12.0
Groundwater management – reinjection and repressurisation options

12.0 Groundwater management – reinjection and repressurisation options

#	Department Condition		Description	Completion date	Status
	Pre-Dec 2012	Post-Dec 2012			
27	49c		Completion of first Injection Management Plan (Precipice Water)	February 2013	● (Commitments completed)
28			Construction of investigation, monitoring and trial injection production bore	April 2013	● (Commitments completed)
29			Update for Stage 3 WMMP – Progress Report on IMP. Drilling of injection well WCK_INJIP	June 2013	● (Commitments completed)
30			Injection Feasibility Study Report (part 1 and part 2)	April 2014/April 2015	● (Firm deliverables for that month)

● Commitments completed
○ Commitments work in progress
△ Evergreen Commitments
● Firm deliverables for that month

12.1 INTRODUCTION

A key element in the mitigation 'toolkit' to address pressure changes is aquifer repressurisation by injecting water to prove the efficacy of reinjection. In Q4 2013, QGC will undertake a trial of aquifer injection at the Woleebee Creek location in the QCLNG Project's Northern Gas Fields, southwest of Wandoan (see Figure 12-1). This chapter describes the subsurface characterisation and hydrogeological work behind the trial, the engineering design of subsurface and surface facilities and the work scheduled for commencement in Q1 2014.

The trial is a part of QGC's three-step approach towards reinjection. The first step was the drilling of a fully-cored groundwater monitoring bore (WCK_GW4), with associated analysis and testing. This produced valuable information for developing a static aquifer model. The second step was to drill an offset monitoring bore (GW10) and to undertake a prolonged production trial (pumping test) to calibrate dynamic modelling. The third step (the proposed injection trial) includes the construction of an injection well (WCK_GW11) and installation of surface infrastructure. The trial's overarching objective is to provide the data necessary to assess the technical feasibility of a repressurisation scheme should it be required.

An Injection Management Plan was submitted to the Department in February 2013. Appendix N contains a revised and updated version of that Plan for submission to DEHP in November 2013. This chapter is a summary of that plan with updates on the continuing trial design and implementation.

Table 12-1 presents the feasibility and success criteria for the trial.

The target formation for the injection trial is the Precipice Sandstone. The Precipice Sandstone at this location has undergone an extensive data acquisition process. Associated analysis and modelling provide the framework necessary to evaluate the formation's injection potential. Figure 12-1 illustrates a cross-section of the sedimentary horizons at the trial site and the network of injection and monitoring wells which will comprise the test subsurface infrastructure.

Two phases of the injection trial are envisaged:

- Phase 1 – injection of Precipice Sandstone formation water for three months from Q4 2013; and
- Phase 2 – injection of treated CSG water from the 100 ML/d capacity Northern WTP (NWTP) currently planned to begin Q4 2014 (lasting three to six months).

Feasibility criteria	Success criteria
Confirm hydrochemical zone	Verify/calibrate size of water plume modelling
Hydrochemistry and injection performance	Demonstrate no hydrochemical change during and after injection
	Assess any plugging or clogging impeding injection rates
Hydraulic Impact Zone and capacity assessment	Verify/calibrate Hydraulic Impact Zone modelling
	Demonstrate Precipice compartmentalisation during injection at well location and away from well
Fracturing conditions of Precipice under injection	Verify/calibrate the geomechanical model
Confirm flow patterns within Precipice	Identify preferential flow intervals within Precipice
	Confirm reservoir inflow (breakthrough at GW10 using tracers)
	Confirm conductivity between wells (WCK_GW4 and WCK_GW11)
Test whole system performance	Test well performance
	Test Monitoring technologies
	Test and Monitor performance and reliability of integrated surface facility

Table 12-1 – Trial feasibility and success criteria

12.2 SITE AND TARGET SELECTION

A review of Surat Basin stratigraphy within QGC tenements identified four potential formations that could be suitable aquifers for injection:

- Gubberamunda Sandstone;
- Springbok Sandstone;
- Hutton Sandstone; and
- Precipice Sandstone.

The position of these aquifers in the sequence is illustrated in Figure 12-1.

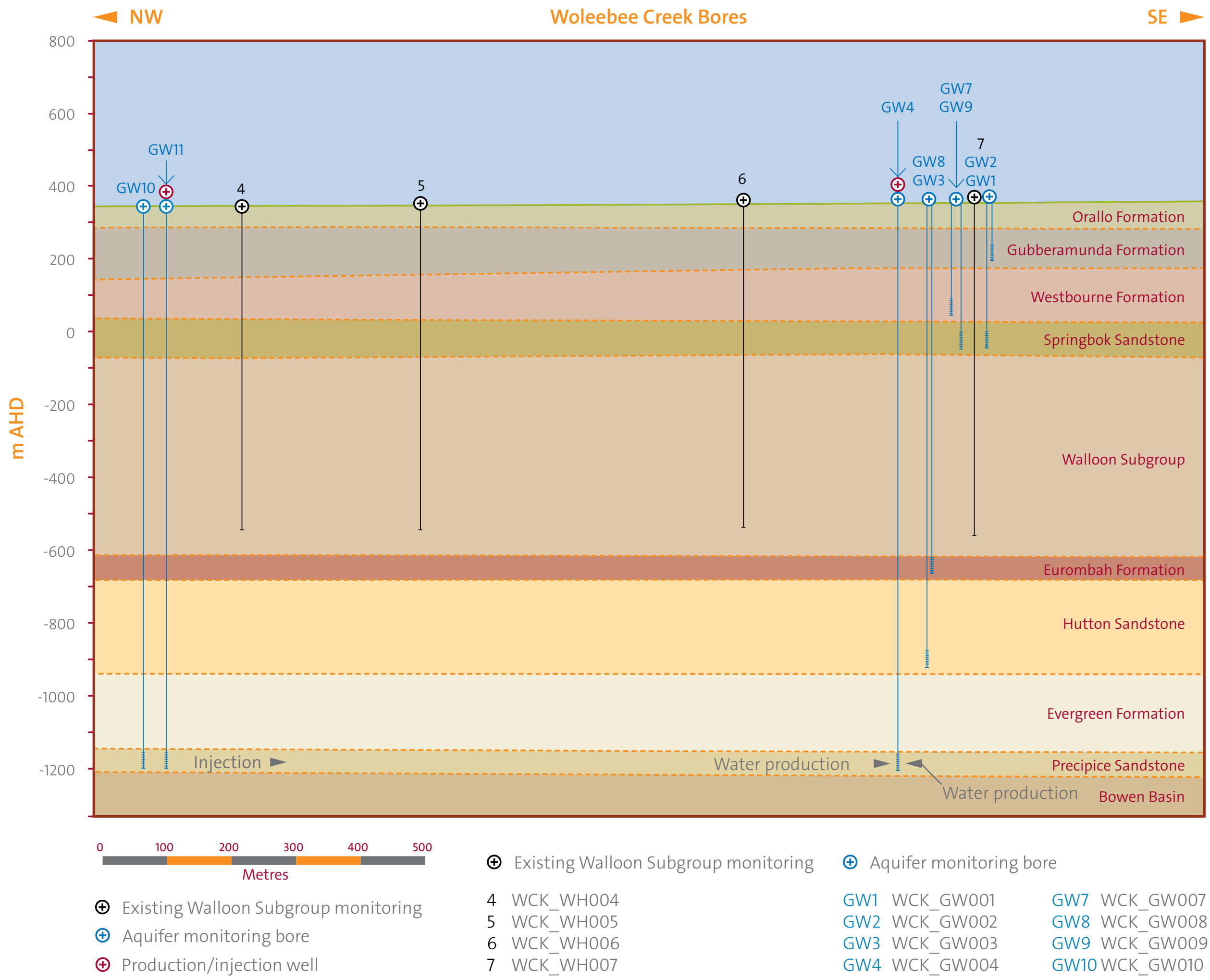

Figure 12-1 – Woleebee Creek schematic cross-section

With the focus on the protection of MNES springs in the north, the choice narrowed to only two of the four aquifers as being potentially the primary source aquifers recharging the springs; namely the Hutton and the Precipice Sandstones. Of these formations, the Hutton Sandstone remains an option for future aquifer injection consideration.

However, the Precipice was selected as the preferred injection target because of the following general characteristics:

- It is a good quality aquifer with a transmissivity of 500 m^2/d and a hydraulic conductivity of 5 m/d;
- It is a consolidated sandstone with good rock strength and low fines which implies a low risk of plugging and clogging;
- It is a regionally extensive (hundreds of km) and thick (100 m) formation;
- Good pressure containment is present with overlying and underlying low permeability barriers in the Evergreen and Moolayember Formations;
- It is a non-reactive formation comprising 99% quartz; and
- There is good water chemistry compatibility between treated CSG water and Precipice Sandstone formation water.

The trial location for testing Precipice reinjection was chosen based on the following factors:

- Proximity to MNES Springs and monitoring bores;
- Thickness of the Lower Precipice Sandstone;
- Proximity to water infrastructure (ponds/Northern WTP (NWTP)/water trunk lines/Precipice Sandstone production bores/Power/Camp);
- On QGC-owned land – for access and speed of project delivery;
- Relative proximal distance to monitoring bores (hydrochemistry and pressure); and
- Potential to retain a permanent long-term injection site.

These criteria led to the selection of the Woleebee Creek site. Not only is the Precipice Sandstone suitable at this location but the Woleebee Creek area is the focus of QGC infrastructure in the Northern Gas Fields.

12.3 DATA ACQUISITION

The first step in the injection process was a substantial data acquisition program to confirm the initial evaluation of the Precipice Sandstone and its hydrogeological system. The program included:

- Drilling of a monitoring well (WCK_GW4) to the Precipice Sandstone aquifer with full coring from ground level to Total Depth (TD);
- An additional production test in that well;
- A monitoring well (WCK_GW10) into the Precipice Sandstone aquifer;
- Monitoring wells (WCK_GW1 to WCK_GW9) for pressure measurement and hydrochemical sampling in the overlying formations;
- Geophysical open hole and cased hole full suite of logging;
- Hydrochemical sampling;
- Full core analysis on core from WCK_GW4;
- Well testing including Drill Stem Test (DST) and Diagnostic Formation Injection Test (DFIT);
- Surveys of existing monitoring and abstraction wells in the area; and
- Data swaps with other CSG operators and mining companies.

Figure 12-2 – Woleebee Creek trial layout

12.3.1 WCK_GW4 PRODUCTION TRIAL

A critical dataset comes from the production trial implemented at the Woleebee Creek GW4 well. This is a long-term pumping test which is providing the dynamic data that is most representative of an injection scenario. Observation wells for the test include the WCK_GW10 Precipice well 3.28 km away and other aquifer monitoring wells at the main Woleebee Creek monitoring site, as illustrated in Figures 12-1 and 12-2.

First production from WCK_GW4 occurred on 12 December 2012. This was the start of the pre-commissioning process for surface facilities (pump, sand filter, telemetry and discharge. Following successful pre-commissioning, the well was put into production at approximately 4 ML/d for two days followed by a 23-hour shut-in. This shut-in period has provided the best opportunity to date to characterise the flow potential of the Lower Precipice formation (see Figure 12-5 showing the log-log derivative plot from the pressure transient analysis of that shut-in). The monitoring well WCK_GW10, which is located 3.28 km (see Figure 12-2), from the production well WCK_GW4, monitors the pressure changes in the Precipice Formation during the pumping test. Figure 12-3 demonstrates the flow and rate history from WCK_GW4 during the first two months of flow.

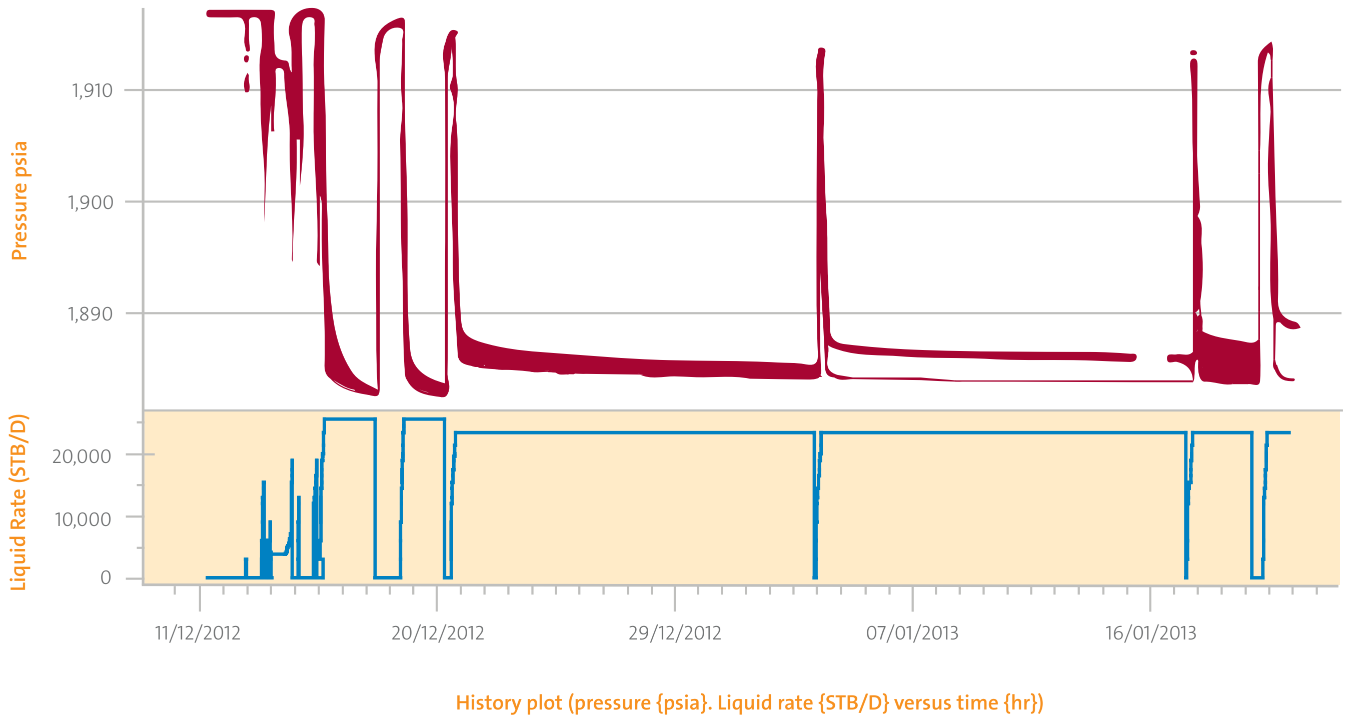

Figure 12-3 – Flow and rate history: WCK_GW4 Production Test

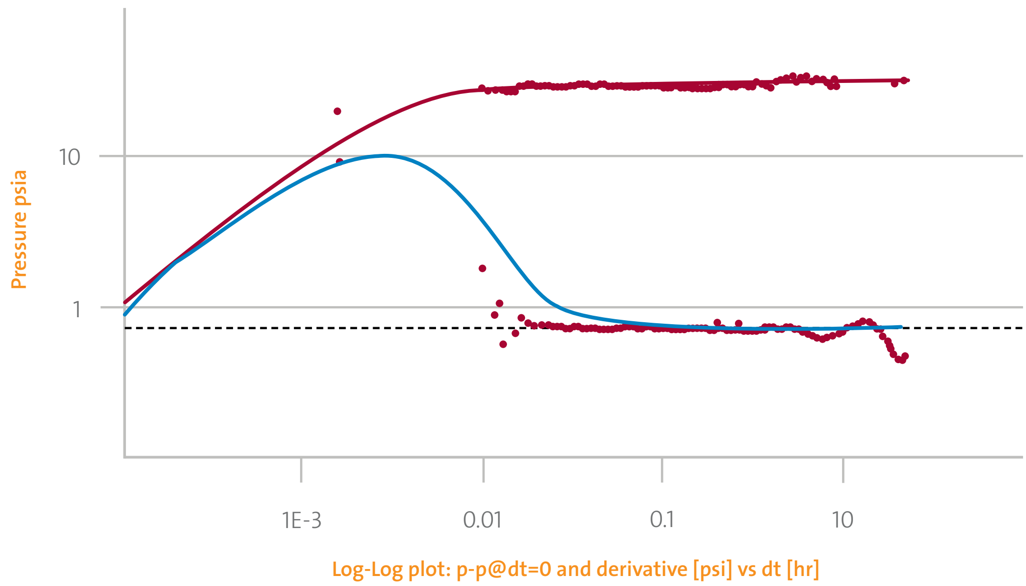

Figure 12-4 – WCK_GW4 pressure response and derivative (log-log)

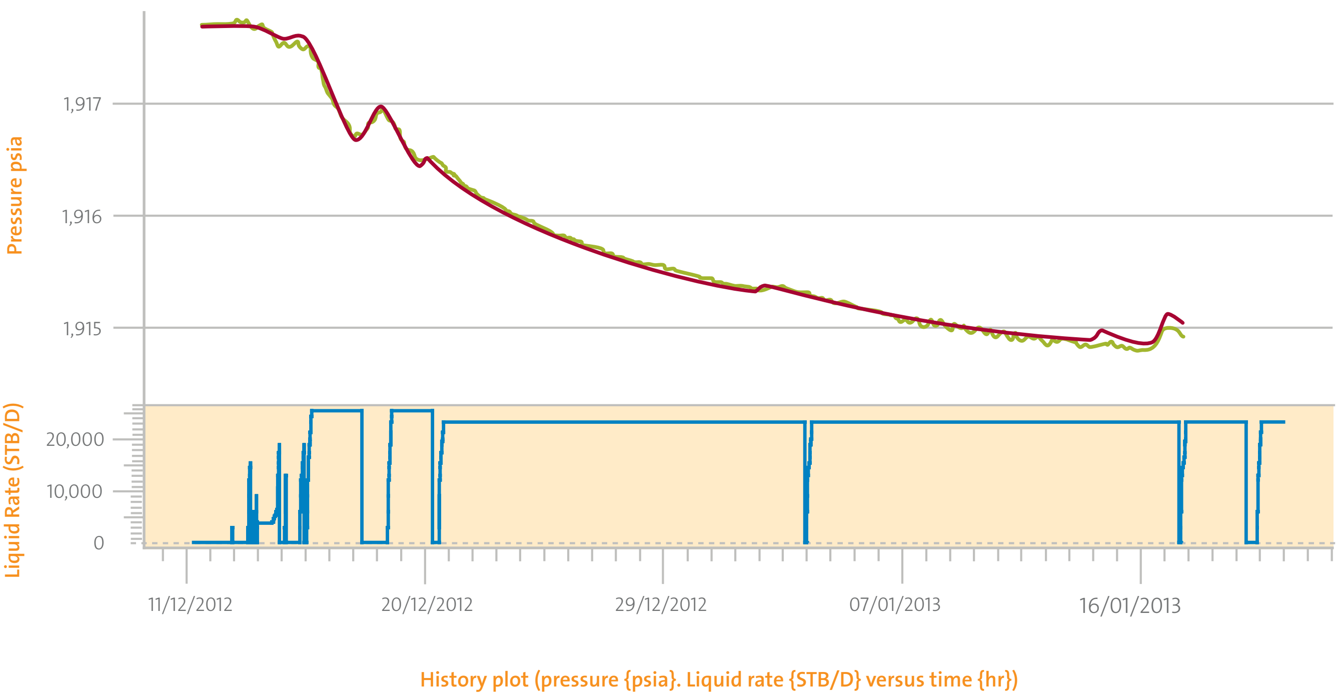

Figure 12-5 – Pressure response at WCK_GW10 from WCK_GW4 production

The permeability in these analyses is estimated to be 3,170 mD (milli Darcies). The radius of investigation for the shut-in period on 17 December, 2012 is about 4.5 km giving a minimum volume of the zone of pressure influence of 1.32 km^3. For the most of the shut-in period the pressure response reflects classic radial flow, suggesting that there are no barriers in the reservoir. However, towards the end of the shut-in period the pressure derivative starts to deviate from the flat line of radial flow (see Figure 12-4). Future testing programs will include longer shut-in periods and flow patterns will be addressed in more detail.

Woleebee Creek GW10 is an observation well drilled 3.28 km north-west of WCK_GW4 with permanent downhole pressure and temperature gauges. Figure 12-5 shows a history of the pressure response at WCK_GW10 during the production of WCK_GW4 and it is very clear that there is strong communication between the wells.

The production trial will continue until Q4 2013 and will be followed by an extended shut-in period to measure pressure recovery.

In addition, QGC has also analysed the Precipice water produced from WCK_GW4 and stored in Woleebee Creek holding cell (WCK Cell 1) where the fluids begin to equilibrate with atmospheric temperature and pressure. QGC observed increases in salinity and pH that were attributed to evaporation and CO_2 degassing, respectively (Table 12-2).

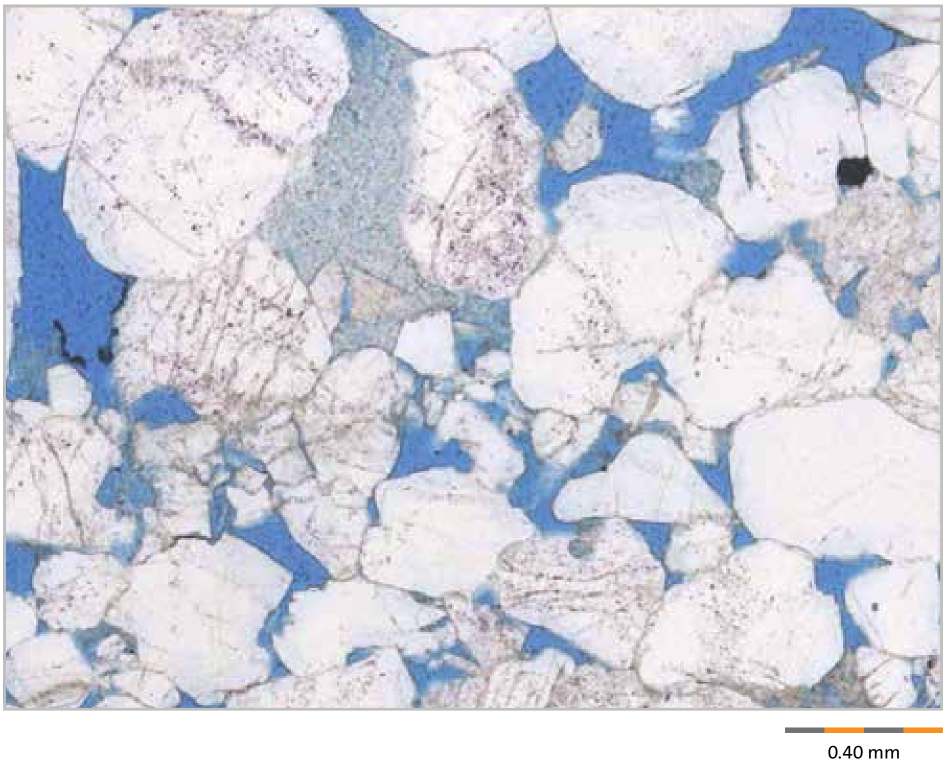

Figure 12-6 – Scanning electron micrograph of precipice core

12.3.2 WATER QUALITY

Baseline groundwater samples were collected in January and April 2013 during continuous WCK_GW4 water production which started in December 2012. Groundwaters were analysed for a full suite of chemicals. Physico-chemical parameters (temperature (T), electrical conductivity (EC), pH, redox potential (ORP) and dissolved oxygen (DO) were also collected. Results are presented in Table 12-2:

- Salinity is very low ~200 mg/L;
- High temperature ~60 to 65ºC;
- Mildly acidic pH 6.7;
- Character is $Na\text{-}HCO_3$ and proposed injectate is Na-Cl;
- Trace element concentrations are less than expected;
- Redox state is dominantly reducing;
- Redox disequilibrium is apparent (calculation of redox couples);
- Modelled $O^2(aq)$ concentrations are very low (direct measurements not currently possible due to high temperatures); and
- Dissolved silica is proportionally high compared to salinity.

Parameter	Units	WCK_GW40	WCK_GW4b	WCK Pond 3 Cell 1
Electrical Conductivity	mS cm^{-1}	200	200	300
Dissolved Solids*	mg/L	211.3	127.5	241.4
Temperature	O^c	67.2	66.4	
pH	-log $^aH+$	6.7	6.8	9.1
Na^+	mg/L	44	32	62
K+	mg/L	2.7	1.5	3.9
Ca^{++}	mg/L	0.35	0.26	0.6
Mg^{++}	mg/L	0.08	0.06	0.16
Cl	mg/L	12	11	36
F	mg/L	0.5	0.5	0.6
HCO_3	mg/L	119.7	80.54	103.3
CO_3	mg/L			6.45
SO_4	mg/L	2	2	4
Al^{+++}	mg/L	0.004		0.035
Ba^{++}	mg/L	0.018	0.01	0.02
$B(OH)_3$	mg/L	0.038	0.021	0.053
Fe^{++}	mg/L	0.66	0.9	0.53
Fe^{+++}	mg/L	0.11		
Mn^{++}	mg/L	0.01	0.009	0.004
Sr^{++}	mg/L	0.01		0.038
$SiO_2(aq)$	mg/L	34		26
NO_2	mg/L	0.12	0.012	
CH_3COO	mg/L	1		1.3
HS	mg/L	149	100	
$CH_4(aq)$	mg/L	3.3	4	
$CO_2(g)$	Log fugacity	-1.453	-1.534	-4.116

**Note: Dissolved solids is a calculated value based on measured analytes, which is more representative of the true state of solute concentration, as opposed to the loss of volatile constituents using evaporative methods.*

Table 12-2 – Physico-chemical parameters and solution composition of groundwater and surface water samples

For the purpose of the injection trial (Phase 1), QGC is planning to minimise residual time of Precipice water into WCK Cell 1 to prevent excessive evaporation and potentially chemical dose with HCL to adjust the pH of Precipice water prior to injection.

12.3.3 AQUIFER PROPERTIES

There is static pressure data available in the Precipice Sandstone for five wells in the area of interest. QGC has downhole pressure data from WCK_GW4 and GW10 from before and during GW4 production. Origin Energy has provided water levels at the Reedy Creek INJ2P and INJ4P wells and Combabula WB1P.

Particle Size Distribution (PSD) is a key characteristic of the formation to develop an effective and safe well injector design according to the risk of fines migration. PSDs were measured from core samples. The results indicate that, according to the industry standard criteria, the Lower Precipice Sandstone is a medium to well sorted, coarse grained sandstone with low fines content. The likelihood of fines migration causing plugging of the aquifer during injection is therefore very low.

A petrological study was conducted on the GW4 core, which included x-ray diffraction analysis, modal mineralogy and rock textural analysis. The data show that the Lower Precipice Sandstone is predominantly composed of quartz arenites. The modal mineralogy of the unit also dominates the bulk composition of the aquifer media, the remainder (typically <5% by weight) is almost exclusively kaolinite. Trace amounts of illite were identified in only one sample.

The petrographic image shown in Figure 12-6 demonstrates the quartz dominated (white grains) nature of the Precipice Sandstone and its high porosity (blue dye). It was established that permeability from core analysis, DST and GW4 production is high for an average porosity of 20%, indicating a high injectivity potential. Table 12-3 summarises the permeability data.

Intrinsic permeability	Value (mD)
Core Permeability (Average)	2,820
Permeability from DST	2,700
Permeability from production test	2,000 to 3,000

Table 12-3 – Permeability summary

12.3.4 AQUITARD PROPERTIES

An evaluation of bounding units is critical to identifying the potential for injection pressure propagation out of the target formation.

The GW4 well intersected approximately 38 m of the Middle Triassic Formation immediately below the Precipice Sandstone. The Moolayember is comprised of predominantly interbedded mudstone and medium-coarse sandstone, and lesser carbonaceous shale, siltstone, mudstone, coal, conglomerate, tuff and limestone. Core data from this interval indicate very low porosity and permeability, averaging 3% and 0.004 mD. Overall, this formation is reported as a major aquitard of the GAB and separates the underlying Clematis Group from the Precipice Sandstone where present (QWC, 2012).

At the GW4 location, the Lower Precipice Sandstone is overlain by 33 m of very fine to fine grained sandstone of the Upper Precipice Sandstone with a much higher proportion of shale and clay. The overall proportion of sand (Net-To-Gross ratio) of the Upper Precipice Sandstone is about 10%.

The Evergreen Formation, which overlies the Upper Precipice Sandstone, is a heterogeneous unit dominated by shale and low permeability fine-grained sandstones with a maximum thickness of over 200 m. Framework composition is quartz-feldspathic with high concentrations of smectitic clays resulting in a net to gross of about 5%. Core analysis suggests that the average permeability of the Evergreen Formation is less than 1 mD for an average total porosity of 7%. Image log analysis on GW4 and GW10 indicates that the Evergreen has a high fracture density. The majority of fractures are cemented and are of limited vertical extent. Geomechanical assessment suggests a low risk of reactivation of the fracture network with only a few fractures predicted to be critically stressed. From WCK_GW4 DFIT results, the fracture gradient is 0.66 psi/ft. At a depth of 1,400 m, the fracture pressure would be 3,030 psi with a maximum Bottom Hole Pressure (BHP) (below 90% of the fracture pressure) not exceeding 2,730 psi. The maximum injection bottom hole pressure will not exceed 2,100 psi during entire injection trial (Phase 1).

Additional CMI-CXD logs and DFITs will be acquired during GW11 (new injection well) drilling to confirm fracturing conditions of the Evergreen Formation at the injection trial site. Hutton Sandstone pressure is currently monitored at the GW3 well to determine any pressure changes during the GW4 production trial and confirm the sealing capacity of the Evergreen Formation prior to the injection trial. In summary, the Evergreen Formation is considered to have a good seal capacity at the GW4 vicinity.

12.3.5 HYDROCHEMISTRY ASSESSMENT

Hydrochemistry data and modelling show that the proposed injectate composition (produced water from the Precipice Sandstone) will not change the groundwater major ion composition. Water-rock reaction, therefore, as a consequence of injection is unlikely to be significant and it is also possible that kinetic factors will inhibit any dissolution-precipitation reactions. Additionally, injectate is predicted to have no significant impact on the aquifer media framework because the stability of both quartz and kaolinite, which is not sensitive to redox conditions. No iron bearing minerals have been unequivocally identified in the aquifer media framework. The concentration of dissolved iron and other minor and trace elements in the groundwater is extremely low and will limit mineral precipitation resulting from a change in redox state within the system. The state of redox disequilibrium may indicate a lack of microbiological activity at depth.

The mildly acidic conditions in the aquifer are likely to be a consequence of the dissociation of the weak acid HS- and CO_2 production from the breakdown of organic matter (CO_2 fugacity is high). Further work is planned to investigate the potential reactions that may take place at the interface between the Upper and Lower Precipice Sandstone. The Upper Precipice Sandstone framework mineralogical composition contains feldspars and higher concentrations of illite, reactive smectites and the iron bearing minerals siderite and haematite. This mineral composition provides greater potential for water-rock interactions, which require evaluation in relation to containment security above the injection target. This work will be included in the April 2014 Injection Feasibility Study, Commitment#30. It will incorporate a one dimensional reactive transport model to compare mineral reaction kinetics and groundwater flow velocity in a radial zone around the injection well. Specifically, the following hypotheses will be tested:

- It is anticipated that groundwater velocity will be faster than mineral reaction kinetics up to a limiting distance from the injection well at which point kinetic reactions will outpace groundwater flow velocity and there could be potential for reaction at the interface; and
- The dilution and mixing effects in the far field environment will potentially limit the reaction between the injectate and the overlying Upper Precipice Sandstone.

12.4 THE INJECTION TRIAL

12.4.1 PROPOSED TRIAL PLAN

The Woleebee Creek Injection Trial will be carried out in two phases:

- Phase 1: Injection trial using Precipice water (three months) starting from Q1 2014; and
- Phase 2: Injection trial using CSG treated water from the 100 ML/d capacity North Water Treatment Plant (NWTP) starting from Q4 2014 (three to six months).

The Phase 1 Trial will involve injection of Precipice water only into the Precipice Sandstone. The proposed plan as illustrated in Figure 12-7 and 12-8 consists of pumping out Precipice water from existing groundwater bore WCK_GW4 into existing pond (WCK Cell 1), transporting via a new ~4.7 km HDPE flowline between WCK Cell 1 and the injection trial site located roughly 3 km north-west of WCK_GW4. Here the Precipice water will be stored and treated at a new preinjection surface facility before being injected via a new injection well GW11. Groundwater pressure response will be monitored in Precipice monitoring well (WCK_GW10) in addition to WCK_GW4 production well as well as other Precipice monitoring wells within the Northern Development Area.

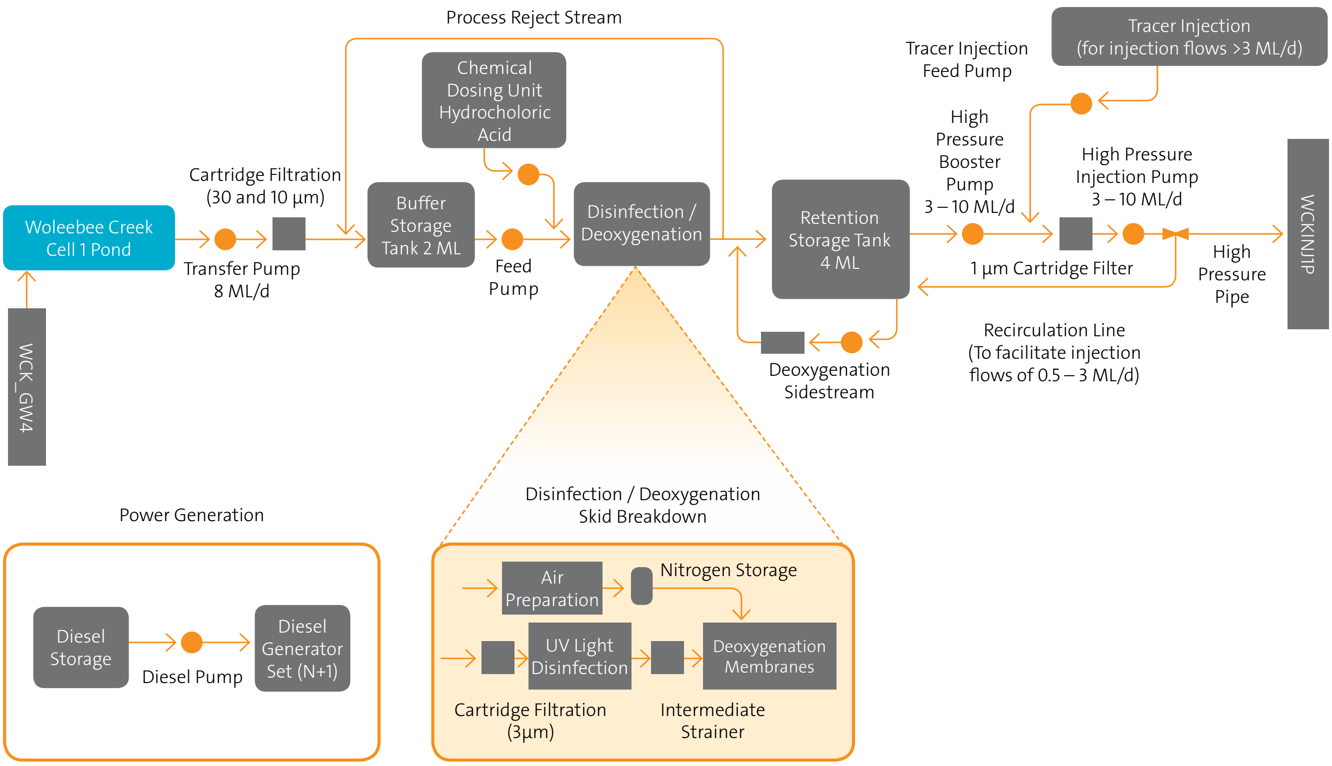

Figure 12-7 – Injection trial surface infrastructure schematic

The trial design laid out in this document will meet all of the key technical objectives of the injection trial to de-risk aquifer injection except for some aspects of the hydrochemistry which will be addressed through Phase 2.

The proposed Aquifer Injection Trial for Phase 1 will comprise:

- Injectate of Precipice water previously produced from the WCK_GW4 well and stored in a pond;
- A targeted injection rate of 8 ML/d with the option to increase rate up to 10 MLD at a maximum pressure (surface) of 600 psi; and
- A total injection volume of 100 ML.

Before injection via the new GW11 well, the Precipice water will undergo:

- Filtration to remove moderate to large particulates as well as potential algal blooms in order to protect pumps, valves, wellhead structures and screens, and assist in the prevention of clogging of reinjection wells;
- Disinfection to minimise the potential for microbial growth not only in the injection well(s) but also in the conveyance pipework;
- De-oxygenation prior to injection to prevent corrosion and reduce DO to match the reducing conditions of the Precipice Sandstone; and
- Pumping at high pressure into the Precipice Sandstone via the WCK_GW11 injection well.
- Subsurface facilities to include:
    - A purposely drilled new injection well (GW11);
    - An existing groundwater monitoring well (GW10) which will be used to monitor near field pressure and hydrochemistry of the injection trial; and
    - Monitoring with existing groundwater wells in all aquifers in the hydrogeological sequences to identify any pressure connections.

Figure 12-8 – Woleebee Creek trial layout

12.4.2 SUBSURFACE INFRASTRUCTURE

A new injection well (WCK_GW11) is planned to be drilled in October 2013 to the following design and construction requirements:

- Design injection rate of up to 15 ML/d with 20-year lifecycle;
- Inert 7" casing to maximise downhole injection rate and meet Queensland regulatory requirements;
- Inert sand face completion to comply with relevant regulatory legislations and regulations;
- Downhole and wellhead pressure and temperature gauges for monitoring variations of pressure and temperature during and after injection tests; and
- Ability to run a Production Logging Tool (PLT) during injection trial to assess heterogeneity of the Precipice Sandstone.

12.4.3 SURFACE INFRASTRUCTURE

The overall surface facility for the injection trial (Phase 1) is illustrated on Figure 12-8 and will include:

- Piping
  - A flowline (approximately 4.7 km HDPE of DN315 SDR17) site to transport up to 8 ML/d Precipice pumped from WCK Cell 1 to the injection trial;
  - Flowline (from WCK Cell 1) outlet;
  - Below ground DN315 PE100 PN10 interconnecting piping;
  - Above ground DN200 carbon steel pipe (epoxy coated) from the high pressure pumps to the wellhead;
  - Out of water specs line to 2 ML tank; and
  - Recirculation line from downstream of high pressure pump to 4 ML tank.
- Filtration
  - Upstream Filtration (before buffer storage tank): 30 and 10 micron upstream cartridge filtration (rental);
  - Midstream Filtration (before UV treatment): 3 micron cartridge filtration; and
  - Downstream Filtration (before injection High Pressure Pump): 1 micron cartridge filtration.
- Storage Tanks
  - 2 ML Water Buffer Storage Tank;
  - 1 x 4 ML Retention Storage Tank; and
  - 1 x Clean In Place Storage Tank.

- Container 1 – GTM and UV treatment
  - UV light disinfection
  - Vacuum gas transfer membrane (GTM) deoxygenation system, incl. additional GTM for side stream;
- Container 2 – compression and motor control centre
  - Nitrogen and air generator
  - Motor control centre (treatment facility)
- Main Pumps
  - Low pressure feed pump (duty/duty assist) (before treatment facility)
  - Downstream booster pumps (duty/duty assist) (after 4 ML)
  - High pressure injection pumps (duty/duty assist)
  - Sidestream pumps
  - CIP pumps
  - Vacuum pumps
  - Chemical dosing pumps (HCL, sodium bisulphite, sodium bicarbonate)
  - Tracer injection feed pump
- Chemical dosing storage bund
  - HCL (Phase 1) – IBC arrangement
  - Sodium Bisulphite (Phase 1 and Phase 2) – IBC arrangement
  - Sodium bicarbonate (Phase 2 only) – Hopper arrangement
  - Additional sodium bisulphite dosing storage (located on side stream from retention storage tank)
- Additional switch/control room/container (for operator)
- Power generation (likely three 800 kVa gensets (2 duty/1 standby) complete with 30 kL diesel storage facility).

It is anticipated that the treated CSG injection trial (Phase 2) will utilise the majority of infrastructure deployed for Phase 1.

A key principal for the engineering infrastructure is to try and use mechanical treatment methods in preference to chemical dosing. This not only avoids the addition of chemicals to the aquifer but reduces the risk of chemical spills and provides a safer operational environment.

12.4.4 SCHEDULE

Figure 12-9 presents the schedule to deliver the trial by the target date of November 2013. Also presented on the schedule is the timing for the Phase 2 trial of treated CSG water but this is dependent on the commissioning and operation of the Northern WTP.

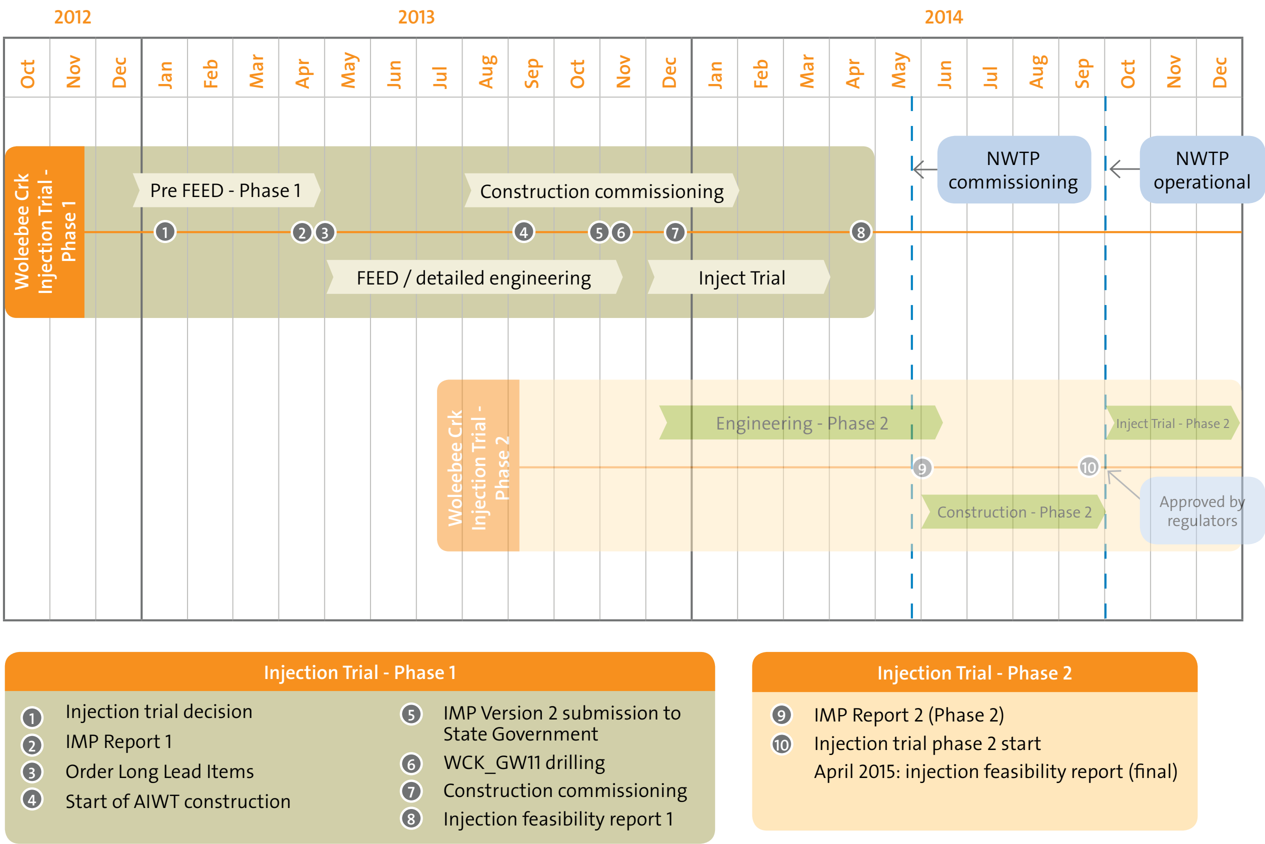

Figure 12-9 – Injection trial schedule

12.5 RISK MANAGEMENT

An essential element of the implementation of injection trials and the design of full scale systems is understanding and objectively evaluating potential system risks. The identification and management of risk determines whether a project is technically and economically feasible. The level of risk is often dependent on the use of the source aquifer (i.e. a potable supply aquifer clearly has higher risks associated with it than a saline formation).

Preceding sections describe the technical information that forms the foundation of the risk assessment. Table 12-4 summarises and ranks the hazards, preventative measures and risks. The analysis is in conformance with the procedure recommended in the Australian Guidelines for Water Recycling: Managed Aquifer Recharge (July 2009). Overall the technical assessments show that inherent risks are low to minimal and any operational risk can be mitigated with adequate system controls and normal environmental management practices.

	Hazard	Consequence	Mitigation incorporated into design	Residual risk
Operational	Excessive bore or aquifer clogging	System doesn't meet performance objectives	• Filtration to remove particulates • Biocides to inhibit bacterial growth	Low
	Loss of mechanical bore integrity	Trial cancellation	• Well designed to DNRM and BG Well Standards	Negligible
	Mechanical failure in surface infrastructure	Trail cancellation postponement	• Systems designed and operated under Australian and BG/QGC engineering standards	Low
Hydrochemistry	Elevated concentrations of microbiological parameters, salinity, nutrients, chemicals, radionuclides	Injectate does not meet aquifer hydrochemistry and impairs aquifer or adversely impacts users	• Pre-treatment system to remove bacteria, salinity (if required), oxygen • High and High-High alarm on PLC to stop injection of out of spec water	Negligible
Environmental Management	Chemicals and fuel	Spills and leaks affecting the environment	• Minimise chemical dosing systems • Implement best practice environmental management	Negligible
Fluid risk interaction	Metals or other constituents mobilised from rock matrix	Adversely affects aquifer hydrochemistry or adversely impacts users	• Hydrochemical modelling shows no mobile metals in rock matrix. Continual real-time pH monitoring to ensure that low pH water is not injected	Negligible
Hydraulic Impacts	Pressure induced fracturing	Induced aquifer connectivity	• Geomechanical modelling has confirmed fracturing pressure – injection pressure to be kept under fracturing pressure with HIGH alarm and HIGH-HIGH process stop	Low
	Land movement	Ground movement causing impacts to surface drainage, infrastructure and aquifer connectivity	• Differential movement monitoring technologies to be assessed	Low
	Aquifer dissolution	Well bore failure	• Detailed geochemistry and mineralogy show rock matrix is non-reactive	Negligible
Impacts on users	Pressure impacts	Impacts on groundwater dependent ecosystems	• Modelling identified no significant far field impacts, to be confirmed with more detailed model. Far field groundwater monitoring will be in place with real time monitoring to confirm non-impact during operation	Negligible
	Hydrochemistry	Waterlogging and drainage impairment	• None – no feasible pathway for increased water pressure to cause water level rise at surface	Negligible
	Hydrochemistry	Water quality changes to users	• Pre-treatment to ensure suitable injectate hydrochemistry with HIGH alarm and HIGH-HIGH process stop to ensure no injection of out of spec water	Negligible
Greenhouse gases	Power use	Increase in greenhouse gas	• None – insignificant additional greenhouse gas emissions	Negligible

Table 12-4 – Risk management matrix

12.6 CONCLUSIONS

The target formation for the injection trial is the Precipice Sandstone at Woleebee Creek. Evaluation of the Precipice Sandstone at this location has been subject to an extensive data acquisition process. Associated analysis and modelling provide the framework necessary to evaluate the formation's injection potential under five key categories, as listed below.

Injectivity Data

Collected to date indicates that the Precipice Sandstone aquifer in the Woleebee Creek area has high hydraulic conductivity (about 5 m/d) and is well-connected over large distances. Production and pressure data show very good conductivity. These results suggest that the Precipice aquifer will be able to accommodate significant volumes of injected water. Analytical studies have shown that an appropriately designed vertical injection well could be expected to deliver sustained injection rates of 10 to 20 ML/d. The aquifer properties will be better defined following completion of the production trial, which is currently underway.

Containment

The Lower Precipice Sandstone is overlain by 33 m of Upper Precipice Sandstone consisting of very fine to fine grained sandstone with a high proportion of shale and clay. The Evergreen Formation, which overlies the Upper Precipice Sandstone, is a heterogeneous unit dominated by low permeability shale, siltstone and fine-grained sandstones with a maximum thickness of more than 200 m. The Evergreen Formation is considered to be a robust top seal and high pressure capacity. This has been confirmed by core analysis. The underlying Mooayember Formation comprises up to xx of low permeability.

Capacity

The longest shut-in period experienced for GW4 during the production trial has provided an investigation radius of 4.5 km in well test analysis and with no observable boundaries. This provides a minimum tested zone of pressure influence of 1.32 km^3 but the final capacity is expected to be much larger. Well testing to date has been limited and a more comprehensive testing program is planned featuring a longer shut-in period to better estimate reservoir capacity by increasing the radius of investigation.

Hydrochemical Compatibility

The initial trials with Precipice Sandstone produced water will provide a close match with the groundwater in the target formation. There may be minor changes to the physico-chemical parameters (pH and redox) of the produced Precipice water due to depressurisation and exposure to the atmosphere, which will be confirmed prior to injection. Injected water will have pH and redox parameters within the acceptable range compared with the receiving groundwater hydrochemistry. There is not anticipated to be any significant water/rock interaction which would inhibit test performance.

Environmental Impact

The injection water will be treated to ensure that no contaminants will be introduced into the aquifer, including disinfection. No water users are predicted to experience impacts from the injection trial. In the vicinity of the trial, there are no environmental features which could be subject to pressure or water quality impacts. QGC will monitor local community bores and, prior to the trial, will have installed a network of deep aquifer monitoring bores to the north of the injection site.

The status of the Commitments relevant to reinjection is as follows:

#	Department Condition		Description	Completion date	Status
	Pre-Dec 2012	Post-Dec 2012			
27	49c		Completion of first Injection Management Plan (Precipice Water)	February 2013	● (Commitments completed)
28			Construction of investigation, monitoring and trial injection production bore	April 2013	● (Commitments completed)
29			Update for Stage 3 WMMP – Progress Report on IMP. Drilling of injection well WCK_INJIP	June 2013	● (Commitments completed)
30			Feasibility Study Report (part 1 and part 2)	April 2014/April 2015	● (Firm deliverables for that month)

● Commitments completed
○ Commitments work in progress
△ Evergreen Commitments
● Firm deliverables for that month

Further actions which will be undertaken primarily include the incorporation of data from the ongoing hydrogeological drilling program in the north to update the subsurface characterisation.