Position Paper by Concerned Scientists

Deficiencies in the scientific assessment of the Carmichael Mine impacts to the Doongmabulla Springs

Appendix A – Detailed Justification

Key point 1:

> ***Adani appears likely to have significantly under-estimated future impacts to the Doongmabulla Springs Complex (DSC) arising from the Carmichael Mine.***

<u>Adani will cause considerable drawdown (groundwater level drop) in the coal-rich sediments (Permian aquifers) that occur beneath the DSC.</u>

In terms of specific estimates, we are not aware of detailed maps of predicted drawdown in the Permian aquifers, e.g., in the Adani SEIS (GHD and Adani, 2013). Their hydrogeology report (Table 7-1) shows three bores in the Permian predicted to experience up to 19.8 m drawdown during mining. Table 5.15 in the GMMP (AECOM, 2019) shows maximum drawdown targets for several springs and bores in the Permian units. Drawdown targets during mine operation range from 1.7 to 8.6 m (AECOM, 2019). Post-closure drawdown targets are between 2.6 and 75.1 m (AECOM, 2019).

The Galilee Basin modelling from Hydrosimulations (2015) includes maps of drawdown and estimates of point-drawdowns in bores from the Permian units. The area impacted by >1 m drawdown as a result of the 8 mines they modelled (including Carmichael) is vast (~80,000 km^2). The maximum spot drawdown is 53.4 m in one bore in the Permian Joe Joe Formation (90259), which is near the Carmichael site and the DSC, and is therefore likely to be primarily affected by drawdown from this mine (as opposed to others) (Hydrosimulations, 2015). Drawdowns between 9 and 27.6 m in the Rewan Formation bores near the proposed mine site are also predicted in this model. Hence the issue of whether the Rewan acts as a significant confining layer is critical, as the Rewan Formation and units immediately below will experience significant drawdown.

<u>The source aquifer for the Doongmabulla Springs Complex (DSC) remains uncertain.</u>

This point is described in detail in Currell et al. (2017), based on the evidence interrogated by the case heard in the Land Court of Queensland in 2015. This is subsequently cited as a key issue in the CSIRO and Geoscience Australia (2019) review of the GDEMP, and the Bioregional Assessment of the Galilee Sub-region – e.g. Lewis et al. (2018). A thorough analysis of vertical hydraulic gradients and groundwater flow patterns in the vicinity of the springs was not included in the GDEMP (Ecological Associates, 2019); although, some additional water level data were reported. Nor was there an assessment based on geochemical or isotopic data of the possible sources of the spring water (although again, some basic hydrochemical parameters were reported beyond what was contained in the

SEIS). No detailed analysis of geological structure outside the mining lease has been conducted to determine possible preferential pathways for groundwater flow to the springs, or (for example) possible faulting or discontinuities in the Rewan Formation.

Studies to date are inconclusive regarding the source aquifer for the DSC, particularly the main Joshua Spring. Adani proposes that the springs are sourced from the shallow Clematis Sandstone aquifer. If this is correct, the groundwater level in the Clematis Sandstone bore nearest to Joshua Spring must always be above the level of the spring. However, this is not the case (Ecological Associates, 2019). Further, if the springs derive water from the Clematis aquifer, the chemistry of the spring water should be similar to that of groundwater in the Clematis Sandstone. However, again, this is not the case, and rather, the spring water is around twice as saline as the Clematis Sandstone groundwater (Ecological Associates, 2019). Other evidence that Joshua Spring is at least partly sourced from the deeper coal-bearing aquifer (Colinlea Sandstone) include: (a) groundwater flow directions in the Colinlea Sandstone converge on the springs (Hydrosimulations, 2015), and (b) groundwater in the Colinlea Sandstone has a variable but often similar salinity and strontium isotope ratio to the springs (Webb, 2015).

<u>Estimates of potential impacts to the DSC from the Carmichael Mine have neglected possible hydraulic connection (i.e., through the Rewan Formation) between deeper coal-bearing Permian-aged sediments and overlying Triassic-aged (and younger) sediments.</u>

Field evidence clearly shows that the values used for hydraulic conductivity of the Rewan Formation in Adani's groundwater model (on which 'best estimates' of the drawdown at the springs are predicted in the final GDEMP) are lower than the best available estimates of mean values based on field data. The IESC (2013) noted this, and it was reiterated in the CSIRO and Geoscience Australia (2019) review of the GDEMP:

> "*Rewan Formation: There is uncertainty around the capacity of the Rewan Formation to act as an aquitard to limit vertical leakage between adjacent formations, with consequent uncertainty on potential impacts to the GAB and Doongmabulla Springs Complex. There is a wide range of horizontal hydraulic conductivity (ranging from $1.0x10^{-1}$ m/d and $9.5x10^{-5}$ m/d) and limited vertical conductivity data. The Committee notes other evidence that suggests that north of this proposal the Rewan Formation appears to grade laterally into the Warang Sandstone, which is described as an aquifer; implying that in this region literature values for the Rewan Formation conductivity may not be appropriate. The numerical model used a 'blanket' figure for hydraulic connectivity which was lower than the mean of the field values. Given that the sensitivity analysis indicated the significance of the Rewan Formation in mitigating impacts on the Doongmabulla Springs and the GAB, the Committee recommends that as part of the revised model the mean of the measured hydraulic conductivity values be used*." (IESC, 2013).

> "*Parameterisation of the Rewan Formation and Clematis Sandstone by the SEIS model. Calibrated hydraulic conductivity values for the Rewan Formation are very low compared with measured values, which minimises vertical water movement, and hydraulic conductivity values for the Clematis Sandstone are high, which increases the lateral transfer of water. In combination these hydraulic conductivity*

values minimise predicted drawdown at the DSC" (CSIRO and Geoscience Australia, 2019).

The Adani GDEMP report (Ecological Associates, 2019) outlines the following about Rewan Formation permeability:

> "*The primary permeability of the upper claystone sequence of the Rewan Formation was measured as consistently low, based on the laboratory analysis of sampled cores. In the predominant claystone strata, both vertical and horizontal hydraulic conductivity ranged from 10^{-6} to 10^{-5} m/day. In the interbedded siltstone strata, permeability was measured as low, but slightly more permeable than the surrounding claystone at 10^{-4} m/day. The primary (formation) permeability of the lower siltstone sequence of the Rewan Formation measured as low to very low, but more variable than the upper sequence (10^{-7} to 10^{-4} m/day), likely as the result of the variance in grainsize within the predominant siltstone and the larger amount of defects*".

There are raw data that remain to be fully examined and interrogated. For example, it is unclear whether the (drill stem) testing referred to was undertaken throughout the sequence, or just on selected samples (e.g. of claystone and siltstone). The text above implies that only the claystone and the siltstone layers were tested; the Rewan Formation notably also contains significant components of Sandstone (clearly shown in the logs provided in the SEIS (GHD and Adani Mining, 2013) – e.g. Borehole C007P2 and Hole C020P2, whose top ~50 m is predominantly <u>sandstone</u>).

The limitations of drill stem tests for bulk hydraulic conductivity estimation should also be acknowledged. Estimates of hydraulic conductivity values in the Rewan Formation from the adjacent mining leases (e.g. China Stone, Alpha) should also be examined. Variations in thickness and lithology must be described and accounted for. Also, these tests don't account for faults, which may create localised zones of high permeability.

These findings contrast the unsubstantiated claim by Adani (2019): "*This source aquifer has been identified as the Clematis Sandstone geological layer, which is separated from the mine by a 250-300m impervious layer of claystone called the Rewan Formation.*"

<u>Hydraulic connection between Permian-aged and Triassic-aged (and younger) sediments is plausible within the expected zone of mine-induced drawdown.</u>

Adani estimates that drawdown (caused by the Carmichael Mine) of water levels in the DSC source aquifer is expected to be in the order of 19 cm (GHD and Adani Mining, 2013). However, this assumes unrealistically low hydraulic conductivity values for the Rewan Formation. Clearly in areas where the Rewan Formation has higher hydraulic conductivity values, is thinner, or contains fractures, there will be greater connectivity through which drawdown caused by the mine can propagate upwards. Moreover, there is the possibility that subsidence-induced fracturing associated with long-wall (underground) mining will affect connectivity across the Rewan Formation in a major way. This was described in the CSIRO and Geoscience Australia (2019) review:

> *"Issue: The hydraulic enhancement after the collapse of the goaf in the long wall panels was not included in the sensitivity analysis. In the SEIS model the hydraulic conductivity was increased by a factor of 50 for 75 m above the long wall panel and*

by a factor of 10 for between 75 m and 150 m above the long wall panel. Poulsen et al. (2018) and Adhikary and Poulsen (2018) have shown that the hydraulic enhancement can be up to 8 orders of magnitude (a factor of 108) immediately above the goaf and decline exponentially with increasing height for up to 500 m (also a smaller hydraulic enhancement below the long wall panels). The recommendations from the SEIS subsidence report for the groundwater modelling include:

"Accordingly the expected height of fracturing at the Carmichael Project, is expected to extend from the AB1 seam to the surface over much of the proposed longwall footprint."

"Conservatively adopting 160 metres based on Klenowski (ACARP C5016, 2000) would be considered a reasonable height for preliminary modelling of the height of direct hydraulic connection. Above this height, it is anticipated that there will be increase in the strata permeability due to fracturing through beds and bedding plane dilation, however the likelihood of hydraulic connectivity from the surface to the seam is anticipated to be low given the presence of aquiclude and aquitard materials in the overburden."

"*The subsidence report shows there is the possibility for the enhancement of hydraulic conductivity from the coal seams to the surface; this includes the full thickness of the Rewan Formation (averaging 250 m) above the longwall panels."*

<u>Permian-Triassic hydraulic connection (in the region of mining drawdown) may lead to greater impacts to the DSC.</u>

This point is supported by the CSIRO and Geoscience Australia (2019) reviews. In addition, they pointed out that over-prediction of hydraulic conductivity in the Clematis Sandstone likely suppressed drawdown at the DSC:

"*Issue: The sensitivity analysis undertaken for the groundwater model shows that the high hydraulic conductivity of the Clematis Sandstone acts to limit drawdown at the DSC (SEIS addendum Figure 12). The sensitivity analysis shows that the drawdown is equally sensitive to the hydraulic conductivity of the Clematis Sandstone as it is to the hydraulic conductivity of the Rewan Formation. The SEIS and SEIS addendum are incorrect when discussing the sensitivity of predictions to the hydraulic conductivity of the Clematis Sandstone (e.g. SEIS addendum Section 3.5.1); high conductivity allows the lateral transfer of water and minimises the drawdown, hence the high value adopted in the calibration being a concern*."

Notably, the CSIRO and Geoscience Australia (2019) findings apply even assuming the Clematis Sandstone is still the only/predominant source aquifer for the springs. The likely drawdown(s) in other layers which may also/alternatively act as sources for the springs have not been analysed or discussed by Adani, CSIRO, or Geoscience Australia as far as we are aware.

The DSC plausibly depend on discharge from Permian-aged sediments through Permian-Triassic hydraulic connection within the DSC or in other locations.

There is evidence of significant faulting based on seismic surveys by Xenith Consulting, as outlined in Currell et al. (2017):

> *"Faults with significant displacement have been interpreted on the basis of these surveys, including at least one that appears to extend vertically hundreds of meters across multiple strata, from the target coal seams in the Colinlea Sandstone through the Rewan Formation (Fig. 3)(McClintock, 2012). These surveys occurred entirely within the mine lease, and did not extend to the vicinity of the springs discussed below. While some faults act as barriers to horizontal groundwater flow in the Galilee and Eromanga Basins (e.g. Ransley and Smerdon, 2012), there is also evidence of groundwater discharging from deep strata to the surface through faults that cross regional aquitards in these basins."*

If faulting is present, this may indicate a significant hydraulic connection between the Triassic and Permian aged formations.

Plausible hypotheses for the source of DSC discharge should be incorporated into estimates of Carmichael Mine impacts.

At no stage has an alternative conceptualisation (e.g. a source aquifer below the Rewan Formation) been assessed or simulated in numerical models of mining impacts – either by Adani, CSIRO or Geoscience Australia. The CSIRO bioregional assessment modelling (Lewis et al., 2018) used the same conceptual model as Adani's original model but explored different hydraulic parameters in key layers. Hence, there are two major issues that remain unresolved:

1) The CSIRO and Geoscience Australia (2019) review indicates that using Adani's conceptual model, but still assuming the Clematis is the source aquifer for the DSC, the drawdown will be greater than modelled by Adani (and will exceed the approved drawdown in the EPBC approval conditions of 20 cm). This results from corrections required to bore heights, more realistic modelling of groundwater-surface water interaction (i.e. leakage from the Carmichael River), and the use of more realistic hydraulic conductivity values in the Rewan and Clematis Formations:

> "*The SEIS model under-predicts groundwater drawdown arising from mine development by up to 0.8 m, which means that the adopted thresholds and triggers will be reached sooner than anticipated and so are not a suitable foundation for the proposed monitoring and management approaches (refer Section 2.2).*" – CSIRO and Geoscience Australia (2019).

2) There is no understanding of what drawdowns might be expected at the DSC under *alternative* (but plausible) conceptualisations, e.g., in which a deeper aquifer is an important water source for the springs, even though the assessment of plausible alternative conceptualisations is critical for developing Adaptive Management strategies and exploring uncertainty and risk of DSC impacts more generally.

Key point 2:

Should the Carmichael Mine cause springs within the DSC to cease flowing, this impact may be irreversible.

<u>Significant drawdown will remain at the end of the Carmichael Mine's life.</u>

The considerable void that is proposed to remain at the end of the mine's life will have dimensions of roughly 4 km by 40 km, and up to 300 m below the existing watertable (GHD and Adani Mining, 2013; Ecological Associates, 2019). This will lead to drawdown in the coal-bearing sediments of tens of metres in the vicinity of the springs following mine closure (Hydrosimulations, 2015). It is important to note that the greatest impacts to the springs will occur after Adani have ceased their operations.

<u>The mine will impact groundwater flow pathways by modifying aquitard properties.</u>

The sediment overlying Adani's underground mining operations will be significantly modified once the coal resources are extracted, leaving behind a void (goaf) that eventually collapses. The effect of this is considerable enhancement of the vertical permeability of the Rewan Formation. As pointed out by CSIRO and Geoscience Australia (2019), the effect of this on the flow to the DSC has not been investigated or tested in modelling to date:

> "*The subsidence report shows there is the possibility for the enhancement of hydraulic conductivity from the coal seams to the surface; this includes the full thickness of the Rewan Formation (averaging 250 m) above the longwall panels.*
>
> ***Recommendation:*** *The way the hydraulic enhancement after the collapse of the goaf has been implemented in the modelling is not conservative (i.e. is likely to underestimate impact) and the omission of the associated parameters from the sensitivity analysis means that the impact these assumptions have on drawdown at the DSC is untested. Future model updates should include analysis of the sensitivity of the model to parameter changes due to underground mining.*" CSIRO and Geoscience Australia (2019).

<u>The DSC may be sensitive to drawdown, although the current relationship (DSC discharge and area versus drawdown) is unknown</u>

Many of the spring wetlands comprising the DSC have water levels which are only marginally above the land surface elevation. As a result, relatively small drawdowns may result in groundwater no longer reaching the surface to provide spring discharge. A comprehensive analysis of groundwater flow patterns in the area including the mine and springs – including analysis of vertical and horizontal hydraulic gradients and points of recharge and discharge - has yet to be published. It is plausible that changes in flow direction(s) and hydraulic gradients may result in loss of spring flows, even where drawdown levels at springs are relatively minor (Werner, 2015; Land Court of Queensland, 2015; Currell, 2016; Ecological Associates, 2019).

Previous cases of mining- and pumping-induced spring extinction demonstrate that permanent cessation of spring flow due to human interference should be considered.

Published examples of permanent impacts to springs from mining activities include Acque Albule basin (Italy; Brunetti et al., 2013), Mingshui Spring Region (China; Wu et al., 2011), and Yushenfu (China; Fan et al., 2018). Younger and Wolkersdorfer (2004) suggest, in relation to post-mining water loss, that "drawdowns of water levels are usually permanent, so that many individual springs will never flow again, no matter how much time elapses after mine closure".

Key point 3:

The safeguard against DSC impacts proposed by Adani, namely Adaptive Management, is unsuitable and unlikely to protect the DSC from extinction.

Protection of the DSC during Carmichael Mine operations depends on the effectiveness of Adaptive Management to identify impacts, investigate causal factors, predict future impacts, and design and implement corrective actions that ensure the long-term viability of the DSC.

The CSIRO and Geoscience Australia (2019) review states that:

> "*Issue: The approach used to model potential impacts to the groundwater system due to mining indicates that the model will under-estimate the amount of drawdown predicted at the DSC and the Carmichael River GDE as a result of model representation of:*
>
> - *the unrealistically high modelled flow in the Carmichael River,*
> - *error in the bore heights used to calibrate the model, and*
> - *hydraulic conductivity in the Clematis Sandstone and Rewan Formation model layers.*
>
> *If the predicted drawdown has been underestimated as a result of these factors, then issues with predicted drawdowns are propagated into the GMMP. It is unclear what impact these limitations will have on the timing of impacts on the DSC. The implication is that the thresholds and triggers will be reached sooner than anticipated based on this modelling, which means that relying on the model in its current form may not be an appropriate approach to deriving monitoring and management regimes."*

Adaptive Management is not a feasible strategy for protecting the DSC from Carmichael Mine impacts because: (a) cessation of DSC flow is likely irreversible, (b) strategies to reverse mining impacts on DSC flow have not been clearly defined (beyond a non-binding commitment to halt mining and review the mine plan; Ecological Associates, 2019), and are likely infeasible, (c) lag times between mining operations and identifiable impacts to the DSC likely preclude effective management responses to DSC decline.

It is important to note that “adaptive management” is not appropriate to irreversible problems. For example, the U.S. Geological Survey guideline on adaptive management, Williams et al. (2009) state that:

> *"If resource management decisions cannot be revisited and modified over time, then adaptive management cannot be meaningfully employed. Many decisions are essentially irreversible in that follow-up adaptation is either infeasible or impossible."*

Given that impacts to the DSC from the Carmichael Coal Mine are likely to be permanent, the use of Adaptive Management to protect the springs is unlikely to be effective.

Adaptive Management requires that methods for addressing impacts should be detailed and assessed at the project outset.

Williams et al. (2009) describe Adaptive Management as a structured approach to decision making, that includes (amongst other requirements): (i) “Identifying the range of decision alternatives from which actions are to be selected”, (ii) “Projecting the consequences of alternative actions”, (iii) “Measuring risk tolerance for potential consequences of decisions”. They add to this:

> *“Thus, an application of adaptive management must involve a real choice among management alternatives that affect resource systems. The variability among alternatives must be consequential (i.e., different alternatives produce substantively different management impacts), and the alternatives must be ecologically, economically, politically, and legally feasible.”*

Adani has not described engineering measures that might reverse impacts that arise from Carmichael Mine project, and therefore, their application of Adaptive Management is deficient.

Key point 4:

> ***Possible cumulative impacts to the DSC from other mining activities in the Galilee Basin have not been adequately considered.***

The Carmichael Mine is one of a number of proposed coal projects of significant size proposed in the Galilee Basin. Additional mines of similar size targeting the same geological layers are also likely to result in significant drawdown. Such drawdown may be additive, and if drawdown cones from multiple mines (such as Carmichael and the adjacent China Stone project, should they go ahead) intersect, then there is a possibility of additional drawdown occurring at the Doongmabulla Springs.

The National Water Commission’s project into the Potential Local and Cumulative Effects of Mining on Groundwater Resources (National Water Commission, 2009) provides clear guidance on the issue of cumulative impacts of mining in Australia. The project recognised the need to:

“Ensure that cumulative effects of mining on groundwater are considered in the mining project approvals process at jurisdictional and Australian Government levels”

They suggest:

“When assessing CE [cumulative effects], all present, past and foreseeable actions have to be taken into consideration”

And:

“proponents and technical personnel, such as consultants acting on behalf of mining proponents, will need to be aware of the framework when planning investigations and studies for mine approvals”

However, the Bioregional Assessment of the Galilee Sub-region (Hydrosimulations, 2015; Lewis et al., 2018) suggests that cumulative impacts to the DSC are highly likely (e.g., including additional drawdown from the proposed China Stone mine, immediately to the north of Carmichael). Such effects have not been incorporated into Adani’s strategy for monitoring and managing impacts to groundwater dependent ecosystems, including the DSC.