Appendix R
Subsidence modelling study
Appendix R: Subsidence Modelling Study

Rev [0]

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Introduction

This appendix includes a report prepared by Golder Associates in 2010 and provides preliminary estimates of subsidence using the findings of the GEN1 model that was developed for the QCLNG EIS. This report was submitted to SEWPaC and Geoscience Australia in August/September 2010 as part of the Australian Government’s review process of the EIS and prior to the setting of approval conditions for referral EPBC 2008/4398.

Subsidence estimates are considered to be conservatively high as the drawdown estimates from which the subsidence estimates were derived were based on a single-phase MODFLOW groundwater model and did not consider dual phase influences.
QUEENSLAND GAS COMPANY

ASSESSMENT OF SUBSIDENCE DUE TO COAL SEAM GAS EXTRACTION

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1.0 INTRODUCTION

This report provides further assessment of surface subsidence that may occur due to Coal Seam Gas (CSG) extraction for the Central Development Area (CDA), South East Development Area (SEDA) and North West Development Area (NWDA) of the Queensland Gas Company’s Surat Basin gas fields. Our initial assessment was presented in Golder Associates' (Golder) Report ‘QGC Groundwater Study’, Ref.087633050/016, dated June 2009.

This further assessment of subsidence is based on the calculated drawdown from groundwater modelling presented in Golder Report ‘Groundwater Modelling for CSG Extraction – QGC’, Ref.087633050/017, dated 30 June 2009.

2.0 SUBSIDENCE MECHANISM

In the CSG process, as depressurisation of coal seams proceeds and the water pressure in the fractures and pores is reduced, there will be an increase in the vertical effective stress (i.e. the stress that is carried on the rock skeleton due to the weight of the overburden to the surface). An increase in the vertical effective stress will result in settlement of those formations, which are affected by the increase. If, as is the case for the proposed development, multiple coal seams are depressurised, there is potential for the interburden formations to also be depressurised. The extent to which interburden formations are depressurised will depend on the spacing between the coal seams that are depressurised, and the hydraulic properties of the interburden (hydraulic conductivity and specific storage). For the cases currently under consideration the interburden layers are of the order of several tens of metres in thickness, and over the period in which the coal seam will be depressurised, it is reasonable to assume that the interburden layers will be depressurised to the same extent as the coal seams.

3.0 METHODOLOGY FOR SUBSIDENCE ASSESSMENT

According to the linear elastic theory, compression $\Delta Z$ of a given geological formation resulting from an increase in effective vertical stress within that formation is given by:

$$\Delta Z = Z_1(P_{12} - P_{11})/E$$

Where:

$Z_1 = \text{thickness of the formation prior to compression;}$

$P_{12} - P_{11} = \text{change in pore pressure resulting from depressurisation (equal to the increase in vertical effective stress); and}$

$E = \text{Young’s Modulus}$

The change in pore pressure resulting from depressurisation that has been used to estimate compression has been taken from the groundwater modelling (Introduction).

In the case of underground coal mining, the settlement that is experienced at surface is generally less than that experienced at depth. This will depend on a number of factors such as the depth and width of the extraction zone. Experience from underground coal mining indicates that about 60% of the coal thickness extracted may reach the surface as subsidence for depths of typically up to about 500 m. In these cases the reduction in surface settlement in relation to the settlement that occurs at depth is a result of the limited width of workings in relation to the depth. For smaller workings or greater depths the settlement at surface will be less; and for larger workings or shallow depths the settlement at surface will be greater, as a proportion of the settlement at depth. The mechanisms of arching and stress re-distribution in the overburden that takes place in these cases and that lead to a reduction in surface settlement also have the potential to induce fracturing in the overburden.

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*Simple one-dimensional analytical calculations based on reasonable ranges of hydraulic conductivity and specific storage indicate that propagation of depressurisation could be significantly in excess of several tens of metres over the anticipated period of depressurisation within the coal seam.*
In the case of CSG development, depressurisation will occur over a wider area than the area in which the CSG wells themselves are located, because of lateral migration of depressurisation through the coal seams. The calculated drawdowns for the QGC development areas are presented in the Golder 2009 modelling report, Figures D-4 to D-6. These figures indicate drawdowns across lateral distances of tens of kilometres. Settlement will therefore occur over a much broader front than is the case for underground mining. Furthermore, because the areas outside the area of greatest drawdown (i.e. the area of the CSG wells themselves) is also subject to some compression of the coal measures, there is little or no potential for a reduction in surface settlements through arching or similar mechanisms. In other words, the compression that occurs at depth in the coal measures is likely to be very closely reflected at surface, however the stresses and strains induced in the overburden will be significantly lower than in the case of underground mining because of the broad extent of settlement. It is therefore far less likely that settlements induced by depressurisation could lead to fracturing of overburden materials and therefore cause an increased interconnection between the coal measures and overlying aquifers.

4.0 CALCULATION ASSUMPTIONS - FORMATION THICKNESS AND DEPRESSURISATION OF VARIOUS FORMATIONS

Salient information for the assessment of compression of depressurised formations, from the results of the report and groundwater modelling (see Introduction), is indicated below.

The CDA, SEDA and NWDA target the Walloon Coal Measures in the Surat Basin to extract coal seam gas. This coal measure sequence is on the average about 300 m thick, i.e. about 25 m thickness of coal seams, and 275 m (300 m minus 25 m of coal seams) of other sedimentary rocks. Because of the limited thickness of sedimentary interburden layers, we have assumed that the full 300 m of coal measures is depressurised.

Drawdown in the Walloon Coal Measures is predicted in the modelling to be a maximum of:

- CDA – 195 m.
- SEDA – 355 m.
- NWDA – 450 m.

Drawdown in adjacent aquifers is predicted in the modelling to be a maximum of:

- CDA
  - Springbok Sandstone - 85 m
  - Hutton Sandstone - <3 m
  - Precipice Sandstone - <2 m

- SEDA
  - Springbok Sandstone - 35 m
  - Hutton Sandstone - 11 m
  - Precipice Sandstone - <4 m

- NWDA
  - Springbok Sandstone - <2 m

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A rock mass modulus of 2 GPa is assumed for the coal seams and 10 GPa for the remainder of the formation.

5.0 PREDICTED SETTLEMENTS AND DIFFERENTIAL SETTLEMENTS

For drawdowns indicated above, the calculated maximum subsidence for the Walloon Coal Measures is:

- **CDA**
  - 0.025 m for the coal seams.
  - 0.055 m for the remaining thickness of the formation.
  - Total of 0.08 m.

- **SEDA**
  - 0.045 m for the coal seams.
  - 0.1 m for the remaining thickness of the formation.
  - Total of 0.145 m.

- **NWDA**
  - 0.055 m for the coal seams.
  - 0.125 m for the remaining thickness of the formation.
  - Total of 0.18 m.

The calculated maximum subsidence for the adjacent sandstone aquifers is <5 mm for the case of the greatest drawdown in the Springbok Sandstone.

As indicated above, it is likely that these settlements would be very closely reflected at surface. There is potential for strain to be induced in the overlying formations due to differential depressurisation, and consequently differential compression, of the coal formations. In principle, these strains will have the potential to influence the overlying formations. From the drawdown curves in Appendix D figures of the Golder 2009 modelling report, we calculate the maximum gradient in settlement to be approximately 0.002%. Based on this very low gradient (i.e. very gradual changes in settlement) we consider that there is a negligible likelihood that the permeability of overburden units would be adversely affected.

5.0 IMPACT OF ADJACENT CSG FIELDS

Multiple adjacent CSG well fields will be operating at the same time as the CSG fields discussed above with neighbouring well fields closely adjacent. The maximum predicted settlements indicated above are applicable to the edge of the well field. The amount of settlement will reduce in proportion to the reduced drawdown away from the edge of the field. If adjacent well field drawdown curves intersect, we do not expect settlement to exceed the maximum values indicated above.

6.0 CONCLUSIONS

Potential subsidence as a result of CSG operations will develop as a result of very different mechanisms to those by which subsidence occurs as a result of underground mining operations. Subsidence will result from elastic compression of the coal seams from which water is extracted, and of the adjacent sedimentary formations, which will also be depressurised by the extraction of water from the coal. Because of the very broad area across which depressurisation occurs, settlement at surface is expected to very closely reflect the compression in underlying formations.

The calculated maximum surface subsidence for the CSG fields considered here are:
CDA – 0.08 m.

SEDA – 0.145 m.

NWDA – 0.18 m.

The calculated differential settlements resulting from proposed CSG operations are extremely small with a maximum estimated gradient in settlement of 0.002%. Because of these very gradual changes in settlement across the development areas we consider that there is a negligible likelihood that the permeability of overburden units would be adversely affected.

Because of the relatively small amount of predicted settlement and the extremely small differential settlement gradients, we consider that there will be no impacts on the following Matters of National Environmental Significance as a result of subsidence induced by CSG production:

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

Notwithstanding the above conclusions, monitoring will be carried out to verify the above assumptions and the assessed risk. Such a monitoring programme will include measurement of water pressure in aquifers in the coal overburden and extensometers installed in key locations to specifically monitor for compression of the coal measures.
APPENDIX A
Limitations
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