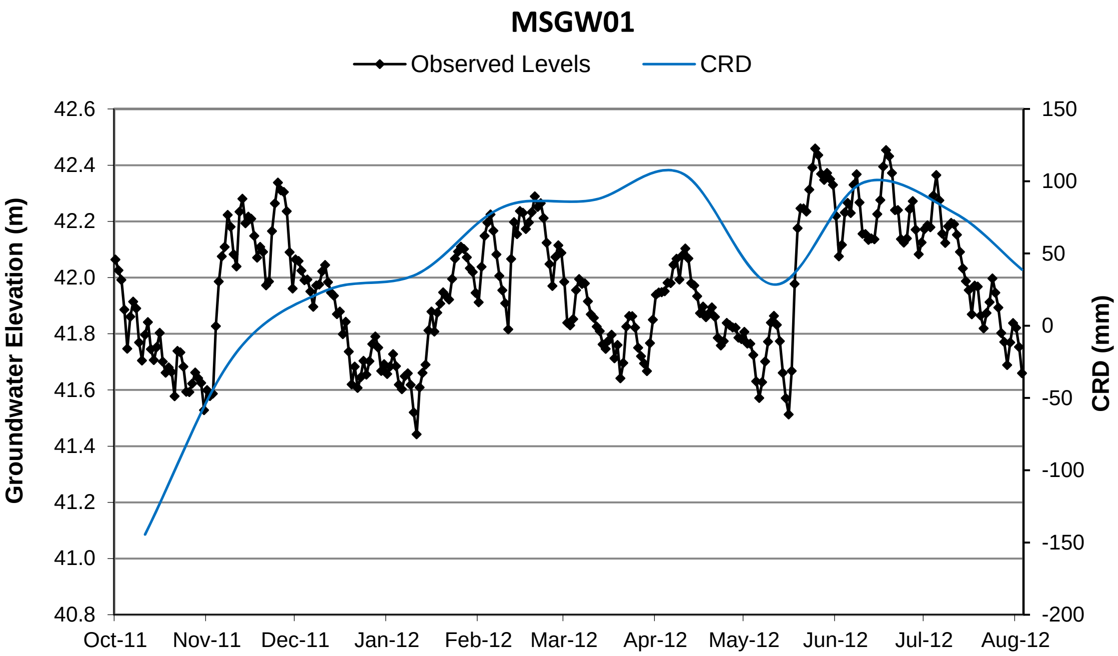
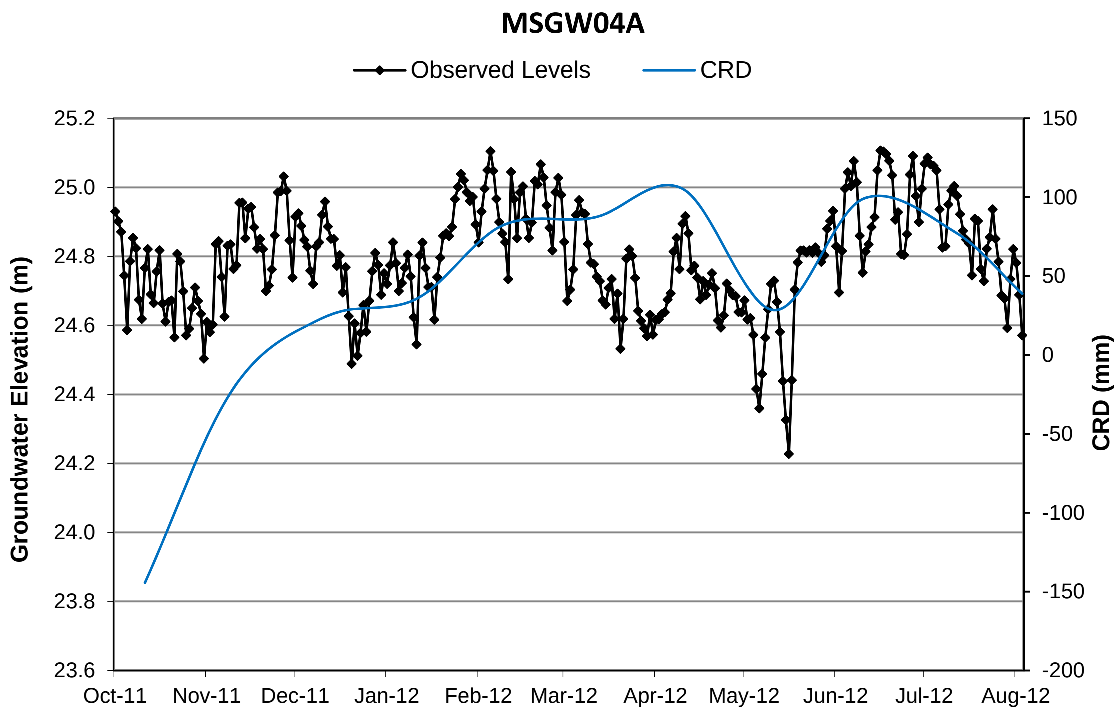
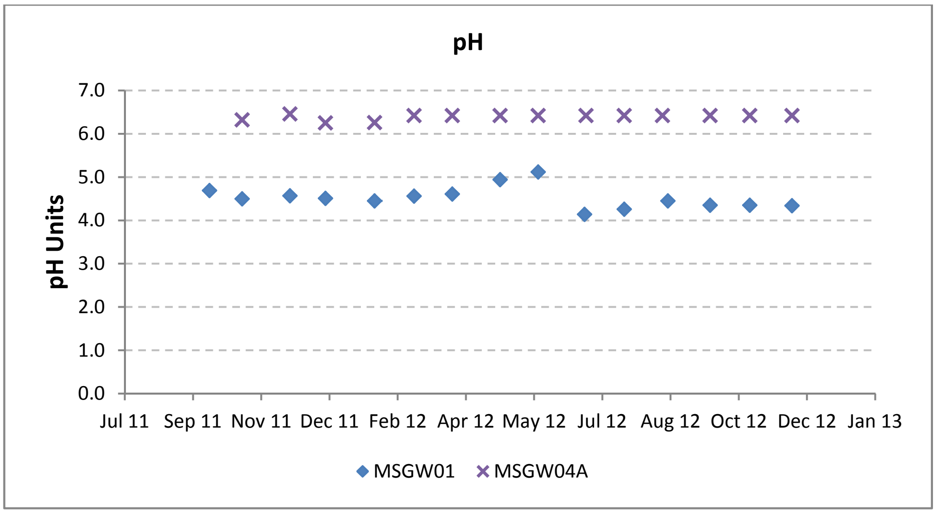
Appendix A

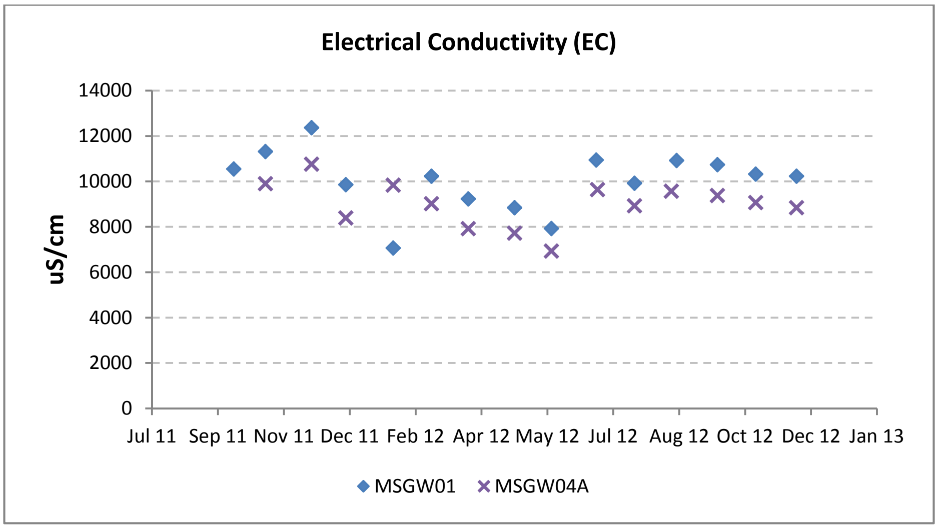
# Baseline Groundwater Data – Southern Extension Area

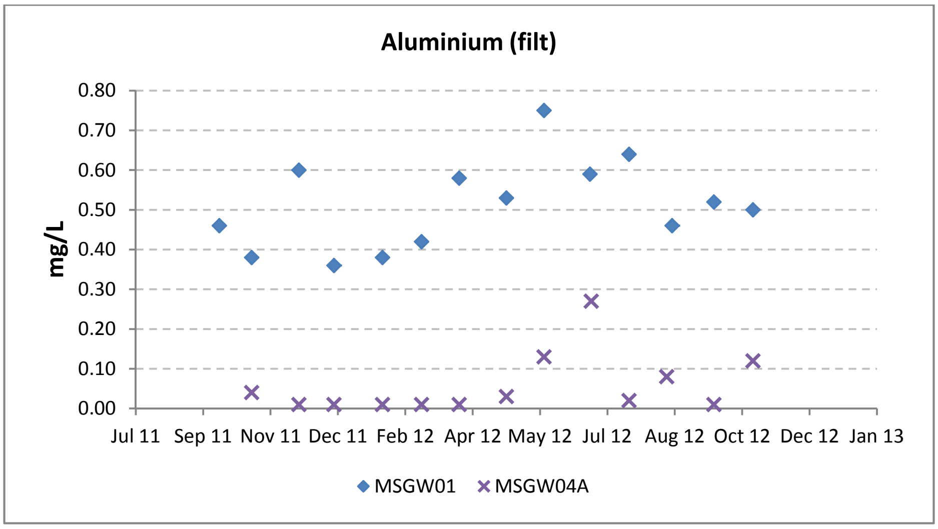
**Alluvial Groundwater**

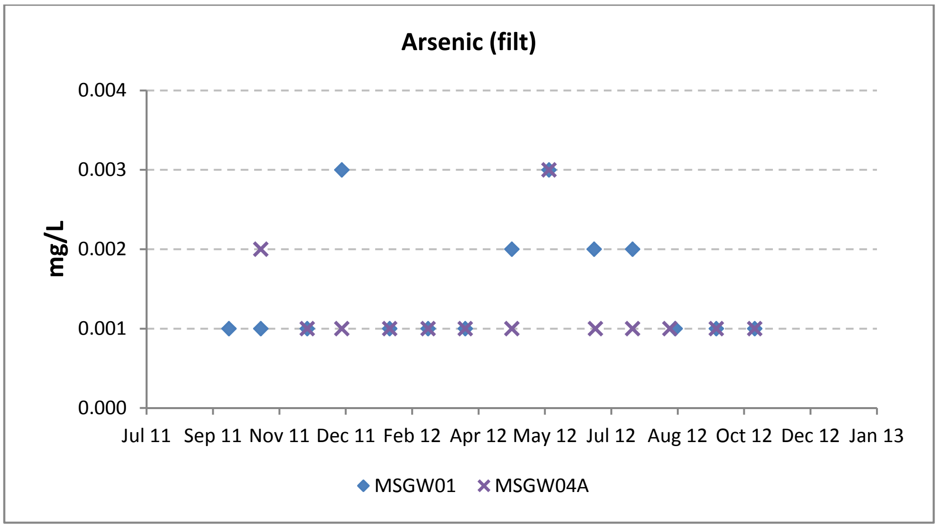


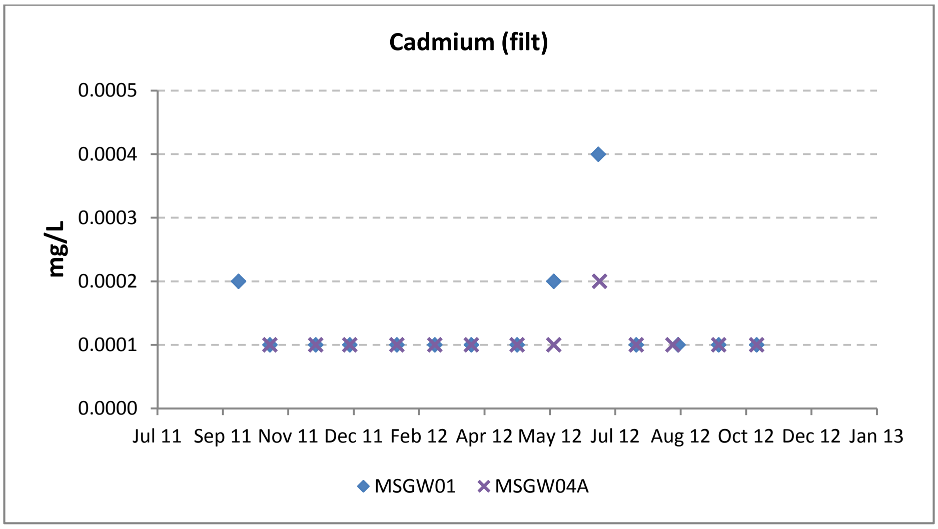

pH
pH Units
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A


Electrical Conductivity (EC)
uS/cm
14000
12000
10000
8000
6000
4000
2000
0
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A

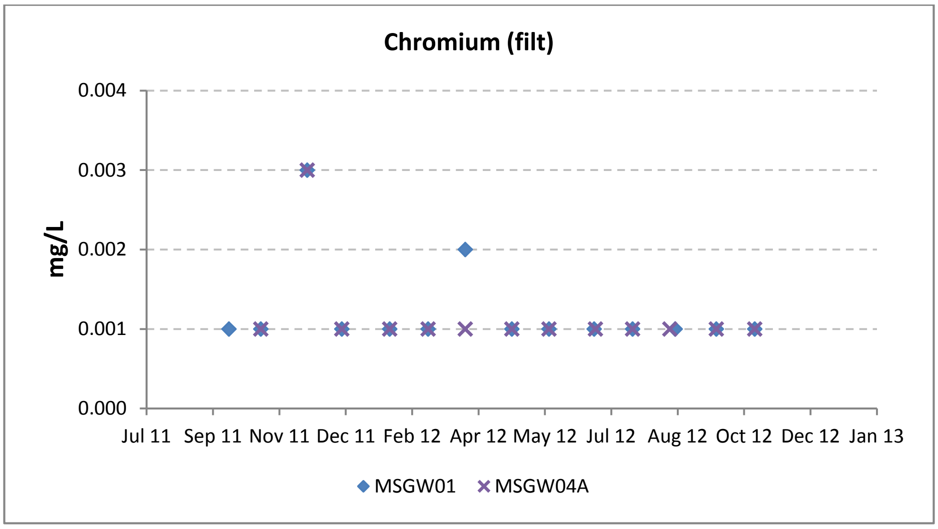

Aluminium (filt)
mg/L
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A



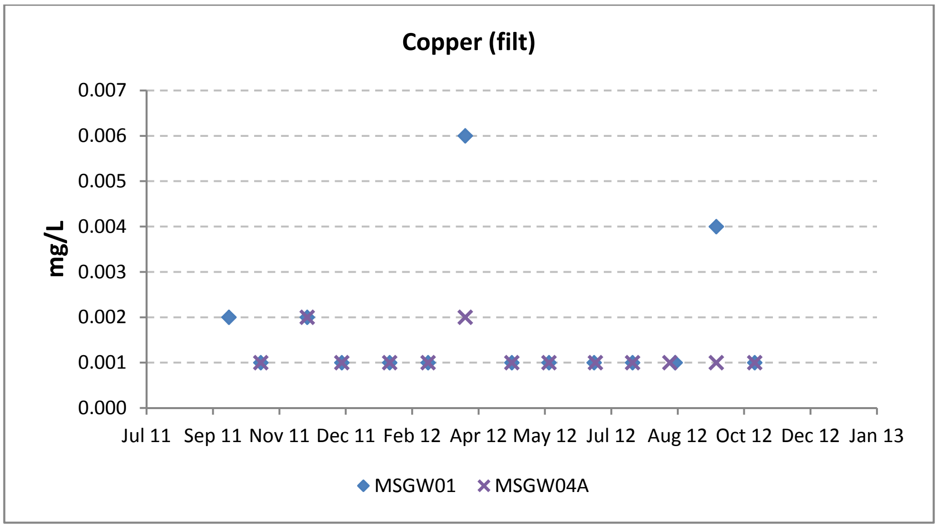
Arsenic (filt)
mg/L
0.004
0.003
0.002
0.001
0.000
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A

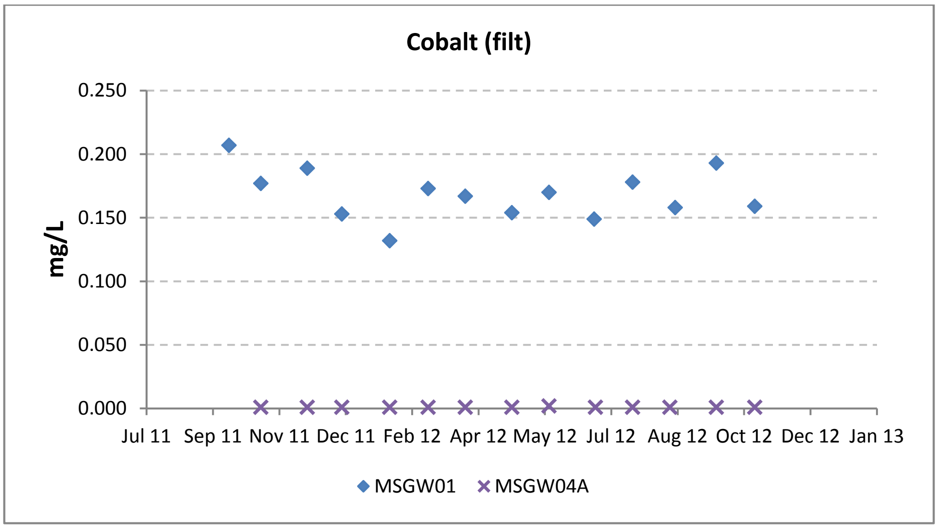



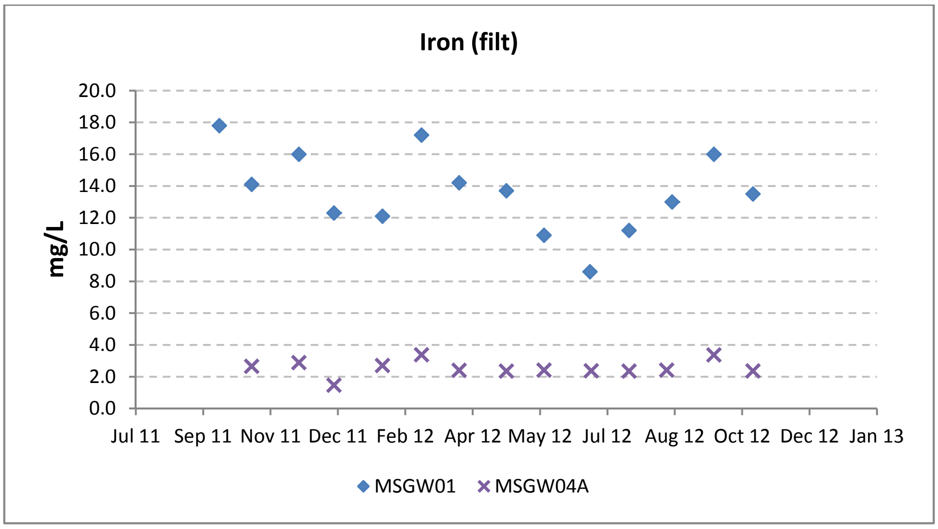
Cadmium (filt)
mg/L
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A

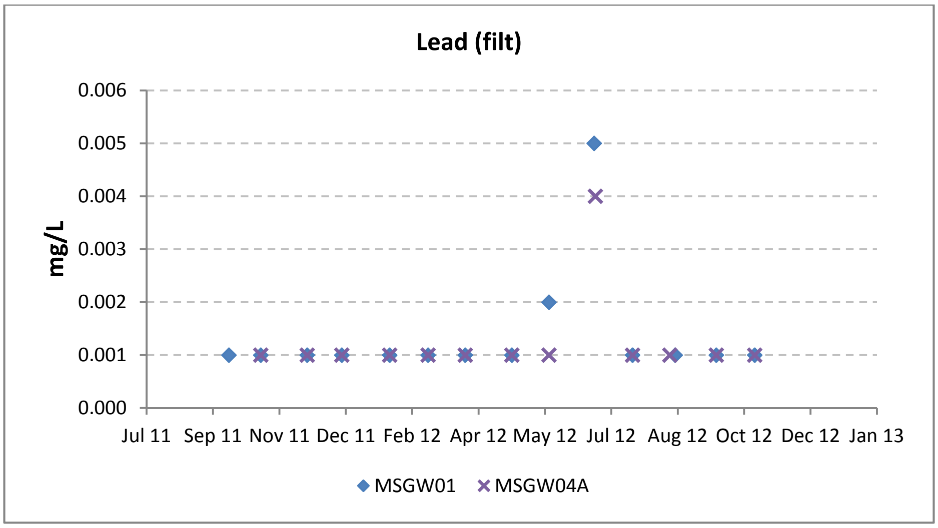



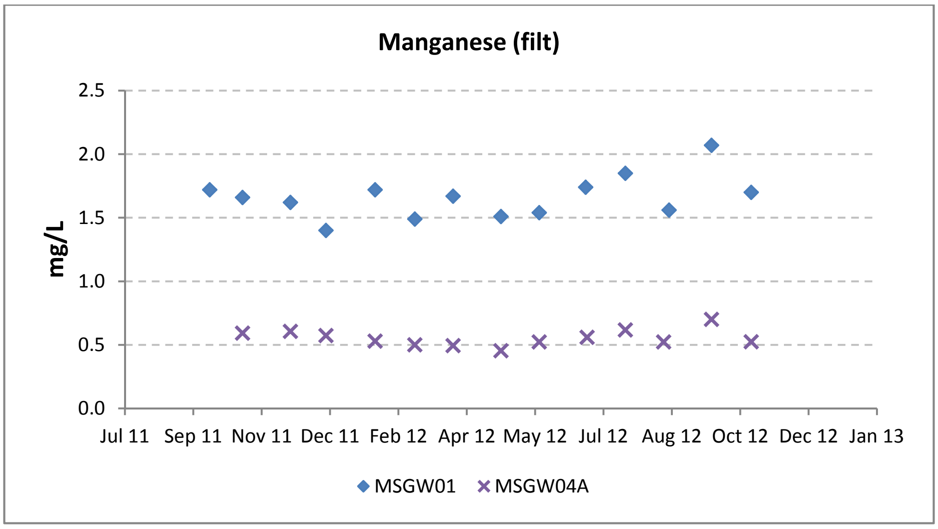
Chromium (filt)
mg/L
0.004
0.003
0.002
0.001
0.000
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A

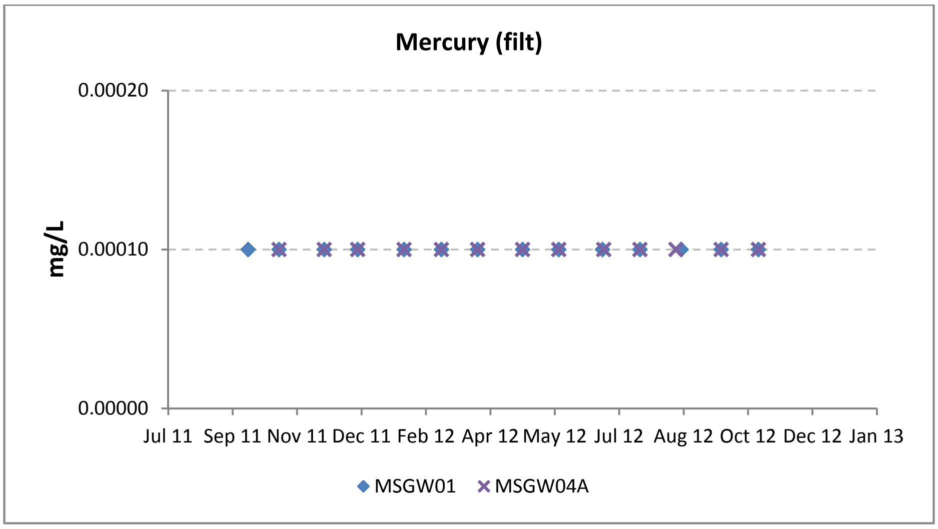

Copper (filt)
mg/L
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Jul 11 Sep 11 Nov 11 Dec 11 Feb 12 Apr 12 May 12 Jul 12 Aug 12 Oct 12 Dec 12 Jan 13
MSGW01 MSGW04A

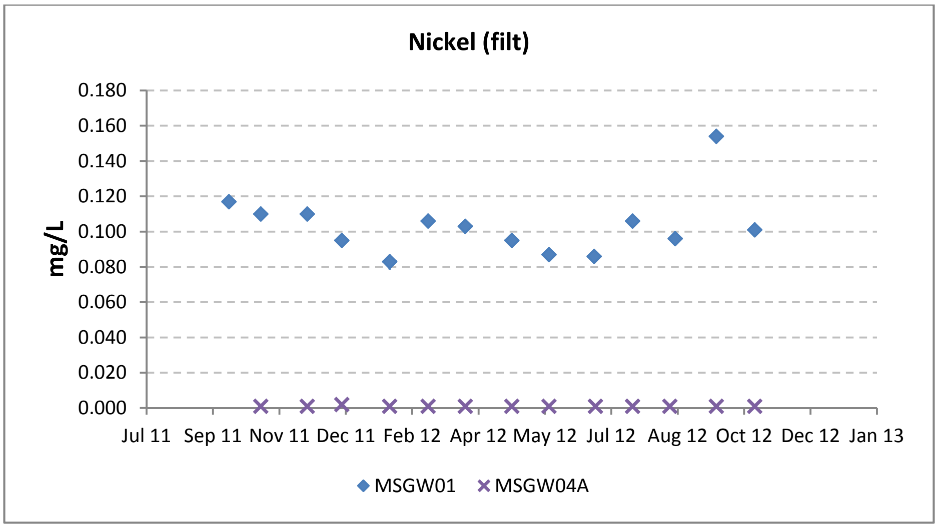

Cobalt (filt)
mg/L
0.250
0.200
0.150
0.100
0.050
0.000
Jul 11 Sep 11 Nov 11 Dec 11 Feb 12 Apr 12 May 12 Jul 12 Aug 12 Oct 12 Dec 12 Jan 13
MSGW01 MSGW04A

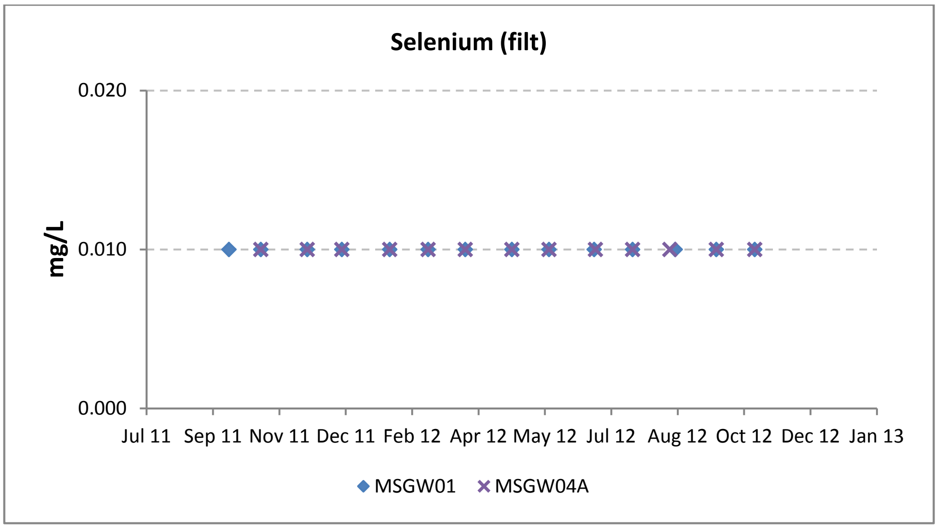

Iron (filt)
mg/L
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jul 11 Sep 11 Nov 11 Dec 11 Feb 12 Apr 12 May 12 Jul 12 Aug 12 Oct 12 Dec 12 Jan 13
MSGW01 MSGW04A

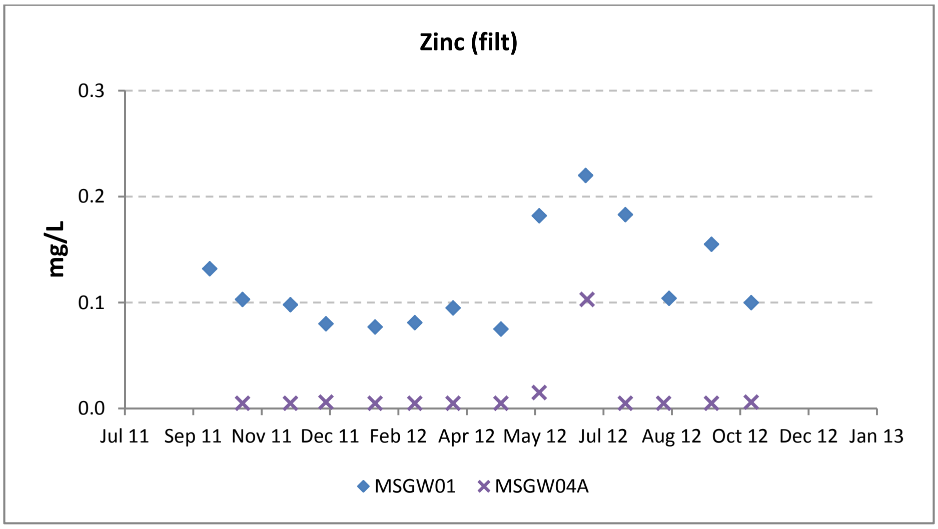

Lead (filt)
mg/L
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Jul 11 Sep 11 Nov 11 Dec 11 Feb 12 Apr 12 May 12 Jul 12 Aug 12 Oct 12 Dec 12 Jan 13
MSGW01 MSGW04A


Manganese (filt)
mg/L
2.5
2.0
1.5
1.0
0.5
0.0
Jul 11 Sep 11 Nov 11 Dec 11 Feb 12 Apr 12 May 12 Jul 12 Aug 12 Oct 12 Dec 12 Jan 13
MSGW01 MSGW04A

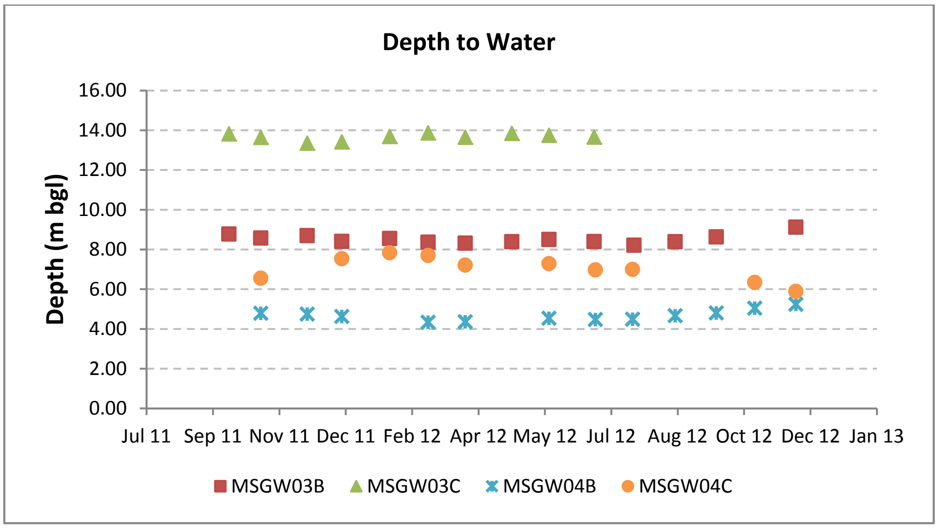

Mercury (filt)
mg/L
0.00020
0.00010
0.00000
Jul 11 Sep 11 Nov 11 Dec 11 Feb 12 Apr 12 May 12 Jul 12 Aug 12 Oct 12 Dec 12 Jan 13
MSGW01 MSGW04A

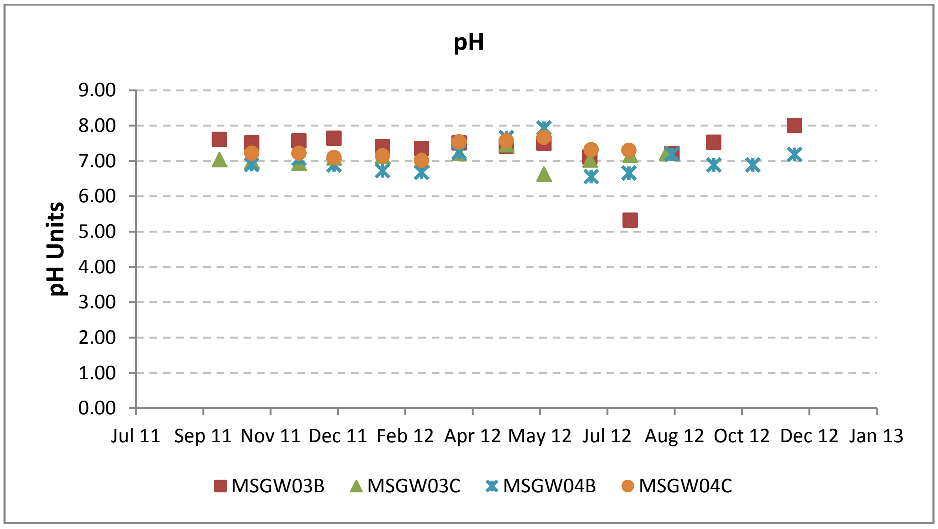

Nickel (filt)
mg/L
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A

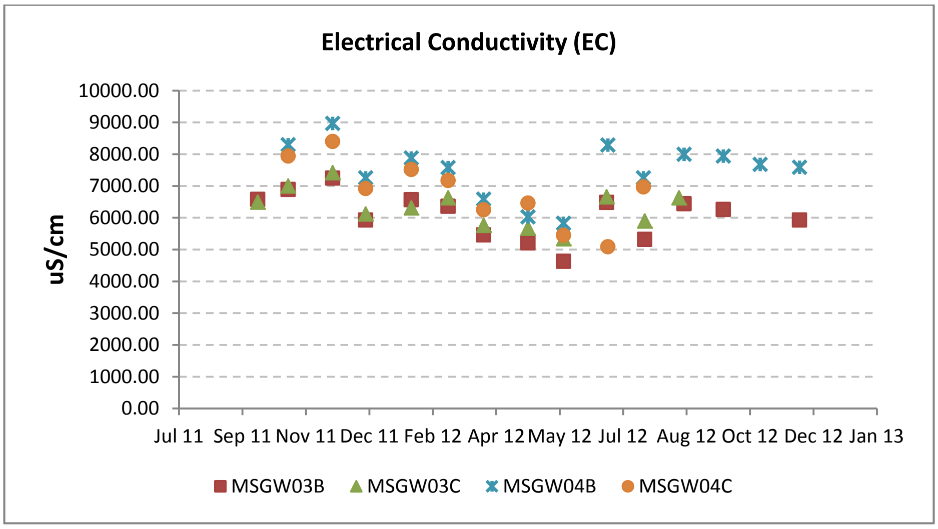

Selenium (filt)
mg/L
0.020
0.010
0.000
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A


Zinc (filt)
mg/L
0.3
0.2
0.1
0.0
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
Jan 13
MSGW01
MSGW04A

**Deeper Groundwater**

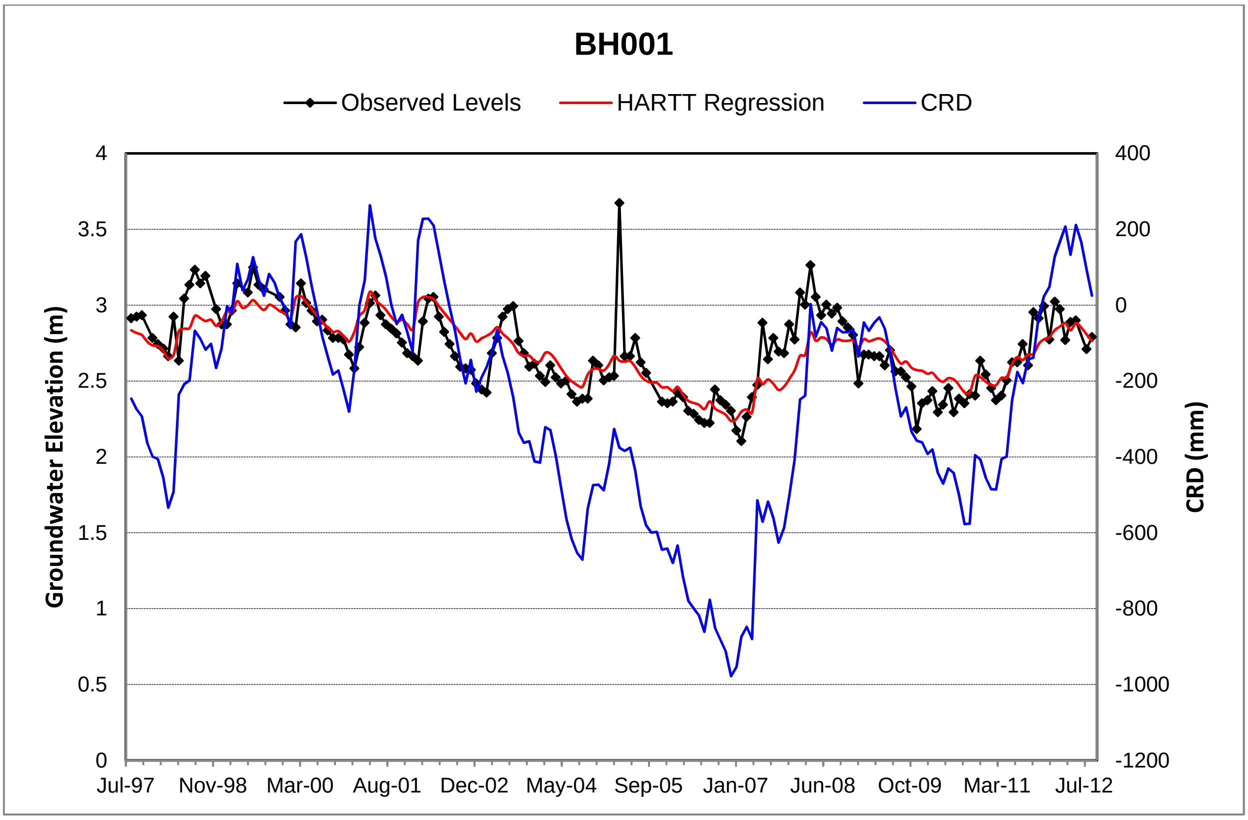


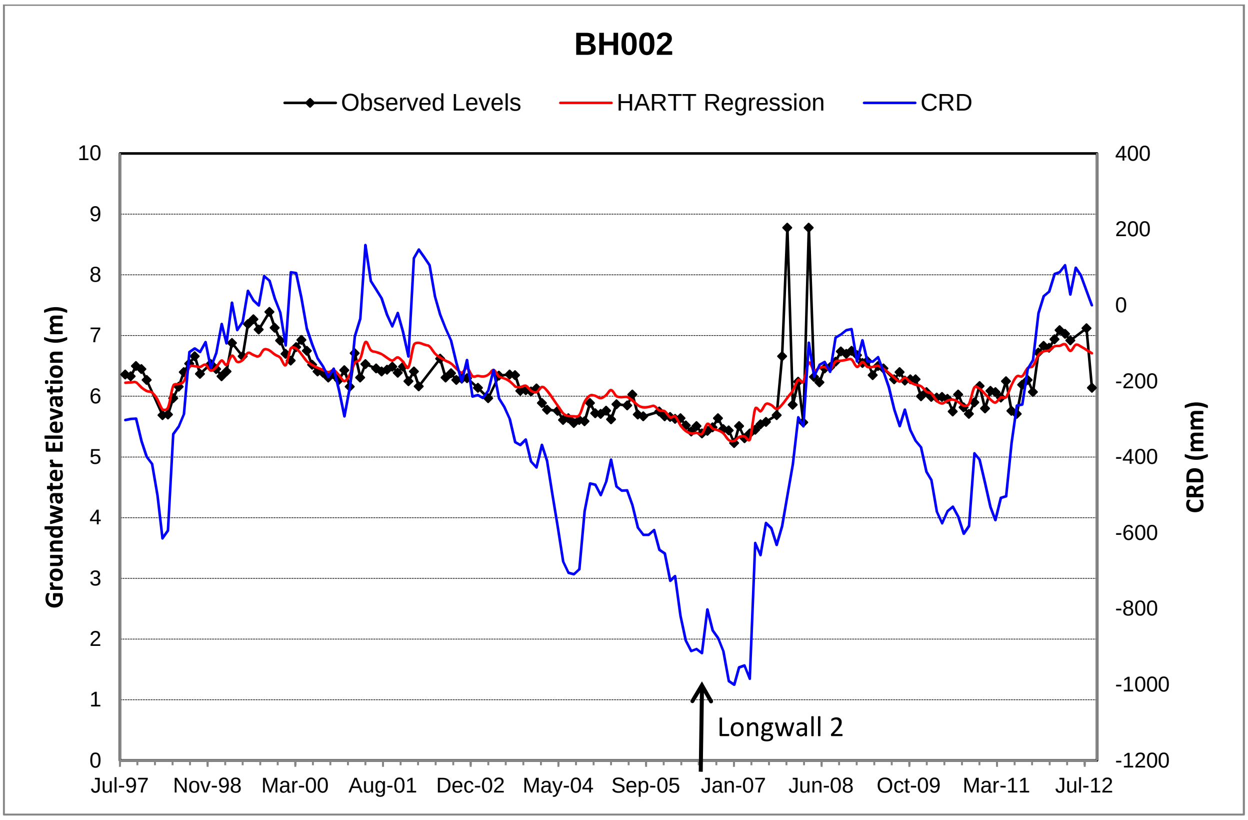



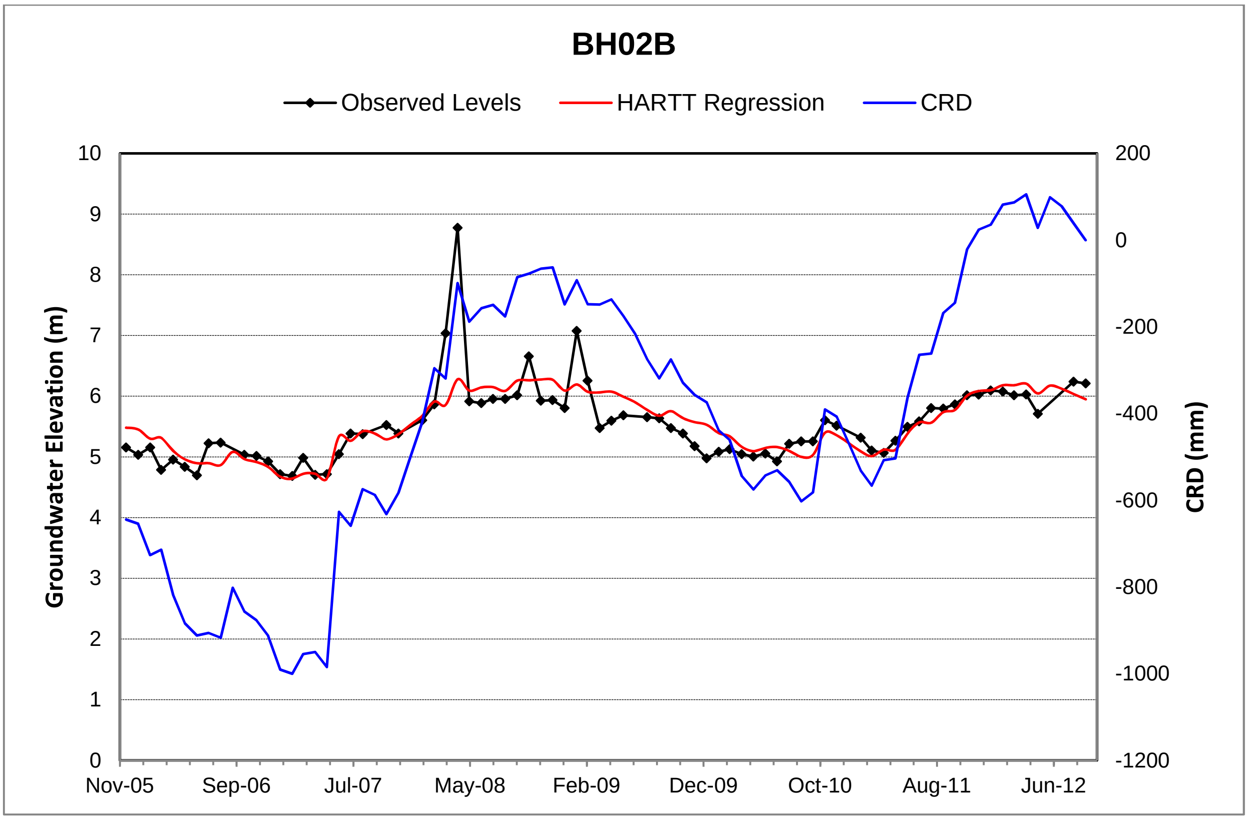



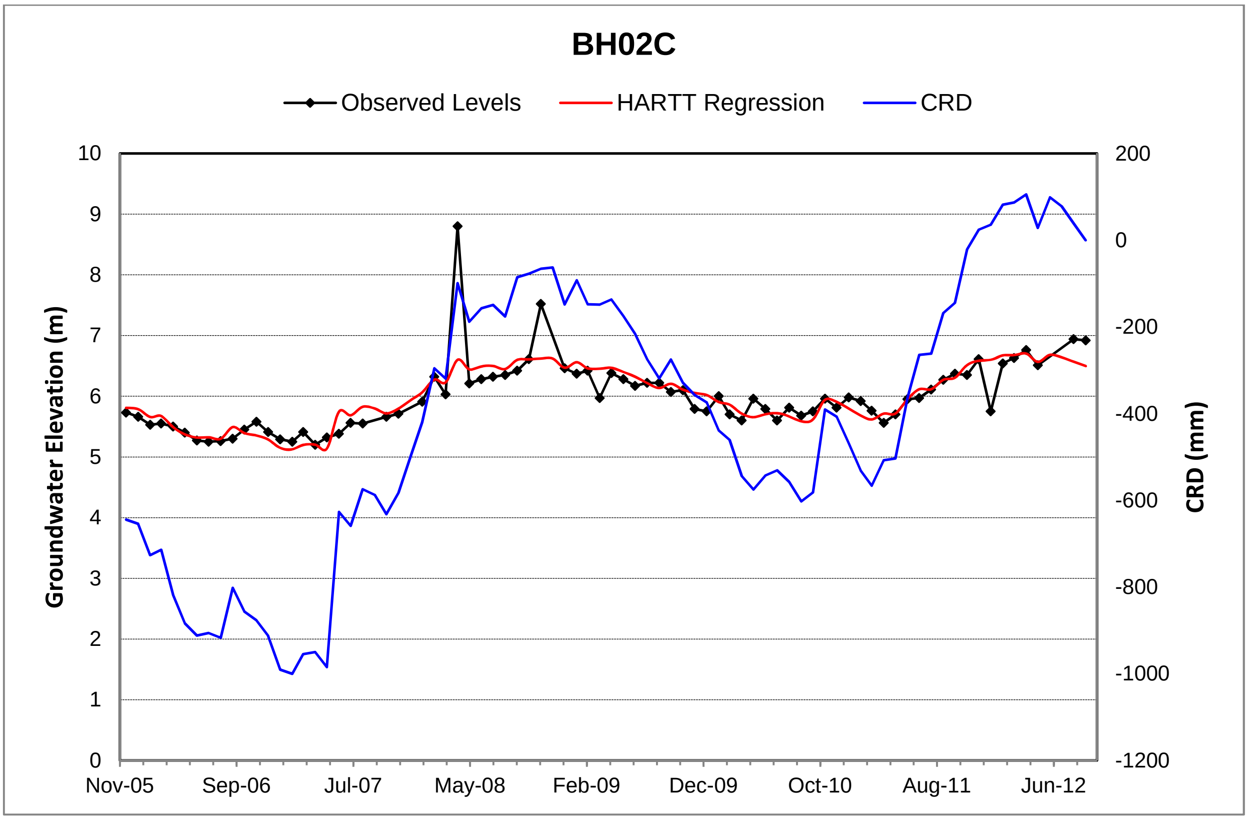
Appendix B

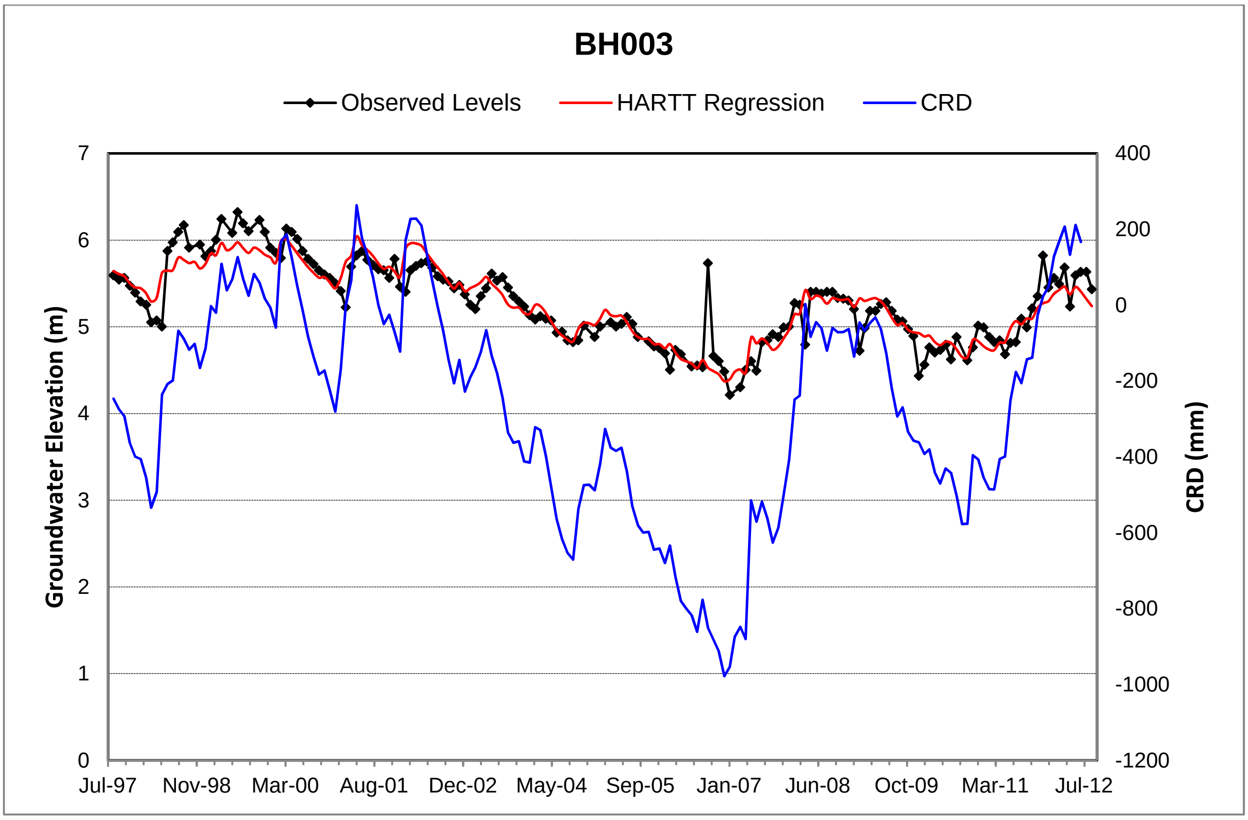
# Groundwater Hydrographs – Mandalong Alluvial Bores

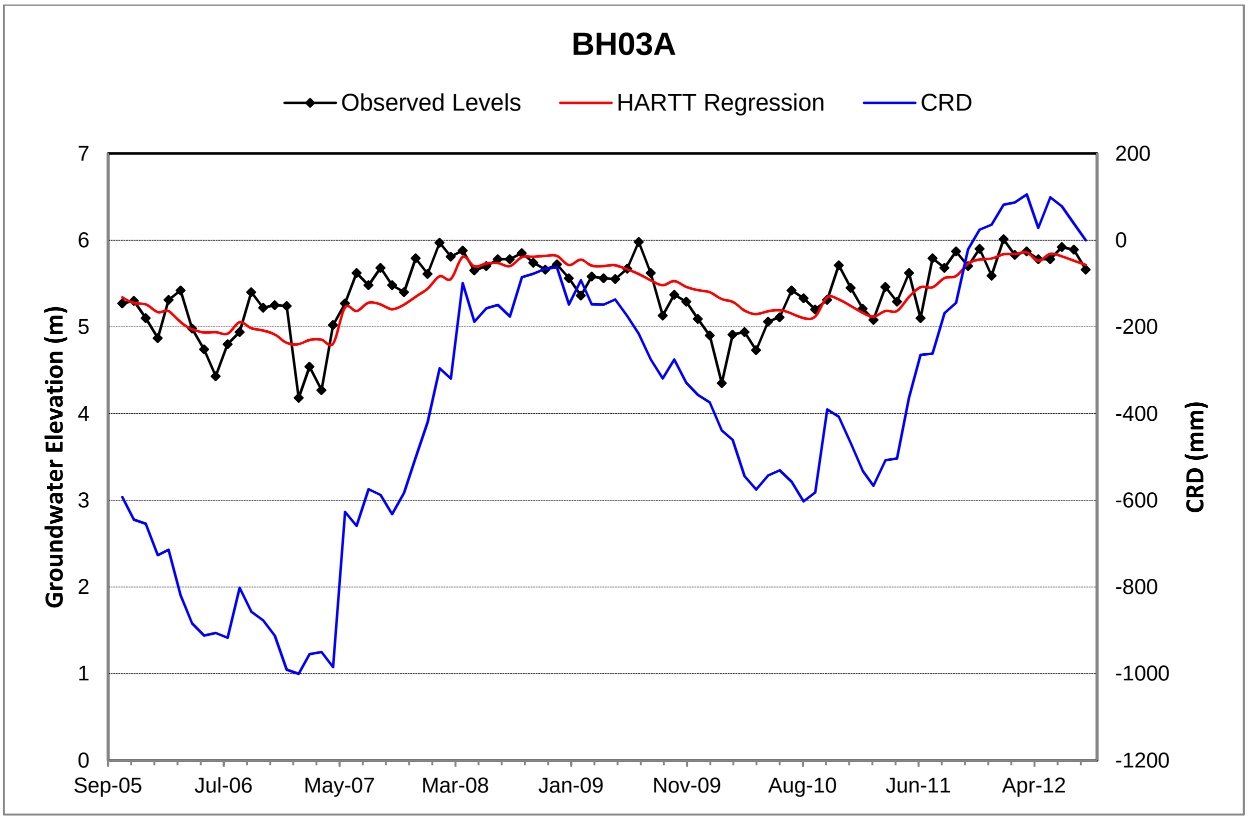

BH001
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
4
3.5
3
2.5
2
1.5
1
0.5
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

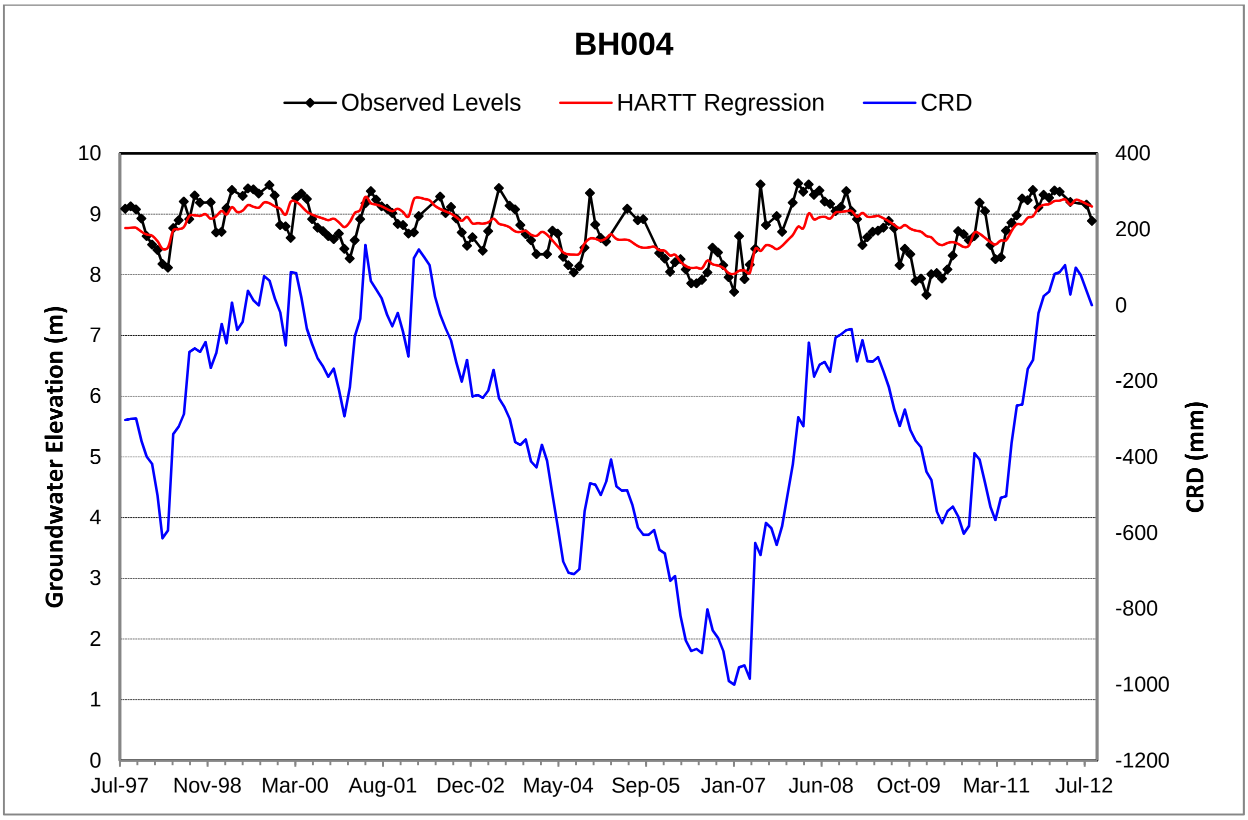

BH002
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
10
9
8
7
6
5
4
3
2
1
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 2
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

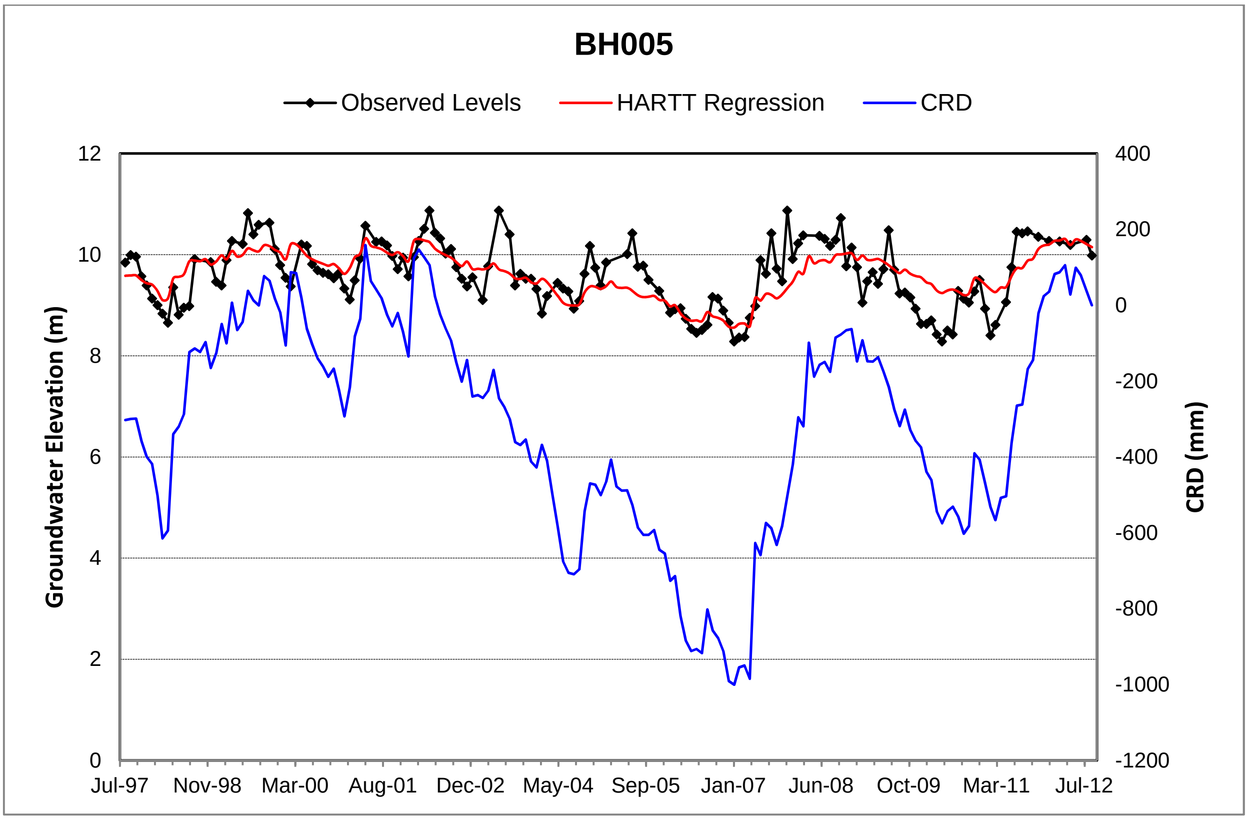

BH02B
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
10
9
8
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Nov-05
Sep-06
Jul-07
May-08
Feb-09
Dec-09
Oct-10
Aug-11
Jun-12

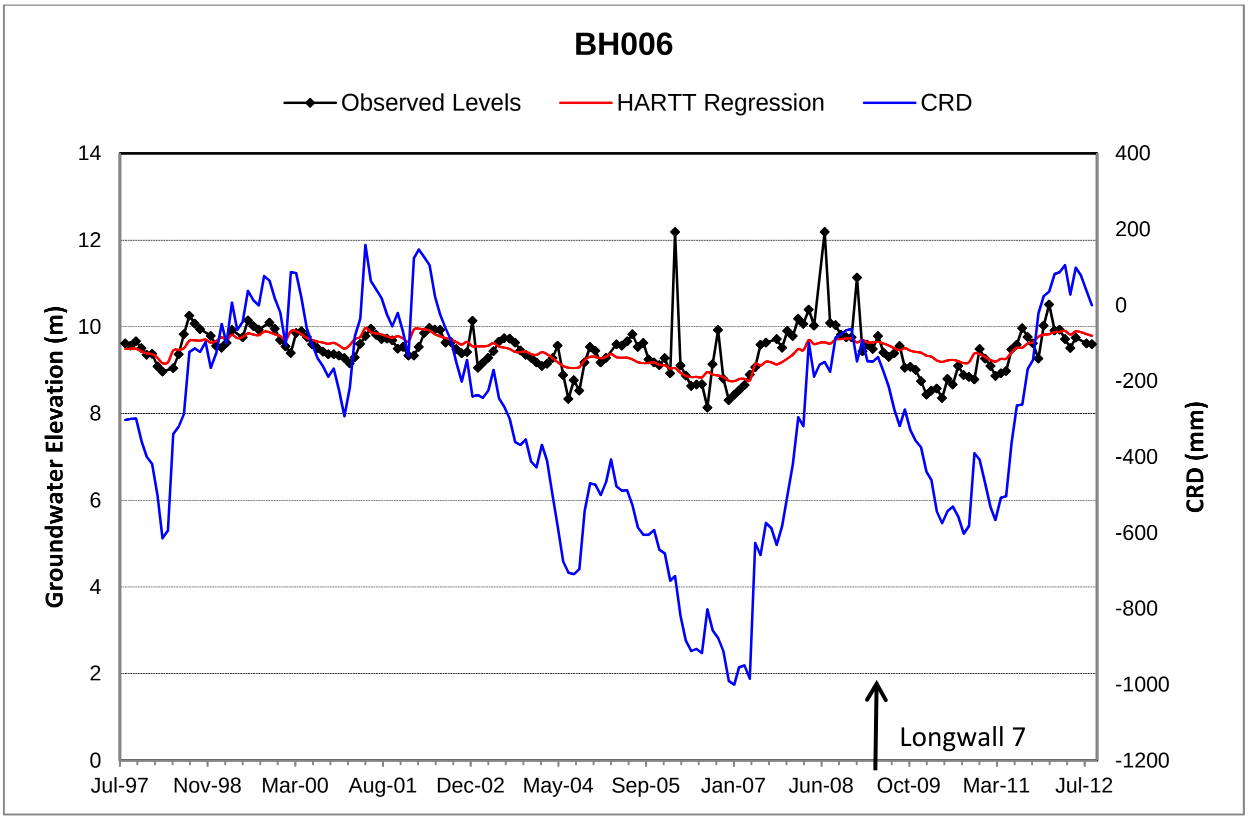

BH02C
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
10
9
8
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Nov-05
Sep-06
Jul-07
May-08
Feb-09
Dec-09
Oct-10
Aug-11
Jun-12

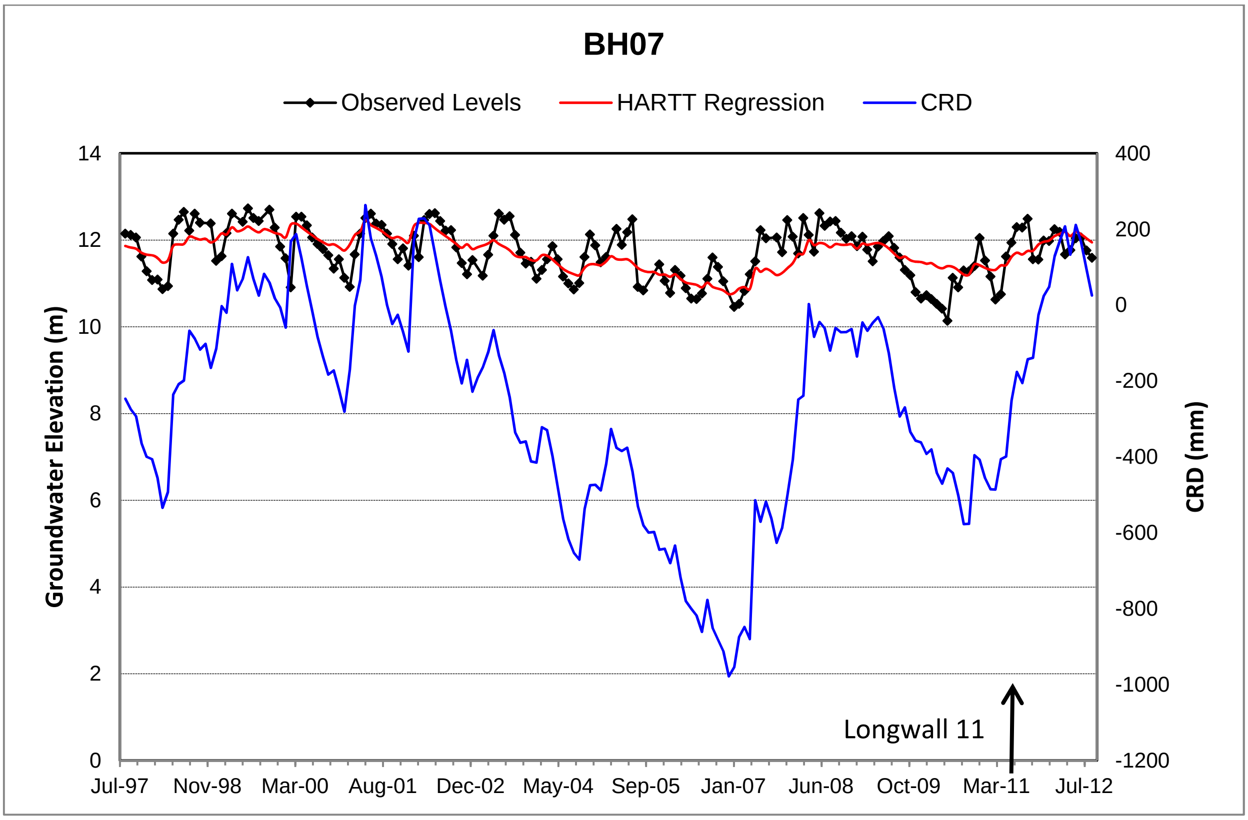

BH003
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
7
6
5
4
3
2
1
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

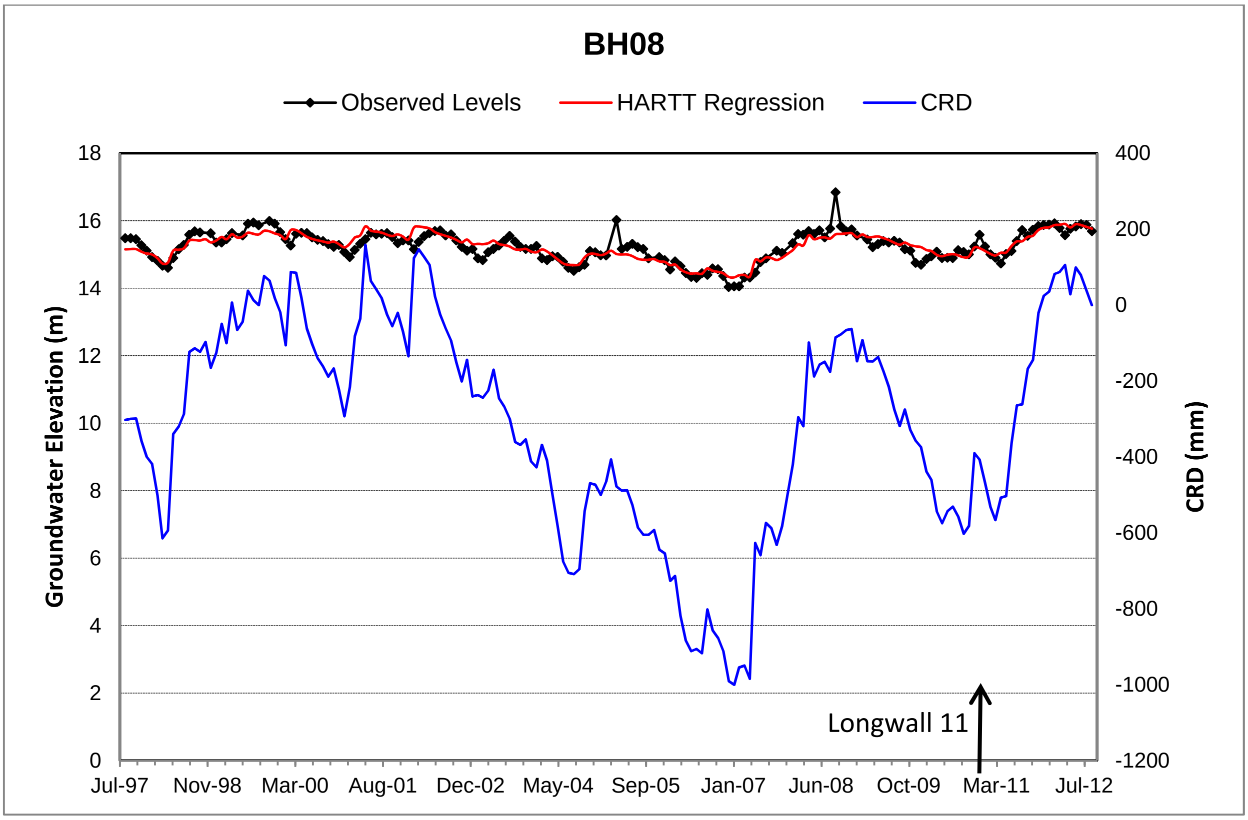

BH03A
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Sep-05
Jul-06
May-07
Mar-08
Jan-09
Nov-09
Aug-10
Jun-11
Apr-12

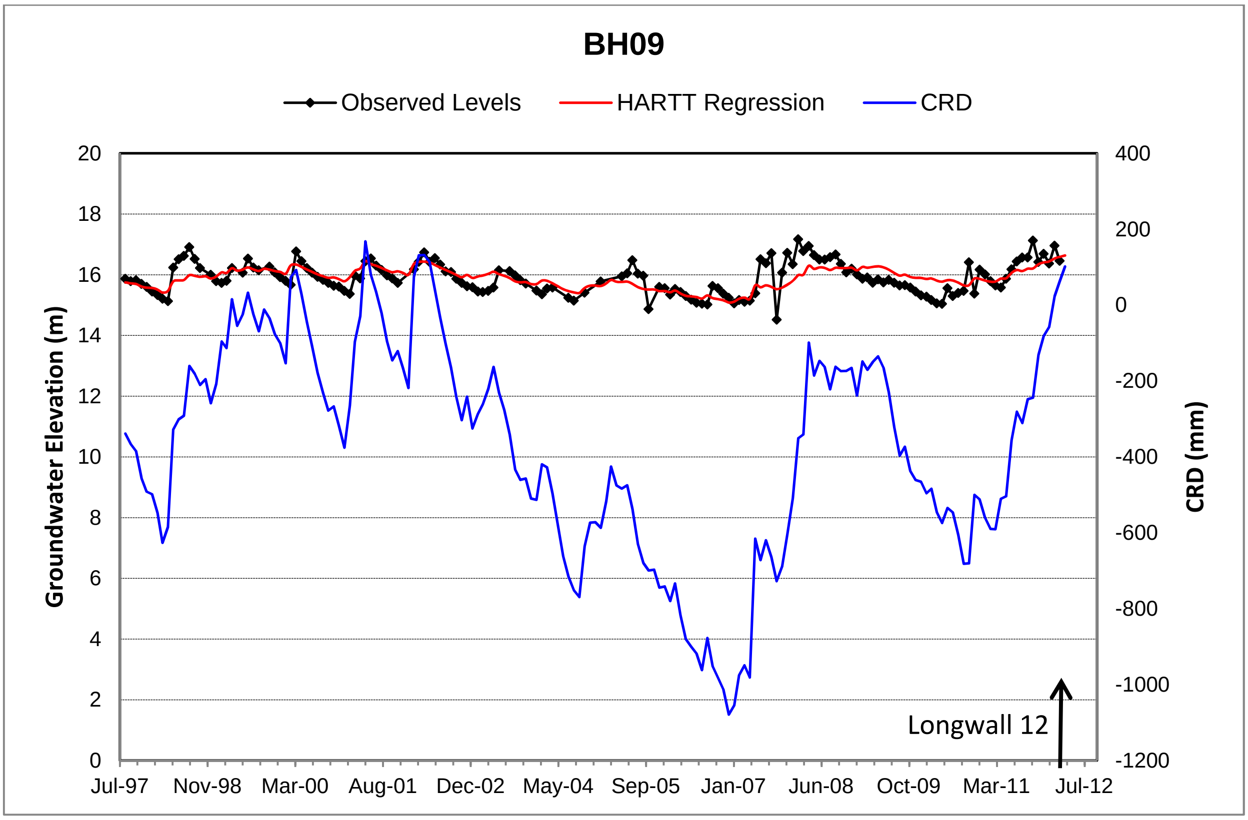

BH004
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
10
9
8
7
6
5
4
3
2
1
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

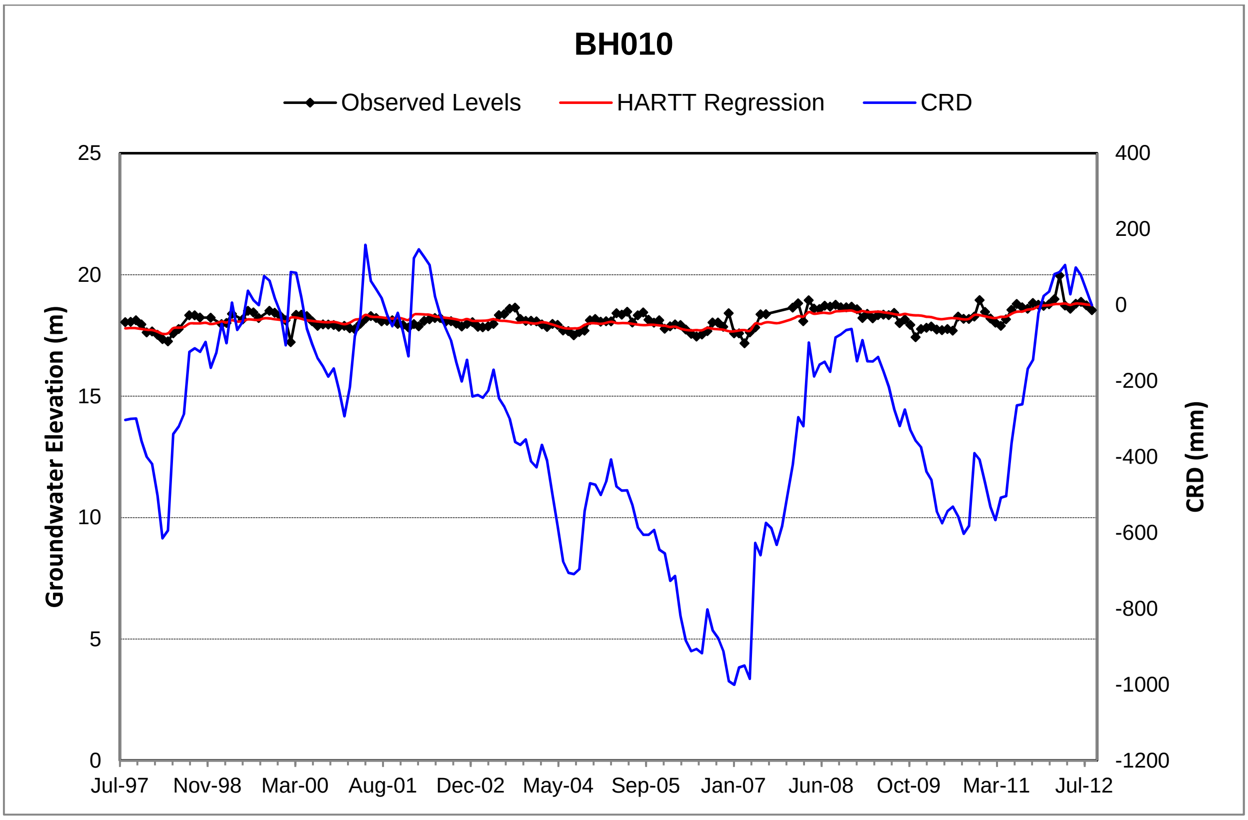

BH005
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

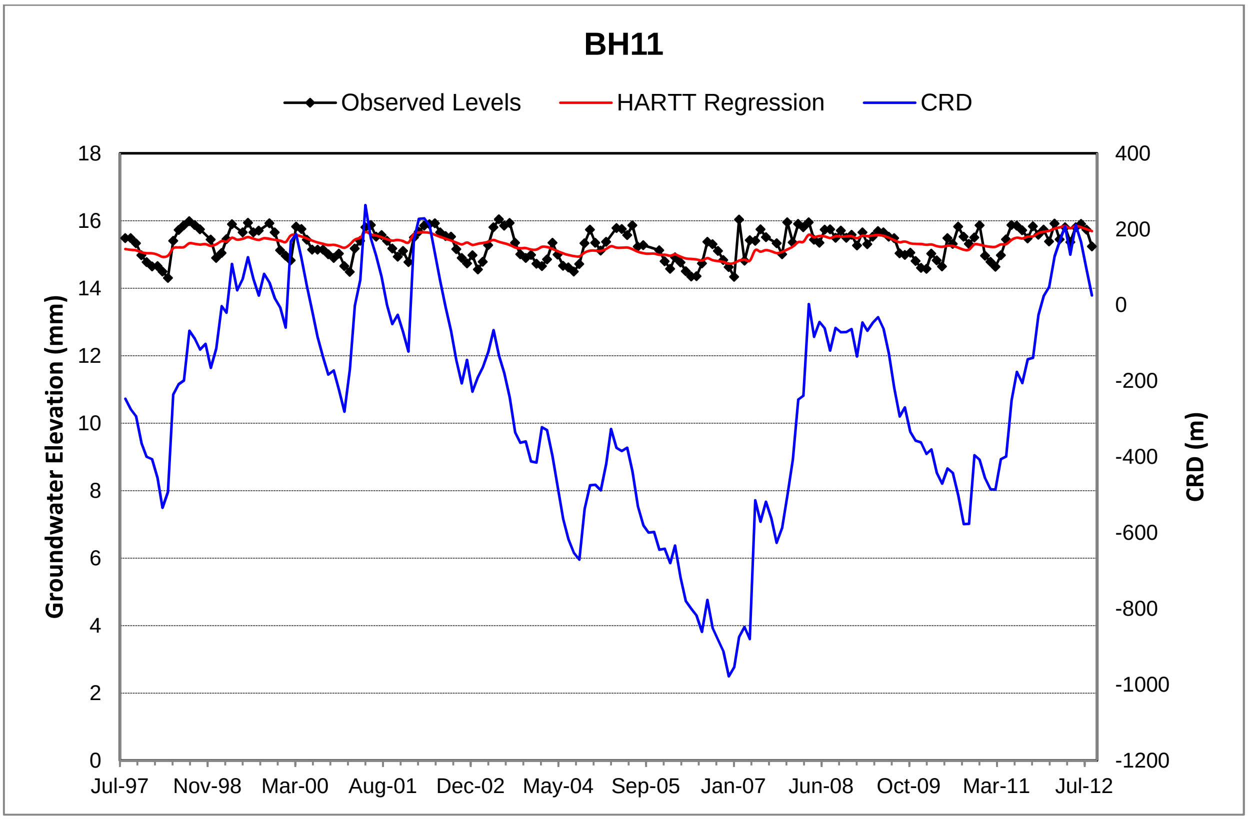

BH006
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 7
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

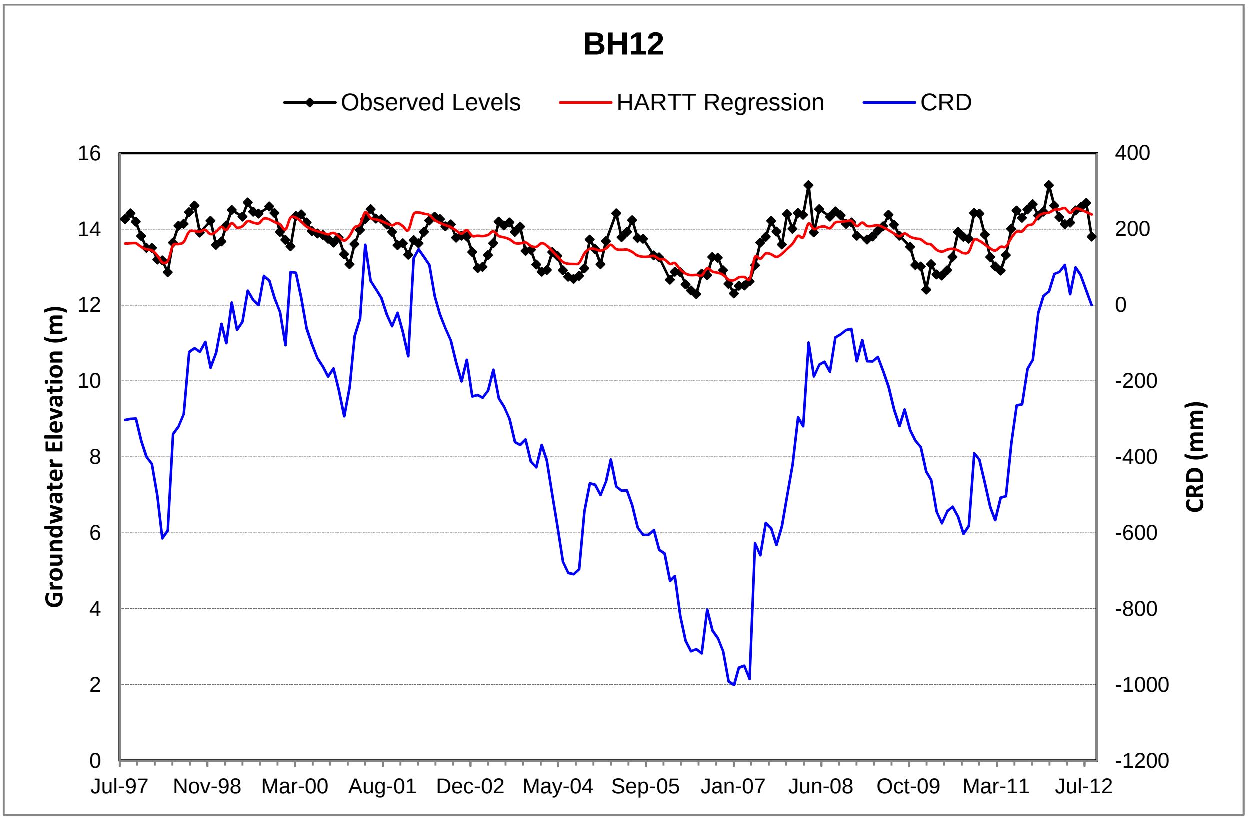

BH07
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 11
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

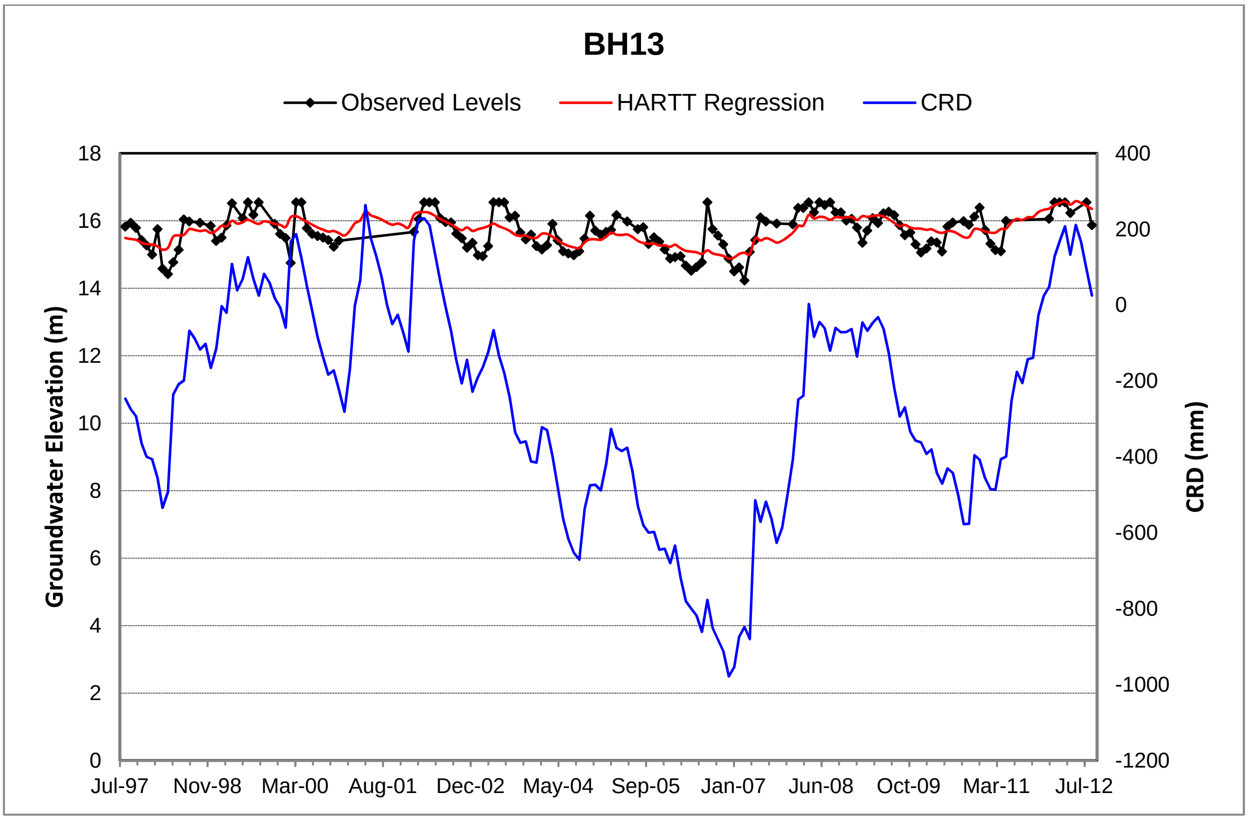

BH08
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
18
16
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 11
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

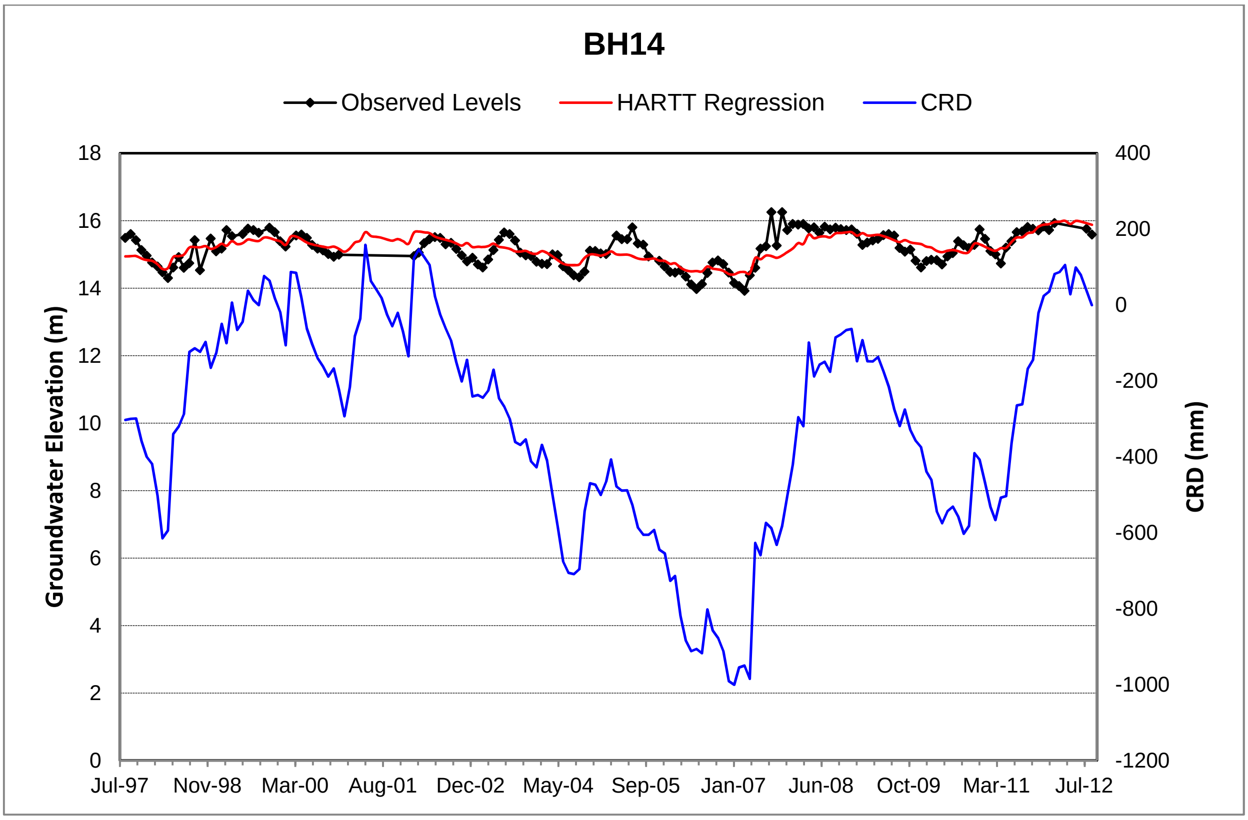

BH09
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
20
18
16
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 12
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

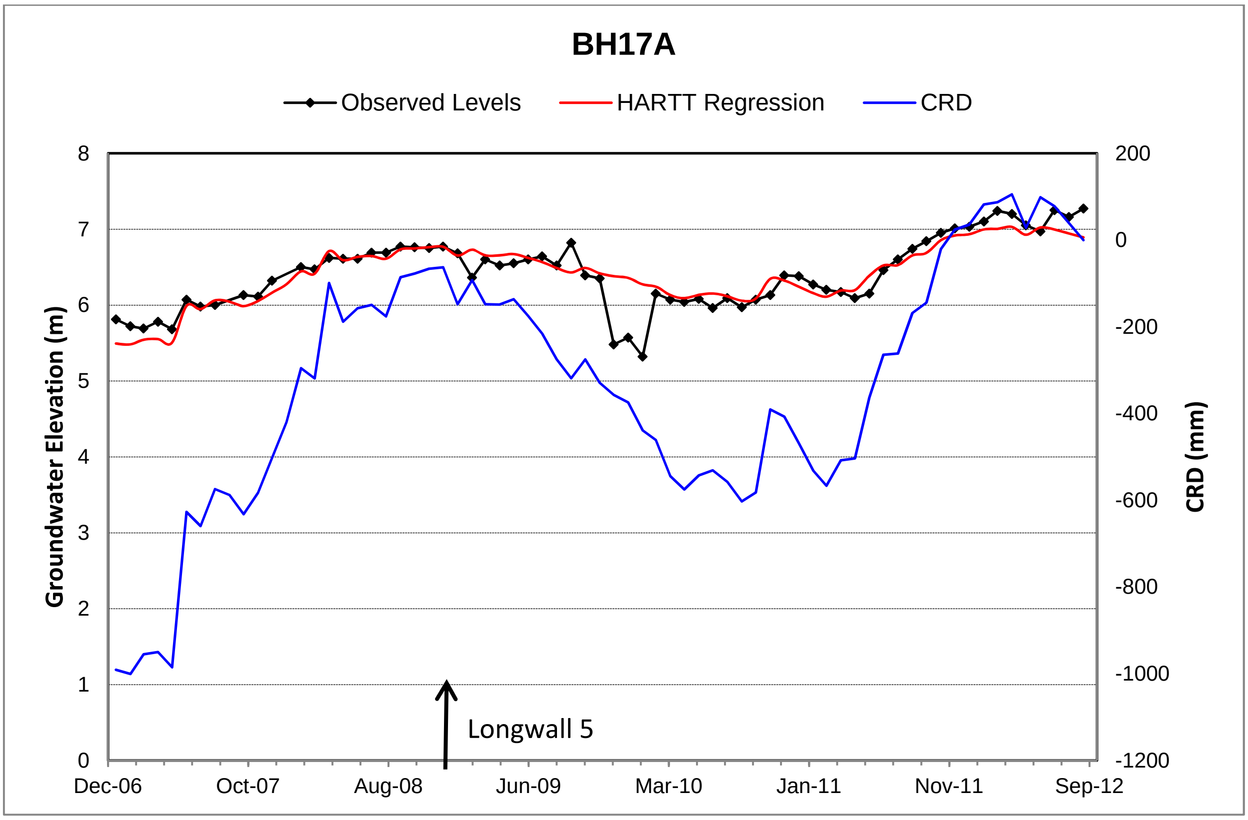

BH010
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
25
20
15
10
5
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

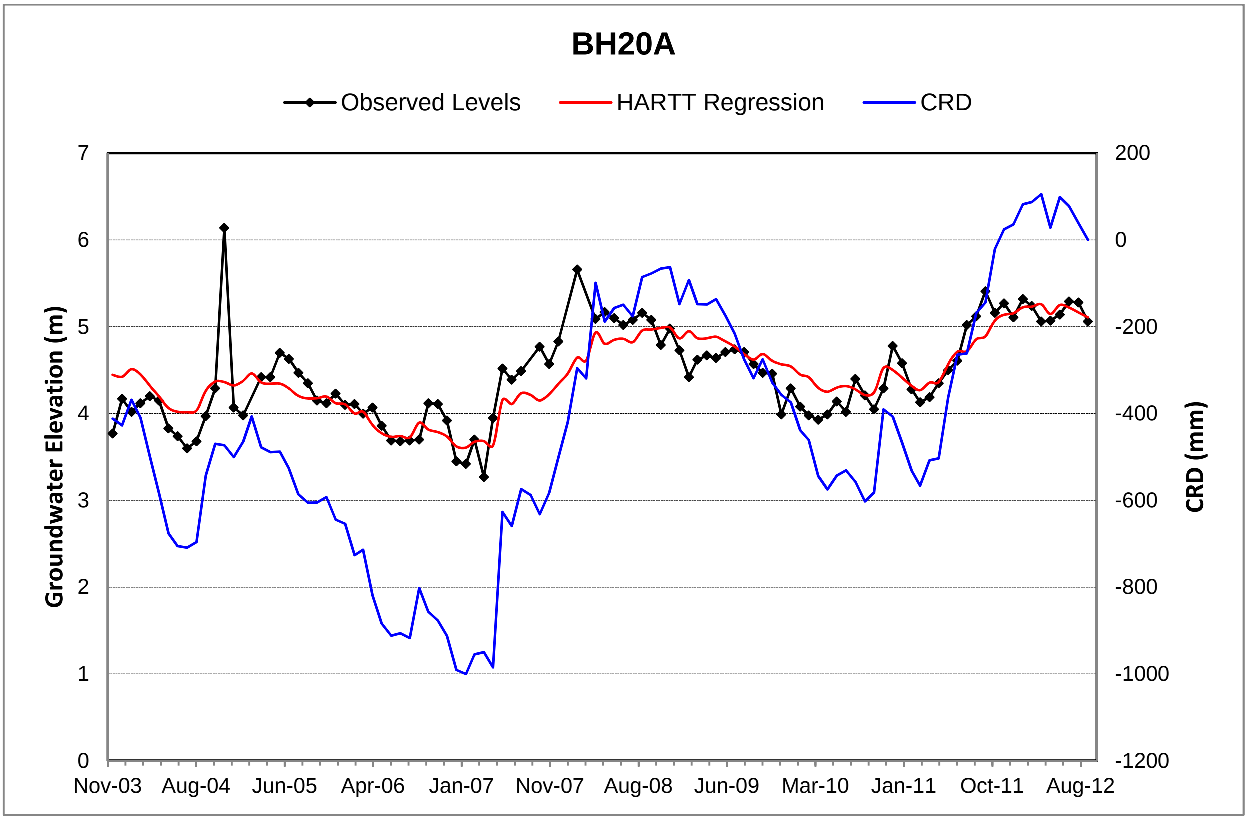

BH11
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (mm)
CRD (m)
18
16
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

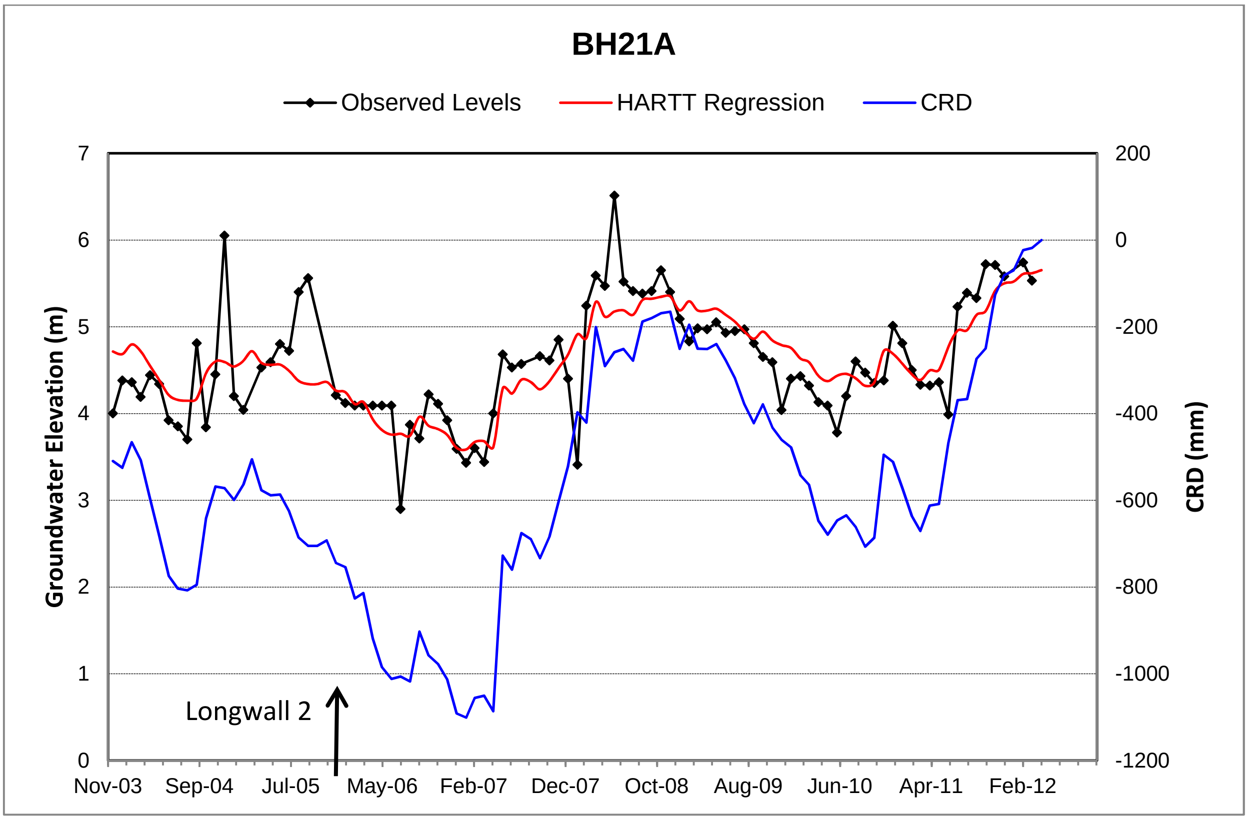

BH12
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
16
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

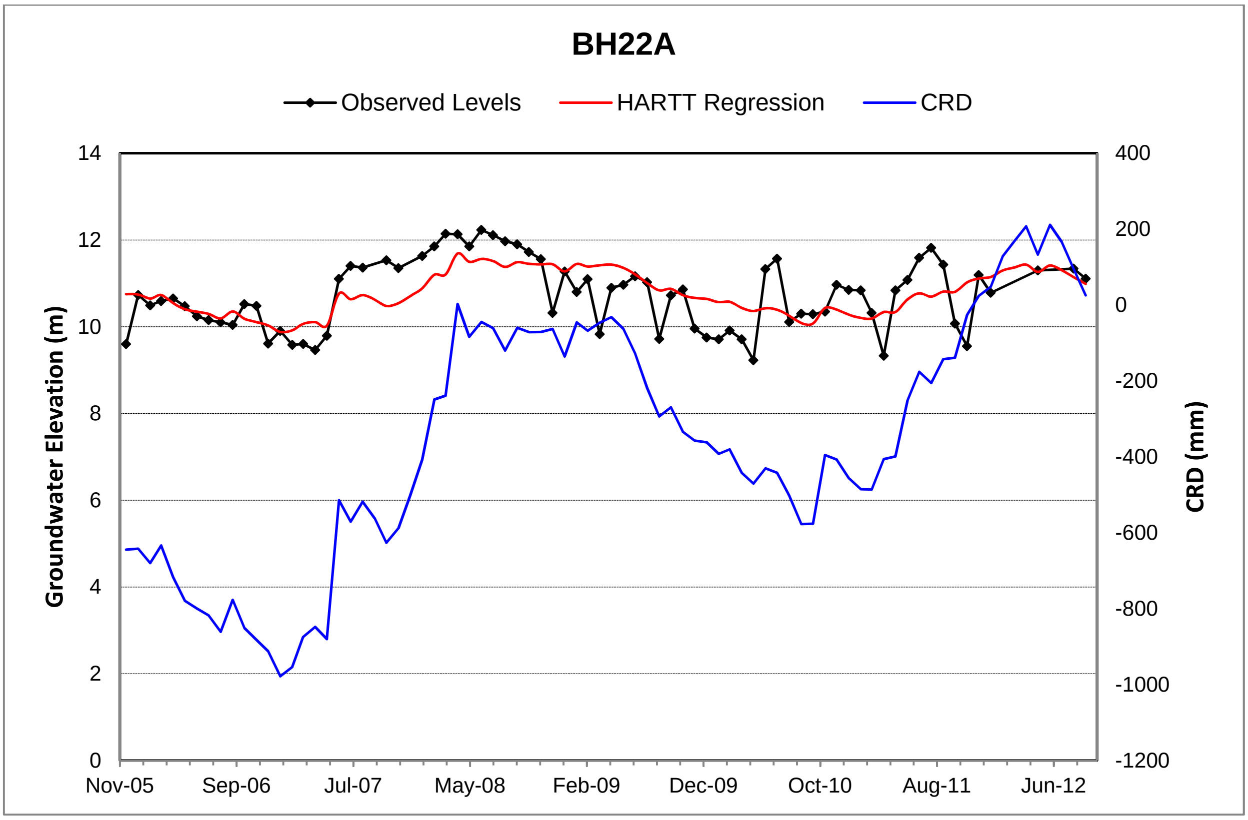

BH13
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
18
16
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

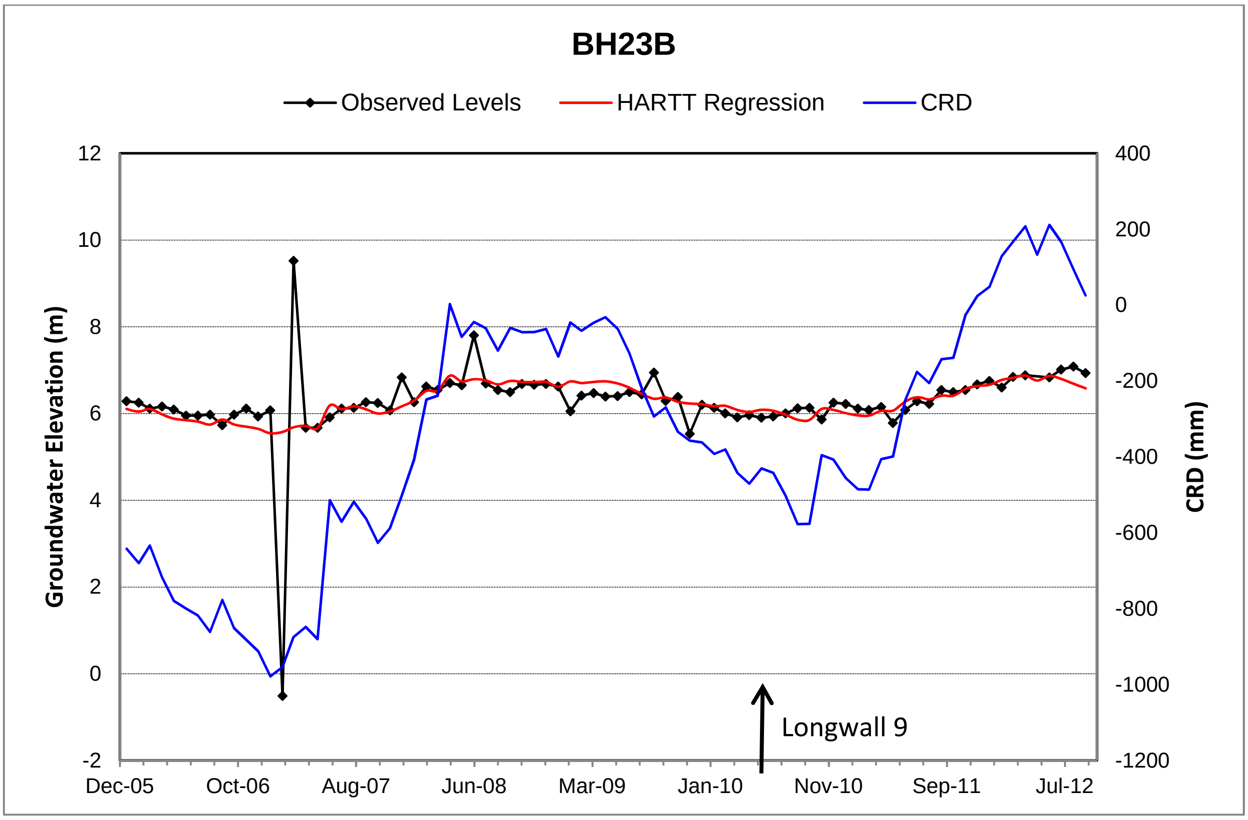

BH14
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
18
16
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12

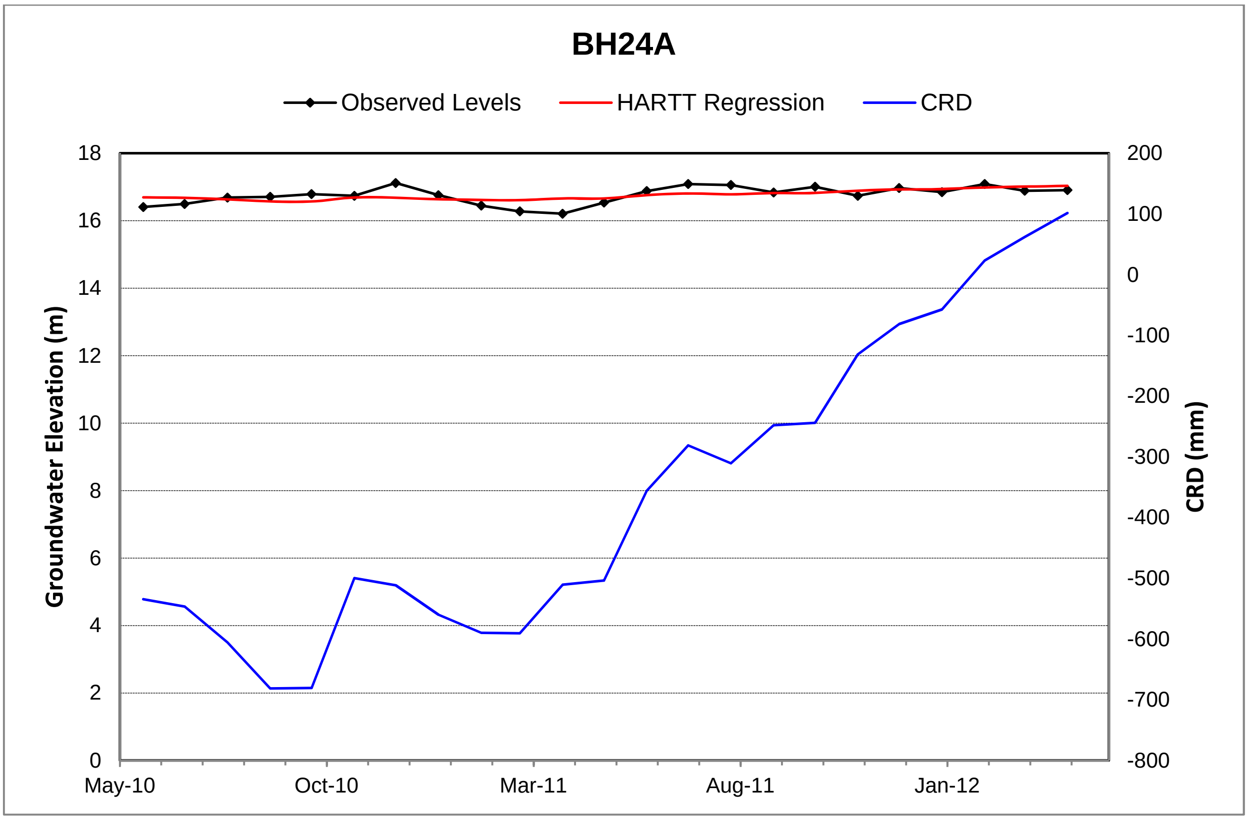

BH17A
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
8
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 5
Dec-06
Oct-07
Aug-08
Jun-09
Mar-10
Jan-11
Nov-11
Sep-12

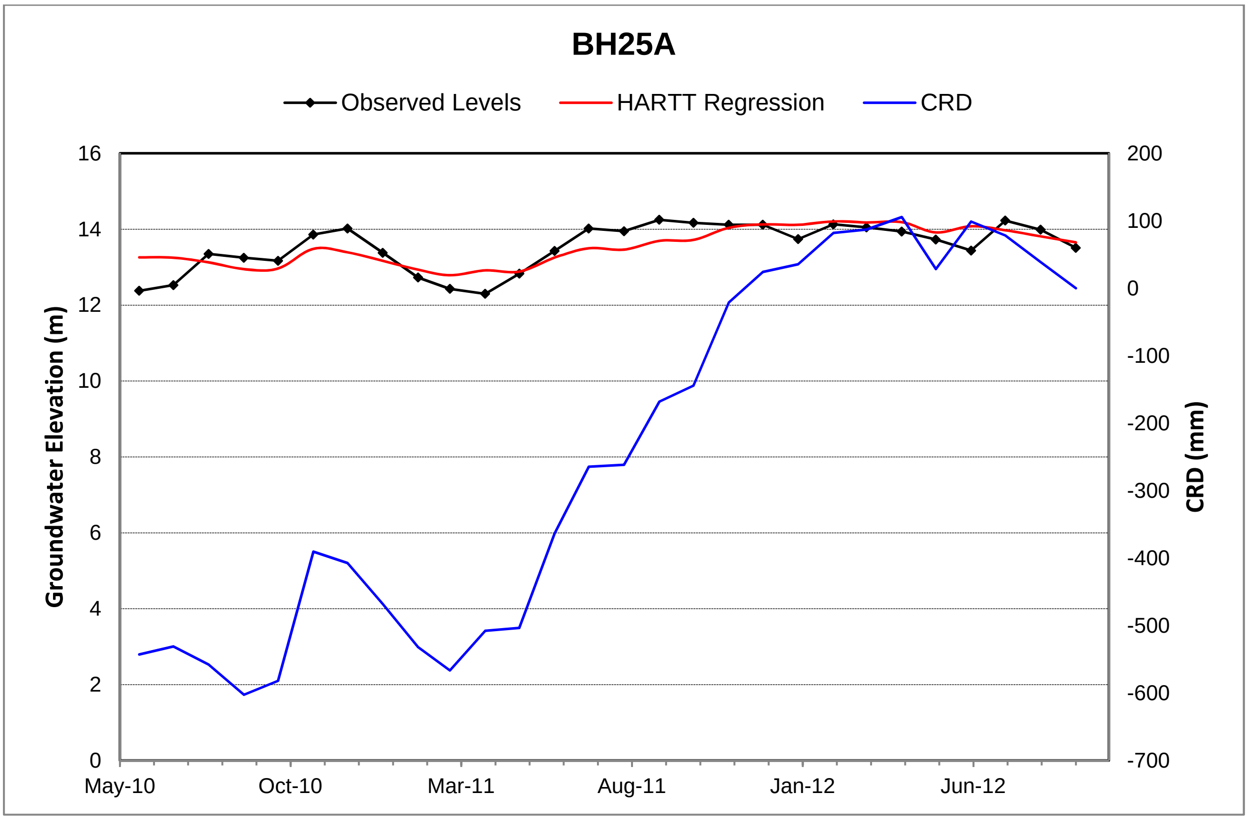

BH20A
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Nov-03
Aug-04
Jun-05
Apr-06
Jan-07
Nov-07
Aug-08
Jun-09
Mar-10
Jan-11
Oct-11
Aug-12


BH21A
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
Longwall 2
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Nov-03
Sep-04
Jul-05
May-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12


BH22A
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
14
12
10
8
6
4
2
0
400
200
0
-200
-400
-600
-800
-1000
-1200
Nov-05
Sep-06
Jul-07
May-08
Feb-09
Dec-09
Oct-10
Aug-11
Jun-12

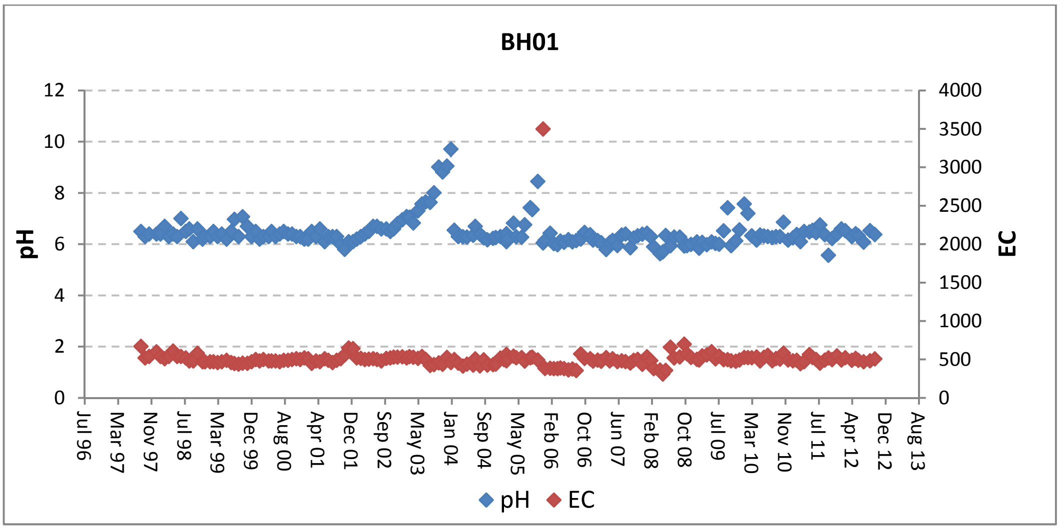

BH23B
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
CRD (mm)
12
10
8
6
4
2
0
-2
400
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 9
Dec-05
Oct-06
Aug-07
Jun-08
Mar-09
Jan-10
Nov-10
Sep-11
Jul-12

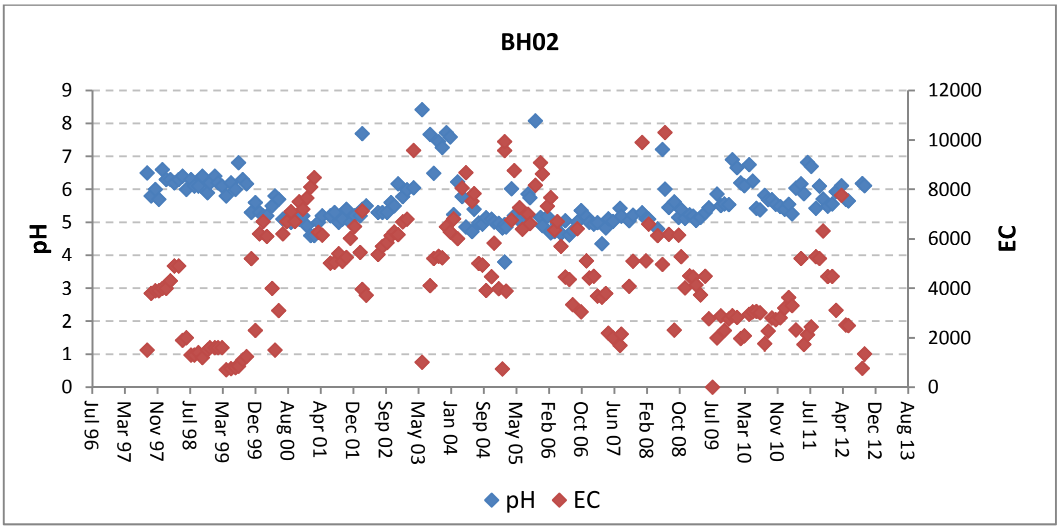

BH24A
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
18
16
14
12
10
8
6
4
2
0
CRD (mm)
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
May-10
Oct-10
Mar-11
Aug-11
Jan-12

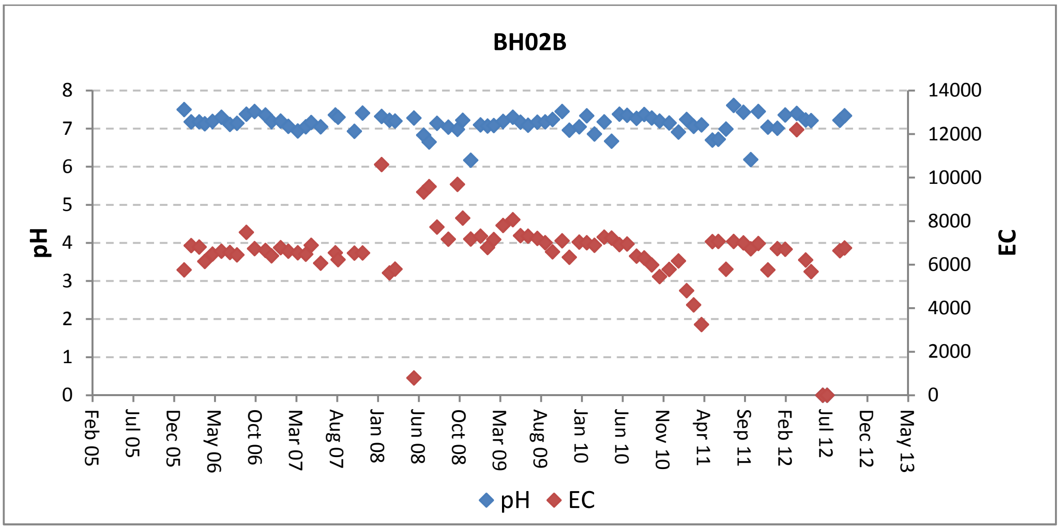

BH25A
Observed Levels
HARTT Regression
CRD
Groundwater Elevation (m)
16
14
12
10
8
6
4
2
0
CRD (mm)
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12

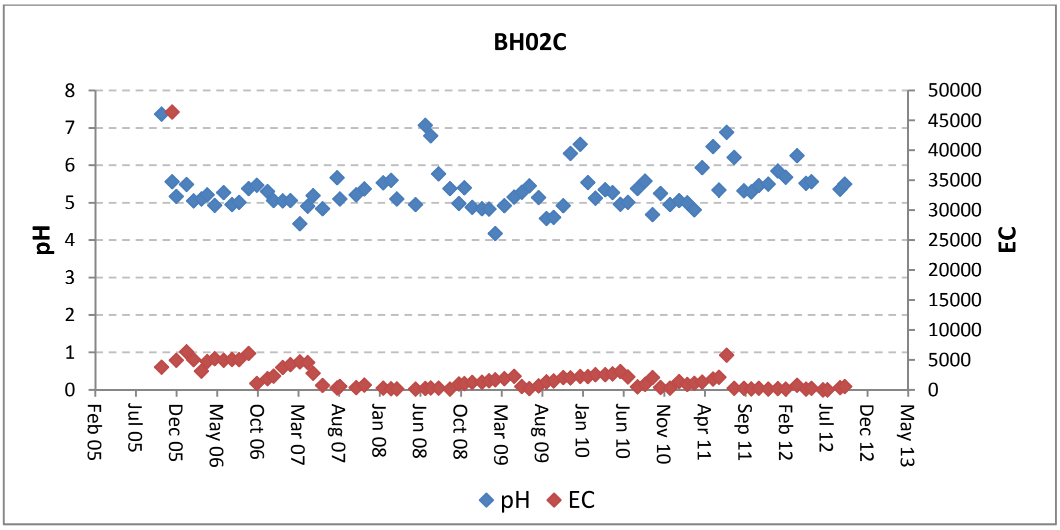
Appendix C

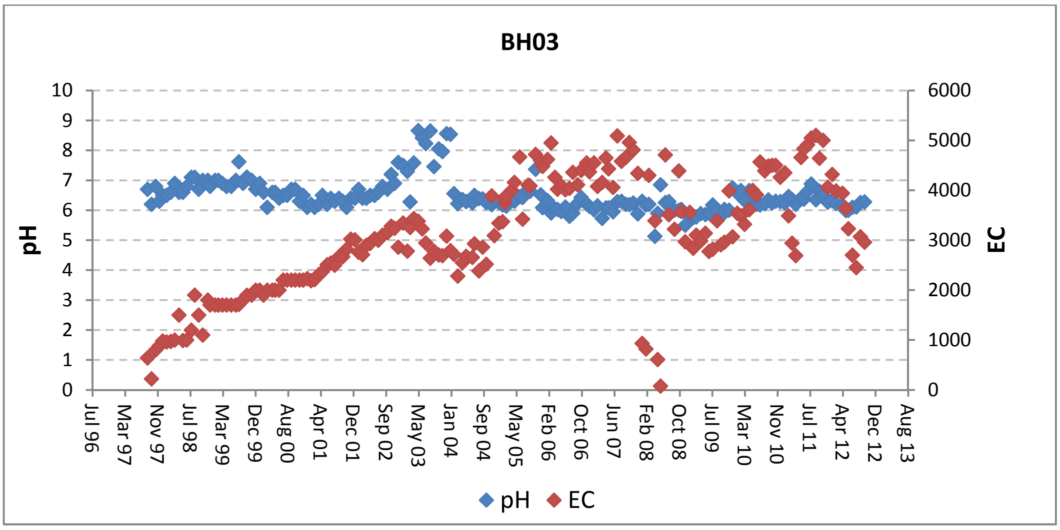
# Groundwater pH and EC – Mandalong Alluvial Bores

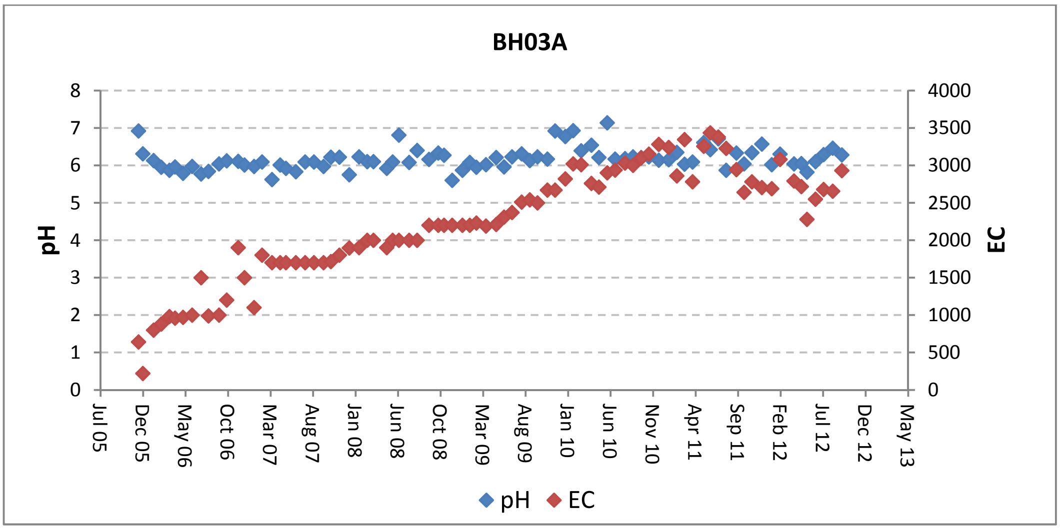

BH01
pH
EC
12
10
8
6
4
2
0
4000
3500
3000
2500
2000
1500
1000
500
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH EC

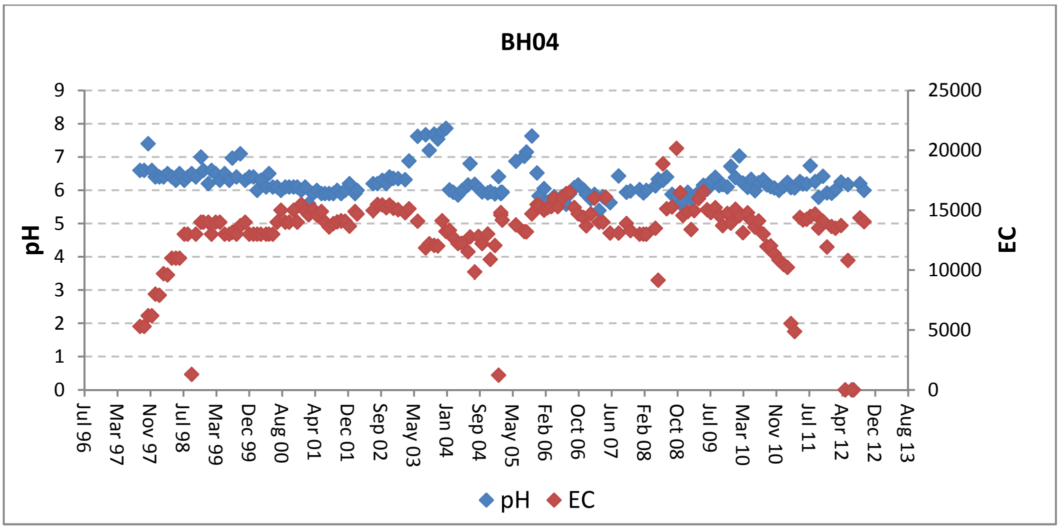

BH02
pH
EC
9
8
7
6
5
4
3
2
1
0
12000
10000
8000
6000
4000
2000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH EC

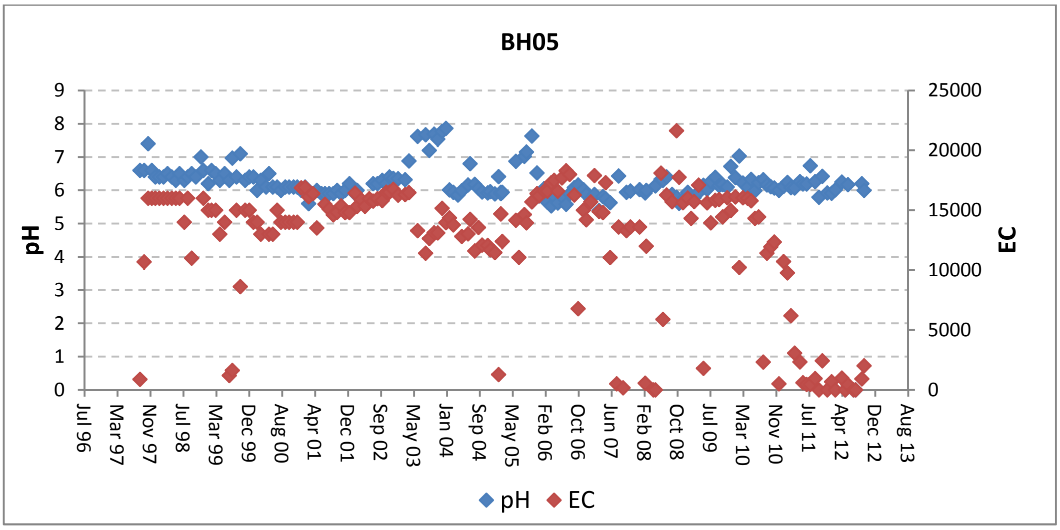

BH02B
pH
EC
8
7
6
5
4
3
2
1
0
14000
12000
10000
8000
6000
4000
2000
0
Feb 05
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH EC

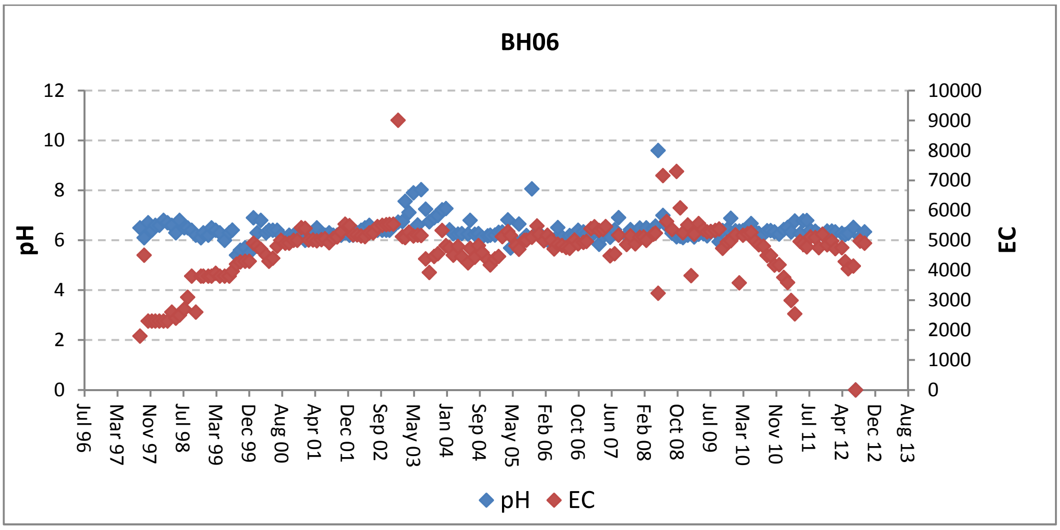

BH02C
pH
EC
0
1
2
3
4
5
6
7
8
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Feb 05
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH
EC

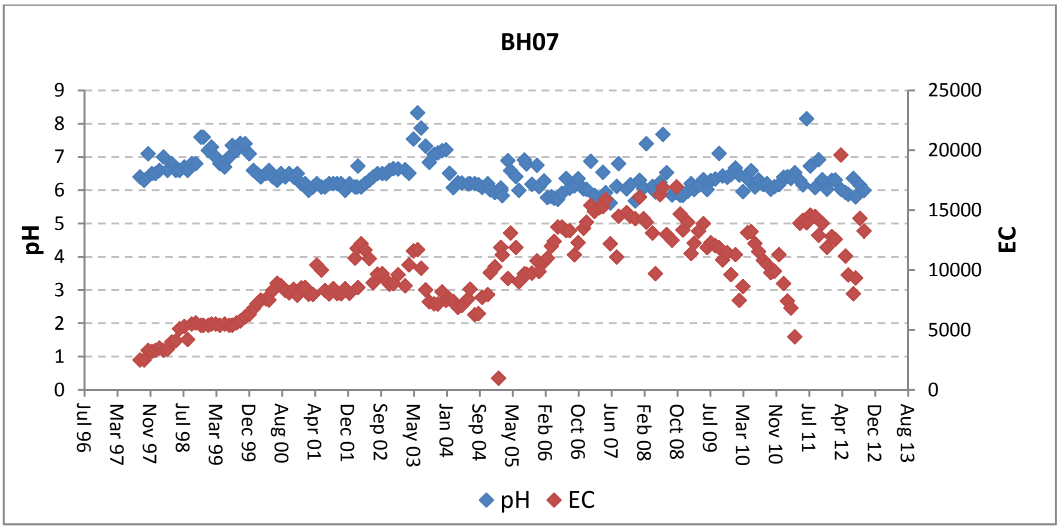

BH03
pH
EC
0
1
2
3
4
5
6
7
8
9
10
0
1000
2000
3000
4000
5000
6000
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC

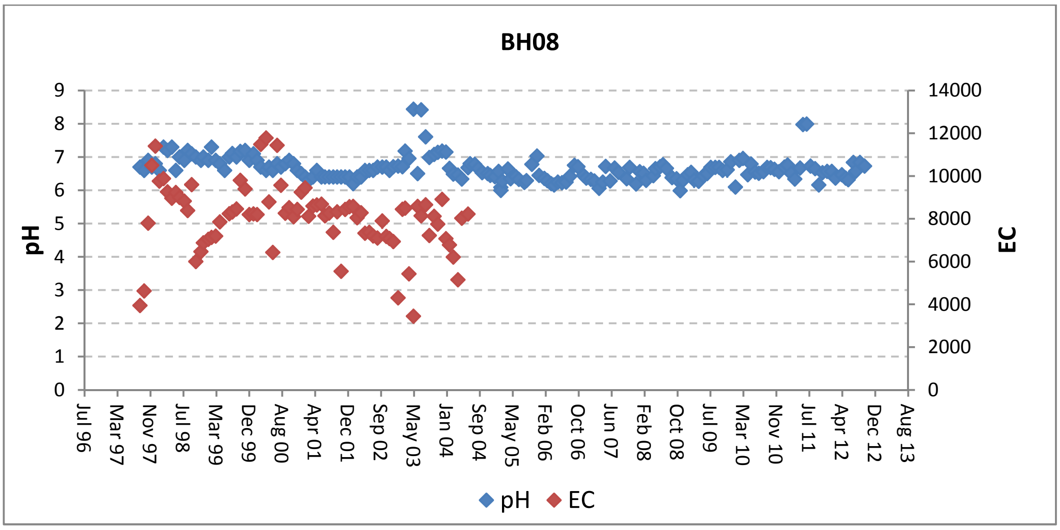

BH03A
pH
EC
0
1
2
3
4
5
6
7
8
0
500
1000
1500
2000
2500
3000
3500
4000
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH
EC

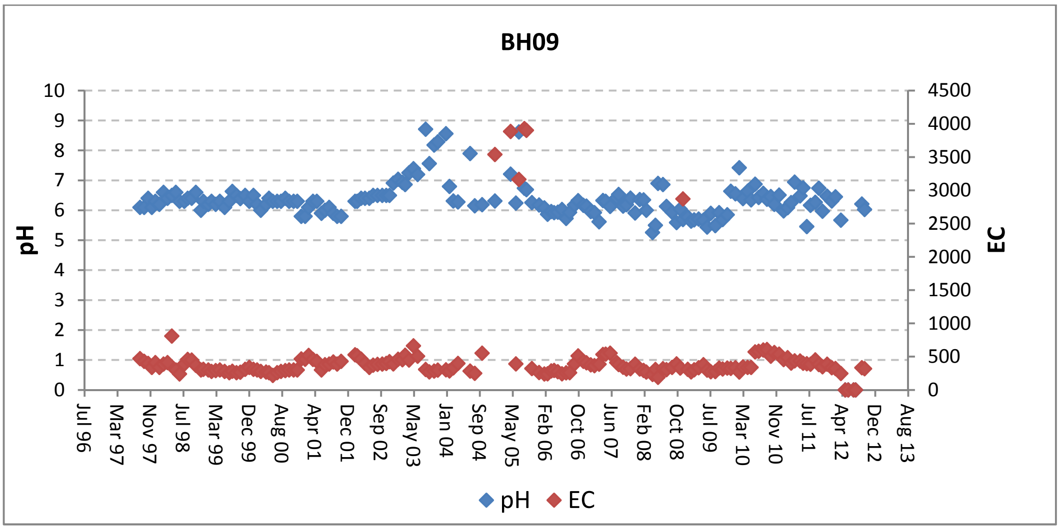

BH04
pH
EC
9
8
7
6
5
4
3
2
1
0
25000
20000
15000
10000
5000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC

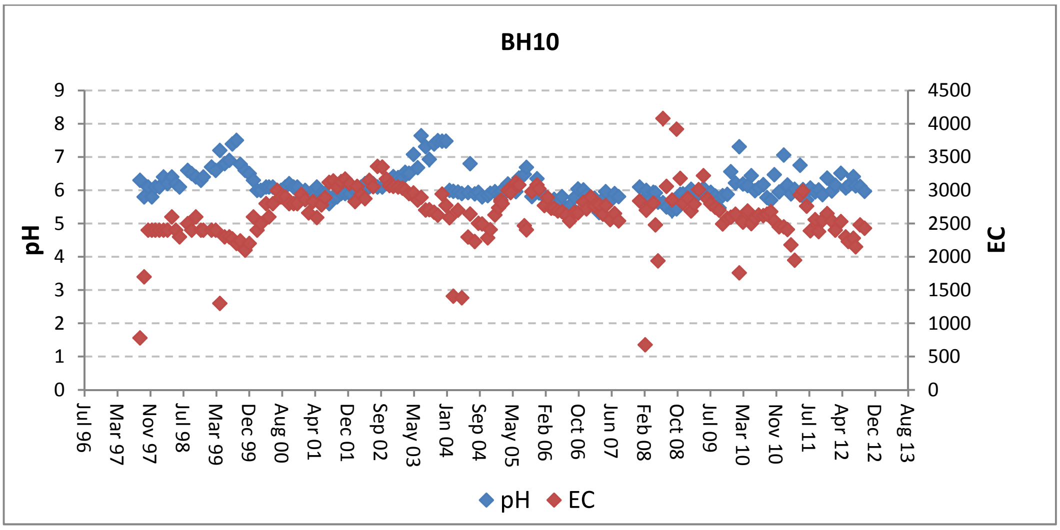

BH05
pH
EC
9
8
7
6
5
4
3
2
1
0
25000
20000
15000
10000
5000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC

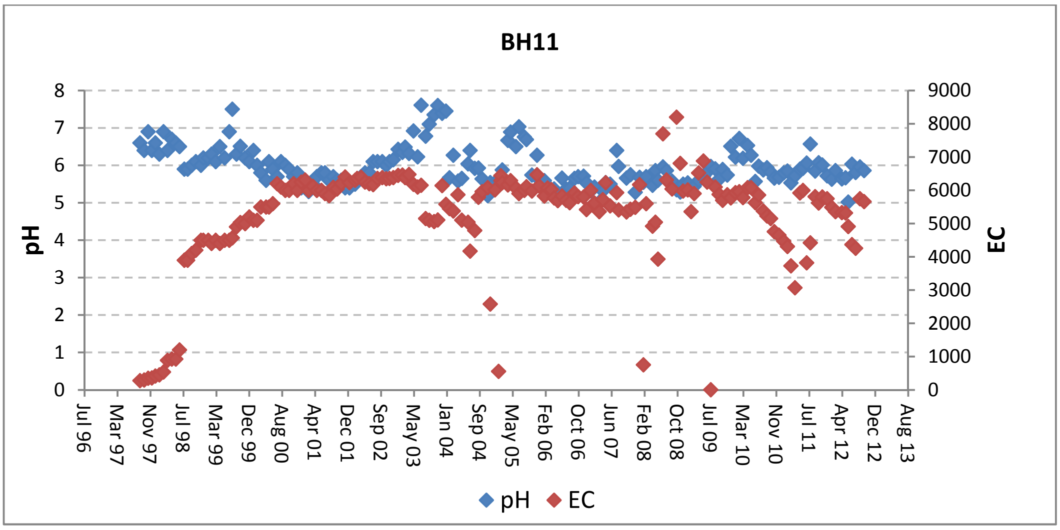

BH06
pH
EC
12
10
8
6
4
2
0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC

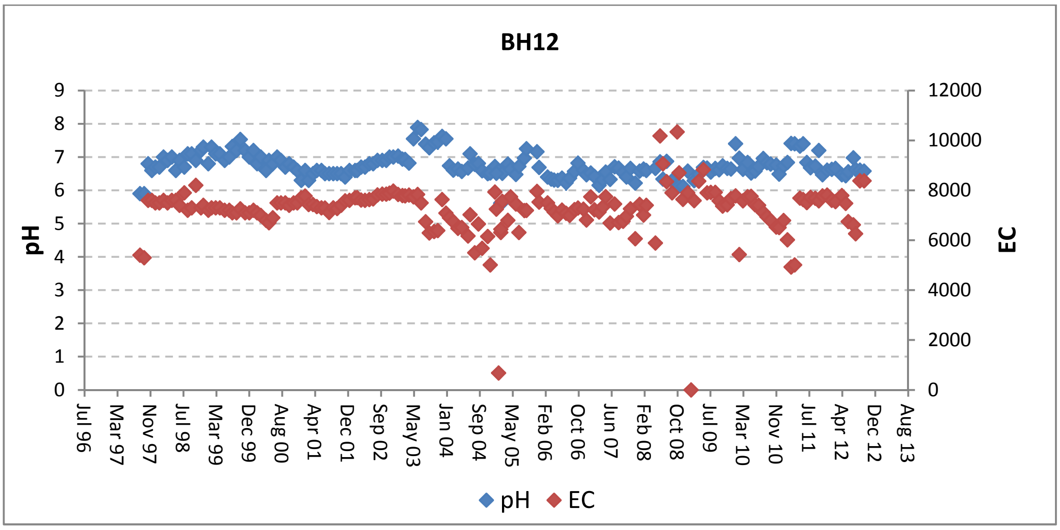

BH07
pH
EC
0
1
2
3
4
5
6
7
8
9
0
5000
10000
15000
20000
25000
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC

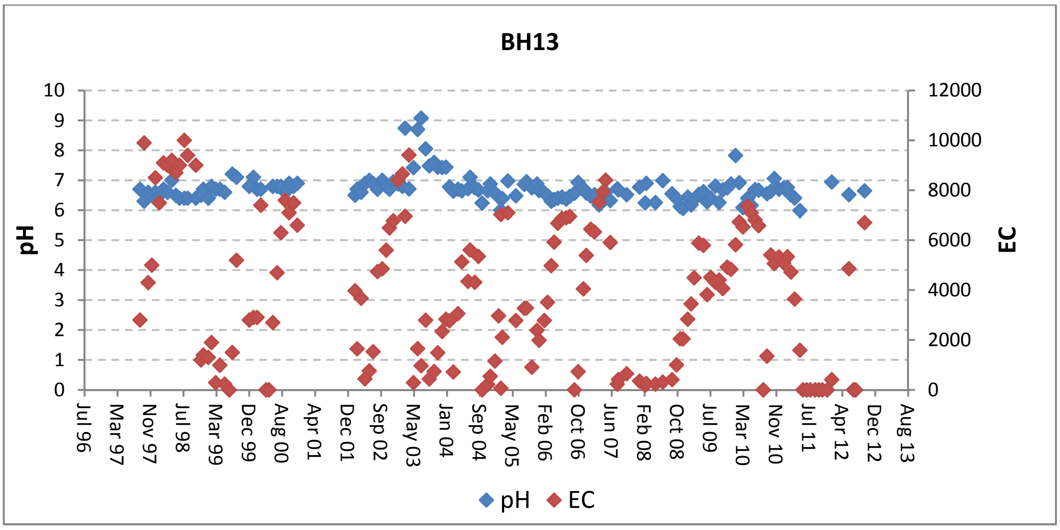

BH08
pH
EC
0
1
2
3
4
5
6
7
8
9
0
2000
4000
6000
8000
10000
12000
14000
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC

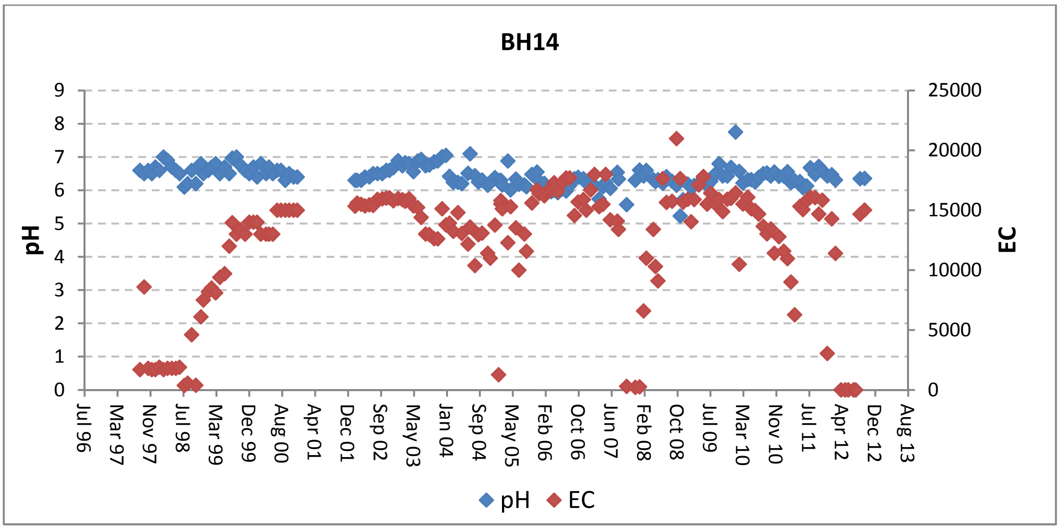

BH09
pH
EC
0
1
2
3
4
5
6
7
8
9
10
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH10
pH
EC
9
8
7
6
5
4
3
2
1
0
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH11
pH
EC
8
7
6
5
4
3
2
1
0
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH12
pH
EC
9
8
7
6
5
4
3
2
1
0
12000
10000
8000
6000
4000
2000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH13
pH
EC
10
9
8
7
6
5
4
3
2
1
0
12000
10000
8000
6000
4000
2000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH EC


BH14
pH
EC
9
8
7
6
5
4
3
2
1
0
25000
20000
15000
10000
5000
0
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
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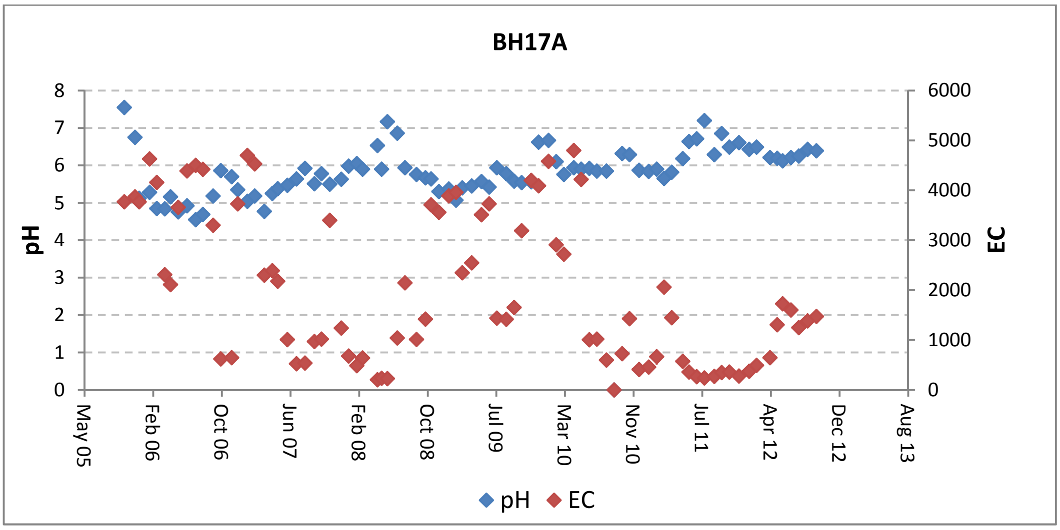
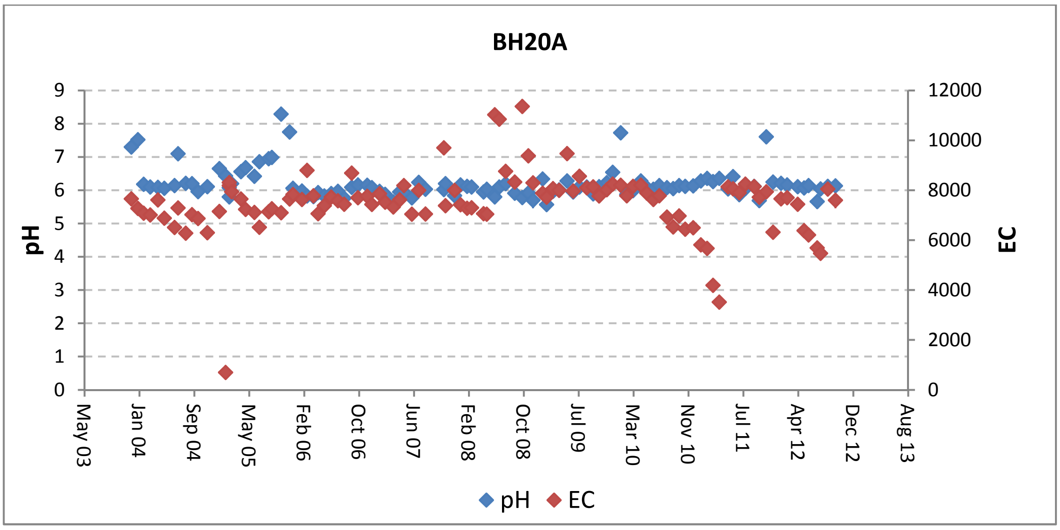
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH EC


BH17A
pH
EC
8
7
6
5
4
3
2
1
0
6000
5000
4000
3000
2000
1000
0
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH EC


BH20A
pH
EC
0
1
2
3
4
5
6
7
8
9
0
2000
4000
6000
8000
10000
12000
May 03
Jan 04
Sep 04
May 05
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Jun 07
Feb 08
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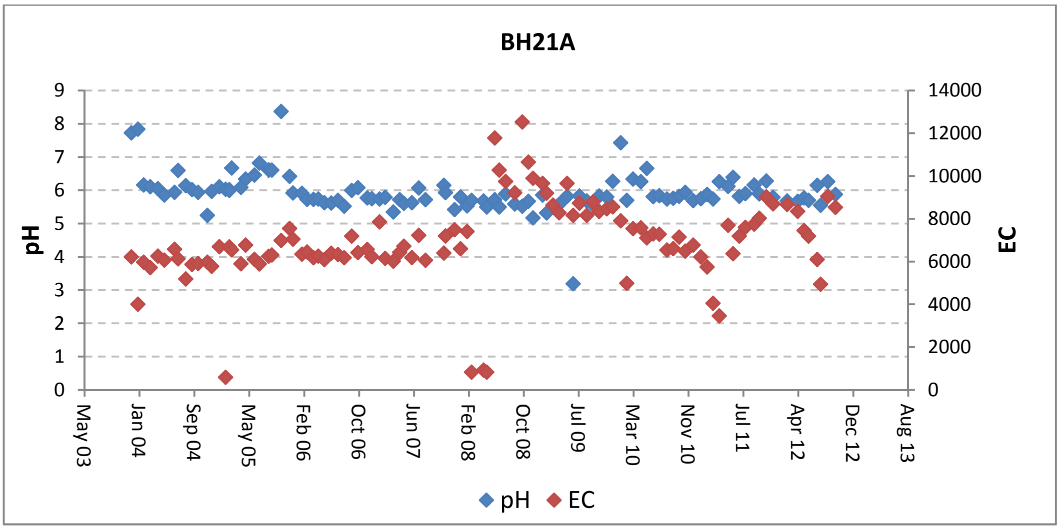
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH21A
pH
EC
0
1
2
3
4
5
6
7
8
9
0
2000
4000
6000
8000
10000
12000
14000
May 03
Jan 04
Sep 04
May 05
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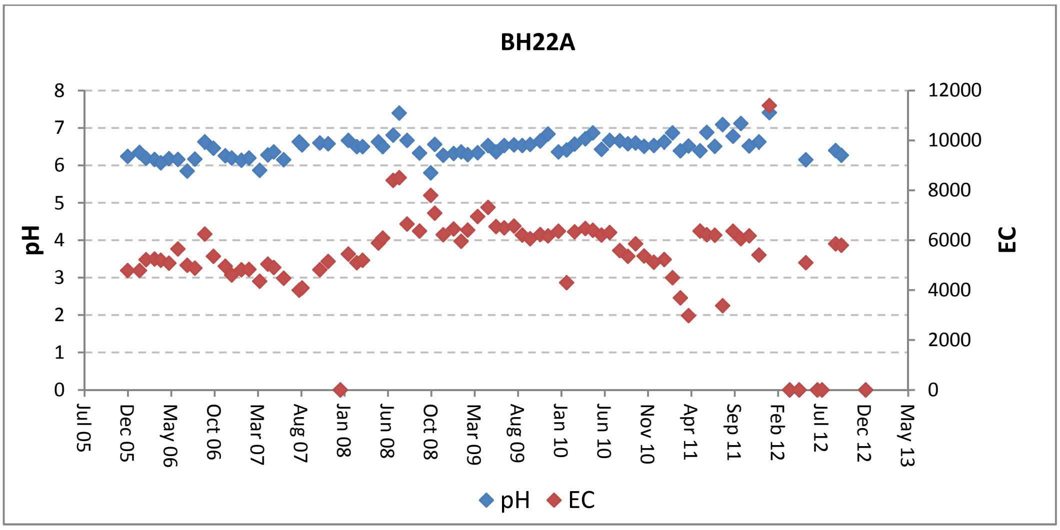
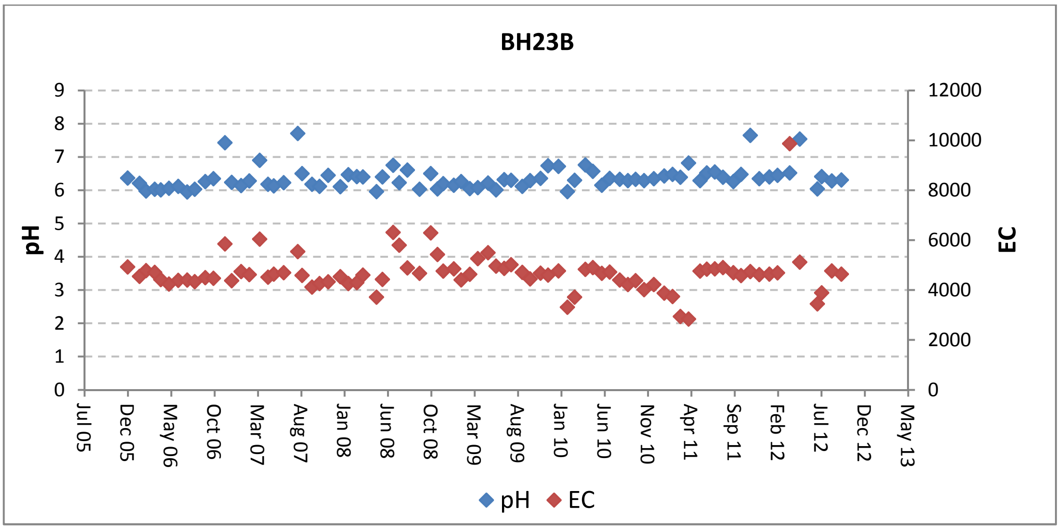
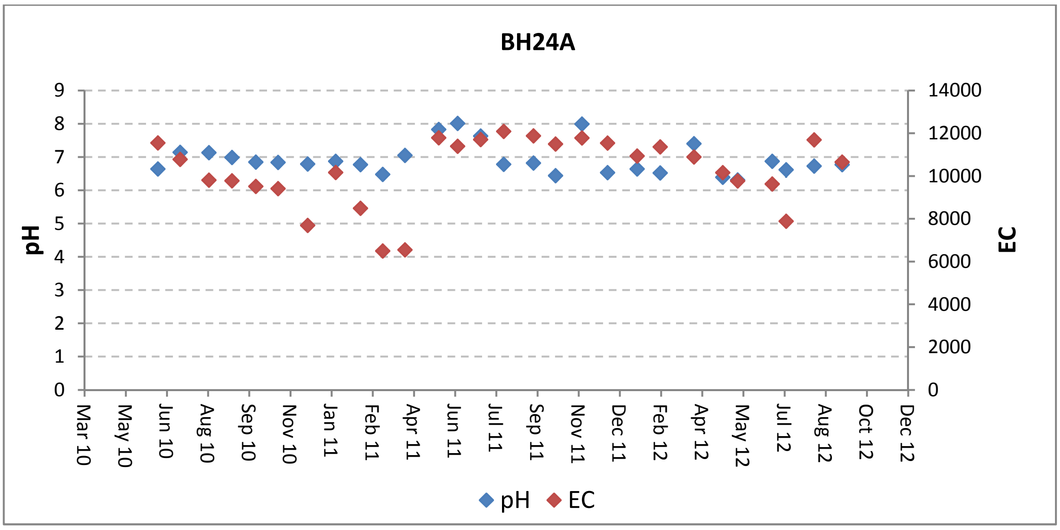
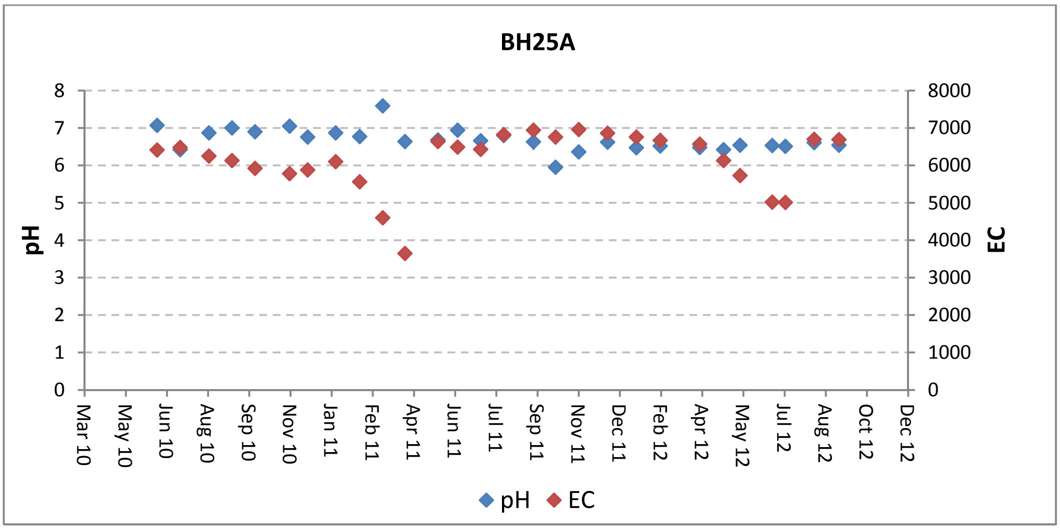
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH22A
pH
EC
0
1
2
3
4
5
6
7
8
0
2000
4000
6000
8000
10000
12000
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH
EC

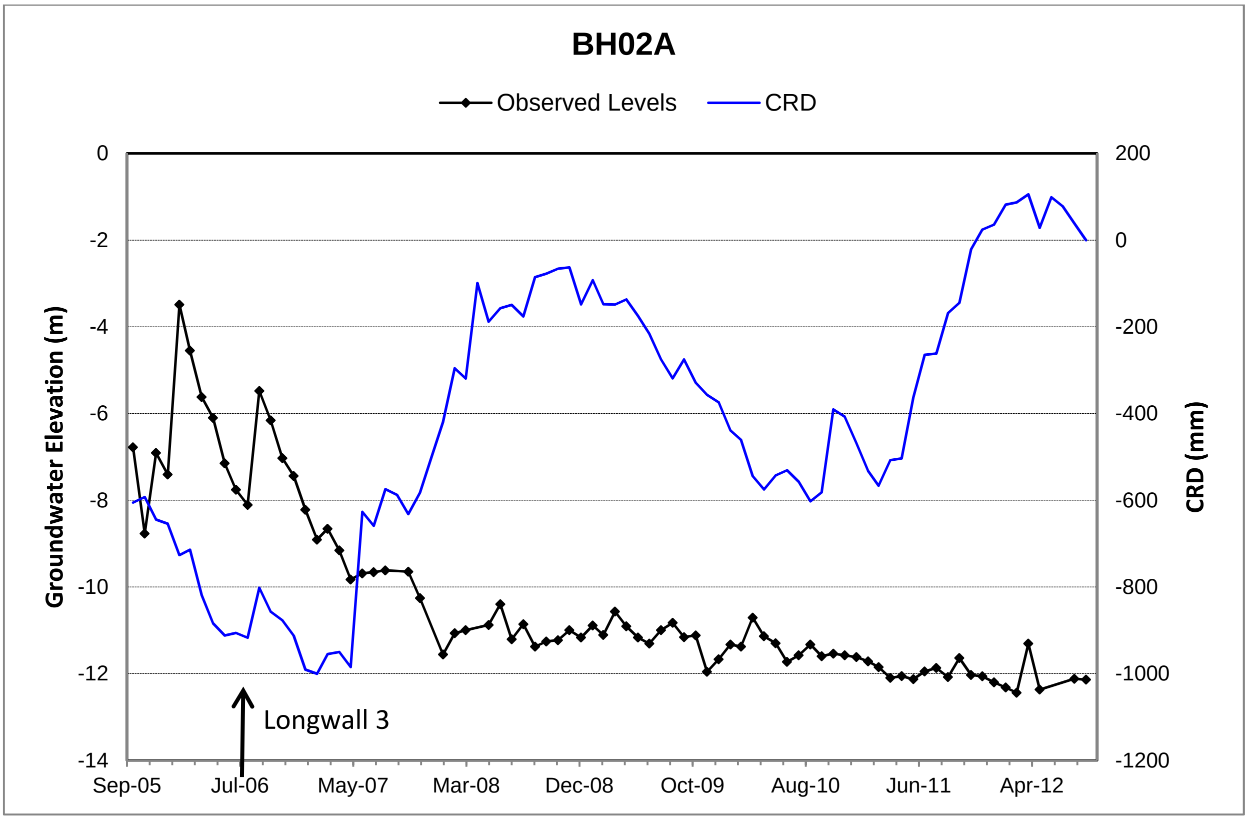

BH23B
pH
EC
0
1
2
3
4
5
6
7
8
9
0
2000
4000
6000
8000
10000
12000
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH EC

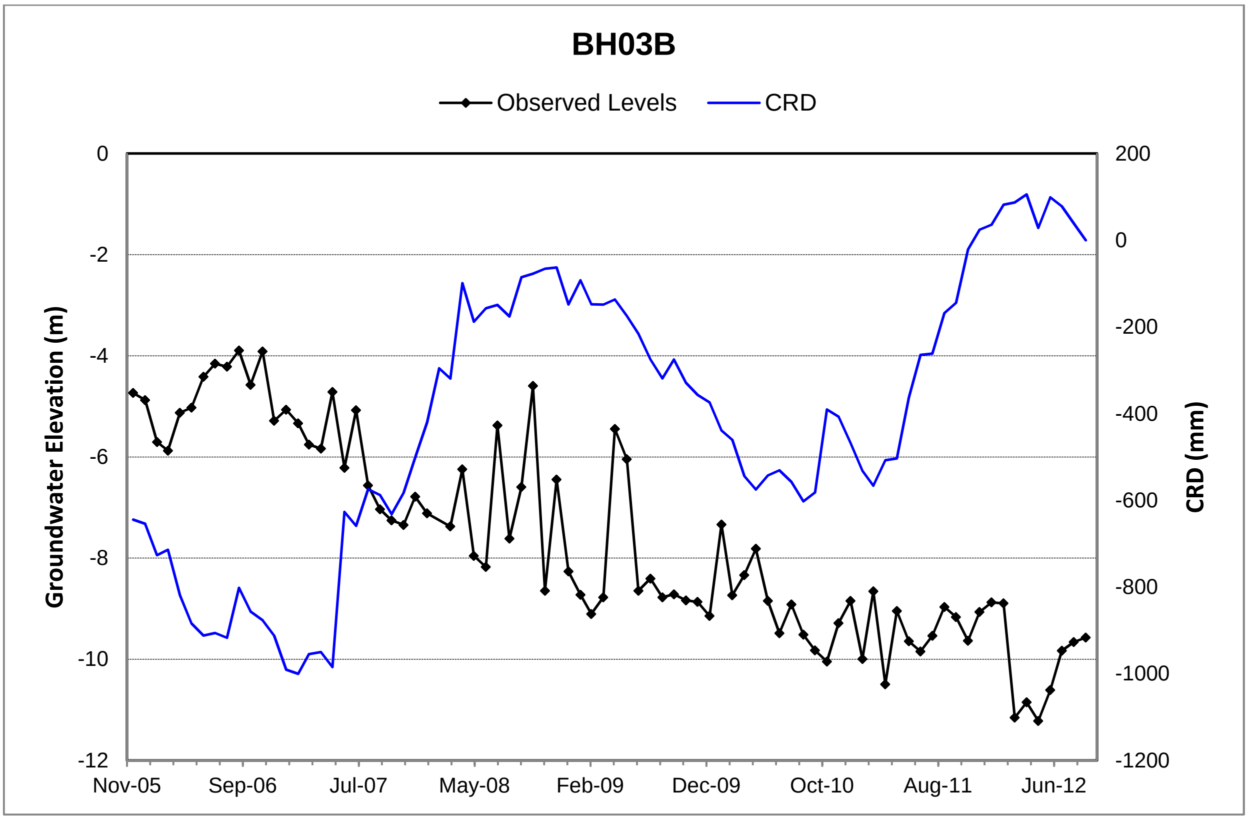

BH24A
pH
EC
0
1
2
3
4
5
6
7
8
9
0
2000
4000
6000
8000
10000
12000
14000
Mar 10
May 10
Jun 10
Aug 10
Sep 10
Nov 10
Jan 11
Feb 11
Apr 11
Jun 11
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
pH EC

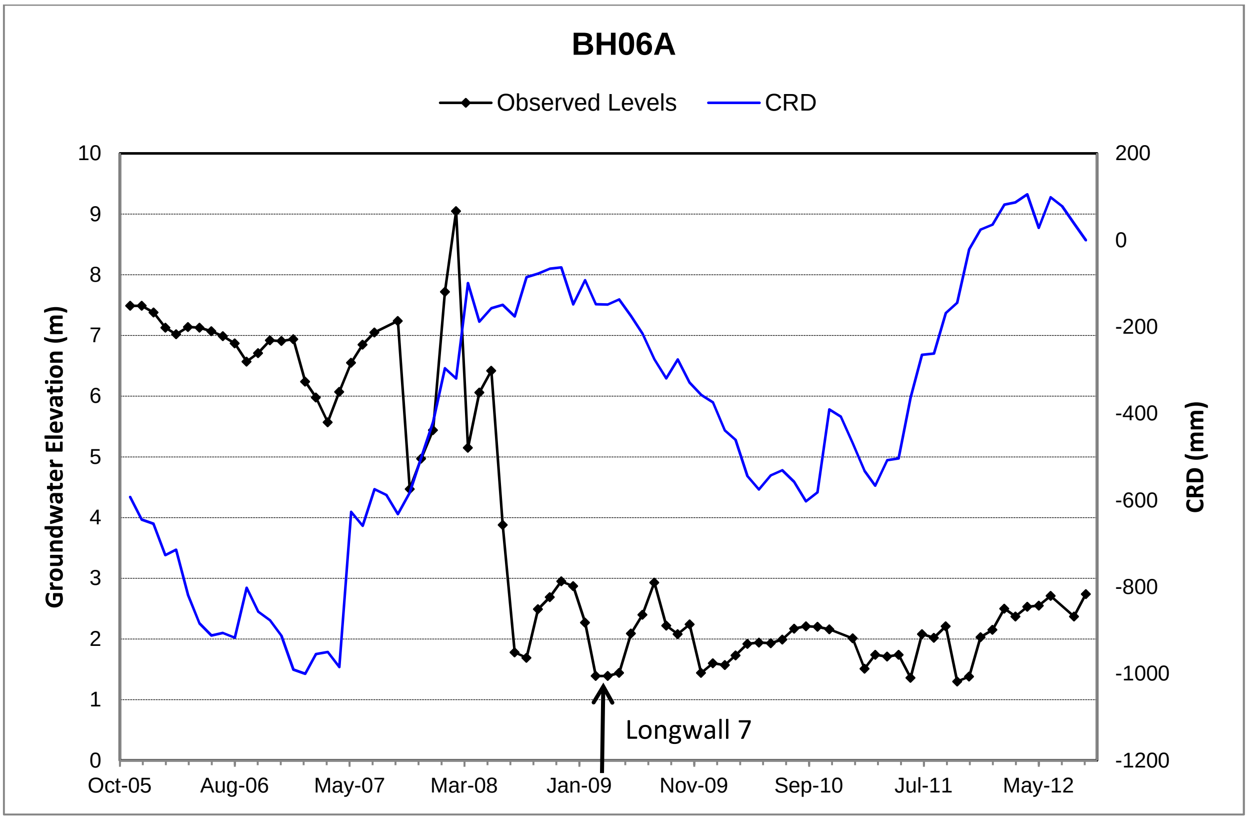

BH25A
pH
EC
0
1
2
3
4
5
6
7
8
0
1000
2000
3000
4000
5000
6000
7000
8000
Mar 10
May 10
Jun 10
Aug 10
Sep 10
Nov 10
Jan 11
Feb 11
Apr 11
Jun 11
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
pH EC

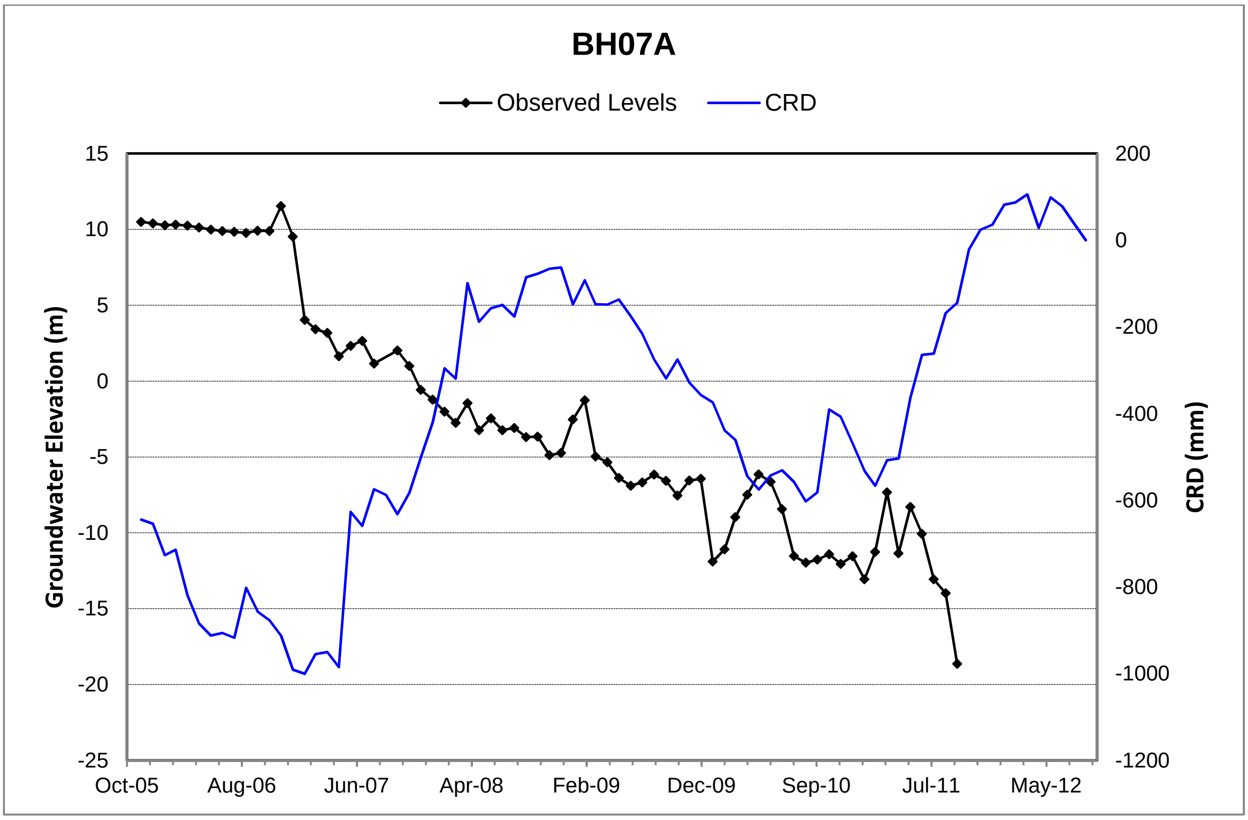
Appendix D

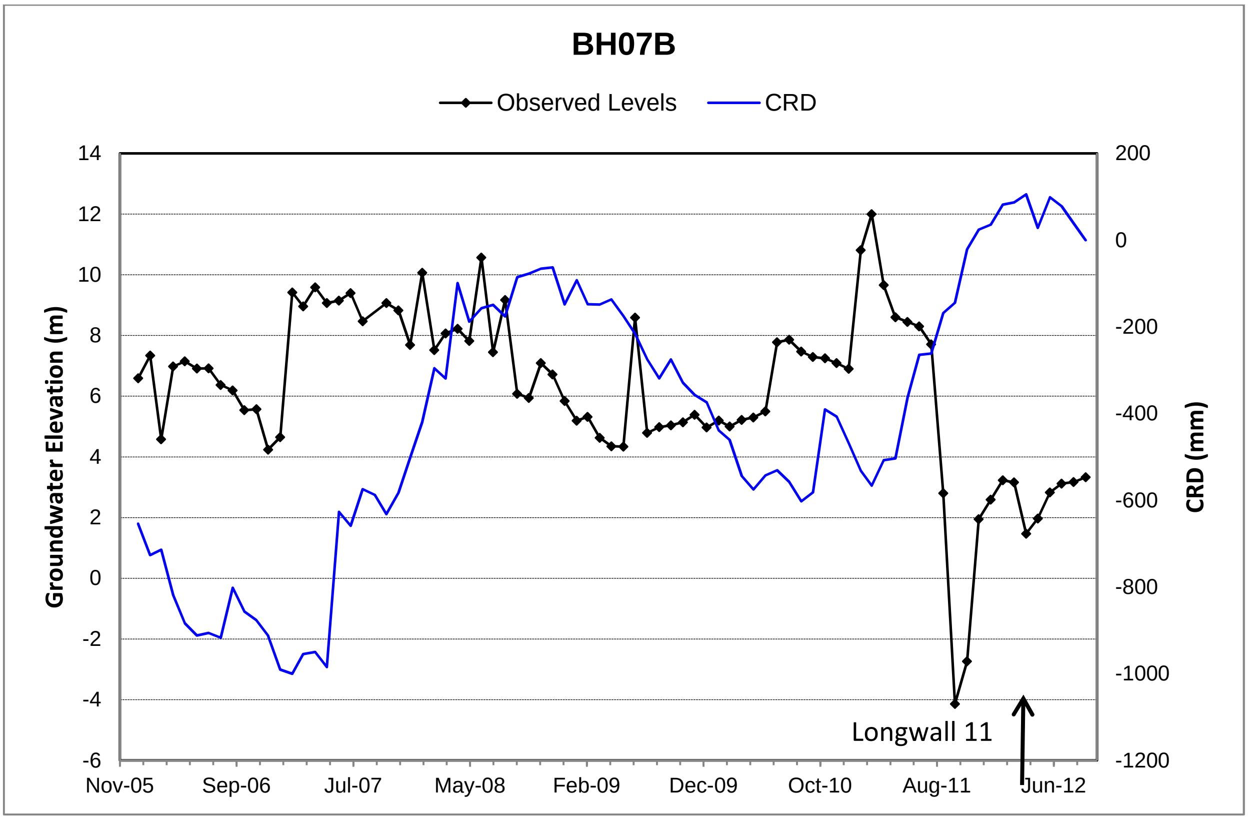
# Groundwater Hydrographs – Deeper Mandalong Bores

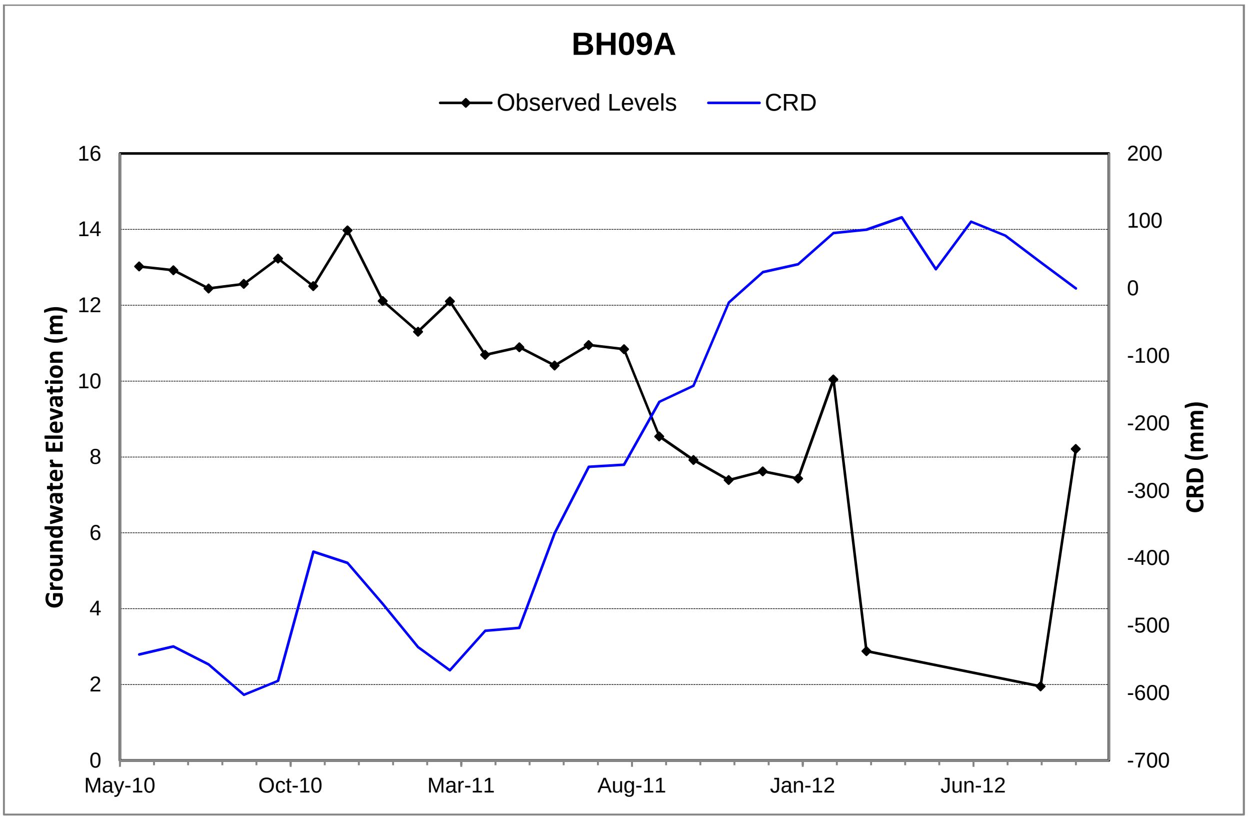

BH02A
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
0
-2
-4
-6
-8
-10
-12
-14
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 3
Sep-05
Jul-06
May-07
Mar-08
Dec-08
Oct-09
Aug-10
Jun-11
Apr-12

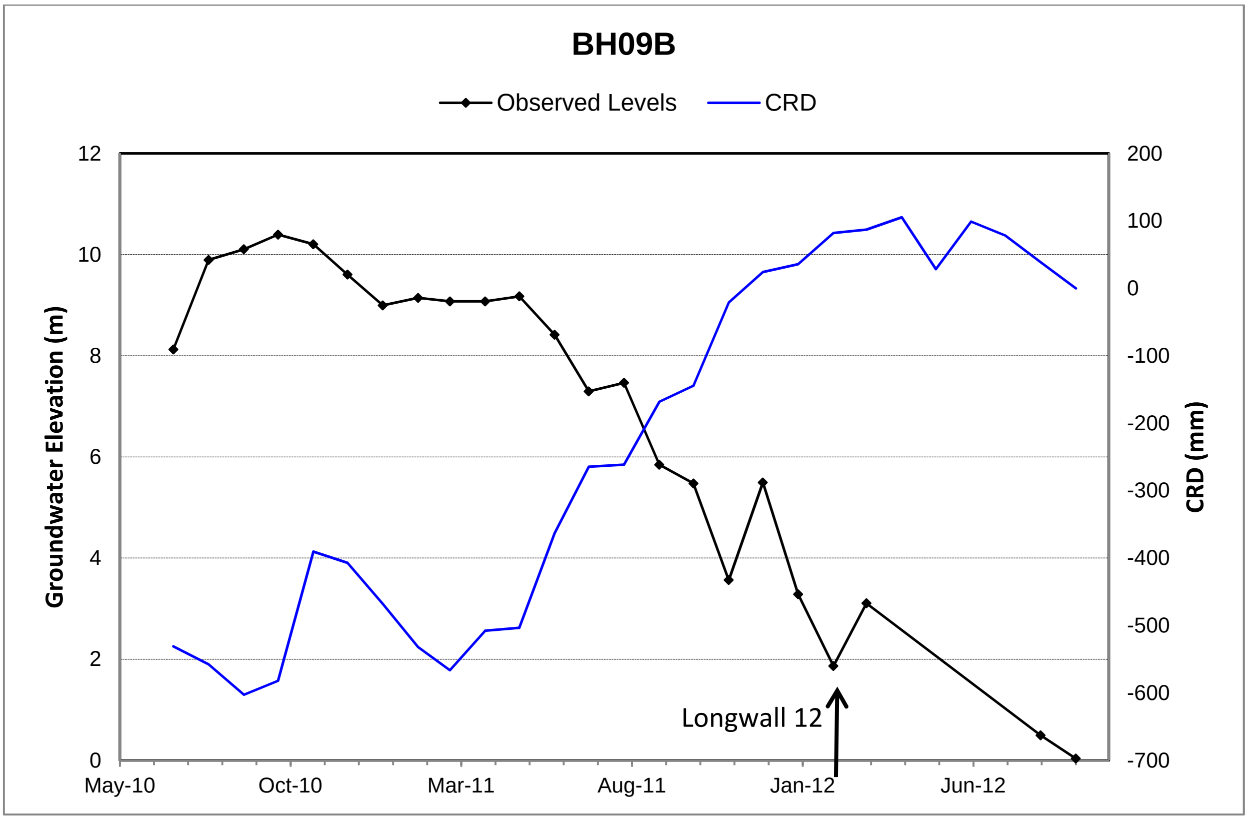

BH03B
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
0
-2
-4
-6
-8
-10
-12
200
0
-200
-400
-600
-800
-1000
-1200
Nov-05
Sep-06
Jul-07
May-08
Feb-09
Dec-09
Oct-10
Aug-11
Jun-12

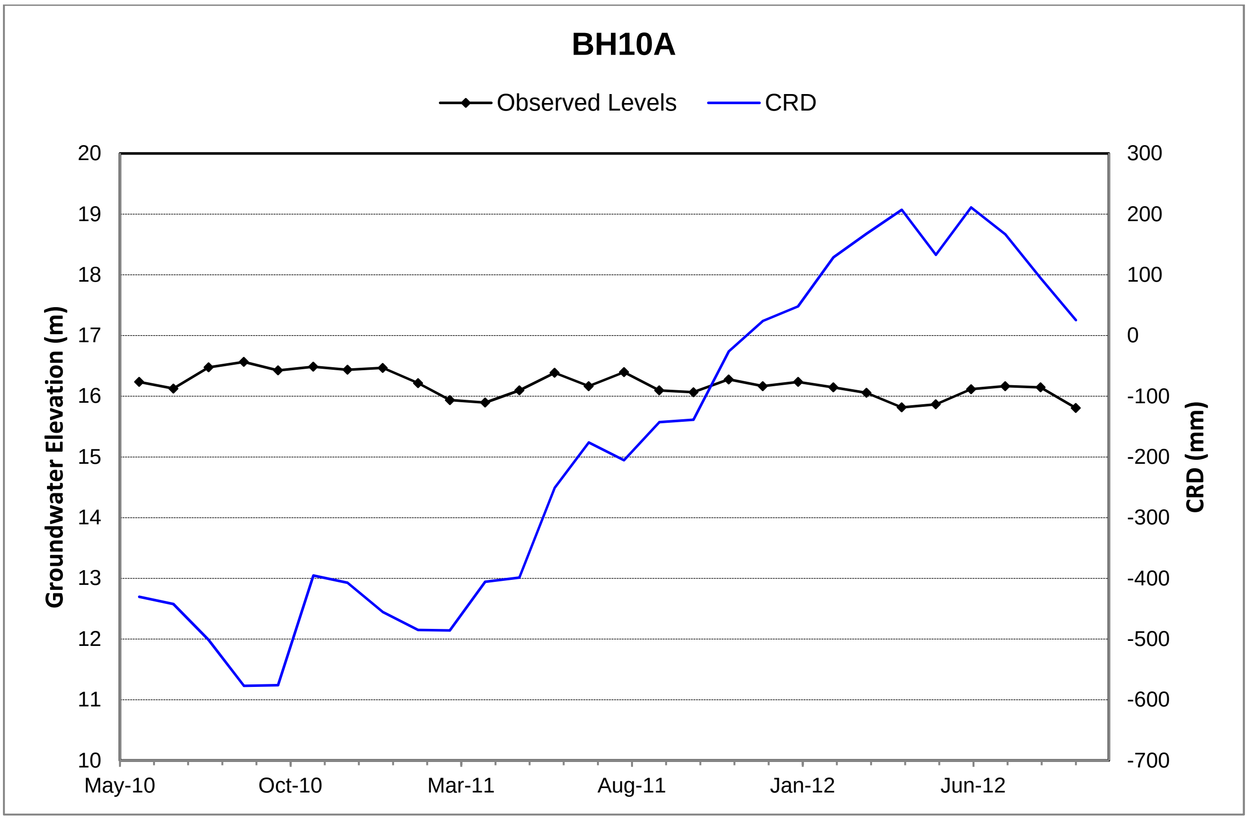

BH06A
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
10
9
8
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Oct-05
Aug-06
May-07
Mar-08
Jan-09
Nov-09
Sep-10
Jul-11
May-12
Longwall 7

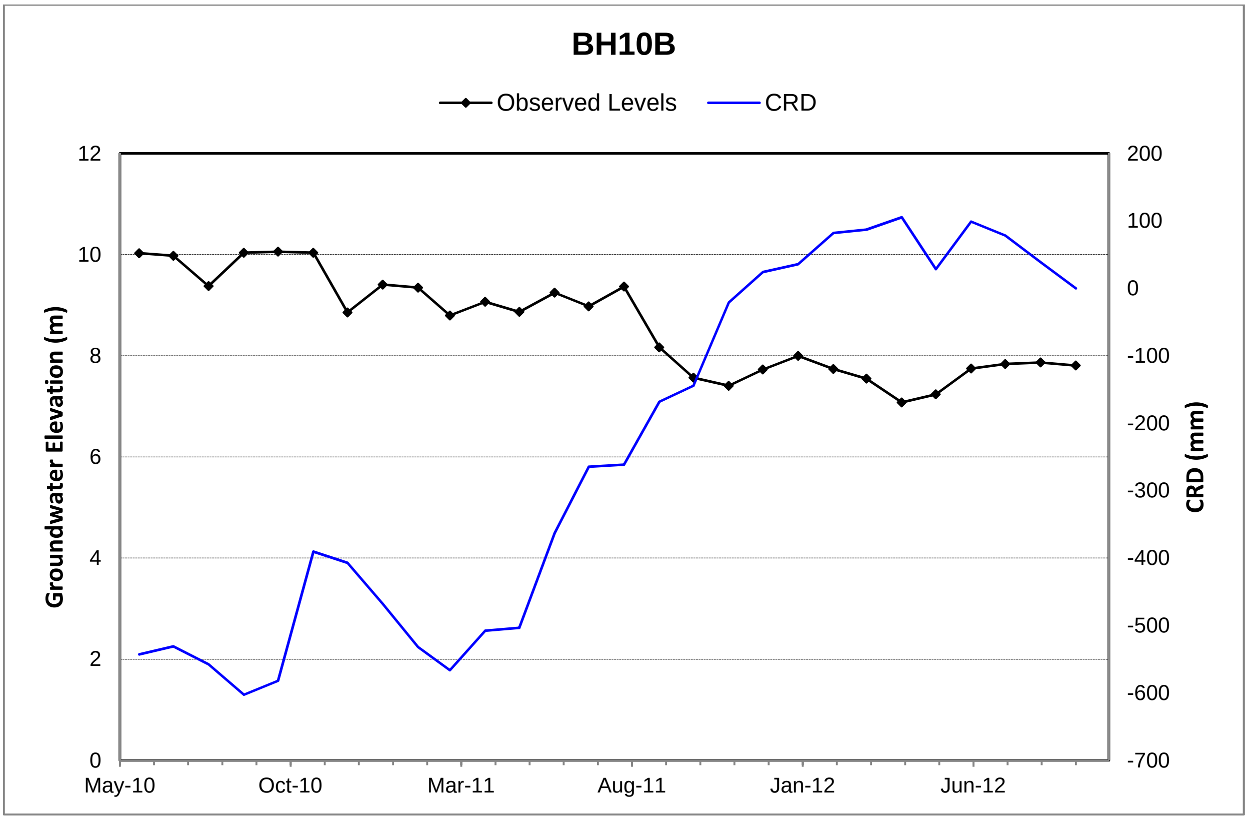

BH07A
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
15
10
5
0
-5
-10
-15
-20
-25
200
0
-200
-400
-600
-800
-1000
-1200
Oct-05
Aug-06
Jun-07
Apr-08
Feb-09
Dec-09
Sep-10
Jul-11
May-12

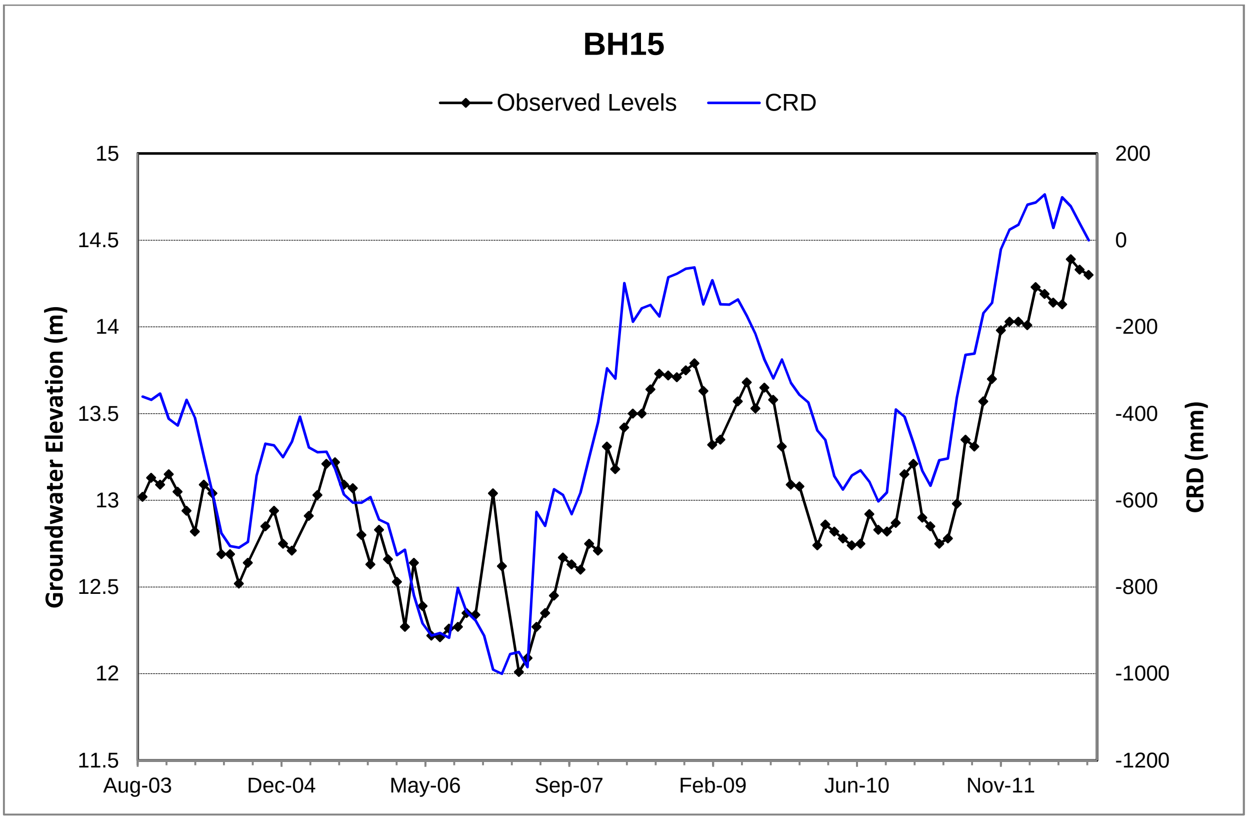

BH07B
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
14
12
10
8
6
4
2
0
-2
-4
-6
200
0
-200
-400
-600
-800
-1000
-1200
Nov-05
Sep-06
Jul-07
May-08
Feb-09
Dec-09
Oct-10
Aug-11
Jun-12
Longwall 11

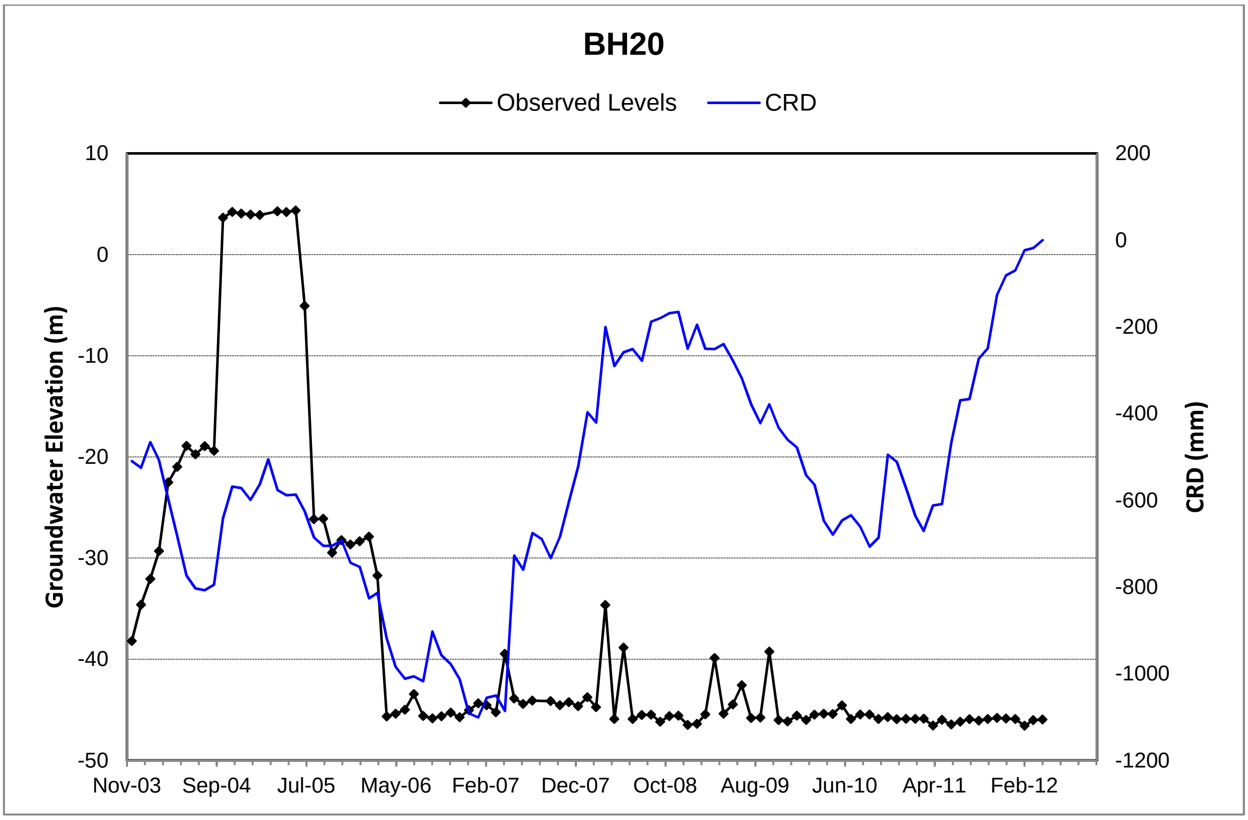

BH09A
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
16
14
12
10
8
6
4
2
0
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12

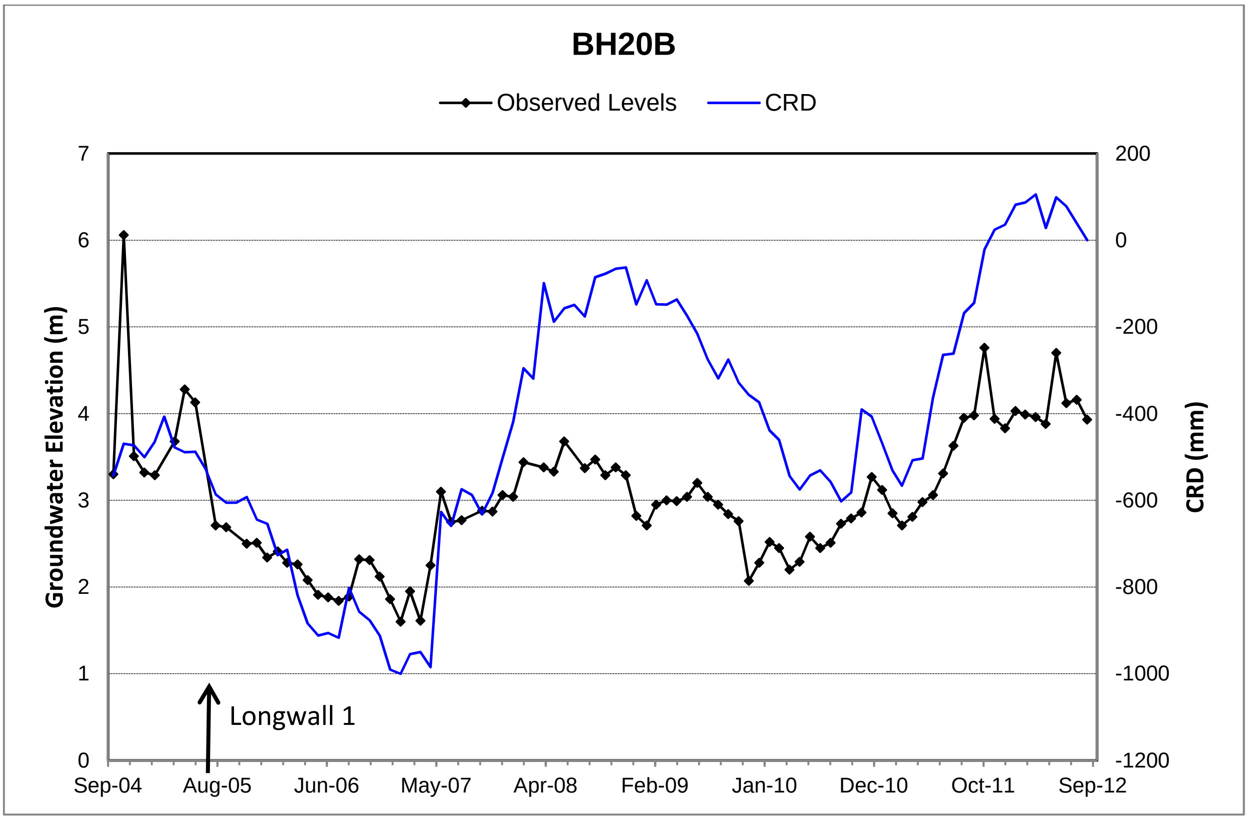

BH09B
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
12
10
8
6
4
2
0
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12
Longwall 12

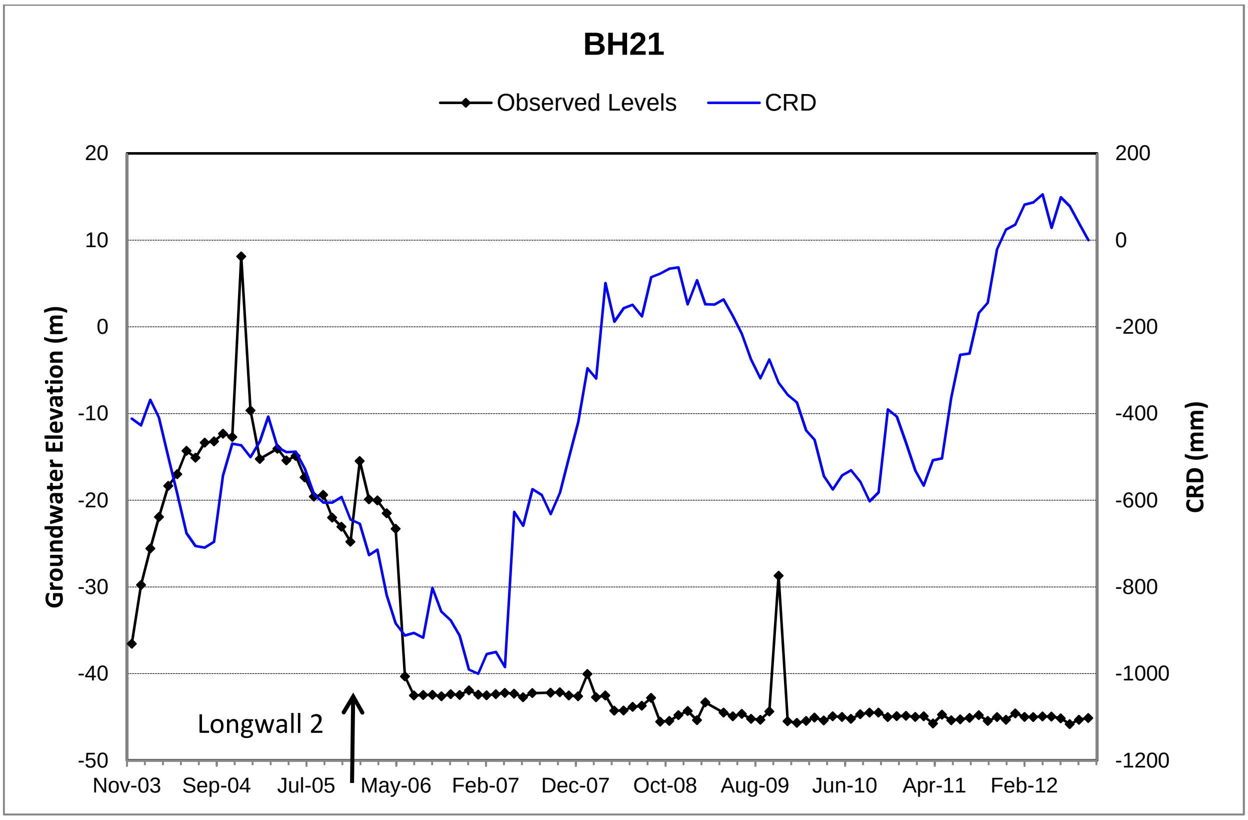

BH10A
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
20
19
18
17
16
15
14
13
12
11
10
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12


BH10B
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
12
10
8
6
4
2
0
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12

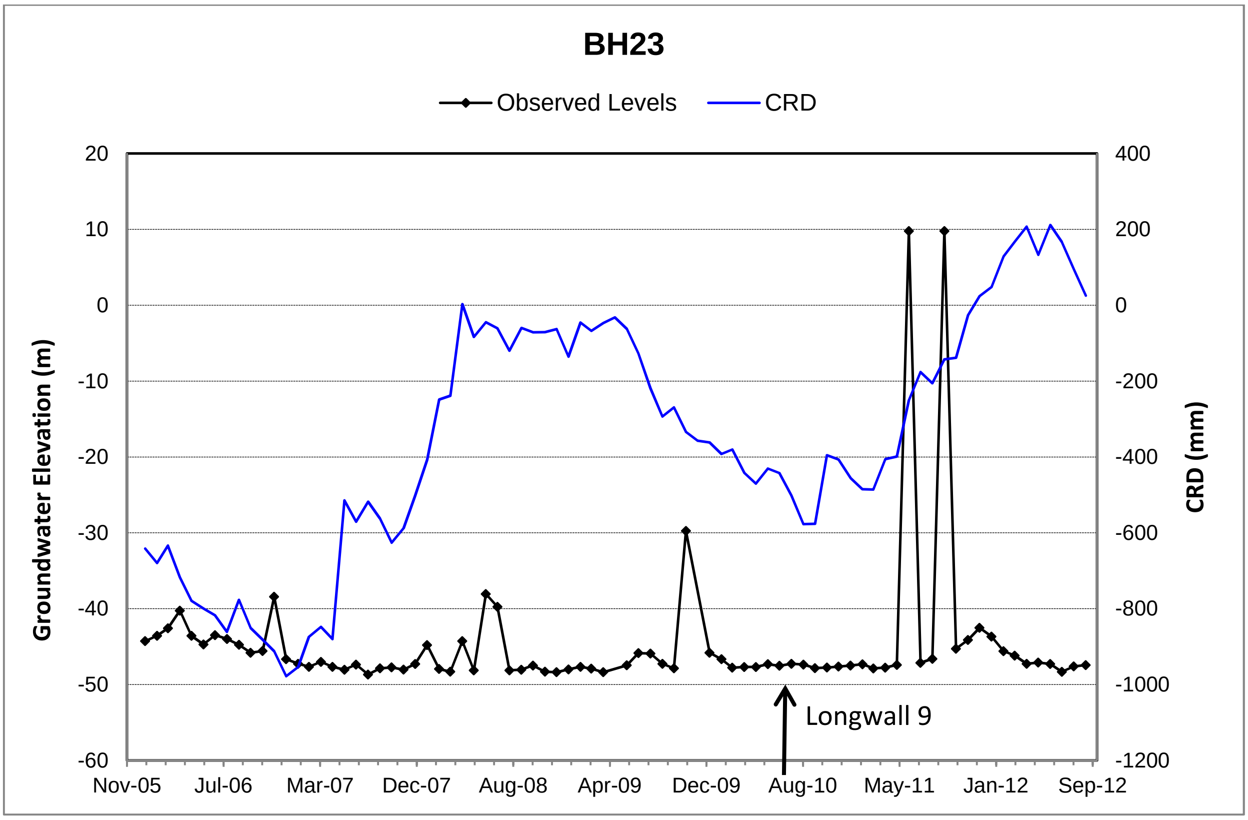

BH15
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
15
14.5
14
13.5
13
12.5
12
11.5
200
0
-200
-400
-600
-800
-1000
-1200
Aug-03
Dec-04
May-06
Sep-07
Feb-09
Jun-10
Nov-11


BH20
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
10
0
-10
-20
-30
-40
-50
200
0
-200
-400
-600
-800
-1000
-1200
Nov-03
Sep-04
Jul-05
May-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12

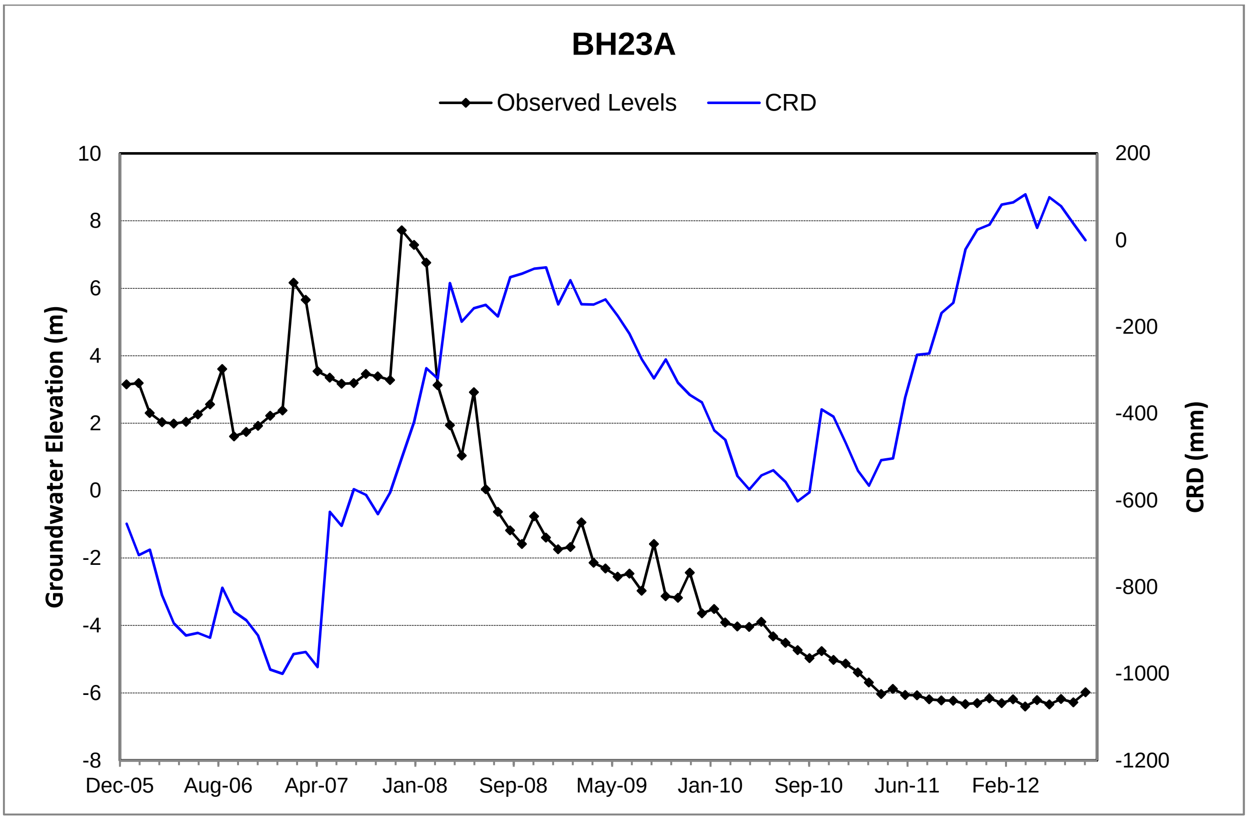

BH20B
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
7
6
5
4
3
2
1
0
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 1
Sep-04
Aug-05
Jun-06
May-07
Apr-08
Feb-09
Jan-10
Dec-10
Oct-11
Sep-12

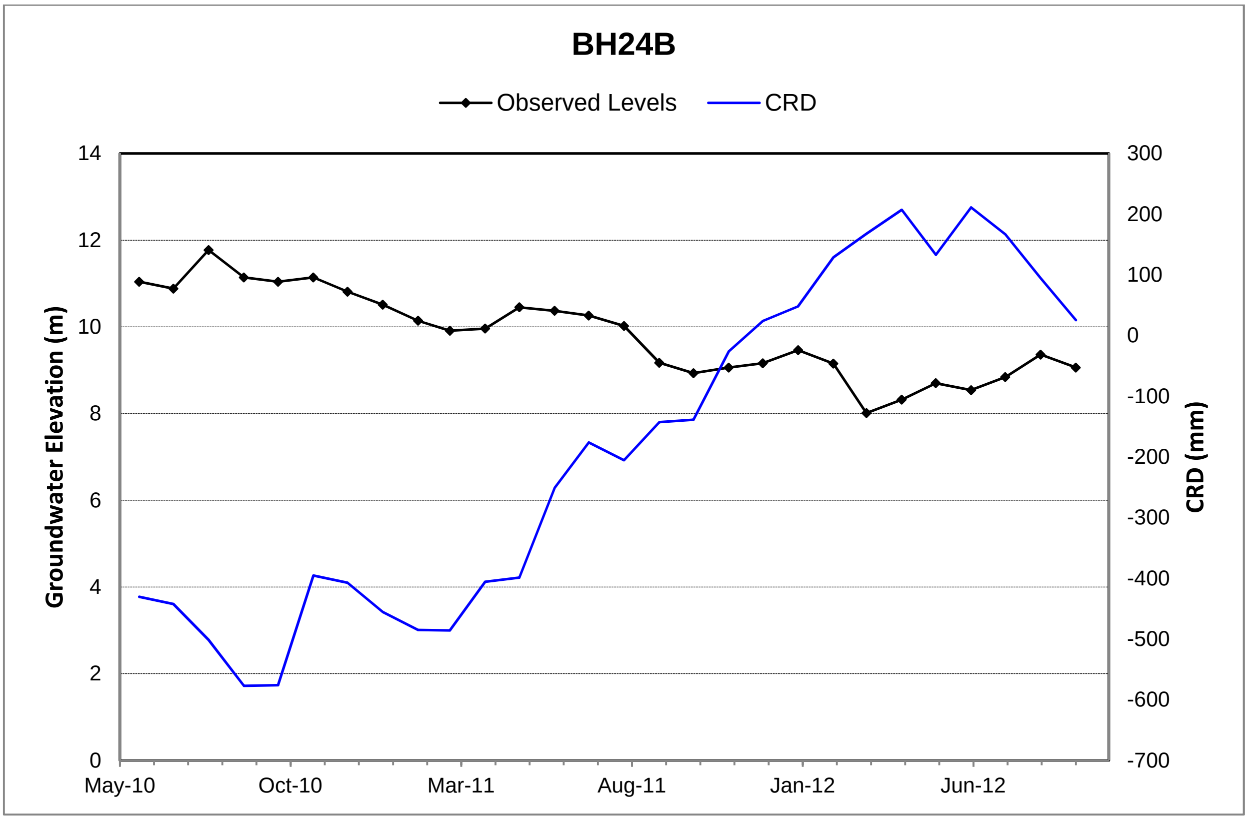


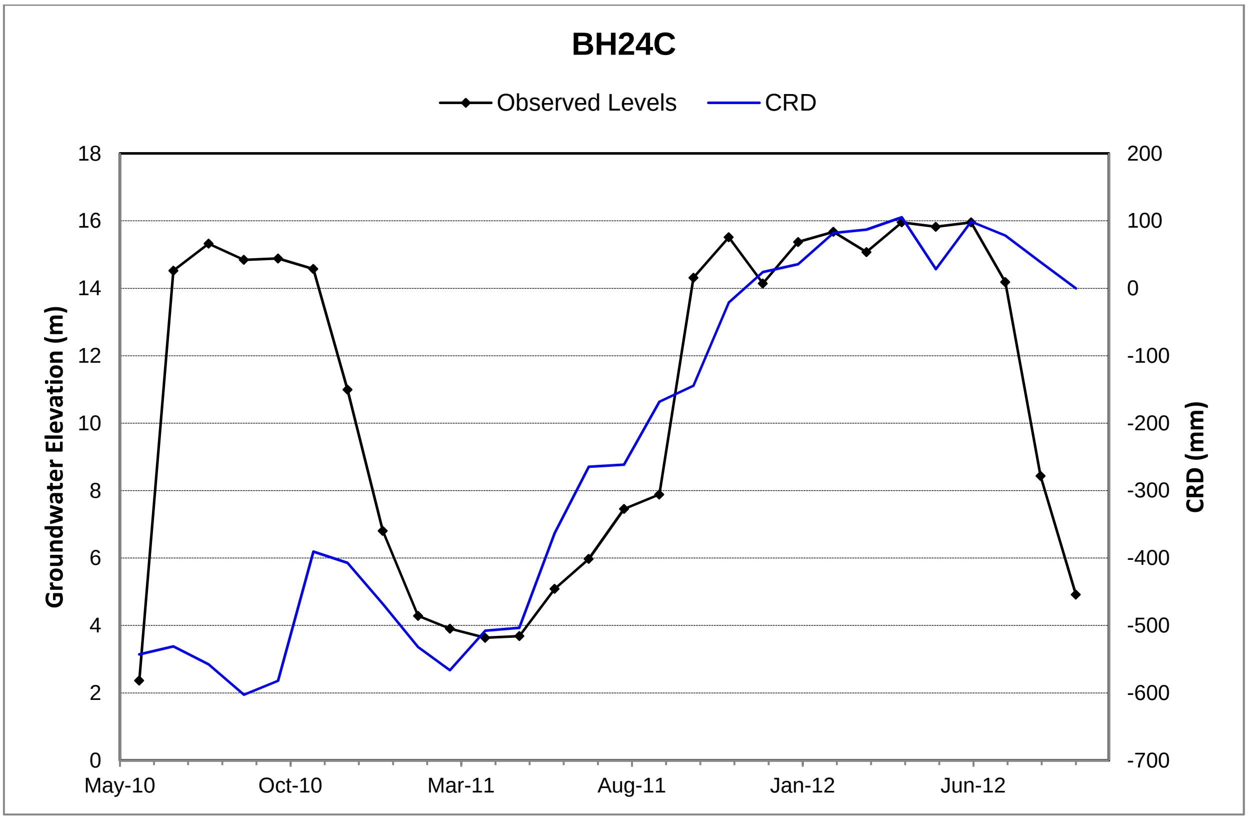
BH21
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
20
10
0
-10
-20
-30
-40
-50
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 2
Nov-03
Sep-04
Jul-05
May-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12

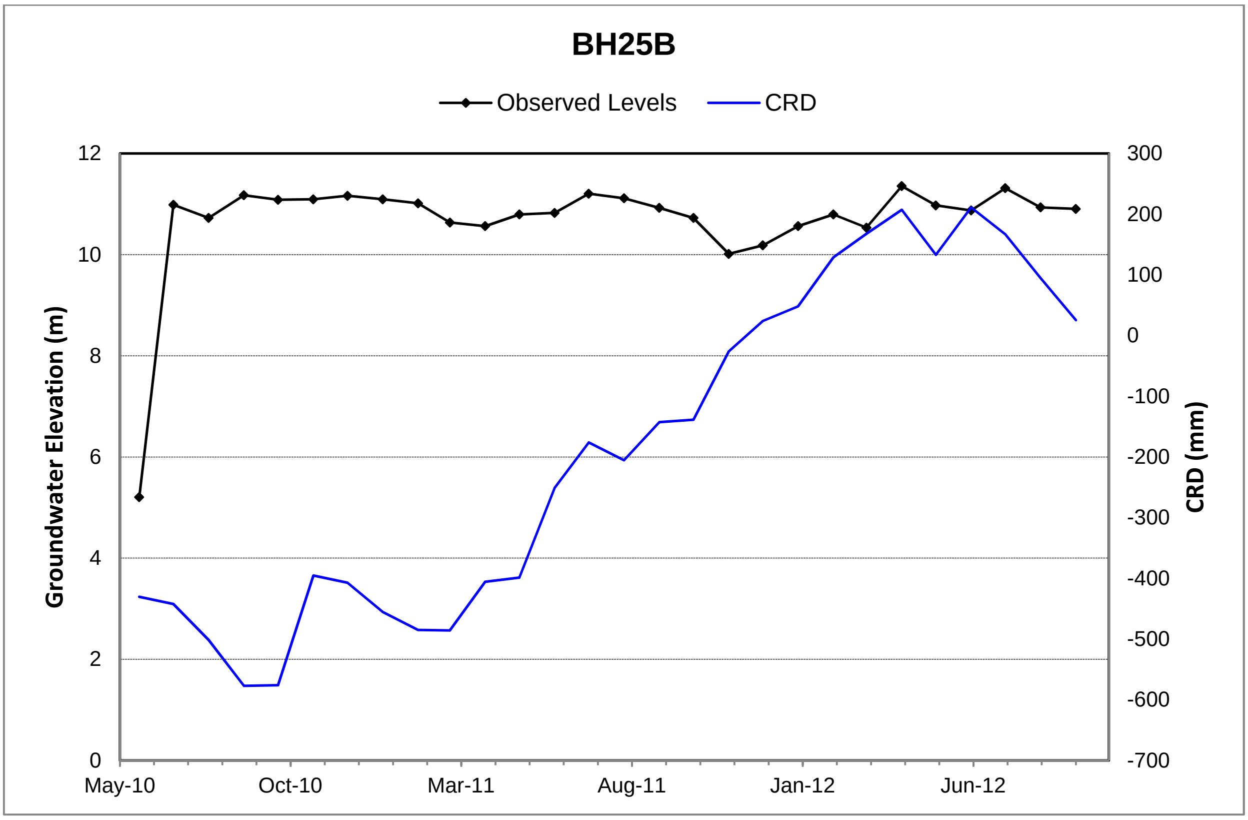



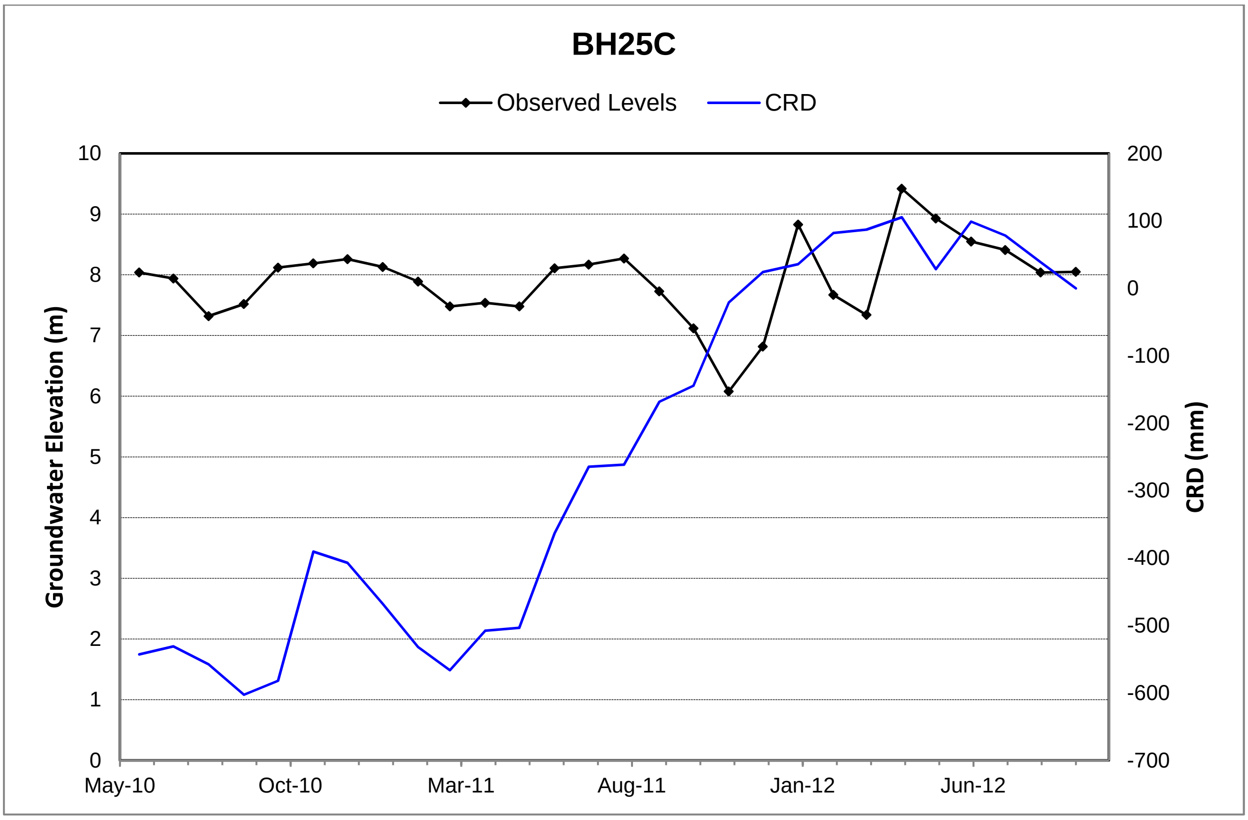
BH23
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
20
10
0
-10
-20
-30
-40
-50
-60
400
200
0
-200
-400
-600
-800
-1000
-1200
Longwall 9
Nov-05
Jul-06
Mar-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
May-11
Jan-12
Sep-12


BH23A
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
10
8
6
4
2
0
-2
-4
-6
-8
200
0
-200
-400
-600
-800
-1000
-1200
Dec-05
Aug-06
Apr-07
Jan-08
Sep-08
May-09
Jan-10
Sep-10
Jun-11
Feb-12


BH24B
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
14
12
10
8
6
4
2
0
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12

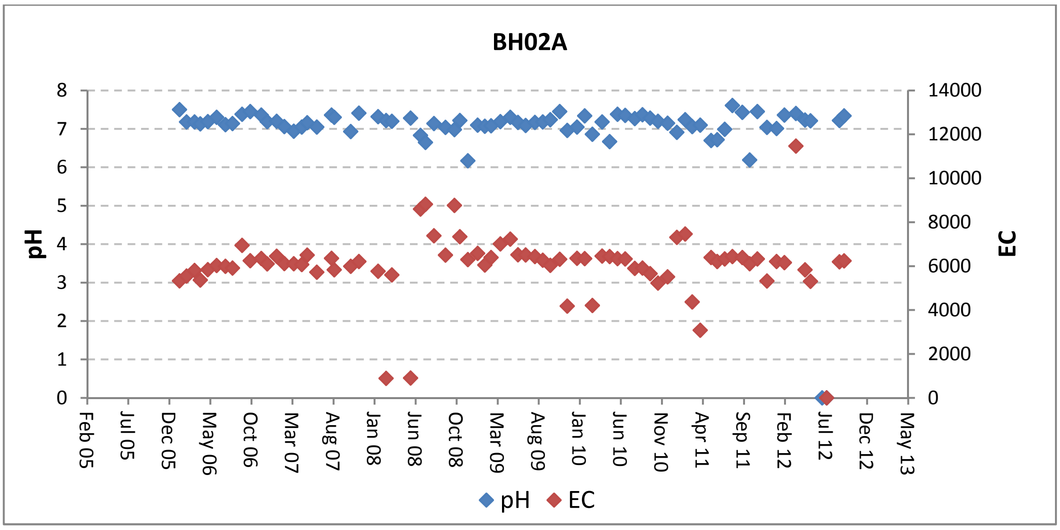

BH24C
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
18
16
14
12
10
8
6
4
2
0
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12

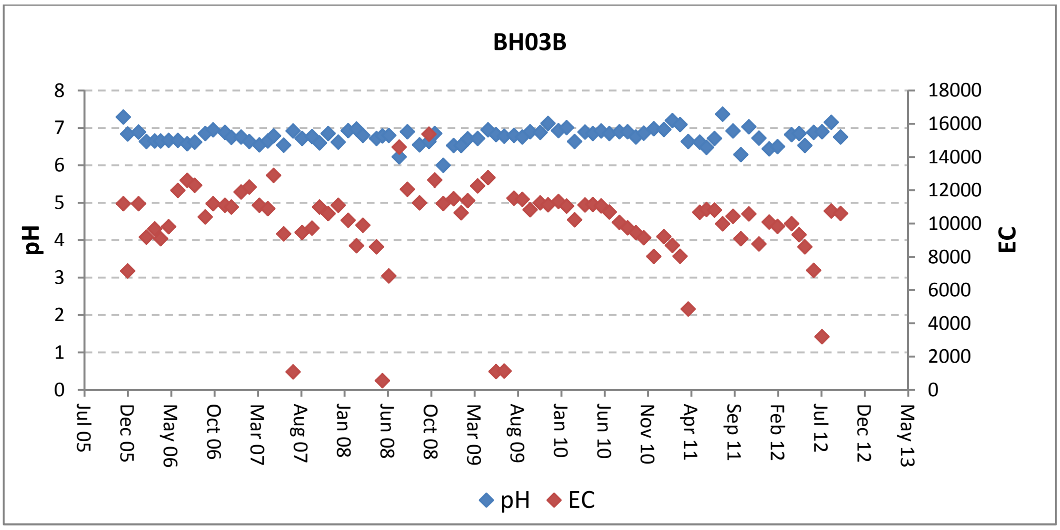

BH25B
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
12
10
8
6
4
2
0
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12

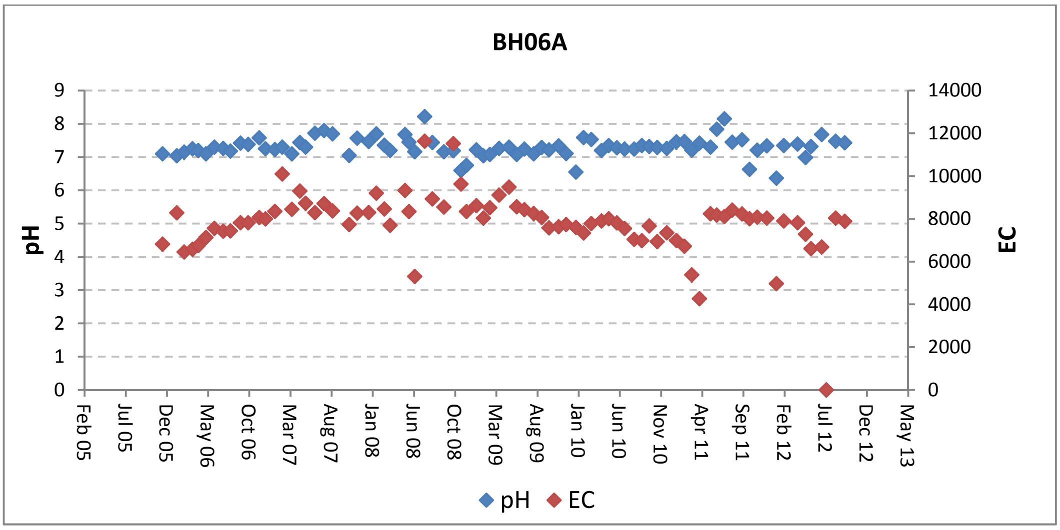

BH25C
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
10
9
8
7
6
5
4
3
2
1
0
200
100
0
-100
-200
-300
-400
-500
-600
-700
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Jun-12

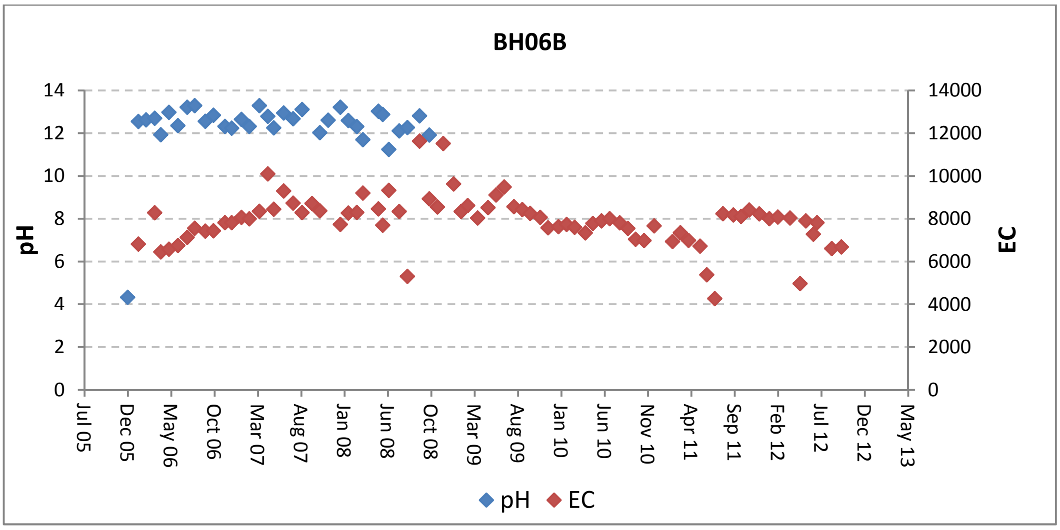
Appendix E

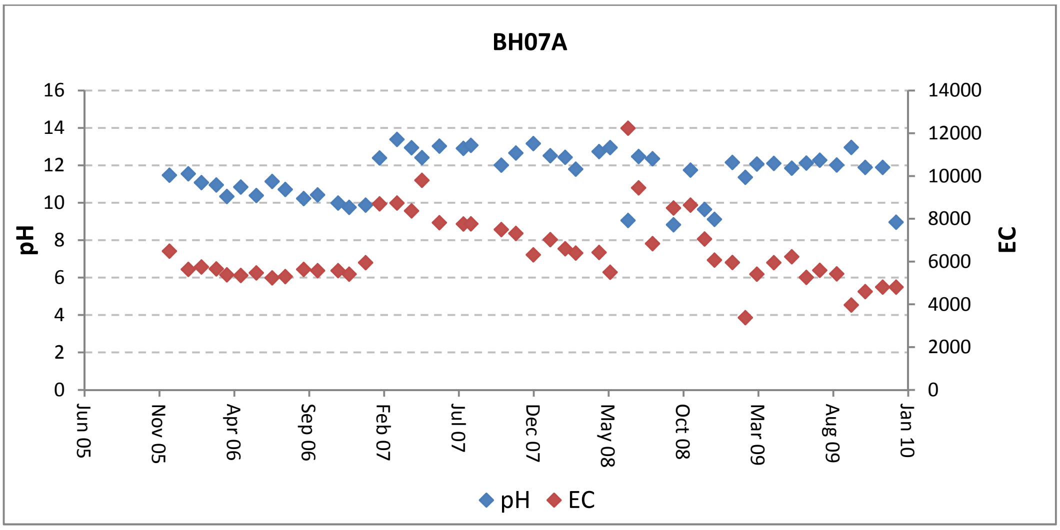
# Groundwater pH and EC – Deeper Mandalong Bores

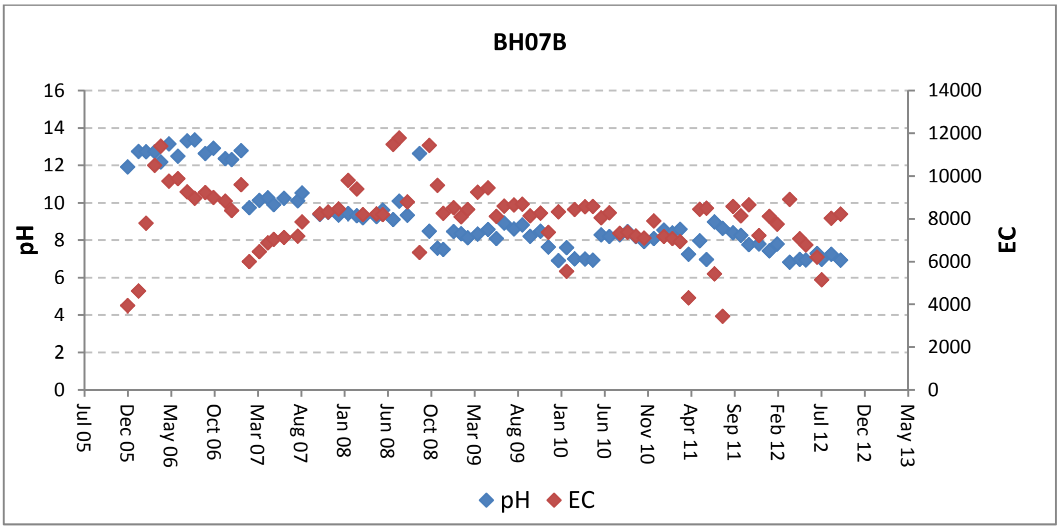

BH02A
pH
EC
pH
EC

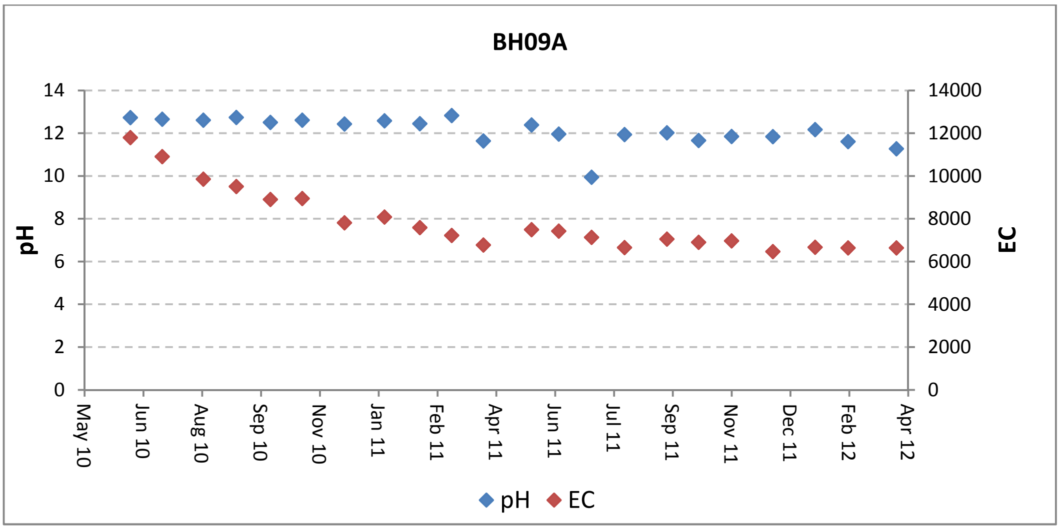

BH03B
pH
EC
pH
EC

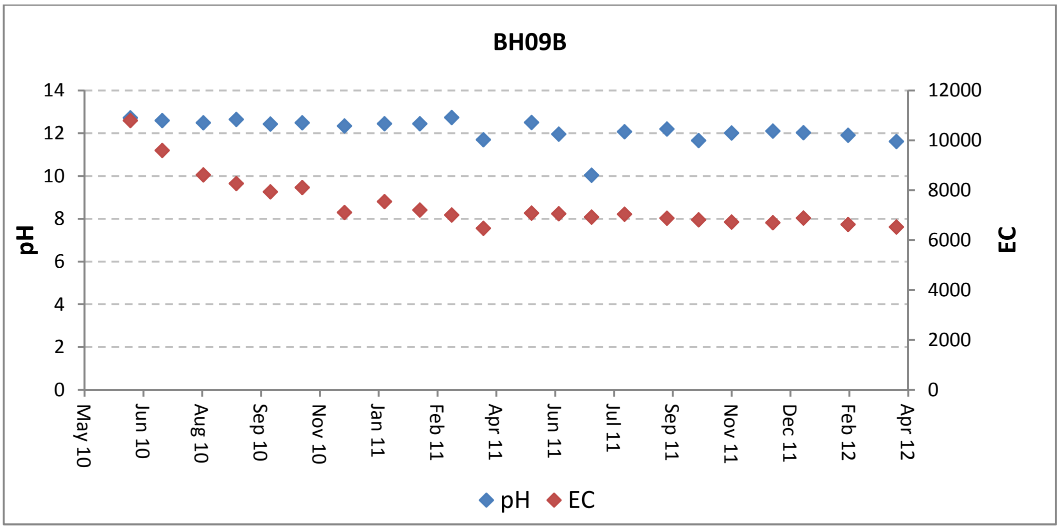

BH06A
pH
EC
pH
EC

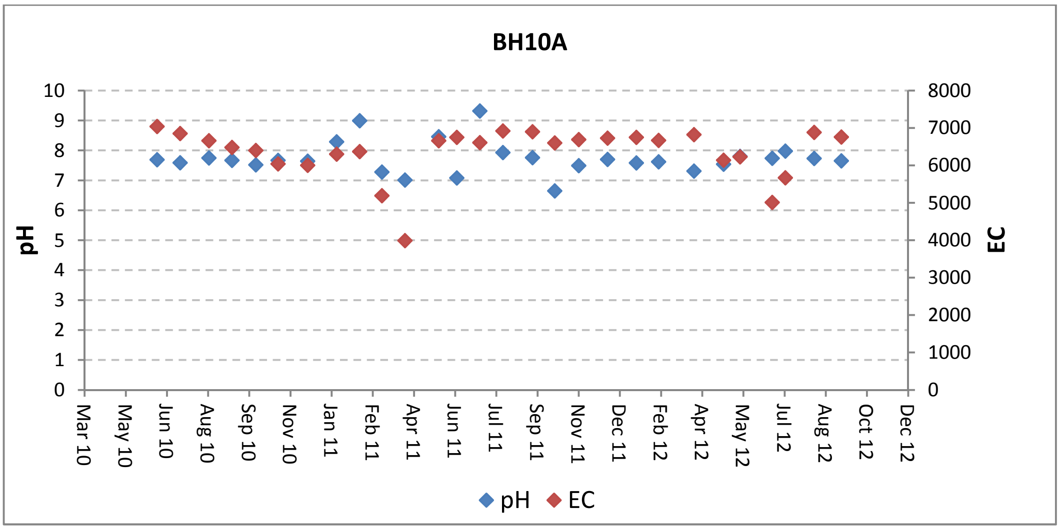

BH06B
14
12
10
8
6
4
2
0
14000
12000
10000
8000
6000
4000
2000
0
pH
EC
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH EC

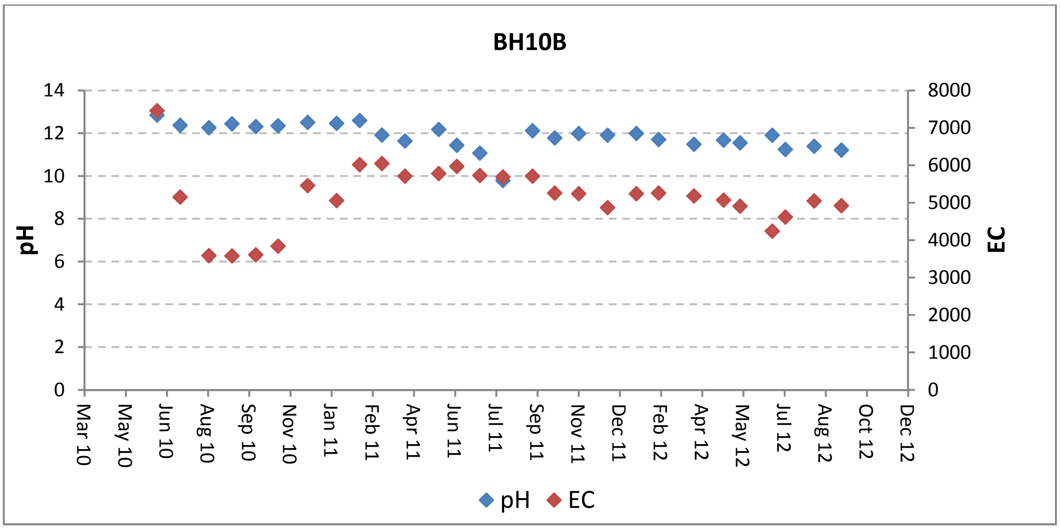

BH07A
16
14
12
10
8
6
4
2
0
14000
12000
10000
8000
6000
4000
2000
0
pH
EC
Jun 05
Nov 05
Apr 06
Sep 06
Feb 07
Jul 07
Dec 07
May 08
Oct 08
Mar 09
Aug 09
Jan 10
pH EC

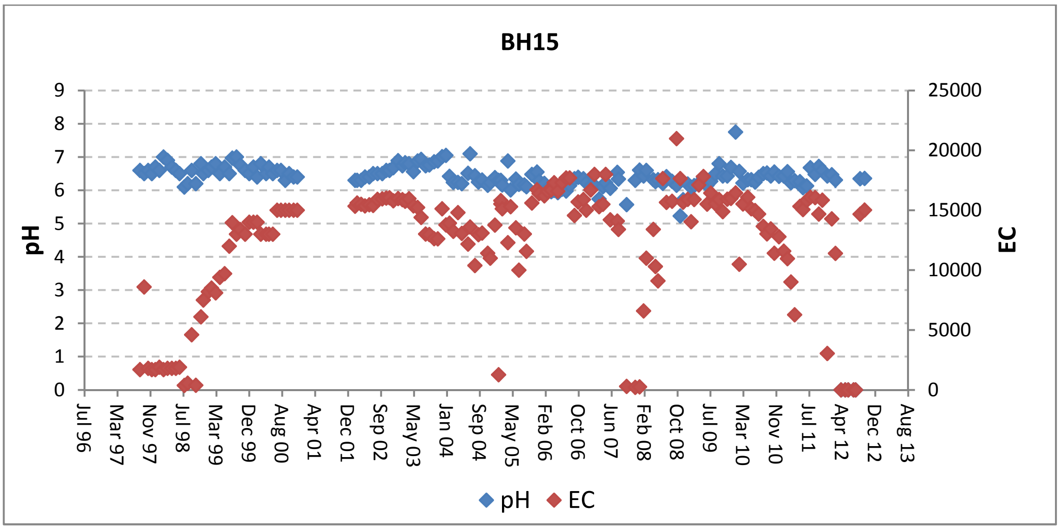

BH07B
16
14
12
10
8
6
4
2
0
14000
12000
10000
8000
6000
4000
2000
0
pH
EC
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH EC

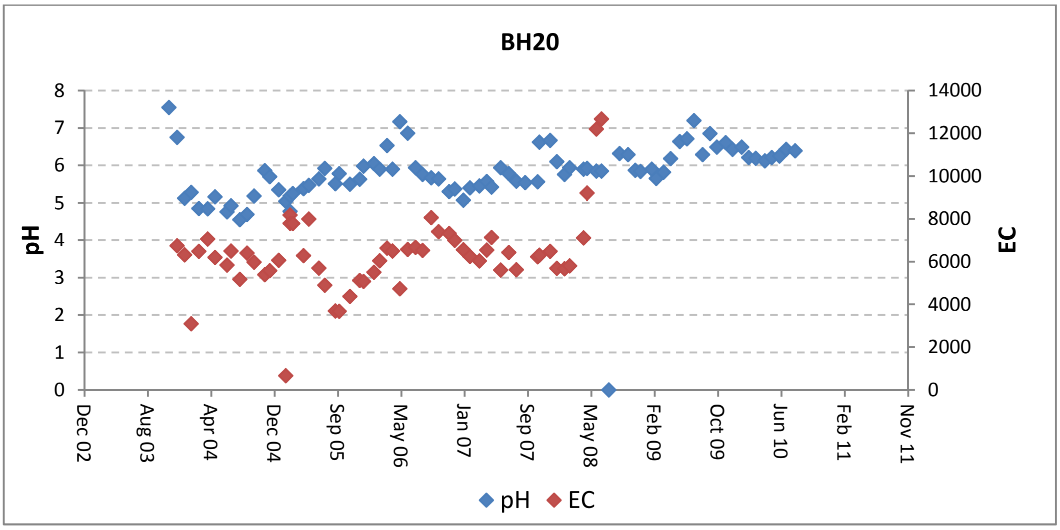

BH09A
pH
EC
14
12
10
8
6
4
2
0
14000
12000
10000
8000
6000
4000
2000
0
May 10
Jun 10
Aug 10
Sep 10
Nov 10
Jan 11
Feb 11
Apr 11
Jun 11
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
pH
EC

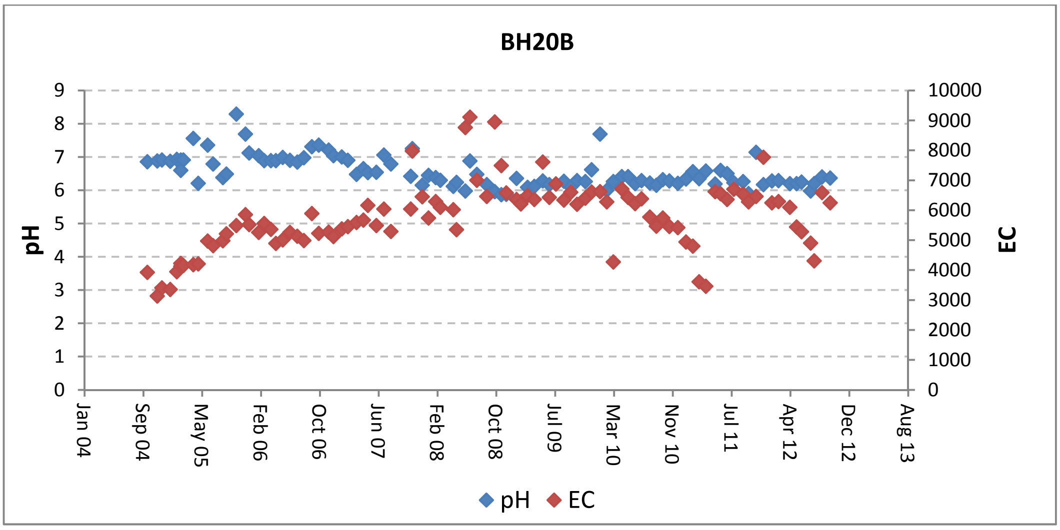

BH09B
pH
EC
14
12
10
8
6
4
2
0
12000
10000
8000
6000
4000
2000
0
May 10
Jun 10
Aug 10
Sep 10
Nov 10
Jan 11
Feb 11
Apr 11
Jun 11
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
pH
EC

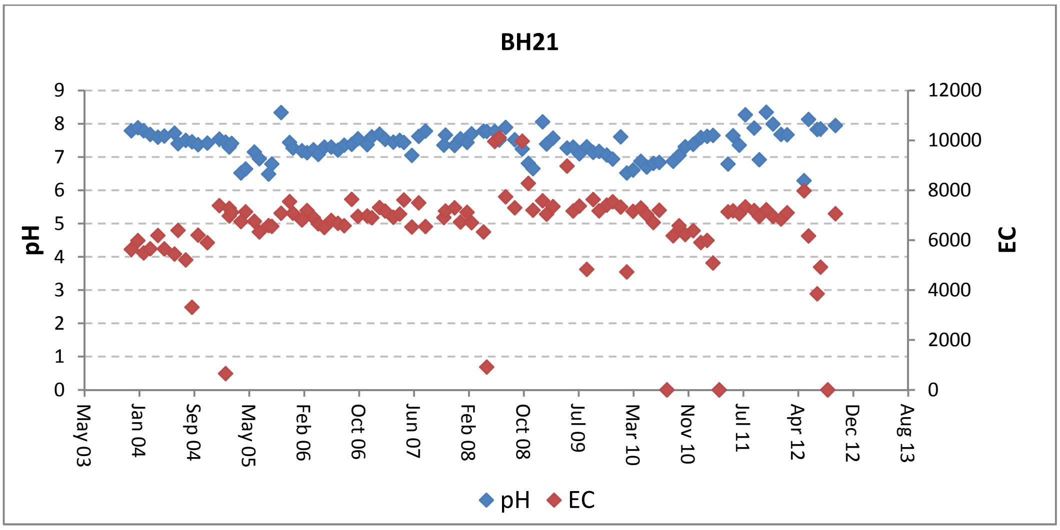

BH10A
pH
EC
10
9
8
7
6
5
4
3
2
1
0
8000
7000
6000
5000
4000
3000
2000
1000
0
Mar 10
May 10
Jun 10
Aug 10
Sep 10
Nov 10
Jan 11
Feb 11
Apr 11
Jun 11
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
pH
EC

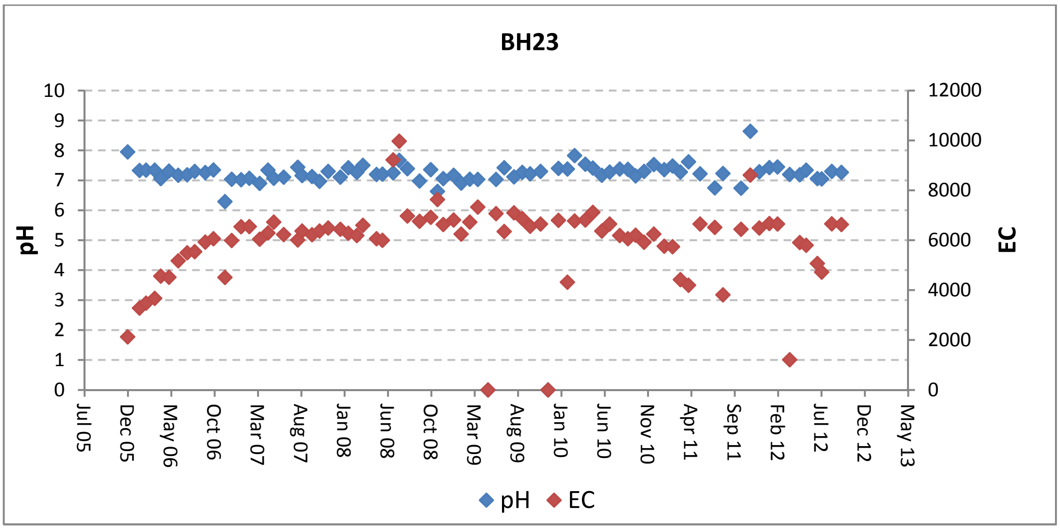

BH10B
pH
EC
Mar 10
May 10
Jun 10
Aug 10
Sep 10
Nov 10
Jan 11
Feb 11
Apr 11
Jun 11
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
pH EC

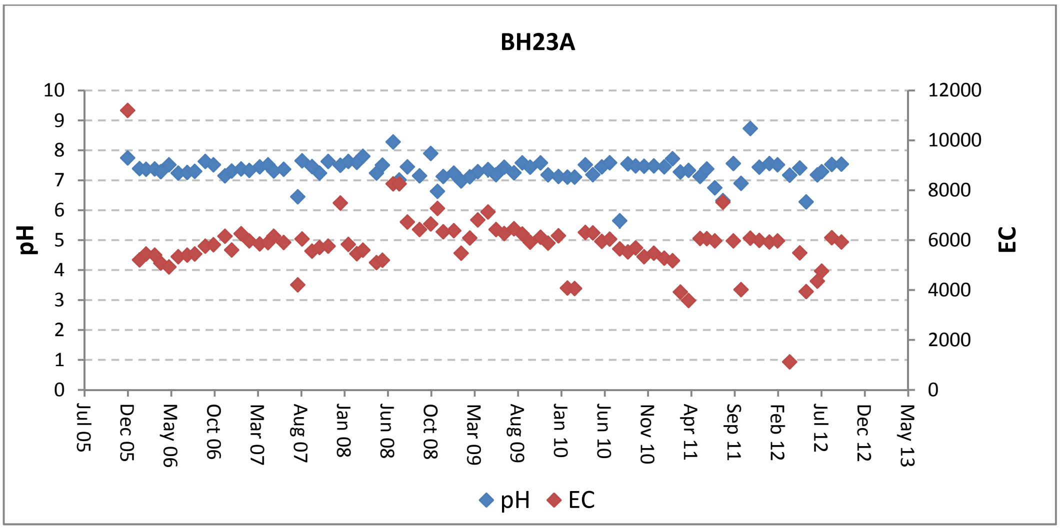

BH15
pH
EC
Jul 96
Mar 97
Nov 97
Jul 98
Mar 99
Dec 99
Aug 00
Apr 01
Dec 01
Sep 02
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH EC

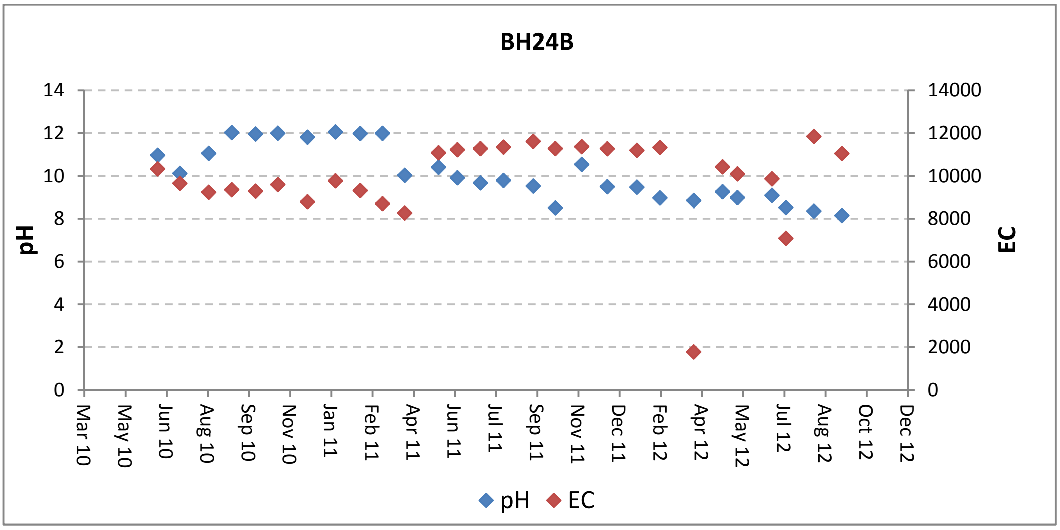

BH20
pH
EC
Dec 02
Aug 03
Apr 04
Dec 04
Sep 05
May 06
Jan 07
Sep 07
May 08
Feb 09
Oct 09
Jun 10
Feb 11
Nov 11
pH EC

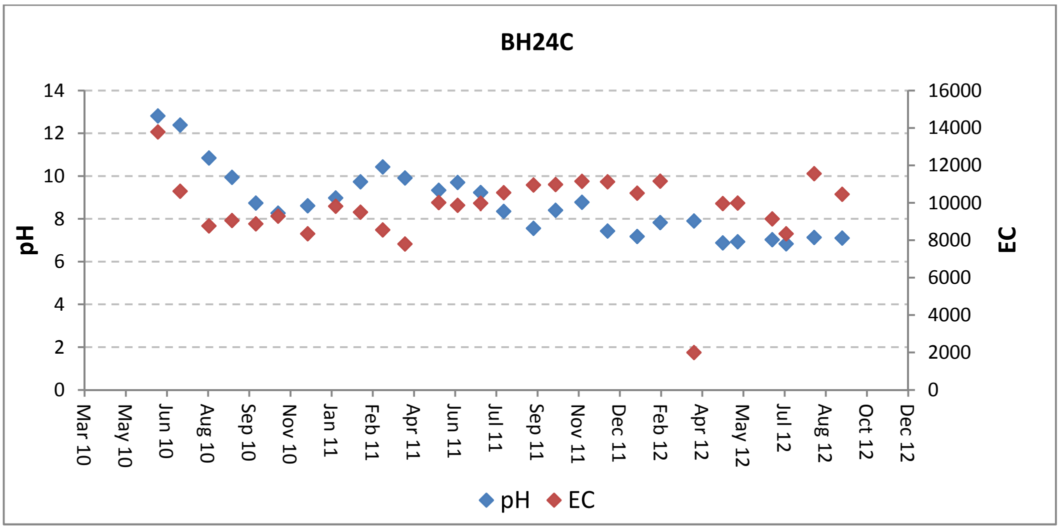

BH20B
pH
EC
0
1
2
3
4
5
6
7
8
9
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH21
pH
EC
0
1
2
3
4
5
6
7
8
9
0
2000
4000
6000
8000
10000
12000
May 03
Jan 04
Sep 04
May 05
Feb 06
Oct 06
Jun 07
Feb 08
Oct 08
Jul 09
Mar 10
Nov 10
Jul 11
Apr 12
Dec 12
Aug 13
pH
EC


BH23
pH
EC
0
1
2
3
4
5
6
7
8
9
10
0
2000
4000
6000
8000
10000
12000
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH
EC


BH23A
pH
EC
10
9
8
7
6
5
4
3
2
1
0
12000
10000
8000
6000
4000
2000
0
Jul 05
Dec 05
May 06
Oct 06
Mar 07
Aug 07
Jan 08
Jun 08
Oct 08
Mar 09
Aug 09
Jan 10
Jun 10
Nov 10
Apr 11
Sep 11
Feb 12
Jul 12
Dec 12
May 13
pH
EC


BH24B
pH
EC
14
12
10
8
6
4
2
0
14000
12000
10000
8000
6000
4000
2000
0
Mar 10
May 10
Jun 10
Aug 10
Sep 10
Nov 10
Jan 11
Feb 11
Apr 11
Jun 11
Jul 11
Sep 11
Nov 11
Dec 11
Feb 12
Apr 12
May 12
Jul 12
Aug 12
Oct 12
Dec 12
pH
EC


BH24C
pH
EC
14
12
10
8
6
4
2
0
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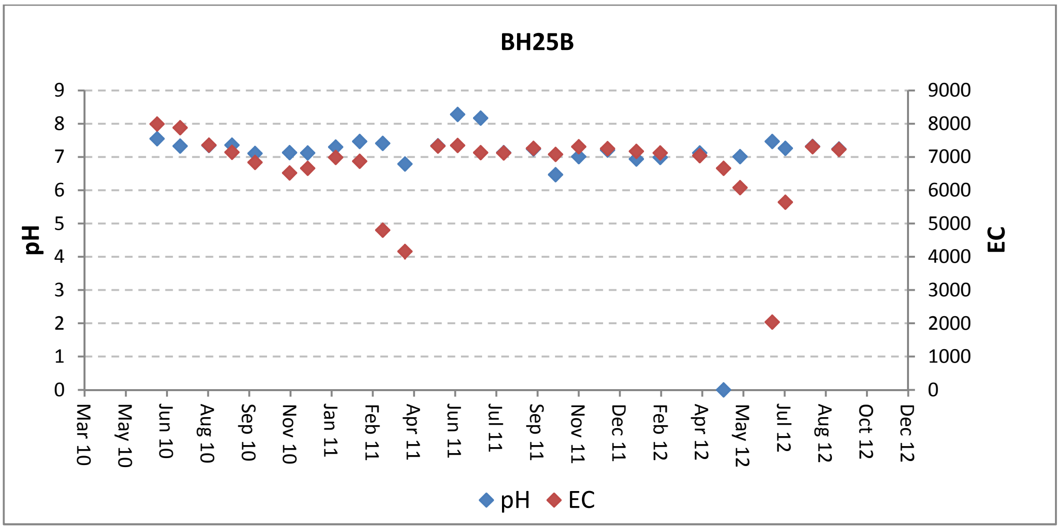
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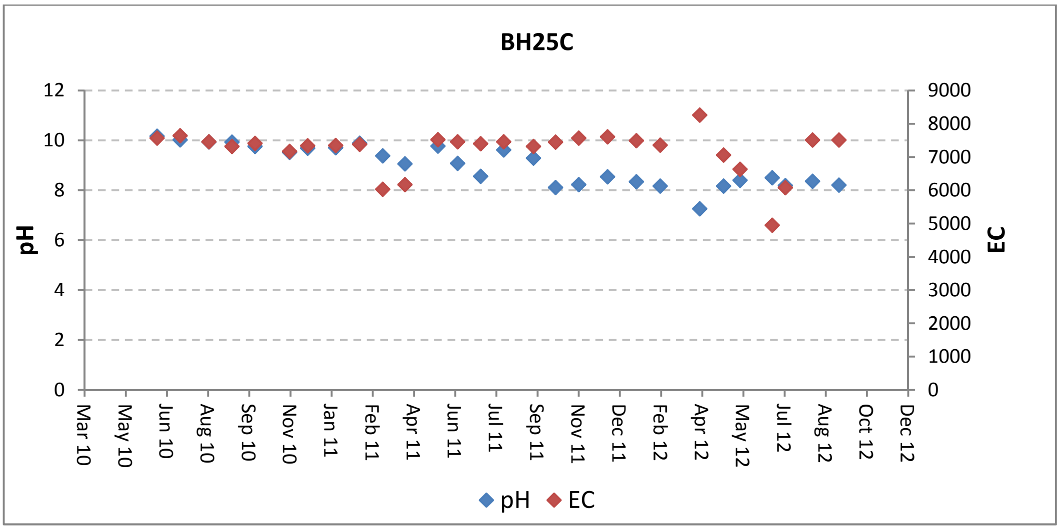
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Appendix F

# Hydrogeological Model Report

# *Mandalong Southern Extension Project*

## *HYDROGEOLOGICAL MODEL REPORT*

## Centennial Mandalong

## August 2013

# Contents

## Table Index



## Figure Index

# Annexures

A Groundwater Hydrographs - Alluvium

# Abbreviations

| | |
|---|---|
| AHD | Australian Height Datum |
| ARI | Average Recurrence Interval |
| AWMF | Awaba Waste Management Facility |
| bgl | Below ground level |
| BOM | Bureau of Meteorology |
| CHP | Coal Handling Plant |
| CRD | Cumulative Rainfall Departure |
| DA | Development Application |
| DGRs | Director General's Requirements |
| EC | Electrical Conductivity |
| EEC | Endangered Ecological Community |
| EIS | Environmental Impact Statement |
| EL | Exploration Lease |
| EPA | Environment Protection Authority |
| EPL | Environment Protection Licence |
| GDE | Groundwater Dependent Ecosystem |
| GHB | General Head Boundary |
| GHD | GHD Pty Ltd |
| GMS | Groundwater Modelling System |
| GWMP | Groundwater Monitoring Program |
| HWC | Hunter Water Corporation |
| LGA | Local Government Area |
| LW | Longwall |
| m | Metres |
| MB | Monitoring bore |
| ML | Megalitres, Mining Lease |
| ML/day | Megalitres per day |
| Mt | Million tonnes |
| Mtpa | Million tonnes per annum |

| | |
|---|---|
| NOW | NSW Office of Water |
| QCCCE | Queensland Climate Change Centre of Excellence |
| ROM | Run of Mine |
| SRMSE | Scaled Root Mean Square Error |
| USGS | United States Geological Survey |
| VWP | Vibrating Wire Piezometer |
| WMIA | Water Management Impact Assessment |
| WSP | Water Sharing Plan |

# Glossary

| | |
|---|---|
| Angle of Draw | The angle between the vertical and the line joining the edge of the mining void with the limit of vertical subsidence, usually taken as 20 mm. |
| Aquifer | A groundwater bearing formation sufficiently permeable to transmit and yield productive volumes of groundwater. |
| Australian Height Datum | A common national surface level datum approximately corresponding to mean sea level. |
| Average Recurrence Interval (ARI) | The long term average number of years between the occurrences of a flood as big as or larger than the selected event. |
| Bord and pillar | A mining system whereby coal is extracted leaving ‘pillars’ of untouched coal to support the strata above. |
| Bore | Constructed connection between the surface and a groundwater source that enables groundwater to be transferred to the surface either naturally or through artificial means. |
| Catchment | The land area draining through the main stream, as well as tributary streams, to a particular site. |
| Cumulative Rainfall Departure | Monthly accumulation of the difference between the observed monthly rainfall and long term average monthly rainfall. |
| Design Rainfall Event | A hypothetical rainfall event representing a specific likelihood of occurrence (for example the 100 year or 1% probability rainfall event). |
| Drawdown | A reduction in piezometric head within an aquifer. |
| Fracture | Cracks within the strata that develop naturally or as a result of underground works. |
| Groundwater | Subsurface water that occurs in soils and geological formations. |
| Headings | A roadway driven in to the coal seam for access to underground operations by personnel and machinery. |
| Hydrogeology | The area of geology that deals with the distribution and movement of groundwater in soils and rocks. |
| Hydrograph | A graph which shows how a water level (either surface or underground) at any particular location changes with time. |
| Infiltration | The downward movement of water into soil and rock. It is largely governed by the structural condition of the soil, the nature of the soil surface (including presence of vegetation) and the antecedent moisture content of the soil. |
| Interseam | The strata between coal seams. |

| | |
|---|---|
| Licensed Discharge Point | A location where a licensed operation discharges water to the environment in accordance with conditions stipulated within the site Environment Protection Licence. |
| Longwall | Longwall mining is a form of underground coal mining where a block of coal is mined using a longwall shearer. The longwall mining method is supported by roadway development, mined using a continuous miner unit. |
| Outcrop | Where the bedrock is exposed at the ground surface. |
| Overburden | The strata between the recoverable topsoil and the upper coal seam. |
| Permian Age | The youngest geological period of the Palaeozoic era, covering a span between approximately 290 and 250 million years. |
| Roadway | Underground tunnel constructed to enable access to working face. |
| Run of Mine | Raw coal production (unprocessed). |
| Runoff | The amount of rainfall which actually ends up as streamflow, also known as rainfall excess. |
| Strata | Geological layers below the ground surface. |
| Structure | The combination or spatial arrangement of primary soil particles (clay, silt, sand, gravel) into aggregates such as peds or clods, and their stability to deformation. |
| Subsidence | Mining-induced movements and deformations at the ground surface where (i) the vertical downward surface movements are greater than 20 mm, or (ii) the potential impacts on major surface infrastructure, structures or natural features may be significant, notwithstanding that the vertical downward surface movements are less than 20 mm. |
| Surface Water | Water that is derived from precipitation or pumped from underground and may be stored in dams, rivers, creeks and drainage lines. |
| Tailings | Fine reject material produced as a result of the coal processing. |
| Vertical Subsidence | Vertical downward movements of the ground surface caused by underground coal mining. |

# 1. Introduction

## 1.1 Project Overview

Mandalong Mine is an existing underground coal mine operation located in the Lake Macquarie Local Government Area (LGA) approximately 130 km north of Sydney near Morisset in New South Wales (NSW) (see Figure 1-1). After purchasing the Mandalong Mine from Powercoal in August 2002, Centennial Mandalong Pty Limited (Centennial Mandalong), which is a wholly owned subsidiary of Centennial Coal Company (Centennial), operates the mine.

Underground longwall mining operations commenced at Mandalong Mine in January 2005 under the provisions of Development Consent DA 97/800. Since this time, Centennial Mandalong has extracted up to 6 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal from the West Wallarah Seam utilising a combination of longwall and continuous mining methods. Mandalong Mine represents a major component to the success of Centennial, producing approximately 30 percent of the company's annual ROM coal.

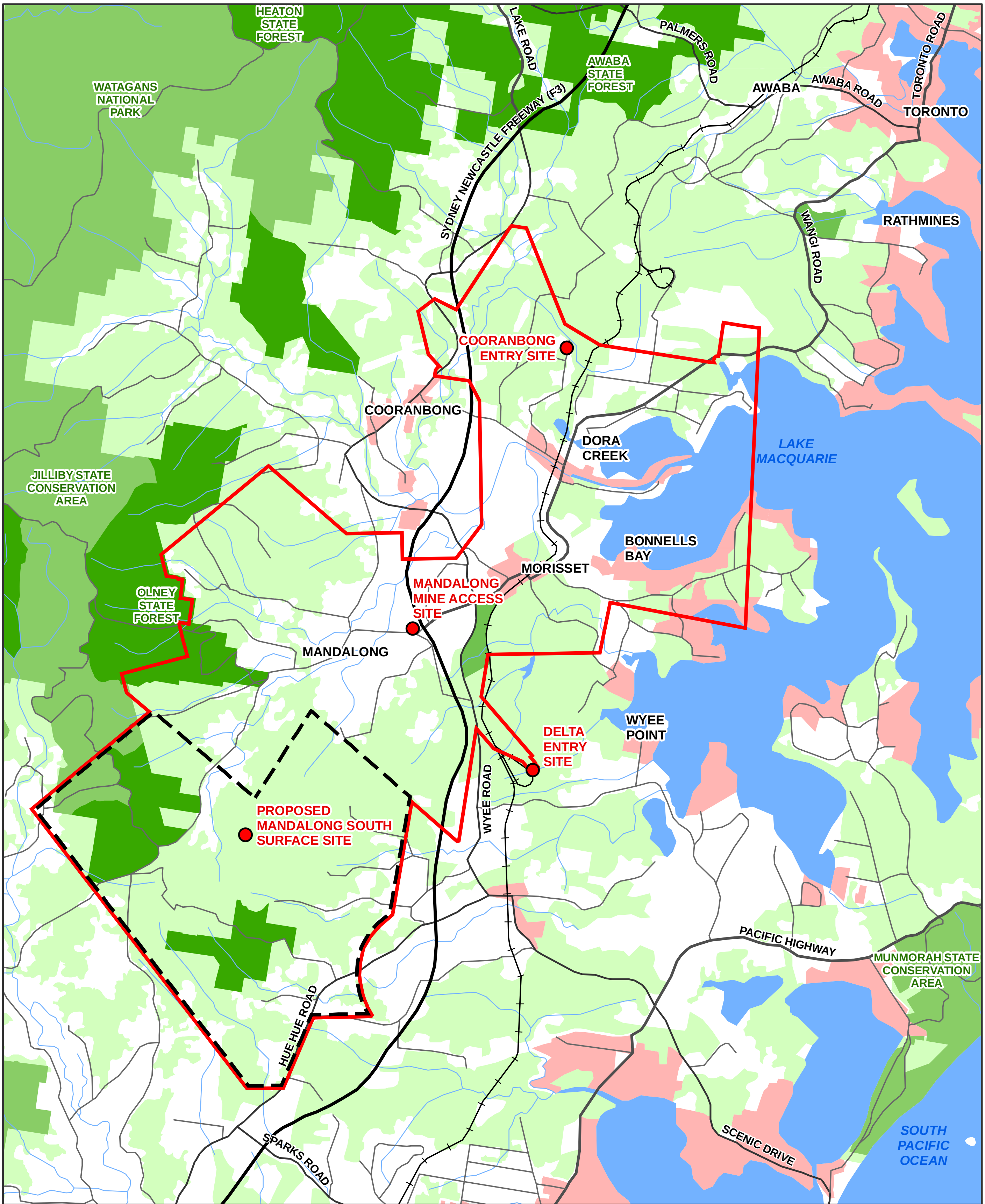
Centennial Mandalong expects to have extracted the final approved longwall panel in the West Wallarah Seam at Mandalong Mine in 2018. As part of the life of mine planning process at Mandalong Mine, Centennial Mandalong obtained Exploration Licence 6317 (EL 6317) in 2005 over an area referred to as the Mandalong Southern Extension Area. This exploration area comprises approximately 4,700 ha of land immediately south of the existing Mandalong Mine. The exploration drilling program, which commenced in 2010, identified additional economic coal reserves within the West Wallarah and the Wallarah - Great Northern Seams that are high in heat energy and low in ash content, making the coal ideal for electricity generation.

The Mandalong Southern Extension Project (the Project) proposes to extend Mandalong Mine's existing underground mining operations into the area covered by EL 6317 in order to access, develop and extract the additional coal reserves identified within the West Wallarah and Wallarah - Great Northern Seams at a rate of up to 6 Mtpa of ROM coal. Among other things, the Project also proposes to utilise existing and proposed surface infrastructure integral to the mining operation in terms of coal delivery, handling and transport.

The objectives of the Project include:

- Develop the on-going underground mining operations, focusing on maximising resource recovery and maintaining continuity of coal production beyond the currently projected life of mine.
- Maximise the use of existing underground and surface infrastructure and equipment.
- Secure increased employment and socio-economic flow-on benefits.
- Continue to conduct mining at Mandalong Mine in an environmentally responsible manner to ensure the potential for adverse impact is minimised.

GHD Pty Ltd (GHD) was engaged by Centennial Mandalong to undertake an assessment of potential impacts to groundwater sources (aquifers) as part of the Environmental Impact Statement (EIS) for this Project, in accordance with the Director General's Requirements (DGRs) and relevant statutory conditions. The relevant DGRs, legislation and policies are outlined in the Groundwater Impact Assessment report for the Mandalong Southern Extension Project (GHD 2013a).

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Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

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GHD

LEGEND
- EL6317 Boundary
- Project Application Area
- Principal Road
- Secondary Road
- Minor Road
- Existing Rail
- Watercourse
- Watercourse Area
- Built Up Area
- Recreation Area
- Nature Conservation
- State Forest
- Forest Or Shrub



| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | West Wallarah |
| DRAWN | R.Towner |
| CHECKED | G. Mcdiarmid |
| APPROVED | I.Joliffe |
| SCALE | Refer to scalebar |

Mandalong Southern Extension Project
Hydrogeological Model Report

Locality Plan

Centennial Mandalong

DATE 28/02/2013

Figure 1-1

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As part of this groundwater impact assessment, a numerical hydrogeological model has been constructed to quantify predicted impacts to aquifers. This report outlines the hydrogeological modelling methodology and results. The objectives and scope of this report are detailed in Sections 1.4 and 1.5.

## 1.2 Project Application Area

The Project Application Area includes:

- The existing Mandalong Mine Access Site encompassing underground workings and associated surface infrastructure near Morisset.
- The existing Delta Entry Site encompassing a coal delivery system near Wyee at the Vales Point Rail Unloader Facility.
- The extent of existing approved workings of the Mandalong Mine and Cooranbong Entry Site for water management, mine ventilation, men and materials access and delivery of coal.
- The proposed Mandalong Southern Extension Project mining area within EL 6317.
- The proposed new surface facilities site for the Mandalong Southern Extension mining area.

The Project Application Area and EL 6317 boundary (Southern Extension Area) are shown in Figure 1-1. Also shown are the locations of the existing Mandalong Mine Access Site, existing Delta Entry Site, existing Cooranbong Entry Site and proposed site for the new surface facilities to be known as Mandalong South Surface Site.

The hydrogeological model domain has been defined by hydrogeological and geological boundaries and extends beyond the Project Application Area. Further details regarding the hydrogeological model boundary are provided in Section 4 of this report.

## 1.3 Existing and Proposed Operations

### 1.3.1 Existing Operations

The existing operations within the Project Application Area consist of:

- Completed longwall and bord and pillar underground workings within the Great Northern Seam to the north of the Mandalong Mine Access Site and to the west of the Cooranbong Entry Site (referred to as the 'Cooranbong workings').
- Completed and existing longwall and continuous miner operations within the West Wallarah Seam to the west of the Mandalong Mine Access Site (referred to as the 'Mandalong workings'). Centennial Mandalong plan to develop 24 longwalls within the existing approval area (LW 1 – 24). The final longwall is scheduled for completion in 2018.
- Surface infrastructure and facilities at the Mandalong Mine Access Site, including a decline tunnel, administration building and bathhouse, car park, mechanical workshop and store, two mine ventilation fans, diesel refuelling station, hydrocarbon storage shed, equipment and materials storage areas, gas drainage, machinery wash-down bay, fire fighting and emergency equipment store, compressor shed, core shed, tube bundle shed, electrical sub-station and solsenic mixing plant. The site has existing connections to Hunter Water Corporation's (HWC) reticulated potable water and sewer systems.

- Surface infrastructure and facilities at the Cooranbong Entry Site, including a Coal Handling Plant (CHP), mechanical workshops and service buildings, administration buildings and bathhouse, one mine ventilation fan, car park, equipment and materials storage areas, machinery wash-down bay, fire fighting and emergency equipment store, compressor building, electrical sub-station, water management infrastructure and emergency services helipad.
- Transport of ROM coal from the Mandalong workings via an underground conveyor system through the Cooranbong workings and south drift conveyor to the Cooranbong Entry Site.
- An underground coal delivery system to the Delta Entry Site at the Vales Point Rail Unloader Facility.
- Transfer of underground water within the Cooranbong and Mandalong workings via a dewatering bore in the Cooranbong workings to the Cooranbong Entry Site and subsequent discharge from licenced discharge points in accordance with the Environmental Protection Licence (EPL) for the Cooranbong Entry Site.

#### 1.3.2 Proposed Operations

The proposed operations within the Project Application Area include:

- The development of 40 longwall panels (LW 25 – 64) using a combination of longwall and continuous miner extraction methods within the current mining lease areas and the area covered by EL 6317. Coal will be extracted from the West Wallarah and Wallarah – Great Northern Seams at a rate of up to 6 Mtpa of ROM coal.
- Utilise the existing underground coal delivery systems to deliver ROM coal to the Cooranbong Entry Site and Delta Entry Site.
- Continue to utilise the existing surface infrastructure at the Mandalong Mine Access Site.
- Continue to utilise the existing underground water management system to transfer underground mine water from the existing and proposed workings to the Cooranbong Entry Site.
- Construction of a new surface facilities site (Mandalong South Surface Site) within the Southern Extension Area to operate surface infrastructure for mine ventilation, storage and underground delivery of stone dust, concrete and ballast, hydrocarbon storage, electrical reticulation, water reticulation, water management, communications and other ancillary services and activities.
- Undertake ongoing exploration drilling activities within the bounds of Centennial Mandalong's mining leases and exploration licences.
- Increase the life of mine to 25 years from the granting of a mining lease(s) over EL 6317.

The development of main headings within the Southern Extension Area is proposed to commence in 2015 and longwall extraction is expected to be undertaken between 2018 and 2036. Existing and proposed workings within the Project Application Area are shown Figure 1-2 and Figure 1-3. The proposed longwalls range in length from approximately 1000 m to 3500 m and range in width from 160 m to 200 m.

The proposed Mandalong South Surface Site will be located above the proposed main headings as shown in Figure 1-2 and Figure 1-3. The site will include a 5 m diameter downcast ventilation shaft and a 6 m diameter upcast shaft, with two surface fans installed at the upcast shaft site. Service shafts will also be installed at the site to transfer materials and mine water as required. A site access road will be constructed from Mandalong Road to the Mandalong South Surface Site and a powerline easement will run parallel to this road. Construction of the proposed Mandalong South Surface Site is expected to commence in 2016.

## 1.4 Objectives of the Hydrogeological Model

A hydrogeological model has been developed to support the assessment of impacts to groundwater sources in the Project Application Area resulting from the construction and operation of the Project. This report provides estimates of dewatering volumes and zone(s) of drawdown in each groundwater source as a result of the development of the 40 Mandalong Southern Extension longwall panels. Predicted impacts on these groundwater sources and impacts on groundwater users, connected water sources and Groundwater Dependent Ecosystems (GDEs) are assessed in GHD (2013a).

Hydrogeological modelling is a requirement of both the DGRs that have been issued for the Project and the NSW Aquifer Interference Policy (NSW Department of Primary Industries, NSW Office of Water (NOW), September 2012).

The following DGRs require that hydrogeological modelling be undertaken:

- Detailed assessment of potential impacts on the quality of existing groundwater resources, including detailed modelling of potential groundwater impacts.
- A description and assessment of any requirements (including potential requirements) and activity that intercept groundwater, including the associated predicted dewatering volumes and zone(s) of drawdown and associated impact.

According to Section 3.2.3 of the NSW Aquifer Interference Policy, proponents of a mining project seeking development consent under Part 4 Division 4.1 of the *Environment Planning and Assessment Act 1979* must provide estimates of all quantities of water that are likely to be taken from any water source during and following cessation of the activity and all predicted impacts associated with the activity, based on a complex modelling platform that is:

- Calibrated and validated (where practical) to the available baseline data that has been collected at an appropriate frequency and scale and over a sufficient period of time to incorporate typical temporal variations.
- Consistent with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).
- Independently reviewed and determined to be robust and reliable[1].

## 1.5 Scope of Work

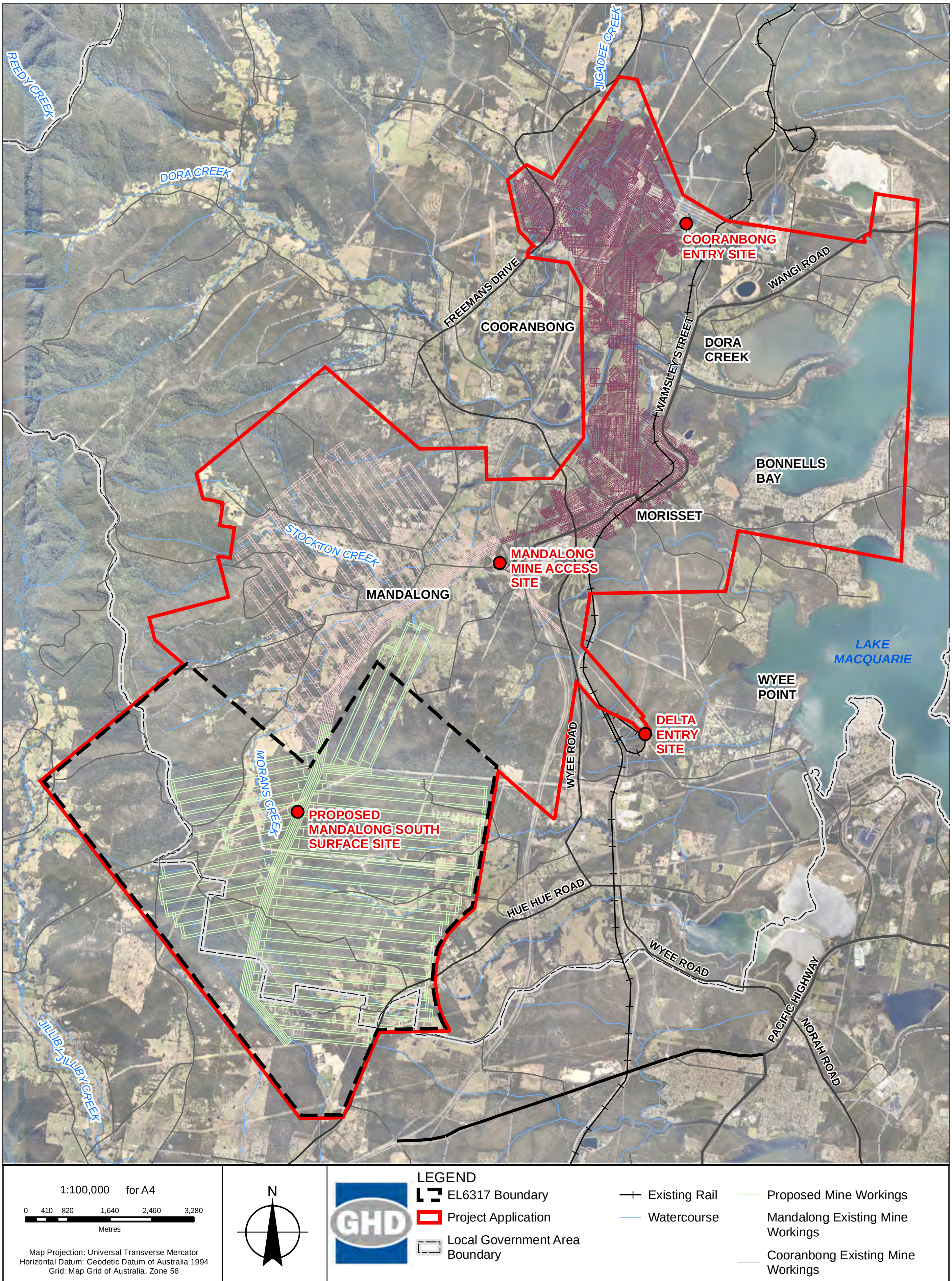
The scope of works for the hydrogeological modelling for the Project is as follows:

- Collate available hydrogeological and mining data (Section 3).

[1] This report has been independently reviewed in accordance with GHD's internal peer review process.

- Development of a conceptual hydrogeological model of the coal seam and overlying strata (Section 4).
- Construction of a MODFLOW numerical hydrogeological model, based on the conceptual model (Sections 5.1 and 5.2).
- Calibration of the model using available data under steady state and transient conditions (Sections 5.3 and 5.4).
- Predict groundwater inflows into the underground workings over the life of the proposed Mandalong Southern Extension Project (Section 6.1).
- Establish the zones of drawdown in the coal seam and overlying groundwater sources, resulting from the development of the 40 longwall panels (Section 6.2).

Note that potential groundwater impacts arising from the construction of the Mandalong South Surface Site are considered to be minor since the proposed footprint does not intercept GDEs and it is not expected that alluvial groundwater will be intercepted during construction. Therefore it is not necessary to incorporate this site into the hydrogeological model. Potential groundwater impacts arising from the construction of this site have been addressed in the Groundwater Impact Assessment report only (GHD, 2013a).






| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | West Wallarah |
| DRAWN | R.Towner |
| CHECKED | G. Mcdiarmid |
| APPROVED | I.Joliffe |
| SCALE | Refer to scalebar |

Mandalong Southern Extension Project
Hydrogeological Model Report

Existing and Proposed Workings

Centennial Mandalong

DATE 28/02/2013

Figure 1-2

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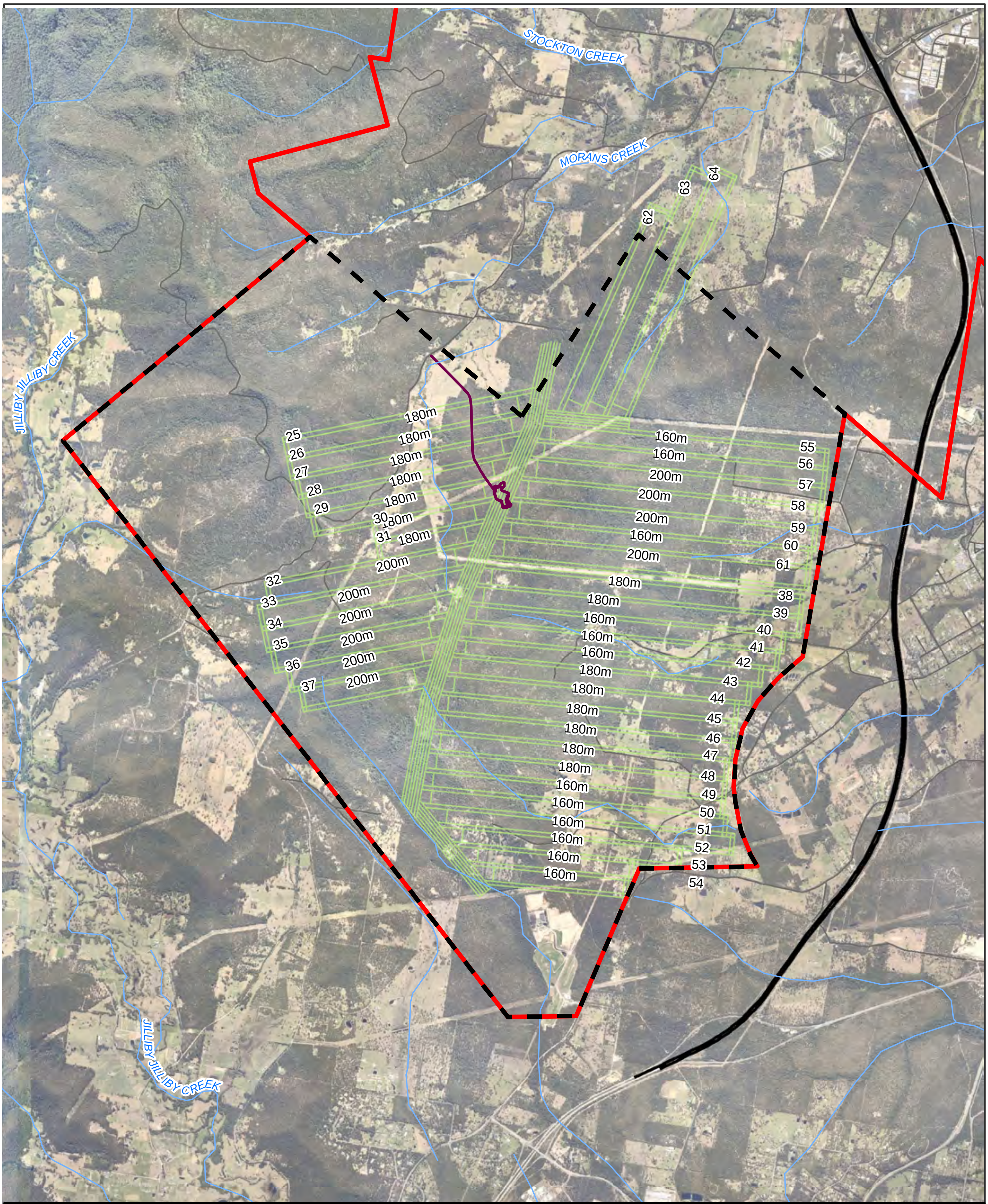
© LPMA: DTDB - 2007 ; Commonwealth of Australia (Geoscience Australia): 250K Topographic Data Series 3 - 2006 ; Centennial: Application Area, EL6317 Boundary, Mine Workings - 2012; GSS: Imagery;

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Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

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GHD

LEGEND

- EL6317 Boundary
- Application Area Boundary
- Freeway
- Local Road
- Watercourse
- Proposed Mandalong South Surface Site
- Proposed Mine Workings



| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | |
| DRAWN | S.M. |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong Southern Extension Project
Hydrogeological Model Report

Proposed Workings showing Longwalls

Centennial Mandalong

DATE 28/02/2013

Figure 1-3

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# 2. Existing Environment

The existing geological, hydrogeological and surface water environment within the Project Application Area, with a focus on the Southern Extension Area, is outlined in this section.

## 2.1 Landforms and Watercourses

The land within the Southern Extension Area is characterised by relatively flat and low lying rural areas bordered by densely timbered ridgelines. Surface topography ranges from less than 30 m Australian Height Datum (AHD) throughout the rural areas and drainage lines up to over 200 m AHD along the ridgelines.

The F3 Freeway is located immediately to the east of the Southern Extension Area while the southern extent of Lake Macquarie, Lake Munmorah and Budgewoi Lake are located approximately 5 km to the east. The Jilliby Creek catchment and Jilliby State Conservation Area are located to the south and west of the Southern Extension Area respectively. The Mandalong Valley is located to the north of the Southern Extension Area while the Watagan State Forest is located to the north-west.

The main watercourses that intersect the Southern Extension Area include:

- Upper reaches of Morans Creek.
- Upper reaches of Wyee Creek.
- Upper reaches of Mannering Creek.
- Upper reaches of Buttonderry Creek.

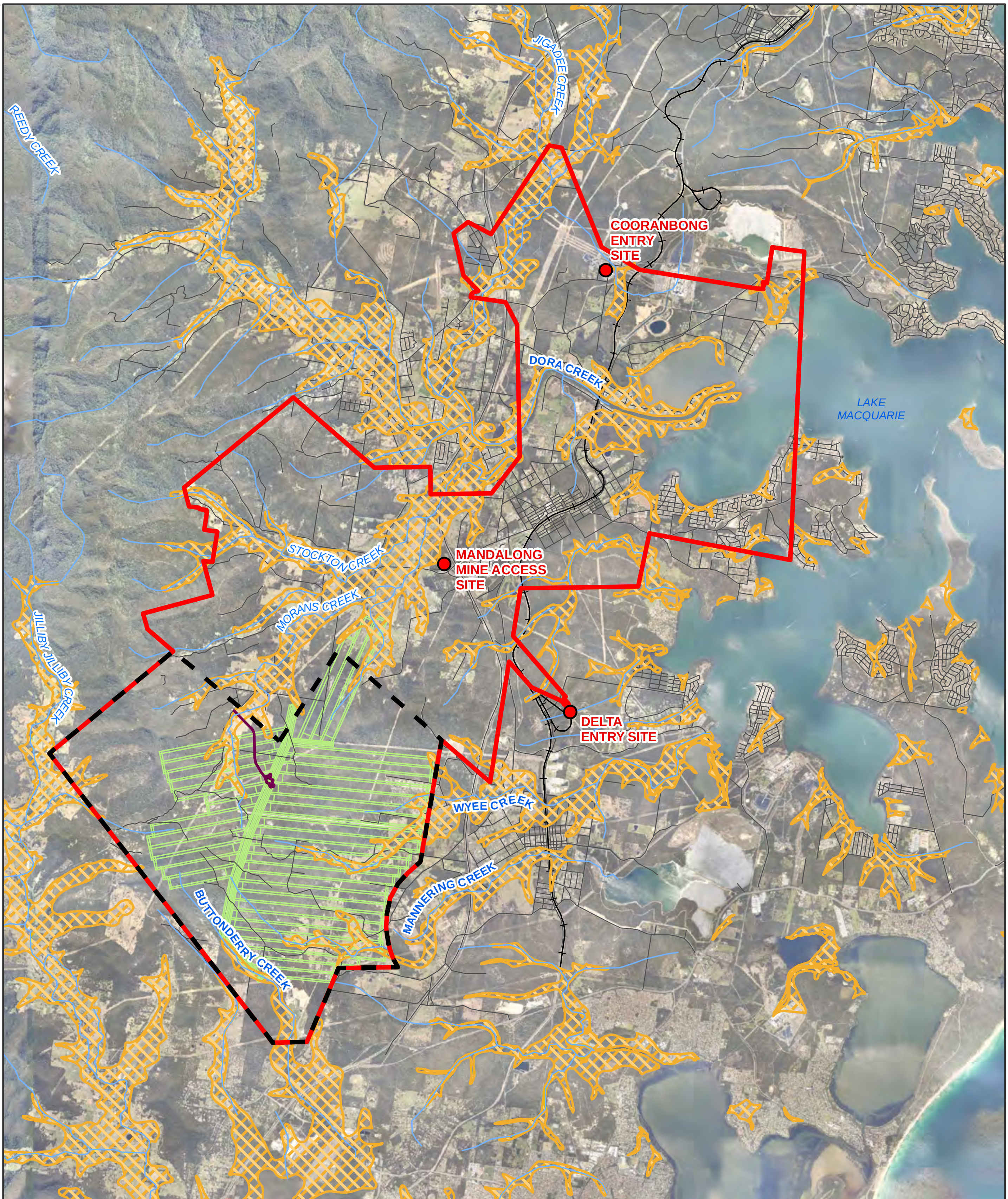
The other main watercourses to the north of the Southern Extension Area that intersect the Project Application Area include:

- Stockton Creek.
- Dora Creek.
- Jigadee Creek.

These watercourses and their locations with respect to the Project workings are shown in Figure 2-1. Morans Creek, a tributary of Stockton Creek and part of the Dora Creek catchment, originates within the Southern Extension Area and drains to the north towards the existing Mandalong Mine Access Site. The majority of the existing Mandalong and Cooranbong workings underlie the Dora Creek catchment. Mannering Creek and Wyee Creek also originate within the Southern Extension Area and flow to the east into Lake Macquarie.

## 2.2 Geology

The Southern Extension Area is located in the south-western part of the Newcastle Coalfield, which occupies the north-eastern portion of the Sydney Basin. The Project Application Area and the Southern Extension Area are underlain by Triassic claystone, sandstone and conglomerate, as well as Quaternary alluvial sediments along watercourses. The Triassic rocks are underlain by the Permian Newcastle Coal Measures, which dips gently at approximately 1 to 2 degrees to the south-west beneath the Southern Extension Area.

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Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

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GHD

LEGEND

- EL6317 Boundary
- Application Area Boundary
- Railway
- Roads
- Watercourse
- Proposed Mine Workings
- Proposed Mandalong South Surface Site
- Alluvial Soils (Lake Macquarie)



| | |
|---|---|
| LOCATION | Newstan |
| SEAM | |
| DRAWN | S.M. |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong South Expansion Project
Hydrogeological Model Report

Approximate Location of
Alluvium near Study Area

Centennial Mandalong

DATE 28/02/2013

Figure 2-1

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The Wallarah and Great Northern Seams are contained within the upper strata of the Newcastle Coal Measures. Exploration programs have indicated that these are the only seams with significant economic potential in the Southern Extension Area. The other seams in the Newcastle Coal Measures stratigraphic section are poorly developed or extensively intruded in this area and are currently considered as having no economic potential.

The stratigraphy at the Southern Extension Area is summarised in Table 2-1. This information has been sourced from the Newcastle Coalfields Regional Geology 1:100,000 map (NSW Department of Mineral Resources, Edition 1 1995), exploration logs for the Mandalong Southern Extension Project and the Cooranbong Colliery Life Extension Project Overburden Strata Groundwater Study (Pacific Power International, 1997).

**Table 2-1 Stratigraphic Sequence – Southern Extension Area (EL 6317)**

| Period | Stratigraphy | | Formation | Lithology |
|---|---|---|---|---|
| | Group | Subgroup | | |
| Quaternary | | | | Alluvium |
| Triassic | Narrabeen | Clifton | Patonga Claystone<br>Tuggerah Formation<br>Munmorah Conglomerate<br>Dooralong Shale | Conglomerate, sandstone, siltstone, claystone |
| Permian | Newcastle Coal Measures | Moon Island Beach | Wallarah / Great Northern Seam | Conglomerate, sandstone, siltstone, tuff, coal |
| | | Awaba Tuff | | Tuff |

The approximate boundaries of the Quaternary alluvial sediments in the vicinity of the Project Application Area are shown in Figure 2-1 and have been derived from the Soil Landscapes of the Newcastle 1:100,000 Sheet (Matthei, 1995) and the Soil Landscapes of the Gosford-Lake Macquarie 1:100,000 Sheet (Murphy, 1993). The alluvium associated with Morans Creek, Wyee Creek, Mannering Creek and Buttonderry Creek generally occur at the northern, eastern and southern areas within the Southern Extension Area. Based on a review of available borelogs, the thickness of the alluvium throughout the Project Application Area (including the Southern Extension Area) extends up to approximately 15 - 20 m and mostly comprises of clays and sandy clays. The extent of alluvium to be undermined by the Project is less than that currently being undermined at Mandalong Mine.

The Moon Island Beach formation of the Newcastle Coal Measures outcrops and/or subcrops to the north and north-east of the Project Application Area, and dips to the south west. The Wallarah and Great Northern seams are coalesced through the central part of the Southern Extension Area forming a seam ranging between 3.5 m to 4.5 m in thickness. This coalesced seam is the continuation of the seam currently being mined at Mandalong Mine, and is known locally as the West Wallarah Seam. In the western part of the Southern Extension Area the coalesced seam is extensively intruded by an igneous sill. In the eastern half of the Southern Extension Area, the West Wallarah Seam is split into two, with only the upper split providing economic potential. This upper split ranges in thickness from 1.6 m in the north-east to 3.0 m in the south-east. The lower split is less than 1 m thick.

The depth to cover to the target seam ranges from approximately 200 metres in the north-east to 450 m in the south-west of the Southern Extension Area. This represents a greater depth of cover than throughout the existing approval area (approximately 150 – 350 m depth of cover above the existing Mandalong workings, and generally less than 100 m depth of cover above the Cooranbong workings). The depth of cover above the Great Northern Seam reduces to less than 15 m (subcrop area) approximately 1 – 3 km to the north of the Cooranbong workings and it is considered that this is a possible recharge zone for this coal seam. Depth of cover and seam thickness contours are shown in Figure 2-2 and Figure 2-3.

The Newcastle Coal Measures are overlain by the Triassic Narrabeen Group which outcrops across the Southern Extension Area. The Narrabeen Group comprises variable sequences of interbedded claystones, siltstones and fine to coarse grained sandstones. The Munmorah Conglomerate is a sandstone-dominated formation within the Narrabeen Group which typically occurs between 60-140 metres above the Newcastle Coal Measures (or a depth of approximately 40 – 340 m bgl). Based on information provided by Centennial Mandalong geologists, the Munmorah Conglomerate at Mandalong Mine has been found to contain a thick pebbly sandstone/conglomerate layer which is geotechnically important in reducing surface subsidence impacts over longwall panels.

Figure 2-4 gives a typical west-east geological cross section through the Southern Extension Area and along to Lake Macquarie in the east, showing geological formations, strata thickness and the proposed mine location. The cross section shows the large variation in topography across the mining area. The proposed mine workings in the Southern Extension Area will not undermine any older workings, although existing workings within the Great Northern Seam are located to the north of the old Cooranbong workings (Awaba Colliery) and to the east of the existing Mandalong workings (Mannering Colliery). These adjacent operations are both owned by Centennial Coal and their locations are shown in Figure 2-5.

In addition there is a proposed mining development known as the Wallarah 2 Project (not owned by Centennial) which intends to mine within the West Wallarah Seam to the south of the Southern Extension Area. A series of NNW-SSE trending intrusive dykes have been identified in the south-west of the Southern Extension Area from airborne and ground magnetic surveys and separate the proposed workings in the Southern Extension Area from the Wallarah 2 Project. The strike length of these dykes in this area is up to over 5 km. Proposed mining operations do not extend into this zone of extensive dykes.

## 2.3 Hydrogeology / Groundwater Sources

The groundwater sources in the vicinity of the Project Application Area are generally low yielding and predominantly within the Quaternary alluvium, weathered and/or fractured sandstone and coal seams. They would be classified as ‘less productive’, in accordance with the NSW Aquifer Interference Policy. Further analysis of available groundwater monitoring data is presented in Section 3.2.2.

### 2.3.1 Alluvial Water Sources

The alluvium throughout the Project Application Area forms an unconfined shallow aquifer with a water table typically ranging in depth from less than 1 m and up to about 3 m bgl, and aquifer thickness less than 20 m. The alluvial groundwater is moderately acidic to slightly alkaline, brackish to saline, extremely hard and of sodium chloride type. Reported groundwater electrical conductivity (EC) throughout the existing Mandalong Mine approval area and the Southern Extension Area exceeds 10,000 µS/cm at some locations (GHD, 2012). Further details are provided in Section 3.2.2.

Due to the relatively high silt and clay content of the alluvium, the groundwater yields are relatively low (typically less than 1 L/s). As a result of the low yield and relatively poor water quality, there are very few registered private alluvial groundwater bores throughout the Project Application Area. The environmental value of the alluvial groundwater is considered to be ‘primary industry’ (specifically stock watering), with the saline groundwater only suitable for stock watering (GHD, 2012).

The alluvial water sources within the Project Application Area are covered under the Water Sharing Plan (WSP) for the Hunter Unregulated and Alluvial Water Sources. This WSP commenced in August 2009 and regulates the interception and extraction of surface water and alluvium within the defined water sharing plan area.

### 2.3.2 Porous and Fractured Rock Water Sources

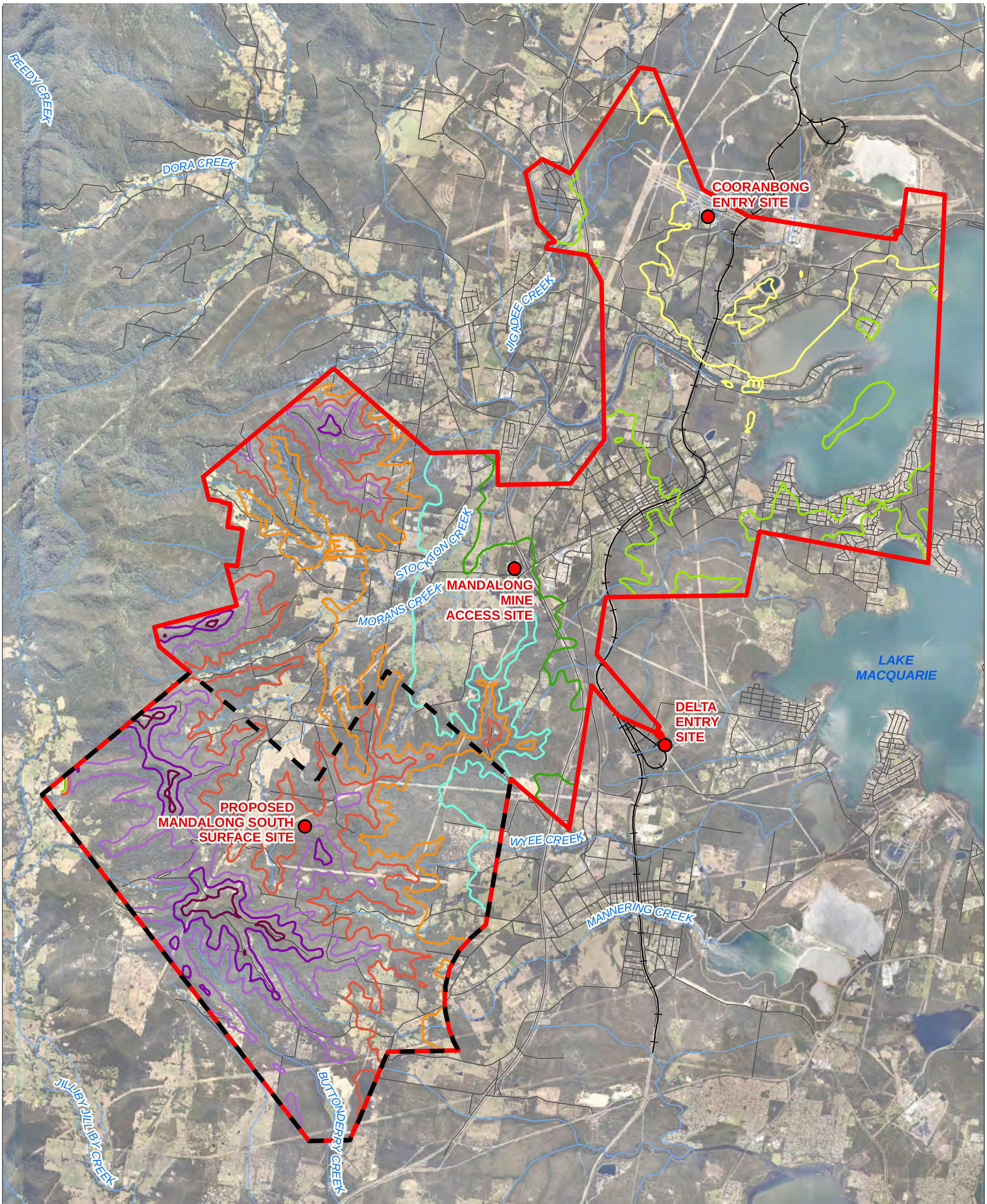
These water sources are not currently managed under any WSPs.

**Coal Seam**

The piezometric head within the Permian coal seams tends to reflect the natural topography and the orientation and dip of the seams, with reduced pressures at major surface drainage areas and in areas of coal extraction. Where coal seam groundwater has not been depressurised, the groundwater head generally tends to be in the order of 0 m AHD due to the coastal environment.

Permeability testing undertaken in 1996 and 1997 on the West Wallarah Seam and overburden strata in the existing Mandalong Mine area is reported in Pacific Power International (1997). Results indicate a variable hydraulic conductivity for the seam, ranging from $10^{-9}$ to $10^{-5}$ m/s (0.03 to 300 m/year). Areas of higher hydraulic conductivity coincide with areas where the coal is more intensively jointed or fractured, although the majority of the seam was generally found to be of lower hydraulic conductivity.

The hydraulic conductivity of the West Wallarah Seam in the Southern Extension Area is generally expected to be lower than in the existing approved area since the seam is deeper. More recent permeability testing of the West Wallarah and Wallarah / Great Northern Seams (at depths of 285 m to 300 m bgl) undertaken in 2011 as part of the Mandalong Southern Extension exploration program measured hydraulic conductivities ranging from approximately 0.75 to 35 m/yr (Sigra, 2011).




1:100,000 for A4

0 0.375 0.75 1.5 2.25 3

Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

N

GHD

LEGEND

| | | | |
|---|---|---|---|
| EL6317 Boundary | Railway | Depth of Cover | 350m, 300m, 250m, 200m |
| Application Area Boundary | Roads | 450m | 150m, 100m, 50m, 0m |
| | Watercourse | 400m | |



| | |
|---|---|
| LOCATION | Newstan |
| SEAM | |
| DRAWN | S.M. |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong South Expansion Project
Hydrogeological Model Report

Depth of Cover Above Seam

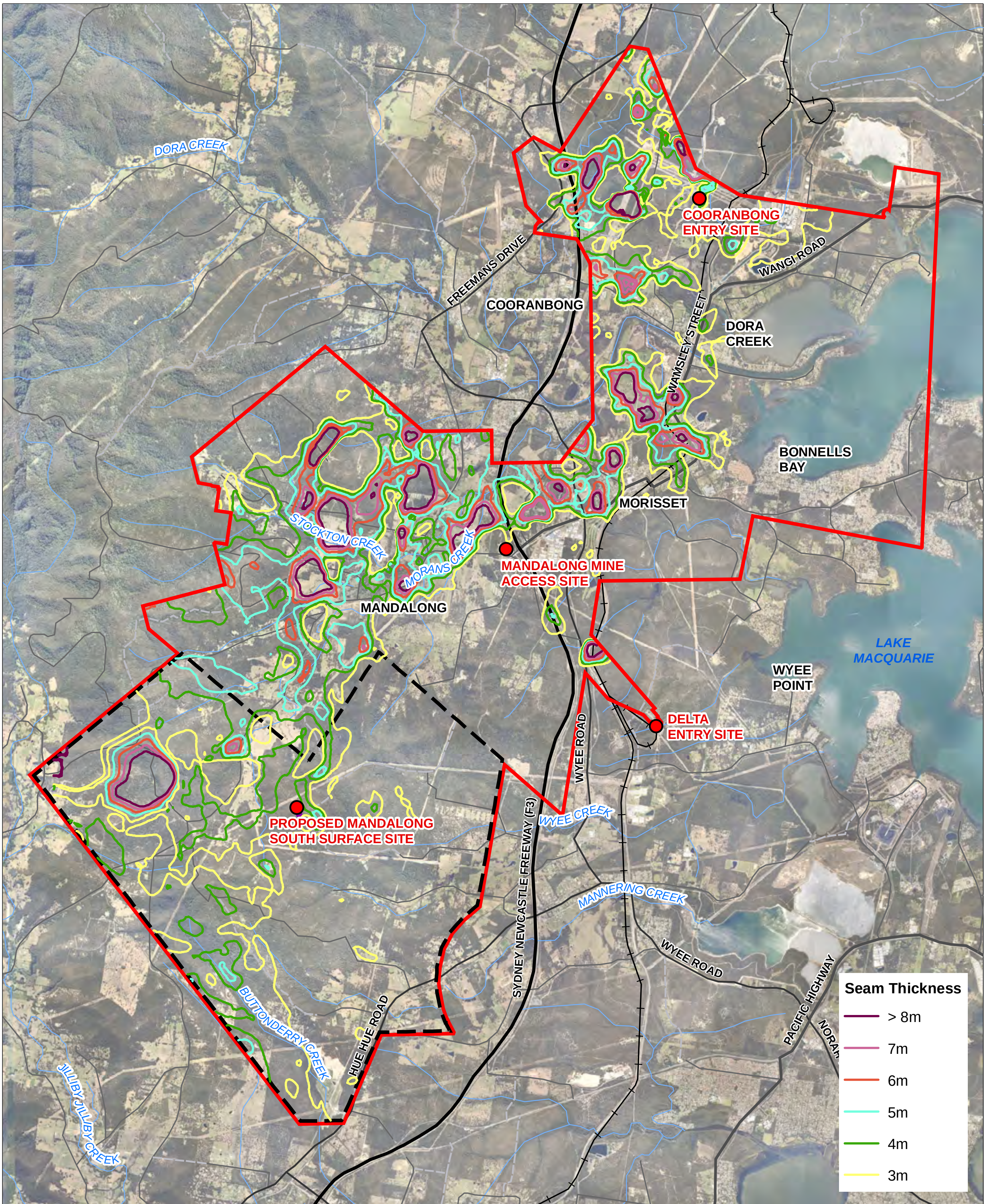
Centennial Mandalong

DATE 8/08/2013

Figure 2-2

GIS Filename: G:\22\0105001\GIS\Maps\Hunter\Mandalong\Deliverables\2216168\Hydrogeological Model Report\2216168_HMR_005_DepthofCover_0.mxd

© LPMA: DTDB - 2006/2007; Centennial: Mine Plan, Study Area - 2012. GSS: Aerial Image - 2012. Commonwealth of Australia (Geoscience Australia): 250K Topographic Data Series 3 - 2006




1:100,000 for A4

0 410 820 1,640 2,460 3,280

Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

N

GHD

LEGEND

- Site Location
- EL6317 Boundary
- Project Application Area
- Existing Rail
- Freeway
- Watercourse



| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | West Wallarah |
| DRAWN | R.Towner |
| CHECKED | G. Mcdiarmid |
| APPROVED | I.Joliffe |
| SCALE | Refer to scalebar |

Mandalong Southern Extension Project
Hydrogeological Model Report

Seam Thickness within the Application Area

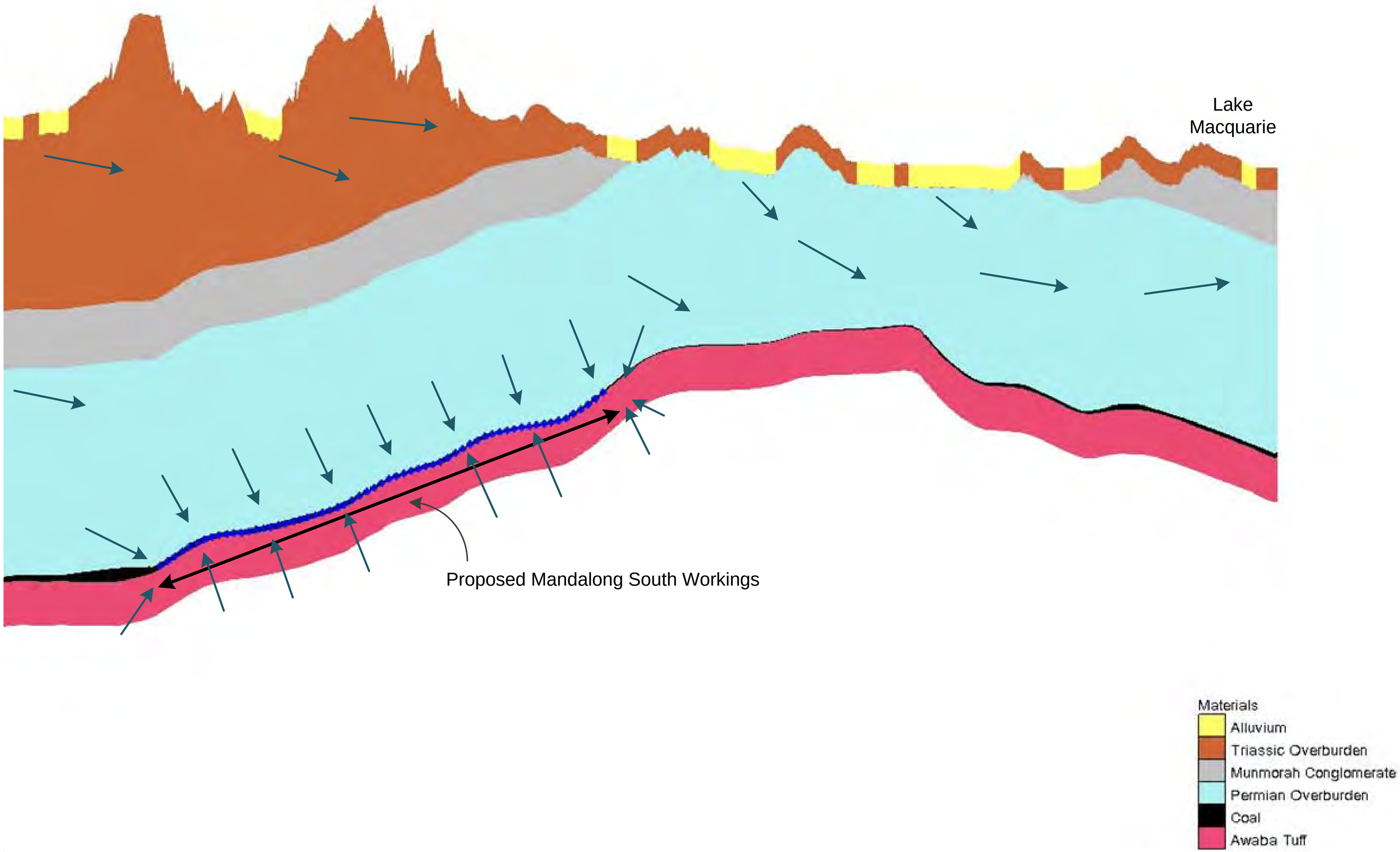
Centennial Mandalong

DATE 9/08/2013

Figure 2-3

GIS Filename: G:\22\0105001\GIS\Maps\Hunter\Mandalong\Deliverables\2216168\Hydrogeological Model Report\2216168_HMR_006_Seam Thickness_0.mxd

© LPMA: DTDB - 2007 ; Commonwealth of Australia (Geoscience Australia): 250K Topographic Data Series 3 - 2006 ; Centennial: Application Area, EL6317 Boundary - 2012; GSS: Imagery;




Typical Detail A – Riser Pit on LDP2

Underground Operations
Surface Operations
Underground Transfers
Underground Diversions
Groundwater Flow Direction
Pumping Transfers
Surface Transfers
Surface Diversions



| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | West Wallarah |
| DRAWN | SM |
| CHECKED | SG |
| APPROVED | |
| SCALE | NTS |

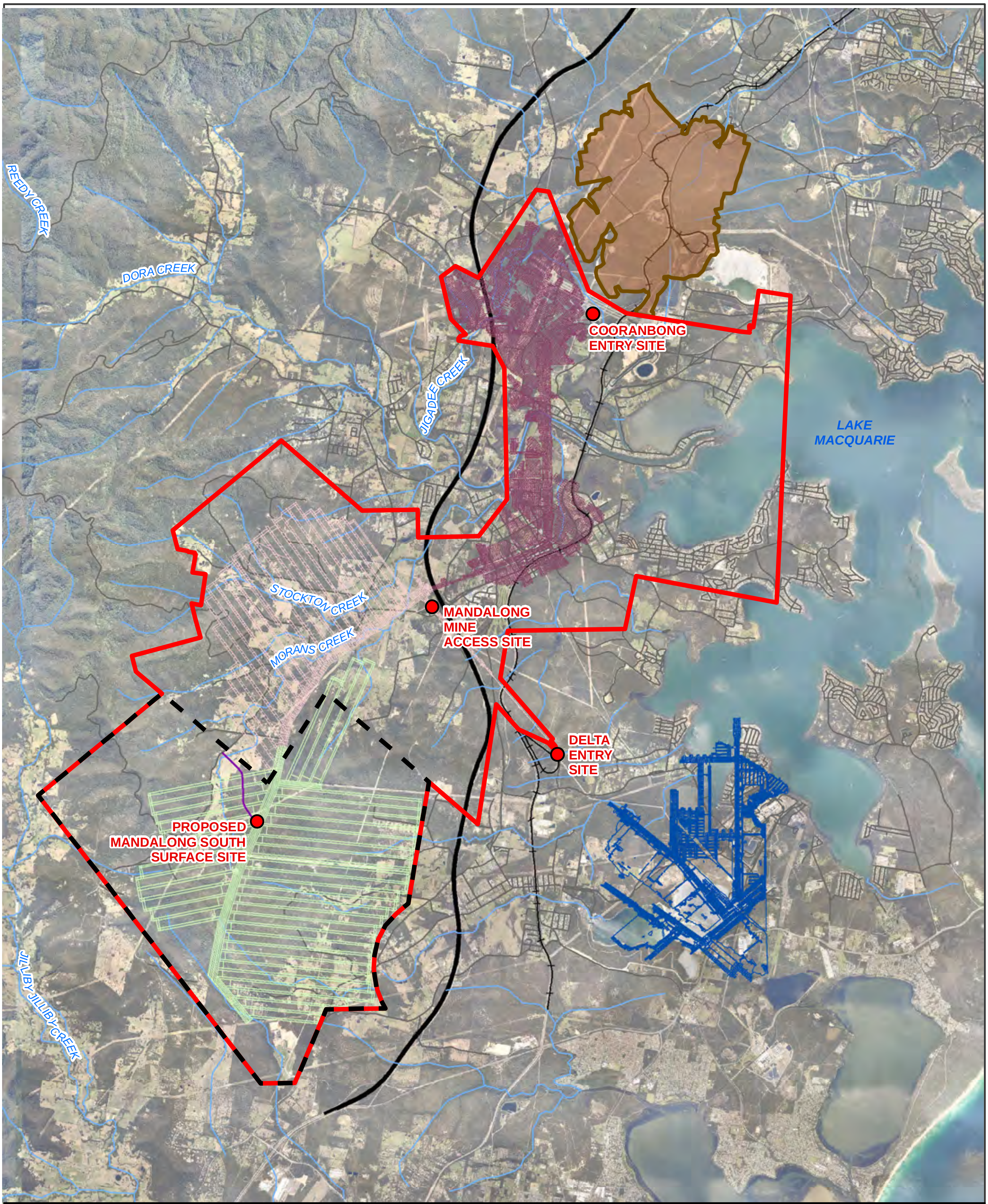
Mandalong Southern Extension Project
Hydrogeological Model Report

Geological Cross Section and Mining Areas

Centennial Mandalong

DATE 22/02/2013

Figure 2-4




1:120,000 for A4

0 0.5 1 2 3 4
Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

N

LEGEND

- EL6317 Boundary
- Application Area Boundary
- Railway
- Watercourse
- Awaba Mine Workings Region
- Proposed Mandalong South Surface Site
- Proposed Mine Workings
- Mandalong Existing Mine Workings
- Cooranbong Existing Mine Workings
- Mannering Existing Mine Workings



| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | |
| DRAWN | S.M. |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong Southern Extension Project
Hydrogeological Model Report

Adjacent Workings - West Wallarah/Great Northern Seam

Centennial Mandalong

DATE 1/03/2013

Figure 2-5

GIS Filename: G:\22\0105001\GIS\Maps\Hunter\Mandalong\Deliverables\2216168\Hydrogeological Model Report\2216168_HMR_007_AdjacentWorkings_0.mxd

Groundwater inflows into the existing Cooranbong and Mandalong workings from the coal seam and adjacent strata are reported by Centennial Mandalong to be relatively low. Further details are provided in Section 3.2.2. Underground water within the existing workings flows either under gravity or is pumped to an underground storage dam located at the northern end of the Cooranbong workings and pumped from this underground dam via a dewatering bore to the Cooranbong Entry Site. This underground water is slightly alkaline and brackish to saline.

**Overburden Rock**

The overburden and interseam strata within the Newcastle Coalfield tend to have very low hydraulic conductivities (in the order of 0.0003 to 0.03 m/year), unless joints or fracturing creates a secondary permeability (Pacific Power International, 1997). Groundwater within the overburden rock above the West Wallarah Seam primarily occurs within weathered or fractured Triassic sandstone.

Permeability testing of the overburden rock was undertaken in 2011 as part of the Mandalong Southern Extension exploration program (Sigra, 2011). The measured hydraulic conductivities and strata depths were as follows:

- 0.02 m/yr (158.8 – 286.5 m bgl).
- 0.007 m/yr (177.4 – 268.4 m bgl).
- 0.03 m/yr (122.4 – 268.4 m bgl).

A search of the NSW Groundwater Bore Database indicates that the majority of registered bores in the vicinity of the Southern Extension Area are within Trassic sandstone and conglomerate formations and generally yield less than 2 L/s. Most of these are registered for domestic and/or stock use. It is assumed that these bores are located in the vicinity of joints or fracturing of the strata.

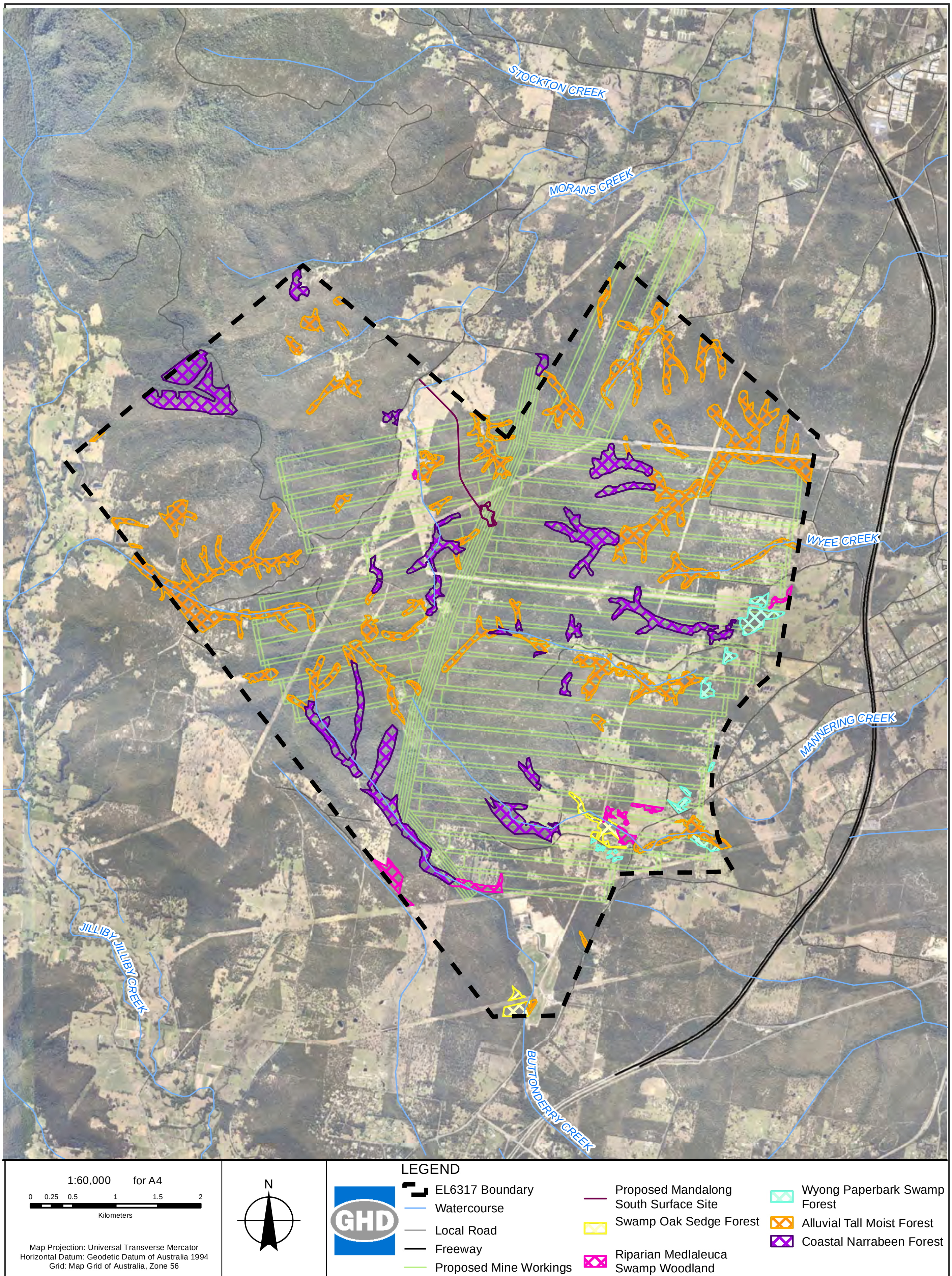
Based on the groundwater monitoring program for the current Mandalong Mine operations, groundwater within the sandstone/siltstone of the Tuggerah Formation and Munmorah Conglomerate has been found to be saline and slightly acidic to strongly alkaline. The groundwater sources exhibit considerable variability in quality, particularly in terms of pH (GHD, 2012).

## 2.4 Groundwater Dependent Ecosystems

The potential vegetation GDEs within the Southern Extension Area have been mapped by RPS (2013) and include:

- Alluvial Tall Moist Forest (Map Unit 5).
- Coastal Narrabeen Forest (Map Unit 6).
- Swamp Oak Sedge Forest (Map Unit 41).
- Riparian Melaleuca Swamp Woodland (Map Unit 42).
- Wyong Paperbark Swamp Forest (Map Unit 43).

It is considered that all or parts of these vegetation communities are potentially GDEs and they are shown in Figure 2-6. It is noted that Map Unit 41 is equivalent to the Swamp Oak Floodplain Forest Endangered Ecological Community (EEC) and Map Unit 42 is equivalent to the Swamp Sclerophyll Forest on Coastal Floodplains EEC. There are no GDEs within the Southern Extension Area that are listed in Schedule 4 of the WSP.






| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | |
| DRAWN | S.M. |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong Southern Extension Project
Hydrogeological Model Report

Potential Groundwater Dependent Ecosystems

Centennial Mandalong

DATE 1/03/2013

Figure 2-6

GIS Filename: G:\22\0105001\GIS\Maps\Hunter\Mandalong\Deliverables\2216168\Hydrogeological Model Report\2216168_HMR_008_GroundwaterDependentEcosystems_0.mxd

# 3. Data Sources and Analysis

The hydrogeological model has been developed with reference to the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). As outlined in Section 1.4, the purpose of the model is to estimate groundwater seepage into the proposed workings and predict drawdown in groundwater sources, to inform the groundwater impact assessment and development of management strategies for the Project. Based on the model objectives, the availability of existing data and the value of the groundwater sources, the model is considered to have a Class 2 level of confidence, as defined under the Guidelines. Class 2 models are considered to be suitable for the prediction of impacts of proposed developments in medium value aquifers.

This section outlines the initial process of data collation and analysis. Data requirements for the hydrogeological model can be divided into hydrogeological framework data, hydrological stress data and groundwater monitoring data for steady state calibration.

## 3.1 Hydrogeological Framework Data

Hydrogeological framework data includes extent, thicknesses and boundaries of geological (and aquifer) units, and aquifer properties (hydraulic conductivity, porosity, storage and specific yield). In typical modelling scenarios these parameters do not change over time, however in a mining context there may be changes due to rock fracturing and subsidence. These data have been sourced from the following:

- 1:100,000 Newcastle Coalfield Regional Geology map (NSW Department of Mineral Resources, 1995).
- Depth of cover and seam thickness drawings (supplied by Centennial Mandalong).
- Exploration logs and groundwater monitoring bore construction details (supplied by Centennial Mandalong).
- 2 m and 5 m topographical contours (supplied by Centennial Mandalong).
- Drawings of geological features such as faults, areas of seam splitting and deterioration, seam thickness and seam outcrops (supplied by Centennial Mandalong).
- Alluvial soils boundaries from the Soil Landscapes of the Gosford-Lake Macquarie 1:100,000 Sheet (Murphy, 1993).
- Existing reports detailing hydrogeological properties of the upper Newcastle Coal Measures, including Pacific Power International (1997) Cooranbong Colliery Life Extension Project: Overburden Strata Groundwater Study.
- Results of permeability testing undertaken during exploration in the Southern Extension Area (supplied by Centennial Mandalong).
- Completed mine plans of adjacent workings, including the Great Northern seam workings at Awaba and Mannering Collieries (supplied by Centennial Mandalong).

## 3.2 Hydrological Stress Data

Hydrological stress data includes the time varying hydrological data such as natural recharge, injection/extraction, drains, creeks and other sources and sinks. These data have been sourced from the following:

- Rainfall data (obtained as SILO Patched Point Data from the Queensland Climate Change Centre of Excellence (QCCCE)).
- Underground water extraction data (detailed in Section 3.2.2).
- Past and future mine plans within the West Wallarah and Wallarah - Great Northern Seams (supplied by Centennial Mandalong).
- The proposed mining schedule for the Project (supplied by Centennial Mandalong) to establish drain cells and their periods of activation.
- Ditton Geotechnical Services (DgS) (2013) subsurface fracturing predictions.

### 3.2.1 Rainfall Data

A continuous daily rainfall dataset was obtained as SILO Patched Point Data, which is based on historical data from a particular Bureau of Meteorology (BOM) station with missing data ‘patched’ in from interpolations from nearby stations. For this assessment SILO data was obtained for the BOM Cooranbong (Avondale) Station (station number 61012) which is located approximately 10 km to the north east of the Southern Extension Area. Daily rainfall records from January 1901 to June 2012 were utilised. Recorded rainfall data from the Mandalong Mine weather monitoring station was not able to be used for modelling purposes because records were not long enough to adequately represent the highs and lows of numerous wet and dry cycles.

Key statistics for the rainfall dataset are as follows:

- Minimum annual rainfall – 529 mm in 1944.
- Average annual rainfall – 1117 mm.
- Median annual rainfall – 1072 mm.
- Maximum annual rainfall – 2013 mm in 1950.

Monthly rainfall averages ranged from 60.6 mm in August to 127.3 mm in February.

The SILO dataset was also used to generate a Cumulative Rainfall Departure (CRD) curve. CRD is the monthly accumulation of the difference between the observed monthly rainfall and long term average monthly rainfall.

The CRD over the period 1901 to 2012 is shown in Figure 3-1. Any increase in the CRD reflects above average rainfall while a decrease in CRD reflects below average rainfall. The CRD curve only deviates from zero due to atypical (above and below average) rainfall.

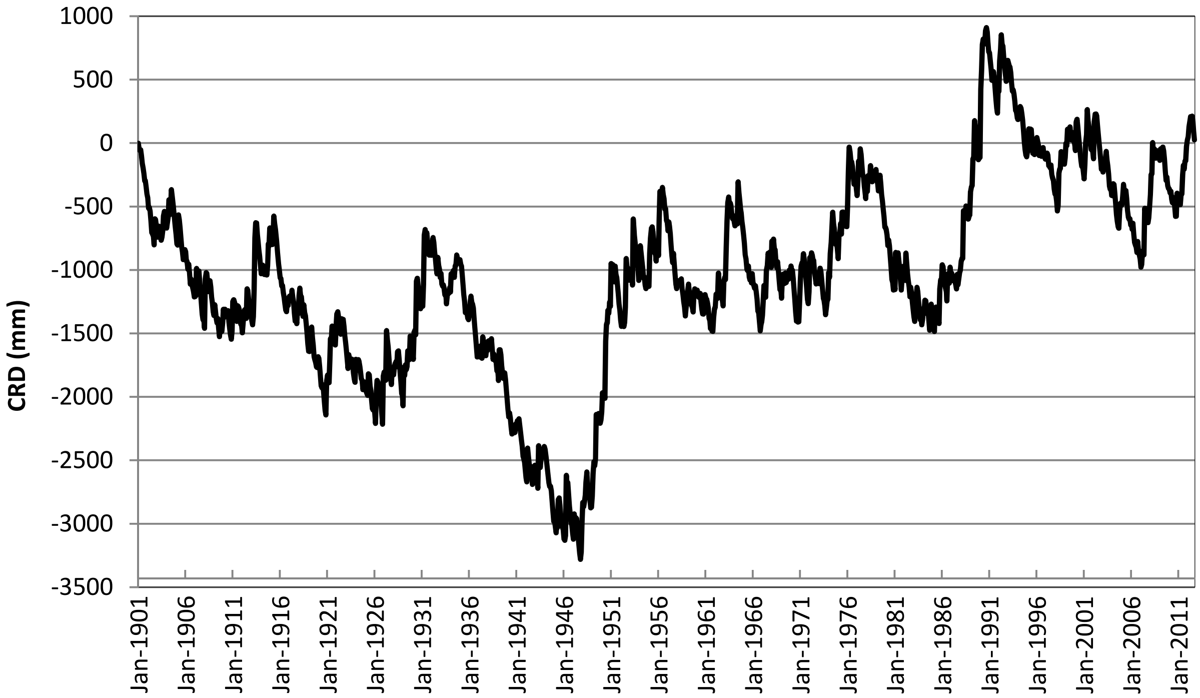



**Figure 3-1 CRD Curve for Cooranbong (1901-2012)**

### 3.2.2 Underground Water Levels

Underground water levels in the Cooranbong underground water storage have been monitored by Centennial Mandalong since December 2011. The measured water levels (corrected to AHD) between December 2011 and March 2013 are shown in Figure 3-2. Over this period the underground water level has risen by approximately 5 m, which represents an increase in storage of approximately 350 - 400 ML. This estimate of storage is based on a void height of 3 m and void ratio of 0.4.

The inputs into the Cooranbong underground void consist of:

- Groundwater seepage from the coal seam and adjacent strata.
- Supply of potable water to mining equipment (approximately 1 ML/day).
- Transfer of surface water from Sediment Dams 1 and 2 (estimated to be 40 ML/year).

The output from the Cooranbong underground void is the extraction of underground water via a dewatering bore and transfer to the Cooranbong Entry Site (approximately 1.59 ML/day).

Based on known inputs and outputs and the measured increase in underground water level between December 2011 and March 2013, the average groundwater seepage into the workings over this period is estimated to be approximately 1.5 – 2.0 ML/day.

Based on an assessment of the floor contours of the Cooranbong workings, the underground water storage dam has a capacity of approximately 4,200 ML. The dewatering bore extends to an elevation of about -95 m AHD, which is above the base on the underground dam. As a result, there is a volume of approximately 1,300 ML that cannot be extracted by the existing infrastructure. Once the underground water storage dam reaches full capacity, the water would spill to the south back towards the active Mandalong workings.

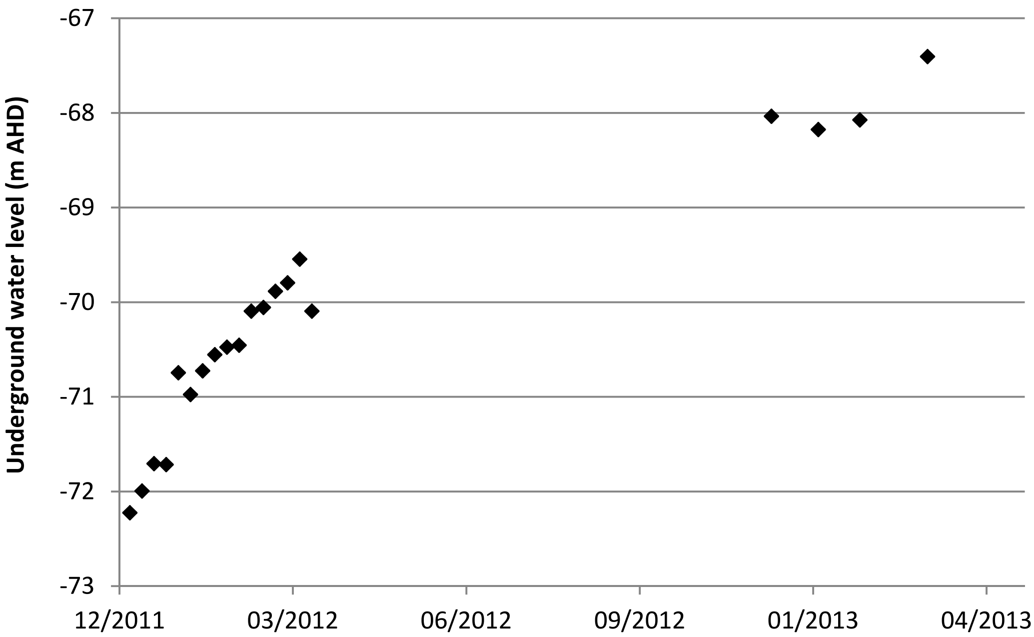



**Figure 3-2 Underground Water Levels – Cooranbong Workings**

### 3.2.3 Subsurface Fracturing Predictions (DgS, 2013)

Predicted subsurface fracturing heights above the 40 longwall panels proposed in the Project have been calculated by DgS (2013). The extent of subsurface fracturing is dependent on mining geometry and overburden geology and results in changes in the hydraulic conductivity of the strata within the fracture zone.

Relevant results reported by DgS (2013) are summarised in this section.

#### Continuous Fracturing

The continuous fracturing zone or 'A-Zone' refers to the zone above a longwall panel in which fractures develop that create a hydraulic connection between overburden groundwater sources and the workings. Predictions by DgS (2013) suggest that continuous fracturing could range from a minimum of 28 – 59 m, up to a maximum of 149 – 198 m. DgS (2013) considers it to be 'very unlikely' for continuous fracturing associated with the Project to come within 15 m from the ground surface or extend to the overlying alluvial water sources.

**Discontinuous Fracturing**

The discontinuous fracturing zone or 'B-Zone' refers to the zone above the continuous fracturing zone in which fractures do not create a hydraulic connection between overburden groundwater sources and the workings however there may be an increase in horizontal and vertical hydraulic conductivity within the overlying rock mass. Predictions by DgS (2013) suggest that discontinuous fracturing could range from a minimum of 122 – 127 m, up to a maximum of 306 – 395 m. DgS (2013) considers it to be 'very unlikely' for continuous fracturing associated with the Project to come within 15 m from the ground surface or interact with the overlying alluvial or surface water sources.

**Surface Cracking**

DgS (2013) notes that the tensile and compressive surface cracking within the surface zone is assumed to extend to depths of 5 to 15 m within the Newcastle Coalfield.

An assessment by Pells Sullivan Meynink (PSM, 2012) of potential impacts of subsidence to rocks below the Awaba Waste Management Facility (AWMF), as a result of proposed longwall panels at Newstan Colliery, found that any increases in the hydraulic conductivity of shallow bedrock would most likely occur in areas of existing defects within the rock, such as joints and bedding planes. Should increases in hydraulic conductivity occur, they are likely to be by less than two times on average (PSM, 2012).

### 3.2.4 Subsurface Fracturing Based on Groundwater Monitoring Data

GHD has previously assessed impacts on deeper groundwater within porous and fractured rock groundwater sources overlying existing longwalls within the existing approved area at Mandalong Mine (GHD, 2012). Analysis of groundwater monitoring data from the Mandalong groundwater monitoring program indicates that loss of groundwater head has been detected up to about 170 m above existing workings at Mandalong. The greatest loss of groundwater head has occurred up to about 120 m above the longwalls.

Based on the available data, the transition between greater impact and lower impact (at up to 120 m above the longwalls) tends to occur within the Munmorah Conglomerate. Groundwater impacts may occur above the Munmorah Conglomerate, however they are not as large and are likely to involve only temporary reductions in groundwater levels.

## 3.3 Groundwater Monitoring Data

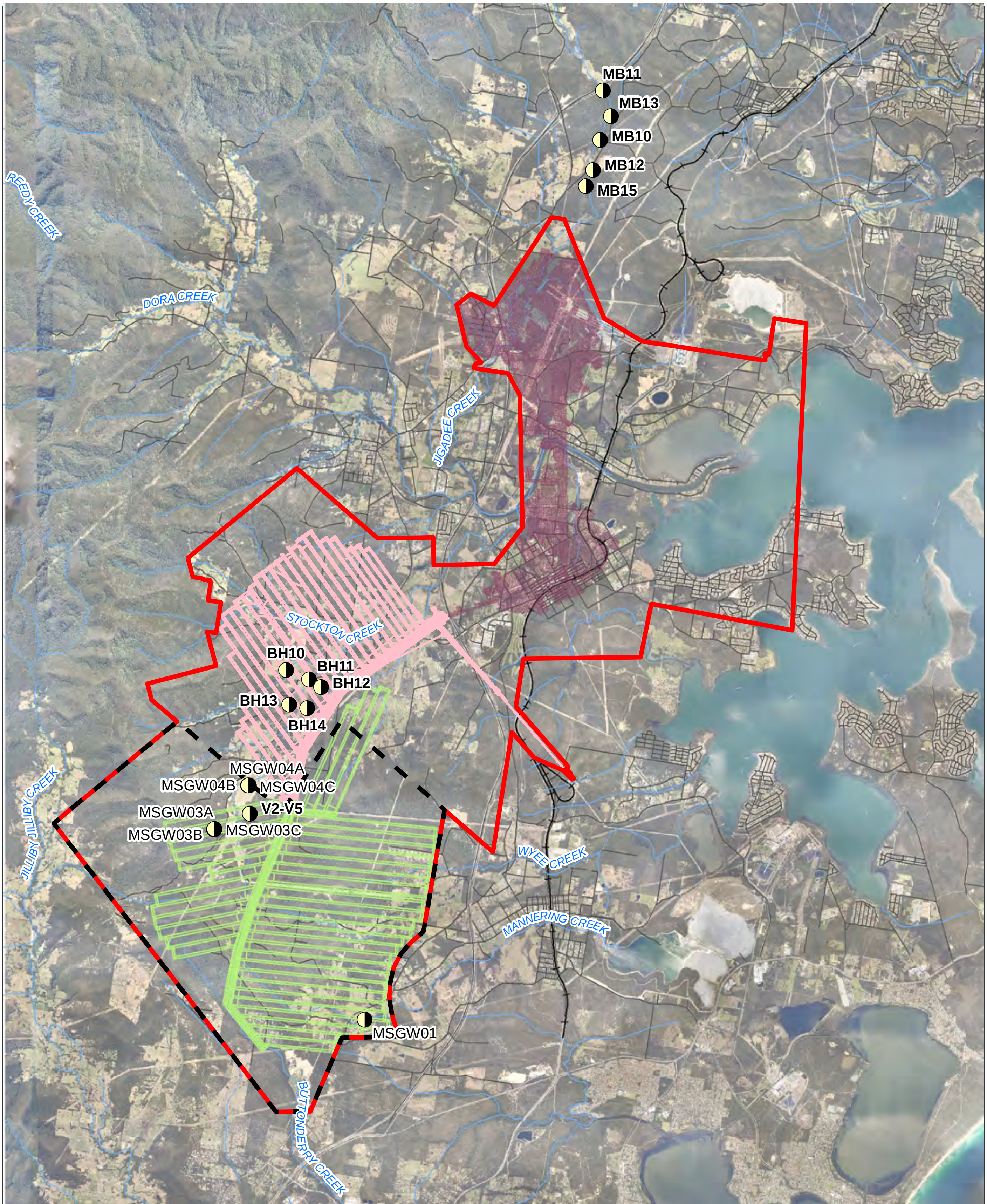
Groundwater monitoring networks have been progressively established at Mandalong Mine (since 1997), Newstan Colliery (since 2005) and the Southern Extension Area (since 2011) and consist of monitoring bores installed in alluvial water sources as well as porous and fractured rock water sources. The bores are generally monitored monthly or quarterly for groundwater levels and groundwater quality, although some alluvial bores also contain water level loggers. In addition, several vibrating wire piezometers (VWPs) have been installed within the porous and fractured rock water sources at Newstan Colliery and within the Southern Extension Area.

Details of the groundwater monitoring bores utilised for the hydrogeological model are summarised in Table 3-1. Monitoring bore locations are shown in Figure 3-3.

Only those monitoring bores and VWPs that have a reliable dataset and not been undermined by longwalls panels (either at Mandalong or Newstan) have been considered, since their groundwater level datasets have been used in the steady state calibration. Note that the Lords Creek alluvial bores are within the domain of the hydrogeological model (and therefore can be used for model calibration) however are not within the Project Application Area.

**Table 3-1 Groundwater Monitoring Bore Details**

| Bore / VWP | Monitoring Period | Lithology |
|---|---|---|
| MB10 | Jan 06 – Oct 11 | Lords Creek Alluvium |
| MB11 | Jan 06 – Mar 12 | Lords Creek Alluvium |
| MB12 | Jan 06 – Mar 12 | Lords Creek Alluvium |
| MB13 | Jan 06 – Mar 12 | Lords Creek Alluvium |
| MB15 | Jan 06 – Mar 12 | Lords Creek Alluvium |
| BH10 | Aug 1997 – Sept 2012 | Morans Creek Alluvium |
| BH11 | Aug 1997 – Sept 2012 | Morans Creek Alluvium |
| BH12 | Aug 1997 – Sept 2012 | Morans Creek Alluvium |
| BH13 | Aug 1997 – Sept 2012 | Morans Creek Alluvium |
| BH14 | Aug 1997 –Sept 2012 | Morans Creek Alluvium |
| MSGW01 | Sept 2011 – Sept 2012 | Mannering Creek Alluvium |
| MSGW03B | Sept 2011 – Sept 2012 | Sandstone (Tuggerah) |
| MSGW03C | Sept 2011 – Sept 2012 | Conglomerate (Munmorah) |
| MSGW04A | Sept 2011 – Sept 2012 | Morans Creek Alluvium |
| MSGW04B | Sept 2011 – Sept 2012 | Sandstone (Tuggerah) |
| MSGW04C | Sept 2011 – Sept 2012 | Conglomerate (Munmorah) |
| V1 | Oct 2011 – Oct 2012 | West Wallarah seam |
| V2 | Oct 2011 – Oct 2012 | West Wallarah seam |
| V3 | Oct 2011 – Oct 2012 | Shale (Dooralong) |
| V4 | Oct 2011 – Oct 2012 | Conglomerate (Munmorah) |
| V5 | Oct 2011 – Oct 2012 | Conglomerate (Munmorah) |




1:120,000 for A4

0 0.5 1 2 3 4
Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

N

GHD

LEGEND

- Application Area Boundary
- EL6317 Boundary
- Monitoring Bores
- Railway
- Roads
- Watercourse
- Mandalong Workings within Current Approval Boundary
- Proposed Mine Workings
- Cooranbong Existing Mine Workings



| | |
|---|---|
| LOCATION | Newstan |
| SEAM | |
| DRAWN | S.M. |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong South Expansion Project
Hydrogeological Model Report

Groundwater Monitoring Bores

Centennial Mandalong

DATE 1/03/2013

Figure 3-3

GIS Filename: G:\22\0105001\GIS\Maps\Hunter\Mandalong\Deliverables\2216168\Hydrogeological Model Report\2216168_HMR_009_GWBoreDatabase_0.mxd

**Alluvial Bores**

Groundwater hydrographs were plotted for each of the alluvial bores in Table 3-1 and compared to the CRD curve for the rainfall dataset to establish the relationship between groundwater levels and rainfall. Hydrographs are included in Annexure A. Alluvial bores MB10, MB11, MB12, MB13, MB15, BH10, BH11, BH12, BH13 and BH14 have been monitored over the full 'post-water sharing plan' period (i.e. from August 2009).

At the Lords Creek alluvium monitoring bores (MB10, MB11, MB12, MB13 and MB15) groundwater elevations ranged from 15 m to 31 m AHD over the full monitoring period. Typical 'post-water sharing plan' variations in groundwater level ranged from 1.4 m at MB12 to 3.7 m at MB15.

At the Morans Creek alluvium monitoring bores (BH10, BH11, BH12, BH13, BH14 and MSGW04A) groundwater elevations ranged from 12 m to 25 m AHD over the full monitoring period. Typical 'post-water sharing plan' variations in groundwater level ranged from 1.3 m at BH11 to 2.8 m at BH12. The maximum groundwater elevations recorded at each monitoring bore within Morans Creek alluvium over the 'post-water sharing plan' period ranged from 15.2 m AHD at BH12 to 25.1 m AHD at MSGW04A.

Groundwater elevations ranged between 41.4 m and 42.5 m AHD at the Mannering Creek alluvium monitoring bore (MSGW01) over the monitoring period.

There has been a relatively close relationship between the alluvial hydrograph and rainfall (CRD) at each monitoring location, although this relationship is more difficult to identify visually at bores MSGW01 and MSGW04A due to the smaller datasets. The relationship between alluvial groundwater levels and rainfall has been assessed statistically in the Groundwater Impact Assessment report (GHD, 2013a).

**Porous and Fractured Rock Bores**

Deeper monitoring bores have been installed within the Tuggerah Sandstone (MSGW03B and MSGW04B) and Munmorah Conglomerate (MSGW03C and MSGW04C) with the Southern Extension Area.

The Tuggerah Sandstone bores were installed to approximately 48 m bgl in 2011 and target water bearing fractures within the Tuggerah Formation, overlying the Munmorah Conglomerate. The average groundwater head elevations reported between September 2011 and September 2012 were approximately 30 m AHD at MSGW03B and 23 m AHD at MSGW04B, with depth to groundwater head consistently within 10 m bgl. Both bores recovered relatively quickly to drawdown ranging from 30 m to 40 m (using an air driven piston pump). The variation in groundwater head elevation at each location over the monitoring period was about 0.6 – 0.7 m.

Bores MSGW03C and MSGW04C are also within the Southern Extension Area and were installed to approximately 150 m bgl in 2011 and mostly target the upper Munmorah Conglomerate. Measured groundwater head elevations at these locations are approximately 25 m AHD at MSGW03C and 20 m AHD at MSGW04C. Recovery of these bores takes longer than the sandstone bores (generally more than one month).

**Vibrating Wire Piezometers**

Five VWPs were installed within exploration hole B850X000 in the Southern Extension Area in October 2011. The piezometers are located at depths 175 m (V5), 200 m (V4), 269 m (V3), 303 m (V2) and 304 m (V1) bgl and readings are taken on a monthly basis. Over the period October 2011 to October 2012, the piezometers have been equilibrating with the surrounding strata. As at October 2012 the measured groundwater head elevations ranged from 18.7 m AHD (at 175 m bgl) to -1.4 m AHD (at 303 m bgl within the West Wallarah Seam), indicating a vertical downward gradient.

# 4. Conceptual Model and Boundary Conditions

A conceptual model of groundwater sources within the Project Application Area has been developed to define the hydrogeological domain, define boundary conditions (including sources and sinks to the groundwater sources), describe groundwater flow, nominate aquifer properties and outline model assumptions and limitations.

## 4.1 Hydrogeological Domain

The horizontal extent of the model (northern, western and southern boundaries) is limited by the extent of available geological data of the West Wallarah / Great Northern Seams, although covers the entire Project Application Area. The eastern extent is defined by Lake Macquarie. The horizontal domain of the hydrogeological model is shown in Figure 4-1.

The vertical domain of the model extends from the ground surface to the Awaba Tuff and has been divided into six hydrogeological units:

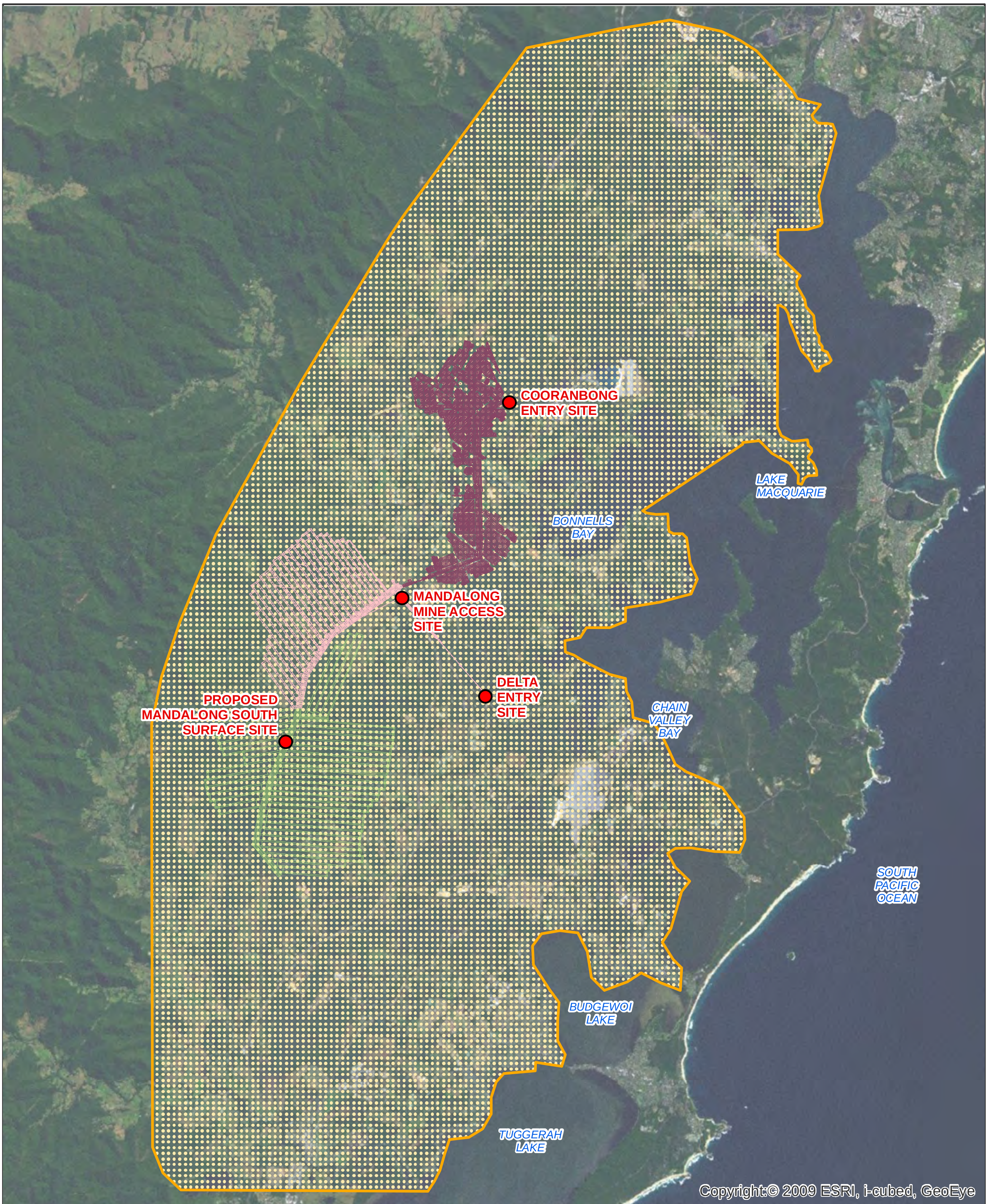
- Alluvium.
- Triassic sandstone (Tuggerah Formation).
- Triassic conglomerate (Munmorah Conglomerate).
- Permian overburden.
- West Wallarah / Great Northern seam.
- Awaba Tuff.

The degree of vertical definition (i.e. six hydrogeological units) reflects the level of detail available in existing data from exploration logs and groundwater monitoring bores. It provides sufficient separation of alluvial water sources from the porous and fractured rock water sources and the coal seam to fulfil the model objectives.

## 4.2 Boundary Conditions and Groundwater Flow

The boundaries to the flow of groundwater within each hydrogeological unit are summarised in Table 4-1.

The alluvial groundwater sources are unconfined aquifers that are associated with the waterways within the hydrogeological domain. They extend to a maximum depth of 15 m bgl and are underlain by Triassic sandstone. The spatial extent of alluvium has been defined using Soil Landscapes of the Gosford-Lake Macquarie 1:100,000 Sheet (Murphy, 1993). The alluvial groundwater sources are recharged by net rainfall and catchment runoff (and by Lake Macquarie at lower reaches along the eastern boundary of the hydrogeological domain) and discharge into connected surface waterways (and into Lake Macquarie at lower reaches). Lake Macquarie is represented by a General Head Boundary (GHB) set at 1 m AHD. It is assumed that the flow of alluvial groundwater across the northern, western and southern boundaries of the hydrogeological domain is relatively small since the boundaries generally cross the upper catchments. Therefore, no flow boundaries have been defined in these areas.




1:180,000 for A4

0 0.5 1 2 3 4 5
Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

N

GHD

LEGEND
- Mandalong Existing Mine Workings
- Proposed Mine Workings
- Cooranbong Existing Mine Workings
- Active Area



| | |
|---|---|
| LOCATION | Mandalong |
| SEAM | |
| DRAWN | S.M. |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong Southern Extension Project
Hydrogeological Model Report

Hydrogeological Domain

Centennial
Mandalong

DATE 1/03/2013

Figure 4-1

GIS Filename: G:\22\0105001\GIS\Maps\Hunter\Mandalong\Deliverables\2216168\Hydrogeological Model Report\2216168_HMR_010_GroundwaterModelBoundary_0.mxd

**Table 4-1 Model Boundary Condition Details**

| Hydrogeological Unit | Boundary Condition | Boundary Details |
|---|---|---|
| Alluvium (Layer 1) | Recharge | Net recharge (ie rainfall and catchment runoff after evaporation) was initially set to 1% of annual rainfall. Based on average annual rainfall between 1901 and 2012, this equates to a net recharge of approximately 0.01 m/year. The final recharge value was established through model calibration. |
| | GHB | The boundary between each alluvial groundwater source and Lake Macquarie has been defined by GHB cells set at 1 m AHD to represent Lake Macquarie. |
| | No Flow | No flow boundaries have been defined where the alluvium crosses the northern, western and southern extents of the hydrogeological domain. These boundaries generally occur within the upper catchment where groundwater flow across these boundaries would be relatively low. |
| | Drain | Main waterways, including Morans Creek, Wyee Creek and Mannering Creek, are represented by drain cells. The drain cell elevations have been determined from topographic elevation data along surface water features. Conductance values have been set to represent the hydraulic conductivity of the surrounding geology.<br>In addition, drain cells have been set at ground level throughout the extent of alluvium to simulate the removal of groundwater that comes to the surface. Conductance values have been set to represent the hydraulic conductivity of the surrounding geology. |
| Triassic Sandstone (Layers 1 and 2) | Recharge | Net recharge to outcropping areas (ie rainfall and catchment runoff after evaporation) was initially set to 1% of annual rainfall. Based on average annual rainfall between 1901 and 2012, this equates to a net recharge of approximately 0.01 m/year. The final recharge value was established through model calibration. |
| | GHB | The southern and eastern boundaries are considered to be the down-gradient extents of this unit (within the modelled domain) and have been defined by GHB cells set at 0 m AHD. |
| | No Flow | The northern and western boundaries are considered to be no flow boundaries since these are generally the up gradient extents of this unit (within the modelled domain) and they generally coincide with catchment boundaries of the main waterways within the model domain. |

| Hydrogeological Unit | Boundary Condition | Boundary Details |
|---|---|---|
| | Drain | Drain cells have been set at ground level throughout the outcropping extent of this unit to simulate the removal of groundwater that comes to the surface. Conductance values have been set to represent the hydraulic conductivity of the surrounding geology. |
| Munmorah Conglomerate (Layer 3) | GHB | The southern and eastern boundaries are considered to be the down-gradient extents of this unit (within the modelled domain) and have been defined by GHB cells set at 0 m AHD. |
| | No Flow | The northern and western boundaries are considered to be no flow boundaries since they represent areas of subcrop for this unit (within the modelled domain). |
| Permian Overburden (Layer 4) | GHB | The southern and eastern boundaries are considered to be the down-gradient extents of this unit (within the modelled domain) and have been defined by GHB cells set at 0 m AHD. |
| | No Flow | The northern and western boundaries are considered to be no flow boundaries since they represent areas of subcrop for this unit (within the modelled domain). |
| West Wallarah / Great Northern seam (Layer 5) | Drain | Drain cells have been used to represent the existing and proposed mine workings of the West Wallarah / Great Northern seams. Conductance values have been set to represent the hydraulic conductivity of the surrounding geology. |
| | GHB | The southern and eastern boundaries are considered to be the down-gradient extents of this unit (within the modelled domain) and have been defined by GHB cells set at 0 m AHD. |
| | No Flow | The northern and western boundaries are considered to be no flow boundaries since they represent areas of subcrop for this unit (within the modelled domain). |
| Awaba Tuff (Layer 6) | GHB | The southern and eastern boundaries are considered to be the down-gradient extents of this unit (within the modelled domain) and have been defined by GHB cells set at 0 m AHD. |
| | No Flow | The northern and western boundaries are considered to be no flow boundaries since these are generally the up gradient extents of this unit (within the modelled domain).<br>The base of this unit has also been defined as a no flow boundary and represents the vertical extent of the model. |

Since there is no surface water level or flow data available, and the waterways are generally ephemeral and intermittent, it is assumed that all connected waterways are 'water-gaining' streams and function as drains. The alluvial groundwater discharges into these waterways (drains) at elevations corresponding to the elevations of the stream beds. In the case where alluvial groundwater rises to the ground surface, the resulting surface water flow must be removed from the model using drains.

The Triassic sandstone is a porous/fractured rock groundwater source that outcrops throughout most of the Project Application Area and underlies the alluvium in lower lying areas. The outcropping areas are recharged by net rainfall and catchment runoff. Piezometric head is generally assumed to reduce towards the southeast, reflecting the dip of the strata and Lake Macquarie to the east. Therefore the southern and eastern boundaries are defined as GHBs and it is along these boundaries that groundwater from the Triassic sandstone exits the hydrogeological domain. GHB elevations are approximate values based on consideration of the coastal environment and limited piezometric head data for deeper aquifers within the Project Application Area. The northern and western boundaries of the model are therefore the up gradient extents of this hydrogeological unit and are defined by no flow boundaries. Groundwater also flows vertically downward from the alluvium to the underlying Triassic sandstone, reflecting the vertical hydraulic gradients observed from the groundwater monitoring program. As with the alluvium, drainage cells have been placed at ground surface along the outcropping areas of the Triassic sandstone to remove water that rises to the surface.

The Munmorah Conglomerate, Permian overburden and Awaba Tuff hydrogeological units are low yielding confined groundwater sources. The piezometric head of these units is also assumed to reduce towards the southeast, reflecting the dip of the strata and Lake Macquarie to the east. Therefore the southern and eastern boundaries are defined as GHBs and the northern and western boundaries represent areas of subcrop and are defined as no flow boundaries. The GHBs have been set at 0 m AHD, as defined for the Triassic sandstone. The base of the Awaba Tuff is defined by a no flow boundary and represents the vertical extent of the hydrogeological domain.

The coal seam (West Wallarah/Great Northern) is a confined porous/fractured rock groundwater source adjacent to lower yielding units. GHBs and no flow boundaries have been defined as for adjacent units. Drain cells have been used to represent existing areas of first workings and secondary extraction within the coal seam throughout the existing approval area (Mandalong and Cooranbong workings) and adjacent workings within the coal seam outside the Project Application Area (Awaba and Mannering Colliery workings). Drain cells have also been used to represent the proposed Mandalong Southern Extension workings. All mine workings included in the hydrogeological model are shown in Figure 2-5. Drain elevations have been set at the floor of the mine workings (where workings are fully drained) or at the level of underground water storages in cases where water is stored within existing workings (applies to sections of the Cooranbong, Awaba and Mannering workings).

## 4.3 Material Properties

The material properties of each of the six hydrogeological units were derived from a combination of data presented in Pacific Power International (1997), previous hydrogeological models developed by GHD for the Newcastle Coalfield, and permeability test data from the Mandalong Southern exploration program.

Pre-calibration values were assigned for hydraulic conductivity, porosity, specific yield and specific storage. These values are shown in Table 4-2. Final values were established through model calibration.

**Table 4-2 Pre-Calibration Hydrogeological Properties**

| Hydrogeological Unit | Model Layers | Horizontal Hydraulic Conductivity "$K_h$" (m/year) | Vertical Hydraulic Conductivity "$K_v$" (m/year) | Specific Storage "Ss" (1/m) | Effective Porosity ($n_e$) |
|---|---|---|---|---|---|
| Alluvium | Layer 1 | 365 | 36.5 | 0.005 | 0.3 |
| Triassic Sandstone | Layers 1 and 2 | 3.65 | 0.365 | 0.005 | 0.1 |
| Munmorah Conglomerate | Layer 3 | 0.00365 | 0.000365 | 0.001 | 0.1 |
| Permian Overburden | Layer 4 | 0.0365 | 0.00365 | 0.001 | 0.1 |
| Fractured Permian Overburden | Layer 4 | 1-10x Permian overburden | 1-10x Permian overburden | 0.001 | 0.1 |
| Coal Seam | Layer 5 | 1.8 | 0.18 | 0.001 | 0.1 |
| Awaba Tuff | Layer 6 | 0.0365 | 0.00365 | 0.001 | 0.1 |

$S_s$ = Specific storage

$n_e$ = effective porosity. NB specific yield for the alluvium set at 0.25

A fractured material zone has been established in model Layer 4, and covers the strata located above the existing and proposed longwalls and areas of secondary extraction in Layer 5. This zone has been used to represent increases in horizontal and vertical hydraulic conductivity that develops due to continuous and discontinuous cracking above longwalls and second workings.

The thickness of Layer 4, and hence the height of the modelled fractured zone, has been set at 140 m and corresponds with the typical height of fracturing (both continuous and discontinuous) observed above existing longwalls at Mandalong Mine (based on groundwater head data as discussed in Section 3.2.4). This height of fracturing is also in the range predicted by DgS (2013) for the Mandalong Southern longwalls.

As shown in Table 4-2, assessment of the potential increase in hydraulic conductivity of the fractured material zone has included values ranging up to ten times the hydraulic conductivity of the undisturbed strata in Layer 4, and has been refined during transient calibration of the hydrogeological model. This represents an average increase throughout the height of fracturing. In reality, the magnitude of increase in hydraulic conductivity tends to be higher within the Caved Zone immediately above the workings, and reduces with height above the workings. Note that the fractured zone is not included in the steady state model since it does not include mine workings, either existing or proposed.

## 4.4 Model Assumptions and Limitations

Since the hydrogeological model is based on limited data and a simplified conceptualisation of the hydrogeological system, it is necessary to make assumptions. General assumptions and limitations are outlined as follows:

- Potential groundwater impacts will not extend beyond the active area of the model. Based on previous hydrogeological modelling undertaken by GHD in the Newcastle Coalfields, the radius of depressurisation is generally within 1 km from the mine workings. The western boundary of the model is the closest boundary to the mine workings, with the existing Mandalong Mine workings and the proposed Mandalong Southern Extension workings coming within 2 km from the western boundary.
- The water level of Lake Macquarie is constant since tidal variations are likely to have little effect on inflows into the deep underground workings or on shallow groundwater levels in the vicinity of the Southern Extension Area.
- All other GHBs have constant piezometric head over time.
- Material properties are homogeneous throughout each hydrogeological unit, with the exception of the Permian Overburden due to fracturing. Material properties do not change with the degree of saturation.
- The thickness of Layer 4, and hence the height of the modelled fractured zone, has been set at 140 m and corresponds with the average height of fracturing (both continuous and discontinuous) observed above existing longwalls at Mandalong Mine. This height of fracturing is also in the range predicted by Ditton Geotechnical Services (DgS) (2013) for the proposed Mandalong Southern longwalls.
- The increase in horizontal and vertical hydraulic conductivity in strata overlying the workings is constant throughout the height of fracturing. In reality, the magnitude of increase in hydraulic conductivity tends to be higher within the Caved Zone immediately above the workings, and reduces with height above the workings.
- Horizontal hydraulic conductivity is ten times the vertical hydraulic conductivity for each hydrogeological unit. This is a typical relationship for essentially horizontal strata.
- Since groundwater utilisation in the vicinity of the Project Application Area is low with relatively few registered bores, it is reasonable to assume that groundwater extractions from registered bores within the hydrogeological domain are negligible and are assumed to have a negligible effect on model results.
- No direct flow pathways will develop between the proposed workings and the ground surface or alluvium. DgS (2013) reports that it would be very unlikely for these pathways to develop.
- Solute transport modelling has not been undertaken as part of the hydrogeological model.
- All workings (existing and proposed) remain fully drained following extraction until the end of the simulation period.

# 5. Numerical Model Construction and Calibration

## 5.1 Model Software

Numerical modelling was undertaken using the MODFLOW-NWT solver with the Upstream Weighting flow package. MODFLOW-NWT is a version of MODFLOW 2005 that provides a different formulation of the groundwater flow equation (Newton formulation) designed to solve models that are non-linear due to unconfined cells or non-linear boundary conditions. MODFLOW 2005 is a three-dimensional finite difference groundwater flow model from the United States Geological Survey (USGS) and is one of the industry standard codes for numerical groundwater modelling. The model was built using the Groundwater Modelling System version 8.2 (GMS) graphical user interface. GMS is a three-dimensional user interface that supports the MODFLOW groundwater modelling code.

It was considered that MODFLOW-NWT and GMS incorporates the features to adequately fulfil the model objectives.

## 5.2 Model Construction

The area of the active model, as shown in Figure 4-1, covers approximately 580 km$^2$. The maximum north-south extent is 39.9 km from N: 6314325 to N: 6354225, while the maximum east-west extent is 23.3 km from E: 348025 to E: 371325. As outlined in Section 4.1, the northern, western and southern boundaries of the hydrogeological domain are limited by the extent of available geological data of the West Wallarah / Great Northern Seams. The western boundary is the closest to the mine workings, with the existing Mandalong Mine workings and the proposed Mandalong Southern Extension workings coming within 2 km from the western boundary. However, based on previous hydrogeological modelling of mine workings in the Newcastle Coalfield, it is considered that model results will not be controlled by the boundary conditions at this distance.

The active area has been divided into a grid consisting of 233 columns and 399 rows, generating equally sized cells with dimensions 100 m × 100 m. It was considered that this degree of discretisation of the model domain would provide adequate refinement throughout the main areas of interest (alluvium, potential GDEs and mine workings) without leading to excessive model run times.

As outlined in the conceptualisation of the hydrogeological system, the model has been divided into six layers of varying thicknesses. It was considered sufficient to use one layer to represent each different hydrogeological unit. In total, the model consists of 328,655 active cells. The top and base elevations of each layer are defined in Table 5-1.

**Table 5-1 Vertical Extent of Model Layers**

| Layer | Hydrogeological Unit(s) | Top | Base |
|---|---|---|---|
| 1 | Alluvium and Triassic Sandstone | Topographic Contours | Topographic Contours - 15 m |
| 2 | Triassic Sandstone | Topographic Contours – 15 m | Coal seam roof + 180 m |

| Layer | Hydrogeological Unit(s) | Top | Base |
|---|---|---|---|
| 3[(a)] | Munmorah Conglomerate | Coal seam roof + 180 m | Coal seam roof + 140 m |
| 4[(b)] | Permian Overburden | Coal seam roof + 140 m | Coal seam roof |
| 5 | West Wallarah / Great Northern Coal | Seam elevation data (provided by Centennial Mandalong) | Seam elevation data (provided by Centennial Mandalong) |
| 6 | Awaba Tuff | Coal seam floor | -540 m AHD |

(a) Typical thickness of the Munmorah Conglomerate, based on exploration data
(b) Fracture zone occurs within Layer 4

## 5.3 Steady State Calibration

Calibration of the hydrogeological model was initially undertaken under steady state conditions. Material properties and the net recharge coefficient (as defined in Sections 4.2 and 4.3) were adjusted in order to minimise the residual errors between modelled and observed steady state groundwater levels and to achieve the other calibration targets outlined in Section 5.3.2. The calibrated steady state heads were used to define initial head conditions for the transient simulation.

### 5.3.1 Observed Groundwater Levels

Observation datasets for the groundwater monitoring bores listed in Table 3-1 were used to define observed steady state groundwater heads. The VWP datasets were not used since they had not equilibrated with the surrounding strata at the time of modelling.

It was considered that the period when the CRD curve (Figure 3-1) is near zero is a reasonable representation of steady state groundwater level for unconfined aquifers (i.e. alluvial monitoring bores), since non-average rainfall effects are at a minimum at this time. In recent years, the CRD was close to zero in April 2008 and December 2011. Therefore, groundwater heads reported in April 2008 (for MB10, MB11, MB12, MB13, MB15, BH10, BH11, BH12, BH13 and BH14) and December 2011 (for MSGW01 and MSGW04A) have been adopted as the observed steady state groundwater heads.

For the deeper groundwater bores (MSGW03B, MSGW03C, MSGW04B and MSGW04C), the average groundwater heads over the monitoring period (September 2011 – September 2012) were adopted as the observed steady state groundwater heads.

### 5.3.2 Steady State Calibration Results

Calibration was undertaken by trial and error. The following calibration targets were adopted:

- The model must converge with a head change criterion between iterations of less than 0.1 m.
- Water balance error must be less than 1%.
- The scaled root mean square error (SRMSE) of residuals must be less than 5%.

Based on previous hydrogeological modelling of the Newcastle Coalfields undertaken by GHD, it is considered that these calibration targets are achievable.

Approximately thirty steady state model runs were undertaken as part of steady state calibration. The lowest SRMSE obtained (using realistic material properties) for a converging steady state run was 4.4%. The water balance error for this run was 0.001%. Table 5-2 gives the hydrogeological properties for the best fit steady state run. The net recharge coefficient for this run was 0.007 m/yr.

**Table 5-2 Hydrogeological Properties – Steady State Calibration**

| Hydrogeological Unit | Model Layers | Horizontal Hydraulic Conductivity "$K_h$" (m/year) | Vertical Hydraulic Conductivity "$K_v$" (m/year) | Specific Storage "Ss" (1/m) | Effective Porosity ($n_e$) |
|---|---|---|---|---|---|
| Alluvium | Layer 1 | 1825 | 182.5 | 0.005 | 0.3 |
| Triassic Sandstone | Layers 1 and 2 | 3.65 | 0.365 | 0.005 | 0.1 |
| Munmorah Conglomerate | Layer 3 | 0.000365 | 0.0000365 | 0.001 | 0.1 |
| Permian Overburden | Layer 4 | 0.0365 | 0.00365 | 0.001 | 0.1 |
| Coal Seam | Layer 5 | 7.2 | 0.72 | 0.001 | 0.1 |
| Awaba Tuff | Layer 6 | 0.0365 | 0.00365 | 0.001 | 0.1 |

A scatterplot of modelled groundwater head (best fit steady state run) versus observed head is shown in Figure 5-1, including monitoring bore names for each point.

## 5.4 Transient Calibration

The transient model was run in calibration mode from 1990 to 2012, using annual stress periods and monthly time steps. The modelled steady state groundwater levels were used as the starting head levels for the transient model.

As outlined in Table 4-1, drain cells were established throughout Layer 5 to coincide with the development of existing workings within the Great Northern / West Wallarah Seam between 1990 and 2012. Drain cells were activated in accordance with available historical mining schedules, including the schedule of development of secondary workings at Mandalong Mine since 2005. To simplify the model setup, drain cells to be activated in a particular year (as specified in the longwall development schedule) were activated at the beginning of the calendar year.

The transient model was calibrated by adjusting horizontal and vertical hydraulic conductivities of the coal seam and the fractured and un-fractured Permian overburden (Layer 4) so that the total groundwater inflow into the Cooranbong and Mandalong workings was as close as possible to the measured inflow in early 2012 of 1.5 – 2.0 ML/day (Section 3.2.2). Recharge was set to 0.007 m/year and was not adjusted during transient calibration so that results were not affected by non-average rainfall.

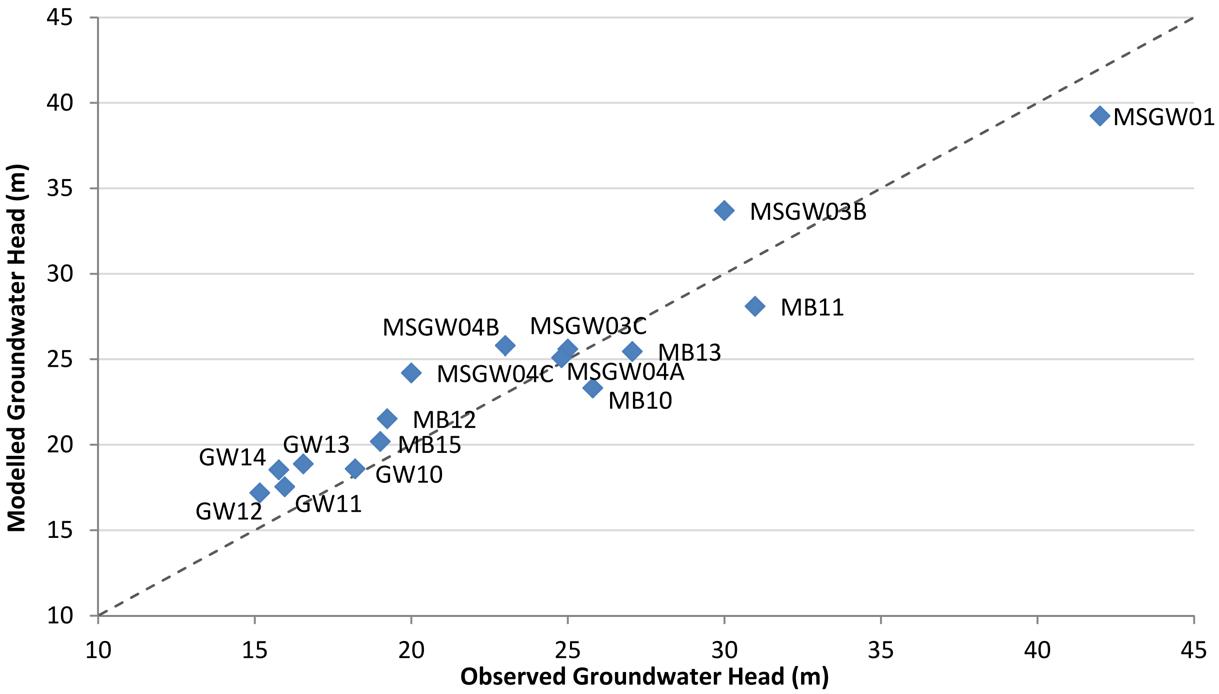



**Figure 5-1 Steady State Calibration Scatterplot**

The modelled change in groundwater inflow into the existing workings within the West Wallarah / Wallarah – Great Northern Seams between 2005 and 2012 is shown in Figure 5-2. Transient runs 2, 3, 4, 5 and 6 have been presented here. The horizontal and vertical hydraulic conductivity values adopted for each of these model runs are outlined in Table 5-3.

**Table 5-3 Hydraulic Conductivity Values for Transient Runs 2, 3, 4, 5 and 6**

| Model Run | Coal Seam $K_h$ (m/year) | Coal Seam $K_v$ (m/year) | Permian Overburden $K_h$ (m/year) | Permian Overburden $K_v$ (m/year) | Fractured Overburden $K_h$ (m/year) | Fractured Overburden $K_v$ (m/year) |
|---|---|---|---|---|---|---|
| Transient Run 2[(a)] | 7.2 | 0.72 | 0.0365 | 0.00365 | 0.0365 | 0.00365 |
| Transient Run 3 | 0.3 | 0.03 | 0.0365 | 0.00365 | 0.0365 | 0.00365 |
| Transient Run 4 | 0.3 | 0.03 | 0.0183 | 0.00183 | 0.0183 | 0.00183 |
| Transient Run 5 | 0.3 | 0.03 | 0.0183 | 0.00183 | 0.0365 | 0.00365 |
| Transient Run 6 | 0.5 | 0.05 | 0.0183 | 0.00183 | 0.0365 | 0.00365 |

(a) Hydrogeological properties for best fit steady state calibration

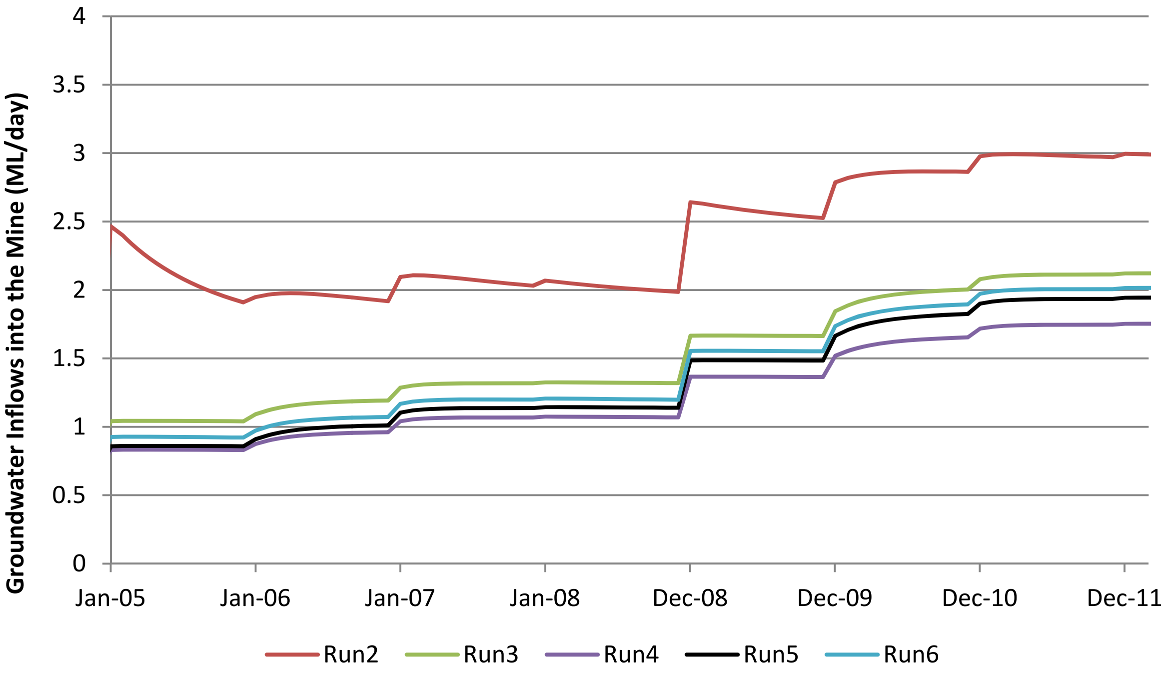



**Figure 5-2 Modelled Groundwater Inflows into the Great Northern / West Wallarah Workings**

In Transient run 2, the hydraulic conductivity values established from steady state calibration were adopted. Modelled groundwater inflow into the Cooranbong workings and Mandalong Mine workings in early 2012 is approximately 3 ML/day, higher than the measured inflow of 1.9 ML/day. It was considered that if the hydrogeological properties established from steady state calibration were used in predictive modelling it would result in an overestimate of future groundwater inflows into the mine.

The hydraulic conductivity of the coal seam in Layer 5 was reduced from 7.2 m/year to 0.3 m/year in Transient run 3. This hydraulic conductivity value is in the lower range of measured values as outlined in Section 2.3.2. As shown in Figure 5-2, the modelled groundwater inflow into the Cooranbong workings and Mandalong Mine workings in early 2012 for Transient run 3 is approximately 2.1 ML/day, slightly higher than the measured inflow of 1.9 ML/day. However, since this run did not consider hydraulic conductivity increases in overburden strata due to existing fracturing, it was necessary to reduce the hydraulic conductivity of the surrounding strata. It was considered that decreasing the coal seam hydraulic conductivity any further should be avoided to keep it within the range of measured values.

The hydraulic conductivities of the Permian overburden, fractured overburden and underlying Awaba Tuff were adjusted in Transient runs 4, 5 and 6. Transient run 5 was found to provide the best transient calibration with realistic material properties, with the modelled groundwater inflow in early 2012 being approximately 1.9 ML/day. This calibration indicates that the hydraulic conductivity has increased on average by about two times throughout the height of fracturing (i.e. throughout Layer 4 of the hydrogeological model) above the existing longwalls at Mandalong. An average increase in hydraulic conductivity in the order of two times has also been predicted within the fractured zone above the existing longwalls at Newstan Colliery to the north, based on hydrogeological modelling undertaken by GHD.

# 6. Predictive Simulations

As specified in Sections 1.4 and 1.5, the calibrated hydrogeological model was used to provide estimates of dewatering volumes and zone(s) of drawdown in each groundwater source as a result of the development of the Mandalong Southern Extension Project longwall panels. Predicted impacts on these groundwater sources and impacts on groundwater users, connected water sources and GDEs are assessed in GHD (2013a).

## 6.1 Groundwater Inflows

The transient model was extended to the end of year 2050 to cover the period of proposed mining up to 2036 plus an additional 14 years following completion of mining. The transient model was used to estimate total groundwater inflows into the Cooranbong, Mandalong and Mandalong Southern Extension workings both during mining and following completion of mining.

Drain cells were established throughout Layer 5 to coincide with the development of proposed workings within the West Wallarah and Wallarah – Great Northern Seams between 2013 and 2036. Drain cells were activated in accordance with the proposed mining schedules for Mandalong and the Mandalong Southern Extension Project. As outlined in Section 5.4, drain cells to be activated in a particular year (as specified in the longwall development schedule) were activated at the beginning of the calendar year. All workings (existing and proposed) remain fully drained after extraction until the end of the simulation period. It is noted that some goaf areas within the Southern Extension Area may be allowed to flood with groundwater following extraction if safe to do so, and this would result in a reduced total groundwater inflow that must be removed from the workings.

The fractured material zone in Layer 4 was extended to coincide with the proposed areas of secondary extraction within the Southern Extension Area.

Figure 6-1 shows the total predicted groundwater inflows into the workings for transient runs 2, 3, 4, 5 and 6. Based on the results from Transient run 5 (best fit from transient calibration), total groundwater inflows into the Cooranbong, Mandalong and Mandalong Southern workings are predicted to peak at approximately 5.9 ML/day in year 2035. The management of this additional groundwater is addressed in the Water Management Impact Assessment (WMIA) for the Mandalong Southern Extension Project (GHD, 2013b).

## 6.2 Aquifer Depressurisation

The hydrogeological model has been used to predict the likely depressurisation of aquifers underlying the Southern Extension Area to support the groundwater impact assessment. The groundwater impact assessment compares the predicted water table and groundwater pressure drawdown against the Minimal Impact Considerations for less productive groundwater sources defined in the NSW Aquifer Interference Policy (DPI/NOW, 2012).

The groundwater sources that may be impacted by the Mandalong Southern Extension workings are the Quaternary alluvium, weathered and/or fractured sandstone and coal seams. The hydrogeological model has been used to predict groundwater depressurisation within these groundwater sources.

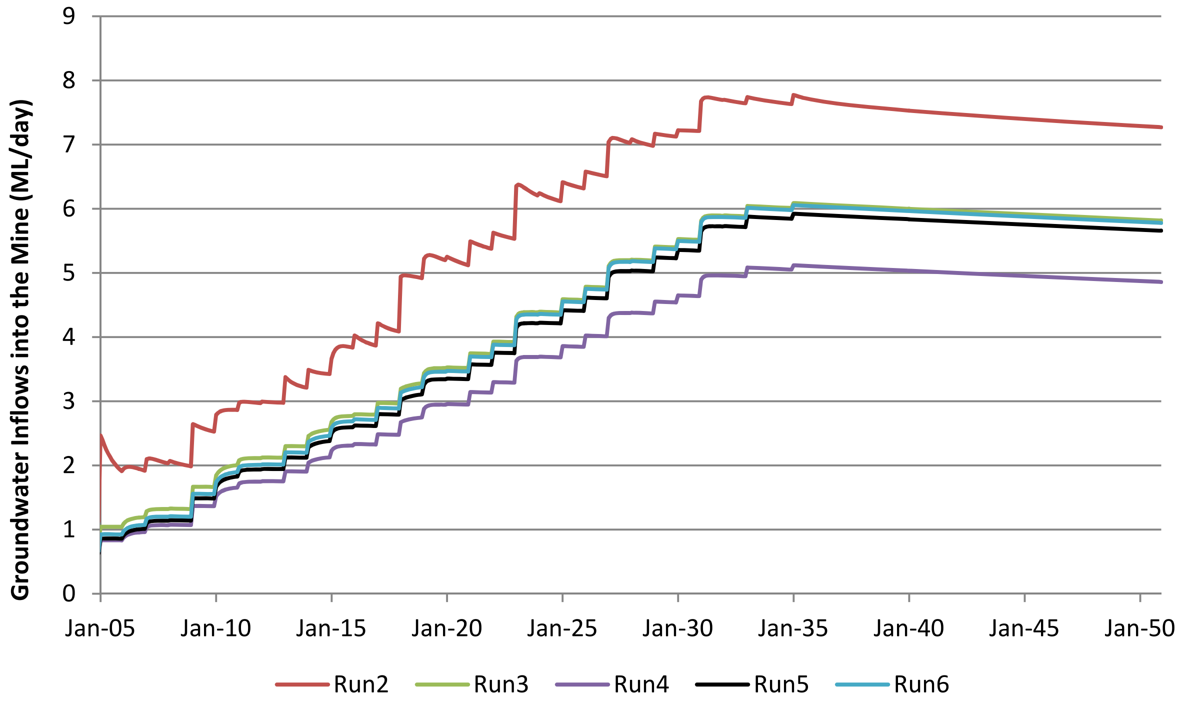



**Figure 6-1 Modelled Groundwater Inflows into the Cooranbong, Mandalong and Mandalong Southern Workings**

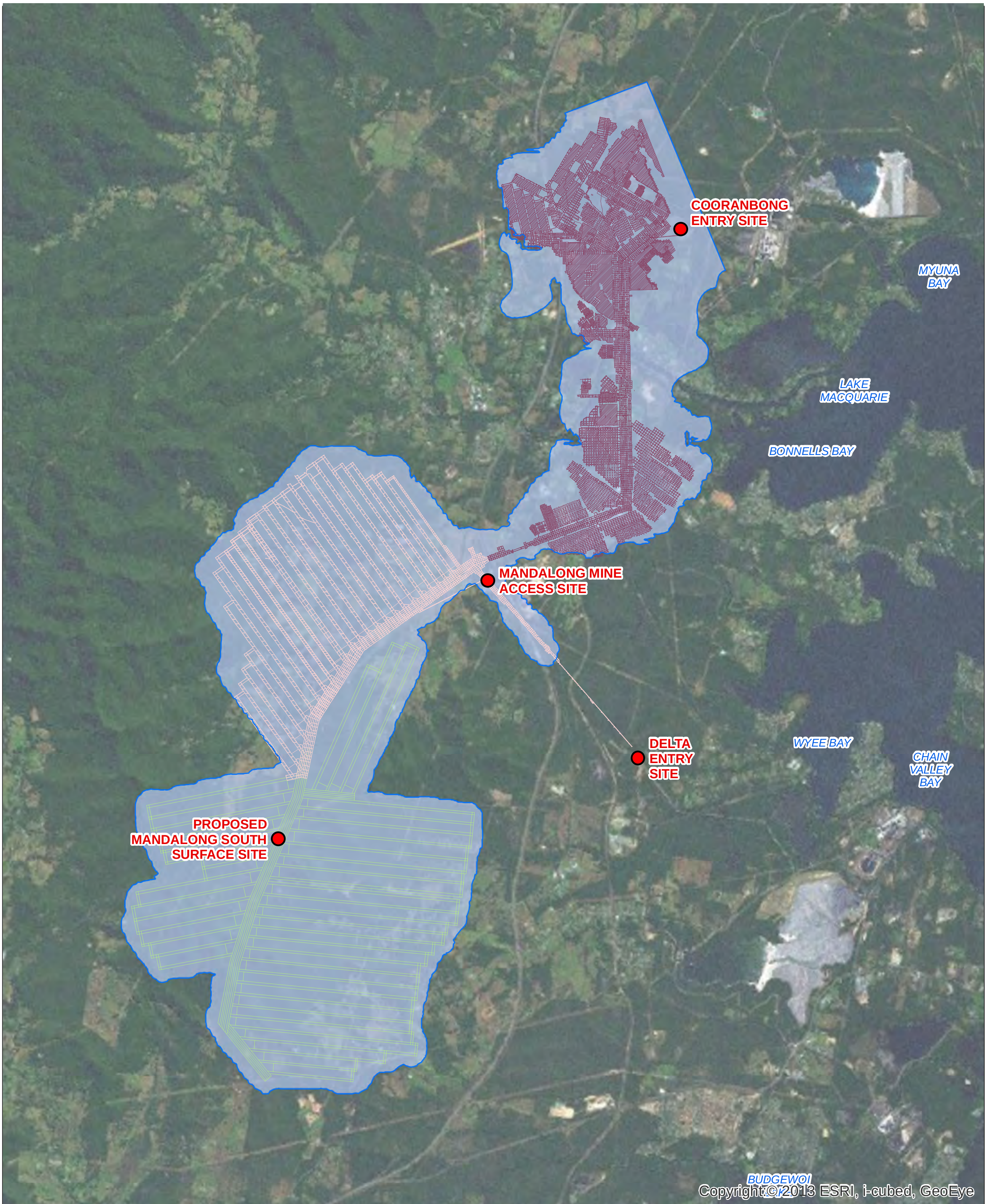
### 6.2.1 Coal Seam Aquifer

The predicted zone of depressurisation within the Great Northern / West Wallarah Seam, based on results from Transient run 5, is shown in Figure 6-2. The boundary of the mapped zone of depressurisation is the 0.1 m drawdown contour, which is considered to be the limit of accuracy of the model based on the limit of accuracy of observation groundwater level data used to calibrate the model. The zone of depressurisation shown in Figure 6-2 is the predicted zone at the completion of mining (2036).

The boundary of the maximum zone of depressurisation within the coal seam underlying the Southern Extension Area is within 500 m from the proposed Mandalong Southern Extension workings.

### 6.2.2 Overburden Rock

Based on the results from Transient run 5 of the hydrogeological model, the predicted location of the 0.1 m drawdown contour within Layer 4 of the hydrogeological model (overburden rock to a height of 140 m above the coal seam) at the completion of mining (2036) is less than 200 m from the proposed Mandalong Southern Extension workings. The maximum predicted drawdown within this zone of depressurisation is approximately 2 m. The predicted drawdown has been averaged over the 140 m height above the seam and is therefore likely to be higher than this value within the Caved Zone immediately above the seam and lower at greater heights above the seam near the top of Layer 4. It is expected that groundwater drawdown would not extend any more than 500 m from the proposed workings within the Caved Zone, since this is the extent of drawdown within the coal seam.




1:100,000 for A4

0 0.275 0.55 1.1 1.65 2.2 2.75
Kilometers

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geodetic Datum of Australia 1994
Grid: Map Grid of Australia, Zone 56

N

GHD

LEGEND

- Site Locations
- Drawdown >0.1m
- Proposed Mine Workings
- Cooranbong Existing Mine Workings
- Mandalong Existing Mine Workings



| | |
|---|---|
| LOCATION | Newstan |
| SEAM | |
| DRAWN | S.M |
| CHECKED | |
| APPROVED | |
| SCALE | refer to scalebar |

Mandalong South Extension Project
Hydrogeological Model Report

Maximum Zone of Depressurisation within Porous and Fractured Rock Groundwater Sources

Centennial Mandalong

DATE 20/09/2013

Figure 6-2

GIS Filename: G:\22\0105001\GIS\Maps\Hunter\Mandalong\Deliverables\2216168\Hydrogeological Model Report\2216168_HMR_011_ZoneOfDepressurisationCoalSeam_0.mxd

It is noted that there is only one registered groundwater supply bore within 500 m of the proposed Mandalong Southern Extension workings (GW078601). This bore is registered for domestic and stock supply and is located above proposed LW 64. The bore extracts shallow groundwater from sandstone at a depth of approximately 15 – 16 m bgl. The model predicts that the water table drop at this location will not exceed 0.1 m.

#### 6.2.3 Alluvial Groundwater

Transient run 5 of the hydrogeological model predicts that the proposed Mandalong Southern Extension workings will not result in a water table drop greater than 0.1 m within the alluvial groundwater in the Southern Extension Area throughout the proposed period of mining. This prediction is based on no increase in the hydraulic conductivity of strata within the surface zone. The water balance results for Transient run 5 suggest that there will be no increase in the movement of shallow groundwater within the surface strata (extending to a depth of 15 m bgl) within the Southern Extension Area to underlying aquifers as a result of the proposed Mandalong Southern Extension workings.

As noted in Section 3.2.3, tensile and compressive cracks may develop within the surface zone and may result in localised increases in hydraulic conductivity and porosity. These stresses were not modelled by the hydrogeological model because it is likely that they will only result in temporary reductions in water table levels within the surface zone (as observed within the existing Mandalong Mine area) and they will not result in an increased movement of shallow groundwater to underlying aquifers. In addition, shallow subsidence cracks tend to fill over time and the hydraulic conductivity and porosity may return to pre-mining values.

# 7. Conclusions

A three-dimensional six layer numerical hydrogeological model has been developed to estimate groundwater inflow into the proposed Mandalong Southern Extension workings throughout the life of the mine and to predict zone(s) of drawdown in each groundwater source overlying the Mandalong Southern Extension Project longwall panels. The groundwater sources underlying the Southern Extension Area have been classified in accordance with the NSW Aquifer Interference Policy (DPI/NOW, 2012) as less productive alluvial groundwater and less productive porous and fractured rock aquifers. Predicted impacts on these groundwater sources and impacts on groundwater users, connected water sources and GDEs are assessed in GHD (2013a).

Hydrogeological modelling was undertaken using the MODFLOW-NWT solver of the MODFLOW 2005 groundwater modelling code. The model was constructed using the GMS graphical user interface with reference to the NSW Aquifer Interference Policy and Australian Groundwater Modelling Guidelines (Barnett et al., 2012). Model assumptions and limitations are detailed in Section 4.4.

The hydrogeological model was calibrated under steady state conditions using available groundwater level data, and under transient conditions using available groundwater flow data.

Based on the results from Transient run 5 (best fit run under transient calibration), total groundwater inflow into the existing and proposed workings (Cooranbong, Mandalong and Mandalong Southern Extension) is predicted to peak at approximately 5.9 ML/day in year 2035. The management of additional groundwater inflows is addressed in the WMIA for the Mandalong Southern Extension Project (GHD, 2013b).

The predicted zone of depressurisation (i.e. greater than 0.1 m) within the coal seam underlying the Southern Extension Area, based on results from Transient run 5, is within 500 m from the proposed Mandalong Southern Extension workings at the completion of mining (2036). Predicted depressurisation within Layer 4 of the hydrogeological model (overburden rock to a height of 140 m above the coal seam) at the completion of mining (2036) is less than 200 m from the proposed Mandalong Southern Extension workings. The maximum predicted drawdown within this zone of depressurisation is approximately 2 m, although it should be noted that the predicted drawdown has been averaged over the 140 m height above the seam.

Transient run 5 of the hydrogeological model also predicts the following:

- The proposed Mandalong Southern Extension workings will not result in a water table drop greater than 0.1 m within the alluvial groundwater in the Southern Extension Area throughout the proposed period of mining. This prediction is based on no increase in the hydraulic conductivity of strata within the surface zone
- No increase in the movement of shallow groundwater within the surface strata (extending to a depth of 15 m bgl) within the Southern Extension Area to underlying aquifers is anticipated.

The hydrogeological model is based on the groundwater data, geological data and subsidence predictions (outlined in Section 3 of this report) available at the time of model construction. It may be necessary to update this hydrogeological model in the future based on future groundwater and subsidence monitoring data for the Mandalong Mine and Southern Extension Areas.

# 8. References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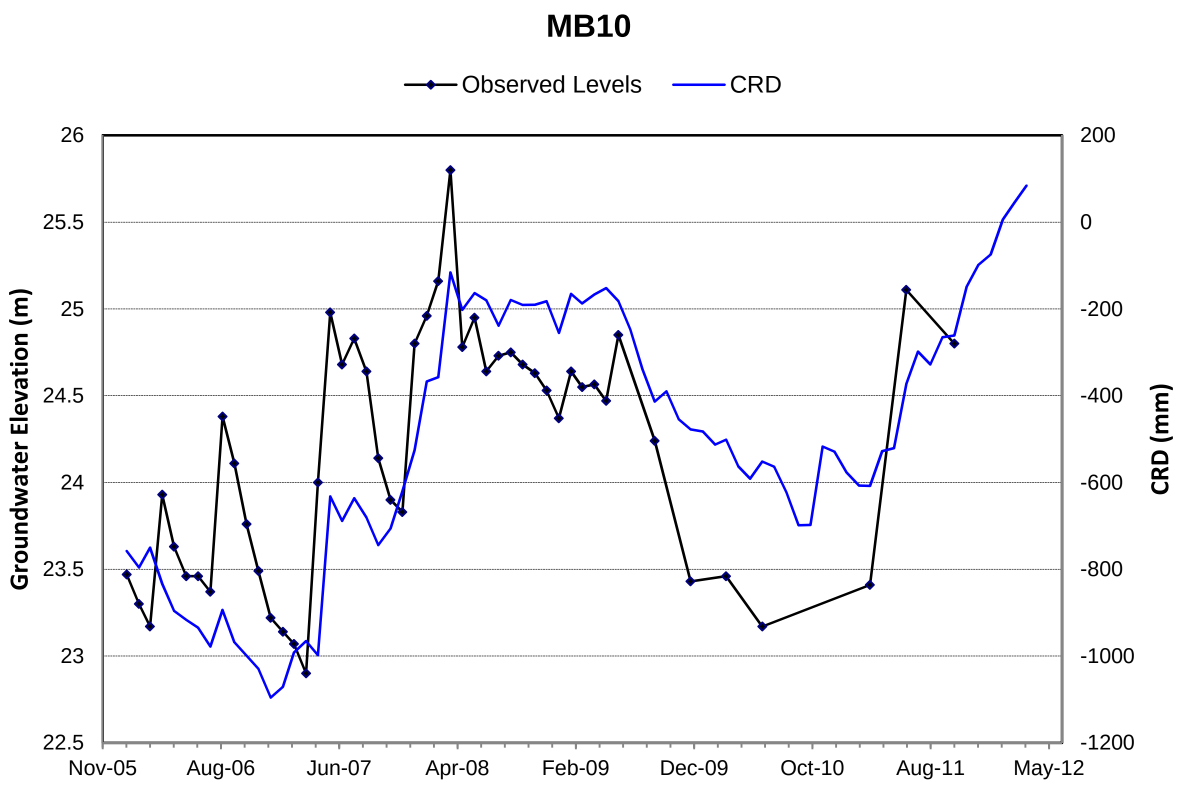
Annexure A

# Groundwater Hydrographs - Alluvium


MB10
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
26
25.5
25
24.5
24
23.5
23
22.5
200
0
-200
-400
-600
-800
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-1200
Nov-05
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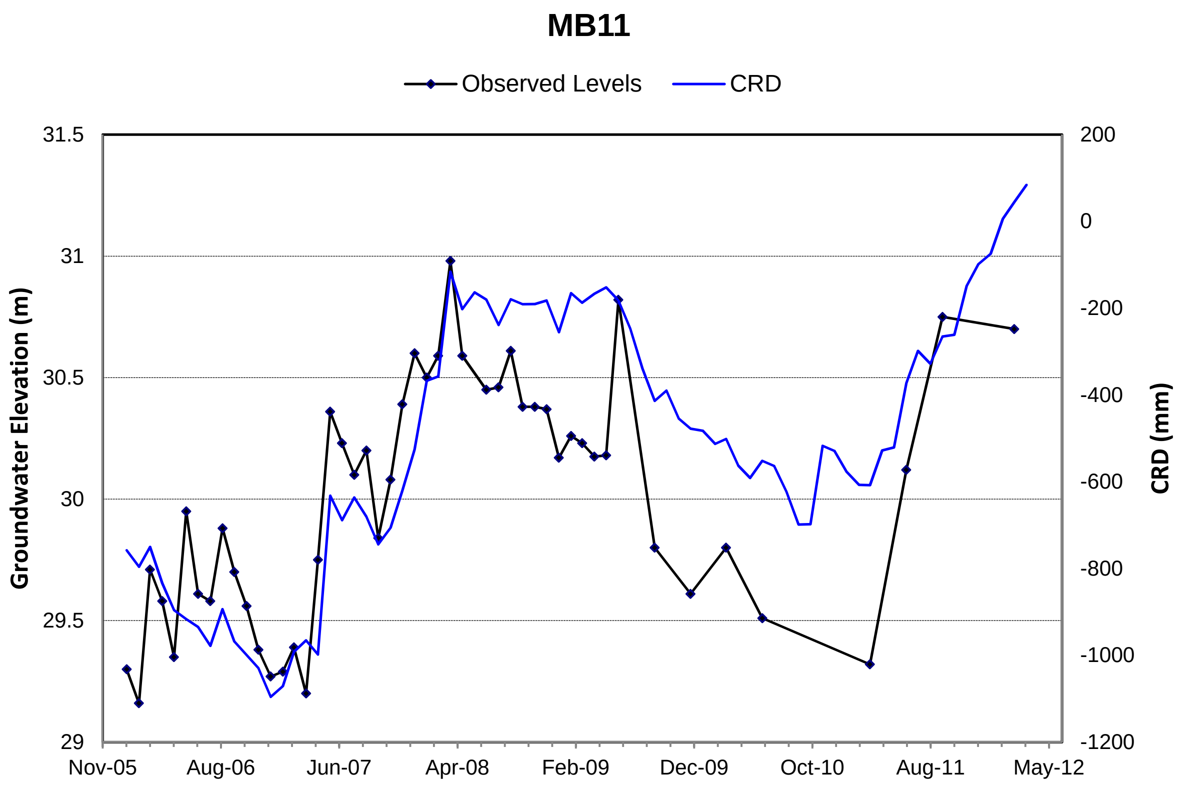
Oct-10
Aug-11
May-12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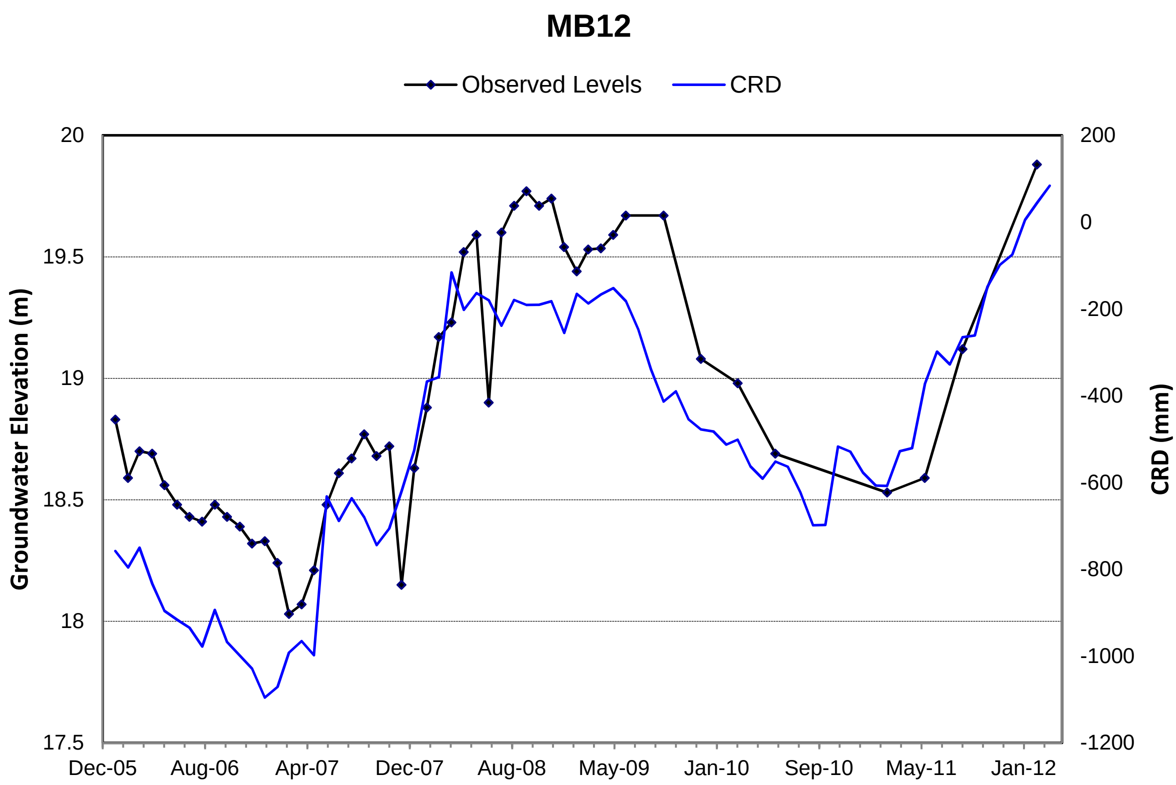
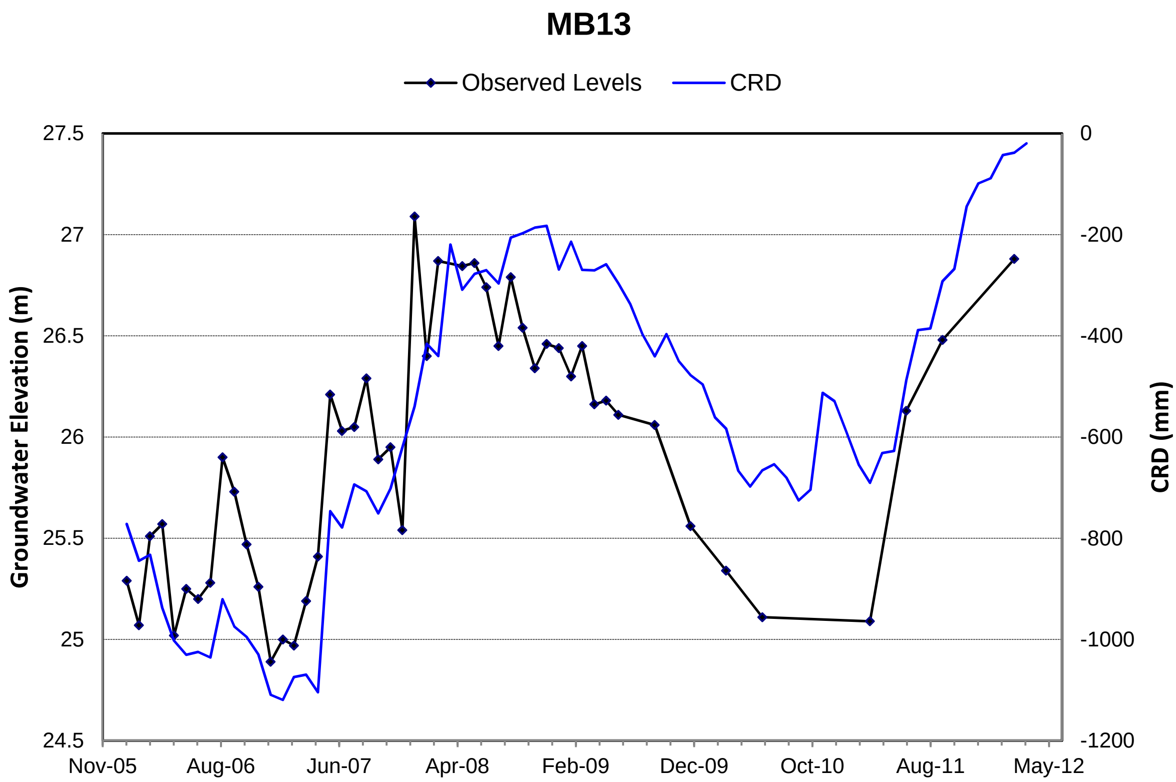
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
31.5
31
30.5
30
29.5
29
200
0
-200
-400
-600
-800
-1000
-1200
Nov-05
Aug-06
Jun-07
Apr-08
Feb-09
Dec-09
Oct-10
Aug-11
May-12


MB12
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
20
19.5
19
18.5
18
17.5
200
0
-200
-400
-600
-800
-1000
-1200
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
May-09
Jan-10
Sep-10
May-11
Jan-12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Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
27.5
27
26.5
26
25.5
25
24.5
0
-200
-400
-600
-800
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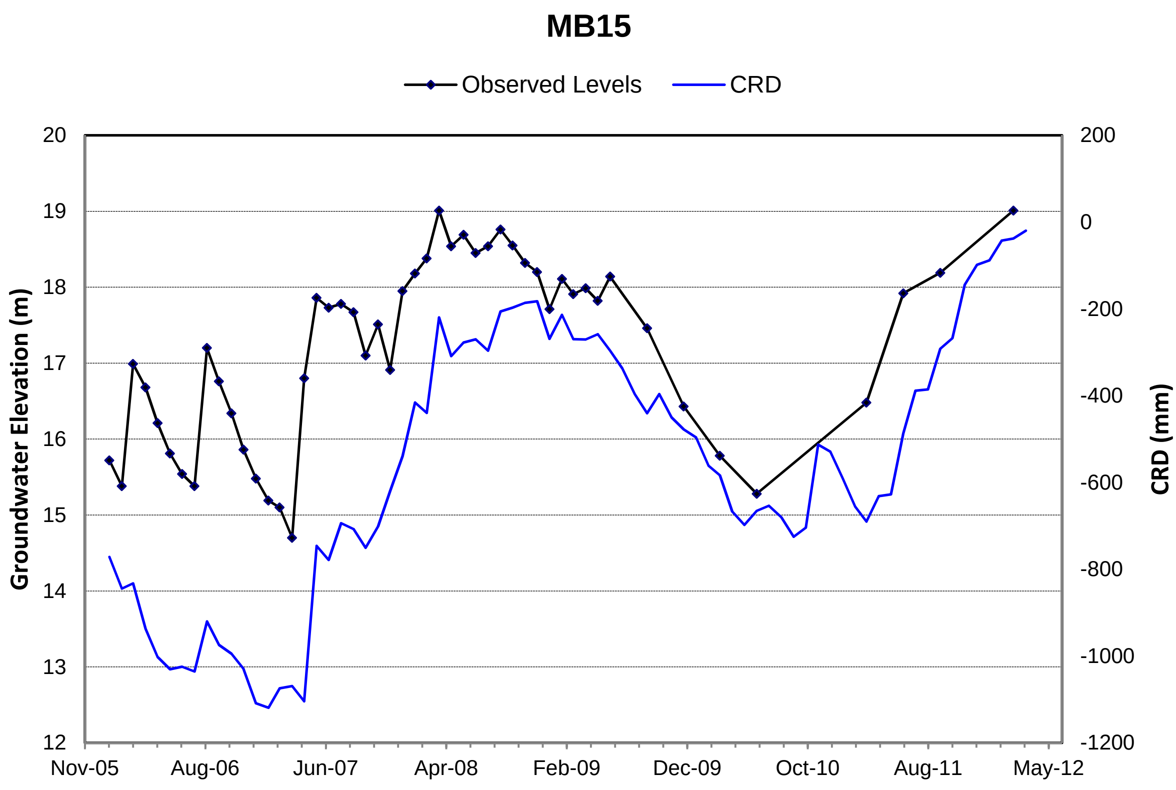
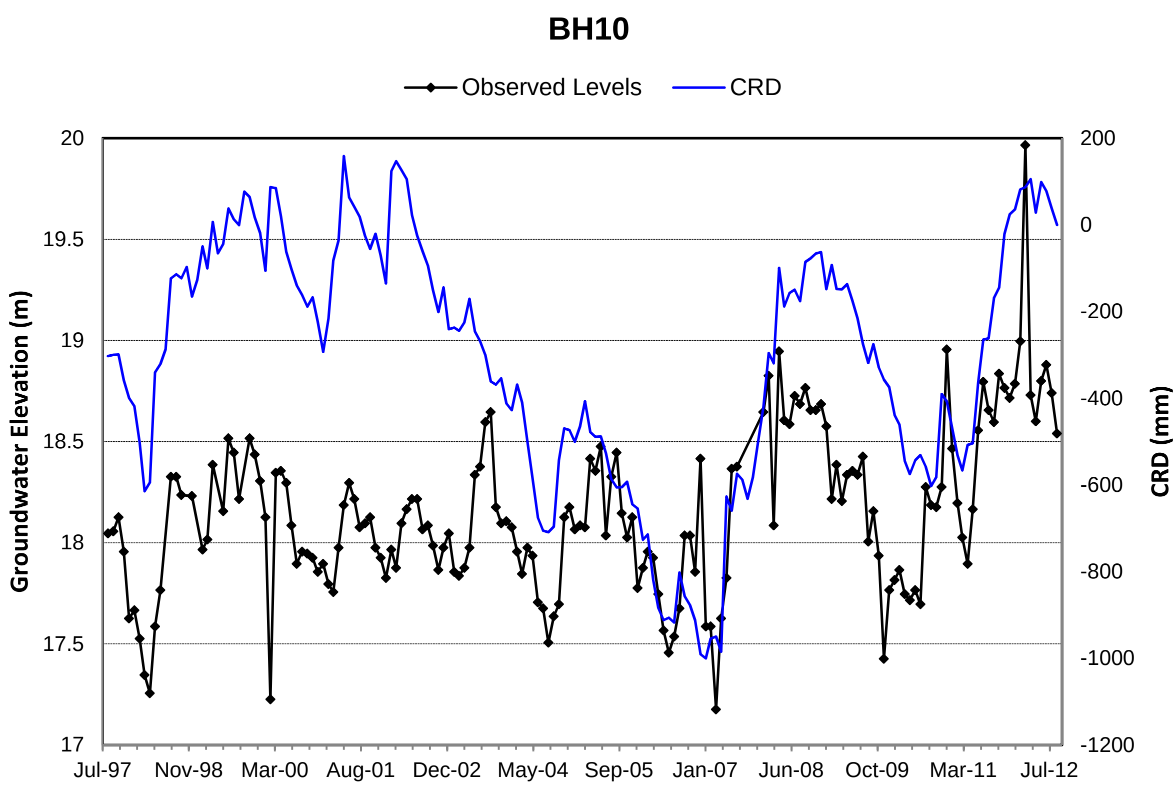
Oct-10
Aug-11
May-12


MB15
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
20
19
18
17
16
15
14
13
12
200
0
-200
-400
-600
-800
-1000
-1200
Nov-05
Aug-06
Jun-07
Apr-08
Feb-09
Dec-09
Oct-10
Aug-11
May-12


BH10
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
20
19.5
19
18.5
18
17.5
17
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
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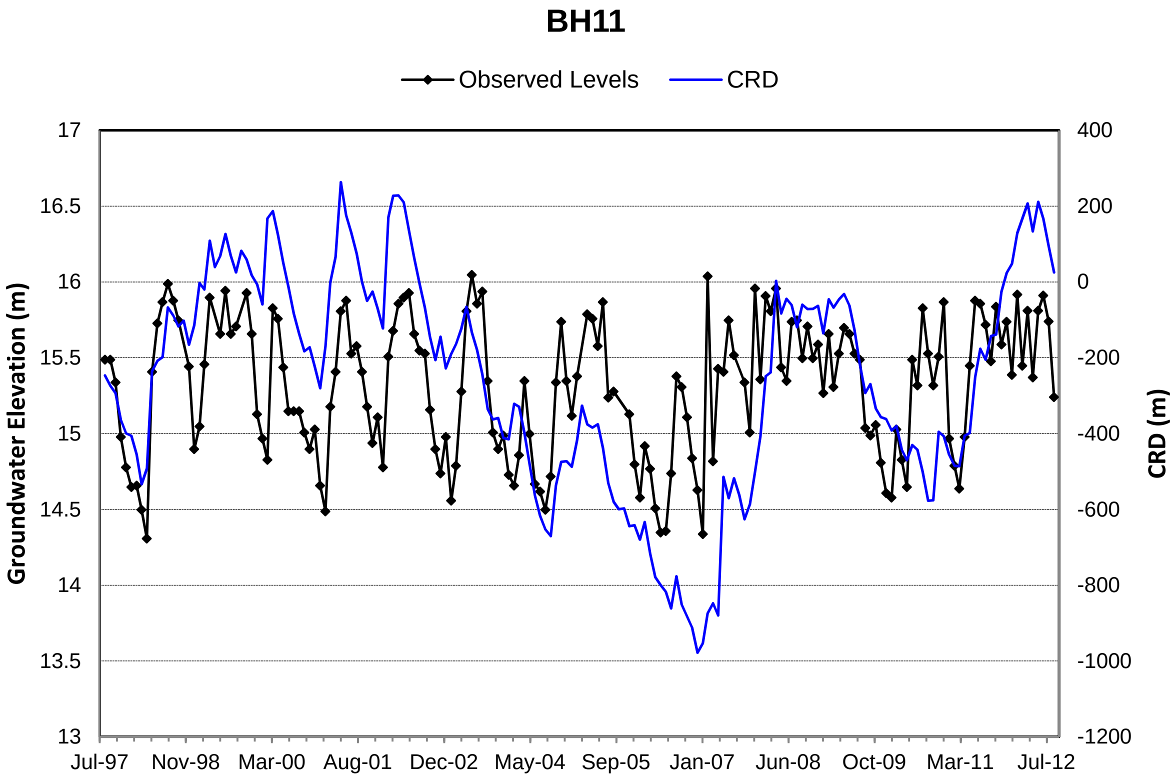
Oct-09
Mar-11
Jul-12


BH11
Observed Levels
CRD
Groundwater Elevation (m)
CRD (m)
17
16.5
16
15.5
15
14.5
14
13.5
13
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
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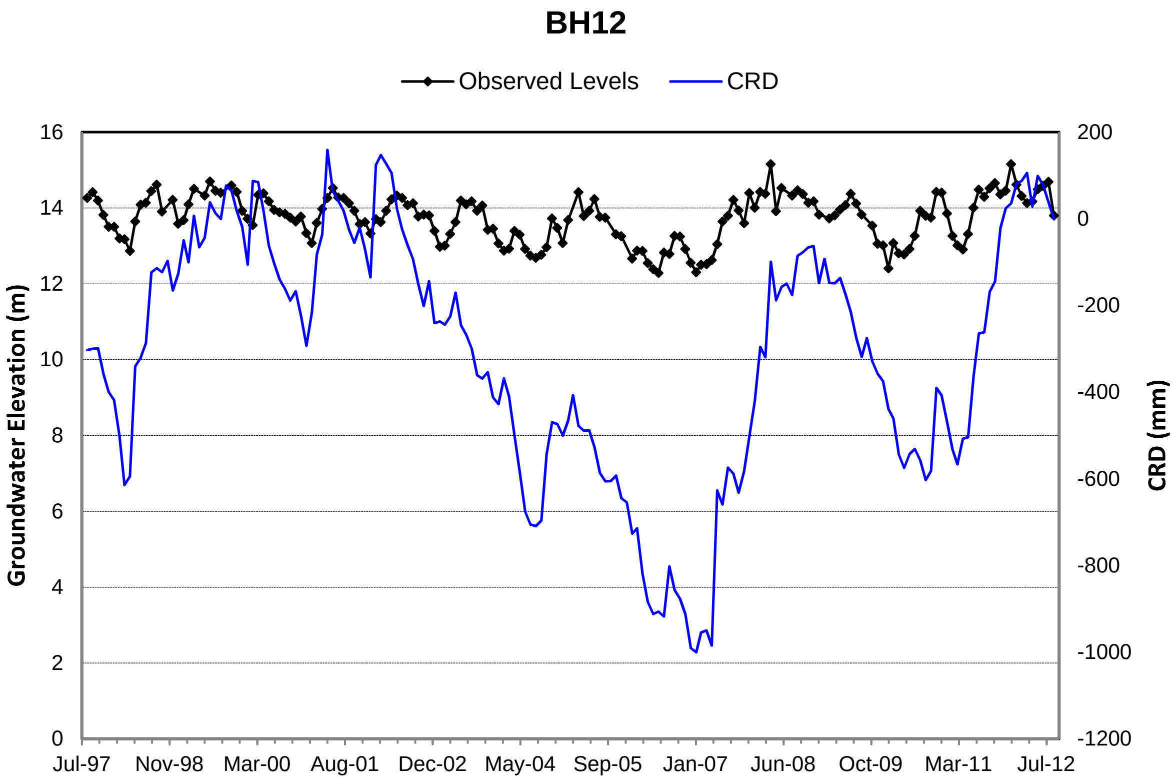
Oct-09
Mar-11
Jul-12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Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
16
14
12
10
8
6
4
2
0
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
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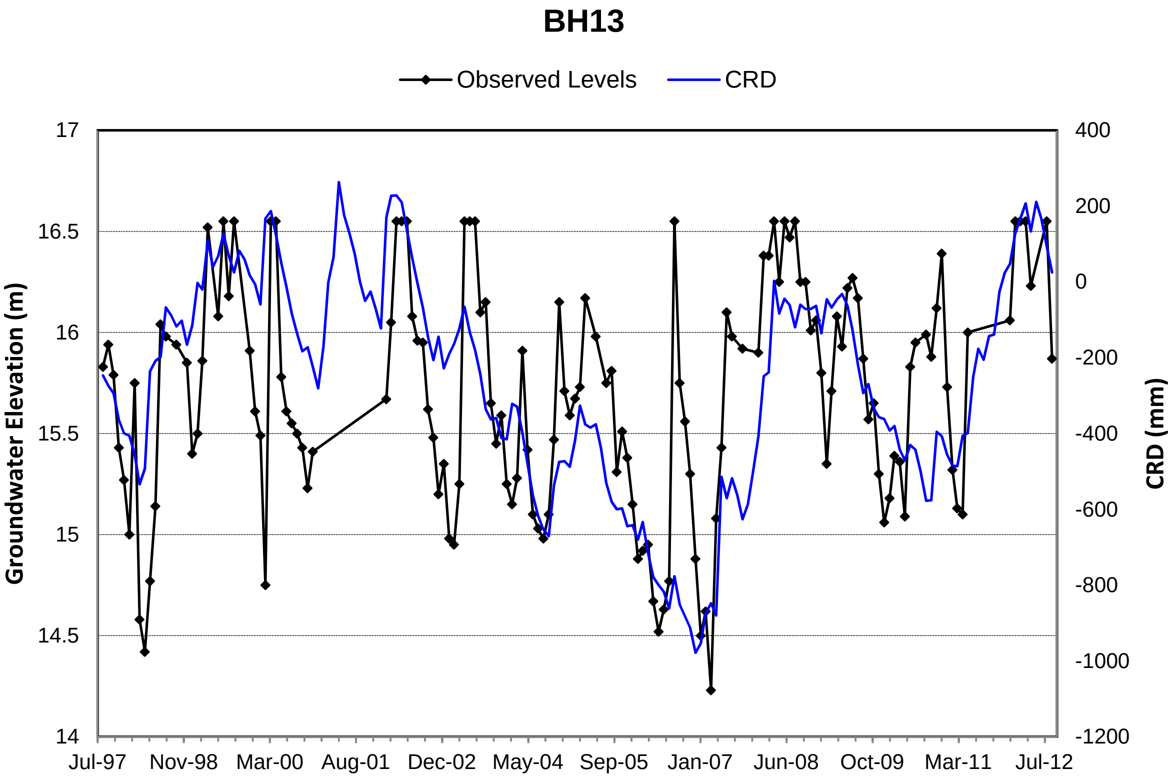
Oct-09
Mar-11
Jul-12


BH13
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
17
16.5
16
15.5
15
14.5
14
400
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
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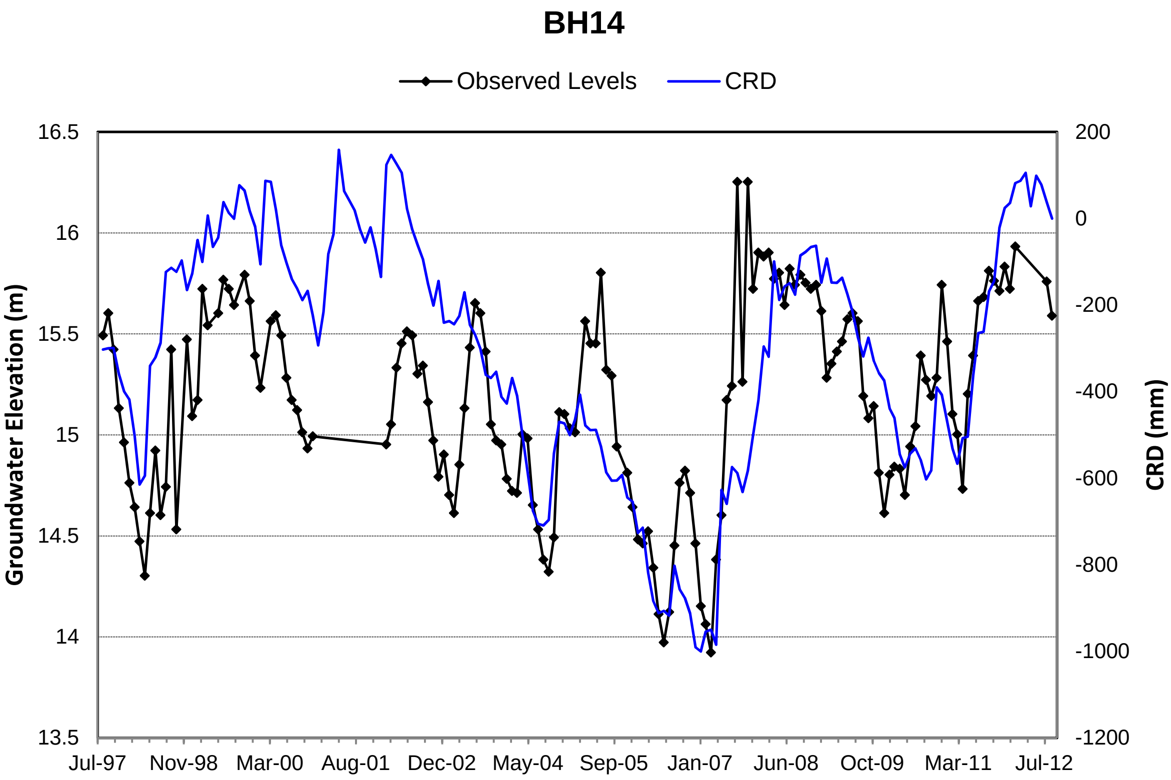
Oct-09
Mar-11
Jul-12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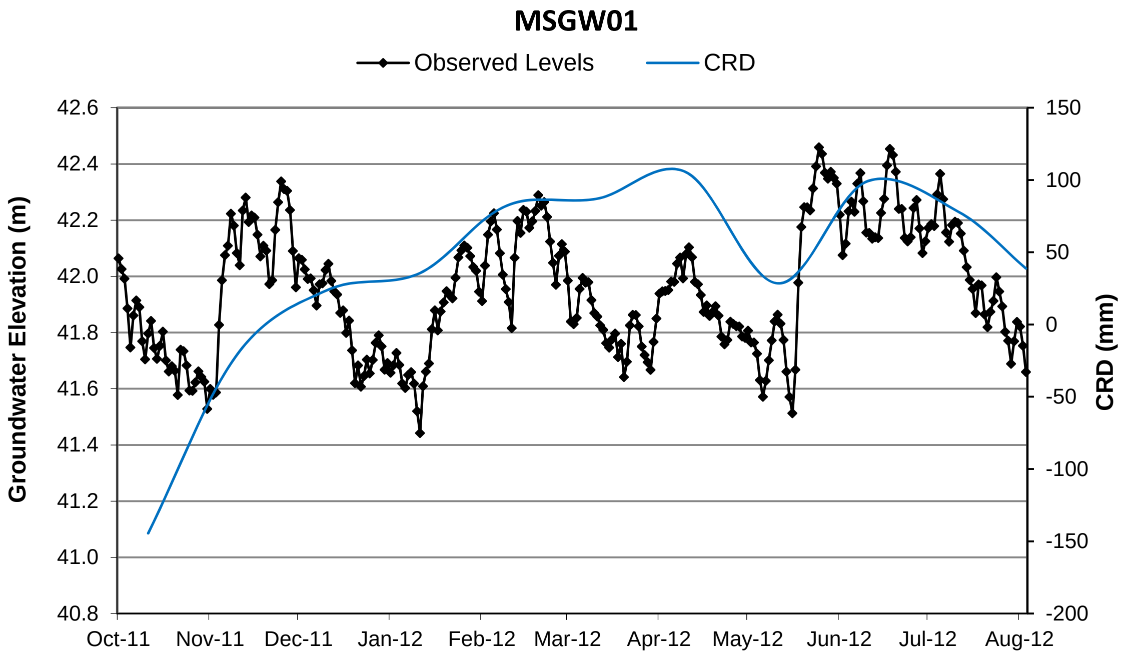
Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
16.5
16
15.5
15
14.5
14
13.5
200
0
-200
-400
-600
-800
-1000
-1200
Jul-97
Nov-98
Mar-00
Aug-01
Dec-02
May-04
Sep-05
Jan-07
Jun-08
Oct-09
Mar-11
Jul-12


MSGW01
Observed Levels
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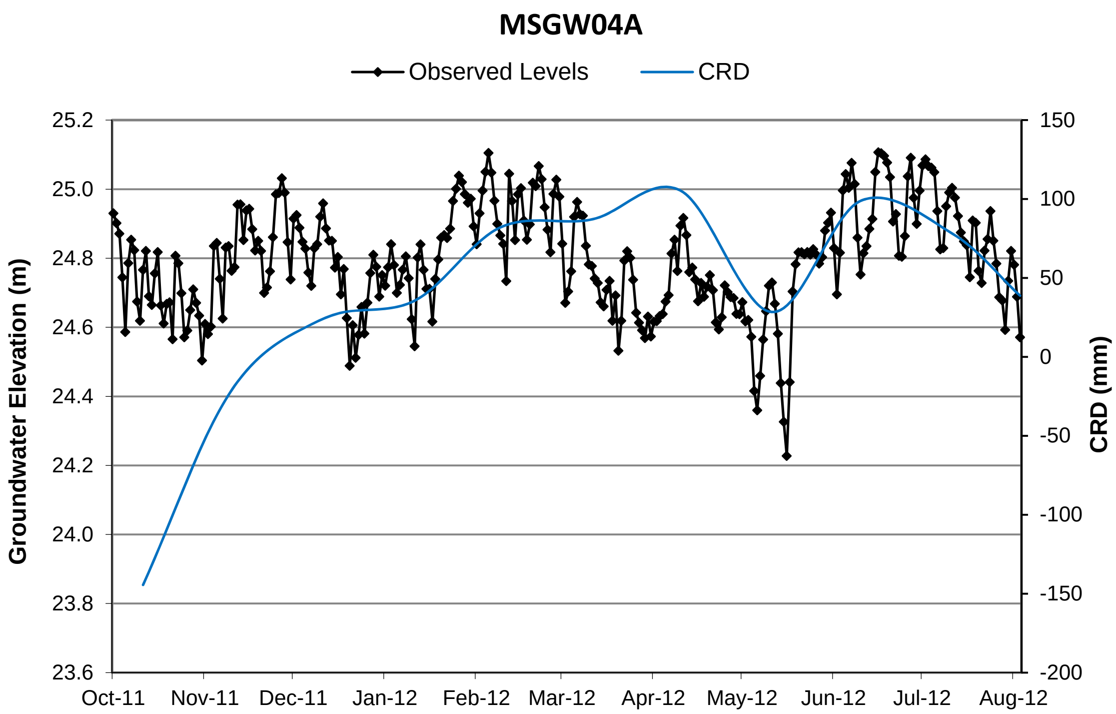
Groundwater Elevation (m)
CRD (mm)
42.6
42.4
42.2
42.0
41.8
41.6
41.4
41.2
41.0
40.8
150
100
50
0
-50
-100
-150
-200
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12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Observed Levels
CRD
Groundwater Elevation (m)
CRD (mm)
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25.0
24.8
24.6
24.4
24.2
24.0
23.8
23.6
150
100
50
0
-50
-100
-150
-200
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12

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| 1 | S Gray | L Evans | | S Gray | | 09/08/13 |

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