A BG Group business

10.0 Ground motion monitoring and management

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#	Department Condition		Description	Completion date	Status
	Pre-Dec 2012	Post-Dec 2012			
22	**65,67**		Completion of Ground Motion Monitoring and Management Plan	April 2013	●
23	**65a**		Completion of Baseline Data Review Report	April 2013	●
24	**65b**		Assessment of hydrological implications of ground motion	April 2014	●
25	**66**		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	△
26	**66**		Submission of ground motion assessment report	October 2015 and thereafter at three-yearly intervals	●

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

10.1 INTRODUCTION

While at a local scale ground motion impacts from CSG water extraction on surface waterways and springs is unlikely, QGC is initiating ground motion studies using satellite data to identify baseline conditions. This work will continue throughout the QGC LNG project's operations phase. Technical studies include a predictive assessment of expected movement using groundwater flow modelling results to investigate how this movement might potentially impact on MNES.

The requirement for ground motion studies is based on the premise that the process of CSG water extraction results in water pressures in the reservoir being reduced. The commensurate change in the stress regime could potentially translate into settlement as pore spaces are 'compacted'. If such ground motion propagates to surface it has a very small potential to impact surface waterways and Matters of National Environmental Significance (MNES), such as springs and nationally important watercourses.

This chapter presents a summary of the Ground Motion Monitoring and Management Plan for the QCLNG project, the full plan is contained in Appendix L. The specific conditions addressed by this Plan are Conditions 65 and 67 (completion of a ground motion and management plan) and Condition 53Be(i)(II) which relates to ground motion aspects of a response plan. It also forms the framework for addressing hydrological implications of ground motion (Condition 65b).

The ground motion monitoring program has been split into two stages:

- The baseline program began by completing an analysis of historical satellite data derived via In-SAR technology for a four year period (January 2007 to January 2011) for the QCLNG tenements; and
- Stage 2 of the ground motion monitoring program consists of the ongoing satellite data acquisition and processing for the QCLNG tenement area for the period 2013 onwards.

The CSG operators in the southern Bowen and Surat Basins, Santos and Origin Energy on behalf of APLNG (hereafter referred to as Origin) and QGC (from hereon jointly referred to as the Proponents) have developed a Joint Industry approach to ground deformation, monitoring and management. This is a requirement of the Proponent's project approvals under the EPBC Act which require the CSG activities to have 'no adverse impacts' to Matters of National Environmental Significance (MNES).

The Proponents cooperatively scoped, tenderered and commissioned a basin-wide radar satellite imagery survey in 2011 using available data for the period 2007 to 2011. This collaboration has continued with further radar satellite imagery collection commissioned in 2012, which together with the 2007 to 2011 survey is intended to build a pre-production baseline across all industry tenements. This is proposed to enable assessment of any current trends in surface deformation not related to CSG to be assessed prior to major gas production commencing in 2014.

10.2 GROUND MOTION PREDICTIONS

The process of CSG water extraction results in water pressures in the reservoir being reduced. In detail this pore pressure reduction translates to an increase in the vertical effective stress the formation is exposed to. The formation response to this change in the stress regime may also result in motion in the form of settlement as pore spaces are 'compacted'. The degree of compaction will be directly related to the geotechnical characteristics of both the reservoir rock and the formations overlaying the reservoir.

The degree of depressurisation that each formation will experience relates directly to:

- The volume of coal in the formation being depressurised;
- The volume of water abstracted;
- The spacing of the seams;
- The hydraulic properties of the interburden within the Walloon Subgroup; and
- The hydraulic properties of the overlying and underlying formations.

A previous study, which examined potential compaction, estimated the following Walloon Subgroup settlement rates for the maximum reported drawdowns modelled for the life of the QCLNG project:

- Central Gas Fields: 0.08 m;
- Northern Gas Fields: 0.18 m; and
- Southern Gas Fields: 0.14 m.

The calculated maximum subsidence for the Springbok Sandstone, which typically lies between 300 and 400 m below ground surface, was less than 5 mm. Based on this, and considering the fact that depressurisation of the formation is expected to occur slowly, no rapid ground motion at the surface is expected. Very small scale (sub mm) above-ground motion (subsidence) may be experienced but may prove impossible to define given ground movement due to natural processes or anthropogenic activities which may mask such small settlement rates.

In an October 2013 Commitment the predictive modelling was redone using the results of the UWIR model. These model results were incorporated into an analytical assessment, together with typical geotechnical characteristics of the formations in the sequence to generate revised deformation rates for the project. The results are repeated in Appendix L.

10.3 DATA ACQUISITION

Following an evaluation of 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 potential deformation of the land surface over the Surat Basin.

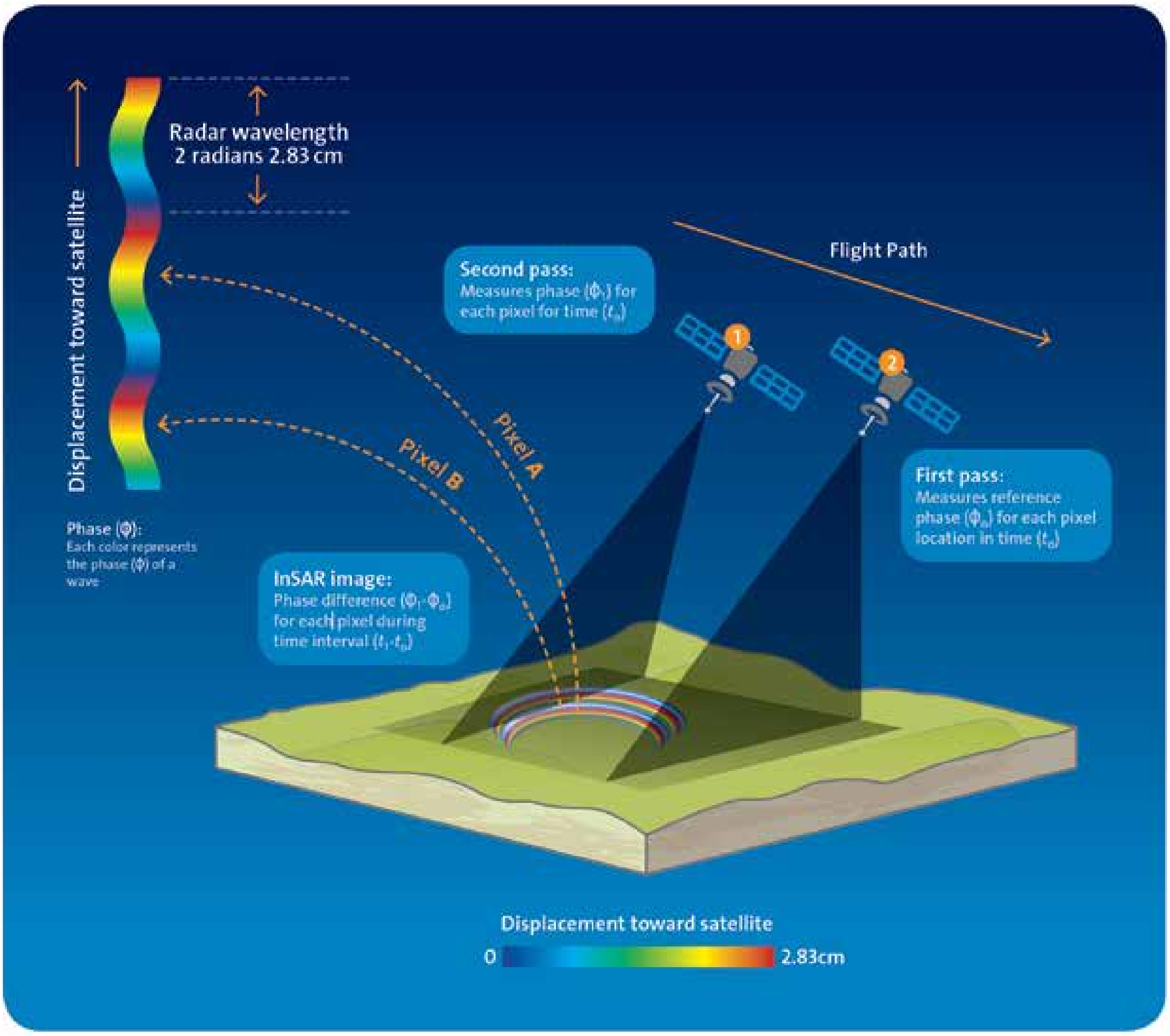


Figure 10-1 – InSAR data acquisition theory

The basis of SAR is the collection of high resolution ground surface radar satellite imagery. The satellite continuously transmits microwaves to the Earth's surface and records the characteristics of the waves reflected back to the satellite (amplitude and phase). The change in amplitude and phase between two images is then measured (representing the satellite's distance from the earth's surface at different moments in time) (see Figure 10-1). The difference between two measurements within a time series indicates a possible spatial deformation at surface (x, y and z).

Considering the mission needs, satellite availability, acquisition mode requirements, frequency of acquisition and continuity of acquisition, the Radarsat-2 satellite operated by the Canadian Space Agency was selected.

This is the package currently being utilised for data acquisition. As with the JAXA satellite the Radarsat mission will conclude at some point in the future, at which time another satellite selection process will be undertaken, ensuring continuous data acquisition.

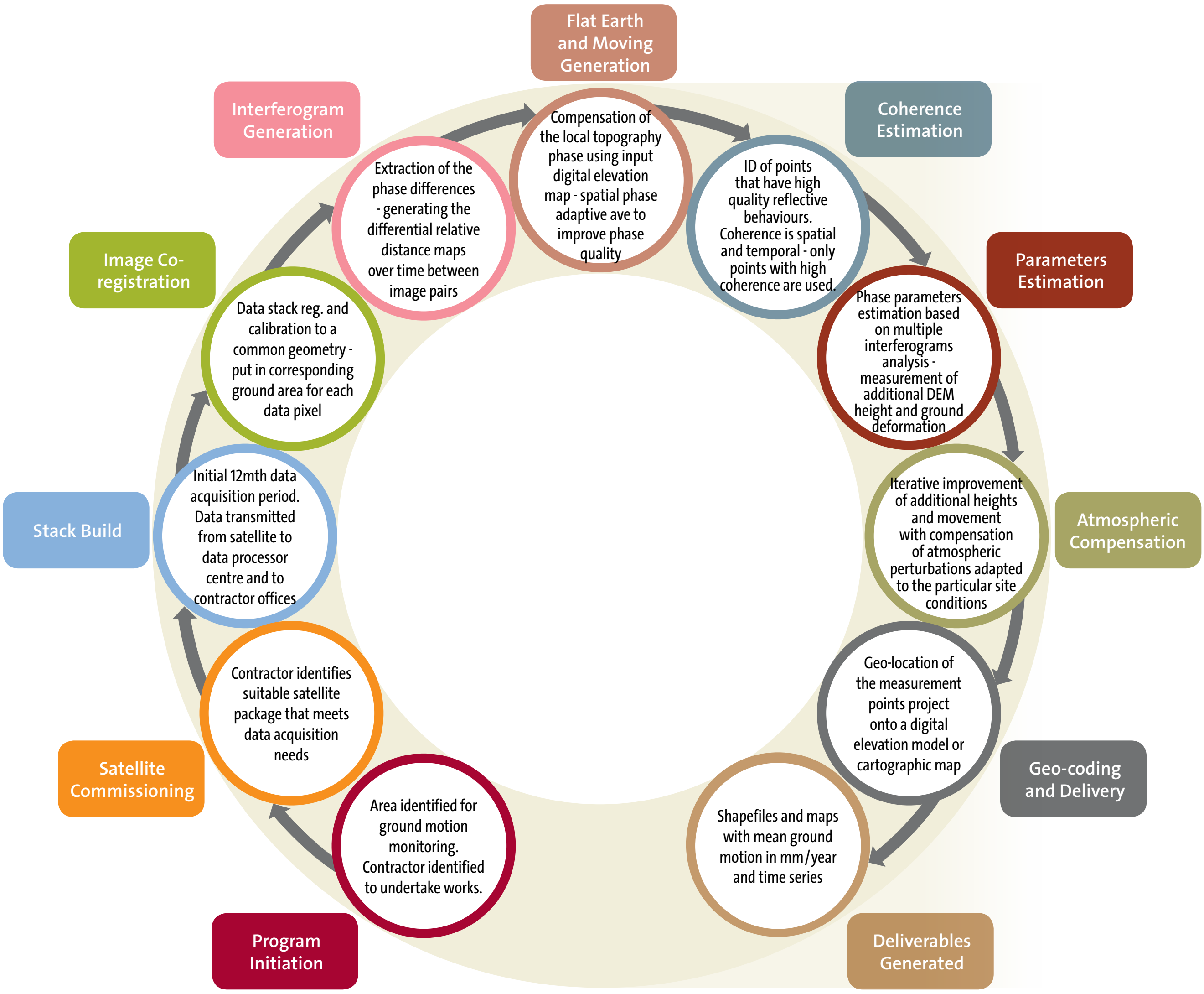


Figure 10-2 – Ground motion data acquisition and processing

Figure 10-2 displays the flow of data acquisition from the satellite to the preparation of ground motion maps. Once collected and processed, data is then reviewed for ground motion. However, consideration is given to the fact that physical changes in ground surface height over time (geomorphology) can be related to a wide number of factors, both natural and anthropogenic, such as ploughing and vegetation growth. In light of this, areas subject to coal mining will be a key part of the assessments.

It is proposed to implement an area specific adaptive management approach to the development and implementation of ground motion trigger values that can be related to CSG activity. Area specific triggers can only be set once sufficient baseline data sets have been refined. In the interim a series of default baseline triggers has been defined. Based on these triggers a ground motion response plan has been developed (see Chapter 13), which identifies the actions that would be taken for any response to a trigger exceedance.

10.4 STAGE 1 BASELINE STUDY FINDINGS

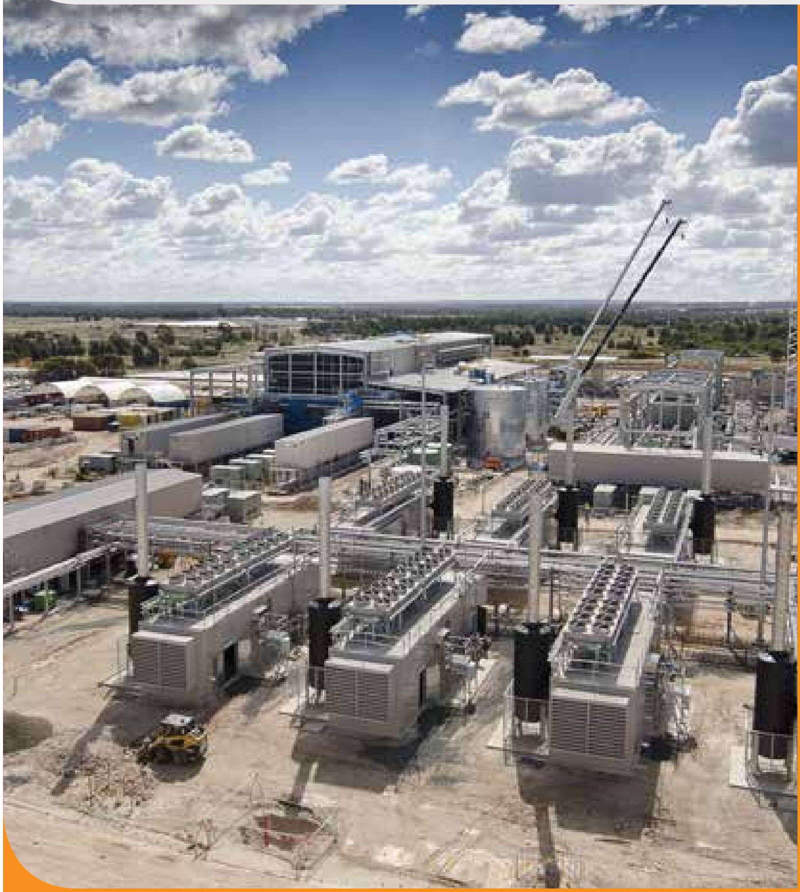
Stage 1 ground motion results were presented as average annual deformation maps along with time series data for the period of study. These data allow an assessment of any ground movement patterns that might be present over the processed area to be completed. A histogram of the Stage 1 data shows that 97% of the total data set demonstrates stability (movement below limits of the study accuracy). Only 0.3% of the points have a magnitude of elevation difference higher than 15 mm/year. In summary the results of this study do not show any large scale pattern of ground motion, with the majority of the study area exhibiting stable conditions (less than 8 mm of ground motion per year of the study).

The InSAR analysis has shown areas of natural/anthropogenic ground deformation in space and time and independent of CSG extraction activities. These areas are heterogeneously distributed within the study area, and examples include fields and rural tracks. Additionally, several uplift patterns are observed along selected riverbanks, possibly related with the heavy rains that occurred during 2010 and 2011. No large deformation patterns are visible for the period assessed, and the region appears to be stable in general.

This ground motion baseline report as provided by Altamira is included in Appendix L, together with a short review of the data.

An average annual displacement map covering the study area is presented in Figure 10-3.

It is notable that there are no measurable ground motion changes in QGC's Central Gas Field after six years of domestic CSG production.



QGC is investing in Queensland's future by creating a new resource for beneficial use.

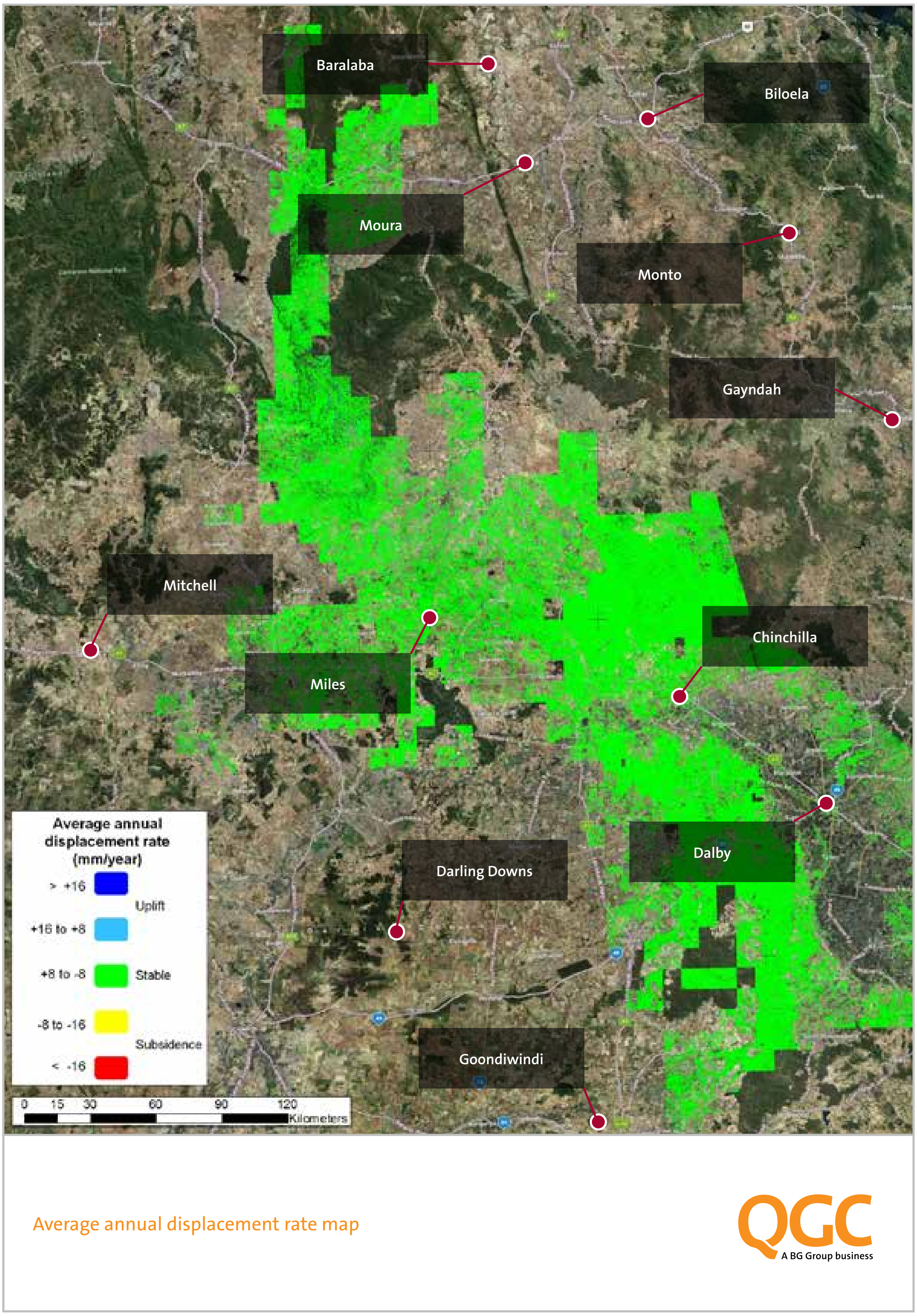


Figure 10-3 – Average annual displacement rate map

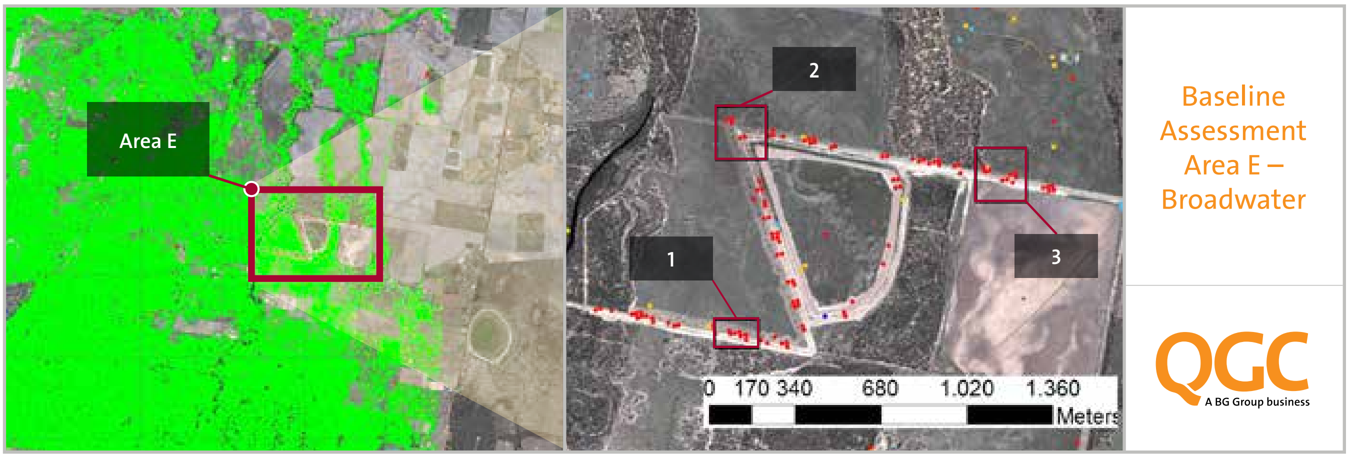


Figure 10-4 – Baseline assessment area E (Broadwater)

Of the six example areas identified by Altamira Information as having ground motion included in the appendices attached to the baseline report, only one area occurred within the QCLNG tenement area, namely 'Area E'. The area identified as 'Area E' in Appendix A of the Altamira Information report is located in the southern portion of the Broadwater field as part of the Southern Gas Fields. It should be noted that there was no CSG abstraction activity occurring at the time the Stage 1 ground motion baseline program was completed.

As can be seen in the accumulated displacement map (Figure 10-4) displacement occurred along lineaments that can be clearly associated with access tracks in and around an earth structure.

The time series data for these data streams are also presented in the Altamira report. These time series results were summarised as presenting a similar time evolution of displacement along the linear features in the area. Altamira go on to state that this could indicate that the motion detected forms part of the same deformation system. In this case the system is most likely compression of the access track as vehicles travel back and forth around the structure. This is a clear demonstration of an anthropogenic activity (construction) impacting ground motion independent of CSG extraction activities.

In summary the baseline study does not show any large scale pattern of ground motion over the period 2007 to 2011, with the majority of the study area exhibiting stable conditions (less than 8 mm of ground motion per year of the study).

The completion of the baseline project has resulted in the development of a regional baseline dataset for ground motion prior to large-scale CSG extraction operations commencing across the Surat and Bowen Basins. The establishment of the regional ground motion baseline allows for comparisons with future ground motion monitoring data to assess the effects of CSG production on ground motion.

10.5 STAGE 2: ONGOING MONITORING

The industry proponents are jointly continuing the ground motion monitoring program. The next stage of the program will extend pre-production (baseline) conditions across all tenement areas. A baseline report has been prepared but baseline conditions can be considered to continue until dewatering begins in 2014. Following early 2014, the dataset can be considered to be ongoing monitoring rather than baseline.

The rate and timing of data acquisition will continue to be based on a 2.5-year data acquisition and processing program.

10.6 GROUND TRUTHING

Condition 65a of the Department approval specifies that the ground motion monitoring program consist of a geodetic survey. The InSAR program as defined provides relative ground motion enabling trends with time to be established, but it does not convert measurements into a geodetic datum such as metres AHD.

Considering this, the ground truthing program consists of two key components:

- Using ground surveys to confirm and detail any ground motion established by the InSAR monitoring; and
- Developing a system to link the InSAR satellite data to relative ground levels such as metres AHD at selected locations.

Currently it uses elements of the existing QCLNG ground survey network that are used for infrastructure construction to 'ground truth' the InSAR data. Ground truthing is required to ensure the motion trends noted by the satellite are reflected via traditional survey methods completed at surface.

The location of the survey points selected for the ground truthing works have been based on:

- Proximity to existing or future aquifer monitoring wells – to enable direct linkage of ground motion data to pressure measurements;
- Proximity to category 1, 2 or 3 sensitive areas (as defined in Section 10-7); and
- Proximity to CSG infrastructure or extraction activities.

Surveys commenced in late 2013. The results will be in the annual report (Commitment 25) and in the updated Ground Motion Monitoring and Management Plan (Commitment 26).

10.7 DATA ASSESSMENT

Two data interpretation approaches will be used to interrogate the data:

- The first approach will be conducted at the tenement scale over the area of the QCLNG project.
  - Each grid cell will be colour coded, with ground motion based on the scale values provided by the InSAR process. On this data scale all average annual ground motion of between -8 and 8 mm is considered to be stable. These values have been selected based on the baseline data and will be refined as additional data are collected;
  - Clusters of grid cells reporting statistically significant mean annual movement will be flagged;
  - Flagged cells will be reviewed from a natural and anthropogenic perspective to determine if external

factors could be influencing ground motion in the area;

- The second approach is a category approach where specific areas within the project area that are considered 'sensitive' would be examined in more detail:
  - The methodology involves the detailed assessment of targeted areas via a GIS desktop assessment. Targeted areas are those where the risks of ground motion are highest or where natural or other anthropogenic (non CSG) impacts might be expected and which need to be defined;
  - Targeted areas include: areas of sensitive ecological environments or related directly to MNES, areas where ground motion might be expected such as intensive cropping or mining, areas where there is surface or underground coal mining, and selected CSG operations areas. Once identified these areas will be categorised, as follows:
    - **Category One:** Areas within 5 km of an EPBC listed springs, areas with noted ephemeral or perennial waterways, areas with high bore water use;
    - **Category Two:** high population areas, other identified sensitive receptors (e.g. high value infrastructure), areas with sensitive land uses (e.g. cropping); and
    - **Category Three:** CSG production areas (both QGC and non-QGC), proposed reinjection areas, coal mining areas.
  - The areas defined above will be overlaid with the latest data package. Total measured motion for each of the Category One, Two and Three areas will then be assessed; and
  - Clusters of significant motion occurring within these areas will then be assessed in detail considering the natural and anthropogenic characteristics of the area of interest, and the subsequent trigger values derived for the area.

Results will be included in the three-yearly assessment reporting cycle.

10.8 PREDICTIVE DEFORMATION ASSESSMENTS

Under Conditions 65 b) and 65 c), QGC is required to undertake predictive modelling to link possible subsurface deformation to surface expression. The first stage in a modelling workflow is to simulate the depressurisation that might occur.

During 2012/2013, QGC has been developing a dual-phase (water and gas) regional scale numerical groundwater model (GEN3) to better understand the potential wider impacts of CSG production on the groundwater environment, see Chapter 6. Moving forward it is proposed to repeat this subsurface deformation approach and model in greater detail utilising formation pressures from both the OGIA's UWIR model outputs and QGC's GEN3 model.

The predictive modelling using the UWIR model has been completed and is included in the annual ground motion report delivered in October 2013 (included in Appendix L). Any future modelling development will be based on these findings.

A new Surat Basin CMA UWIR groundwater flow model is due to be competed in December 2015. Once the results of this are available a revised predictive deformation assessment will be undertaken based on the updated depressurisation values. The results of that calculation will identify any potential impacts that might take place. To address those impacts a range of typical mitigation options will be identified and evaluated, refer to

Commitment 26.
The response plan process for ground motion is outlined in Chapter 13 (Figure 13-6). If satellite or ground surveys identify any significant impacts before mitigation options are developed then location/impact specific mitigation options will be established as part of the management of that impact.

10.9 ASSESSMENT OF HYDROLOGICAL IMPLICATIONS

No discernible hydrological implications are expected due to CSG extraction, based on deformation rates established by Golder Associates (2010).

It has been concluded that, because of the relatively small amount of predicted settlement and the extremely small differential settlement gradients as a result of potential subsidence induced by CSG production, there will be no impacts on the:

- Integrity of the Great Artesian Basin aquifers; and
- Quantity or quality of surface water flows in the Murray Darling Basin.

A more detailed assessment given the baseline results and data from predictive modelling will be implemented and reported in October 2014. Should the assessment identify a likelihood of potential hydrological impacts, a more intensive staged approach to ground motion studies will be included in the report.

10.10 CONCLUSION

The ground motion monitoring and management process has begun and initial baseline findings are proving the concept by providing evidence of natural and other anthropogenic (non-CSG) mechanisms for ground motion. Further research will back up these findings with modelling and the assessment of implications.

The InSAR analysis has shown areas of natural/anthropogenic ground deformation in space and time and independent of CSG extraction activities. These areas are heterogeneously distributed within the study area, and examples include fields and rural tracks. Additionally, several uplift patterns are observed along selected riverbanks, possibly related to the heavy rains that occurred during 2010 and 2011.

A predictive deformation assessment using groundwater modelling data has been prepared for October 2013 and will be revised with new iterations of the UWIR groundwater model. Ground motion interim progress reports will be submitted annually (commencing in October 2013) detailing monitoring program progress, alignment with the monitoring and management plan (including support programs) and available preliminary findings.

Detailed ground motion assessment reports, together with a revision of this ground motion monitoring and management plan will be generated at three year intervals, with the first report and management plan revision to be delivered in Q4 2015.

The status of the Commitments relevant to ground motion is as follows:

#	Department Condition		Description	Completion date	Status
	Pre-Dec 2012	Post-Dec 2012			
22	**65,67**		Completion of Ground Motion Monitoring and Management Plan	April 2013	● Commitments completed
23	**65a**		Completion of Baseline Data Review Report	April 2013	● Firm deliverables for that month
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