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Water Studies Update – AGL Upstream Gas – CSG Projects

John Ross| 14 September 2011| Sydney

CSG developments:
Community and regulatory issues

Land access, compensation and regulatory approvals

Hydraulic fracturing

Water resource impacts

- Impact of exploration / production programs on water resources
- Integrity of gas well construction
- Connectivity of aquifers with deep coal seams

Long term certainty

- No land degradation
- No water impacts and no contamination

Groundwater 101

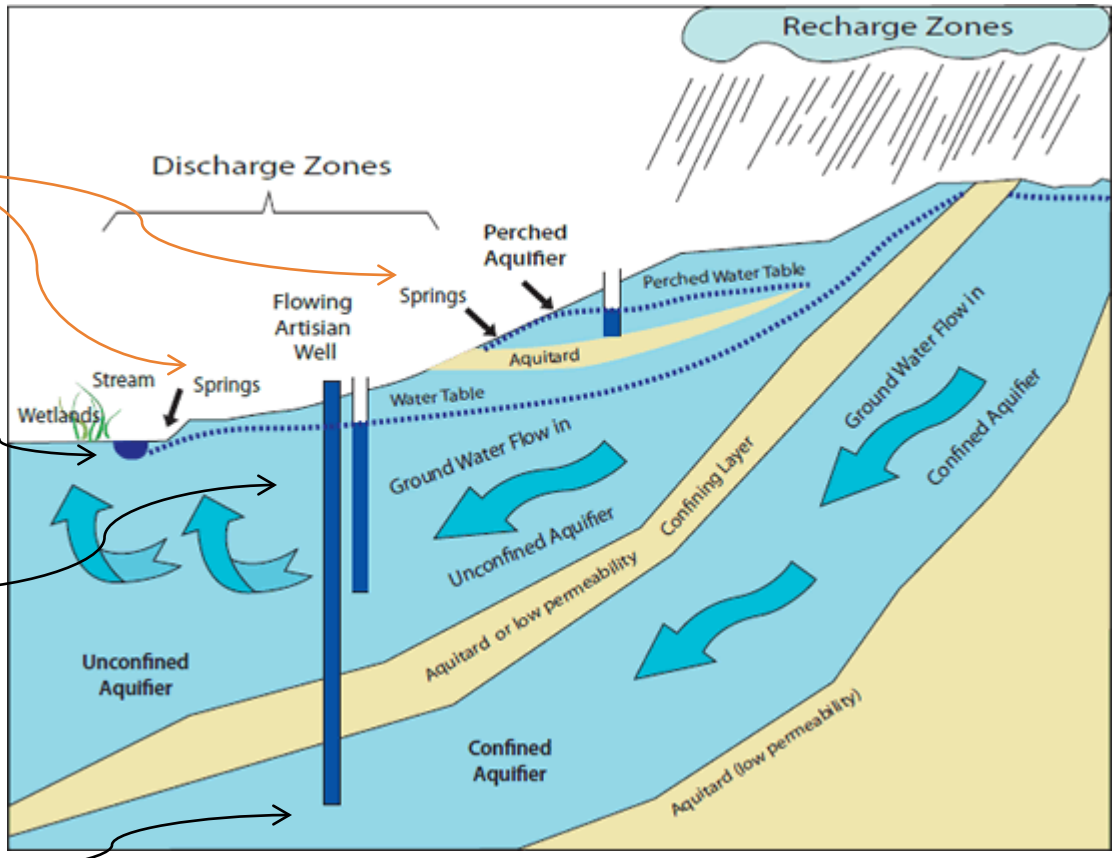
Conceptual groundwater occurrence and flow

Typical spring locations in the landscape

Alluvial aquifers

Shallow fractured rock aquifers

CSG water bearing zones



NOTE - This is a schematic only of groundwater flow through porous rocks and is not necessarily representative of any particular NSW coal basin area

Importance of hydrogeology in CSG developments

Today:

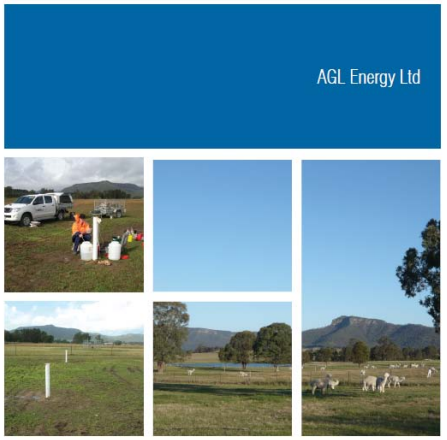
- Why is NSW different to QLD?
- Water resource impacts
  - NSW groundwater resources
  - Gas well construction
  - Connectivity – investigation methodology
  - Hunter conceptual model
  - Hunter Investigation Proofs
    - Water levels
    - Water quality
    - Isotopes
  - Other areas
- Produced water management

Gloucester Basin Stage 1 Gas Field Development Project
Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model

Report prepared by

SRK Consulting

July 2010
Project Code: AGL002



PARSONS BRINCKERHOFF

NSW vs Queensland

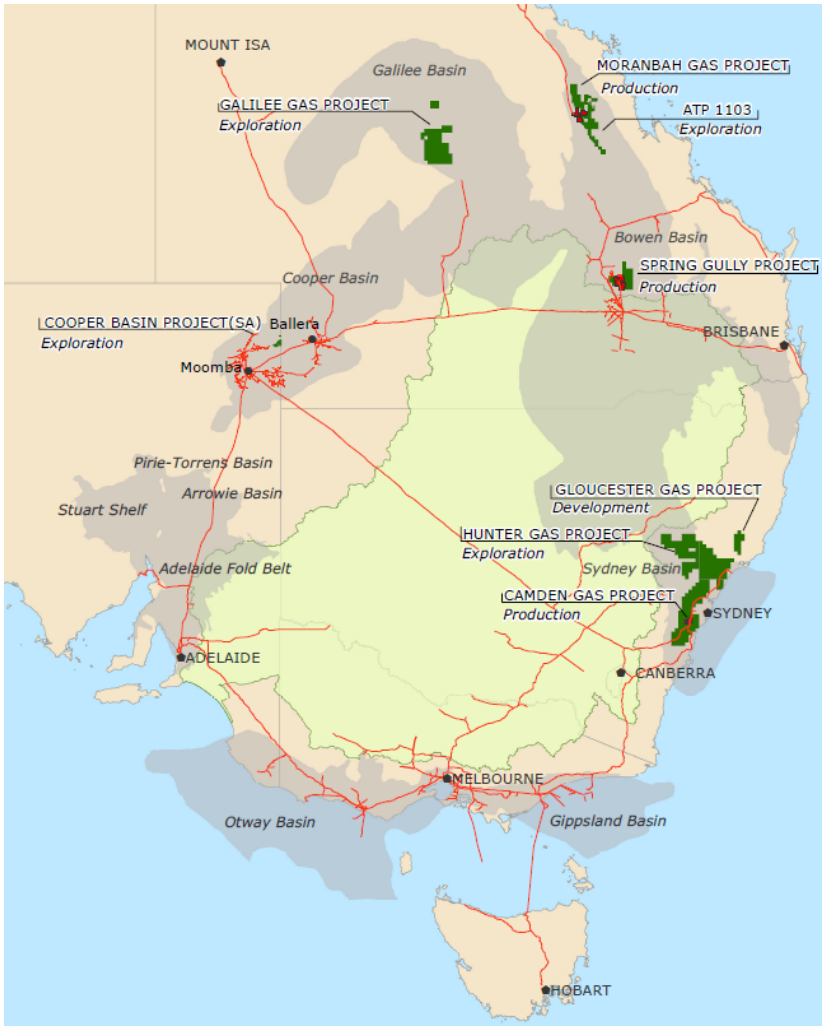
Why are NSW water issues different to QLD

It's all about knowing the geology and hydrogeology (both regionally and locally):

- Permian-Triassic basins
  - Older rocks
  - Lower permeabilities
  - Few (low value) aquifers
  - Lower water volumes
- Jurassic-Cretaceous basins
  - Younger rocks
  - Higher permeabilities
  - Adjacent (high value) aquifers
  - Higher water volumes

NSW vs QLD coal basins

- NSW (**Sydney**, **Gloucester**, Gunnedah, Surat, Clarence-Moreton)
- QLD (Surat, **Bowen**, **Galilee**, Cooper)



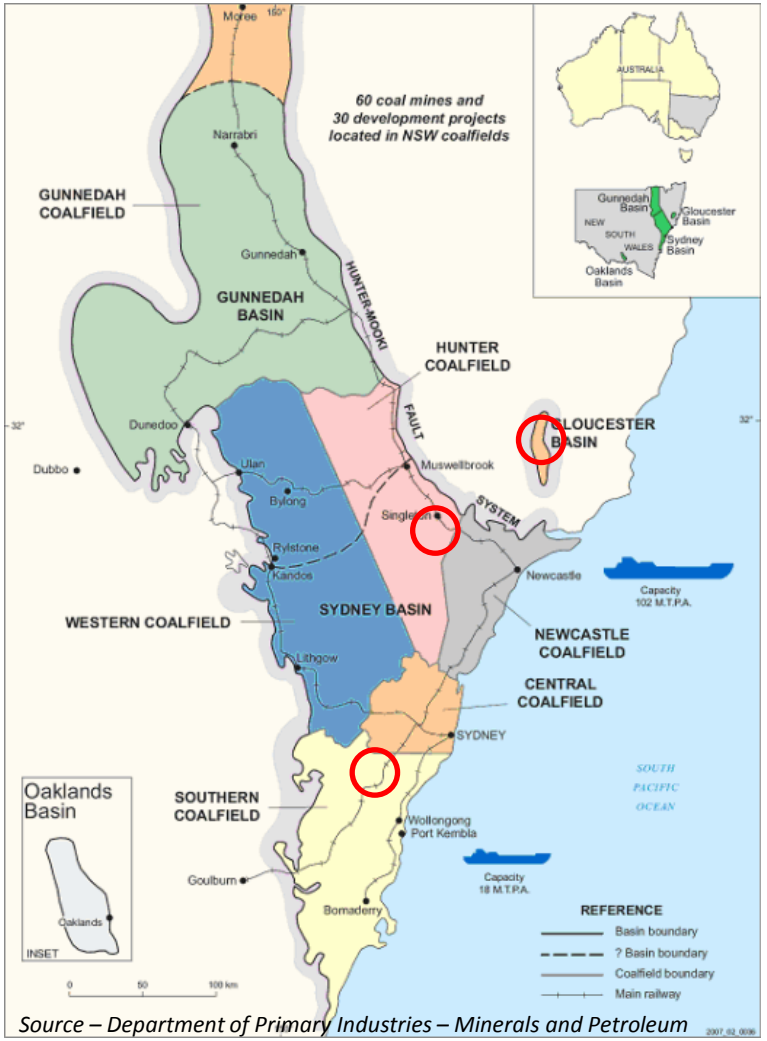
AGL (NSW) PEL and PPL areas

AGL knows the (coastal) Permian-Triassic Basins in NSW:

- Southern Sydney Basin (Camden Gas Project)
- Northern Sydney Basin (Hunter exploration program)
- Gloucester Basin (Gloucester Gas Project)

Compared to QLD (Surat, Galilee, Cooper), coastal NSW has:

- Tighter geology
- Fewer aquifers
- Lesser water volumes
- Poorer water quality



Source – Department of Primary Industries – Minerals and Petroleum

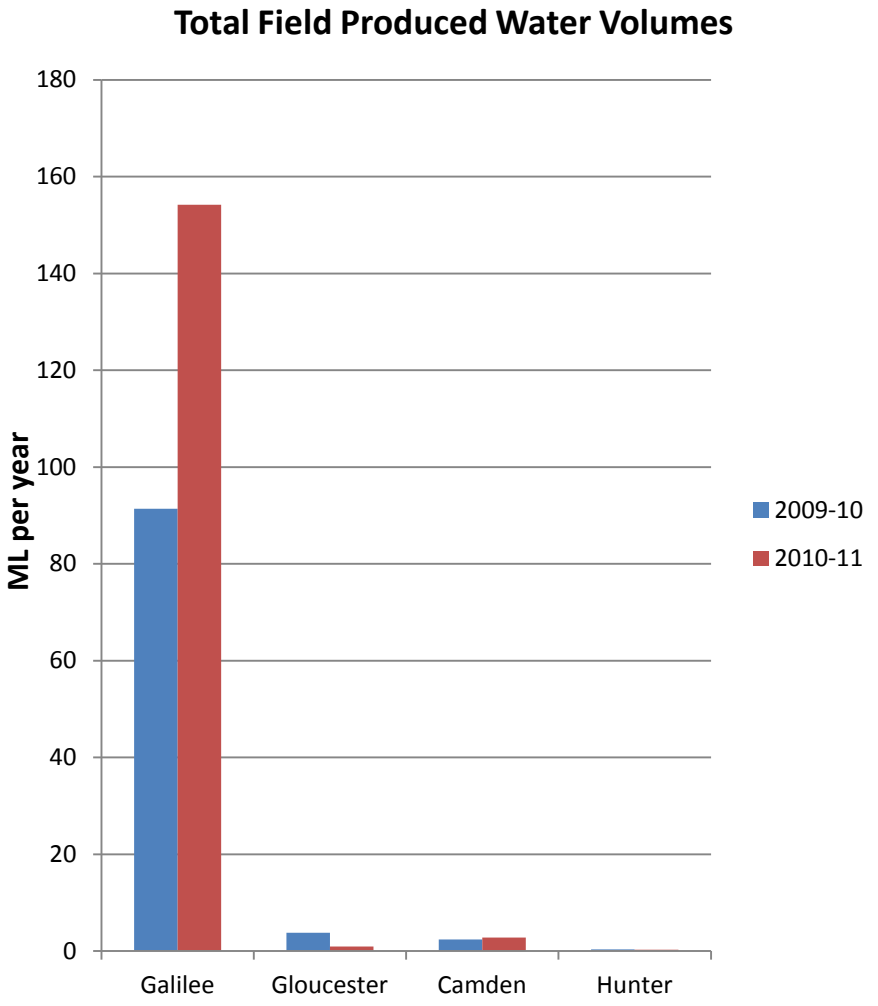
CSG water volumes

Produced water volumes are a function of:

- Geology (rock type and permeability)
- Proximity to shallow aquifers and recharge areas
- Degree of confinement/isolation

Produced waters are small for NSW (coastal) Permian Basins:

- Camden (~80 wells operational - mature)
  - Currently less than 3 ML pa
- Hunter (2 wells - exploration)
  - Programs in recent years - < 1 ML pa
- Gloucester (~15 wells – exploration, awaiting development)
  - Programs in recent years - < 4 ML pa



CSG water chemistry

Groundwater chemistry is a function of:

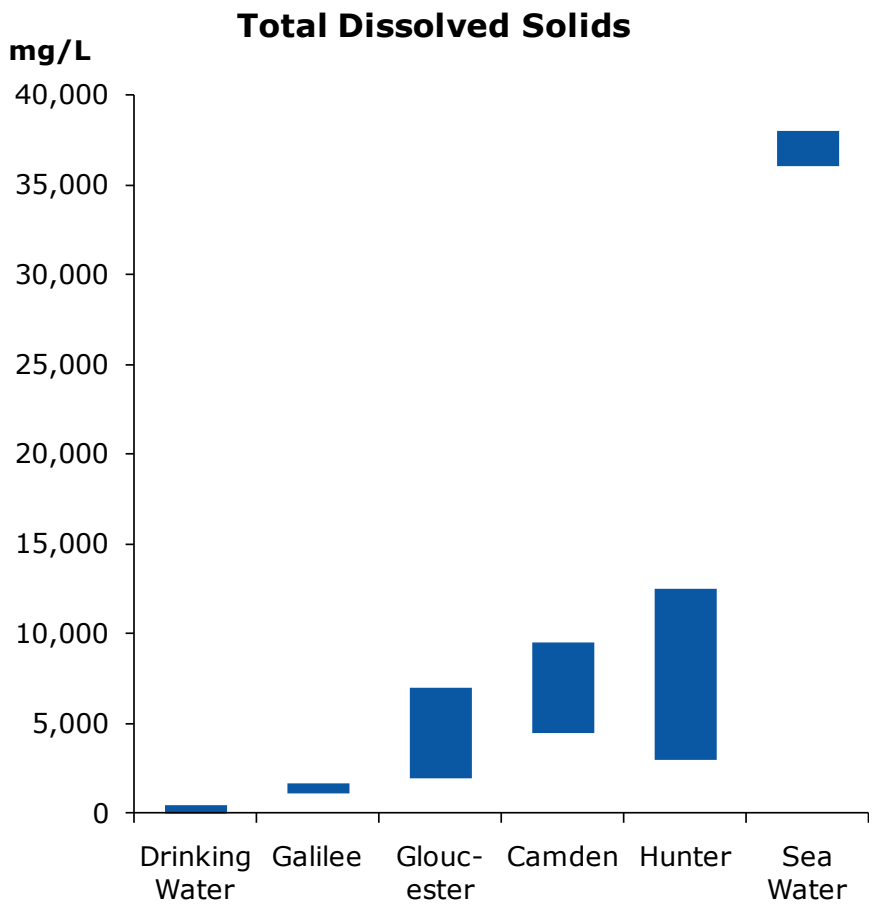
- Geology (rock type)
- Proximity to recharge areas, recharge rates and flow
- Residence time

Produced waters are typically slight to moderate salinity:

- Camden (Na-HCO3)
  - 4500 to 9500 mg/L
- Hunter (Na-Cl-HCO3)
  - 3000 to 12500 mg/L
- Gloucester (Na-Cl-HCO3)
  - 2000 to 7000 mg/L

Also for produced waters:

- Low heavy metals
- No nutrients
- No TPH/BTEX



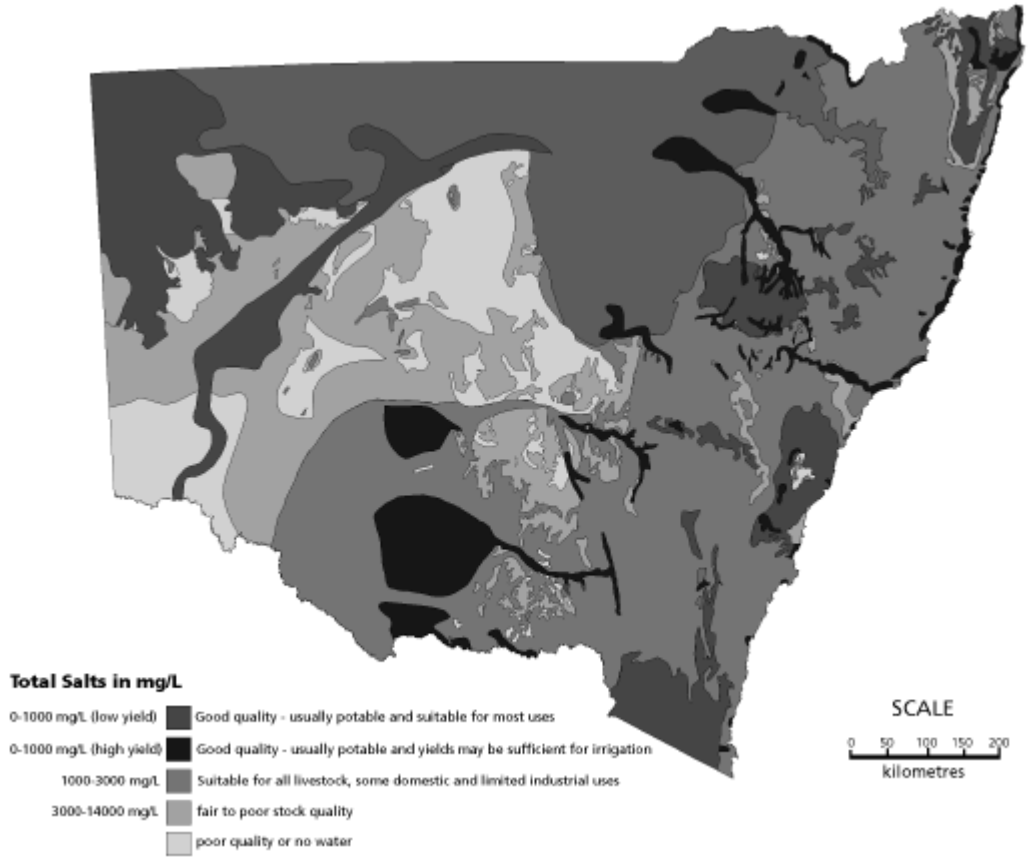
NOTE Water salinity is typically measured as the concentration of total dissolved solids (TDS)

Water resource impacts

Important NSW groundwater resources

- Murray Darling Basin
  - Top 6 alluvial valleys / fans
    - Gwydir
    - Namoi
    - Macquarie
    - Lachlan
    - Murrumbidgee
    - Murray
- Great Artesian Basin
- Oxley Basin
- Coastal NSW
  - Alluvial sediments
  - Sand dunes
  - Basalt plateaus
  - Sydney Basin sandstones

Salinity of Shallowest Groundwater Sources



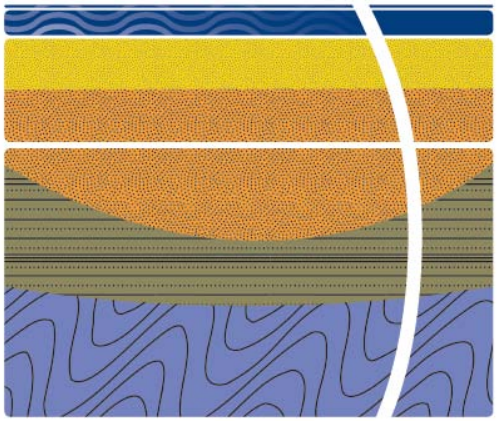
Source – Department of Land and Water Conservation (WQ Protection Policy)

Water management in NSW

- Water Act (1912)
  - Part V bore licences (CSG wells and monitoring bores)
    - 137 for Camden
    - 30 for Gloucester
    - 10 for Hunter
- Water Management Act (2000)
  - Water Sharing Plans
    - Greater Metropolitan (July 2011)
  - Aquifer Interference Approvals
- Other Policies
  - Buried Groundwater Sources Policy (July 2011)

NSW Office of Water

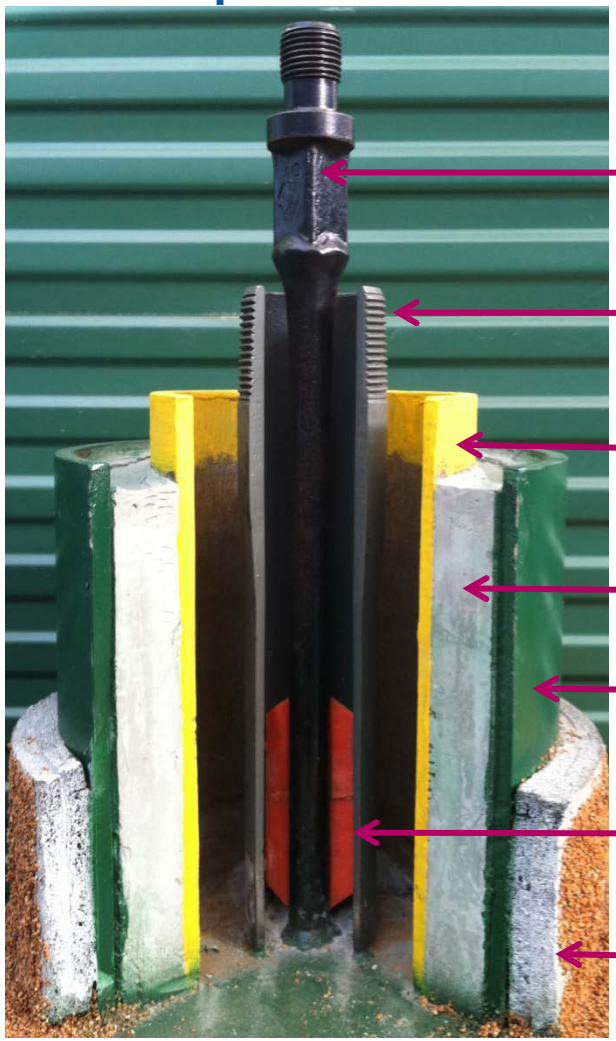
NSW policy for managing access to buried groundwater sources



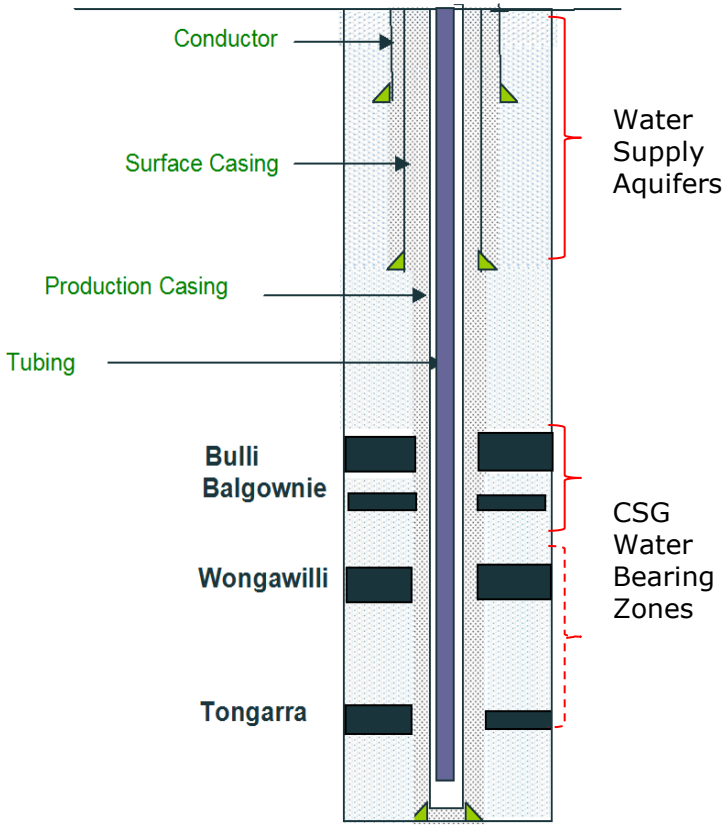
Leading policy and reform in sustainable water management

Gas production well design and construction

(1) Well design and (2) From non aquifers



Cross section of well design



Typical vertical well design

Connectivity: Investigation methodology - Groundwater

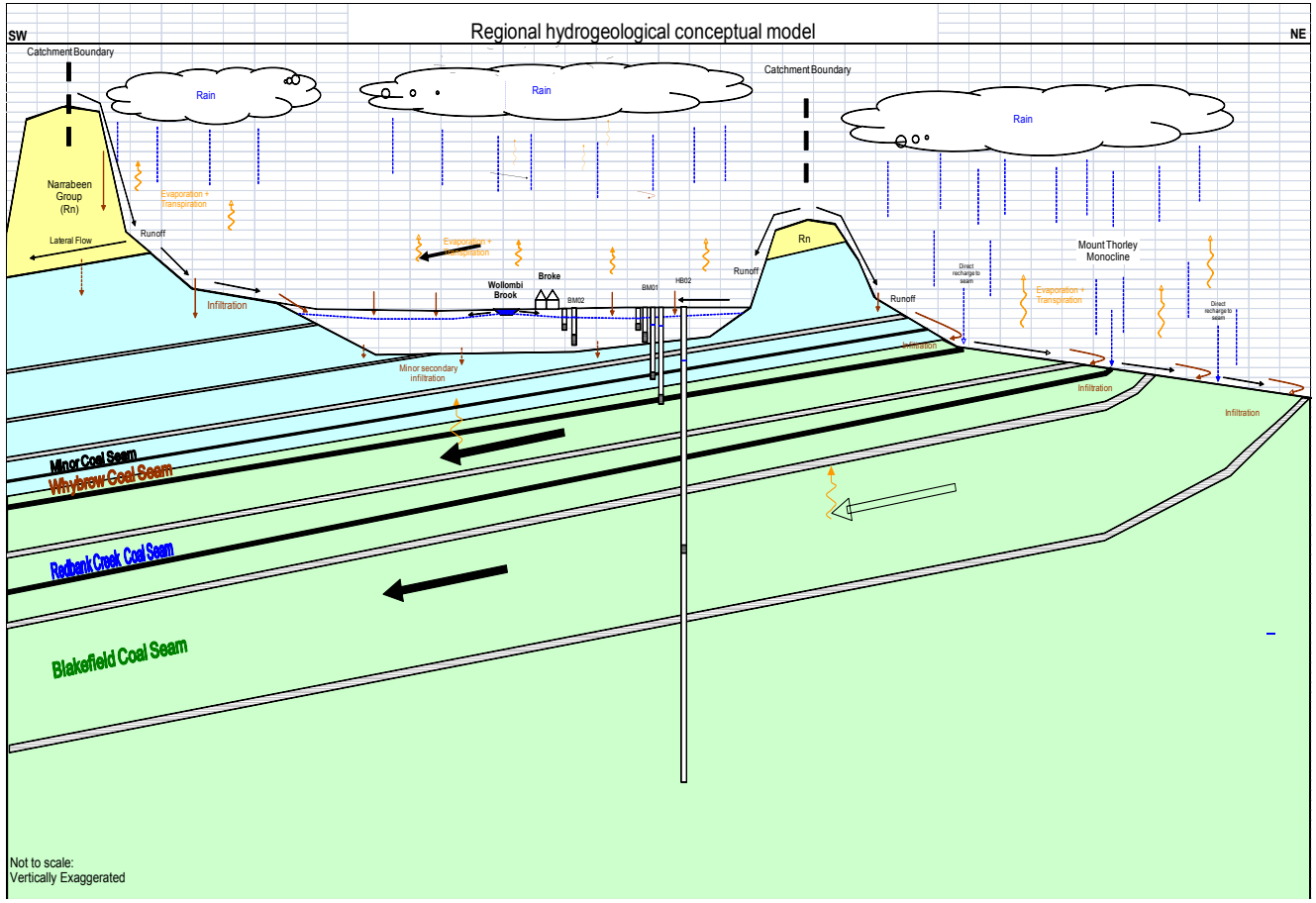
AGL's staged approach to groundwater studies involves:

- **Phase 1: Desktop study** – review of existing data, field visit, compilation of an initial conceptual hydrogeological model and recommendations regarding future phases.
- **Phase 2: Detailed groundwater investigation** – geological re-appraisal, drilling, monitoring, testing and aquifer classification (age and geochemical signature), data analysis and reporting, and establishment of an appropriate monitoring network. *(with peer review)*
- **Phase 3: Modelling** – update of the conceptual hydrogeological model and construction of numerical model(s) to describe initial steady state conditions and then predict groundwater impacts for various staged development scenarios. *(with peer review)*
- **Phase 4: Monitoring program** – monitoring plan, ongoing long-term monitoring and compliance reporting. *(with peer review)*
- **Phase 5: Project updates** – further investigations, periodic update of the monitoring network and numerical model(s) (as required).

Hunter water studies

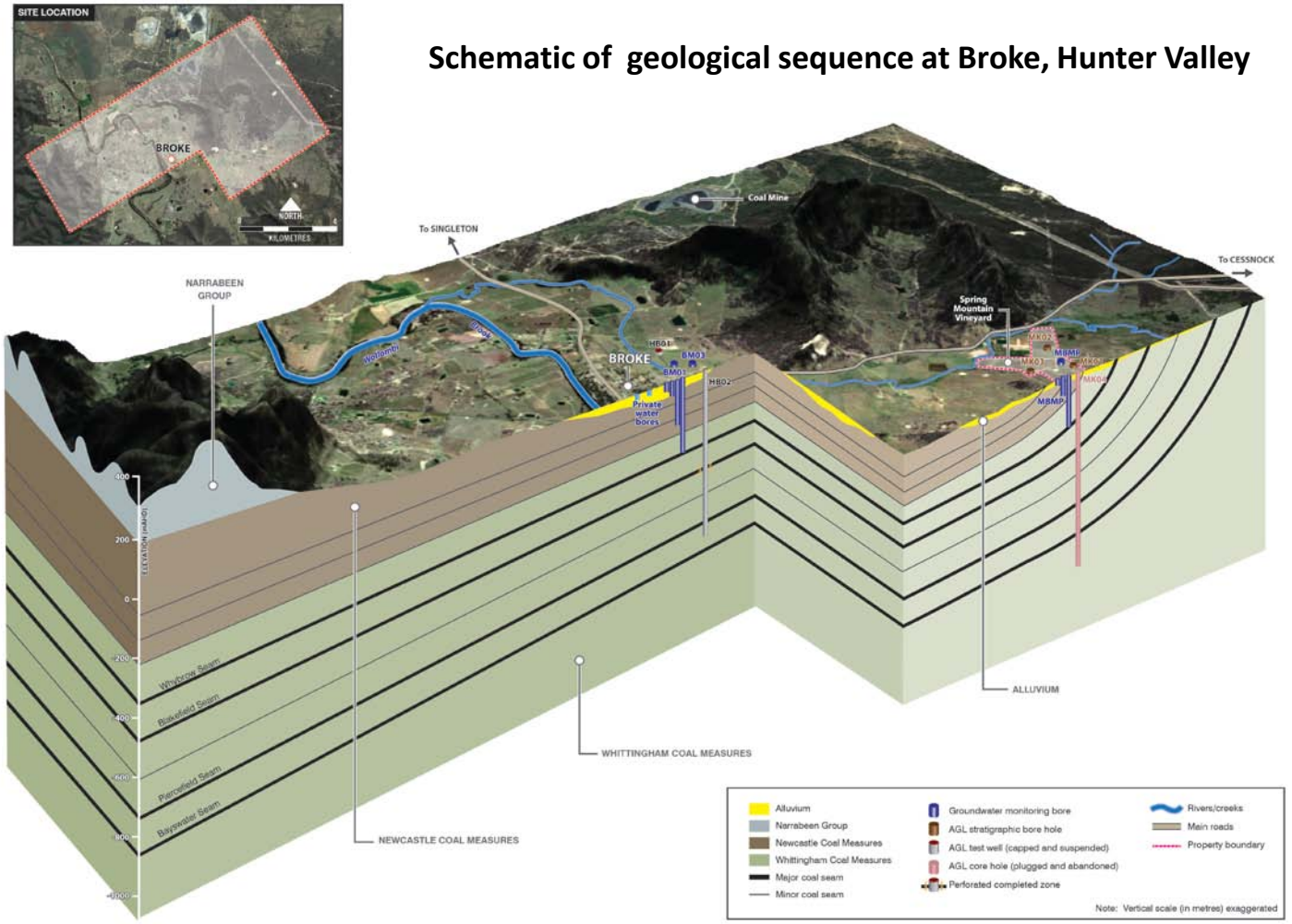
Initial conceptual model: Recharge, discharge and flow

- Hunter (Bulga-Broke)
  - Direct rainfall recharge to the alluvium
  - Nearby fractured rock recharge (~1-5 km)
  - Remote recharge of coal seam waters (~5-10 km)
  - Flow is lateral through aquifers, no vertical flow known
  - Final discharge areas (for deep coal seams) uncertain



Hunter (Broke) Conceptual Cross sectional model (after PB, 2010)

Permian geology



Aquifer and coal seam permeabilities

- Many coal seams across the Sydney Basin are NOT aquifers

High to moderate permeability aquifers (sand, gravel and highly fractured rocks)

Low permeability aquifers

Very low permeability zones (clay, coal seams, claystones, unfractured rock etc)

Permeability	Pervious					Semi-Pervious					Impervious			
Aquifer	Good					Poor					None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam								
Unconsolidated Clay & Organic					Peat			Layered Clay		Fat / Unweathered Clay				
Consolidated Rocks	Highly Fractured Rocks			Oil Reservoir Rocks			Fresh Sandstone			Fresh Limestone		Fresh Granite	
κ (cm^2)	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}	10^{-15}
κ (millidarcy)	10^{+8}	10^{+7}	10^{+6}	10^{+5}	10000	1000	100	10	1	0.1	0.01	0.001	0.0001
K (cm/s)	10^{2}	10	10^{0}=1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (m/d)	86400	8640	864	86.4	8.64	0.864	0.0864	0.00864	0.000864	8.64E-05	8.64E-06	8.64E-07	8.64E-08

Permeability Matrix (after PB, 2010)

Alluvial aquifers at Broke

Shallow bedrock at Broke

Coal seams at Broke

Updated conceptual model: Recharge, discharge and flow

- Geology

- Hunter (Broke-Bulga)
  - Siltstones and cemented sandstones common within and above the coal measures
  - Claystones are the main confining layers which isolate aquifers
  - Coal seams have low permeability and are mostly non aquifers at depth
  - Some geological structure but not highly disturbed

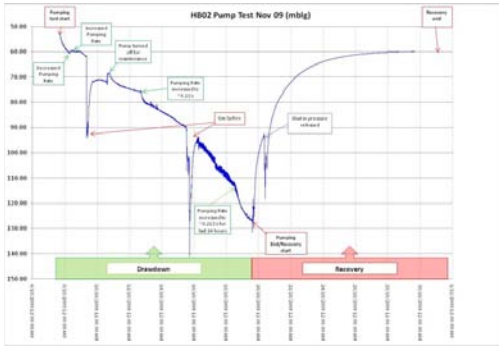
- Hydrogeology

- Hunter (Broke-Bulga)
  - Shallow (limited extent) alluvial aquifer
    - Shallow water – fresh to brackish
    - Deeper water - brackish
  - Shallow/minor fractured rock aquifers (all Permian)
  - Recharge – same
  - Discharge – same
  - Flow
    - Some natural connection between shallow aquifers
    - No natural connection between aquifers and coal seams

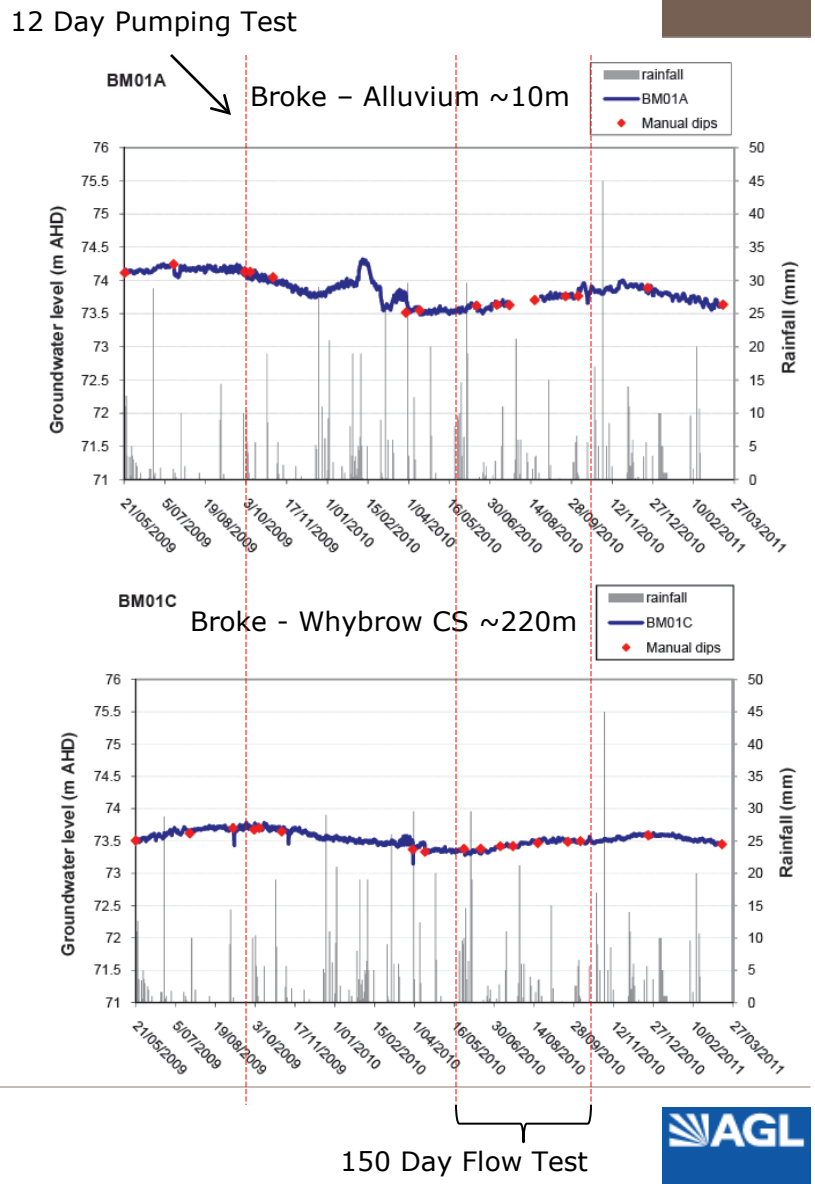
(Lack of) connectivity proofs

Water level proofs

- Hunter (Broke) example
  - 12 day pumping test (2009)
  - 150 day flow test (2010)
- Pumping test:
  - Shallowest gas well (HB02) operational
  - Slotted opposite Blakefield CS (~323 m)
  - Drawdown to 130 mbgl (Q averaged 0.17 L/s)



- Flow test:
  - Both wells operational (HB01 and HB02)
  - Drawdowns to top of slotted intervals (collective Q averaged 0.0425 L/s)

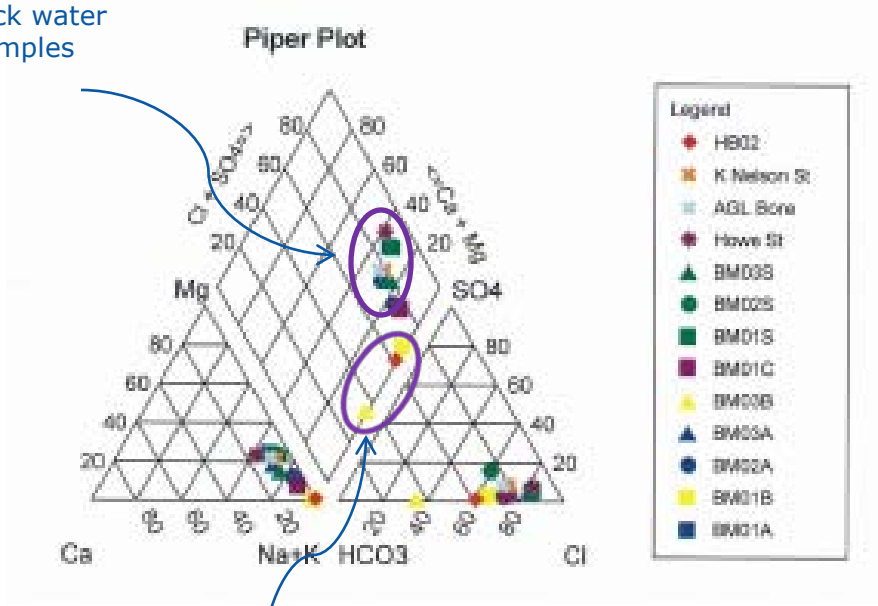


Water chemistry proofs

- Hunter (Broke) water types
  - Uppermost (alluvial) aquifer – mostly Na-Cl
  - Deep coal seam water bearing zone – Na-Cl-HCO_3
  - Discrete differences between alluvial groundwater and fractured rock groundwater /coal seam water

Hunter (Broke) Sampling Program – September 2009

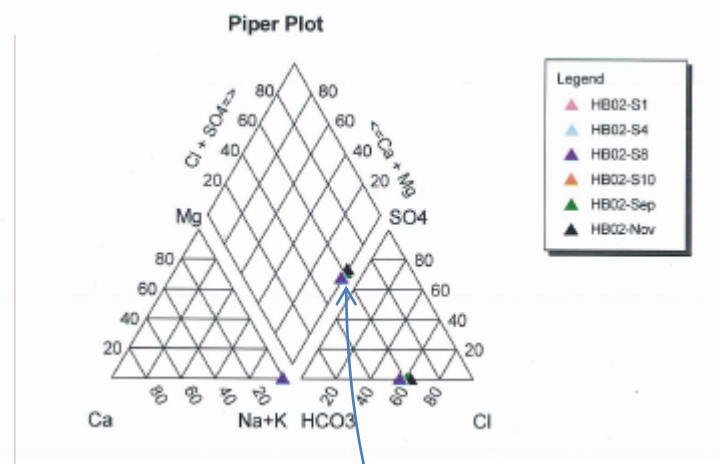
Alluvial and shallow fractured rock water samples



Coal seam water samples

Water chemistry proofs

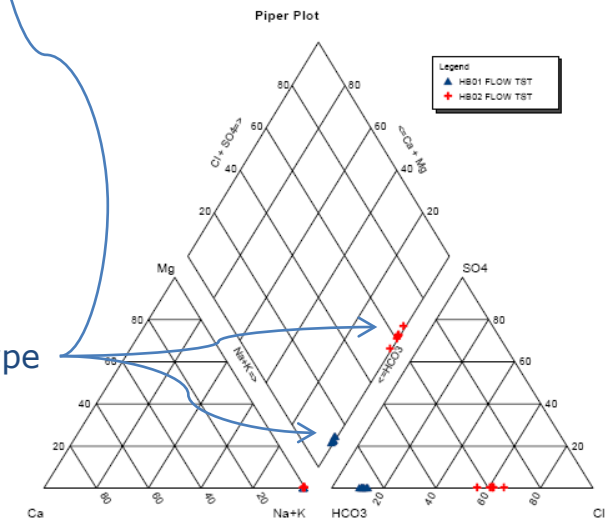
- Hunter (Broke) – deep coal seams
  - Water types remained unchanged for coal seams over both 2009 pumping test and 2010 flow testing programs



Hunter (Broke) 2009 Sampling Program (HB02)

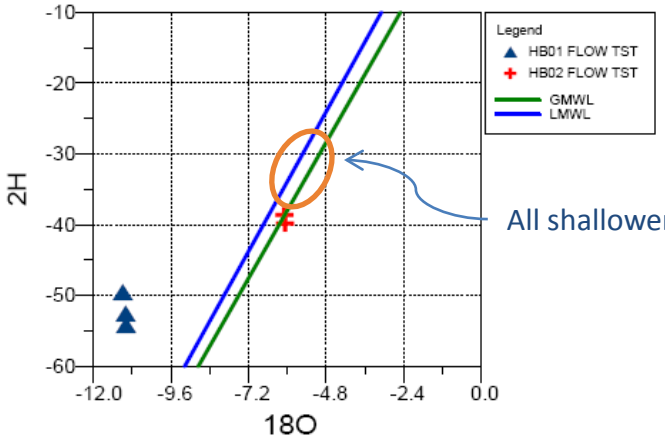
Hunter (Broke) 2010 Sampling Program (HB01 and HB02)

Water type



Isotope proofs

- Environmental isotopes (H^2 and O^{18})
  - All groundwater is derived from rainfall
  - More depleted signatures with depth suggest older water and longer residence times
- Radiogenic isotopes (H^3 and C^{14})
  - Tritium only present in alluvial groundwater
  - Corrected C^{14} ages suggest coal seam waters are tens of thousands of years old
  - Results suggest increasing age with depth and natural isolation of aquifers

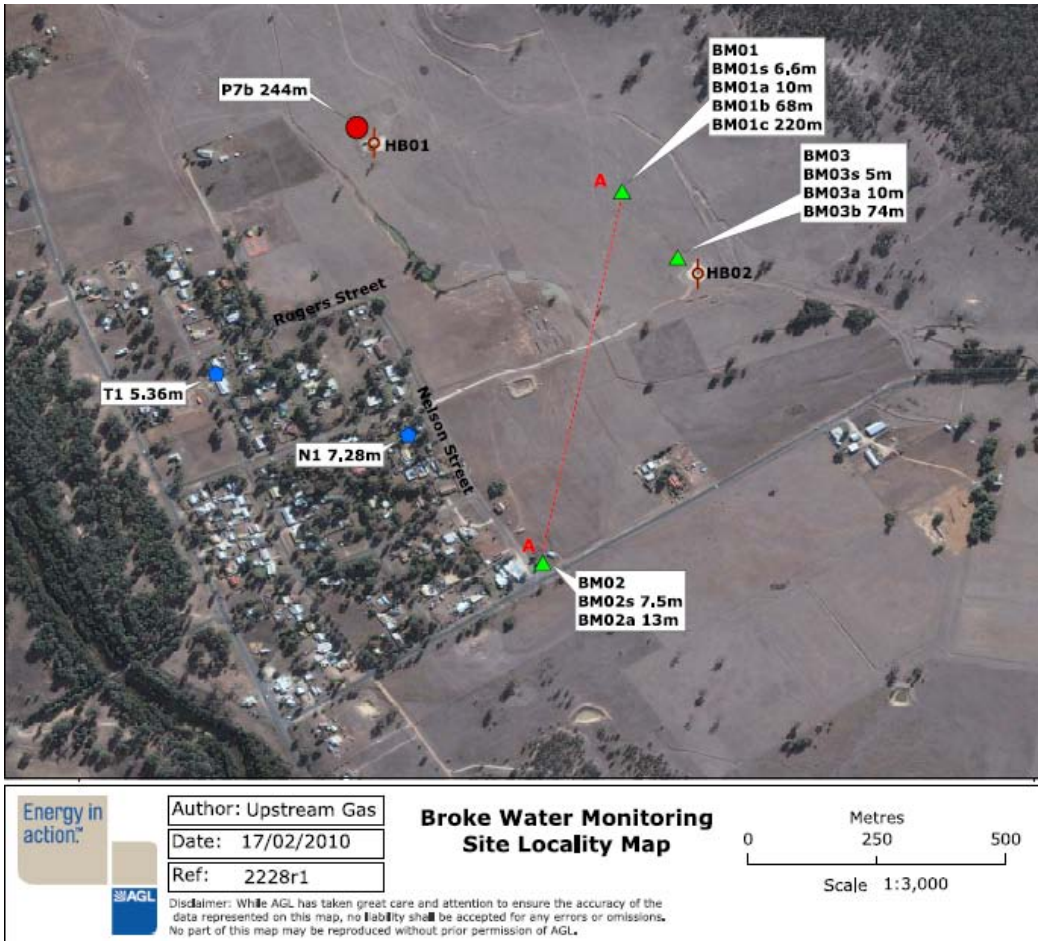


Hunter (Broke) examples

	Modern	<10000 years BP	10000-20000 years BP	20000-30000 years BP	30000-40000 years BP	40000-50000 years BP	>50000 years BP
Wyong							
Newcastle CMs							(400 - 425m)
Hunter (Broke)							
Alluvium	(0 - 12m)						
Fractured Rock		(50 - 200m)					
Wybrow CS			(130 - 220m)				
Blakefield CS				(240 - 330m)			
Piercefield etc CS							(425 - 475m)

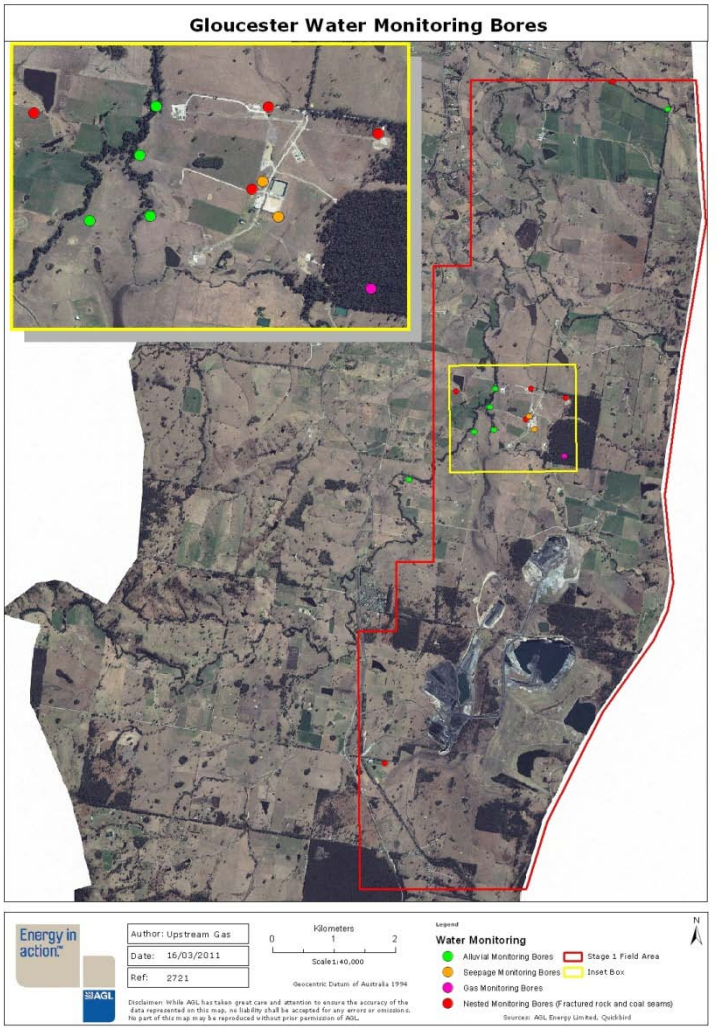
Hunter monitoring networks

- Hunter (Broke)
  - 9 (dedicated AGL) bore locations
    - 6 alluvial
    - 2 fractured rock
    - 1 coal seam
- Other Hunter
  - 9 (dedicated AGL) bore locations
    - 2 alluvium
    - 2 fractured rock
    - 5 coal seam (3 MB and 2 VWP)
- Monitoring programs
  - Baseline monitoring
    - 6 months + in advance of pumping test
    - Both WLs and WQ
  - Pumping test and flow test monitoring
    - More intensive WL monitoring
    - More intensive WQ monitoring
  - Ongoing
    - WLs ongoing (continuous loggers)
    - Repeat WQ closer to any project EA/EIS



Other monitoring networks

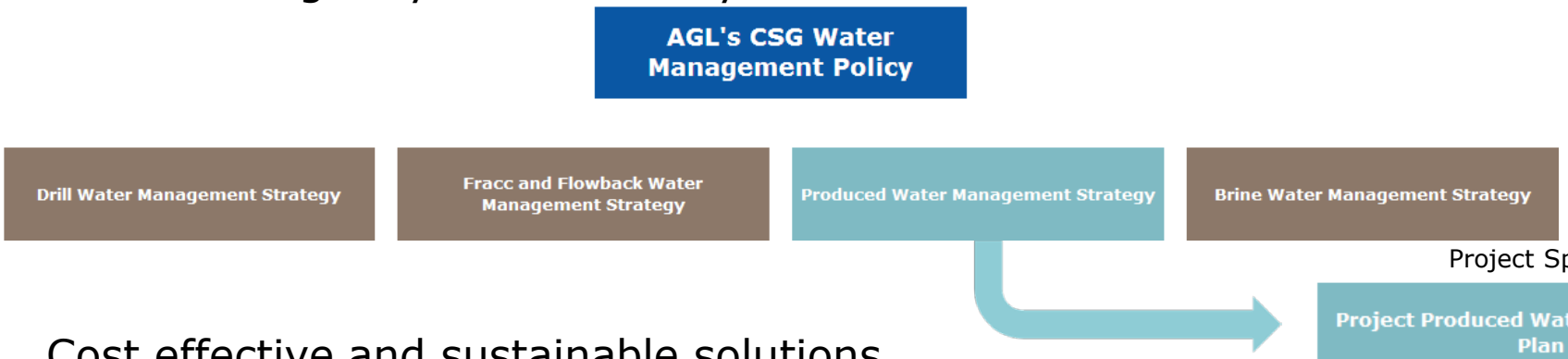
- Gloucester
  - 28 (dedicated AGL) bore locations
    - 2 seepage
    - 2 gas drainage
    - 6 alluvial
    - 14 fractured rock
    - 4 coal seam
  - 3 surface water locations
- Camden
  - 15 (dedicated AGL) bore locations
    - 3 sandstone/shale (new)
    - 12 coal seam (for WQ)
- Galilee
  - 6 (dedicated AGL) bore locations
    - 3 sandstone (1 MB and 2 VWP)
    - 3 seepage
  - 4 surface water locations
  - Private locations (under BAP)
    - 3 GAB sandstone



Produced water management

Produced water management

- Think strategically but act locally



- Sub-Plans include both monitoring and management requirements

- Cost effective and sustainable solutions
  - Industrial and commercial
  - Mining
  - Primary production
  - Raw water for domestic water supply

  Beneficial reuses

  - Offsite disposal at licensed facility
  - Reinjection
  - Environmental flows
  - Evaporation
  - Recreation

  Disposal options

Conclusions

Water levels, quantity and quality are directly related to the geological and hydrogeological characteristics

- Different basins have different characteristics
  - In Sydney Basin
    - Permian coal seams are overlain by low permeability cap rocks
- Hunter hydrogeology
  - Groundwater in the Hunter River / tributary alluvium is the primary water resource
  - Few aquifers in the bedrock
  - Effective (natural) separation between aquifers and coal seams
  - Deep groundwater flow systems are mostly regional and lateral flow dominates
- Lots of groundwater studies completed, monitoring ongoing and more studies / monitoring planned
  - Negligible connectivity of aquifers with coal seam water bearing zones
    - Water level proofs
    - Chemistry proofs
    - Isotope proofs

Links

- Links
  - Camden - http://www.agk.com.au/camden/
  - Hunter - http://www.agk.com.au/hunter/
  - Gloucester - http://www.agk.com.au/gloucester/