Appendix F9

CGSS 2013

Follow-up Review of Reports on Possible Subsidence at Scott Reef: Torosa Field

BROWSE FLNG DEVELOPMENT
Draft Environmental Impact Statement

EPBC 2013/7079
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FOLLOW-UP REVIEW OF REPORTS ON POSSIBLE SUBSIDENCE AT SCOTT REEF: TOROSA FIELD

REPORT NO. SEWPC002

FOR SEWPC

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1 EXECUTIVE SUMMARY

This report provides a follow-up review of reports provided to CO_2 Geological Storage Solutions (CGSS) by the Department of Sustainability Environment, Water, Population and Communities as regards to potential subsidence at Scott Reef associated with future gas production in the Torosa field by Woodside.

The initial CGSS review stated:

- Overall the methods documented by Woodside were considered appropriate for the current phase of the project and the conclusions were reasonable.
- A range of further details that could be provided are recommended and a few inconsistencies in the report were noted.
- The high level analysis of the estimate of subsidence was considered to be, at a preliminary level, of a low magnitude; less than is reported in other regions of the world. The reason for this may in part be due to the geological settings and rock types at the Torosa field.

Responses were received to the detailed comments by CGSS. Some responses were adequate and some require further consideration.

As for the earlier review, the subsequent report and methods documented by Woodside are appropriate for the current phase of the project and the conclusions are reasonable.

However:

- There is a major discrepancy between the Executive Summary in the subsequent report where it quotes incorrect values (too low) for the estimated magnitude of subsidence, compared with the specific details in the report, and
- Woodside did not adequately respond to several suggestions and requests which should be addressed. CGSS has provided answers to SEWPaC on those matters.

The Woodside responses essentially claim that the laboratory analysis conducted are definitive; implying that further analysis is not warranted. CGSS recommends that both InSAR and tidal analysis should be seriously considered for implementation at this site if feasible, both prior to and during production activities. These technologies will provide confirmation of whether the laboratory analysis are representative and definitive and provide ongoing assessment data for subsidence during the field activities.

Further details that could be provided have been recommended, including;

- The impact of geomechanical effects during field production, and if there is a likelihood of and how fault reactivation could impact on the predicted subsidence, and
- A review of the parameters influencing the uncertainty range for subsidence in terms of the revised (~18 – 26% upwards) subsidence estimates.

CGSS recommends that a metric be established as to what is likely to be an unacceptable magnitude and rate of subsidence for the area of interest. Establishment of that metric would then inform the geoscience modelling and assist in the nature and extent of the planning for a monitoring regime.

2 SCOPE

The Department of Sustainability Environment, Water, Population and Communities initially requested CO_2 Geological Storage Solutions (CGSS) to review two reports provided by Woodside as part of the assessment documentation for the Browse Upstream Development (EPBC 2008/4111) regarding the possible subsidence of Scott Reef associated with future gas production in the Torosa field. Woodside responded to this initial review by CGSS and then updated its report. This current report is a review and follow up to the updated report.

The initial deliverables of the first review included;

1. Review and report on the information provided to the Service provider, including:
    a. An assessment of the
        i. conservativeness of any calculations
        ii. confidence in the predictions, and
        iii. include a comparison of the predicted ground deformation against other observed ground deformation levels for comparable scenarios.
    b. Advise whether any additional information is required and, if so, the nature of that information,
    c. Recommendations regarding possible monitoring approaches to observe ground deformation, including the level of confidence in the effectiveness and sensitivity of these approaches.
    d. Recommendations regarding possible management options to manage subsidence so as to not subside below a prescribed level, including the level of confidence in the effectiveness of these management options.
    e. Review additional material(s) and amend any assessment of the confidence of the prediction or recommendations regarding monitoring and management options, if required.

The subsequent additional deliverables of the follow up review included:

2. Amend any assessment of the confidence of the prediction or recommendations regarding monitoring and management options related to those provided in the "Review of Reports on Possible Subsidence at Scott Reef: Torosa Field Report (No. SEWPC001).
3. Review additional material(s) and amend any assessment of the confidence of the prediction or recommendations regarding monitoring and management options, if required.
    a. Provide further information and clarification to the Department on questions which have arisen from the report produced by the Service Provider.
    b. Add further detail, studies, conclusions or recommendations to the report produced by the Service Provider, if required.
    c. Clarify any assessment of the confidence of the prediction or recommendations, if required, and amend, if appropriate.

2.1 DOCUMENTATION PROVIDED

CGSS were initially provided with two reports, being;

1. First Order Analytical Estimates of Scott Reef Subsidence as a result of Reservoir Compaction in the Torosa Field, Browse Basin (van Ruth, 2012) – pp25.

2. A Review of Analytical Compaction and Subsidence Modelling (Rahman, 2012) – pp17.

Subsequent reports were provided to CGSS, being;

1. Woodside Response to CGSS Peer Review of Analysis of Subsidence (Parnum,2013)
2. First Order Analytical Estimates of Scott Reef Subsidence as a result of Reservoir Compaction in the Torosa Field, Browse Basin (van Ruth, 2013)
    a. Revision 2 : 7/03/2013
3. Response from Woodside to SEWPaC information requests on CGSS comments (single page table)

Note: CGSS has not had access to any reports in regard to the production plans or reservoir simulation for the planned area of interest.

3 OVERVIEW

The approach adopted by Woodside in estimation of ground deformation is an appropriate methodology for the late appraisal phase of reservoir development. In terms of the reliability of the analysis, most of the uncertainty will depend on the quality of the limited laboratory data that has been analysed and calculated. Of significance are the levels of effective stress conditions applied to the samples during the course of the laboratory tests.

The compaction coefficient estimates that have been reported would, at a preliminary level of analysis, appear to be on the low side of what has been observed in other industry applications. This has been responded to by Woodside in that the Torosa field is deeper and comprises a higher rock strength than samples from other studied locations. It may be prudent for Woodside to consider committing to surveillance and monitoring data acquisition in regards compaction as well as obtaining some additional data and analysis associated with future appraisal wells at the field location (e.g. InSAR and tidal analysis).

Further considerations should be provided in terms of the potential impact of fault reactivation on the estimated subsidence in the area of interest.

4 WOODSIDE RESPONSES

The following addresses the items from Woodside that were not responded to and those that were responded to in the various documents following the CGSS review.

4.1 NO RESPONSE

SEWPaC suggested to CGSS that Woodside either did not respond directly or in specific detail or only partially to several questions. These include;

1. “What are the longer term surveillance plans and mitigations for compaction? (a) What happens if compaction turns out to be different from that predicted? (b) How and when will that be known?”
   <u>CGSS Response</u>:
    a. Woodside make reference to InSAR and a desk top analysis of monitoring options and their suitability.
        i. The response Woodside provided to monitoring with InSAR is adequate but should be followed up with a desk top assessment of the most viable and likely implementable techniques.
    b. As noted later in this report, Woodside did not respond to the suggestions of tidal studies.

   i. Implementation of this analytical technique should have been seriously considered by Woodside rather than ignored.

c. A response to mitigation and the timing for identifying subsidence was not specifically addressed by Woodside.

d. In the absence of any adequate responses to parts of those questions, CGSS were asked specifically by SEWPaC to comment as regards to their question which was "we are interested in if there could be a time lag to subsidence being observed, the ability to implement a response and if cessation of activities which result in subsidence would be an option."

   CGSS Response:

   i. CGSS has considerable experience with the use of InSAR and ground deformation observation and modelling due to subsurface extraction activities having been involved in numerous studies at the prospect (local) and basinal (regional) level. The observations and experience obtained from that work in relation to the question posed is that;

      1. Ordinarily, the time lag for identification of subsidence from extraction subsurface fluids is very short; of the order of weeks or months, not years.

         a. This is not an unexpected outcome as the effect being observed is due to reservoir pressure change which is transmitted relatively rapidly and is ubiquitous through any connected pore space.

      2. Due to the short time frame involved for a measureable effect from subsidence, any observation of subsidence could thus be correlated in a timely sense in terms of a likely cause and effect scenario.

            i. Note: CGSS has previously worked on examples documenting uplift and subsidence associated with well injection and production over very short time periods, so our experience is that documenting a cause and effect observation is possible; provided a baseline study and incremental InSAR observations are made on a regular basis.

         b. The short time period over which it is possible to observe any subsidence effects enhances the possibility of responding in a timely fashion to alleviate the cause of the subsidence if it is considered as being unacceptable.

      3. If the cause of an unacceptable rate of subsidence was identified to be due to production of fluids and consequent pressure decline, then stopping that production would stop further pressure decline and subsidence.

         a. If the reservoir is hydrodynamically connected and has access to a large aquifer system, then over time pressure may return to near the original pressure, and subsidence would cease and perhaps absidence (uplift) could occur over time. If the reservoir is either not connected or poorly hydrodynamically connected, then the pressure would stabilise at the level when production was ceased and subsidence would cease.

            i. The Woodside comments supplied imply that the field is likely compartmentalised and has variable connectivity.

4. If production lead to unacceptable subsidence outcomes, then two potential options are possible to alleviate or rectify the situation.
    a. Continue production but inject fluids to maintain the pressure during the course of the field development.
        i. This option, whilst technically feasible, was rejected by Woodside in their responses on the basis of cost, volumes of gas recovered and pragmatic issues associated with the level and location of new infrastructure (new injector wells).
    b. If the concept of co-production and injection is not acceptable for whatever reasons, and unacceptable subsidence has occurred, then if production is ceased (to stop subsidence) then the existing production wells could be used to reinject fluid and reverse the subsidence; thus alleviating the additional cost of new wells for injection.
        i. Note: It is possible that if the field is substantially compartmentalised and unacceptable subsidence is occurring locally associated with specific compartments, then individual wells might be identified in terms of the ones producing from the areas of pressure reduction and which are contributing to the unacceptable subsidence. Production from these wells could cease and reinjection could occur through those wells.
            1. However, the likelihood of both substantial compartmentalisation and reservoir pressure drop that would lead to unacceptable subsidence is likely low, as the two factors may be mutually exclusive and/or a very complex or subdued pattern of subsidence may occur. However, having adjacent compartments that have reservoir pressure drop and near virgin reservoir pressure, could lead to other geomechanical effects such as fault reactivation in response to the pressure differential that occurs.
    c. Woodside comment on page 24 (Parnum, 2013) that “the only way to produce gas under injection, would be to place wells directly on the reef itself, to allow appropriate separation from the production wells, including pipelines and well heads.” CGSS is unable to provide any comment in detail, not having seen the production plans or reservoir simulation. However, given the use of directional drilling, and that for the area of interest to subside there must be reservoir connectivity (producing the pressure decline), CGSS would consider that locating wells not on the reef would be technically feasible to deliver the desired outcome of pressure maintenance.

2. “The potential impact on subsidence of the permutations of (3a) and (3b)?”

a. The Woodside response to this question, while not compiled into a single location, is adequate.

4.2 RESPONSES

4.2.1 INITIAL COMMENTS

In the initial review of the Woodside analysis (van Ruth, 2012) by CGSS, a range of detailed comments were made by CGSS and subsequently responded to by Woodside. The CGSS comments included:

"*The Woodside methods, to estimate average levels of subsidence, are based on use of Geertsma (1973) methods and that publication is considered as an industry norm and is 'best practice'. The methodology used is therefore considered to be both robust and acceptable. The method does however rely on accurate estimates of the uniaxial compressibility coefficient, and the stress conditions under which to run these measurements*

For Woodside these estimates were obtained from laboratory measurements conducted in the United Kingdom. In the work reviewed here, CGSS only have had access to the Woodside report and its descriptions of the tests. CGSS have not seen the corresponding data for bulk compressibility mentioned by the Baker Hughes review (Rahman, 2012). CGSS note that the reported laboratory tests indicated that the samples displayed reasonably low values of compaction coefficient. This is the prime reason why the estimates of subsidence are also reasonably low (around the 7cm mark for lifetime depletion at a 95% confidence level). A compaction of 7cm is considered to represent relatively minor, even insignificant, levels of compaction. Therefore, the key question, in the review by CGSS, concerns whether the low uniaxial compaction coefficients can be considered meaningful and reliable. CGSS further note from information provided by Woodside that at initial pore pressure conditions, the effective overburden pressure was some 4800 to 5000 psia. This is a relatively large stress condition and, is in large part responsible for the resulting low compaction coefficients. The logic and reasoning behind the choice of initial effective stress appears sound and consistent with both measured formation pressures and estimates for overburden stress. We note that had the initial effective overburden stress been some 3500 psia, then higher compaction coefficients would have resulted (on the same rock samples).

We conclude therefore that the low reported compaction coefficients, while low by analogy to other offshore gas reservoirs, is a reasonable outcome given the consolidated rock quality and net stress conditions."

CGSS thus felt that there were some questions requiring clarification that were asked of Woodside, and which were responded to be Woodside. Those detailed questions and responses are documented in (Parnum 2013). Most comments are adequately addressed and explained, with corrections and additions made into the subsequent documentation.

4.2.2 SUBSEQUENT COMMENTS

Several items require raising in terms of subsequent comments to the responses received. These include:

1. "What is the scope to acquire more data in the event of further appraisal at the field? For example: making use of in-situ tidal pressure fluctuations to estimate compaction coefficients."
    a. The Woodside response essentially states that based on the core samples being analysed in the laboratory and that high side estimates have been used in their modelling, there is no value in acquiring any more data. The essence of the Woodside position is that the laboratory data is definitive and that this sample set when applied

to their modelling provides an accurate estimate of what will happen at the site in terms of subsidence; and thus no more data acquisition is required.

b. CGSS believe this is an inadequate response based on the following observations and rationale;
    i. It is the experience of CGSS that laboratory data in general is not always definitive.
        1. As the data set indicates it is at the extreme boundary when compared with other data sets, then questioning the result and testing is appropriate.
    ii. Acquisition and analysis of laboratory data is not always perfect and follow up analysis to confirm or modify results can always be beneficial. A cost benefit / risk analysis can be done to determine how relevant any additional sampling and testing may be to confirm other potential outcomes or sources of error.
    iii. Questions should always be posed as to how representative a small sample set may be when dealing with use of that data to model a large region.
    iv. Sampling of geological sequences can be subject to variability and uncertainty as rock units have varying degrees of heterogeneity that are never fully understood at the commencement of any resource extraction activity. The geoscience industry is fraught with examples of poor or non-representative sampling and testing that has been shown to be inaccurate or invalid once reliable production data is acquired from a field.
    v. Specifically, the technique that CGSS referred to is tidal analysis from reservoir pressure measurement in down-hole pressure gauges. See Chang and Firoozabadi (2000), Foulser (2011), and Merritt (2004). The suggestion of using this technique is not commented upon by Woodside; in fact it is completely ignored. CGSS have used this technique in the past extremely successfully for predicting and understanding absidence (uplift) and subsidence associated with reservoir fluid movement; it can also identify whether reservoirs are in pressure communication or not. Woodside would benefit greatly from having this information prior to substantial production activities proceeding; both for their commercial production activities where they could optimise the field plans, and subsidence studies. The additional benefit of this technique is that the result obtained gives a formation level result for rock compressibility; not just a small ~5cm core plug analysis (as is the current case). The results are thus an approximation of how the reservoir as a large unit will respond to pressure depletion, compaction and subsidence. It thus will give confirmation of whether the laboratory analysis on a small sample set and modelling based on that sample set is both definitive and representative of the entire connected reservoir sequences. Reliance on a small core plug (perhaps a few cubic centimetres in volume) that is then extrapolated to cubic kilometres of reservoir sequence does introduce considerable risk that it may not be geologically representative of the reservoir sequence even if the actual laboratory measurement is accurate for that specific sample.
        1. The cost to Woodside of tidal analysis is minimal, as down hole pressure gauges are likely required in the production plan. The only additional cost to Woodside would thus be work time for the analysis.

Such analysis would at a very early stage in the project, and would produce potentially more reliable reservoir scale results of the likelihood of subsidence; as well as assisting in their commercial activities in terms of production planning.

2. Woodside should give significant consideration to use of this technique. Ignoring the potential application of such a technique to both Woodside's commercial production planning and potential subsidence modelling is believed by CGSS to be an inadequate response.

2. CGSS identified several instances of graphs with no unit of measure. Whilst some of these have been addressed in the subsequent reviews, new graphs have been produced with no units of measure; specifically stress gradient.
    a. These should be corrected.
3. CGSS was asked by SEWPaC to consider ways to alleviate subsidence if it occurred. As part of that response, the possibility of reinjection of fluid was raised by CGSS. Note: CGSS has not had access to the production plan or reservoir simulation for the Torosa field to fully comprehend the characteristics of the field development.
    a. Woodside responded that to the best of their knowledge there were no examples of fluid reinjection being done in gas fields and that the CGSS comments were too generalist in nature.
        i. The K12B field in the North Sea is a well documented and publicised example of reinjection of CO_2 as a mechanism of enhanced gas recovery (as a cushion gas) in a gas field.
        ii. There are other non-oil field examples of injection of fluids into gas fields where the fluid has either a role of pressure maintenance, enhanced recovery, or for emissions reductions (of CO_2). As the Torosa field is also high in CO_2, it was thought appropriate to consider examples from around the world; albeit from operator's in the oil and gas industry which include an emissions abatement aspect to their production planning. It is the understanding of CGSS that such CO_2 injection formed part of the initial plan for the Brecknock field development, the specific example of which influenced the development of the greenhouse gas storage components of the OPGGS Act (2006) to formulate legislation to allow for the possibility of injection down-dip of a production licence into an exploration lease. CGSS believe it is appropriate to raise such injection scenarios as a comparison to the Torosa development; especially where it may also help alleviate potential subsidence effects on Scott Reef, as these sites are also subject to considerable study associated with subsidence and absidence.
    b. Woodside also responded that if reinjection was undertaken, then it would reduce production from the field.
        i. Dynamic reservoir modelling and simulations comprise many variables and scenarios both in the modelling parameters in the software used, as well as the geological heterogeneity in the static models. Thus a variety of production outcomes are likely possible for any field using a reservoir simulation. As stated earlier, CGSS have not had access to any reservoir simulations for this field. CGSS are unable to comment on if decreased production would occur in

all scenarios. Without access to the reservoir model, CGSS are unable to comment any further.

5 REPORT INCONSISTENCIES

A significant inconsistency was noted in the revised Woodside report (van Ruth, 2013):

1. The report includes a new section (7) on page 30 titled “Torosa Field Subsidence Update (2013)” that describes the update to the subsidence estimates based on new interpretations and data and outputs from the modelling. This update identifies the range of subsidence values that could occur based on the new information and documents an increase from the previous estimates of subsidence of ~ 18 to 26%. However, the Executive Summary does not quote these higher values, but instead quotes the earlier modelling / out of date estimates that are lower than the new estimates.
    a. This anomaly must be corrected as the Executive Summary provides a misleading/incorrect overview as to what the report actually states the estimates of subsidence could be.

6 ADDITIONAL COMMENTS

Additional comments requiring consideration have emerged from examination of the revised document (van Ruth, 2013) and responses to questions (Parnum, 2013). These include;

1. Woodside discuss the likelihood of fault/seal, reservoir pressure communication and compartmentalisation on the production planning and reservoir compaction modelling.
    a. What is not presented or discussed are the geomechanical outcomes that are likely for the scenarios envisaged.
    b. CGSS suggests that discussions should be provided of the likelihood of fault reactivation due to pressure compartments developing across the field with variable reservoir pressure.
    c. Of specific interest would be to be provided with knowledge of if fault reactivation is likely to occur, and how that may impact on the predicted subsidence outcomes for the area of interest.
        i. This should include a detailed structural map of fault locations known within the area of interest, including a geomechanical analysis of the presence or absence of sub-seismic faults and their likely impact on subsidence in the area of interest.
            1. CGSS are aware that the existing seismic data set in the area of interest may be limited and thus a response to this may include an assessment that the subsurface is poorly understood or imaged in terms of the ability to do a detailed geomechanical analysis. If this is the case, then a statement should be made as to the level of uncertainty that the project is carrying due to a scarcity of data for an accurate geomechanical analysis; including commenting on the impact that this has on the anticipated subsidence scenarios and modelling.
            2. The recently acquired 3D seismic survey over the area of interest will no doubt substantially inform the project as to the geomechanical issues that may exist and the likelihood of fault reactivation. However the timeliness of the processing and interpretation of that seismic data may create a delay in fully understanding the issue that has been identified.

   d. Given the above discussion, and depending on the responses provided, the critical importance of monitoring (e.g. InSAR) and tidal studies needs to be emphasised as appropriate, and probably essential measures, to ensure that the subsidence predictions are being appropriately assessed and monitored as the field development proceeds.
2. Woodside present updated subsidence estimates in a new section (7) on page 30 titled "Torosa Field Subsidence Update (2013)". This section describes the update to the subsidence estimates based on new interpretations and data and outputs from the modelling. Principally the new estimates are derived from a difference in the estimated reservoir thickness, extent and distribution and increased predicted gas production.
   a. Such variation and update in these parameters is a normal occurrence at the stage that this project has reached, especially with the limited data that exists.
   b. Given that this new interpretation has documented an increase from the previous estimates of subsidence of ~18 to 26%, comment should be provided as to:
      i. the scenarios and magnitudes of change that could be anticipated from further likely modifications of these parameters, and
      ii. whether the changes to the parameters already made were within the range of the uncertainty analysis of the original earlier work, and a statement regarding that outcome, and
      iii. the impact that such variation may have on the predicted subsidence outcomes for the project.

7 METRIC

In light of the foregoing discussions, CGSS believe that future planning would benefit from establishment of a metric as to what is acceptable in terms of subsidence, both in terms of its magnitude and the relative rate of subsidence and its impact on the reef and lagoon environment. This should be based on scientific recommendations that consider:

- Rate of reef growth, including;
    - Environmental effects that affect reef growth such as sea water salinity/acidity changes and sea-water temperature changes
- Rate of sea-level rise or fall
- Observations of natural impact of storms and cyclones
- Impact of drilling activities (if any) in the area of interest on the health of the reef ecosystem.

If an unacceptable rate and magnitude of subsidence falls well within the likely predicted range of subsidence from modelling, then consideration can then focus on how to avoid or alleviate an unacceptable outcome, as well as to provide an alert metric for monitoring and testing during production activities. If the modelled and predicted estimates of subsidence and the unacceptable rate and magnitude of subsidence are a similar order of magnitude, then a frequent and rigorous regime of measuring and monitoring may then be appropriate. If the unacceptable rate and magnitude of subsidence are an order of magnitude greater than the predicted subsidence from modelling, then a less intensive approach for monitoring may be acceptable, once initial baseline and monitoring activities have been established and the modelled and predicted has been shown to be matching the observed.

Deriving a metric of an acceptable/unacceptable relative rate of subsidence would be invaluable to inform the geoscientific modelling and allow it to produce scenarios with appropriate sensitivity studies to identify the likelihood of an outcome that would be either acceptable or unacceptable. CGSS believes this would be a significant step forward in development of the subsidence modelling for Scott Reef by providing a benchmark for both modelling and future monitoring and analysis.

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