# Fwd: Andréassian review of water loss from Waratah Rivulet and a couple of other relevant docs

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Date: 26 March 2014 23:31
Subject: Andréassian review of water loss from Waratah Rivulet and a couple of other relevant docs
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Hi Chris and Leah, attached is the previously mentioned review of Waratah Rivulet and Woronora River water loss estimates and modelling completed in 2010 on behalf of the SCA by Prof. Vazken Andréassian from the Université Pierre et Marie Curie Paris.

In brief it estimates between 1.5 and 5.4 Ml/day are being lost from the Waratah Rivulet - and possibly from the Woronora Reservoir catchment as a result of water being diverted into subsidence cracks and then joining regional groundwater flows that take water away from the local storage catchment. The average inflow to Woronora Reservoir is 18 Ml/day - though the range can be 0 to 180 Ml/day.

Complicating this finding is poor quality data and the possibility water loss from Woronora River that the review suggests would reflect 'natural' leakage, under the assumption that the river is not directly undermined and so is not effected by mining. Natural leakage is possible, but its also possible that 'far field' horizontal effects from neatby mine subsidence may cause or exacerbate leakage on the Woronora River. This is discussed in the attached comments on the proposed water management plan (WMP) for the next set of longwalls to be extracted as part of the 2009 approved expansion of the Metropolitan Colliery. BHP have reported far field movements at up to 5km (reference in the attached).

The Andréassian review highlights a lack knowledge and understanding of mining impacts.

I hope you'll find time to read the comments on the WMP, as they give an insight into how the approval and compliance process works, or may fail to work, in the Special Areas. In short, Peabody make important assumptions but don't test them and DoPI evidently don't have resources/time to check. Related to the assumption that Woronora River is not a mining effected watercourse, the comments doc includes a map showing the relationship of Metropolitan Colliery to the Woronora Special Area, nearby mines and iron springs on Woronora River as mapped by a PAC panel in 2010. The 2010 PAC panel (see ref. 2 in attached) concluded it was likely mining at Metropolitan Colliery was effecting Woronora River.

You may think the comments on setting a benchmark for iron levels in water entering Woronora River from Waratah Rivule are an exercise in hair splitting, but the PAC Panel for the project was concerned to ensure there was no further degradation in the quality of water entering Waratah Rivulet. Prior to mining Waratah Rivulet was a pristine stream (see the second attached Jankowski paper). The 2012 Annual Review for the Metropolitan Colliery shows iron levels in water reaching the Woronra Reservoir from the Waratah Rivulet reaching the SCA's bulk water supply agreement limit of 1.0 mg/l.

The current WMP is a second revision, they were required to revise the first draft when I pointed out to DoPI that it included an essentially hidden redefinition of the baseline period to include the first set of longwalls of the expansion project. DoPI agreed this was inappropriate. Peabody had hoped to have the WMP approved by November-December 2013; I gather a decision will be made this week.

Attached are two 2010 papers from the SCA's principle scientist Jerzy Jankowski; they give a good summary of the public concerns of the SCA wrt Waratah Rivulet. The rivulet is a case study of impacts suffered by other watercourses in the Special Areas.

Cheers, Peter

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**4 attachments**

**44_Draft Final Report_SCA_Report_VA.pdf**
1561K

**jankowski_Surface-Groundwater Connectivity in Longwall Mining Impacted Catchment Part2__IAH_2010.pdf**
736K

**jankowski_Surface-Groundwater Connectivity in Longwall Mining Impacted Catchment Part1__IAH_2010.pdf**
818K

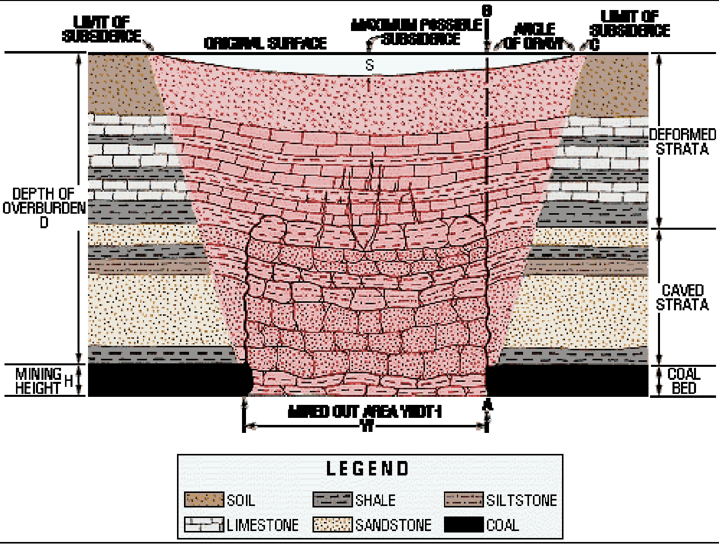
**some_comments_on_the_revised_water_management_plans_for_Metrop_LWs23-27_Peter_Turner_140317.pdf**
771K

SYDNEY CATCHMENT AUTHORITY

# A review of the surface water hydrology studies carried out on the Woronora catchment

**by**


**Vazken Andréassian, *ICPEF, PhD, DrHab***
**Hydrologist**


**July 2010**

## CONTENTS

## LIST OF ABBREVIATIONS

| | |
|---|---|
| FDC | Flow Duration Curve |
| HCPL | Helensburgh Coal Pty Ltd |
| IGF | Intercatchment Groundwater Flows |
| SCA | Sydney Catchment Authority |

## LIST OF TABLES

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# EXECUTIVE SUMMARY

The Waratah Rivulet, a tributary to the Woronora reservoir, is impacted by land subsidence caused by longwall mining below the catchment surface. Some of the hydrological effects are clear (notably in terms of time distribution of flows, of water quality). Other are still a matter of debate, and the Sydney Catchment Authority is looking for evidence to conclude whether or not subsidence is causing water to leak outside the catchment.

This report regroups the different sources of hydrological information and discusses of their validity. It also analyses the different assessment studies which have been implemented up to now.

Then, complementary analyses are carried out using two different methods to come to a quantitative estimate of water leakage from the Waratah Rivulet catchment. A water balance computation by flow classes (between the midstream and the downstream gauge) yields a value of 1.5 ML/d as best estimate, and a rainfall-runoff modelling study yields a value of 5.7 ML/d. The reality lies probably closer to this latter value.

However, it is impossible to conclude that the leakages are the consequence of mining, notably because of a double paradox: the upper Waratah catchment (first affected by longwall mining), shows no evidence of leakage, and the Woronora River catchment, which has not been affected by mining, seems to experience twice as much leakage as the lower Waratah.

It is likely that at least part of this leakage has a natural geological origin. Note also that we cannot say whether the leaking water still reaches Woronora dam by underground routes, or whether it is diverted towards a regional aquifer or towards the sea.

At the end, we formulate recommendations in order (i) to improve the monitoring at SCA stations, (ii) to make the best possible use of historic data in the catchment, and (iii) to design an integrated model capable to represent the rainfall-reservoir volume relationship, in order to make use of the only continuous dataset in the catchment: the reservoir volumes.

# 1 CONTEXT OF THIS REVIEW

The Waratah Rivulet is a tributary to the Woronora reservoir, managed by the Sydney Catchment Authority for potable water supply.

Since 1995, Helensburgh Coal Pty Ltd (HCPL) has started mining under the upper Waratah Rivulet catchment and the impact of mining-induced subsidence has been progressively noticed in the water course. Some effects are spectacular: cracks are large and the effect on aquatic habitats is obvious. However, the impact on the water resource is still a matter of debate. In particular, the question whether subsidence has caused water to leak outside the catchment has not been settled.

HCPL has now applied for an extension of the mining lease, and aims to move further North under the lower Waratah Rivulet catchment. It is thus essential at this point to bring an answer to the leakage question.

This report examines the hydrological studies made preliminary to the extension, focusing on quantitative aspects, based on all available data. The analysis is structured as follows:

- in section 2, we give a short overview summarizing the potential impact of mining subsidence on catchments;

- then, in section 3, we examine the different sources of hydrological information available for this review;

- in section 4, we discuss the different assessment studies which have been implemented up to now;

- in section 5, we provide our own analysis, based on available hydro-meteorological data, and try to address the issue of catchment leakages;

- last, in section 6, we list possible follow-up measures and studies, that could help in improving the present monitoring and further quantifying the leakage issue.

An appendix (section 8) provides greater details on some problems identified in the hydro-meteorological datasets analysed.

# 2 MINING-INDUCED SUBSIDENCE AND ITS POTENTIAL IMPACT ON CATCHMENTS


**Figure 1: Coal reserves and Sydney reservoirs (Loveday et al., 1983)**

Underground mining – and especially longwall mining – is known to cause subsidence at the ground surface; its impact on buildings, roads and bridges is often spectacular and thus well documented.

Much less is known about the impact of mining-induced subsidence on catchment hydrology: indeed, this impact will depend on a number of factors such as bedrock type, pre-existing fracture systems, local aquifer porosity, geometry of the succession of aquifer and aquiclude formations, etc. Because mining-induced bedrock fracturing can potentially create new underground connexions, there is a concern that it can alter water flow pathways at the local and regional scale. As Loveday et al. (1983) summarized it, '*there are a range of possible impacts from catastrophy to annoyance*'.

- **Potential impact on water quantity**

Mining-induced subsidence can have an impact on water quantities, through its effect on increasing bedrock fracturation. New fractures can potentially create connexions which did not exist previously, and cause:

- *local effects* – i.e. a change of flow pathways within the basin, while all water fluxes keep converging towards the original catchment outlet;
- *regional effects* – i.e. the creation of flow pathways able to carry water below the catchment boundary, either to neighbour rivers or directly to the sea. These fluxes are termed Intercatchment Groundwater Flows (IGF).

- **Potential impact on the surface flow regime**

Mining-induced subsidence can have an impact on the streamflow regime, with possible changes in the time-distribution of flows (what hydrologists summarize by the *Flow Duration Curve* – FDC). Most of the impact is expected on low-flows, which can be either:

- *reduced* – with a greater proportion of low-flows using the newly created underground pathways;
- *enhanced* – mostly on bedrock with very low porosity, and where the aquifer storage capacity is increased by mining-induced fracturation.

Note that these opposite effects can occur on the same catchment simultaneously: reaches with reduced low-flows (just above the mined area) can be followed by reaches showing increased low-flows further downstream.

- **Potential impact on water quality**

Mining-induced subsidence can alter significantly on water quality, because increased bedrock fracturing will increase the surface of contact between water and the geological parent material, and provide an occasion for increased weathering and faster mineral leaching.

- **Potential impact on water habitats**

Mining-induced subsidence can have an impact on water habitats, through its effects on the flow regime and on water quality. It can also have a detrimental effect on the 'dead' storages (pools) which occur within watercourses and provide shelter to aquatic species during periods of low flows. Indeed, pools are dependent on the occurrence of impermeable rock barriers, which may become porous due to subsidence-induced fractures.

- **Potential impact on groundwater**

Mining-induced subsidence can affect groundwater levels and groundwater yield, through its role on increased bedrock fracturing, which can potentially create connexions between different aquifer levels through aquitards or aquicludes.
Increased fracturing can also reduce the transfer time of groundwater (i.e. speed up underground water movement), and increase the porosity (and thus the reserve) of the less porous bedrock types.

# 3 REVIEW OF AVAILABLE DATA

***Synthesis***

We examined the sources of flow and rainfall data:

- Flow gauges: three historic flow gauges are available on and near the catchments (Waratah @ Sanatorium, Woronora @ Engadine, O'Hares @ Darkes Forest), and six modern flow gauges are available on the Waratah catchment (unfortunately, their records start long after longwall mining was initiated). All flow gauges seem unreliable at high flows. Differential assessment on the Waratah River (to detect possible transmission losses between gauges) can thus only be trusted when performed at low and moderate flows;

- Rain gauges: three high quality, consistent rain gauges are available to compute the precipitation input over the Waratah catchment (Darkes Forest, Reverces, Helensburgh). Another long-term rain gauge available further North (Woronora Dam) is also consistent wit the three first. The records from the recently installed raingauges (at the centre of the Waratah and Woronora catchments) seem unreliable. We recommend trusting only the long-term raingauges to compute catchment average precipitation.

Our analysis was based on all available rainfall and runoff data, in the Woronora dam catchment, as well as in neighbouring catchments. Since our aim was to assess possible changes, we did try to compensate for the lack of continuous flow records just before and after the start of mining below the catchment by using historic time series that were recorded long ago, between the 1920s and the 1940s.

### *3.1 Streamflow gauges*

In this section, we discuss the availability and the reliability of streamflow datasets.

Table 1 presents of list of 13 streamflow gauges which were available over and at proximity of the study area, and Figure 2 shows the location of some of them. A large variability exists in terms of specific discharge (i.e. the flow expressed in mm/yr), one which cannot be explained by differences in rainfall input or land cover: this variability is probably linked to complex underground flow pathways and witnesses the existence of large intercatchment groundwater flows (IGF). We will come back later to this point.

Note that to be rigorously comparable, mean average flow values should be computed on a common period (which is not the case in Table 1). This would however not change the orders of magnitude for the historic streamflow gauges: if we compute the average discharge on the common part of the record only, Waratah Rivulet (@ Sanatorium) would still yield 1.5 times more flow than O'Hares Creek (@ Darkes Forest) – 272 *vs.* 176 ML/yr/km².

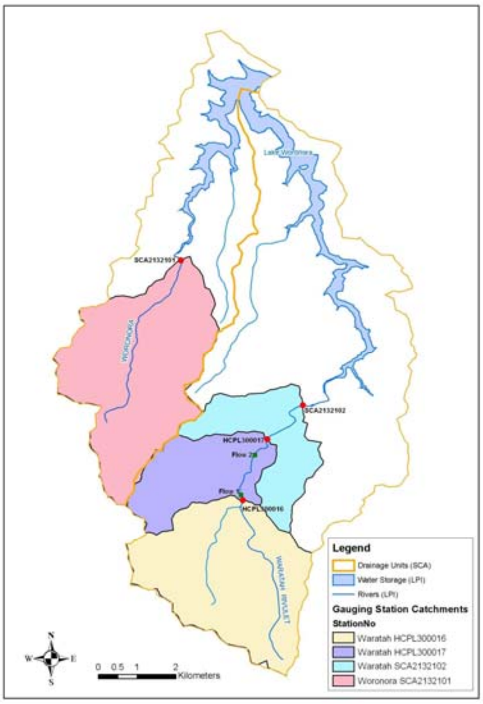


**Figure 2 : Map of the nested sub-catchments on the Woronora and Waratah rivers corresponding to the present stream gauges**

**Table 1: List of available streamflow gauges around the study area (*note: to be rigorously comparable, mean average flow values should be computed on a common period, which is not the case here*)**

| Station | Code | Catchment area (km²) | Days in record | Average flow | | Time step (H/D) | starts | ends |
|---|---|---|---|---|---|---|---|---|
| ***Historic gauges*** | | | | | | | | |
| Waratah Rivulet @ Sanatorium | 213001 | 31 | 6438 | 47 ML/d | 555 mm/y | *D* | *13/02/1925* | *30/11/1942* |
| Woronora River @ Engadine | 213003 | 72 | 9763 | 95 ML/d | 480 mm/y | *D* | *02/06/1924* | *01/08/1951* |
| O'Hares creek @ Darkes Forest | 213002 | 16 | 2063 | 7 ML/d | 167 mm/y | *D* | *01/12/1924* | *30/11/1930* |
| ***Modern gauges*** | | | | | | | | |
| Woronora River @ new gauge | SCA 2132101 | 12.4 | 625 | 5 ML/d | 149 mm/y | *D&H* | *21/02/2007* | *03/05/2010* |
| Waratah Rivulet @ G1 | HCPL 300016 | 11.2 | 971 | 9 ML/d | 302 mm/y | *D* | *04/04/2007* | *11/02/2010* |
| Waratah Rivulet @ G2 | HCPL 300017 | 16.3 | 997 | 12 ML/d | 260 mm/y | *D* | *04/04/2007* | *11/02/2010* |
| Waratah Rivulet @ G3 | SCA 2132102 | 20.9 | 1066 | 15 ML/d | 257 mm/y | *D&H* | *21/02/2007* | *29/04/2010* |
| Waratah Rivulet @ F1 | F1 | ? | 1501 | 10 ML/d | - | *D* | *21/02/2002* | *01/02/2007* |
| Waratah Rivulet @ F2 | F2 | ? | 1206 | 15 ML/d | - | *D* | *15/02/2002* | *31/10/2006* |
| Waratah Rivulet @ F3 | F3 | ? | 666 | 10 ML/d | - | *D* | *09/12/2004* | *28/02/2007* |
| ***Neighbour gauges*** | | | | | | | | |
| O'Hares creek @ Wedderburn | 213200 | 73 | 14375 | 69 ML/d | 345 mm/y | *D* | *25/12/1965* | *22/02/2010* |
| Nepean River @ Wallacia | 212202 | 1760 | 32630 | 712 ML/d | 148 mm/y | *D* | *26/01/1917* | *20/05/2009* |
| Jigadee Creek @ Avondale | 211008 | 55 | 9929 | 51 ML/d | 336 mm/y | *D* | *18/12/1969* | *31/12/1998* |

We did a preliminary quality check of the available streamflow data, based on the classical "double mass curve" technique (see Appendix 8.1 p. 51 for details), on the basis of which we can conclude that:

1. The historic measurements on the Woronora and the Waratah rivers are completely incoherent (see Figure 3), especially during very high flow events where there are obvious errors in the record (see Table 3). This does not mean that these datasets could not be used at all, but prior to any use, the time series should be carefully inspected visually to detect the periods of inconsistency and to recode the values as 'missing'. Calibrating a rainfall-runoff model could probably be useful too in order to detect these periods[1].

[1] The interesting fact is that the calibration of such a model does not require continuous streamflow series; it could be done on truncated time series including low and moderate flows only.

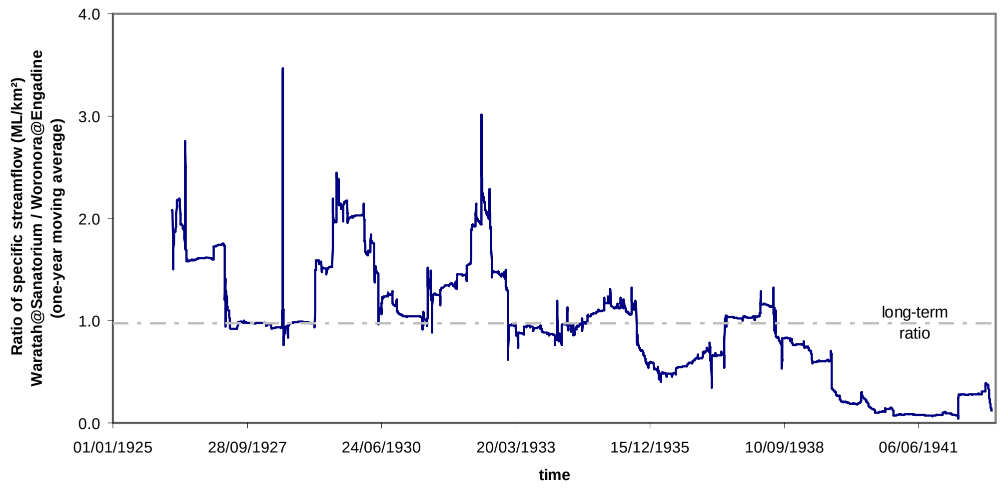


**Figure 3: illustration of the incoherence of historic flow measurements on the Waratah Rivulet and the Woronora Rivers**

2. The recent measurements (F1 to F3) and (G1 to G3) are consistent with one another. We could not however assess the consistency of F vs. G gauges, because the overlap was too limited (anyway, we will not use in this analysis the F gauges, because we do not know their exact location and the size of their respective catchments).

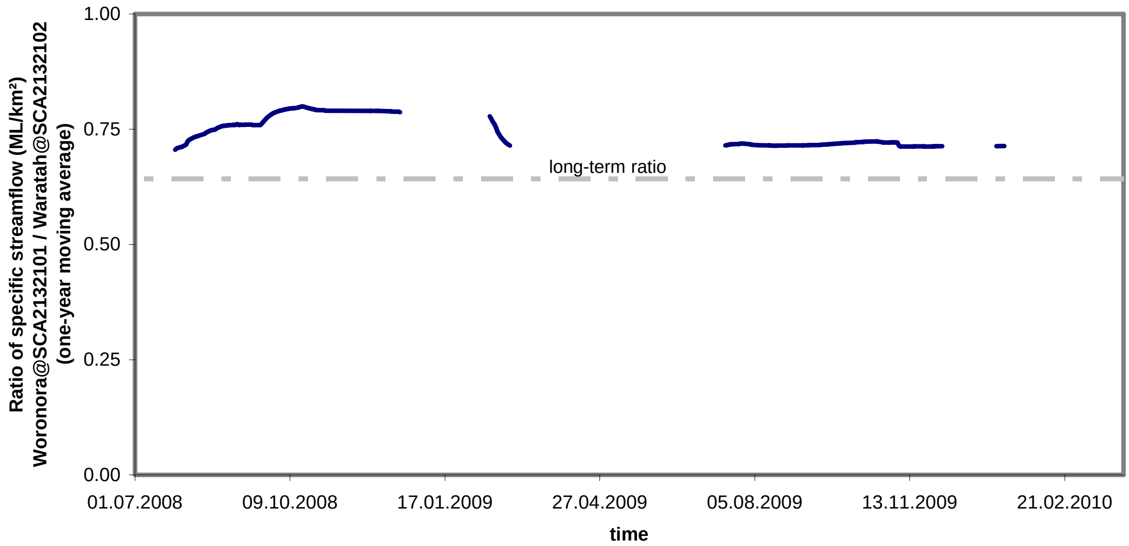


**Figure 4: illustration of the relative consistency of modern flow records on the Waratah Rivulet and the Woronora Rivers**

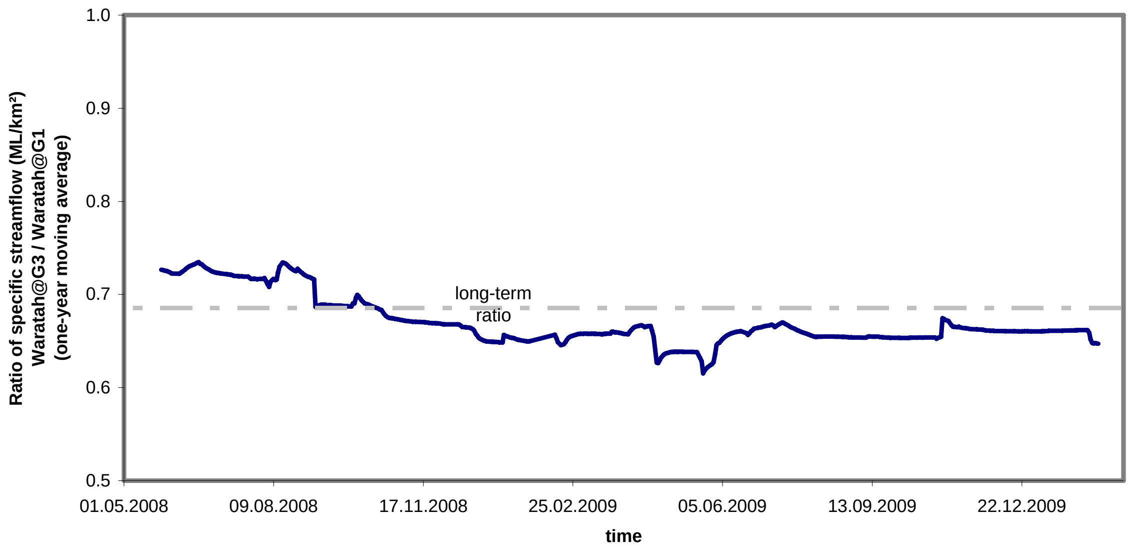


**Figure 5: illustration of the upstream-downstream consistency of 'modern' Waratah streamflow records**

## *3.2 Rating curves*

In this section, we discuss the validity of the rating curves at some of the streamflow gauging stations.

We only had access to the rating curves of the three modern Waratah Rivulet gauges (G1 to G3). Since the flow data of these stations has been used for a differential analysis aiming at quantifying losses (see section 5.1 p. 38), it was particularly important to focus on them, because errors typically cumulate (i.e. if there is a 5% uncertainty on both Q1 and Q2, the uncertainty of Q1-Q2 will be larger than 5%).

### *3.2.1 Rating curves at the three Waratah gauging stations*

In order to assess quantitatively the reliability of rating curves, more point measurements would be needed: they were not available. Thus, we limited our analysis to a qualitative judgement, based on the maximum level which has been effectively measured. Above this level, the rating curve is in extrapolation mode, and the higher water rises above this limit, the more uncertain the height-discharge relationship becomes (Figure 6):

- For G1, 15 point measurements exist, the largest measured flow is 26.2 ML/d (i.e. an instantaneous value of 0.30 $m^3$/s);
- For G2, 14 point measurements exist, the largest measured flow is 40.2 ML/d (i.e. an instantaneous value of 0.47 $m^3$/s);
- For G3, ca 30 point measurements exist, the largestl measured flow is 100 ML/d (i.e. an instantaneous value of 1.16 $m^3$/s).

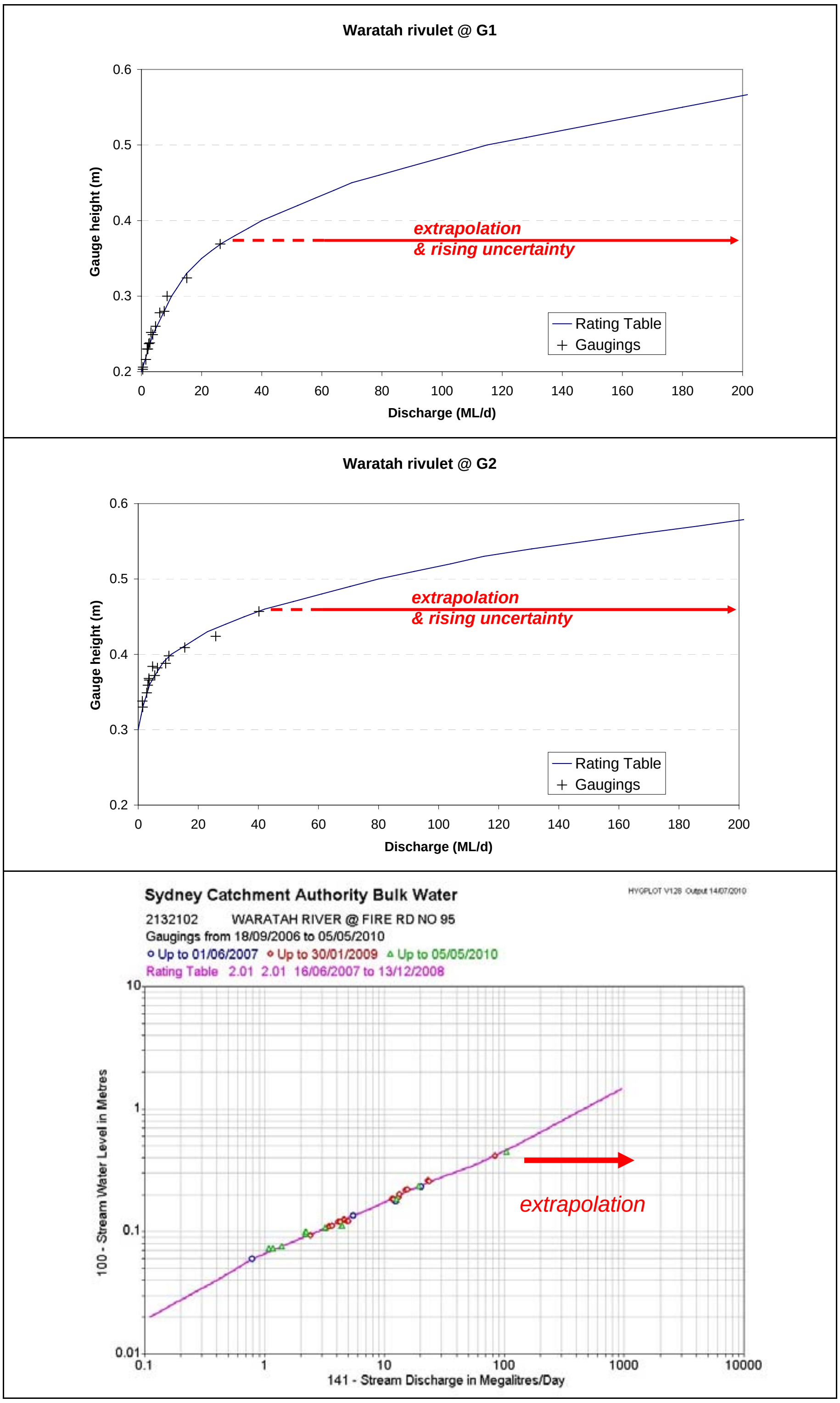


**Figure 6: rating curves and corresponding point gaugings for the three gauges of the Waratah Rivulet**

Note that in order to be able to judge of the degree of extrapolation, it is not sufficient to look at daily flows, since the catchments have a sub-daily dynamic (see an example in Figure 7: a daily discharge of 200 ML/d corresponds to a peak flow which can reach 500 ML/d on the Waratah Rivulet).

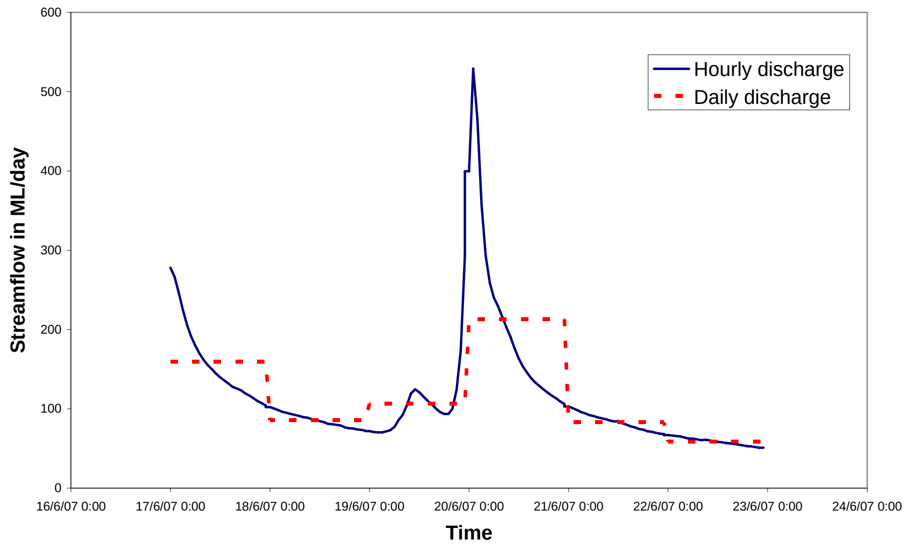


**Figure 7: differences observed with daily and hourly discharges on the Waratah Rivulet**

To propose a hierarchy of flow uncertainty, we defined three classes:

- ***low uncertainty flow class -*** when none of the hourly flow amount has been recorded in extrapolation of the rating curve (i.e. above the last measured point);
- ***medium uncertainty flow class -*** when up to 25% of the daily flow amount has been recorded in extrapolation of the rating curve;
- ***high uncertainty flow class -*** when more than 25% of the daily flow amount has been recorded in extrapolation of the rating curve.

This analysis was only[2] possible at the downstream Waratah gauge (G3): and the results are presented in Table 2.

**Table 2: qualitative assessment of the level of uncertainty in relation with the streamflow rating curves on the Waratah Rivulet @ G3**

| | uncertainty class | | | Total |
|---|---|---|---|---|
| | low | medium | high | |
| **Number of days in record** | 1013 | 15 | 38 | 1066 |
| **Average flow (ML/day)** | 10 | 58 | 131 | 15 |

Table 2 shows clearly that the higher flow volumes on record are extremely uncertain. This must be taken into account when working on differences between gauges (we illustrate this in section 5.1 p. 38).

### *3.2.2 Rating curves at historic gauging stations*

Although we did not have access to the rating curves of the historic gauging stations, we looked at the extreme events, for which we could at least compare flow amounts

[2] It was the only Waratah Rivulet streamgauge for which we had sub-daily flow data.

with incoming precipitation (a method which unfortunately only allows detecting large flow overestimation though).

Clearly, Table 3 shows a huge overestimation of stream flow rates on the two most extreme events: specific flow (i.e. flow expressed in ML/km² = mm to be directly comparable with rainfall totals) is much larger that rainfall. This is naturally impossible, and we believe it to be a problem of rating curve extrapolation.

**Table 3: water balance of the extreme events for the extreme flow events on the historic streamgauges**

| Date of the rainfall event | Raingauges | | | Streamgauges | |
|---|---|---|---|---|---|
| | Darkes Forest | Helensburgh | Woronora dam | Woronora River @ Engadine | Waratah Rivulet @ Sanatorium |
| 16-27 June 1925 | 291 mm | 280 mm | - | 75797 ML = 1052 mm | 15556 ML = 502 mm |
| 14-20 April 1927 | 559 mm | 571 mm | - | 64186 ML = 891 mm | 40983 ML = 1322 mm |

### *3.3 Available raingauges*

In this section, we discuss the availability and the reliability of the precipitation datasets.

Table 4 presents the list of the eight raingauges which were available over and at proximity of the study area, and Figure 8 shows the location of some of them. A South to North downward rainfall gradient is apparent, with the highest values at the upstream end of the catchment, and the lowest values North towards the downstream end of the catchment (Woronora dam).

**Table 4: List of available raingauges over the study area**

| N° | Name | Code | Number of days in the record (excluding missing values) | Average annual rainfall over the length of the record (mm) | Date of start |
|---|---|---|---|---|---|
| P1 | Darkes Forest | 68024 | 31520 | 1 474 | 01/01/1924 |
| P2 | Woronora Dam | 566052 | 29715 | 1 105 | 01/01/1928 |
| P3 | Helensburgh | 68028 | 28370 | 1 512 | 01/01/1924 |
| P4 | Letterbox | 568065 | 16712 | 1 415 | 02/02/1964 |
| P5 | Reverces | 568069 | 15608 | 1 209 | 02/02/1964 |
| P6 | Waterfall | 68063 | 1331 | 990 | 01/08/1931 |
| P7 | Waratah Rivulet | - | 1270 | 1 100 | 01/09/2006 |
| P8 | Woronora River | - | 1091 | 1 141 | 06/03/2007 |

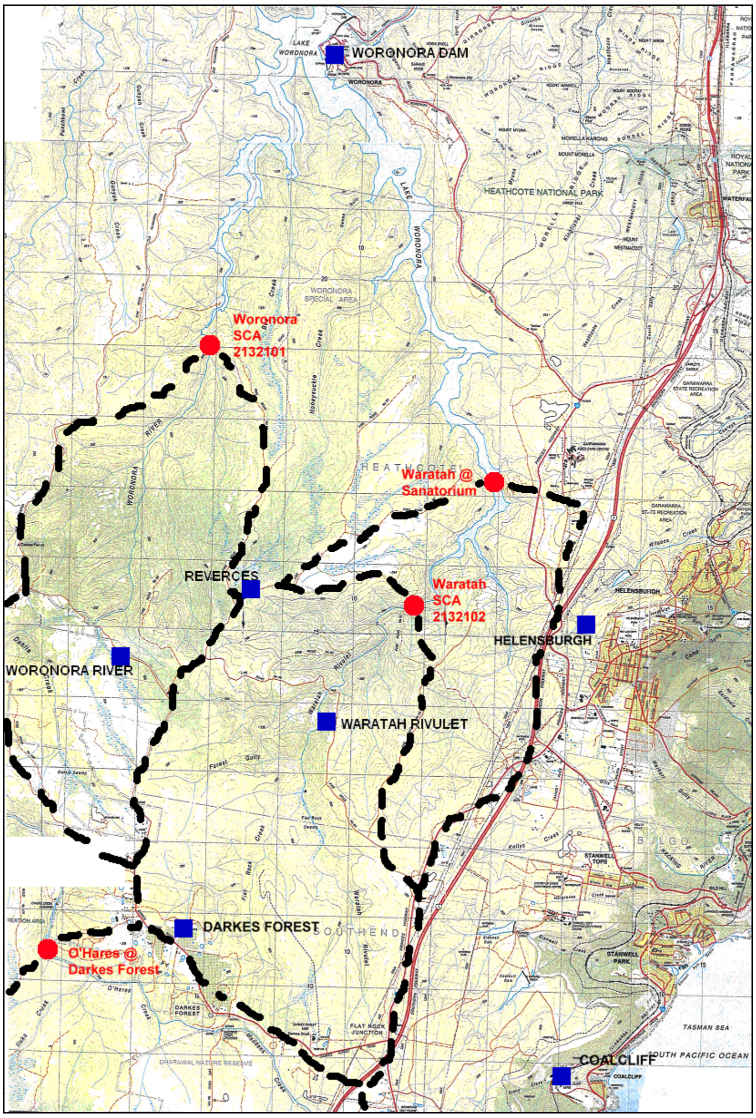


**Figure 8: location of some of the study raingauges**

We did a preliminary quality check of the available precipitation data, by looking at the relative consistency of raingauge pairs, based on the classical 'double mass curve' technique (see appendix 8.2 p. 52 for details). Our main conclusions are that:

1. Woronora River raingauge is completely unreliable ;
2. Waratah Rivulet raingauge also shows signs of unreliability – although it is rather well correlated with the Woronora Dam raingage in terms of monthly totals;
3. The three long-term precipitation gages (Darkes Forest, Helensburgh and Woronara Dam) show a very consistent behaviour: no break is apparent in the double mass curve (Figure 9-a), and the ratio of the running average rainfall always remains close to its long-term value (Figure 10-a). Unfortunately, Helensburgh data is missing from January 1$^{st}$ 2006;
4. Reverces raingauge is also very consistent with the above gauges (see Figure 9-b and Figure 10-b);
5. Strangely, Waterfall raingauge has very little available data (anyway, it is not close to our catchments, and we did not need to use it);

6. Letterbox can only be useful for the O'Hares creek catchment.

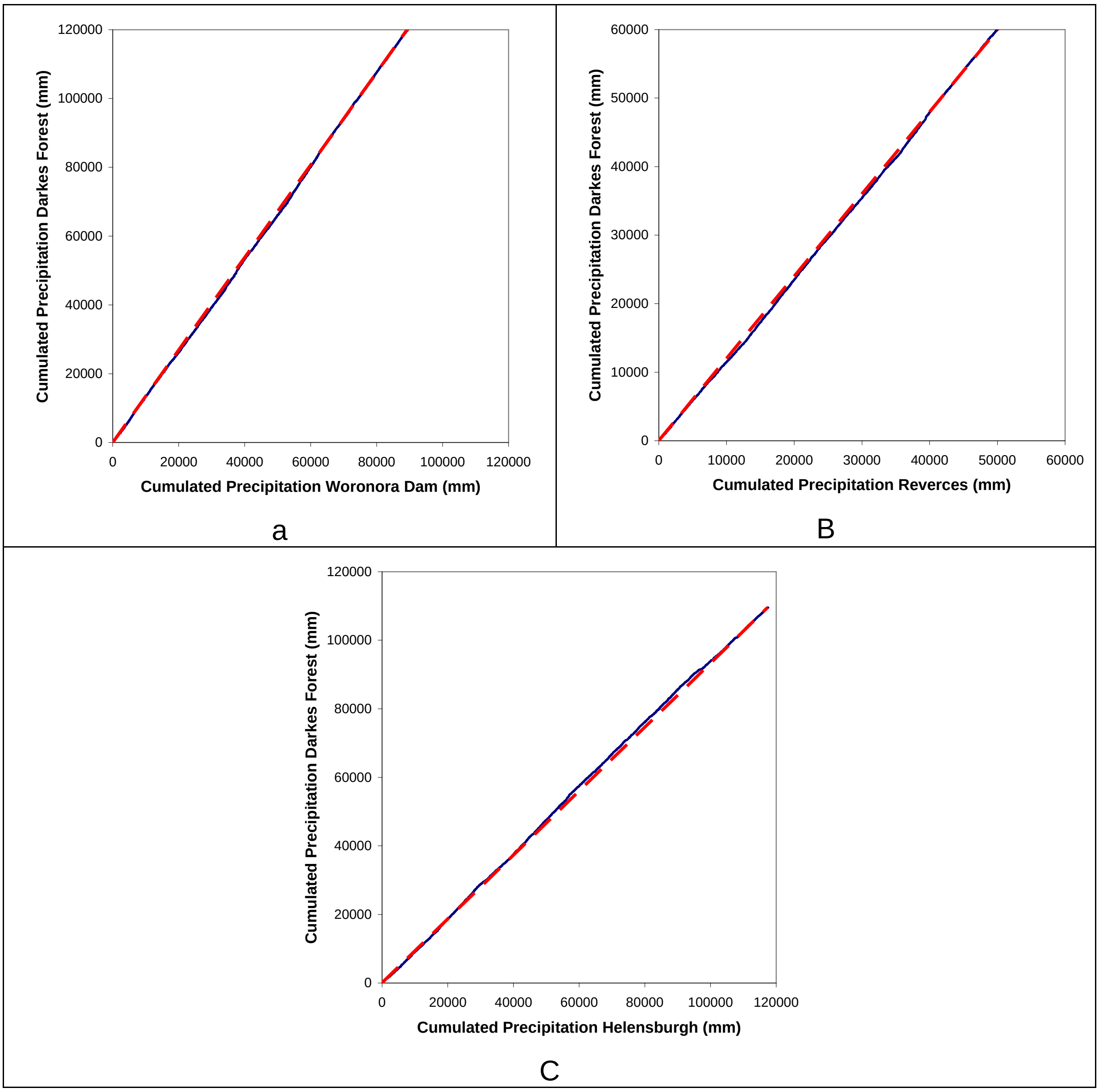


**Figure 9: double mass curve (cumulative totals over the common record period) showing the co-evolution of precipitation records. a - Darkes Forest vs. Woronora Dam; b - Darkes Forest vs. Reverces; c - Darkes Forest vs. Helensburgh**

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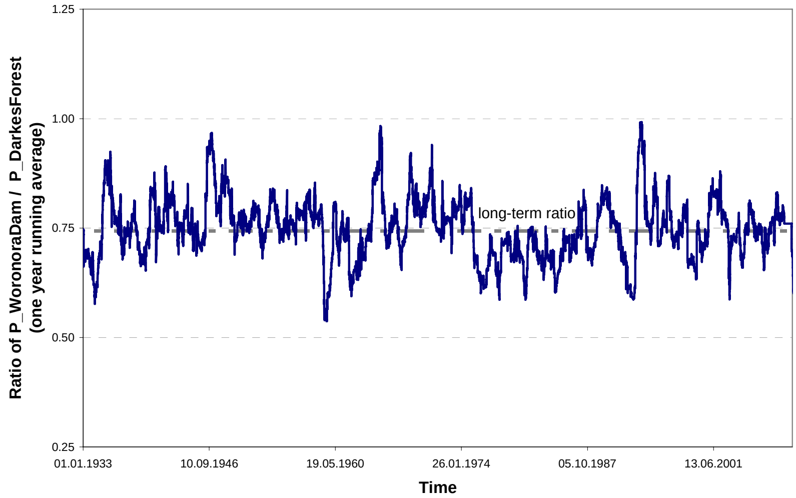
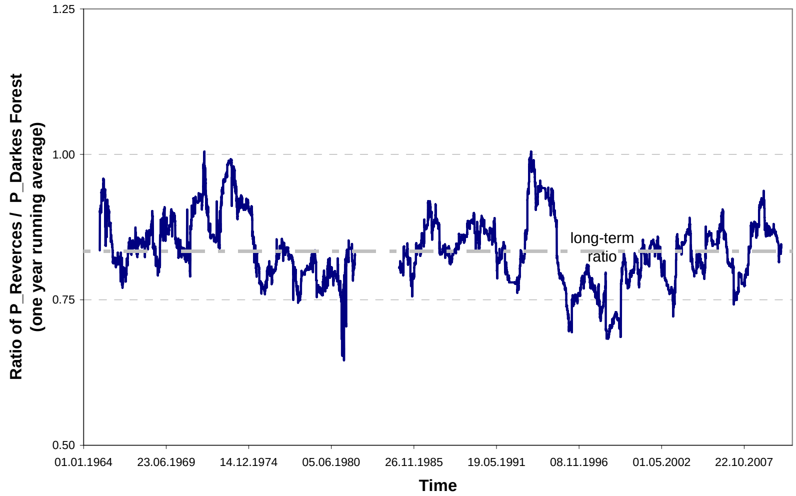
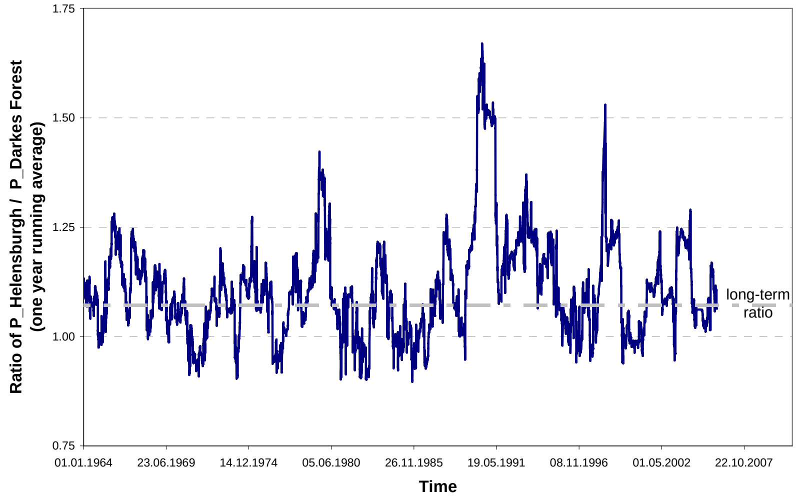
| a |  |
| b |  |
| c |  |

**Figure 10: evolution of the one-year running average rainfall ratio. a – Woronora Dam / Darkes Forest (long-term ratio: 0.74); b – Reverces / Darkes Forest (long-term ratio: 0.83); c – Helensburgh / Darkes Forest (long-term ratio: 1.07)**

# 4 REVIEW OF AVAILABLE STUDIES CONCERNING THE WORONORA CATCHMENT

***Synthesis***

Here, we summarize the following studies which we analyzed for this assessment, and comment their conclusions

1. Metropolitan Coal Project Surface Water Assessment (Gilberts & Associates)
2. Assessment of Waratah Rivulet catchment yield using rainfall and runoff records (Parsons-Brinckerhoff)
3. Woronora dam daily inflow model (SCA)
4. Draft report on the Mining Impacts on Water Resources in the Woronora Catchment (SCA)
5. Comments the 'Metropolitan Colliery's Part 3a Environmental Assessment Document – Surface Hydrology' (SCA)

Report 1 (Gilbert & Associates) is a very serious analysis of the existing data, although it sometimes goes too far too fast in clearing longwall mining of its responsibilities. Report 5 points out rightfully several flaws in the reasoning (but report 1 remains a serious work).

Report 2 is extremely simplistic; report 3 is unfortunately not detailed enough for a proper analysis.

Report 4 points out real leakages, but probably overestimates them by trusting high flows estimates which are likely to be extremely uncertain.

In this section, we summarize the studies which we reviewed. We will focus here on the hydrological analysis part of the reports (although some of them, such as the Metropolitan Coal Project Surface Water Assessment report, have a wider scope and also address the groundwater and water quality aspects).

For each report, we summarize the nature of the analysis, the conclusion given in the report, and we give briefly our point of view.

### *4.1 Metropolitan Coal Project Surface Water Assessment (Gilberts & Associates - 26/08/2008)*

This report describes the physical setting of the Waratah Rivulet catchment: hydro-meteorology, topography, hydrography, sub-catchments, as well as the pools occurring in the streambed, the swamps and the groundwater levels. It describes the observable effects of past mining activities below the upstream part of the catchment, and discusses the possible future impact of subsidence on the downstream part of the catchment. The hydrological analysis involves the following steps:

**a. Visual examination of concurrent recorded streamflow hydrographs for the Waratah Rivulet and two reference (unaffected) catchments**

No difference is apparent, the Waratah Rivulet even has the highest baseflow among the three gauges.

*In our opinion, the differences are rather significant, but it is true that the Waratah Rivulet has a singular behaviour in baseflow.*

**b. Rainfall-runoff modelling of the Waratah Rivulet and the two reference (unaffected) catchments**

Model parameters confirm the similarity of catchment behaviour; a virtual experiment is made with the rainfall-runoff model to show how a 'leaky' catchment hydrograph would look like. No evidence of leak in the Waratah Rivulet catchment.

*This is an interesting point, but which may be model-specific (i.e. it may depend on the way water leakage is parameterized within the rainfall-runoff model, see section 5.2).*

**c. Analysis of a reconstituted reservoir inflow time series (for the entire catchment Woronora + Waratah rivers): comparison of inflow based on a Woronora reservoir water balance computation with the inflow simulated with a rainfall-runoff model**

Cumulative flow curves follow each other closely: no evidence of behavioural change after the start of mining in the upper catchment in 1995.

*We lack here information to fully appreciate the work which was done. First, how was the inflow simulated? We assume that the consultant used the parameter set calibrated for Waratah Rivulet over 2007-2008, and the rainfall input time series over the 1997-2008 period in order to simulate the cumulative inflow: is it right? If yes, this is definitely an interesting analysis. However, we would have preferred to look at the double mass curve (i.e. simulated cumulative as a function of the computed cumulative), which makes easier the visual inspection of the curve.*

**d. Conclusions of the report**

p.39 – 'extensive analysis of streamflow data […] since 1977 has shown that there has been no loss of water to the reservoir as a result of mining'

p. 46 – 'recorded streamflow data from Waratah Rivulet indicates that there is no evidence of flow loss at low flows in periods of prolonged dry weather and flow recession'

*Although we believe that the hydrologic analysis performed by the consultant is of very good quality, we would probably not be as definitive as them. Further analyses are required: see section 5.1 and 5.2.*

### *4.2 Assessment of Waratah Rivulet catchment yield using rainfall and runoff records (Parsons-Brinckerhoff, 26/11/2008)*

This report starts with an analysis of available data, discusses missing values. The hydrological analysis involves the following steps:

**e. Analysis of the yield curves (double mass curves: cumulative runoff vs. cumulative rainfall for the three nested Waratah Rivulet subcatchments**

The analysis of the runoff coefficient illustrates the difference between the three nested subcatchments and shows a continuous decrease of runoff yield from the upstream gauge to the downstream gauge.

*Analysing the yield curves is of course interesting, but… the linear 'best fit line' such as drawn on the graphs here is pure nonsense! The curve is extremely non linear, and it just reflects the seasonality of catchment yield (which is here due the seasonality of evapotranspiration). The average runoff coefficient should simply be computed as* $\sum_t Q \Big/ \sum_t P$.

*The continuous decrease of runoff yield from the upstream gauge to the downstream gauge is interesting, but since it is very dependent on high flow values, it is certainly extremely dependent on the accuracy of each station rating curve in high flows. I would not trust this computation, and I would prefer a stratified analysis such as the one presented in section 5.1.*

**f. Analysis of flow depth hydrographs**

When looking at the flow depth hydrograph, it seems that there is a loss between the upstream and the downstream part of the catchment.

*Same remark as above: the difference of area-corrected streamflow is apparent, both for high flows and low flows, so that there is something for sure. But I would not trust a value based on an average of high and low flows, because high flows are too uncertain given the rating curves. An analysis stratified by flow groups is needed (see section 5.1).*

### *4.3 Woronora dam daily inflow model (SCA, January 2008)*

This report describes the setup of a daily rainfall-runoff model, which is used at the monthly time step. The model is calibrated on reconstituted reservoir inflow time series, obtained through a water balance approach. Two modes of model validation are tested: confrontation with reservoir water balance estimates from a different time period (1976-1986 and 2006-2007) and confrontation with data from a historic flow gauge. An analysis of inaccuracies linked with the water balance approach is made, and shows very large errors.

*The report is a bit confusing, at least not detailed enough for a proper analysis. Several points remain unclear. The calibration of the hydrological model seems very uncertain, with large annual errors. It is unclear why the authors have not just discarded from their analysis the days when spill occurred (just considering them as missing values in the record).*

*In my opinion, the reservoir water balance is crucial to assess the impact of mining, because reservoir water levels are the only record starting before longwall mining, and continuing up to now. But again, I was not able to understand fully what was done. From a modelling point of view, I would have preferred a unique model allowing computing reservoir levels from catchment rainfall (and thus a unique calibration), rather than this two step approach (rainfall-runoff on one side, and reservoir to runoff on the other side).*

### *4.4 Draft report on the Mining Impacts on Water Resources in the Woronora Catchment (SCA, November 2009)*

This report provides a synthesis of all relevant information relative to the Waratah Rivulet catchment. From a hydrological point of view, the report is mainly looking at the upper catchment leakages, in order to assess whether they re-emerge downstream of the lower streamgauge, or whether they join the regional groundwater flow.

The report provides a detailed review of the scientific literature,

Several issues raised by the report require a comment:

**g. Surface water monitoring**

The report underlines the occurrence of missing values at high flows, and the problem it causes for an accurate estimation of leakages

*More than the missing values, I am worried by the uncertainty of flow estimates at high flows, the quality of the rating curve must be improved (at present, all high flows are extrapolated). Indeed, where the rating curve is too uncertain, differential approaches between streamgauges loose their meaning.*

**h. Analyse of flow differences for the three nested sub-catchments of the Waratah Rivulet**

The report provides an analysis of flow discrepancies at the three nested streamgauges on the Waratah, which shows that the intermediary station often has a higher flow than the downstream one.

*This analysis is interesting: flow discrepancies are for sure contrary to the norm (flow increasing proportionally to the surface). This can be a 'natural' singularity (a loosing reach feeding an underground aquifer), or one caused by the mining-induced subsidence. Since none of the stations pre-existed mining operations, it is impossible to conclude at this point. Figure 14 and 15 are difficult to interpret. Figure 16 is very useful, and the clustering by flow groups (p.35) allow for an easier interpretation (see also section 5.1).*

**i. BACI test**

*More information is required to understand what was done.*

### *4.5 SCA comments the 'Metropolitan Colliery's Part 3a Environmental Assessment Document – Surface Hydrology'*

This document has been set up by SCA to contest several points of the above cited report. Below are my views on each of the points raised.

**j. Observed Effects on Flow Waratah Rivulet**

*I agree that the reservoir balance issue is unclear (but note that the similar work by the SCA team was not clear either). This reservoir water balance issue is here crucial to assess the impact of mining, because reservoir water levels are the only record starting before longwall mining, and continuing up to now.*

**k. Review of Available Data**

*Stating whether two neighbour catchments are similar or different is like stating that a glass of water is half full or half empty. Since I am used to analyse neighbour catchments (which are often extremely similar), I would rather emphasize the differences (which are quite large in terms of water yield, and not justified by rainfall differences, see Table 1).*

*Concerning the sentence 'that there is no evidence of flow loss at low flows in periods of prolonged dry weather and flow recession as might be expected if flow were being affected by mining activity', I agree with the SCA comment: people (and even good hydrologists such as those who prepared this report) live with the false feeling that all Intercatchment Groundwater Flows are necessarily large and massive, like those of karstic type. But many rivers experience so-called 'transmission losses' which can be extremely gradual and difficult to localize.*

**l. Streamflow Modelling**

*Here, I would not be too severe concerning the work of the authors, who seem to have been trying to do their best with the available data. Of course, presenting a graph in calibration mode is usually a bad practice (but here, the time series is really too short to perform a validation…).*

*It is true that the calibrated parameters may already account for the impact of mining. But my feeling is that the authors of the report have attempted to interpret rather honestly the available data. Of course, instead of concluding 'there is not enough evidence to conclude in one sense or the other', they conclude in favour of their client 'there is nothing apparent'. Again, it comes to the half full/half empty glass comparison.*

**m. Conclusions**

*I agree with the SCA comment: the fact that a model which does not account for IGF (leakages) can be calibrated on the Waratah catchment is by no means a proof of the absence of leakages: this has been well demonstrated by Le Moine et al. (2007) who showed that many hydrological models used alternatives to 'adjust' their water balance (such as PE correction factors or Precipitation correction factors). In AWBM, it is the Runoff Characteristic (RC) parameter which plays this role and that will account for any leakage or gain of water to/from another catchment. When the consultant write that 'the model used does not have a loss term', he does make a mistake: RC plays the role of a loss term, just as a PE correction factor or a Precipitation correction factor would have done in an other model.* ***The actual (hydrological) role played by a model parameter***

***is unfortunately not conditioned by the 'physically-like' name which was given to it by its modeller.***

# 5 COMPLEMENTARY ANALYSES ON THE CATCHMENT LEAKAGES ISSUE

***Synthesis***

The complementary analyses presented here aim at assessing the amount of leakages on the Waratah Rivulet catchment:

- A water balance computation by flow classes between the midstream and the downstream gauge yields a value of 1.5 ML/d as best estimate;
- A rainfall-runoff modelling study yields 5.7 ML/d.

Note that part of the difference may be due to the fact that the first approach focused only on the low and moderate flows (high flows were discarded).

At this point:

- although it would be tempting to conclude that the leakages are the consequence of mining, we have no proof. It seems somewhat paradoxical that the upper Waratah catchment, which was the first affected by longwall mining, shows no evidence of leakage (which seem to appear somewhere before the downstream gauge). Moreover, the Woronora River catchment, which has not been affected by mining, seems to experience twice as much leakage as the lower Waratah. It is likely that at least part of this leakage has a natural geological origin;
- we do not know whether the leaking water reaches Woronora dam by underground routes, or whether it is diverted towards a regional aquifer or towards the sea.

In this section, we concentrate on the question of whether it is possible to detect leakages on the Waratah Rivulet.

For us, the best would have been to analyse two concurrent streamflow records, one from the Waratah Rivulet, and the other from the Woronora River, before and after the introduction of longwall mining under the Waratah catchment. We would have then applied methods used traditionally to analyse *paired catchments*, an experimental design which has been widely used to study the impact of catchment treatments (see e.g. Andréassian, 2004; Andréassian and Trinquet, 2009).
Unfortunately, no such records exist:

- we do have flow records of the Woronora, but since they were started after the introduction of longwall mining under the Waratah catchment, we cannot tell whether the differences which we could observe are natural or not;

- we do have historic flow records on both catchments, which can be used to study the rainfall-runoff relationship before and after mining (using a hydrological rainfall-runoff model) but our analysis has shown that both records (Waratah @ Sanatorium and Woronora @ Engadine) require a specific analysis, which would carefully ‘dissect’ them to separate data errors from the usable part of the record;

At this point, two types of quantitative analyses were possible:

- quantification of flow transmission losses between the upper (G1) and the lower (G3) Waratah flow gauges. This was made by Jerzy Jankowski of the Sydney Catchment Authority, and we propose here to repeat his work while limiting ourselves to the sector to the flows that we consider as reliable based on our rating curve analysis (see 3.2);

- quantification of catchment leakages using a hydrological rainfall-runoff model. Such an analysis was made in the ‘Appendix C’ report by Gilbert & associates (p. 44-45), and we produce a similar analysis using the GR4J model (Perrin et al., 2003), which present the particularity to explicitly account for Intercatchment Groundwater Flows (IGF). A second interesting point is that we can use the recent comprehensive study on IGF occurrence by Le Moine et al. (2007) to discuss the uncertainty of the method.

**We wish to stress here that we realize that none of these analyses can bring a definitive answer to the question. They both have their limits, which we will discuss in depth. We consider however, that they are likely to bring food for thought on the topic of interest, and suggest potential ways to continue the hydrologic analysis of the Waratah and Woronora River catchments.**

### 5.1 What can we conclude from the differences between the three stream gauging stations on the Waratah Rivulet?

In section 3.2, we discussed the quality of the rating curves of the three Waratah Rivulet stream gauges (G1 to G3). For G3[3], we defined three groups of increasing uncertainty:

- the high uncertainty group is made of flows for which the extrapolation of the rating curve is strong;
- the medium uncertainty group is made of days when only part of the flows are extrapolated,
- the low uncertainty group is made of days when no extrapolation above the largest measured flow is made.

Although Table 5 confirms the finding of the SCA Draft report on the Mining Impacts (SCA, November 2009), it also shows that the large amounts of water disappearing from upstream to downstream is only apparent for the most uncertain flows, so that it can well be an artefact caused by the uncertainty on flow rating curves for high flows.

**Table 5: Differences in flow estimates from upstream to downstream on the Waratah Rivulet**

| Uncertainty class | Number of days | Average flow at Waratah Rivulet gauging stations (ML/d) | | |
|---|---|---|---|---|
| | | G1 (upstream) | G2 (midstream) | G3 (downstream) |
| **High** | 38 | 108.4 | 133.8 | 97.0 |
| **Medium** | 15 | 72.7 | 70.4 | 60.4 |
| **Low** | 1013 | 6.6 | 9.1 | 9.7 |

From now on, we will restrict ourselves to the most reliable part of the discharge record (i.e. the 1013 days with 'low' uncertainty at G3 streamgauge), and we look at differences by flow groups. We divided our sample in 13 groups (each one counting at least 30 elements). Table 6 gives the numeric values, which are presented graphically in Figure 11.

How should these elements be interpreted?

First, we could state what looks perfectly 'normal':

- The specific discharge (Figure 11-b) of the larger catchment (G3) is always less than the specific discharge of the two upstream catchments (G1 and G2). This comes simply from the rainfall gradient (ca 1500 mm/yr upstream vs. 1100 mm/yr downstream).
- At high flows (Figure 11-a) the absolute flow (i.e. the flow expressed in ML/day) increases from downstream to upstream, which is the usual way in humid catchments, where flow is a growing function of catchment area. Obviously, the phenomenon described in Table 5 is an artefact caused by uncertain rating curves.

[3] Note that this analysis was only possible for the G3 gauge (for which we had the highest discharge measurement, 100 ML/day), thus basing our analysis on this will provide a rather optimistic view of uncertainty.

- The fact that in Figure 11-b the curves of the two upstream gauges cross over is not surprising. High flows follow usually the pattern of precipitation (in this case the upstream gets the most rain on average and should thus have the highest specific flow. But the behaviour at very low flows depends strongly on the geology, and it seems possible to have higher specific flows at mid-elevations, where lines of springs may develop. However, it is a little surprising that for these lowest flows, the lowest gauge (G3) remain far from the others in terms of specific discharge.

Now, let us state what appears rather 'anomalous':

- In Figure 11-a and Table 6, the cross-over of absolute flow is clearly apparent at low and medium flows (up to class 6). This means that the river itself is loosing water to the underground between gauges G2 and G3. This is obviously linked with a local hydrogeological singularity. Note that at this point, in the absence of historical hydrological data it is impossible to say whether longwall mining is the cause of this 'local hydrogeological singularity'. However, we can say that such singularities are usually associated with limestone bedrock (see e.g. Le Moine et al., 2007).

**Table 6: streamflow averaged over several classes, with a significant number of days (>30) in each class, from upstream to downstream on the Waratah Rivulet. Only the days where the measurements at gauge G3 have been identified as reliable (low uncertainty) have been considered**

| Class # | *Range of flows at the reference gauge (G3)* | Number of days | Average flow in ML/d @ gauges: | | |
|---|---|---|---|---|---|
| | | | G1 | G2 | G3 |
| **1-** ***Low flows*** | *1-2 ML/d* | 92 | 1.0 | 2.0 | 1.5 |
| **2** | *2-3 ML/d* | 107 | 1.8 | 3.3 | 2.5 |
| **3** | *3-4 ML/d* | 139 | 2.7 | 4.3 | 3.5 |
| **4** | *4-5 ML/d* | 85 | 3.4 | 5.1 | 4.5 |
| **5** | *5-6 ML/d* | 52 | 4.4 | 6.1 | 5.5 |
| **6** | *6-7 ML/d* | 46 | 4.7 | 6.3 | 6.4 |
| **7-** ***Medium flows*** | *7-8 ML/d* | 34 | 5.2 | 7.0 | 7.5 |
| **8** | *8-9 ML/d* | 30 | 6.8 | 8.3 | 8.5 |
| **9** | *9-10 ML/d* | 34 | 6.7 | 8.7 | 9.5 |
| **10** | *10-20ML/d* | 93 | 7.5 | 9.8 | 12.0 |
| **11** | *20-30 ML/d* | 43 | 14.5 | 20.3 | 24.6 |
| **12-** ***High flows*** | *30-50 ML/d* | 37 | 23.7 | 32.5 | 35.1 |

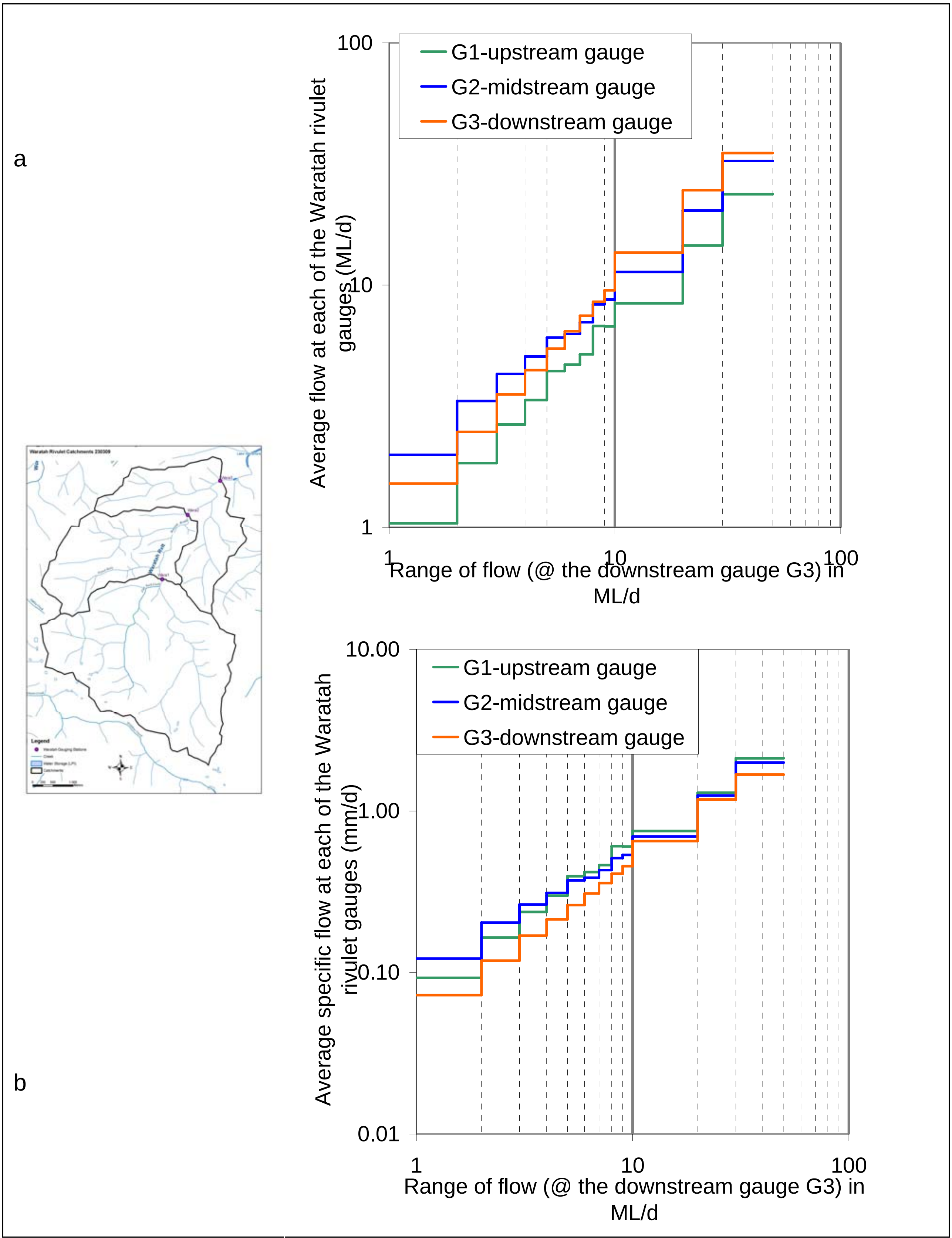



**Figure 11: Average differences in flows from upstream to downstream on the Waratah Rivulet. a- true flows in ML/day; b- specific flows in mm/day (or ML/day/km²)**

In order to give an estimate of the amount of water leaking towards the aquifers between G2 and G3, we can propose the following reasoning:

- the leakage comes from a combination of 'transmission losses' (leaks in the streambed) and 'production losses' (leaks from the hill slope).
- to estimate the production of the intermediary 4.6 km² catchment located between the midstream and downstream gauges, we can assume that it is proportional to the specific production of G2, the coefficient of proportionality being equal to the ratio of average annual rainfall (approximately 1150/1300)

Given the number of hypotheses, we cannot aim at a precise value. Table 7 shows however that the values obtained for each flow class vary mostly between 1 and 2 ML/day. The value of 5.6 seems to be an outlier, it could be due to uncertainty of the G2 rating curve (the highest measured value is 40 ML/d in instantaneous value). As our best estimate, we propose to take the average for classes 2 to 11. It is 1.5 ML/d.

**Table 7 : computation of estimated leakages between the midstream (G2) and the downstream (G1) gaging station**

| Flow class | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | Absolute flow of G2 catchment (ML/d) | Absolute flow of G3 catchment (ML/d) | Specific production of G2 catchment (ML/km²) | Specific production of the intermediary catchment (ML/km²) | Theoretic production of the G3 catchment (ML/d) | Estimate of total leakages between G2 and G3 (ML/d) |
| | - | - | = [1]/16.3 | =[3]*1150/1300 | =[1]+[4]*4.6 | =[5]-[2] |
| 1- Low flows | 2.0 | 1.5 | 0.12 | 0.11 | 2.5 | 1.0 |
| 2 | 3.3 | 2.5 | 0.20 | 0.18 | 4.2 | 1.7 |
| 3 | 4.3 | 3.5 | 0.26 | 0.23 | 5.4 | 1.8 |
| 4 | 5.1 | 4.5 | 0.31 | 0.27 | 6.3 | 1.9 |
| 5 | 6.1 | 5.5 | 0.37 | 0.33 | 7.6 | 2.1 |
| 6 | 6.3 | 6.4 | 0.39 | 0.34 | 7.9 | 1.4 |
| 7- Medium flows | 7.0 | 7.5 | 0.43 | 0.38 | 8.8 | 1.3 |
| 8 | 8.3 | 8.5 | 0.51 | 0.45 | 10.4 | 1.9 |
| 9 | 8.7 | 9.5 | 0.53 | 0.47 | 10.9 | 1.4 |
| 10 | 11.3 | 13.6 | 0.70 | 0.61 | 14.2 | 0.5 |
| 11 | 20.3 | 24.6 | 1.25 | 1.10 | 25.4 | 0.7 |
| 12- High flows | 32.5 | 35.1 | 2.00 | 1.77 | 40.6 | 5.6 |

### 5.2 *Can a rainfall-runoff modelling approach provide an estimate of Intercatchment Groundwater Flows?*

There are many different hydrological models in the world, that one could wonder why none of them would be able to provide an estimate of possible 'leakages' on the Woronora and the Waratah river catchments.

The recent study by Le Moine et al. (2007) has reviewed models which attempt to identify leakages term, and they have then identified the sources of uncertainties can introduce perturbations in the leakage identification process. Based on two different rainfall-runoff models (GR4J and SMAR), as well as on a very large catchment dataset (more than 1000 catchments):

1. they conclude that it is preferable (from both the hydrological likelihood and the modelling efficiency point of view) to explicitly represent intercatchment groundwater transfers;

but …

2. they show that surrogate corrective solutions are possible (correcting or scaling factors applied to the climatic input data or to the catchment area), and indeed they are frequently used in practice. They are most of the time inferior from a streamflow simulation efficiency point or view, from the IGF-explicit models (but unfortunately not always).

The important thing to note here, since we wish to use a hydrological model to detect catchment leakages, is that biases in catchment PE or catchment-scale precipitation can interact with the leakage identification process. Indeed, a "watertight" catchment where PE would be underestimated or P overestimated would simulate a non-existing leak in order to adjust the water balance. **What must be remembered is that a hydrological model can only provide an IGF estimate *conditionally* to a PE and catchment P estimate.**

Thhis being said, we will in this section use the GR4J model (Figure 12) and test:

- whether differences exist between the simulated IGF of three neighbour catchments: Woronora River, Waratah Rivulet and O'Hares Creek. We will use the modern gauges (2007-2010);
- whether differences exist between the simulated IGF at the three nested Waratah Rivulet stream gauges:

Each time, we will calibrate the model on the available time series (2007-2010 for Woronora and Waratah stations, 1965-2010 for the O'Hares station), and we will compute the elements of the water balance equation:

$$Q_{\text{Long-term}} = P_{\text{Long-term}} - E_{\text{Long-term}} + IGF_{\text{Long-term}}$$

Values will be expressed in ML/yr/km² (=mm/yr), and in order to make things comparable, they will be computed and averaged using thirty years of climatic input (1965-1994), like it is recommended in climatology. Thus, the figures will be independent of the peculiarities of their calibration climatic period, and will be directly comparable.

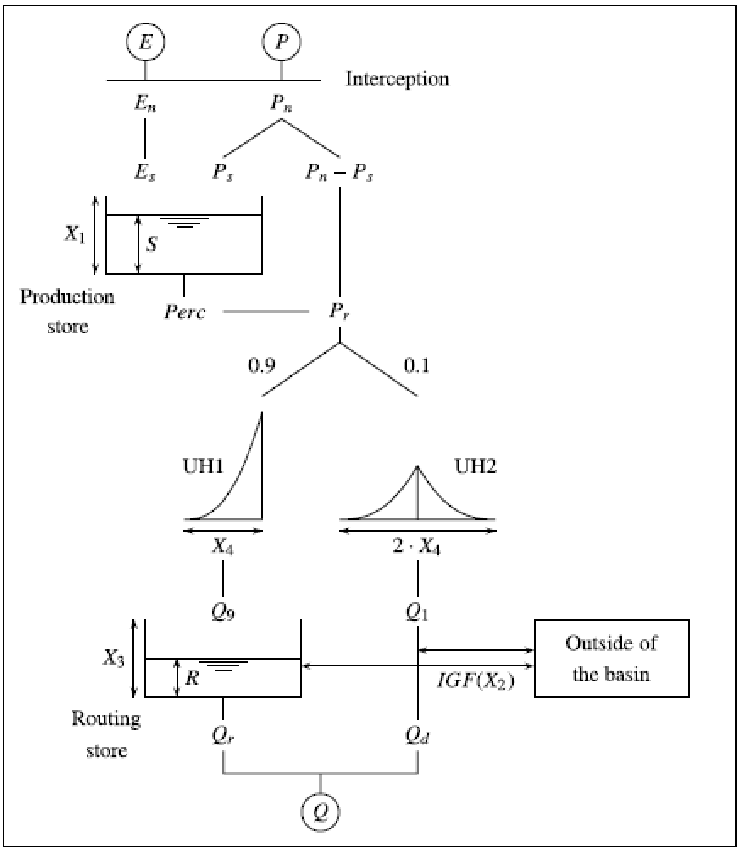



**Figure 12: Structure of the GR4J daily rainfall-runoff model showing the Intercatchment Groundwater Flow (IGF) function**

Table 8 shows the long-term water balance simulated by GR4J for the three catchments which we modelled. Interestingly, based on available rainfall input data and on an annual Potential Evapotranspiration estimate of 1210 mm, the model requires a leakage for the three catchments (a negative IGF value means a leakage, a positive value would mean a contribution from outside the catchment). Woronora and O'Hares loose a similar amount of water, and the better low-flows of the Waratah Rivulet are explained by a lesser loss. Given that the model was calibrated on the 2007-2010 period, we have no possibility to assess whether this leakage is natural or whether it is a consequence of longwall mining.

**Table 8: Simulated long-term water balance for the three modern gauges**

| | **Woronora River** SCA2132101 **(12.4 km²)** | **Waratah Rivulet** SCA2132102 **(20.9 km²)** | **O'Hares creek @ Wedderburn (73 km²)** |
|---|---|---|---|
| **P (mm)** | 1370 | 1430 | 1410 |
| **=** | | | |
| **Q (mm)** | 230 | 420 | 290 |
| **-** | | | |
| **IGF (mm)** | - 220 | - 100 | - 200 |
| **+** | | | |
| **AE (mm)** | 920 | 910 | 920 |

Morover, even if we consider the figures given in Table 8 as our best estimates, we consider necessary to precise that they were obtained with an annual PE amount of 1210 mm (which seemed consistent with BOM PE maps for the area). As Le Moine et al. (2007) demonstrated it, IGF values are dependent on this choice. We give as an illustration in Table 9 the IGF values that would have been simulated for different Potential Evapotranspiration scenarios.

**Table 9: sensitivity of GR4J's IGF estimate to the choice of the annual Potential Evapotranspiration amount (IGF in mm/yr = ML/yr/km²)**

| **Catchment** | **Scenario:** | **-20%** | **-10%** | **central** | **+10%** | **+20%** |
|---|---|---|---|---|---|---|
| | **PE (mm)=** | **968** | **1089** | **1210** | **1331** | **1452** |
| **Woronora River (12.4 km²)** | | -350 | -270 | -220 | -170 | -120 |
| **Waratah Rivulet (20.9 km²)** | | -230 | -160 | -100 | -50 | 0 |
| **O'Hares creek @ Wedderburn (73 km²)** | | -320 | -250 | -200 | -160 | -100 |

Last, we used again GR4J to simulate the elements of water balance for the three nested gauges on the Waratah Rivulet. The results presented in Table 10 confirm the analysis carried out in the previous section: while the two upper catchments appear as conservative (+30 mm and -10 mm cannot be considered as significantly different from 0, because rainfall input is not known with this precision), a net leakage is apparent at the lower location. Its value is 100 mm or ML/yr/km². For a catchment of 20.9 km², this is equivalent to 5.7 ML/d.

**Table 10: Simulated long-term water balance for the three nested gauges on the Waratah Rivulet**

| | **Waratah upstream gauge (11.2 km²)** | **Waratah midstream gauge (16.3 km²)** | **Waratah downstream gauge (20.9 km²)** |
|---|---|---|---|
| **P (mm)** | 1430 | 1430 | 1430 |
| **=** | | | |
| **Q (mm)** | 600 | 530 | 420 |
| **-** | | | |
| **IGF (mm)** | 30 | - 10 | - 100 |
| **+** | | | |
| **AE (mm)** | 860 | 890 | 910 |

# 6 RECOMMENDATIONS

On the basis of my analysis of reports and datasets, I can formulate the following recommendations:

### *6.1 Field data collection should be continued but with higher standards*

a) Our present inability to assess quantitatively and objectively the impact of longwall mining is due to the lack of continuous streamflow records spanning long enough in the past. Rainfall and streamflow data acquisition must continue, but its standards must be dramatically increased. The data of the two SCA rain gauges look so unreliable, that I did not dare using them for my analysis. The SCA stream gauges are of poor quality (the most recent records are so full of obvious errors that I had to discard them). Flow measurements campaigns to improve gaging stations' rating curve must continue.

If additional funding was available, I would also recommend:

b) Intensive flow & water temperature measurement campaigns at low and medium flows, up the Woronora River, the Waratah Rivulet and their tributaries, in order to localize the sites of leakages / seepage;

c) 3-D surveying of the Woronora reservoir in order to improve our knowledge of the Height-Volume relationship. Having several height gages in the reservoir could also improve the precision.

### *6.2 An integrated model capable to represent the rainfall-reservoir volume relationship should be set up and a trend study implemented*

There are two different studies concerning the modelling of Woronora Dam inflow in the reports which I reviewed (one by Gilberts & Associates, the other by SCA). In my opinion, the reservoir water balance is crucial in that it could allow quantifying catchment leakages: by calibrating the hydrological part of the water balance model on successive time periods, before and after longwall mining, one will be able to show whether or not mining has had a significant impact on the Woronora dam water resources.

Even if I do not want to raise doubt concerning the quality of both studies (there was not enough detailed information to understand fully what was done), I believe that there is room for an improved hydrological model, one allowing the computation of reservoir levels from catchment rainfall (and thus requiring a single-step calibration), rather than this two step approach (rainfall-runoff on one side, and reservoir to runoff on the other side).

### *6.3 Historical dataset cleansing*

Last, another option for quantifying the change of hydrologic behaviour lies in the use of the historic flow records on the Woronora River @ Engadine, and the Waratah Rivulet @ Sanatorium. These datasets have the potential to inform us about the pre-mining catchment behaviour, but they are full of errors and require first a serious cleansing before hydrological analysis (modelling).

Since long-term rainfall data is available at Darkes Forest, Woronora Dam and Helensburgh, we would be then able to simulate flows which would have occurred in absence of mining.

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# 8 APPENDIX

## *8.1 Problems detected in the streamflow time series*

### *8.1.1 Historic flow gauging stations on the Woronora and the Waratah Rivers*

Figure 13 shows clearly that there are serious problems in the two historic time series. Flat and straight portions of the double mass curve indicate periods where most probably missing values are wrongly coded at 0.

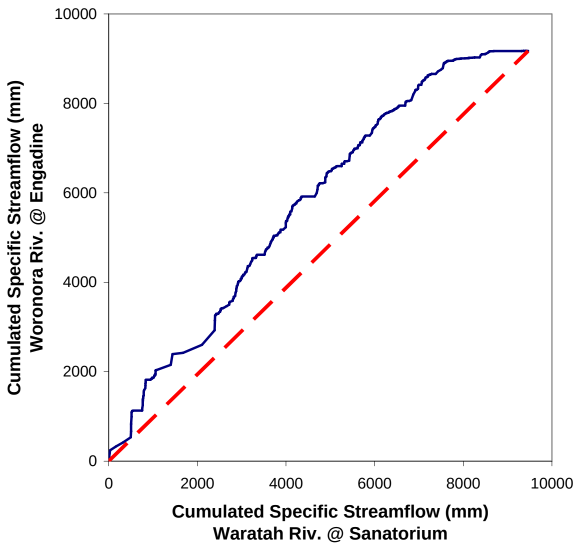



**Figure 13: double mass curves for streamflow records – Woronora River @ Engadine = *f* (Waratah Rivulet @ Sanatorium)**

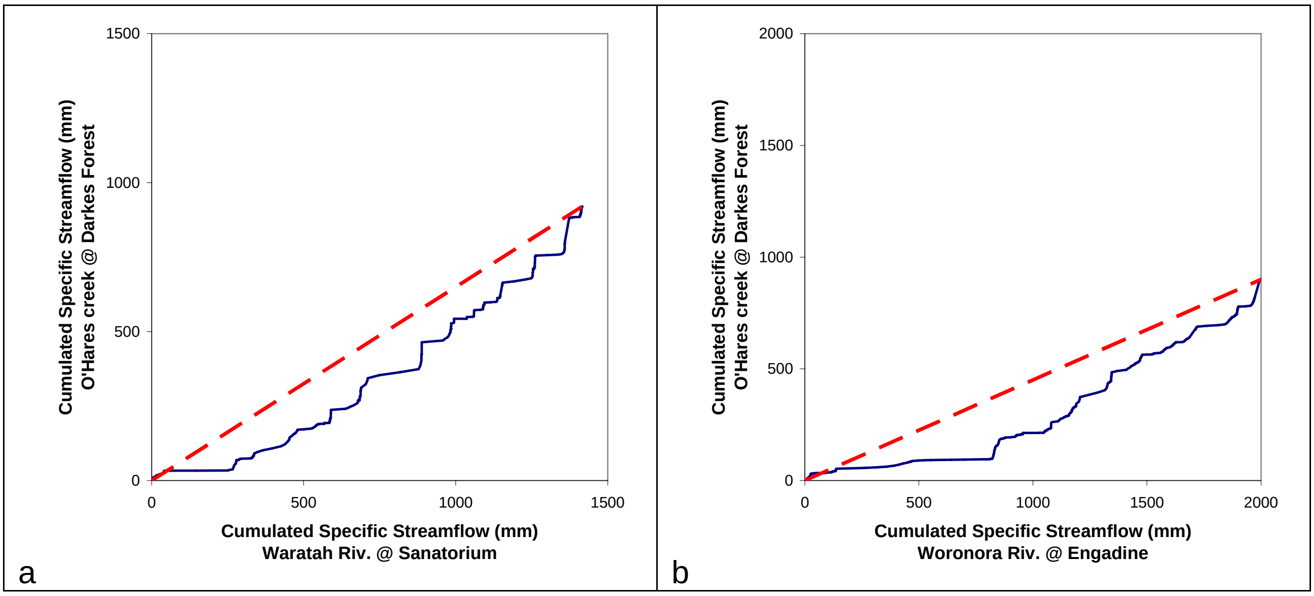



**Figure 14: double mass curves for streamflow records: a – O'Hares creek @ Dark Forest = *f* (Waratah Rivulet @ Sanatorium); b – O'Hares creek @ Dark Forest = *f* (Woronora River @ Engadine)**

## 8.2 Problems detected in the rainfall time series

### 8.2.1 SCA raingauge at Woronora River

The time series provided for the SCA raingauge at Woronora River shows a clear lag with its neighbours. Figure 15 illustrate this: steps are only apparent in the double mass curve a (Woronora=*f*(Waratah) and are absent in all the others, which show the good coherence of regional rainfall.

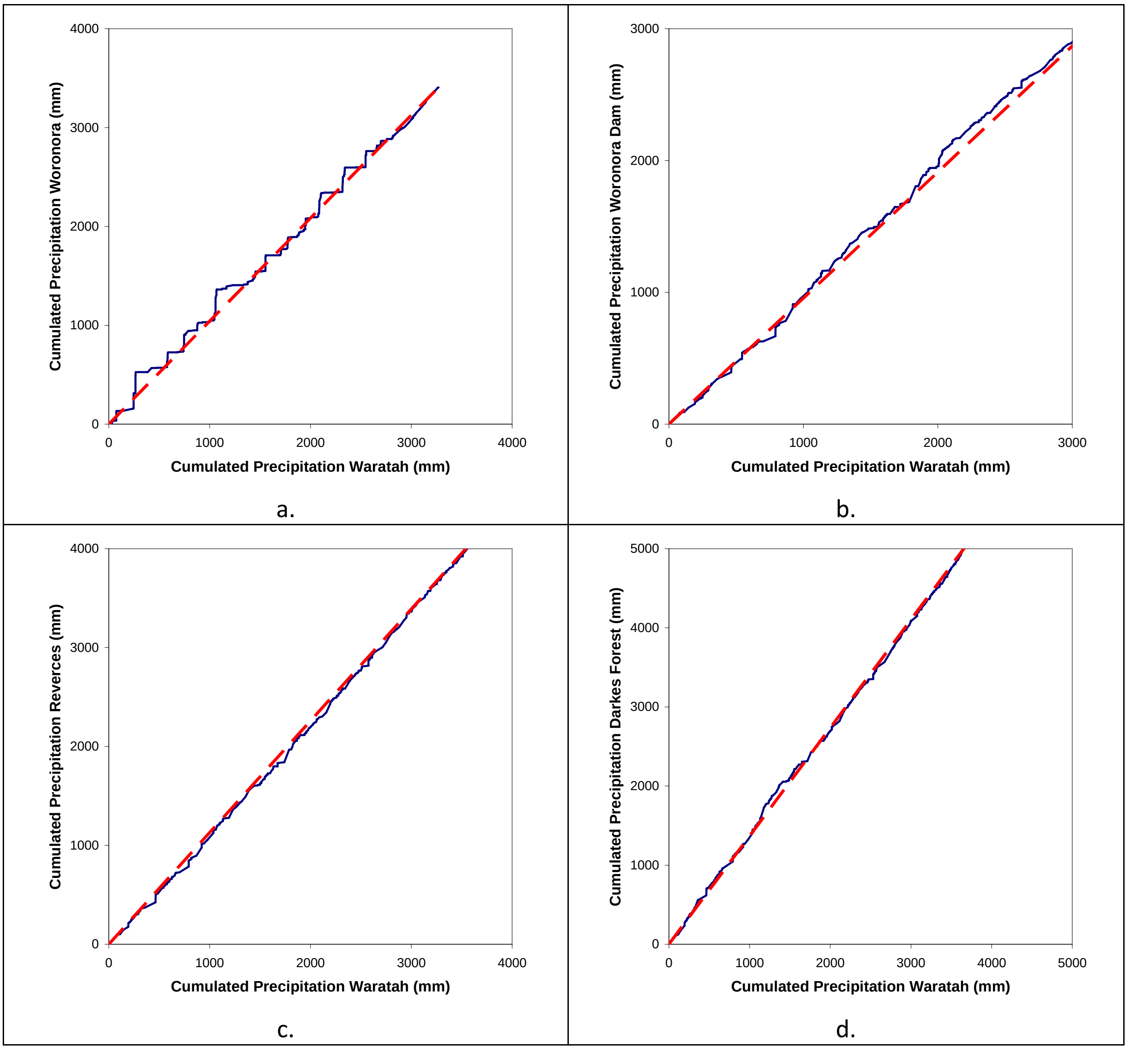



**Figure 15 : double mass curves for rainfall records – a. Woronora River = *f* (Watratah Rivulet) ; b. Woronora Dam = *f* (Waratah Rivulet) ; c. Reverces = *f* (Waratah Rivulet) ; d. Darkes Forest = *f* Waratah Rivulet)**

### 8.2.2 SCA raingauge at Waratah Rivulet

Although the SCA raingauge at Waratah Rivulet shows overall good and stable relationships with the neighbour catchments (see Figure 15), we still suspect of clock problem, because it appears lagged with its neighbours on large events.
Table 11 clearly shows that the correlation coefficient is larger when we introduce a lag of -1 day (i.e. when we compare $P_{Reverces}(j)$ with $P_{Waratah}(j-1)$). This incoherence between gauges may come from a clock problem, or perhaps from a time window difference (i.e. daily precipitation computed on a window 9:00-9:00 vs a window 0:00-0:00).

**Table 11 : correlation coefficient obtained between the rainfall of Reverces and Waratah Rivulet, depending on the time lag (computation for daily rainfall larger than 5 mm)**

| Lag | Correlation coefficient |
|---|---|
| -2 day | 0.11 |
| -1 day | 0.65 |
| No lag | 0.61 |
| +1 day | -0.03 |

In the absence of more information from the data manager, we are reluctant to introduce ourselves a correction. But since the Waratah Rivulet catchment shows rainfall totals which are on the long run extremely well correlated with the Woronara Dam totals, we will exclude for the moment this gage from our analysis.

## 8.3 Description of the associated rainfall and runoff database

Two text files are provided, with all the data provided for this study.
The missing data are clearly identified by a negative value (-9.9), to differentiate it from zero values.

P_WORONORA.dat
Precipitation data for 9 rain gauges

Q_WORONORA.dat
Streamflow data for 13 stream gauges

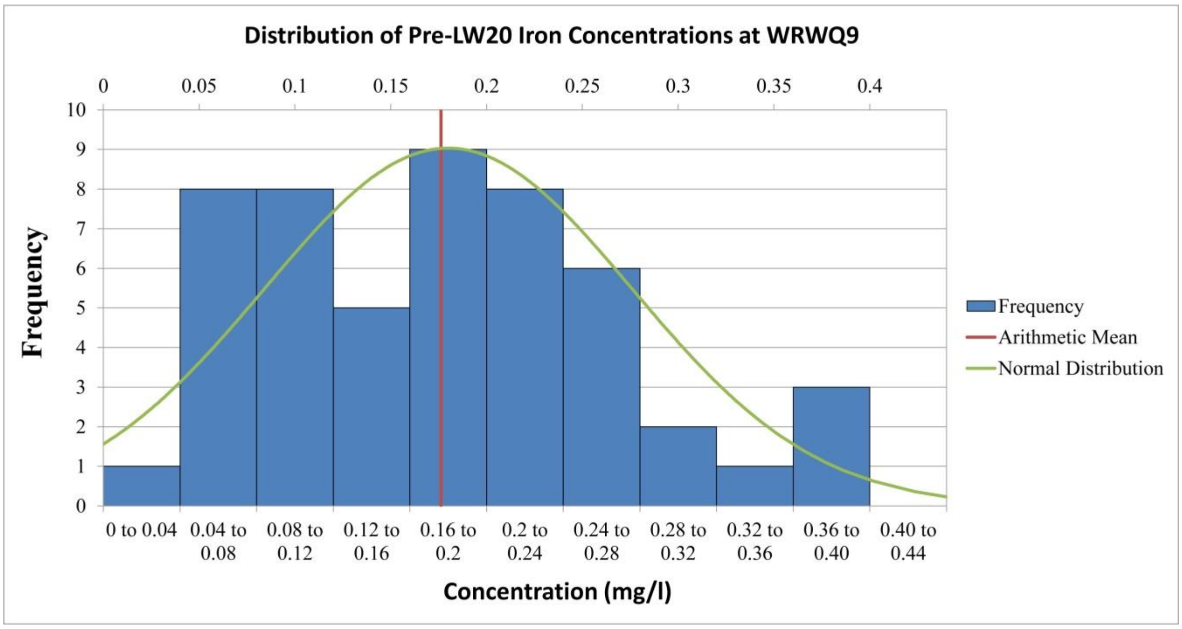
## Some Comments on the Revised Draft Water Management Plan for Longwalls 23 to 27

### Inappropriate Transformation of Metal Concentration Data

The revised draft water management plan retains the following footnote to Table 19: "*Log transformations (i.e. base 10 logs of the water quality concentrations) may be used to calculate the arithmetic means and standard deviations. Metal concentrations in water quality are measured as a positive value and therefore have a positively skewed distribution. Log transformations can be used to standardise the variance of a sample (Bland, 2000).*" This footnote is referenced in the definition of the water quality performance measures given in Table 19 and advises that the water quality performance measure benchmark, defined as the "*baseline mean plus two standard deviations*", will be calculated from a base 10 logarithmic transformation of metal concentration data.

The footnote isn't referred to elsewhere and its advice is not given or discussed in the main text. Other than the Table 19 footnote apparently suggesting that positive numbers are positively skewed, which is not the case, no justification for logarithmically transforming the data seems to be given in the proposed water management plan document. The baseline data to which the transformation is to be applied have been available for several years, yet the nature of the distribution of the data, for each metal contaminant, is not presented or discussed in the proposed water management plan document.

Below is a histogram showing the distribution of the baseline (pre-Longwall 20) iron concentrations for WRWQ9, the site used to assess water quality entering the Woronora Reservoir. The graph includes the arithmetic mean of the concentrations and a normal distribution with the same mean and standard deviation. The concentrations were obtained by digitising Chart 31 in the 2012 Metropolitan Colliery Annual Review; Peabody have refused repeated requests for access to their water quality data.




The irregular data distribution cannot be regarded as being significantly positively skewed. The arithmetic mean and the median are both the same at 0.18 mg/litre and the histogram shows deviation from what would be expected of a normal distribution at both low and high concentrations. **The nature of the iron data distribution does not justify the application of a logarithmic transformation.**

To further demonstrate this, the histogram below shows the distribution of the base 10 logarithmic transformation of the data; the transformed data does not have a normal distribution and is not a better approximation to a normal distribution than the untransformed data. In this case **the logarithmic transformation of the data is deleterious**, with the transformed data being further removed from having a normal distribution. As indicated above, the statement that "*Log transformations can be used to standardise the variance of a sample (Bland, 2000)*." assumes that the transformation will result in a better approximation to a normal distribution. This is not the case however, at least for the baseline iron data at WRWQ9, and there is no statistical benefit in applying a logarithmic transformation.

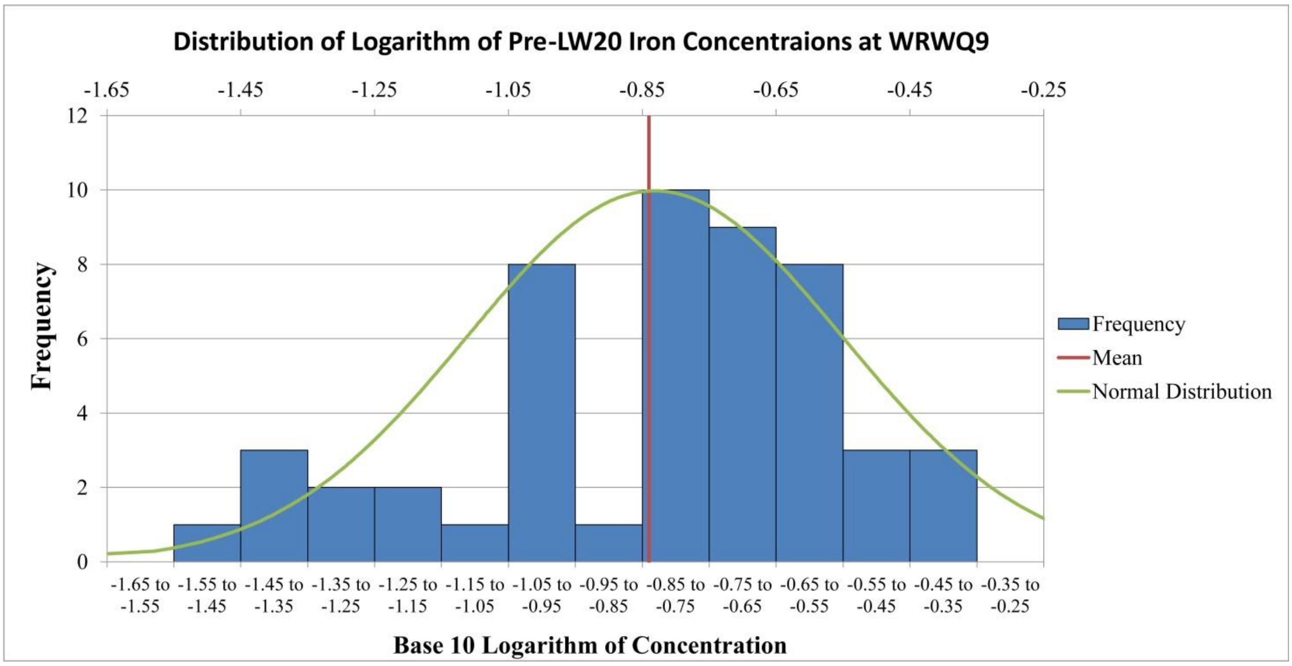



Table 1 below lists goodness of fit values for fitting a normal distribution to the original and the logarithmically transformed WRWQ9 baseline data, using the Chi-squared, Anderson-Darling and Kolmogorov-Smirnov methods provided in the Palisade StatTools package. Consistent with the histograms, in each case the goodness of fit is worse for the logarithmically transformed data.

**Table 1**. **Goodness of Fit for Normal Distribution**[1]

| Data | Chi-squared | Anderson-Darling | Kolmogorov-Smirnov |
|---|---|---|---|
| Untransformed | 7.765 | 0.576 | 0.096 |
| Log transformed | 12.353 | 1.097 | 0.141 |

[1]Provided by Assoc. Prof. Stuart Khan, School of Civil and Environmental Engineering, UNSW.

The intent of the Table 19 footnote comment that "*Log transformations (i.e. base 10 logs of the water quality concentrations) may be used to calculate the arithmetic means and standard deviations"* isn't clear. It seems to suggest that a logarithmic transformation can be used obtain an arithmetic mean and standard deviation. If so, this isn't correct; the mean obtained from a log transformation followed its inverse is a geometric mean and the standard deviation of the log transformed data can't be used to obtain a measure with concentration units.

It's puzzling that the intent to apply what would be a significant data transformation is provided as a table footnote and is not presented, discussed and justified in the main text.

## Setting a Reasonable Performance Indicator Benchmark

The arithmetic mean of the base 10 logarithmically transformed data is -0.83 and the standard deviation of the transformed data is 0.28. Ignoring for now that the use of a logarithmic transformation is not appropriate for the baseline data, the footnote of Table 19 advises that the performance indicator benchmark for metal concentrations would be obtained by adding twice the standard deviation of the transformed data to the arithmetic mean of the transformed data and then applying the inverse transformation (antilog). Applying this advice gives a performance indicator benchmark of 0.54 mg/l for iron concentrations at monitoring site WRWQ9 (as appears to be shown in Chart 31 of the 2012 Annual Review).

Using the 0.54 mg/l benchmark evidently proposed in the management plans would be equivalent to adding 3.75 times the standard deviation of the untransformed data to the arithmetic mean of the untransformed data. **This would allow concentrations significantly greater than found in the baseline data (which has a peak concentration of 0.39 mg/l) and so contradict the requirement that there should be no more than a negligible change in the quality of water reaching the Woronora Reservoir from the Waratah Rivulet.**

That is, the application of a logarithmic transformation to the WRWQ9 iron concentration data is inappropriate and results in a benchmark concentration that is too high to be consistent with the requirement of no more than negligible change in water quality entering the Woronora Reservoir from the Waratah Rivulet.

The arithmetic mean of the original (untransformed data) is 0.18 mg/l and its standard deviation is 0.096 mg/l, the interquartile range for the baseline data is 0.10 to 0.23 mg/l and the minimum and maximum concentrations are 0.03 and 0.39 mg/l. Only 6 of the 51 baseline concentrations are above the Australian Drinking Water Guideline of 0.3 mg/l; the 87th percentile is 0.29 mg/l. Given this context, **the proposed benchmark of 0.54 mg/l is too high.**

The high value of 0.54mg/l is a consequence of the use of the standard deviation being compromised by transformed data deviating from being normal. Emphasising this, the geometric mean, obtained by taking the antilogarithm (inverse transformation) of the mean of the logarithmically transformed data, is 0.15 mg/l – less than the 0.18 mg/l arithmetic mean of the untransformed data. Yet adding twice the standard deviation of the logarithmically transformed data to the mean of the logarithmically transformed data and applying the inverse transformation (antilogarithm) gives a value equivalent to adding 3.75 times the standard deviation of the untransformed data to the arithmetic mean of the untransformed data - 0.54 mg/l

As noted above, the untransformed data also deviates from being normal, though to a lesser extent than the transformed data. Illustrating the deviation from normality of the untransformed data, if the iron data did in fact have a normal data distribution, then adding three times the standard deviation of the data to the mean of the data would capture 99.7% of the data, which has a maximum of 0.39 mg/l. That is, all of the data is less than 0.40 mg/l. Yet adding three times the standard deviation of the data to the mean of the data gives a value of 0.46 mg/l, which is greater than the peak value of 0.39 mg/l. The proposed value of 0.54 mg/l is greater still.

Given the use of the standard deviation is compromised by both the untransformed and transformed data distributions iron deviating from being normal, the performance indicator benchmark should be set by a means that does not depend on the nature of the data distribution. A simple and statistically sound approach that is independent of the character of the data distribution would be to set a benchmark at the 95$^{th}$ percentile. There is then no need to consider or justify the application of a data transformation.

It is worth noting that in the case of a true normal distribution, the 95$^{th}$ percentile is effectively equivalent to the mean plus twice the standard deviation. This is presumably the reason the proposed water management plan adds twice the standard deviation of the logarithmically transformed to the mean of the logarithmically transformed data. The transformed data however is not normal in character and the use of the standard deviation is accordingly flawed.

**Recommendation 1:** The performance indicator benchmark for metal concentrations should be set at the 95$^{th}$ percentile, this being independent of the nature of the data distributions and equivalent to adding twice the standard deviation of a normal distribution to the mean of that distribution. In the case of the baseline data for iron concentrations at WRWQ9, the 95$^{th}$ percentile is 0.37 mg/l. Benchmark concentrations for other water quality indicators should be based on the same considerations

**Recommendation 2:** Water quality is to be judged to have more than negligibly changed if more than 20% of the data collected during an assessment period exceeded the 95$^{th}$ percentile of the baseline data. This being equivalent to four times the percentage of the baseline data above the 95$^{th}$ percentile of that data.

**Recommendation 3:** Water quality changes should be assessed with respect to all monitored water quality indicators and not just iron, manganese and aluminium. In addition, given the nature of the Hawkesbury Sandstone[1], nickel and cobalt concentrations should be monitored. Aquatic ecology monitoring should also be included in the parameters used to assess the quality of water entering the Woronora Reservoir from Waratah Rivulet.

## Setting a Reliable Performance Indicator

The proposed water management plan advises that water quality will be judged, in part, to have significantly changed if any water quality parameter exceeds "*the baseline mean plus two standard deviations for two consecutive months*". The requirement that a concentration should remain above the performance benchmark for two consecutive months ignores the possibility that heavy rain may temporarily dilute concentrations otherwise elevated by mining activity. That is, a requirement of two consecutive months of elevated concentrations renders the performance indicator unreliable.

As suggested above, a more robust performance indicator would instead require that the percentage of concentrations measured during an assessment period that exceed the 95$^{th}$ percentile of the baseline should not exceed 20%. For a twelve month assessment period, the limit of 20% is a little more than the equivalent of two months in a year (16.7%).

Water quality parameters should be measured at least fortnightly.

## Inappropriate Use of Woronora River as a Control Site

The revised management plans retain the water quality assessment qualification "*Changes in the quality of water entering Woronora Reservoir are not significantly different post-mining compared to pre-mining concentrations that are not also occurring at control site WOWQ2*." That is, Woronora River would still be used as a control or reference site for water entering the Woronora River from the Waratah Rivulet.

As discussed in comments sent to the Department last year regarding the first draft of the water management plans, there is currently no scientific basis for the assumption that Woronora River metal concentrations are independent of mining activity. That is the assumption has not been scientifically tested. That the assumption should not be accepted without validation is made clear in the 2010 Bulli Seam Operations (BSO) PAC Panel report[2], which suggests there is likely to be a relationship between mining activity and metals concentrations in the Woronora River.

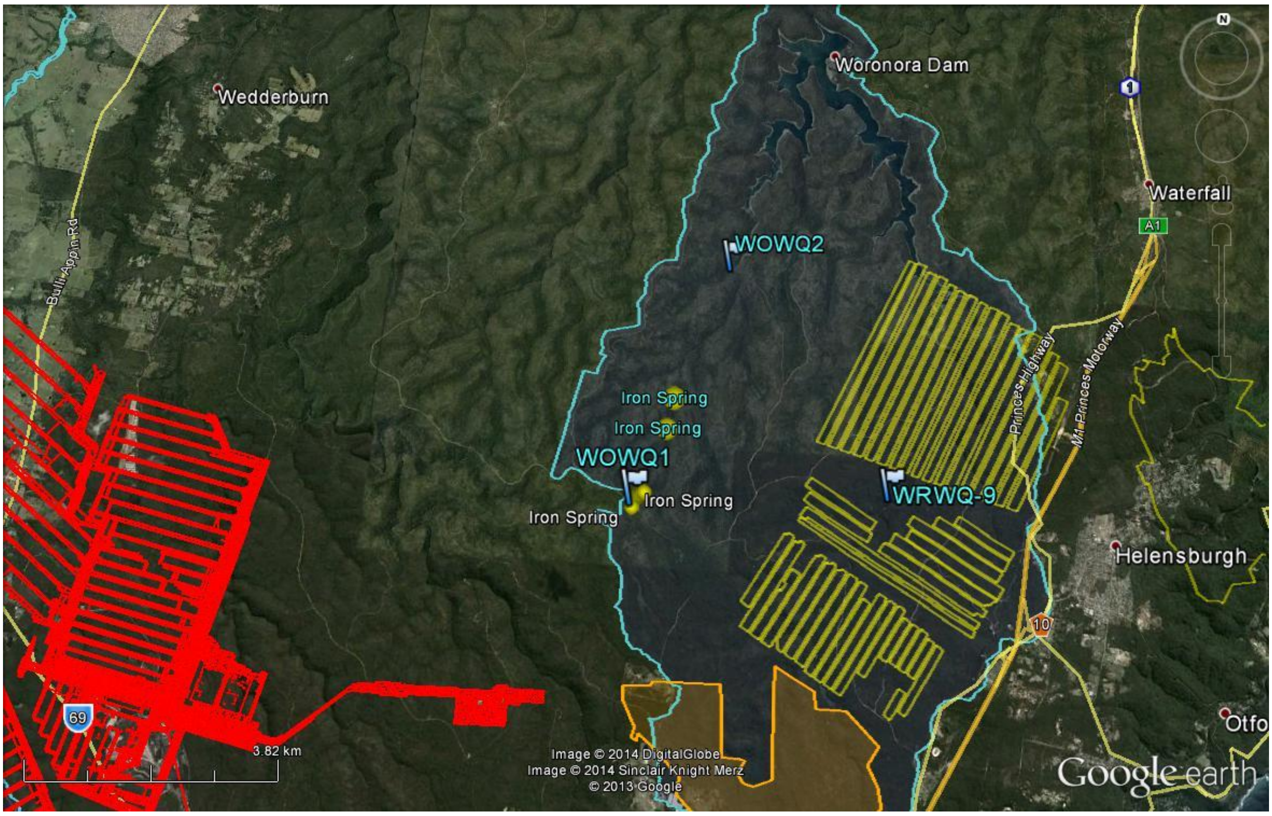
The PAC Panel report states: "*The Panel members have observed iron staining frequently during their field and aerial inspections associated with the BSO Project and with previous Inquiries. On a number of occasions, the attention of the Panel members has been drawn to what is purported to be examples of natural iron staining. The Panel accepts that iron staining can have natural causes, however it has yet to be presented with information that confirms these examples were natural. The scale, location and, in some instances, the intensity of the iron staining that Panel members have observed prompted the Panel to map the sites of these observations together with sites that it could interpret from the stream photo base provided by ICHPL. The outcomes, which need to be validated by 'ground truthing', are shown in Figure 33. The Panel has concluded that there appears to be a strong correlation between past mining activities and iron staining."* And "*Isolated stain occurrences located in the upper reaches of O"Hares Creek and* ***Woronora River*** *are remote from existing mining, but may still be associated with far field movements of the rock strata*."; bold text emphasis added here. Once initiated, iron springs may last for decades.

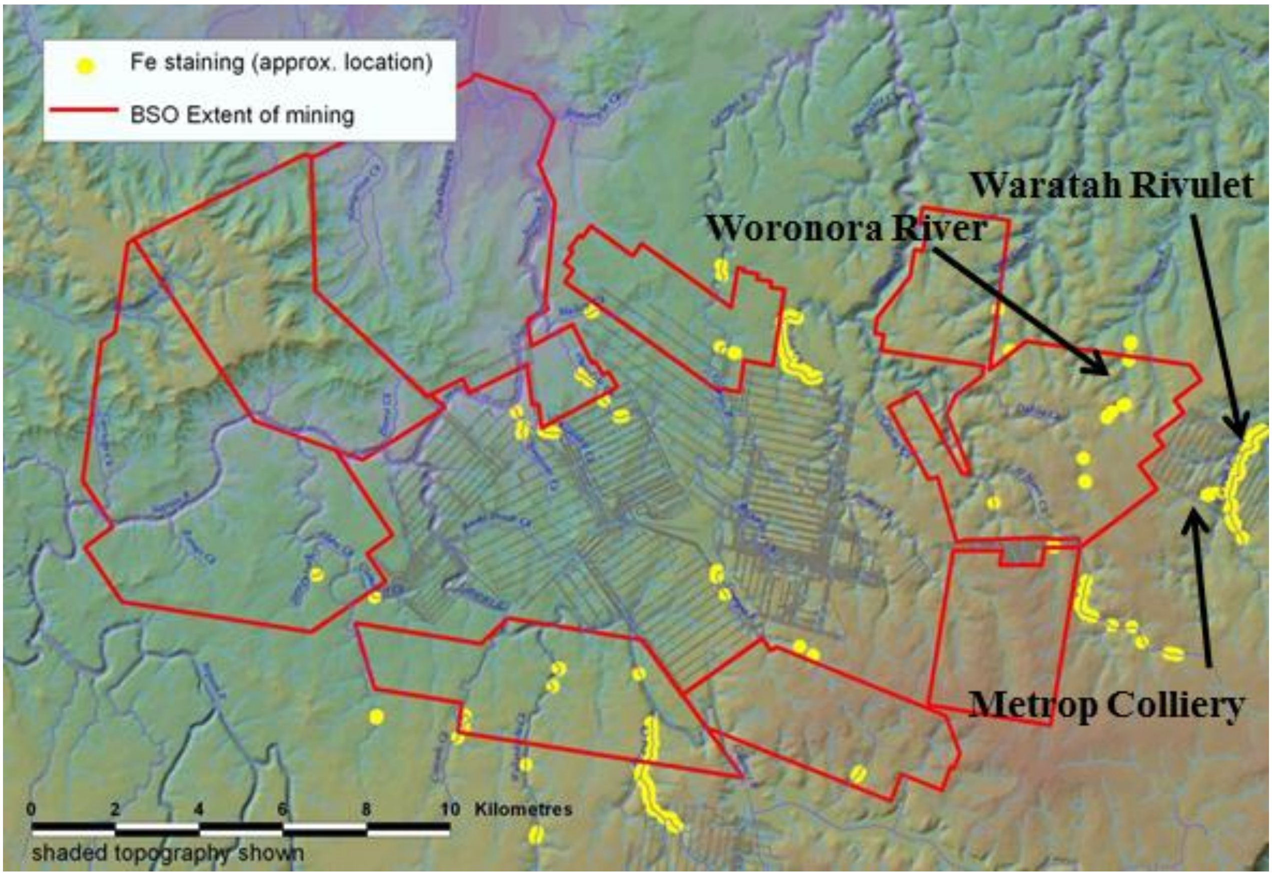
While iron springs can and do occur as a consequence of movements in the sandstone bedrock arising from natural stress relief impulses, water-rock interactions on the Woronora Plateau have otherwise largely equilibrated over geologic time.

The BSO report attributes iron spring activity to far-field horizontal movement arising from mining induced subsidence. Such effects have been recorded at up to five kilometres from the vertical subsidence area.[3-5] Movements occur soon after mining and are generally in the direction of the goaf, though they can also be dependent upon the scale and proximity of previous mining in adjacent areas.[4] The movement can trigger the release or redistribution of otherwise confined stress with shearing across bedding planes and weak strata horizons and movement below valleys and gorges may result in buckling of strata.[5] Massive strata cantilevering can cause subsidence and uplift effects at great distance. Mining induced horizontal movement can (re)activate geological structures such as faults or joint surfaces and this can influence both the direction and extent of horizontal movement.[5] Mining can accordingly trigger iron spring formation far from the subsidence zone and may reactivate or aggravate existing iron springs distant from the mine.

Below is a Google Earth image showing the location of the iron springs mapped on the Woronora River by the BSO PAC Panel, with respect to the Metropolitan and Appin mine longwalls and the northern extent of the old Darkes Forest mine. The map also shows monitoring sites WOWQ1, WOWQ2 and WOWQ9 and the boundary of the Woronora Special Area.

Figure 33 from the BSO PAC report, with some annotation, is included below for reference. The distance between the Metropolitan longwalls and the iron springs is 2.3 to 3 kilometres; far-field movements have been detected at distances of this kind in the Southern Coalfield.



There are anecdotal reports that, when viewed from the air, the pattern of iron spring discolouration of water courses effectively maps the mining below.

Graphs in the proposed management plan and the 2012 Annual Review suggest a correlation between concentrations on Waratah Rivulet and those on Woronora River. Chart 52 from the 2012 Annual Review is shown below. This graph plots iron levels at WOWQ2 and WRWQ9 from 2008 to December 2012. And suggests a significant level of correlation between changes at the two sites. Mining was taking place throughout the period covered by the graph, with the 'old' longwalls preceding the commencement of Longwall 20 in May 2010.

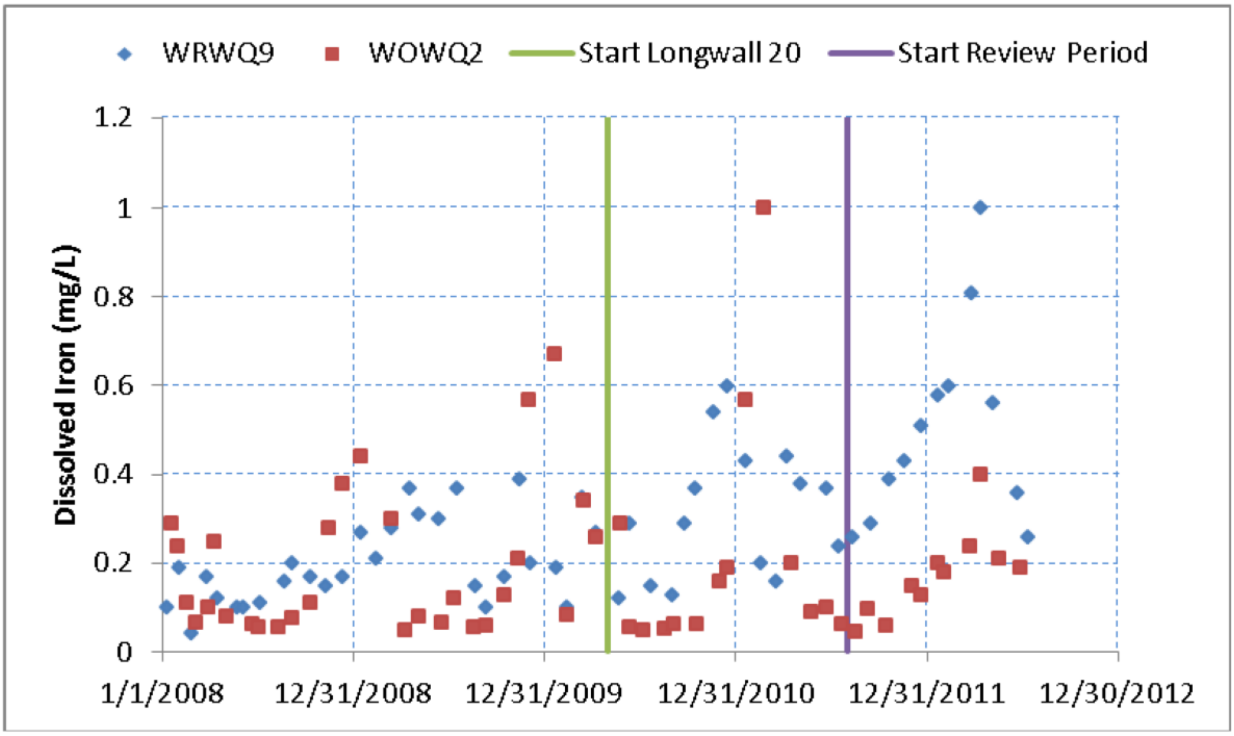



**Chart 52 Comparison of Dissolved Iron Concentrations at WRWQ9 (Waratah Rivulet downstream) and WOWQ2 (Woronora River downstream)**

As previously pointed out, Chart 51 in the 2012 AR indicates correlation between changes to aluminium concentrations on the Waratah Rivulet and Woronora River, with higher concentrations presumably reflecting higher levels of Dickite on the Woronora River.

The table below reproduces statistics from the management plans for Longwalls 20 to 23 and 23 to 27. Noting that the expansion project commenced in May 2010, the statistics indicate an influence of the new longwalls on iron spring activity in the vicinity of Waratah Rivulet (the site locations are identified in the management plans). The available data isn’t however sufficient to determine the nature and extent of any correlation between iron spring activity on the Waratah Rivulet and that at other sites in the vicinity.

| Site | Start Date | End Date | Ave. (mg/l) | Max. (mg/l) | Min. (mg/l) | Std. Dev. (mg/l) |
|---|---|---|---|---|---|---|
| **BCWQ1** | 7/9/07 | 1/12/09 | 0.15 | 0.96 | 0.01 | 0.08 |
| **BCWQ1** | 17/1/08 | 22/4/13 | 0.63 | 5.40 | 0.03 | 1.08 |
| **HCWQ1** | 7/9/07 | 1/12/09 | 0.22 | 1.60 | 0.01 | 0.35 |
| **HCWQ1** | 17/1/08 | 23/4/13 | 0.37 | 3.70 | 0.04 | 0.57 |
| **FEWQ 1** | 7/9/07 | 1/12/09 | 0.27 | 0.39 | 0.03 | 0.10 |
| **FEWQ 1** | 17/1/08 | 11/4/13 | 0.41 | 4.00 | 0.07 | 0.54 |
| **ETWQ N** | 7/9/07 | 1/12/09 | 0.28 | 0.97 | 0.03 | 0.17 |
| **ETWQ N** | 17/1/08 | 11/4/13 | 0.32 | 0.97 | 0.03 | 0.17 |
| **WOWQ 1** | 7/9/07 | 1/12/09 | 0.24 | 3.10 | <0.001 | 0.55 |
| **WOWQ 1** | 17/1/08 | 19/4/13 | 0.79 | 15.00 | 0.01 | 2.06 |
| **WOWQ 2** | 7/9/07 | 1/12/09 | 0.19 | 1.30 | 0.05 | 0.24 |
| **WOWQ 2** | 17/1/08 | 22/4/13 | 0.25 | 1.50 | 0.05 | 0.30 |

**Blue rows**: Table 14 page 44 Water Management Plan Longwalls 20-22 Metropolitan Mine.
**Orange rows**: Table 13 page 50 Draft Water Management Plan Longwalls 23- 27 Metropolitan Mine.

In the absence of a detailed and genuinely independent study of the iron springs on all of the monitored watercourses that establishes that emissions beyond the subsidence impact zone are in no way influenced by the mining of the expansion project, there is no scientific basis for the use of WOWQ2 as a control site. Allowing Woronora River to be used as a control in the absence a rigorous and genuinely independent scientific determination that Woronora River cannot be influenced by nearby mining operations would undermine the credibility of the project approval conditions. Consultants selected and funded by the company are not independent, as highlighted in the 2010 BSO PAC Panel report.[1]

**Recommendation 4:** Given the proximity of the mining, the comments by the 2010 PAC Panel, the reports of horizontal movements at up to five kilometres from mining operations, the indications of correlation between metal concentrations in the Waratah Rivulet and Woronora River, the anecdotal reports of iron spring activity effectively mapping mining and the absence of an established scientific basis for assuming mining will not affect iron spring activity on Woronora River, it would not be appropriate to use Woronora River as a control site for changes to water quality reaching the Woronora Reservoir from the Waratah Rivulet. Woronora River cannot be regarded as suitable control site unless and until it can be rigorously, genuinely independently and transparently demonstrated that the Woronora River has not been affected by underground mining.

## Misleading Table 13

While the revised water management plan no longer redefines the baseline period to include the extraction period, and hence impacts, of Longwalls 20 22, the table associated with the earlier redefinition is retained. The footnote to Table 13 was the only notice given in the previous draft of the intent to change the baseline period.

Table 13 is presented as an historical summary of water quality parameters and in doing so it does not distinguish between the pre and post expansion project periods. This is both unhelpful and misleading. Clearly it is important to know what changes have occurred as a consequence of the new longwalls and Table 13 obscures those changes and these changes should be presented in the management plan.

**Recommendation 5:** Table 13 should be replaced with a table that clearly summarises pre and post expansion project commencement data.

## Water Quantity

The revised draft makes no mention of catchment modelling that suggests water is being last from the Waratah Rivulet. The evidence increasingly points to water loss and the uncertainties highlight the need for caution. There is an urgent need for significantly more reliable estimates for water loss and this requires much better data and modelling.

In a briefing sent to the Minister in September 2012, the SCA states "*There is no evidence to date that suggests the cracking in the Waratah Rivulet has affected supply yield from Woronora Dam in a substantial way*." The mining approval requires no more than a negligible reduction in yield.

A 2010 review undertaken by Prof. Vazken Andréassian on behalf of the SCA suggests between 1.5 and 5.4 Ml/day are being lost from the Waratah Rivulet, and possibly from the Woronora Reservoir catchment as a result of water being diverted into subsidence cracks and then joining regional groundwater flows that take water away from the local storage catchment. There is no mention of this or discussion of the differences between the modelling undertaken by Peabody's consultants and that of the SCA, in the draft Water Management Plan.

The 2010 Andreassian review comments on the loss modelling as follows; "*A water balance computation by flow classes (between the midstream and the downstream gauge) yields a value of 1.5 ML/d as best estimate, and a rainfall-runoff modelling study yields a value of 5.7 ML/d. The reality lies probably closer to this latter value*." The average inflow to Woronora Reservoir from the Waratah Rivulet is 18 Ml/day and in this context, the possibility of water loss of up to 5.7 Ml/day is a significant concern. Historically Waratah Rivulet delivers more water to Woronora Reservoir than Woronora River, providing approximately 30% of the inflow during periods of good rainfall and up to 50% during dry conditions. While there is uncertainty in the Andreassian review estimates of loss, there is also the potential for significant consequence. That is, the pre-conditions for application of the Precautionary Principle are present. Justice Preston advises that if "*there is a threat of serious or irreversible environmental damage and there is the requisite degree of scientific uncertainty – the precautionary principle will be activated. At this point, there is a shifting of an evidentary burden of proof. A decision-maker must assume that the threat of serious or irreversible environmental damage is no longer uncertain but is a reality. The burden of showing that this threat does not in fact exist or is negligible effectively reverts to the proponent of the economic or other development plan, programme or project*". The benefit of doubt arising from a lack of knowledge and understanding of mining impacts on water supply should be given to the catchment.

The Andreassian report finds that there may be pre-existing natural leakage from both the Waratah Rivulet and the Woronora River through natural joints and cracks. **It's unlikely that any pre-existing leakage would not have been made worse by subsidence**. In the case of the Woronora River it's possible, if not likely, that mining operations could initiate or aggravate leakage through far-field movements, as appears to be the case for iron spring activity. That is, the assumption that water quantity in Woronora River is not effected by the nearby mining is questionable and would seem likely to be incorrect. As noted above, the river has the Metropolitan Colliery immediately to the east, the now closed Darkes Forest mine to the south and Appin to the south west.

Recent dye and salt tracer injection tests undertaken by the SCA during the passage of Longwall 21 evidently demonstrate water loss from the Waratah Rivulet into groundwater flows without subsequent return to the surface. Previous tests, during the passage of Longwall 16, had found that the water did return to the surface downstream, at least in moderate to high flow conditions. This change appears to be a consequence of the extraction of Longwalls 20 and 21. Presumably then updated and improved modelling would find increased water loss. There are concerns water is joining groundwater flows that leave the local storage catchment, possibly via a geological discontinuity.

Mining is being undertaken in the absence of knowledge and understanding of the impacts on water supply to Woronora Reservoir. There should be a genuinely independent assessment of the impact of mining on the supply of water from the Waratah Rivulet and Woronora River before the next stage of mining is approved.

**Recommendation 6:** The proposed WMP should not be approved until there is agreement between the SCA and Peabody Energy that mining activity has not and will not cause more than negligible change to the quantity of water entering the Woronora Reservoir form the Waratah Rivulet *and* the Woronora River. Given the advice of the Andreassian review, this will require improved data and modelling.

**References**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