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DATE: 3 February 2015

TO: Mr Llewellyn Lezar
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FROM: Dr Noel Merrick

RE: **Adani - Carmichael Coal Project: Assessment of Potential Reduction in Spring Flow**

OUR REF: HC2015/5

This document has been prepared in response to a request in the *Joint Experts Report: Springs Ecology*, by Mr Bruce Wilson and Dr Roderick Fensham, dated 15 January 2015:

> "*We require an assessment of the predicted change in flow rates to fully assess the impact on ecological values of Doongmabulla Springs*."

Background

The GHD SEIS groundwater model (GHD, 2013b) has predicted that the maximum source aquifer (Clematis Sandstone) drawdown would occur at Joshua Spring within the Doongmabulla spring complex. The maximum drawdowns are estimated to be about 0.19 m in the operational phase and 0.16 m in the post-closure phase. A sensitivity analysis in which either the Clematis Sandstone or Rewan Formation hydraulic conductivity is increased by one order of magnitude gives rise to a maximum drawdown of about 0.3 m (GHD, 2013a). In the Moses spring group, predicted maximum drawdowns range from <0.05 m to 0.12 m at various springs during the operational phase (GHD, 2013b).

Joshua Spring is a heavily modified spring, as attested by photographs in **Figure 1**. It is now a turkeys nest dam with an associated wetland that is watered by discharge through an overflow pipe.

At a site inspection on 8 December 2014, the water level in the dam was about 3 m above natural ground surface. Judging from the incision of an adjacent creek, and the knowledge that the water table at monitoring bore HD02 (3 km east) is 2-3 m below ground level, the water table in the vicinity of Joshua Spring is estimated at 2-3 m below ground. Therefore, the head difference between the water table and the artesian head, which drives the spring flow, is estimated at 5-6 m.

It the Moses spring group, the mound springs are less elevated, ranging from about 0.2 m to a maximum of about 1.5 m (GHD, 2012).

The cumulative discharge at all springs within the Doongmabulla spring complex is estimated at approximately 1.35 ML/day (GHD, 2012). The discharge at individual springs is not known.

Spring Flow Physics

The discharge of groundwater at a spring is governed by Darcy's Law:

$$Q = K\,A\,\frac{\Delta H}{\Delta z}$$

where *Q* is the discharge rate, *K* the vertical hydraulic conductivity, *A* the area of the spring vent through which water is released, *ΔH* is the driving head difference, and *Δz* is the vertical separation between the water table and the mid-point elevation of the source aquifer.

By use of subscripts *B*, before mining, and *A*, after mining, the reduction in discharge rate due to mining can be expressed as:

$$\Delta Q = Q_B - Q_A$$

and the relative reduction in flow can be written as (assuming negligible change in *Δz* and unchanged *K* and *A*):

$$\frac{\Delta Q}{Q_B} = 1 - \frac{Q_A}{Q_B} = 1 - \frac{\Delta H_A}{\Delta z}\Big/\frac{\Delta H_B}{\Delta z} = 1 - \frac{\Delta H_A}{\Delta H_B} = 1 - \frac{(\Delta H_B - DD)}{\Delta H_B} = \frac{DD}{\Delta H_B}$$

where *DD* is the drawdown in the source aquifer due to mining.

This expression shows that the flow reduction is proportional to drawdown. If drawdown were one percent of the driving head difference, then the flow rate would be expected to reduce by one percent also. The relationship would be linear until the artesian head declined to a threshold elevation, at which point flow would cease abruptly. The threshold would be ground surface for discharge of water to pools, but would be at a higher elevation (the lip of the mound or other overflow elevation or pipe invert level) for water that is transferred from the mound pool to an associated wetland.

The decline in spring flow and upflow (from the source aquifer) is illustrated in **Figure 2**. The reduction in spring flow is shown to be approximately linear with drawdown. Upflow (the blue line) would cease if the drawdown were large enough to nullify the head difference between the water table and the source aquifer. For marginally less drawdown, there would still be upflow but it might not appear at ground surface and would instead provide recharge to the water table. Spring flow, the upflow that appears above ground as a spring, would cease when drawdown causes the head difference to match either ground level (the green line) or a geomorphic threshold (the red line) such as the lip of a mound or other point of overflow.

Joshua Spring Flow Impact

For the case of Joshua Spring, the values for the relevant terms are:

DD = 0.19 m (operational); 0.16 m (post-closure); 0.3 m (sensitivity extreme)

ΔH_B = 5 m or 6 m.

The expected percentage reductions in spring flow are listed in **Table 1.** the effect is expected to be in the order of about 3% to 6%.

Table 1. Anticipated Spring Flow Impacts at Joshua Spring.

DRIVING HEAD	Drawdown 0.16 m	Drawdown 0.19 m	Drawdown 0.3 m
5 m	3.2%	3.8%	6%
6 m	2.7%	3.2%	5%

Moses Springs Flow Impact

For the case of springs in the Moses complex, the driving head is less well defined but it would be lower than at Joshua Spring. As a worst case, suppose the water table is at 2 m below ground and the artesian head is 0.5 m above ground. Then, the worst case values for the relevant terms in the flow reduction equation are:

DD = 0.12 m

ΔH_B = 2.5 m.

The expected worst case flow reduction would be about 5%.

Conclusion

My findings are:

- Spring flow rate would reduce in the same proportion as drawdown to the driving head;
- For substantial drawdown, flow would cease abruptly when a geomorphic threshold is reached;
- Flow reductions are most unlikely to exceed 10 percent at the Doongmabulla Springs; and
- Flow reductions are more likely to be in the 3-5 percent range at the Doongmabulla Springs.

Yours sincerely

Dr Noel Merrick

Director

REFERENCES

GHD, 2012, Report for Carmichael Coal Mine and Rail Project: Mine Technical Report - Doongmabulla Springs Existing Environment Report. Report 23244-D-RP-17, October 2012.

GHD, 2013a, Carmichael Coal Mine and Rail Project SEIS: Mine Hydrogeology Report Addendum. Report G:\41\26422\WP\452475.docx, 24 October 2013.

GHD, 2013b, Carmichael Coal Mine and Rail Project SEIS: Report for Mine Hydrogeology Report. Report G:\41\26422\WP\449522.docx, 13 November 2013.

JOSHUA SPRING

Figure 1. Photographs at Joshua Spring, taken 8 December 2014

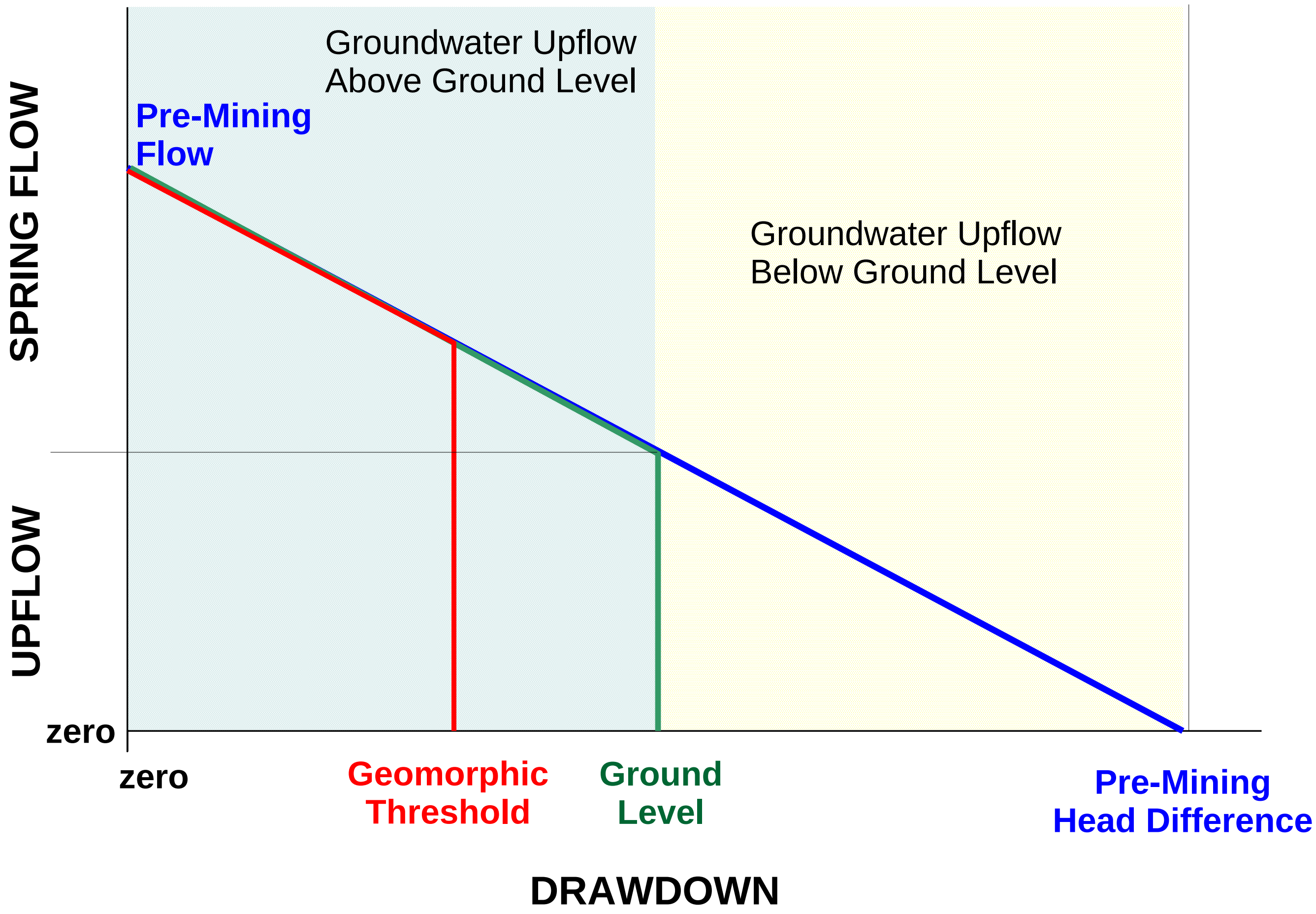

Figure 2. Schematic Illustration of Spring Flow Reduction with Increased Drawdown