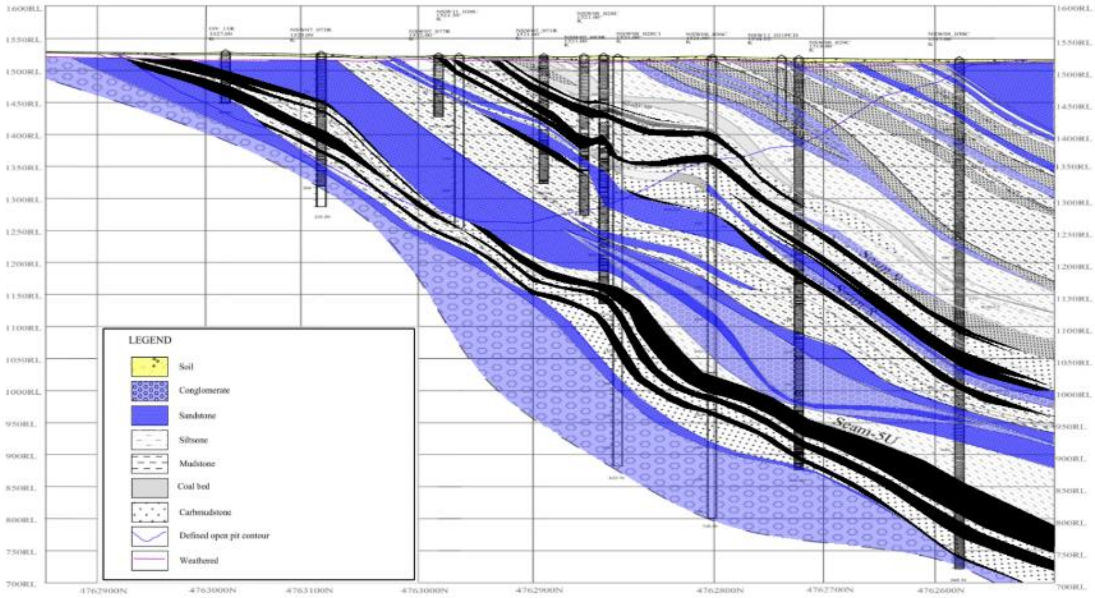
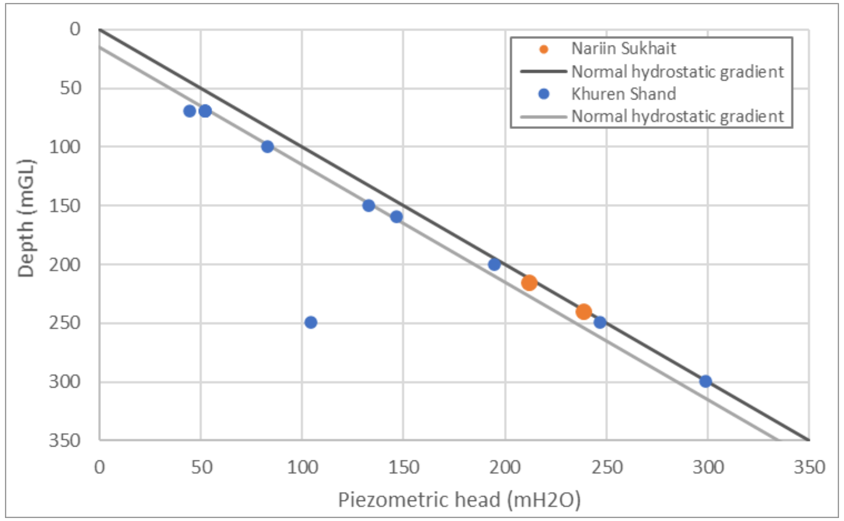
Nariin Sukhait

- Coal seams appear to be separated from aquifer material
- Active system with inferred groundwater flow to the south
- Some compartmentalisation of the aquifers
- Coal permeability of ~85 mD (MAK Mining)





Nariin Sukhait Water Quality

- Groundwater quality fresh to brackish
  - 530 – 5,870 mg/L TDS)
- May require treatment
- Sulphate-chloride/sodium-calcium water type
  - Unusual for CBM waters
- Presence of sulphate (SO_4) may inhibit biogenic methane generation

Australia Mongolia Extractives Program Phase 2 (AMEP 2) is supported by the Australian Government through the Department of Foreign Affairs and Trade (Australian Aid) and implemented by Adam Smith International.

Adam Smith International

Ryan Morris

RDM HYDRO

- A hydrogeologist with over 20 years of experience from Australia, Europe and southern Africa
- Project experience from a wide range of different industries, including oil and gas, mining (iron ore, gold, heavy minerals, vanadium, lithium, phosphate, base metals, coal etc), town water supply, power generation and manufacturing
- Worked on staff for a CBM producer for ~10 years
- His main interests are in water resource investigations for extractable resource development and water management as an enabler of sustainable development

- Proudest technical achievement is the design and ongoing management of CBM water injection projects:
  - 12 injection bores to ~1,350m
  - Up to 36 ML/day, >35GL total water injected (83% of produced water from >2,000 wells)
  - Identification of thermal effects on injectivity
  - Identification of cost effective means of extending injection bore life
  - Custom built performance monitoring tools

Got Questions?

RDM HYDRO

Please visit our website for more information about activities or contact Oyunbileg Purev, Partnership Manager at oyunbileg@amep.mn.

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