

## *Appendix A*

### **Fieldwork Appendix**

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## United Wambo Open Cut Coal Mine Project

### Fieldwork Appendix

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#### A1 Introduction

This appendix describes the available groundwater data for the project site. The field data was used to conceptualise and develop a numerical groundwater model of the Project Area. The field data includes:

- monitoring bore network;
- groundwater levels;
- water quality analysis; and
- surrounding private bores (bore census).

The sections below describe the raw data.

#### A2 Groundwater monitoring network

Wambo Coal and United Collieries have a combined groundwater monitoring network that comprises a total of 77 bores and 24 vibrating wire piezometers (VWP) with a total of 152 sensors. The network was first established in 2000, and over time several of the bores have been abandoned and destroyed due to mine progression and deterioration. A list of all bores and VWPs installed across the project area is included in Appendix A1 and the location of the bores is shown in Figure A- 1.

Groundwater monitoring is currently undertaken at 27 monitoring bores and 11 VWPs (55 sensors) across the project site, as detailed in Table A-1. The existing bores target a range of lithological units, including:

- Quaternary alluvium and colluvium;
- Newcastle Coal Measures;
- Coal seams of the Wittingham Coal Measures; and
- Interburden and overburden material of the Wittingham Coal Measures.

##### A2.1 Groundwater levels

Groundwater monitoring at Wambo and United is undertaken in accordance with each site's Groundwater Monitoring Program (GWMP). Currently groundwater monitoring is conducted at Wambo and United on a monthly to bi-monthly basis for groundwater levels. Table A-1 presents a 'snap shot' of the most recent groundwater levels recorded in 2015 for each of the site monitoring bores.

**Table A-1 Monitoring bore construction details**

| Hole ID | Type | Coordinates |         | Geological unit | Lithology                        | Ground elevation (mAHD) | Screen/ Sensor (mbGL) | Date sampled | Groundwater level (mAHD) |
|---------|------|-------------|---------|-----------------|----------------------------------|-------------------------|-----------------------|--------------|--------------------------|
|         |      | mE          | mN      |                 |                                  |                         |                       |              |                          |
| P106    | MB   | 311518      | 6391084 | Qa              | Alluvium                         | 60.0                    | -                     | 1/04/2015    | 39.5                     |
| P109    | MB   | 311215      | 6390768 | Qa              | Alluvium                         | 62.1                    | -                     | 1/04/2015    | 57.6                     |
| P110    | MB   | 311217      | 6390690 | Qa              | Alluvium                         | 64.1                    | -                     | 1/04/2015    | 59.5                     |
| P111    | MB   | 311301      | 6390761 | Qa              | Alluvium                         | 61.5                    | -                     | 1/04/2015    | 56.1                     |
| P114    | MB   | 311057      | 6391293 | Qa              | Alluvium                         | 61.9                    | -                     | 1/04/2015    | 55.8                     |
| P116    | MB   | 311205      | 6391288 | Qa              | Alluvium                         | 64.4                    | -                     | 1/04/2015    | 59.3                     |
| GW13    | MB   | 313810      | 6388990 | Qa              | Alluvium, shallow overburden     | 67.8                    | 6 - 15                | 1/02/2015    | 62.5                     |
| GW15    | MB   | 313164      | 6392807 | Qa              | Alluvium, shallow overburden     | 60.7                    | 13.8 - 17.4           | 1/04/2015    | 49.7                     |
| GW16    | MB   | 306641      | 6396034 | Qa              | Alluvium, shallow overburden     | 110.6                   | 6.15 - 12.15          | 1/04/2015    | 106.0                    |
| GW17    | MB   | 306895      | 6396048 | Qa              | Alluvium, shallow overburden     | 109.5                   | 11 - 14               | 1/04/2015    | 99.8                     |
| GW22    | MB   | 311335      | 6389535 | Qa              | Alluvium, shallow overburden     | 91.3                    | 42 - 54               | 1/04/2015    | 55.4                     |
| P301    | MB   | 309311      | 6391425 | Qa              | Alluvium, shallow overburden     | 89.2                    | -                     | 1/04/2015    | 73.5                     |
| P315    | MB   | 309091      | 6391852 | Qa              | Alluvium, shallow overburden     | 98.4                    | -                     | 1/04/2015    | 94.1                     |
| P12     | MB   | 313644      | 6394797 | Qa              | East Wollombi Brook Alluvium     | 55.2                    | 7 - 13                | 1/04/2015    | 51.3                     |
| P13     | MB   | 313722      | 6394412 | Qa              | East Wollombi Brook Alluvium     | 56.1                    | 9 - 15                | 1/04/2015    | 52.8                     |
| GW12    | MB   | 309841      | 6391056 | Qa              | Stony Creek Alluvium             | 99.3                    | 6.1 - 12.1            | 1/04/2015    | 86.5                     |
| GW02    | MB   | 309109      | 6389680 | Qa              | Upper South Wambo Creek Alluvium | 79.8                    | -                     | 1/04/2015    | 73.0                     |
| GW11    | MB   | 309228      | 6389699 | Qa              | Upper South Wambo Creek Alluvium | 79.3                    | -                     | 1/04/2015    | 75.0                     |
| P15     | MB   | 313431      | 6394803 | Qa/Qr           | West Wollombi Brook Colluvium    | 56.7                    | 5 - 8.1               | 1/04/2015    | 51.4                     |
| P16     | MB   | 313480      | 6394655 | Qa/Qr           | West Wollombi Brook Colluvium    | 57.5                    | 5 - 10.5              | 1/04/2015    | 51.2                     |
| P17     | MB   | 313376      | 6394631 | Qa/Qr           | West Wollombi Brook Colluvium    | 56.8                    | 5 - 7.5               | 1/04/2015    | 51.4                     |

| Hole ID     | Type | Coordinates |         | Geological unit | Lithology                            | Ground elevation (mAHD) | Screen/ Sensor (mbGL) | Date sampled | Groundwater level (mAHD) |
|-------------|------|-------------|---------|-----------------|--------------------------------------|-------------------------|-----------------------|--------------|--------------------------|
|             |      | mE          | mN      |                 |                                      |                         |                       |              |                          |
| P18         | MB   | 313503      | 6394512 | Qa/Qr           | West Wollombi Brook Colluvium        | 57.3                    | 5.5 - 8               | 1/04/2015    | 51.0                     |
| P20         | MB   | 313639      | 6394166 | Qa/Qr           | West Wollombi Brook Colluvium        | 57.4                    | 6 - 9.2               | 1/04/2015    | 51.5                     |
| P1          | MB   | 312199      | 6395840 | Pswj            | Interburden - Blakefield - unnamed C | 86.0                    | 31 - 37               | 1/04/2015    | 61.3                     |
| P11         | MB   | 312728      | 6395462 | Pswj            | Interburden Blakefield - unnamed D   | 71.8                    | 19 - 28               | 1/04/2015    | 40.6                     |
| P202        | MB   | 311859      | 6391330 | Pswj            | Overburden Whybrow                   | 59.2                    | -                     | 1/04/2015    | 53.6                     |
| P206        | MB   | 311772      | 6391293 | Pswj            | Overburden Whybrow                   | 59.0                    | -                     | 1/04/2015    | 46.1                     |
| P33_113m    | VWP  | 313756.6    | 6394659 | Pswj            | Arrowfield Seam                      | 56.7                    | 113                   | 19/06/2015   | 8.4                      |
| UG133_96m   | VWP  | 313297.2    | 6396177 | Pswj            | Arrowfield Seam                      | 62.6                    | 96                    | 7/08/2015    | 6.4                      |
| UG138_245m  | VWP  | 308516.9    | 6396181 | Pswj            | Arrowfield Seam                      | 145.0                   | 245                   | 17/04/2015   | 47.3                     |
| UG192R_60m  | VWP  | 313683.3    | 6396084 | Pswj            | Arrowfield Seam                      | 58.9                    | 60                    | 14/08/2015   | 23.0                     |
| UG193_61m   | VWP  | 313757.3    | 6396090 | Pswj            | Arrowfield Seam                      | 58.2                    | 61                    | 14/08/2015   | 36.5                     |
| UG225_58.5m | VWP  | 313214.4    | 6397095 | Pswj            | Arrowfield Seam                      | 68.9                    | 58.5                  | 31/07/2015   | 38.1                     |
| P33_58m     | VWP  | 313756.6    | 6394659 | Pswj            | Blakefield Seam                      | 56.7                    | 58                    | 19/06/2015   | 27.7                     |
| UG138_250m  | VWP  | 308516.9    | 6396181 | Pswj            | Bowfield Seam                        | 145.0                   | 250                   | 17/04/2015   | -4.8                     |
| UG192R_94m  | VWP  | 313683.3    | 6396084 | Pswj            | Bowfield Seam                        | 58.9                    | 94                    | 14/08/2015   | 15.5                     |
| UG193_85m   | VWP  | 313757.3    | 6396090 | Pswj            | Bowfield Seam                        | 58.2                    | 85                    | 14/08/2015   | 33.6                     |
| UG225_93.2m | VWP  | 313214.4    | 6397095 | Pswj            | Bowfield Seam                        | 68.9                    | 93.2                  | 31/07/2015   | 33.3                     |
| UG133_219m  | VWP  | 313297.2    | 6396177 | Pswj            | Broonie Seam                         | 62.6                    | 219                   | 7/08/2015    | 13.1                     |
| UG192R_210m | VWP  | 313683.3    | 6396084 | Pswj            | Broonie Seam                         | 58.9                    | 210                   | 14/08/2015   | 29.7                     |
| UG193_210m  | VWP  | 313757.3    | 6396090 | Pswj            | Broonie Seam                         | 58.2                    | 210                   | 14/08/2015   | 24.1                     |
| UG196_230m  | VWP  | 312364.5    | 6397122 | Pswj            | Broonie Seam                         | 81.1                    | 230                   | 14/08/2015   | 33.6                     |
| UG133_45m   | VWP  | 313297.2    | 6396177 | Pswj            | Glen Munro Seam                      | 62.6                    | 45                    | 7/08/2015    | 46.3                     |

| Hole ID      | Type | Coordinates |           | Geological unit | Lithology                                  | Ground elevation (mAHD) | Screen/ Sensor (mbGL) | Date sampled | Groundwater level (mAHD) |
|--------------|------|-------------|-----------|-----------------|--------------------------------------------|-------------------------|-----------------------|--------------|--------------------------|
|              |      | mE          | mN        |                 |                                            |                         |                       |              |                          |
| UG138_215m   | VWP  | 308516.9    | 6396181   | Pswj            | Glen Munro Seam                            | 145.0                   | 215                   | 14/08/2015   | 59.0                     |
| UG147_090    | VWP  | 311245.4    | 6397207   | Pswj            | Glen Munro Seam                            | 108.0                   | 90                    | 7/08/2015    | 15.0                     |
| UG193_27m    | VWP  | 313757.3    | 6396090   | Pswj            | Glen Munro Seam                            | 58.2                    | 27                    | 14/08/2015   | 38.2                     |
| UG196_45m    | VWP  | 312364.5    | 6397122   | Pswj            | Glen Munro Seam                            | 81.1                    | 45                    | 14/08/2015   | 59.6                     |
| UG192R_30m   | VWP  | 313683.3    | 6396084   | Pswj            | Interburden Arrowfield - Glen Munro        | 58.9                    | 30                    | 14/08/2015   | 29.7                     |
| UG147_157    | VWP  | 311245.4    | 6397207   | Pswj            | Interburden between Warkworth and Bowfield | 108.0                   | 157                   | 7/08/2015    | 35.9                     |
| UG224_69m    | VWP  | 313860      | 6396243   | Pswj            | Interburden Bowfield - Arrowfield          | 58.8                    | 69                    | 31/07/2015   | 18.8                     |
| UG224_172m   | VWP  | 313860      | 6396243   | Pswj            | Interburden Vaux - Piercefield             | 58.8                    | 172                   | 31/07/2015   | 26.4                     |
| UG133_146m   | VWP  | 313297.2    | 6396177   | Pswj            | Interburden Warkworth - Bowfield           | 62.6                    | 146                   | 7/08/2015    | -20.4                    |
| UG138_292m   | VWP  | 308516.9    | 6396181   | Pswj            | Interburden Warkworth - Bowfield           | 145.0                   | 292                   | 17/04/2015   | 37.2                     |
| UG192R_110m  | VWP  | 313683.3    | 6396084   | Pswj            | Interburden Warkworth - Bowfield           | 58.9                    | 110                   | 14/08/2015   | 16.9                     |
| UG192R_140m  | VWP  | 313683.3    | 6396084   | Pswj            | Interburden Warkworth - Bowfield           | 58.9                    | 140                   | 14/08/2015   | 16.4                     |
| UG196_110m   | VWP  | 312364.5    | 6397122   | Pswj            | Interburden Warkworth - Bowfield           | 81.1                    | 110                   | 14/08/2015   | 33.8                     |
| UG196_137m   | VWP  | 312364.5    | 6397122   | Pswj            | Interburden Warkworth - Bowfield           | 81.1                    | 137                   | 14/08/2015   | 26.5                     |
| UG220_106m   | VWP  | 312521.6    | 6397233.3 | Pswj            | Interburden Warkworth - Bowfield           | 82.0                    | 106                   | 14/08/2015   | 33.1                     |
| UG220_110m   | VWP  | 312521.6    | 6397233.3 | Pswj            | Interburden Warkworth - Bowfield           | 82.0                    | 110                   | 14/08/2015   | 32.9                     |
| UG224_105m   | VWP  | 313860      | 6396243.1 | Pswj            | Interburden Warkworth - Bowfield           | 58.8                    | 105                   | 31/07/2015   | 32.6                     |
| UG225_100.5m | VWP  | 313214.4    | 6397094.7 | Pswj            | Interburden Warkworth - Bowfield           | 68.9                    | 100.5                 | 31/07/2015   | 29.9                     |
| UG133_168m   | VWP  | 313297.25   | 6396177.4 | Pswj            | Mt. Arthur Seam                            | 62.6                    | 168                   | 7/08/2015    | 12.5                     |
| UG196_160m   | VWP  | 312364.48   | 6397122.4 | Pswj            | Mt. Arthur Seam                            | 81.1                    | 160                   | 14/08/2015   | 29.6                     |
| UG220_152m   | VWP  | 312521.6    | 6397233.3 | Pswj            | Mt. Arthur Seam                            | 82.0                    | 152                   | 14/08/2015   | 50.3                     |
| UG225_128m   | VWP  | 313214.4    | 6397094.7 | Pswj            | Mt. Arthur Seam                            | 68.9                    | 128                   | 31/07/2015   | 30.7                     |

| Hole ID      | Type | Coordinates |           | Geological unit | Lithology                       | Ground elevation (mAHD) | Screen/ Sensor (mbGL) | Date sampled | Groundwater level (mAHD) |
|--------------|------|-------------|-----------|-----------------|---------------------------------|-------------------------|-----------------------|--------------|--------------------------|
|              |      | mE          | mN        |                 |                                 |                         |                       |              |                          |
| UG133_180m   | VWP  | 313297.25   | 6396177.4 | Pswj            | Piercefield Seam                | 62.6                    | 180                   | 7/08/2015    | 12.1                     |
| UG193_179.5m | VWP  | 313757.25   | 6396090.3 | Pswj            | Piercefield Seam                | 58.2                    | 179.5                 | 14/08/2015   | 18.9                     |
| UG224_163m   | VWP  | 313860      | 6396243.1 | Pswj            | Piercefield Seam                | 58.8                    | 163                   | 31/07/2015   | 20.2                     |
| UG147_242    | VWP  | 311245.45   | 6397206.9 | Pswj            | Piercefield Seam?               | 108.0                   | 242                   | 7/08/2015    | -2.0                     |
| P33_13m      | VWP  | 313756.59   | 6394659.3 | Pswj            | Glen Munro (Unnamed C) Seam     | 56.7                    | 13                    | 19/06/2015   | 52.3                     |
| P33_19m      | VWP  | 313756.59   | 6394659.3 | Pswj            | Glen Munro (Unnamed D) Seam     | 56.7                    | 19                    | 19/06/2015   | 46.6                     |
| P33_46.5m    | VWP  | 313756.59   | 6394659.3 | Pswj            | Woodlands Hill (Unnamed E) Seam | 56.7                    | 46.5                  | 19/06/2015   | 39.9                     |
| UG138_175m   | VWP  | 308516.95   | 6396180.7 | Pswj            | Woodlands Hill (Unnamed E) Seam | 145.0                   | 175                   | 14/08/2015   | 51.0                     |
| UG133_208m   | VWP  | 313297.25   | 6396177.4 | Pswj            | Vaux Seam                       | 62.6                    | 208                   | 7/08/2015    | -1.2                     |
| UG220_207m   | VWP  | 312521.6    | 6397233.3 | Pswj            | Vaux Seam                       | 82.0                    | 207                   | 14/08/2015   | 28.1                     |
| UG224_191m   | VWP  | 313860      | 6396243.1 | Pswj            | Vaux Seam                       | 58.8                    | 191                   | 31/07/2015   | 37.2                     |
| UG225_178m   | VWP  | 313214.4    | 6397094.7 | Pswj            | Vaux Seam                       | 68.9                    | 178                   | 31/07/2015   | 25.9                     |
| UG193_160m   | VWP  | 313757.25   | 6396090.3 | Pswj            | Warkworth Seam                  | 58.2                    | 160                   | 14/08/2015   | 17.9                     |
| UG220_136m   | VWP  | 312521.6    | 6397233.3 | Pswj            | Warkworth Seam                  | 82.0                    | 136                   | 14/08/2015   | 32.8                     |

**Notes:**

*Coordinates GDA94, Zone 56*

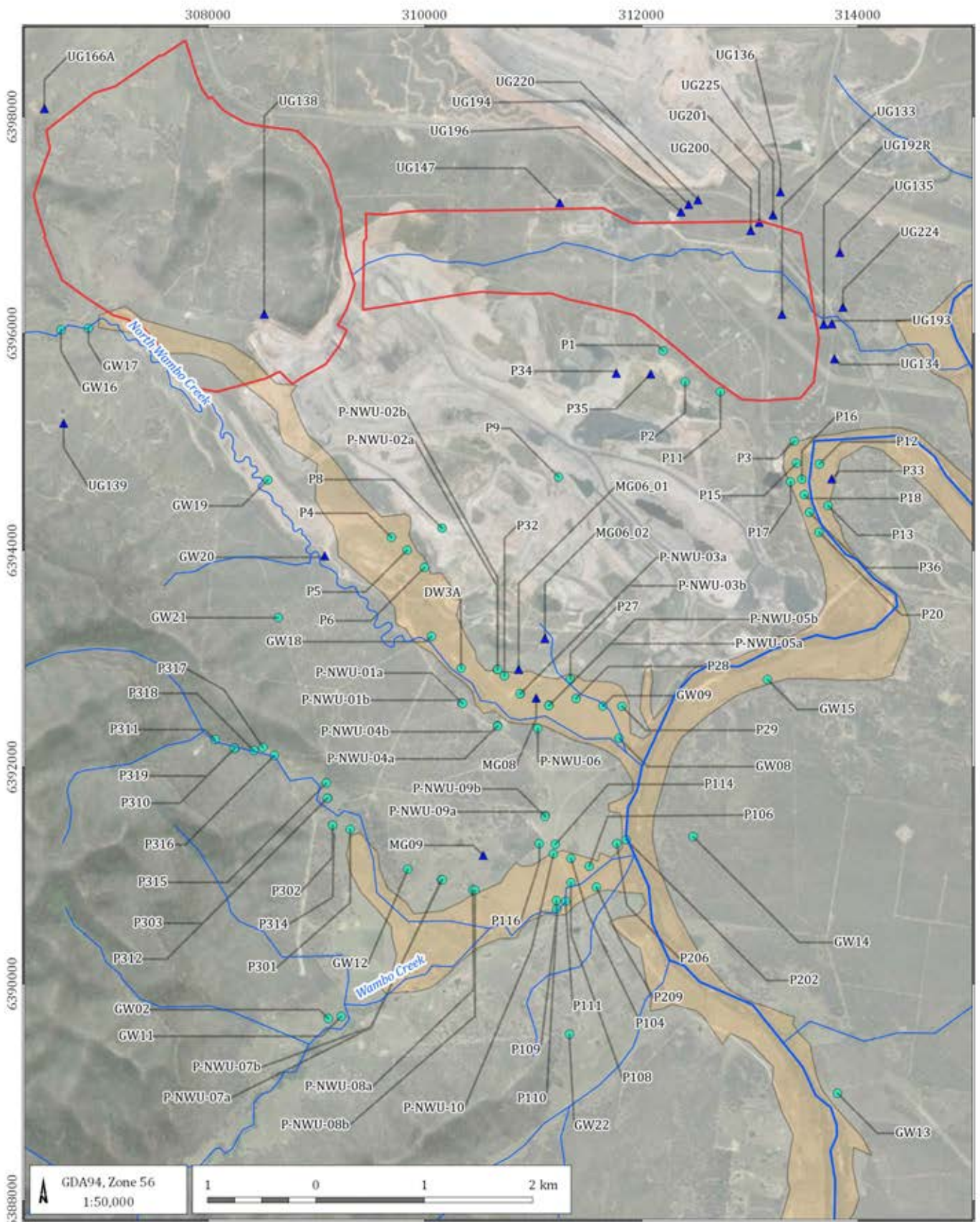
*Qa – Quaternary alluvium*

*Pswj – Jerrys Plains Subgroup coal measures*

*mAHD - metres above height datum*

*Qr – Quaternary regolith*

*mbGL - metres below ground level*



#### LEGEND

#### Monitoring point

- Monitoring bore
- ▲ Vibrating wire piezometer
- ▭ Project area
- Major drainage
- Minor drainage
- Quaternary alluvium (1:25k AGE)

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#### Groundwater monitoring network



DATE  
11/12/2015

FIGURE No:  
**A-1**

## A2.2 Groundwater quality

Currently groundwater monitoring is conducted at Wambo and United on a monthly to bi-monthly basis for groundwater levels, bi-monthly for field parameters (electrical conductivity [EC] and pH), and on an annual basis for comprehensive water quality analysis at selected bores. The comprehensive water quality analysis includes pH, EC, total dissolved solids (TDS), major ions (Ca, Cl, K, Na, Mg and SO<sub>4</sub>), hardness, bicarbonate and nitrate.

The historic water quality results collected by Wambo and United, as well as available data from neighbouring mine operations, has been reviewed. Table A-2 provides a summary table comparing the water quality results across the main groundwater bearing units, the alluvium (“highly productive” and “less productive”), coal measures (interburden and coal) and spoil. The results are also compared against the ANZECC (2000)<sup>1</sup> livestock drinking guidelines and irrigation guidelines (long-term and short-term).

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<sup>1</sup> ANZECC, (2000), “Australian Water Quality Guidelines for Fresh and Marine Waters”, Australia and New Zealand Environment and Conservation Council and the Agricultural and Resource Management Council of Australia and New Zealand.

**Table A-2 Water quality summary**

| Analyte          |      | Unit    | ANZECC (2000) Short term irrigation | ANZECC (2000) Long term irrigation | ANZECC (2000) Stock Water | Hunter River† | Wollombi Brook‡ | Less productive alluvium‡ | Highly productive alluvium† | Interburden‡ | Coal†  | Spoil† |
|------------------|------|---------|-------------------------------------|------------------------------------|---------------------------|---------------|-----------------|---------------------------|-----------------------------|--------------|--------|--------|
| pH (Field)       | Av.  | pH unit | 6.0 - 8.5                           | 6.0 - 8.5                          | -                         | 8.1           | 7.7             | 7.3                       | 7.2                         | 7.2          | 7.2    | 7.1    |
|                  | Min. |         |                                     |                                    |                           | 5.5           | 6.4             | 5.8                       | 6.3                         | 5.9          | 6.1    | 6.1    |
|                  | Max. |         |                                     |                                    |                           | 9.1           | 8.8             | 9.9                       | 8.3                         | 9.9          | 9.9    | 8.8    |
| EC (Field)       | Av.  | µS/cm   | -                                   | -                                  | -                         | 693           | 1,084           | 4,609                     | 1,019                       | 7,487        | 7,041  | 6,915  |
|                  | Min. |         |                                     |                                    |                           | 70            | 105             | 13                        | 21                          | 17           | 500    | 1,189  |
|                  | Max. |         |                                     |                                    |                           | 1,490         | 7,310           | 27,900                    | 8,050                       | 23,100       | 23,100 | 13,280 |
| TDS (Laboratory) | Av.  | mg/L    | -                                   | -                                  | 3,000 - 13,000*           | 506           | 311             | 2,068                     | 569                         | 5,873        | 6,405  | 5,242  |
|                  | Min. |         |                                     |                                    |                           | 81            | 116             | 212                       | 24                          | 74           | 692    | 794    |
|                  | Max. |         |                                     |                                    |                           | 3,800         | 898             | 8,894                     | 2,600                       | 15,200       | 15,200 | 10,790 |
| TSS (Laboratory) | Av.  | mg/L    | -                                   | -                                  | -                         | 37            | 16              | 81                        | 162                         | 80           | 290    | 50     |
|                  | Min. |         |                                     |                                    |                           | 1             | 1               | 16                        | 1                           | 2            | 290    | 12     |
|                  | Max. |         |                                     |                                    |                           | 988           | 815             | 268                       | 8,900                       | 580          | 290    | 111    |
| Silicon (t)      | Av.  | mg/L    | -                                   | -                                  | -                         | 14            | 9               | 30                        | 23                          | 23           | 23     | 11     |
|                  | Min. |         |                                     |                                    |                           | 3             | 7               | 12                        | 14                          | 12           | 12     | 0      |
|                  | Max. |         |                                     |                                    |                           | 19            | 13              | 75                        | 30                          | 56           | 56     | 16     |
| Chloride (t)     | Av.  | mg/L    | -                                   | -                                  | -                         | 212           | -               | 1,019                     | 147                         | 2,513        | 2,899  | 1,634  |
|                  | Min. |         |                                     |                                    |                           | 202           | -               | 21                        | 60                          | 3            | 213    | 188    |
|                  | Max. |         |                                     |                                    |                           | 222           | -               | 3,510                     | 574                         | 7,740        | 7,740  | 3,830  |

| Analyte       |      | Unit | ANZECC (2000) Short term irrigation | ANZECC (2000) Long term irrigation | ANZECC (2000) Stock Water | Hunter River† | Wollombi Brook‡ | Less productive alluvium‡ | Highly productive alluvium† | Interburden‡ | Coal†       | Spoil†       |
|---------------|------|------|-------------------------------------|------------------------------------|---------------------------|---------------|-----------------|---------------------------|-----------------------------|--------------|-------------|--------------|
| Calcium (t)   | Av.  | mg/L | -                                   | -                                  | 1,000                     | 34            | 10              | 120                       | 48                          | 129          | 116         | 120          |
|               | Min. |      |                                     |                                    |                           | 2.7           | 1.8             | 3.0                       | 9.0                         | 2.0          | 10.0        | 14.0         |
|               | Max. |      |                                     |                                    |                           | 66            | 19              | 2,877                     | 196                         | 2,172        | 288         | 232          |
| Sodium (t)    | Av.  | mg/L | -                                   | -                                  | -                         | 62            | 74              | 498                       | 98                          | 1,606        | 1,729       | 1,125        |
|               | Min. |      |                                     |                                    |                           | 14            | 11              | 16                        | 36                          | 13           | 140         | 258          |
|               | Max. |      |                                     |                                    |                           | 174           | 276             | 2,500                     | 735                         | 4,350        | 4,350       | 2,130        |
| Magnesium (t) | Av.  | mg/L | -                                   | -                                  | -                         | 26            | 11              | 84                        | 34                          | 321          | 309         | 287          |
|               | Min. |      |                                     |                                    |                           | 2.70          | 2.10            | 0.05                      | 8.00                        | 0.11         | 6.00        | 33.00        |
|               | Max. |      |                                     |                                    |                           | 50            | 36              | 386                       | 111                         | 2,590        | 726         | 592          |
| Sulphate (t)  | Av.  | mg/L | -                                   | -                                  | 1,000 – 2,400 (pigs)      | 35            | 28              | 255                       | 39                          | 554          | 642         | <b>1,134</b> |
|               | Min. |      |                                     |                                    |                           | 8.2           | 5.7             | 0.5                       | 4.0                         | 0.5          | 0.5         | 128.0        |
|               | Max. |      |                                     |                                    |                           | 80            | 129             | 1,930                     | 364                         | 7,470        | 7,470       | 2,560        |
| Potassium (t) | Av.  | mg/L | -                                   | -                                  | -                         | 3.8           | 5.2             | 42.9                      | 3.9                         | 48.3         | 38.1        | 30.2         |
|               | Min. |      |                                     |                                    |                           | 2.0           | 3.9             | 0.5                       | 0.5                         | 1.4          | 1.4         | 13.0         |
|               | Max. |      |                                     |                                    |                           | 7             | 7               | 1,874                     | 28                          | 1,586        | 390         | 58           |
| Iron (d)      | Av.  | mg/L | -                                   | -                                  | -                         | 0.3           | 1.0             | 1.4                       | 0.4                         | 0.5          | 0.5         | 4.7          |
|               | Min. |      |                                     |                                    |                           | 0.00          | 0.15            | 0.01                      | 0.01                        | 0.01         | 0.01        | 0.02         |
|               | Max. |      |                                     |                                    |                           | 1.3           | 1.8             | 28.6                      | 8.2                         | 6.6          | 6.6         | 38.8         |
| Aluminium (t) | Av.  | mg/L | 20                                  | 5                                  | 5                         | 2.0           | 1.0             | <b>11.1</b>               | <b>12.8</b>                 | <b>11.8</b>  | <b>14.9</b> | <b>1.2</b>   |
|               | Min. |      |                                     |                                    |                           | 0.060         | 0.060           | 0.003                     | 0.003                       | 0.020        | 0.020       | 0.005        |
|               | Max. |      |                                     |                                    |                           | 12            | 5               | 410                       | 260                         | 255          | 255         | 20           |

| Analyte       |      | Unit | ANZECC (2000) Short term irrigation | ANZECC (2000) Long term irrigation | ANZECC (2000) Stock Water | Hunter River† | Wollombi Brook‡ | Less productive alluvium‡ | Highly productive alluvium† | Interburden‡ | Coal†      | Spoil† |
|---------------|------|------|-------------------------------------|------------------------------------|---------------------------|---------------|-----------------|---------------------------|-----------------------------|--------------|------------|--------|
| Arsenic (t)   | Av.  | mg/L | 2                                   | 0.1                                | 0.5                       | <0.001        | 0.001           | 0.002                     | 0.001                       | <b>0.2</b>   | <b>0.2</b> | 0.04   |
|               | Min. |      |                                     |                                    |                           | <0.001        | 0.001           | 0.001                     | 0.001                       | 0.001        | 0.001      | 0.001  |
|               | Max. |      |                                     |                                    |                           | <0.001        | 0.002           | 0.02                      | 0.01                        | 8.00         | 8.00       | 0.25   |
| Barium (t)    | Av.  | mg/L | -                                   | -                                  | -                         | 0.1           | 0.1             | 0.3                       | 0.2                         | 19.4         | 23.6       | 0.1    |
|               | Min. |      |                                     |                                    |                           | 0.00          | 0.03            | 0.005                     | 0.018                       | 0.01         | 0.01       | 0.02   |
|               | Max. |      |                                     |                                    |                           | 0.6           | 0.1             | 6.1                       | 1.5                         | 660          | 660        | 0.4    |
| Beryllium (t) | Av.  | mg/L | 0.5                                 | 0.1                                | -                         | <0.001        | -               | <0.001                    | <0.001                      | -            | -          | -      |
|               | Min. |      |                                     |                                    |                           | <0.001        | -               | <0.001                    | <0.001                      | -            | -          | -      |
|               | Max. |      |                                     |                                    |                           | <0.001        | -               | <0.001                    | <0.001                      | -            | -          | -      |
| Boron (t)     | Av.  | mg/L | refer to guideline                  | 0.5                                | 7 (cattle)                | 0.04          | 0.03            | 0.06                      | 0.04                        | 0.2          | 0.2        | 0.1    |
|               | Min. |      |                                     |                                    |                           | 0.00002       | 0.03            | 0.03                      | 0.02                        | 0.03         | 0.03       | 0.03   |
|               | Max. |      |                                     |                                    |                           | 0.2           | 0.1             | 0.5                       | 0.2                         | 0.8          | 0.8        | 0.2    |
| Cadmium (t)   | Av.  | mg/L | 0.05                                | 0.01                               | 0.01                      | <0.0001       | -               | <0.0001                   | -                           | <0.0001      | -          | -      |
|               | Min. |      |                                     |                                    |                           | <0.0001       | -               | <0.0001                   | -                           | <0.0001      | -          | -      |
|               | Max. |      |                                     |                                    |                           | <0.0001       | -               | <0.0001                   | -                           | <0.0001      | -          | -      |
| Chromium (t)  | Av.  | mg/L | 1                                   | 0.1                                | 1                         | 0.0008        | -               | 0.0008                    | 0.0008                      | 0.001        | -          | -      |
|               | Min. |      |                                     |                                    |                           | 0.0005        | -               | 0.0005                    | 0.0005                      | 0.001        | -          | -      |
|               | Max. |      |                                     |                                    |                           | 0.001         | -               | 0.0010                    | 0.0010                      | 0.001        | -          | -      |
| Cobalt (t)    | Av.  | mg/L | 0.1                                 | 0.05                               | 1                         | <0.001        | -               | <0.001                    | <0.001                      | 0.002        | -          | -      |
|               | Min. |      |                                     |                                    |                           | <0.001        | -               | <0.001                    | <0.001                      | 0.002        | -          | -      |
|               | Max. |      |                                     |                                    |                           | <0.001        | -               | <0.001                    | <0.001                      | 0.002        | -          | -      |

| Analyte        |      | Unit | ANZECC<br>(2000)<br>Short<br>term<br>irrigation | ANZECC<br>(2000)<br>Long term<br>irrigation | ANZECC<br>(2000)<br>Stock<br>Water | Hunter<br>River† | Wollombi<br>Brook‡ | Less<br>productive<br>alluvium‡ | Highly<br>productive<br>alluvium† | Interburden‡ | Coal†      | Spoil†     |
|----------------|------|------|-------------------------------------------------|---------------------------------------------|------------------------------------|------------------|--------------------|---------------------------------|-----------------------------------|--------------|------------|------------|
| Copper (t)     | Av.  | mg/L | 5                                               | 0.2                                         | 1 (cattle)                         | 0.002            | -                  | 1.1                             | <0.001                            | 1.0          | -          | -          |
|                | Min. |      |                                                 |                                             |                                    | 0.001            | -                  | 0.001                           | <0.001                            | 0.001        | -          | -          |
|                | Max. |      |                                                 |                                             |                                    | 0.003            | -                  | 8.5                             | <0.001                            | 4.3          | -          | -          |
| Iron (t)       | Av.  | mg/L | 10                                              | 0.2                                         | -                                  | 0.6              | -                  | 46.5                            | 0.003                             | 13.7         | -          | -          |
|                | Min. |      |                                                 |                                             |                                    | 0.4              | -                  | 0.1                             | 0.003                             | 0.2          | -          | -          |
|                | Max. |      |                                                 |                                             |                                    | 0.8              | -                  | 397                             | 0.003                             | 123.0        | -          | -          |
| Lead (t)       | Av.  | mg/L | 5                                               | 2                                           | 0.1                                | <0.001           | -                  | 0.03                            | <0.001                            | 0.04         | <0.001     | <0.001     |
|                | Min. |      |                                                 |                                             |                                    | <0.001           | -                  | 0.001                           | <0.001                            | 0.001        | <0.001     | <0.001     |
|                | Max. |      |                                                 |                                             |                                    | <0.001           | -                  | 0.1                             | <0.001                            | 0.3          | <0.001     | <0.001     |
| Lithium (t)    | Av.  | mg/L | 2.5                                             | 2.5                                         | -                                  | <0.005           | -                  | 0.02                            | 0.01                              | 0.2          | 0.2        | 0.05       |
|                | Min. |      |                                                 |                                             |                                    | <0.005           | -                  | 0.0005                          | 0.0005                            | 0.003        | 0.003      | 0.008      |
|                | Max. |      |                                                 |                                             |                                    | <0.005           | -                  | 0.6                             | 0.1                               | 1.0          | 1.0        | 0.1        |
| Manganese (t)  | Av.  | mg/L | 10                                              | 0.2                                         | -                                  | 0.1              | <b>0.3</b>         | <b>2.6</b>                      | <b>0.7</b>                        | <b>1.9</b>   | <b>2.9</b> | <b>0.7</b> |
|                | Min. |      |                                                 |                                             |                                    | 0.02             | 0.07               | 0.0030                          | 0.0005                            | 0.006        | 0.006      | 0.03       |
|                | Max. |      |                                                 |                                             |                                    | 0.4              | 1.1                | 60                              | 4                                 | 61           | 61         | 2          |
| Mercury (t)    | Av.  | mg/L | 0.002                                           | 0.002                                       | 0.002                              | <0.0001          | -                  | <0.0001                         | <0.0001                           | -            | -          | -          |
|                | Min. |      |                                                 |                                             |                                    | <0.0001          | -                  | <0.0001                         | <0.0001                           | -            | -          | -          |
|                | Max. |      |                                                 |                                             |                                    | <0.0001          | -                  | <0.0001                         | <0.0001                           | -            | -          | -          |
| Molybdenum (t) | Av.  | mg/L | 0.05                                            | 0.01                                        | 0.15                               | <0.001           | -                  | 0.003                           | 0.004                             | -            | -          | -          |
|                | Min. |      |                                                 |                                             |                                    | <0.001           | -                  | 0.003                           | 0.001                             | -            | -          | -          |
|                | Max. |      |                                                 |                                             |                                    | <0.001           | -                  | 0.00                            | 0.01                              | -            | -          | -          |

| Analyte       |      | Unit | ANZECC (2000) Short term irrigation | ANZECC (2000) Long term irrigation | ANZECC (2000) Stock Water | Hunter River† | Wollombi Brook‡ | Less productive alluvium‡ | Highly productive alluvium† | Interburden‡ | Coal†       | Spoil† |
|---------------|------|------|-------------------------------------|------------------------------------|---------------------------|---------------|-----------------|---------------------------|-----------------------------|--------------|-------------|--------|
| Nickel (t)    | Av.  | mg/L | 2                                   | 0.2                                | 1                         | 0.002         | -               | 0.018                     | 0.001                       | 0.02         | -           | -      |
|               | Min. |      |                                     |                                    |                           | 0.002         | -               | 0.003                     | 0.001                       | 0.002        | -           | -      |
|               | Max. |      |                                     |                                    |                           | 0.002         | -               | 0.06                      | 0.00                        | 0.10         | -           | -      |
| Selenium (t)  | Av.  | mg/L | 0.05                                | 0.02                               | 0.02                      | 0.03          | 0.004           | 0.004                     | 0.004                       | <b>0.06</b>  | <b>0.06</b> | 0.006  |
|               | Min. |      |                                     |                                    |                           | 0.0001        | 0.001           | 0.001                     | 0.001                       | 0.001        | 0.001       | 0.001  |
|               | Max. |      |                                     |                                    |                           | 0.5           | 0.01            | 0.02                      | 0.02                        | 0.5          | 0.50        | 0.05   |
| Strontium (t) | Av.  | mg/L | -                                   | -                                  | -                         | 0.3           | 0.2             | 1.1                       | 0.5                         | 5.4          | 5.4         | 3.0    |
|               | Min. |      |                                     |                                    |                           | 0.101         | 0.05            | 0.1                       | 0.3                         | 0.2          | 0.2         | 0.001  |
|               | Max. |      |                                     |                                    |                           | 1             | 0.5             | 13                        | 2                           | 14           | 14          | 6      |
| Zinc (t)      | Av.  | mg/L | 2                                   | 2                                  | 20                        | 0.009         | 0.02            | 0.2                       | 0.3                         | 0.1          | 0.1         | 0.1    |
|               | Min. |      |                                     |                                    |                           | 0.002         | 0.003           | 0.003                     | 0.003                       | 0.003        | 0.003       | 0.003  |
|               | Max. |      |                                     |                                    |                           | 0.07          | 0.3             | 11                        | 16                          | 2            | 2           | 2      |

**Notes:** Values below the limit of reporting were set at half of the limit for the calculations

\* Maximum concentration at which good condition might be expected, with 13,000 mg/L for sheep, 5,000 mg/L for beef cattle, 4,000 mg/L for dairy cattle, 6,000 mg/L for horses and 3,000 mg/L for pigs and poultry.

† Results derived from data from neighbouring mine, no site specific data

‡ Includes water quality data from Wambo, United and available water quality data collected from neighbouring mine

## A3 Bore census

A review of the National Groundwater Information System database<sup>2</sup> indicates there are 66 registered bores within 4 km of the Project Area. Table A-3 presents a summary of the data held within the government database while Figure A- 2 shows the location of all known bores.

Following a data-gap analysis, 25 registered bores were identified within the vicinity of the Project Area to be included within the bore census. Where bores were located on private land, the proponent contacted the landholders in September 2015, and five landholders responded and allowed access to the property and bores. In October 2015, the proponent conducted a bore census at the five properties and bores on mine-owned land, which identified four active bores and one abandoned bore. The bore census results are presented in Table A-3 and have been combined with available information from previous bore census conducted within the region. In total, 66 registered bores and two unregistered bores have been identified within 4 km of the proposed extraction area. An additional registered bore (GW201515), located over 7 km north-west of the Project Area, was also visited during the bore census. Of the five bores that were assessed, four were found to be in use and one abandoned but usable.

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<sup>2</sup> <http://www.bom.gov.au/water/groundwater/ngis/>

**Table A-3 Bore census results**

| Registered number                 | Bore Census  | Easting | Northing | Ground elevation | Date drilled | SWL (mbgl) | EC            | pH  | Yield (L/s) | Bore depth (mbGL) | Aquifer            | Status  | Bore Use   | Comment                                                                                                                                                                               |
|-----------------------------------|--------------|---------|----------|------------------|--------------|------------|---------------|-----|-------------|-------------------|--------------------|---------|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                   |              |         |          | (mAHD)           |              |            | (µS/cm)       |     |             |                   |                    |         |            |                                                                                                                                                                                       |
| Unregistered bore (near GW029155) | Bore visited | 305430  | 6401656  | 76               | -            | 8.2        | -             | -   | -           | 9.8               | Alluvium           | EX      | Stock      | Private bore, well at least 50 years old, 1 m concrete well, casing 0.6 m above surface. Windmill in place and pumps at rate of 2.4 L/minute. Used for stock water supply year round. |
| Unregistered bore                 | -            | -       | -        | 79               | -            | 10.15      | 1767          | 8.1 | -           | 10.68             | Alluvium           | EX      | Irrigation | Concrete well approx. 200 m south of GW029155. Within irrigated paddock.                                                                                                              |
| GW005327                          | -            | 314683  | 6394498  | 59.92            | 1945         | -          | -             | -   | -           | 10.4              | Alluvium           | EX      | Unknown    | Bore not visited, located in township of Warkworth.                                                                                                                                   |
| GW017644                          | -            | 306708  | 6399431  | 75.3             | 1/01/1959    | -          | salty*        | -   | -           | 11.6*             | Weathered Permian  | EX      | Irrigation | Located on Wambo owned land                                                                                                                                                           |
| GW017646                          | -            | 306937  | 6399774  | 72.7             | 1/01/2009    | -          | 3,001-7,000*  | -   | -           | 11*               | Alluvium           | Unknown | Unknown    | Located on Wambo owned land                                                                                                                                                           |
| GW017647                          | -            | 307326  | 6399905  | 72               | 1/01/2019    | -          | 7,001-10,000* | -   | -           | 9.1*              | Weathered Permian  | EX      | Unknown    | Located on Wambo owned land                                                                                                                                                           |
| GW017648                          | -            | 307397  | 6400276  | 70.3             | 1/01/1954    | -          | 3,001-7,000*  | -   | 25.26*      | 12.8*             | Alluvium           | Unknown | Irrigation | Located on Wambo owned land                                                                                                                                                           |
| GW017798                          | -            | 307290  | 6399042  | 86.6             | 1/01/1959    | -          | 1,001-3,000*  | -   | -           | 12.2*             | Weathered Permian  | EX      | Unknown    | Located on Wambo owned land                                                                                                                                                           |
| GW017799                          | -            | 306598  | 6398412  | 108.7            | 1/01/2029    | -          | Salty*        | -   | -           | 12.2*             | Weathered Permian  | EX      | Unknown    | Located on Wambo owned land                                                                                                                                                           |
| GW017800                          | -            | 304413  | 6398000  | 133.2            | 12/05/1905   | -          | -             | -   | -           | 27.4*             | Triassic Narrabeen | Unknown | Unknown    | Access restrictions, bore not assessed.                                                                                                                                               |
| GW017801                          | -            | 304320  | 6397443  | 149              | 19/04/1905   | -          | -             | -   | -           | 42.7*             | Triassic Narrabeen | EX      | Stock      | Access restrictions, bore not assessed.                                                                                                                                               |

| Registered number | Bore Census  | Easting | Northing | Ground elevation | Date drilled | SWL (mbgl) | EC         | pH  | Yield (L/s)    | Bore depth (mbGL) | Aquifer                        | Status  | Bore Use        | Comment                                                                                                                                                                                  |
|-------------------|--------------|---------|----------|------------------|--------------|------------|------------|-----|----------------|-------------------|--------------------------------|---------|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   |              |         |          | (mAHD)           |              |            | (µS/cm)    |     |                |                   |                                |         |                 |                                                                                                                                                                                          |
| GW018045          | -            | 302941  | 6398556  | 0                | 13/03/1905   | -          | -          | -   | -              | 27.4*             | Coal (Newcastle Coal Measures) | EX      | Unknown         | Access restrictions, bore not assessed.                                                                                                                                                  |
| GW018046          | -            | 303013  | 6398866  | 0                | 12/05/1905   | -          | -          | -   | -              | 18.3*             | Coal (Newcastle Coal Measures) | Unknown | Unknown         | Access restrictions, bore not assessed.                                                                                                                                                  |
| GW201515          | Bore visited |         |          | 76.9             | 1971         | 9.9        | -          | -   | -              | -                 | Alluvium (gravel)              | EX      | Stock           | Private bore, 1.1 m wide concrete well in use for stock and domestic (toilets). Equipped with Grundfos mono-pump and used year-round. Bore located over 7 km north-west of project site. |
| GW021773          | -            | 309559  | 6401872  | 79               | 1/01/1953    | -          | 501-1,000* | -   | 11.37*         | 12.5*             | Alluvium                       | AD      | Irrigation      | Bore blocked                                                                                                                                                                             |
| GW022685          | -            | 309088  | 6401184  | 75               | 1/03/1965    | 10.67      | 1022       | 7.2 | Continuous use | 14.6              | Alluvium                       | EX      | Stock           | Concrete well with pump infrastructure in place. Continuously used for stock and domestic supply. Water quality sample taken.                                                            |
| GW027120          | -            | 309501  | 6401185  | 77               | 1/08/1964    | 10.75      | 822        | 7.8 | 25.26*         | 13.4              | Alluvium                       | AU      | Irrigation      | Concrete well at surface with metal lid. Currently disused.                                                                                                                              |
| GW027121          | -            | 309563  | 6401648  | 78               | 1/03/1965    | -          | -          | -   | 1.26*          | 15.8*             | Alluvium                       | AD      | Irrigation      | Below surface cement well filled in with soil.                                                                                                                                           |
| GW029155          | -            | 305661  | 6402042  | 76               | 1/01/1968    | -          | 0-500*     | -   | -              | 10.1*             | Alluvium                       | AD      | Stock           | Bore possibly destroyed during 2007 floods, covered with soil.                                                                                                                           |
| GW030731          | -            | 316680  | 6397640  | 63               | -            | 13.33      | 2460       | 7   | No Pump        | 17.02             | Alluvium                       | AU      | -               | Steel bore with marker post, disused. Water quality sample taken.                                                                                                                        |
| GW030732          | -            | 316743  | 6397646  | 69               | -            | 8.17*      | -          | -   | -              | 16*               | Alluvium                       | AU      | Monitoring bore | Concrete well. Has old pump infrastructure in place but not in use.                                                                                                                      |

| Registered number | Bore Census | Easting | Northing | Ground elevation | Date drilled | SWL (mbgl) | EC      | pH  | Yield (L/s) | Bore depth (mbGL) | Aquifer                | Status | Bore Use        | Comment                                                                              |
|-------------------|-------------|---------|----------|------------------|--------------|------------|---------|-----|-------------|-------------------|------------------------|--------|-----------------|--------------------------------------------------------------------------------------|
|                   |             |         |          | (mAHD)           |              |            | (µS/cm) |     |             |                   |                        |        |                 |                                                                                      |
| GW030733          | -           | 316743  | 6397646  | 69               | -            | 12.91*     | -       | -   | -           | 15.9*             | Alluvium               | AU     | Monitoring bore | Concrete well with metal lid. In paddock, disused.                                   |
| GW030734          | -           | 316595  | 6397799  | 62               | 1/02/1979    | 14.4*      | -       | -   | -           | 16.5*             | Alluvium               | AD     | Monitoring bore | Bore destroyed, star picket at location, in paddock.                                 |
| GW030735          | -           | 316484  | 6397827  | 62               | 1/03/1979    | 13.8*      | -       | -   | -           | -                 | Alluvium               | AD     | -               | Unable to locate                                                                     |
| GW030736          | -           | 316628  | 6397985  | 54.1             | 1/02/1979    | 14.45*     | -       | -   | -           | 17.5*             | Alluvium               | AD     | Monitoring bore | Unable to locate                                                                     |
| GW030737          | -           | 316500  | 6398112  | 63               |              | -          | -       | -   | -           | -                 | Alluvium               | AD     | -               | Bore destroyed, covered in vegetation.                                               |
| GW030738          | -           | 316598  | 6398200  | 55.8             | 1/03/1979    | -          | -       | -   | -           | -                 | Alluvium               | AD     | -               | Unable to locate bore                                                                |
| GW030739          | -           | 316569  | 6398354  | 58.1             | 1/03/1979    | -          | -       | -   | -           | -                 | Alluvium               | AD     | -               | Unable to locate bore                                                                |
| GW030740          | -           | 316640  | 6398365  | 63               | 1/04/1979    | 12.31      | 2540    | 7.4 | -           | 16.3              | Alluvium               | EX     | Monitoring bore | 100 mm PVC casing in steel monument. Used for monitoring (HVO land)                  |
| GW034568          | -           | 316674  | 6398325  | 63               | 1/06/1971    | -          | -       | -   | -           | 12.2*             | Alluvium               | AD     | -               | No bore found at location. Mine surface water pump present at location.              |
| GW034569          | -           | 316745  | 6398696  | 55.1             | 1/06/1971    | -          | -       | -   | -           | 12.2*             | Alluvium               | AD     | Industrial      | Unable to locate bore                                                                |
| GW037184          | -           | 309685  | 6393911  | 0                | 27/05/1905   | -          | -       | -   | -           | 21*               | Sandstone (overburden) | -      | Exploration     | Located on Wambo owned land                                                          |
| GW037734          | -           | 309553  | 6401502  | 83               | 1/01/1965    | 11.36      | 1022    | 7.5 | 15.16*      | 13.4              | Alluvium               | AU     | Irrigation      | Concrete well structure in paddock. No pump infrastructure present, appears disused. |
| GW037998          | -           | 311589  | 6392530  | 62.38            | 13/03/1905   | -          | -       | -   | -           | 10.9*             | Alluvium               | -      | Irrigation      | Located on Wambo owned land                                                          |
| GW037999          | -           | 311482  | 6392713  | 64.01            | 13/03/1905   | -          | -       | -   | -           | 13.7*             | Shale                  | -      | Irrigation      | Located on Wambo owned land                                                          |
| GW038000          | -           | 311457  | 6392620  | 63.59            | 13/03/1905   | -          | -       | -   | -           | 9.4*              | Shale                  | -      | Irrigation      | Located on Wambo owned land                                                          |

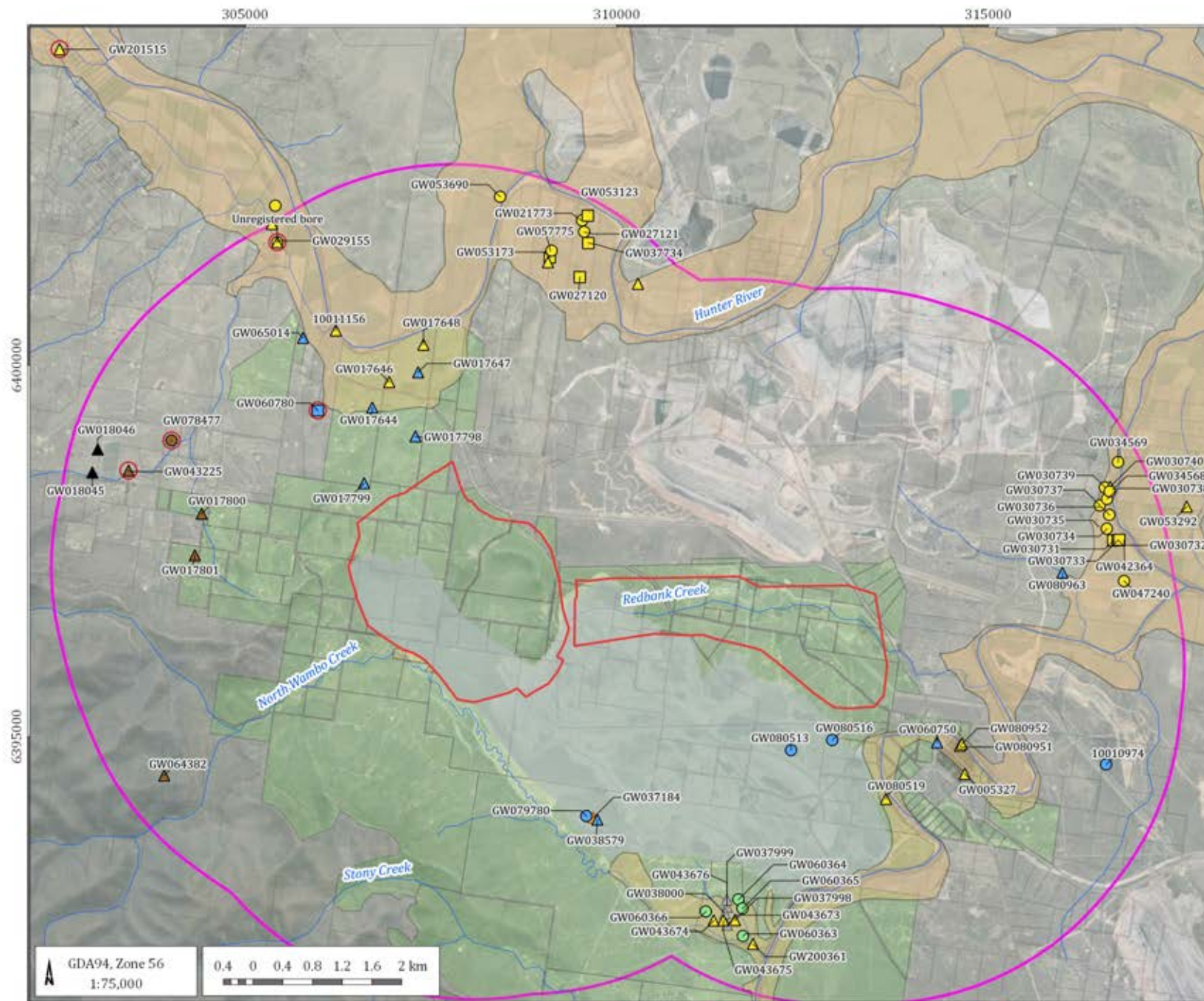
| Registered number | Bore Census  | Easting | Northing | Ground elevation | Date drilled | SWL (mbgl) | EC      | pH  | Yield (L/s) | Bore depth (mbGL) | Aquifer                | Status | Bore Use             | Comment                                                                                                                                                                             |
|-------------------|--------------|---------|----------|------------------|--------------|------------|---------|-----|-------------|-------------------|------------------------|--------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   |              |         |          | (mAHD)           |              |            | (µS/cm) |     |             |                   |                        |        |                      |                                                                                                                                                                                     |
| GW038579          | -            | 309738  | 6393882  | 0                | 27/05/1905   | -          | -       | -   | -           | 20.9*             | Weathered Permian      | -      | Exploration          | Located on Wambo owned land                                                                                                                                                         |
| GW042364          | -            | 316824  | 6397645  | 63               | 30/12/1899   | 12.77      | 1077    | 7.2 | -           | 13.3              | Alluvium               | AU     | Unknown              | Steel bore with marker post, was used for irrigation but hasn't been used for some time.                                                                                            |
| GW043225          | Bore visited | 303653  | 6398949  | 116              | 26/05/1905   | 12.1       | -       | -   | -           | 22.5*             | Sandstone              | EX     | Irrigation           | Private bore, 150 mm diameter PVC bore, equipped with Kenrahn LCS2DE pump. Pump currently not working, but normally used regularly for stock, and used to fill dams in dry weather. |
| GW043673          | -            | 311486  | 6392467  | 63.11            | 13/03/1905   | -          | -       | -   | -           | 9.4*              | Shale                  | -      | Exploration          | Located on Wambo owned land                                                                                                                                                         |
| GW043674          | -            | 311303  | 6392525  | 64.6             | 13/03/1905   | -          | -       | -   | -           | 8.2*              | Alluvium               | -      | Exploration          | Located on Wambo owned land                                                                                                                                                         |
| GW043675          | -            | 311433  | 6392527  | 63.73            | 13/03/1905   | -          | -       | -   | -           | 8.5*              | Alluvium               | -      | Exploration          | Located on Wambo owned land                                                                                                                                                         |
| GW043676          | -            | 311480  | 6392805  | 64.24            | 13/03/1905   | -          | -       | -   | -           | 10.6*             | Shale                  | -      | Exploration          | Located on Wambo owned land                                                                                                                                                         |
| GW047240          | -            | 316827  | 6397095  | 55.2             | 1/01/1952    | -          | -       | -   | -           | 12.7*             | Alluvium               | AD     | Irrigation           | Unable to locate                                                                                                                                                                    |
| GW053123          | -            | 309631  | 6402062  | 78               | 1/03/1981    | 12.55      | 993     | 7.6 | -           | 13.1              | Alluvium               | AU     | Irrigation           | Concrete well structure, disused.                                                                                                                                                   |
| GW053173          | -            | 309101  | 640317   | 76               | 1/03/1981    | 13.38      | 967     | 8.1 | 10.1*       | 14.8              | Alluvium               | AU     | Irrigation and stock | Concrete well with old pump infrastructure present, but appears disused.                                                                                                            |
| GW053292          | -            | 317670  | 6398097  | 53.3             | 1/08/1981    | -          | -       | -   | -           | 10*               | Alluvium               | EX     | Irrigation           | Bore not visited, located on east side of Hunter River.                                                                                                                             |
| GW053690          | -            | 308429  | 6402268  | 77               | 1/07/1982    | -          | -       | -   | 7.58*       | 11.3*             | Alluvium               | AD     | Irrigation           | Unable to locate                                                                                                                                                                    |
| GW057775          | -            | 309074  | 6401517  | 78               | 1/03/1981    | -          | -       | -   | -           | 13.4*             | Alluvium               | AD     | -                    | Unable to locate                                                                                                                                                                    |
| GW060363          | -            | 311698  | 6392317  | 61.01            | 13/03/1905   | -          | -       | -   | -           | 6.3*              | Nth Wambo Crk Alluvium | AD     | Irrigation           | Located on Wambo owned land                                                                                                                                                         |

| Registered number | Bore Census  | Easting | Northing | Ground elevation | Date drilled | SWL (mbgl) | EC      | pH  | Yield (L/s) | Bore depth (mbGL) | Aquifer                | Status  | Bore Use           | Comment                                                                                                                                                                         |
|-------------------|--------------|---------|----------|------------------|--------------|------------|---------|-----|-------------|-------------------|------------------------|---------|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   |              |         |          | (mAHD)           |              |            | (µS/cm) |     |             |                   |                        |         |                    |                                                                                                                                                                                 |
| GW060364          | -            | 311636  | 6392808  | 63.17            | 13/03/1905   | -          | -       | -   | -           | 5.1*              | Nth Wambo Crk Alluvium | AD      | Irrigation         | Located on Wambo owned land                                                                                                                                                     |
| GW060365          | -            | 311691  | 6392686  | 62.06            | 13/03/1905   | -          | -       | -   | -           | 6.6*              | Nth Wambo Crk Alluvium | AD      | Irrigation         | Located on Wambo owned land                                                                                                                                                     |
| GW060366          | -            | 311196  | 6392646  | 65.06            | 13/03/1905   | -          | -       | -   | -           | 5.2*              | Nth Wambo Crk Alluvium | AD      | Irrigation         | Located on Wambo owned land                                                                                                                                                     |
| GW060750          | -            | 314310  | 6394923  | 59               | 1/02/1985    | -          | -       | -   | -           | 24.4*             | Weathered Permian      | Unknown | Domestic           | Bore not visited, located in township of Warkworth.                                                                                                                             |
| GW060780          | Bore visited | 305961  | 6399379  | 104.1            | unknown      | 18.62      | 1552    | 7.1 | No Pump     | 25.5              | Weathered Permian      | AU      | Stock and domestic | Steep bore within vegetation. Uncapped and appears disused (no pump infrastructure present).                                                                                    |
| GW064382          | -            | 303908  | 6394477  | 414.4            | 9/06/1905    |            |         |     |             | 60*               | Sandstone              | -       | HUSE               | Access restrictions, bore not assessed.                                                                                                                                         |
| GW065014          | -            | 305777  | 6400368  | 85               | 15/01/1991   | -          | -       | -   | -           | 14.5*             | Weathered Permian      | Unknown | Irrigation         | Located on Wambo owned land                                                                                                                                                     |
| GW078477          | Bore visited | 304007  | 6398988  | 109.8            | 21/06/1905   | 11.05      | 3630*   | 6.8 |             | 102.5*            | Sandstone              | EX      | Domestic           | Private bore, bore in use with water license 20BL167575. 150 mm diameter PVC casing. Grundfos pump installed to 29 m depth, used approximately every 3 months and yields 3 L/s. |
| GW079780          | -            | 309589  | 6393931  | -                | 13/03/1905   | -          | -       | -   | -           | -                 | Weathered Permian      | AD      | Unknown            | Located on Wambo owned land                                                                                                                                                     |
| GW080513          | -            | 312345  | 6394818  | 335              | 22/06/1905   | 7.53*      | -       | -   | -           | 10*               | Weathered Permian      | AD      |                    | Located on Wambo owned land                                                                                                                                                     |
| GW080516          | -            | 312899  | 6394954  | 71.93            | 24/06/1905   | 7.11*      | -       | -   | -           | 15*               | Weathered Permian      | AD      | Unknown            | Located on Wambo owned land                                                                                                                                                     |
| GW080519          | -            | 313622  | 6394161  | 57.98            | 25/06/1905   | 7.42*      | 6490*   | -   | -           | 10.5*             | Alluvium               | -       | Unknown            | Located on Wambo owned land                                                                                                                                                     |

| Registered number | Bore Census | Easting | Northing | Ground elevation | Date drilled | SWL (mbgl) | EC      | pH  | Yield (L/s) | Bore depth (mbGL) | Aquifer           | Status       | Bore Use        | Comment                                                     |
|-------------------|-------------|---------|----------|------------------|--------------|------------|---------|-----|-------------|-------------------|-------------------|--------------|-----------------|-------------------------------------------------------------|
|                   |             |         |          | (mAHD)           |              |            | (µS/cm) |     |             |                   |                   |              |                 |                                                             |
| GW080951          | -           | 314619  | 6394878  | 55               | 15/04/2005   | -          | -       | -   | -           | 3.14*             | Alluvium          | Unknown      | -               | Bore not visited, located in township of Warkworth.         |
| GW080952          | -           | 314643  | 6394904  | 54               | 15/04/2005   | -          | -       | -   | -           | 1.59*             | Alluvium          | EX           | -               | Bore not visited, located in township of Warkworth.         |
| GW080963          | -           | 315997  | 6397208  | 59               | 7/10/2005    | 31.8       | 1258    | 5.9 | -           | 81.3*             | Weathered Permian | EX           | Monitoring bore | 100 mm PVC bore with steel riser, equipped with datalogger. |
| GW200361          | -           | 311833  | 6392209  | 60.97            | 2006         | -          | -       | -   | -           | -                 | Alluvium          | -            | Unknown         | Located on Wambo owned land                                 |
| 10010974          | -           | 316585  | 6394626  | 67.89            | 1899         | -          | -       | -   | -           | -                 | Alluvium          | Unknown / AD | Unknown         | HVO land – Lemington South                                  |
| 10011156          | -           | 306219  | 6400469  | 66.03            | 1899         | -          | -       | -   | -           | -                 | Alluvium          | Unknown      | Unknown         | Access restrictions, bore not assessed.                     |
| 10011371          | -           | 309989  | 6401106  | 63.67            | 1899         | -          | -       | -   | -           | -                 | Alluvium          | AD           | Unknown         | Bore not located                                            |

**Note:** Coordinates are in MGA94, Zone 56  
EX – existing bore  
AD – abandoned and destroyed

\* - value derived from Pineena  
AU – abandoned but in usable condition



## *Appendix A-1*

### **Bore Details**

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| Hole ID   | In current GWMP | Type | Status | Coordinates |           | Geological unit | Lithology                                         | Ground elevation (mAHD) | Bore depth (mbGL) | Screen/ Sensor (mbGL) |
|-----------|-----------------|------|--------|-------------|-----------|-----------------|---------------------------------------------------|-------------------------|-------------------|-----------------------|
|           |                 |      |        | mE          | mN        |                 |                                                   |                         |                   |                       |
| DW3A      | -               | MB   | EX     | 310335      | 6392911   | Pswj            | Permian overburden (dewatering bore)              | 72.0                    | 327               | -                     |
| GW02      | Yes (A)         | MB   | EX     | 309109      | 6389680   | Qa              | Upper South Wambo Creek Alluvium                  | 79.8                    | -                 | -                     |
| GW08      | Yes (A)         | MB   | EX     | 311793      | 6392266   | Qa              | North Wambo Creek Alluvium                        | 60.5                    | 6.3               | 0 - 6.3               |
| GW09      | Yes (A)         | MB   | EX     | 311643      | 6392563   | Qa              | North Wambo Creek Alluvium                        | 61.7                    | 6.2               | 0 - 6.2               |
| GW11      | Yes (A)         | MB   | EX     | 309228      | 6389699   | Qa              | Upper South Wambo Creek Alluvium                  | 79.3                    | -                 | -                     |
| GW12      | Yes (B)         | MB   | EX     | 309841      | 6391056   | Qa              | Stony Creek Alluvium                              | 99.3                    | 12.1              | 6.1 - 12.1            |
| GW13      | Yes (A)         | MB   | EX     | 313810      | 6388990   | Qa              | Alluvium, shallow overburden                      | 67.8                    | 15                | 6 - 15                |
| GW14      | Yes (B)         | MB   | EX     | 312478      | 6391358   | Qa              | Alluvium, shallow overburden                      | 65.2                    | 18                | 6.05 - 8.05           |
| GW15      | Yes (A)         | MB   | EX     | 313164      | 6392807   | Qa              | Alluvium, shallow overburden                      | 60.7                    | 17.4              | 13.8 - 17.4           |
| GW16      | Yes (A)         | MB   | EX     | 306641      | 6396034   | Qa              | Alluvium, shallow overburden                      | 110.6                   | 12.15             | 6.15 - 12.15          |
| GW17      | Yes (A)         | MB   | EX     | 306895      | 6396048   | Qa              | Alluvium, shallow overburden                      | 109.5                   | 14                | 11 - 14               |
| GW18      | Yes (A)         | MB   | EX     | 310061      | 6393206   | Qa              | Alluvium, shallow overburden                      | 75.2                    | 11.69             | 5.5 - 11.5            |
| GW19      | Yes (B)         | MB   | EX     | 308550      | 6394648   | Qa              | Alluvium, shallow overburden                      | 96.6                    | 11                | 4.5 - 10.5            |
| GW21      | Yes (B)         | MB   | EX     | 308647      | 6393378   | Qa              | Alluvium, shallow overburden                      | 119.4                   | 36                | 24 - 36               |
| GW22      | Yes (A)         | MB   | EX     | 311335      | 6389535   | Qa              | Alluvium, shallow overburden                      | 91.3                    | 54                | 42 - 54               |
| P1        | Yes (A)         | MB   | EX     | 312199      | 6395840   | Pswj            | Interburden - Blakefield - Glen Munro (Unnamed C) | 86.0                    | 37                | 31 - 37               |
| P2        | -               | MB   | EX     | 312403      | 6395552   | Pswj            | Interburden Blakefield - unnamed B                | 85.0                    | 30                | 24 - 30               |
| P3        | Yes (A)         | MB   | AD     | 313412      | 6395006   | Pswj            | Interbuden Warkworth - unnamed                    | 56.9                    | 51.02             | -                     |
| P4        | -               | MB   | EX     | 309691      | 6394119   | Qa              | North Wambo Creek Alluvium                        | 79.8                    | 9                 | 2.5 - 5.5             |
| P5        | Yes (A)*        | MB   | AD     | 309836      | 6394001   | Qa              | North Wambo Creek Alluvium                        | 78.6                    | 11.5              | 8 - 11                |
| P6        | Yes (A)*        | MB   | AD     | 309996      | 6393841   | Qa              | North Wambo Creek Alluvium                        | 77.2                    | 11.5              | 7.5 - 10.5            |
| P8        | -               | MB   | AD     | 310159      | 6394204   | Pswj            | Interburden Wambo - unnamed                       | 113.8                   | 49                | 42 - 48               |
| P9        | -               | MB   | AD     | 311235      | 6394676   | Pswj            | Woodlands Hill Seam?                              | 127.0                   | -                 | -                     |
| P11       | Yes (A)         | MB   | EX     | 312728      | 6395462   | Pswj            | Interburden Blakefield - Glen Munro (Unnamed D)   | 71.8                    | 31                | 19 - 28               |
| P12       | -               | MB   | EX     | 313644      | 6394797   | Qa              | East Wollombi Brook Alluvium                      | 55.2                    | 15                | 7 - 13                |
| P13       | -               | MB   | EX     | 313722      | 6394412   | Qa              | East Wollombi Brook Alluvium                      | 56.1                    | 15                | 9 - 15                |
| P15       | -               | MB   | EX     | 313431      | 6394803   | Qa/Qr           | West Wollombi Brook Colluvium                     | 56.7                    | 8.1               | 5 - 8.1               |
| P16       | Yes (A)         | MB   | EX     | 313480      | 6394655   | Qa/Qr           | West Wollombi Brook Colluvium                     | 57.5                    | 11.5              | 5 - 10.5              |
| P17       | -               | MB   | EX     | 313376      | 6394631   | Qa/Qr           | West Wollombi Brook Colluvium                     | 56.8                    | 8.5               | 5 - 7.5               |
| P18       | -               | MB   | EX     | 313503      | 6394512   | Qa/Qr           | West Wollombi Brook Colluvium                     | 57.3                    | 10.8              | 5.5 - 8               |
| P20       | Yes (A)         | MB   | EX     | 313639      | 6394166   | Qa/Qr           | West Wollombi Brook Colluvium                     | 57.4                    | 10.6              | 6 - 9.2               |
| P27       | -               | MB   | EX     | 311344      | 6392810   | Qa              | North Wambo Creek Alluvium                        | 64.8                    | 6                 | -                     |
| P28       | -               | MB   | EX     | 311396      | 6392632   | Qa              | North Wambo Creek Alluvium                        | 63.1                    | -                 | -                     |
| P29       | -               | MB   | EX     | 311820      | 6392560   | Qa              | North Wambo Creek Alluvium                        | 60.8                    | 10.9              | 0 - 10.9              |
| P32       | -               | MB   | EX     | 310735      | 6392842   | Qa              | North Wambo Creek Alluvium                        | 67.8                    | 5.2               | 0 - 5.2               |
| P36       | -               | MB   | AD     | 313550.8    | 6394349.9 | Qa              | Alluvium?                                         | 56.7                    | -                 | -                     |
| P104      | -               | MB   | AD     | 311349.17   | 6391155.9 | Qa              | Alluvium?                                         | 91.0                    | -                 | -                     |
| P106      | Yes (A)         | MB   | EX     | 311518      | 6391084   | Qa              | Alluvium                                          | 60.0                    | -                 | -                     |
| P108      | -               | MB   | AD     | 311348.51   | 6390933.3 | Qa              | Alluvium?                                         | 60.6                    | -                 | -                     |
| P109      | Yes (A)         | MB   | EX     | 311215      | 6390768   | Qa              | Alluvium                                          | 62.1                    | -                 | -                     |
| P110      | -               | MB   | EX     | 311217      | 6390690   | Qa              | Alluvium                                          | 64.1                    | -                 | -                     |
| P111      | -               | MB   | EX     | 311301      | 6390761   | Qa              | Alluvium                                          | 61.5                    | -                 | -                     |
| P114      | Yes (A)         | MB   | EX     | 311057      | 6391293   | Qa              | Alluvium                                          | 61.9                    | -                 | -                     |
| P116      | Yes (A)         | MB   | EX     | 311205      | 6391288   | Qa              | Alluvium                                          | 64.4                    | -                 | -                     |
| P202      | Yes (A)         | MB   | EX     | 311859      | 6391330   | Pswj            | Overburden Whybrow                                | 59.2                    | -                 | -                     |
| P206      | Yes (A)         | MB   | EX     | 311772      | 6391293   | Pswj            | Overburden Whybrow                                | 59.0                    | -                 | -                     |
| P209      | -               | MB   | AD     | 311584.12   | 6390892.7 | Pswj            | Weathered coal measures (Whybrow?)                | 60.5                    | -                 | -                     |
| P301      | Yes (A)         | MB   | EX     | 309311      | 6391425   | Qa              | Alluvium, shallow overburden                      | 89.2                    | -                 | -                     |
| P302      | -               | MB   | AD     | 309148.63   | 6391462.3 | Psl             | Weathered Newcastle Coal Measures                 | 94.9                    | -                 | -                     |
| P303      | -               | MB   | AD     | 309102.85   | 6391712.8 | Psl             | Weathered Newcastle Coal Measures                 | 92.7                    | -                 | -                     |
| P310      | -               | MB   | AD     | 308245.03   | 6392171.9 | Psl             | Weathered Newcastle Coal Measures                 | 122.5                   | -                 | -                     |
| P311      | -               | MB   | EX     | 308064      | 6392255   | Pswj            | Shallow Permian overburden                        | 131.8                   | -                 | -                     |
| P312      | -               | MB   | AD     | 309099.75   | 6391712.8 | Psl             | Weathered Newcastle Coal Measures                 | 92.7                    | -                 | -                     |
| P314      | -               | MB   | AD     | 309148.63   | 6391462.3 | Psl             | Weathered Newcastle Coal Measures                 | 94.9                    | -                 | -                     |
| P315      | Yes (A)         | MB   | EX     | 309091      | 6391852   | Qa              | Alluvium, shallow overburden                      | 98.4                    | -                 | -                     |
| P316      | -               | MB   | AD     | 308610.85   | 6392106.3 | Psl             | Weathered Newcastle Coal Measures                 | 110.9                   | -                 | -                     |
| P317      | -               | MB   | AD     | 308505.61   | 6392180.7 | Psl             | Weathered Newcastle Coal Measures                 | 117.0                   | -                 | -                     |
| P318      | -               | MB   | AD     | 308421.78   | 6392153   | Psl             | Weathered Newcastle Coal Measures                 | 114.9                   | -                 | -                     |
| P319      | -               | MB   | AD     | 308241.93   | 6392171.9 | Psl             | Weathered Newcastle Coal Measures                 | 122.5                   | -                 | -                     |
| P-NWU-01a | -               | MB   | EX     | 310341.34   | 6392592   | Pswj            | Regolith - clay                                   | 73.7                    | 10.5              | 6.92 - 8.92           |
| P-NWU-01b | -               | MB   | EX     | 310348.15   | 6392587.7 | Pswj            | Weathered overburden - sandstone                  | 73.5                    | 24.55             | 21.2 - 24.2           |
| P-NWU-02a | -               | MB   | EX     | 310669.8    | 6392898.8 | Qa              | Alluvium - sand and gravel                        | 69.4                    | 10                | 6.5 - 9.5             |
| P-NWU-02b | -               | MB   | EX     | 310673.3    | 6392900.5 | Pswj            | Weathered overburden - sandstone                  | 69.3                    | 25                | 21.2 - 24.2           |
| P-NWU-03a | -               | MB   | EX     | 310882.28   | 6392676.9 | Qa              | Alluvium - clay and sand                          | 66.7                    | 10                | 6 - 9                 |
| P-NWU-03b | -               | MB   | EX     | 310878.94   | 6392676.8 | Pswj            | Weathered overburden - sandstone                  | 66.9                    | 25.67             | 19.6 - 22.6           |
| P-NWU-04a | -               | MB   | EX     | 310671.84   | 6392381.4 | Qa              | Alluvium - clay and gravel                        | 70.4                    | 10                | 6 - 9                 |
| P-NWU-04b | -               | MB   | EX     | 310671.46   | 6392375.5 | Pswj            | Weathered overburden - sandstone                  | 70.3                    | 25                | 20.5 - 23.5           |
| P-NWU-05a | -               | MB   | EX     | 311146.18   | 6392570.2 | Qa              | Alluvium - clay and sand                          | 65.4                    | 9                 | 4.7 - 7.7             |
| P-NWU-05b | -               | MB   | EX     | 311144.44   | 6392566.4 | Pswj            | Weathered overburden - sandstone                  | 65.3                    | 24.5              | 20.35 - 23.35         |
| P-NWU-06  | -               | MB   | EX     | 311042.97   | 6392356.5 | Qa              | Alluvium - clayey silt and clay with gravel       | 69.1                    | 10                | 6 - 9                 |
| P-NWU-07a | -               | MB   | EX     | 310152.17   | 6390960.2 | Qa              | Alluvium - clay and gravel                        | 76.1                    | 10                | 6 - 9                 |
| P-NWU-07b | -               | MB   | EX     | 310160.91   | 6390960.6 | Pswj            | Weathered overburden - sandstone                  | 75.9                    | 24.2              | 20 - 23               |
| P-NWU-08a | -               | MB   | EX     | 310441.04   | 6390865.3 | Qa              | Alluvium - clay and sand                          | 69.2                    | 25                | 6.16 - 9.16           |

| Hole ID       | In current GWMP | Type | Status | Coordinates |           | Geological unit | Lithology                                                       | Ground elevation (mAHD) | Bore depth (mbGL) | Screen/ Sensor (mbGL) |
|---------------|-----------------|------|--------|-------------|-----------|-----------------|-----------------------------------------------------------------|-------------------------|-------------------|-----------------------|
|               |                 |      |        | mE          | mN        |                 |                                                                 |                         |                   |                       |
| P-NWU-08b     | -               | MB   | EX     | 310462.98   | 6390862.7 | Pswj            | Weathered overburden - sandstone                                | 69.4                    | 24.1              | 19.67 - 22.67         |
| P-NWU-09a     | -               | MB   | EX     | 311111.46   | 6391550.8 | Qa              | Sandy clay and weathered sandstone                              | 66.8                    | 10                | 6 - 9                 |
| P-NWU-09b     | -               | MB   | EX     | 311109.29   | 6391543.9 | Pswj            | Weathered overburden - sandstone                                | 66.7                    | 24.2              | 20 - 23               |
| P-NWU-10      | -               | MB   | EX     | 311187.33   | 6391198.5 | Qa              | Alluvium - clay and gravel                                      | 61.4                    | 10                | 5.4 - 8.4             |
| GW20_VW1      | -               | VWP  | EX     | 309075.5    | 6393949   | Qa              | Alluvium                                                        | 91.0                    | -                 | 9.3                   |
| GW20_VW2      | -               | VWP  | EX     | 309075.5    | 6393949   | Pswj            | Whybrow Seam                                                    | 91.0                    | -                 | 61.5                  |
| GW20_VW4      | -               | VWP  | EX     | 309075.5    | 6393949   | Pswj            | Redbank Seam                                                    | 91.0                    | -                 | 93                    |
| GW20_VW5      | -               | VWP  | EX     | 309075.5    | 6393949   | Pswj            | Wambo Seam                                                      | 91.0                    | -                 | 129.5                 |
| MG06_01_88m   | -               | VWP  | AD     | 310866.1    | 6392901   | Pswj            | -                                                               | 68.9                    | -                 | 88                    |
| MG06_01_89.5m | -               | VWP  | AU     | 310866.1    | 6392901   | Pswj            | -                                                               | 68.9                    | -                 | 89.5                  |
| MG06_01_91.5m | -               | VWP  | AU     | 310866.1    | 6392901   | Pswj            | -                                                               | 68.9                    | -                 | 91.5                  |
| MG06_01_94m   | -               | VWP  | AU     | 310866.1    | 6392901   | Pswj            | -                                                               | 68.9                    | -                 | 94                    |
| MG06_02_67.5m | -               | VWP  | AU     | 311108      | 6393187   | Pswj            | -                                                               | 73.5                    | -                 | 67.5                  |
| MG06_02_69.5m | -               | VWP  | AU     | 311108      | 6393187   | Pswj            | -                                                               | 73.5                    | -                 | 69.5                  |
| MG06_02_71m   | -               | VWP  | AU     | 311108      | 6393187   | Pswj            | -                                                               | 73.5                    | -                 | 71                    |
| MG06_02_74m   | -               | VWP  | AU     | 311108      | 6393187   | Pswj            | -                                                               | 73.5                    | -                 | 74                    |
| MG08_009m     | -               | VWP  | EX     | 311028      | 6392637   | Qa              | Alluvium                                                        | 65.4                    | -                 | 9                     |
| MG08_037m     | -               | VWP  | EX     | 311028      | 6392637   | Pswj            | Permian overburden                                              | 65.4                    | -                 | 37                    |
| MG08_046m     | -               | VWP  | EX     | 311028      | 6392637   | Pswj            | Whybrow Seam                                                    | 65.4                    | -                 | 46                    |
| MG08_060m     | -               | VWP  | EX     | 311028      | 6392637   | Pswj            | Interburden                                                     | 65.4                    | -                 | 60                    |
| MG08_077m     | -               | VWP  | EX     | 311028      | 6392637   | Pswj            | Redbank Seam                                                    | 65.4                    | -                 | 77                    |
| MG08_090m     | -               | VWP  | EX     | 311028      | 6392637   | Pswj            | Interburden                                                     | 65.4                    | -                 | 90                    |
| MG08_101m     | -               | VWP  | EX     | 311028      | 6392637   | Pswj            | Wambo Seam                                                      | 65.4                    | -                 | 101                   |
| MG09_009m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Regolith                                                        | 69.8                    | -                 | 9                     |
| MG09_030m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Permian overburden                                              | 69.8                    | -                 | 30                    |
| MG09_060m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Permian overburden (fresh)                                      | 69.8                    | -                 | 60                    |
| MG09_103m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Whybrow Seam                                                    | 69.8                    | -                 | 103                   |
| MG09_130m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Interburden                                                     | 69.8                    | -                 | 130                   |
| MG09_153m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Redbank Seam                                                    | 69.8                    | -                 | 153                   |
| MG09_170m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Interburden                                                     | 69.8                    | -                 | 170                   |
| MG09_192m     | -               | VWP  | EX     | 310539      | 6391186   | Pswj            | Wambo Seam                                                      | 69.8                    | -                 | 192                   |
| P33_13m       | -               | VWP  | EX     | 313756.59   | 6394659.3 | Pswj            | Glen Munro (Unnamed C)                                          | 56.7                    | -                 | 13                    |
| P33_19m       | -               | VWP  | EX     | 313756.59   | 6394659.3 | Pswj            | Glen Munro (Unnamed D)                                          | 56.7                    | -                 | 19                    |
| P33_46.5m     | -               | VWP  | EX     | 313756.59   | 6394659.3 | Pswj            | Woodlands Hill (Unnamed E)                                      | 56.7                    | -                 | 46.5                  |
| P33_58m       | -               | VWP  | EX     | 313756.59   | 6394659.3 | Pswj            | Blakefield Seam                                                 | 56.7                    | -                 | 58                    |
| P33_113m      | -               | VWP  | EX     | 313756.59   | 6394659.3 | Pswj            | Arrowfield Seam                                                 | 56.7                    | -                 | 113                   |
| P34_35m       | -               | VWP  | EX     | 313757      | 6393961   | Pswj            | Glen Munro (Unnamed D)                                          | 59.2                    | -                 | 35                    |
| P34_68.5m     | -               | VWP  | EX     | 313757      | 6393961   | Pswj            | Blakefield Seam                                                 | 59.2                    | -                 | 68.5                  |
| P34_144m      | -               | VWP  | EX     | 313757      | 6393961   | Pswj            | Bowfield Seam                                                   | 59.2                    | -                 | 144                   |
| P35_16m       | -               | VWP  | EX     | 313611      | 6395196   | Pswj            | Interburden Woodlands Hill (Unnamed E) - Glen Munro (Unnamed D) | 59.3                    | -                 | 16                    |
| P35_19m       | -               | VWP  | EX     | 313611      | 6395196   | Pswj            | Interburden Woodlands Hill (Unnamed E) - Glen Munro (Unnamed D) | 59.3                    | -                 | 19                    |
| P35_51m       | -               | VWP  | EX     | 313611      | 6395196   | Pswj            | Blakefield Seam                                                 | 59.3                    | -                 | 51                    |
| P35_60m       | -               | VWP  | EX     | 313611      | 6395196   | Pswj            | Blakefield Seam                                                 | 59.3                    | -                 | 60                    |
| P35_112m      | -               | VWP  | EX     | 313611      | 6395196   | Pswj            | Arrowfield Seam                                                 | 59.3                    | -                 | 112                   |
| UG133_45m     | -               | VWP  | EX     | 313297.25   | 6396177.4 | Pswj            | Glen Munro Seam                                                 | 62.6                    | -                 | 45                    |
| UG133_96m     | -               | VWP  | EX     | 313297.25   | 6396177.4 | Pswj            | Arrowfield Seam                                                 | 62.6                    | -                 | 96                    |
| UG133_146m    | -               | VWP  | EX     | 313297.25   | 6396177.4 | Pswj            | Interburden Warkworth - Bowfield                                | 62.6                    | -                 | 146                   |
| UG133_168m    | -               | VWP  | EX     | 313297.25   | 6396177.4 | Pswj            | Mt Arthur Seam                                                  | 62.6                    | -                 | 168                   |
| UG133_180m    | -               | VWP  | EX     | 313297.25   | 6396177.4 | Pswj            | Piercefield Seam                                                | 62.6                    | -                 | 180                   |
| UG133_208m    | -               | VWP  | EX     | 313297.25   | 6396177.4 | Pswj            | Vaux Seam                                                       | 62.6                    | -                 | 208                   |
| UG133_219m    | -               | VWP  | EX     | 313297.25   | 6396177.4 | Pswj            | Broonie Seam                                                    | 62.6                    | -                 | 219                   |
| UG134_45m     | -               | VWP  | EX     | 313782.25   | 6395766.9 | Pswj            | Interburden Arrowfield - Glen Munro                             | 61.3                    | -                 | 45                    |
| UG134_116m    | -               | VWP  | EX     | 313782.25   | 6395766.9 | Pswj            | Interburden Warkworth - Bowfield                                | 61.3                    | -                 | 116                   |
| UG134_175m    | -               | VWP  | EX     | 313782.25   | 6395766.9 | Pswj            | Warkworth Seam                                                  | 61.3                    | -                 | 175                   |
| UG134_190m    | -               | VWP  | EX     | 313782.25   | 6395766.9 | Pswj            | Mt Arthur Seam                                                  | 61.3                    | -                 | 190                   |
| UG134_198m    | -               | VWP  | EX     | 313782.25   | 6395766.9 | Pswj            | Piercefield Seam                                                | 61.3                    | -                 | 198                   |
| UG134_215m    | -               | VWP  | EX     | 313782.25   | 6395766.9 | Pswj            | Vaux Seam                                                       | 61.3                    | -                 | 215                   |
| UG134_224m    | -               | VWP  | EX     | 313782.25   | 6395766.9 | Pswj            | Broonie Seam                                                    | 61.3                    | -                 | 224                   |
| UG135_50m     | -               | VWP  | EX     | 313831.48   | 6396748   | Pswj            | Interburden Arrowfield - Glen Munro                             | 65.3                    | -                 | 50                    |
| UG135_110m    | -               | VWP  | EX     | 313831.48   | 6396748   | Pswj            | Warkworth Seam                                                  | 65.3                    | -                 | 110                   |
| UG135_129m    | -               | VWP  | EX     | 313831.48   | 6396748   | Pswj            | Mt Arthur Seam                                                  | 65.3                    | -                 | 129                   |
| UG135_146m    | -               | VWP  | EX     | 313831.48   | 6396748   | Pswj            | Piercefield Seam                                                | 65.3                    | -                 | 146                   |
| UG135_176m    | -               | VWP  | EX     | 313831.48   | 6396748   | Pswj            | Vaux Seam                                                       | 65.3                    | -                 | 176                   |
| UG135_186m    | -               | VWP  | EX     | 313831.48   | 6396748   | Pswj            | Broonie Seam                                                    | 65.3                    | -                 | 186                   |
| UG136_21m     | -               | VWP  | EX     | 313282.4    | 6397307.7 | Pswj            | Glen Munro Seam                                                 | 72.9                    | -                 | 21                    |
| UG136_55m     | -               | VWP  | EX     | 313282.4    | 6397307.7 | Pswj            | Arrowfield Seam                                                 | 72.9                    | -                 | 55                    |
| UG136_101m    | -               | VWP  | EX     | 313282.4    | 6397307.7 | Pswj            | Warkworth Seam                                                  | 72.9                    | -                 | 101                   |
| UG136_133m    | -               | VWP  | EX     | 313282.4    | 6397307.7 | Pswj            | interburden Piercefield - Mt. Arthur                            | 72.9                    | -                 | 133                   |
| UG136_167m    | -               | VWP  | EX     | 313282.4    | 6397307.7 | Pswj            | Vaux Seam                                                       | 72.9                    | -                 | 167                   |
| UG136_178m    | -               | VWP  | EX     | 313282.4    | 6397307.7 | Pswj            | Vaux - below floor                                              | 72.9                    | -                 | 178                   |
| UG136_193m    | -               | VWP  | EX     | 313282.4    | 6397307.7 | Pswj            | Broonie Seam                                                    | 72.9                    | -                 | 193                   |
| UG138_153m    | -               | VWP  | EX     | 308516.95   | 6396180.7 | Pswj            | Glen Munro (Unnamed D)                                          | 145.0                   | -                 | 153                   |
| UG138_175m    | -               | VWP  | EX     | 308516.95   | 6396180.7 | Pswj            | Woodlands Hill (Unnamed E)                                      | 145.0                   | -                 | 175                   |

| Hole ID      | In current GWMP | Type | Status | Coordinates |           | Geological unit | Lithology                                           | Ground elevation (mAHD) | Bore depth (mbGL) | Screen/ Sensor (mbGL) |
|--------------|-----------------|------|--------|-------------|-----------|-----------------|-----------------------------------------------------|-------------------------|-------------------|-----------------------|
|              |                 |      |        | mE          | mN        |                 |                                                     |                         |                   |                       |
| UG138_202m   | -               | VWP  | EX     | 308516.95   | 6396180.7 | Pswj            | Blakefield Seam                                     | 145.0                   | -                 | 202                   |
| UG138_215m   | -               | VWP  | EX     | 308516.95   | 6396180.7 | Pswj            | Glen Munro Seam                                     | 145.0                   | -                 | 215                   |
| UG138_245m   | -               | VWP  | EX     | 308516.95   | 6396180.7 | Pswj            | Arrowfield Seam                                     | 145.0                   | -                 | 245                   |
| UG138_250m   | -               | VWP  | EX     | 308516.95   | 6396180.7 | Pswj            | Bowfield Seam                                       | 145.0                   | -                 | 250                   |
| UG138_292m   | -               | VWP  | EX     | 308516.95   | 6396180.7 | Pswj            | interburden Warkworth - Bowfield                    | 145.0                   | -                 | 292                   |
| UG139_263m   | -               | VWP  | EX     | 306665.45   | 6395172.7 | Pswj            | Glen Munro (Unnamed D)                              | 128.9                   | -                 | 263                   |
| UG139_281m   | -               | VWP  | EX     | 306665.45   | 6395172.7 | Pswj            | Woodlands Hill (Unnamed E)                          | 128.9                   | -                 | 281                   |
| UG139_319m   | -               | VWP  | EX     | 306665.45   | 6395172.7 | Pswj            | interburden Glen Munro - Woodlands Hill (Unnamed E) | 128.9                   | -                 | 319                   |
| UG139_329m   | -               | VWP  | EX     | 306665.45   | 6395172.7 | Pswj            | Glen Munro Seam                                     | 128.9                   | -                 | 329                   |
| UG139_375m   | -               | VWP  | EX     | 306665.45   | 6395172.7 | Pswj            | interburden Arrowfield - Glen Munro                 | 128.9                   | -                 | 375                   |
| UG139_382m   | -               | VWP  | EX     | 306665.45   | 6395172.7 | Pswj            | Arrowfield Seam                                     | 128.9                   | -                 | 382                   |
| UG139_402m   | -               | VWP  | EX     | 306665.45   | 6395172.7 | Pswj            | interburden Warkworth - Bowfield                    | 128.9                   | -                 | 402                   |
| UG147_090    | -               | VWP  | EX     | 311245.45   | 6397206.9 | Pswj            | Glen Munro Seam                                     | 108.0                   | -                 | 90                    |
| UG147_157    | -               | VWP  | EX     | 311245.45   | 6397206.9 | Pswj            | Interburden between Warkworth and Rowfield          | 108.0                   | -                 | 157                   |
| UG147_209    | -               | VWP  | EX     | 311245.45   | 6397206.9 | Pswj            | Mt Arthur                                           | 108.0                   | -                 | 209                   |
| UG147_242    | -               | VWP  | EX     | 311245.45   | 6397206.9 | Pswj            | Piercefield??                                       | 108.0                   | -                 | 242                   |
| UG147_249    | -               | VWP  | EX     | 311245.45   | 6397206.9 | Pswj            | Vaux??                                              | 108.0                   | -                 | 249                   |
| UG147_260    | -               | VWP  | EX     | 311245.45   | 6397206.9 | Pswj            | Broonie??                                           | 108.0                   | -                 | 260                   |
| UG166A_130m  | -               | VWP  | EX     | 306488.43   | 6398076   | Pswj            | Glen Munro (Unnamed D)                              | 141.5                   | -                 | 130                   |
| UG166A_153m  | -               | VWP  | EX     | 306488.43   | 6398076   | Pswj            | Woodlands Hill (Unnamed E)                          | 141.5                   | -                 | 153                   |
| UG166A_183m  | -               | VWP  | EX     | 306488.43   | 6398076   | Pswj            | Blakefield Seam                                     | 141.5                   | -                 | 183                   |
| UG166A_200m  | -               | VWP  | EX     | 306488.43   | 6398076   | Pswj            | Glen Munro Seam                                     | 141.5                   | -                 | 200                   |
| UG166A_238m  | -               | VWP  | EX     | 306488.43   | 6398076   | Pswj            | Arrowfield Seam                                     | 141.5                   | -                 | 238                   |
| UG166A_254m  | -               | VWP  | EX     | 306488.43   | 6398076   | Pswj            | Bowfield Seam                                       | 141.5                   | -                 | 254                   |
| UG166A_260m  | -               | VWP  | EX     | 306488.43   | 6398076   | Pswj            | Bowfield Seam                                       | 141.5                   | -                 | 260                   |
| UG192R_30m   | -               | VWP  | EX     | 313683.26   | 6396084.2 | Pswj            | interburden Arrowfield - Glen Munro                 | 58.9                    | -                 | 30                    |
| UG192R_60m   | -               | VWP  | EX     | 313683.26   | 6396084.2 | Pswj            | Arrowfield Seam                                     | 58.9                    | -                 | 60                    |
| UG192R_94m   | -               | VWP  | EX     | 313683.26   | 6396084.2 | Pswj            | Bowfield Seam                                       | 58.9                    | -                 | 94                    |
| UG192R_110m  | -               | VWP  | EX     | 313683.26   | 6396084.2 | Pswj            | interburden Warkworth - Bowfield                    | 58.9                    | -                 | 110                   |
| UG192R_140m  | -               | VWP  | EX     | 313683.26   | 6396084.2 | Pswj            | interburden Warkworth - Bowfield                    | 58.9                    | -                 | 140                   |
| UG192R_170m  | -               | VWP  | EX     | 313683.26   | 6396084.2 | Pswj            | Mt Arthur Seam                                      | 58.9                    | -                 | 170                   |
| UG192R_210m  | -               | VWP  | EX     | 313683.26   | 6396084.2 | Pswj            | Broonie Seam                                        | 58.9                    | -                 | 210                   |
| UG193_27m    | -               | VWP  | EX     | 313757.25   | 6396090.3 | Pswj            | Glen Munro Seam                                     | 58.2                    | -                 | 27                    |
| UG193_61m    | -               | VWP  | EX     | 313757.25   | 6396090.3 | Pswj            | Arrowfield Seam                                     | 58.2                    | -                 | 61                    |
| UG193_85m    | -               | VWP  | EX     | 313757.25   | 6396090.3 | Pswj            | Bowfield Seam                                       | 58.2                    | -                 | 85                    |
| UG193_160m   | -               | VWP  | EX     | 313757.25   | 6396090.3 | Pswj            | Warkworth Seam                                      | 58.2                    | -                 | 160                   |
| UG193_179.5m | -               | VWP  | EX     | 313757.25   | 6396090.3 | Pswj            | Piercefield Seam                                    | 58.2                    | -                 | 179.5                 |
| UG193_210m   | -               | VWP  | EX     | 313757.25   | 6396090.3 | Pswj            | Broonie Seam                                        | 58.2                    | -                 | 210                   |
| UG194_20m    | -               | VWP  | EX     | 312435.96   | 6397190.8 | Pswj            | Blakefield Seam                                     | 81.7                    | -                 | 20                    |
| UG194_60m    | -               | VWP  | EX     | 312435.96   | 6397190.8 | Pswj            | interburden Glen Munro - Blakefield                 | 81.7                    | -                 | 60                    |
| UG194_100m   | -               | VWP  | EX     | 312435.96   | 6397190.8 | Pswj            | Blakefield Seam                                     | 81.7                    | -                 | 100                   |
| UG194_150m   | -               | VWP  | EX     | 312435.96   | 6397190.8 | Pswj            | interburden Mt. Arthur - Warkworth                  | 81.7                    | -                 | 150                   |
| UG194_190m   | -               | VWP  | EX     | 312435.96   | 6397190.8 | Pswj            | interburden Piercefield - Mt. Arthur                | 81.7                    | -                 | 190                   |
| UG194_210m   | -               | VWP  | EX     | 312435.96   | 6397190.8 | Pswj            | Vaux Seam                                           | 81.7                    | -                 | 210                   |
| UG196_45m    | -               | VWP  | EX     | 312364.48   | 6397122.4 | Pswj            | Glen Munro Seam                                     | 81.1                    | -                 | 45                    |
| UG196_80m    | -               | VWP  | EX     | 312364.48   | 6397122.4 | Pswj            | Arrowfield Seam                                     | 81.1                    | -                 | 80                    |
| UG196_110m   | -               | VWP  | EX     | 312364.48   | 6397122.4 | Pswj            | interburden Warkworth - Bowfield                    | 81.1                    | -                 | 110                   |
| UG196_137m   | -               | VWP  | EX     | 312364.48   | 6397122.4 | Pswj            | interburden Warkworth - Bowfield                    | 81.1                    | -                 | 137                   |
| UG196_160m   | -               | VWP  | EX     | 312364.48   | 6397122.4 | Pswj            | Mt Arthur Seam                                      | 81.1                    | -                 | 160                   |
| UG196_230m   | -               | VWP  | EX     | 312364.48   | 6397122.4 | Pswj            | Broonie Seam                                        | 81.1                    | -                 | 230                   |
| UG200_30m    | -               | VWP  | EX     | 313009.2    | 6396950.2 | Pswj            | Glen Munro Seam                                     | 70.7                    | -                 | 30                    |
| UG200_60m    | -               | VWP  | EX     | 313009.2    | 6396950.2 | Pswj            | interburden Arrowfield - Glen Munro                 | 70.7                    | -                 | 60                    |
| UG200_90m    | -               | VWP  | EX     | 313009.2    | 6396950.2 | Pswj            | interburden Bowfield - Arrowfield                   | 70.7                    | -                 | 90                    |
| UG200_120m   | -               | VWP  | EX     | 313009.2    | 6396950.2 | Pswj            | interburden Warkworth - Bowfield                    | 70.7                    | -                 | 120                   |
| UG200_150m   | -               | VWP  | EX     | 313009.2    | 6396950.2 | Pswj            | interburden Piercefield - Mt. Arthur                | 70.7                    | -                 | 150                   |
| UG200_180m   | -               | VWP  | EX     | 313009.2    | 6396950.2 | Pswj            | Piercefield Seam                                    | 70.7                    | -                 | 180                   |
| UG200_210m   | -               | VWP  | EX     | 313009.2    | 6396950.2 | Pswj            | Broonie Seam                                        | 70.7                    | -                 | 210                   |
| UG201_16m    | -               | VWP  | EX     | 313086.72   | 6397025.4 | Pswj            | Blakefield Seam                                     | 68.8                    | -                 | 16                    |
| UG201_24m    | -               | VWP  | EX     | 313086.72   | 6397025.4 | Pswj            | interburden Glen Munro - Blakefield                 | 68.8                    | -                 | 24                    |
| UG201_65m    | -               | VWP  | EX     | 313086.72   | 6397025.4 | Pswj            | Arrowfield Seam                                     | 68.8                    | -                 | 65                    |
| UG201_95m    | -               | VWP  | EX     | 313086.72   | 6397025.4 | Pswj            | Bowfield Seam                                       | 68.8                    | -                 | 95                    |
| UG201_120m   | -               | VWP  | EX     | 313086.72   | 6397025.4 | Pswj            | Warkworth Seam                                      | 68.8                    | -                 | 120                   |
| UG201_165m   | -               | VWP  | EX     | 313086.72   | 6397025.4 | Pswj            | Piercefield Seam                                    | 68.8                    | -                 | 165                   |
| UG201_190m   | -               | VWP  | EX     | 313086.72   | 6397025.4 | Pswj            | Broonie Seam                                        | 68.8                    | -                 | 190                   |
| UG220_52.5m  | -               | VWP  | EX     | 312521.6    | 6397233.3 | Pswj            | overburden Arrowfield                               | 82.0                    | -                 | 52.5                  |
| UG220_77m    | -               | VWP  | Error  | 312521.6    | 6397233.3 | Pswj            | Arrowfield Seam                                     | 82.0                    | -                 | 77                    |
| UG220_106m   | -               | VWP  | EX     | 312521.6    | 6397233.3 | Pswj            | interburden Warkworth - Bowfield                    | 82.0                    | -                 | 106                   |
| UG220_110m   | -               | VWP  | EX     | 312521.6    | 6397233.3 | Pswj            | interburden Warkworth - Bowfield                    | 82.0                    | -                 | 110                   |
| UG220_136m   | -               | VWP  | EX     | 312521.6    | 6397233.3 | Pswj            | Warkworth Seam                                      | 82.0                    | -                 | 136                   |
| UG220_152m   | -               | VWP  | EX     | 312521.6    | 6397233.3 | Pswj            | Mt Arthur Seam                                      | 82.0                    | -                 | 152                   |
| UG220_207m   | -               | VWP  | EX     | 312521.6    | 6397233.3 | Pswj            | Vaux Seam                                           | 82.0                    | -                 | 207                   |
| UG224_25m    | -               | VWP  | Error  | 313860      | 6396243.1 | Pswj            | overburden Arrowfield                               | 58.8                    | -                 | 25                    |
| UG224_69m    | -               | VWP  | EX     | 313860      | 6396243.1 | Pswj            | interburden Bowfield - Arrowfield                   | 58.8                    | -                 | 69                    |

| Hole ID      | In current GWMP | Type | Status | Coordinates |           | Geological unit | Lithology                        | Ground elevation (mAHD) | Bore depth (mbGL) | Screen/ Sensor (mbGL) |
|--------------|-----------------|------|--------|-------------|-----------|-----------------|----------------------------------|-------------------------|-------------------|-----------------------|
|              |                 |      |        | mE          | mN        |                 |                                  |                         |                   |                       |
| UG224_105m   | -               | VWP  | EX     | 313860      | 6396243.1 | Pswj            | interburden Warkworth - Bowfield | 58.8                    | -                 | 105                   |
| UG224_163m   | -               | VWP  | EX     | 313860      | 6396243.1 | Pswj            | Piercefield Seam                 | 58.8                    | -                 | 163                   |
| UG224_172m   | -               | VWP  | EX     | 313860      | 6396243.1 | Pswj            | interburden Vaux - Piercefield   | 58.8                    | -                 | 172                   |
| UG224_191m   | -               | VWP  | EX     | 313860      | 6396243.1 | Pswj            | Vaux Seam                        | 58.8                    | -                 | 191                   |
| UG225_23m    | -               | VWP  | Error  | 313214.4    | 6397094.7 | Pswj            | overburden Glen Munro            | 68.9                    | -                 | 23                    |
| UG225_58.5m  | -               | VWP  | EX     | 313214.4    | 6397094.7 | Pswj            | Arrowfield Seam                  | 68.9                    | -                 | 58.5                  |
| UG225_93.2m  | -               | VWP  | EX     | 313214.4    | 6397094.7 | Pswj            | Bowfield Seam                    | 68.9                    | -                 | 93.2                  |
| UG225_100.5m | -               | VWP  | EX     | 313214.4    | 6397094.7 | Pswj            | interburden Warkworth - Bowfield | 68.9                    | -                 | 100.5                 |
| UG225_128m   | -               | VWP  | EX     | 313214.4    | 6397094.7 | Pswj            | Mt Arthur Seam                   | 68.9                    | -                 | 128                   |
| UG225_178m   | -               | VWP  | EX     | 313214.4    | 6397094.7 | Pswj            | Vaux Seam                        | 68.9                    | -                 | 178                   |

**Notes:** Coordinates in MGA94 Zone 56

Yes (A) Bore with individual trigger level for SWL, pH and EC Yes (B) Trigger level to be developed once sufficient data has been collected

\* Bore removed with mine progression and replaced with GW08 and GW09

MB Monitoring bore VWP Vibrating wire piezometer

EX Existing AU Abandoned and usable

AD Abandoned and destroyed

Qa Quaternary alluvium Qr Quaternary colluvium

Psl Permian Newcastle Coal Measures Pswj Permian Wittingham Coal Measures

*Appendix B*

**Numerical Modelling Report**

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# United Project

## Numerical Modelling Report

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### B1 Introduction

Predictive numerical modelling was undertaken to assess the impact of the project on the groundwater regime. The objectives of the predictive modelling were to:

- assess the groundwater inflow to the mine workings as a function of mine position and timing;
- simulate and predict the extent and area of influence of dewatering and the level and rate of drawdown at specific locations; and
- identify areas of potential risk where groundwater impact mitigation/control measures may be necessary.

The key to the modelling exercise is the adequate conceptualisation of the groundwater regime, and calibration of the model against observed data. The conceptual model is a demonstration of how the groundwater system operates given the available data, and is an idealised and simplified representation of the natural system. The conceptual groundwater model of the project site and surrounding area was developed based on various data sources, including:

- geological and topographical maps;
- geological information from coal exploration bores drilled across the project site;
- geological models developed by the proponent and Coal & Allied through a data sharing agreement; and
- results from previous hydrogeological investigations and relevant data from the publicly available datasets.

The main report details the conceptual understanding of the hydrogeological regime at the project site.

### B2 Model construction and development

#### B2.1 Model code

MODFLOW-USG Beta (Panday *et al.* 2015) was determined to be the most suitable modelling code to meet the model objectives. MODFLOW-USG is the latest derivative of the standard MODFLOW code, and has some distinct advantages. MODFLOW-USG allows use of an unstructured mesh, meaning that the cells in the model are not restricted to rectangular shapes. Small cells can be used in the area of interest to represent geological or mining features, with larger cells outside these areas where refinement is not required. This produces an optimal model grid, aiding numerical stability and limiting the number of cells. In addition, model layering does not need to be continuous over the model domain, and layers can stop where geological units pinch out or outcrop. This is also particularly useful when simulating thin, discontinuous hydrostratigraphic units, such as coal seams and faults. Flow transfer processes between systems such as bedrock and alluvial groundwater systems can therefore be more accurately represented. The upstream weighting function and the CONSTANTCV setting for vertical conductivity correction were adopted in the model.

MODFLOW-USG also allows for the lateral connection across pinched model layers, better replicating the flow transfer process between systems such as bedrock and alluvial groundwater systems. In earlier versions of MODFLOW, flow between these systems was limited to vertical connections, or required separate zonation within the same layer.

MODFLOW-USG also simulates unsaturated conditions, allows the process of progressive dewatering during active mine operations, and then re-wetting following closure to be represented. The upstream-weighting method was used to simulate the unsaturated zone, and vadose zone properties were not included in the simulation, which is recommended practice. MODFLOW-USG also has robust numerical solution schemes to handle the more complex numerical problem resulting from the unsaturated flow formulation. Added to the more robust numerical solution schemes is an adaptive time-stepping function that aids the progression of the solution past difficult and complex situations such as numerical oscillations.

The input files for the MODFLOW-USG model were created using Fortran code and a MODFLOW-USG edition of the Groundwater Data Utilities by Watermark Numerical Computing. These were used to allow for the additional capabilities of MODFLOW-USG. The mesh was generated using Algomesh (HydroAlgorithmics, 2014).

## B2.2 Model design

### B2.2.1 Model grid

The model grid was designed to be sufficiently extensive that the depressurisation caused by the mining activities associated with the project was contained well within the model boundaries. Where appropriate, natural hydrogeological boundaries such as geological units and regional catchment boundaries were adopted as boundaries in the model.

The model domain is of rectangular shape, 23km wide (west to east direction) and 27.8km long (north to south direction) as shown in Figure B- 1. The boundaries of the model domain are:

- West – set approximately 11km west of the project site, encompassing the Hunter River alluvium and Triassic escarpment of the Wollemi National Park.
- North – set approximately 15km north of the project site, the boundary accommodates the northernmost extent of the basal coal seam targeted at the project site (Bayswater Seam). The northern extent also encompasses the HVO, Ravensworth and Narama mines, which target equivalent geological units to the project site.
- East – set approximately 11.5km east of the project site, the boundary again includes the full lateral extent of the basal coal seam targeted at the project site (Bayswater Seam). The eastern extent also encompasses HVO South (i.e. Lemington) as well as the Mount Thorley and Warkworth (MTW) mines, which target equivalent geological units to the project site.
- South – set approximately 12km south of the project site, the boundary lies at the southern boundary of MTW and whilst topographically up-gradient, is down-dip in the coal measures sequence.

The model domain was discretised and arranged into 34 layers comprising up to 54,382 cell nodes in each layer with the dimensions of the cells varying. Within the mining areas at Wambo and United the cells were aligned with the proposed mine plan and refined into 50m by 50m regular hexagonal cells. Greater refinement was also focused along the major waterways (i.e. Hunter River and Wollombi Brook) and alluvium. Where possible the cells were also aligned to the progression of surrounding mines, except in areas where underground longwall panels overlie each other (i.e. Wambo). Overall, the model comprises 859,959 cells across the 34 layers.

As shown in Figure B- 1, the model includes the full extents of the existing Hunter Valley Operations (HVO) North and HVO South, Ravensworth and Narama operations as well as MTW operations. These mining areas were encompassed within the model domain as they target several of the equivalent coal seams intersected at the project site and are necessary to assess the potential for cumulative impacts.

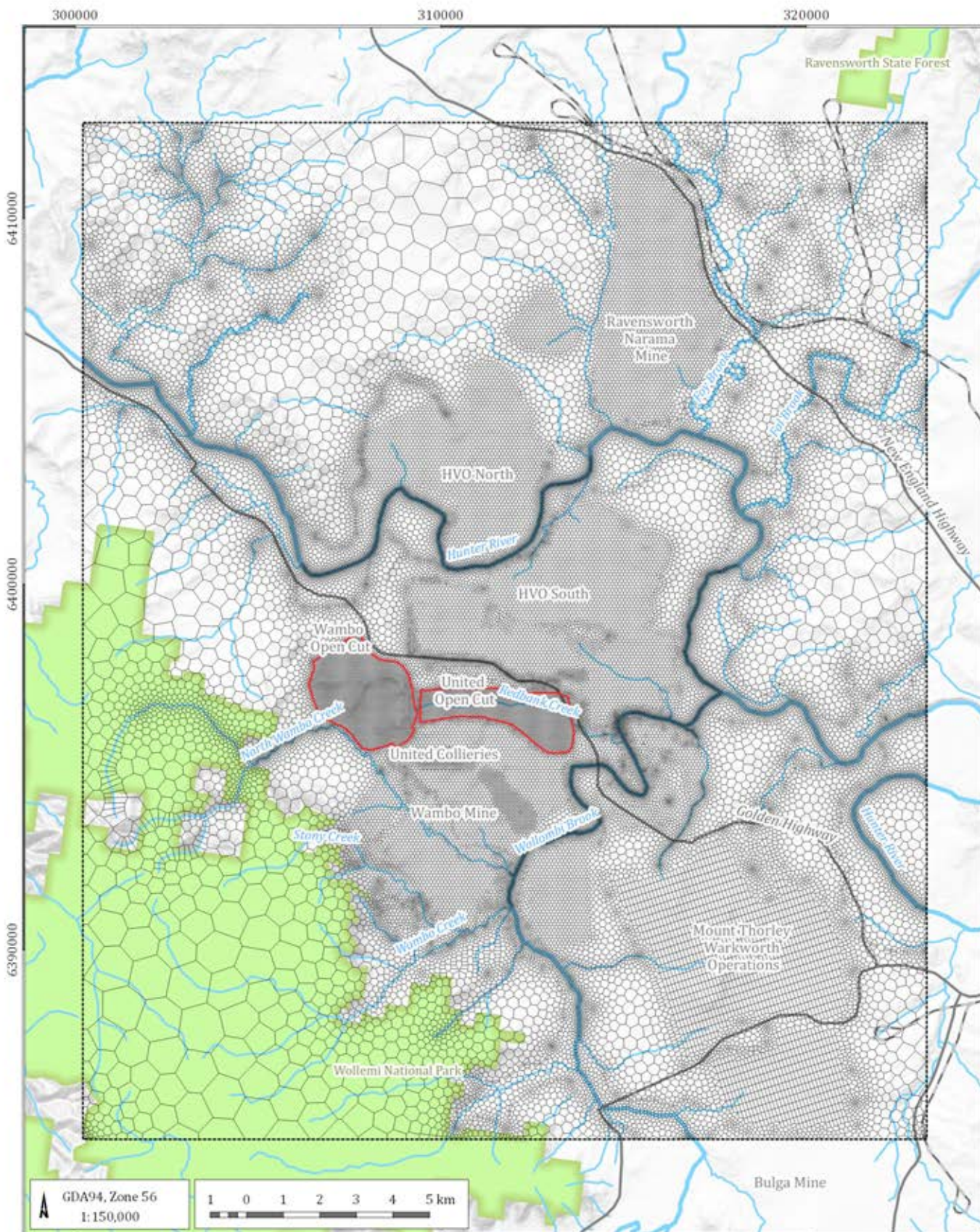
### *B2.2.2 Model boundary conditions*

No flow boundary conditions were adopted for the northern and eastern edges of model domain. These boundaries lie beyond the outcrop/subcrop limit of the Bayswater Seam, which is the lowermost coal seam of Wittingham Coal Measures and is also the lowermost coal seam to be mined by the project. This approach is considered conservative as it does not allow depressurisation impacts to be buffered by groundwater inflow beyond the defined limit of the boundary.

The western boundary was set as a general head boundary, which uses a linear relationship based on a reference head to control the flux into and out of the model.

The southern extent of the model domain occurs between MTW and Bulga Mine. Bulga Mine was not included within the model due to its distance from the project site and position down-dip and up-gradient of the coal measures intercepted by the project. However, in order to account for the potential influence of Bulga Mine, a general head boundary was assigned along the southern border of the model domain. The heads assigned at the boundary were from publicly available, modelled groundwater levels generated for Bulga Mine (Mackie, 2013).

Further flows into the model domain were in the form of recharge from rainfall. Flows into and out of the model domain occur through baseflow in creeks and out through evapotranspiration across the ground surface. Groundwater is also removed from the system using drain and well packages representing mine dewatering and pumping.



#### LEGEND

- Proposed extraction area
- Model extent
- Model mesh
- Rail
- Major road
- Major drainage
- Minor drainage
- Reserve

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#### Grid layout



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FIGURE No:  
**B-1**

### B2.2.3 Model layers

The model has 34 layers, as summarised in Table B- 1. The layers were based on hydro-stratigraphic horizons in available geological models, and extrapolated beyond the limit of geological models using all available data and experience.

**Table B- 1 Model layers**

| Geological age | Stratigraphic unit (Wambo nomenclature)                              |                                             | Model layer |
|----------------|----------------------------------------------------------------------|---------------------------------------------|-------------|
| Quaternary     | Colluvium / regolith (CSIRO, 2015) and less productive alluvium (Qa) |                                             | 1           |
|                | Highly productive alluvium (basal gravels)                           |                                             | 2           |
| Triassic       | Narrabeen Group                                                      |                                             | 3           |
| Permian        | Newcastle Coal Measures                                              | Newcastle Coal Measures                     | 4           |
|                |                                                                      | Watts Sandstone                             | 5           |
|                | Wittingham Coal Measures (Jerrys Plains Sub-group)                   | Sandstone / siltstone / shale               | 6           |
|                |                                                                      | Whybrow Seam                                | 7           |
|                |                                                                      | Sandstone / siltstone / shale               | 8           |
|                |                                                                      | Wambo Seam                                  | 9           |
|                |                                                                      | Sandstone / siltstone / shale               | 10          |
|                |                                                                      | Whynot Seam                                 | 11          |
|                |                                                                      | Sandstone / siltstone / shale               | 12          |
|                |                                                                      | Blakefield Seam                             | 13          |
|                |                                                                      | Sandstone / siltstone / shale               | 14          |
|                |                                                                      | Glen Munro Seam                             | 15          |
|                |                                                                      | Sandstone / siltstone / shale               | 16          |
|                |                                                                      | Woodlands Hill Seam                         | 17          |
|                |                                                                      | Sandstone / siltstone / shale               | 18          |
|                |                                                                      | Arrowfield Seam                             | 19          |
|                |                                                                      | Sandstone / siltstone / shale               | 20          |
|                |                                                                      | Bowfield Seam (localised split)             | 21          |
|                |                                                                      | Sandstone / siltstone / shale               | 22          |
|                |                                                                      | Warkworth Seam                              | 23          |
|                |                                                                      | Sandstone / siltstone / shale)              | 24          |
|                |                                                                      | Mt Arthur Seam                              | 25          |
|                |                                                                      | Sandstone / siltstone / shale               | 26          |
|                |                                                                      | Piercefield Seam                            | 27          |
|                |                                                                      | Sandstone / siltstone / shale               | 28          |
|                |                                                                      | Vaux Seam                                   | 29          |
|                |                                                                      | Sandstone / siltstone / shale               | 30          |
|                |                                                                      | Broonie Seam                                | 31          |
|                |                                                                      | Sandstone / siltstone / shale               | 32          |
|                |                                                                      | Bayswater Seam                              | 33          |
|                |                                                                      | Sandstone / siltstone / shale (underburden) | 34          |

**Note:** Naming scheme based on Wambo Mine coal seam nomenclature.

LIDAR data was provided across the mine areas, which formed the basis for the top of Layer 1. Beyond the extent of the LIDAR data, one second SRTM derived digital elevation model (DEM) was used.

The Quaternary sediments are represented in the model as zones within the top two model layers. The extent of Quaternary sediments was defined by regional geology maps and site specific data, including previous reports and lithological logs. The thickness of the Quaternary alluvium was largely derived from the CSIRO (2015) soil and landscape grid, with localised adjustments again using lithological logs and previous studies that identified the depth of alluvium. As detailed within the main report, the site specific data indicates that along the major waterways (i.e. Hunter River and Wollombi Brook) the Quaternary alluvium contains a basal gravel unit overlain by silty sands and clays. Therefore, two alluvial layers were created:

- an upper layer with a maximum thickness of 8 m that represents the silty sands and clays of the less productive alluvium; and
- a second layer representing the basal sands and gravels within the extent of the highly productive alluvium.

Where the Quaternary sediments were not present, a regolith layer was included in the model.

The proponent provided surfaces of key units from the United geological resource model and an existing groundwater model for Wambo. The model layers were based on the available geological surfaces, which included the individual coal seams of the Wittingham Coal Measures. Where data gaps existed, regional geological mapping (Beckett, 1988; Glenn and Beckett, 1993) and available data from registered bore lithological logs were used to interpolate surfaces beyond the mining areas.

The thickness of each coal seam was calculated by combining each seam ply within the geological model, ensuring that the groundwater model represented the full thickness of coal, and therefore the equivalent transmissivity of the separate plies in a single layer. The geological surface for the lowermost coal seam was used for the base of the seam, with the thickness of combined coal seams used to define the top of the seam. The depressurisation within the Wittingham Coal Measures is more enhanced within the coal seams, as they exhibit higher permeability compared to the interbedded rocks that comprise sandstones, conglomerates, siltstones and shales.

It should be noted that while the seams are largely contiguous, there are differences in the nomenclature for the coal seams between the different mining operations. The coal seam nomenclature used within this report reflects that used for Wambo Mine.

### B2.2.4 Timing

The calibration involved an initial steady state calibration to obtain pre-mining conditions, followed by a transient calibration. The transient calibration covered historic mining from 1970 to 2015. Due to limited detail on historic mining and groundwater levels prior to 2003, the transient calibration was set up in two stages as follows:

- **Initial** (1970 to 2003) representing mining across the model domain prior to 2003. There is limited historical data available on the progress of mines during this period, therefore the initial run was divided into three stress periods in order to approximate mining induced drawdown and recovery within rehabilitated / abandoned mine areas up to 2003. The stress periods were divided as follows:
  - Stress period 1 = 1970 to 1982;
  - Stress period 2 = 1982 to 1992; and
  - Stress period 3 = 1992 to 2003.
- **Historic** (2003 to 2015) represented the period when more detailed water level monitoring data and information on mining was available for calibration. This period ends at the present day (2015) and covers 13 years with 52 quarterly stress periods.

The calibration model captures historical mining that occurred at the project site and surrounding mines that intersected the Jerrys Plains Sub-group of the Wittingham Coal Measures. Table B-2 depicts the timing and coal seams mined at the various open cut and underground coal mines surrounding the project site.

**Table B-2 Model domain historic and approved mine progression**

| Jerrys Plains Sub-group lithology | Mine                 |              |             |                      |             |                                           |             |             |             |                    |  |
|-----------------------------------|----------------------|--------------|-------------|----------------------|-------------|-------------------------------------------|-------------|-------------|-------------|--------------------|--|
|                                   | Wambo                |              | United      |                      | MTW         | North Lemington and Lemington Underground |             | HVO North   | HVO South   | Ravensworth Narama |  |
| Main coal seams                   | OC                   | UG           | OC          | UG                   | OC          | OC                                        | UG          | OC          | OC          | OC                 |  |
| Whybrow                           | 1974 - 2017          | 1979 - 2018  |             |                      |             |                                           |             |             |             |                    |  |
| Redbank Creek                     |                      |              |             |                      |             |                                           |             |             |             |                    |  |
| Wambo                             |                      | 1969 - 2019  | 1989 - 1992 |                      |             |                                           |             |             |             |                    |  |
| Whynot                            |                      |              |             |                      |             |                                           |             |             |             |                    |  |
| Blakefield                        | Proposed 2017 - 2039 |              |             |                      |             |                                           |             |             |             |                    |  |
| Glen Munro                        |                      |              |             |                      |             |                                           |             |             |             |                    |  |
| Woodlands Hill                    |                      | 2019 - 2029* |             |                      |             |                                           |             |             |             |                    |  |
| Arrowfield                        |                      | 2017 – 2032* |             | Proposed 2017 - 2039 | 1992 - 2002 | 1980 - 2035                               |             |             |             | 1997 – 2030**      |  |
| Warkworth                         |                      |              |             |                      |             |                                           |             |             |             |                    |  |
| Mt. Arthur                        |                      |              |             |                      |             |                                           | 1971 - 1999 | 1971 - 1992 | 1979 - 2021 |                    |  |
| Piercefield                       |                      |              |             |                      |             |                                           |             |             |             |                    |  |
| Vaux                              |                      |              |             |                      |             |                                           |             |             |             |                    |  |
| Broonie                           |                      |              |             |                      |             |                                           |             |             |             | 1972 - 2039        |  |
| Bayswater                         |                      |              |             |                      |             |                                           |             |             |             |                    |  |

**Note:** OC – open cut                      UG – underground  
 \* - includes Wambo Modification 12  
 \*\* - includes modification currently proposed at HVO South

The predictive model runs from 2015 to 2039 and is the simulation for assessing the impact of the proposed and approved mining activities. The model was divided into quarterly (3 month) stress periods with the mining activities associated with the project commencing in 2017. The predictive model covered 24 years with 96 stress periods. Figure B- 2 shows the progress of proposed mining at the project site, with future mining at the surrounding mines detailed in Table B-2.

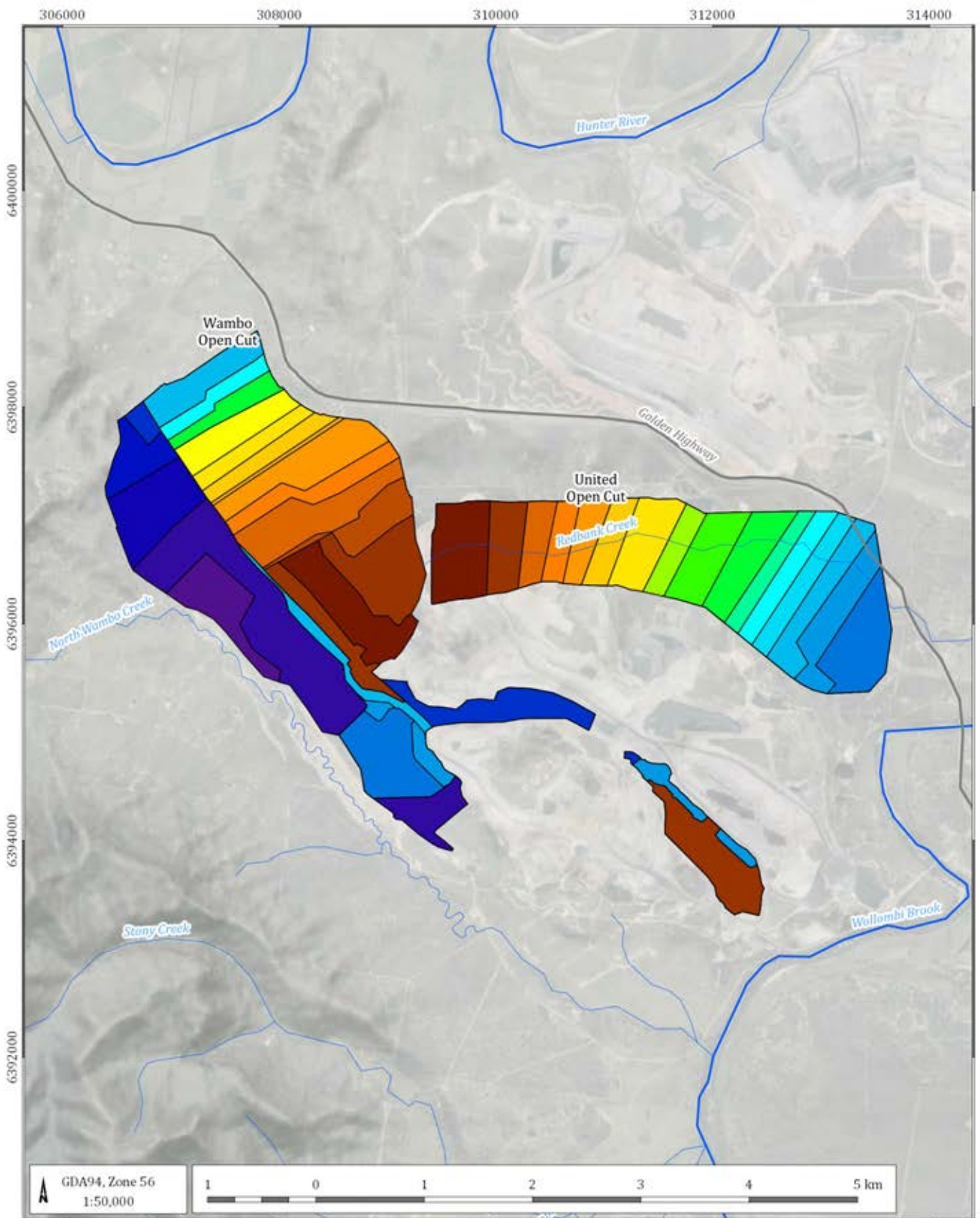
In order to assess the influence of the Project, a model scenario was run with approved and foreseeable operations at United and Wambo (no Project) as well as surrounding mining. Previously approved mine plans were derived from work conducted by HydroSimulations (2014). In order to assess the cumulative interception of groundwater for all United and Wambo operations, a model scenario was run with all surrounding mining (i.e. HVO, MTW), but no future mining at Wambo and United.

Quarterly stress periods were used so that seasonal variability in recharge and stream flows could be represented in the model. The drains representing mining were advanced in quarterly intervals and turned off after a four year delay. Within the open-cut mine areas, drain cells were applied to all intersected model cells, at reference elevations set to the floor of each layer down to the target coal seam. Hydraulic parameters for the spoil were assigned once the drains became inactive. Spoil recharge rates were adjusted at the end of mining.

The model simulated the gradual changes to the hydrostratigraphic units in response to mining (e.g. longwall goafing and spoil emplacement) using the MODFLOW-USG TVM (time varying materials) package. Goafing and fracturing was simulated by changing the parameters within the coal seam and overlying strata as the longwall panel was developed. This was achieved by applying a ramp function to vertical hydraulic conductivity ( $K_v$ ), gradually decaying to the estimated maximum height of connective cracking. The maximum height of connective cracking was calculated from the average width of the longwall panels (275 m) multiplied by 0.4. Hydraulic connection caused by longwall mining is not anticipated to reach the surface for any proposed underground mines at United (i.e. longwall mining is greater than 110m depth). Changes to hydraulic parameters used a logarithmic stepping function across stress periods. Storage was changed in a step-wise manner above the mined seam to avoid creating water in partly saturated layers. Further details about the calibrated hydraulic parameters are included in Section B3.2.

The model represented the growth of spoil piles for the open-cut by progressively changing the hydraulic properties of cells ( $K_h$ ,  $K_v$ ,  $S_y$  and  $S_s$ ) behind the active open cut mining area. For underground mining, once the drain cells were removed, changes to horizontal hydraulic conductivity, specific yield and specific storage parameters in the fracture zone were applied to the goaf layer only (i.e. mined coal seam). Recharge to the spoil emplacement areas upon the removal of drain cells was not adjusted. This was a conservative approach implemented to represent the gradual rewetting of the unsaturated spoil over time.

The river package (RIV) represented the approved tailings emplacements in the predictive model. A constant height of water above the tailings sediment was assumed, which provided a constant water flux through the tailings sediments.



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### Predictive mine progression



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FIGURE No:  
**B-2**

## B2.3 System stresses

### B2.3.1 Recharge and evapotranspiration

MODFLOW USG simulates diffuse rainfall recharge using the recharge package (RCH), and evapotranspiration from shallow water tables with the evapotranspiration package (EVT). The model represented evapotranspiration in the upper most model cells across the model domain with an extinction depth of 1.5m and maximum rate of 365mm/yr.

The dominant mechanism for recharge to the groundwater system is through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. River leakage can also provide significant recharge to underlying groundwater systems in alluvial areas. In general, the clayey nature of the upper alluvial sediments and the low permeability of the regolith, means recharge rates to the groundwater regime are relatively low. A spreadsheet based soil moisture deficit calculation (SMDC) was used to estimate the timing and magnitude of recharge events used in the model. The simple soil moisture balance calculates when the soil profile reaches field capacity and deep drainage occurs.

Table B-3 represents the calibrated rate of recharge for each geological unit, while Figure B- 3 shows the recharge distribution zones.

**Table B-3 Modelled recharge rates**

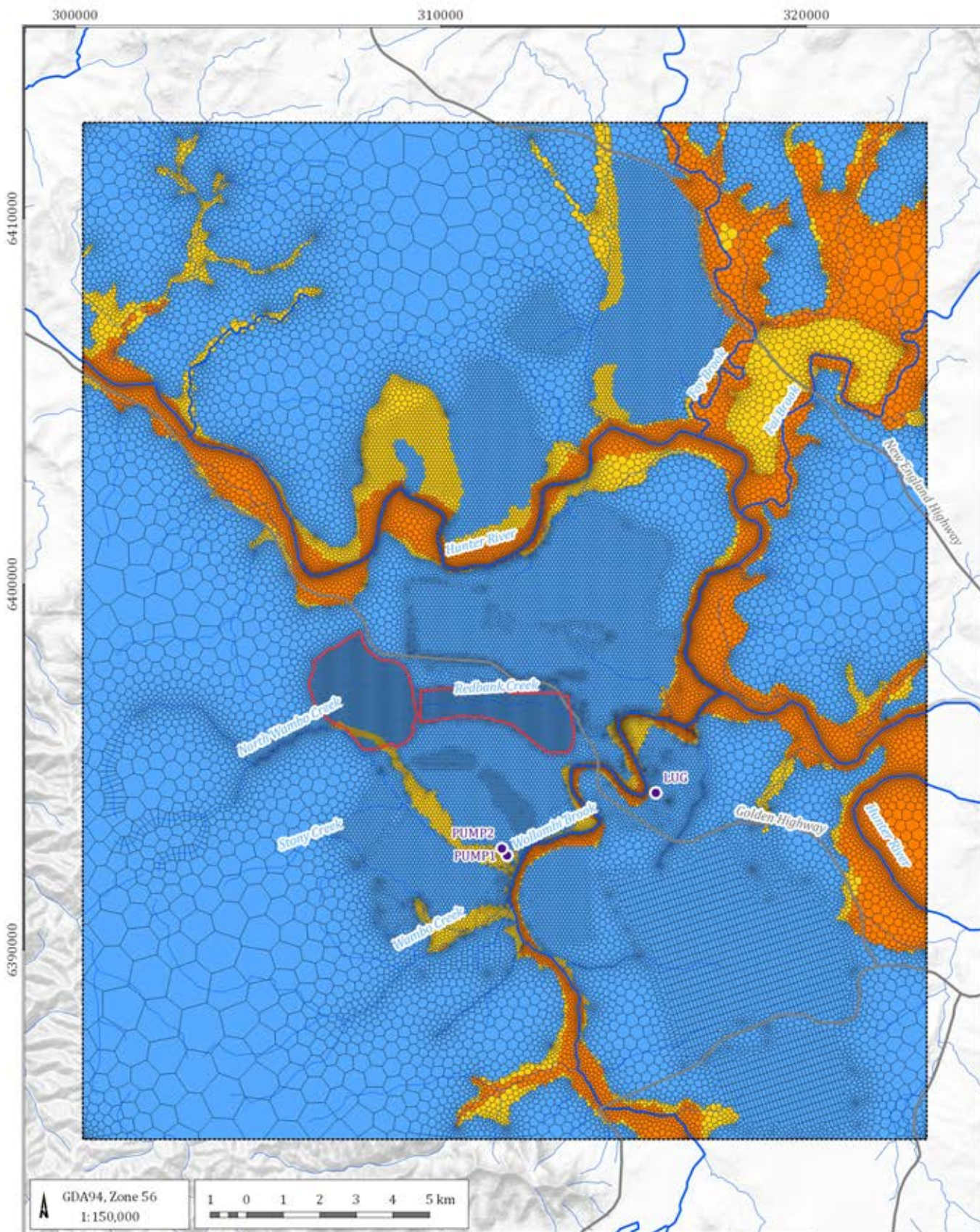
| Zone                                   | Diffuse recharge rate – steady state<br>(% of annual rainfall) | Diffuse recharge rate - transient |                     |
|----------------------------------------|----------------------------------------------------------------|-----------------------------------|---------------------|
|                                        |                                                                | % of annual rainfall              | % of quarterly SMDC |
| Colluvium and less productive alluvium | 5.4                                                            | 4.5                               | 15.0                |
| Highly productive (basal) alluvium     | 12.0                                                           | 9.9                               | 30.0                |
| Regolith                               | 1.0                                                            | 1.5                               | 5.0                 |
| Spoil                                  | -                                                              | 3.3                               | 10.0                |

**Note:** SMDC - soil moisture deficit calculation

### B2.3.2 Abstraction

Based on data provided by the proponent, Wambo mine have abstracted a small volume of water from old underground workings within the Wambo Seam since 2012. Records indicate two bores (known as “pump1” and “pump2”) have removed up to 0.4ML/day (142ML/year). Groundwater has also been abstracted from the Lemington Underground (LUG) bore by Coal & Allied since 2013. When in operation, LUG bore abstracts between 0.3ML/day and 1.2ML/day.

The MODFLOW Well (WEL) package simulated the water abstraction from the bores. The WEL package assigned the quarterly seasonal pumping rates to a model cell and layer according to the coordinates and screen depth of each individual bore. The pumping rates varied at each bore on a quarterly basis according to available individual monthly abstraction volumes. The location of the bores is included on Figure B- 3.



#### LEGEND

- Proposed extraction area
- Model extent
- Major road
- Major drainage
- Minor drainage

• WEL

#### Recharge zones

- Highly productive alluvium
- Less productive alluvium
- Regolith

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#### Recharge zones



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FIGURE No:  
**B-3**

### B2.3.3 Surface drainage

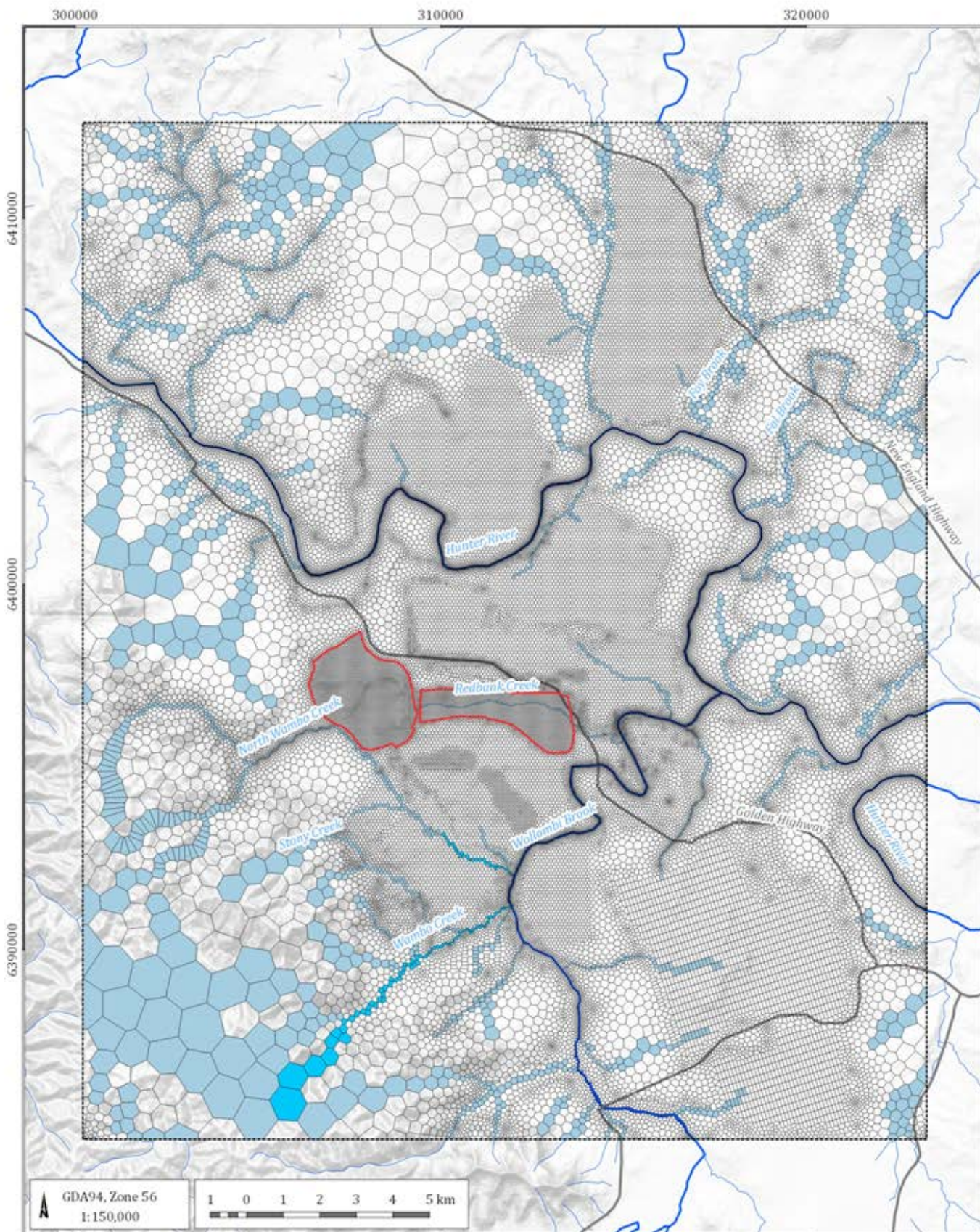
Groundwater interaction with surface drainage was modelled using the river package. This package requires the level of the river bed and the depth of water above this level. The river bed conductance was calculated from river width, length, riverbed thickness, and the vertical hydraulic conductivity of the riverbed material. The water level above the river bed was set at 0m for all minor ephemeral streams and creeks within the model domain. Table B-4 summarises the parameters representing the drainage lines and creeks.

The stage height for rivers and creeks where perennial stream flow occurs (i.e. Hunter River and Wollombi Brook) was based on interpolated gauge levels from NOW stream gauges (NSW DPI, 2014). The river stage heights recorded from these gauges were linearly interpolated and applied at a cell-by-cell level to the model river cells, per stress period. The location of the river cells in the groundwater model was assigned to Layer 2 along the Hunter River and Wollombi Brook to replicate the conceptualised hydraulic connection to the productive alluvial aquifer. The river cells representing North Wambo Creek aligns with the creek diversion, which occurred with progression of Wambo open-cut mining from 2004. River cells representing the Redbank Creek diversion (minor drainage) commence with the predictive model (from 2016). Figure B- 4 displays the different river zones.

**Table B-4      Modelled river bed parameters**

| Zone | ID                                | Vertical hydraulic conductivity Kz (m/day) | Width (m) | Incised depth (m) | Stage height (m) | Bed thickness (m) |
|------|-----------------------------------|--------------------------------------------|-----------|-------------------|------------------|-------------------|
| 1    | Hunter River                      | <b>0.5</b>                                 | 15.5      | 1 (Layer 2)       | 0 – 2.4          | 5                 |
| 2    | Wollombi Brook                    | <b>1.0</b>                                 | 9.8       | 1 (Layer 2)       | 0 – 1.5          | 5                 |
| 3    | Wambo Creek and North Wambo Creek | <b>0–1.0</b>                               | 6.0       | 2                 | 0                | 1.8               |
| 4    | Minor drainage                    | <b>3.0</b>                                 | 3.5       | 2                 | 0                | 1.8               |

**Note:**      \* Hunter River and Wollombi Brook assigned to Layer 2 to represent direct connection to the highly productive alluvium



#### LEGEND

- |                                                                                                         |                                                                                                                                                            |
|---------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <span style="border: 2px solid red; padding: 2px;"> </span> Proposed extraction area                    | <b>River and surface drainage cells</b>                                                                                                                    |
| <span style="border: 1px dashed black; padding: 2px;"> </span> Model extent                             | <span style="display: inline-block; width: 15px; height: 10px; background-color: darkblue; border: 1px solid black;"></span> Hunter River                  |
| <span style="border-bottom: 2px solid black; width: 20px; display: inline-block;"></span> Major road    | <span style="display: inline-block; width: 15px; height: 10px; background-color: blue; border: 1px solid black;"></span> Wolombi Brook                     |
| <span style="border-bottom: 2px solid blue; width: 20px; display: inline-block;"></span> Major drainage | <span style="display: inline-block; width: 15px; height: 10px; background-color: cyan; border: 1px solid black;"></span> North Wambo Creek and Wambo Creek |
| <span style="border-bottom: 1px solid blue; width: 20px; display: inline-block;"></span> Minor drainage | <span style="display: inline-block; width: 15px; height: 10px; background-color: lightblue; border: 1px solid black;"></span> Other drainage               |

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#### River and surface drainage cells



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FIGURE No:  
**B-4**

## B3 Model calibration

The groundwater model was calibrated with a pre-mining steady state run, and a transient run (1970 to 2015) using available groundwater level data and documented pit inflows. The model was calibrated by adjusting aquifer parameters and stresses to produce the best match between the observed and simulated water levels. Manual testing and automated parameterisation software (PEST, Doherty 2010) were used to determine optimal hydraulic parameters and recharge rates to achieve the best statistical calibration of the groundwater model.

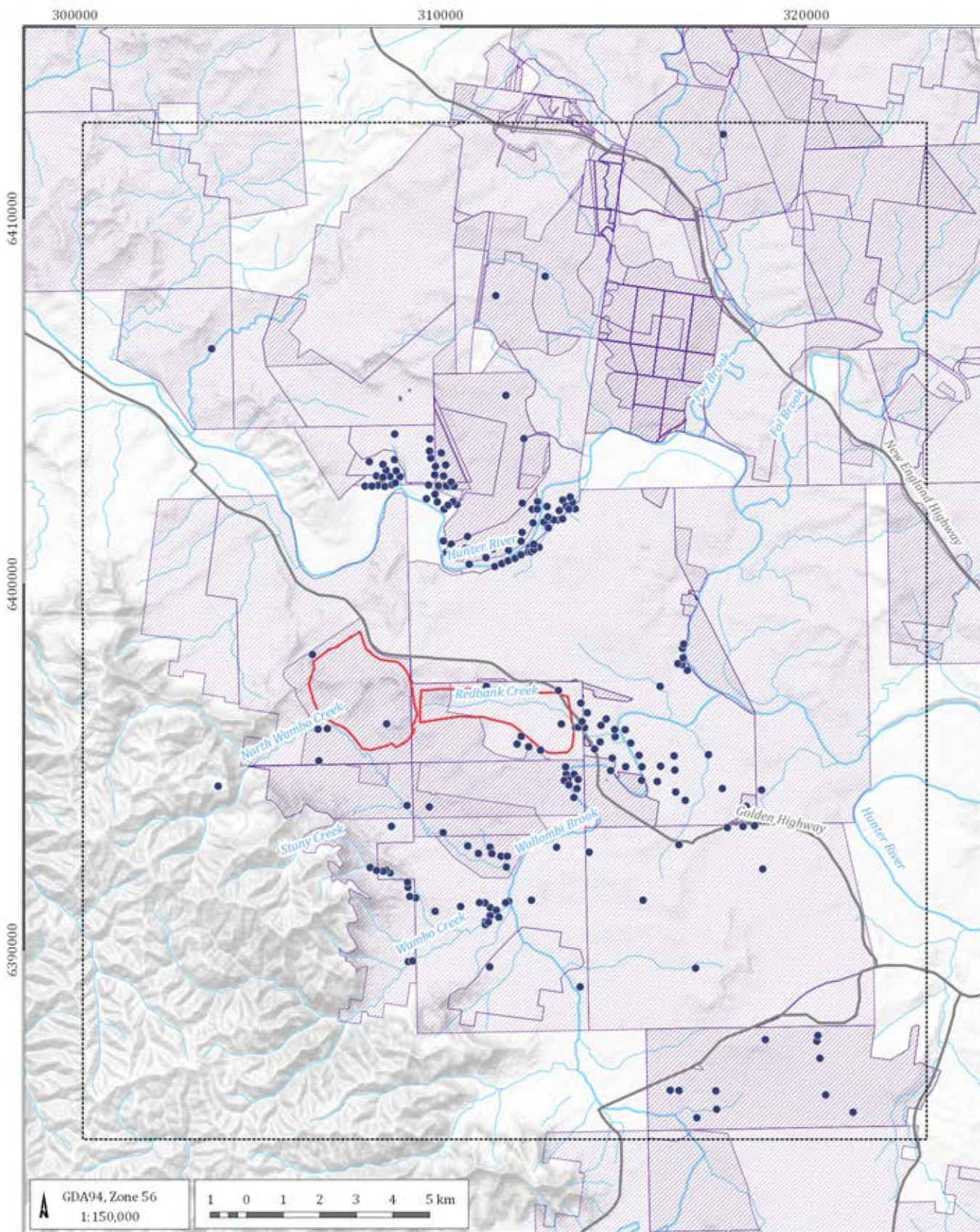
### B3.1 Calibration targets

Steady state targets were selected from 13 bores in the model that were deemed “un-impacted” by cumulative mining, and were used to verify the starting conditions.

The transient model simulated water levels in all available monitoring bores within the bedrock and alluvial aquifers. A total of 301 monitoring points were used to calibrate the model, comprising:

- 119 monitoring points at 74 locations from the United and Wambo monitoring network, which included bores and VWPs that screen the alluvium and Permian coal measures;
- 10 private registered bores with available water level data, the majority of which intersect Quaternary alluvium;
- 25 monitoring points across MTW that screen the alluvium and Permian coal measures; and
- 147 monitoring points from HVO that screen the alluvium and Permian coal measures.

Figure B- 5 presents the observation bores that were used in the transient calibration.



LEGEND

- Proposed extraction area
- Model extent
- Coal titles
- Major road
- Major
- Minor
- Observation target location

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**Observation target locations**



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FIGURE No:  
**B-5**

## B3.2 Calibration results

Figure B- 6 presents the observed and simulated groundwater levels graphically as a scattergram for the initial and historic transient calibration (1970 to 2015). Appendix B-1 presents the historic calibration hydrographs, showing the fit between modelled and observed groundwater levels from 1970 to 2015.

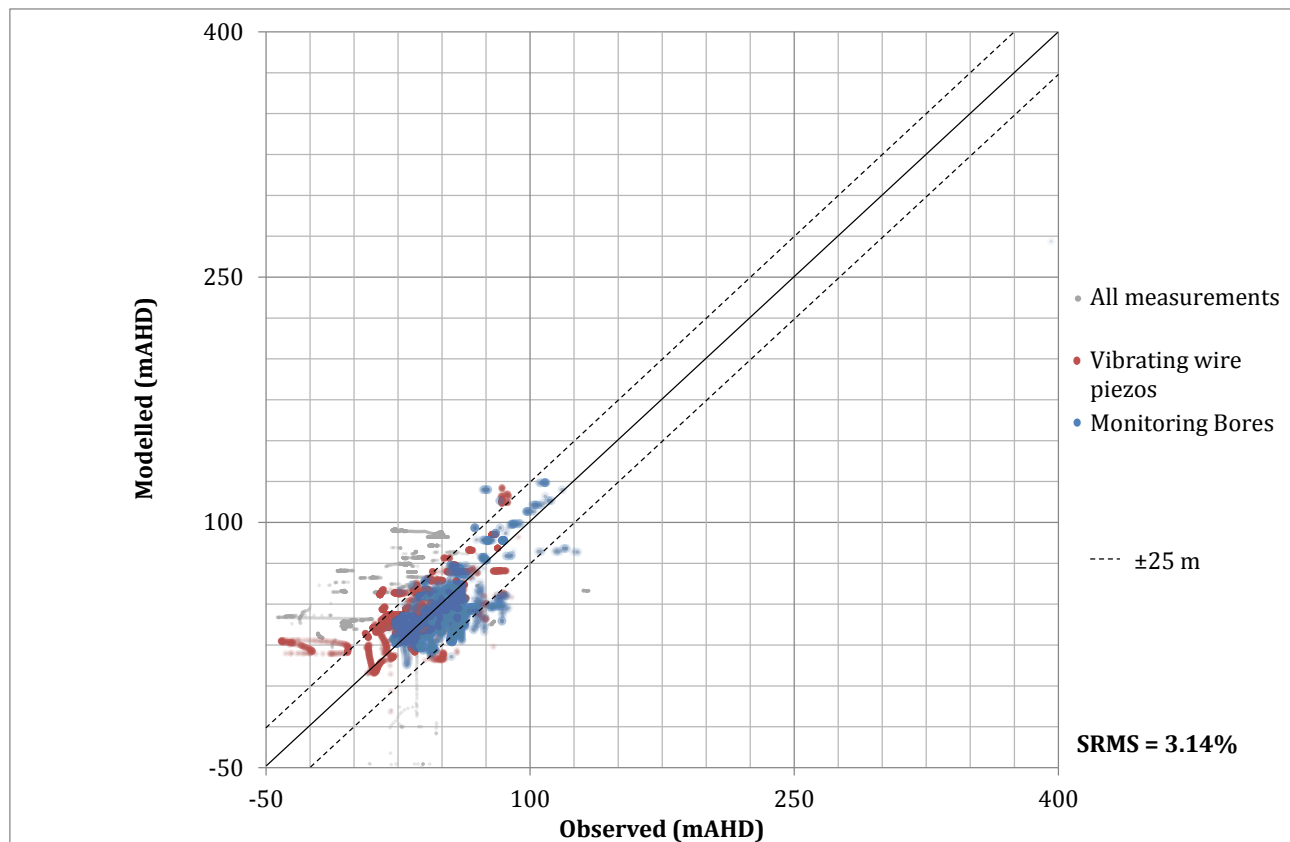


**Figure B- 6 Transient calibration – modelled vs observed groundwater levels**

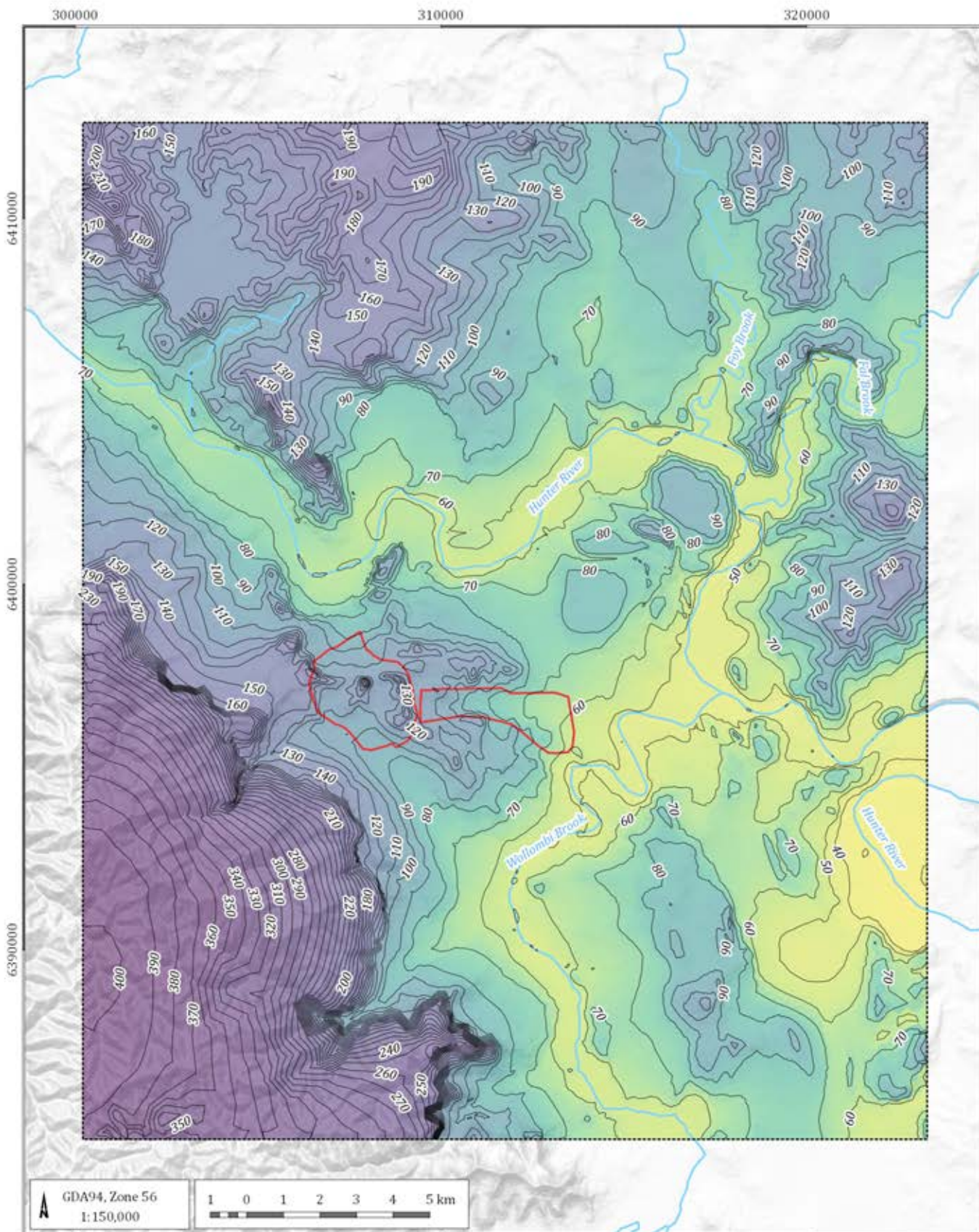
The root mean square (RMS) error calculated for the calibrated model was 13.66m. The total measured head change across the model domain was 434.49m, with a standardised RMS (SRMS) of 3.14%, indicating a good calibration. Excluding bore GW064382, which is located within the Narrabeen Group sandstones within Wollemi National Park, reduces the range in measured head to 159.53m. This results in an SRMS of 8.55%, which still indicates a good match between measured and simulated water levels. It should be noted that 82% of all available groundwater measurements were used in the calibration. It was deemed that 18% of the observations were detrimental to the calibration process, as they were representative of micro groundwater processes a regional model of this size was not able to replicate.

Appendix B1 includes a table of calibration target details and residuals, as well as hydrographs from the transient calibration model. Generally, the model has replicated the complex response to the numerous mining activities over the 45 year calibration period. In some instances the model does not replicate water level changes in the groundwater system, and this is most likely due to the limits on information for historic mining across the model domain. However, it is considered the major responses to depressurisation from longwall mining and open cut mining have been replicated adequately to meet the modelling objectives. Groundwater level responses to seasonal fluctuations have also been replicated, which is most evident in the hydrographs (Appendix B1) for bores within the Hunter River alluvium (i.e. PZCH bores).

### *B3.2.1 Calibration heads*

The calibrated heads from the steady state calibration model are presented in Figure B- 7 and Figure B- 8 for the unconsolidated sediments (alluvium and regolith) and coal seams (Arrowfield and Vaux seams) respectively. The figures show groundwater generally flows northeast to the local drainage systems without the presence of active open-cut and longwall mining.

The calibrated heads at the end of the transient calibration model (2015) are presented in Figure B- 9 and Figure B- 10 for the unconsolidated sediments (alluvium and regolith) and coal seams (Arrowfield and Vaux seams) respectively. Groundwater levels representing 2015 conditions show the depressurised zones within the potentiometric surface caused by the advancement of mining since 2003. Depressurisation within the Arrowfield Seam reflects the recent completion of mining at the United Underground, as well as open cut operations at HVO and MTW. Figure B- 10 also shows depressurisation within the Vaux Seam, which relates to current mining of the seam at HVO South (Cheshunt Pit), as well as minor influence from mining of the shallower Warkworth Seam at MTW.



#### LEGEND

- Proposed extraction area
- Model extent
- Major drainage
- Predicted groundwater level contours (mAHD, 10m interval)

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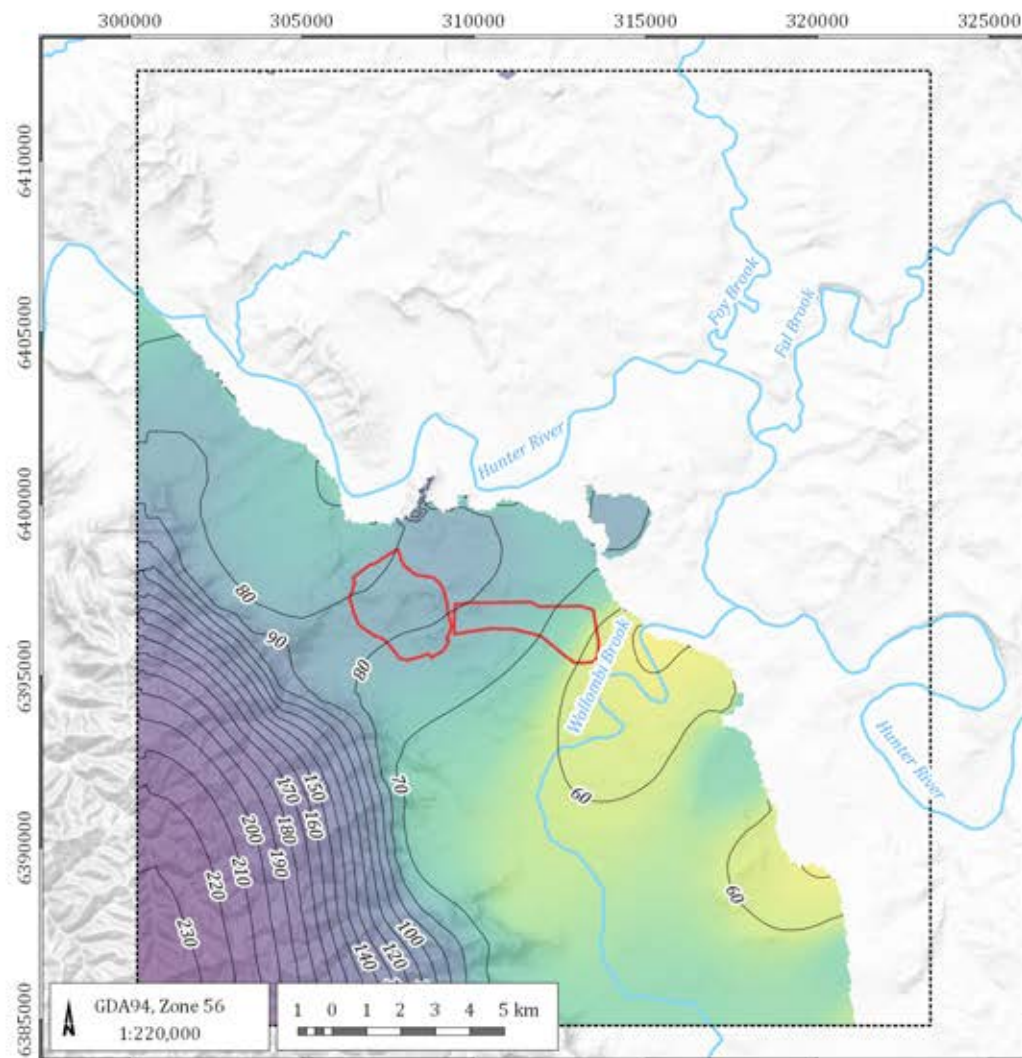
#### Predicted pre-mining groundwater levels - alluvium and regolith



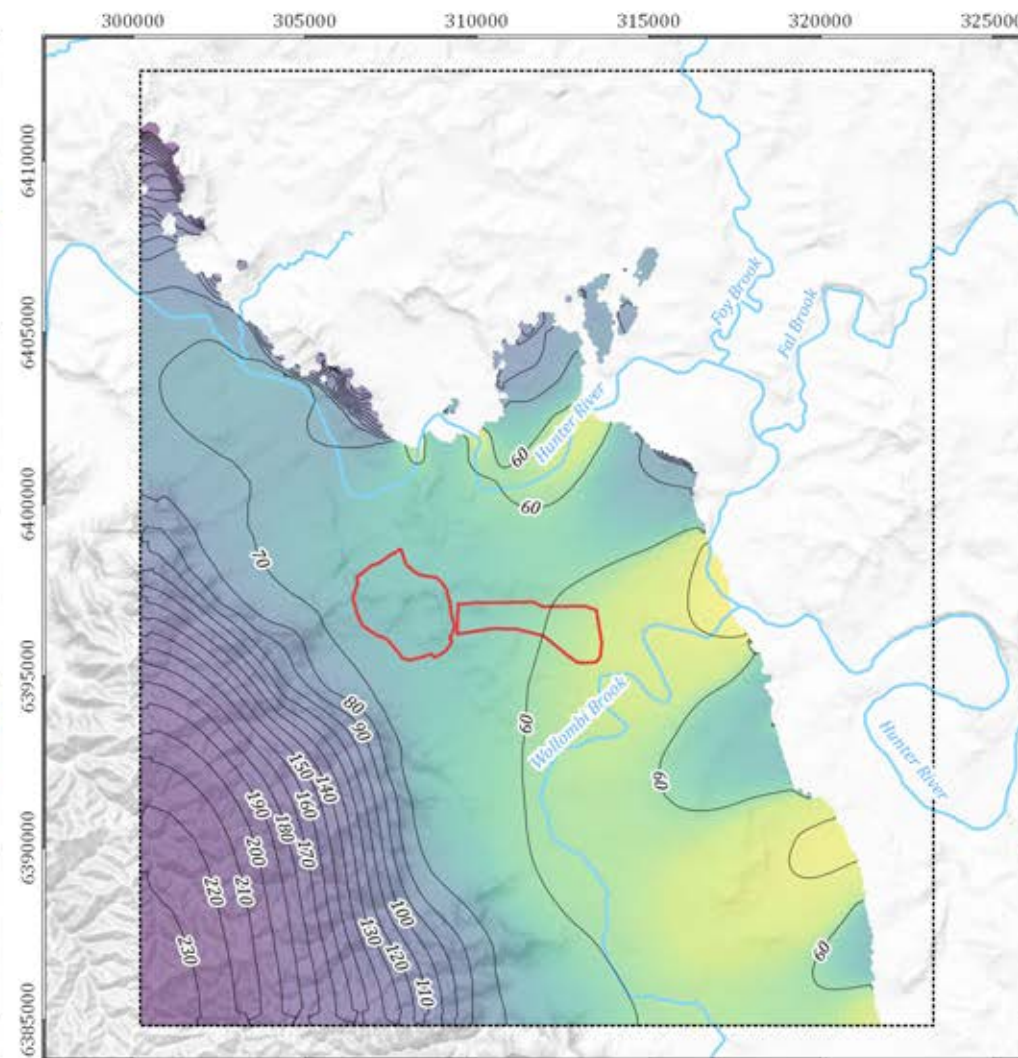
DATE  
15/01/2016

FIGURE No:  
**B-7**

## Arrowfield Seam



## Vaux Seam



### LEGEND

- Proposed extraction area
- Model extent
- Major drainage
- Predicted groundwater level contours (mAHD, 10m interval)

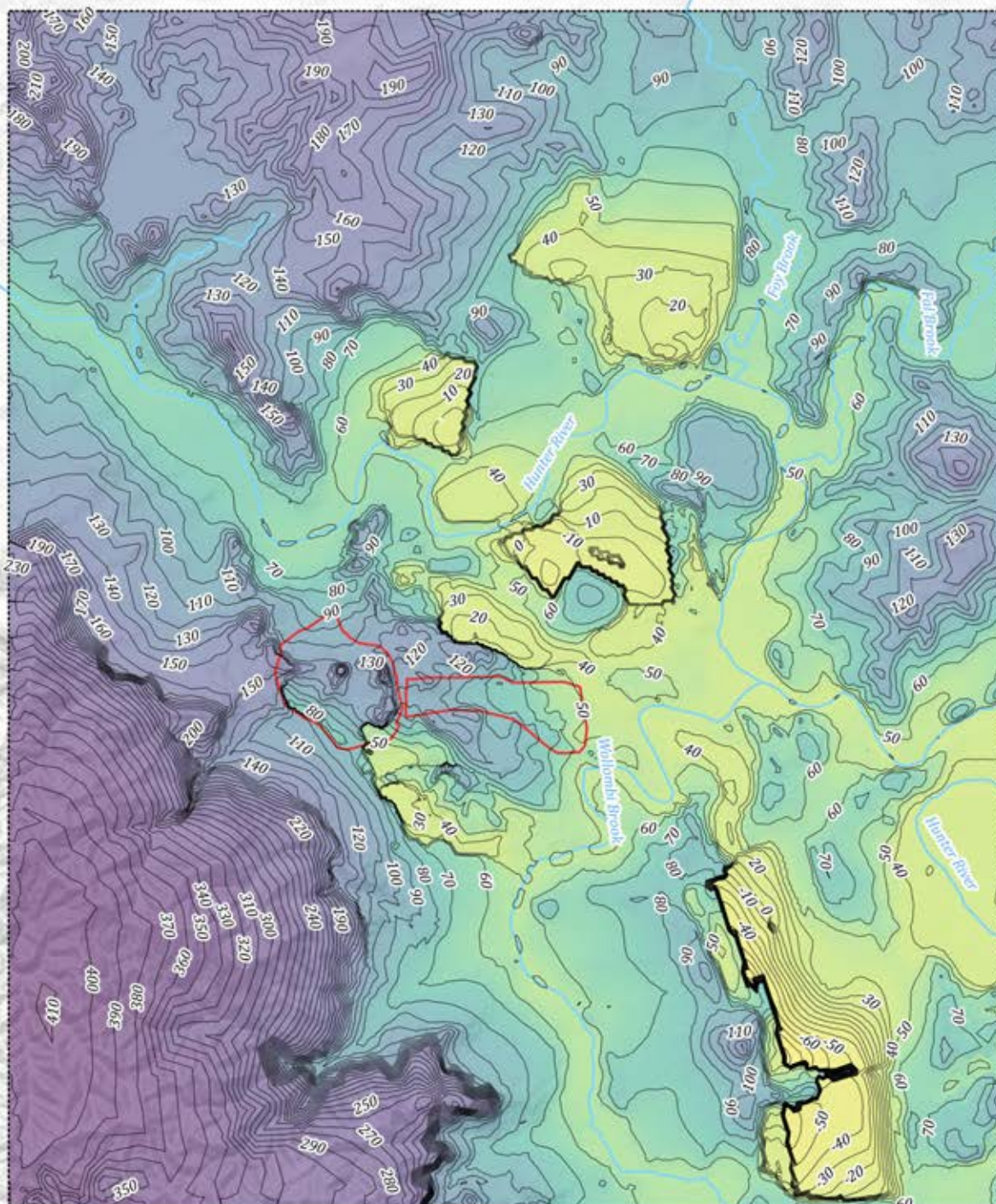


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**Predicted pre-mining groundwater  
levels - Arrowfield and Vaux seams**

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FIGURE No:  
**B-8**



GDA94, Zone 56  
1:150,000

1 0 1 2 3 4 5 km

#### LEGEND

- Proposed extraction area
- Model extent
- Major drainage
- Predicted groundwater level contours (mAHd, 10m interval)

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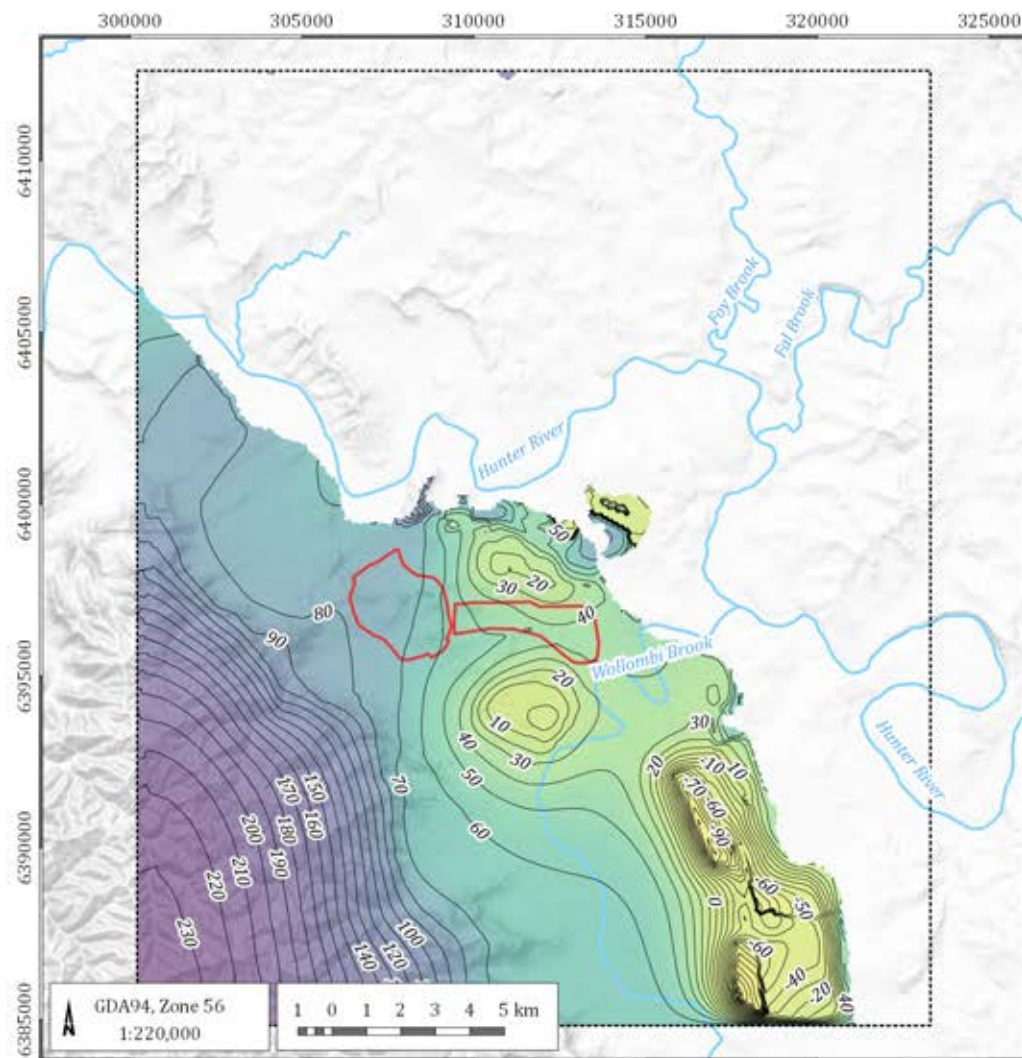
**Predicted groundwater levels (2015) -  
alluvium and regolith**



DATE  
15/01/2016

FIGURE No:  
**B-9**

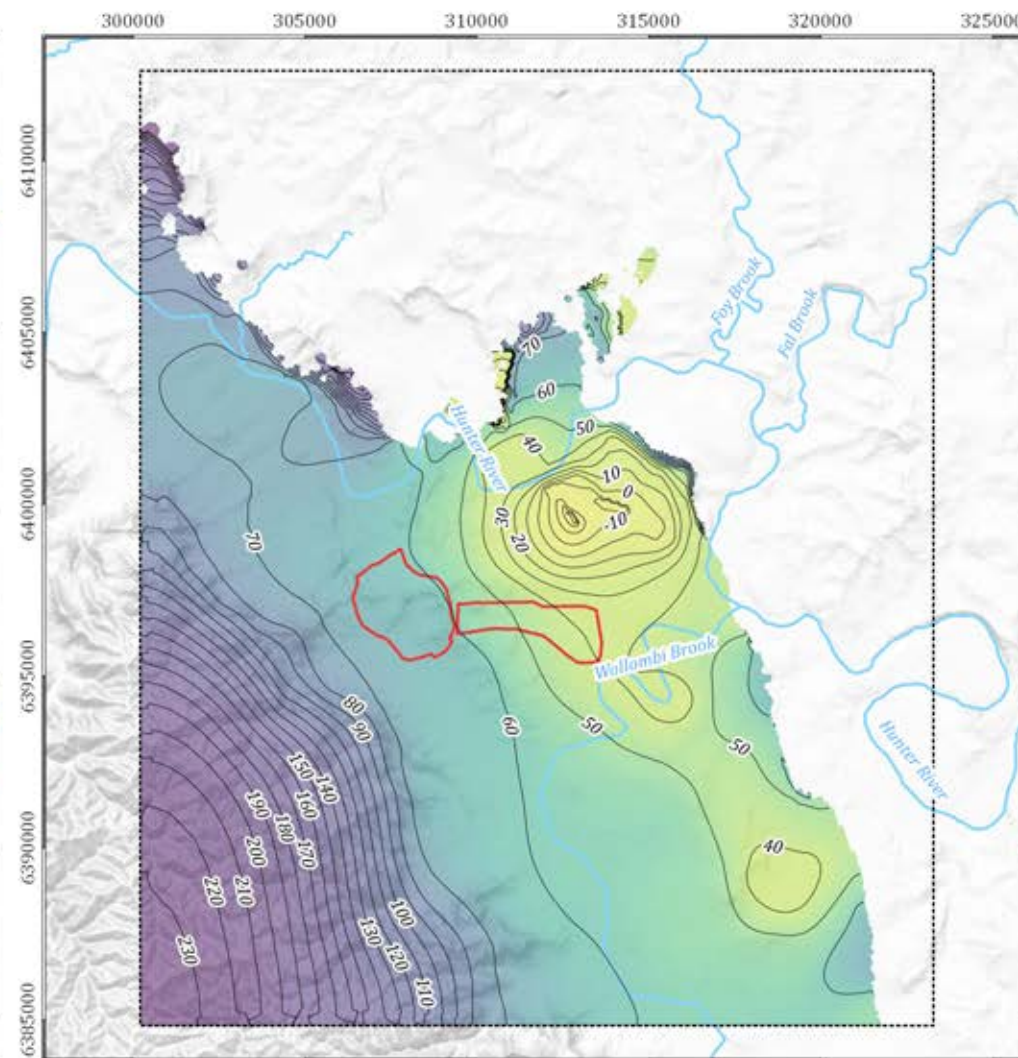
## Arrowfield Seam



### LEGEND

- Proposed extraction area
- Model extent
- Major drainage
- Predicted groundwater level contours (mAHD, 10m interval)

## Vaux Seam



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**Predicted groundwater levels (2015) -  
Arrowfield and Vaux seams**

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FIGURE No:  
**B-10**



### B3.2.2 Hydraulic parameters

Table B-5 summarises the calibrated maximum hydraulic conductivity for each of the hydrostratigraphic units within the model domain. Table B-5 presents the set hydraulic conductivity values for Layers 1, 2, 3 and 5. The hydraulic properties of the coal measures (Layer 4 and Layers 6 to 35) change with depth. Therefore, the values presented for the coal and interburden in Table B-5 are the uppermost hydraulic conductivity value for each layer. The relationship with depth is further discussed below.

**Table B-5 Calibrated hydraulic conductivity values (at surface)**

| Model layer | Lithology                                  | Horizontal hydraulic conductivity (m/day)* | Vertical hydraulic conductivity multiplier |
|-------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|
| 1,2         | Less productive alluvium (Qa)              | 1.0                                        | $1.00 \times 10^{-2}$                      |
| 1,2         | Colluvium / regolith                       | 0.5                                        | $5.00 \times 10^{-2}$                      |
| 1           | Highly productive alluvium (Qa)            | 2.13                                       | $5.98 \times 10^{-1}$                      |
| 2           | Highly productive alluvium (basal gravels) | 10                                         | $5.00 \times 10^{-2}$                      |
| 3           | Narrabeen Group                            | $7.24 \times 10^{-3}$                      | $5.00 \times 10^{-2}$                      |
| 4           | Newcastle Coal Measures                    | $1.19 \times 10^{-2}$                      | $2.78 \times 10^{-2}$                      |
| 5           | Watts Sandstone                            | $5.0 \times 10^{-3}$                       | $5.00 \times 10^{-1}$                      |
| 6           | Sandstone / siltstone / shale              | $5.66 \times 10^{-3}$                      | $5.10 \times 10^{-2}$                      |
| 7           | Whybrow Seam                               | $5.83 \times 10^{-1}$                      | $1.28 \times 10^{-2}$                      |
| 8           | Sandstone / siltstone / shale              | $9.82 \times 10^{-3}$                      | $1.11 \times 10^{-1}$                      |
| 9           | Wambo Seam                                 | $6.87 \times 10^{-1}$                      | $1.90 \times 10^{-2}$                      |
| 10          | Sandstone / siltstone / shale              | $9.83 \times 10^{-3}$                      | $1.49 \times 10^{-1}$                      |
| 11          | Whynot Seam                                | $7.88 \times 10^{-1}$                      | $1.88 \times 10^{-2}$                      |
| 12          | Sandstone / siltstone / shale              | $8.92 \times 10^{-3}$                      | $1.08 \times 10^{-1}$                      |
| 13          | Blakefield Seam                            | $6.44 \times 10^{-1}$                      | $1.98 \times 10^{-2}$                      |
| 14          | Sandstone / siltstone / shale              | $3.53 \times 10^{-3}$                      | $4.74 \times 10^{-2}$                      |
| 15          | Glen Munro Seam                            | $1.83 \times 10^{-1}$                      | $2.06 \times 10^{-2}$                      |
| 16          | Sandstone / siltstone / shale              | $1.18 \times 10^{-2}$                      | $1.18 \times 10^{-1}$                      |
| 17          | Woodlands Hill Seam                        | $6.39 \times 10^{-1}$                      | $2.06 \times 10^{-2}$                      |
| 18          | Sandstone / siltstone / shale              | $2.34 \times 10^{-2}$                      | $1.02 \times 10^{-1}$                      |
| 19          | Arrowfield Seam                            | 1.55                                       | $2.00 \times 10^{-2}$                      |
| 20          | Sandstone / siltstone / shale              | $1.31 \times 10^{-2}$                      | $1.47 \times 10^{-1}$                      |
| 21          | Bowfield Seam (localised split)            | $7.13 \times 10^{-1}$                      | $2.10 \times 10^{-2}$                      |
| 22          | Siltstone / shale (interburden)            | $1.31 \times 10^{-2}$                      | $1.22 \times 10^{-1}$                      |
| 23          | Warkworth Seam                             | 1.25                                       | $2.08 \times 10^{-2}$                      |
| 24          | Siltstone / shale (interburden)            | $5.74 \times 10^{-3}$                      | $6.14 \times 10^{-2}$                      |
| 25          | Mt Arthur Seam                             | 1.46                                       | $2.09 \times 10^{-2}$                      |
| 26          | Siltstone / shale (interburden)            | $9.18 \times 10^{-3}$                      | $1.19 \times 10^{-1}$                      |
| 27          | Piercefield Seam                           | $7.37 \times 10^{-1}$                      | $2.14 \times 10^{-2}$                      |
| 28          | Siltstone / shale (interburden)            | $1.91 \times 10^{-2}$                      | $1.27 \times 10^{-1}$                      |
| 29          | Vaux Seam                                  | $5.16 \times 10^{-1}$                      | $3.46 \times 10^{-2}$                      |
| 30          | Siltstone / shale (interburden)            | $3.97 \times 10^{-3}$                      | $1.90 \times 10^{-1}$                      |

| Model layer | Lithology                       | Horizontal hydraulic conductivity (m/day)* | Vertical hydraulic conductivity multiplier |
|-------------|---------------------------------|--------------------------------------------|--------------------------------------------|
| 31          | Broonie Seam                    | 2.05                                       | $2.06 \times 10^{-2}$                      |
| 32          | Siltstone / shale (interburden) | $2.73 \times 10^{-2}$                      | $2.00 \times 10^{-1}$                      |
| 33          | Bayswater Seam                  | $1.70 \times 10^{-1}$                      | $2.49 \times 10^{-2}$                      |
| 34          | Siltstone / shale (interburden) | $1.11 \times 10^{-2}$                      | $2.00 \times 10^{-1}$                      |
| -           | Spoil                           | 1.00                                       | $1.00 \times 10^{-1}$                      |

**Note:** \* upper hydraulic conductivity derived from depth of 20 m below surface and using dependence formula

Figure B- 11 compares the distribution of available field hydraulic conductivity (horizontal) data against the modelled hydraulic conductivity for each unit at 20m below surface. It should be noted that the depth interval for the field data is variable, with some units (i.e. Wambo Seam underburden) only having available data at depths of over 200m. Accounting for the limitations of the available field data, Figure B- 11 graphically shows a relatively good match between the field data and the model parameters.

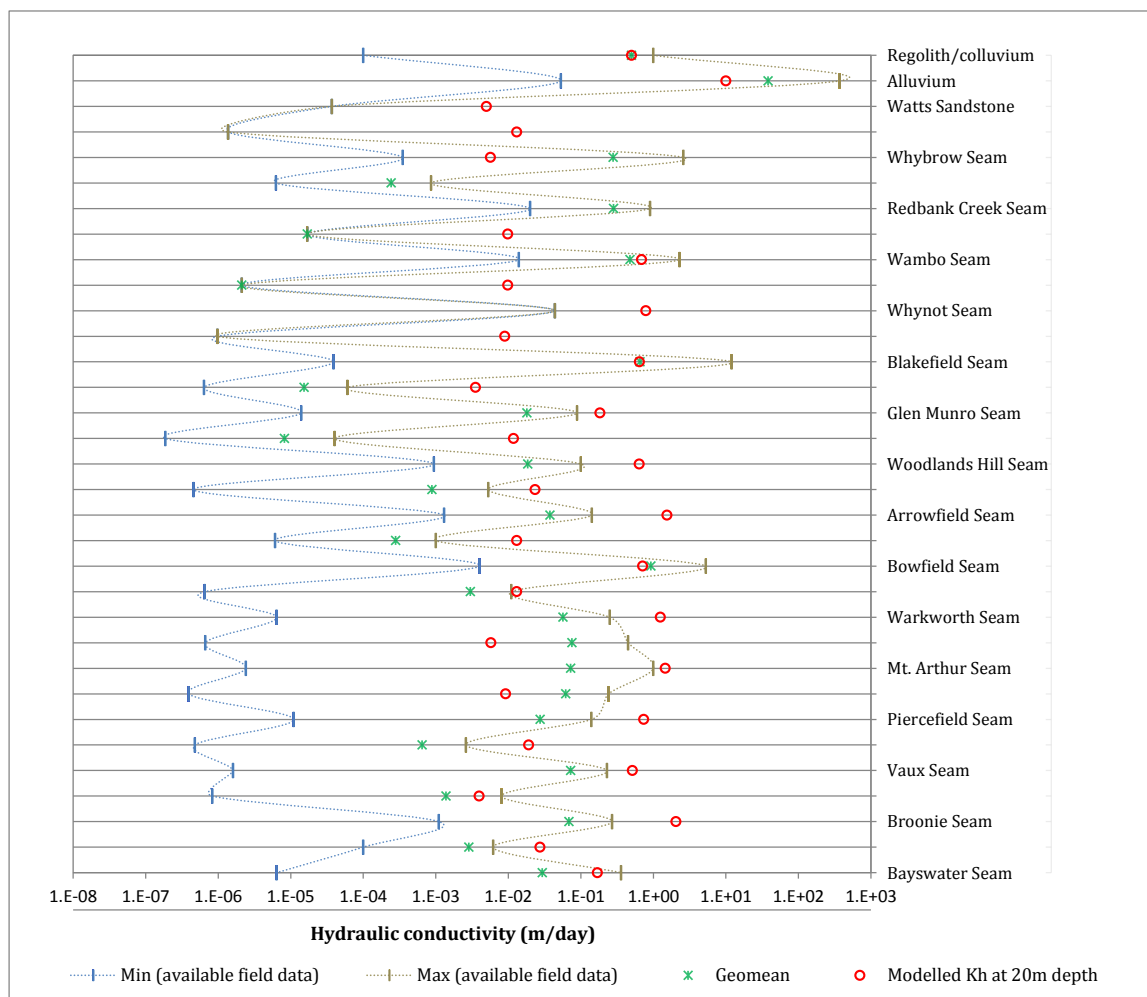


**Figure B- 11 Hydraulic conductivity distribution graph**

The hydraulic conductivity of the Permian interburden (conglomerate, siltstone and sandstone) material in the model reduces with depth in order to reflect field observations. Because the decrease of Kh within the interburden rock units is driven by an increase in overburden pressure, the relationship between Kh and depth is different from that of coal seams. The hydraulic conductivity for the interburden material is capped at a minimum between  $4.8 \times 10^{-7}$  m/day and  $7.4 \times 10^{-7}$  m/day and the hydraulic conductivity of the coal seams is capped at a minimum between  $5 \times 10^{-7}$  m/day and  $2.0 \times 10^{-6}$  m/day.

The hydraulic conductivity of the coal seam and interburden layers decreases with depth according to Equations 1 (exponential) and 2 (power):

Coal:  $HC = HC_0 \times e^{(slope \times depth)}$  (Eq. 1)

Interburden:  $HC = HC_0 \times depth^{slope}$  (Eq. 2)

Where: *HC* is horizontal hydraulic conductivity at specific depth.  
*HC<sub>0</sub>* is horizontal hydraulic conductivity at depth of 0m (intercept of the curve).  
*depth* is depth of the floor of the layer (thickness of the cover material).  
*slope* is a term representing slope of the formula (steepness of the curve).

The slope function and coefficient of the coal and interburden depth dependence equations were calibrated. The Kh vs. depth relationship for the individual coal seams are presented in Figure B- 12, while the calibrated relationship for interburden units is presented in Figure B- 13.

As shown in Figure B- 12 and Figure B- 13, the calibrated depth dependence trends for the various coal and interburden layers largely follow the averaged trend identified for the available field data within the main report.

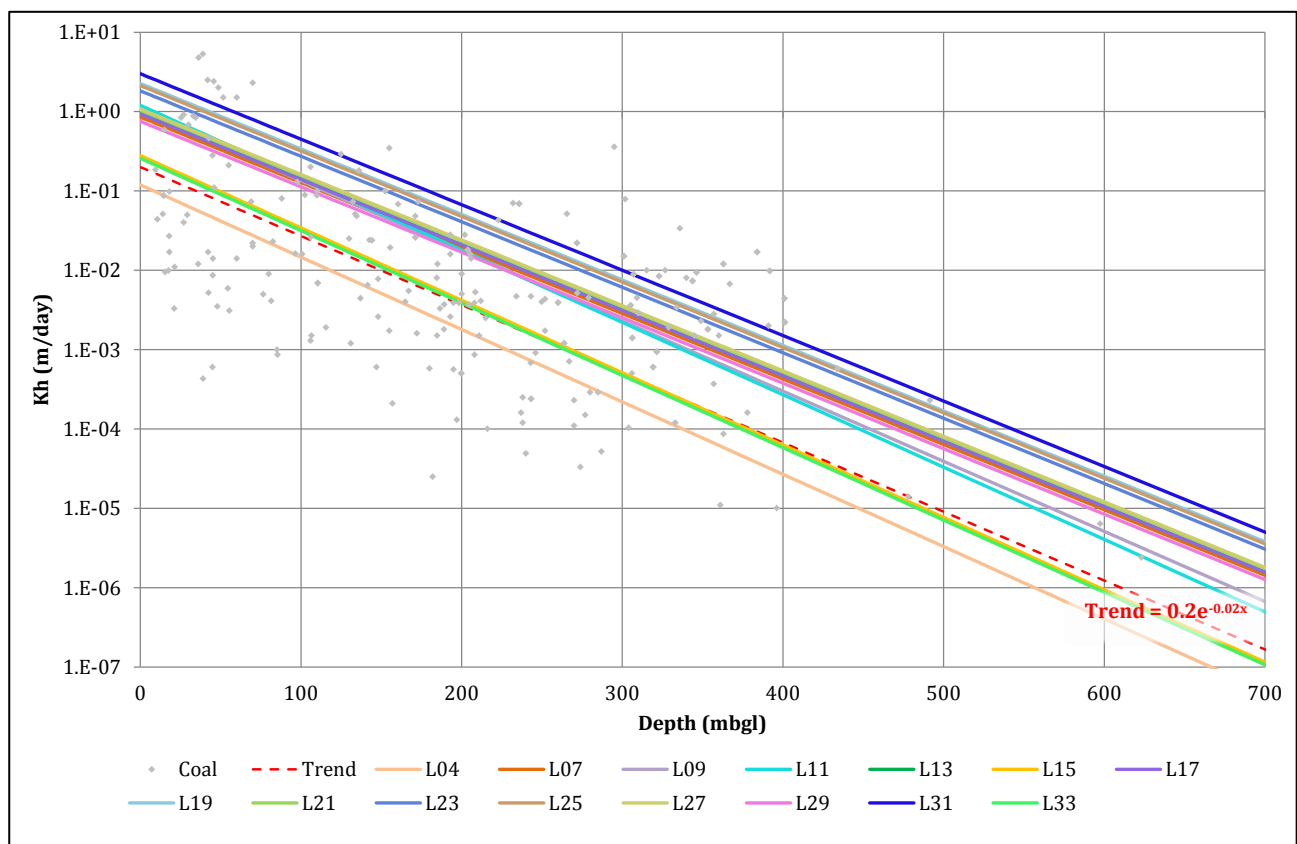


**Figure B- 12 Hydraulic conductivity vs. depth – coal layers**

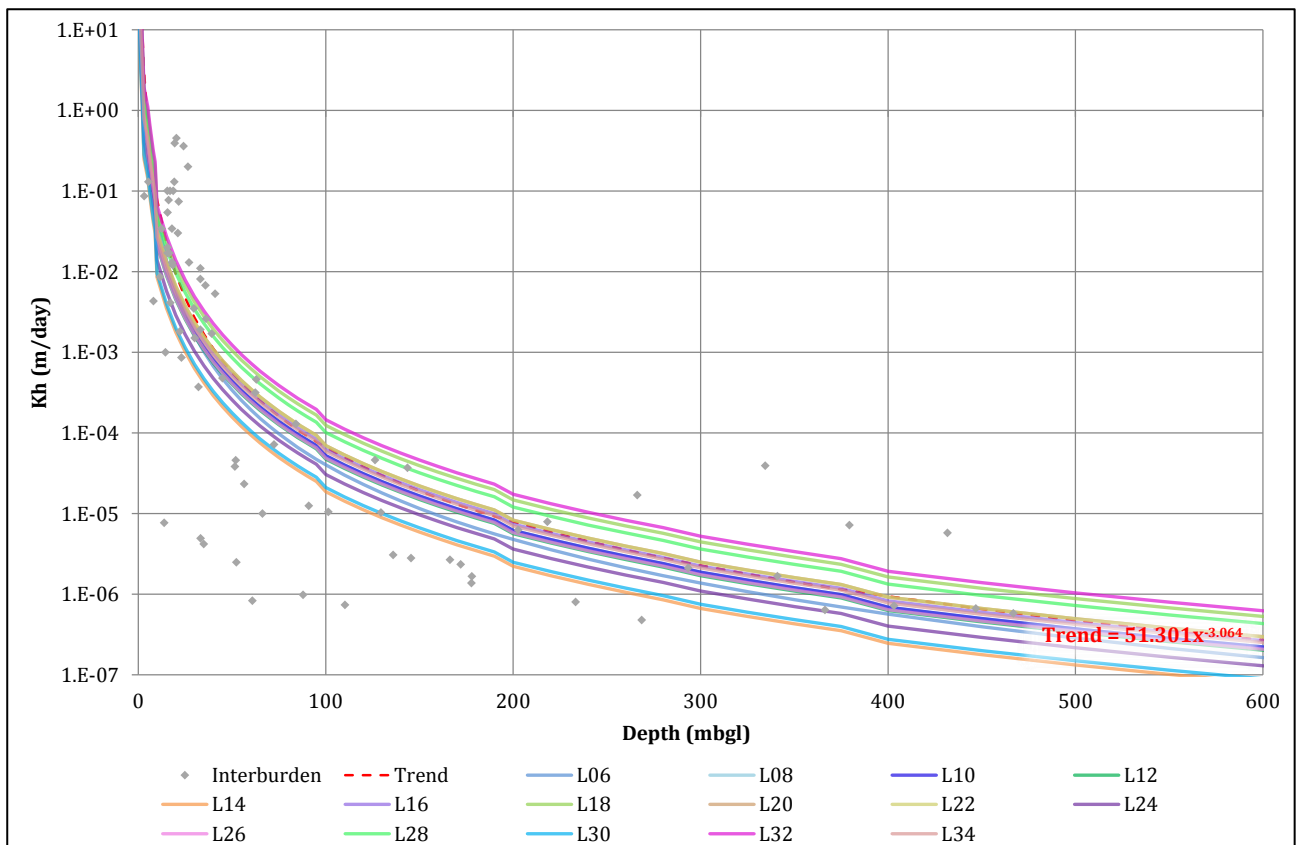
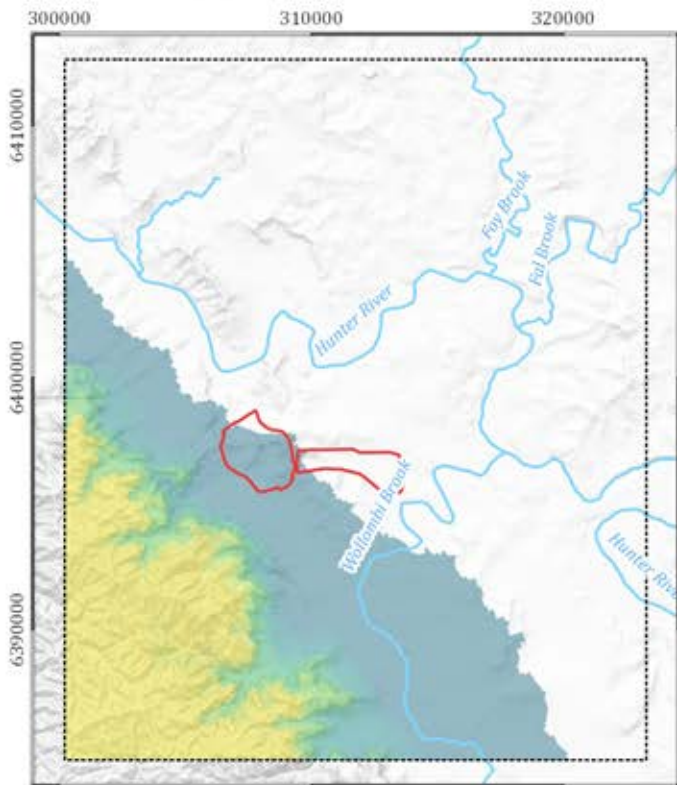


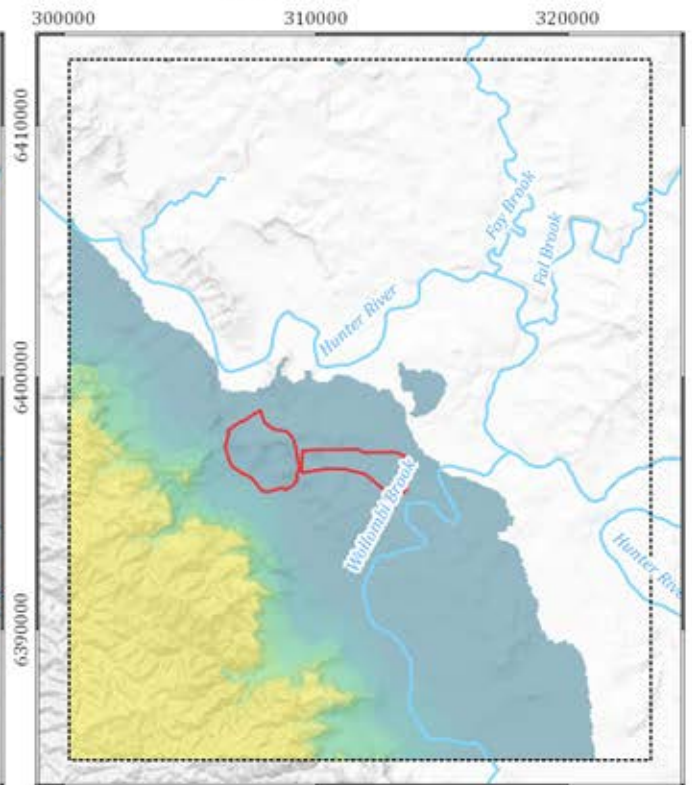
**Figure B- 13                      Hydraulic conductivity vs. depth – interburden layers**

In order to demonstrate the application of the depth dependence function, the spatial distribution of hydraulic conductivity values is presented in Figure B- 14 for a selection of layers. Figure B- 14 shows a decline in hydraulic conductivity towards the south-west, which corresponds with the general dip of the coal measures.

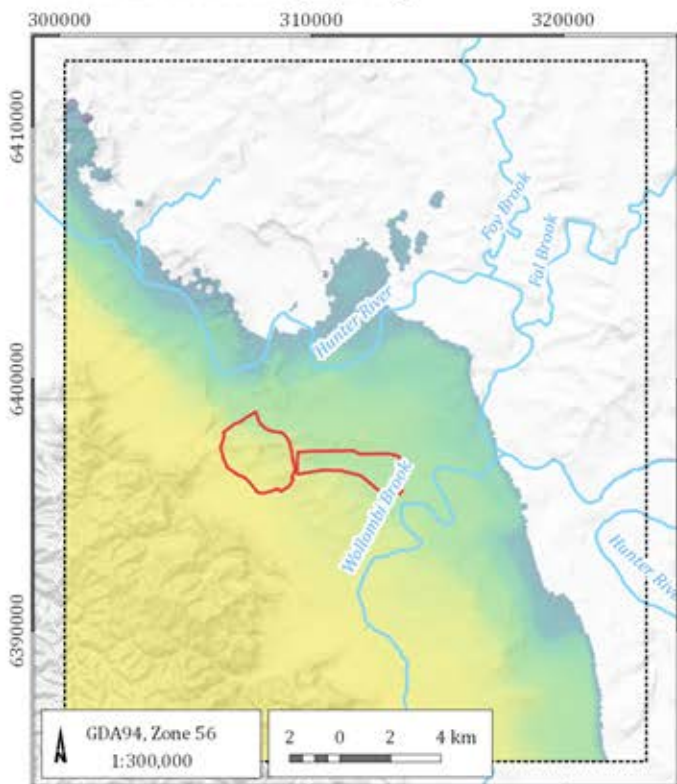
**Wambo Seam (Layer 9)**



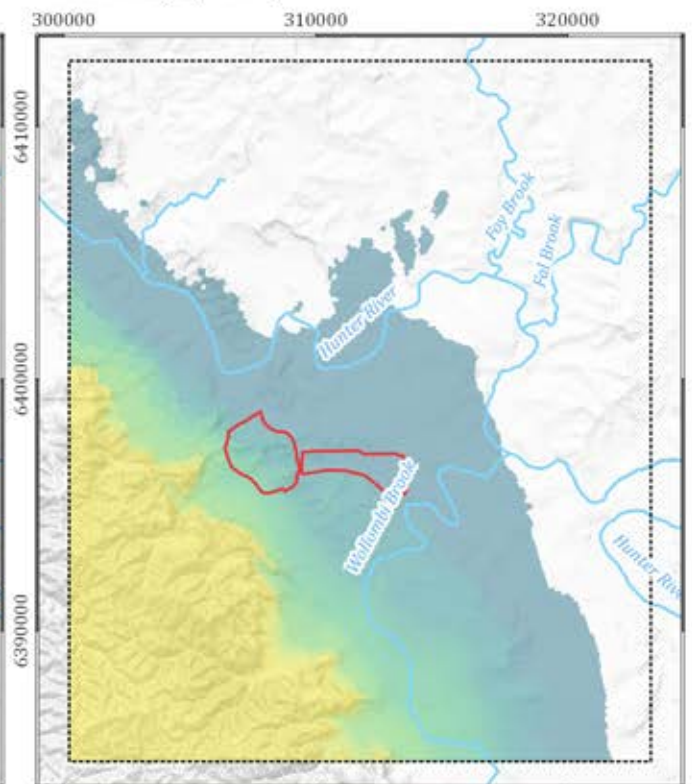
**Arrowfield Seam (Layer 19)**



**Vaux Seam overburden (Layer 28)**



**Vaux Seam (Layer 29)**



**LEGEND**

- Model extent
- Project area
- Major drainage
- Minor drainage

**Hydraulic conductivity (m/day)**

- 30
- 1
- $1.0 \times 10^{-2}$
- $1.0 \times 10^{-3}$
- $1.0 \times 10^{-4}$
- $1.0 \times 10^{-5}$
- $1.0 \times 10^{-7}$

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**Modelled hydraulic conductivity spatial distribution**



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FIGURE No:  
**B-14**

Table B-6 shows the changes to the vertical hydraulic conductivity made during calibration of the transient model.

**Table B-6 TVM fractured parameters**

| Parameter       | Fracture height (m) | Vertical Hydraulic conductivity (m/day) |
|-----------------|---------------------|-----------------------------------------|
| Goaf            | 0                   | $5.30 \times 10^{-2}$                   |
| Fracture zone 1 | 12.5                | $1.52 \times 10^{-2}$                   |
| Fracture zone 2 | 25                  | $5.63 \times 10^{-3}$                   |
| Fracture zone 3 | 50                  | $1.95 \times 10^{-3}$                   |
| Fracture zone 4 | 78                  | $6.98 \times 10^{-4}$                   |
| Fracture zone 5 | 110                 | $1.40 \times 10^{-4}$                   |

The maximum fracture height (110m) was based on the average panel width from the numerous panels within the model domain and multiplied by a factor 0.4x to estimate the connective fracturing height. Vertical hydraulic conductivity within the fracture zone was applied using a ramping function, which was optimised during the calibration process. The vertical fracture changes were applied immediately above the active longwall drain cells using a logarithmic increase during the first stress period. Once the drain cells were removed, changes to horizontal hydraulic conductivity, specific yield and specific storage parameters in the goaf zone were applied to the coal seam layer only at 0.01m/day, 20% and  $1 \times 10^{-4} \text{ m}^{-1}$  respectively. Parameters for the overlying fracture zone layers maintain the perturbed Kz values assigned during active mining. If the fracture zone extends into previously fractured strata, the overlying layers remain fractured with perturbed Kz values.

### B3.2.3 Storage properties

Table B-7 summarises the calibrated values for specific storage and specific yield.

**Table B-7 Model layer storage properties**

| Model layer | Lithology                                              | Specific yield - Sy                            | Specific storage - Ss ( $\text{m}^{-1}$ )      |
|-------------|--------------------------------------------------------|------------------------------------------------|------------------------------------------------|
| 1           | Colluvium / regolith and less productive alluvium (Qa) | $3.00 \times 10^{-2}$ to $6.00 \times 10^{-2}$ | $3.00 \times 10^{-3}$ to $3.10 \times 10^{-4}$ |
| 2           | Productive alluvium (basal gravels)                    | $3.00 \times 10^{-2}$ to $7.00 \times 10^{-2}$ | $3.00 \times 10^{-3}$ to $2.78 \times 10^{-4}$ |
| 3           | Narrabeen Group                                        | $2.9 \times 10^{-2}$                           | $1.65 \times 10^{-4}$                          |
| 4           | Newcastle Coal Measures                                | $7.00 \times 10^{-3}$                          | $2.86 \times 10^{-4}$                          |
| 5           | Watts Sandstone                                        | $9.00 \times 10^{-3}$                          | $1.65 \times 10^{-4}$                          |
| 6           | Sandstone / siltstone / shale                          | $6.00 \times 10^{-3}$                          | $3.40 \times 10^{-5}$                          |
| 7           | Whybrow Seam                                           | $8.69 \times 10^{-3}$                          | $3.12 \times 10^{-4}$                          |
| 8           | Sandstone / siltstone / shale                          | $6.53 \times 10^{-3}$                          | $5.21 \times 10^{-5}$                          |
| 9           | Wambo Seam                                             | $6.18 \times 10^{-3}$                          | $3.73 \times 10^{-5}$                          |
| 10          | Sandstone / siltstone / shale                          | $5.65 \times 10^{-3}$                          | $7.18 \times 10^{-5}$                          |
| 11          | Whynot Seam                                            | $6.02 \times 10^{-3}$                          | $3.49 \times 10^{-5}$                          |

| Model layer | Lithology                       | Specific yield - Sy   | Specific storage - Ss (m <sup>-1</sup> ) |
|-------------|---------------------------------|-----------------------|------------------------------------------|
| 12          | Sandstone / siltstone / shale   | 5.05x10 <sup>-3</sup> | 6.20x10 <sup>-5</sup>                    |
| 13          | Blakefield Seam                 | 8.16x10 <sup>-3</sup> | 2.57x10 <sup>-5</sup>                    |
| 14          | Sandstone / siltstone / shale   | 7.48x10 <sup>-3</sup> | 5.71x10 <sup>-5</sup>                    |
| 15          | Glen Munro Seam                 | 5.29x10 <sup>-3</sup> | 3.20x10 <sup>-5</sup>                    |
| 16          | Sandstone / siltstone / shale   | 7.00x10 <sup>-3</sup> | 1.00x10 <sup>-4</sup>                    |
| 17          | Woodlands Hill Seam             | 5.07x10 <sup>-3</sup> | 3.38x10 <sup>-5</sup>                    |
| 18          | Sandstone / siltstone / shale   | 8.99x10 <sup>-3</sup> | 6.41x10 <sup>-5</sup>                    |
| 19          | Arrowfield Seam                 | 6.71x10 <sup>-3</sup> | 2.96x10 <sup>-5</sup>                    |
| 20          | Sandstone / siltstone / shale   | 6.20x10 <sup>-3</sup> | 3.78x10 <sup>-5</sup>                    |
| 21          | Bowfield Seam (localised split) | 6.35x10 <sup>-3</sup> | 2.78x10 <sup>-5</sup>                    |
| 22          | Sandstone / siltstone / shale   | 5.29x10 <sup>-3</sup> | 6.89x10 <sup>-5</sup>                    |
| 23          | Warkworth Seam                  | 6.61x10 <sup>-3</sup> | 3.08x10 <sup>-5</sup>                    |
| 24          | Sandstone / siltstone / shale   | 7.47x10 <sup>-3</sup> | 4.33x10 <sup>-5</sup>                    |
| 25          | Mt Arthur Seam                  | 6.07x10 <sup>-3</sup> | 2.79x10 <sup>-5</sup>                    |
| 26          | Sandstone / siltstone / shale   | 5.51x10 <sup>-3</sup> | 6.21x10 <sup>-5</sup>                    |
| 27          | Piercefield Seam                | 5.51x10 <sup>-3</sup> | 2.81x10 <sup>-5</sup>                    |
| 28          | Sandstone / siltstone / shale   | 6.47x10 <sup>-3</sup> | 4.74x10 <sup>-5</sup>                    |
| 29          | Vaux Seam                       | 1.00x10 <sup>-2</sup> | 2.45x10 <sup>-5</sup>                    |
| 30          | Sandstone / siltstone / shale   | 7.05x10 <sup>-3</sup> | 6.05x10 <sup>-5</sup>                    |
| 31          | Broonie Seam                    | 6.01x10 <sup>-3</sup> | 2.76x10 <sup>-5</sup>                    |
| 32          | Sandstone / siltstone / shale   | 7.65x10 <sup>-3</sup> | 5.97x10 <sup>-5</sup>                    |
| 33          | Bayswater Seam                  | 1.00x10 <sup>-3</sup> | 2.78x10 <sup>-5</sup>                    |
| 34          | Sandstone / siltstone / shale   | 8.03x10 <sup>-3</sup> | 6.00x10 <sup>-5</sup>                    |
| -           | Spoil                           | 1.00x10 <sup>-1</sup> | 1.00x10 <sup>-3</sup>                    |

**Note:** Parameters used in the model are conservative estimates using a combination of field data, hydrogeological expertise and knowledge of the region.

Direct testing data are not generally available for specific storage (Ss) of coal seams or interburden. However, good estimates can be made based on Young's Modulus and porosity. For coal, Ss generally lies in the range  $5 \times 10^{-6} \text{ m}^{-1}$  to  $5 \times 10^{-5} \text{ m}^{-1}$ , and interburden is generally slightly higher than this due to the greater porosity (Mackie, 2009). The calibrated parameters for coal fall within these bounds.

### B3.2.4 Water budget

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0.00%. This value indicates that the model is stable and achieves an accurate numerical solution. Table B-8 shows the water budget for the steady state (pre-mining) model.

**Table B-8 Model budgets – steady state**

| Parameter             | In (ML/day) | Out (ML/day) | In - Out (ML/day) |
|-----------------------|-------------|--------------|-------------------|
| Rainfall recharge     | 31.1        | -            | 31.1              |
| River                 | 32.0        | 55.2         | -23.2             |
| Evapotranspiration    | -           | 4.9          | -4.9              |
| General head boundary | 18.6        | 21.6         | -3.0              |
| Total                 | 81.7        | 81.7         | 0.0               |

The water budget indicates that recharge to the groundwater system within the model averages 81.7ML/day, with approximately 55.2ML/day being discharged via surface drainage, and 4.9ML/day lost to evapotranspiration in areas where the water table is within 1.5m of the land surface. This value of evapotranspiration is comparatively low, namely because surface drainage via the river cells removes a significant portion of the total evapotranspiration in the model.

Table B-9 shows the average water budget for the transient calibration (1970 to 2015).

**Table B-9 Model budgets – transient calibration**

| Parameter          | In (ML/day) | Out (ML/day) | In - Out (ML/day) |
|--------------------|-------------|--------------|-------------------|
| Storage            | 17.5        | 18.7         | -1.2              |
| Rainfall recharge  | 36.3        | -            | 36.3              |
| River              | 27.3        | 46.6         | -19.3             |
| Evapotranspiration | -           | 2.4          | 2.4               |
| Wells              | -           | 0.1          | 0.1               |
| GHB                | 21.2        | 19.9         | 1.3               |
| Drains             | -           | 14.6         | 14.6              |
| Total              | 102.3       | 102.3        | 0                 |

The water budget indicates that the groundwater system slightly departs from steady state conditions because of extensive mining in the model domain. Recharge (rainfall and river leakage) within the model averages 36.3ML/day, with approximately 46.6ML/day being discharged via surface drainage surface. The differences between the steady state recharge rates are due to different climatic conditions during the transient calibration period (1970 to 2015) when compared to the annual average (steady state).

### B3.2.5 Baseflow verification

Figure B- 15 shows estimated baseflow at Wollombi Brook downstream of the mine at Warkworth (station 210004), compared to simulated baseflow. Flow out of the model domain is displayed as a negative value and observed baseflow was calculated using the Lyne and Hollick filter (1979).

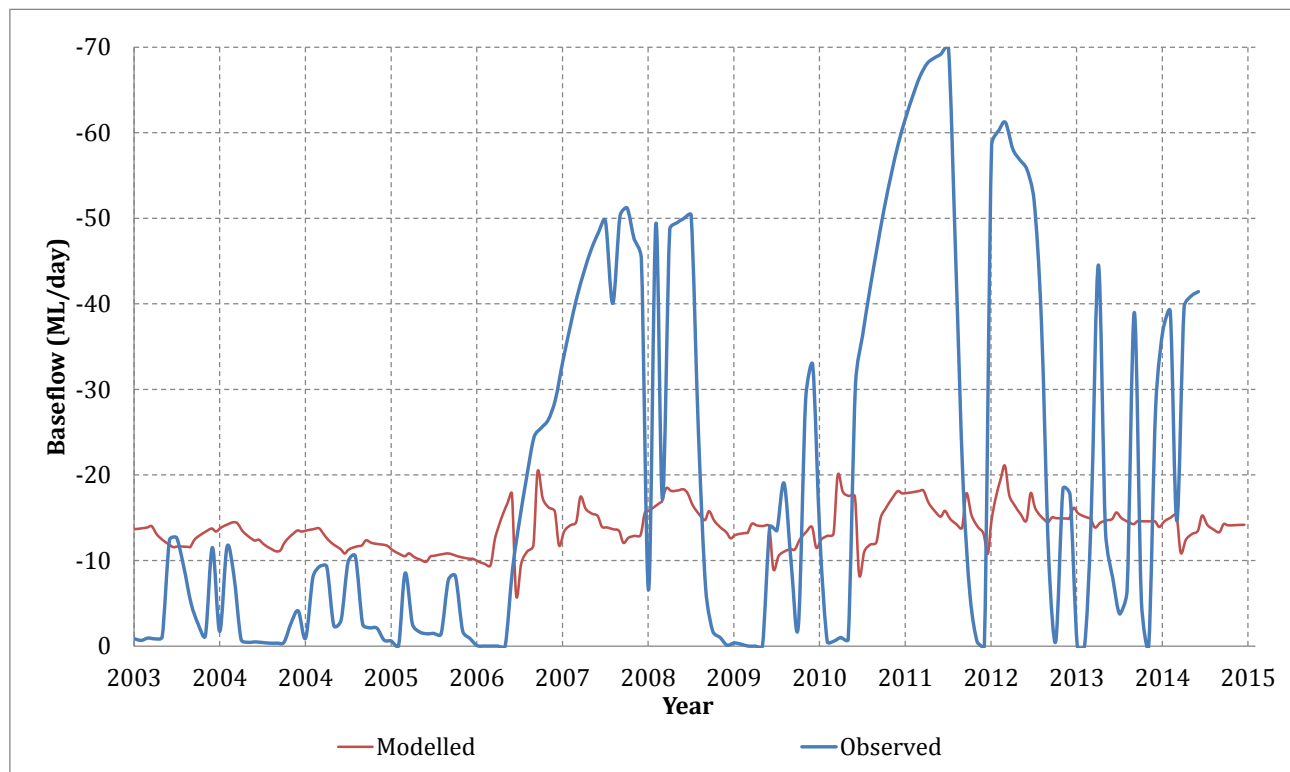


**Figure B- 15 Modelled vs observed baseflow analysis at Wollombi Brook**

The results show that the model is replicating the correct order of magnitude in baseflow rates at Wollombi Brook. It should be noted that this chart displays the modelled net baseflow component from the entire Wollombi Brook captured within the model domain, which is comprised of approximately 4ML/day of positive flux from river cells, and 18ML/day gaining conditions from the groundwater cells.

### B3.2.6 Mine inflow verification

The open-cut workings at United and Wambo are estimated to have had average inflows of less than 1ML/day, peaking at 5ML/day in 2015. The underground workings are estimated to have had average inflows of less than 1ML/day within each longwall mining areas, with peak short term inflows of 5ML/day from the Wambo Seam. These results are comparable with previous modelling for the underground workings by HydroSimulations (2014). HydroSimulations (2014) predicted inflows of less than 1ML/day from the Wambo Seam for the North Wambo Underground, and average inflows of 2ML/day from the Whybrow Seam for mining between 2008 and 2013.

### B3.2.7 Model parameter sensitivity and contribution

The calibration process employed the use of singular value decomposition assistance and regularisation of parameters. To indicate which parameters and observations were contributing to the calibrated solution, a linear analysis on the transient model (1970 to 2015) was performed.

One of the key impacts of this study is to assess the impact on the surrounding alluvium. The main objective of the calibration process is to replicate real world conditions so that the uncertainty of a particular impact is reduced to an acceptable level. To quantify the contribution each model parameter has on the interruption of flow to the alluvium (and consequently drawdown to bores and impacts on surface water systems), the amount of interrupted water flowing from the Permian to the alluvium during the transient model was analysed.

The information derived from this type of analysis allows us to quantify the benefit the calibration process has had on the uncertainty of the main objectives to this study. It also allows us to quantify the data worth of the observation targets used to calibrate the model.

#### B3.2.7.1 Identifiability

The linear analysis identified that there are 104 identifiable parameters in the transient calibration model. This means that achieving a calibrated solution is a very complex, non-linear problem, which is a result of the complex mining stresses and large number of hydrostratigraphic units in the model.

Figure B- 16 shows the identifiability of the key parameter groups in the transient calibration model. Identifiability is the capability of model calibration to constrain parameters used by the model, and is quantitatively defined as the direction cosine between a parameter and its projection onto the calibration solution space. Identifiability results range between zero and one, with zero indicating complete non-identifiability and one indicating complete identifiability (Doherty & Hunt, 1999).

The results show that horizontal hydraulic conductivity, diffuse rainfall recharge, and fracture vertical hydraulic conductivity are the most contributable parameters to the calibrated solution. As detailed in the main report and Section B3.2.2, extensive field data is available for the horizontal hydraulic conductivity of the Wittingham Coal Measures and alluvial units.

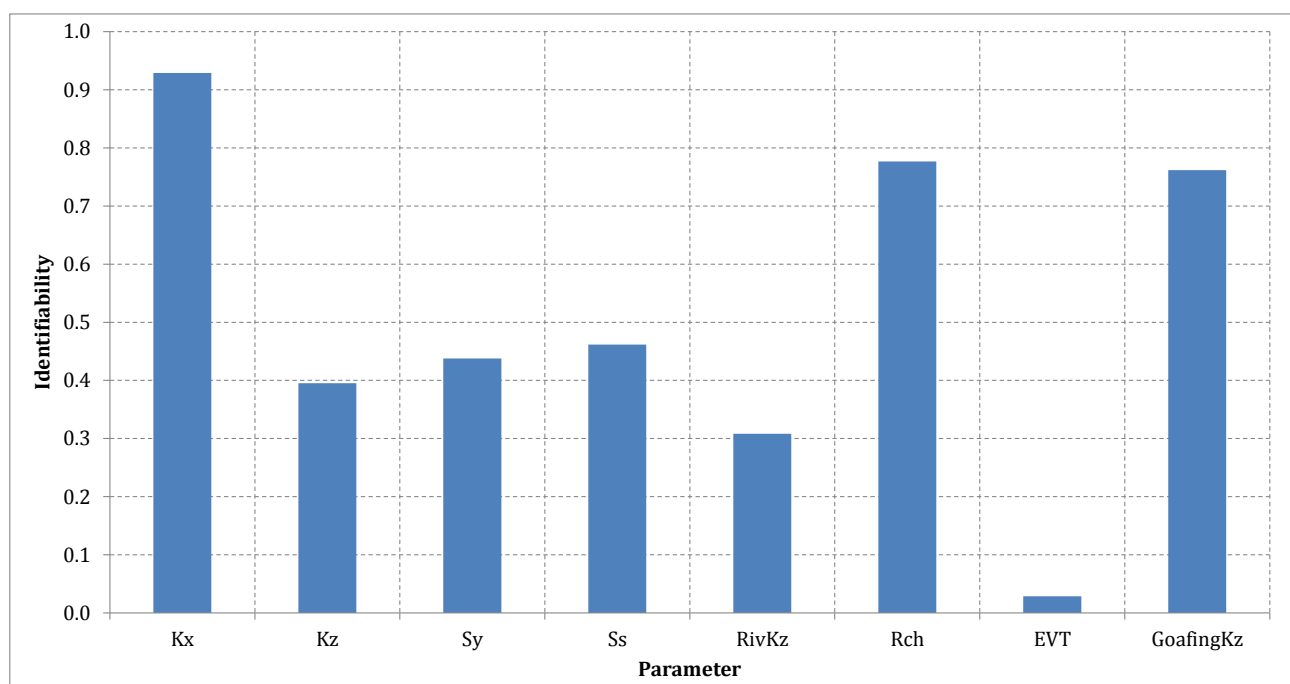


**Figure B- 16 Identifiability of parameter groups**

### B3.2.7.2 Calibration worth

The linear analysis also provides us with the reduction in uncertainty of impacts to the alluvial groundwater system, given the parameter bounds and changes to the objective function through the optimisation.

Figure B- 17 shows the reduction in the uncertainty of alluvial impacts through the calibration process. The results show changing a few key inputs has the greatest impact on reducing the uncertainty of alluvial groundwater impacts. These key inputs are diffuse recharge rates, goafing vertical fracture hydraulic conductivities, and horizontal hydraulic conductivity.

Figure B- 18 also shows a quantified representation in the benefit the calibration process has had on reducing the uncertainty of impacts to the alluvium during the calibration process. At a high level, Figure B- 18 shows a significant lowering of the total predictive error of alluvial flow transfer uncertainty within the calibrated dataset (indicated by the blue arrow) in m<sup>3</sup>/day, and illustrates the complexity of the calibrated model, indicated by a high number of identifiable parameters on the x-axis. This suggests that the information in the calibration dataset is sufficient to considerably lower the uncertainty of the impacts to the alluvium.

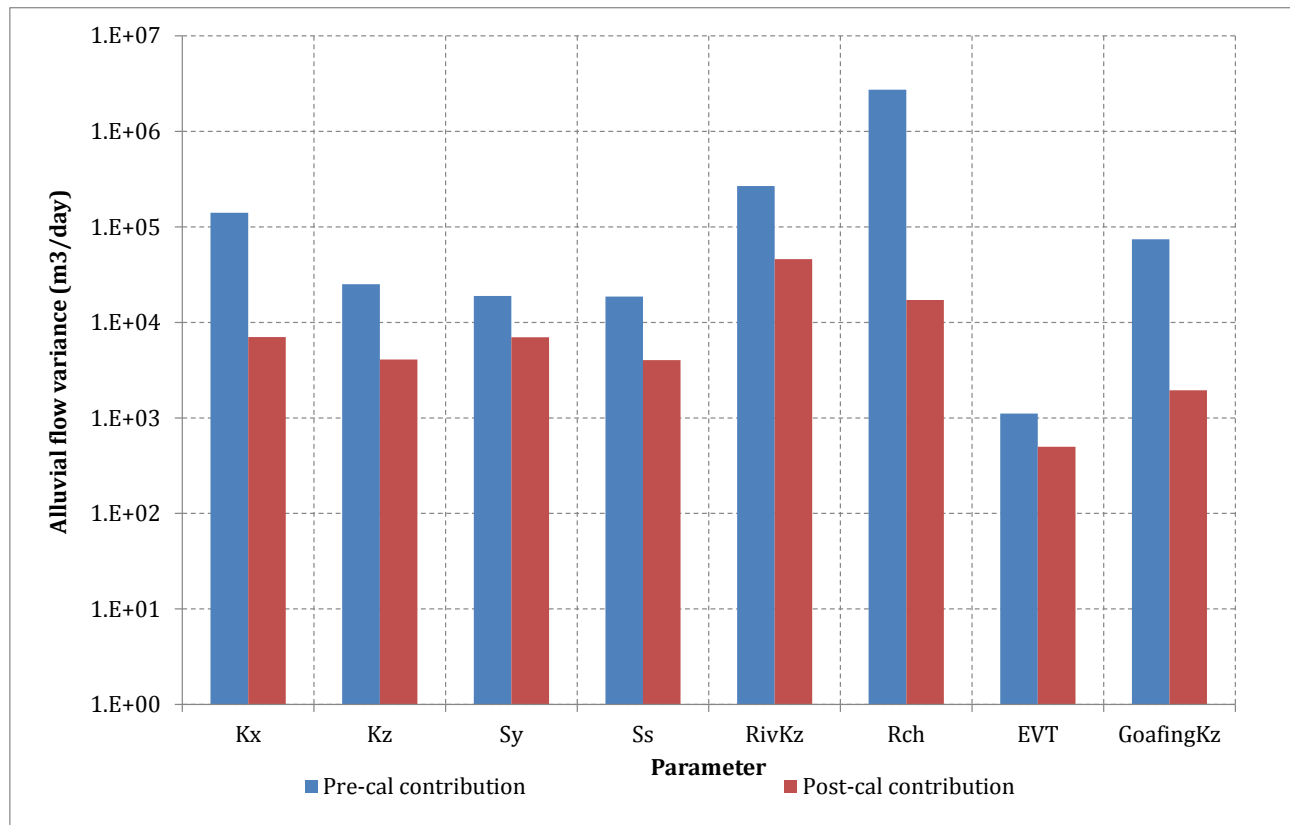


**Figure B- 17**                      **Reduction in alluvial flow uncertainty through calibration**

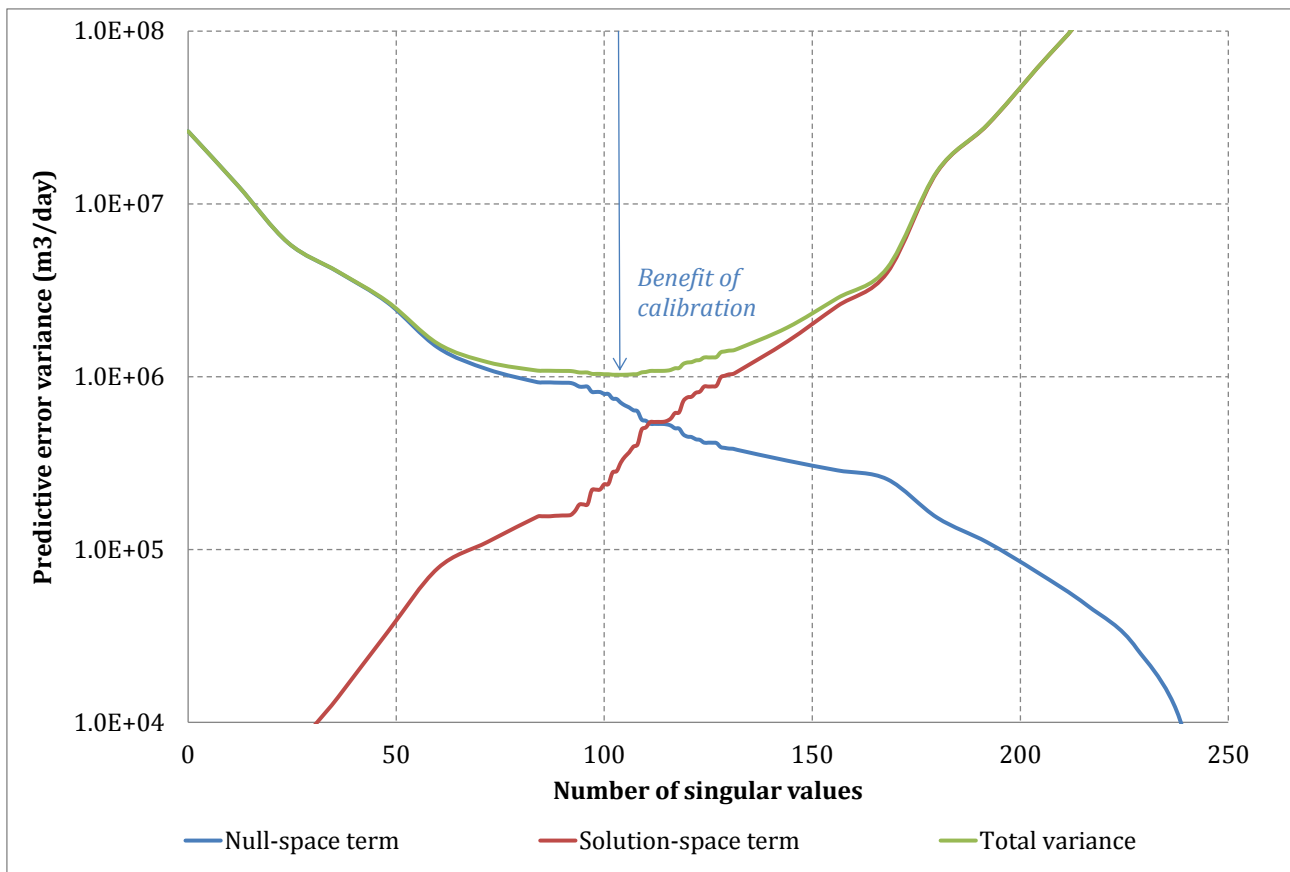


**Figure B- 18** Predictive error variance of alluvial water intercepted

#### B3.2.8 Model confidence level classification

Barnett *et al.*, (2012) developed a system to classify the confidence-level for groundwater models. Models are classified as either Class 1, Class 2 or Class 3 in order of increasing confidence (i.e. Class 3 has the highest level of confidence). Several factors are considered in determining the model confidence level:

- available data;
- calibration procedures;
- consistency between calibration and predictive analysis; and
- level of stresses.

The model was developed to achieve the criteria considered for a Class 2 model, and to meet some of the criteria for a Class 3 confidence level classification. It does this by simulating a similar calibration period to the predictive model, replicating seasonal responses to surface water/rainfall interaction, and meeting calibration and model error statistics.

## **B4 Predictive simulations**

### **B4.1 Time slices**

The staged transient model ran from 1/12/2015 in Year 1 to 1/12/2039 (Year 24). The model simulates mining with drain cells, which progress on a quarterly basis. At each quarter the mine progression within the open-cut was assessed for completion of the assumed four year operational window, and when an area has reached this, the drains undertaking the dewatering are removed and spoil parameters are assigned to these model cells. At each quarter the mine progression within the underground was assessed for completion based on the specified timing for each individual panel. When the allocated completion date (quarterly) was reached, the drain cells were removed and changes to horizontal hydraulic conductivity, specific yield and specific storage parameters in the fracture zone were applied to the goaf layer only. Hydraulic fracturing above the longwall panel was applied to the overlying cells immediately above the longwall drain cells.

### **B4.2 Mine drainage**

The model represented mining using the drain (DRN) package. During the predictive run, drain cells were used to simulate the effect of the proposed mine and other mines in the area. A nominally high drain conductance of 100m<sup>2</sup>/day was applied to the drain cells and the elevation of the base of the modelled layer was used as the drain level. For the open-cut mines, the drain cells were set in all layers from the lowermost mined seam to the surface. Groundwater levels in the model are compared to the reference elevation in each cell, and when the groundwater level was above the reference level, water was removed from the model domain at a rate determined by the head difference and the conductance term.

### **B4.3 Recovery modelling**

At the completion of mining, drain cells were removed and the model simulated post-mining conditions (e.g. final void). A transient model was created to ascertain post-mining inflows. A 1000 year recovery simulation was run, with all drain cells removed, thus allowing the groundwater levels in the coal seams and the overlying water-bearing strata to recover. Model cells located within the final voids were assigned a high horizontal and vertical hydraulic conductivity (1000m/day) and storage parameters (specific yield of 1.0, storage coefficient of  $5.0 \times 10^{-5}$ ), to simulate free water movement within the void. This approach is often referred to as a 'high-k' lake.

The percentage of the rainfall becoming recharge across the void pit was set to 120% annual rainfall recharge and the pan evaporation rate was set at 0.7.

Groundwater inflows to the void during recovery were provided to the surface water consultants and the results were incorporated in a high-resolution surface water model. Pit lake level recovery rates from the surface water model were reinstated to the groundwater model using the CHD package and the model was rerun for 1000 years. This ensures the two assessments are consistent and simulated at the higher level of accuracy.

Water level within the pit void lake was predicted to recover to an equilibrium water level lower than the pre-mining water level. This still provides for a sink whereby regional groundwater will migrate towards the void and any contamination of the water in the void is contained.

The predicted water level within the United pit void recovers to an elevation of 18mAHD to 19.5mAHD. After 100 years the water has recovered to 80% of its final level, while at 200 years the recovery is at 95%. At 400 years the pit void lake is fully recovered.

## B5 Sensitivity analysis

A sensitivity analysis was carried out to assess the response of the model to varying input parameters. The objective of the sensitivity analysis was to rank the input parameters in terms of their influence on the predicted results. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters. The changes to the parameter sets were changed according to the 95<sup>th</sup> percentile confidence interval of the expected range in parameters, which was invariably  $\pm 1$  order of magnitude from the median parameter value. The relative change from the base case parameter set is dependent on the calibrated value within the 95<sup>th</sup> confidence interval, i.e. if calibrated value is close to upper realistic bound, relative parameter changes are less than one magnitude.

This was achieved by changing and assessing the following:

- $\sim \pm 0.2$  to 1 order of magnitude change in hydraulic conductivity (K) of all geological units (excluding overburden emplacements);
- $\sim \pm 1$  order of magnitude change in vertical hydraulic conductivity of all of the fracture and goaf zone associated with longwall mining (Goaf+);
- $\sim \pm 0.1$  to 1 order of magnitude change in specific yield and specific storage (S) of all geological units (excluding overburden emplacements); and
- $\pm 0.5$  order of magnitude change in the rainfall recharge (Rch) rate across the model domain.

These changes represent the expected bounds of the groundwater regime. The following sections present the results of these sensitivity analyses in terms of their influence on the drawdown, changes to alluvial flow transfer and baseflow changes.

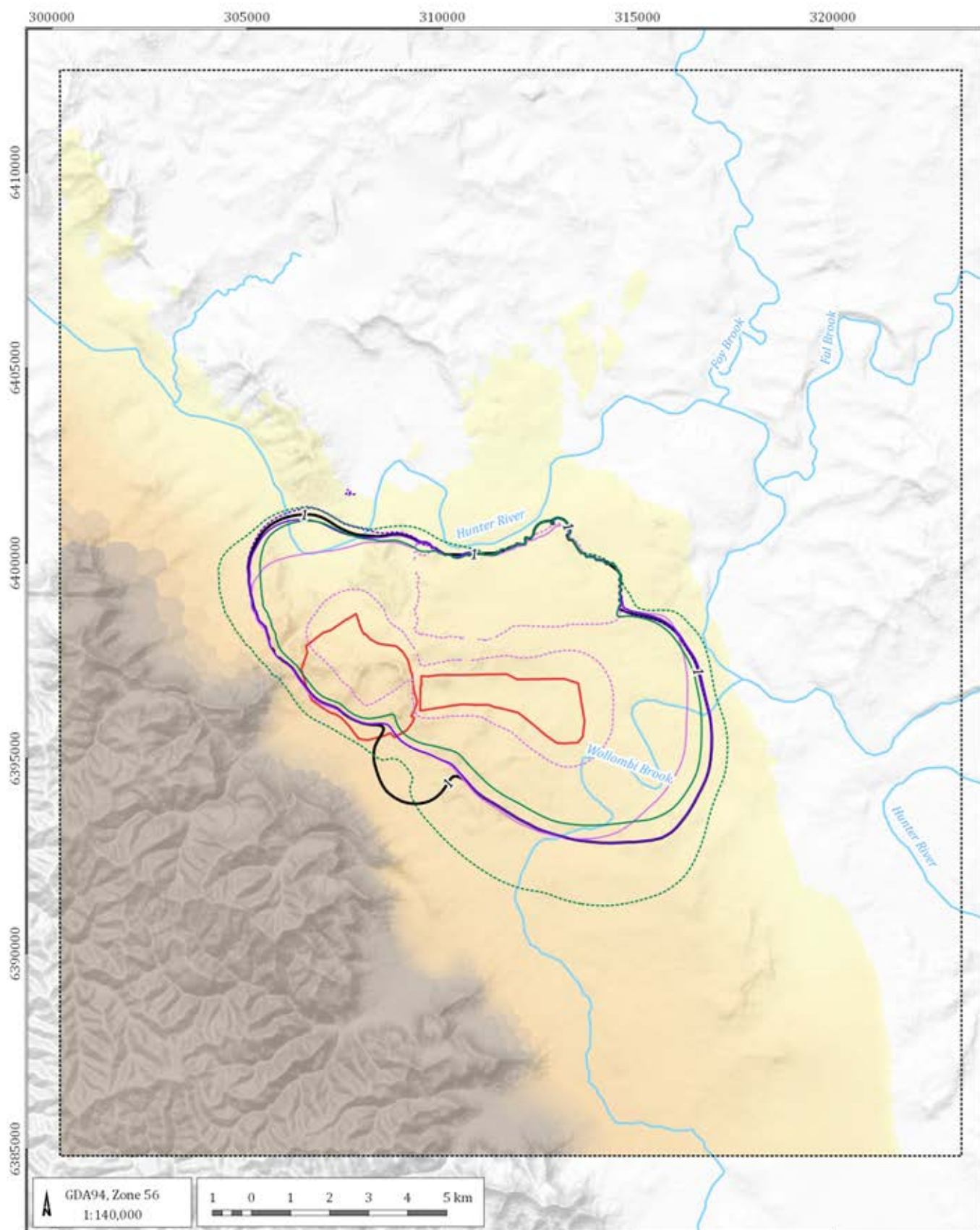
### B5.1 Zone of depressurisation

The sensitivity analysis assessed the change in depressurisation in the deepest seam mined as part of the Project, the Vaux Seam. Figure B- 19 shows the 1 m maximum groundwater drawdown extent from the sensitivity analysis for the Vaux Seam. The results show that predicted groundwater depressurisation resulting from the proposed modification is most sensitive to changes in hydraulic conductivity. The higher hydraulic conductivity extends the impacts further by offering increased connection between cells, while the lower hydraulic conductivity restricts the extent of drawdown impacts.

The change in drawdown extent is largely localised along the strike of the coal seam, to the north-west and south-east of United, where the Vaux Seam is shallowest. This is most likely due to the decreasing depth of the coal measures to the south-west, and the corresponding reduction in hydraulic conductivity with depth. Changes in recharge have minimal influence on the extent of drawdown. This shows climatic conditions have minimal influence on the groundwater predictions compared to other system stresses, such as the extensive approved mining within the region.

Changes to the hydraulic conductivity of all units in the groundwater model produced non-linear impact results, particularly when increasing the parameter above the calibrated value. Increasing hydraulic conductivity slightly reduced the extent of drawdown in the Vaux Seam from the base case (Figure B- 19) which is a likely result of the increased through flow and connectivity of regional groundwater flow in the vicinity of depressurisation.

Decreasing the storativity of the hydrostratigraphic units causes the 1m drawdown contour to extend up to approximately 2k from the base case. This is because there is less water in the system, increasing the drains ability to offset water as groundwater drawdown.



#### LEGEND

- Proposed extraction area
- Model extent
- Major drainage
- Basecase
- S+
- ... S-
- RCH+
- ... RCH-
- K+
- ... K-

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#### Sensitivity of zone of depressurisation during mining - Vaux Seam



DATE  
16/03/2016

FIGURE No:  
**B-19**

## B5.2 Impacts on alluvial groundwater sources

A key model prediction is the water take from the alluvial aquifers due to mining. Figure B- 20 and Figure B- 21 present the sensitivity of the predicted water take to changes in aquifer parameters and climatic conditions to the Hunter alluvium and Wollombi alluvial systems, respectively. The results were derived by running two model scenarios for each change in aquifer parameter, a model scenario with the approved mine plans and a model scenario with the Project and regional approved mine plans.

Figure B- 20 shows the sensitivity of flow change between the approved and Project mine plans for the Wollombi Brook alluvium. As presented within the main report, the basecase model predicted that the Project will reduce baseflow contributions from the Permian to the Wollombi Brook alluvium by up to 40ML/year.

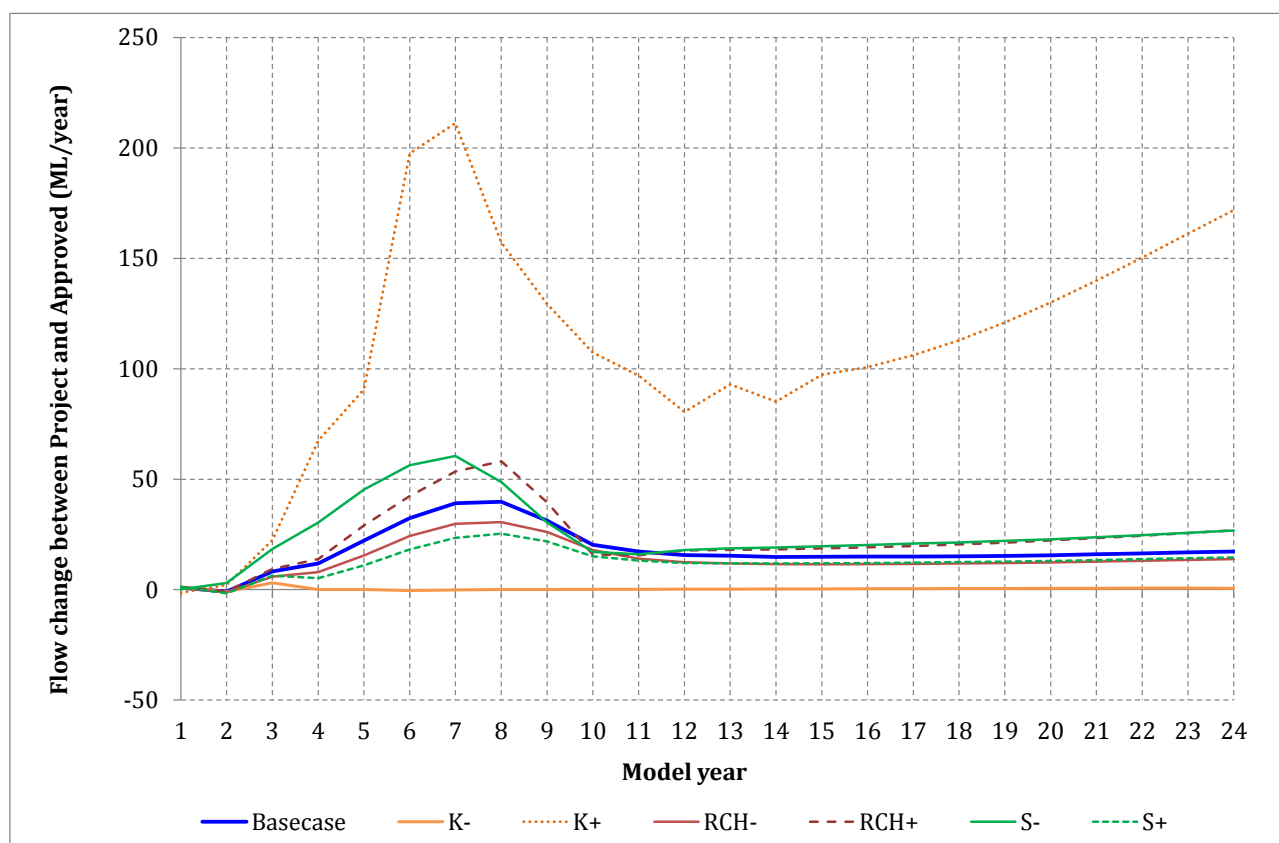


**Figure B- 20** Sensitivity of Permian to alluvial flow change – Wollombi alluvium

Figure B- 20 shows that flow change within the Wollombi Brook alluvium is most sensitive to changes in hydraulic conductivity (K). Increasing the hydraulic conductivity of the geological units suggests that the ‘water-take’ from the Wollombi Brook alluvium could increase to a peak of 211ML/year. Decreasing the hydraulic conductivity of the geological units suggests that the ‘water-take’ from the Wollombi Brook alluvium could reduce to a peak of 3ML/year.

Figure B- 21 shows the sensitivity of flow change between the approved and Project mine plans for the Hunter River alluvium. As presented within the main report, the basecase model predicted that the Project will reduce baseflow contributions from the Permian to the Hunter River alluvium by up to 58ML/year.

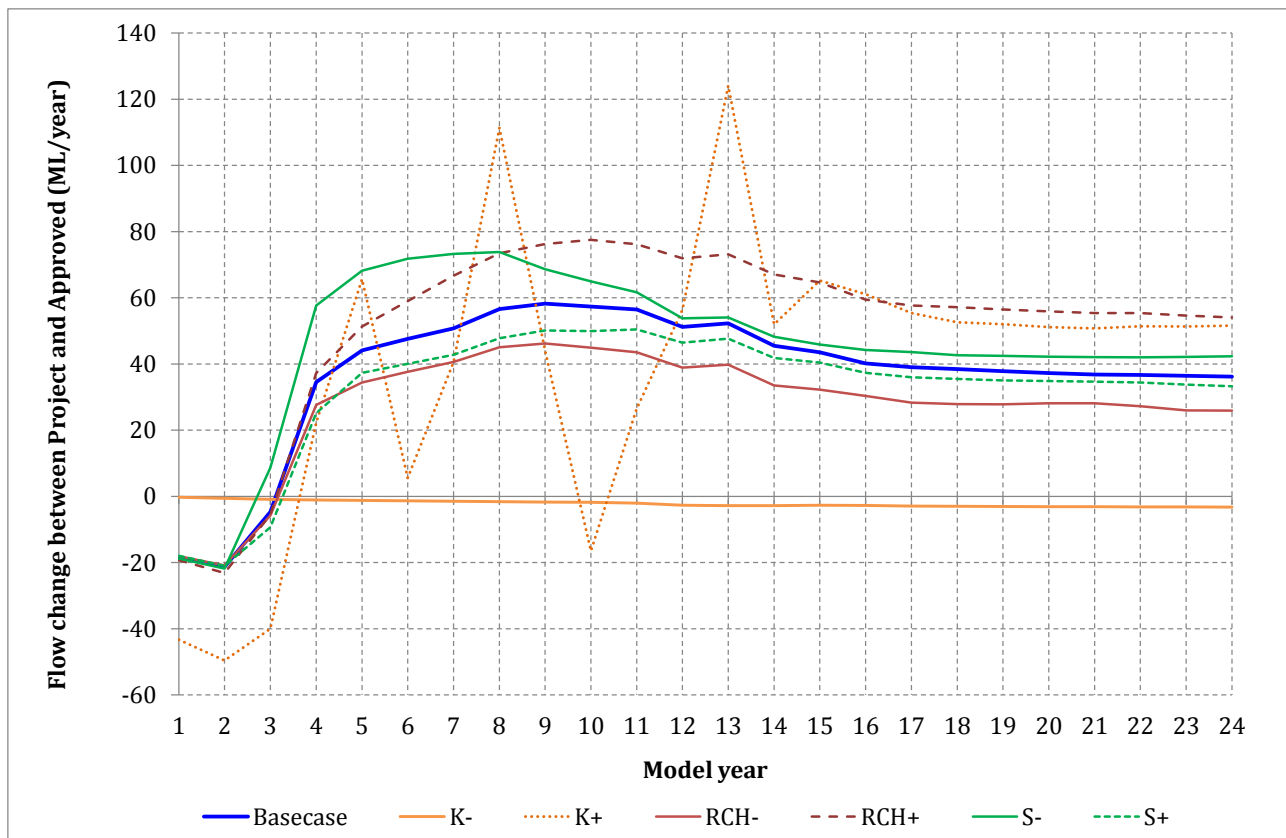


**Figure B- 21 Sensitivity of Permian to alluvial flow change – Hunter alluvium**

Figure B- 21 demonstrates the ‘water take’ from the Hunter alluvium is most sensitive to changes in the hydraulic conductivity (K). This is because the hydraulic conductivity increases the radial depressurization extent underneath the alluvium, interrupting the flow. Increasing the hydraulic conductivity of the geological units suggests that the ‘water-take’ from the Hunter River alluvium could increase to a peak of 124ML/year. Decreasing the hydraulic conductivity results in increased baseflow contributions from the Permian to the alluvium of up to 3ML/year compared to the approved mine plan.

Changing the other parameters in the model has a minimal impact on flux changes to the Wollombi Brook alluvium and Hunter River alluvium.

### B5.3 Sensitivity classification

The Murray Darling Basin Modelling Guidelines (MDBC, 2000) recommends classifying sensitivity by the resultant changes to the model calibration and predictions. The four sensitivity types are as follows:

- Type I: Insignificant changes to calibration and prediction;
- Type II: Significant changes to calibration – insignificant changes to predictions;
- Type III: Significant changes to calibration –significant changes to predictions; and
- Type IV: Insignificant changes to calibration –significant changes to predictions.

Types I and II are of no concern as these sensitivities have an insignificant impact on model predictions. Type III is only of concern for un-calibrated models. Types I to III are of no concern for the current assessment, as the model developed for the proposed modification is a well calibrated, high complexity model.

Type IV is classed as ‘a cause for concern’ as non-uniqueness in a model input might allow a range of valid calibrations but the choice of value impacts significantly on a prediction (MDBC, 2000).

There are no Type IV parameters in the model, which provides confidence in the range of predictions. The limited impact of the vertical hydraulic conductivity changes on the level of calibration made it a potential issue, however the corresponding extent of drawdown, and predicted mine inflow make it a Type I sensitivity. The other parameters tested in this analysis were either Type II or III and thus are also of no concern.

## B6 Uncertainty Analysis

To quantify the uncertainty in the model predictions a linear uncertainty analysis was undertaken according to the methods described by Doherty (2015). The process involves assessing the statistical uncertainty around model predictions, and projecting these linearly to estimate the likely range of impacts due to uncertainty in model parameters.

This type of analysis tests parameter wide changes to the model within possible ranges, rather than exploring spatial variability within the calibrated solution. The analysis works by running many different versions of the model with slightly altered parameters to assess the predicted impact. A total of 192 identifiable parameters were assessed in the linear uncertainty analysis, and were projected across the 95<sup>th</sup> confidence interval of the likely parameter ranges ( $\sim\pm 0.1$  to 1 order of magnitude), using the same bounds as prescribed in the sensitivity analysis. The advantage this has is that the method assesses possible parameter interactions at the upper and lower bounds, with respect to a calibrated model solution. The results of the analysis are shown graphically in:

- Figure B- 22 and Figure B- 23 which show the net change in groundwater flow from the Permian to the Hunter River Alluvium and the Wollombi Alluvium respectively; and
- Figure B- 24 and Figure B- 25 which show the range in the total amount of water intercepted from the Permian by the United Pit and Wambo Pits respectively.

It should be noted that 40% of the parameter changes failed to run because sufficient virtual memory was not available.

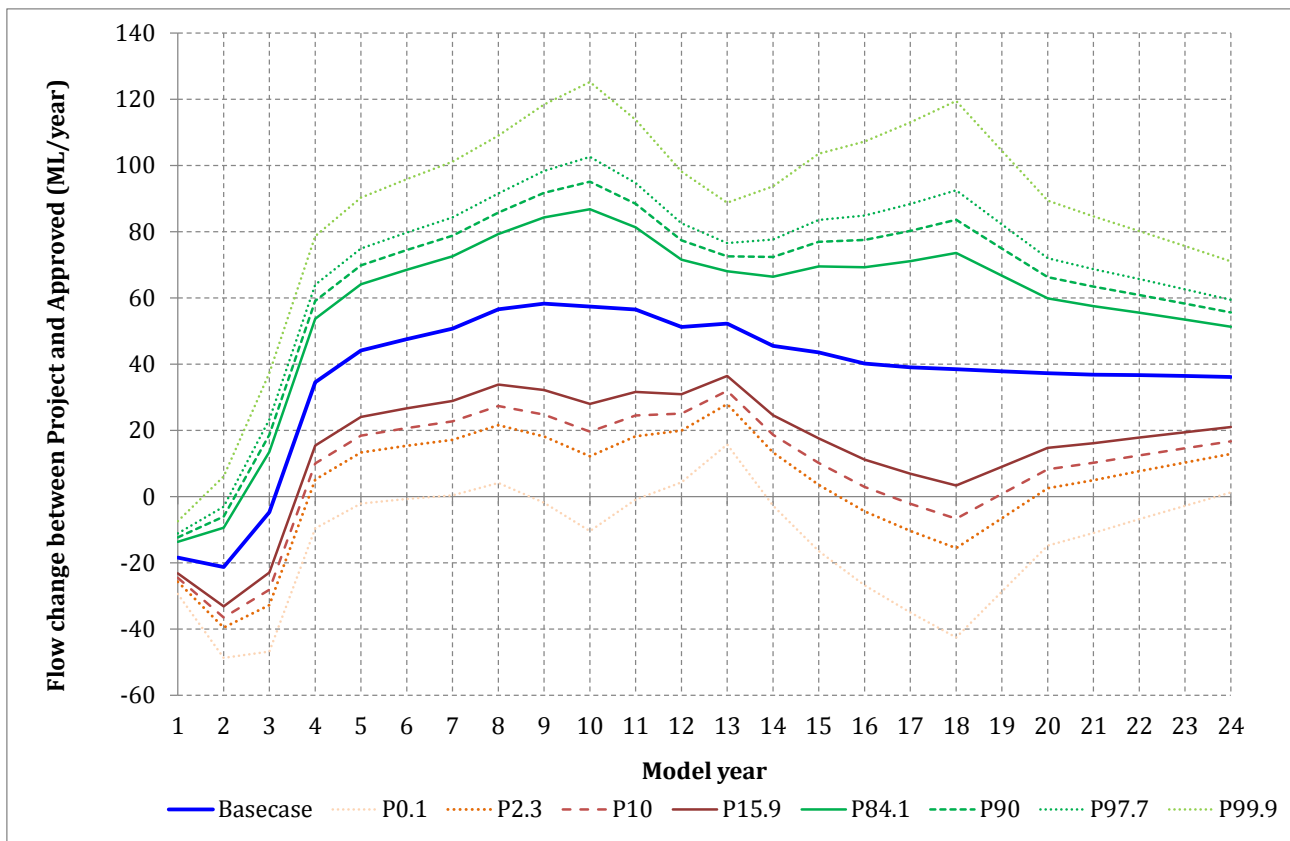


**Figure B- 22 Uncertainty of flow change to Hunter alluvium**

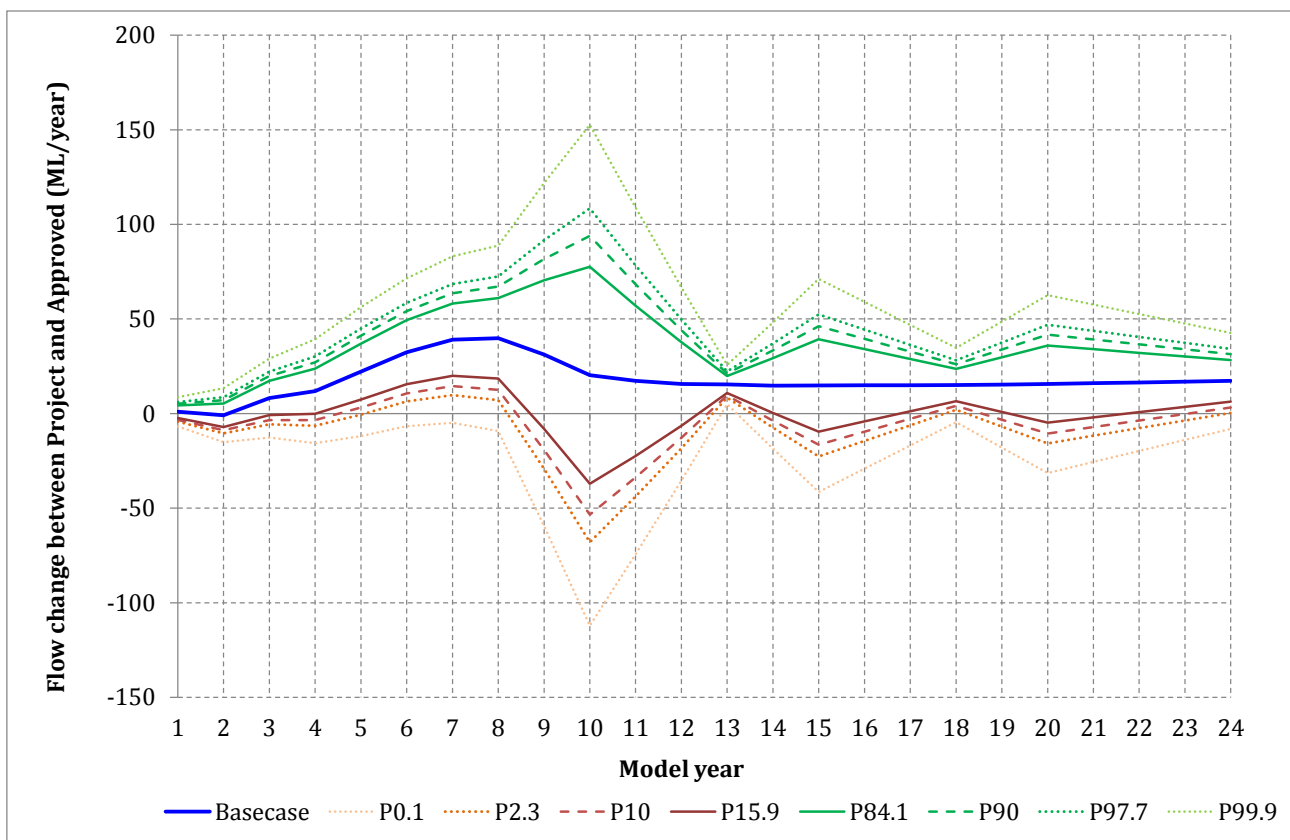


**Figure B- 23 Uncertainty of flow change to Wollombi alluvium**

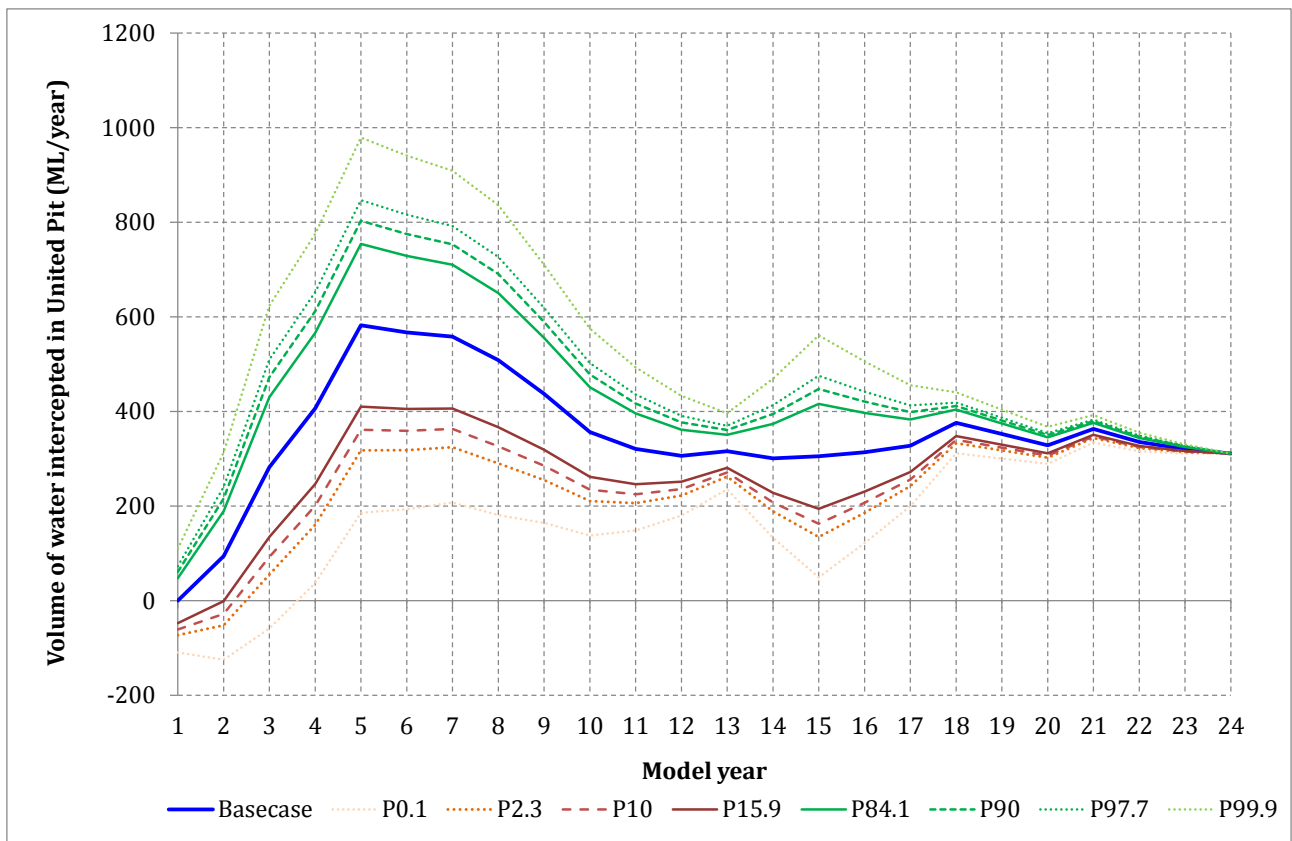


**Figure B- 24 Uncertainty of Permian inflow to United Pit**

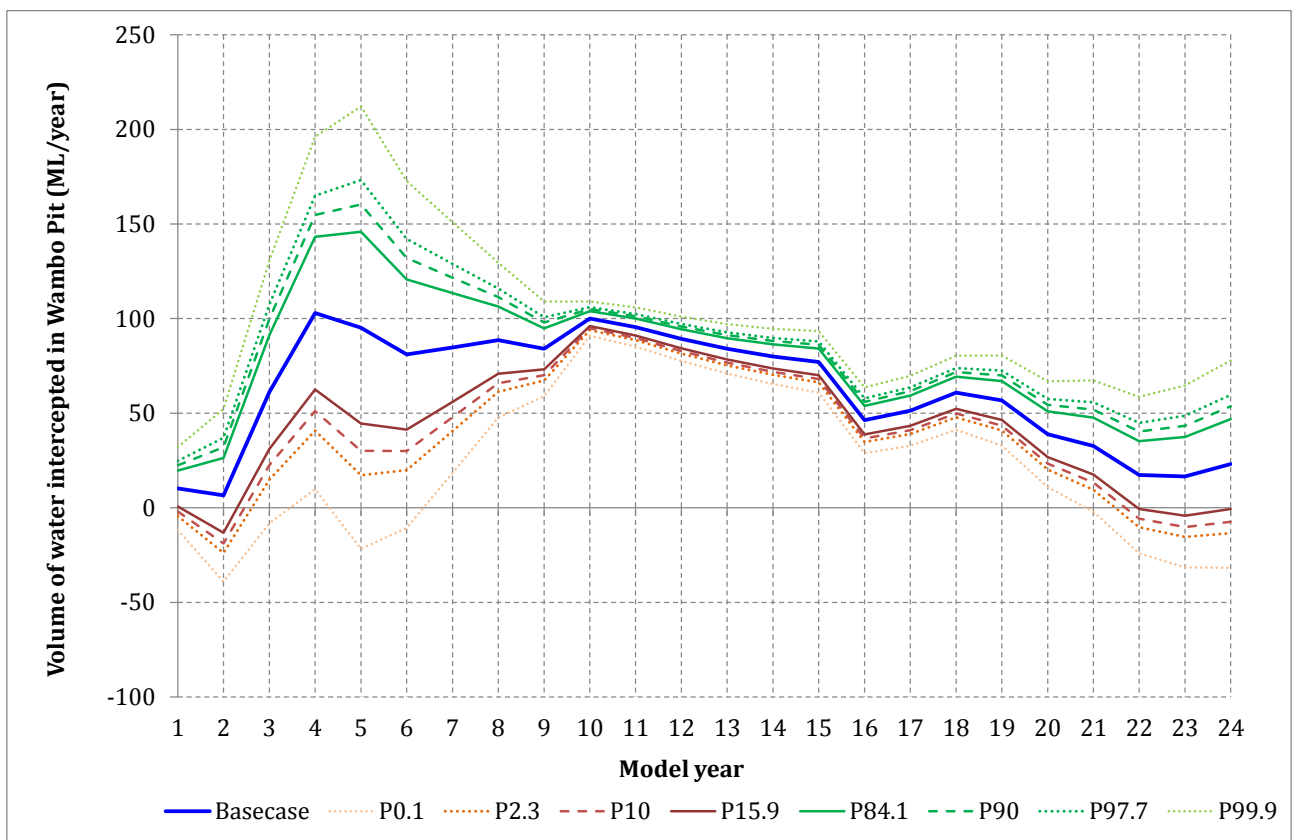


**Figure B- 25 Uncertainty of Permian inflow to Wambo Pit**

The results indicate the water take from the alluvium due to reduced Permian groundwater pressures could be approximately double the basecase estimates at the 99.9<sup>th</sup> percentile upper end. The volumes of groundwater intercepted from the Permian by the mining also reach approximately double the basecase estimates. These outcomes have a low likelihood of occurring given they are at the extreme of the end of the impact range predicted.

The uncertainty of the predicted drawdown at the only private bore to be potentially impacted by more than 2 m (GW060780) was also investigated. The basecase modelling indicated the drawdown due to the project was 6.1 m at this bore GW060780 during mining. The analysis indicated a relatively limited uncertainty at this bore with a standard deviation of  $\pm 0.1$  m in the drawdown. This therefore indicates a 99<sup>th</sup> percentile upper end of approximately 6.4 m. The water column in this bore is estimated at 6.9 m, and therefore the uncertainty analysis indicates there is a high potential for this bore to have a significantly impaired yield.

## B7 References

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*Appendix B-1*

**Calibration Details and Hydrographs**

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| Bore     | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|----------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|          |                        |                         |       |                     | Minimum            | Maximum |
| 4032P    | 308609                 | 6402945                 | 2     | 10.5                | 9.2                | 14.2    |
| 4033P    | 308877                 | 6402939                 | 2     | 11.1                | 8.8                | 14.6    |
| 4034P    | 308239                 | 6402959                 | 2     | 16.4                | 11.2               | 20.7    |
| 4035P    | 308386                 | 6402778                 | 2     | 10.4                | 9.0                | 13.3    |
| 4036C    | 308272                 | 6402688                 | 32    | -1.5                | -7.0               | 3.0     |
| 4037P    | 308277                 | 6402702                 | 2     | 9.8                 | 8.3                | 12.4    |
| 4038C    | 308502                 | 6403116                 | 2     | 15.4                | 13.5               | 26.1    |
| 4039C_1  | 308468                 | 6402673                 | 2     | 9.4                 | 8.3                | 10.3    |
| 4039C_2  | 308468                 | 6402673                 | 31    | -3.3                | -9.6               | 0.3     |
| 4039C_3  | 308468                 | 6402673                 | 33    | 17.1                | 16.0               | 19.0    |
| 4040P    | 308675                 | 6402724                 | 2     | 4.9                 | 3.2                | 9.3     |
| 4051C    | 308664                 | 6402721                 | 30    | -6.8                | -8.3               | -3.9    |
| 4052P    | 307924                 | 6402680                 | 2     | 14.1                | 12.7               | 16.4    |
| 4053P    | 308112                 | 6402680                 | 2     | 14.9                | 11.0               | 18.5    |
| 4113p    | 310729                 | 6401304                 | 30    | -3.6                | -5.2               | -2.5    |
| 4116p    | 310681                 | 6400978                 | 24    | 1.3                 | -0.1               | 2.7     |
| 4117p    | 310670                 | 6400980                 | 29    | -5.2                | -6.5               | -4.3    |
| 4119p    | 312501                 | 6402048                 | 26    | 5.5                 | 4.2                | 6.7     |
| APP_FARM | 315491                 | 6394639                 | 2     | 3.1                 | 2.8                | 4.3     |
| B334_BFS | 316684                 | 6394088                 | 19    | -2.1                | -6.5               | 2.5     |
| B425_WDH | 316010                 | 6395024                 | 15    | -10.2               | -14.1              | -8.2    |
| B631_BFS | 316425                 | 6394319                 | 19    | 12.6                | 7.9                | 24.6    |
| B631_WDH | 316424                 | 6394319                 | 15    | 8.5                 | 6.6                | 11.2    |
| B925_BFS | 315921                 | 6394604                 | 19    | -6.0                | -13.5              | 17.6    |
| BC1      | 312421                 | 6401010                 | 2     | 3.9                 | 2.9                | 5.7     |
| BC1a     | 312421                 | 6400872                 | 25    | 6.2                 | 3.4                | 8.8     |
| BUNC12   | 313180                 | 6401753                 | 2     | 12.7                | 10.2               | 14.6    |
| BUNC45D  | 313677                 | 6402060                 | 27    | 6.4                 | 5.3                | 8.4     |
| BUNC46D  | 313328                 | 6401782                 | 25    | 13.2                | 7.1                | 22.2    |
| BZ1-2    | 311472                 | 6400483                 | 1     | 17.5                | 16.3               | 21.3    |
| BZ1-3    | 311472                 | 6400483                 | 25    | 1.3                 | -8.6               | 9.1     |
| BZ2A_1   | 311671                 | 6400561                 | 25    | -0.9                | -6.7               | 8.3     |
| BZ2A_2   | 311671                 | 6400561                 | 24    | 9.2                 | 6.6                | 14.9    |
| BZ2B     | 311668                 | 6400560                 | 1     | 21.2                | 19.4               | 25.9    |
| BZ3-2    | 311840                 | 6400640                 | 24    | 18.4                | 15.0               | 21.8    |

| Bore      | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|-----------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|           |                        |                         |       |                     | Minimum            | Maximum |
| BZ3-3     | 311840                 | 6400640                 | 25    | -0.1                | -9.5               | 9.2     |
| BZ4A_2    | 312029                 | 6400705                 | 25    | -0.1                | -5.8               | 8.8     |
| BZ5-1     | 312192                 | 6400804                 | 25    | 14.8                | 9.9                | 17.3    |
| BZ8-2     | 312685                 | 6401010                 | 24    | -7.0                | -9.0               | -4.8    |
| BZ8-3     | 312685                 | 6401010                 | 25    | -3.6                | -7.2               | 0.6     |
| C122_WDH  | 315501                 | 6395007                 | 15    | 1.7                 | 1.2                | 2.1     |
| C130_AFS1 | 316400                 | 6394916                 | 17    | 10.7                | 8.7                | 12.0    |
| C130_BFS  | 316400                 | 6394916                 | 19    | 1.1                 | -2.0               | 4.4     |
| C130_WDH  | 316400                 | 6394916                 | 15    | 11.8                | 9.9                | 14.6    |
| C317_BFS  | 315054                 | 6395007                 | 19    | -7.9                | -13.1              | -5.2    |
| C317_WDH  | 315054                 | 6395007                 | 15    | 0.0                 | -0.5               | 0.5     |
| C613_BFS  | 314688                 | 6395243                 | 19    | -2.0                | -4.8               | 3.5     |
| C621_BFS  | 315421                 | 6395321                 | 19    | -8.1                | -11.6              | -5.5    |
| C630_BFS  | 316378                 | 6395306                 | 19    | 3.7                 | 0.2                | 8.4     |
| C809_WDH  | 314207                 | 6395493                 | 15    | -0.6                | -1.5               | 0.4     |
| C919_ALL  | 315192                 | 6395655                 | 2     | 2.3                 | 2.0                | 3.4     |
| CFW55R    | 310439                 | 6402180                 | 2     | 24.9                | 12.8               | 28.4    |
| CFW56     | 310333                 | 6402255                 | 2     | 30.1                | 15.6               | 33.9    |
| CFW57     | 310084                 | 6402053                 | 2     | 9.0                 | 5.2                | 15.9    |
| CFW57A    | 310088                 | 6402049                 | 2     | 12.4                | 8.7                | 20.2    |
| CGW1      | 309930                 | 6402690                 | 2     | 6.6                 | 4.2                | 12.9    |
| CGW2      | 310156                 | 6402685                 | 2     | 8.7                 | 6.3                | 12.5    |
| CGW3      | 310360                 | 6402679                 | 2     | 9.0                 | 8.0                | 12.4    |
| CGW34     | 310012                 | 6403588                 | 2     | 5.7                 | 4.9                | 8.5     |
| CGW35     | 309725                 | 6403446                 | 2     | 3.7                 | 3.4                | 3.9     |
| CGW38     | 309691                 | 6403638                 | 2     | 5.9                 | 4.3                | 8.3     |
| CGW40     | 309853                 | 6403220                 | 2     | 4.8                 | 3.4                | 7.9     |
| CGW41     | 310132                 | 6403259                 | 2     | 5.8                 | 4.4                | 8.9     |
| CGW42     | 309833                 | 6402991                 | 2     | 6.3                 | 2.6                | 11.9    |
| CGW43     | 310074                 | 6402959                 | 2     | 3.8                 | -2.4               | 6.8     |
| CGW44     | 310281                 | 6402794                 | 2     | 10.3                | 7.8                | 13.8    |
| CGW45     | 308042                 | 6403349                 | 33    | 7.5                 | -0.9               | 18.6    |
| CGW46     | 308413                 | 6403276                 | 33    | 20.5                | 3.9                | 27.4    |
| CGW46a    | 308415                 | 6403276                 | 31    | 17.1                | 3.1                | 27.6    |
| CGW47     | 308729                 | 6403406                 | 33    | -2.7                | -6.4               | -0.8    |

| Bore     | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|----------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|          |                        |                         |       |                     | Minimum            | Maximum |
| CGW47a   | 308731                 | 6403405                 | 31    | 13.1                | -17.6              | 27.1    |
| CGW48    | 308418                 | 6402919                 | 30    | -1.1                | -21.1              | 7.9     |
| CGW48a   | 308418                 | 6402919                 | 2     | 3.9                 | -0.5               | 12.1    |
| CGW49    | 308778                 | 6403098                 | 33    | 21.0                | 5.8                | 31.4    |
| CGW5     | 309666                 | 6402712                 | 2     | 6.4                 | 3.0                | 11.1    |
| CGW52    | 309906                 | 6402255                 | 31    | 12.3                | 2.0                | 24.9    |
| CGW52a   | 309902                 | 6402249                 | 2     | 13.2                | 4.6                | 21.4    |
| CGW53    | 309606                 | 6402333                 | 31    | 9.0                 | 0.2                | 21.2    |
| CGW53a   | 309606                 | 6402333                 | 2     | 7.9                 | 2.8                | 15.4    |
| CGW54a   | 310196                 | 6402159                 | 2     | 15.2                | 6.6                | 21.8    |
| CGW55a   | 309840                 | 6402457                 | 2     | 15.4                | 4.6                | 22.7    |
| CGW6     | 308756                 | 6402770                 | 2     | 2.8                 | 0.5                | 5.9     |
| CHPZ10A  | 313334                 | 6402297                 | 2     | 6.2                 | 5.1                | 7.1     |
| CHPZ11A  | 313429                 | 6402129                 | 2     | 9.1                 | 7.4                | 11.2    |
| CHPZ12A  | 313238                 | 6402013                 | 2     | 8.5                 | 6.5                | 10.2    |
| CHPZ13A  | 313009                 | 6401801                 | 2     | 7.8                 | 5.7                | 10.2    |
| CHPZ14A  | 312883                 | 6401639                 | 2     | 2.4                 | 0.0                | 6.0     |
| CHPZ14D  | 312891                 | 6401639                 | 25    | 2.7                 | -0.2               | 4.9     |
| CHPZ1A   | 312820                 | 6401697                 | 2     | 4.0                 | 1.1                | 8.6     |
| CHPZ2A   | 312941                 | 6401539                 | 2     | 1.6                 | -1.3               | 3.5     |
| CHPZ3A   | 313086                 | 6401756                 | 2     | 8.8                 | 6.9                | 11.1    |
| CHPZ4A   | 312904                 | 6402123                 | 2     | 5.2                 | 3.3                | 8.3     |
| CHPZ5A   | 312926                 | 6401838                 | 2     | 6.2                 | 3.7                | 9.1     |
| CHPZ7A   | 313600                 | 6402238                 | 1     | 4.9                 | 4.3                | 5.6     |
| CHPZ8A   | 313503                 | 6402051                 | 1     | 10.9                | 9.7                | 12.0    |
| CHPZ9A   | 313538                 | 6402383                 | 2     | 2.4                 | 1.8                | 4.0     |
| D010_BFS | 314355                 | 6395687                 | 19    | -6.8                | -11.6              | -2.0    |
| D010_GM  | 314355                 | 6395687                 | 15    | 1.1                 | 0.5                | 1.9     |
| D010_WDH | 314355                 | 6395687                 | 15    | -0.2                | -0.9               | 0.5     |
| D214_BFS | 314768                 | 6395831                 | 19    | -8.8                | -14.2              | 1.6     |
| D317_ALL | 315044                 | 6396018                 | 2     | 0.3                 | -0.1               | 4.3     |
| D317_BFS | 315043                 | 6396019                 | 19    | -8.6                | -15.6              | 13.1    |
| D406_AFS | 313931                 | 6396074                 | 17    | -3.2                | -7.5               | -1.0    |
| D406_BFS | 313931                 | 6396074                 | 19    | -9.4                | -15.4              | -1.9    |
| D406_WDH | 313931                 | 6396074                 | 15    | -7.8                | -7.9               | -7.7    |

| Bore     | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|----------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|          |                        |                         |       |                     | Minimum            | Maximum |
| D510_AFS | 314380                 | 6396141                 | 19    | -8.0                | -11.2              | -5.6    |
| D510_BFS | 314380                 | 6396141                 | 19    | -13.1               | -15.7              | -1.1    |
| D612_AFS | 314524                 | 6396314                 | 17    | -1.5                | -2.6               | 1.0     |
| D612_BFS | 314524                 | 6396314                 | 19    | -12.3               | -13.7              | -10.9   |
| D807_BFS | 314002                 | 6396484                 | 19    | -10.3               | -14.9              | -4.3    |
| DM1      | 311778                 | 6405164                 | 30    | 29.4                | 26.5               | 33.3    |
| DM4      | 312222                 | 6401418                 | 28    | 6.3                 | 4.1                | 8.3     |
| DM5_40   | 311431                 | 6400961                 | 28    | 7.8                 | 7.8                | 7.8     |
| DM5_75   | 311431                 | 6400961                 | 28    | 2.3                 | -6.3               | 11.0    |
| DM6      | 310796                 | 6400980                 | 28    | -5.3                | -15.5              | 4.4     |
| DM7      | 311136                 | 6400961                 | 28    | -1.2                | -4.1               | 0.9     |
| DM9      | 310284                 | 6401095                 | 28    | -4.9                | -6.8               | -3.9    |
| F1_WF533 | 316607                 | 6398247                 | 29    | 0.0                 | -1.5               | 1.4     |
| GA3      | 310159                 | 6400876                 | 1     | 5.7                 | 2.4                | 23.7    |
| GW_100   | 303729                 | 6406436                 | 1     | -4.1                | -4.9               | -3.6    |
| GW_107   | 308738                 | 6404103                 | 33    | -9.1                | -9.4               | -8.1    |
| GW_108   | 309695                 | 6403971                 | 33    | -7.2                | -7.6               | -5.3    |
| GW_114   | 312272                 | 6403981                 | 29    | 26.4                | 20.4               | 36.8    |
| GW_114B  | 312272                 | 6403981                 | 33    | 24.7                | 24.7               | 24.7    |
| GW_115   | 312227                 | 6402216                 | 26    | 6.8                 | 6.1                | 7.5     |
| GW02     | 309109                 | 6389680                 | 1     | -5.3                | -6.7               | -3.6    |
| GW030732 | 316678                 | 6397633                 | 2     | -7.3                | -8.1               | -6.7    |
| GW030734 | 316578                 | 6397861                 | 2     | -13.1               | -14.0              | -12.7   |
| GW030735 | 316447                 | 6397858                 | 2     | 0.9                 | 0.1                | 1.3     |
| GW030736 | 316628                 | 6397985                 | 2     | -2.7                | -3.4               | -2.3    |
| GW030740 | 316641                 | 6398365                 | 2     | -2.9                | -4.4               | -1.3    |
| GW035474 | 317725                 | 6412301                 | 1     | 2.5                 | 2.5                | 2.5     |
| GW064382 | 303908                 | 6394477                 | 3     | 124.0               | 124.0              | 124.0   |
| GW066742 | 309685                 | 6393911                 | 1     | 55.4                | 55.4               | 55.4    |
| GW08     | 311793                 | 6392266                 | 1     | 0.0                 | -0.6               | 0.8     |
| GW080952 | 310826                 | 6401143                 | 1     | 0.0                 | 0.0                | 0.0     |
| GW080963 | 310760                 | 6400495                 | 24    | -20.1               | -25.6              | -15.8   |
| GW09     | 311643                 | 6392563                 | 1     | -0.2                | -1.3               | 1.4     |
| GW11     | 309228                 | 6389699                 | 1     | -2.2                | -3.7               | -1.3    |
| GW12     | 309841                 | 6391056                 | 4     | 8.6                 | 7.0                | 9.7     |

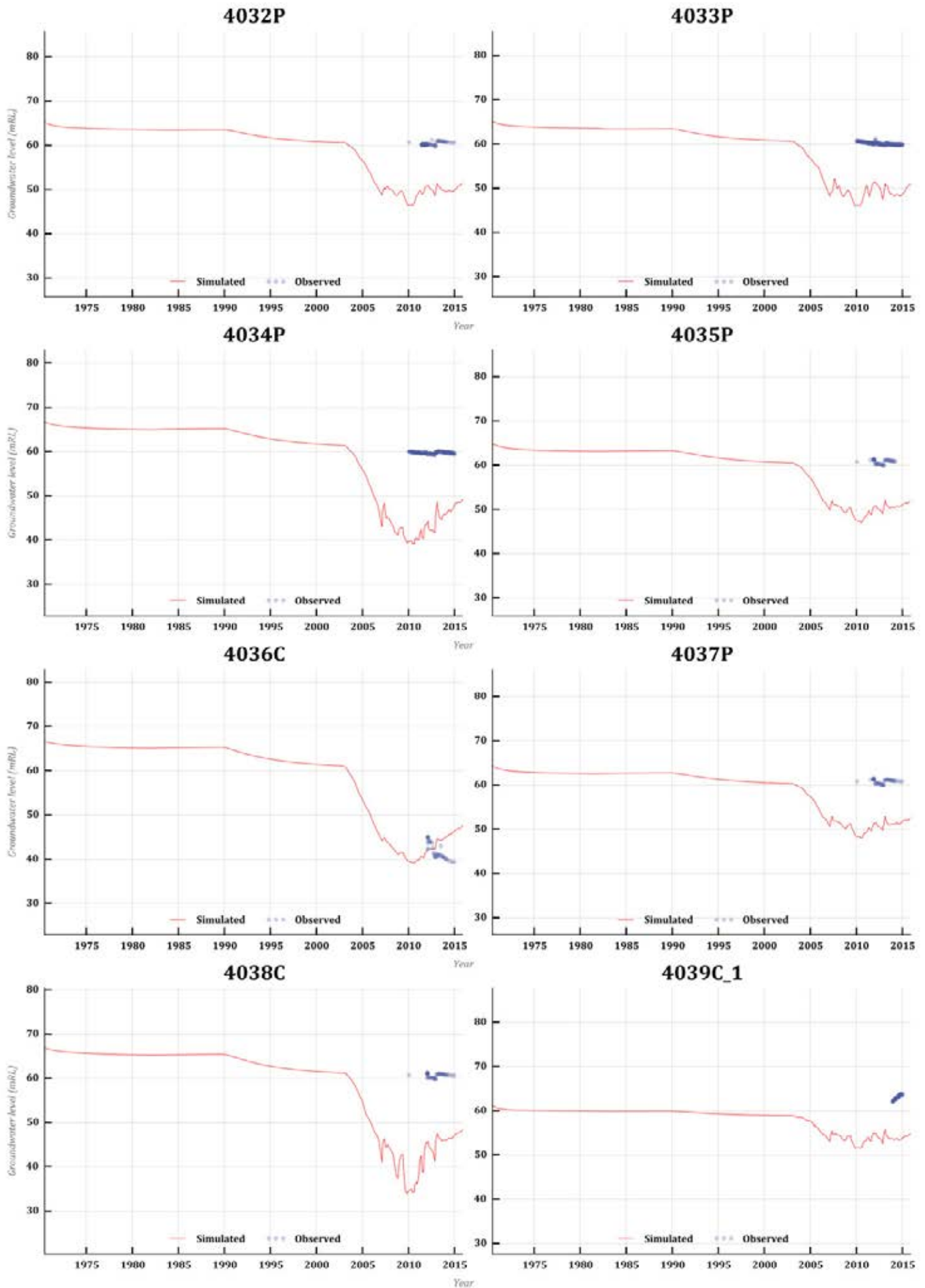
| Bore      | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|-----------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|           |                        |                         |       |                     | Minimum            | Maximum |
| GW13      | 313810                 | 6388990                 | 6     | 1.0                 | 0.5                | 1.3     |
| GW14      | 312478                 | 6391358                 | 2     | -3.1                | -3.4               | -2.8    |
| GW15      | 313164                 | 6392807                 | 8     | -1.5                | -2.1               | -0.6    |
| GW16      | 306641                 | 6396034                 | 6     | -7.1                | -9.7               | -4.3    |
| GW17      | 306895                 | 6396048                 | 2     | -7.5                | -8.9               | -4.2    |
| GW18      | 310061                 | 6393206                 | 8     | 1.2                 | 0.4                | 2.5     |
| GW20_009  | 309076                 | 6393949                 | 1     | -2.5                | -2.7               | -2.4    |
| GW20_061  | 309076                 | 6393949                 | 7     | -25.6               | -27.0              | -23.6   |
| GW21      | 308647                 | 6393378                 | 5     | -30.3               | -30.5              | -30.0   |
| GW22      | 311335                 | 6389535                 | 4     | -18.4               | -19.1              | -16.5   |
| HG1       | 312390                 | 6400882                 | 24    | 3.3                 | 2.1                | 5.1     |
| HG2       | 312469                 | 6400886                 | 24    | 2.1                 | 0.6                | 4.1     |
| HG2A      | 312469                 | 6400886                 | 25    | -2.5                | -5.7               | 0.5     |
| HG3       | 312541                 | 6400940                 | 26    | 22.1                | 18.2               | 27.8    |
| Hobden    | 312540                 | 6401093                 | 1     | 1.6                 | -2.7               | 5.8     |
| HV3       | 310776                 | 6400546                 | 2     | -2.2                | -9.0               | 2.2     |
| HV4       | 310069                 | 6401183                 | 2     | 4.2                 | 1.6                | 9.8     |
| MG09_009  | 310539                 | 6391186                 | 2     | -10.3               | -10.3              | -10.3   |
| MG09_030  | 310539                 | 6391186                 | 6     | -22.8               | -24.1              | -20.8   |
| MG09_170  | 310539                 | 6391186                 | 8     | -18.1               | -20.1              | -16.3   |
| MG09_192  | 310539                 | 6391186                 | 9     | 7.7                 | -0.1               | 13.1    |
| MG8_009   | 311028                 | 6392637                 | 2     | -5.8                | -6.4               | -4.9    |
| MG8_046   | 311028                 | 6392637                 | 7     | -18.4               | -20.4              | -13.7   |
| MTD517_P1 | 317521                 | 6386147                 | 25    | -19.4               | -21.0              | -16.5   |
| MTD517_P2 | 317521                 | 6386147                 | 15    | -10.1               | -15.6              | -6.3    |
| MTD517_P3 | 317521                 | 6386147                 | 9     | 7.3                 | -0.2               | 22.8    |
| MTD518_P2 | 316512                 | 6386156                 | 15    | -0.6                | -1.2               | 0.7     |
| MTD518_P3 | 316512                 | 6386156                 | 9     | -16.0               | -16.4              | -15.7   |
| MTD605_P1 | 316274                 | 6386162                 | 6     | -16.4               | -16.6              | -16.2   |
| MTD605_P2 | 316274                 | 6386162                 | 7     | -8.7                | -20.4              | -3.2    |
| MTD605_P3 | 316274                 | 6386162                 | 12    | -3.5                | -4.4               | -2.3    |
| MTD605_P4 | 316274                 | 6386162                 | 13    | 0.8                 | -0.4               | 1.4     |
| MTD639_2  | 320369                 | 6387036                 | 25    | -15.9               | -15.9              | -15.9   |
| MTD640    | 321275                 | 6385562                 | 1     | -38.0               | -38.0              | -38.0   |
| MTD642    | 320284                 | 6387508                 | 1     | 36.8                | 36.8               | 36.8    |

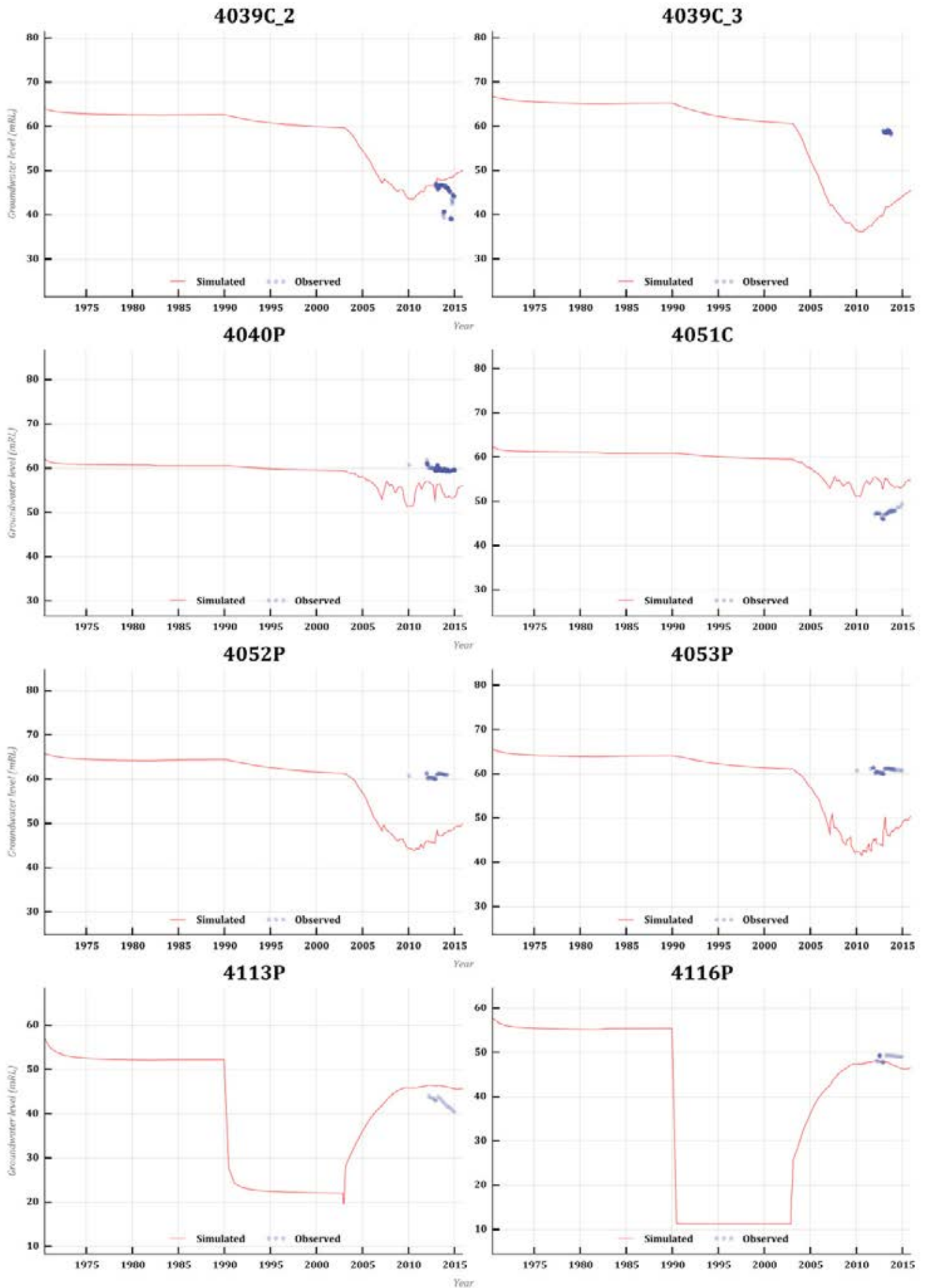
| Bore     | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|----------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|          |                        |                         |       |                     | Minimum            | Maximum |
| MTD643   | 320311                 | 6387660                 | 1     | 24.3                | 24.3               | 24.3    |
| MTOH611  | 320528                 | 6386035                 | 19    | 13.7                | 13.7               | 13.7    |
| MTOH612  | 318876                 | 6387547                 | 15    | 8.0                 | 8.0                | 8.0     |
| OH1123_1 | 316967                 | 6389501                 | 15    | -0.1                | -5.1               | 4.2     |
| OH1125_2 | 316511                 | 6392875                 | 15    | 0.0                 | -19.0              | 9.8     |
| OH1125_3 | 316511                 | 6392875                 | 19    | 21.4                | 10.7               | 38.4    |
| OH1126   | 318579                 | 6393394                 | 29    | -12.8               | -27.3              | -3.0    |
| OH1137   | 318266                 | 6393377                 | 29    | 2.7                 | -1.1               | 6.3     |
| OH1138_1 | 317835                 | 6393346                 | 26    | 6.7                 | 2.7                | 11.1    |
| OH1138_2 | 317835                 | 6393346                 | 26    | -12.4               | -21.7              | -2.3    |
| P1       | 312199                 | 6395840                 | 14    | -12.3               | -15.2              | -5.4    |
| P104     | 311349                 | 6391156                 | 2     | -5.8                | -6.7               | -3.1    |
| P106     | 311518                 | 6391084                 | 2     | -6.9                | -12.7              | -2.5    |
| P108     | 311349                 | 6390933                 | 2     | -6.5                | -6.9               | -6.2    |
| P109     | 311215                 | 6390768                 | 2     | -3.6                | -6.6               | -2.3    |
| P11      | 312728                 | 6395462                 | 14    | -23.0               | -24.9              | -19.9   |
| P110     | 311217                 | 6390690                 | 2     | -2.3                | -5.2               | -0.2    |
| P111     | 311301                 | 6390761                 | 2     | -5.0                | -6.2               | -3.3    |
| P114     | 311057                 | 6391293                 | 2     | -4.4                | -5.8               | -3.4    |
| P116     | 311205                 | 6391288                 | 2     | -2.7                | -4.6               | -0.7    |
| P12      | 313644                 | 6394797                 | 14    | 1.9                 | -1.1               | 4.5     |
| P13      | 313722                 | 6394412                 | 14    | -0.2                | -1.7               | 1.3     |
| P15      | 313431                 | 6394803                 | 1     | 1.7                 | 0.8                | 2.7     |
| P16      | 313480                 | 6394655                 | 1     | 3.3                 | 2.6                | 4.2     |
| P17      | 313376                 | 6394631                 | 1     | -0.9                | -1.7               | 0.0     |
| P18      | 313503                 | 6394512                 | 1     | 2.6                 | 1.8                | 3.9     |
| P2       | 312403                 | 6395552                 | 14    | -9.0                | -14.8              | -3.4    |
| P20      | 313639                 | 6394166                 | 2     | 2.0                 | 1.6                | 4.2     |
| P202     | 311859                 | 6391330                 | 6     | -1.7                | -3.0               | 3.7     |
| P206     | 311772                 | 6391293                 | 6     | -14.7               | -18.5              | -8.8    |
| P209     | 311584                 | 6390893                 | 6     | -11.8               | -11.9              | -11.4   |
| P27      | 311344                 | 6392810                 | 1     | -1.0                | -2.3               | 0.4     |
| P28      | 311396                 | 6392632                 | 1     | -2.7                | -4.6               | -1.2    |
| P29      | 311820                 | 6392560                 | 14    | -16.2               | -29.4              | -2.6    |
| P3       | 313412                 | 6395006                 | 14    | -2.7                | -4.0               | -1.7    |

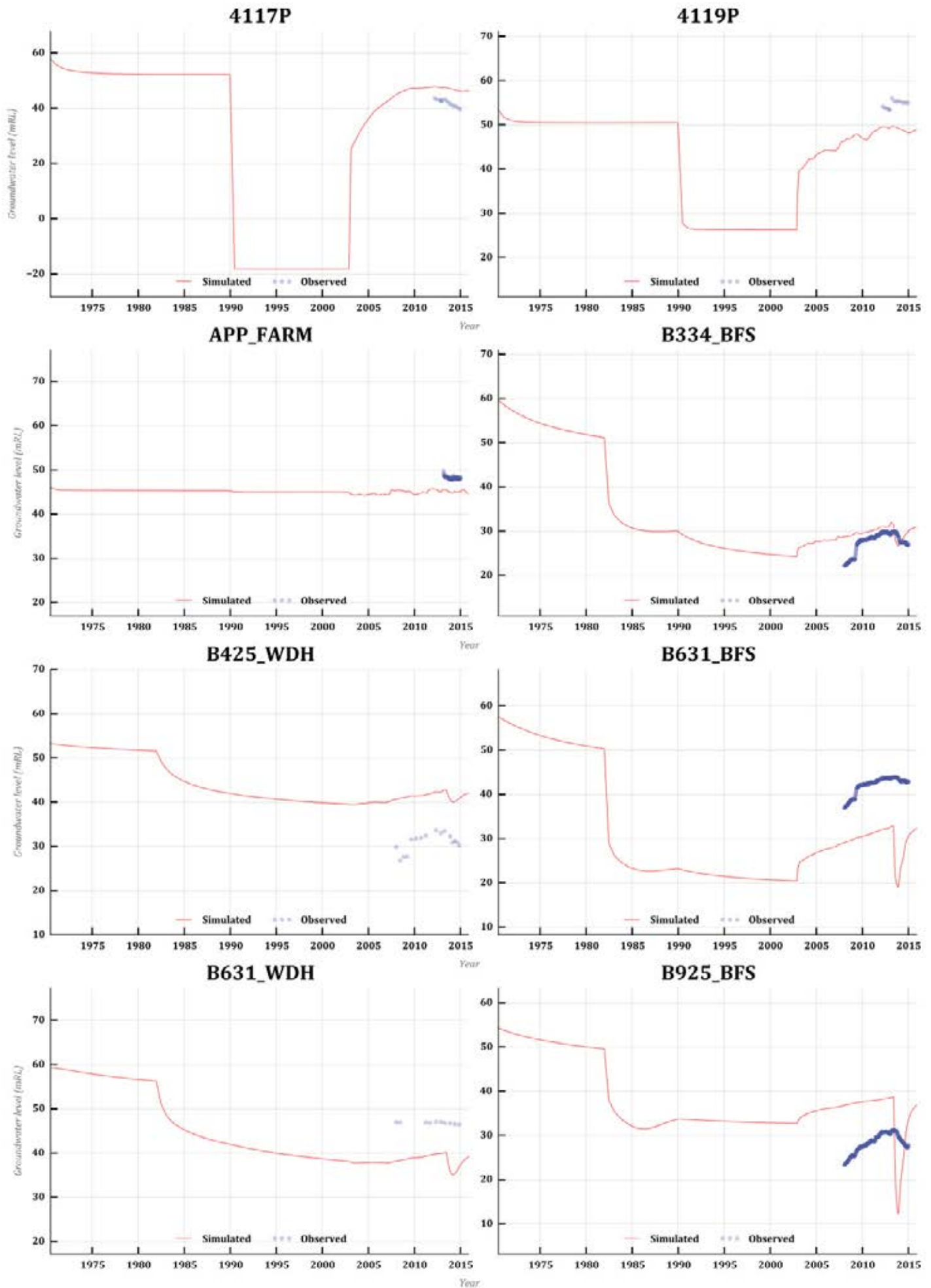
| Bore      | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|-----------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|           |                        |                         |       |                     | Minimum            | Maximum |
| P301      | 309311                 | 6391425                 | 4     | -13.2               | -20.0              | -10.1   |
| P302      | 309149                 | 6391462                 | 4     | -12.9               | -13.1              | -12.6   |
| P303      | 309103                 | 6391713                 | 4     | -28.0               | -28.1              | -27.8   |
| P310      | 308245                 | 6392172                 | 4     | -45.1               | -47.0              | -43.7   |
| P311      | 308064                 | 6392255                 | 4     | -16.3               | -18.9              | -14.6   |
| P312      | 309100                 | 6391713                 | 4     | -12.5               | -13.8              | -8.6    |
| P314      | 309149                 | 6391462                 | 4     | -7.2                | -7.4               | -7.1    |
| P315      | 309091                 | 6391852                 | 4     | -7.7                | -9.9               | -4.7    |
| P316      | 308611                 | 6392106                 | 4     | -4.4                | -6.1               | -3.6    |
| P317      | 308506                 | 6392181                 | 4     | -2.0                | -3.0               | -1.0    |
| P318      | 308422                 | 6392153                 | 4     | -7.4                | -7.5               | -7.3    |
| P319      | 308242                 | 6392172                 | 4     | -1.8                | -2.3               | -1.2    |
| P32       | 310735                 | 6392842                 | 1     | -5.2                | -7.9               | -4.0    |
| P33_113   | 313757                 | 6394659                 | 18    | -4.7                | -26.0              | 5.1     |
| P33_13    | 313757                 | 6394659                 | 14    | 4.4                 | 3.0                | 7.3     |
| P33_58    | 313757                 | 6394659                 | 15    | -12.3               | -15.8              | -6.8    |
| P35_112   | 313611                 | 6395196                 | 19    | -38.8               | -62.9              | -23.7   |
| P35_60    | 313611                 | 6395196                 | 17    | -2.9                | -8.2               | 5.4     |
| PB01_ALL  | 314754                 | 6396026                 | 2     | 2.2                 | 1.7                | 2.7     |
| PZ1CH200  | 312646                 | 6402256                 | 2     | 7.0                 | 3.3                | 18.4    |
| PZ2CH400  | 312635                 | 6402051                 | 2     | 8.6                 | 1.7                | 26.4    |
| PZ3CH800  | 312522                 | 6401674                 | 2     | 6.1                 | 2.9                | 17.7    |
| PZ4CH1380 | 312196                 | 6401176                 | 2     | 3.9                 | 2.9                | 5.0     |
| PZ5CH1800 | 311852                 | 6400928                 | 2     | 11.7                | 9.3                | 14.6    |
| PZ6CH2450 | 311233                 | 6400727                 | 2     | 17.3                | 10.6               | 27.6    |
| PZ7D      | 314057                 | 6392684                 | 8     | -20.5               | -20.8              | -20.3   |
| PZ7S      | 314055                 | 6392671                 | 1     | -21.5               | -23.0              | -20.7   |
| PZ8D      | 317001                 | 6385418                 | 6     | -25.5               | -25.8              | -25.3   |
| PZ8S      | 317002                 | 6385411                 | 1     | -20.4               | -21.2              | -20.0   |
| PZ9D      | 317541                 | 6385652                 | 8     | -24.0               | -27.2              | -18.3   |
| PZ9S      | 317542                 | 6385642                 | 1     | -16.9               | -17.3              | -16.6   |
| S2        | 311502                 | 6407889                 | 32    | 35.8                | 35.1               | 36.9    |
| S4        | 312853                 | 6408417                 | 34    | -11.6               | -15.6              | -1.6    |
| SR007     | 318772                 | 6394373                 | 34    | -23.2               | -31.7              | -9.5    |
| SR010     | 317319                 | 6395338                 | 25    | 3.3                 | 1.1                | 4.7     |

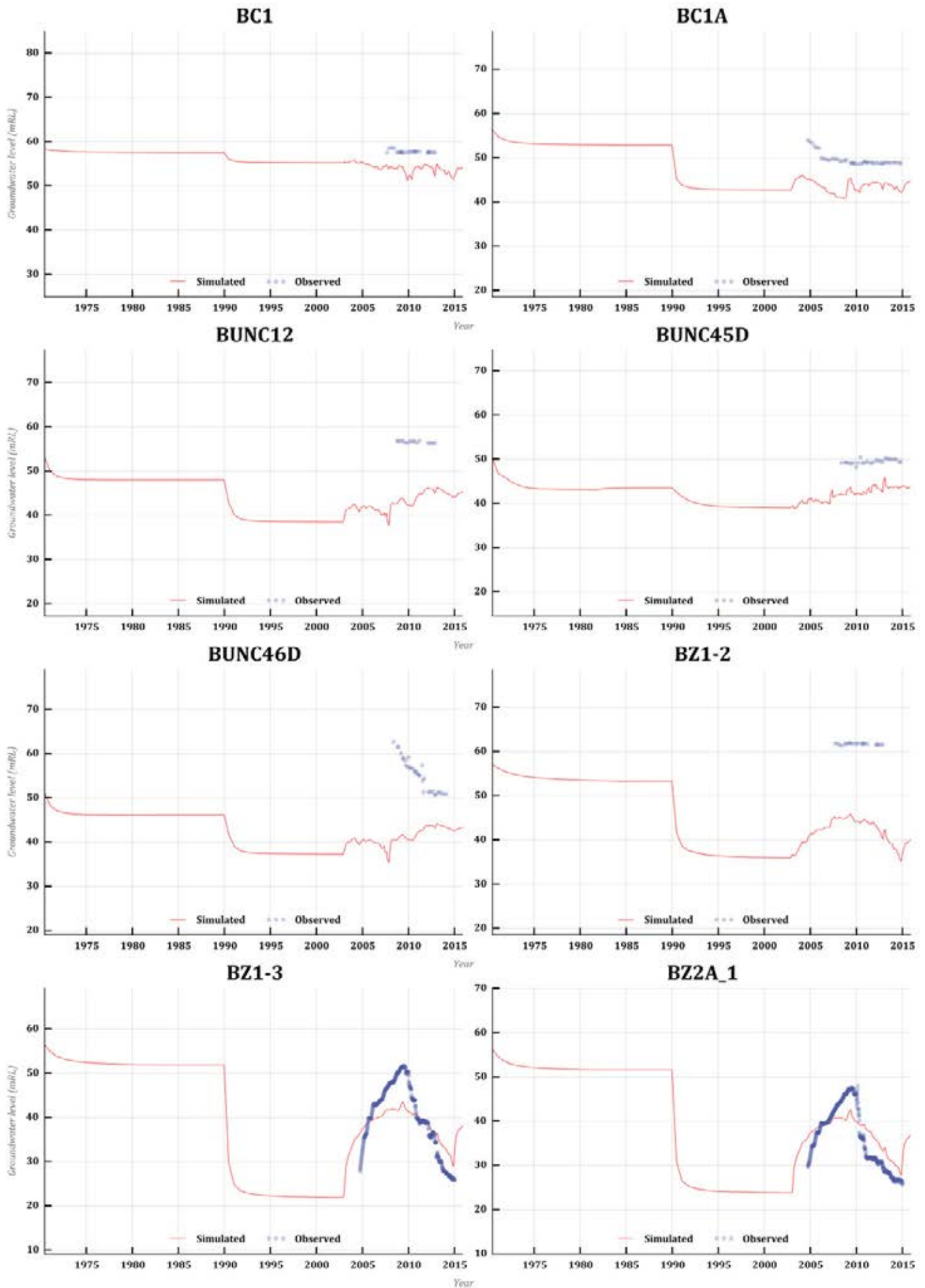
| Bore       | Easting<br>(GDA94 Z56) | Northing<br>(GDA94 Z56) | Layer | Average<br>residual | Range in residuals |         |
|------------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|            |                        |                         |       |                     | Minimum            | Maximum |
| SR011      | 317699                 | 6394412                 | 26    | -9.9                | -10.4              | -9.4    |
| SR012      | 318354                 | 6393926                 | 28    | -8.3                | -8.9               | -7.4    |
| UG133_168  | 313297                 | 6396177                 | 25    | -20.4               | -20.9              | -20.1   |
| UG133_180  | 313297                 | 6396177                 | 27    | -20.1               | -23.0              | -16.6   |
| UG133_45   | 313297                 | 6396177                 | 16    | -1.8                | -2.5               | -0.7    |
| UG133_96   | 313297                 | 6396177                 | 20    | -23.3               | -25.8              | -21.0   |
| UG135_110  | 313831                 | 6396748                 | 23    | -18.8               | -19.2              | -18.4   |
| UG135_129  | 313831                 | 6396748                 | 25    | -19.4               | -22.1              | -17.8   |
| UG135_176  | 313831                 | 6396748                 | 28    | -24.4               | -24.6              | -24.1   |
| UG135_186  | 313831                 | 6396748                 | 31    | -30.6               | -31.9              | -29.6   |
| UG135_50   | 313831                 | 6396748                 | 18    | -14.1               | -15.7              | -12.4   |
| UG138_215  | 308517                 | 6396181                 | 16    | -13.6               | -16.7              | -10.3   |
| UG138_245  | 308517                 | 6396181                 | 18    | -15.5               | -17.3              | -13.5   |
| UG139_329  | 306665                 | 6395173                 | 17    | -17.0               | -17.8              | -15.7   |
| UG139_375  | 306665                 | 6395173                 | 19    | 12.2                | 9.0                | 16.4    |
| UG139_402  | 306665                 | 6395173                 | 22    | -11.1               | -25.3              | -4.3    |
| UG147_090  | 311245                 | 6397207                 | 16    | -41.2               | -42.5              | -40.5   |
| UG147_157  | 311245                 | 6397207                 | 22    | 1.5                 | -2.0               | 4.1     |
| UG147_249  | 311245                 | 6397207                 | 29    | -4.1                | -4.1               | -4.1    |
| UG166A_130 | 306488                 | 6398076                 | 6     | -29.3               | -37.2              | -24.5   |
| UG166A_153 | 306488                 | 6398076                 | 14    | -13.5               | -14.1              | -11.9   |
| UG166A_200 | 306488                 | 6398076                 | 17    | -16.9               | -17.9              | -15.1   |
| UG166A_238 | 306488                 | 6398076                 | 20    | -12.9               | -14.4              | -10.1   |
| UG192R_110 | 313683                 | 6396084                 | 16    | -30.4               | -31.1              | -29.6   |
| UG192R_140 | 313683                 | 6396084                 | 22    | -23.6               | -25.0              | -21.3   |
| UG192R_170 | 313683                 | 6396084                 | 26    | -20.6               | -21.4              | -18.3   |
| UG192R_210 | 313683                 | 6396084                 | 30    | -31.7               | -34.1              | -27.0   |
| UG192R_30  | 313683                 | 6396084                 | 16    | -17.1               | -17.6              | -16.5   |
| UG192R_60  | 313683                 | 6396084                 | 18    | -15.3               | -20.7              | -6.6    |
| UG192R_94  | 313683                 | 6396084                 | 22    | -22.7               | -24.5              | -21.7   |
| UG193_160  | 313757                 | 6396090                 | 25    | -16.2               | -17.2              | -13.1   |
| UG193_27   | 313757                 | 6396090                 | 16    | -6.2                | -8.9               | -3.5    |
| UG193_61   | 313757                 | 6396090                 | 18    | -0.4                | -7.3               | 8.9     |
| UG193_85   | 313757                 | 6396090                 | 22    | -3.3                | -10.4              | 0.0     |
| UG196_137  | 312364                 | 6397122                 | 22    | -0.6                | -2.0               | 0.4     |

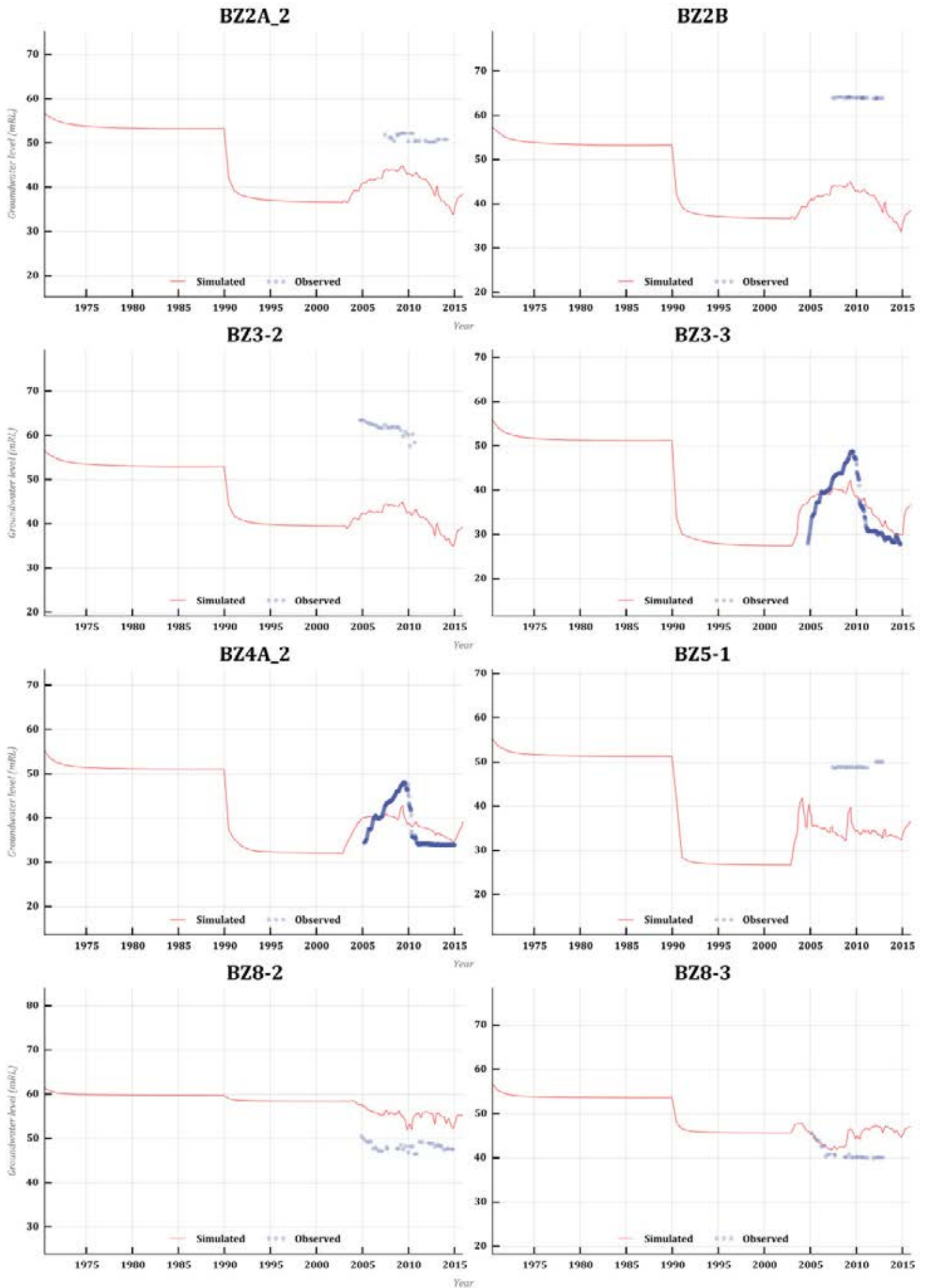
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|------------|------------------------|-------------------------|-------|---------------------|--------------------|---------|
|            |                        |                         |       |                     | Minimum            | Maximum |
| UG196_160  | 312364                 | 6397122                 | 25    | 0.3                 | -1.4               | 3.2     |
| UG196_230  | 312364                 | 6397122                 | 30    | -24.1               | -24.9              | -23.3   |
| UG196_45   | 312364                 | 6397122                 | 16    | 7.2                 | -3.6               | 12.1    |
| UG196_80   | 312364                 | 6397122                 | 18    | 3.2                 | 1.4                | 7.2     |
| UG220_106  | 312522                 | 6397233                 | 20    | 11.1                | 8.6                | 14.4    |
| UG220_110  | 312522                 | 6397233                 | 22    | 7.2                 | 6.4                | 8.1     |
| UG220_152  | 312522                 | 6397233                 | 24    | 31.9                | 26.3               | 35.5    |
| UG220_207  | 312522                 | 6397233                 | 28    | -5.2                | -5.5               | -4.5    |
| UG224_105  | 313860                 | 6396243                 | 22    | -5.3                | -7.1               | -4.1    |
| UG224_163  | 313860                 | 6396243                 | 26    | -15.1               | -17.1              | -12.1   |
| UG224_172  | 313860                 | 6396243                 | 28    | -9.7                | -13.9              | -7.1    |
| UG224_191  | 313860                 | 6396243                 | 30    | -19.4               | -23.3              | -17.9   |
| UG224_69   | 313860                 | 6396243                 | 20    | -18.4               | -22.1              | -16.2   |
| UG225_100  | 313214                 | 6397095                 | 22    | 4.4                 | 2.1                | 6.3     |
| UG225_128  | 313214                 | 6397095                 | 25    | -5.6                | -8.5               | -0.6    |
| UG225_178  | 313214                 | 6397095                 | 29    | -8.6                | -8.9               | -8.2    |
| UG225_58.5 | 313214                 | 6397095                 | 19    | 7.3                 | 2.7                | 9.8     |
| UG225_93.2 | 313214                 | 6397095                 | 20    | 1.4                 | 0.7                | 1.9     |
| WD462_P1   | 315529                 | 6391358                 | 29    | -18.4               | -21.8              | -17.6   |
| WD462_P3   | 315529                 | 6391358                 | 15    | 1.8                 | -3.9               | 5.0     |
| WD609      | 318803                 | 6392211                 | 1     | 6.8                 | 6.5                | 7.3     |

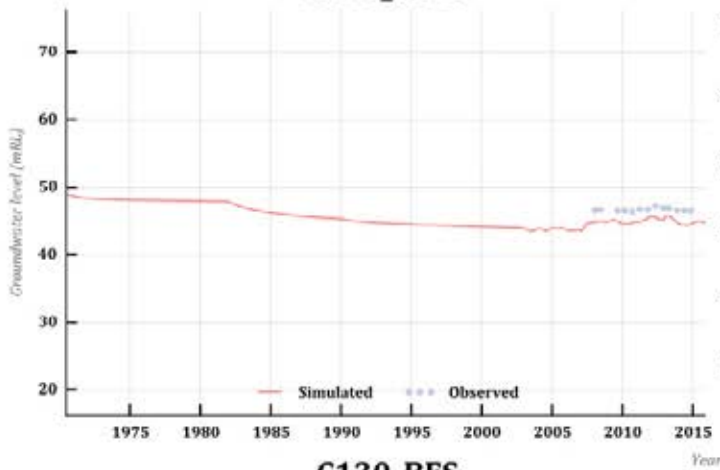
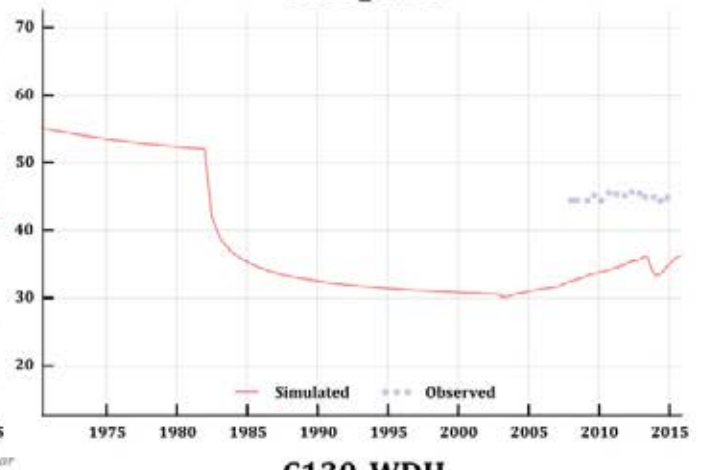
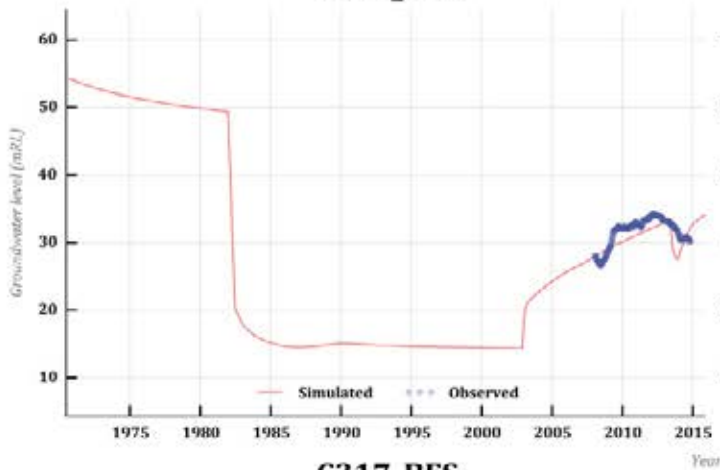
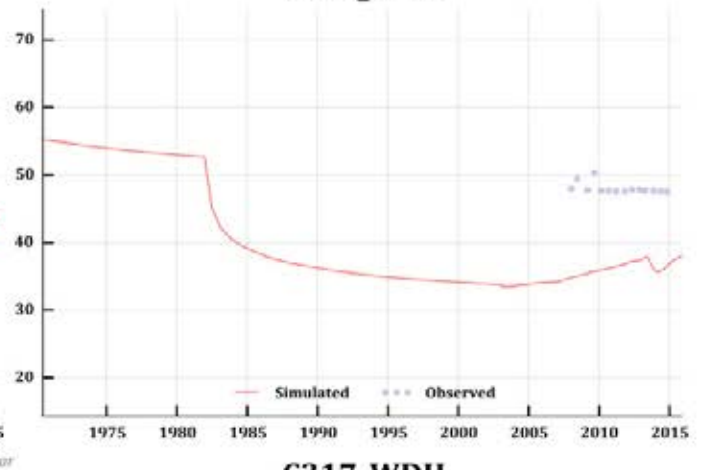
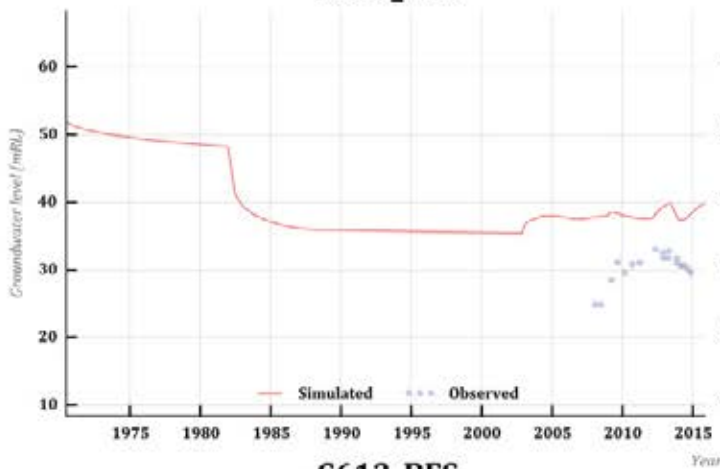
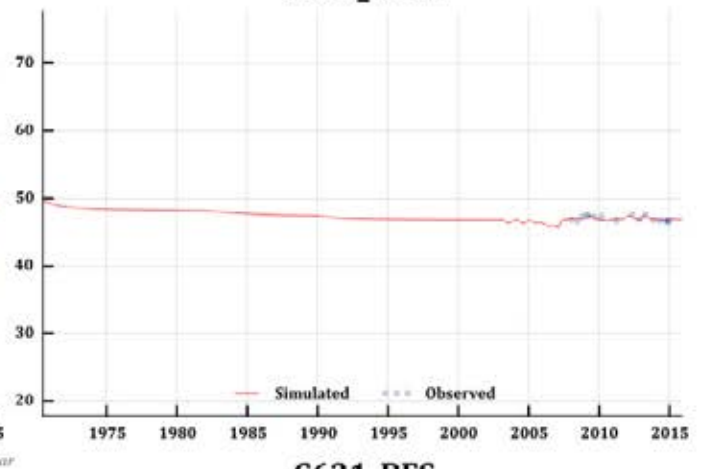
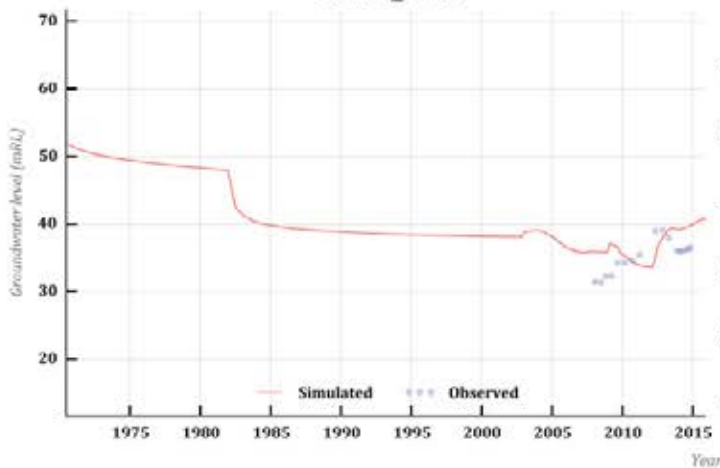
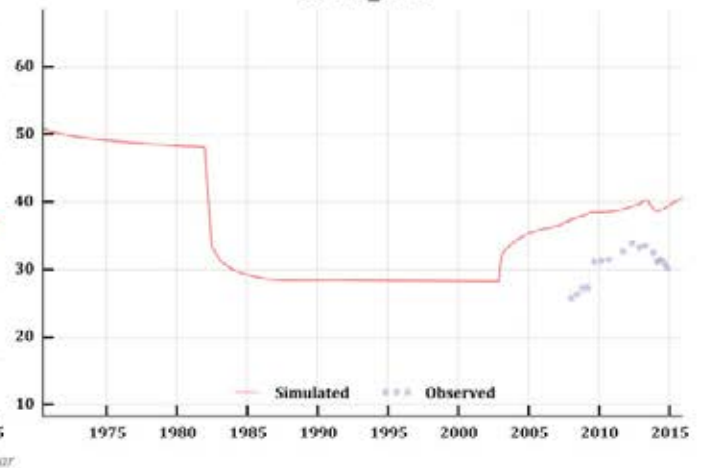


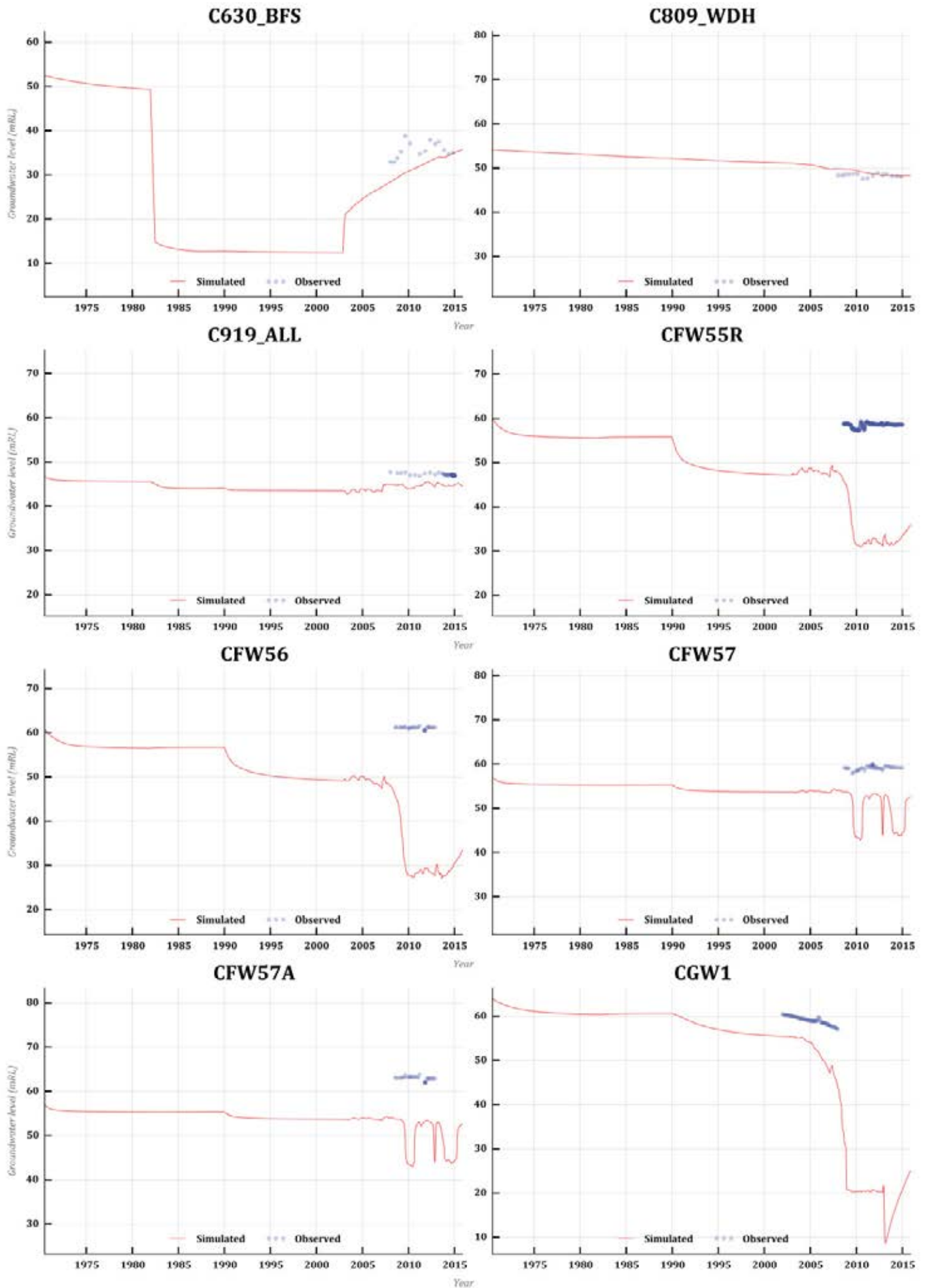


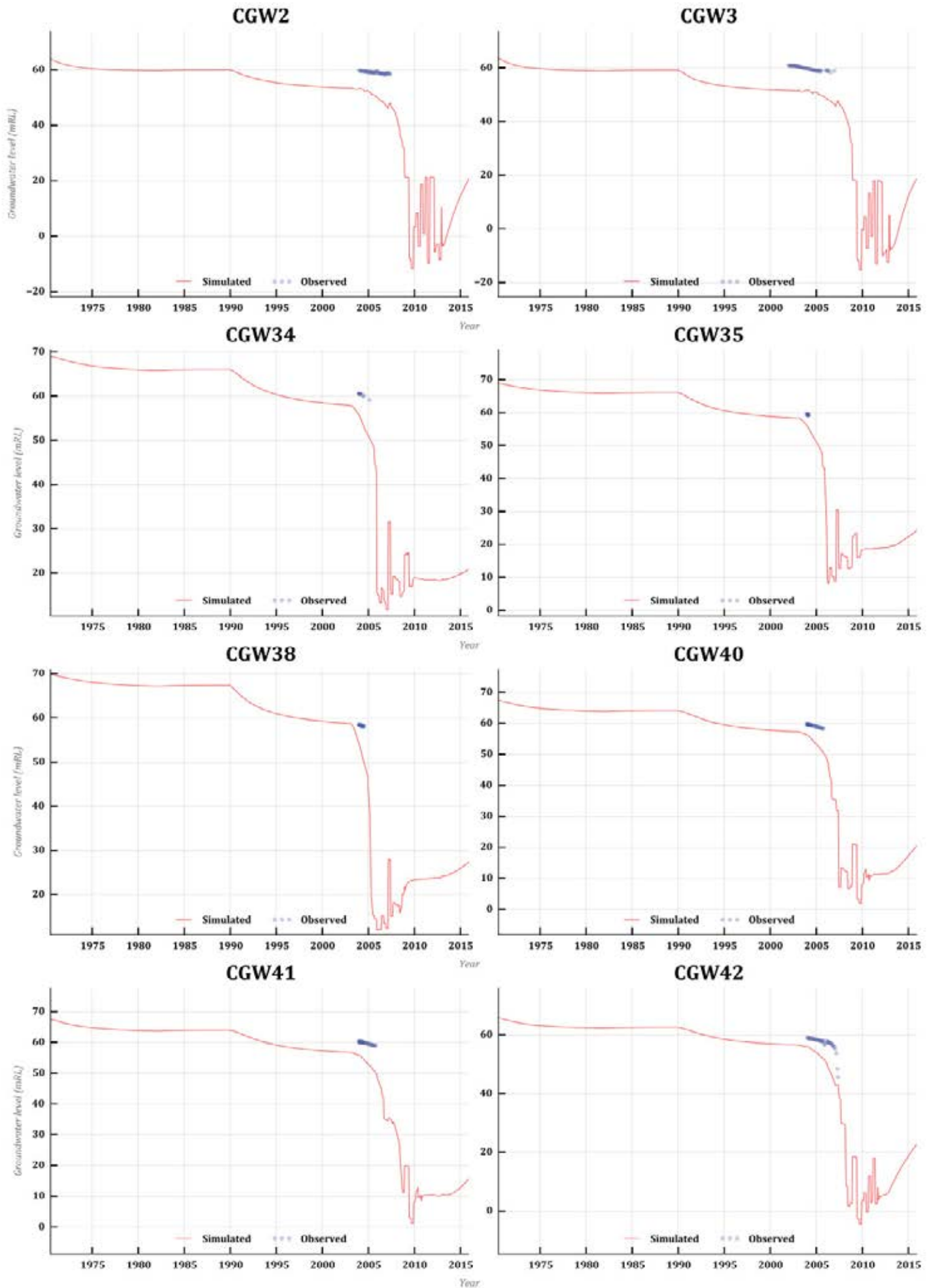


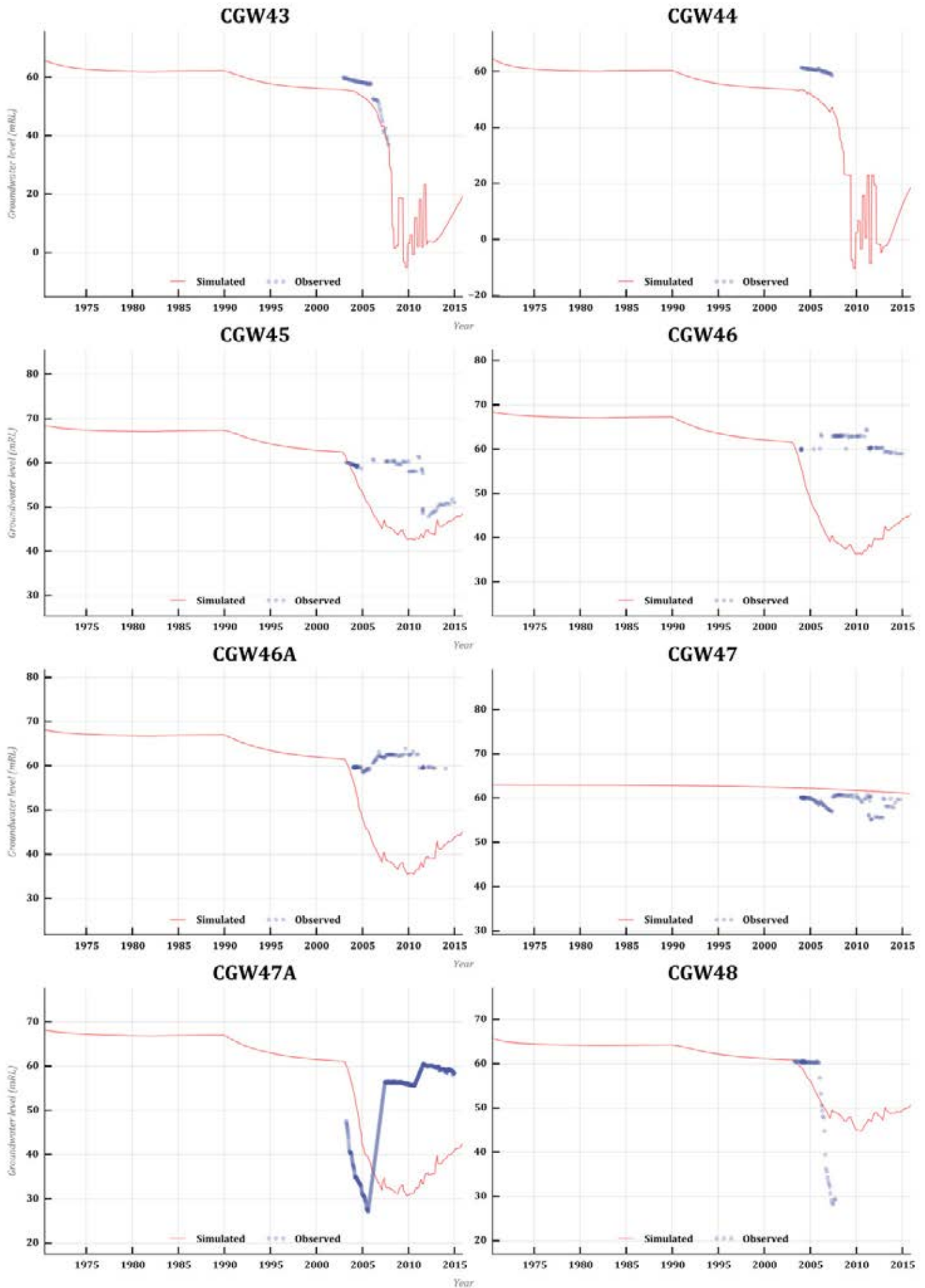


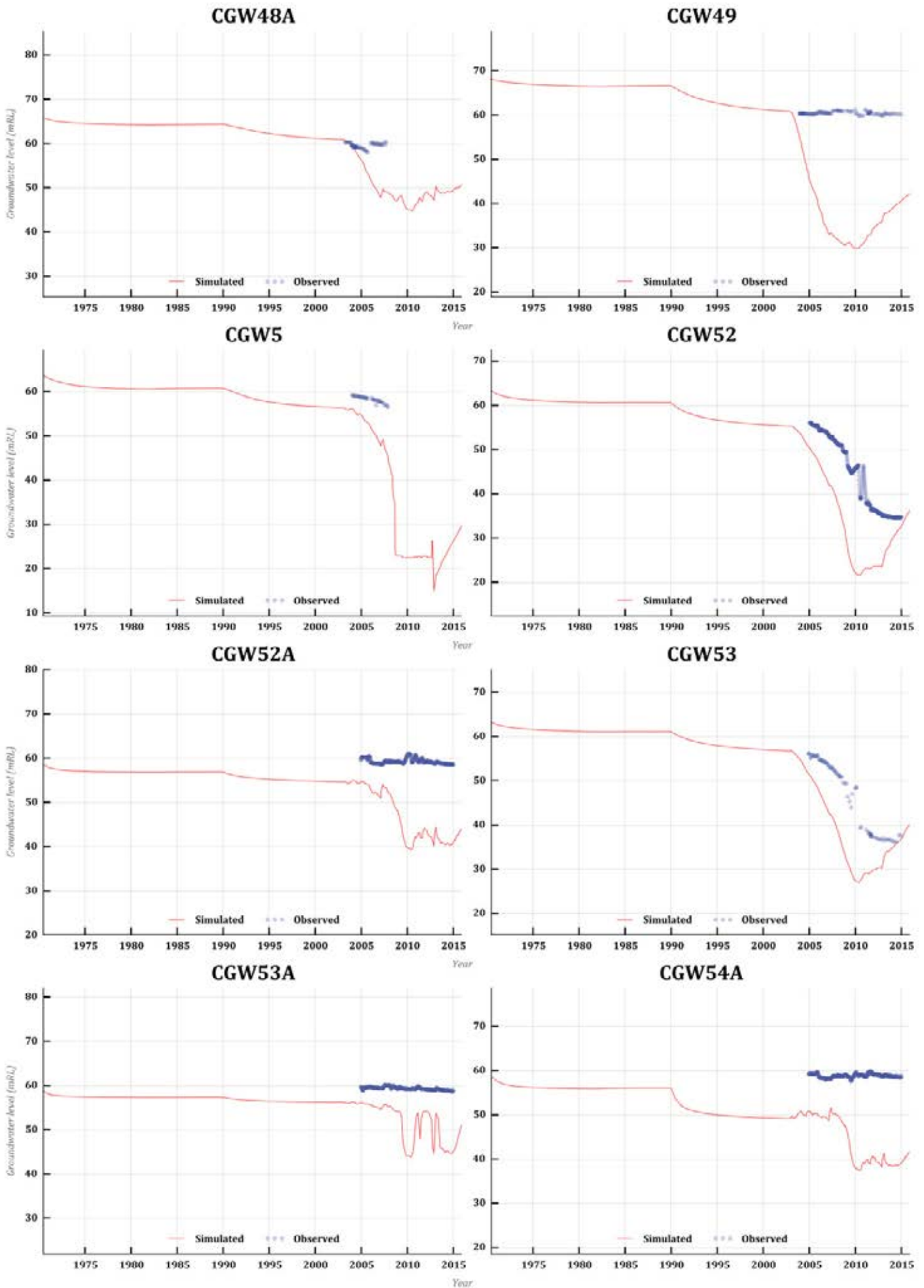


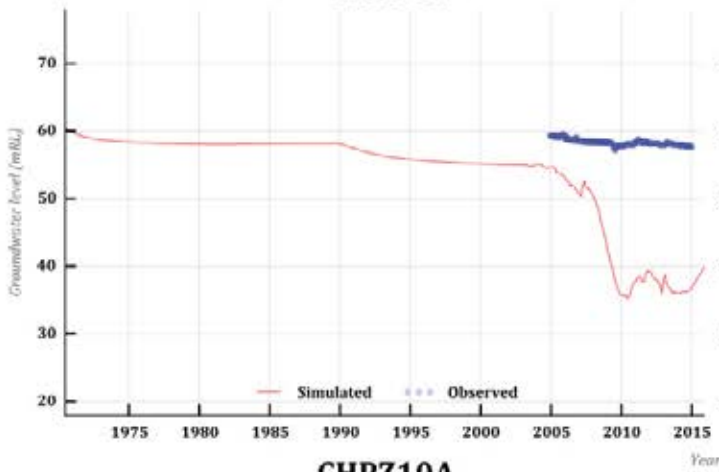
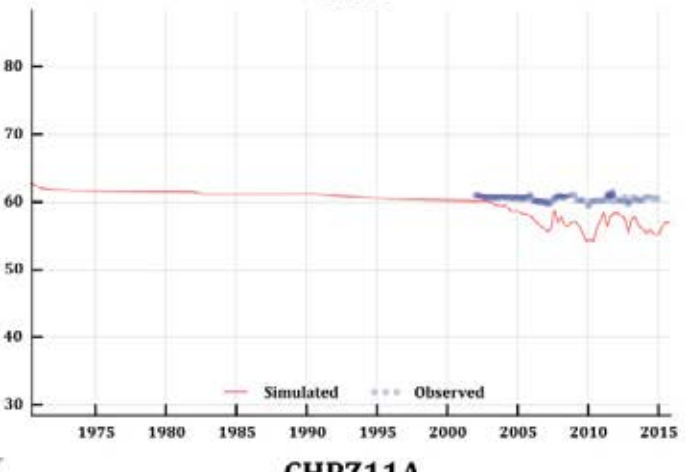
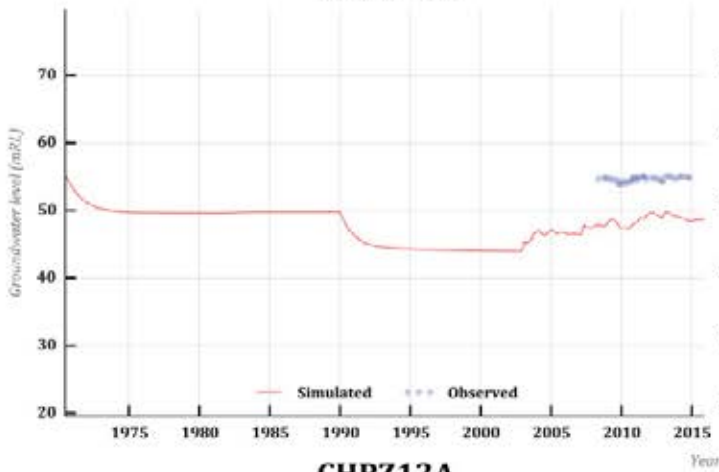
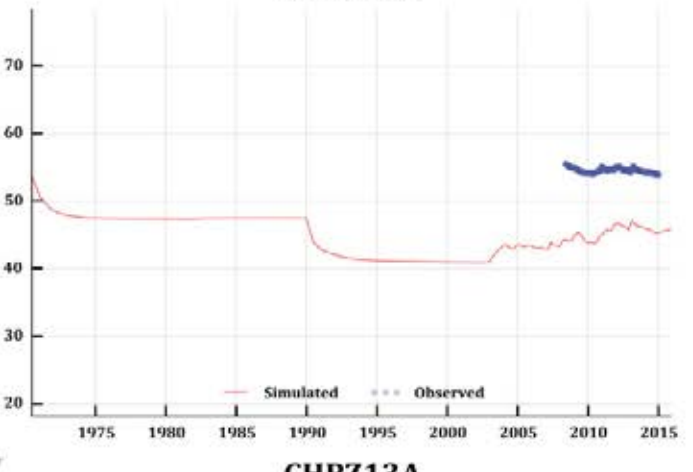
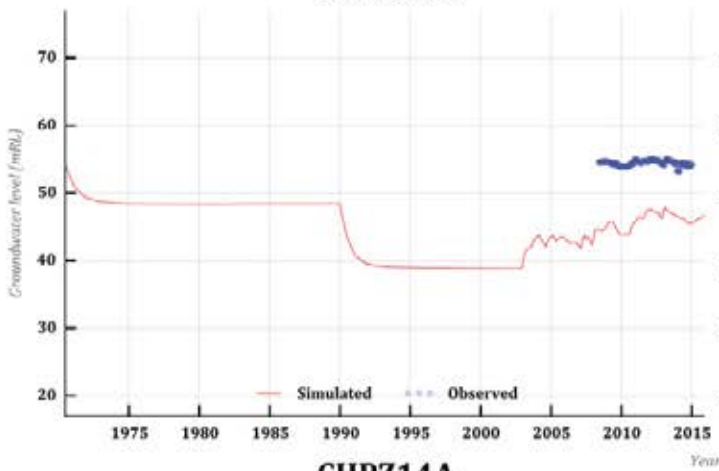
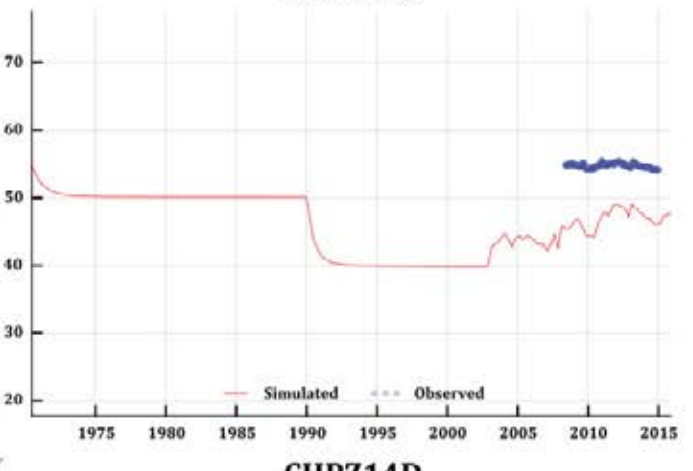
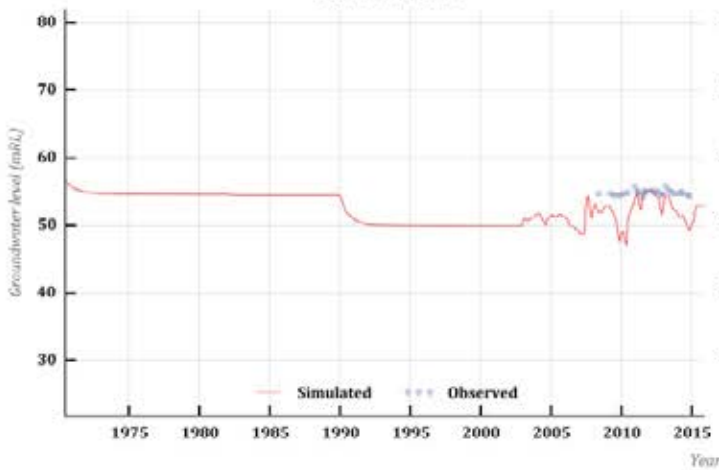
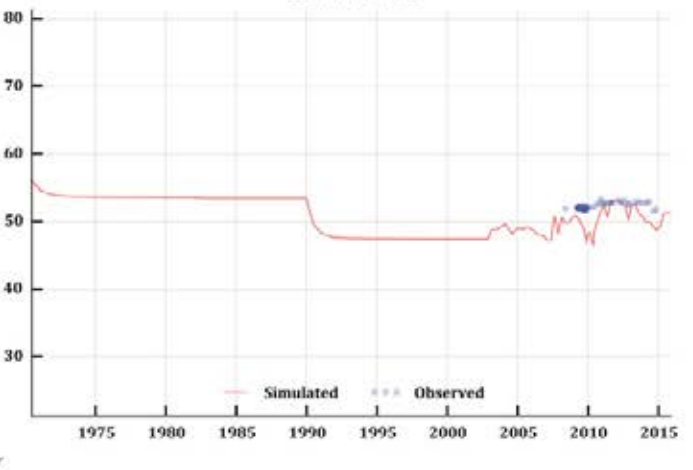
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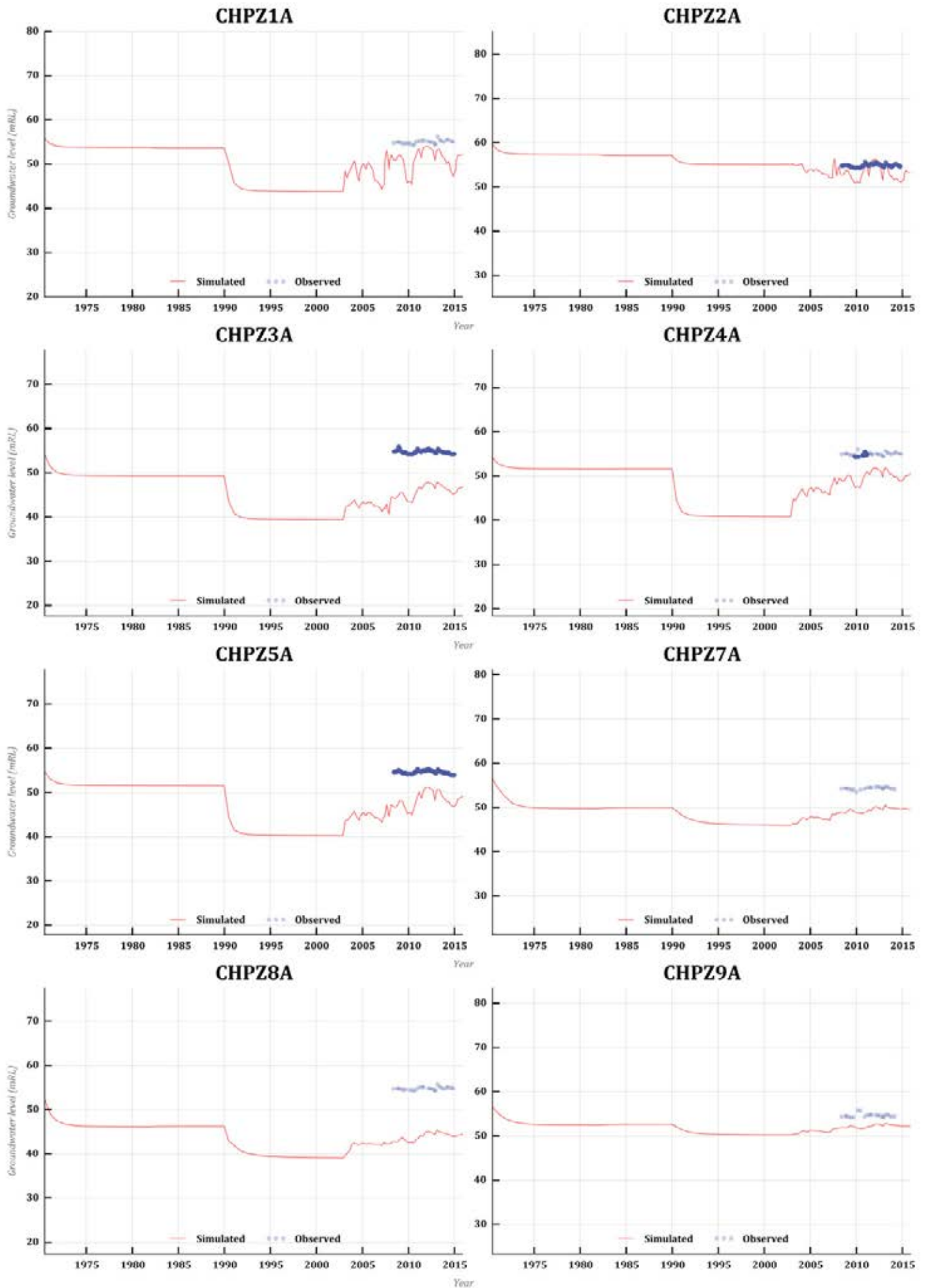


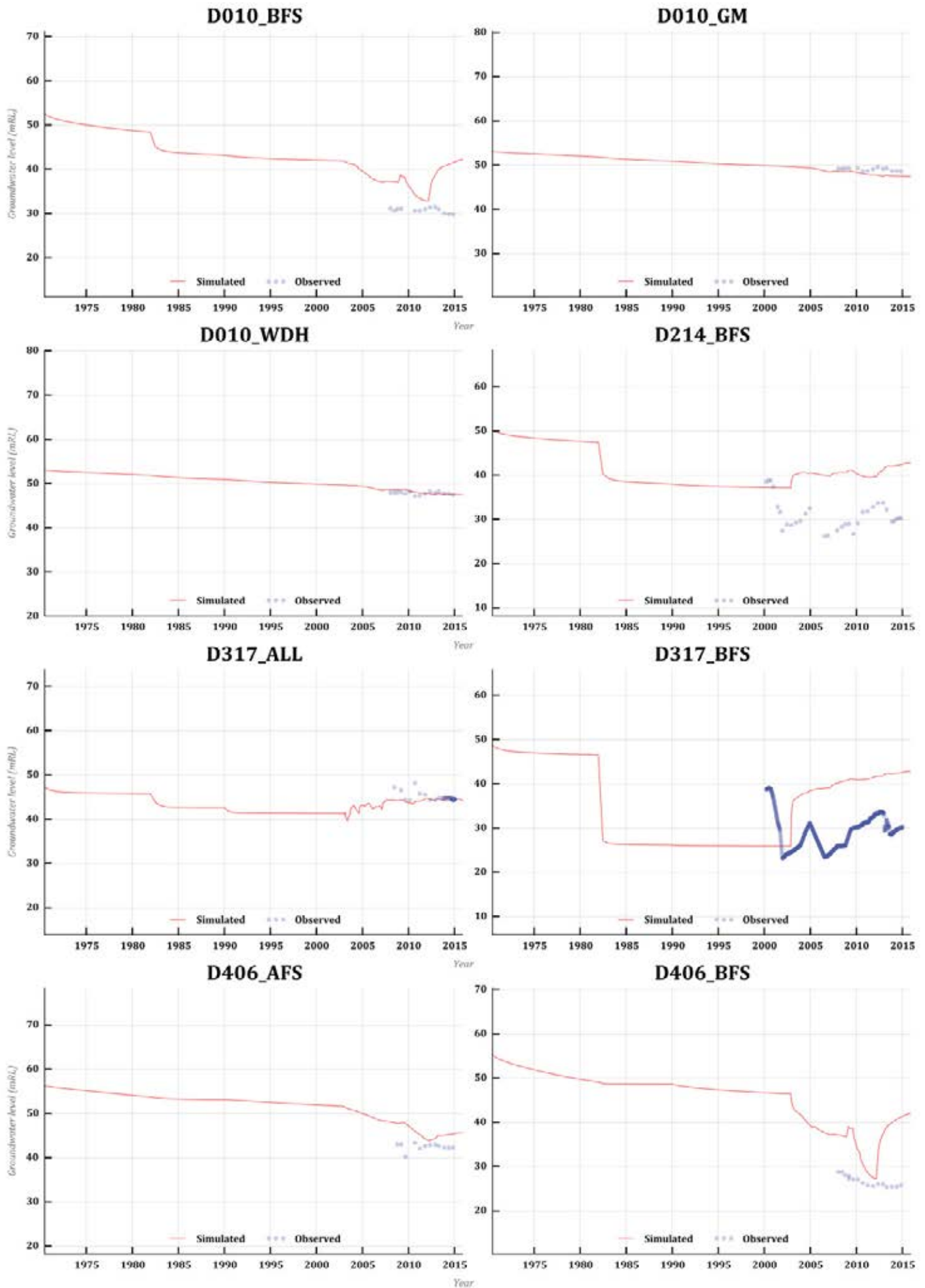


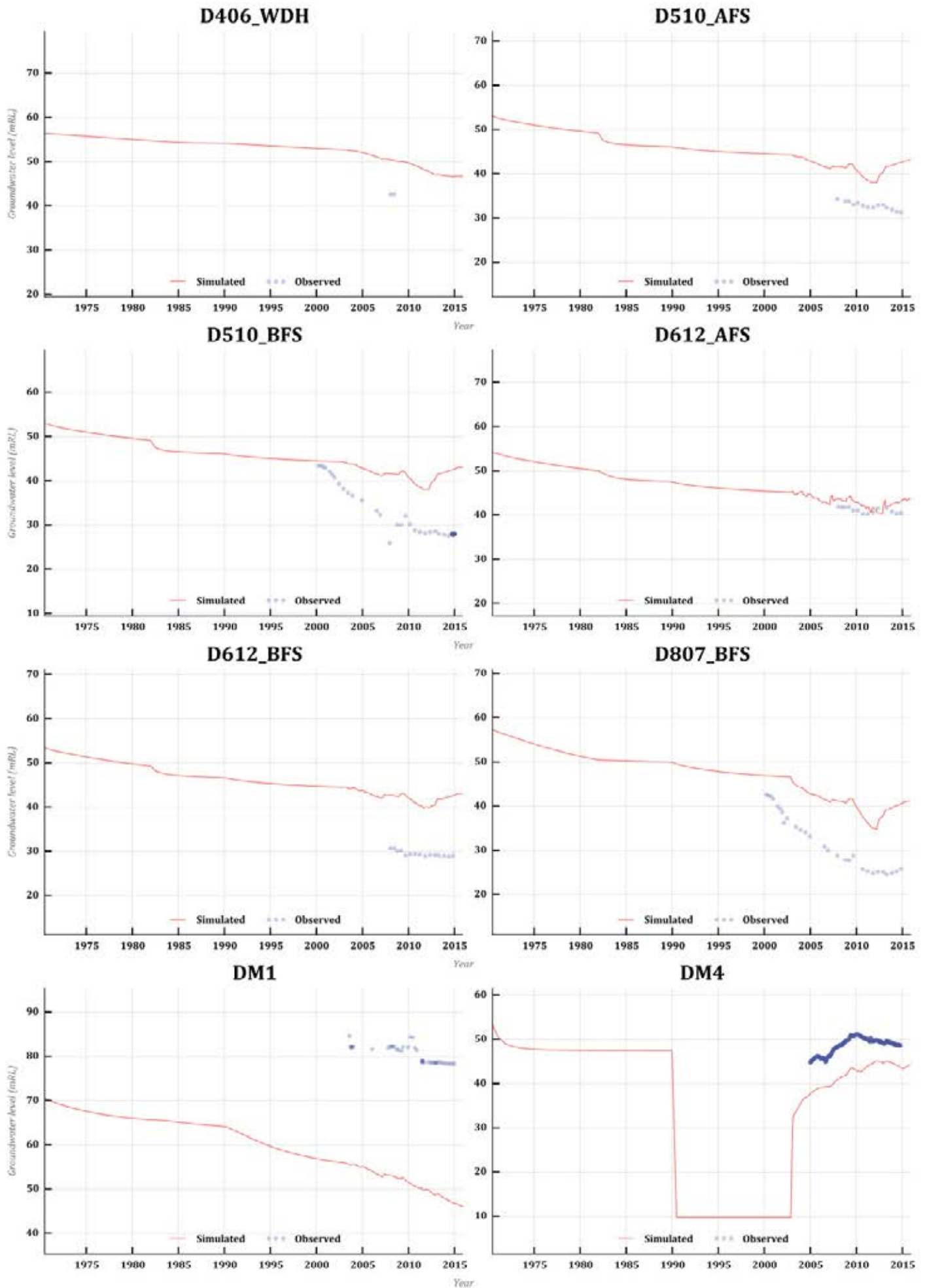


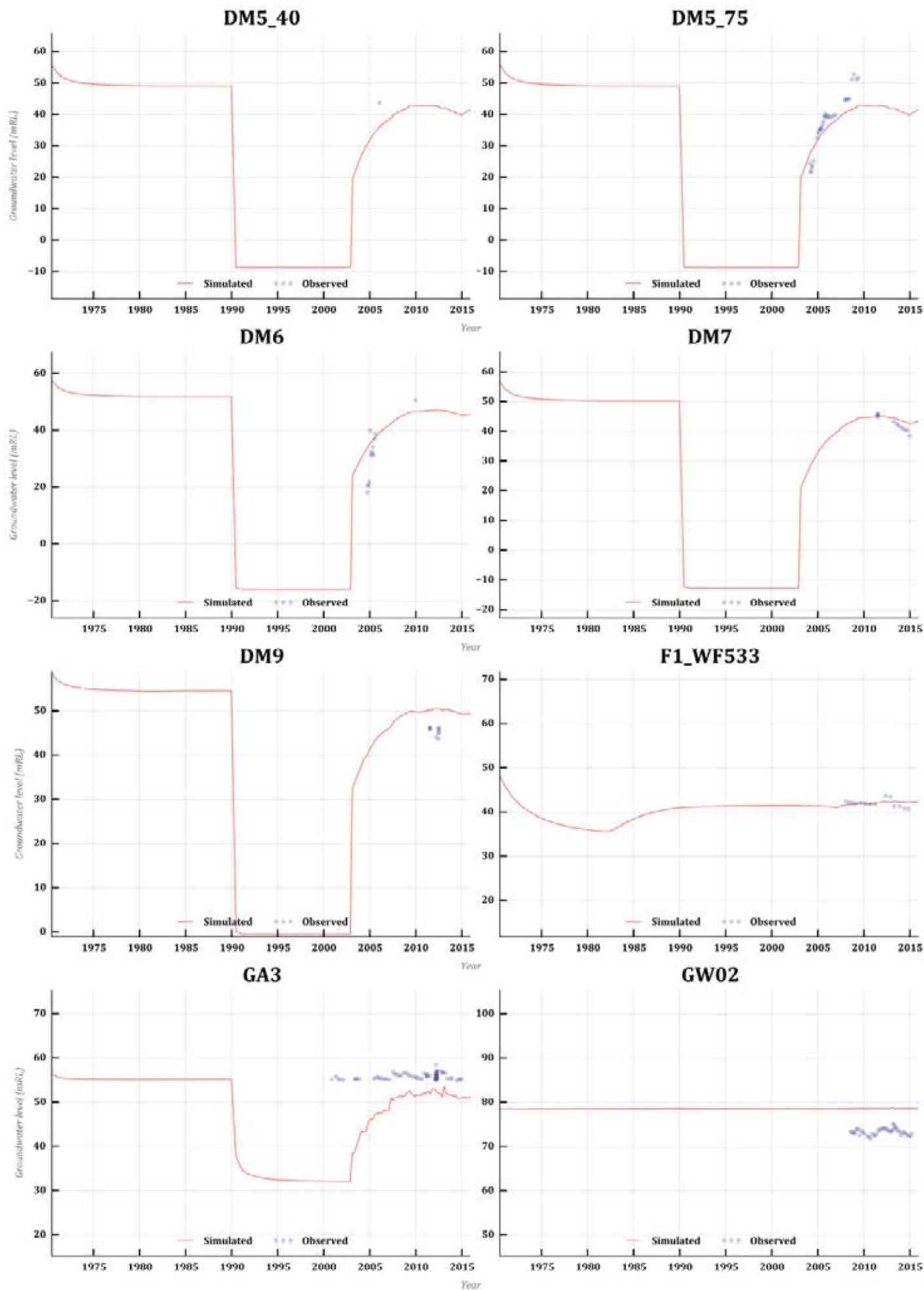


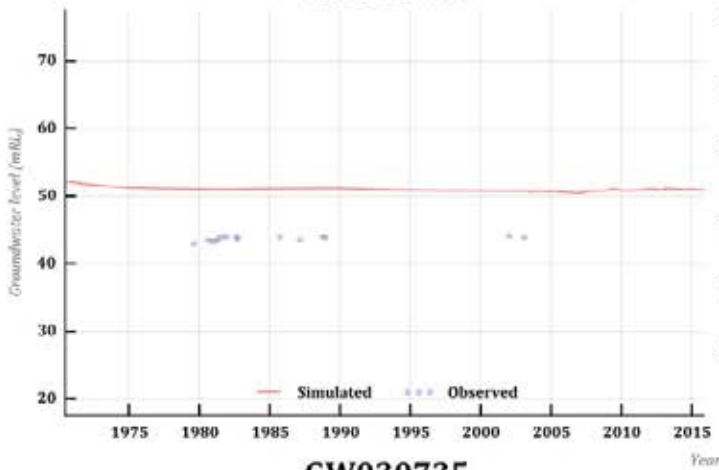
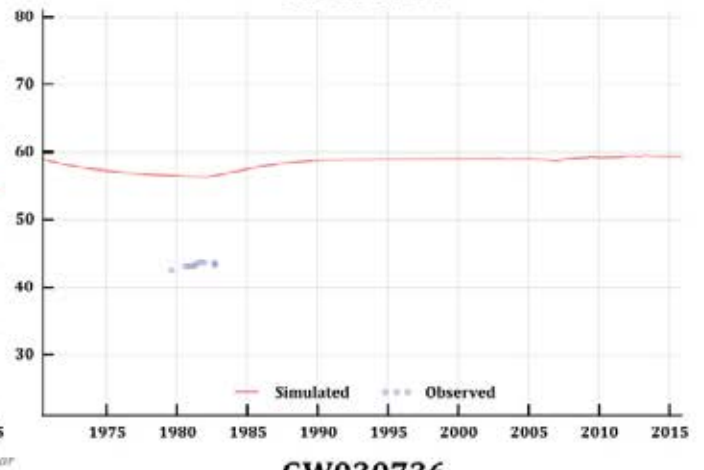
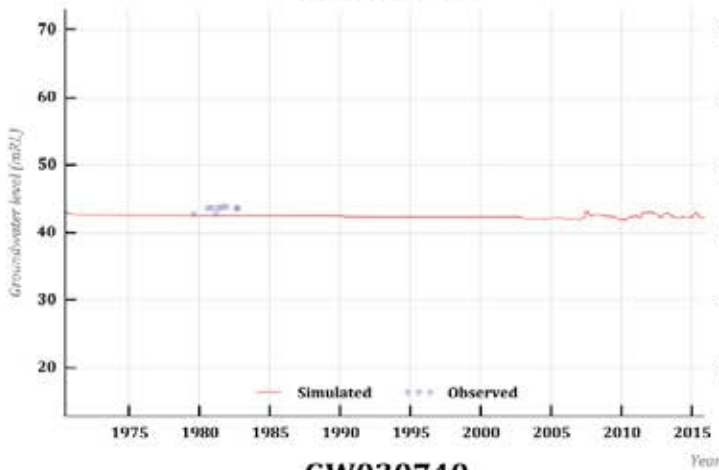
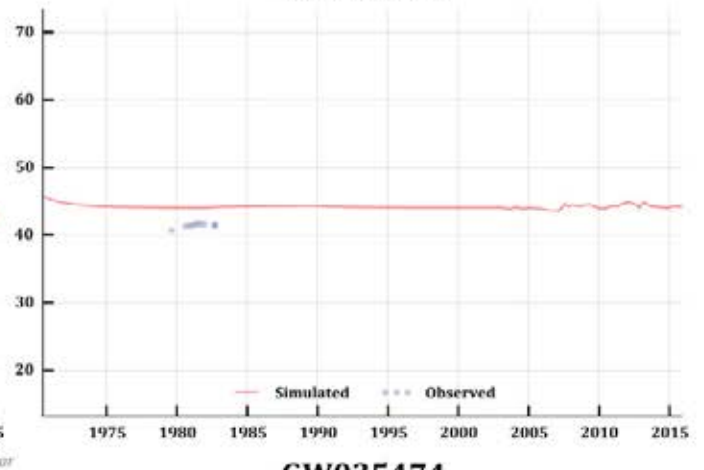
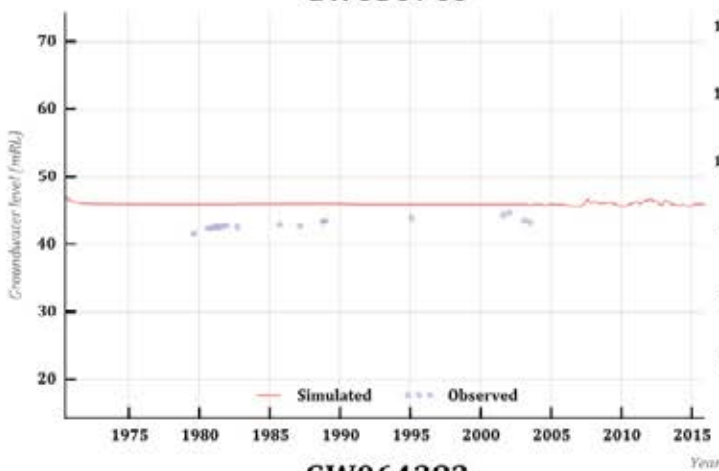
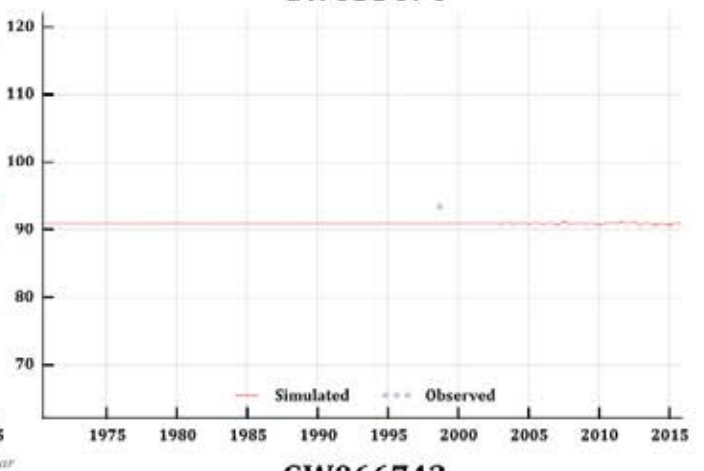
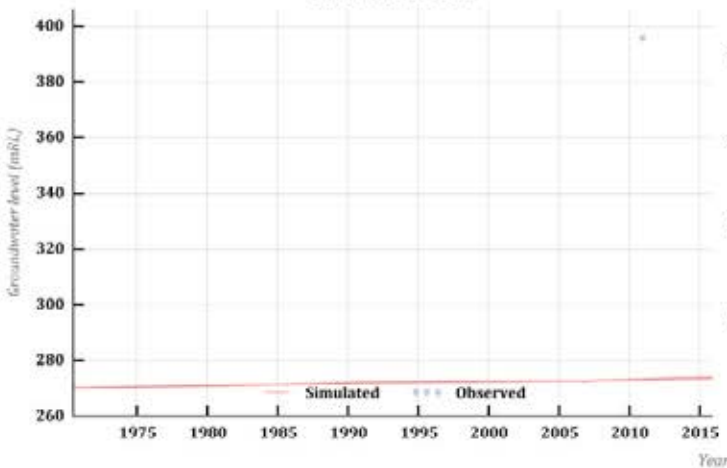
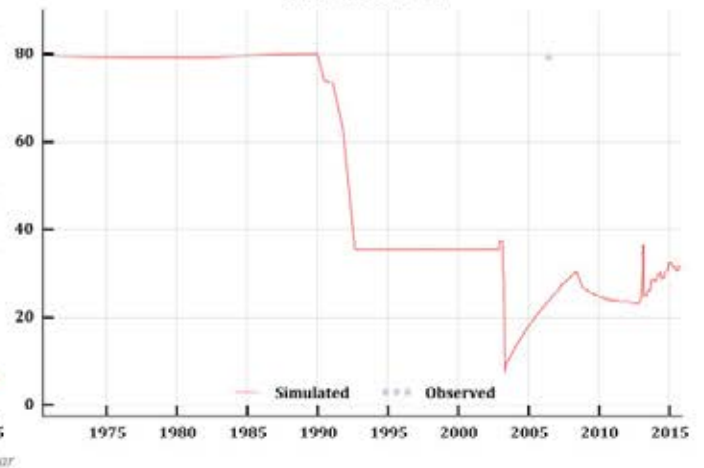
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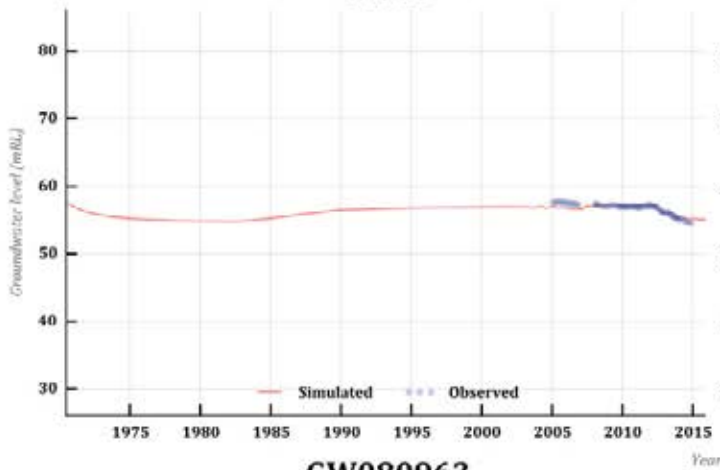




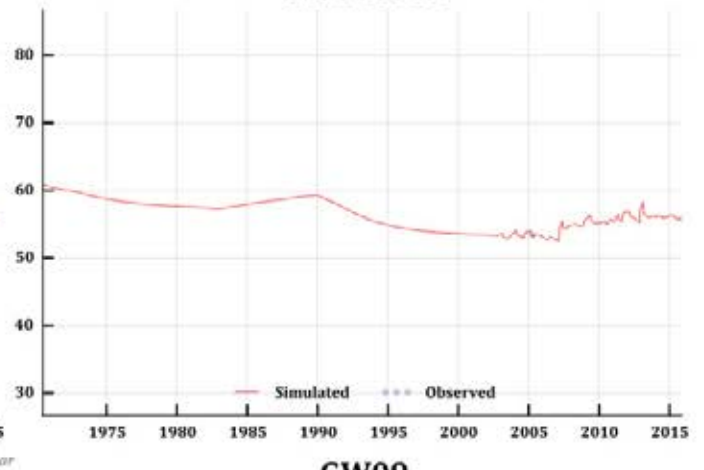


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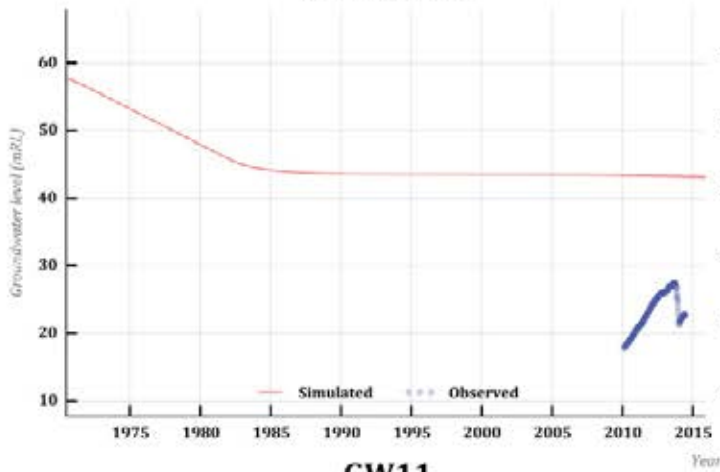
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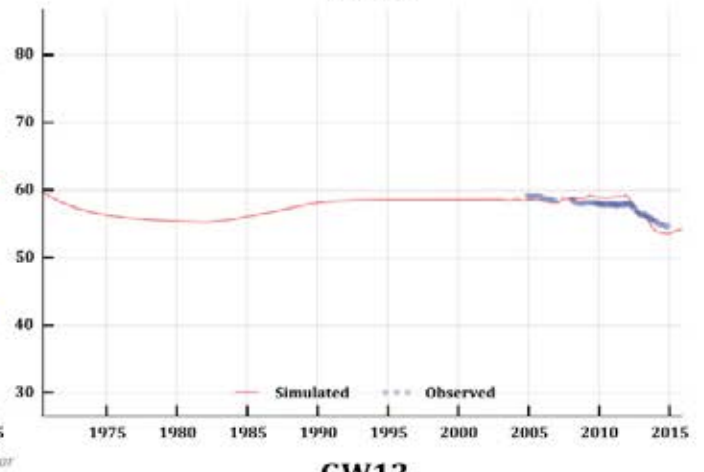
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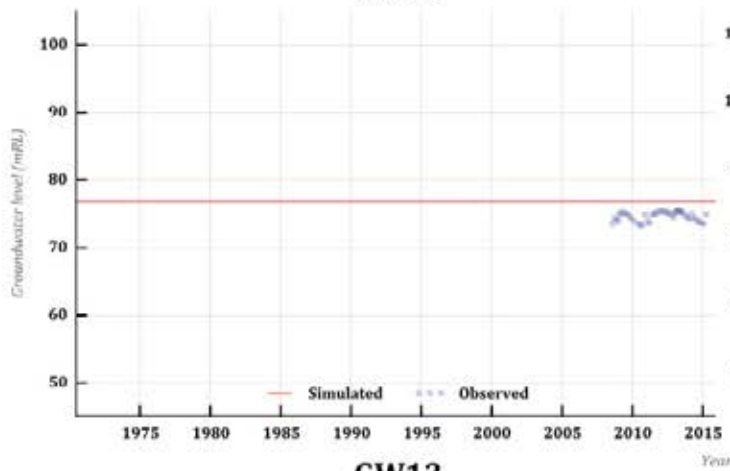
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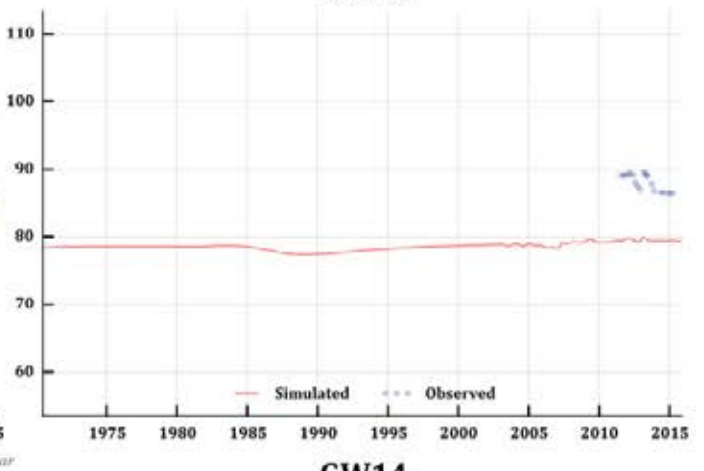
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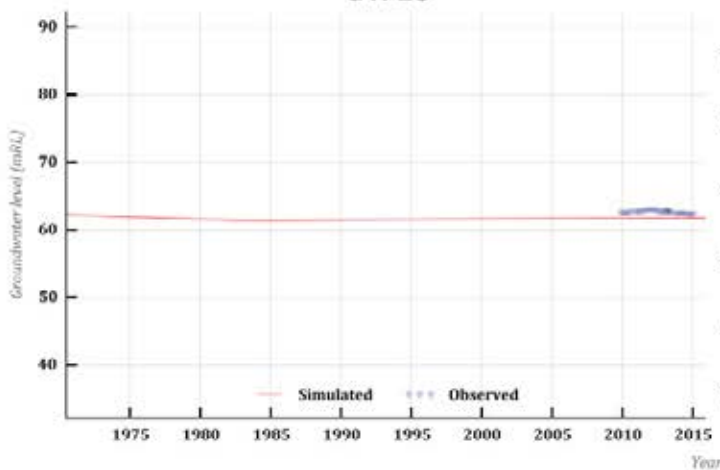
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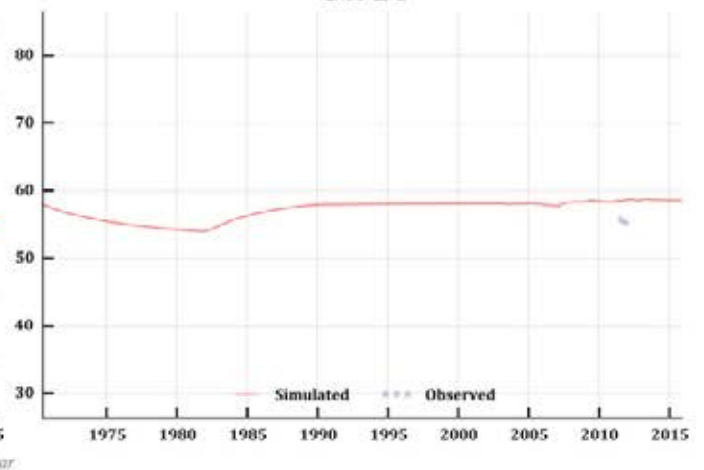
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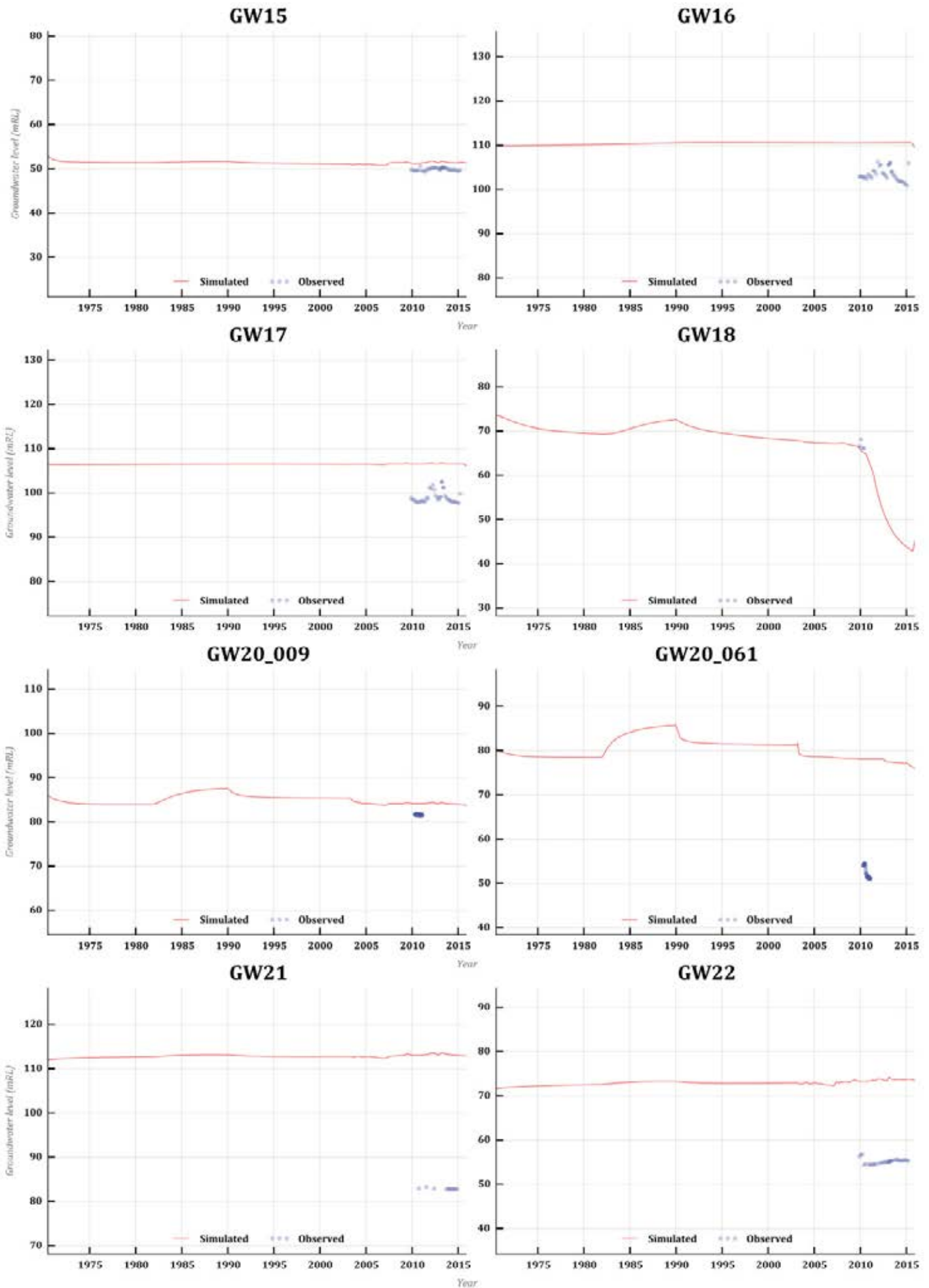


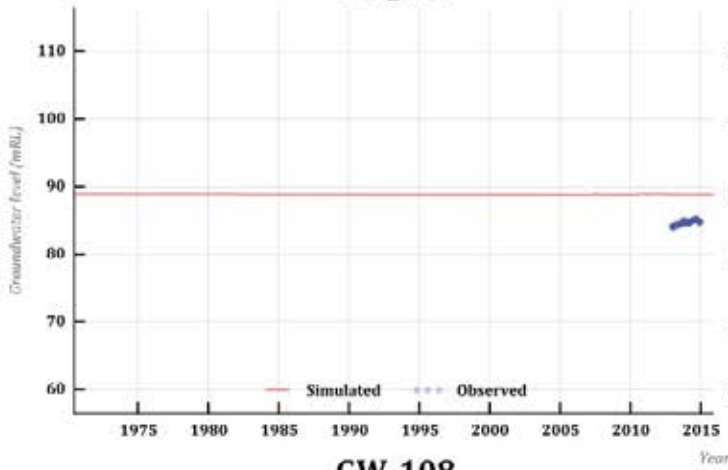
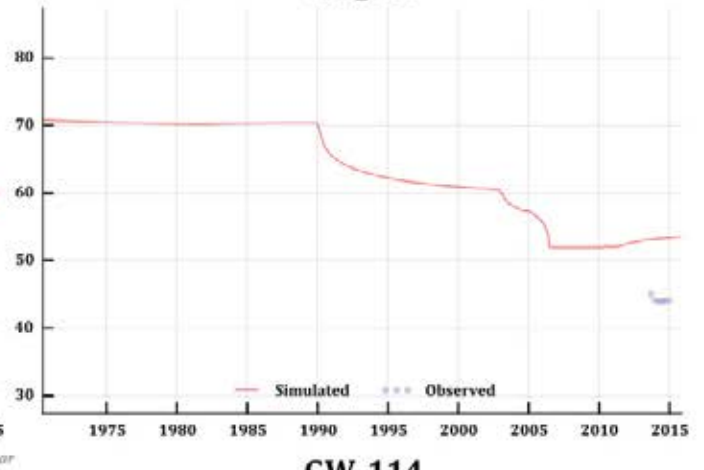
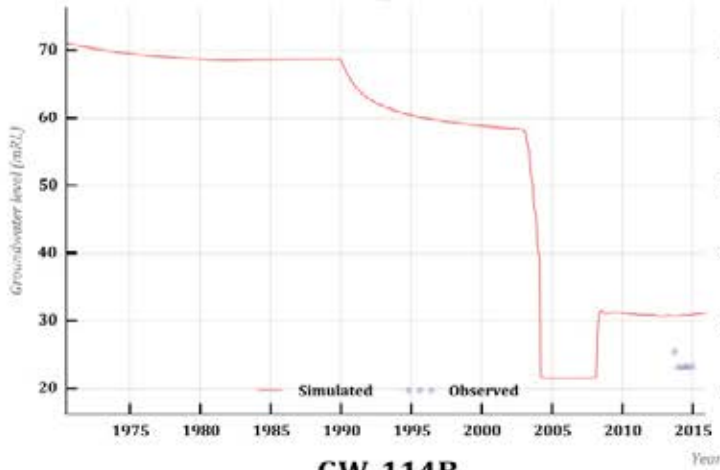
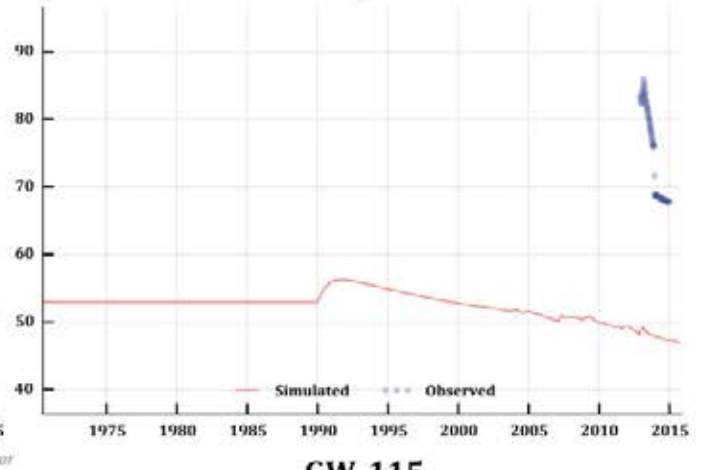
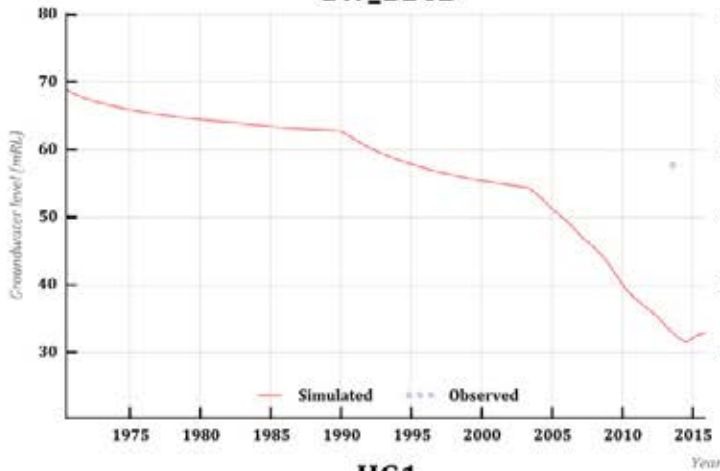
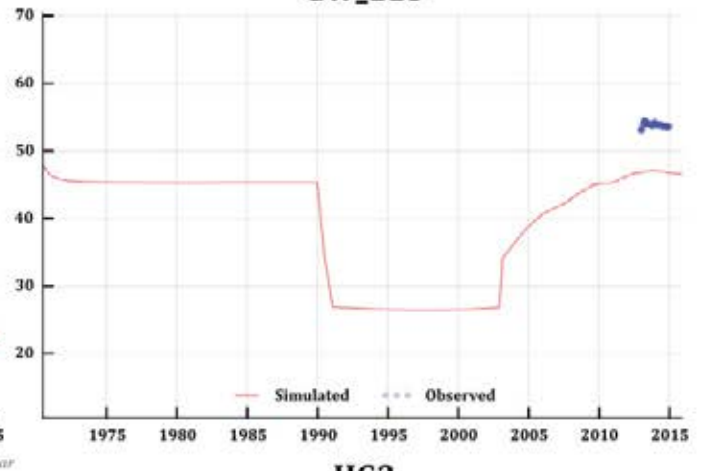
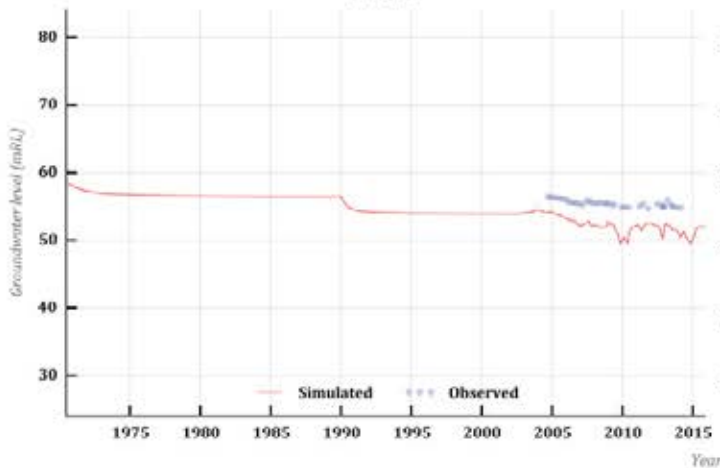
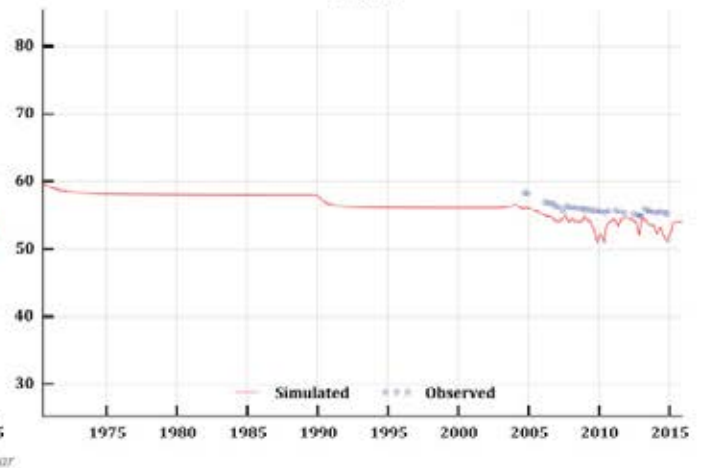
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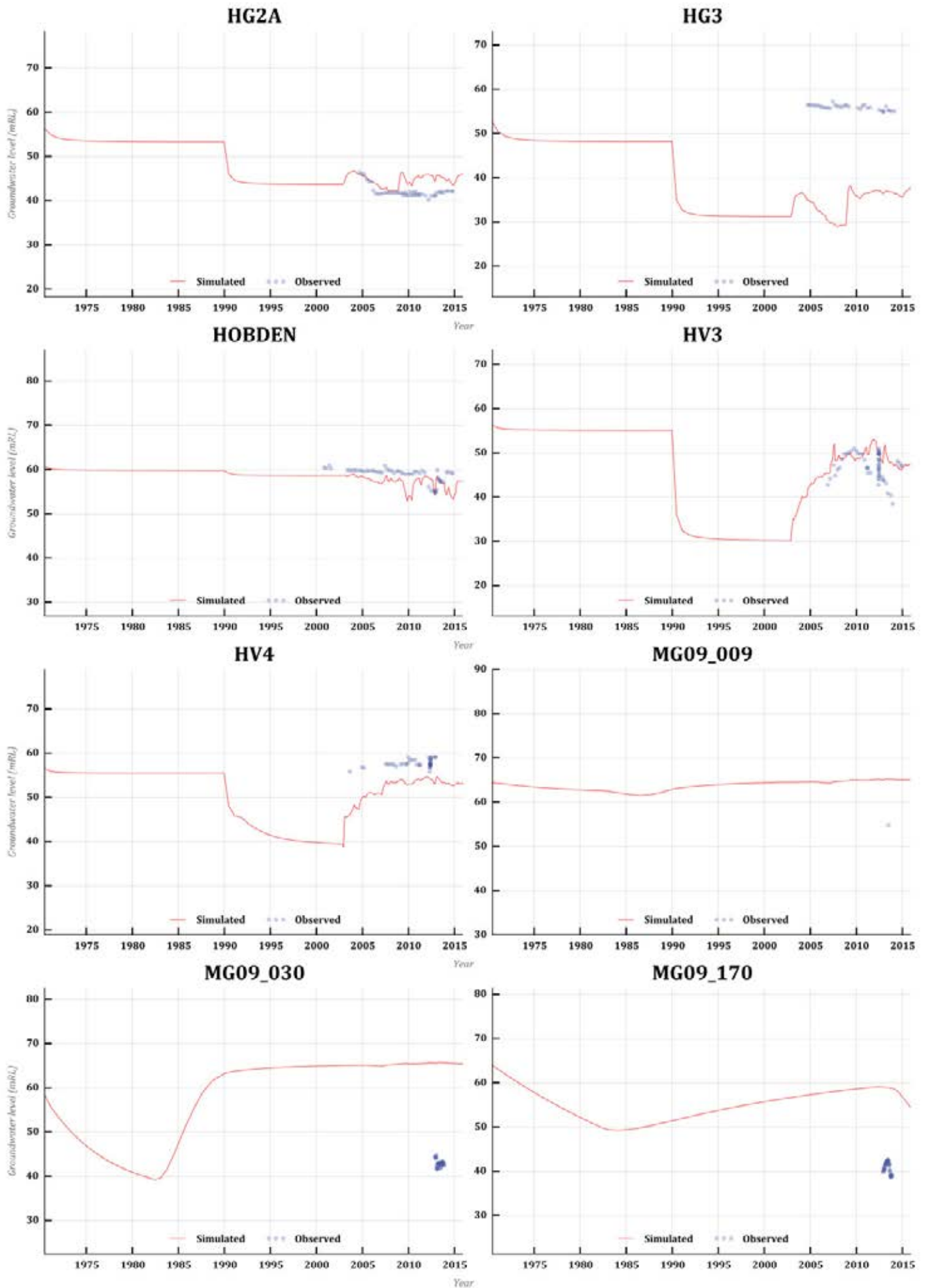


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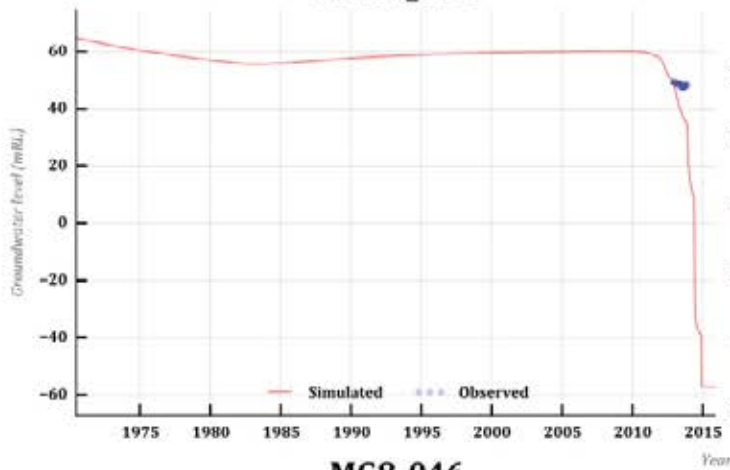




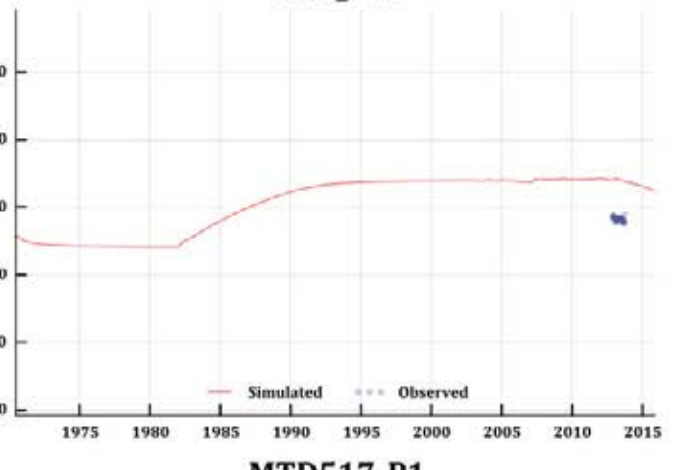
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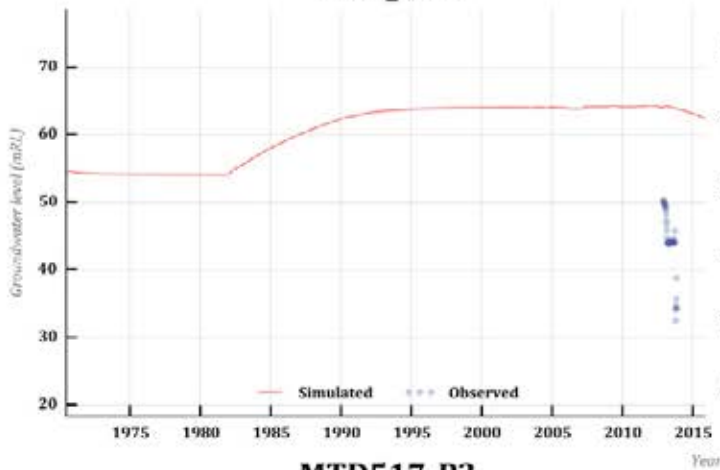
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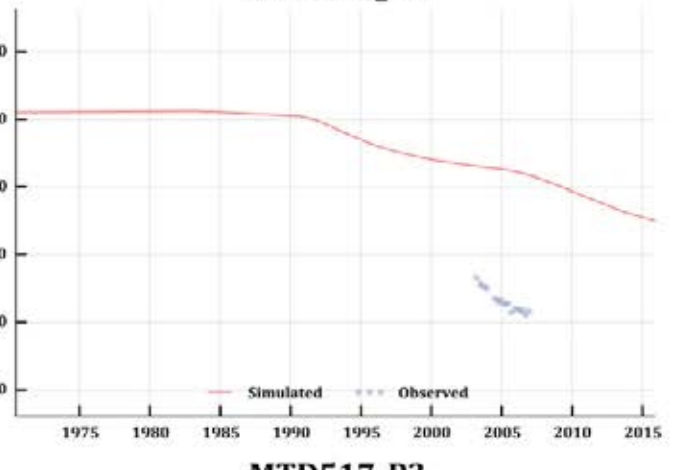
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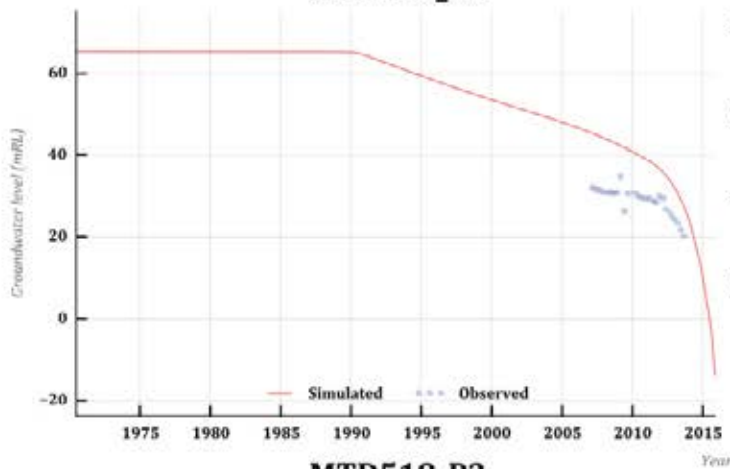
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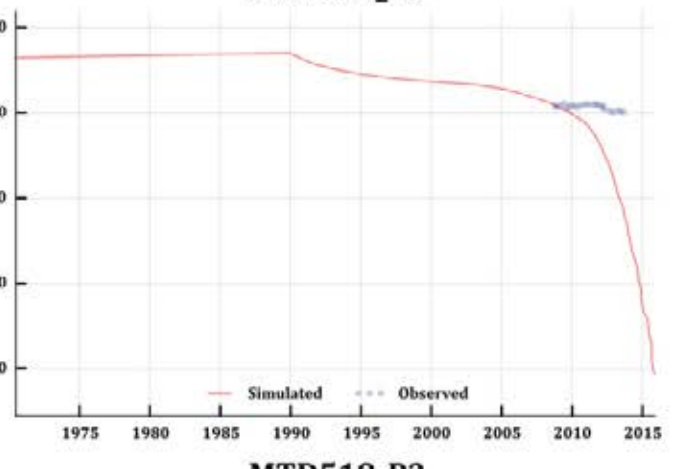
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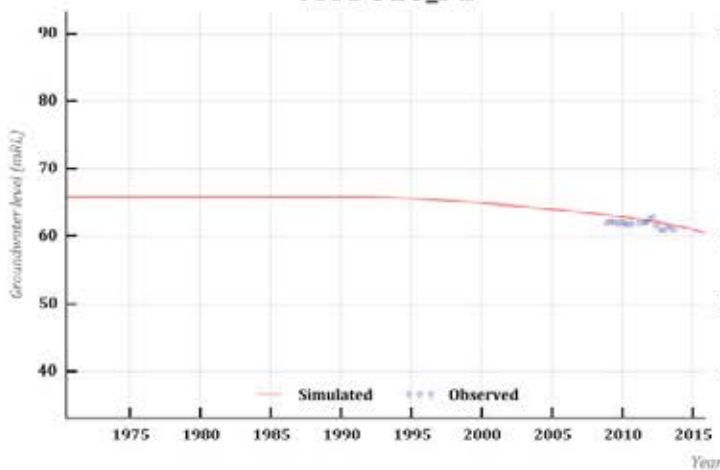
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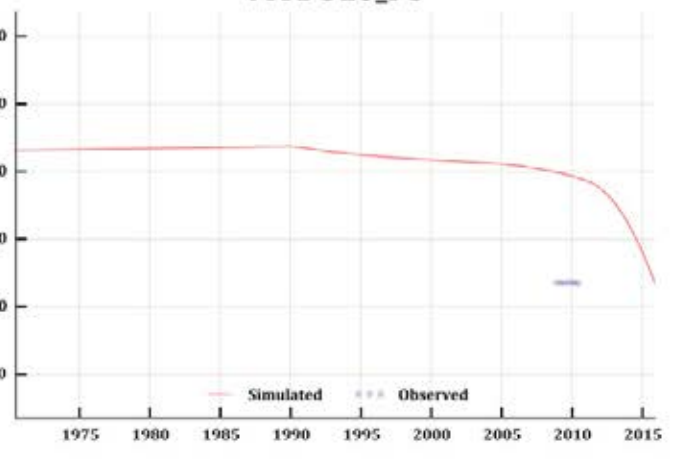
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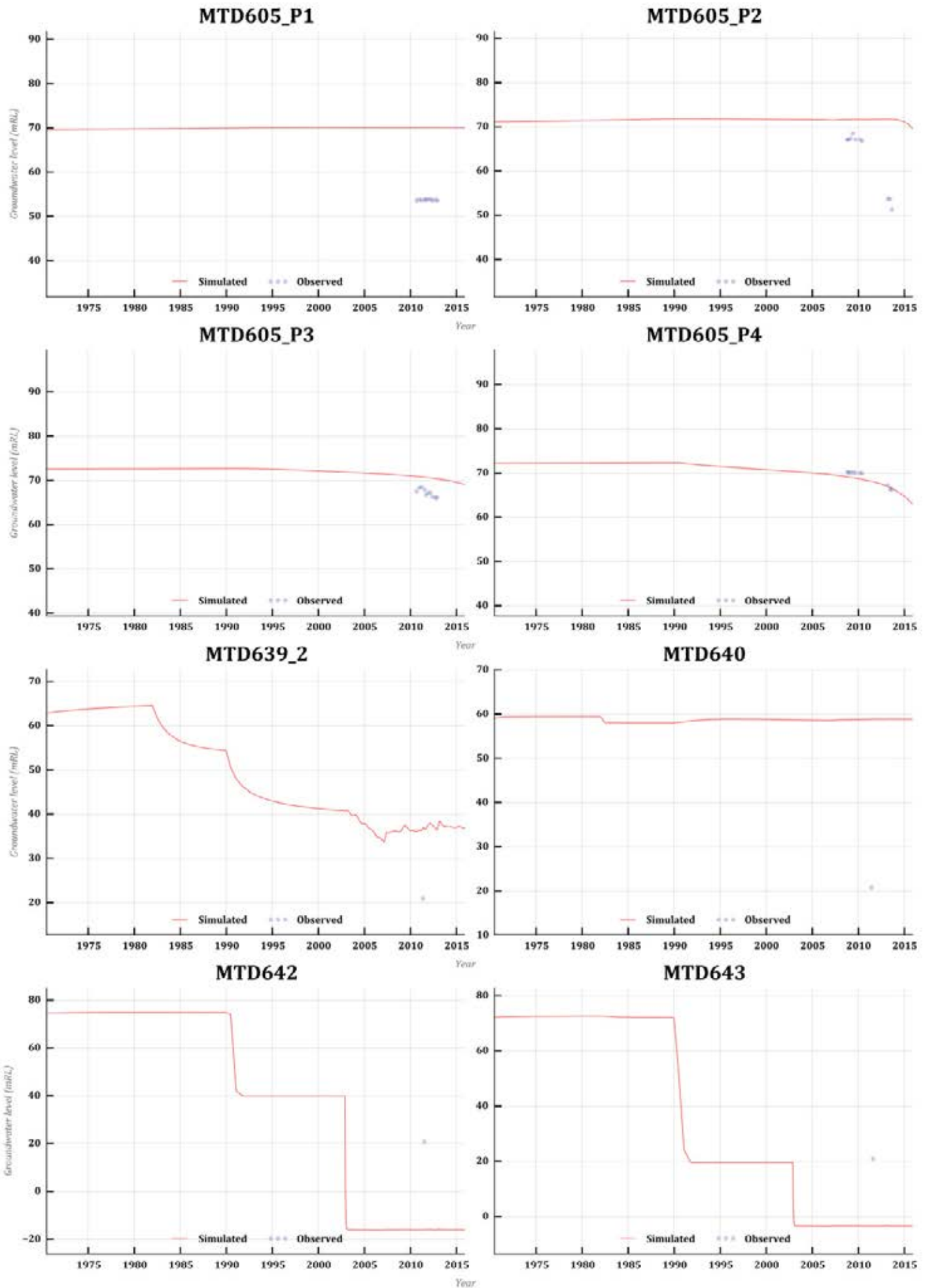


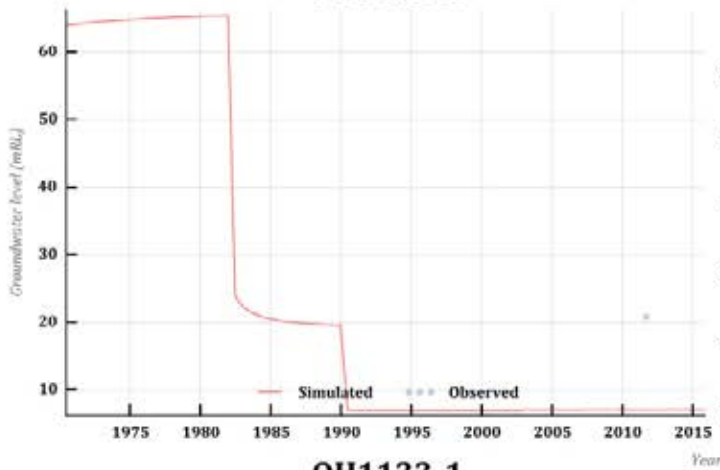
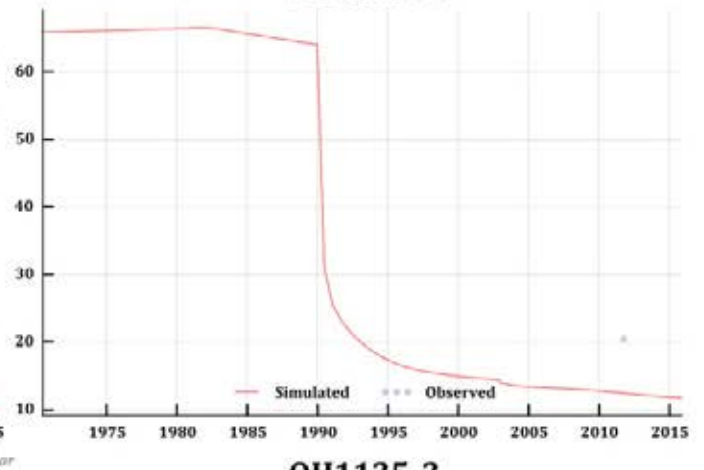
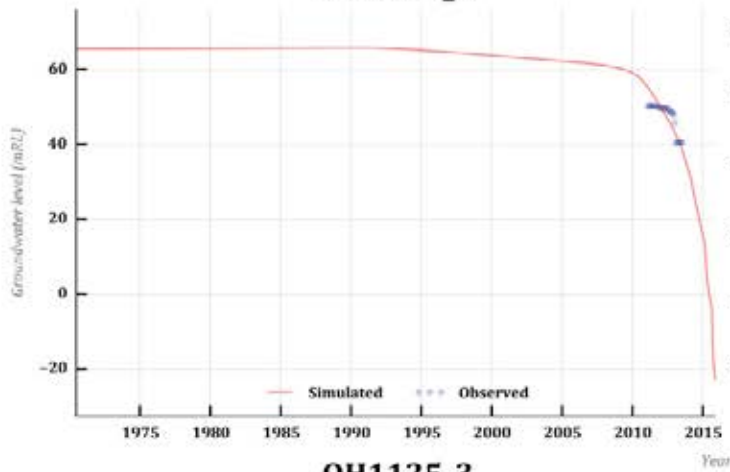
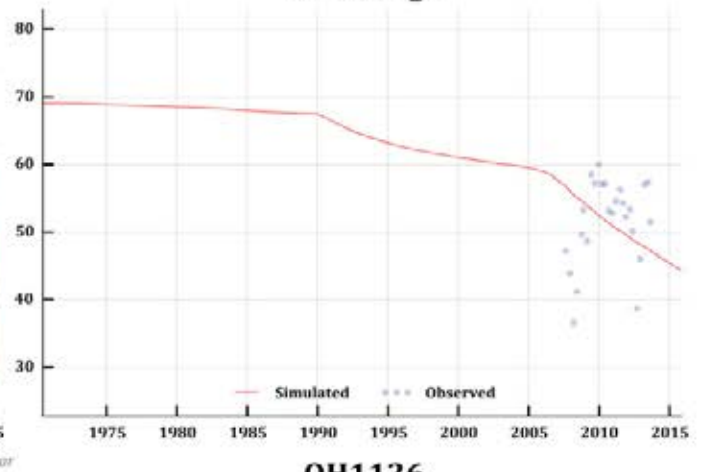
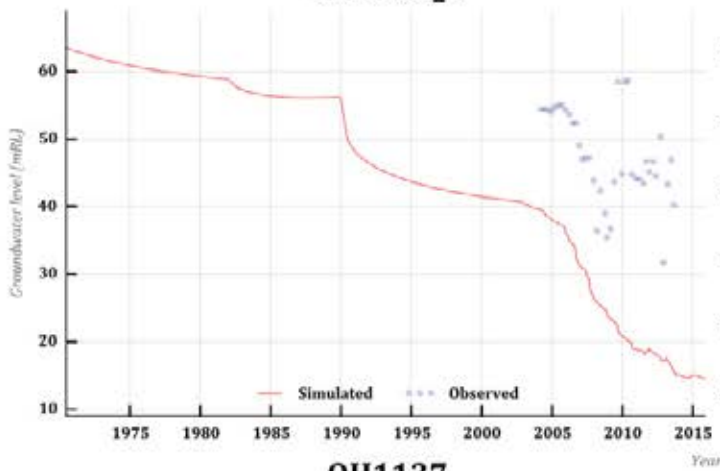
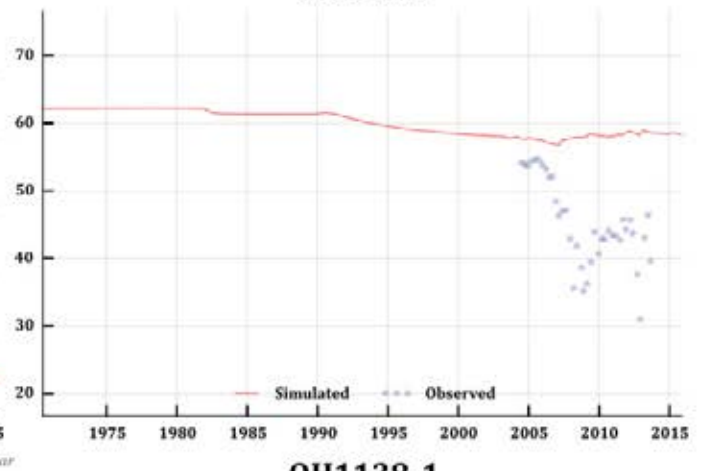
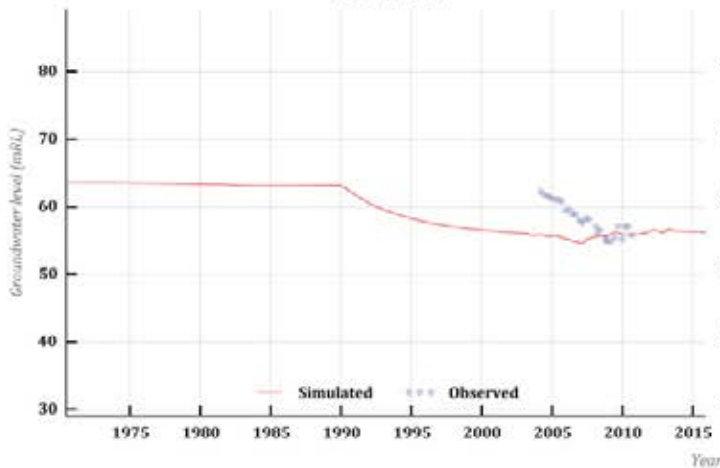
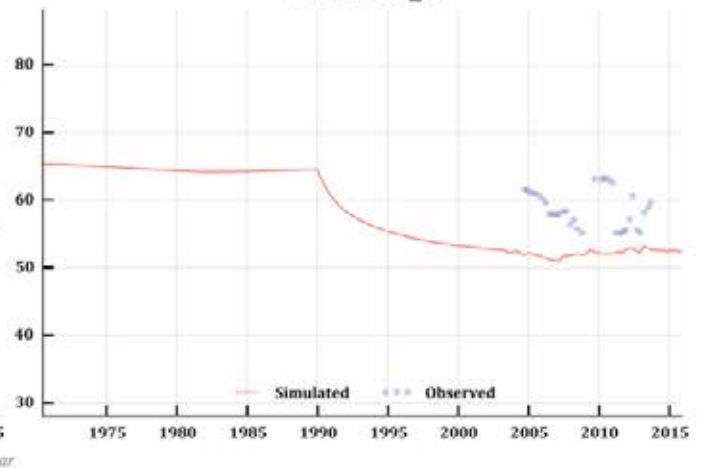
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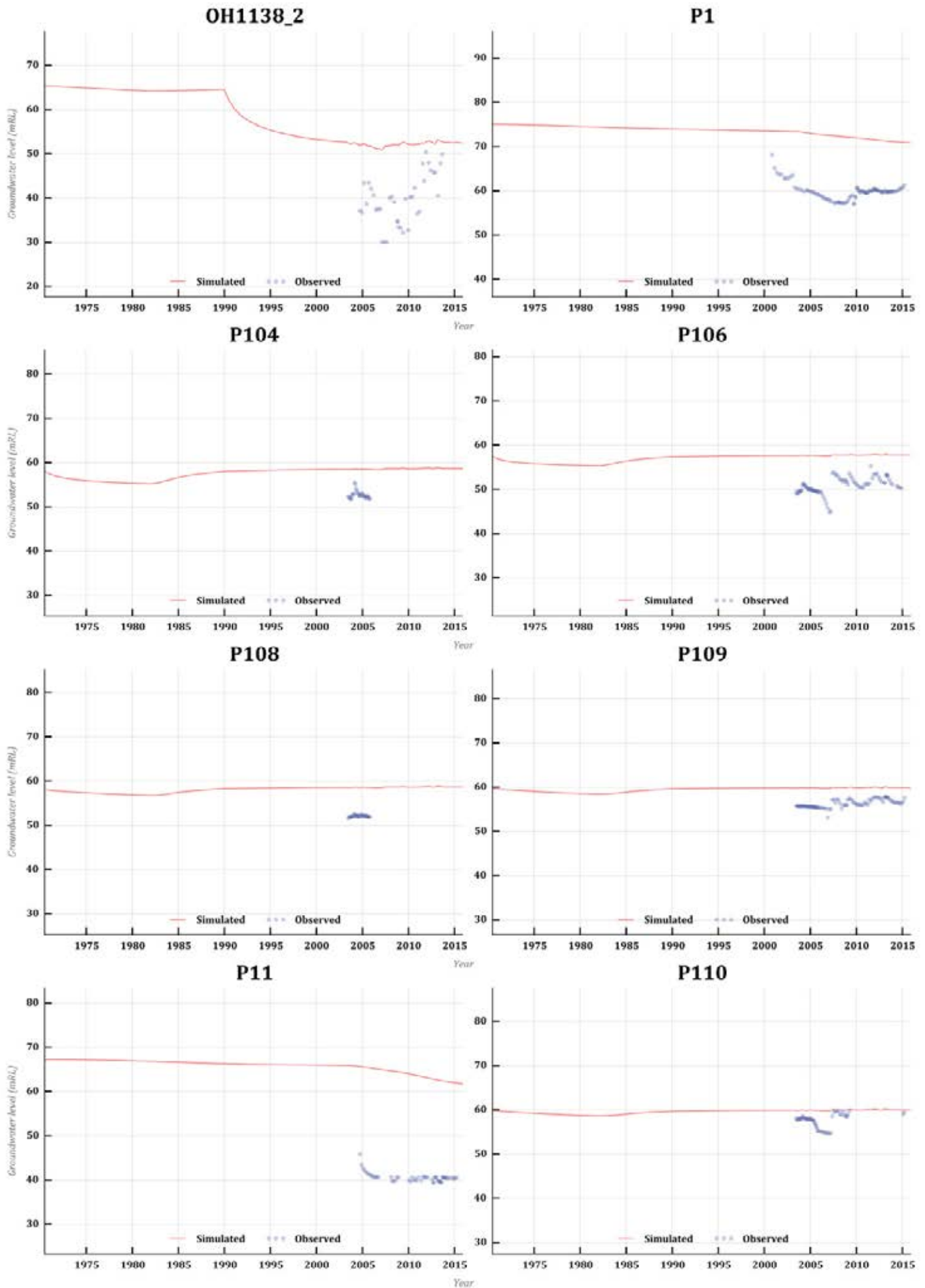


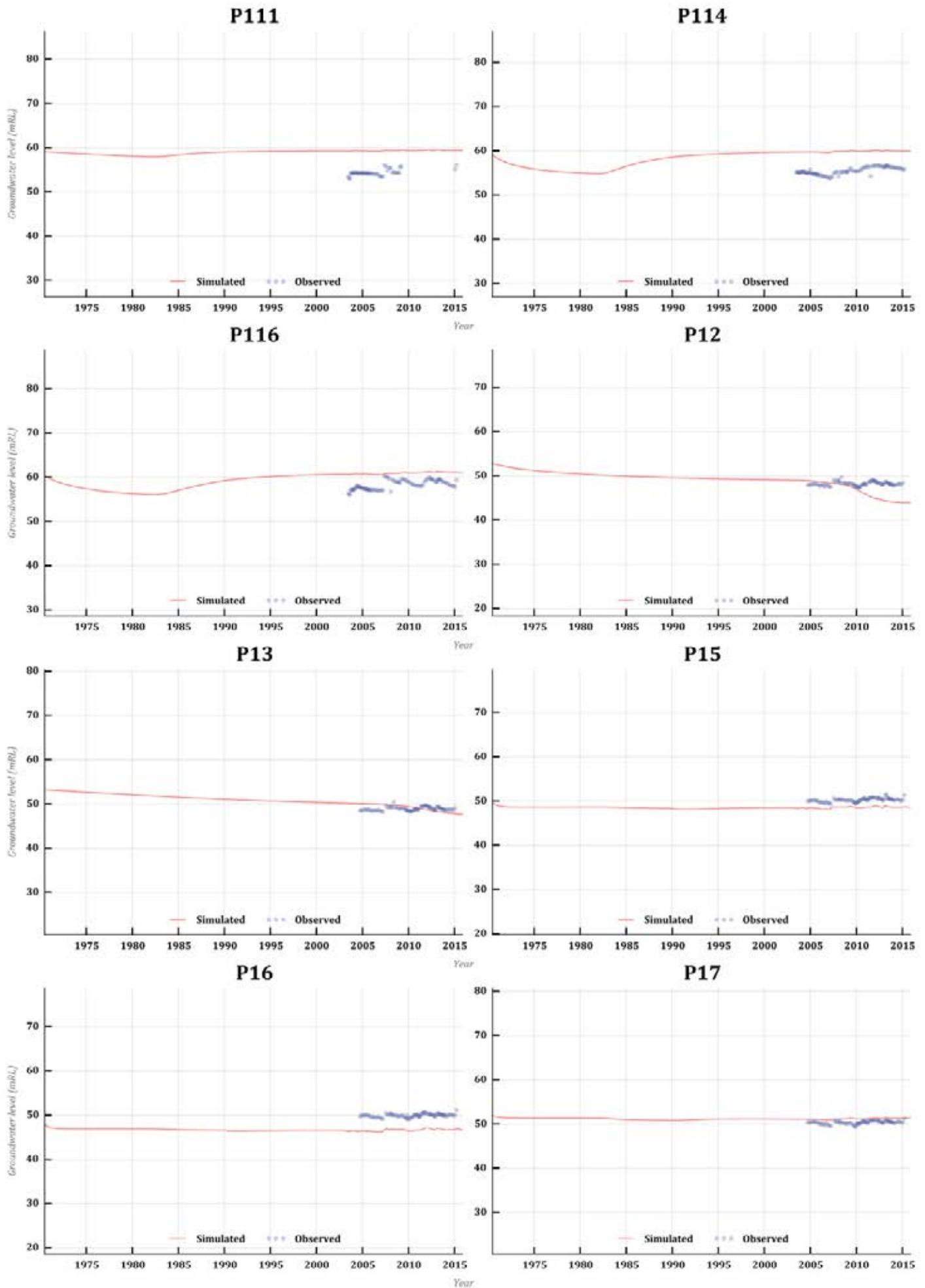
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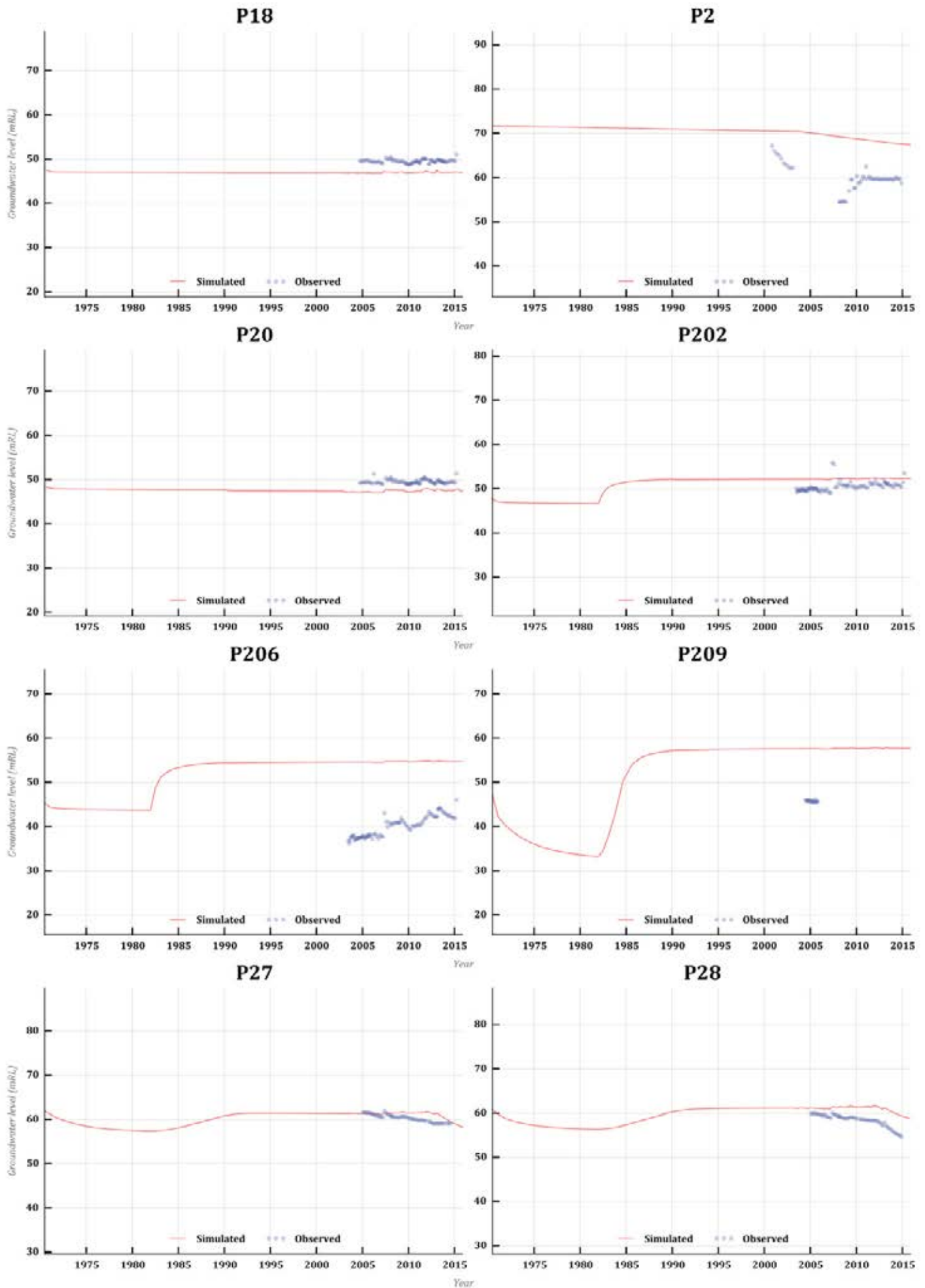


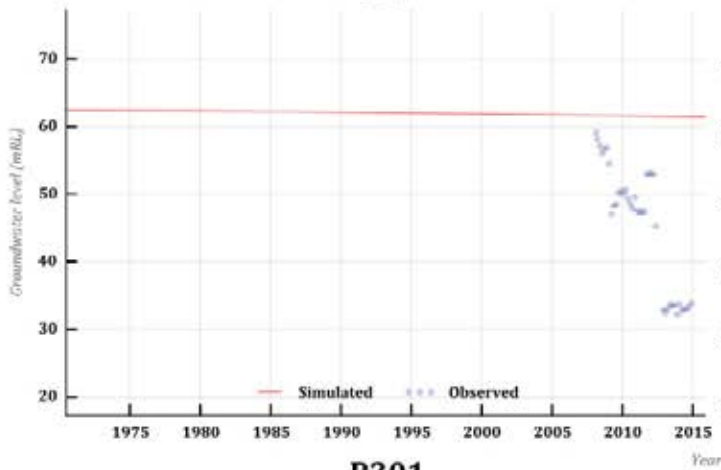
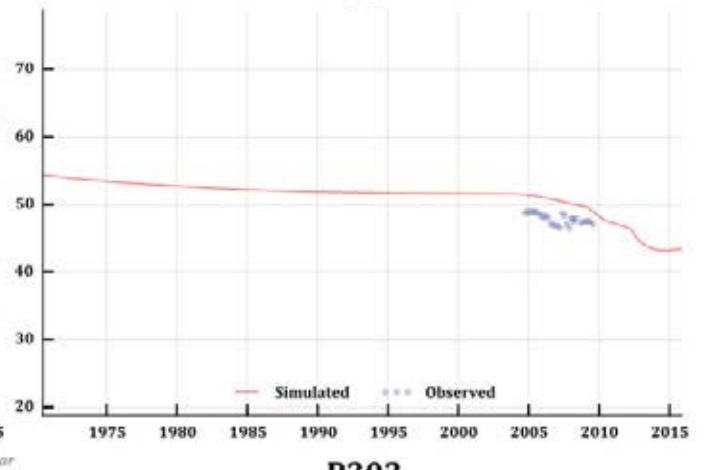
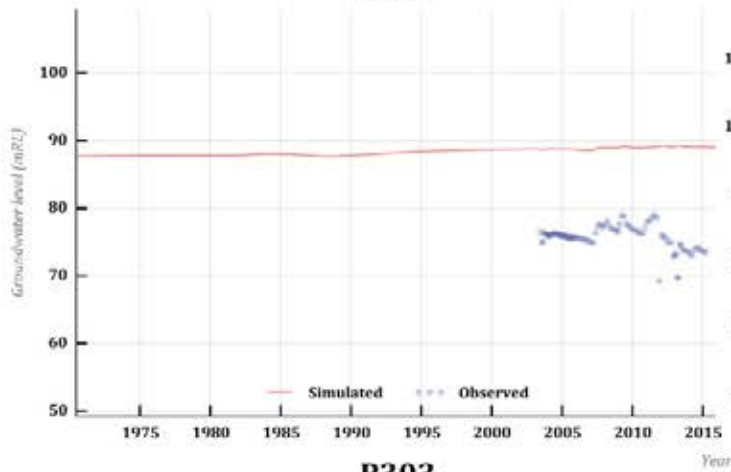
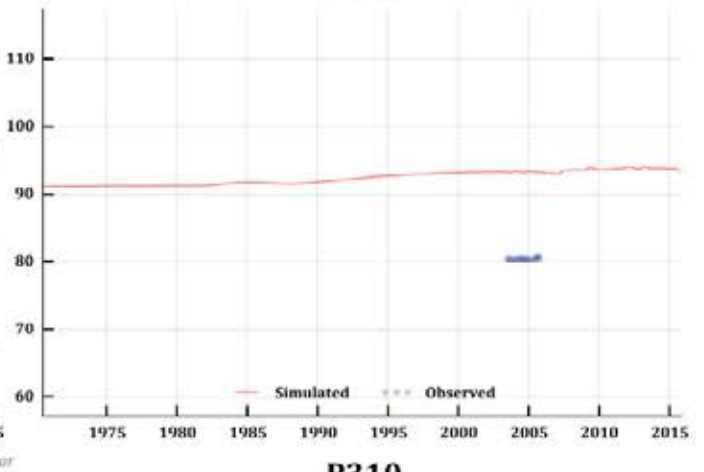
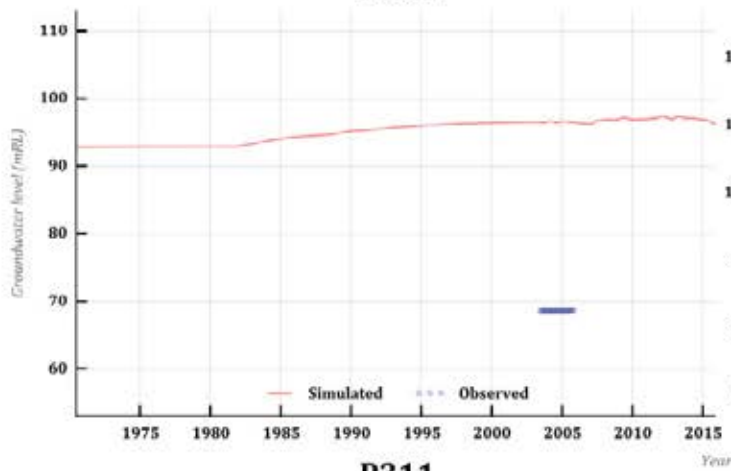
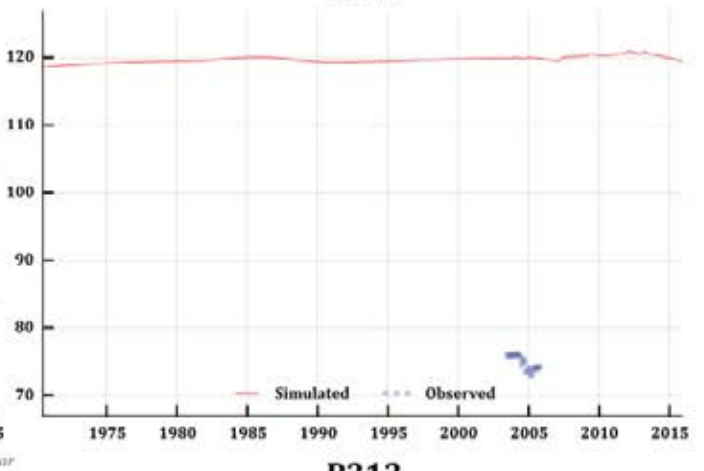
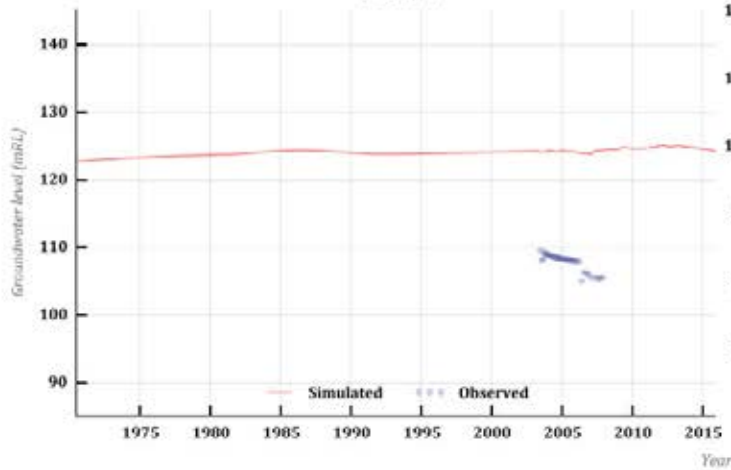
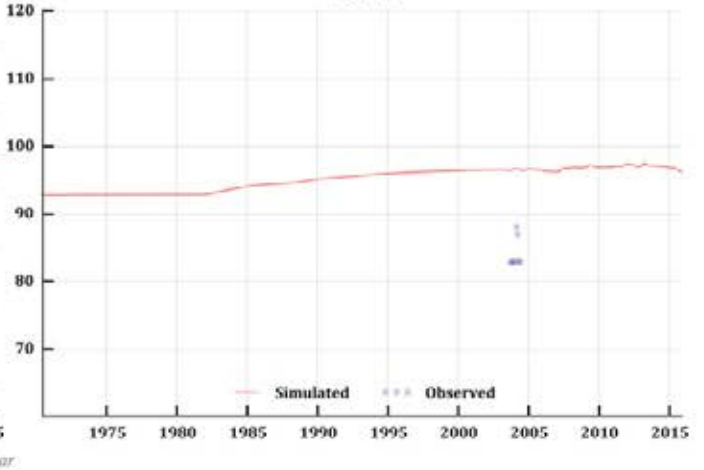


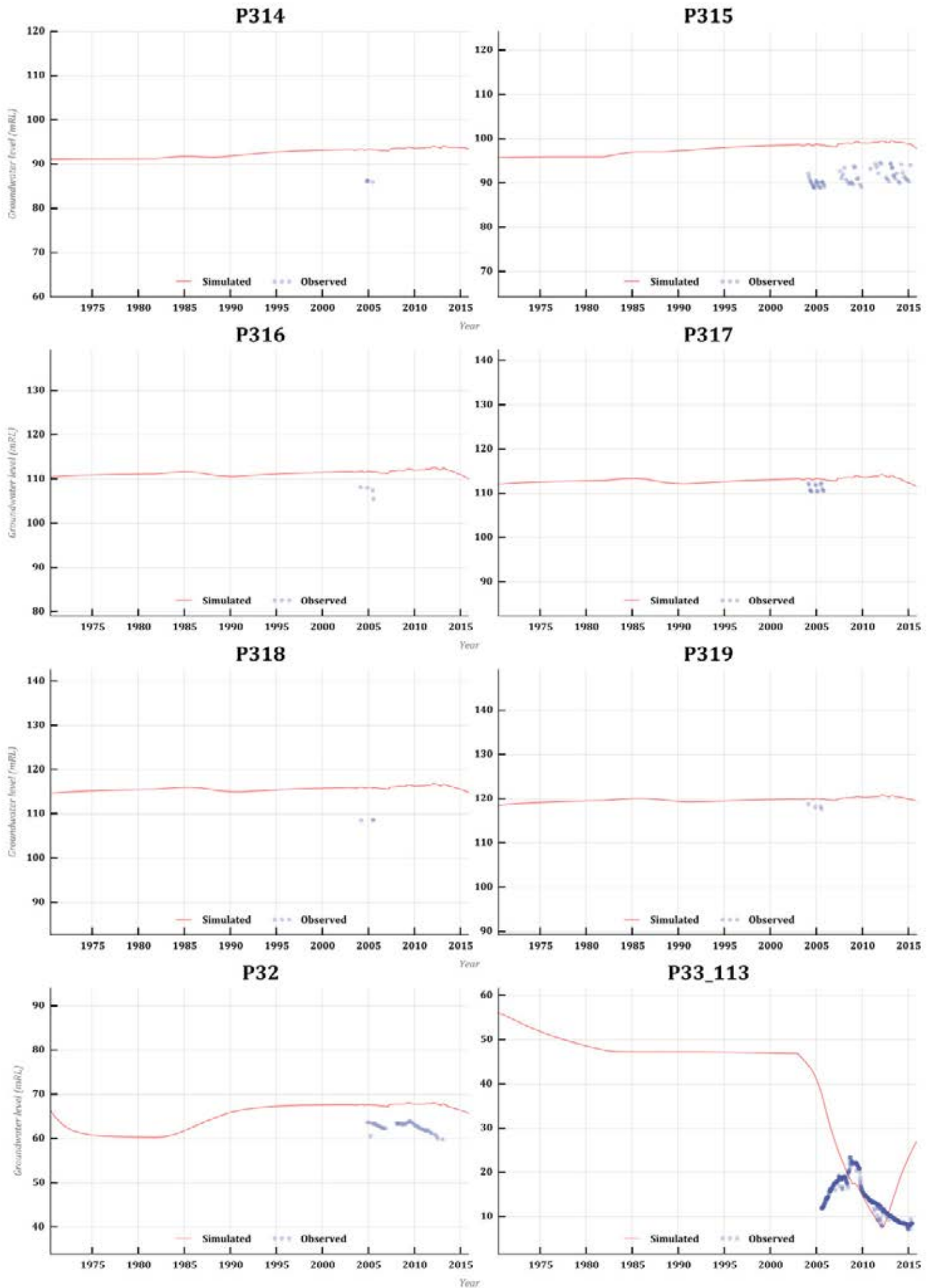
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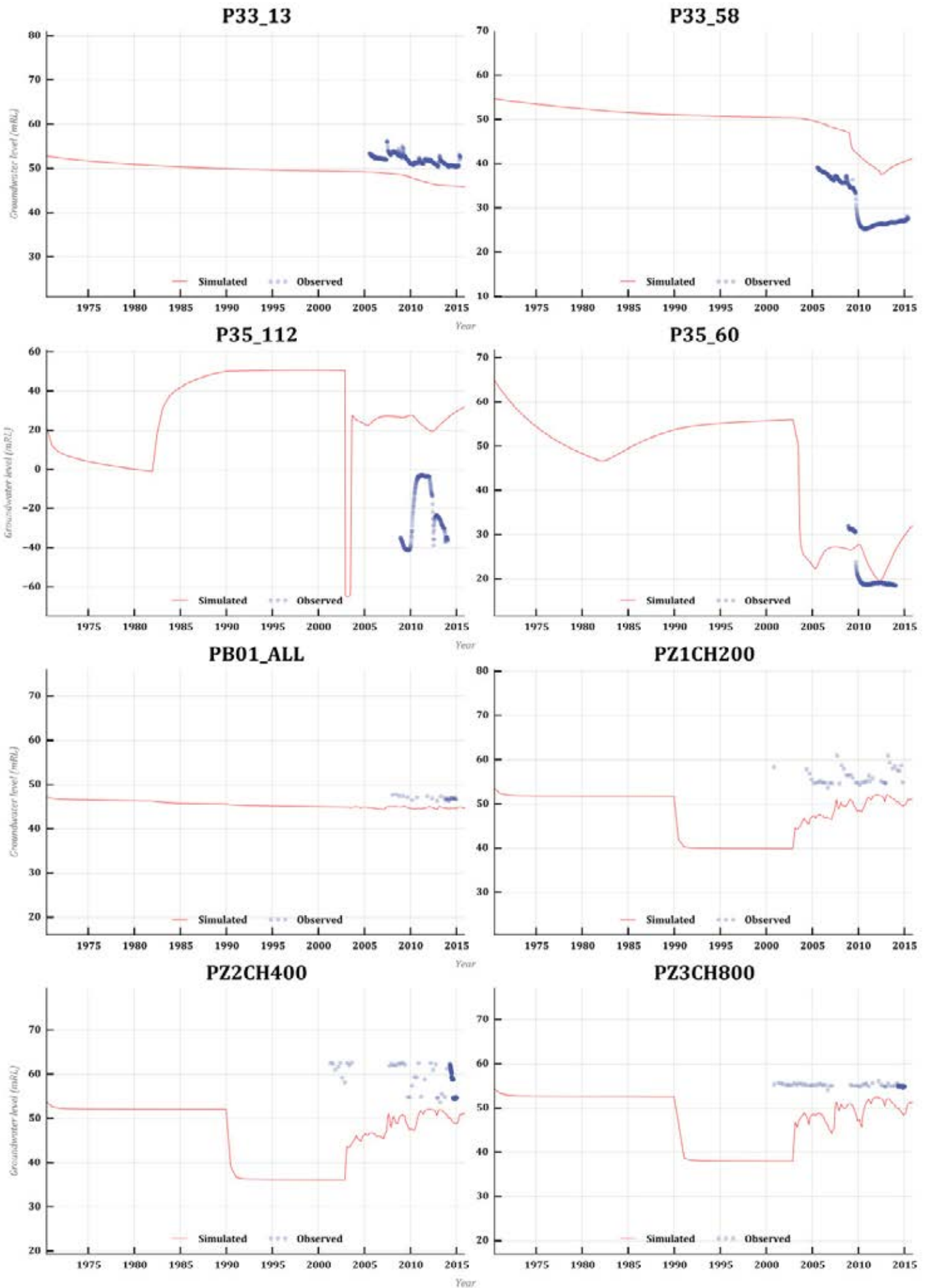


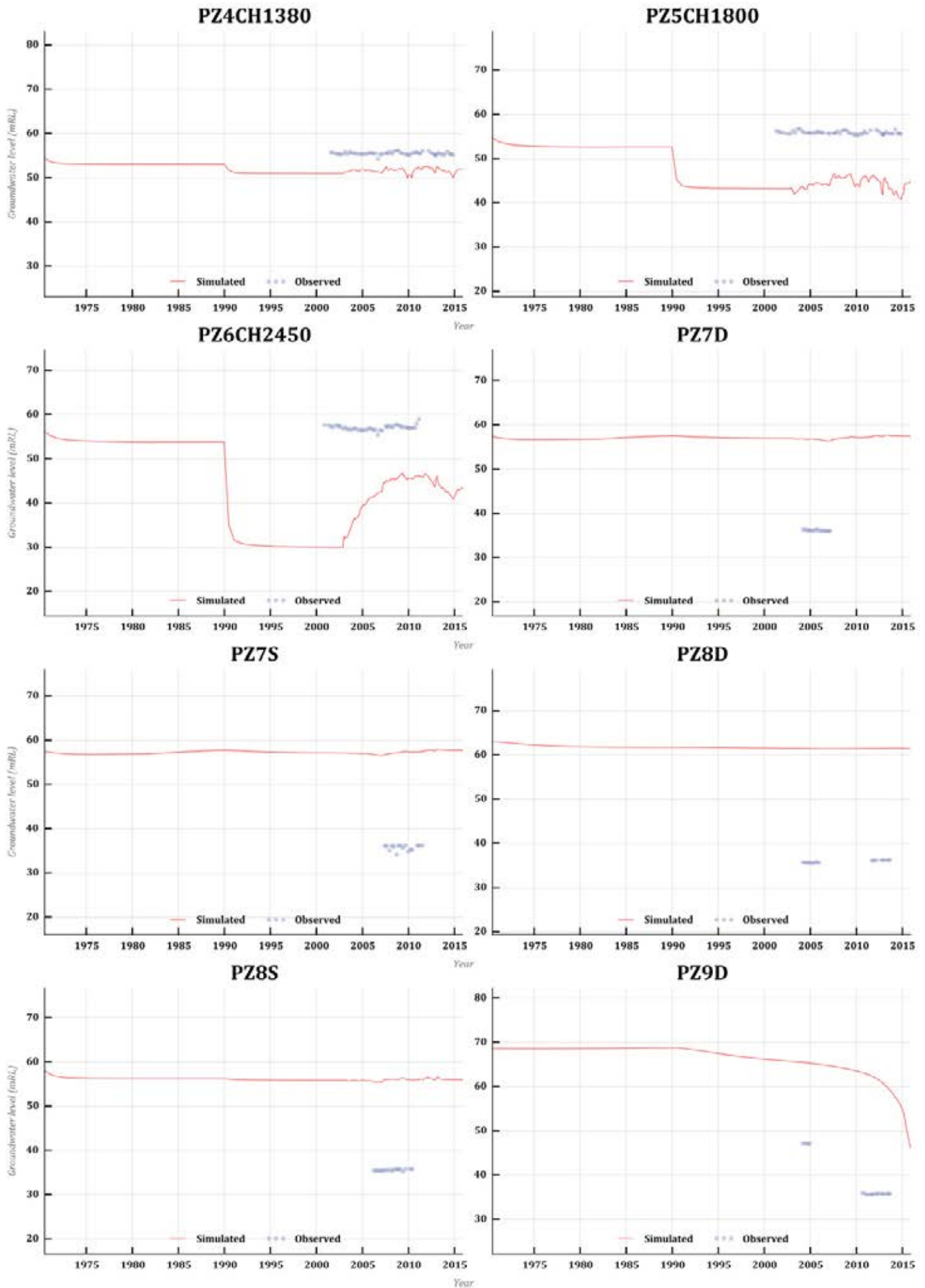


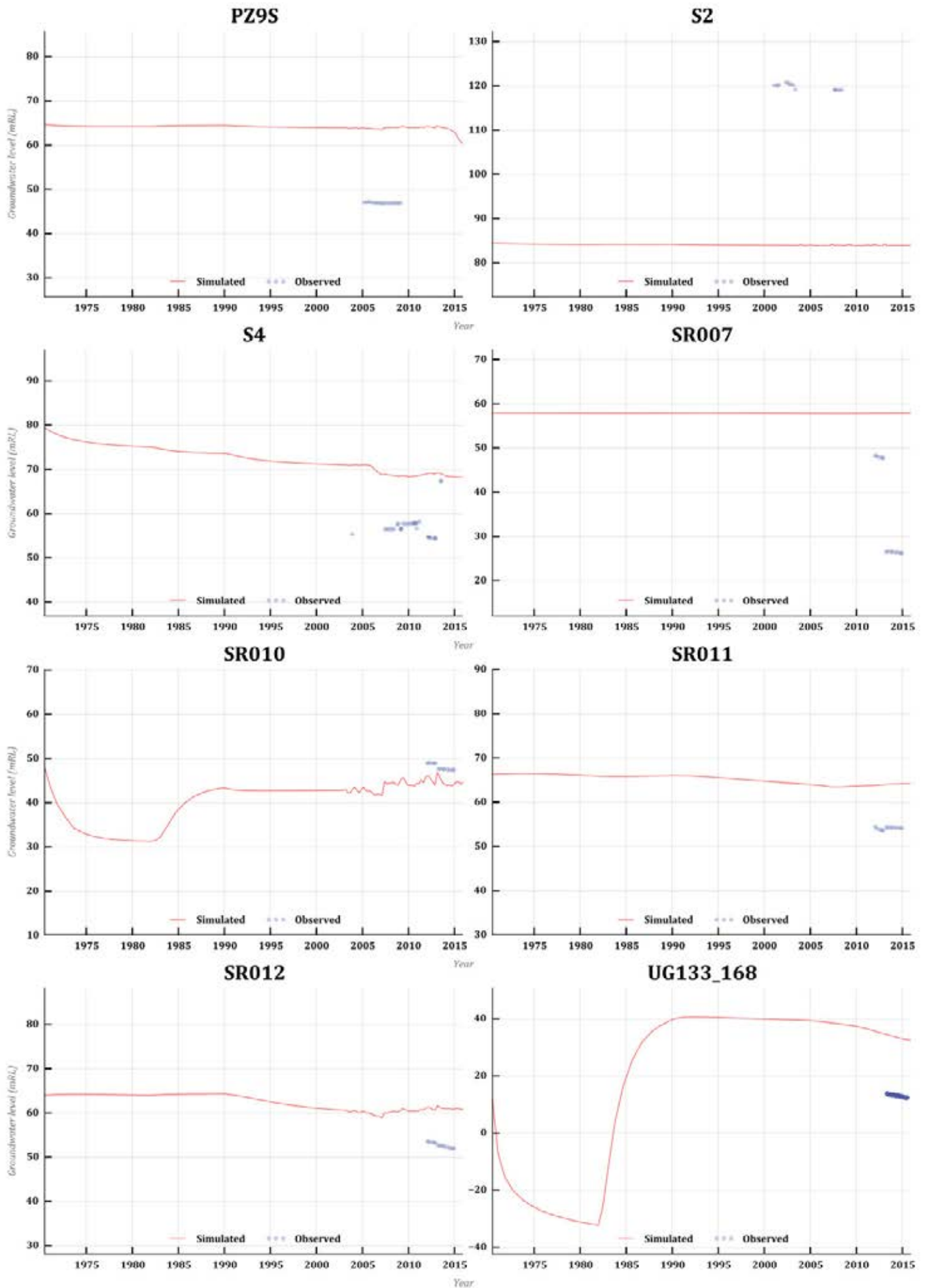


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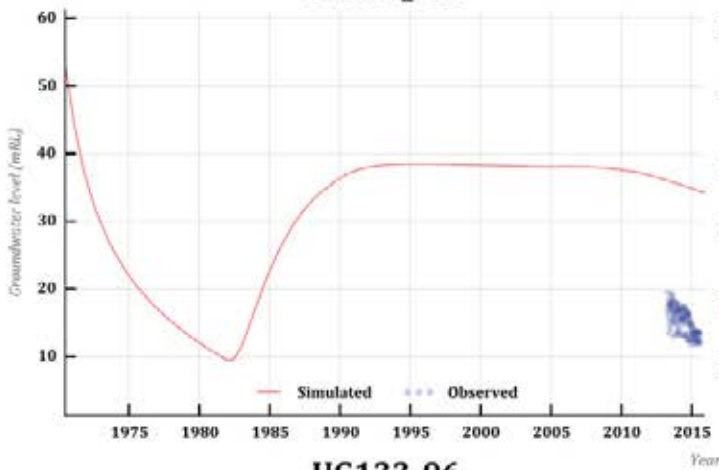




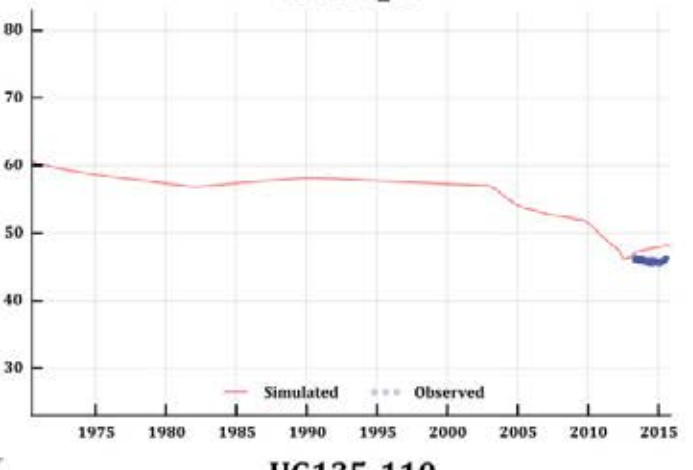




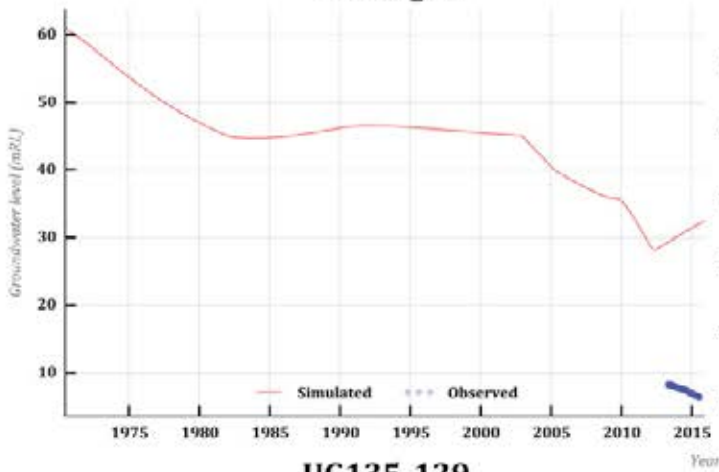
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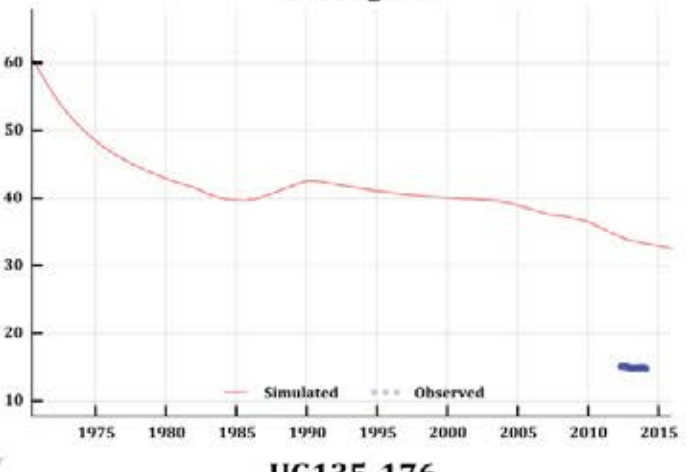
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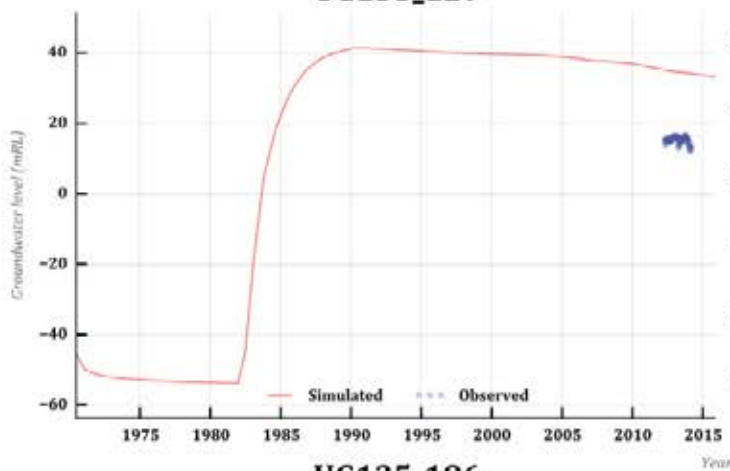
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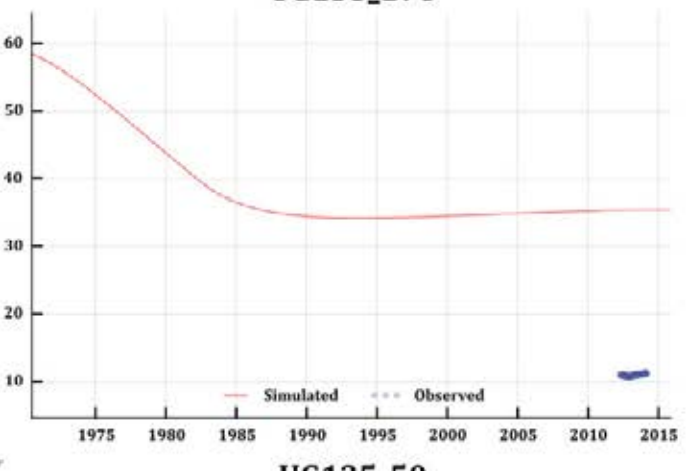
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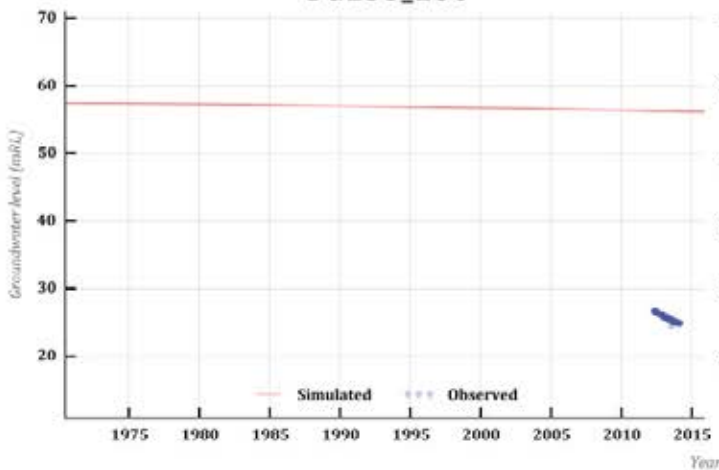
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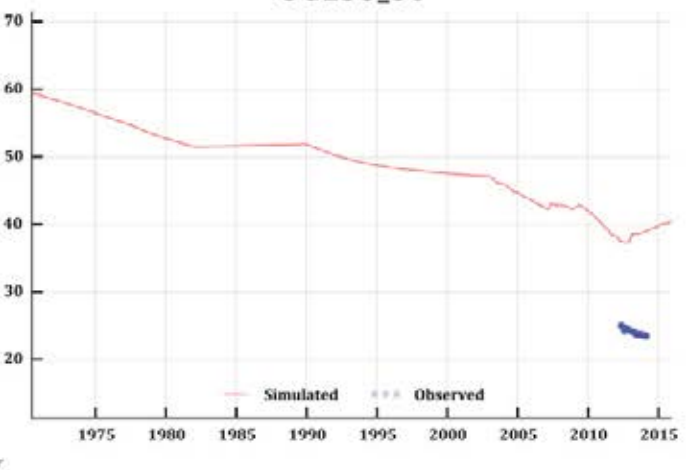
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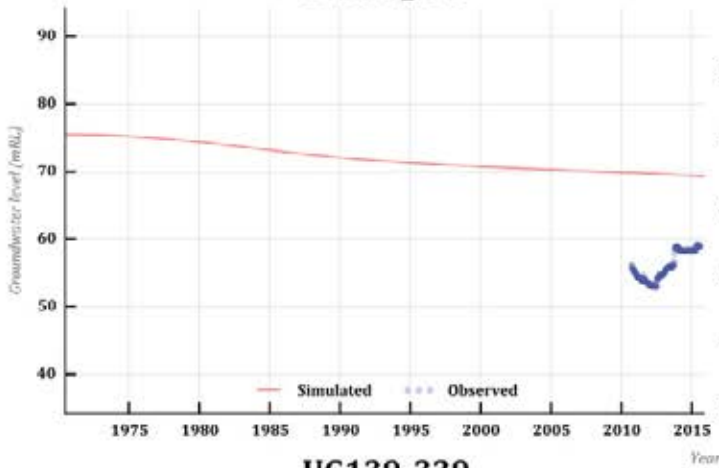
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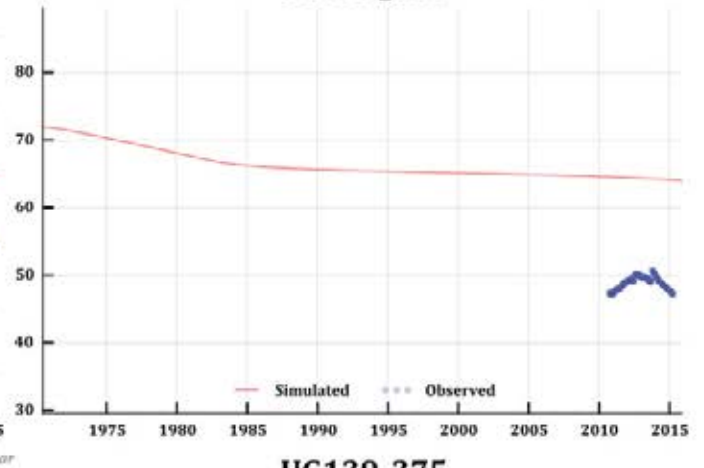
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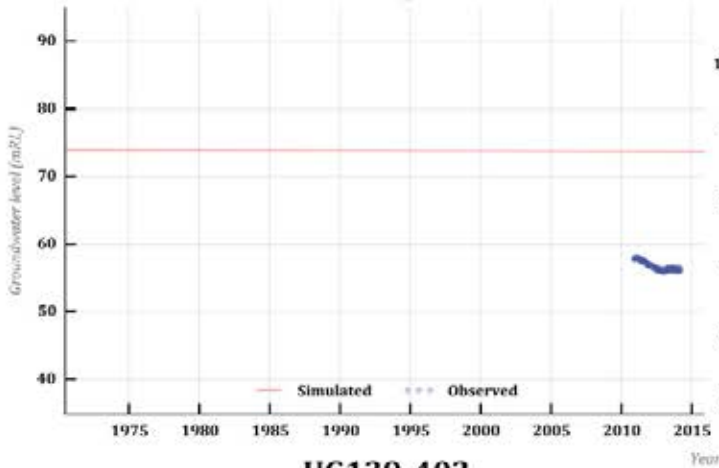
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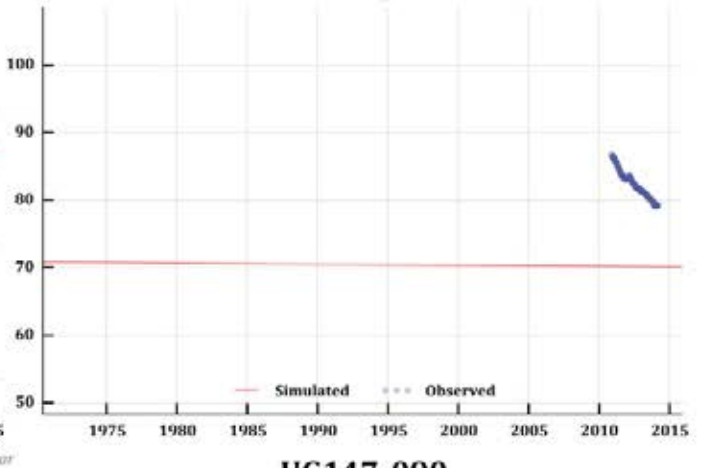
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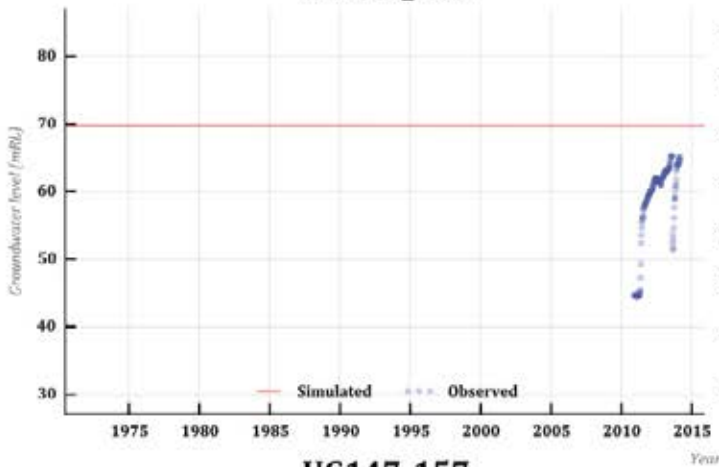
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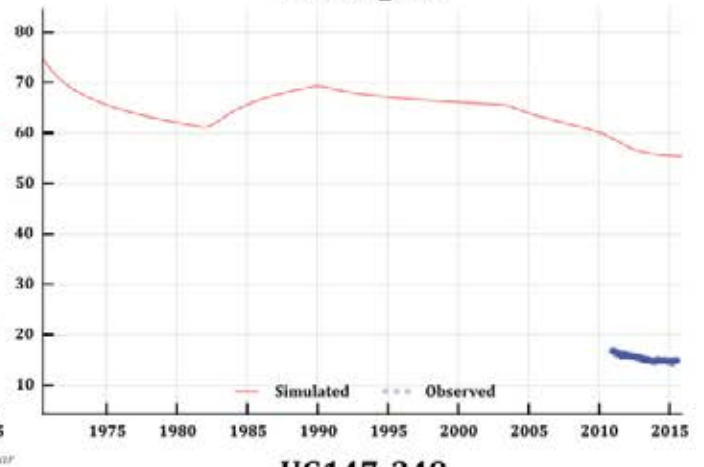
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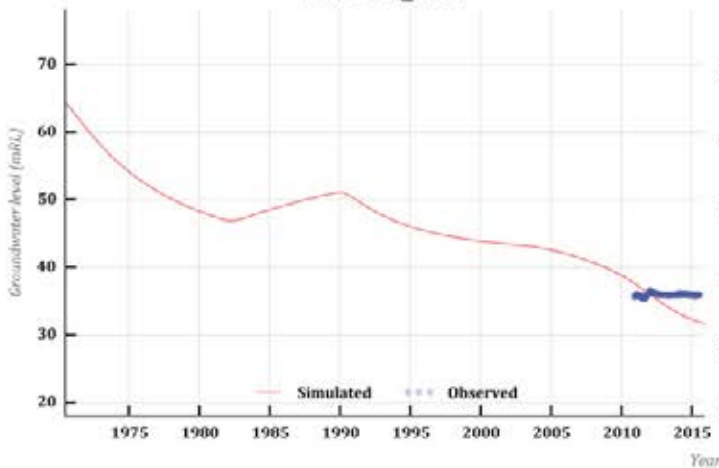
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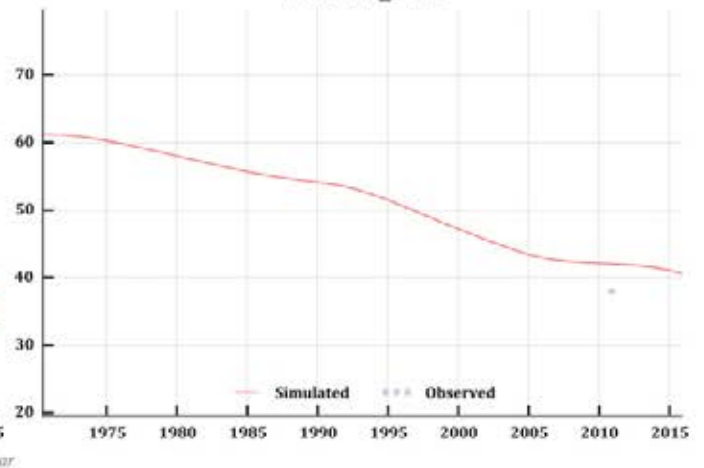
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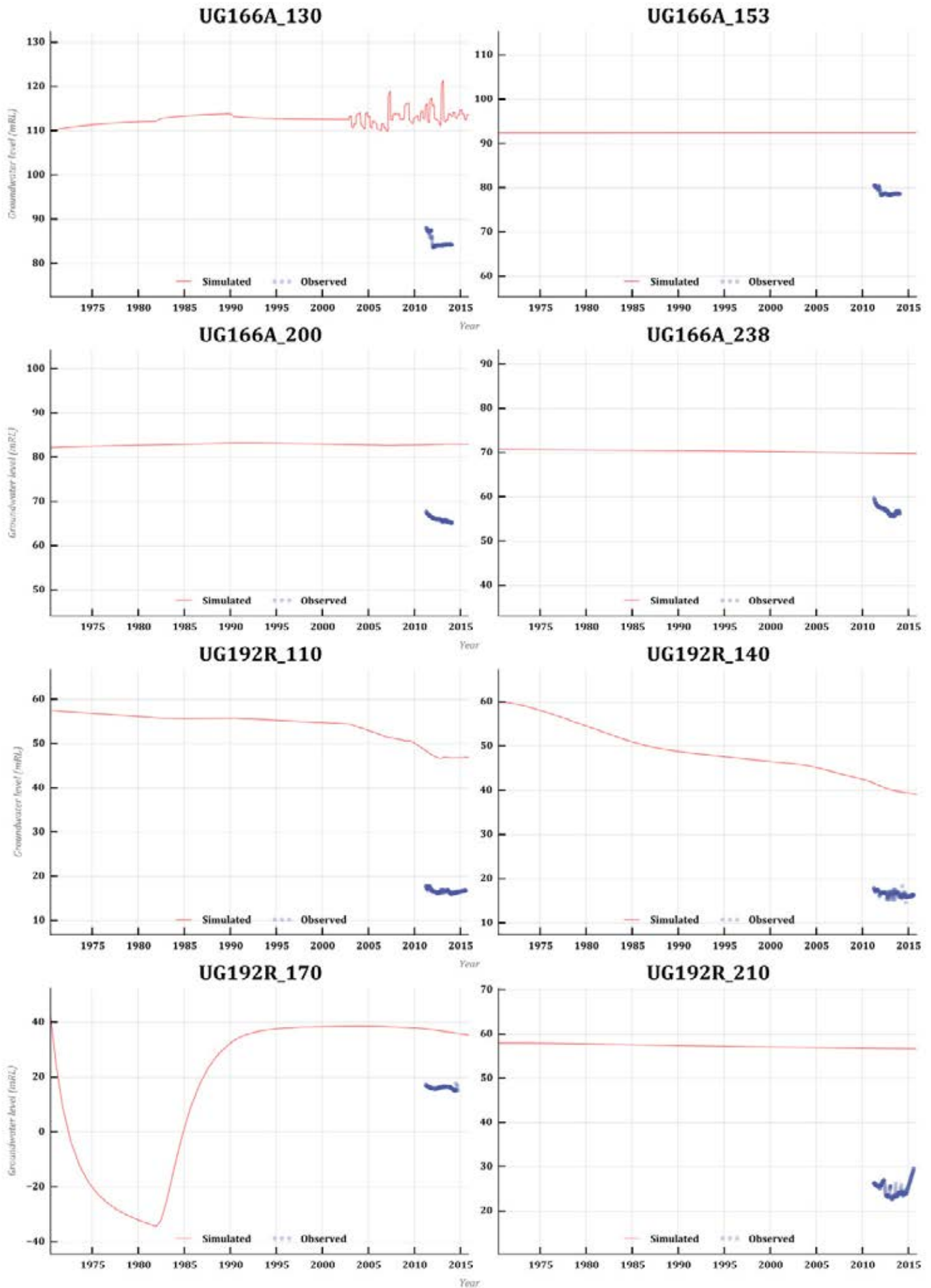


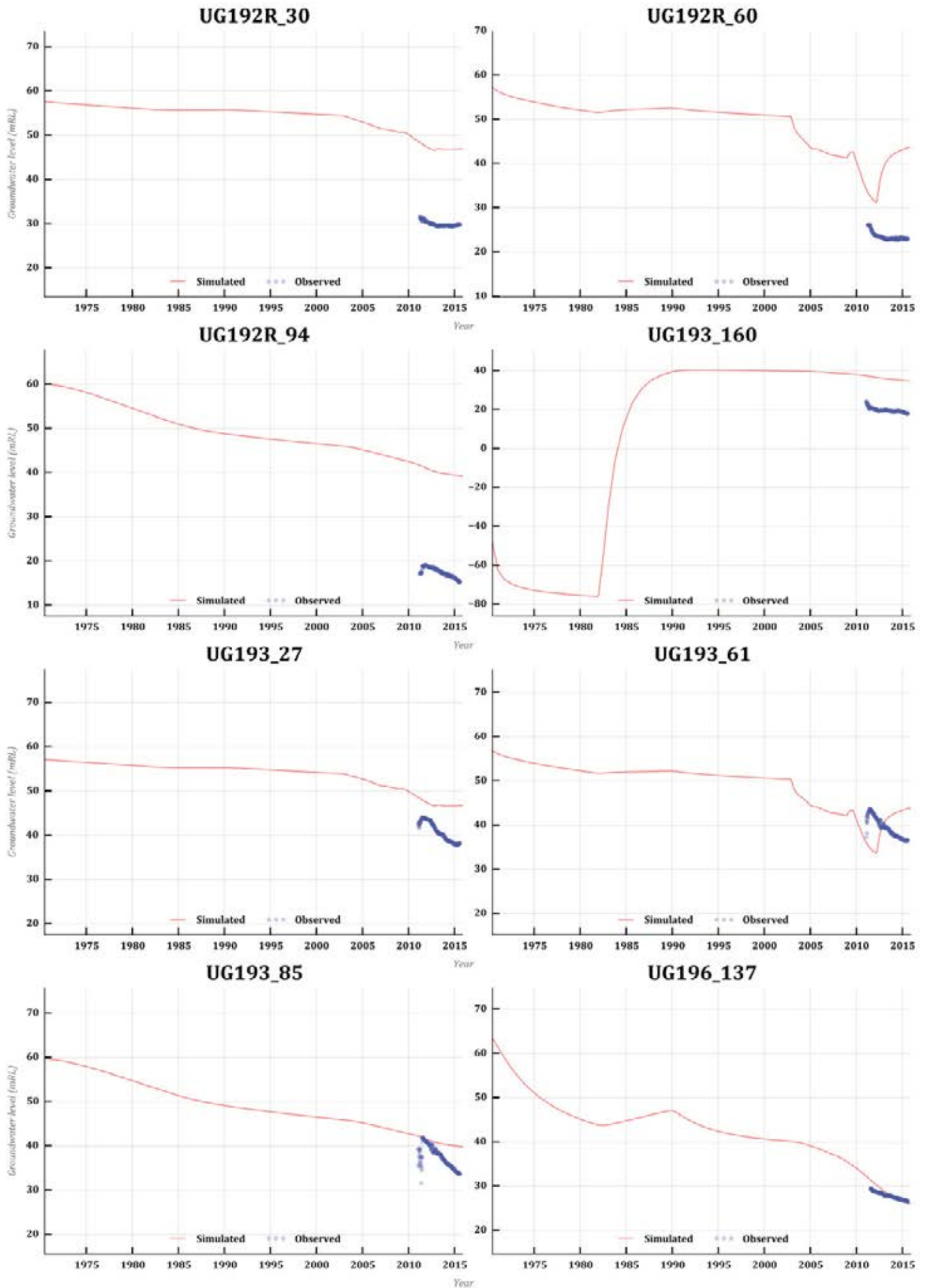
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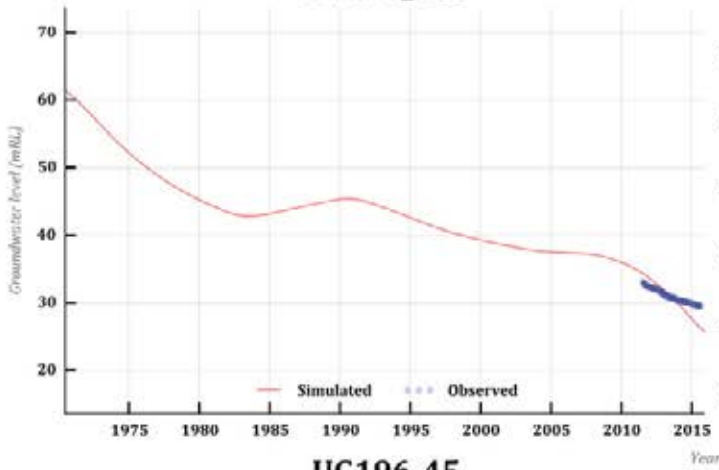
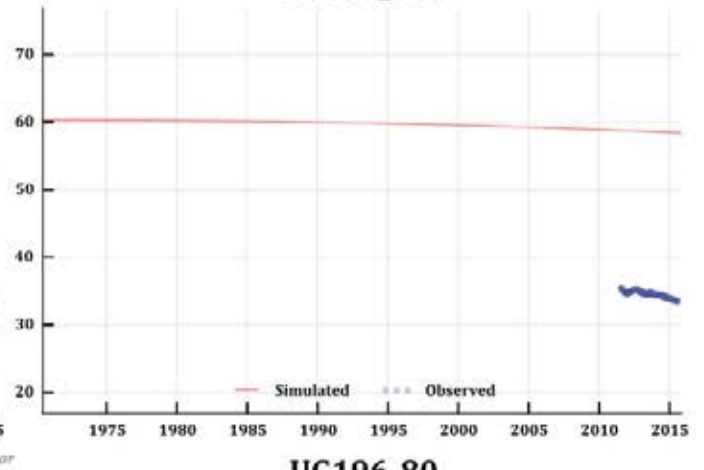
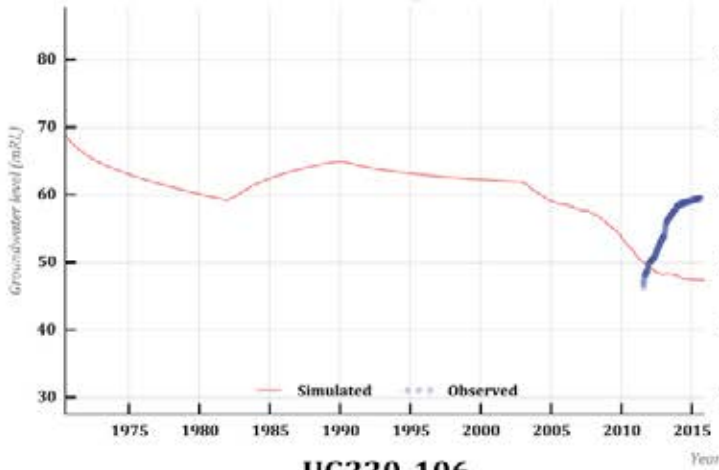
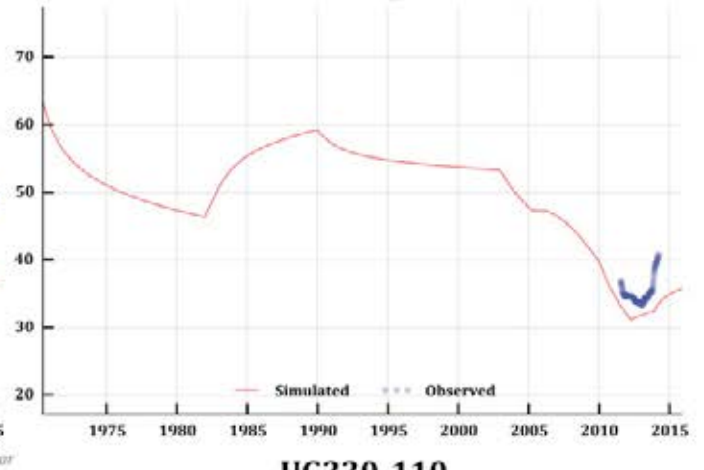
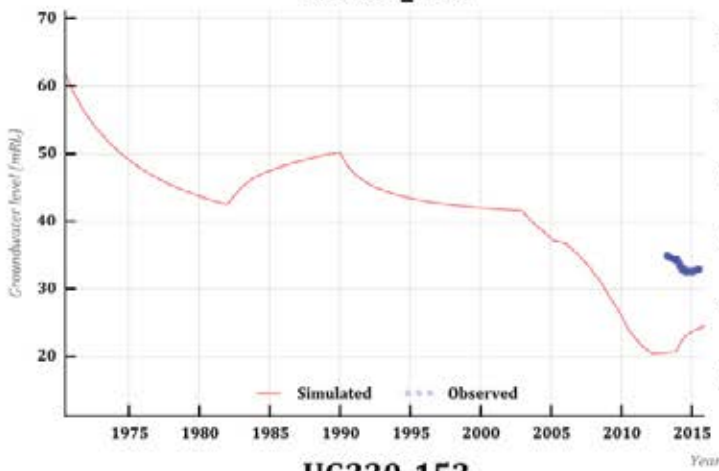
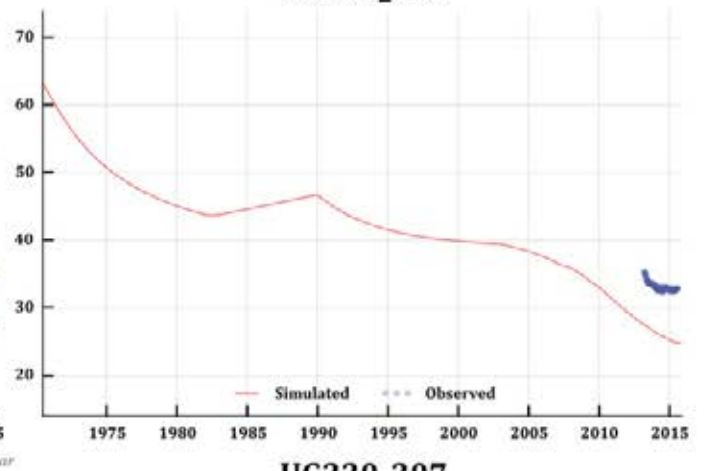
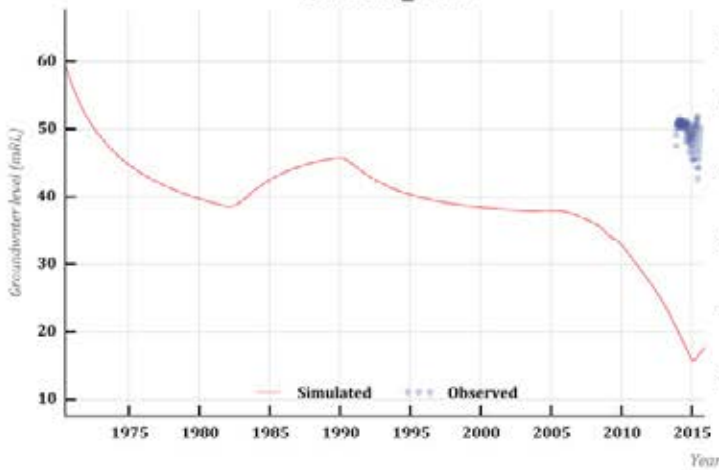
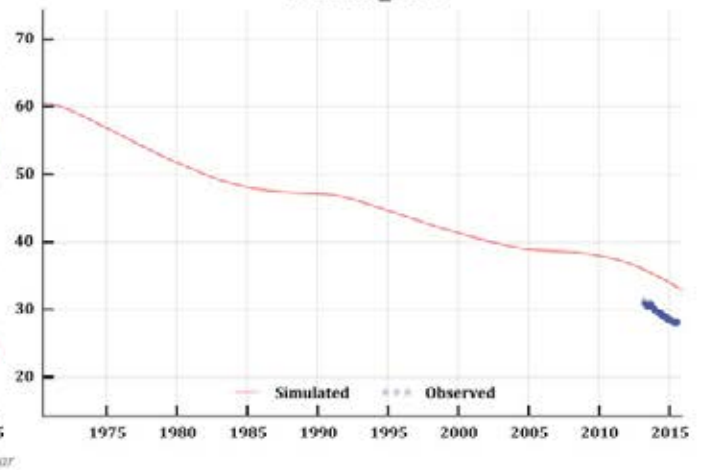


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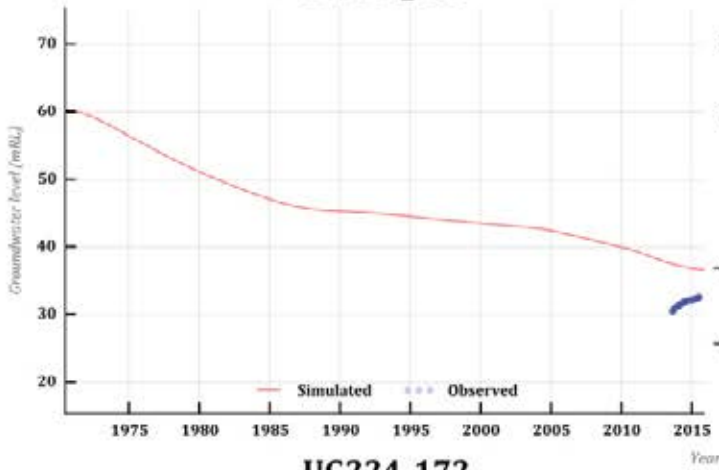




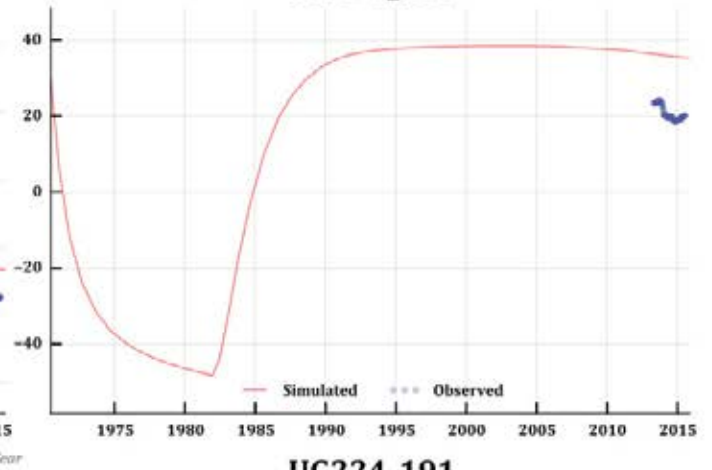


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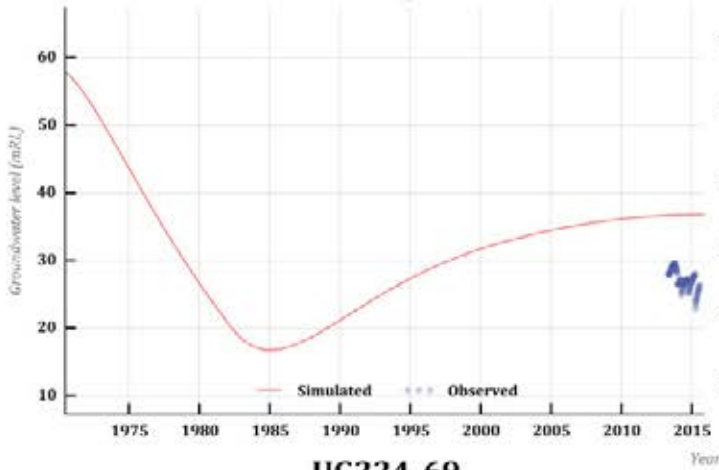
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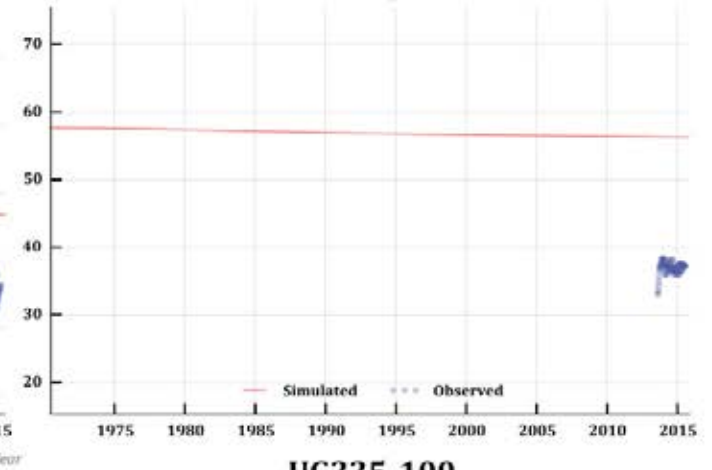
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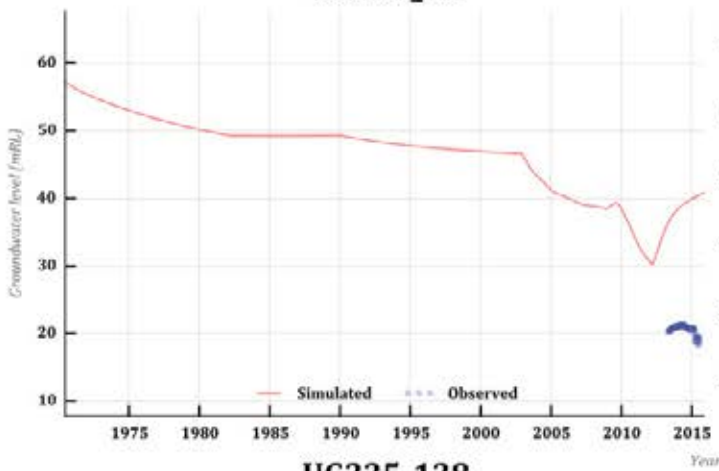
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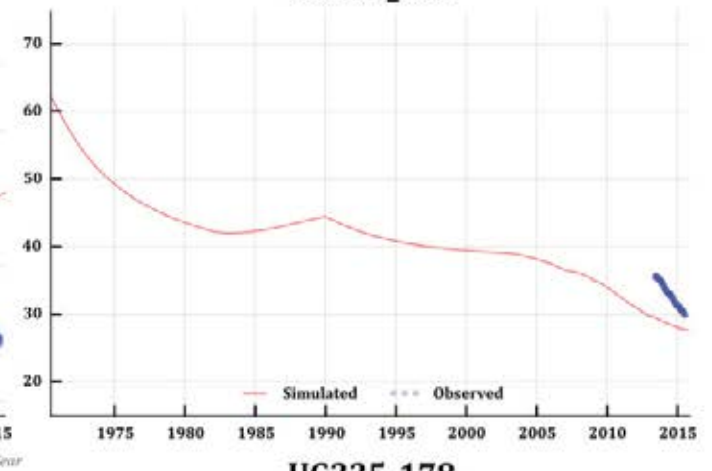
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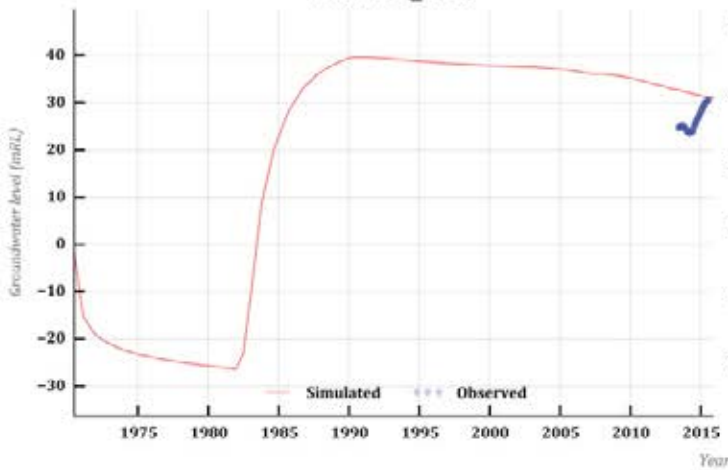
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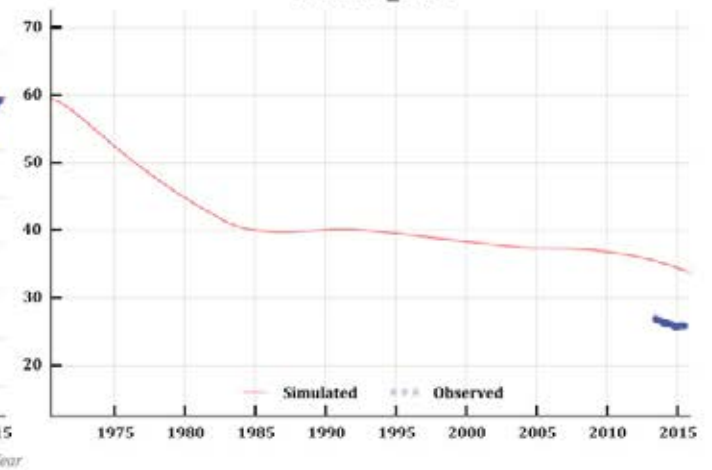
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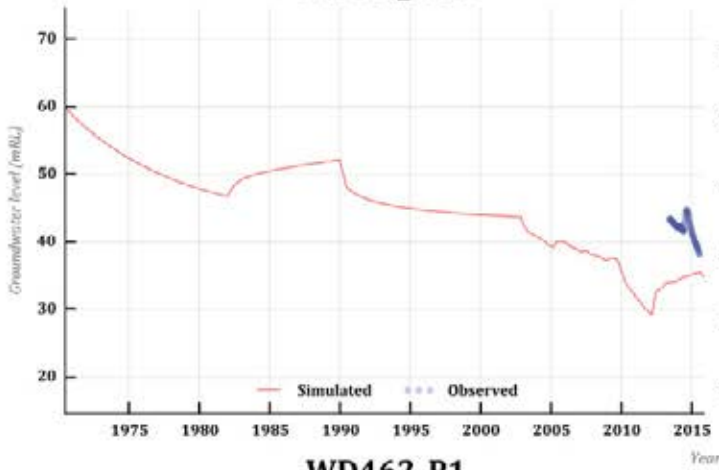
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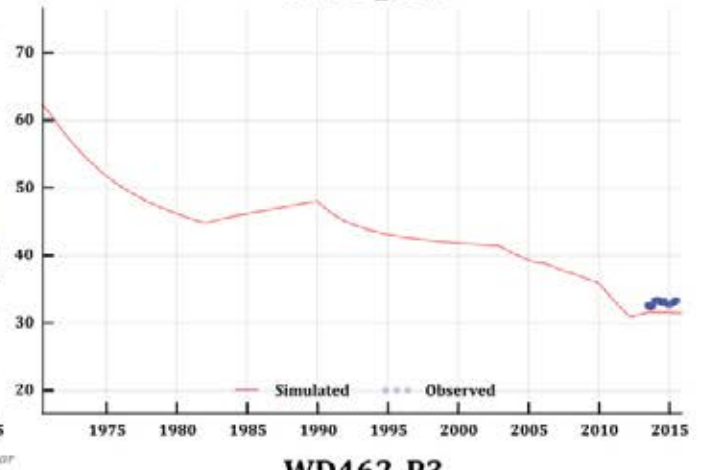
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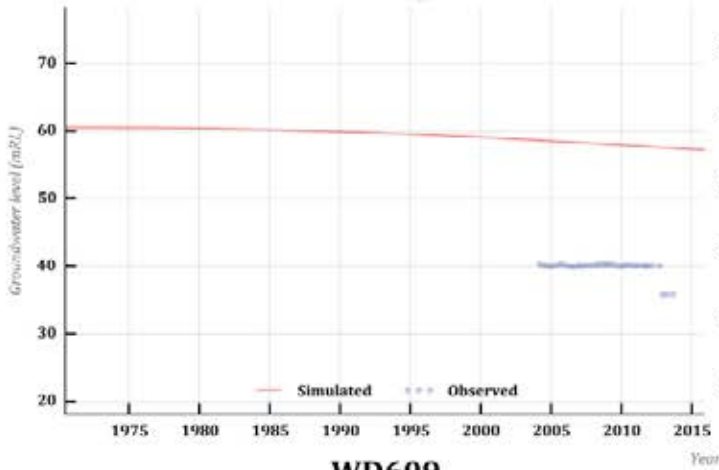
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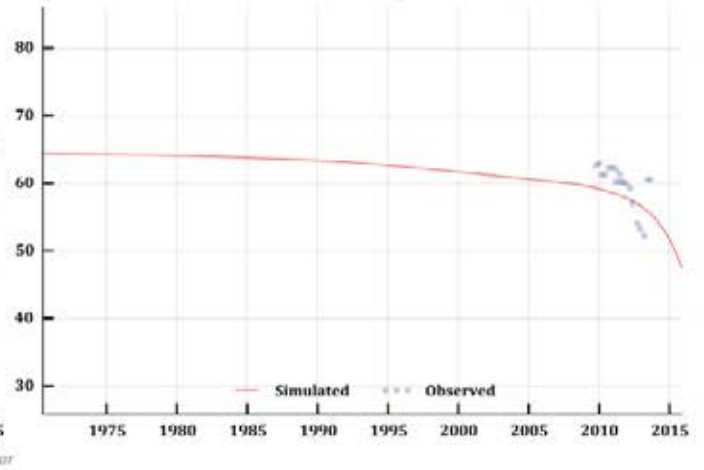
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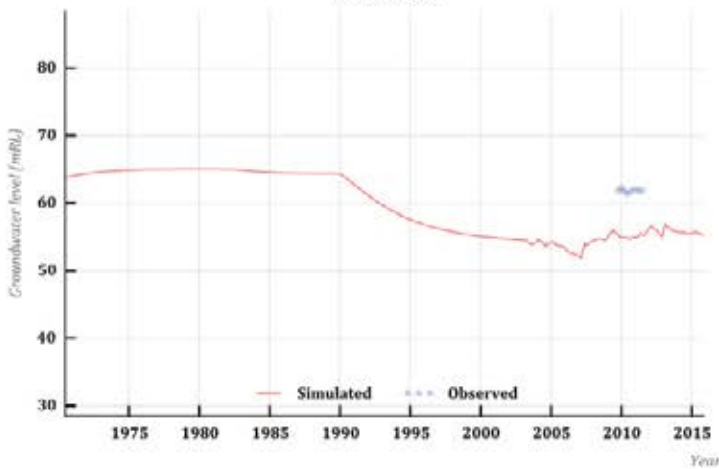
WD462\_P1



WD462\_P3



WD609



## *Appendix C*

# **Study Requirements**

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## C1 Study requirements

### C1.1 Secretary's Environmental Assessment Requirements

The Department of Planning and Environment (DP&E) collated the requirements from all NSW government departments and provided these for the United Wambo Project. These are known as the Secretary's Environmental Assessment Requirements (SEARs).

The main focus of the SEARs is to ensure assessment of the likely impacts of the development on the quantity and quality of existing surface and groundwater resources. The groundwater assessment presents the current understanding of the hydrogeological system, identification and classification of groundwater resources and prediction of groundwater levels drawdown and inflow rate in response to the Project. Overall, the groundwater assessment identified that there would be no substantial changes to the hydrogeological regime as a result of the Project, due in large to existing cumulative impacts from approved mines within the region.

The sections below tabulate the requirements that relate to groundwater, and where these requirements are addressed within this report.

#### C1.1.1 DPI Water

| Recommendations – General recommendations                                                                                                                                                                                                                                                                                                                                      | addressed in section                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| It is recommended that the EIS be required to include:                                                                                                                                                                                                                                                                                                                         |                                                 |
| <ul style="list-style-type: none"><li>Annual volumes of groundwater proposed to be taken by the activity (including through inflow and seepage) from each surface and groundwater sources as defined by the relevant water sharing plan</li></ul>                                                                                                                              | Section 7                                       |
| <ul style="list-style-type: none"><li>Assessment of any volumetric water licensing requirements (including those for ongoing water take following completion of the Project).</li></ul>                                                                                                                                                                                        | Section 7                                       |
| <ul style="list-style-type: none"><li>A detailed assessment against the NSW Aquifer Interference Policy (2012) using DPI Water's assessment framework</li></ul>                                                                                                                                                                                                                | Section 8                                       |
| <ul style="list-style-type: none"><li>Assessment of impacts on surface and ground water sources (both quality and quantity), watercourses, riparian land, wetlands, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.</li></ul>                                                                                                | Section 7 and Section 10<br>No wetlands present |
| <ul style="list-style-type: none"><li>Full technical details and data of all groundwater modelling, and an independent peer review of the groundwater model.</li></ul>                                                                                                                                                                                                         | Appendix B                                      |
| <ul style="list-style-type: none"><li>Proposed groundwater monitoring activities and methodologies.</li></ul>                                                                                                                                                                                                                                                                  | Section 10                                      |
| <ul style="list-style-type: none"><li>Assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts.</li></ul>                                                                                                                                                                                                  | Section 7 and Section 10                        |
| <ul style="list-style-type: none"><li>Consideration of relevant policies and guidelines.</li></ul>                                                                                                                                                                                                                                                                             | Section 8 and Section 9                         |
| <ul style="list-style-type: none"><li>Assessment of whether the activity may have a significant impact on water resources, with reference to the Commonwealth Department of Environment Significant Impact Guidelines.</li></ul>                                                                                                                                               | Section 9                                       |
| <ul style="list-style-type: none"><li>If the activity may have a significant impact on water resources, then provision of information in accordance with the Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals, including completion of the information requirements checklist.</li></ul> | All sections                                    |

| Recommendations – General recommendations                                                                                                                                                                                                                                                                                                                                                                                                                  | addressed in section     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| <ul style="list-style-type: none"> <li>A statement of where each element of the SEARs is addressed in the EIS (i.e. in the form of a table.</li> </ul>                                                                                                                                                                                                                                                                                                     | C1 Study Requirements    |
| <ul style="list-style-type: none"> <li>Demonstrate how the proposal is consistent with the relevant rules of the Water Sharing Plan including rules for access licences, distance restrictions for water supply works and rules for the management of local impacts in respect to surface water and groundwater sources, ecosystem protection (including groundwater dependent ecosystems), water quality and surface-groundwater connectivity.</li> </ul> | Section 2 and Section 7  |
| <ul style="list-style-type: none"> <li>Details on all bores and excavations for the purpose of investigation, extraction dewatering, testing and monitoring. All predicted groundwater take must be accounted for through adequate licensing.</li> </ul>                                                                                                                                                                                                   | Section 2 and Appendix A |

| Recommendations – Groundwater assessment                                                                                                                                                                                                                                                                                           | addressed in section                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| To ensure the sustainable and integrated management of groundwater sources, the EIS needs to include adequate details to assess the impact of the Project on all groundwater sources including:                                                                                                                                    |                                                                                                             |
| <ul style="list-style-type: none"> <li>The predicted and highest groundwater table at the site</li> </ul>                                                                                                                                                                                                                          | Section 5.3                                                                                                 |
| <ul style="list-style-type: none"> <li>Works likely to intercept, connect with or infiltrate the groundwater sources.</li> </ul>                                                                                                                                                                                                   | Section 1.1.2 and Appendix B                                                                                |
| <ul style="list-style-type: none"> <li>Any proposed groundwater extraction, including purpose, location and construction details of all proposed bores and expected annual extraction volumes</li> </ul>                                                                                                                           | Section 7                                                                                                   |
| <ul style="list-style-type: none"> <li>Bore construction information is to be supplied to DPI Water by submitting a “Form A” template. DPI Water will supply “GW” registration numbers (and licence/approval numbers if required) which must be used as consistent and unique bore identifiers for all future reporting</li> </ul> | No bores were constructed as part of the Project. Any bores constructed in future will adhere to this item. |
| <ul style="list-style-type: none"> <li>A description of the watertable and groundwater pressure configuration, flow directions and rates and physical and chemical characteristics of the groundwater source (including connectivity with other groundwater and surface water sources).</li> </ul>                                 | Section 5                                                                                                   |
| <ul style="list-style-type: none"> <li>Sufficient baseline monitoring for groundwater quantity and quality for all aquifers and GDEs to establish a baseline incorporating typical temporal and spatial variations.</li> </ul>                                                                                                     | Section 5 and Appendix A, plus EIS ecology report                                                           |
| <ul style="list-style-type: none"> <li>The predicted impacts of any final landform on the groundwater regime</li> </ul>                                                                                                                                                                                                            | Section 7                                                                                                   |
| <ul style="list-style-type: none"> <li>The existing groundwater users within the area (including the environment), any potential impacts on these users and safeguard measures to mitigate impacts</li> </ul>                                                                                                                      | Section 5.5, Section 7.1.5 and Section 10                                                                   |
| <ul style="list-style-type: none"> <li>An assessment of the quality, its beneficial use classification and prediction of any impacts on groundwater quality.</li> </ul>                                                                                                                                                            | Section 5.4 and Section 7.4                                                                                 |
| <ul style="list-style-type: none"> <li>An assessment of the potential for groundwater contamination (considering both the impacts of the proposal on groundwater contamination and the impacts on contamination on the proposal)</li> </ul>                                                                                        | Section 7.4                                                                                                 |

| Recommendations – Groundwater assessment                                                                                                                                                                                                                                                             | addressed in section                                                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>Measures proposed to protect groundwater quality both in the short and long term</li> </ul>                                                                                                                                                                   | Section 7.4 and Section 10                                                                                                                                                         |
| <ul style="list-style-type: none"> <li>Measures for preventing groundwater pollution so that remediation is not required.</li> </ul>                                                                                                                                                                 | Section 7 and Section 10                                                                                                                                                           |
| <ul style="list-style-type: none"> <li>Protective measures for any groundwater dependent ecosystems (GDEs)</li> </ul>                                                                                                                                                                                | Refer to EIS Ecology Assessment                                                                                                                                                    |
| <ul style="list-style-type: none"> <li>The results of any predictive models or predictive tools used</li> </ul>                                                                                                                                                                                      | Section 7                                                                                                                                                                          |
| Where potential impact/s are identified the assessment will need to identify limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users including | Section 10.3                                                                                                                                                                       |
| <ul style="list-style-type: none"> <li>Any proposed monitoring programs, including water levels and quality data</li> </ul>                                                                                                                                                                          | Section 10                                                                                                                                                                         |
| <ul style="list-style-type: none"> <li>Reporting procedures for any monitoring program including mechanism for transfer of information</li> </ul>                                                                                                                                                    | Section 10                                                                                                                                                                         |
| <ul style="list-style-type: none"> <li>An assessment of any groundwater source/aquifer that may be sterilised from future use as a water supply as a consequence of the proposal</li> </ul>                                                                                                          | not applicable                                                                                                                                                                     |
| <ul style="list-style-type: none"> <li>Identification of any nominal thresholds as to the level of impact beyond which remedial measures or contingency plans would be initiated (this may entail water level triggers or a beneficial use category)</li> </ul>                                      | Section 10.3                                                                                                                                                                       |
| <ul style="list-style-type: none"> <li>Description of the remedial measures or contingency plans proposed</li> </ul>                                                                                                                                                                                 | Section 10                                                                                                                                                                         |
| <ul style="list-style-type: none"> <li>Any funding assurances covering the anticipated post development maintenance cost, for example on-going groundwater monitoring for the nominated period.</li> </ul>                                                                                           | United will fund throughout the mine closure process. The NSW Government Mining Lease security bond process provides an appropriate security deposit for the mine closure process. |

| Recommendations - GDEs                                                                                                                                                                                                    | addressed in section |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| The EIS must consider the potential impacts on any Groundwater Dependent Ecosystems (GDEs) at the site and in the vicinity of the site and identify any potential impacts on GDEs as a results of the proposal including: |                      |
| <ul style="list-style-type: none"> <li>The effect of the proposal on the recharge to groundwater systems</li> </ul>                                                                                                       | Section 7            |
| <ul style="list-style-type: none"> <li>The potential to adversely affect the water quality of the underlying groundwater system and adjoining groundwater systems in hydraulic connections</li> </ul>                     | Section 7            |
| <ul style="list-style-type: none"> <li>The effect on the function of GDEs (habitat, groundwater levels, connectivity)</li> </ul>                                                                                          | Section 7.1.7        |

| Recommendations - GDEs                                                                    | addressed in section            |
|-------------------------------------------------------------------------------------------|---------------------------------|
| <ul style="list-style-type: none"> <li>Provide safeguard measures for any GDEs</li> </ul> | Refer to EIS Ecology Assessment |

| Recommendations – Landform rehabilitation (including final void management)                                                                                                                                                                                                                                          | addressed in section    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| Where significant modification to landform is proposed, the EIS must include:                                                                                                                                                                                                                                        |                         |
| <ul style="list-style-type: none"> <li>Detailed modelling of potential groundwater volume, flow and quality impacts of the presence of an inundated final void (where relevant) on identified receptors specifically considering those environmental systems that are likely to be groundwater dependent.</li> </ul> | Section 6 and Section 7 |

### C1.1.2 Department of Industry- Resources and Energy

| Recommendations                                                                                                                                                                                                                                                                                                                                                                                                          | addressed in section |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| Where a void is proposed to remain as part of the final landform, the assessment is to provide details in regards to the outcomes of the groundwater assessment in relation to the likely final water level in the void. This should include an assessment of the potential for fill and spill along with measures required be implemented to minimise associated impacts to the environment and downstream water users. | Section 7.3          |

### C1.1.3 New South Wales EPA

| Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                     | addressed in section |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| <u>Surface water and groundwater impacts</u> – In relation to surface and groundwater management Table 3.1 of the PEA states “ <i>Construction of mine water management controls. Use of the United underground mining voids for water storage</i> ”. The EIS must include an assessment of the potential impacts to groundwater systems from the proposed storage of mine water in underground voids.                                              | Section 7.4          |
| 4. Describe existing surface and groundwater quality. As assessment needs to be undertaken for any water resources likely to be affected by the proposal.                                                                                                                                                                                                                                                                                           | Section 5.4          |
| 5. Where groundwater may be impacted the assessment should identify the appropriate environmental values.                                                                                                                                                                                                                                                                                                                                           | Section 5.4          |
| 6. State the indicators and associated trigger values or criteria for the identified environmental values.                                                                                                                                                                                                                                                                                                                                          | Section 10.3         |
| 12. Assess impacts on groundwater and groundwater dependent ecosystems                                                                                                                                                                                                                                                                                                                                                                              | Section 7.1.7        |
| 16. Describe how predicted impacts will be monitored and assessed over time. Including a Trigger Action Response Plan, or similar response management plan, that will be implemented in response to any adverse impacts identified from the activity. This plan is to identify appropriate trigger values for the site and provide appropriate response actions to be implemented if adverse impacts are identified through the monitoring program. | Section 10           |

#### C1.1.4 New South Wales Office of Environment and Heritage

| Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                    | addressed in section           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| 7. The EIS must map the following features relevant to water and soils including:<br>a) Groundwater<br>b) Groundwater dependent ecosystems                                                                                                                                                                                                                                                                                         | a) Section 5<br>b) Figure 5-12 |
| 8. The EIS must describe background conditions of any water resources likely to be affected by the development:<br>a) Existing surface and groundwater<br>c) Water Quality Objectives (as endorsed by the NSW Government) including groundwater as appropriate that represent the community's uses and values for the receiving waters                                                                                             | Section 5.4                    |
| 9. The EIS must assess the impacts of the development on water quality, including:<br>a) The nature and degree of impact on receiving waters for both surface and <b>groundwater</b> , demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. | Section 7.4                    |
| 10. The EIS must assess the impact of the development in hydrology, including:<br>e) Changes to environmental water availability, both regulated/licensed and unregulated/rules – based sources of such water.                                                                                                                                                                                                                     | Section 7                      |
| 9. <b>Water and soils</b> – E. The description of existing water quality/hydrology in the EIS must be based on suitable data (meaning data collection may be required) and must include:<br>h) An outline of baseline groundwater information, including, for example, depth to water table, flow direction and gradient, groundwater quality, reliance on groundwater by surrounding users and by the environment.                | Appendix A and Section 5       |
| 9. <b>Water and soils</b> – F. The assessment of the development on water quality and hydrology in the EIS must include:<br>b) Changes to hydrology (including groundwater).                                                                                                                                                                                                                                                       | Section 7                      |

## C1.2 Local government

### C1.2.1 Singleton Council

| Recommendations                              | addressed in section |
|----------------------------------------------|----------------------|
| Quantification of the net cumulative impacts | Section 7.2          |

## C1.3 Federal Government

### C1.3.1 Department of the Environment

| Recommendations                                                                                                                                                                                                                                                                                                                                                                                                       | addressed in section                     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| The EIS must include a description of the environment and management practices of the proposal site and the surrounding areas and other areas that are affected by the action. Include the relevant MNES protected by controlling provisions of Part 3 of the EPBC Act:                                                                                                                                               |                                          |
| a) A description of the important water resources within the site and in surrounding areas, which is consistent with the most recent version of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Developments' <i>Information Guidelines for Proposals Relating to the Development of Coal Seam Gas and Large Coal Mines where there is significant impact on water resources</i> . | Section 5                                |
| b) The EIS should identify and address cumulative impacts.                                                                                                                                                                                                                                                                                                                                                            | Section 7.2                              |
| 12. The EIS should provide a description of the location, extent and ecological characteristics and values of the identified water resources potentially affected by the project.                                                                                                                                                                                                                                     | Section 5                                |
| 13. The assessment of impacts should include information on:                                                                                                                                                                                                                                                                                                                                                          |                                          |
| - Any substantial and measurable changes to the hydrological regime of the water resource, for example a substantial change in the volume, timing, duration or frequency of ground and surface water flows;                                                                                                                                                                                                           | Section 7                                |
| - The habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the water resource being seriously affected; and                                                                                                                                                                                                                                                          | See EIS Ecology Assessment               |
| - Substantial and measurable change in the water quality and quantity of the water resource – for example, a substantial change in the level of salinity, pollutants, or nutrients in the wetland; or water temperature that may adversely impact on biodiversity, ecological integrity, social amenity or human health.                                                                                              | Section 7 and see EIS Ecology Assessment |
| 14. The EIS must provide adequate information to allow the project to be reviewed by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, as outlined in the <i>Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals (2015)</i> .                                                        | Section C1.3.2 checklist included        |

### C1.3.2 Independent Expert Scientific Committee (IESC)

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) has information guidelines for advice on coal seam gas and large coal mining development proposals. The following section specifies where the IESC information requirements for individual proposals have been addressed within this report.

### *C1.3.2.1 Description of the proposal*

| Does the description of the proposal include details of the:        | addressed in section        |
|---------------------------------------------------------------------|-----------------------------|
| purpose                                                             | Section 1.2 and Section 6.2 |
| location                                                            | Section 1                   |
| scale                                                               | Section 1                   |
| proposal's status within the regulatory assessment process          | Section 1 and Section 2     |
| character                                                           | Section 1                   |
| duration                                                            | Section 1                   |
| means by which a significant impact on water resources is likely    | Section 1                   |
| water management policies or regulations applicable to the proposal | Section 2                   |

### *C1.3.2.2 Contextual information*

| Does the contextual information include details of the:                                                                                                       | addressed in section                                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| water resources of the site and region                                                                                                                        | Section 5 and refer to EIS Surface Water Assessment |
| geological sequence of the area, including names and descriptions of the formations                                                                           | Section 4 and refer to main EIS report              |
| hydraulic characteristics for each hydrogeological unit                                                                                                       | Section 5                                           |
| likely recharge sources, direction of discharge and discharge pathways for all hydrogeological units                                                          | Section 5.3                                         |
| assessments of the frequency, volume and direction of interactions between water sources                                                                      | Section 5                                           |
| relevant information generated by a bioregional assessment, or best available information                                                                     | see EIS Ecology Assessment                          |
| geology and hydrogeology at an appropriate level of spatial and vertical resolution                                                                           | Section 4 and Section 5                             |
| geological structures and their influence on groundwater                                                                                                      | Section 4.3                                         |
| depths to the hydrogeological units and associated standing water levels or potentiometric heads, including, contours, maps and hydrochemical characteristics | Section 5 and Appendix A                            |
| descriptions of hydrology, water quality data and geomorphology for all watercourses across the site                                                          | refer to EIS Surface Water Assessment               |
| water related assets                                                                                                                                          | refer to EIS Surface Water Assessment               |
| conceptual modelling                                                                                                                                          | Section 5.6                                         |

### C1.3.2.3 Model-data analysis, including water and salt balances

| Model-data analysis builds on background data and conceptual modelling to enable an analysis. The information provided should include: | addressed in section                                  |
|----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| surface water and groundwater assessments and modelling, including detailed hydrology and water quality assessments                    | This report and refer to EIS Surface Water Assessment |
| quality of and risks and uncertainty inherent in the data and modelling                                                                | Appendix B                                            |

| Has a groundwater model that is calibrated to baseline conditions and enables a probabilistic evaluation of potential future scenarios been provided? Does the groundwater modelling include: | addressed in section       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| the model conceptualisation of the hydrogeological system or systems, including key assumptions and model limitations                                                                         | Section 5.6 and Appendix B |
| the various stages of the proposed development and predictions of water level/pressure declines in each hydrogeological unit                                                                  | Appendix B                 |
| the volumes predicted to be dewatered with an indication of the proportion supplied from each a hydrogeological unit                                                                          | Section 7                  |
| consider a variety of boundary conditions for stream across model domain                                                                                                                      | Appendix B                 |
| be undertaken in accordance with the Australian groundwater modelling Guidelines, including being peer reviewed                                                                               | Appendix B                 |
| each hydrogeological unit, including storage and flow characteristics, their existing recharge/discharge pathways and any linkages between units                                              | Appendix B                 |
| maximum drawdown and the time for post development drawdown equilibrium to be reached                                                                                                         | Section 7                  |
| potential water level recovery rates and timeframes for each hydrogeological unit                                                                                                             | Section 7.3                |
| include a sensitivity analysis of stream boundary conditions and justification of the conditions applied in the final model                                                                   | Appendix B                 |
| recommendations and a program for review and update of the model                                                                                                                              | Section 10                 |

| Do the water and salt balances provide details on specific flows and changes, including: | addressed in section                  |
|------------------------------------------------------------------------------------------|---------------------------------------|
| any changes that occur to the salt loads of the groundwater and surface water systems    | Section 7.27.2                        |
| water infiltration from surface stores                                                   | Appendix B                            |
| waste water from the operation                                                           | refer to EIS Surface Water Assessment |
| volumes and quality of water used during mining                                          | refer to EIS Surface Water Assessment |

| Do the water and salt balances provide details on specific flows and changes, including:                    | addressed in section |
|-------------------------------------------------------------------------------------------------------------|----------------------|
| all interactions and flows that exist that are part of the background (baseline) water flows                | Appendix B           |
| hydrogeological unit storage properties and groundwater flows and pressures resulting from depressurisation | Appendix B           |
| an estimation of flow/exchange of water between hydrogeological units and the target coal measure           | Section 7            |
| all volumes and quality of water intended for injection                                                     | not applicable       |
| any water that must be imported from elsewhere                                                              | not applicable       |
| estimates of water use in transpiration by vegetation, and the predicted changes to vegetation water use    | Appendix B           |

#### *C1.3.2.4 Assessment of impacts on water resources and water related assets*

| Does the assessment of impacts include details of:                                    | addressed in section                  |
|---------------------------------------------------------------------------------------|---------------------------------------|
| likely changes to water and salt balances                                             | Section 7                             |
| the hydrogeological units that will be directly impacted by mining operations         | Section 7                             |
| impacts on hydrological interactions between water resources                          | Section 7                             |
| impacts associated with surface water diversions                                      | refer to EIS Surface Water Assessment |
| impacts on hydraulic properties of hydrogeological units                              | not addressed as part of this report  |
| effects of depressurisation due to gas extraction                                     | not applicable                        |
| the quality and quantity of operational discharges of water                           | refer to EIS surface water report     |
| landscape modifications                                                               | Section 7.3 (final voids)             |
| the cumulative impacts (see section titled Assessment of cumulative impacts)          | Section 7.2                           |
| proposed mitigation actions for each identified impact                                | Section 10                            |
| subsidence and effects from dewatering and depressurisation                           | not applicable                        |
| the hydrogeological units that will be dewatered or indirectly impacted by dewatering | Section 5 and Section 7               |
| the extent of the cone of depression and consequential impacts on water resources     | Section 7                             |
| direct and indirect impacts on water related assets                                   | Section 7                             |

| Does the assessment of impacts include details of:                                              | addressed in section                 |
|-------------------------------------------------------------------------------------------------|--------------------------------------|
| potential for physical transmission of water within and between hydrogeological units           | Section 7                            |
| estimates of likelihood of leakage of contaminants from coal beds through geological formations | not addressed as part of this report |
| vulnerability to contamination and likely impacts of contamination on water related assets      | Section 7                            |
| long term impacts from final landform design                                                    | Section 7.3                          |
| measures taken to avoid and minimise impacts                                                    | Section 10                           |

#### *C1.3.2.5 Assessment of cumulative impacts*

| Does the assessment of cumulative impacts include:                                                                                         | addressed in section      |
|--------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| a summary of CSG and large coal mining developments within the region                                                                      | Section 3                 |
| existing and planned water entitlements, and the actual take of water for consumptive, industrial and agricultural purposes                | Section 5.5               |
| the proportional increase in water resource use                                                                                            | Section 7                 |
| catchment and regional scale information (from bioregional/other relevant assessments)                                                     | Section 4 and Section 5   |
| existing water quality guidelines, targets, environmental flow objectives and requirements for the surface catchment and groundwater basin | Section 2 and Section 5.4 |
| the overall level of risk to water related assets                                                                                          | Section 7                 |

#### *C1.3.2.6 Assessment of risk*

| Does the assessment of risk identify:                                                                             | addressed in section    |
|-------------------------------------------------------------------------------------------------------------------|-------------------------|
| water related assets in the area                                                                                  | Section 5 and Section 7 |
| the likelihood and consequence of impacts occurring                                                               | Section 7               |
| the overall level of risk to assets that combine probability of occurrence with consequence or severity of impact | Section 7               |
| potential impacts to water related assets                                                                         | Section 7               |
| the magnitude or severity of impact in the event that the impact was to occur                                     | Section 7               |
| the residual risk following the application of mitigation measures                                                | Section 10              |

### C1.3.2.7 Ongoing management and monitoring

| Does ongoing management and monitoring include:                                                                                                   | addressed in section                                                                                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| a robust monitoring plan to inform management and mitigation of all impacts identified through the assessment                                     | Section 10                                                                                           |
| comprehensive baseline monitoring dataset prior to commencement of the development                                                                | Appendix A and Section 10                                                                            |
| the hypotheses to be tested                                                                                                                       | Section 10                                                                                           |
| the analytical methods to be used                                                                                                                 | Section 10                                                                                           |
| water quality monitoring that is managed in accordance with the relevant National Water Quality Management Strategy (NWQMS) guideline             | Section 10                                                                                           |
| regular reviews and revisions of the monitoring program                                                                                           | Section 10                                                                                           |
| clearly defined monitoring objectives and performance indicators                                                                                  | Section 10                                                                                           |
| maps and coordinates of monitoring locations                                                                                                      | Section 10                                                                                           |
| the ability to capture seasonal and inter-annual variability and enable valid statistical analysis of results                                     | Section 10                                                                                           |
| groundwater, surface water and associated ecological attributes and be capable of tracking changes from pre-development conditions                | Section 10                                                                                           |
| the rationale and design for the monitoring program                                                                                               | Section 10                                                                                           |
| the temporal and spatial frequency of monitoring and the potential indicators to be monitored                                                     | Section 10                                                                                           |
| the identified triggers and threshold and proposed management actions if levels are reached and exceeded                                          | Section 10                                                                                           |
| a commitment to regular reporting of findings from monitoring programs, including raw data, analysis of data, and the results and conclusions     | Section 10                                                                                           |
| an adaptive management approach to manage changes in the predicted impacts                                                                        | Section 10                                                                                           |
| a description of local and regional surface water regime/s and detailed historical baseline data against which monitoring results can be assessed | Section 10                                                                                           |
| the number and spatial distribution of monitoring sites and monitoring frequency                                                                  | Section 10                                                                                           |
| a monitoring network that extends beyond the predicted impact area                                                                                | Section 10 – due to extensive mining in region, unable to extend outside the cumulative impacts zone |

| Does the groundwater monitoring program include:                                                                                                  | addressed in section      |
|---------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| a network to collect sufficient physical aquifer parameters and hydrogeochemical data to establish pre-development (baseline) conditions          | Section 10 and Appendix A |
| dedicated groundwater monitoring wells                                                                                                            | Section 10 and Appendix A |
| information on the groundwater regime, recharge and discharge processes and identify changes over time in the groundwater system                  | Section 10 and Appendix A |
| a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events | Section 10 and Appendix A |
| specific aquifers for monitoring and management                                                                                                   | Section 10 and Appendix A |
| appropriate management responses to mitigate impacts to groundwater resources                                                                     | Section 10 and Appendix A |

| Does the surface water monitoring program include:                                                                | addressed in section                  |
|-------------------------------------------------------------------------------------------------------------------|---------------------------------------|
| sufficient data to detect and identify the cause of any changes from baseline conditions                          | refer to EIS Surface Water Assessment |
| a rationale for selected monitoring variables                                                                     | refer to EIS Surface Water Assessment |
| dedicated sites to monitor hydrology, water quality and channel geomorphology throughout the life of the proposal | refer to EIS Surface Water Assessment |
| satellite or aerial impact, if required.                                                                          | refer to EIS Surface Water Assessment |

| Does the ecological monitoring program include:                                                                                       | addressed in section            |
|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|
| an evaluation of the effectiveness of impact prevention or mitigation measures                                                        | refer to EIS Ecology Assessment |
| measurements of trends in ecological responses and whether ecological responses are within identified thresholds of acceptable change | refer to EIS Ecology Assessment |

*Appendix D*

**Peer Review Report**

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noel.merrick@hydroalgorithmics.com

DATE: 5 May 2016

TO: John Merrell  
Group Manager, Environment and Communities - NSW  
Umwelt (Australia) Pty Limited  
75 York Street  
Teralba NSW 2284  
Tel: (02) 4950 5322

FROM: Dr Noel Merrick

RE: United Project – Groundwater Assessment Final Peer Review

YOUR REF: 3509/JM/KD/300315

OUR REF: HA2016/4

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A peer review has been conducted by Dr Noel Merrick of HydroAlgorithmics Pty Ltd of the groundwater impact assessment (GIA) for the United Project joint venture between Glencore and Peabody, to the west of Singleton. The GIA has been documented by Australasian Groundwater and Environmental Consultants under the project management of Umwelt (Australia) Pty Limited.

The review has been conducted in accordance with national groundwater modelling guidelines, with a focus on compliance with the NSW Aquifer Interference Policy and addressing the requirements of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development.

The GIA has been reviewed progressively on four occasions at the completion of major phases of the assessment from June 2015 to April 2016.

A detailed peer review report is provided as an **Attachment** to this summary. At the outset it should be noted that the very extensive distribution of coal mining in the district, laterally and especially vertically with a number of multi-seam operations in the past and more in the future, makes numerical modelling very complex and extremely challenging, with few (if any) equivalent counterparts elsewhere in New South Wales. The modelling component of the GIA satisfies the national guidelines for groundwater flow modelling.

Overall, there are no matters of concern in the GIA as to report structure or depth of coverage. There is a clear focus on the Secretary's Environmental Assessment Requirements, including those associated with the Aquifer Interference Policy, as well as Federal Government and Local Government requirements. The objectives expressed in terms of State Government, Federal Government and Local Government requirements have been addressed satisfactorily.

This reviewer finds that the model underpinning the groundwater impact assessment is robust and "fit for purpose", where the primary purpose of the model is the prediction of environmental impacts in the context of the Aquifer Interference Policy, and estimation of water takes for licensing.

The quantitative estimates of water takes for licensing purposes are reasonable and the investigation of environmental impacts related to groundwater extraction during mining is sufficiently thorough.

A very thorough analysis of the uncertainty in the estimates has been conducted. In the opinion of the reviewer, the uncertainty analysis has called into question the precision expected of water licence estimation. In consequence, commitments to licensed volumes should not extend beyond (say) the first five years, with refinement over time based on ongoing improvement in numerical modelling and continued monitoring, as some of the licensable volumes of water are not measureable (particularly alluvial water loss and baseflow reduction). The uncertainty analysis also calls into question the adoption of the simulated maximum as the annual rate required to be licensed; an average rate over the duration of mining would be more reasonable, and could be accommodated in practice through introduction of carryover and borrowing conditions on a water licence.

Yours sincerely

A handwritten signature in black ink, appearing to read 'hP Merrick', written in a cursive style.

Dr Noel Merrick

# ATTACHMENT

## Introduction

This report is provided in response to a written request of 30 March 2015 for conducting a peer review of the groundwater impact assessment (GIA) for the United Project joint venture between Glencore and Peabody, to the west of Singleton. The GIA has been done by Australasian Groundwater and Environmental Consultants (AGE) under the project management of Umwelt (Australia) Pty Limited (Umwelt).

The review has been conducted by Dr Noel Merrick in accordance with national groundwater modelling guidelines, with a focus on compliance with the NSW Aquifer Interference Policy (AIP) and addressing the requirements of the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development.

The GIA has been reviewed progressively:

1. After conceptualisation, software selection and model design planning.
2. After model calibration.
3. After revised model calibration, prediction, and issue of the draft GIA report.
4. After issue of the draft final GIA report.

The scope of work for the peer review was to focus on:

- model selection and modelling approach;
- definition and mapping of alluvial areas and other features and users potentially affected by groundwater impacts;
- approach to cumulative effects;
- impact assessment criteria and analysis including compliance with the NSW AIP and the likely requirements of the IESC;
- satisfaction of the Secretary's Environmental Assessment Requirements;
- proposed mitigation and monitoring measures; and
- presentation of results and interpretation.

## Documentation

The peer review has been based primarily on a number of draft reports, the latest of which is:

1. *AGE, 2016, United Wambo Open-Cut Coal Mine Project Groundwater Impact Assessment. Project No. G1733 report prepared for Umwelt Australia Pty Ltd. 117p + 4 Appendices. 18 March 2016.*

Appendix B provides specific detail on the groundwater modelling component of the GIA:

2. *AGE, 2016, Appendix B: Numerical Modelling Report. 43p + Appendix B-1 48p.*

This review is the fifth in a series of staged reviews.

Apart from examination of written reports, the reviewer participated in a workshop on 12 August 2015 and a number of teleconferences on the following occasions:

- 24 June 2015;
- 3 September 2015;
- 14 April 2016.

Some clarifications by email were requested on Documents #1 and #2, which are likely to appear in the final AGE report. One email providing more information and a new Figure 5-4 was received

on 28 April 2016.

The major sections in Document #1 are:

1. Introduction
2. Regulatory framework
3. Environmental setting
4. Geological setting
5. Hydrogeology
6. Numerical groundwater model
7. Model predictions and impact assessment
8. Compliance with NSW government policy
9. Compliance with Commonwealth government policy
10. Groundwater monitoring and management plan
11. References
12. Glossary & Acronyms

The appendices are:

- A. Field investigation report
- B. Numerical modelling report
- C. Study requirements
- D. Peer review report

The major and minor sections in Document #2 (Appendix B) are:

1. Introduction
  2. Model construction and development
    - Model code
    - Model design
    - System stresses
  3. Model calibration
    - Calibration targets
    - Calibration results
  4. Predictive simulations
    - Time slices
    - Mine drainage
    - Recovery modelling
  5. Sensitivity analysis
    - Zone of depressurisation
    - Impacts on alluvial groundwater sources
    - Sensitivity classification
  6. Uncertainty analysis
  7. References
- Appendix B-1 Calibration Details and Hydrographs

This peer review is to form Appendix D of the final GIA report.

## Review Methodology

While there are no standard procedures for peer reviews of entire groundwater assessments, there are two accepted guides to the review of groundwater models: the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline<sup>1</sup>, issued in 2001, and the newer guidelines issued by the National Water Commission (NWC) at the end of June 2012 (Barnett et al., 2012<sup>2</sup>). Both guides also offer techniques for reviewing the non-modelling components of a

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<sup>1</sup> MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: [www.mdbc.gov.au/nrm/water\\_management/groundwater/groundwater\\_guides](http://www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides)

<sup>2</sup> Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission,

groundwater impact assessment.

The 2012 NWC guide builds on the 2001 MDBC guide, with substantial consistency in model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. The new guide is almost silent on coal mine modelling and offers no direction on best practice methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

The groundwater impact assessment has been reviewed according to the 2-page Model Appraisal checklist<sup>3</sup> in MDBC (2001). This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. Non-modelling components of the groundwater impact assessment are addressed by the first three sections of the checklist.

The review has also considered compliance with the Secretary's Environmental Assessment Requirements (SEARs) listed in Appendix C of Document #1, NSW DPI Water requirements, and the Commonwealth EPBC Act (in respect of the "water trigger"). Particular attention is given to whether the minimal harm considerations of the NSW Aquifer Interference Policy (AIP) (NSW Government, 2012<sup>4</sup>) have been addressed adequately. They are summarised in Table 2-1 of Document #1.

It should be recognised that the effort put into the modelling component of a groundwater impact assessment is very dependent on possible timing and budgetary constraints that are generally not known to a reviewer.

A detailed assessment has been made in terms of the peer review checklists in **Table 1** and **Table 2**. Supplementary comments are offered in the following sections.

## Report Matters

The GIA report is a good quality document of about 250 pages length, including a number of appendices that contain more detail on field investigations, numerical modelling and regulatory requirements. It is well structured, well written and the graphics are of high quality. The report serves well as a standalone document, with no undue dependence on earlier work.

Previous review comments of a technical nature have been addressed satisfactorily, except for a few instances that are explored further in following sections. Earlier recommendations for editorial corrections have been addressed in full.

Overall, there are no matters of concern in the report as to structure or depth of coverage. There is a clear focus on the Secretary's Environmental Assessment Requirements, including those associated with the Aquifer Interference Policy, as well as Federal Government and Local Government requirements. Licensable takes are estimated for appropriate water sources. They consist of mine inflow take from porous rock, alluvium-Permian upflow/downflow take, and alluvium-stream baseflow/leakage take in excess of natural conditions.

## Data Matters

An extensive monitoring network has resulted from combining the data recorded by a number of mining operations in the district, facilitated by a joint venture agreement between Peabody and

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Canberra.

<sup>3</sup> The NWC guide includes a more detailed checklist with yes/no answers but without the graded assessments of the 2001 checklist, which this reviewer regards as less academic and more informative for readers.

<sup>4</sup> NSW Government, 2012, NSW Aquifer Interference Policy – NSW Government policy for the licensing and assessment of aquifer interference activities. Office of Water, NSW Department of Primary Industries, September 2012.

Glencore, and data sharing agreements with other neighbouring mines. In all, 301 groundwater monitoring sites have been identified. The baseline groundwater level record is generally much more than the minimum required two years, with some mine monitoring going back to 2001, and a few government monitoring bores dating back 35 years. Groundwater quality is documented in terms of minimum/average/maximum values for pH, electrical conductivity (EC), total dissolved solids (TDS), major ions (Ca, Cl, K, Na, Mg and SO<sub>4</sub>), hardness, bicarbonate and nitrate, across the Wambo and United networks. Stream water quality is examined in terms of time-varying TDS.

The stratigraphy of the area is complex, in that there is an alternating sequence of coal seams within coal measures that dip to the south-west and are progressively eroded at outcrop to the east. However, structural deformations are mild and uncommon. Due to a long history of mining in the area, and much prior groundwater modelling, the physical properties of the groundwater system are well characterised.

Document #1 includes a cumulative rainfall deviation (CRD, or residual mass) analysis to highlight weather and climate contexts during historical mining. In an addendum<sup>5</sup> to the report under review, the CRD curve has been compared with representative groundwater and stream hydrographs to reveal cause-and-effect relationships and to discriminate rainfall effects from mining effects. Suffice to say that many hydrographs have conclusive mining effects. Vertical hydraulic gradients have not been explored in full, to provide insight into current up/down groundwater directions, but an illustration is provided in a recently received addendum to Document #1<sup>5</sup>.

To inform river/aquifer interactions, topographic levels, groundwater levels and interpolated stream water levels have been examined in detail to indicate likely gaining/losing conditions along Wollombi Brook and the Hunter River.

Potential groundwater dependent ecosystems (GDEs) are examined in detail. The most important GDE appears to be the stands of River Red Gums.

Overall, data acquisition and data analysis have been sufficiently thorough to provide a firm foundation for the conceptual model depicted in Figures 5-12 and 5-13. The reviewer endorses this conceptualisation. No significant stresses have been omitted in the transition from the conceptual model to the numerical model.

## Model Matters

At the outset it should be noted that the very extensive distribution of coal mining in the district, laterally and especially vertically with a number of multi-seam operations in the past and more in the future, makes numerical modelling very complex and extremely challenging, with few (if any) equivalent counterparts elsewhere in New South Wales.

Modelling objectives are focused on addressing the minimal harm considerations of the AIP and on estimation of licensable takes from designated water sources. A Class 2 model is appropriate for this purpose, as put forward in Document #2 (Section B3.2.8).

Model extent is broader than previous modelling in this district, so that all mines that extract coal from the lowermost Bayswater Seam can be included in the assessment of cumulative impacts. The model extent is approximately 23 km x 28 km. The broad extent of the model minimises potential boundary effects. The reviewer is confident that the modelling results show no boundary, or edge, effects.

## Modelling methodology

The modelling methodology, which was reviewed initially in September 2015, is endorsed by the reviewer.

In order to accommodate the full suite of coal seams that are mined by various companies, the

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<sup>5</sup> Email dated 28 April 2016

model has been built with 34 layers, much more than normally is the case. With traditional MODFLOW software, such a large number of layers would generally be prohibitive. However, the use of MODFLOW-USG (Beta) coupled with AlgoMesh software allows this extra stratigraphic detail without compromising memory requirements or simulation runtime. This new software allows (Voronoi) cells of variable size so that detail can be focused only where necessary, with a minimum cell resolution of 50 m, and in addition eroded or pinched-out layers can be excised from the model space. The entire model has less than 1 million cells, an industry benchmark for a large model that is tractable in practice<sup>6</sup>.

The use of the time-variant materials (TVM) facility has allowed simulation to be continuous, generally in quarterly stress periods, instead of stitched time-slices as has been done often in the past.

The horizontal hydraulic conductivity (Kx) field has been varied with depth, with separate decay functions for coal and interburden (see Figures B-12 and B-13).

As the focus of the GIA is on a modification to approved open cut mining, less emphasis is put on simulation of underground mining, although that is included approximately for consideration of cumulative effects. As the Voronoi mesh design must be the same in each model layer, priority has been given to the shape and sequencing of open cut operations, rather than simulation of precise longwall panel dimensions.

Similarly, less effort has been put into the simulation of the fracture zones above longwall panels, although they are handled approximately. A uniform fracture height of 110 m<sup>7</sup> is applied progressively and universally, over underground mine footprints, with specified enhanced Kz values<sup>8</sup> for model layers that lie within 110 m of the top of a mined coal seam. No specific attention is given to the compounding effects of multi-seam mining, and it is unclear from Document #2 whether interburden layers between vertically adjacent coal seams are always fully fractured, or whether some deep undeformed buffers are retained in places. Given the number of coal seams that are simulated, it is probable that no interburden exceeds 110 m in thickness, so that full fracturing can be assumed at depth.

Open cut drains are progressed quarterly and are deactivated at the end of four years, after which spoil is emplaced. Recharge to spoil heaps is delayed until end of mining. Longwall drains also are deactivated after four years, but in practice this could vary from mine to mine and could be longer than assumed. The consequence of a longer active duration would be slightly higher mine inflow and delayed groundwater level recovery.

### Model calibration

Model calibration is satisfactory for steady-state and transient conditions. The calibration performance (for groundwater levels) is about 3.1 %RMS in relative terms and about 14 mRMS in absolute terms, both of which are acceptable for coal mining models. Given the recognised complexity of the area, calibration is unlikely to be improved materially with further effort.

It is not possible for a reviewer to readily discern whether vertical head gradients are reproduced well as the hydrographs in Appendix B-1 are displayed one by one, rather than as stacked curves for vibrating wire piezometer (VWP) sites. The alphabetical sorting on bore name also precludes ready assessment of performance in different regions of the model extent. Collation of hydrograph matches into regional groups in Appendix B-1 would assist a reader.

No spatial map of average residuals is provided to allow an appreciation of where calibration is good and where it is poor.

Calibrated formation properties are consistent with field measurements and are generally within a half-order of magnitude of values adopted in earlier modelling.

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<sup>6</sup> For technical readers, it is noted that the model has not employed Richards Equation for an unsaturated soil. Activated options are: upstream weighting; TVM; CONSTANTCV.

<sup>7</sup> Calculated as 0.4 x representative panel width of 275 m.

<sup>8</sup> Perturbed Kz ranges from 5.3E-2 to 1.4E-4 m/day. See Table B-6.

The adopted rainfall recharge rates are controlled through a soil moisture model. When recharge is expressed as a fraction of rainfall, the rates vary from 1.5% on regolith to 10% on high-productivity alluvium, with 4.5% on less-productive alluvium and 3.3% on spoil. These rates are similar to, but generally higher than, rates adopted in other models at Wambo.

In Tables B-8 and B-9 of Document #2, percentages for each water balance component would be more informative for comparing steady-state and transient water balances, as the throughflows differ in absolute levels. Then comment could be made on the overall mining effect. At present the text compares net rain and river recharge in absolute terms, which is not valid without normalisation. A reader might mistakenly assume the differences from the steady-state values are caused by mining.

### Model prediction

Three scenarios are defined for predictive analysis, although Document #2 mentions only two. Their definition should be clearer. Essentially, they comprise a Null run, an Approved run, and a Modification run. The reviewer's understanding of the runs is:

- A. Approved run - consisting of completed and currently approved open cut and underground United and Wambo operations, plus all neighbouring approved and reasonably foreseeable mining operations.
- B. Modification run - consisting of completed and approved underground United and Wambo operations, completed and currently proposed United and Wambo open cut operations, plus all neighbouring approved and reasonably foreseeable mining operations.
- C. Null run - consisting of completed underground United and Wambo operations, completed United and Wambo open cut operations, plus all neighbouring approved and reasonably foreseeable mining operations; all future underground and open cut United and Wambo operations are deactivated.

The differential responses between A and B would isolate the effects of the Modification over what has been Approved. The differential responses between B and C would isolate the effects of future mining at United and Wambo compared to the situation having no future open cut or underground mining. All runs include background mining, as they should, so that cumulative effects are properly accounted for.

A rare occurrence for coal mining applications is that the prediction period of 24 years is shorter than the calibration period of 45 years, though the lack of many calibration records in early years reduces the effective calibration period to a decade or so.

Predicted maximum drawdown maps (during mining) due to the Project are provided for a sufficient number of model layers so that the evolution of drawdown extent can be followed from the mined seam up to land surface (Figures 7-2 to 7-6). Maximum cumulative drawdown is shown in Figures 7-14 to 7-18. The results are plausible. Post-mining equilibrium drawdown and heads are shown in Figures 7-20 to 7-24.

Water exchanges and differential effects are presented for the alluvium/Permian interface and the alluvium/stream interface for Wollombi Brook and the Hunter River. They are shown in Figures 7-7 to 7-10 during mining and in Figures 7-25 and 7-26 during a recovery simulation of 1000 years. The model predicts that the Project would cause a reduction of about 10% in Permian upflow to Wollombi Brook alluvium. It is agreed that this would provide a beneficial impact on alluvial water quality during mining and for some years afterwards. Similarly, the model predicts that the Project would cause an increase of about 10% in downflow from Hunter River alluvium to Permian rocks.

The most informative map for drawdown extent is found in Document #2 where uncertainty in the extent of Vaux Seam drawdown is assessed through traditional sensitivity analysis via perturbation of hydraulic conductivity, storage and rainfall recharge fields (Figure B-19).

The most informative graphs for alluvium/Permian water exchange and pit inflow are found in

Document #2 where uncertainty is explored through linear uncertainty analysis on 192 parameters, allowing specified-percentile graphs to be drawn (Figures B-22 to B-25). Uncertainties generally up to about 50% are recognised, calling into question the precision expected of water licence estimation. In consequence, commitments to licensed volumes should not extend beyond (say) the first five years, with refinement over time based on ongoing improvement in numerical modelling and continued monitoring, as some of the licensable volumes of water are not measureable. The uncertainty analysis also calls into question the adoption of the simulated maximum as the annual rate required to be licensed; an average rate over the duration of mining would be more reasonable, and could be accommodated in practice through introduction of carryover and borrowing conditions on a water licence.

There is substantial and adequate examination of model outputs in terms of expected groundwater effects and impacts with reference to the minimal harm considerations of the AIP.

## Conclusion

This reviewer finds that the model underpinning the groundwater impact assessment is "fit for purpose", where the primary purpose of the model is the prediction of environmental impacts in the context of the Aquifer Interference Policy, and estimation of water takes for licensing.

The objectives expressed in terms of State Government SEARs, Federal Government and Local Government requirements have been addressed satisfactorily.

The quantitative estimates of water takes for licensing purposes are reasonable and the investigation of environmental impacts related to groundwater extraction during mining is sufficiently thorough.

The proposed mitigation and monitoring measures are satisfactory.

A very thorough analysis of the uncertainty in the estimates has been conducted.

In the opinion of the reviewer, the uncertainty analysis has called into question the precision expected of water licence estimation. In consequence, commitments to licensed volumes should not extend beyond (say) the first five years, with refinement over time based on ongoing improvement in numerical modelling and continued monitoring, as some of the licensable volumes of water are not measureable (particularly alluvial water loss and baseflow reduction). The uncertainty analysis also calls into question the adoption of the simulated maximum as the annual rate required to be licensed; an average rate over the duration of mining would be more reasonable, and could be accommodated in practice through introduction of carryover and borrowing conditions on a water licence.

Table 1. MODEL APPRAISAL: United-Wambo Model Preparation

| Q.         | QUESTION                                                                                                       | Not Applicable or Unknown | Score 0 | Score 1   | Score 3  | Score 5   | Score | Max. Score (0, 3, 5) | COMMENT                                                                                                                                                                                                                    |
|------------|----------------------------------------------------------------------------------------------------------------|---------------------------|---------|-----------|----------|-----------|-------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1.0</b> | <b>THE REPORT</b>                                                                                              |                           |         |           |          |           |       |                      |                                                                                                                                                                                                                            |
| 1.1        | Is there a clear statement of project objectives in the modelling report?                                      |                           | Missing | Deficient | Adequate | Very Good |       |                      | Section 1.2. Appendix C: Study Requirements.                                                                                                                                                                               |
| 1.2        | Is the level of model complexity clear or acknowledged?                                                        |                           | Missing | No        | Yes      |           |       |                      | Section B3.2.8. Reference to 2012 national guidelines. Class 2 confidence classification, partly Class 3. Equivalent to Impact Assessment Model, medium complexity (2001 guide).                                           |
| 1.3        | Is a water or mass balance reported?                                                                           |                           | Missing | Deficient | Adequate | Very Good |       |                      | Section B3.2.4. Table B-8 for steady-state. Table B-9 for transient (46 years). Provided for prediction scenarios for AIP measures, but not full components. Focus on licensable takes (alluvium, porous rock & baseflow). |
| 1.4        | Has the modelling study satisfied project objectives?                                                          |                           | Missing | Deficient | Adequate | Very Good |       |                      | SEARs, Local Government and Federal Government requirements are assessed fully.                                                                                                                                            |
| 1.5        | Are the model results of any practical use?                                                                    |                           |         | No        | Maybe    | Yes       |       |                      | Clear assessment of AIP minimal harm considerations and licensable takes.                                                                                                                                                  |
| <b>2.0</b> | <b>DATA ANALYSIS</b>                                                                                           |                           |         |           |          |           |       |                      |                                                                                                                                                                                                                            |
| 2.1        | Has hydrogeology data been collected and analysed?                                                             |                           | Missing | Deficient | Adequate | Very Good |       |                      | Sections 4 & 5. Complex geology. Detailed stratigraphy. Sufficient historical measurements of physical properties. Water quality in Section 5.4 and Appendix A.                                                            |
| 2.2        | Are groundwater contours or flow directions presented?                                                         |                           | Missing | Deficient | Adequate | Very Good |       |                      | Provided for alluvium and deep Vaux Seam (Figures 5-4 & 5-5). Also saturated thickness for alluvium. Not done for regolith in general - not much data on unimpacted pre-mining water levels.                               |
| 2.3        | Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.) |                           | Missing | Deficient | Adequate | Very Good |       |                      | Primarily diffuse rainfall recharge. Flood recharge not warranted, so is excluded.                                                                                                                                         |

|     |                                                                                                                              |  |         |           |          |           |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----|------------------------------------------------------------------------------------------------------------------------------|--|---------|-----------|----------|-----------|--|--|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2.4 | Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.) |  | Missing | Deficient | Adequate | Very Good |  |  | Baseflow analysis on stream flow records. Also Wollombi Brook TDS(time). Detailed consideration of expected gaining/losing conditions of Wollombi Brook and Hunter River, noting spatial variability and complexity (Figure 3-6). Assessment of potential GDEs. Actual ET (BoM) not noted - instead, pan evaporation and plant ET. Private groundwater usage assumed negligible - not readily available to the public. Minor bore abstraction by mines - included. |
| 2.5 | Have the recharge and discharge datasets been analysed for their groundwater response?                                       |  | Missing | Deficient | Adequate | Very Good |  |  | Cumulative Rainfall Departure (residual mass) is shown in Figure 3-1. It is compared with representative groundwater and stream hydrographs to demonstrate active stresses - climate or mining effects - in a new Figure 5-4 provided by email as an addendum. There is some discussion on vertical head gradients.                                                                                                                                                |
| 2.6 | Are groundwater hydrographs used for calibration?                                                                            |  |         | No        | Maybe    | Yes       |  |  | Extensive monitoring network: 301 monitoring points. Shallow and deep hydrographs date back to 2001 - long record. Some to 1980.                                                                                                                                                                                                                                                                                                                                   |
| 2.7 | Have consistent data units and standard geometrical datums been used?                                                        |  |         | No        | Yes      |           |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 3.0 | CONCEPTUALISATION                                                                                                            |  |         |           |          |           |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 3.1 | Is the conceptual model consistent with project objectives and the required model complexity?                                |  | Unknown | No        | Maybe    | Yes       |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 3.2 | Is there a clear description of the conceptual model?                                                                        |  | Missing | Deficient | Adequate | Very Good |  |  | Section 5.6.                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 3.3 | Is there a graphical representation of the modeller's conceptualisation?                                                     |  | Missing | Deficient | Adequate | Very Good |  |  | Figures 5-12, 5-13: E-W and N-S cross-sections before and during mining.                                                                                                                                                                                                                                                                                                                                                                                           |
| 3.4 | Is the conceptual model unnecessarily simple or unnecessarily complex?                                                       |  |         | Yes       | No       |           |  |  | Major processes are included. Stratigraphy is very detailed.                                                                                                                                                                                                                                                                                                                                                                                                       |
| 4.0 | MODEL DESIGN                                                                                                                 |  |         |           |          |           |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

|     |                                                                  |  |         |           |          |           |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----|------------------------------------------------------------------|--|---------|-----------|----------|-----------|--|--|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4.1 | Is the spatial extent of the model appropriate?                  |  |         | No        | Maybe    | Yes       |  |  | Dimensions 23 km x 28 km. Unstructured grid of Voronoi cells. Minimum cell size 50m. 34 layers, 860,000 active cells.                                                                                                                                                                                                                                                                                            |
| 4.2 | Are the applied boundary conditions plausible and unrestrictive? |  | Missing | Deficient | Adequate | Very Good |  |  | Reasonable no-flow boundaries (north & east) beyond coal outcrop. GHB boundary to west - heads not provided. GHB boundary to south - heads set at mine-affected simulated heads. are not shown or defended, as there is no supplied regional observed groundwater contour map. RCH algorithm is soil moisture deficit calculation. Predicted drawdown contours for proposed development do not reach boundaries. |
| 4.3 | Is the software appropriate for the objectives of the study?     |  |         | No        | Maybe    | Yes       |  |  | MODFLOW-USG Beta + AlgoMesh and custom Fortran software.                                                                                                                                                                                                                                                                                                                                                         |

Table 2. MODEL APPRAISAL: United-Wambo Model Implementation

| Q.         | QUESTION                                                            | Not Applicable or Unknown | Score 0 | Score 1   | Score 3  | Score 5   | Score | Max. Score (0, 3, 5) | COMMENT                                                                                                                                                                                                                                                                                                               |
|------------|---------------------------------------------------------------------|---------------------------|---------|-----------|----------|-----------|-------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>5.0</b> | <b>CALIBRATION</b>                                                  |                           |         |           |          |           |       |                      | 1970-2015: 45-46 years. First mining 1979.                                                                                                                                                                                                                                                                            |
| 5.1        | Is there sufficient evidence provided for model calibration?        |                           | Missing | Deficient | Adequate | Very Good |       |                      | Sufficient for performance against groundwater levels, and anecdotal historical mine inflow. No indication of spatial distribution of residuals, but average residual at each site is given in a table (APP.B-1). Scattergram and performance statistics are given. Entire set of observed vs. simulated hydrographs. |
| 5.2        | Is the model sufficiently calibrated against spatial observations?  |                           | Missing | Deficient | Adequate | Very Good |       |                      | Valid contour pattern.                                                                                                                                                                                                                                                                                                |
| 5.3        | Is the model sufficiently calibrated against temporal observations? |                           | Missing | Deficient | Adequate | Very Good |       |                      | Hydrographs for all bores are presented for comparison in App.B-1. Full range from poor to very good matches. Mine inflows of sensible magnitudes. Multi-level bores not shown together to see if vertical gradients are reproduced.                                                                                  |
| 5.4        | Are calibrated parameter distributions and ranges plausible?        |                           | Missing | No        | Maybe    | Yes       |       |                      | Consistent with previous studies and site tests.                                                                                                                                                                                                                                                                      |
| 5.5        | Does the calibration statistic satisfy agreed performance criteria? |                           | Missing | Deficient | Adequate | Very Good |       |                      | 3.1%RMS, 14mRMS.                                                                                                                                                                                                                                                                                                      |
| 5.6        | Are there good reasons for not meeting agreed performance criteria? | N/A                       | Missing | Deficient | Adequate | Very Good |       |                      |                                                                                                                                                                                                                                                                                                                       |
| <b>6.0</b> | <b>VERIFICATION</b>                                                 |                           |         |           |          |           |       |                      | <i>Not a necessary step.</i>                                                                                                                                                                                                                                                                                          |
| 6.1        | Is there sufficient evidence provided for model verification?       | N/A                       | Missing | Deficient | Adequate | Very Good |       |                      | All data used for calibration.                                                                                                                                                                                                                                                                                        |

|     |                                                                                                         |     |         |           |          |           |  |  |                                                                                                                                                    |
|-----|---------------------------------------------------------------------------------------------------------|-----|---------|-----------|----------|-----------|--|--|----------------------------------------------------------------------------------------------------------------------------------------------------|
| 6.2 | Does the reserved dataset include stresses consistent with the prediction scenarios?                    | N/A | Unknown | No        | Maybe    | Yes       |  |  |                                                                                                                                                    |
| 6.3 | Are there good reasons for an unsatisfactory verification?                                              | N/A | Missing | Deficient | Adequate | Very Good |  |  |                                                                                                                                                    |
| 7.0 | PREDICTION                                                                                              |     |         |           |          |           |  |  | 2015-2039: 24 years.                                                                                                                               |
| 7.1 | Have multiple scenarios been run for climate variability?                                               |     | Missing | Deficient | Adequate | Very Good |  |  | A single average climate has been used in accordance with standard practice.                                                                       |
| 7.2 | Have multiple scenarios been run for operational /management alternatives?                              |     | Missing | Deficient | Adequate | Very Good |  |  | One proposed modified mine plan. Three scenarios: Null, Approved, Modified. All scenarios include background mining cumulative stresses.           |
| 7.3 | Is the time horizon for prediction comparable with the length of the calibration / verification period? |     | Missing | No        | Maybe    | Yes       |  |  | Transient calibration 45-46 years from 1970 to 2015. Prediction period is 24 years from 2015 to 2039. Transient recovery simulation to 1000 years. |
| 7.4 | Are the model predictions plausible?                                                                    |     |         | No        | Maybe    | Yes       |  |  | Plausible drawdown magnitudes and drawdown extent. Plausible stream and alluvial losses.                                                           |
| 8.0 | SENSITIVITY ANALYSIS                                                                                    |     |         |           |          |           |  |  |                                                                                                                                                    |
| 8.1 | Is the sensitivity analysis sufficiently intensive for key parameters?                                  |     | Missing | Deficient | Adequate | Very Good |  |  | Traditional perturbation analysis on Kx, Kz, Sy, Ss, rain recharge. Also linear identifiability analysis using PEST SVD.                           |
| 8.2 | Are sensitivity results used to qualify the reliability of model calibration?                           |     | Missing | Deficient | Adequate | Very Good |  |  | Figures 3-8 to 3-12. Adopted parameter ranges are not limited by calibration performance, but only by successful convergence.                      |
| 8.3 | Are sensitivity results used to qualify the accuracy of model prediction?                               |     | Missing | Deficient | Adequate | Very Good |  |  | Comparison of graphical drawdown extents; alluvial water exchange with Permian; stream-alluvium water exchange. Discussion of Type I to IV.        |

|     |                                                                         |  |         |    |       |     |  |  |                                                                                                                                                                                                    |
|-----|-------------------------------------------------------------------------|--|---------|----|-------|-----|--|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9.0 | UNCERTAINTY ANALYSIS                                                    |  |         |    |       |     |  |  |                                                                                                                                                                                                    |
| 9.1 | If required by the project brief, is uncertainty quantified in any way? |  | Missing | No | Maybe | Yes |  |  | Rigorous linear uncertainty analysis on 192 parameters. Effectively calibrated realisations.<br>Examination of effect on alluvial water exchange with Permian, and stream-alluvium water exchange. |

## *Appendix E*

# **Stygofauna Assessment**

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**United Wambo Open Cut Coal Mine Project**  
**Baseline Stygofauna Assessment**  
**Study 1, Survey 1, December 2015.**  
**Ref No. 3509**



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**United Wambo Open Cut Coal Mine Project - Baseline Stygofauna Assessment (Ref No: 3509)**

**Document Control**

|                              |                                                                                                |                    |             |
|------------------------------|------------------------------------------------------------------------------------------------|--------------------|-------------|
| <b>Business Unit</b>         | Stygoecologia                                                                                  |                    |             |
| <b>Project No.</b>           | <b>United Wambo Open Cut Coal Mine Project – Baseline Stygofauna Assessment (Ref No: 3509)</b> |                    |             |
| <b>Document Description</b>  | Stygofauna baseline assessment of the United and Wambo Open Cut Coal Project area.             |                    |             |
| <b>Supervising</b>           | <b>Name</b>                                                                                    | <b>Signed</b>      | <b>Date</b> |
| <b>Director</b>              | Dr Peter Serov                                                                                 | <i>Peter Serov</i> | 24-May-16   |
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| <b>Document Prepared for</b> | Umwelt (Australia) Pty Ltd & United Collieries Pty Ltd                                         |                    |             |
| <b>Document Status</b>       | Final, 24/05/2016                                                                              |                    |             |

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Cover photograph: Parabathynellidae, Syncarida

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- Plate 2. Syncarida, Parabathynellidae. (©P.Serov 2015).
- Plate 3. Ostracoda, Candonidae. (©P.Serov 2015)
- Plate 4. Bore No. GW13. 5. Bore No. GW15.
- Plate 6. Bore No.GW16.
- Plate 7. Bore No.GW17.
- Plate 8. Bore No.10A.
- Plate 9. Bore No. P103/Unnamed 14.
- Plate 10. Bore No.P104.
- Plate 11. Bore No.P106.
- Plate 12. Bore No.P109.
- Plate 13. Bore No.P110.
- Plate 14. Bore No.P111.
- Plate 15. Bore No.P116.
- Plate 16. Bore No.P120.
- Plate 17. Bore No.202.
- Plate 18. Bore No. Unnamed 10.
- Plate 19. Well No.P31.
- Plate 20. Well No.1.
- Plate 21. Bore No.GW22.
- Plate 22. Bore No.P315.
- Plate 23. Bore No.P301.

## **United Wambo Open Cut Coal Mine Project - Baseline Stygofauna Assessment (Ref No: 3509)**

### **Executive Summary**

The United mine (United) and Wambo mine (Wambo) are situated approximately 16 kilometres (km) west of Singleton in the Hunter Valley of New South Wales (NSW). The United and Wambo coal mining operations were established in 1989 and the late 1960's, respectively. There have been a range of underground and open cut coal mining operations at both of these adjoining coal mines since that time.

In November 2014, a 50:50 Joint Venture between United Collieries Pty Limited (United) and Wambo Coal Pty Limited (Wambo) was announced which combines the extraction and exploration rights for a number of mining tenements at United and Wambo. The Joint Venture will look to develop the United Wambo Open Cut Coal Mine Project (the Project) that combines the existing open cut operations at Wambo with a proposed new open cut coal mine at United. The joint venture is a State Significant Development as defined under the State Environmental Planning Policy (State and Regional Development) 2011 and therefore requires development consent under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP & A Act).

As part of developing the Environmental Impact Statement (EIS), Stygoecologia was commissioned by Umwelt (Australia) Pty Ltd on behalf of United to conduct an investigation to determine the presence of subterranean stygofauna communities within the United and Wambo Open Cut mining area. The object of the assessment is to assess the presence of stygofauna and to identify potential ecological risks to any subterranean stygofauna communities that may be present in the area of operations from the proposed development. This report is the first environmental assessment of the subterranean groundwater dependant ecosystems (GDEs) associated with United and Wambo. Specifically, this report assesses whether subterranean GDEs occur within the area of the current or future open cut mining activities, and if they exist, whether the proposed activities are likely to have a significant impact on them. This assessment included a baseline aquifer ecosystem evaluation for stygofauna across both the potential area of impact and the future proposed extraction areas. It provides a risk assessment of the proposed development to these ecosystems. There has been no previous sampling for stygofauna conducted in the United and Wambo open cut mining lease areas although stygofauna have previously been recorded from the Hunter Valley.

The stygofauna baseline survey included one round of surveys in order to identify the presence of stygofauna within the Study Area. The survey was conducted on the 1-2nd of December 2015. The survey included 20 sites separated into 18 bores and two wells. The sites were selected to cover as broad a coverage of the Study Area as possible, with sites located both within (impact) and outside (controls) the potential area of impact, as well the broadest range of habitat types. The bore types range from shallow alluvial monitoring piezometers accessing groundwater situated in unconsolidated alluvial/colluvial sediments with most bores reaching approximately 5-8m, and deeper observation bores into the shallow Permian Coal measures that extend down to 35m. The deeper aquifers could not be accessed as they were obstructed by Vibrating Wire Piezometers (VWP) which precluded sampling. A total of ten taxa of invertebrates were recorded which included eight families of stygofauna. The other taxa belonged to the terrestrial edaphic or soil environments.

The results showed stygofauna exist in small isolated populations within the Study Area. Of the 20 sites sampled, 11 bores contained stygofauna species. While stygofauna are present within the piezometers, they were not assessed or collected from the deeper coal seam aquifers due the installation of Vibrating Wire Piezometers as explained above. The community composition included five orders of crustaceans, one order of mites and two families of insects. There were no listed

## **United Wambo Open Cut Coal Mine Project - Baseline Stygofauna Assessment (Ref No: 3509)**

threatened species collected, however, as is the case for most assessments in this emerging field, all species are likely to be new to science. The biological and water quality data indicates that the fauna is associated with the Quaternary alluvial aquifers. These aquifers are shallow aquifers, composed of coarse to fine sediments with low electrical conductivity and relatively neutral pH water quality. The relative consistency of the community composition within the bores that recorded stygofauna across the Study Area is an indication of connectivity within the shallow alluvial aquifers and of consistency in the environmental conditions of this aquatic ecosystem. For this reason the shallow alluvial aquifer was assessed as having a high ecological value for the purpose of this study. The fine grained nature of the coal measure and some of the alluvial soils on the hill slopes and alluvial sediments and the high electrical conductivity of the coal measures are suggested as reasons for the lack fauna in the other sites.

The results of the current survey indicate that the ecosystem condition within Wollombi Brook Alluvium is currently stable along this subcatchment as indicated by the relatively consistent invertebrate community composition. There appears at this stage to have been no adverse effects on the subterranean aquatic ecosystem as a result of previous mining operations at Wambo or United although the original extent of the community is not possible to determine.

Stygofauna are potentially threatened by activities that change the quality or quantity of groundwater, disrupt connectivity between the surface and aquifer, or remove living space. Subsidence and aquifer drawdown are identified as the main risks to stygofauna associated with both the current and future proposed United Wambo Open Cut mine. The potential impacts include changes to:

- ☐ water table levels;
- ☐ aquifer flow paths;
- ☐ aquifer discharge volume to off-site GDEs;
- ☐ the frequency/timing of water table level fluctuations;
- ☐ river base flow;
- ☐ spring water pressure;
- ☐ natural groundwater chemistry; and
- ☐ groundwater salinity levels.

The stygofauna recorded are assessed as having a low risk of mining related impacts based on the modelled drawdown to the Quaternary alluvial aquifers from water extraction and the highly connected nature of the alluvials with the underlying coal seams. A risk assessment ranked ecological risk to sites where stygofauna were present as Class A (high value/low risk). The remaining bores which did not record stygofauna were ranked as Class G (low value/low risk). The short term management actions relevant to these risk ratings include: continue the ongoing risk monitoring of physicochemical parameters such as water level and water chemistry; periodic biological survey monitoring for the identified hot spot sites; and the exploration of more appropriate monitoring locations. This is to be carried out within a long term adaptive management and monitoring program.

## 1. Introduction

The United and Wambo mines are neighbouring mining operations located approximately 16 kilometres (km) west of Singleton in the Hunter Valley of New South Wales (NSW) (Map 1). United Collieries Pty Limited (United) the operator of United mine and Wambo Coal Pty Limited (Wambo) the operator of Wambo mine, have formed a Joint Venture which includes the proposed development of the United Wambo Open Cut Coal Mine Project (the Project).



FIGURE 1.1  
Locality Plan

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**Map 1.** Location the United Wambo Open Cut Coal Mine Project Area in a regional context within the Hunter Valley.

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The Project proposes open cut coal mining for a period of 23 years, with mining in a new open cut mine at United (the United Open Cut) combined with ongoing mining at the existing, approved Wambo Open Cut under a modified mine plan. The Project will optimise future mining operations across these two adjoining open cut mining areas, maximising coal recovery and the efficient use of existing mining infrastructure, while providing the operational flexibility required to actively manage the mine to minimise environmental impacts.

The Project is a State Significant Development as defined under State Environmental Planning Policy (State and Regional Development) 2011 and requires development consent under Part 4 of the Environmental Planning and Assessment Act 1979 (EP&A Act). The Project will also require a modification to the existing Wambo development consents under section 75W of the EP&A Act to harmonise these consents with the Project. An Environmental Impact Statement (EIS) has been prepared to accompany these applications.

Mining has been occurring at Wambo since the late 1960's and at United since 1989, with both mines previously undertaking both open cut and underground mining operations. Over this time the two mines have regularly cooperated, including sharing access to coal resources where appropriate, to provide for more efficient recovery of the State's coal resources. The two mines have also shared some mining infrastructure, including the joint use of the Wambo train loading facility, and share water to minimise external water demand.

Building on this long history of cooperative operations, in November 2014 United and Wambo announced a 50:50 Joint Venture between the two companies. The Joint Venture agreement outlines how the two companies will work together to further develop open cut coal resources held by the two mines.

Whilst open cut coal mining has previously been undertaken at United, over the last two decades the focus has been on underground mining. Underground longwall mining operations were approved to provide up to 2.95 million tonnes per annum (Mtpa) of saleable coal. Mining operations were suspended at United in March 2010 with the mine entering a period of care and maintenance. At that time, exploration and pre-feasibility works were commenced to determine the potential for future mining activities within United's mining lease. Ongoing exploration has identified substantial reserves of coal suitable for open cut mining.

Ongoing open cut and underground mining is occurring at Wambo, with the mine having approval to extract up to 8 million tonnes per annum (Mtpa) of run of mine (ROM) coal by open cut methods. The combined Wambo underground and open cut operations have approval to extract up to 14.7 Mtpa ROM coal, and to transport up to 15 Mtpa of product coal via the train loading facility.

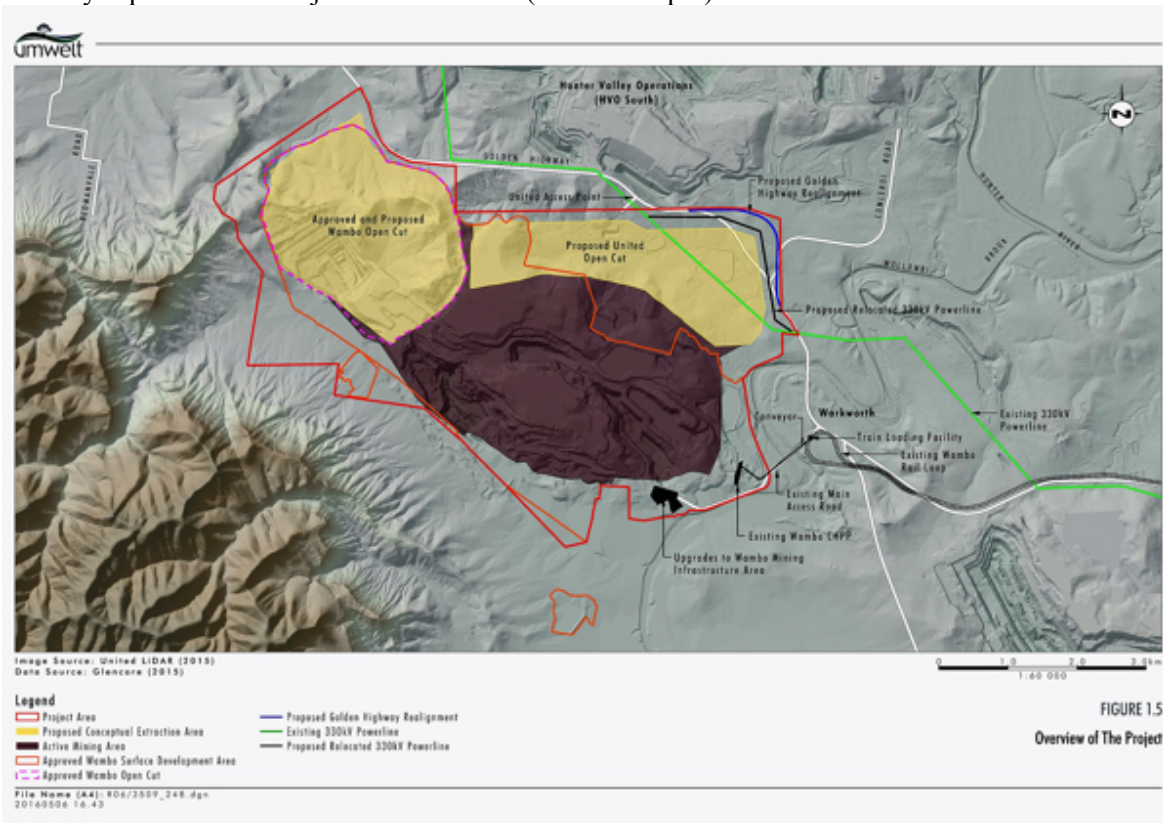
As discussed above, the Project includes open cut mining operations in two areas, the proposed United Open Cut and modified operations in the approved Wambo Open Cut for a period of approximately 23 years. The existing Wambo Open Cut has approval for continued open cut mining until March 2017 (with a modification lodged to extend this to 2020). Due to the progression of mining being slower than originally planned, there will be substantial coal resources remaining in this approved mining area at March 2017 and the Project proposes to continue mining in this approved area. The Project also seeks some minor extensions to the approved Wambo Open Cut surface mining area and will seek approval to mine deeper resources below the approved Wambo Open Cut area.

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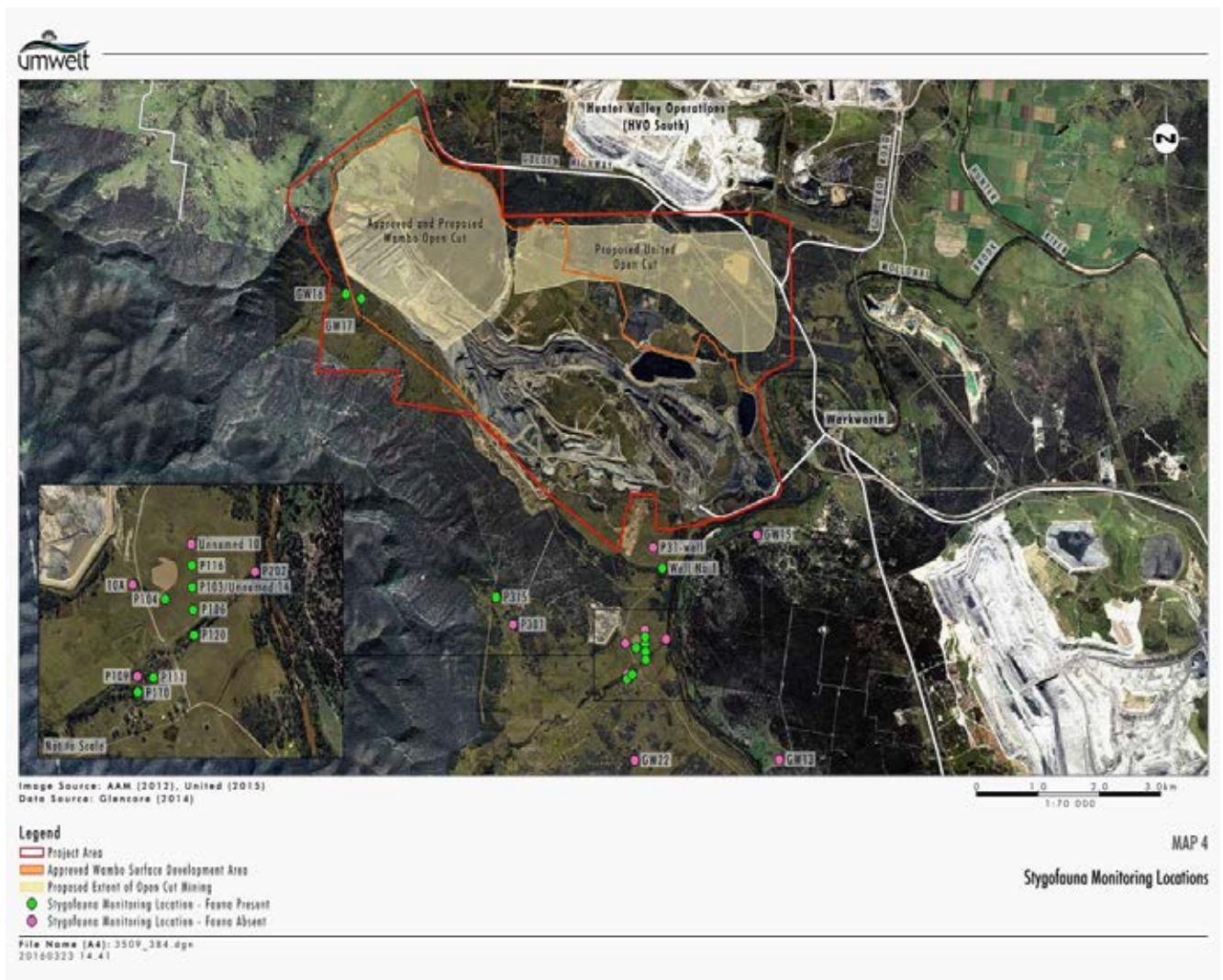
The Project will produce up to 10 Mtpa of ROM coal. The existing Wambo CHPP and train loading facility will be utilised for the Project. These facilities will also continue to receive coal from the ongoing Wambo underground mine (that is not the subject of this Project).

The Project also requires a number of changes to the layout of existing mining, public and private infrastructure within the Project Area.

The key aspects of the Project are shown on (refer to Map 2).



**Map 2.** The boundaries and extent of the United Wambo Open Cut Coal Mine Project Area. The Joint Venture will look to develop the United Wambo Open Cut Coal Mine Project (the Project) that combines the existing open cut operations at Wambo with a proposed new open cut coal mine at United (refer to Map 3).



**Map 3.** Location of all surveyed sites within and adjacent to the United Wambo Open Cut Coal Mine Project Area. The green circles represent sites that were positive for fauna and the pink circles were negative to fauna.

The Study Area examined in this investigation is defined in Section 2 and includes the area to the southwest and south east of the existing Wambo Open Cut. Surface features include Wollombi Brook and the upper section of its tributary North Wambo Creek and the Sandstone escarpment to the south west. The area is mostly cleared grazing land with patches of woodland on the surrounding hills and a patchy distribution of riparian communities within the riparian zones of the stream sections. The area borders the northern edge of the Wollemi region and its Triassic Narrabeen Group Sandstone escarpment complexes with numerous sandstone rock formations on the upper slopes. This is the dominant lithology that forms the sediment in the alluvial aquifers.

The object of this assessment is to determine if subterranean stygofauna communities may be present in the area of proposed operations. Specifically this report assesses whether subterranean

## **United Wambo Open Cut Coal Mine Project - Baseline Stygofauna Assessment (Ref No: 3509)**

groundwater dependent ecosystems (GDEs) occur within the area of the current development or in potential future extraction areas, and if they exist, whether the current activities are having an impact on them. This assessment is a baseline aquifer ecosystem evaluation for stygofauna across control areas and proposed future impact areas associated with the Project. There has been no previous published sampling for stygofauna conducted in the United and Wambo lease areas although stygofauna have previously been recorded from the Hunter River Alluvium and catchment (Hancock, 2004, Hancock and Boulton, 2008).

The uniqueness of Australia's biodiversity is encapsulated and magnified tenfold by its groundwater dependent biodiversity. Groundwater in an aquifer is a body of underground water but it is not isolated or stationary. Neither is it devoid of life or an inexhaustible supply of clean water. It flows in much the same way as a river from its surface recharge zone to its surface discharge areas and will transport impacts such as pollutants or reductions of quantity throughout the subsurface environments to the surface land and waters. Therefore, there is always a flow-on effect from one point of impact on the groundwater quantity or quality to the rest of the landscape. The parameters that make groundwater environments a separate entity to many surface water environments and which has contributed to the development of many specialised, highly endemic ecosystems, communities and species, is the relatively consistent nature of its flow, pressure, level, and water chemistry.

### **1.1 Purpose of this Report**

This Baseline Stygofauna Assessment Report has been prepared as part of an Environmental Impact Statement for the Project to accompany an application under Part 4 of the EP&A Act. Threatened biodiversity as listed by the NSW *Threatened Species Conservation Act 1995* (TSC Act) and *Fisheries Management Act 1994* (FM Act) have been considered in this assessment. It also serves to provide baseline information to inform future monitoring of impacts in the Project Area.

### **1.2 Impact Assessment Objectives**

The aim of the stygofauna baseline surveys and impact assessment is to determine the presence of stygofauna within the Project area and to assess the potential impacts of the Project on groundwater ecology including aquatic threatened species, populations, communities or their habitats that are dependent on groundwater. The assessment addresses the impacts of subsidence from underground coal mining.

The specific objectives were to:

- ☐ Describe the natural/pre-mine development characteristics of the groundwater ecology through quantitative and qualitative surveys of stygofauna;
- ☐ Identify or determine the likelihood of occurrence of threatened species, populations, habitat and/or communities within the Study Area;
- ☐ Assess whether these impacts will cause significant adverse effects to groundwater and baseflow stream ecology; and
- ☐ Determine whether these impacts will significantly impair any identified threatened species, populations, habitat or communities.

### **1.3 Legislation, Policy, Criteria and/or Guidelines**

Groundwater ecosystem dependence is an increasingly important component of surface and groundwater initiatives in NSW and has been incorporated within Groundwater Management Plans under the Water Reform Agenda. The Project is assessed in accordance with the NSW Government's "Risk Assessment Guidelines for Groundwater Dependent Ecosystems" (Serov et al. 2012) to determine risk and provide a baseline for future mine planning.

The NSW State Government also has an obligation under the *Water Management Act 2000* (WM Act) and the Groundwater Dependent Ecosystem Policy (2002) to "manage GDEs in such a way that it:

- ☐ Applies the principles of ecologically sustainable development;
- ☐ Protects, enhances and restores water sources, their associated ecosystem, ecological processes and biological diversity and their water quality;
- ☐ Integrates the management of water sources with the management of other aspects of the environment, including the land, its soils, its native vegetation and its native fauna."

The WM Act also provides water management principles that are relevant to the management of GDEs. These include:

- ☐ water sources, floodplains and dependent ecosystems (including groundwater and wetlands) should be protected and restored and, where possible, land should not be degraded;
- ☐ habitats, animals and plants that benefit from water or are potentially affected by managed activities should be protected and (in the case of habitats) restored; the quality of all water sources should be protected and, wherever possible, enhanced;
- ☐ the cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised;
- ☐ The principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirement.

The following policies are relevant to the protection and management of GDEs in NSW:

- ☐ NSW State Groundwater Policy Framework document, Department of Land and Water Conservation, 1997. <http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/>
- ☐ NSW State Groundwater Dependent Ecosystems Policy, Department of Land and Water Conservation, 2002. <http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/>
- ☐ NSW Groundwater Quality Protection Policy, Department of Land and Water Conservation, 1998. <http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/>
- ☐ NSW Wetlands Management Policy, Department of Environment, Climate Change and Water, 2010a.
- ☐ State Environmental Planning Policy No. 14 – Coastal Wetlands, SEPP 14.
- ☐ Risk assessment guidelines for groundwater dependent ecosystems – the conceptual framework NSW Office of Water, September 2012
- ☐ NSW State Rivers and Estuaries Policy – NSW Water Resources Council NSW Government, 1993. <http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/>
- ☐ Water Compliance Policy (NSW Office of Water, 2010a). <http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies>
- ☐ NSW Water Extraction Monitoring Policy. <http://www.water.nsw.gov.au/Waterlicensing/Metering/default.aspx>

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The following legislation and strategies are also considered in this assessment for the protection and management of GDEs in NSW:

- ❑ *Threatened Species Conservation Act 1995*. This Act and its listings are used in the determination of the ecological value of a GDE, i.e. if a GDE contains a threatened species as listed under this Act; the GDE is taken to have higher ecological value.
- ❑ *Native Vegetation Act 2003*. This Act is relevant to the protection of vegetation which may be or form part of a GDE community.
- ❑ *Fisheries Management Act 1994*. This Act is relevant to the determination of the ecological value of a GDE (i.e. if the GDE contains a threatened species as listed under this Act, the GDE is taken to have higher ecological value).
- ❑ Draft New South Wales Biodiversity Strategy, Department of Environment, Climate Change and Water NSW and Industry and Investment NSW, 2010. The Strategy is directly relevant as its objectives include the: smarter biodiversity investment and improved partnerships whole of landscape planning effectively managing threats sustainable production environments.
- ❑ NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010-2015.

### 1.4. Stygofauna Ecology

Stygofauna are animals that live in underground water. They are generally comprised of invertebrates including crustaceans and other invertebrate groups such as worms, snails, mites and even blind insects. Stygofauna are animals that spend their entire lives in groundwater and due to their specific habitat requirements, the species are generally highly endemic. As such, these organisms have highly specialised adaptations to survive in relatively resource-poor aquifers, where there is limited light, space, and food supply (Humphreys 2008).

Stygofauna are blind, colourless, have slow metabolisms, reduced body size, specialised anatomies and low reproduction rates (Coineau 2000). As there is no photosynthesis below ground, these groundwater environments rely on inputs of organic matter from the surface to provide the basis of the food web on which stygofauna depend (Schneider et al. 2011). Despite their small size, the cumulative effect of stygofauna activity plays an important part in maintaining groundwater quality. This process is evident in alluvial aquifers where water flowing through sediment particles is cleaned during transit by stygofauna, in much the same way as water moving through slow sand filters or trickle filters in water and sewage treatment (Hancock et al. 2005). Stygofauna therefore play a functional role in aquifers and are also considered a direct and sensitive indicator of the quality of an underground water source.

#### 1.4.1 Stygofauna ecological requirements

Stygofauna are intricately linked both ecologically and physiologically to the aquifer environment and are adapted to the relative stability of their surroundings. Compared to surface environments, groundwater fluctuates less both in level and physico-chemical variables such as electrical conductivity, temperature, and pH (Hancock et al. 2005). Groundwater is also generally lower in dissolved oxygen and has less readily available organic matter than surface water environments (Humphreys 2002). As there is no direct photosynthesis in aquifers, stygofauna rely on connections to the land surface to provide them with food. These connections may be hydrological, with infiltrating water bringing dissolved or particulate organic matter to form the basis of subterranean food webs, or it may be more direct, with tree roots that extend below the water table providing leachates, organic

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carbon or fine rootlets for food (Hancock et al. 2005). Generally, stygofauna biodiversity is highest near the water table and declines with depth (Datry et al. 2005).

Stygofauna biodiversity is also higher in areas of recharge where the water table is close ( $< 20$  m) to the land surface (Humphreys 2001, Hancock and Boulton 2008). This is because the water table is likely to have the highest concentration of oxygen and organic matter. Stygofauna can occur at considerable depth below the water table, but are fewer in number, have lower diversity, and may change in community composition (Datry et al. 2005).

In Australia, stygofauna are known from alluvial, limestone, fractured rock, and calcrete aquifers (Hancock et al. 2005; Humphreys 2008). As yet, no species are known from coal aquifers. Most coal aquifers occur as confined aquifers and as such have very low dissolved oxygen, high salinity and have a general lack of connectivity with surface environments. Stygofauna require space to live, which is dependent on the porosity of the sediments, degree of fracturing, or extent of cavity development. These requirements must be sufficient to enable fauna to move through the substrate.

### **1.4.2 Processes that Threaten Stygofauna**

There are three critical factors that are essential requirements for stygofauna communities in aquifers. These include:

#### **1) Stable water quality/physicochemical parameters;**

Many groundwater species have evolved under strict physiochemical constraints and require a level of stability of these parameters for their continued existence. Stygofauna are able to tolerate natural fluctuations in water parameters such as level, electrical conductivity, and temperature, and this has been demonstrated experimentally (Tomlinson et al. 2007) for stygofauna amphipods, copepods, and syncarids. However, changes outside the natural range of water quality, water chemistry and levels such as rapid drawdown or changes to water chemistry such as a pollution plume is likely to have significant impacts on the community composition, biodiversity and overall sustainability of the community.

#### **2) Surface connectivity;**

Groundwater communities require links to the surface environment to provide organic matter and oxygen. If that linkage is broken or disrupted, the stygofauna community in the area affected could decline over time.

#### **3) Subterranean connectivity.**

The third critical factor is their high degree of endemism (Humphreys 2008). This comes about because, unlike many surface-dwelling aquatic invertebrates, stygofauna do not have aerially dispersing life stages. To migrate between areas, stygofauna must be able to swim or crawl through the aquifer matrix. However, as aquifers are not homogenous in porosity and change over geological time, natural hydrological barriers within the matrix restrict their movement. Over time, these natural barriers encourage genetic isolation and ultimately, speciation. Barriers, however, can also be created rapidly by changes in water levels or water chemistry/quality such as an area of lower porosity and

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sections of poor water quality. If any area is impacted by a disturbance that results in a loss of biodiversity, these new barriers to dispersal may prevent recolonization of the habitat.

Many species of stygofauna are restricted to small geographical areas. This is particularly the case in non-alluvial aquifers such as some of the limestone karsts of NSW (Eberhard & Spate 1995; Thurgate et al. 2001), and calcrete aquifers in Western Australia, where one or more species are known only from a single aquifer, or part of an aquifer (Humphreys 2002). This means that any process that threatens the aquifer, potentially threatens an entire species and community. There is also a high degree of endemism in alluvial aquifers, even between adjacent systems (Hancock and Boulton 2008). However, providing there is sufficient hydrological connectivity within the aquifer, and physico-chemical conditions are suitable, the distribution of species will not be restricted to small parts of an aquifer.

Stygofauna are potentially threatened by activities that change the quality or quantity of groundwater, disrupt connectivity between the surface and aquifer, or remove living space. These impacts to groundwater and aquifer conditions have become a particular issue for mining proponents over the last decade or so, principally because of the perceived biodiversity value of stygofauna and the fact that little is known of their environmental water requirements.

### 1.4.3. Effects of mining on stygofauna

Mining operations may incorporate a range of activities in their operations that may result in impacts on water resources, including some or all of the following (Serov et al. 2012):

- ☐ Below water table mining;
- ☐ Water supply development (e.g. groundwater, dewatering, surface water);
- ☐ Desalination for potable supply (with subsequent brine disposal);
- ☐ Dust suppression;
- ☐ Tailings disposal;
- ☐ Overburden storages;
- ☐ Backfilling and rehabilitation works;
- ☐ Water diversions and surface sealing;
- ☐ Hazardous and dangerous goods storage;
- ☐ Water storages including waste water ponds; and
- ☐ Disturbance/removal of terrestrial vegetation.

In recognition of the above mining activities, direct effects on GDEs may be as follows:

- ☐ Quantity (groundwater levels, pressures and fluxes);
- ☐ Quality (changes outside of natural ranges, concentrations of salts, heavy metals and other toxic water quality constituents);
- ☐ Groundwater interactions (interactions between groundwater systems and between groundwater and surface systems); and
- ☐ Physical disruption of aquifers (excavation of mining pits and underground workings, compaction of aquifer matrix through dewatering, increase in porosity by blasting, or overburden compaction).

The existence and extent of these water affecting activities, and their potential impact on local to regional scale groundwater resources will depend largely on the scale of the mining operation, mining method, and process water requirements, as well as the climatic and geological setting.

#### **1.4.4. Other studies**

The National Water Commission (NWC) has reported (RPS 2011) that extensive gaps exist in our knowledge of the distribution, composition and biodiversity value of Australian stygofauna. Despite this incomplete inventory it is apparent that stygofauna are present across a variety of Australian subsurface environments and are generally characterised by high diversity and local-scale endemism. They are also often of high scientific interest; for example, the occurrence of the only known southern hemisphere representatives of several phylogenetic relict lineages.

In Australia, at least 750 stygofauna species have been described (Humphreys 2008), but this is a conservative estimate of total continental biodiversity as more than 66 % of known species come from just two regions of Western Australia (Humphreys 2008) and large parts of Australia remain unsurveyed. In NSW there are approximately 400 species of stygofauna known, but this estimate is likely to increase as more surveys are conducted and taxonomic knowledge improves.

Knowledge of GDEs in eastern Australia is limited and patchy (e.g. Eberhard and Spate 1995; Thurgate et al. 2001; Hancock 2002; 2004, Hancock & Boulton 2008; Hose et al. 2005; SMEC 2006; Watts et al. 2007).

One coal mining area that has a longer history of stygofauna sampling is the Hunter Valley in NSW, where surveys of alluvial aquifers were conducted between 2000 and 2008. Surveys of the groundwater/surface water interface along the Hunter River between Singleton and Glenbawn Dam from 2000 and 2003 found a diverse community of stygofauna (Hancock 2004). A follow-up project from 2004 to 2008 surveyed groundwater monitoring bores in agricultural areas and several mine sites of the upper Hunter Valley (Hancock and Boulton 2008). This latter work found at least 40 taxa new to science (this number is likely to increase since not all specimens have yet been identified to species level) and confirmed that stygofauna can exist in areas dominated by coal mining.

It is worth mentioning that although the Hunter Valley has one of the richest known communities of stygofauna in Australia, no animals thus far have been collected from coal seams in this catchment. All of the bores that contained stygofauna were in alluvial aquifers of the Hunter River and its tributaries. This may reflect a sampling bias, since most of the bores surveyed entered alluvium rather than coal seams, and the presence of stygofauna in coal seams should not be ruled out. It is, however, likely that the majority of taxa in the Hunter Valley do live in alluvial aquifer as well as the upland alluviums as highlighted in the Kangaloon studies (Hose 2008).

#### **1.5 Terminology Used in This Report**

Stygofauna is an all-encompassing term for animals that occur in subsurface waters (Ward et al. 2000). They are classified by the degree to which they are dependent on groundwater. Those that are completely dependent on groundwater are termed stygobites or phreatobites and consist predominantly of crustaceans. Those that rely on groundwater to a lesser extent and can live in mixed surface and groundwater are termed stygoxenes or stygophiles depending on their adaptation to the subterranean environment (Marmonier et al. 1993). The distinction is often ambiguous because it is difficult to know the degree of surface/groundwater mixing in an aquifer, and the classifications are regularly disputed (Sket 2010). However, classifications based on affiliation to groundwater can be useful when assessing the conservation status of species and their vulnerability to potential impacts. In this report we adopt the following definitions:

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*Stygoxenes* - organisms that have no affinities with groundwater systems but regularly occur by accident in caves and alluvial sediments. Some planktonic groups (e.g. Calanoida Copepoda) and a variety of benthic crustacean and insect species (e.g. Simuliid larvae, Caenidae Mayflies) may passively infiltrate alluvial sediments (Gibert et al.1994).

*Stygophiles* - organisms that have greater affinities with the groundwater environment than stygoxenes because they appear to actively exploit resources in the groundwater system and/or actively seek protection from unfavourable surface water conditions. Stygophiles can be divided into occasional/temporary hyporheos and permanent hyporheos.

*Stygobites* - obligate subterranean species, restricted to subterranean environments and typically possessing specialised character traits related to a subterranean existence (troglomorphisms), such as reduced or absent eyes and pigmentation, and enhanced non-optic sensory structures.

*Phreatobites* - stygobites that are restricted to the deep groundwater substrata of alluvial aquifers (phreatic waters). All species within this classification have specialised morphological and physiological adaptations (Gibert et al 1994).

### **1.6 Assumptions and Limitations**

This report is a baseline assessment, which focuses on identifying the presence and biodiversity of stygofauna within the Study Area. The Study Area has been assessed using monitoring and insitu field information and will serve as a baseline for ongoing monitoring and impact assessment.

Groundwater bore sites sampled are assumed to be representative of the groundwater ecosystems present across the Study Areas, temporally and spatially. While every effort was given to maximize the representativeness of the system it does not cover the full extent of the bores and potential subterranean and groundwater dependent habitats in the Study Area. Temporal variations between autumn and spring also cannot be assessed at this stage as there has been no seasonal replication.

## **2. Study Area and Sampling Sites**

The Study Area for the purposes of this report encompasses the United Wambo Open Cut Coal Mine Project Area (refer to Map 3) and adjacent alluvial lands to the south and west containing groundwater bores and wells.

### **2.1. General Description**

The Study Area is located within the Wollombi Brook catchment and includes the upper section of its tributary North Wambo Creek and Stony Creek. Wollombi Brook and its associated alluvial lands are located in the south of the Study Area. Wollombi Brook flows in a north-easterly direction into the Hunter River approximately 5 kilometres east of the Study Area. The Study Area is dominated by existing mining areas including the previous United underground mining infrastructure, the existing Wambo open cut mine along with areas of rehabilitated land and native vegetation. Land immediately surrounding the existing mining areas consists of cleared agricultural land with patches of dry sclerophyll forest on the surrounding hills and stands of Casuarinas forming the riparian zones of the stream sections. Beyond the agricultural land to the west, the area borders the northern edge of the Wollemi National Park and its Triassic Narrabeen Group Sandstone escarpment complexes with

numerous sandstone rock formations on the upper slopes. These deposits overlay the Permian Wittingham Coal Measures in the Study area, the coal measures are unconformably overlain by thin Quaternary deposits that compose the alluvial deposits. These deposits consist of silt, sand and gravel in the alluvial floodplain of the Wollombi Brook (AGE, 2016)

## 2.2 Groundwater

The main aquifers in the area occur within the Permian Coal Measures and the Quaternary alluvial aquifers of Wollombi Brook and North Wambo Creek. These alluvials are also directly connected to the Hunter River Alluvial several kilometers to the east. Groundwater is recharged by rainfall along the ridgelines and discharges as springs in the mid to lower slope areas, providing base flow to most of the small streams. The Quaternary alluvial aquifers are the widespread shallow aquifers and range in depth from 4.84 to 14.76m (Figures 1 and 2) whereas the Permian Coal Measures aquifer represented by GW22 is at a depth of 35.77m. Graphs displaying the water levels and the thickness of the water column at each sample site, and therefore the available habitat, are presented below in Figures 1-4. Water column thickness is also presented in Figure 3-4. Most of the alluvial aquifer bores have only small water columns ranging from 0.23-14.76m of water whereas the deeper bore, GW22 has a water column of 55m. Whether this is a true measure of aquifer thickness or an artefact of the bore depths is not known at this time however it needs to be considered in terms of habitat availability. The bores /aquifers with a small water column thickness are vulnerable to impacts from drawdown and therefore will be more impacted via a loss of habitat if there are significant changes to aquifer levels.

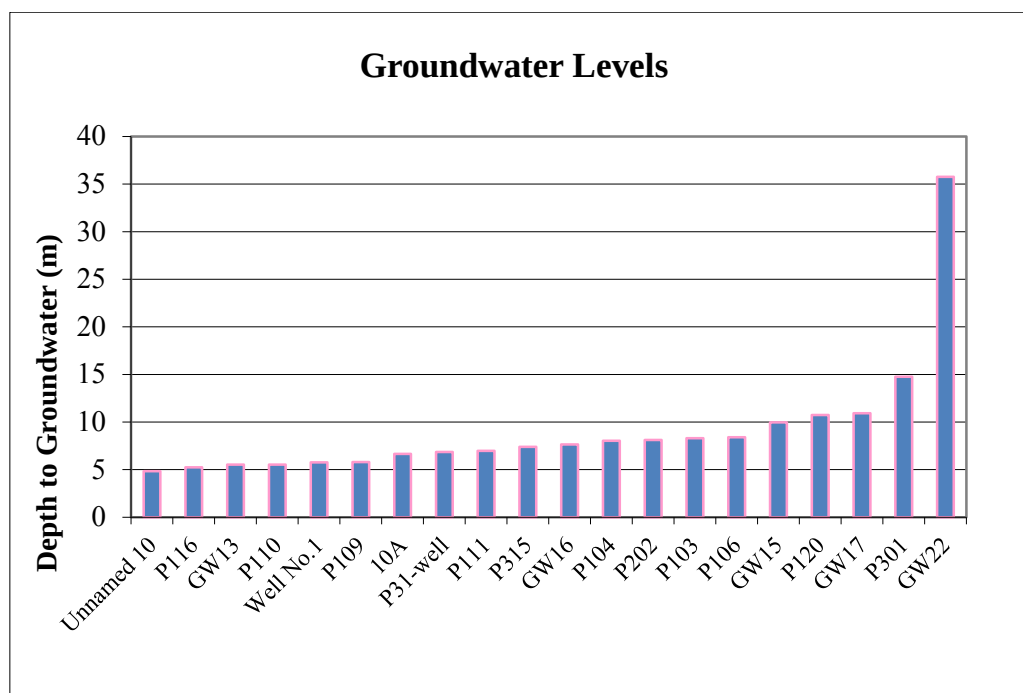


Figure 1. Surface water levels recorded at each bore during the survey.

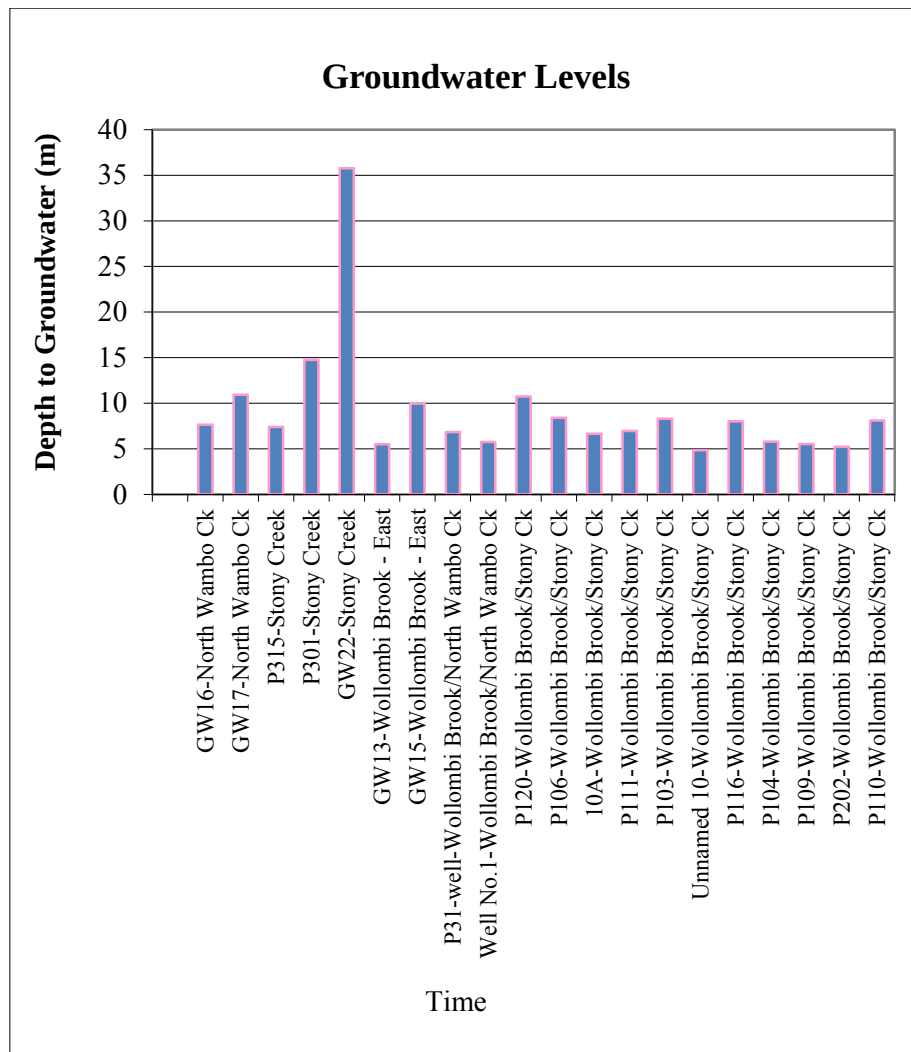


Figure 2. Surface water levels recorded at each bore and subcatchment during the survey.

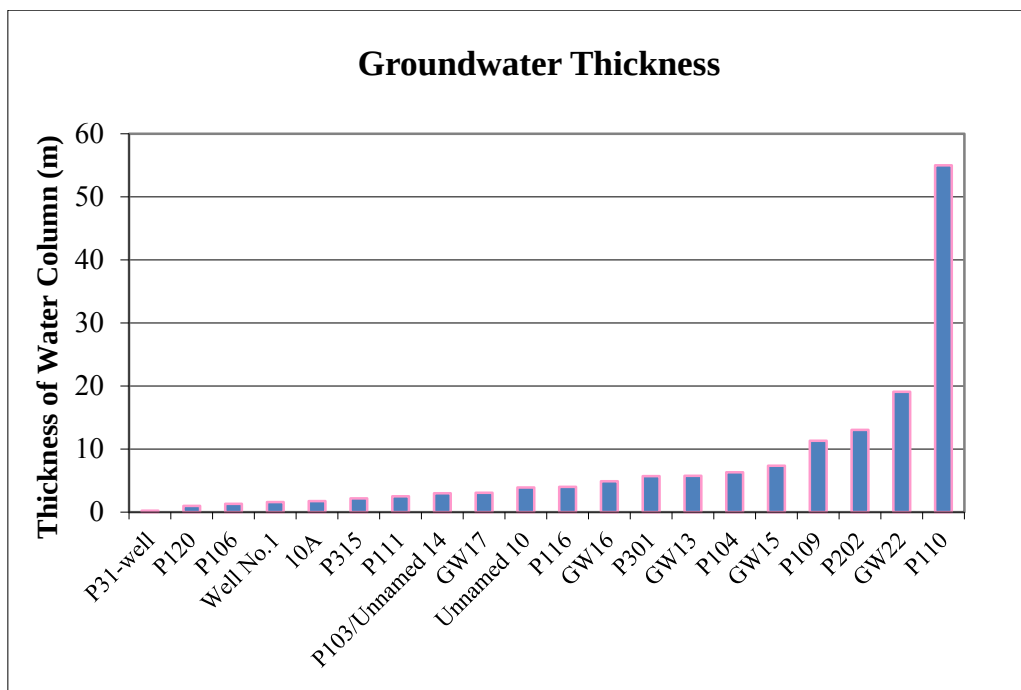


Figure 3. Water column thickness recorded at each bore during the survey.

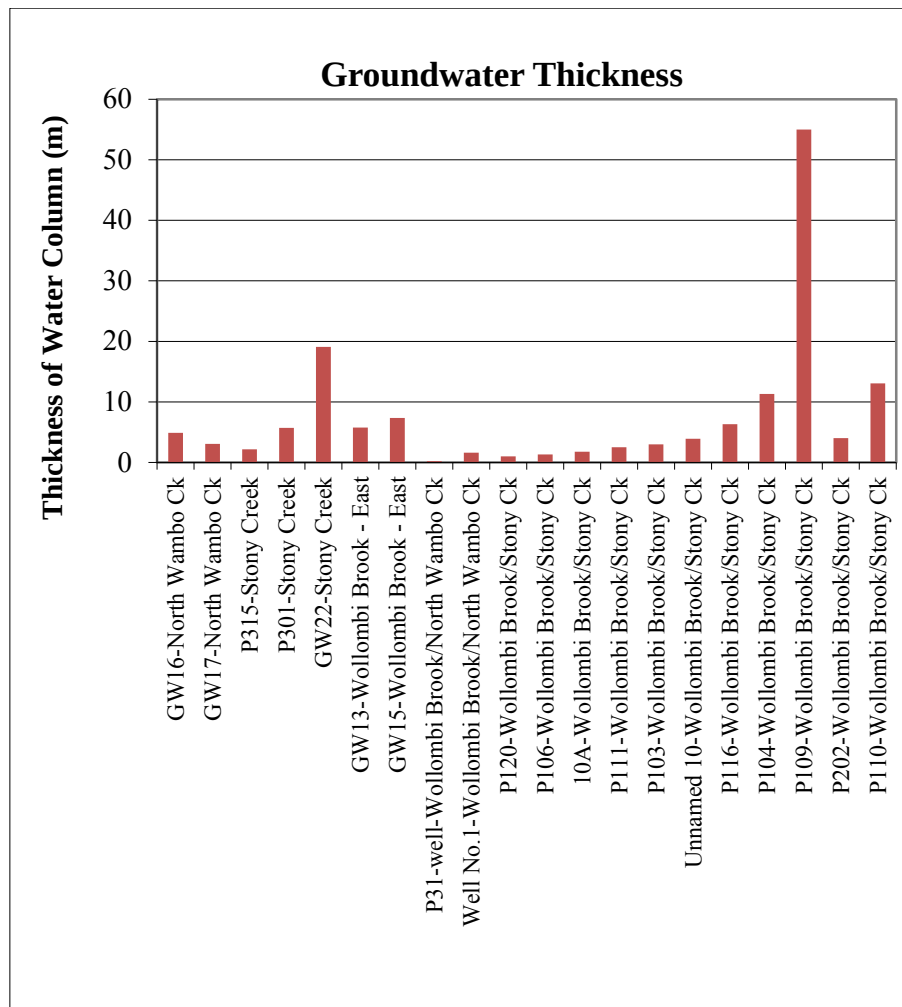


Figure 4. Water column thickness recorded at each bore and subcatchment during the survey.

### 2.3 Study Sites

As noted in Section 2.1, the Study Area encompasses the United Wambo Open Cut Coal Mine Project Area and adjacent alluvial lands to the south and west containing groundwater bores and wells (refer to Map 4). The sites and bores used for this study have been selected to cover as broad a range of habitats and geographic distribution as possible as well as including where possible bores from both within the Development Area (Impact Sites) and outside (Control Sites) the area of operation (Table 2). This allows for comparison between sites in similar habitats and depths and the identification of biological hotspots for incorporation into a future ongoing monitoring program. The bores in each area have also been separated into each of the main drainage systems or catchments in order to determine if any subterranean species are endemic to specific water shed.

## **2.4 Bore Data**

Twenty bores were selected as representatives of each of the major alluvial and coal measure lithologies that contained monitoring bores (Table 1). All bores sampled are located within the Wambo area as the bores within the United area were deemed unsuitable for stygofauna for the following reasons: most of the bores were equipped with vibrating wire devices; the other monitoring bores were either excessively deep and/or had very high salinity. The bores rejected included 'Abandoned and destroyed bores' and all of the piezometers that were installed with Vibrating Wire Piezometers (VWP) surface water depth devices due to the difficulty of accessing the water. A number of other bores were rejected as they appeared to contain significant quantities of clay or excessively high salinity (EC) which would limit/preclude the presence of stygofauna. The resultant selected bores were concentrated within the alluvials of Wollombi Brook, North Wambo Creek and Stony Creek in both flood plain and riparian habitats. The bores surveyed were shallow monitoring piezometers accessing groundwater situated in the unconsolidated alluvial sediments and several within the shallow coal deposits along Wollombi Brook. The bores were surveyed using two techniques on one occasion.

Of the 20 bores sampled, two bores are considered as potential impact sites as they are located on the alluvial land in the upper reaches of North Wambo Creek within the Project area (GW16, GW17) and the Wambo open cut mine (GW17). The remaining bores are located outside of the operations area as well as outside of the area of modelled drawdown (See Figure 7.3, AGE 2016) and therefore classed as control sites. The remaining 18 control bores are located on the south western floodplain formed by the confluence of North Wambo Creek, Wollombi Brook and Stony Creek. These include two wells (Well No.1, P31) located on the northern margin of the junction of North Wambo Creek and Wollombi Brook and one bore (GW15) located downstream on Wollombi Brook. Two control bores (GW13, GW15) are located in eastern side of Wollombi Brook. Two control bores (P301, P315) are located in the northern upper reaches of Stony Creek and GW22 is located in an elevated position on the southern margin of Stony Creek. There were three potential monitoring bores suitable for stygofauna that were not sampled as these were located in the upper Wollombi Brook area on private property.

The water bores selected are typically constructed with a short steel casing extending from ground level to approximately 3-6m below the surface which surrounds a 50mm plastic casing extending the length of the bore with a terminal cap to prevent sediment entering from the bottom. The section of the casing that corresponds with the water bearing zone, that is required to be monitored, is equipped with slots to allow the water to enter. The bores did not contained water level loggers however were semi-regularly surveyed for water level, ph and conductivity. The survey sites are listed below in Table 1. Site images are presented in Appendix 2.

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| Bore No.        | Fauna Presence | Site status | Easting | Northing | Depth to Water (m) | Total Depth (m) | GW Thickness (m) | Bore Diameter (mm) | Bore Material | Catchment                     |
|-----------------|----------------|-------------|---------|----------|--------------------|-----------------|------------------|--------------------|---------------|-------------------------------|
| GW16            | Yes            | Impact      | 306639  | 6396171  | 7.5                | 12.41           | 4.91             | 50                 | PVC           | North Wambo Ck                |
| GW17            | Yes            | Impact      | 306889  | 6396100  | 10.84              | 14.81           | 3.07             | 50                 | PVC           | North Wambo Ck                |
| P315            | Yes            | Control     | 309084  | 6391856  | 7.3                | 9.48            | 2.18             | 50                 | PVC           | Stony Creek                   |
| P301            | No             | Control     | 309360  | 6391466  | 14.71              | 20.44           | 5.73             | 50                 | PVC           | Stony Creek                   |
| GW22            | No             | Control     | 311341  | 6389535  | 35.81              | 54.91           | 19.1             | 50                 | PVC           | Stony Creek                   |
| GW13            | No             | Control     | 313695  | 6389545  | 9.92               | 15.68           | 5.76             | 50                 | PVC           | Wollombi Brook - East         |
| GW15            | No             | Control     | 313330  | 6392747  | 9.92               | 17.29           | 7.37             | 50                 | PVC           | Wollombi Brook - East         |
| P31-well        | No             | Control     | 311641  | 6392564  | 6.84               | 7.07            | 0.23             | 1040               | Concrete      | Wollombi Brook/North Wambo Ck |
| Well No.1       | Yes            | Control     | 311792  | 6392268  | 5.82               | 7.44            | 1.62             | 1500               | Concrete      | Wollombi Brook/North Wambo Ck |
| P120            | Yes            | Control     | 311523  | 6390961  | 10.7               | 11.71           | 1.01             | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P106            | Yes            | Control     | 311518  | 6391082  | 8.61               | 9.94            | 1.33             | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| 10A             | No             | Control     | 311190  | 6391200  | 6.49               | 8.26            | 1.77             | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P111            | Yes            | Control     | 311302  | 6390759  | 6.92               | 9.43            | 2.51             | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P103/Unnamed 14 | Yes            | Control     | 311512  | 6391189  | 8.1                | 11.1            | 3                | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| Unnamed 10      | No             | Control     | 311508  | 6391393  | 4.82               | 8.75            | 3.93             | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P116            | Yes            | Control     | 311511  | 6391292  | 5.19               | 9.21            | 4.02             | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P104            | Yes            | Control     | 311366  | 6391133  | 7.74               | 14.08           | 6.34             | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P109            | No             | Control     | 311215  | 6390766  | 5.73               | 17.05           | 11.32            | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P202            | No             | Control     | 311854  | 6391262  | 7.97               | 21.03           | 13.06            | 50                 | PVC           | Wollombi Brook/Stony Ck       |
| P110            | Yes            | Control     | 311217  | 6390692  | 5.4                | 10.9            | 55               | 50                 | PVC           | Wollombi Brook/Stony Ck       |

Table 1. Bore survey station list

### **3. Methodology**

The “Risk Assessment Guidelines for Groundwater Dependent Ecosystems” (Serov et al. 2012) methods were structured to specifically reflect current relevant legislation, as well as to address the Secretary’s Environmental Assessment Requirements for the Project. These methods include monitoring design and impact assessment criteria.

In preparing for each round of stygofauna sampling it is necessary to keep in mind the needs of a future monitoring program that will be required to determine if there has been any significant changes to either the water resource or the dependent ecosystems. This is best done by using a BACI (Before/After Control/Impact) experimental design i.e. before and after sampling at experimental and control (reference) sites. The development of any sampling protocol involves:

- ☐ Selecting sampling location points (bores, wells, piezometers, appropriate hyporheic habitat etc.);
- ☐ Deciding on an appropriate sampling method (pumps, bailers, plankton nets, Bou Rouché pump etc.);
- ☐ Determining sample handling procedures (such as filtration, transfer, preservation, etc.); and minimum disturbance to biological specimens.

#### **3.1. Stygofauna Sampling**

In order to sample a habitat effectively it is often necessary to use a combination of techniques to comprehensively collect all possible biota as the stygofauna community occupies a range of habitat niches. For routine surveying or monitoring of bores and wells, a submersible pump or hand pump, bailer and/or plankton nets (Mathieu et al. 1991) are the preferred devices. The sampling techniques used for the stygofauna surveys are described below.

##### **The Phreatic/hypogean zone**

The phreatic zone is the subsurface area within an aquifer where voids in the rock are completely filled with water. This is occupied by phreatobites. Phreatobites have adapted to tolerate suboxic conditions (dissolved oxygen concentration (DO) less than 3.0 milligrams per litre) or limited food supply (Malard and Hervant 1999; Hervant and Renault 2000; Datry et al. 2005) and even hypoxia (DO less than 0.01 milligrams per litre) (Thomlinson & Boulton, 2008). Dissolved oxygen (DO) concentrations below 1.0 to 0.5 mg/l are the critical threshold for most groundwater fauna (metazoans) (Hahn 2006). The stygofauna community was sampled using two standardised methods and one non-standard method.

The first technique is the Phreatobiology Net. This is the standard technique that has been used successfully overseas and in Australia (Bou, 1974). This method involves using a weighted long haul or plankton net with a 150 µm mesh. Sampling consisted of dropping the net down to the bottom of the bore and taking at least three consecutive hauls from the entire water column at each bore. Upon removal from the bore the net is washed of sediment and animals and the contents of the sampling jar (the weighted container at the bottom of the net) are decanted through a 150 µm mesh sieve. The contents of the sieve are then transferred to a labelled sample jar and preserved with 100% ethanol.

The second standard method is the use of a groundwater bailer. A bailer is typically used by hydrogeologists to take water samples from bores for water quality/water chemistry analysis. The bailer used for this study is 1 meter long by 40mm clear plastic tube with a running ball valve at the bottom. The advantage of using a bailer is twofold. The main reason for using a bailer is that it is able

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to sample the bottom sediment of a bore that cannot be sampled by a haul net and therefore enables the collection of cryptic invertebrates that do not inhabit the water column or sides of the bore. The second advantage is that in shallow bores down to 5 meters in sediments with low transitivity porosity, a bailer is able to empty the entire contents of a bore and thereby confidently collect all animals within the bore. The contents of the bailer are emptied into a cleaned bucket from which the water is then decanted through a 150 µm mesh sieve. The contents of the sieve are transferred to a labelled sample jar and preserved with 100% ethanol. Following sampling and preservation of the sample and prior to the next sampling, all equipment including the bailer, net and sieves must be rinsed clean with clean water via a spray bottle to remove any sediment and animals that may have remained attached to the sampling devices. This is to reduce the possibility of cross contamination of organisms (stygofauna or bacteria) or pollutants from one aquifer or bore to another.

### **3.2. Laboratory Methods**

#### **3.2.1. Identification**

All samples are preserved in the field with 100% ethanol and returned to the laboratory where each sample is sorted under a stereomicroscope and stored in 100% alcohol. All specimens are identified to the lowest possible taxonomic level, generally to genus, where possible. Specimens are identified under a compound microscope using a combination of current taxonomic works and keys such as Williams (1981) and the taxonomic identification series (Serov 2002) produced by the Murray Darling Freshwater Research Centre as well as the authors taxonomic expertise and experience.

#### **3.2.2. Physico-Chemical Data**

Physical and chemical parameter data was supplied by United and Wambo from their regular water quality monitoring program. Water quality parameters including temperature, electrical conductivity and ph were collected in the field using a water quality multimeter. Bore depth was collected in the field during the initial survey and water level (SWL) data was collected at each site during each survey.

### **3.3 Data Analysis**

#### **3.3.1. Impact Assessment Methodology**

The ecological valuation and risk assessment process used to assess the risk and potential impacts of the proposed development for the identified GDEs is the "Risk Assessment Guidelines for Groundwater Dependent Ecosystems (Serov *et al*, 2012)".

In summary, GDEs are first identified and classified and the level of dependency on groundwater for individual GDEs inferred. Once the current ecological value of individual aquifers has been determined, the ecological value of the GDEs associated with that aquifer must then be assessed. The individual value of each GDE within the aquifer can also be assessed as a stand-alone unit. Following an assessment of the aquifer and associated GDEs current value, the potential future impact of a proposed activity on the aquifer and associated GDEs must then be determined. The magnitude of risk from that activity to the ecological value of the GDE(s) and aquifer is then determined. Finally, the Risk Matrix is applied to determine the most appropriate management response for a given environmental value. The process is illustrated in Diagram 1 below.

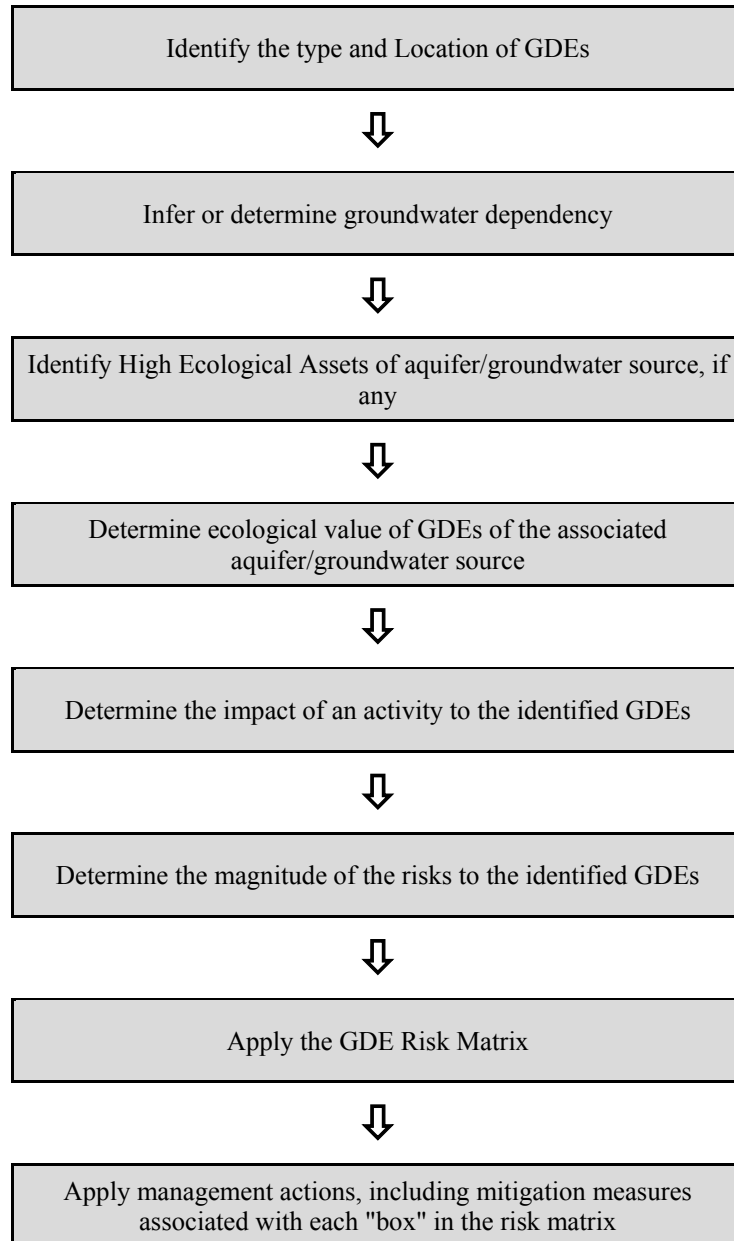


Diagram 1. Ecological valuation and risk assessment process. (Serov et al. 2012).

### 3.3.2. Aquifer Risk Assessment

The aquifer risk assessment considers the risk that groundwater extraction and open cut mining places on the groundwater source and its GDEs. In this process the ecological value of a GDE is assessed in association with the risk that a groundwater source and associated GDEs would be under from these

impacts, which in turn dictates the level of management action required. That is, if the aquifer has a high conservation value or a number of high priority GDEs and therefore is of high ecological value, its value has a high risk of being altered by extraction. Conversely if a groundwater source/GDE has low ecological value then there is a low risk of altering its value by extraction. This assessment was completed for each groundwater source and identifies risks to three main aquifer assets according to several attributes as follows:

- ☐ Ecological Assets;
  - Risk of a change in groundwater levels/pressures on GDEs,
  - Risk of a change in the timing of groundwater level fluctuations on GDEs,
  - Risk of changing base flow conditions on GDEs.
  - Risk of changing aquifer flow paths.
- ☐ Water Quality Assets;
  - Risk of changing the chemical conditions of the water source,
  - Risk on the water source by a change in the freshwater/salt water interface, and
  - Likelihood of a change in beneficial use of the water source.
- ☐ Aquifer Integrity Assets;
  - Risk of substrate compaction.

### **3.3.3. The Risk Matrix**

The Risk Matrix (Table 2) was built on the concept developed for the Macro Water Sharing Plan process. It is a method of outlining the most appropriate management response for a given environmental value under a particular activity. The Risk Matrix is a component of adaptive management and is designed to:

1. Recommend the most appropriate management strategies for each given scenario at the outset; and
2. Test the effectiveness of the management strategies over a time period by combining a monitoring program with an effective framework for adaptive management (i.e. responding to the monitoring outcomes).

The aim of the management strategies is to:

1. Maintain and/or improve the ecological value of an aquifer and its associated GDEs; and
2. To reduce the level of risk to that aquifer and associated GDEs.

The management strategies for an aquifer and its associated GDEs are based on the comparison of the ecological value of the aquifer and its associated GDEs against the risk to them by the proposed or current activity. The risk is a combination of the likelihood that an altered groundwater regime will impact adversely on the ability of the asset to access sufficient groundwater to meet its requirements and the degree of threat posed to the groundwater regime by the proposed or current activity.

The matrix consists of two axes, the vertical axis plots the level of ecological value and the horizontal axis plots the level of risk of an activity does or may impose on the aquifer and its associated GDEs. For the purpose of matrix function and structure, the ranking of both ecological values and risk is

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divided into a three category system of “High, Medium and Low” values. These categories and associated management actions apply to both aquifers and their associated GDEs.

The Risk Matrix identifies both the level of management action required and the time frame in which this action needs to be implemented (Action Priority) as illustrated in the Risk Matrix Management Actions Table 3. Each component aligns with each of the axes. The management action is aligned with ecological value and does not vary with changes in risk (i.e. the rules for the management of high ecological value ecosystems or aquifers are the same whether the risk is high or low). However, the timing of the management action is aligned and determined by the level of risk. For example, if an ecosystem or aquifer has been identified as of high ecological value and the risk assessment process has identified a proposal or current activity that poses a high risk, the management strategy would require immediate action before the impact occurs, or undertaken with significant protection measures if the activity is unavoidable. If the impact is a current activity, the strategy would be to either immediately stop the activity or commence mitigation works in a short time frame to limit damage to the identified ecological values.

The management strategies for aquifers and GDEs are largely vested in the legislative controls of the Water Management Act (2000). A requirement of Water Sharing Plans is to monitor plan performance using a standard set of Performance Indicators. For the purpose of Section 35 (1) (b) of the Water Management Act, the following broad indicator categories are to be used to determine the performance of each plan against its objectives:

- a) Change in ecological condition and value of these groundwater sources and their dependent ecosystems. This includes changes in species/community numbers and composition.
- b) Change in groundwater extraction relative to the extraction limit.
- c) Change in climate adjusted water levels.

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|                                                                                                          |                                       |                                            |                                        |
|----------------------------------------------------------------------------------------------------------|---------------------------------------|--------------------------------------------|----------------------------------------|
| <b>Category 1</b><br><b>High Ecological Value (HEV)</b><br><b>Sensitive Environmental Area (SEA)</b>     | <b>A</b>                              | <b>B</b>                                   | <b>C</b>                               |
| <b>Category 2</b><br><b>Moderate Ecological Value (MEV)</b><br><b>Sensitive Environmental Area (SEA)</b> | <b>D</b>                              | <b>E</b>                                   | <b>F</b>                               |
| <b>Category 3</b><br><b>Low Ecological Value (LEV)</b>                                                   | <b>G</b>                              | <b>H</b>                                   | <b>I</b>                               |
|                                                                                                          | <b>Category 1.</b><br><b>Low Risk</b> | <b>Category 2.</b><br><b>Moderate Risk</b> | <b>Category 3.</b><br><b>High Risk</b> |

Table 2. Risk Matrix.

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| Risk Matrix Box | Descriptor                   | Management action short term                    | Management action mid term                          | Management action long term **               |
|-----------------|------------------------------|-------------------------------------------------|-----------------------------------------------------|----------------------------------------------|
| <b>A</b>        | High value/Low risk          | Protection measures for aquifer and GDEs.       | Continue protection measures for aquifers and GDEs. | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.                       | Periodic monitoring and assessment.                 |                                              |
| <b>B</b>        | High value/Moderate Risk     | Protection measures for aquifer and GDEs.       | Protection measures for aquifer and GDEs.           | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.<br>Mitigation action. | Monitoring and periodic assessment of mitigation.   |                                              |
| <b>C</b>        | High Value/High Risk         | Protection measures for aquifer and GDEs.       | Protection measures for aquifer and GDEs.           | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.<br>Mitigation.        | Monitoring and annual *assessment of mitigation.    |                                              |
| <b>D</b>        | Moderate Value/Low Risk      | Protection of hotspots.                         | Protection of hotspots.                             | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.                       | Baseline Risk monitoring.                           |                                              |
| <b>E</b>        | Moderate Value/Moderate Risk | Protection of hotspots.                         | Protection of hotspots.                             | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.                       | Monitoring and periodic assessment of mitigation.   |                                              |
|                 |                              | Mitigation action.                              |                                                     |                                              |
| <b>F</b>        | Moderate Value/High Risk     | Protection of hotspots.                         | Protection of hotspots.                             | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.<br>Mitigation Action. | Monitoring and annual *assessment of mitigation.    |                                              |
| <b>G</b>        | Low value/Low risk           | Protect hotspots (if any).                      | Protect hotspots (if any).                          | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.                       | Baseline Risk monitoring.                           |                                              |
| <b>H</b>        | Low Value/Moderate Risk      | Protect hotspots (if any).                      | Protect hotspots (if any).                          | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.<br>Mitigation action. | Monitoring and periodic assessment of mitigation.   |                                              |
| <b>I</b>        | Low Value/High Risk          | Protect hotspots (if any).                      | Protect hotspots (if any).                          | Adaptive management.<br>Continue monitoring. |
|                 |                              | Baseline Risk monitoring.<br>Mitigation Action. | Monitoring and annual *assessment of mitigation.    |                                              |

Table 3. Risk Matrix Management Actions

### 3.3.4. Comparative Indices (Number of Taxa)

**Number of Taxa.** All macroinvertebrate taxa are separated and counted. The number of families present generally decreases with decreasing water quality and is used as a comparative measure of community change over time.

## 4. Results

### 4.1 Environmental Physico-chemical Conditions

All physico-chemical parameters were remarkably consistent over the length of the Study Area (Table 4). The groundwater chemistry for the sites that recorded stygofauna is well within the minimum requirements as set out by the ANZECC and ARMCANZ guidelines (2000) except for GW17 which recorded a high level of salinity (5149 $\mu$ S). At the time of sampling Wollombi Brook and North Wambo Creek was mainly dry with isolated pools occurring along their length. The data availability for a number of parameters is limited and patchy due to the short time period that monitoring has been conducted for some bores. Therefore a limited data set including water levels, electrical conductivity and pH is presented here.

| Survey 1               | SWL (m) | Conductivity (mS) | pH (pH Units) | Temperature (°C) |
|------------------------|---------|-------------------|---------------|------------------|
| <b>GW13</b>            | 5.52    | 7390              | 7.16          | 21.2             |
| <b>GW15</b>            | 9.97    | 671               | 7.04          | 21.2             |
| <b>GW16</b>            | 7.65    | 533               | 7.62          | 20.1             |
| <b>GW17</b>            | 10.93   | 5149              | 7.17          | 20               |
| <b>10A</b>             | 6.66    | 612               | 6.81          | 19.2             |
| <b>P103 Unnamed 14</b> | 8.3     | 859               | 6.9           | 20.2             |
| <b>P104</b>            | 8.03    | 668               | 6.84          | 20.3             |
| <b>P106</b>            | 8.4     | 643               | 6.92          | 20.6             |
| <b>P109</b>            | 5.8     | 715               | 6.89          | 19.1             |
| <b>P110</b>            | 5.53    | 743               | 6.7           | 18.8             |
| <b>P111</b>            | 6.97    | 707               | 6.64          | 18.5             |
| <b>P116</b>            | 5.24    | 594               | 6.97          | 19.6             |
| <b>P120</b>            | 10.74   | 559               | 6.8           | 20.2             |
| <b>P202</b>            | 8.11    | 6.67              | 7.3           | 18.9             |
| <b>Unnamed 10</b>      | 4.84    | 863               | 7.49          | 19.6             |
| <b>P31-well</b>        | 6.85    | 1155              | 7.61          | 19.7             |
| <b>Well No.1</b>       | 5.76    | 1779              | 7.32          | 18.3             |
| <b>GW22</b>            | 35.77   | 7775              | 8.22          | 23.1             |
| <b>P301</b>            | 14.76   | 5803              | 7.08          | 20.4             |
| <b>P315</b>            | 7.4     | 312.8             | 6.37          | 19.3             |

Table 4. Physico-chemical data from each site collected on 1-2nd December, 2015.

#### 4.1.1 Rainfall

The rainfall pattern over the last 12 months (Figures 3 and 4) has been low to moderate with only a few small sporadic events in the six months leading to this survey as illustrated in Figure 2 below. The majority of the rainfall has occurred over the summer and autumn months. The last major event (> 20 mm) occurred on December 2014 to February 2015 and again in April 2015. There have been only two events exceeding 50mm which occurred on the 20<sup>th</sup> January 2015 of 51.9mm and 21<sup>st</sup> of April 2015 of 81mm. The remaining rainfall events have consisted of only small sporadic events over the 12 months. This rainfall pattern is quite similar to that experienced in the previous 12 month period (2013/2014) and sufficient to ensure the overall water levels at each bore have remained relatively constant. This can be seen in Figures 5 and 6.

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The annual rainfall for the past 12 months (2014-2015) was 724.1mm. This level of rainfall contributed to the streams within the Study Area experiencing a continuation of the low flow conditions prior to the time of the survey.

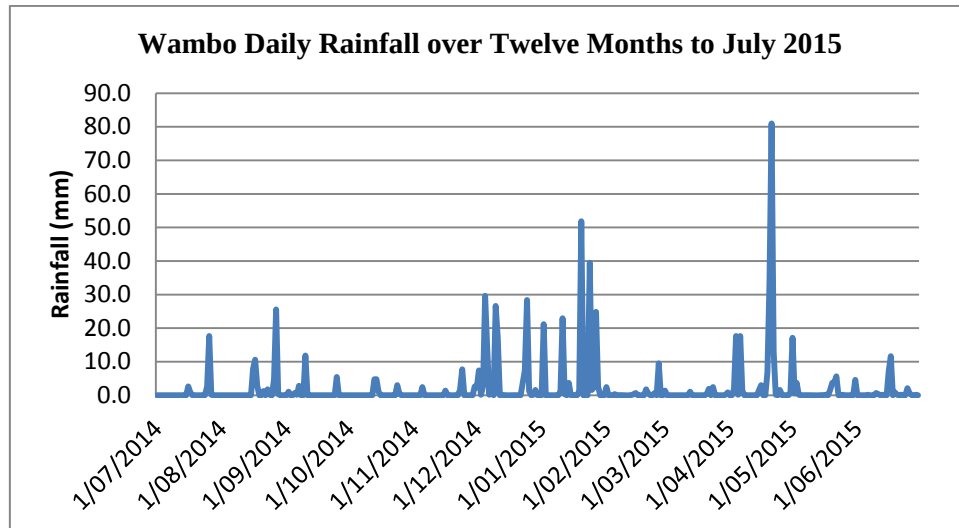


Figure 5. Daily rainfall values for Wambo from June, 2014 to June, 2015.

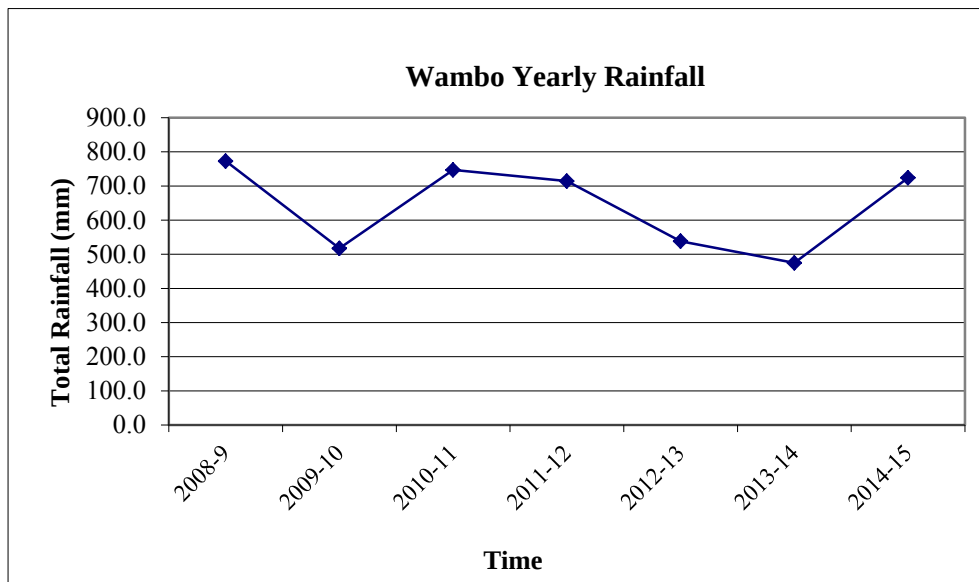


Figure 6. Annual rainfall values for Wambo from 2008 to 2015.

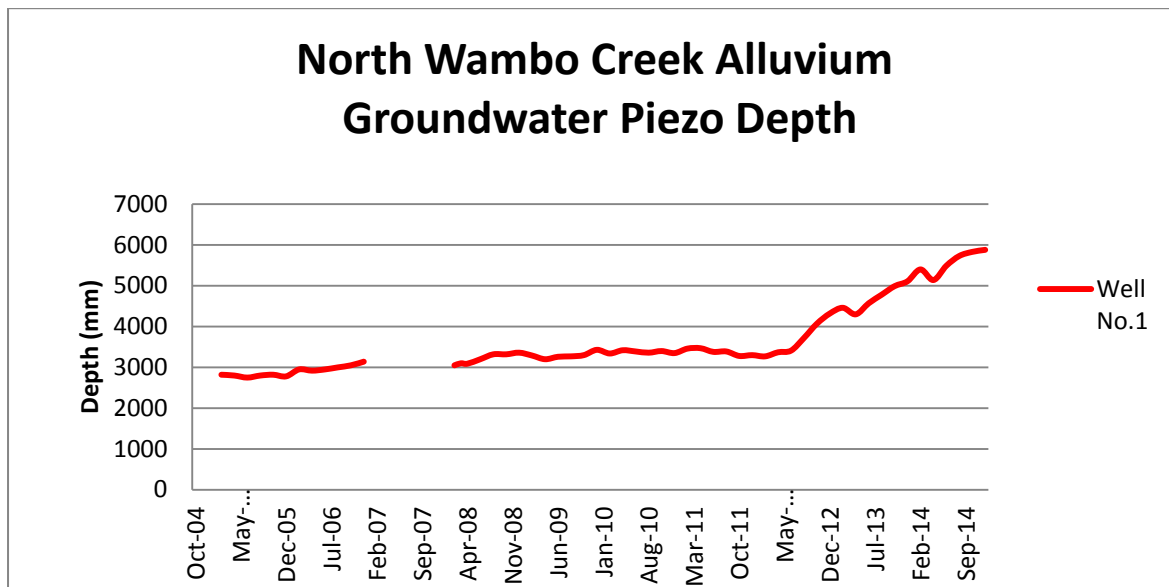


Figure 7. Groundwater level values for Well No.1 in North Wambo Creek from December 2004 to December 2014.

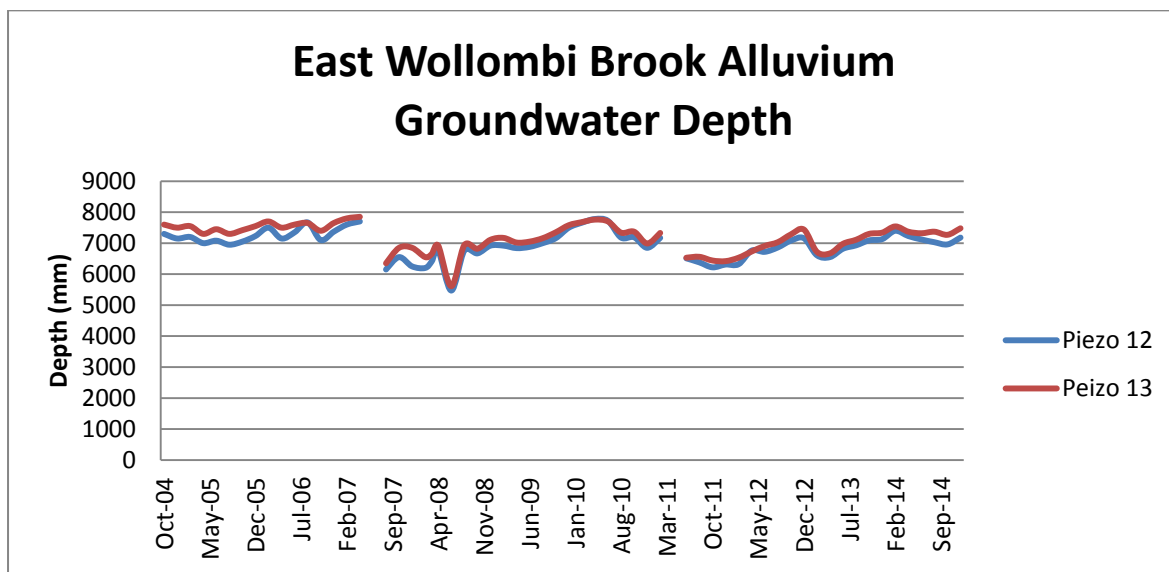


Figure 8. Groundwater level values for piezometers in East Wollombi Alluvium from October 2004 to September 2014.

#### 4.1.2 Conductivity

Figure 7-8 compares the salinities between the surveyed sites (Figure 7) and subcatchments (Figure 8) and illustrates that there were two salinity ranges; bores with low salinities (312.8-863  $\mu\text{S}/\text{cm}$ ) to bores with high salinities (1779-7775  $\mu\text{S}/\text{cm}$ ). This distinct separation of the bores based on salinity represents the separation of the bores in the alluvium and those that are in contact with the saline coal

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measures. This is particularly important as it also delineates the areas occupied by stygofauna from the areas devoid of fauna. Apart from the outlier, GW17, all stygofauna are present in bores with a salinity below 860  $\mu\text{S}/\text{cm}$  and also separates out the two well sites both in terms of salinity (1155-1779  $\mu\text{S}/\text{cm}$ ) and fauna composition where the wells are dominated by Ostracoda or pea clams. This indicates that these groups of invertebrates favour these conditions whereas the other groups prefer a much lower salinity. The annual variation in salinity between the Wollombi Brook and North Wambo Creek bores has remained quite constant since 2004 and therefore is not likely to be adversely impacting the stygofauna community. Indeed, it is most likely this consistency that has contributed to the delineation of the community composition of each bore.

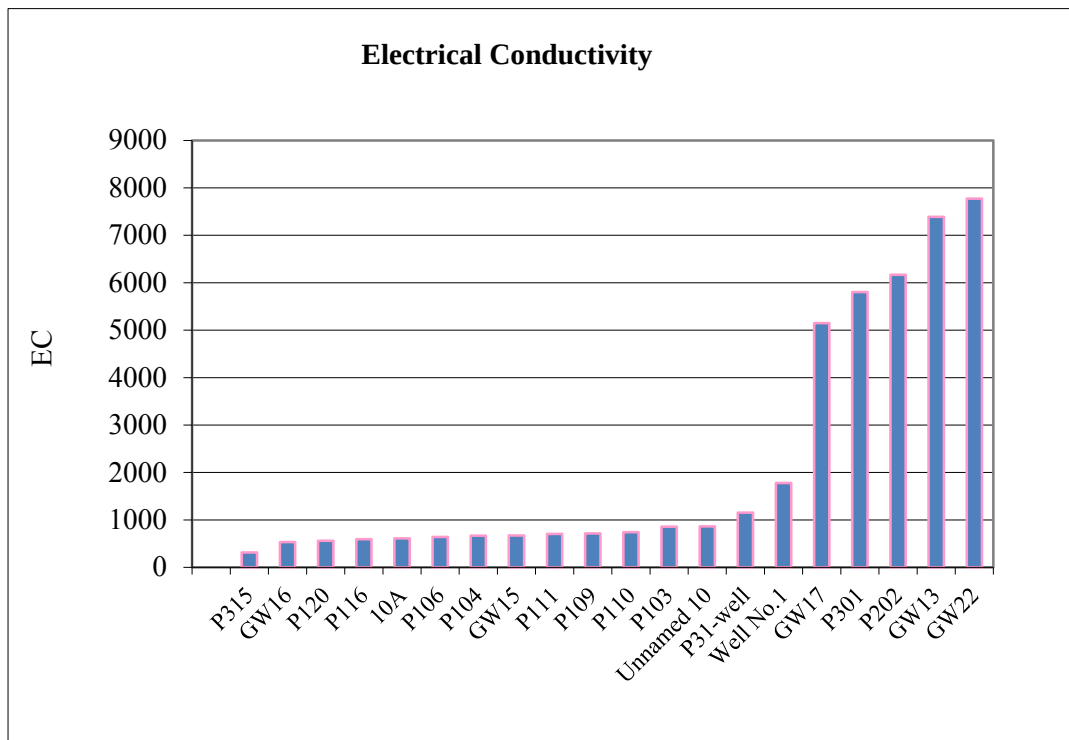


Figure 9. Fluctuations in electrical conductivity of bores within the Study Area, 1-2 December 2015.

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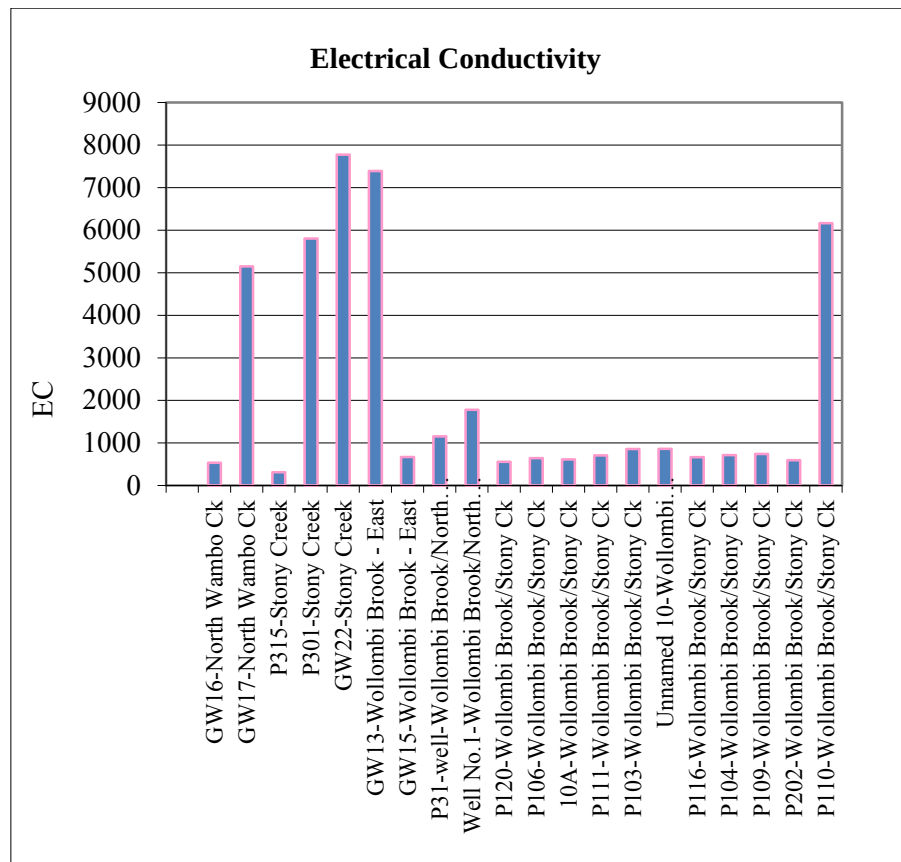


Figure 10. Fluctuations in electrical conductivity with the subcatchments within the Study Area, 1-2 December 2015.

In terms of subcatchments North Wambo Ck and Stony Ck are characterised as having higher salinity levels exceeding 5000  $\mu\text{S}/\text{cm}$  whereas Wollombi Brook has a low salinity profile of generally less than 1000  $\mu\text{S}/\text{cm}$ .

Figures 9-10 illustrate the annual changes in conductivity in Wollombi Brook and North Wambo Creek alluvial bores recorded as part of the Wambo monthly monitoring program. The low rainfall over the year has resulted in little to no change in the groundwater salinity in these locations.

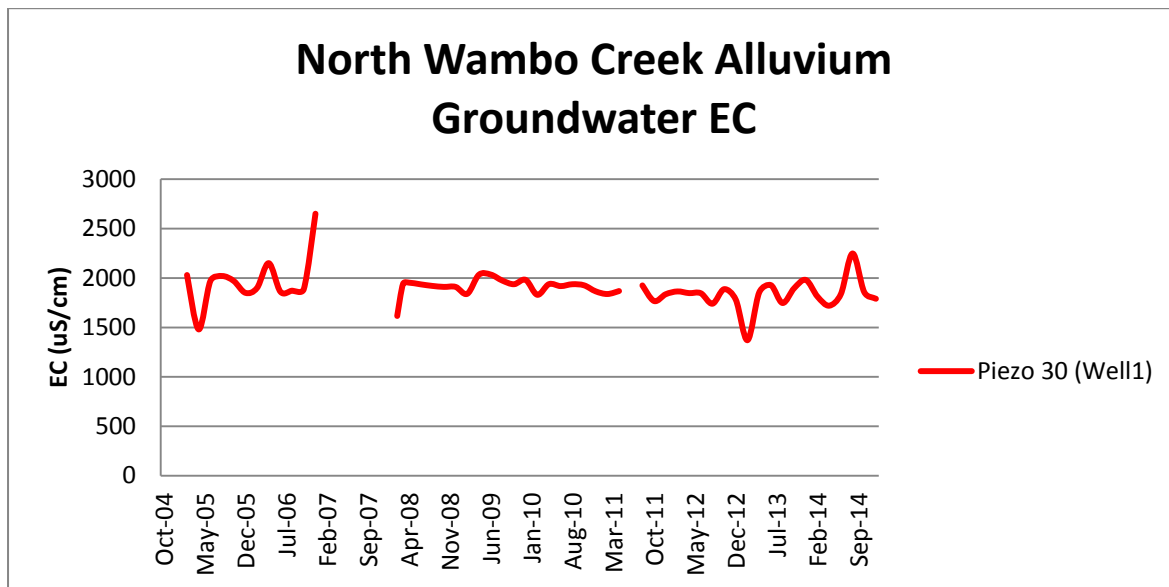


Figure 11. Fluctuations in field conductivity for Well No.1 in North Wambo Creek from December 2004 to December 2014.

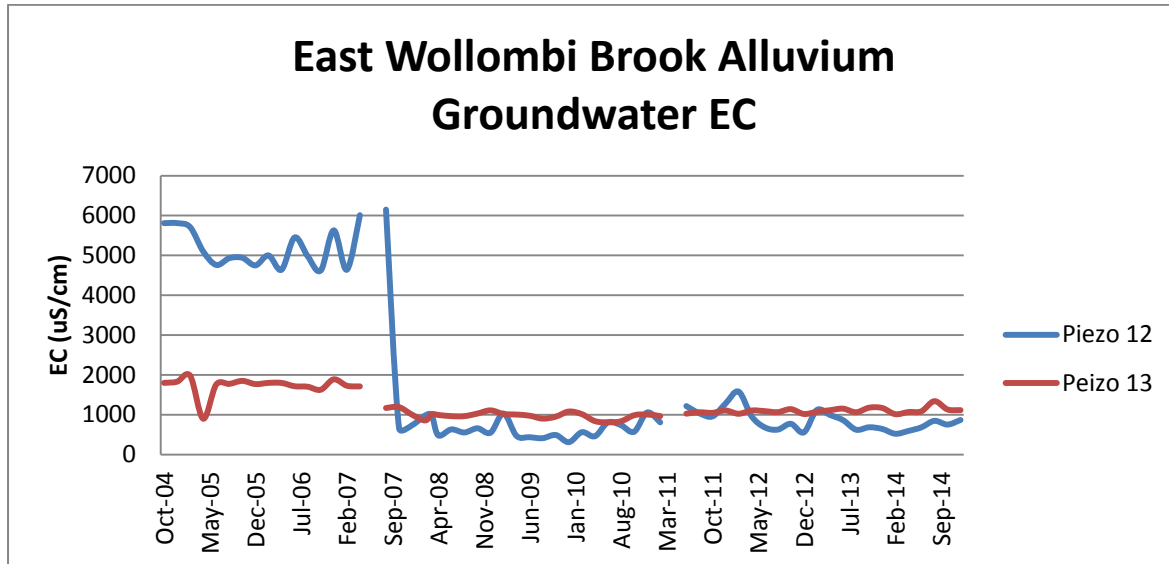


Figure 12. Fluctuations in field conductivity for piezometers in East Wollombi Alluvium from October 2004 to September 2014.

#### 4.1.3 pH

The range in pH sampled insitu (Figure 11) between the sites sampled is small varying from 6.37 at P315 to 8.22 at GW22 whereas all bores with stygofauna were essentially neutral as demonstrated in

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Table 3. As there has been very little fluctuation of pH throughout the system over time, it is therefore not considered to have any major impact on groundwater biodiversity. The long-term pH data recorded in the Wollombi Brook and North Wambo Creek alluvial bores is presented in Figures 12-13 and as with the salinity data illustrates that there has been little change since 2004.

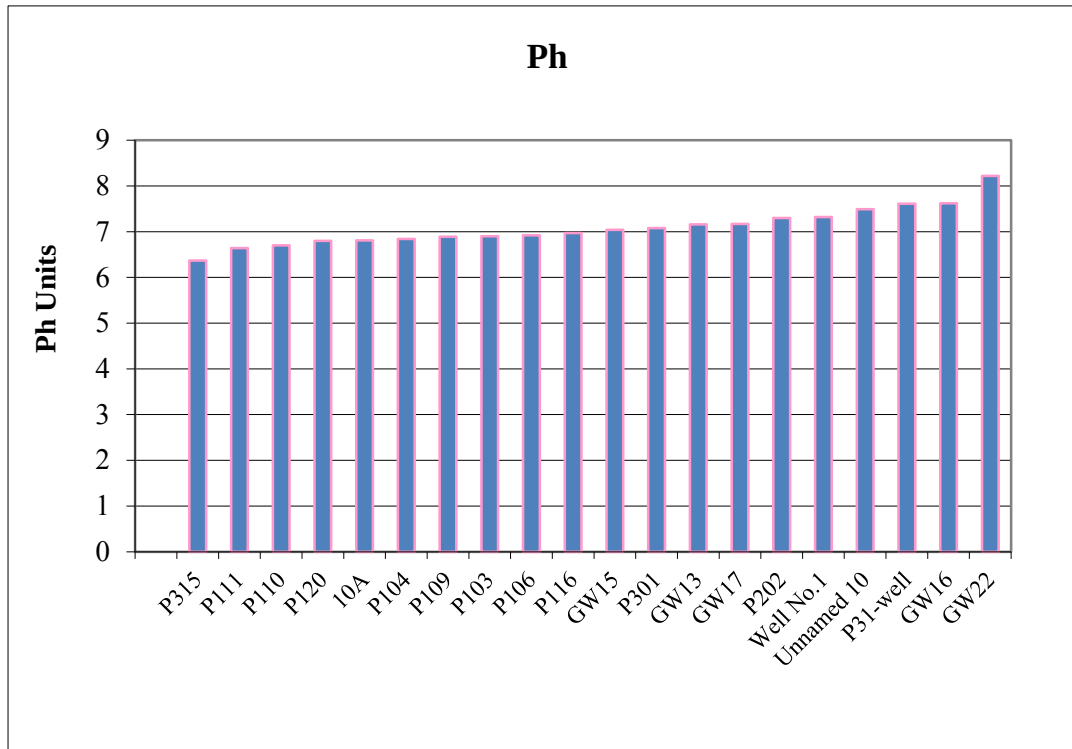


Figure 13. Variations in pH of the bores within the Study Area, 1-2 December 2015.

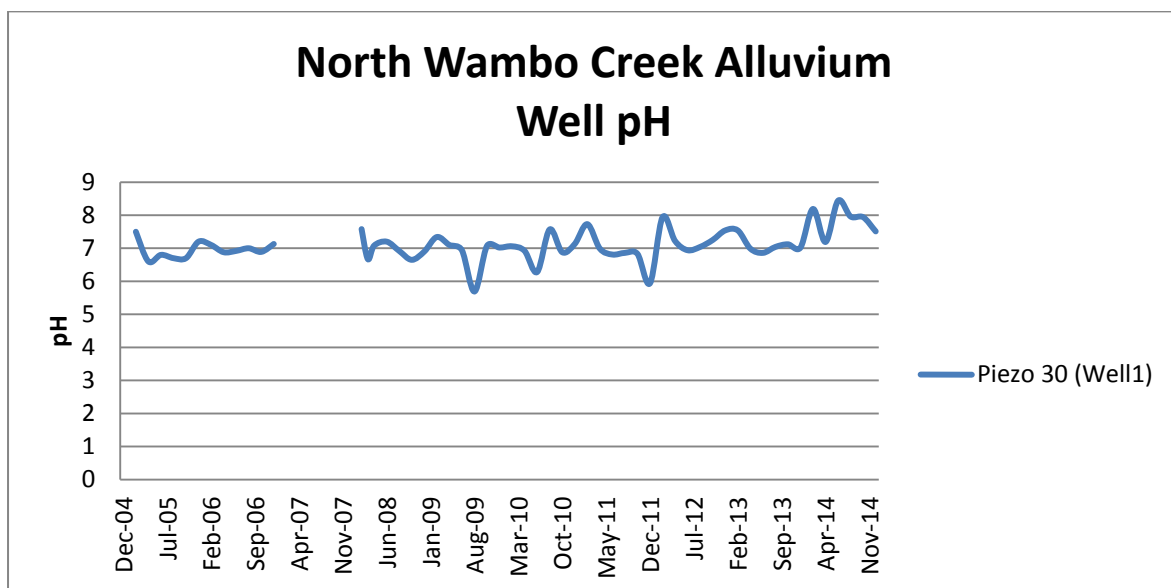


Figure 14. Fluctuations in pH for Well No.1 in North Wambo Creek Alluvium from December 2004 to December 2014.

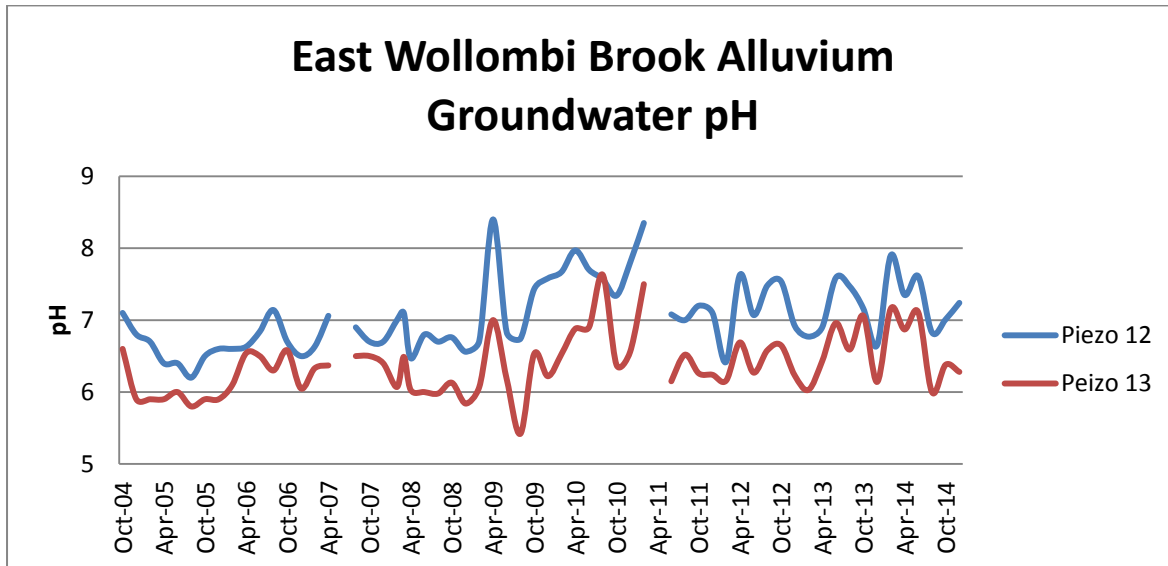


Figure 15. Fluctuations in pH for piezometers in East Wollombi Brook Alluvium from October 2004 to September 2014.

#### 4.1.4 Temperature

During the current round of sampling the water temperatures (Figure 14) for the sites were very similar across the Study Area. The values were very consistent throughout the system ranging from 18.3°C at Well No.1 to 23.1 °C at GW22 with all others below 21 °C.

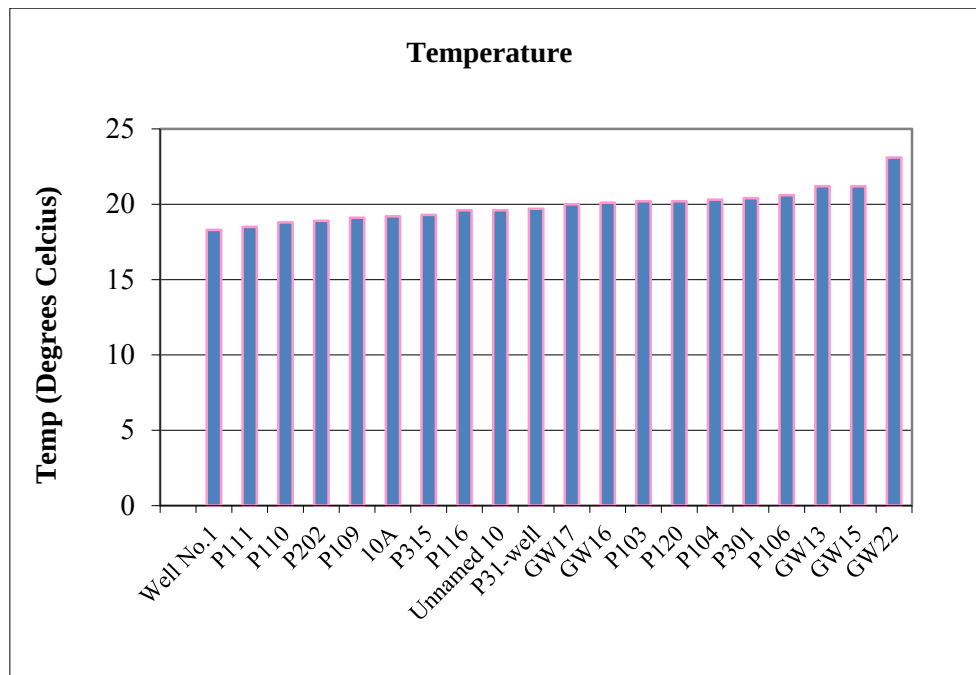


Figure 16. Variations in water temperature of the bores within the Study Area, 1-2 December 2015

## 4.2 Ecological Response - Stygofauna Data

### 4.2.1 Community Structure

The survey sampled 18 bores and two wells across the Study area and recorded 11 bores that contained 10 stygofauna species. The species list and habitus for each site is listed in Table 5 below. The stygofauna were present within the shallow alluvial piezometers only and were not collected from the deeper coal seam aquifers due to the installation of Vibrating Wire Piezometers as explained above. The most ecologically productive horizons within the alluvials appear to be in the depth range of 5.24m (P116) down to 11 m (GW17) with the majority occurring from 6-10m. The community composition included five orders of crustaceans, one order of mites and two families of insects. There were no listed threatened species collected, however, as is the case with most assessments in this emerging field, most species are likely to be new to science and restricted in distribution due to the short range endemic nature of stygofauna species

Most species collected are morphologically specialised, which includes total lack of eyes i.e. blind and unpigmented. Although the species have not been identified to species level as yet, the significant taxa include the Syncarida Family Psammaspidae and Parabathynellidae, the second only record of subterranean Oligochaete families Enchytraeidae and Haplotaxidae as well as the microcrustaceans, the Ostracoda and Copepoda. Descriptions of the recorded families are presented below.

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| Phylum     | Class          | Order          | Family            | Genus                     | Habitus    | P120       |
|------------|----------------|----------------|-------------------|---------------------------|------------|------------|
| Annelida   | Oligochaeta    | Tubificida     | Haplotaxidae      | sp.                       | Stygobite  | P31        |
| Annelida   | Oligochaeta    | Tubificida     | Enchytraeidae     | sp.                       | Stygobite  | P106       |
| Arthropoda | Malacostraca   | Syncarida      | Parabathynellidae | <i>Notobathynella</i> sp. | Stygobite  | P111       |
| Arthropoda | Malacostraca   | Syncarida      | Psammaspididae    | <i>Psammaspides</i> sp.   | Stygobite  | GW16       |
| Arthropoda | Maxillopoda    | Cyclopoida     | Cyclopidae        | <i>Mesocyclops</i>        | Stygobite  | P110       |
| Arthropoda | Ostracoda      | Myodocopida    | Candonidae        | <i>Candonopsis</i> cf.    | Stygobite  | P104       |
| Nematoda   | Not identified | Not identified | Not identified    | sp.                       | Stygobite  | P103       |
| Arthropoda | Acarina        | Asigmata       | Halacaridae       | sp.                       | Stygobite  | GW17       |
| Arthropoda | Insecta        | Collembola     | Isotomidae        | <i>Isotomodes</i> c.f.    | Edaphobite | Well No. 1 |
| Arthropoda | Insecta        | Collembola     | Smunthuridae      | <i>Sphaeridia</i> c.f.    | Edaphobite | P116       |

Table 5. Habitus separation of stygobite and edaphobite taxa. The white rows represent stygobites (stygofauna) whereas the blue rows represent edaphobites or soil fauna.

Table 5 also separates the bore sites into ecotone types. The blue colour represents the bore site that registered positive to soil fauna with the remaining white colour representing stygofauna. The bores that contained no fauna were not included. A complete species list is presented in Appendix 2.

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The majority of fauna recorded during the survey were crustaceans and worms. The moderate number of taxa and numbers of specimens collected at each site indicates a rich fauna within the alluvial aquifers at the bore sites and a high level of hydrological connectivity within the aquifer, possibly due to the substrate consisting of unconsolidated sands. This alluvial aquifer has a high degree of connectivity between the sample sites as indicated by the similarity of fauna across the Study Area particularly with those bores that are close to Wollombi Brook. This may also indicate that there is a series of palaeochannels present with the alluvium.

The relative consistency of the faunal composition across the bores sampled suggests that the subterranean community diversity is naturally high compared with other regions in NSW such as the Peel River in NW NSW and certainly comparable with the fauna found in the Hunter River. The fauna composition indicates a shallow groundwater system which is directly connected to the river system. The fact that sections of Wollombi Brook contain water while other sections are dry indicates a variable gaining/losing flow situation whereby the groundwater is partly feeding into the river. The variability of the porosity of the aquifer substrate appears to be one of the significant factors in determining the fauna composition as well as the presence or absence of fauna from bores. The porosity varies from low porosity in the clays and finer alluvial sediment zones and high porosity in the coarser unconsolidated sands sediments close to the river. The relative small size of the phreatic fauna collected is also an indication that the sediments are generally fine in nature.

The fauna is separated into two major ecotone groups and one minor ecotone group. The major separation is into the Stygobites groundwater fauna that contained the Syncarida, Oligochaeta, Ostracoda and Copepoda and the incidental Edaphobite or Soil Fauna represented by the Insect Order, the Collembola. The minor ecotone separation is between the well sites that contained a predominance of Candonidae Ostracoda and the sites to the south that was dominated by the Syncarida and Oligochaetes. These ecotones are described below in more detail.

### **Ecotone 1 - Stygobites – Sites: P116, Well No. 1, GW17, P103, P104, P110, GW16, P111, P106, P31, P120**

Eleven sites recorded the presence of stygofauna located entirely within the alluvial aquifers. This first ecotone is characterised by the community of obligate groundwater fauna represented by crustaceans Syncarida (Family Psammaspidae and Parabathynellidae), the Oligochaeta (Family Enchytraeidae and Haplotaxidae) and the Copepoda and Ostracoda. This faunal assemblage can be found in both the shallow hypogean (true groundwater) ecosystem as well as the temporary and permanent hyporheic zone ecosystems of stream and rivers within the Hunter River.

Although other aquifer ecosystems have been identified within the region, there are none so far identified within Wollombi Brook or its smaller tributaries. The community appears to be restricted to an area encompassing the floodplains upstream of the mining operations however separated into discreet pockets. The two main areas identified thus far is the upper section of North Wambo Creek and the lower confluence between North Wambo Creek, Wollombi Brook and Stony Creek and continuing downstream of Wollombi Brook. A detailed examination of each group of fauna is presented below.

### ***Syncarida***

The Division Syncarida is one of the most common invertebrate groups found in Australian groundwaters. They are an ancient group that branched off from the main stream of the Eumalacostraca or higher Crustacea at a very early period perhaps as far back as the Late Devonian (about 400-380mya), with today's extant taxa still retaining a primitive body structure (Schram, 1984).



Plate 1. Syncarida, Psammaspididae. (©P.Serov 2015).



Plate 2. Syncarida, Parabathynellidae. (©P.Serov 2015).

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The current classification of the Syncarida is broken up into: the minute, interstitial Bathynellacea, which have a world-wide distribution and are suggested to be the most primitive; the fossil Palaeocaridacea which were restricted to North America and Europe during the Carboniferous to Permian (approximately 360-250mya) and the Anaspidacea. The Anaspidacea have a distinctly Gondwana distribution from NZ, Australia and South America and include the shrimp like *Anaspides* and *Allanaspides*, found only in Tasmania. The Psammaspididae, known currently from 10 undescribed species in caves in NSW (Eberhard and Spate, 1995) and one described hyporheic species *Psammaspides williamsi* Schminke 1974, in northern NSW (Schminke, 1974) and one in Northern Tasmania.

The syncarids have always been indicators of cool temperate permanently wet habitats as they have no stage in their life cycle that can tolerate desiccation. The syncarid fauna collected from the alluvial aquifer represent the main group of obligate groundwater fauna. All species collected will be undescribed as there have been no described species from this area. The syncarids collected belong to the Family Parabathynellidae were collected from seven sites and, the Psammaspididae was collected from the one lower site (P106).

The importance of the discoveries of this obligate groundwater fauna is that they represent relics of a bygone era and give us a glimpse of another time before the browning of Australia, to a time when Australia was covered in lush, wet, rainforest with numerous waterways, alluviums and deltas. The fact the groundwater habitats have served as refuges and centres of speciation in fluctuating environments of generally increasing and spreading aridity, particularly in the Pleistocene, provides tools for studying the past history of particular taxa. The syncarids are one of these groups. They have a wide distribution at the family and generic level but appear to be highly restricted at the species level due to their inability to withstand any degree of desiccation in any stage of their life cycle and have narrow environmental requirements. In effect they represent biological time capsules and are very useful as bioindicators (Serov, 2002).

### **Oligochaeta**

In Australasia, the Oligochaeta are represented in freshwaters by the families Haplotaxidae, Aeolosomatidae, Lumbriculidae, Phreodrilidae, Naididae, and Tubificidae (Brinkhurst 1971). Of these families, the Haplotaxidae has a Gondwana, South East Australia and New Zealand distribution but is poorly represented in Australia, (Pinder 2001) although increasingly prominent in groundwaters.

The obligate groundwater fauna is characterised by the two Oligochaete Families, the Enchytraeidae and Haplotaxidae. The Enchytraeidae are a small family of aquatic worms that are poorly known although they have been found in freshwater environments in Victoria, NSW and recently in groundwaters in Queensland. They are a poorly known group that requires further taxonomic work (Pinder & Brinkhurst, 1994). In terms of their use within current environmental sensitivity indices such as the SIGNAL Index ranking, they can only be assessed at the Order level of Oligochaeta which has a ranking of 2. This equates to a family which is quite tolerant of environmental disturbance. This, however, is misleading as the family is usually associated with high water quality environments.

In a review of the stygobitic oligochaete fauna of the world, Juget & Dumnicka (1986) noted 66 species in seven families (Aeolosomatidae, Potamodrilidae, Haplotaxidae, Lumbriculidae, Dorydriidae, Tubificidae, and Enchytraeidae). More recently, Giani et al. (2001) reported 57 species that can be classified as stygobites in southern Europe alone, suggesting the global diversity far exceeds initial estimates (e.g., Juget & Dumnicka 1936). Indeed, Giani et al. (2001) estimated that, when records from other areas of the world (e.g., North America, Africa, Europe) are added, a total of

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96 stygobitic freshwater oligochaetes are known in the world (they excluded Australasia from their estimate for some reason). It should be noted that it is often difficult to make a clear separation between stygobitic and stygophilic oligochaetes. For example, the features that distinguish stygobitic crustaceans from epigean forms, such as absence of eyes, lack of pigmentation, and elongation of body, do not distinguish between stygobitic and epigean oligochaetes. Giani et al. (2001) noted that very few species of Naididae are stygobites.

The presence of Oligochaete worms in bores (P116, Well No. 1, GW17, P103, P104, P110, GW16, P111, P106, P31, and P120) indicates that the water quality is characterised by elevated organic carbon, and possibly high levels of dissolved iron. The relatively small size (1-30mm) of the Oligochaete (worm) species present indicates a moderate hydraulic connectivity within the river/aquifer environment. The shallow water table levels within the alluvial phreatic zone and the presence of the two families of worms suggests a direct association/connectivity with a slow base flow river system with a shallow alluvial aquifer. There is very little known about the diversity and distribution of freshwater Oligochaeta, therefore the identification can only be given to the family level. Subterranean Oligochaetes are an increasingly important component of Australia's groundwater fauna that contain a large number of short range endemic species with large faunas along the continental marginal areas, particular in the southwest and eastern seaboard.

### ***Ostracoda***

Ostracods are present in all groundwater habitats from fractured rock aquifers, to karst and alluvial aquifer systems, as well as in hyporheic and parafluvial habitats within rivers.

Research indicates that species have quite distinct distributions and, apparently, habitat preferences, with highest biodiversity adjacent to rivers and lower diversity in alluvial aquifers more distant from surface rivers (Ward et al. 1994). Other studies indicate that proximity to running water rich in organic matter is important (Rouche & Danielopol 1997). Their distributions are more complicated than simple proximity to rivers or concentration of organic content. There appear to be few meaningful correlations between ostracod abundances and individual physical factors (organic content, alkalinity, calcium, oxygen concentration). Instead, differences in habitat stability in terms of complexes of physico-chemical factors (e.g., water temperature and organic content) and the upwelling or downwelling nature of interstitial flows seem important, with some taxa more common in variable habitats and others more abundant where conditions are more constant (Ward & Palmer 1994).

The four bore sites (bores P116, Well No.1, P110 and P31) characterised by the presence of the Candonidae Ostracoda (Seed Shrimp) indicate connectivity between these sites as these fauna can only disperse via hydrological connectivity. Further examination of these taxa is necessary to determine if these represent one species or more separate, short range endemic species.



Plate 3. Ostracoda, Candonidae. (©P.Serov 2015)

### ***Copepoda***

The Copepoda are a subclass of Crustacea comprising over 10,000 known species (Williamson and Read 2001). Copepoda are predominantly marine, although 3 of the 10 orders are widespread and abundant in freshwater habitats. These are the Calanoida, Cyclopoida and Harpacticoida. The first order occurs in the water column as plankton only, whereas the latter two are common in benthic habitats of surface waters and are important components of many groundwater communities.

The Copepoda Cyclopidae is normally associated with fine to coarse sandy substrates of still water environments of rivers, wetlands, the hyporheic zone and shallow groundwaters. Although they are a ubiquitous component of these habitats, their small size means that they are often overlooked and undercounted. In terms of management, therefore, they are potentially very useful bioindicators, particular of base flow fed streams or alluvial aquifers or flow through wetlands, as they are sensitive to changes in the environment (Tomlinson & Boulton, 2008). The Cyclopidae were collected at 3 sites (bores P116, Well No. 1, GW17) which are all located within the shallow alluvials. Sites P116 and Well No.1 are situated on the flood plain of Wollombi Brook and GW17 are located on North Wambo Creek. These three sites are characterised as being shallow (7-14m), occurring within the alluvium and having neutral to slightly alkaline pH. The conductivity levels however vary considerably from low to high suggesting that the fauna is either very tolerant of salinity changes or composed of different taxa. It is suggested that fauna is composed of different species with differing salinity tolerance ranges.

### **Acarina (Water mites)**

The other species of stygofauna collected from one site (P111) belongs to the Acarina or water mites. There is at least one species of water mite present belonging to the Family Halacaridae. Although subterranean water mites are classed as phreatobites they have their highest biodiversity within the riverine, hyporheic zones and are also classed as members of the “permanent hyporheos or the community that occurs within the deep sand and gravel beds associated with areas of groundwater

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discharge (Gilbert, 1994). They typically characterize the transition zone between the temporary or shallow hyporheic ecozone and the groundwater hypogean environment. (Boulton & Hancock, 2006, Gilbert, 1994, Humphreys, 2006, Serov, *et al*, 2011.). It is therefore not unusual to find this group within the shallow phreatic zone (groundwater). It is another indication that this aquifer is or has been connected to surface water sources as a discharge source where the discharge can be either point source springs or diffuse discharge through a moderate to coarse grained substrate such as sand or gravels (Gilbert, 1994). The presence of these species/groups within the phreatic or shallow groundwater zone is therefore a direct indicator of groundwater connectivity between the local rivers systems and shallow unconfined aquifers.

### **Ecotone 2 – Edaphobites – Soil Fauna. Sites: P116, P103, P104 and P111.**

Four sites recorded the presence of terrestrial invertebrates. As they have physiological requirements for high humidity they occupy the transition zone between the terrestrial and aquatic environments and other refugial environments such as inside bores. Their presence in these habitats including bores is therefore regarded as incidental although their dominance in the dryer sites (and absence from the wetter alluvium sites) is a strong indicator they are using the bores as a refuge site from dry conditions.

The dominant group collected belonged to the primitive soil insects, the Collembola. The Collembola specimens collected belongs to the Family Isotomidae. This is a large family of Collembola, with all subfamilies occurring in Australia. They are common in leaf litter. They are typically detrital or fungal feeders associated with the ground litter layer and tree bark. Their presence in the samples is most likely coincidental either by falling in or occupying the vegetation adjacent to the bore or living within the bore above the water table, as they have a preference for humid environments. As they are terrestrial soil and leaf litter fauna and not associated with groundwater environments, no further description will be given.

## **5.0 Ecological Value and Risk Assessment**

The assessment of the ecological value and risk value the stygofauna community at each of the sites surveyed as well as an overall assessment of the shallow aquifers that supply the water to the identified GDEs is presented below.

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| Locality Name          | Habitat      | Survey Result | Ecological Value | Ecological Risk | Matrix Ranking |
|------------------------|--------------|---------------|------------------|-----------------|----------------|
| Overall Aquifer Values |              |               | High             | Low             | A              |
| P116                   | Interstitial | Positive      | High             | Low             | A              |
| Well No. 1             | Interstitial | Positive      | High             | Low             | A              |
| GW17                   | Interstitial | Positive      | High             | Low             | A              |
| P103                   | Interstitial | Positive      | High             | Low             | A              |
| P104                   | Interstitial | Positive      | High             | Low             | A              |
| P110                   | Interstitial | Positive      | High             | Low             | A              |
| GW16                   | Interstitial | Positive      | High             | Low             | A              |
| P111                   | Interstitial | Positive      | High             | Low             | A              |
| P106                   | Interstitial | Positive      | High             | Low             | A              |
| P31                    | Interstitial | Positive      | High             | Low             | A              |
| P120                   | Interstitial | Positive      | High             | Low             | A              |
| Unnamed 10             | Interstitial | Negative      | Low              | Low             | G              |
| 10A                    | Interstitial | Negative      | Low              | Low             | G              |
| GW13                   | Interstitial | Negative      | Low              | Low             | G              |
| GW15                   | Interstitial | Negative      | Low              | Low             | G              |
| GW22                   | Interstitial | Negative      | Low              | Low             | G              |
| P109                   | Interstitial | Negative      | Low              | Low             | G              |
| P202                   | Interstitial | Negative      | Low              | Low             | G              |
| P301                   | Interstitial | Negative      | Low              | Low             | G              |
| P315                   | Interstitial | Negative      | Low              | Low             | G              |

Table 6. Study Area Ecological Value and Risk Assessment Table.

The ecological value and risk value assessment undertaken for the Project was based on current data which is a snapshot of the current condition of the subterranean environments as of mid to late-2015 and modelled hydrogeological data as presented in the Groundwater Impact Assessment by AGE (2016). The AGE (2016) modelled data on the hydrogeological impacts of the Project on the Quaternary alluvial aquifers of North Wambo Creek and Wollombi Brook are summarised below.

- The most significant modelled drawdown within the Quaternary alluvium is predicted to occur east of United Open Cut along Wollombi Brook and Redbank Creek, as well as north along the closest edge of the Hunter River alluvium to the Project. This is well downstream of the bores surveyed.
- The drawdown for all sites that recorded stygofauna is expected to be negligible as they are outside of the area of predicted drawdown, therefore the stygofauna community is unlikely to be adversely impacted by drawdown.
- The Hunter River stays saturated. Predicted impacts are in relation to changes in flux between Permian aquifer and alluvium which will be addressed by licences within requirements of Water Sharing Plan (which provides for sustainable flows).
- As the Permian strata become depressurised, flow from the Permian to the alluvium within the zone of depressurisation will progressively decrease. This can be considered beneficial as it reduces the inflow rate of higher salinity groundwater from the Permian to the overlying alluvium. The Project is therefore not predicted to adversely affect groundwater quality within alluvial aquifers.

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- Within Wollombi Brook there are two areas predicted to be impacted, labeled as GDE 1 and GDE 2 in the groundwater assessment. At GDE2, around 1m in groundwater level decline is predicted due to cumulative impacts from mining (approved mining and the Project). The alluvium stays saturated and impacts are associated with change in flux between Permian aquifer and alluvium to be addressed by licences within requirements of WSP (which provides for sustainable flows). GDE1 is predicted to become largely desaturated as a result of the cumulative impacts of mining in the surrounding area – this desaturation will occur anyway without the Project.
- North Wambo Creek alluvial aquifer is approved for impact and Project will result in no change to this level of approved impact.

An overall value and risk assessment was conducted focusing on the shallow aquifers of the Study Area as a whole in order to place the sites into a landscape perspective and to demonstrate the condition and ecosystem function performed by these aquifers. The results of this assessment demonstrated that currently the aquifers in general are in very good condition in regards to water levels, water quality, as well as supporting a range of GDE types.

As shown in Table 5, the sites that registered stygofauna were assessed as having high ecological value due to importance of the fauna and the high water quality and consistent water levels within the aquifer. Those bores that did not contain fauna typically had poor water quality (high salinity) and were assessed as having low ecological value in terms of subterranean ecosystems. The locations that recorded higher values were the alluvial sites in close proximity to the streams and riparian areas. These sites recorded a high ecological value compared with the other sites due to the higher water quality, intact nature of the groundwater habitat, the presence of indicator species and potentially endemic stygofauna within the aquifer, the ecosystem services the aquifer contributes via the seepage of groundwater from the unconfined alluvial aquifers into baseflows and the riparian and terrestrial vegetation communities associated with the alluvium.

The Study Area recorded an overall low risk value for the ecological risk assessment for those sites that recorded stygofauna, as there was low potential for impact from the Project as a result of the modelled drawdown levels outlined by AGE (2016) in the groundwater impact assessment (refer to Map 7.3, AGE, 2016). This risk value also recognizes that as the populations were still intact after a long period of mining activity prior to the survey indicates that there has not been sufficient change over time to impact them.

In summary, in terms of the stygofauna community across the Study Area, the following points are noted:

- ☐ Limited and localised subterranean ecosystems exist in the shallow, unconfined alluvial aquifers of the Wollombi Brook and North Wambo Creek. None of these species are currently listed as endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities as listed under the TSC Act, FM Act or the Commonwealth EPBC Act. They do have a high potential to be short range endemic species, relictual and rare.
- ☐ The ecological values of the sites that contain stygofauna were high due to the presence of the fauna as well as the ecological condition of the aquifers.
- ☐ The presence of the same or similar species in both aquifer types indicate a direct connectivity between the shallow alluvial aquifers and the aquifers in the underlying sandstones.

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- ❑ The risk of the proposed development to these subterranean ecosystems was rated as low based on the modelled drawdown particularly to the Quaternary alluvial aquifers and the highly connected nature of the alluvials with the underlying coal seams.
- ❑ There was sufficient long term data to determine whether past land use practices have impacted aquifers and associated GDEs. As a result, the confidence of the overall risk assessment is moderate to high. It is likely that the GDEs are in a moderate to high condition given the biodiversity in the area and the consistency of the stygofauna occurrence across both control and potential impact sites.

## **6.0 Management**

This baseline stygofauna assessment has identified the presence of subterranean fauna within the shallow alluvial and colluvial aquifers in the Study Area. Since the numbers of animals and diversity was high they indicate good water quality and a strong connectivity between the river and groundwater system (Serov et al. 2012.). The restricted distribution of the stygobitic fauna recorded would strongly suggest that there is strong connectivity within and between the alluvial aquifers and the associated streams. The fauna should be considered as short range endemics (SREs) species that are associated with this area. From a management perspective stygobites (phreatobites) usually face a higher risk of extinction than other invertebrate communities as they live only in small geographical areas and typically have narrow physiological tolerance ranges.

The risk assessment presented in Section 5 identified the overall Study Area to have a Class A risk ranking for the current ecological conditions and the risk from the current and proposed development. This indicates that the ecological values of the aquifers and the stygofauna community where present in the Study Area are high, however the potential for detrimental impacts from the current and proposed developments is low. The nine sites that did not record the presence of stygofauna were ranked as Class G, indicating a low ecological value for the aquifer in terms of its stygofauna community and a low risk from the current and proposed development.

The current controls to manage GDEs are largely vested in the legislative controls of the *Water Management Act 2000*. A requirement of Water Sharing Plans (WSPs) is to monitor plan performance using a standard set of performance indicators as set out by the *Water Management Act 2000*. There are five main types of relevant rules which operate to protect GDEs in NSW WSPs, which are summarised as follows:

### **Distance Rules**

- Rules for water supply works located near sensitive environmental areas. This rule specifies the distance restriction for new bores from high priority GDEs, karsts (Karst Rule), escarpments (Scarp Rule) and rivers. This rule is designed to minimise the impacts of extraction on these environments.
- Rules for the use of water supply works located within restricted distances. This rule specifies the maximum amount of water that may be taken on a yearly basis from existing water supply works that are located within the restricted distance from a high priority GDE, karst, escarpment or river. This rule is designed to minimise the impacts of extraction on these systems.

### **Drawdown Rule:**

- Drawdown rules apply to minimise the negative effects of extraction on water levels. No drawdown is permitted to occur at the outside edge of the perimeter of any high priority GDE listed in the WSP. This rule is designed to minimise the impacts of extraction on high priority GDEs.

### **Cease to Pump Rule:**

- Base flows in streams are protected by cease to pump rules. Most licensed users are required to cease pumping when there are no visible flows in the river or when flows are less than the 95<sup>th</sup> percentile.

### **Dealing (trading) Rules:**

- Dealing (trading) rules are intended to promote trade of entitlement, including for new development, while minimising environmental impacts. Ideally, dealing arrangements result

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in environmental improvement rather than harm, for example, by avoiding the concentration of extraction in a particular area. In most groundwater sources covered by macro plans, trade is allowed within a groundwater source but not into or out of the groundwater source. This recognises that groundwater sources as defined in WSPs represent discrete aquifer systems.

### **Local Impact Rules:**

- All macro groundwater sharing plans include local impact management rules. These rules are intended to ensure that water levels in a groundwater source are not depleted detrimentally, beyond seasonal variations. Water quality can also decline as a result of excessive extraction. All the macro groundwater sharing plans include local impact management rules to manage water quality across a groundwater source. Water quality changes resulting from extraction are to be managed consistently with the designated category.

### **6.2. Cumulative Impacts**

Cumulative effects may result from a number of activities interacting with the environment. The nature and scale of these effects can vary depending on factors such as the type of activity performed, the proximity of activities to each other and the characteristics of the surrounding natural, social and economic environments. They may also be caused by the synergistic and antagonistic effects of different individual activities, as well as the temporal or spatial characteristics of the activities. Importantly, cumulative effects are not necessarily just additive. The implication of multiple mining activities in one region, as exhibited within the Study Area, is that impacts may overlap and result in larger impacts than would be expected for a single mining operation (cumulative effects).

Due to the long history of mining within the region, the cumulative drawdown was determined by comparing predicted changes to 2015 groundwater levels. The cumulative drawdown within the Quaternary alluvium extends along Wollombi Brook and Hunter River, adjacent to mining operations (i.e. Wambo, HVO South, HVO North, Ravensworth and Mount Thorley Warkworth). It should be noted that the model predicted drawdown in certain areas exceeds the saturated thickness of the alluvium. The most significant modelled drawdowns within the Quaternary alluvium are visible east of United Open Cut, along Wollombi Brook and Redbank Creek (AGE, 2016)

### **6.3. Suggested Management Actions**

Further work suggested for future stygofauna monitoring includes:

- ☐ Identify stygofauna to species (particularly those listed as phreatobites) to determine levels of endemism of the stygofauna community, particularly between the community within Wollombi Brook, North Wambo Creek and the Hunter River. The determination of whether these populations contain the same species or are isolated, separate species is an important consideration particularly as stygofauna are known to be highly localised and endemic with several species often occurring in the same aquifer.
- ☐ Conduct annual biodiversity surveys in line with the water quality monitoring program to monitor potential changes/impacts to the stygofauna community;
- ☐ Continue ongoing monitoring of water levels, and water chemistry, with the addition of water temperature.



## 7.0. Conclusions

The baseline sampling and assessment of the groundwater ecosystems that exist in the Study Area has demonstrated that:

- ☐ Stygofauna were present within the alluvial aquifers;
- ☐ The biodiversity of the stygofauna community across the shallow alluvial aquifers is high with hotspots of biodiversity which will potentially have a high degree of endemism.
- ☐ Stygofauna were present within the groundwater drawdown zone of the Project (i.e. the impact zone) and outside the impact zone of the Project i.e. the control sites;
- ☐ There is a connectivity within and along the alluvial aquifers;
- ☐ Stygofauna were not surveyed from within the deep aquifer of the coal bearing zone, although they are considered unlikely to be present, or if so, to have high values for the reasons discussed earlier in this report;
- ☐ The groundwater fauna of the hypogean (groundwater) environments/sites are quite rich as result of the
  - Water chemistry, i.e. low levels of salinity, neutral pH levels ranging from approximately 6.5-7.5 pH units; and
  - moderate grained nature of the geology and sediments;

## 8 Acknowledgements

We are grateful to Kirsty Davies and Gabrielle Allan from Umwelt Pty Ltd, Aislinn Farnon from Glencore (United and Wambo Open Cut mine) and Ralph Brown AECOM (Singleton) Pty Ltd for their continued assistance and in particular, Scott McDonald from AECOM (Singleton) Pty Ltd for his invaluable assistance in the field and for providing background information on water quality and site history.

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## Appendix 1 - Site Images

### East Wollombi Brook



4. Plates 4. Bore No. GW13. 5. Bore No. GW15.



### North Wambo Ck



6. Plates 6. Bore No. GW16. 7. Bore No. GW17.



Stony Ck/Wollombi Brook



8. Plates 8. Bore No.10A. 9. Bore No. P103/Unnamed 14.



10. Plates 10. Bore No.P104. 11. Bore No.P106.



12.



13.

Plates 12. Bore No.P109. 13. Bore No.P110.



14.



15.

Plates 14. Bore No.P111. 15. Bore No.P116.



16.



17.

Plates 16. Bore No.P120. 17. Bore No.202.



18.



19.

Plates 18. Bore No. Unnamed 10. 19. Bore No.P31- well.

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20.



21.

Plates 20. Bore No. Well No.1. 21. Bore No. GW22.



22.



23.

Plates 22. Bore No. P301. 23. Bore No. P315.

## Appendix 2 - Species List

| Phylum     | Class          | Order          | Family            | Genus                | Habitat    | Date      |
|------------|----------------|----------------|-------------------|----------------------|------------|-----------|
| Annelida   | Oligochaeta    | Tubificida     | Haplotaxidae      | sp.                  | Syngobite  | 1/12/2015 |
| Annelida   | Oligochaeta    | Tubificida     | Eteobryidae       | sp.                  | Syngobite  | 1/12/2015 |
| Arthropoda | Malacostraca   | Synbranchia    | Parabathynellidae | Parabathynella sp.   | Syngobite  | 1/12/2015 |
| Arthropoda | Malacostraca   | Synbranchia    | Psammopodidae     | Psammopodidae sp.    | Syngobite  | 1/12/2015 |
| Arthropoda | Maxillopoda    | Cyclopoida     | Cyclopidae        | Mesocyclops          | Syngobite  | 1/12/2015 |
| Arthropoda | Ostracoda      | Myodocopida    | Candona           | Candonopsis cf.      | Syngobite  | 1/12/2015 |
| Nematoda   | Not identified | Not identified | Not identified    | sp.                  | Syngobite  | 1/12/2015 |
| Arthropoda | Acarina        | Stigmatina     | Halacaridae       | sp.                  | Syngobite  | 1/12/2015 |
| Arthropoda | Insecta        | Collembola     | Isotomidae        | Isotomodes cf.       | Edaphobite | 1/12/2015 |
| Arthropoda | Insecta        | Collembola     | Sminthuridae      | Sphaeridia c.f.      | Edaphobite | 1/12/2015 |
|            |                |                |                   | Total No. species    |            | 1/12/2015 |
|            |                |                |                   | Total No. of animals |            | 1/12/2015 |

Table 7. Survey Species List.

### Appendix 3 - Risk Assessment Tables

| Locality                                                                                                                                                                  | North Wambo Creek and Wollombi Brook Alluvial Aquifers (Bores: P116, Well No. 1, GW17, P103, P104, P110, GW16, P111, P106, P31, P120) |          |     |         |          |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|----------|-----|---------|----------|
| GDE ENVIRONMENT                                                                                                                                                           | High                                                                                                                                  | Moderate | Low | Unknown | Comments |
| GDE or part thereof occurs or is reserved in National Estates, listed wetlands, SEPP 26 etc.                                                                              |                                                                                                                                       |          | No  |         |          |
| Presence of exotic flora or fauna within GDE                                                                                                                              | None exist                                                                                                                            |          |     |         |          |
| Removal or alteration of GDE type or subtype                                                                                                                              | No detectable change in physical structure, species composition or size in GDE type or subtype.                                       |          |     |         |          |
| AQUIFER                                                                                                                                                                   |                                                                                                                                       |          |     |         |          |
| Water quantity parameters                                                                                                                                                 | High                                                                                                                                  | Moderate | Low | Unknown | Comments |
| Alteration of the frequency and/or magnitude and/or timing of watertable level fluctuations.                                                                              | No detectable change from natural seasonal variation.                                                                                 |          |     |         |          |
| Alteration to direction of hydraulic gradients                                                                                                                            | No detectable change from natural seasonal variation.                                                                                 |          |     |         |          |
| Alteration of base flow conditions                                                                                                                                        | No detectable change from natural seasonal variation.                                                                                 |          |     |         |          |
| Water quality parameters                                                                                                                                                  | High                                                                                                                                  | Moderate | Low | Unknown | Comments |
| Degree of acid runoff or acidification of groundwater source.                                                                                                             | No detectable change from natural seasonal variation.                                                                                 |          |     |         |          |
| Degree of nutrient load.                                                                                                                                                  | No detectable change from natural seasonal variation.                                                                                 |          |     |         |          |
| Degree of groundwater salinity.                                                                                                                                           | No detectable change from natural seasonal variation.                                                                                 |          |     |         |          |
| Degree of bioaccumulation i.e. heavy metal contamination                                                                                                                  | No detectable change from natural seasonal variation.                                                                                 |          |     |         |          |
| Aquifer structure                                                                                                                                                         | High                                                                                                                                  | Moderate | Low | Unknown | Comments |
| Degree of alteration of aquifer structure (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction, compaction of aquifer, etc). | No detectable change in aquifer structure                                                                                             |          |     |         |          |

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| BIODIVERSITY                                                                                                                                |      |                                                                          |      |                |                                                                                            |
|---------------------------------------------------------------------------------------------------------------------------------------------|------|--------------------------------------------------------------------------|------|----------------|--------------------------------------------------------------------------------------------|
| Rarity within catchment/groundwater source                                                                                                  | High | Moderate                                                                 | Low  | Unknown        | Comments                                                                                   |
| Presence of Threatened, Rare, Vulnerable or Endangered species, population or ecological community within GDE.                              |      |                                                                          |      | X              | It is unknown at this point whether this community is locally rare or endemic at this time |
| Presence of indicator, keystone, flagship, endemic or significant species, populations or communities within GDE ***                        | Yes  |                                                                          |      |                | The community recorded are recognised as indicators of high water quality                  |
| Patch size rank of GDE relative to other patches of the same GDE type/subtype (as appropriate)                                              | >50  | 49-30                                                                    | < 30 |                |                                                                                            |
| Patch size % of GDE relative to original/historic extent                                                                                    |      |                                                                          |      | X              |                                                                                            |
| Diversity within catchment/groundwater source                                                                                               | High | Moderate                                                                 | Low  | Unknown        | Comments                                                                                   |
| Diversity of groundwater dependent native flora and fauna species within a GDE.                                                             |      | Presence of 2-4 species or 80-50% of species relative to reference sites |      |                |                                                                                            |
| SPECIAL FEATURES WITHIN CATCHMENT/GROUNDWATER SOURCE                                                                                        | High | Moderate                                                                 | Low  | Unknown        | Comments                                                                                   |
| Provides drought refuge for terrestrial or aquatic species                                                                                  |      |                                                                          |      | Not applicable |                                                                                            |
| Presence of rare physical/physico-chemical features or environments (e.g. karsts, mound springs, natural saline wetlands, peat swamps etc.) |      |                                                                          |      | X              |                                                                                            |

# United Wambo Open Cut Coal Mine Project - Baseline Stygofauna Assessment (Ref No: 3509)

|                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                        |          |          |  |  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|--|--|
| Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation through aquifer connectivity               | Unconfined aquifer with connection to terrestrial and aquatic ecosystems.                                                                                                                                                                                                                                                                                                                                                                              |          |          |  |  |
| Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation relating to aquifer structure and porosity | Unconsolidated aquifer with connection to terrestrial and aquatic ecosystems.                                                                                                                                                                                                                                                                                                                                                                          |          |          |  |  |
| <b>TOTAL NUMBER OF ATTRIBUTES</b>                                                                                                                                         | <b>11</b>                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>1</b> | <b>1</b> |  |  |
| <b>OVERALL VALUE</b>                                                                                                                                                      | High                                                                                                                                                                                                                                                                                                                                                                                                                                                   |          |          |  |  |
| <b>COMMENTS</b>                                                                                                                                                           | The alluvial aquifer that contains the stygofauna community recorded in this round of survey has remained stable in terms of water levels, pH and salinity over the period of monitoring for this mine. The presence of stygofauna both upstream and downstream of North Wambo Creek is a strong indication that the aquifer environment has been stable and in good ecological condition over time. Therefore the high ecological value is justified. |          |          |  |  |

Table 8. Overall ecological value assessment for Study Area.

| Locality                                                                                                | North Wambo Creek and Wollombi Brook Alluvial Aquifers (Bores: P116, Well No. 1, GW17, P103, P104, P110, GW16, P111, P106, P31, P120) |          |                                                  |                              |
|---------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------------------------------|------------------------------|
| Water Quantity Asset                                                                                    | High                                                                                                                                  | Moderate | Low                                              | Insufficient data or unknown |
| What will be the risk of a change in groundwater levels/pressure on GDEs?                               |                                                                                                                                       |          | No change to aquifer water levels or pressure.   |                              |
| What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs? |                                                                                                                                       |          | No change in timing of water level fluctuations. |                              |
| What will be the risk of changing base flow conditions on GDEs?                                         |                                                                                                                                       |          | No change in direction of flow.                  |                              |
| Water Quality Asset                                                                                     | High                                                                                                                                  | Moderate | Low                                              | Insufficient data or unknown |
| What is the risk of changing the chemical conditions of the groundwater source?                         |                                                                                                                                       |          | Negligible change (<5%)                          |                              |

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|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-----------------|-------------------------------------------------|-------------------------------------|
| What is the risk on the groundwater source by a change in the freshwater/salt water interface?                                                                     |             |                 | No change or not applicable                     |                                     |
| What is the likelihood of a change in beneficial use (BU) of the groundwater source?                                                                               |             |                 | Negligible change for identified triggers (<5%) |                                     |
| <b>Aquifer Integrity Asset</b>                                                                                                                                     | <b>High</b> | <b>Moderate</b> | <b>Low</b>                                      | <b>Insufficient data or unknown</b> |
| What is the risk of damage to the geologic structure?                                                                                                              |             |                 | No change                                       |                                     |
| <b>Biological Integrity Asset</b>                                                                                                                                  | <b>High</b> | <b>Moderate</b> | <b>Low</b>                                      | <b>Insufficient data or unknown</b> |
| What is the risk of alterations to the number of native species within the groundwater dependent communities (fauna and flora)?                                    |             |                 | No reduction in No. of species.                 |                                     |
| What is the risk of alterations to the species composition of the groundwater dependent communities (fauna and flora)?                                             |             |                 | No change in species composition.               |                                     |
| What is the risk of increasing the presence of exotic flora or fauna?                                                                                              |             |                 | None exist.                                     |                                     |
| What is the risk of removing or altering a GDE subtype habitat (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction)? |             |                 | No removal or alteration of habitat.            |                                     |
| <b>Risk Valuation</b>                                                                                                                                              |             |                 | 11                                              |                                     |
| <b>Risk</b>                                                                                                                                                        | <b>low</b>  |                 |                                                 |                                     |

Table 9. Overall risk assessment for the Study Area