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10.0
Ground motion monitoring and management plan

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10.1 INTRODUCTION

Approval for the QCLNG Project included conditions relating to subsidence. The premise is that, as CSG and associated waters are extracted, formation pressures are lowered. A degree of subsidence at surface may occur because the pressure decrease allows for compaction of depressurised formations beneath the surface. Such ground motion has a very small potential to impact surface waterways and MNES, such as springs.

QGC has commenced a series of programs to define a baseline and to monitor potential subsidence. Presented below is a summary of the strategy in relation to how this ground motion is to be measured by QGC in order to satisfy the relevant federal conditions. A short summary of the proposed ground motion monitoring program that is to be implemented by QGC moving forward is also provided.

It is noted that re-injection or groundwater repressurisation activities have the potential to cause ground heave. Where such CSG water management measures are put in place the ground motion monitoring program detailed below is intended to satisfy any monitoring needs in this regard.

10.2 INDUSTRY COLLABORATION

QGC and the other industry proponents (Santos, Arrow Energy and Origin Energy) have jointly defined a ground motion program at both regional level and local tenement level.

QGC and other Surat Basin CSG proponents cooperatively, scoped, tendered and commissioned a basin-wide radar satellite imagery survey in 2011 using available data for the period 2007 to 2011. This provided a pre-production baseline across all QGC tenements and has enabled assessment of any current trends in surface deformation to be assessed prior to production decisions.

Subsidence modelling by Golder Associates for QGC (completed as part of the QCLNG Environmental Impact Statement) predicted only minor subsidence for the QGC tenements (of less than 10 cm) for the life of the project. Geoscience Australia concurred that this level of subsidence was unlikely to be an issue with EPBC listed springs.

Approval Condition 65 requires QGC to provide a surface geodetic baseline survey (preferably pre-production) and to then be able to regularly re-survey during the production phase. Data is utilised to determine CSG extraction-related subsidence, review surface drainage changes to be undertaken and determine if noted changes may impact EPBC listed springs.

Condition 65: CSG proponents have collaborated to develop an effective baseline data collection and monitoring strategy.

10.3 FEDERAL APPROVAL

Following the collective review of other options through which ground motion could be measured the use of Synthetic Aperture Radar (SAR) technology was identified as the most effective way to quantify deformation. Details on SAR methodology and imagery processing are detailed below.

The proposed methodology and willingness of CSG industry proponents to work collaboratively were explained in correspondence with SEWPAC in May 2011. Approval was received on 10 August 2011 for acquiring baseline geodetic data through the use of radar satellite imagery. The approval acknowledged that the Expert Panel had 'noted that the proposed approach for acquiring satellite data seems reasonable for the development of a pre-CSG impact geodetic survey.'

QGC has since progressed with baseline monitoring and planning for ongoing monitoring.

10.4 NATURAL AND ANTHROPOGENIC CONSIDERATIONS

Ground motion data collection and processing methodology does not differentiate between natural processes, anthropogenic activities or CSG operations. These types of ground motion include:

- Rainfall effects on shallow soils – potential swelling
- 'Wetting and drying' effects on soils due to seasonal change
- Vegetation growth or removal
- Erosion, particularly on poorly vegetated hill slopes, and subsequent valley floor sedimentation (uplift)
- Natural long-term basin-wide compaction in both shallow and deeper formations
- Anthropogenic activities – the effects of ploughing fields, cropping, grazing and general land development
- Existing water use (e.g. irrigation, town supply, mining)
- Industry cumulative impacts including existing water use.

Each potential factor must feature in any data interpretation and analysis.

10.5 PREVIOUS STUDIES

Water extraction from coal seams during CSG production lowers formation pressures in the wider WCM and associated formations. On a local scale, this means reduced water pressures in fractures and rock pores. Changing pore pressure increases a formation's vertical effective stress and the response is settlement as pore spaces are 'compacted'.

Golder Associates was commissioned in 2010 to evaluate potential subsidence related to coal seam gas extraction and to study the effects of increased vertical stress and potential settlement rates. This utilised the groundwater model findings (Golder GEN1 Model) to determine maximum drawdowns (changes in formation pressure). In summary, their findings estimated the following WCM settlement rates expected for the maximum reported drawdowns modelled:

- Central Gas Fields: 0.08 m
- Northern Gas Fields: 0.18 m
- Southern Gas Fields: 0.14 m

The calculated maximum subsidence for an adjacent sandstone formation was less than 5 mm for the Springbok Sandstone. Considering the above a maximum expected settlement of 3 mm per year is expected. Based on this, and that depressurisation of the formation is to occur slowly no rapid ground motion is expected. Very small-scale above-ground motion (subsidence) is expected but may prove impossible to define given natural processes or anthropogenic activities which may mask such small settlement rates. The report is attached as Appendix R.

QGC commits to repeating ground motion modelling using the outputs of the QWC cumulative groundwater model.

10.6 DERIVING TRIGGER THRESHOLDS AND RESPONSE ACTIONS

Various natural processes or anthropogenic activities are expected at different scales across the areas of interest. Once datasets are large enough to be statistically valid, the following process is proposed to derive trigger values:

- Quantify the range of ground motion related to natural processes
- Quantify the range of ground motion related to anthropogenic inputs
- Merge findings to develop an area-specific ground motion range, represented as upper and lower control limits using standard statistical methods
- Utilise the upper and lower control limits defined as trigger values – any recorded specific-area movement outside those values will lead to a detailed area review.

This work is scheduled for completion by October 2013 and, when specific trigger thresholds can be calculated, QGC will finalise its management response process). The methodology will focus on exceedance investigations and subsequent response actions. A preliminary risk assessment and response process for ground motion has been developed and is detailed further in Section 12.10.

10.6.1 POTENTIAL PHYSICAL DEFORMATION TRIGGERS

While expected ground movement is forecast to be small, QGC is aware that this may still directly affect surface features. QGC will also assess and monitor natural settings and other man-made infrastructure to assess direct impacts.

QGC has tentatively identified the following deformation events that constitute a physical deformation trigger:

- Movement that affects surface water drainage
- Movement in and around MNES or areas identified as a sensitive receptor
- Movement in and around existing surface infrastructure
- Defined cracking (cracks in roads etc.)
- General ground motion.

The proposed ground truthing and surface water/hydrologic/ecologic assessment works are discussed further in Section 10.14.4.

10.7 AN ADAPTIVE MANAGEMENT FRAMEWORK

QGC proposes an area-specific adaptive management approach to the development and implementation of ground motion trigger values related to CSG production activity. Natural processes, anthropogenic activities and CSG activities will vary in time and space across the tenements, potentially resulting in the triggers developed for one area being invalid elsewhere. By adapting and modifying triggers for specific areas and relating them to specific activities, more valid trigger values can be derived and responses to trigger level exceedance managed more appropriately.

This adaptive approach requires regular trigger redevelopment and revision for existing and new operational areas to ensure:

- Risk levels are re-assessed regularly against relevant parameters (e.g. land use, production etc.) using a consistent approach across all operation areas
- Assigned triggers are current and relevant to each area's activities and ground conditions
- Elevated risk (production or re-injection) areas receive additional trigger level validity reviews.

10.8 INSAR THEORY

High resolution ground surface radar satellite imagery collects data for a number of applications, including ground motion measurement, using a satellite's distance from the Earth's surface taken at set time intervals (refer Figure 36). Changes indicate ground movement and measure annual vertical movement at a millimetre scale.

Datasets compiled for the baseline ground motion assessment comprised 31 Advanced Land Observation Satellite (ALOS) frames which, in turn, contain between 14 and 21 images. Each frame covers 70 km by 70 km with 600 to 800 quality data points per square kilometre. A continuous processing technique then merges and calibrates them.

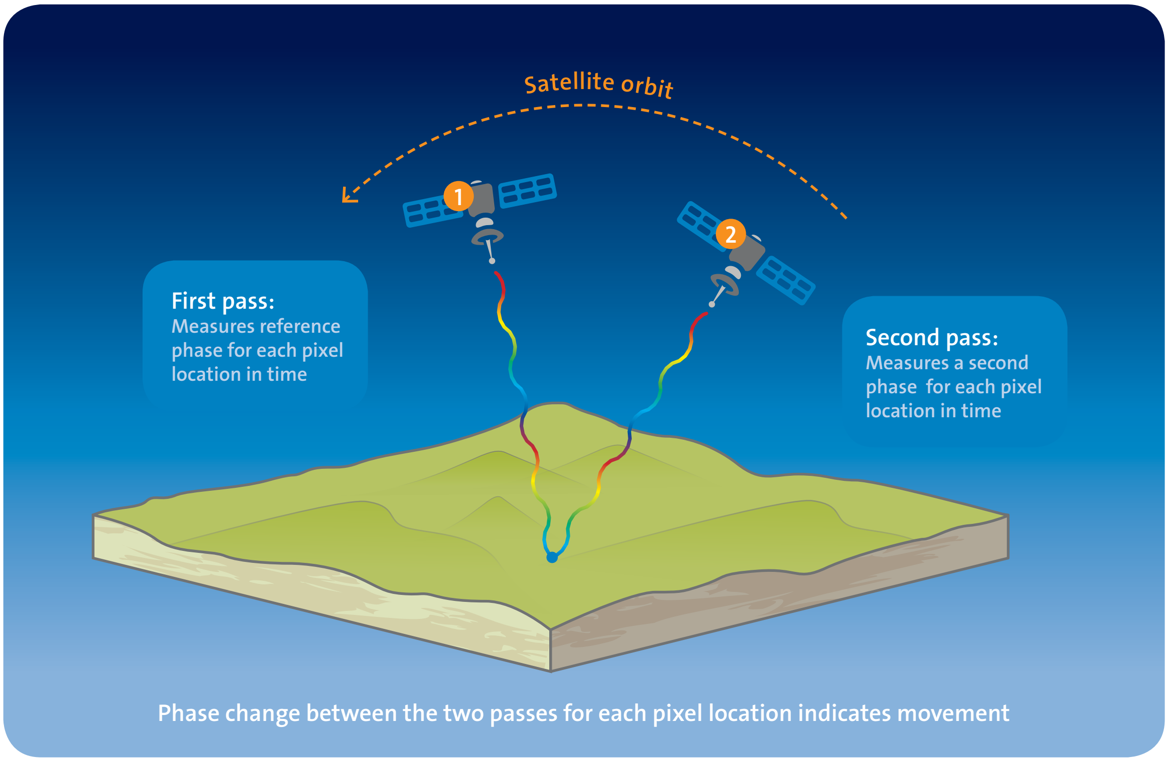

Figure 36 – Basic InSAR principles in action

10.9 GROUND MOTION BASELINE PROGRAM

10.9.1 PROGRAM SCOPE

An analysis of historical satellite data derived from Synthetic Aperture Radar (InSAR) technology over four years (January 2007 to January 2011) for QGC's tenements was prepared by data acquisition and processing specialist, Altamira Information. Data purchasing and processing was done via industry collaboration with Altamira Information providing the completed work for each proponent's tenements.

10.9.2 CURRENT STATUS

The baseline program is currently underway. Because of the scale of coverage, data delivery was broken into four area-related tranches for processing. Two data tranches have been delivered, a third was due in March 2012, and the fourth in May 2012. Upon program completion, Altamira Information will provide detailed program findings and QGC will make them available.

A preliminary summary figure of the baseline program findings to date has been provided by Altamira Information and is attached as Appendix S.

10.10 GROUND MOTION: ONGOING MONITORING PROGRAM

10.10.1 PROGRAM SCOPE

QGC, in collaboration with other industry proponents, is also undertaking ongoing ground movement monitoring:

- Establishment of pre-production (baseline) conditions across QGC tenement areas where production has yet to commence
- Enabling of future ground movement comparison against the baseline program
- Provision of an effective method for assessing potential future ground motion and any cumulative impacts.

10.10.2 PROPOSED SCOPE OF WORKS

The ongoing ground motion monitoring process includes:

- Satellite selection and engagement for consistent coverage and quality data
- Definition of the required satellite coverage (rates, resolution etc.)
- Data processing and data delivery within the desired timeframes.

Satellite data acquisition rates and timings will be in line with service provider advice to achieve QGC's desired resolution and precision requirements, such as:

- A satellite pass every 24 days for the first year to build the data 'stack'
- A satellite pass every 48 days for the following 18 months to maintain data precision.

This schedule is expected to meet ongoing monitoring requirements but, should the resolution and precision delivered not provide desired results, the program will be redefined.

It is QGC's intention that any modification to the sampling frequency across any area, including in relation to MNES, as defined above will only occur when:

- A suitably sized and verified / validated data set is available that accurately depicts long-term ground motion has been compiled
- This dataset has enabled site specific trigger values to be developed
- That the data collected has not exceeded a trigger level defined
- That a site specific assessment of the area of interest has been completed, and a risk profile established that demonstrates a reduction in sampling frequency will not adversely affect the effective monitoring of the environment of interest.

QGC commit to the submission of a full assessment, risk profile and findings to SEWPAC for review/comment and approval prior to any amendments to the sampling frequency being implemented.

10.10.3 CURRENT STATUS

CSG proponents are reviewing tenements and areas where ongoing monitoring is required. Altamira Information is preparing a formal proposal and QGC expects commissioning of the work in Q2, 2012.

10.10.4 DATA DELIVERY

Baseline and ongoing ground motion data processing will be based on current industry best practice and be in two forms:

- Calibrated global maps showing mean deformation rates, produced as Geotiff files in a defined ground projected coordinates system which is importable into any GIS software for overlays of other spatial data (geology etc.)
- Time series vector files demonstrating location-specific vertical ground movement and including information on data point locations, measurement timings, motion, data quality and deformation values for each acquisition date.

In addition to this the data acquisition and processing specialist will deliver a short report unique to QGC with each data delivery summarising and detailing the following for the study area:

- The scope of works and areas of interest
- The satellite used and methodology applied
- The available dataset
- The results of the study
- Detailed analysis of areas of significant motion
- Detailed analysis of any areas of interest that are highlighted by QGC, where practicable.

10.11 DATA ASSESSMENT

Time series data demonstrating vertical ground movement for a location will be provided to QGC to evaluate 'raw' data for appropriate applications. The first step in the proposed data assessment process is to categorise QGC's tenement areas:

- Category One: Areas within 20 km of EPBC listed springs, and major ephemeral or perennial waterways, or high bore water use
- Category Two: CSG production areas (both QGC and non-QGC), proposed re-injection areas
- Category Three: high population areas.

Upon data receipt, QGC plans to overlay areas with the latest data package. Total ground motion for each Category One, Two and Three area will then be assessed.

Measurements with high degrees of motion (> 16 mm/yr) will be assessed and 'one off' motion measurements – those surrounded by other low/no ground motion readings – will be discarded.

High motion measurement groups will be evaluated with reference to natural and anthropogenic characteristics (detailed as part of the trigger value process). Findings will determine an appropriate path of action.

10.12 GROUND MOTION REPORTING

Data packages will be submitted from Altamira to QGC on a 12 month or 18 month basis – a timeframe that reflects the requirement for Altamira to 'build' a valid dataset (stack) prior to processing.

Considering the expected long timeframes involved in any ground motion expression (as highlighted in Section 10.5), QGC has implemented the following reporting framework. This reporting plan has been developed in order to ensure data packages are reviewed regularly as soon as they become available from Altamira, and assessments are forwarded to the appropriate authority in a timely manner:

- Ground motion interim progress reports to be submitted annually (commencing in Q3, 2013, a year after the start-up of ongoing monitoring) detailing monitoring program progress, alignment with the monitoring and management plan (including support programs) and available preliminary findings
- Detailed ground motion assessment report generated at five-year intervals, with the first baseline report delivered in Q3, 2013.

10.13 IMPLEMENTATION SCHEDULE

QGC proposes the following monitoring and management plan implementation:

- Ground Motion Baseline Program:
  - Data collection and processing – April 2013
- Ground Motion Baseline Program:
  - Assessment report preparation and delivery – Q3 2013
- QGC Ground Motion Monitoring and Management Plan:
  - Report preparation, preliminary data analysis, development of support programs – April 2013
- Ground Motion – Ongoing Monitoring:
  - Annual data collection and processing – July 2012 ongoing at yearly intervals.
- Ground Motion Interim Reports:
  - Q3 2013, Q3 2014 etc.
- Ground Motion Assessment Report:
  - Summary report as provided by the data acquisition and processing specialist – Baseline assessment report scheduled for completion Q3 2013, ongoing at six year intervals.

QGC wish to note once again that the rates and magnitude of deformation are expected to be small given the modelled WCM settlement showing only 0.08 m to 0.145 m given the maximum depressurisation expected. Given these very low settlement estimates any reflection of this settlement at surface is expected to occur very slowly over long timeframes. This has been one of the fundamental reason behind the selection of the annual interim reporting periods and the five year detailed reporting period.

10.14 SUPPORT PROGRAMS

10.14.1 DATABASE DEVELOPMENT

Using InSAR will potentially generate very large point datasets. The baseline program alone could deliver data equivalent to 90 million rows, with x, y, z and time series components for each row. Proposed future monitoring with potentially higher resolution satellites adds considerably to expected data volumes. Currently this involves manual extraction and viewing of data from multiple very large (often > 1 Gb) delivered DBF files.

To manage such large datasets and enable efficient data querying, development of a purpose-built relational database is proposed. An Oracle database system was selected for development by an external service provider (SARDAT) for efficient dataset storage, filtering and selection for export to mapping software (e.g. ArcGIS). Industry proponents are together undertaking this database acquisition and implementation so that all data relating to ground motion will be stored in identical formats, with standardised data querying, assessment and reporting needs.

As a server-based system, operating under existing Oracle licensing conditions, it will have a custom-built front-end (.Net) and a series of functions and query tools. The data model uses a suite of Oracle functions, SQL scripts and views of normalised tables for efficient data – and output functions will take selected data to other applications.

Commissioning is expected in Q4, 2012, with delivery and implementation planned to coincide with baseline program completion.

10.14.2 GROUND TRUTHING

The proposed ground truthing program consists of two key components:

- Developing a system to link the InSAR satellite data to relative ground levels such as m RL
- Using ground survey to confirm and detail any ground motion established by the InSAR monitoring.

Currently QGC proposes to use the existing ground survey networks used for infrastructure construction linking InSAR results to these relative ground levels.

The second component uses ground surveys to verify, validate and monitor instances of ground motion detected by the InSAR program. This process is discussed in more detail in the exceedance response Section 12 and in sections below.

QGC and industry proponents are in discussions with the Geoscience Earth Monitoring Department of Geoscience Australia (GA) to establish a comprehensive ground survey network across the Surat Basin, including the addition of ground survey points to the current network.

10.14.3 SUBSURFACE TO SURFACE DEFORMATION – MONITORING AND MODELLING

CSG generation involves lowering formation water pressures. On a local scale, that water removal results in reduced water pressures in fractures and rock pores, reflected in pressure measurements and as a static water level change. Conversion of pressure changes to vertical effective stress changes and potential deformation (subsidence) has been completed. Expected WCM settlement rates for the maximum modelled drawdowns reported range from 0.08 m to 0.145 m (refer Section 10.5) with the calculated maximum subsidence for an adjacent sandstone aquifer less than 5 mm for the Springbok Sandstone.

Expected changes in vertical effective stress rates, due to formation water pressure decreases, results in very low subsidence rates. However, this must be reconciled continually to ensure accuracy. Once suitable groundwater level/pressure datasets are compiled, QGC will complete:

- A desktop study (once valid datasets are available) of actual against modelled pressure values and accuracy evaluation of the groundwater model from a pressure perspective.
- Calculation re-runs to derive the settlement/deformation rates as defined by Golder Associates (2010), utilising the desktop study findings. This refines expected rates and validates the pressure regime defined by the groundwater model as a predictive tool.

Additional monitoring needs will then be identified. Strain gauges or exostensiometers may be used, although instrument sensitivity to such small movements needs evaluation prior to program implementation.

With regard to ground motion modelling, it should be noted that QGC are only privy to ground motion data for their tenements and not beyond. As such, any ground motion modelling will in the first instance be linked to QGC's internal numerical groundwater modelling programs. Given the GEN2/GEN3 model developed by QGC is more advanced than that provided by QWC (dual phase etc), QGC believe that ground motion modelling utilising data from the GEN2/GEN3 model would be more accurate, and better represent the tenement environs.

However, in the interests of thoroughness, QGC commit to repeat ground motion modelling using the outputs of the QWC cumulative groundwater model. It should be noted that, given the limitations of available ground motion data to QGC tenements only, any use of the QWC model and associated data in the ground motion program would be limited to QGC tenements. Should ground motion data become available from other proponents, then a wider application of the QWC cumulative groundwater model and links to the ground motion program could be explored further.

10.14.4 ASSESSMENT OF HYDROLOGIC IMPLICATIONS

QGC expects no discernible hydrologic implications due to CSG extraction, based on deformation rates established by Golder Associates (2010). However, the following staged approach to baseline assessments in relation to MNES and natural environs will provide more detail where practicable.

Stage 1

- A desktop study of all perennial surface waterways on and adjacent to tenements of interest, including system mapping where practicable
- A topographic and surface water modelling study to identify areas of potential drainage line changes.

Stage 2

- If required, using the desktop results QGC proposed a field based surface water/hydrologic/ecologic assessment of the relevant surface waterways within its tenement areas. Through this process sensitive surface water bodies and waterways will be identified and quantified. Once identified these features will be surveyed in detail by survey field teams. The aim is to identify permanent ground motion station locations adjacent to valid potentially sensitive waterways.
- A desktop study of potential impacts on aquifer systems from deformation rates described by Golder (2010). The aim is to establish if this impacts aquifer flow regimes and potentially impacts on aquifers above the WCM.

10.14.5 CONCEPTUAL ASSESSMENT PROCESS – DEVELOPMENT

As noted in Section 10.13 the baseline program data delivery is due to be finalised with Altamira shortly. Considering this QGC have begun to develop high level conceptual approaches to how this data could best be evaluated relative to the protection of MNES and other sensitive receptors and surface water bodies within QGC tenements.

An indicative outline of possible approaches being considered is presented below, and is split into two paths. The first approach path being considered would involve the identification of sensitive areas within QGC tenements via a GIS desktop assessment.

The types of environments that could be considered 'sensitive' include:

- Areas related directly to MNES
- Areas that contain sensitive ecological environs such as wetlands, streams, or other small springs
- Areas where the land use is related to specialised cropping or other specialised agricultural use
- Areas sensitive to erosion or contain unique shallow soil environments
- Areas where infrastructure or residential housing is concentrated
- Selected CSG operations areas.

The intention would be that, following data collection and evaluation and ground truthing, these areas would form the reporting component of any future ground motion assessment works. QGC would review and assess these specific areas in detail for ground motion to determine and evaluate impacts should they occur.

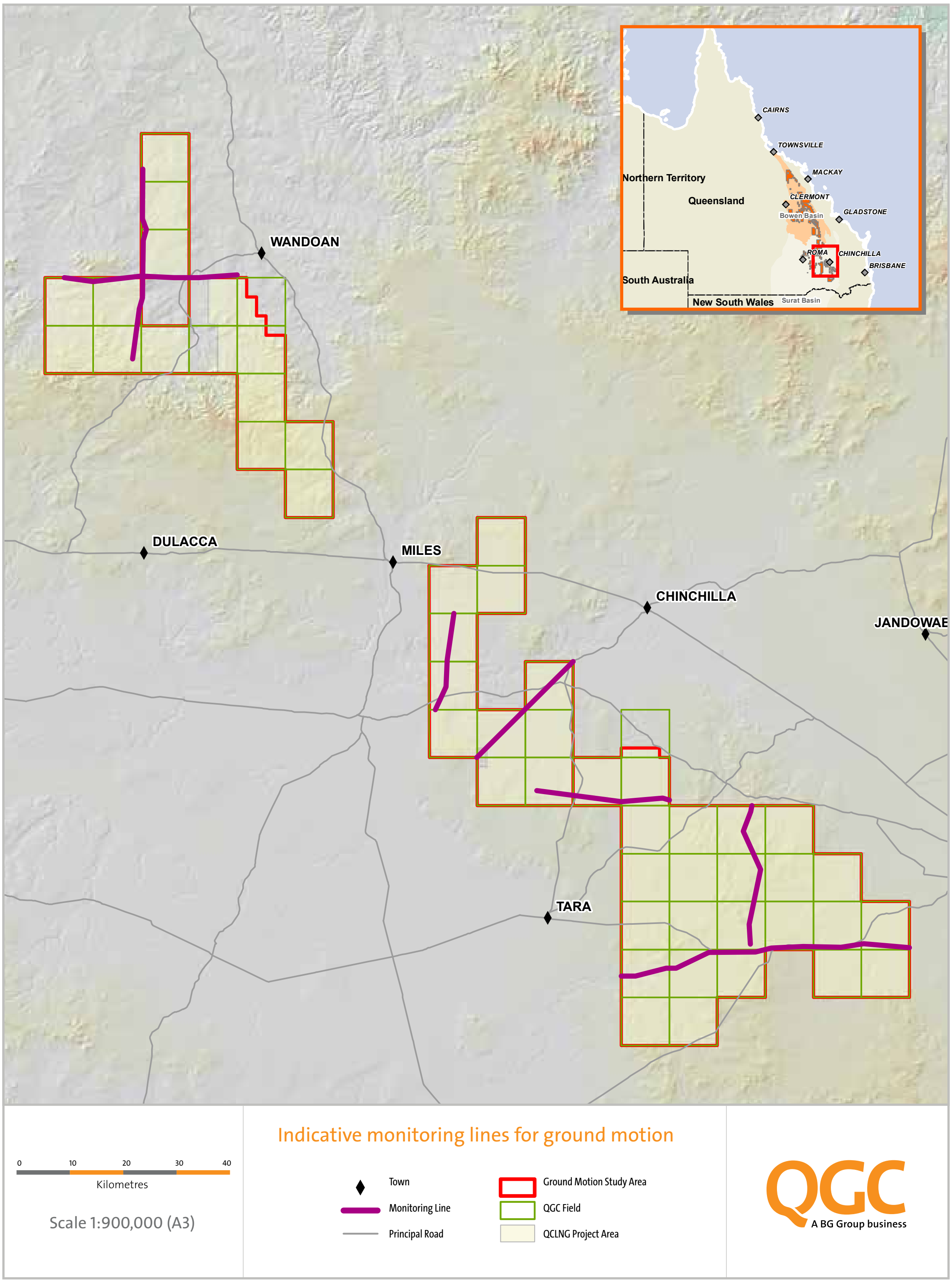

Figure 37 – Indicative monitoring lines for ground motion

The second approach path being considered is the use of monitoring 'section' lines through the tenements. Ground motion would be plotted against these section lines and any motion reported accordingly. A preliminary assessment of available geophysical section lines has been completed and a number of potential monitoring section lines have been identified. The section lines selected are based on geophysical (seismic) section lines that QGC have completed as part of subsurface assessment works. This approach to the location of the section lines has been undertaken in this way as the geophysical work enables any reported ground motion to be evaluated against valid geological structural data.

The intention would be that these monitoring 'section' lines would form the reporting component of any future ground motion assessment works. QGC would review and assess these specific lines in detail for ground motion to determine and evaluate impacts should they occur.

Indicative monitoring 'section' lines that could be considered are presented in Figure 37.

Further evaluation of these options will be considered in the Ground Motion Monitoring and Management Plan that will be submitted in April 2013.

10.15 SUMMARY

QGC expects only small-scale subsidence to occur with no discernible hydrological implications due to CSG production.

CSG proponents (Arrow Energy, Origin Energy, QGC and Santos) have collaborated to initiate a program of utilising InSAR technology to quantify land surface deformation, an approach approved by SEWPAC. Baseline data collection has commenced and a baseline data assessment report has been commissioned by each proponent. QGC is working with other proponents and an ongoing monitoring program is being developed and is expected to commence in late 2012. A detailed Ground Motion Monitoring and Management Plan is currently being developed.

Commitments	Target completion date
Completion of Ground Motion Monitoring and Management Plan	April 2013
Completion of Baseline Data Review Report	April 2013
Assessment of hydrological implications of ground motion	April 2014
Derivation of trigger thresholds and finalisation of response actions	April 2013
Submission of ground motion progress reports. October 2013 report will include ground motion modelling using the outputs of the QWC cumulative groundwater model	October 2013 and annually thereafter
Submission of ground motion assessment report	October 2015 and thereafter at three-yearly intervals