WATERMARK
COAL PROJECT
ENVIRONMENTAL IMPACT STATEMENT

February 2013

T

Groundwater
Impact Assessment
(Appendices)



APPENDIX 2

Laboratory Permeability Testing – Weatherford


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ROUTINE CORE ANALYSIS FINAL REPORT

of

WATERMARK PROJECT

for

AUSTRALASIAN GROUNDWATER & ENVIRONMENTAL CONSULTANTS PTY LTD

by

WEATHERFORD LABORATORIES (AUSTRALIA) PTY LTD

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30th November, 2011

Australasian Groundwater & Environmental Consultants Pty Ltd
Level 2, 15 Mallon Street
BOWEN HILLS QLD 4006

Attention: Neil Manewell

FINAL REPORT: 0544-02

CLIENT REFERENCE:	Purchase Order No 00004554
MATERIAL:	HQ Core Sections
LOCALITY:	Unknown
WORK REQUIRED:	Routine Core Analysis

Please direct technical enquiries regarding this work to the signatory below under whose supervision the work was conducted.

KEVIN H FLYNN
General Manager
SCAL Technical Director

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I. EQUIPMENT SCHEMATICS

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

This final report presents the results of a routine core analysis project performed on various HQ whole core samples provided. Following inspection of the samples and discussions with AGE Consultant representatives, samples were either analysed as full diameter or 1½" diameter core plugs drilled. All carbonaceous samples were deemed unsuitable for cleaning due to the possibility of sample damage. The subsequent chapter contains descriptions of procedures and test results.

CHAPTER 2

SAMPLE PREPARATION AND BASE PARAMETER DETERMINATIONS

2.1 Test and Calculation Procedures

2. SAMPLE PREPARATION AND BASE PARAMETER DETERMINATIONS

2.1 Test and Calculation Procedures

2.1.1 Sample Preparation

On receipt all samples were inspected for analysis suitability. If the samples were deemed suitable a 1½" diameter core plug was drilled in the vertical and horizontal directions using brine as the bit lubricant. Samples were trimmed to right cylinders of standard length using a diamond impregnated cutting blade. Conglomerate and carbonaceous samples were considered to be unsuitable for core plugging and were therefore trimmed to right cylinders.

2.1.2 Cleaning and Drying

Following inspection of samples all carbonaceous samples were deemed unsuitable for cleaning and proceeded to humidity drying only. All other samples were cleaned in a modified Soxhlet system (Appendix II) using a 3:1 chloroform:methanol azeotrope. Cleaning continued until tests for oil (fluorescence under UV lights) and salt (silver nitrate precipitation) showed negative. The samples were dried to constant weight in a humidity oven at 60°C and 40% relative humidity. Once dry, the samples were cooled to room temperature in an airtight chamber.

2.1.3 Base Parameters

Porosity

Porosity was determined in two stages. Initially each sample was placed in a sealed matrix cup. Helium held at 100 psi reference pressure was then introduced to the cup. From the resultant pressure drop the unknown grain volume was determined from Boyle's Law.

The bulk volume of each plug was determined by Archimedes Principle. The difference between the grain volume and the bulk volume is the pore volume. The porosity was calculated as the volume percentage of pore space with respect to the bulk volume.

$$P_1 V_1 = P_2 V_2$$

$$\Rightarrow \quad P_1 Vr = P_2 (Vr + Vc - Vg)$$

$$Vp = Vb - Vg$$

$$\text{Ambient Porosity \%} = \frac{Vp}{Vb} \times 100\%$$

P_1 = *initial pressure (psig)*
P_2 = *final pressure (psig)*
Vr = *reference cell volume (cm^3)*
Vc = *matrix cup volume (cm^3)*
Vg = *grain volume (cm^3)*
Vp = *pore volume (cm^3)*
Vb = *bulk volume (cm^3)*

Permeability to Air (plug samples)

The plug samples (horizontal and vertical) were placed into a hassler cell (Appendix I) with an ambient confining pressure of 300 psi applied. The confining pressure was used to prevent bypassing of air around the sample when the measurement was made. In order to determine permeability a known air pressure was applied to the upstream face of each sample, creating a flow of air through the core plug. Air permeability for each core sample was calculated using Darcy's Law through knowledge of the upstream pressure, flow rate, viscosity of air and sample dimensions.

$$Ka = \frac{2000.BP.\mu.q.L}{(P_1^2 - P_2^2).A}$$

where
Ka = *air permeability (milliDarcy's)*
BP = *barometric pressure (atmospheres)*
μ = *gas viscosity (cP)*
q = *flow rate (cm^3/s) at barometric pressure*
L = *sample length (cm)*
P_1 = *upstream pressure (atmospheres)*
P_2 = *downstream pressure (atmospheres)*
A = *sample cross sectional area (cm^2)*

Permeability to Air (full diameter samples)

Vertical permeability was determined by placing the samples into a hydrostatic cell with an ambient confining pressure of 400 psi applied. A known air pressure was applied to the end-face of each sample, creating a vertical flow of air through the full diameter sample. Air permeability for each core sample was calculated using Darcy's Law through knowledge of the upstream pressure, flow rate, viscosity of air and sample dimensions as described above.

Horizontal full diameter permeability was determined by mounting samples into a specially designed confining boot and loaded into a hydrostatic cell at ambient confining pressure. The samples were mounted with mesh screens at inlet and outlets covering 90° of the sample end face for the full sample length (Appendix I). A known air pressure was applied to the inlet screen flowing air across the sample into a similarly designed outlet placed diametrically across from the inlet screen.

By using platens covering 90° the geometrical factor equals one. Air permeability was then calculated through knowledge of upstream pressure, flow rate, viscosity of air and sample dimensions. Permeability K_{max} was measured along the direction of principal fracturing or permeability strike and K_{90} was measured at 90° to the maximum.

$$K_{horizontal} = \frac{2000.BP.\mu.q}{(P_1^2 - P_2^2).L}$$

where

$K_{horizontal}$	=	*horizontal air permeability (milliDarcy's)*
BP	=	*barometric pressure (atmospheres)*
μ	=	*gas viscosity (cP)*
q	=	*flow rate (cm^3/s)*
L	=	*sample length (cm)*
P_1	=	*upstream pressure (atmospheres)*
P_2	=	*downstream pressure (atmospheres)*

CHAPTER 2

SAMPLE PREPARATION AND BASE PARAMETER DETERMINATIONS

2.2 Test Results

CORE ANALYSIS REPORT

Client : Australasian Groundwater & Environmental Consultants Pty Ltd
Well : Watermark Project

Date : 11/11/2011
File : 0544-02

Sample Number	Depth (m)	Dir	Porosity Helium (percent)	Grain Density (g/cm^3)	Horizontal Permeability to Air (mD)	Vertical Permeability to Air (mD)	Horizontal Full Diameter Permeability to Air K_{MAX} (mD)	Horizontal Full Diameter Permeability to Air K_{90} (mD)	Remarks
WM12-1	52.05	H							failed
WM12-1V	52.15	V	7.7	2.49		<0.001			†
WM42-1	32.88	H	5.4	2.71	0.001				
WM42-1V	32.81	V	5.6	2.70		0.001			
WM42-2	67.85	H							failed
WM42-2V	67.90	V							failed
WM42-3	216.20-216.33	V	10.8	2.63		0.002	1.14	0.86	WC, congl
WM42-4	292.36	H	7.8	2.67	0.032				congl
WM42-4V	292.45	V							failed
WM42-5	318.46-318.66	V	4.0	1.78		0.002	10.4	7.8	† WC, coal/shale
WM66-1	45.70-45.87	V	15.6	2.63		95.9	635	501	WC, congl, irreg
WM66-2	116.85	H	13.4	2.56	0.18				irreg
WM66-2V	116.75	V	13.1	2.56		0.053			
WM66-3	151.49-151.69	V	5.8	2.28		0.003	1.18	0.51	† WC, intbd carb/shale/sst
WM66-4	158.98	H	12.3	2.63	0.060				
WM66-4V	158.88	V	12.4	2.63		0.036			
WM66-5	186.01	H	17.0	2.65	9.5				congl, irreg
WM66-5V	185.95	V	18.2	2.65		5.5			congl, irreg
WM66-6	225.67	H	14.5	2.63	0.046				
WM66-6V	225.75	V	14.8	2.63		0.038			
WM66-7	240.90	H	4.2	2.67	0.002				
WM66-7V	240.82	V	1.8	2.65		0.001			

Sample Number	Depth (m)	Dir	Porosity Helium (percent)	Grain Density (g/cm^3)	Horizontal Permeability to Air (mD)	Vertical Permeability to Air (mD)	Horizontal Full Diameter Permeability to Air		Remarks
							K_{MAX} (mD)	K_{90} (mD)	
WM66-8	243.24-243.36	V	2.1	1.93		0.002	31.4	0.87	† WC, coal/shale, frac
WM74R-1	42.30	H	13.0	2.62	0.15				
WM74R-1V	42.40	V	13.0	2.77		0.029			
WM74R-2	86.74	H	13.3	2.58	0.12				†
WM74R-2V	86.50	V							failed
WM74R-3	103.78	H	19.9	2.64	973				crs gr, vugs, irreg
WM74R-3V	103.68	V	17.8	2.64		114			crs gr, vugs, irreg
WM74R-4	105.40-105.50	V	7.2	1.45		0.29	3.86	1.05	† WC, coal
WM74R-5	104.30	H	12.4	2.67	0.024				
WM74R-5V	140.15	V	12.5	2.66		0.016			
WM74R-6	164.49	H	0.8	2.72	0.002				
WM74R-6V	164.44	V	0.5	2.70		0.001			
WM239-1	14.03	H	11.1	2.61	0.054				
WM239-1V	14.21	V	12.0	2.62		0.026			
WM255-1	69.00-69.15	V	7.4	2.62		0.001	2.88	2.48	† WC, silt
WM255-2	153.08	H	17.9	2.63	0.12				
WM255-2V	153.16	V	17.2	2.62		0.10			
WM258-1	40.84-40.99	V	6.6	1.63		0.10	7.8	5.6	† WC, coal/shale
WM291-1	67.40-67.60	V	12.1	2.66		0.23	7.0	3.61	WC, congl, vugs
WM291-2	72.95	H	21.4	2.63	24.9				S.P, irreg
WM291-2V	73.05	V							failed
WM291-3	96.18	H	13.9	2.75	0.15				
WM291-3V	96.28	V	15.2	2.72		0.13			
WM291-4	99.38	H	17.3	2.64	4.40				congl
WM291-4V	99.31	V	17.2	2.64		2.90			congl
WM291-5	101.30-101.45	V	19.7	2.64		3.17	24.0	23.5	WC, congl
WM291-6	103.03	H	13.6	2.67	0.063				
WM291-6V	102.92	V	13.3	2.68		0.030			

Sample Number	Depth (m)	Dir	Porosity Helium (percent)	Grain Density (g/cm^3)	Horizontal Permeability to Air (mD)	Vertical Permeability to Air (mD)	Horizontal Full Diameter Permeability to Air K_{MAX} (mD)	Horizontal Full Diameter Permeability to Air K_{90} (mD)	Remarks
WM291-7	105.15-105.30	V	7.7	1.64		0.85	9.6	5.9	† WC, coal/shale
WM291-8	131.86	H	13.9	2.65	0.32				congl
WM291-8V	131.75	V	13.7	2.64		0.40			congl, irreg
WM291-9	141.22	H	7.6	2.59	2.15				† slty
WM291-9V	141.23	V	7.6	2.59		0.001			† slty
WM291-10	143.10	H	16.5	2.66	0.95				
WM291-10V	143.18	V	16.8	2.66		1.21			

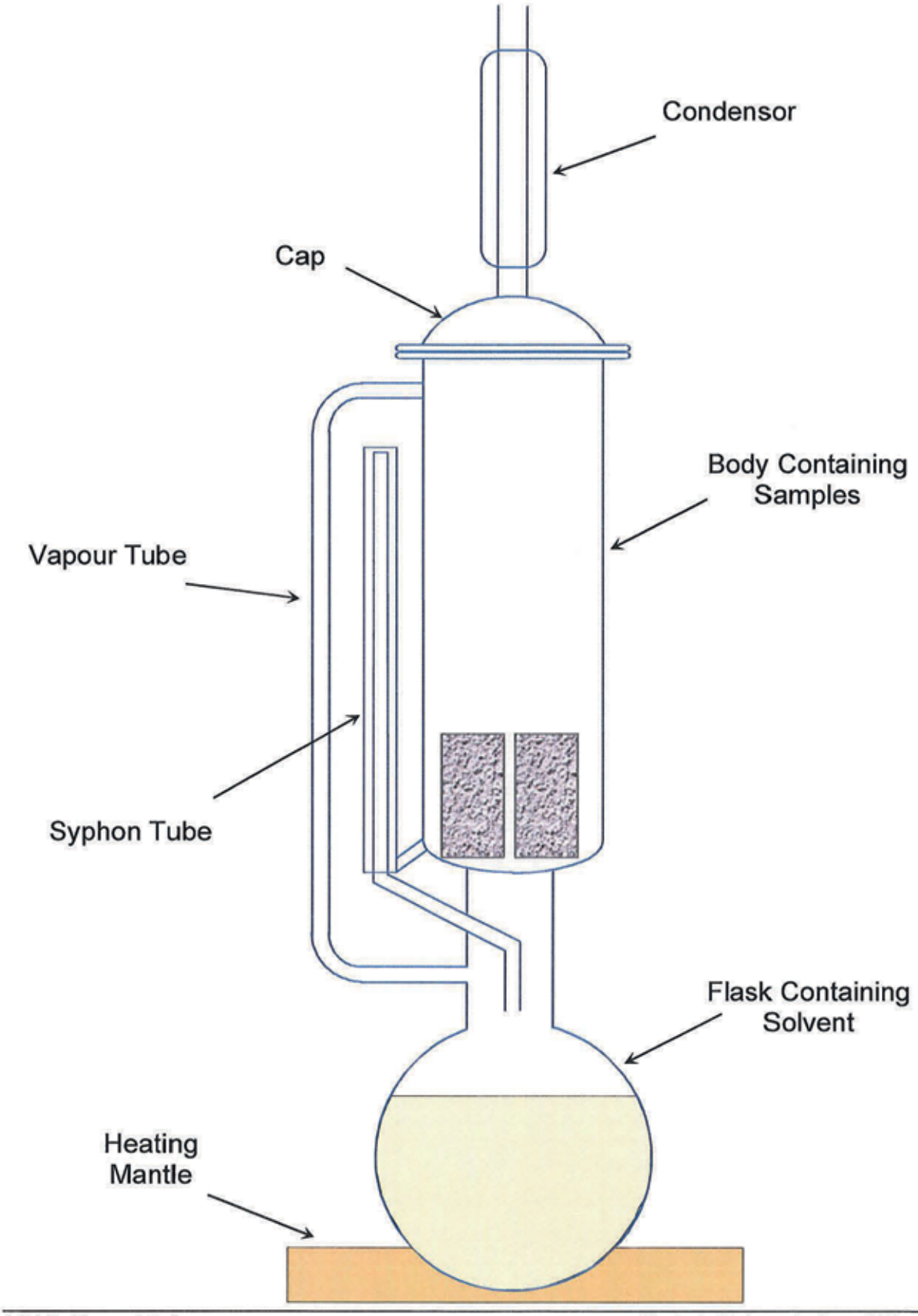
†	Samples not cleaned as contain carbonaceous material possibility of sample damage
congl	Conglomerate
S.P.	Short Plug (Length < Diameter)
WC	Whole Core
irreg	Irregual sampels surface

APPENDIX I

EQUIPMENT SCHMATICS

SOXHLET CLEANING APPARATUS

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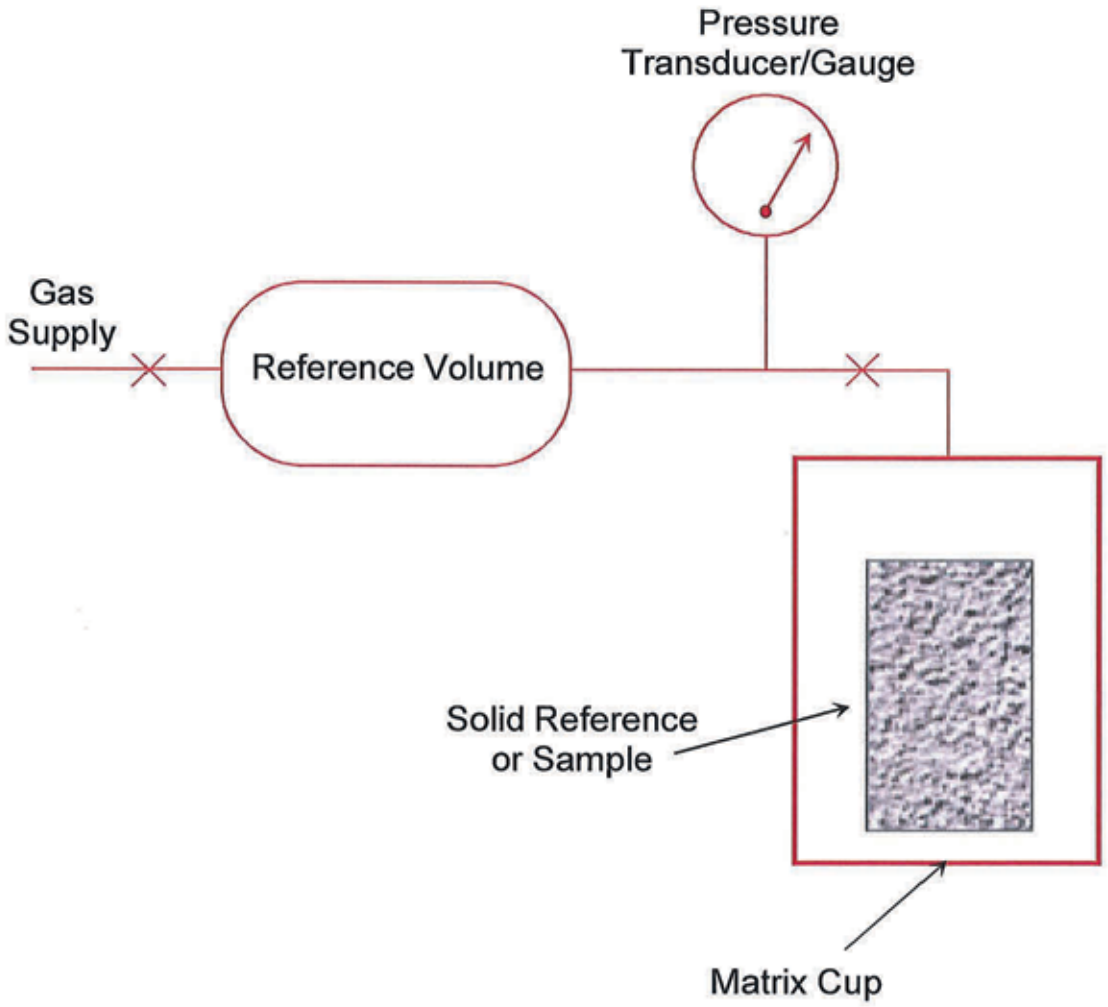


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POROSIMETER SCHEMATIC

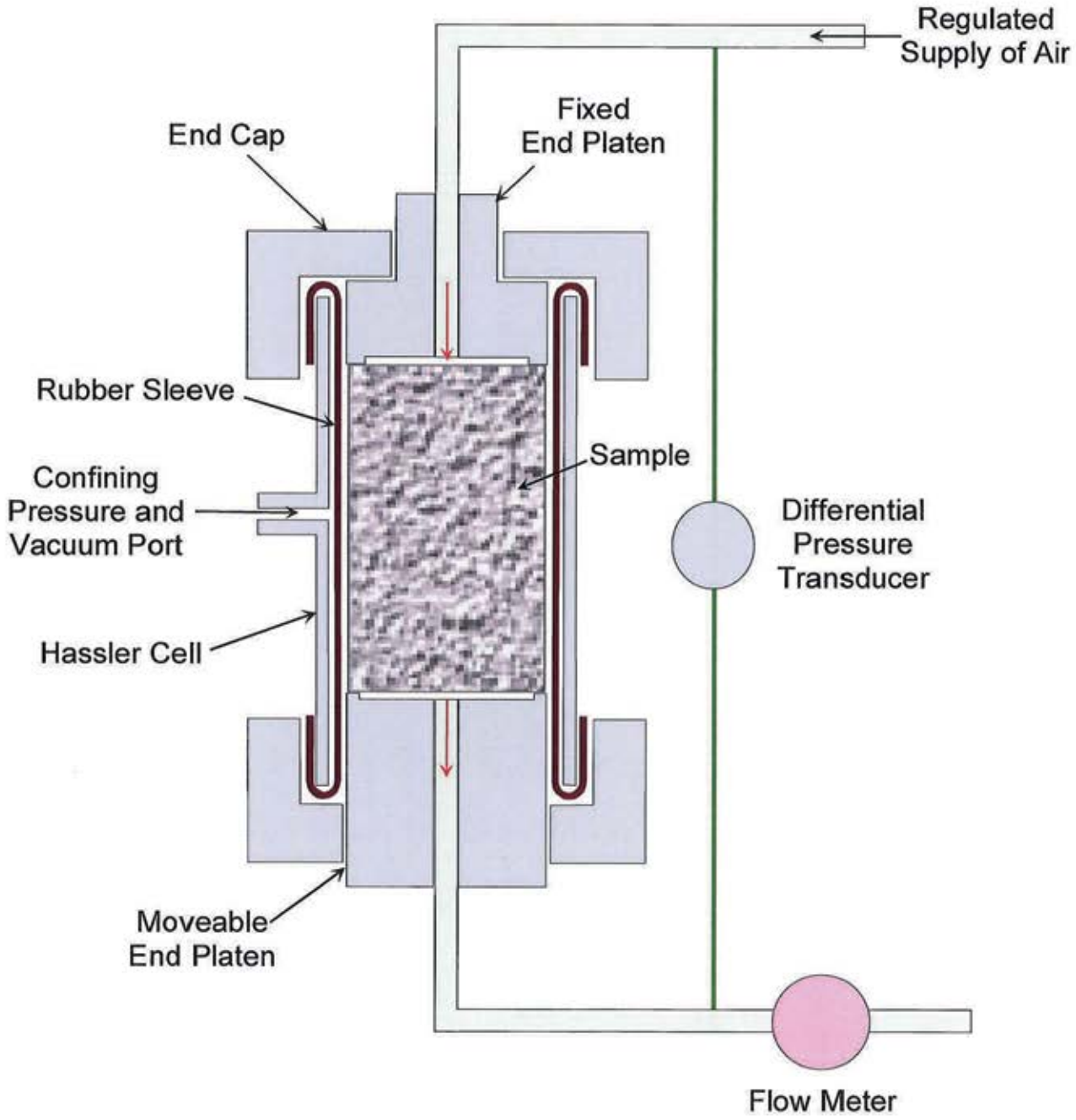
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P1.V1 (reference) = P2.V2 (sample)

GAS PERMEAMETER SCHEMATIC (Hassler)

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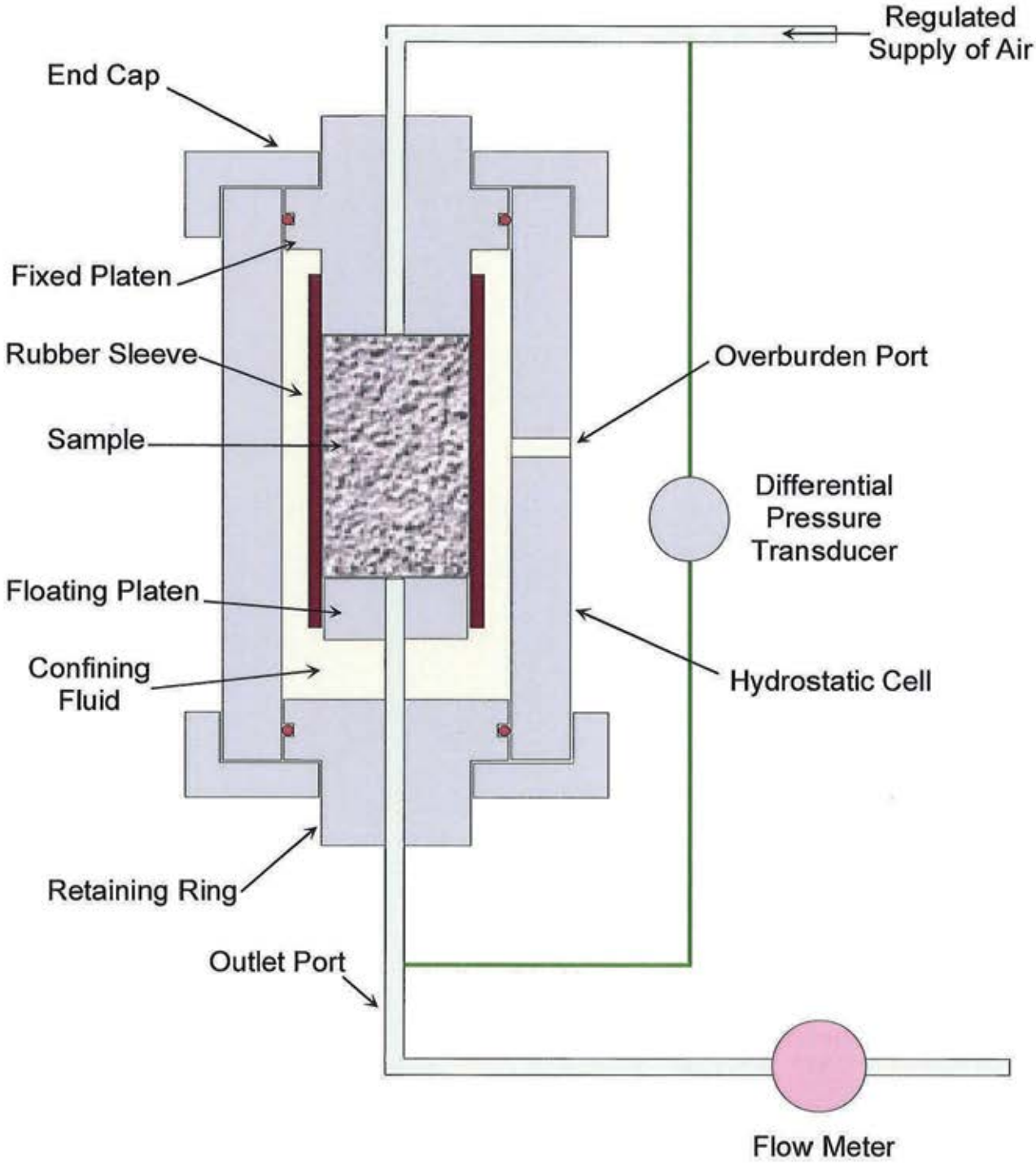


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GAS PERMEAMETER SCHEMATIC (Hydrostatic)

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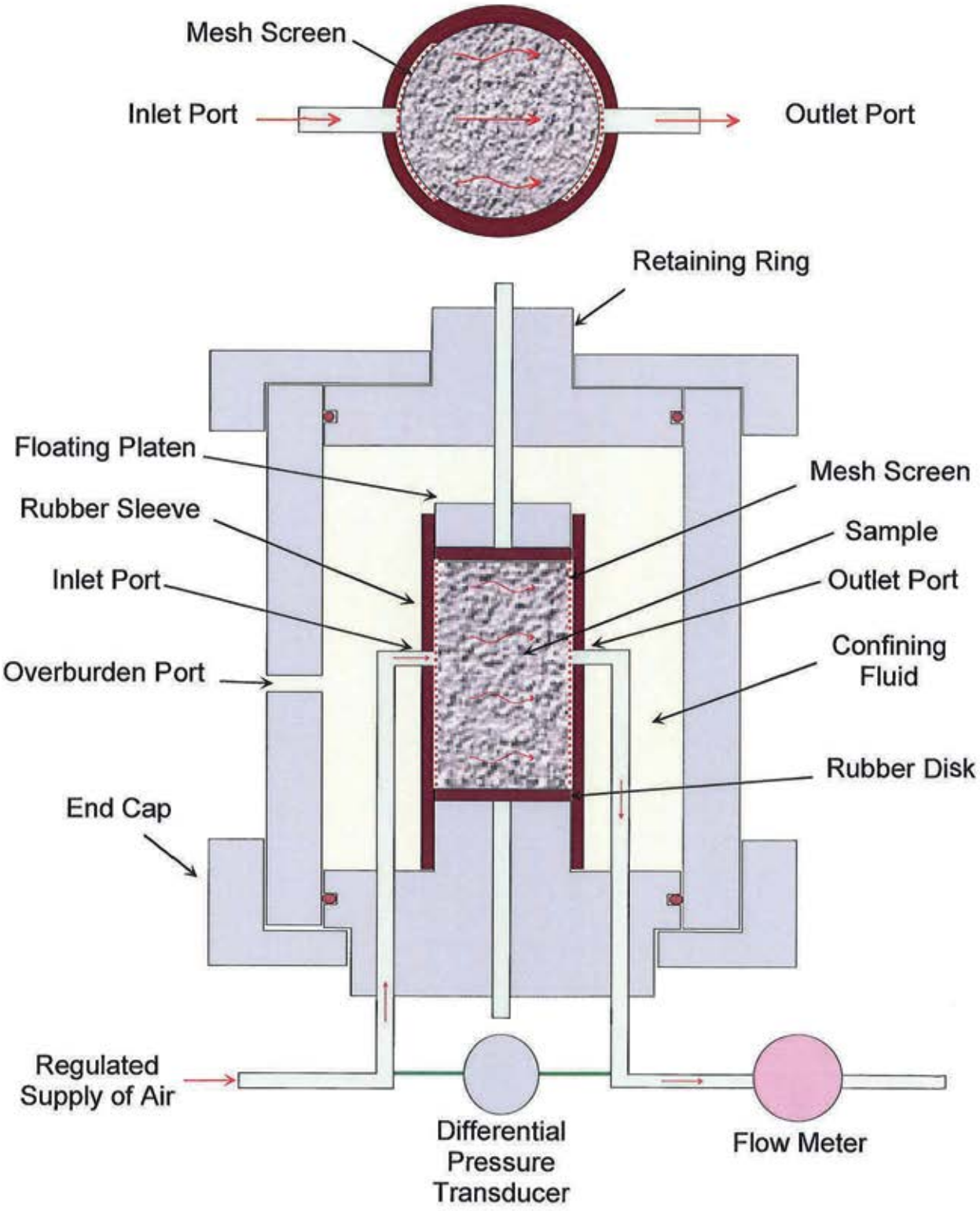


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GAS PERMEAMETER SCHEMATIC (Horizontal)

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APPENDIX 3

Radiocarbon Age Dating – GNS Science

8 June 2012

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Attention: Melissa Walker

Dear Melissa

Tritium and radiocarbon results for Watermark isotope samples

This report presents the analytical results of tritium and radiocarbon analyses for the Watermark isotope samples (Table 1). Radiocarbon ages have also been calculated. It appears that complex mixing and exchange processes take place in this groundwater system, with the presence of modern tritium in conjunction with low radiocarbon concentrations.

Radiocarbon age determination

As water passes through the unsaturated zone it gains dissolved inorganic carbon (DIC) from plant respiration and through the oxidation of soil organic matter. This DIC has a distinct isotopic signature which is characteristic of modern organic matter ($\delta^{13}C \approx -25‰$, 100 %mC; Mook & de Vries, 2001). In addition, the dissolution of fossil carbonates present in the soil or within the aquifer matrix dilutes the concentration of ^{14}C, as these fossil carbonates typically contain no modern carbon. The ^{13}C isotopic signature also moves away from that of plant material towards the signature of marine carbonates (around 0‰). The relationship between ^{13}C and ^{14}C concentrations for DIC in groundwater is illustrated in Figure 1.

Radiocarbon ages are calculated using the equation:

$$t = (1/\lambda) \ln (q.a_0 / a_t)$$

where λ is the ^{14}C decay factor ($1/\lambda = 8267$ yr), a_0 is the initial ^{14}C activity, a_t is the ^{14}C activity after time t and q is a parameter that defines how much the radiocarbon signal has been diluted by sources of "dead" (i.e radiocarbon free) carbon. (Stewart et al., 2004). For this report q was determined from $\delta^{13}C$ values of the DIC using a simple isotopic mixing model and assuming an initial ^{14}C input of 100 %mC.

Table 1 Analytical results and calculated radiocarbon ages

Site ID	Sampling Date	Tritium [1] (TU)	$\delta^{13}C$ [2] (‰)	^{14}C [3] (%mC)	TDIC [4] (mmol.kg^{-1})	^{14}C age [5] (years)	^{14}C age range (years)
WM0009B	18/09/2011	0.437 ± 0.016	-12.4	76.70	17.3	<100	-
WM0009R	18/09/2011	0.015 ± 0.012	-13.3	6.69	6.1	17141	15906 – 18259
WM0012	22/09/2011	0.037 ± 0.012	-10.7	0.67	8.2	34309	32937 – 35600
WM0012A	22/09/2011	0.220 ± 0.014	-11.0	76.06	14.9	<100	-
WM0067A	02/10/2011	0.092 ± 0.012	-9.5	49.20	5.9	<100	-
WM0233	03/10/2011	0.047 ± 0.012	-11.7	8.67	13.2	13938	12705 – 15055
WM0274A	03/10/2011	0.057 ± 0.013	Insufficient carbon			-	-
WM0290	04/10/2011	0.107 ± 0.015	-0.1	0.52	83.2	<100	-
WM0291	21/09/2011	0.099 ± 0.013	-7.6	0.75	23.9	30596	29248 - 31855
WM0291A	21/09/2011	0.264 ± 0.015	-7.3	1.50	22.5	24528	23265 - 25679
WM0291B	21/09/2011	0.030 ± 0.012	-6.1	0.07	30	48135	43512 - 58551
WM0421	21/09/2011	0.038 ± 0.015	-9.5	2.28	11.2	23241	21996 - 24371
WM0426A	05/10/2011	0.084 ± 0.013	-8.7	20.28	10.6	4465	3233 - 5580
WM0426	05/10/2011	0.081 ± 0.013	-8.8	1.94	6.76	23964	22714 - 25100
WM0427A	22/09/2011	0.000 ± 0.012	-9.4	8.26	10	12530	11297 - 13646
WM0427	22/09/2011	0.109 ± 0.013	-9.6	0.82	14.3	31804	30474 - 33039
WM0432A	22/09/2011	0.038 ± 0.013	-8.2	41.09	3.8	<100	-
WM0432	22/09/2011	0.012 ± 0.012	-11.2	14.81	7.5	9148	7916 - 10263
WM0091	01/11/2011	0.282 ± 0.016	-9.8	14.73	12.5	8090	6857 - 9205
WM0428A	23/10/2011	0.038 ± 0.013	-9.6	65.03	7.1	<100	-
WM0091B	01/11/2011	-0.016 ± 0.011	-9.8	0.98	8.5	30470	29169 - 31669
WM0055	22/10/2011	0.065 ± 0.013	-12.4	23.08	18.8	6325	5092 - 7440
WM0093A	31/10/2011	-0.019 ± 0.012	-9.9	23.42	7.9	4342	3109 - 5457
WM0036C	31/10/2011	0.037 ± 0.013	-16.1	10.28	7	15168	13935 - 16284
WM0157	30/10/2011	0.297 ± 0.016	-12.8	32.77	10.6	3689	2457 - 4804
WM0091A	02/11/2011	0.006 ± 0.012	-9.8	12.70	9.3	9320	8087 - 10436
GW040832(D)	05/12/2011	0.675 ± 0.020	-11.6	103.96	13.1	<100	-
GW036203(S)	06/12/2011	-0.013 ± 0.012	-10.9	18.52	5.4	7078	5845 - 8193
WM0062	23/11/2011	0.071 ± 0.013	-13.6	28.49	9	5347	4115 - 6462
DUPE01	23/11/2011	0.067 ± 0.016	-12.1	23.18	9	6084	4852 - 7199
WM0011	07/11/2011	0.151 ± 0.014	-12.3	52.03	2.3	<100	-
GW036305(D)	11/12/2011	0.005 ± 0.012	-13.5	34.03	5.3	3816	2584 - 4931
WM0424	19/11/2011	0.017 ± 0.012	-10.0	0.51	10.2	36033	34571 - 37447
GW036203(D)	06/12/2011	0.017 ± 0.012	-7.7	9.39	8.7	9822	8589 - 10938
GW030060(S)	05/12/2011	0.130 ± 0.013	-12.9	35.67	7.3	3052	1820 - 4166
GW030060(D)	05/12/2011	-0.009 ± 0.012	-12.0	23.52	5.8	5899	4667 - 7013
GW030176(D)	11/12/2011	0.033 ± 0.013	-3.9	0.06	42.8	45675	40515 - 60529
WM0021	11/12/2011	0.020 ± 0.013	-13.3	14.69	12	10638	9406 - 11753
GW040832(S)	0512/2011	0.865 ± 0.022	-11.3	106.63	13.6	<100	-

[1] Tritium concentrations are expressed as $^{3}H/^{1}H$ ratios where 1 tritium unit (TU) signifies a ratio of 1×10^{-18}.

[2] ^{13}C concentrations are expressed as δ values in ‰ with respect to VPDB (Vienna PDB, the international standard).

[3] Concentrations of ^{14}C in percent modern carbon (relative to the NBS oxalic acid standard corrected for decay since 1950; Stuiver & Polach, 1977) as reported by the Rafter radiocarbon laboratory have been de-normalised and corrected to the year of sampling for the groundwater age calculation and are denoted as %mC (Mook & de Vries, 2001).

[4] TDIC = total dissolved inorganic carbon expressed in mmol.kg^{-1}.

[5] ^{14}C age is in uncalibrated radiocarbon years.

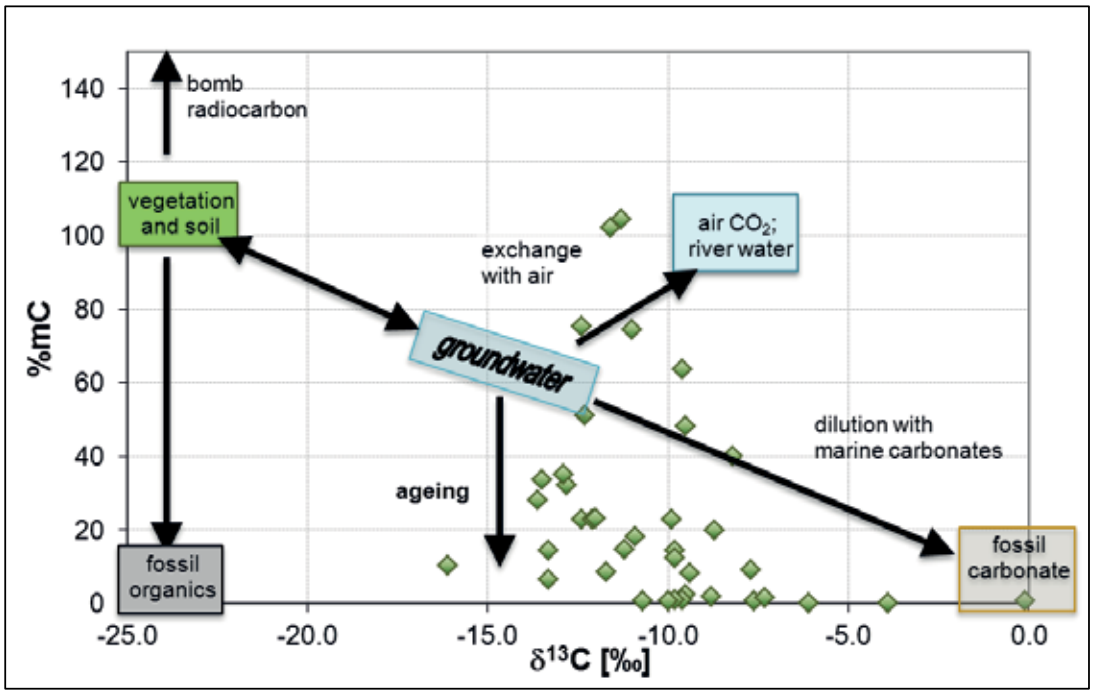


Figure 1 The relationship between $^{13/12}C$ ratios and ^{14}C concentrations for dissolved inorganic carbon in groundwater (After Mook & de Vries, 2001).

Major assumptions which may affect the calculated dates are:

(1) that the ^{14}C input to the system at the time of recharge was the same as modern input (i.e. ~ 100 %mC). Comparison to ^{14}C calibration curves indicates that actual recharge ages may be slightly older due to higher radiocarbon concentrations in the past; the offset is approximately +3000 years for an uncalibrated radiocarbon age of 14000 years and +4000 years for an uncalibrated radiocarbon age around 33000 years (Reimer et al., 2009).

(2) the isotopic signature of bicarbonate sourced from the decay of organic material is of modern origin at the time of recharge (i.e. $\delta^{13}C \approx$ -25‰, 100 %mC). It is also possible that carbon may originate from older organic carbon present within the aquifer matrix, with low or even zero modern carbon. If some of the bicarbonate originates from older organic carbon, then the radiocarbon ages could be younger than those shown in Table 1.

(3) recharge is predominantly from land surface recharge and acquires DIC from soil CO2 and decay of modern organic material with $\delta^{13}C \approx$ -25‰. If there is significant recharge from rivers, then the initial ^{13}C signature of the DIC may be different and the resulting dilution factor *q* would vary.

To illustrate how these assumptions can affect the radiocarbon ages, an age range has been calculated by varying the calculation parameters (a_0, q) each by ±10%. These age ranges are indicative only and should not be considered as the absolute uncertainties for these calculations.

The majority of samples exhibit substantial dilution of the initial ^{14}C input by marine carbonate (Figure 2). For instance sample WM0290 which, although having a radiocarbon concentration of 0.52 %mC, has a radiocarbon age of <100 years. This is due to nearly all the DIC from this sample being derived from marine carbonates with $\delta^{13}C \approx 0$ ‰.

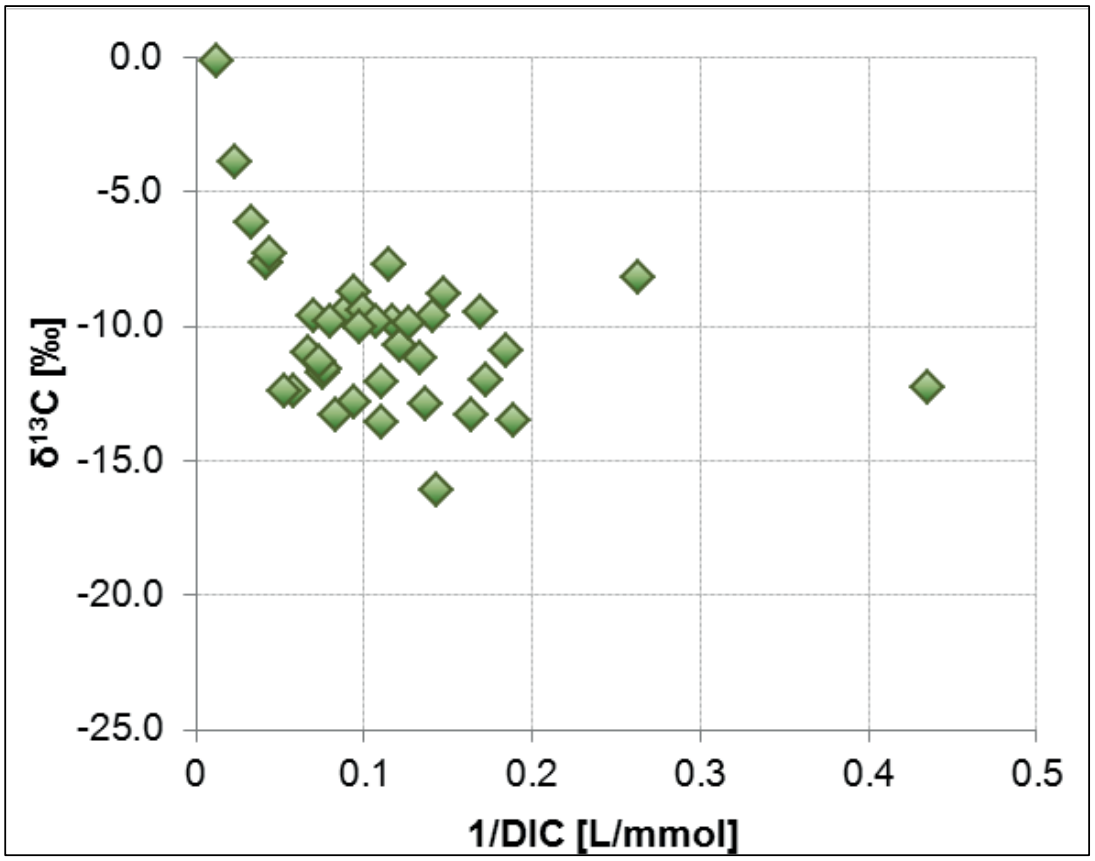


Figure 2 Plot of 1/DIC vs $\delta^{13}C$. As DIC concentrations increase (i.e. 1/DIC decreases), $\delta^{13}C$ tends towards zero (i.e. the isotopic signature of marine carbonate).

Comparison of radiocarbon to tritium concentrations.

Radiocarbon ages greater than 100 years should have tritium concentrations that are statistically indistinguishable from zero (i.e. within ± 2 x the standard error). However for the Watermark samples there are many instances where the radiocarbon age is substantially older than 100 years but there is still significant tritium present in the water. This is illustrated in Figure 3. Samples with modern radiocarbon ages (<100 years) are indicated as triangles. Samples with older radiocarbon ages (green diamonds) can be distributed into two groups, those with zero tritium (which plot between the blue vertical dashed lines) and those with significant tritium concentrations (which plot to the right of the dashed lines).

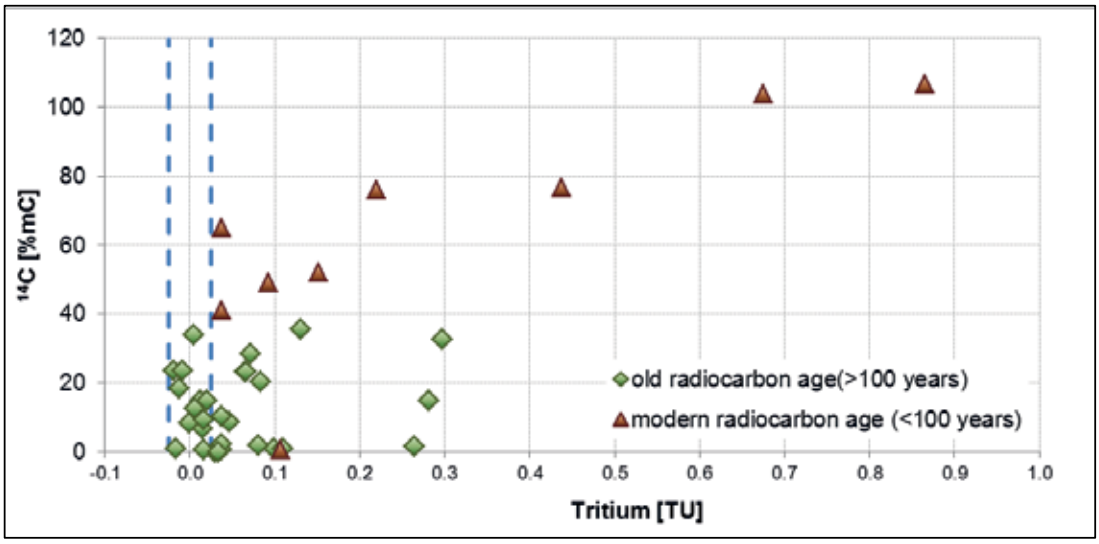


Figure 3 The relationship between ^{14}C and tritium concentrations.

The reason for the discrepancy between radiocarbon and tritium is unclear. Several possible reasons include:

(1) Inadequate bore construction leading to leakage of modern water down the bore. In some cases a substantial proportion of modern water would be necessary to achieve the observed tritium concentrations.

(2) Contribution of organic carbon which is not modern to the system (i.e. not 100 %mC). Modelling shows that in order to reconcile the radiocarbon and tritium results, the radiocarbon concentrations of the organic carbon contribution to the system would have to range from 0.3 %mC to 100 %mC.

(3) Contamination of samples with tritium, such as exposure to extraneous tritium while sampling due to the sampler wearing a luminous watch.

It is not possible with the present data to exclude any one of these possibilities. If the presence of young water is a concern, it is recommended that further monitoring of tritium concentrations is undertaken at appropriate intervals to establish the proportion of young water present.

Yours sincerely

Rob van der Raaij
Scientist, Isotope Hydrology

Uwe Morgenstern
(Reviewer)

References

Mook. W.G., de Vries, J.J. 2001. Ch 8. Natural abundance of radioactive isotopes of C and H. *Environmental Isotopes in the Hydrological Cycle – Principles and Applications. Volume I: Introduction: Theory, Methods, Review*. Mook, W.G. (Ed). UNESCO/IAEA series 1998-2001. p125-142. Available online at : http://www.iaea.org/programmes/ripc/ih/volumes/volumes.htm

Reimer, P.J., et al. 2009. Intcal09 and marine09 radiocarbon age calibration curves,0–50,000 years cal BP. *Radiocarbon,* 51 (4), 1111–1150.

Stewart, M.K., Thomas, J.T., Norris, M. Trompetter, V. 2004. Paleogroundwater in the Moutere Gravel near Nelson, New Zealand. *Radiocarbon.*, 46 (2), 517-529.

Stuiver, M., Polach, H.A. 1977. Discussion: Reporting of ^{14}C data. *Radiocarbon*. 19 (3), 355-363.

APPENDIX 4

Monitoring Bore Hydrographs

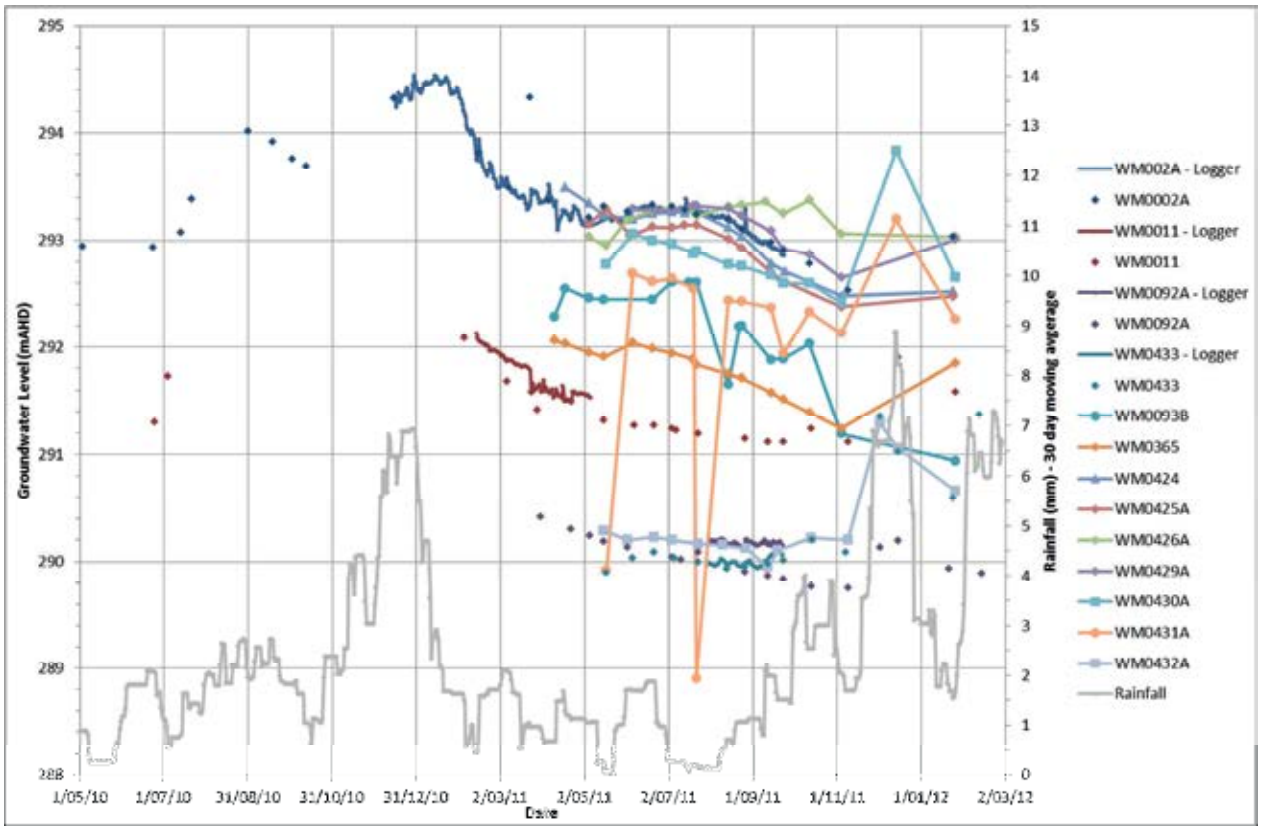


Figure A4-1 – Hydrograph - Narrabri Formation (RL 288-295 mAHD)

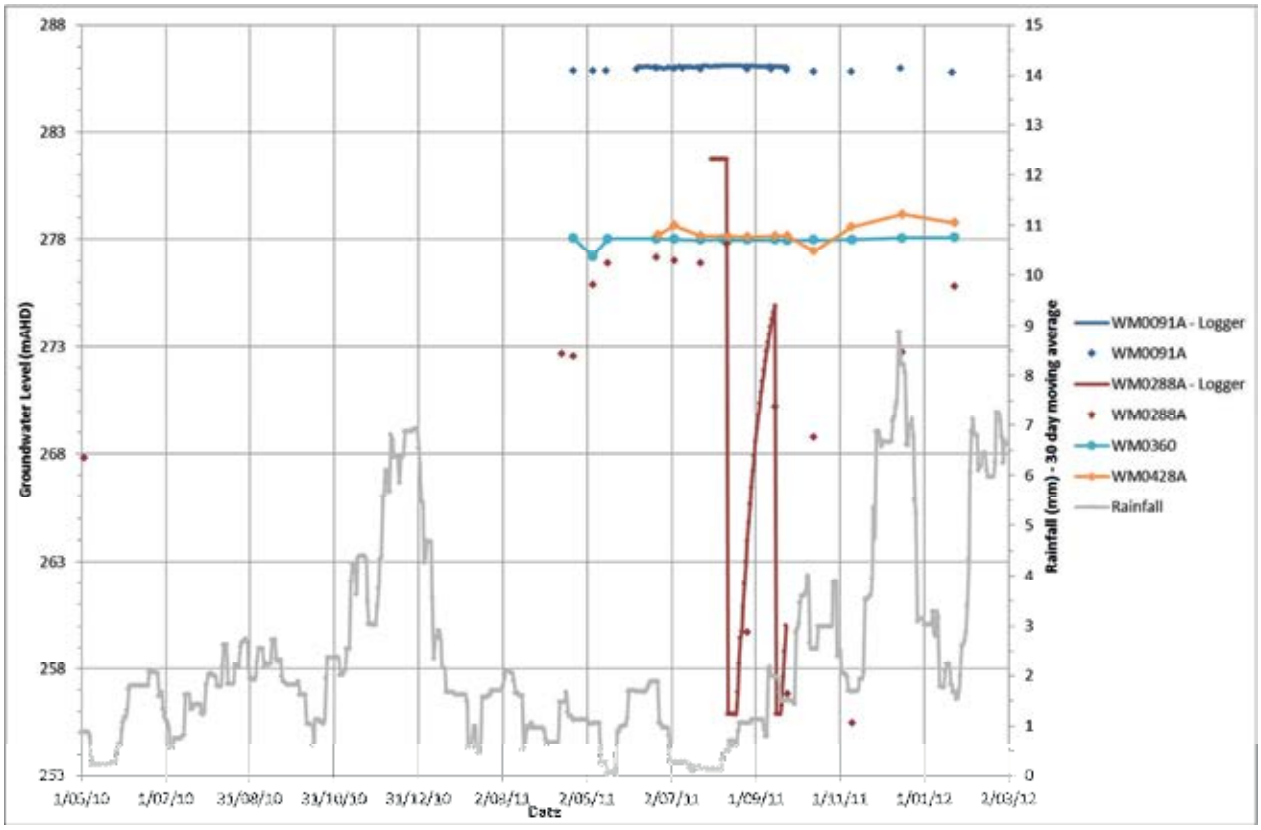


Figure A4-2 – Hydrograph - Narrabri Formation (RL 253-288 mAHD)

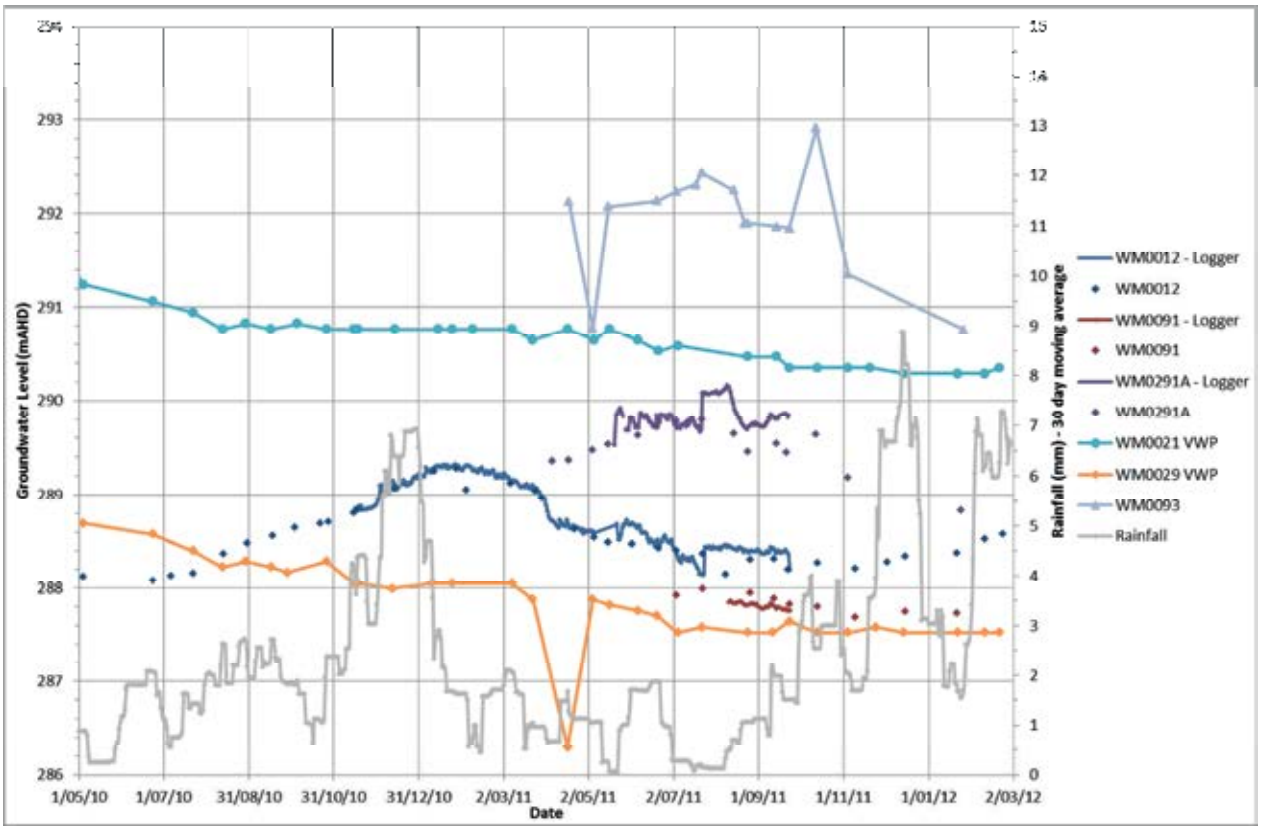


Figure A4-3 – Hydrograph – Hoskissons Seam (RL 286-294 mAHD)

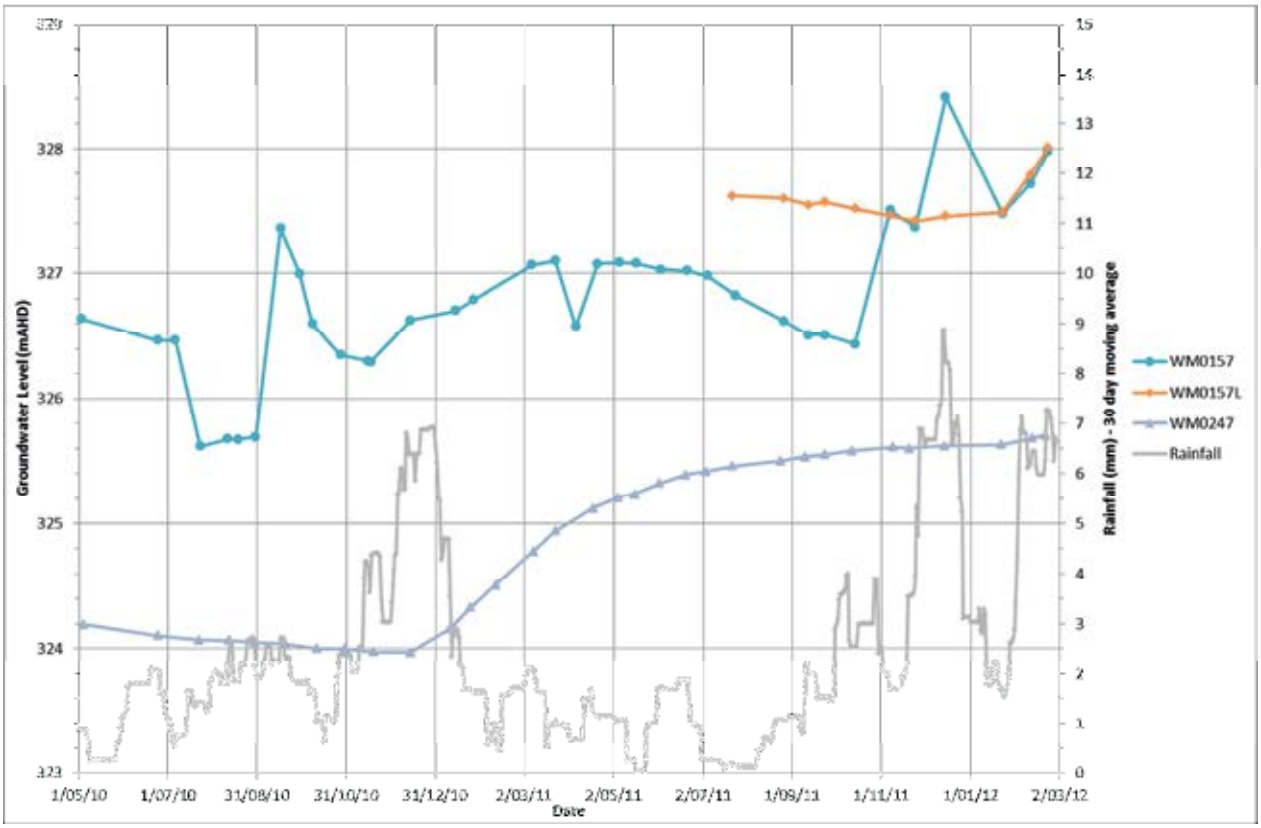


Figure A4-4 – Hydrograph – Hoskissons Seam (RL 323-329 mAHD)

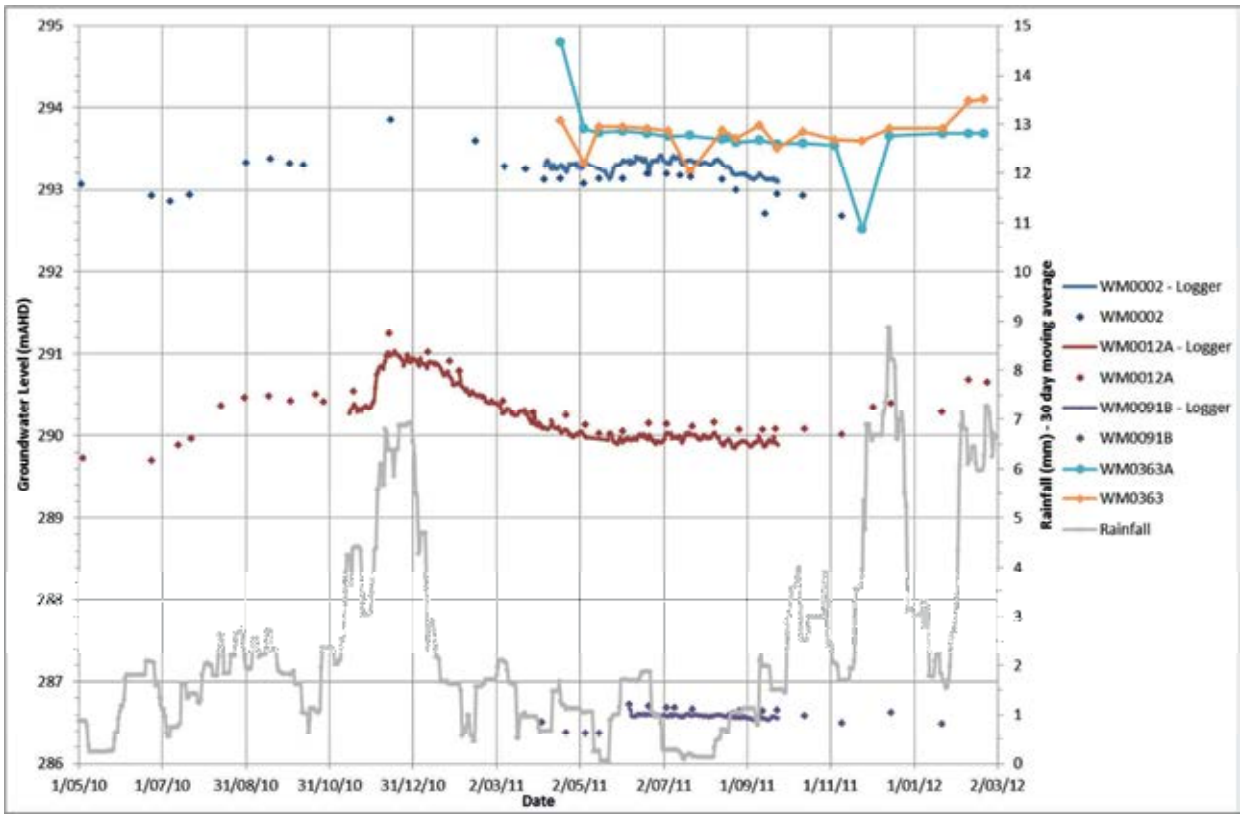


Figure A4-5 – Hydrograph – Benelabri Formation

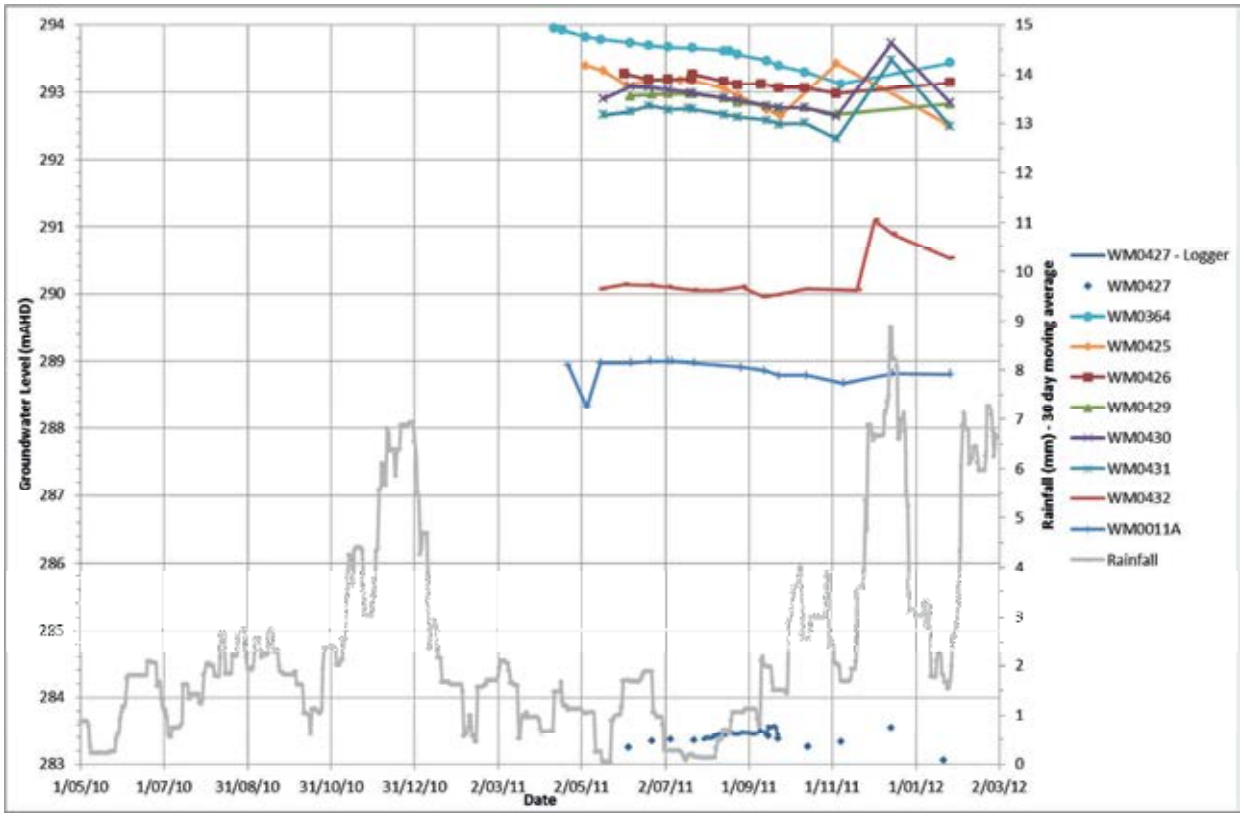


Figure A4-6 – Hydrograph – Weathered Permian

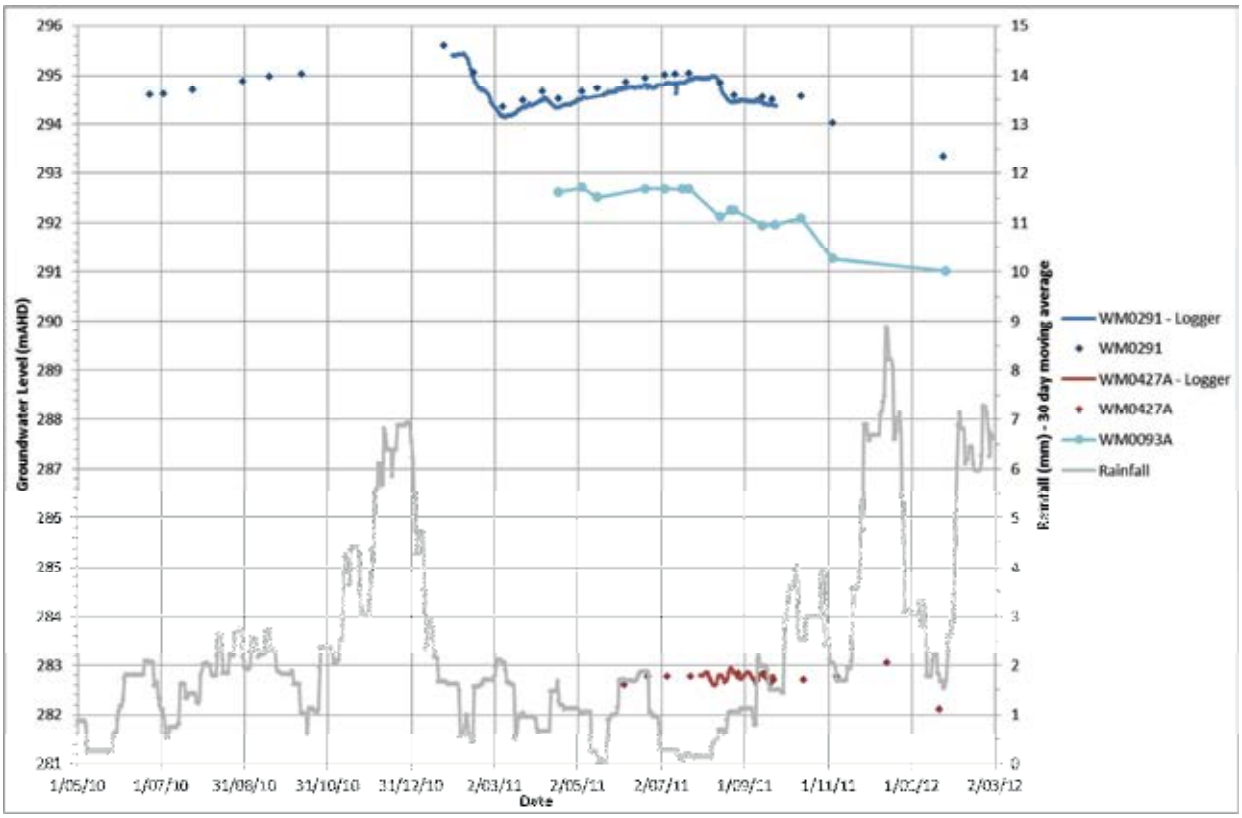


Figure A4-7 – Hydrograph – Gunnedah Formation (RL 281-296 mAHD)

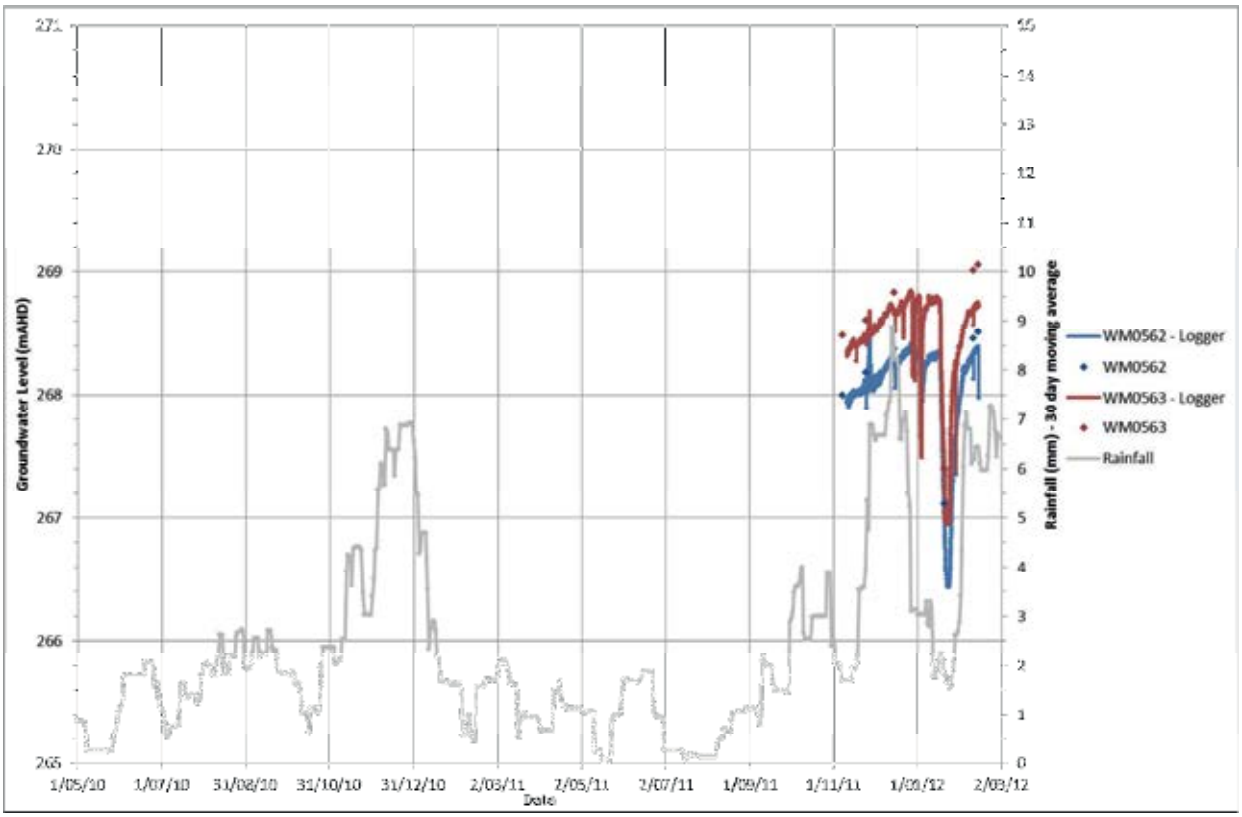


Figure A4-8 – Hydrograph – Gunnedah Formation (RL 265-271 mAHD)

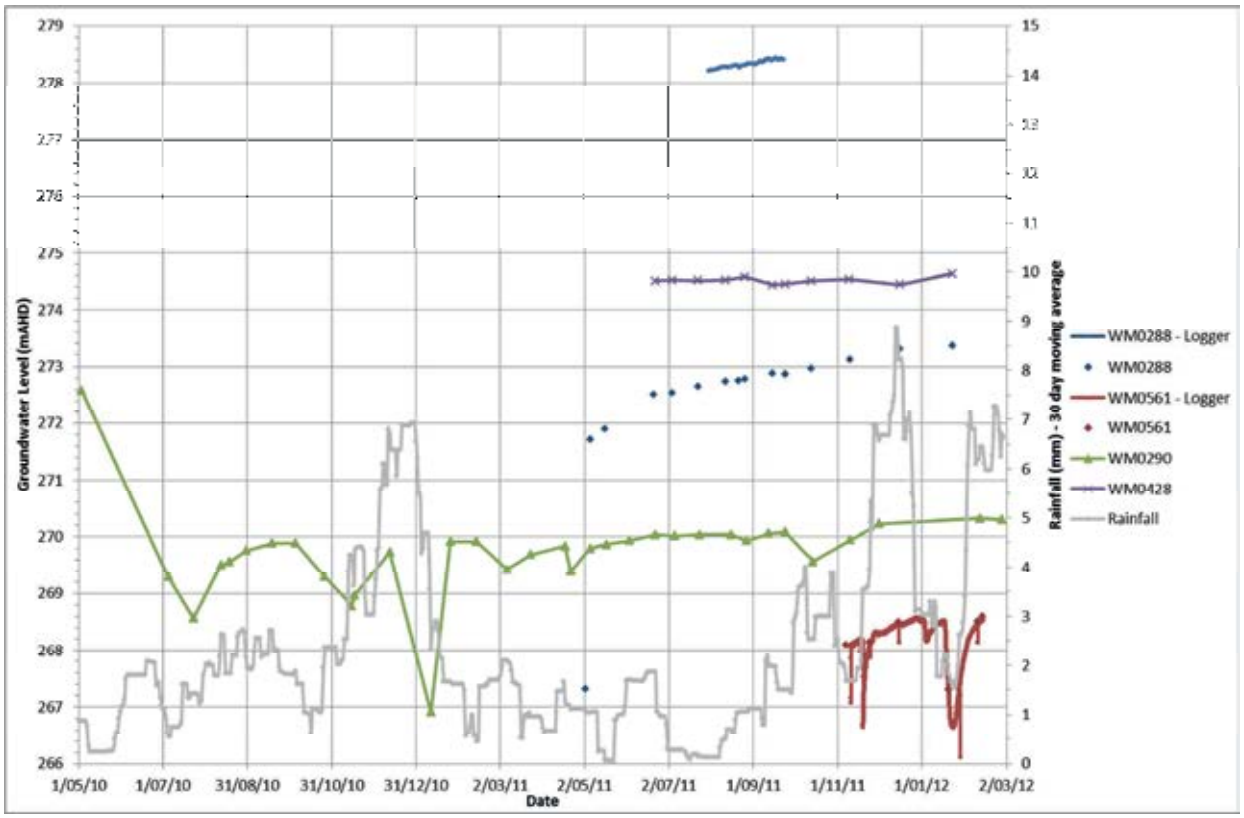


Figure A4-9 – Hydrograph – Watermark Formation (RL 266-279 mAHD)

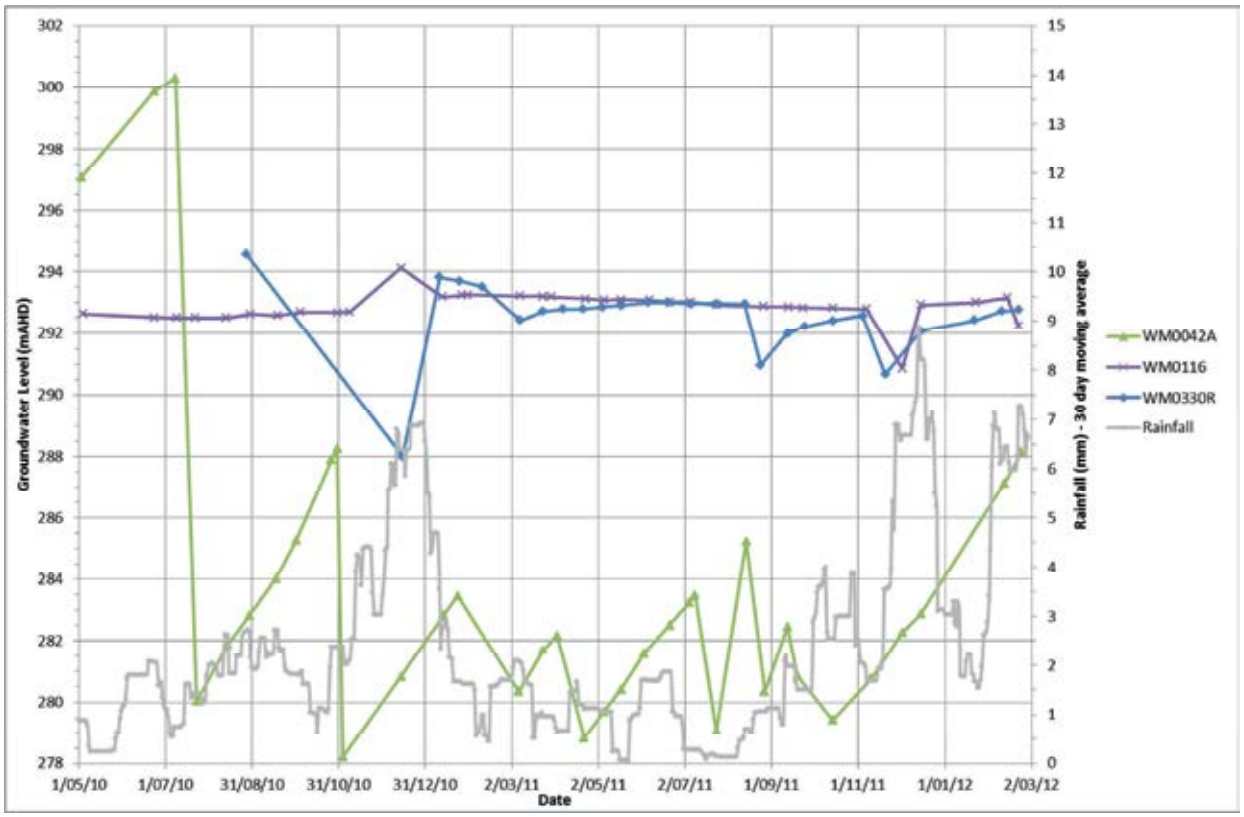


Figure A4-10 – Hydrograph – Watermark Formation (RL 278-302 mAHD)

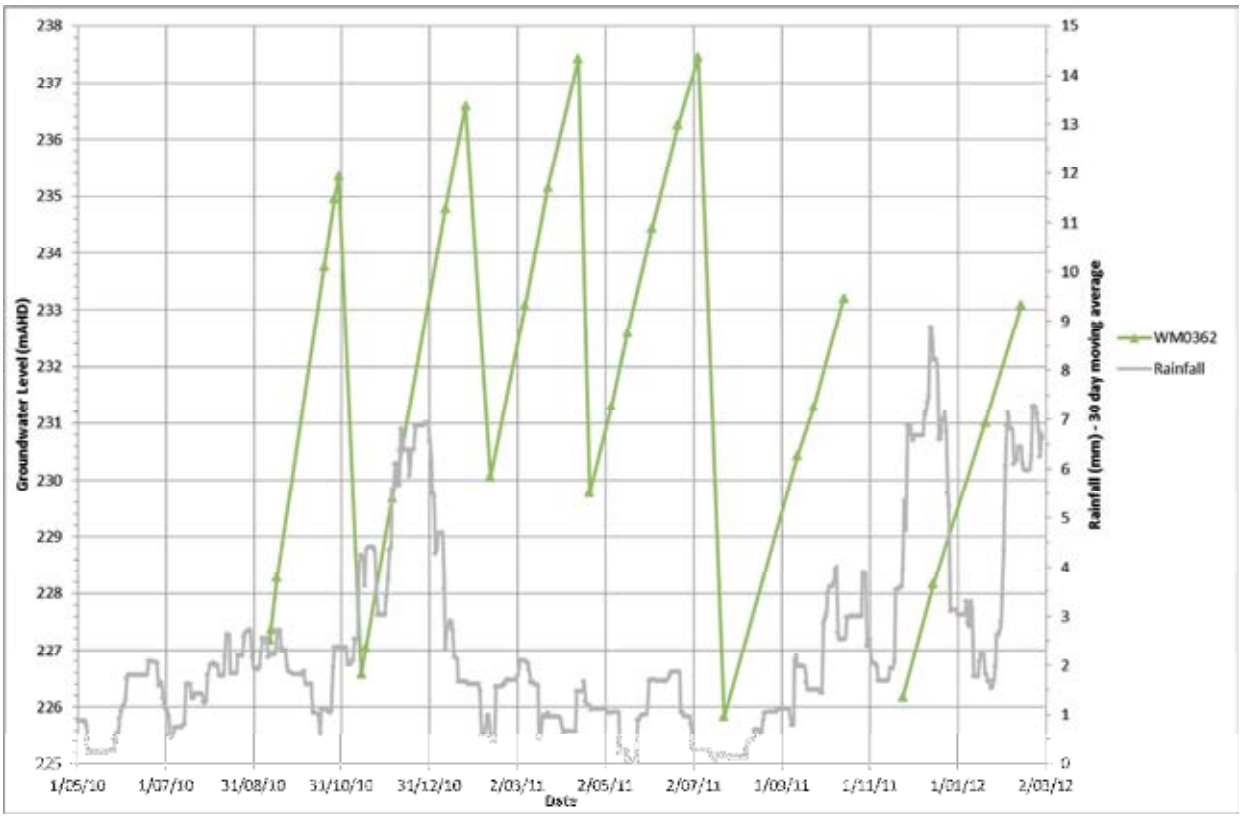


Figure A4-11 – Hydrograph – Watermark Formation (RL 225-238 mAHD)

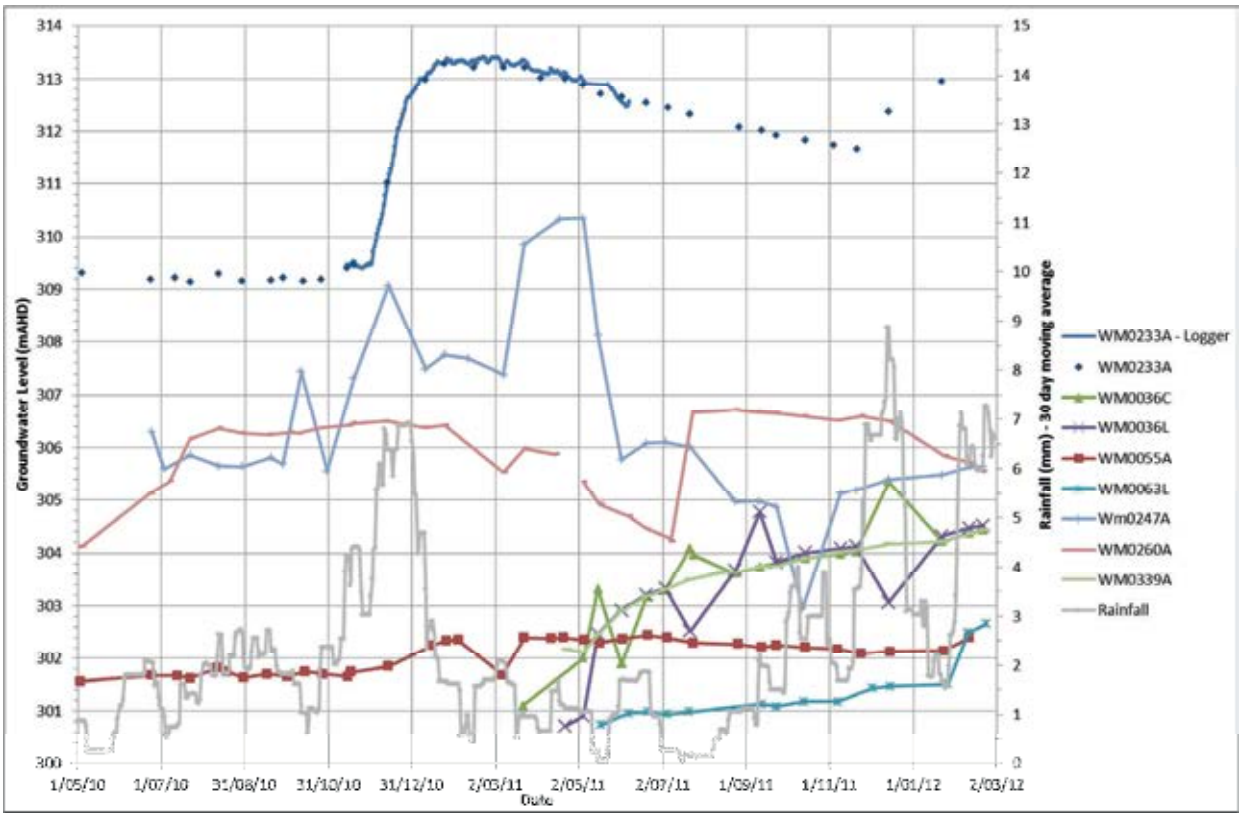


Figure A4-12 – Hydrograph – Interburden (RL 300-314 mAHD)

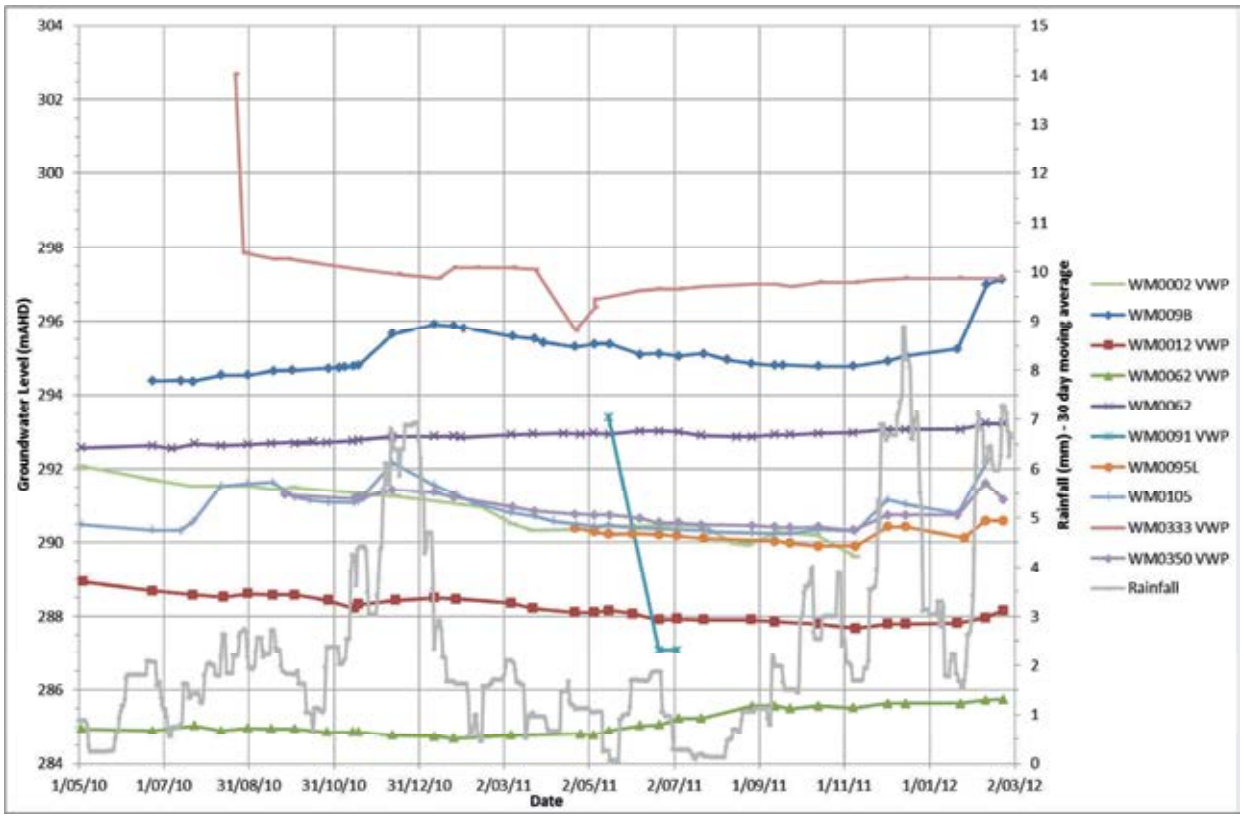


Figure A4-13 – Hydrograph – Interburden (RL 284-304 mAHD)

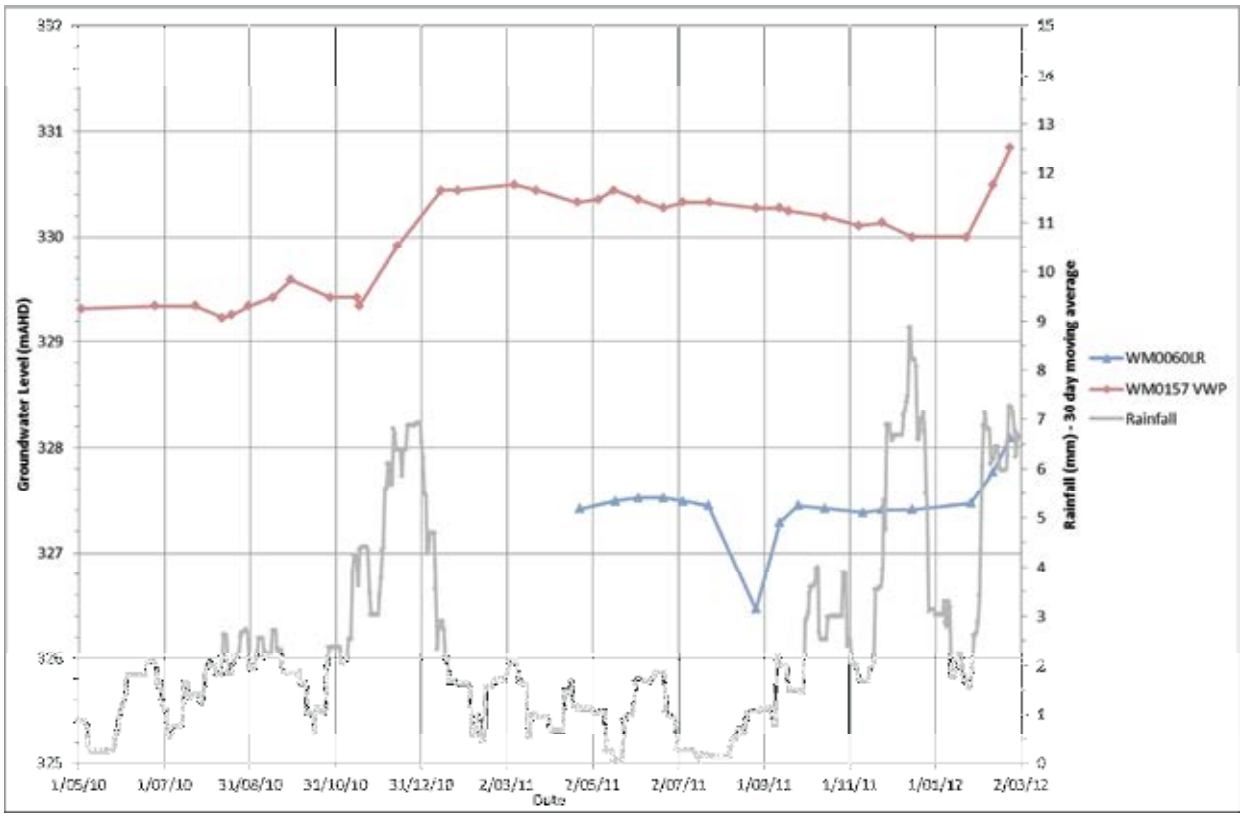


Figure A4-14 – Hydrograph – Interburden (RL 325-332 mAHD)

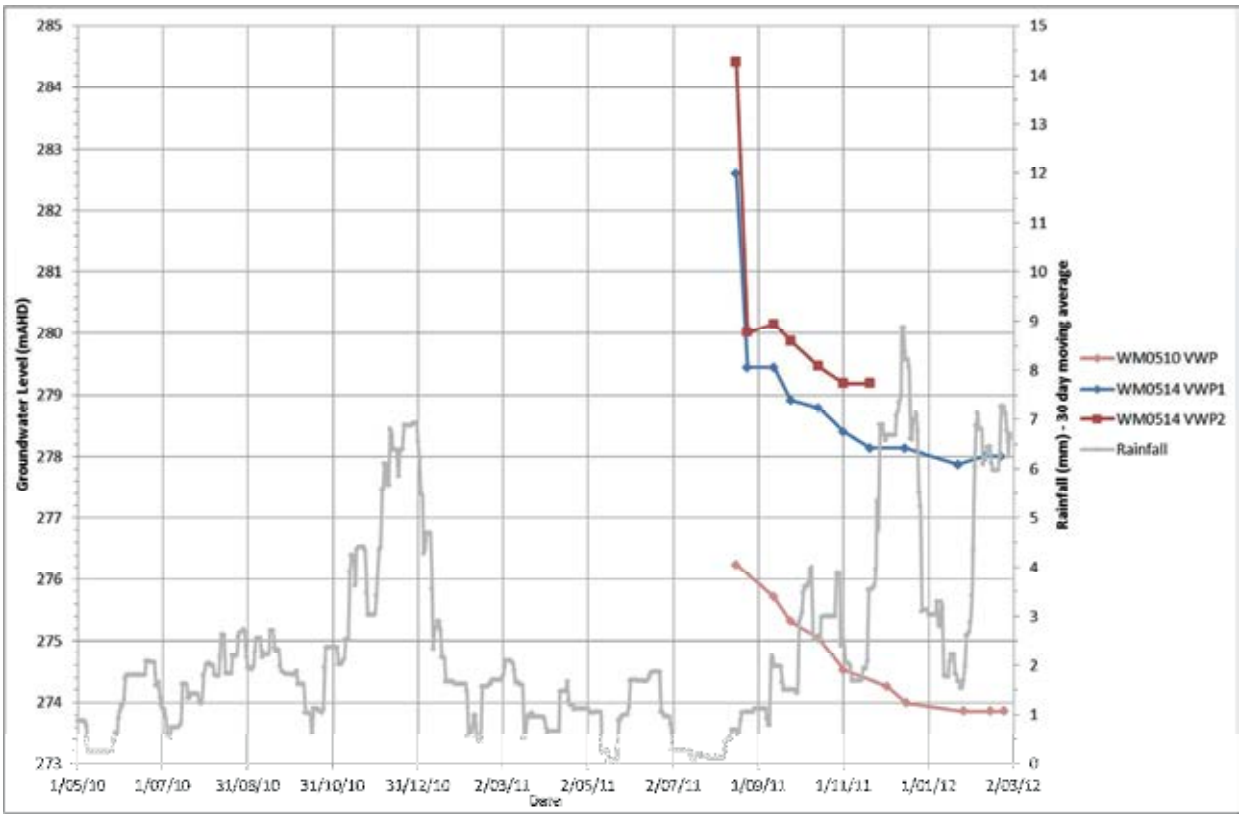


Figure A4-15 – Hydrograph – Maules Creek Formation (RL 273-285 mAHD)

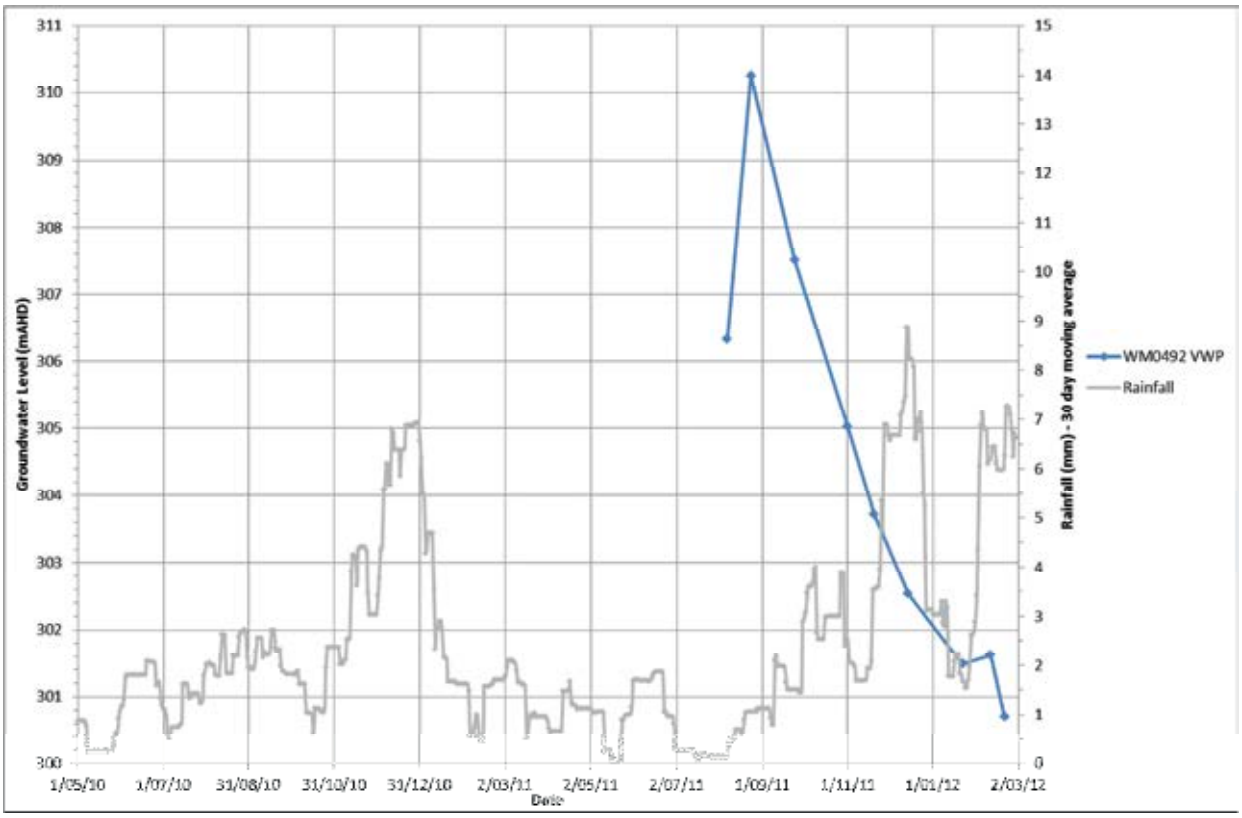


Figure A4-16 – Hydrograph – Maules Creek Formation (RL 300-311 mAHD)

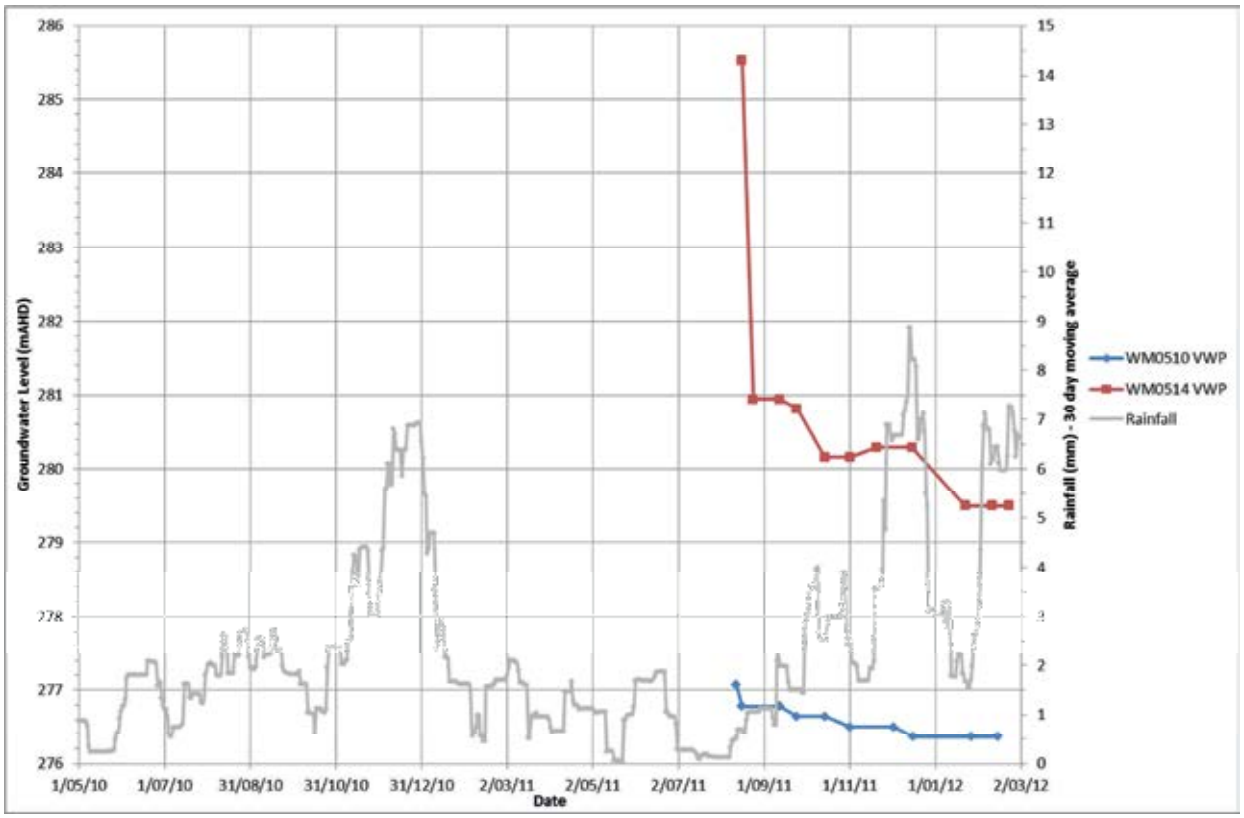


Figure A4-17 – Hydrograph – Porcupine Formation (RL 276-286 mAHD)

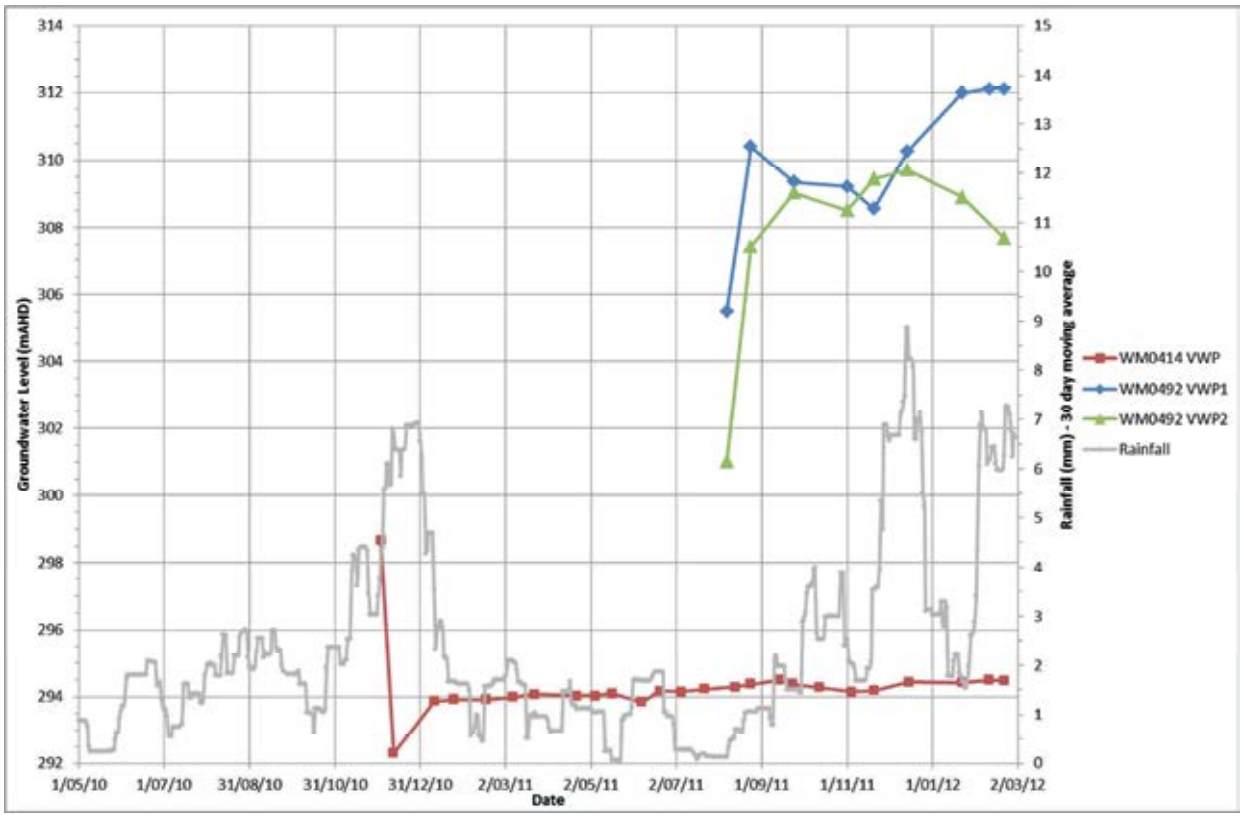


Figure A4-18 – Hydrograph – Porcupine Formation (RL 292-314 mAHD)

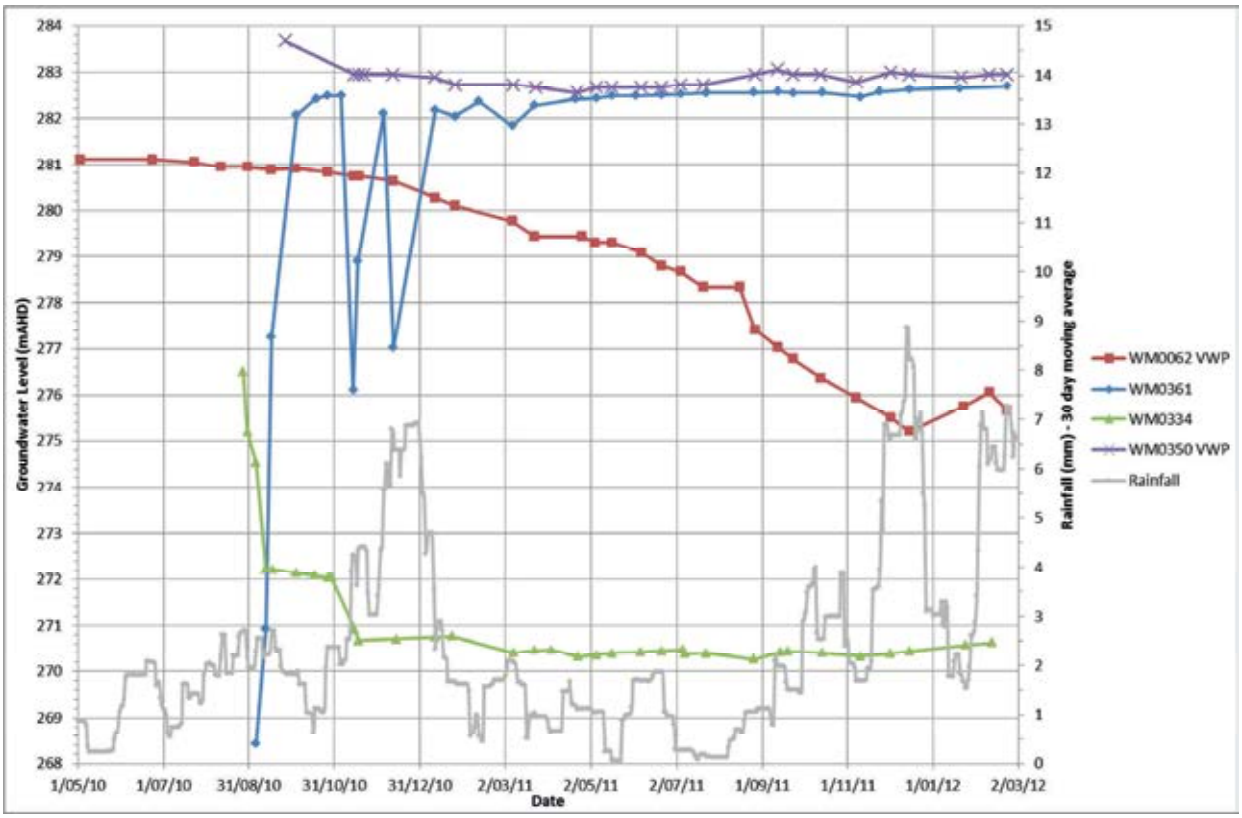


Figure A4-19 – Hydrograph – Melvilles Coal Seam/Pamboola Formation (RL 268-284 mAHD)

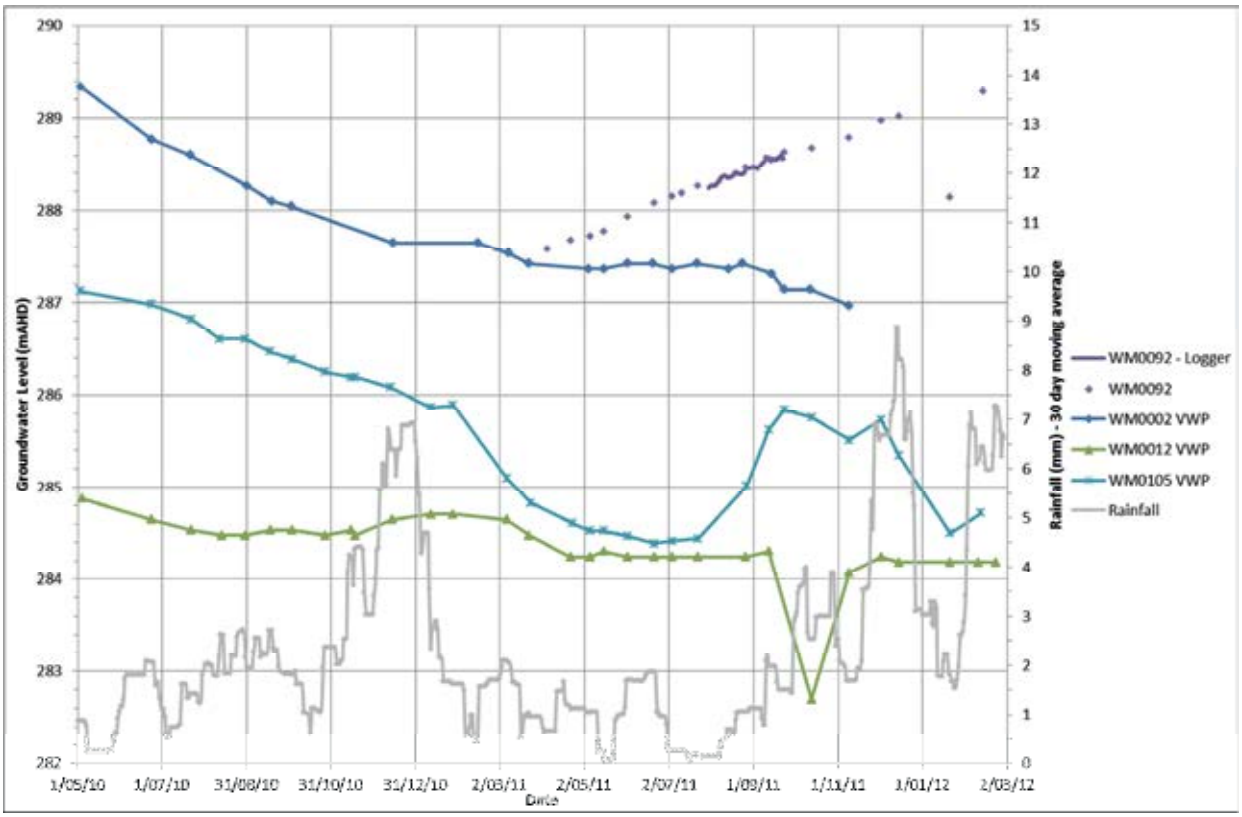


Figure A4-20 – Hydrograph – Melvilles Coal Seam/Pamboola Formation (RL 282-290 mAHD)

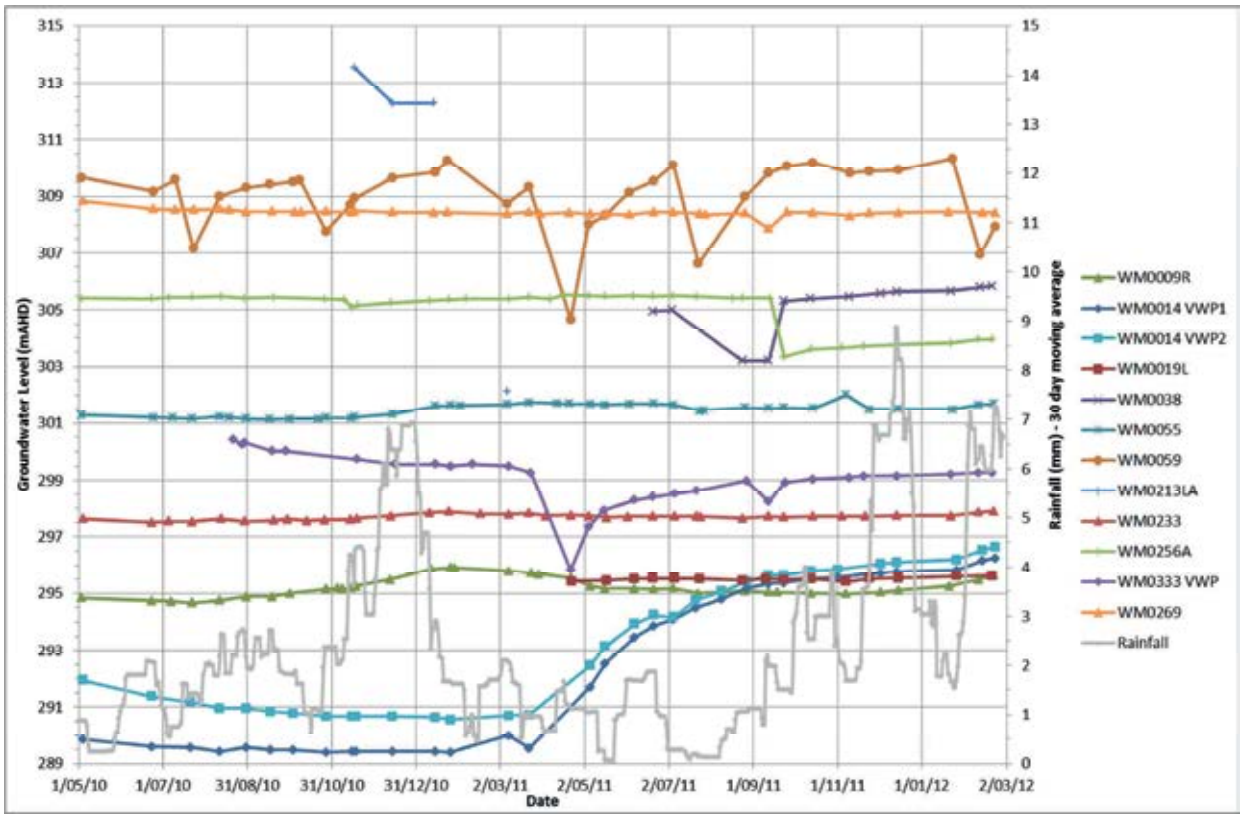


Figure A4-21 – Hydrograph – Melvilles Coal Seam/Pamboola Formation (RL 289-315 mAHD)

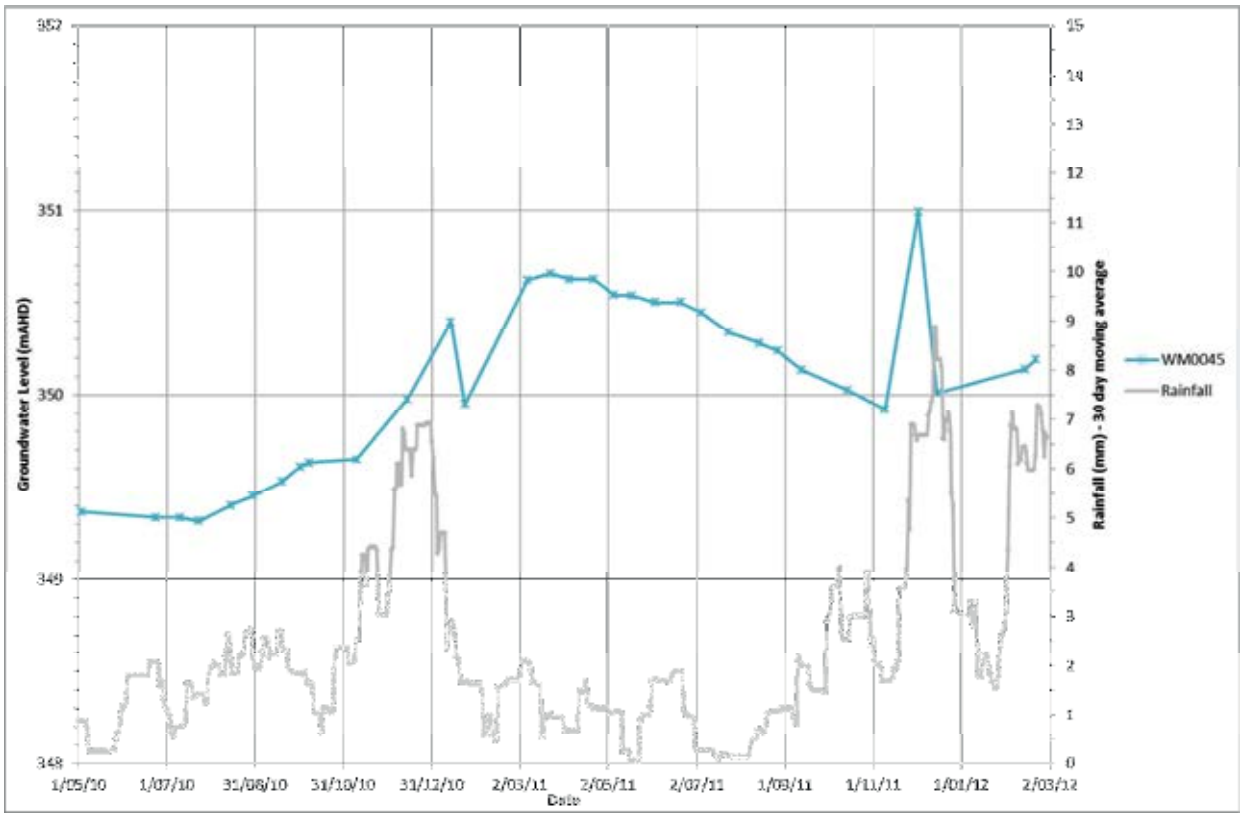


Figure A4-22 – Hydrograph – Melvilles Coal Seam/Pamboola Formation (RL 348-352 mAHD)

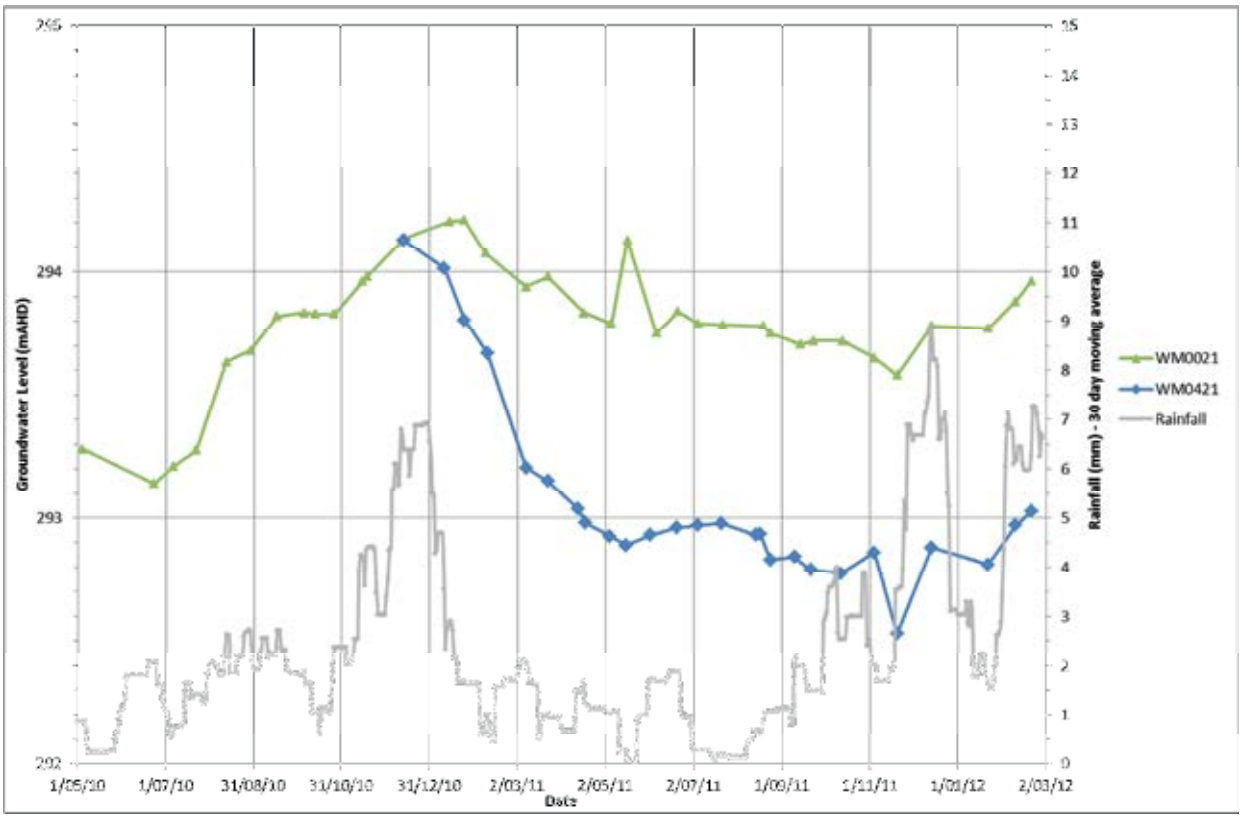


Figure A4-23 – Hydrograph – Howes Hill Seam/Clare Sandstone

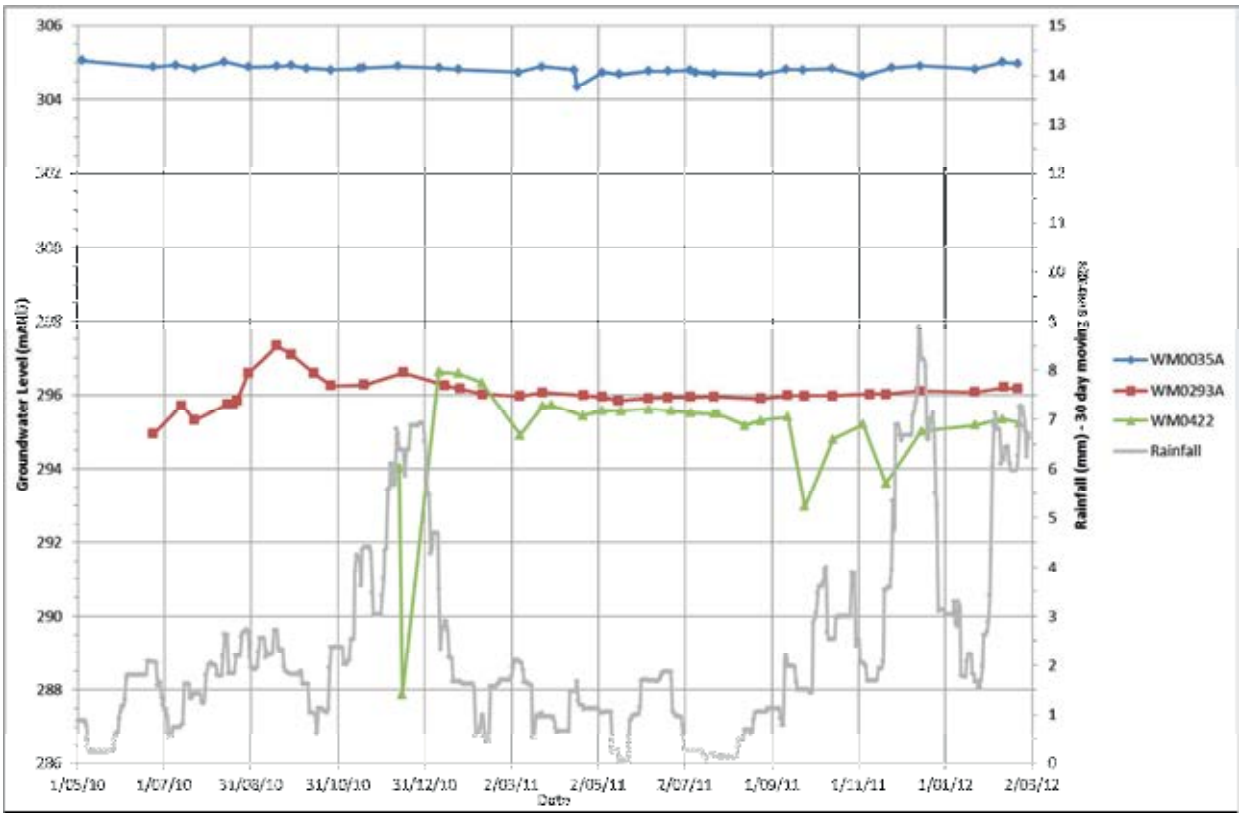


Figure A4-24 – Hydrograph - Colluvium

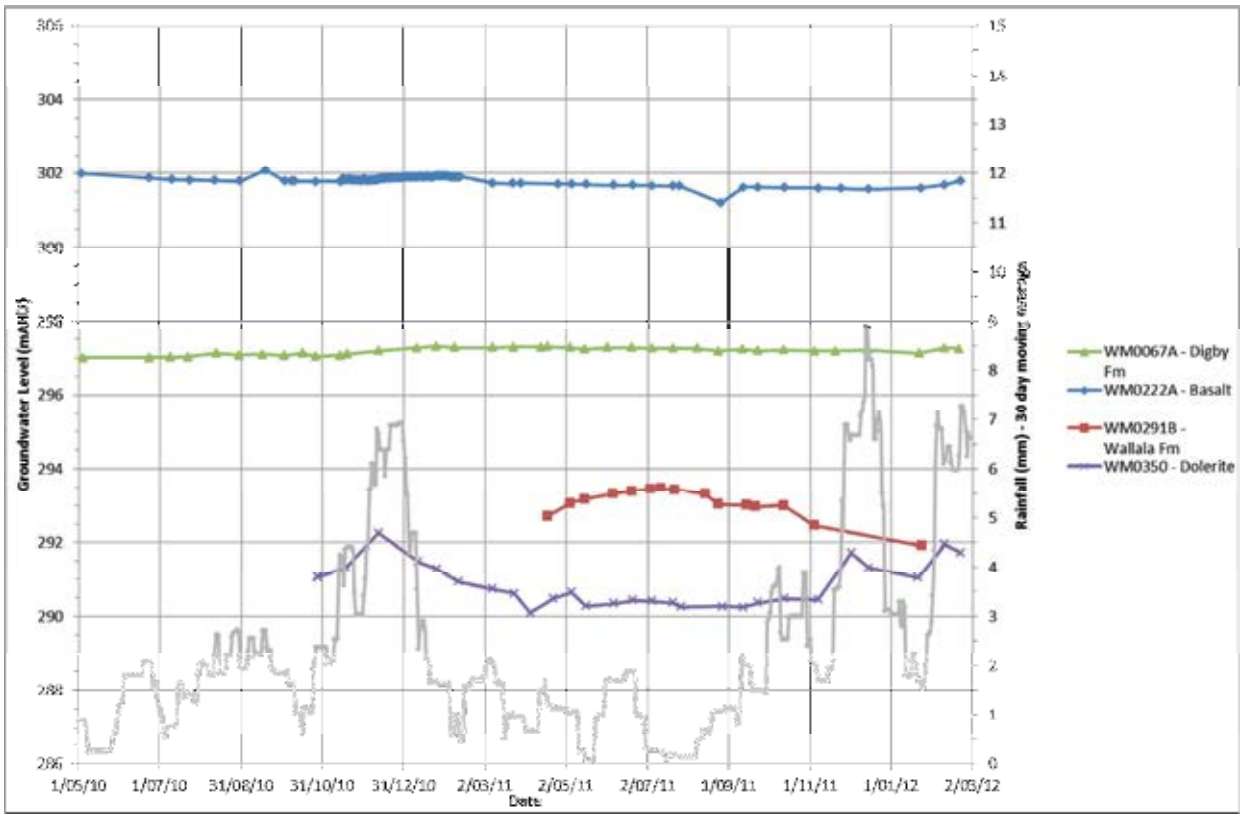


Figure A4-25 – Hydrograph – Digby Formation, Basalt, Wallala Formation, Dolerite

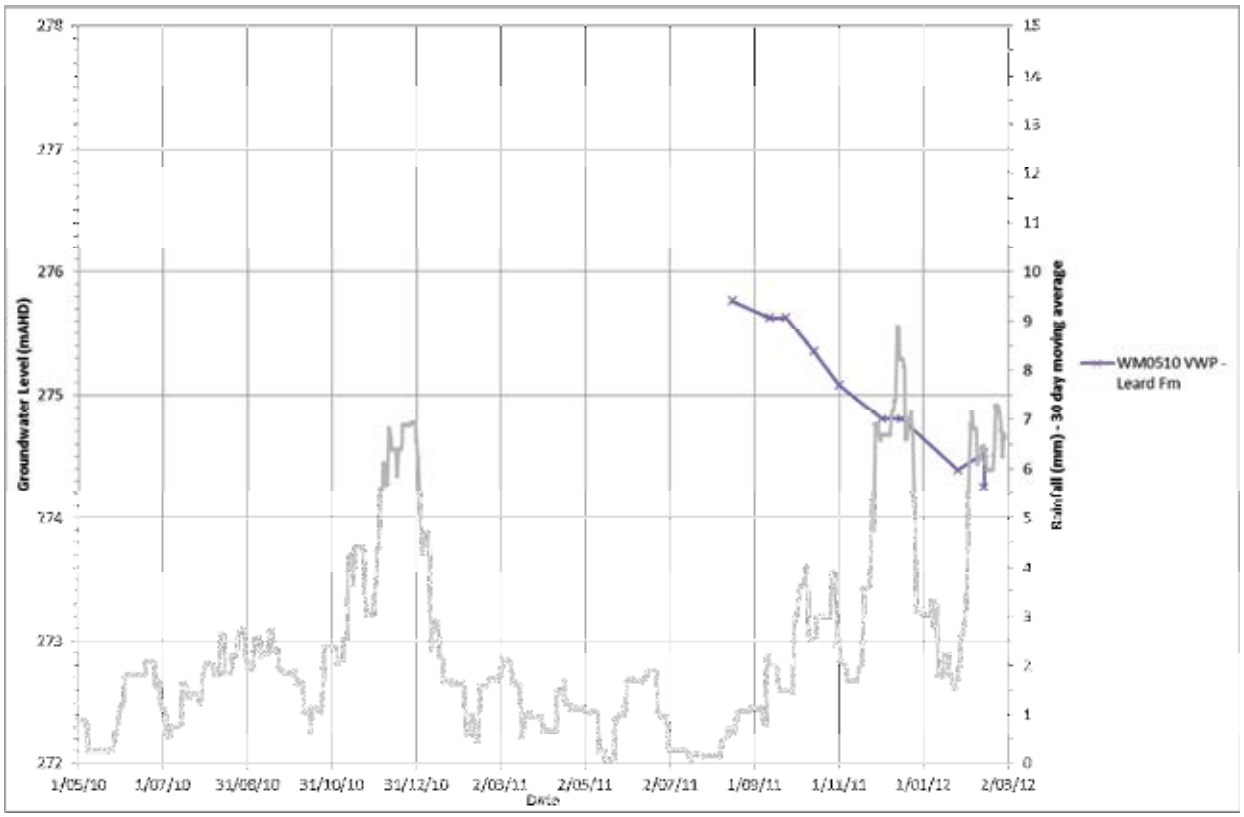
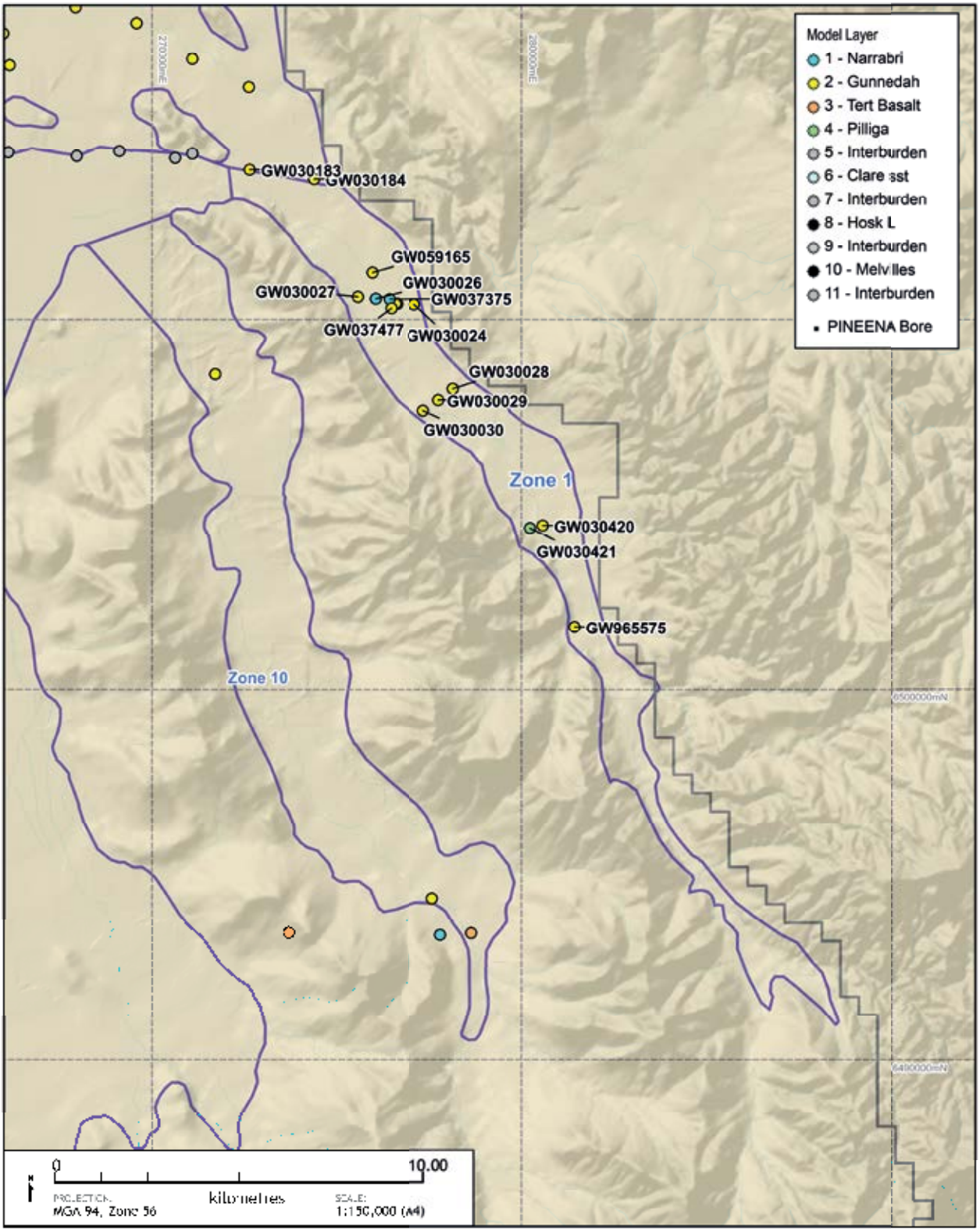


Figure A4-26 – Hydrograph – Leard Formation

APPENDIX 5

Calibration Hydrographs



LEGEND

- Groundwater Management Zone
- Proposed Mining Area
- EL 7223
- Project Boundary
- PINEENA Bore

Watermark Coal Project (G1501)
Groundwater Assessment

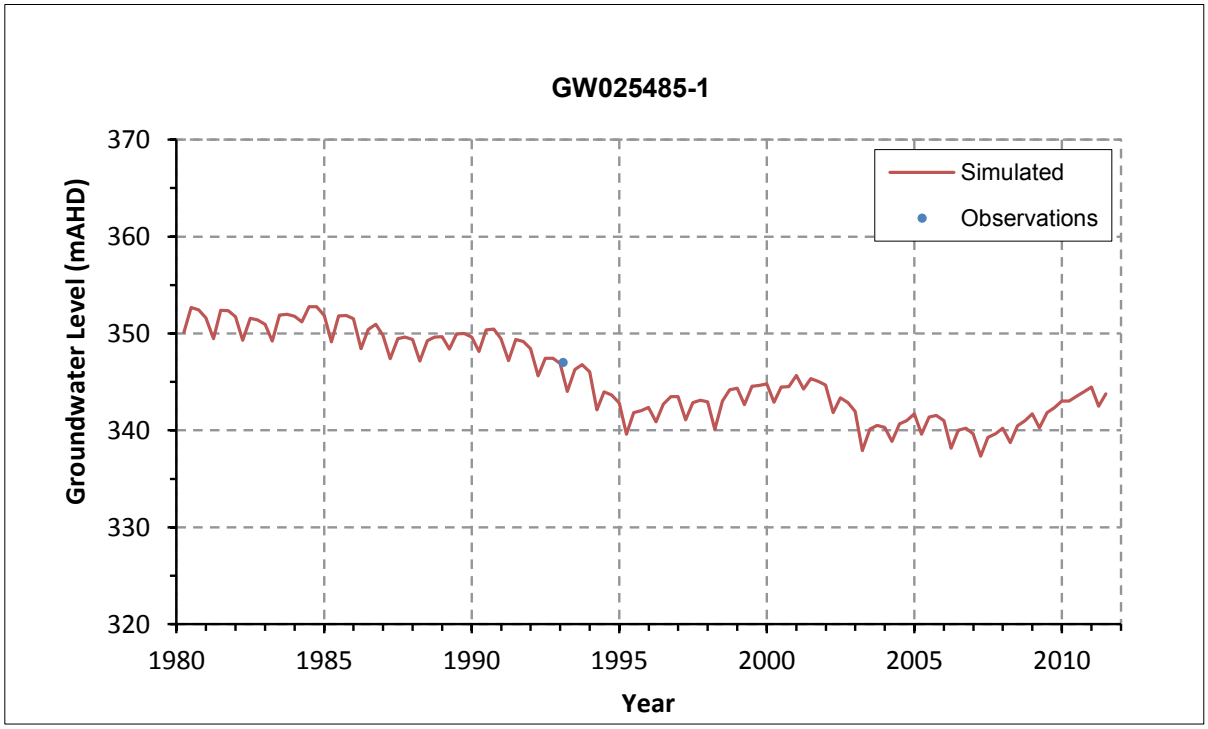
Groundwater Monitoring Bores: Shenhua and Pineena - Zone 1

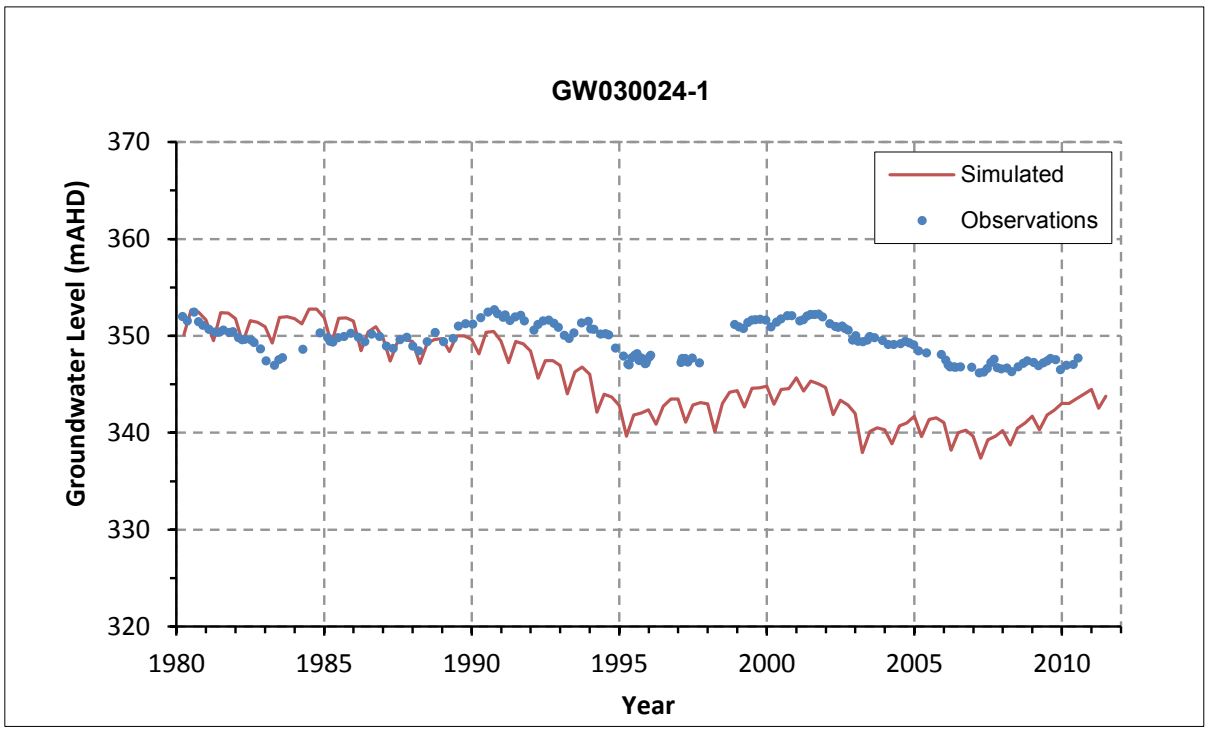
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GHD Groundwater Monitoring Database, 2011

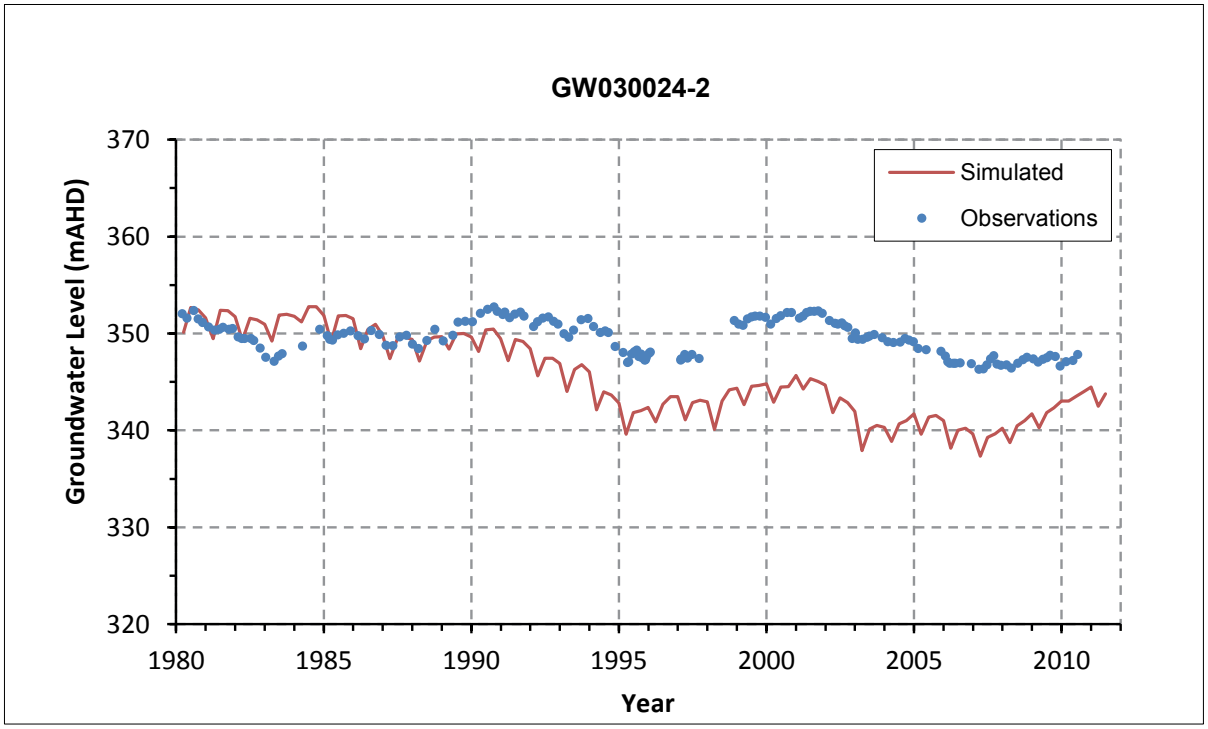
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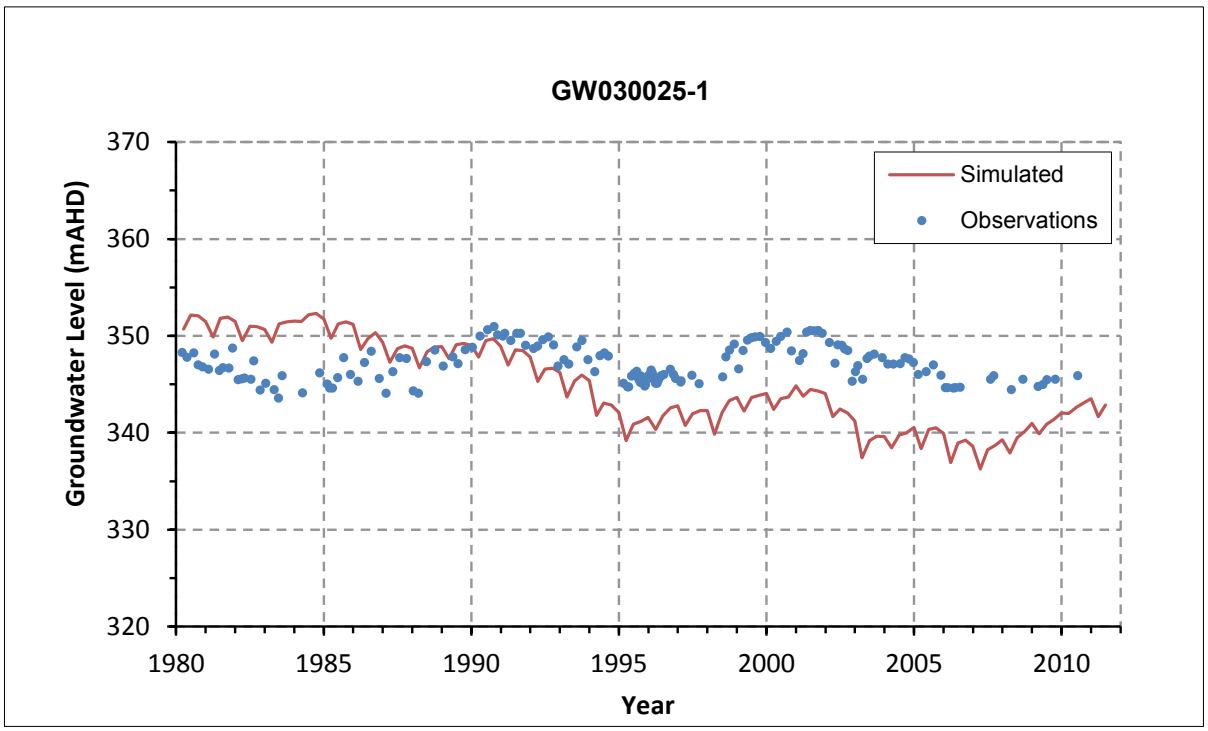
FIGURE No: **A.1**

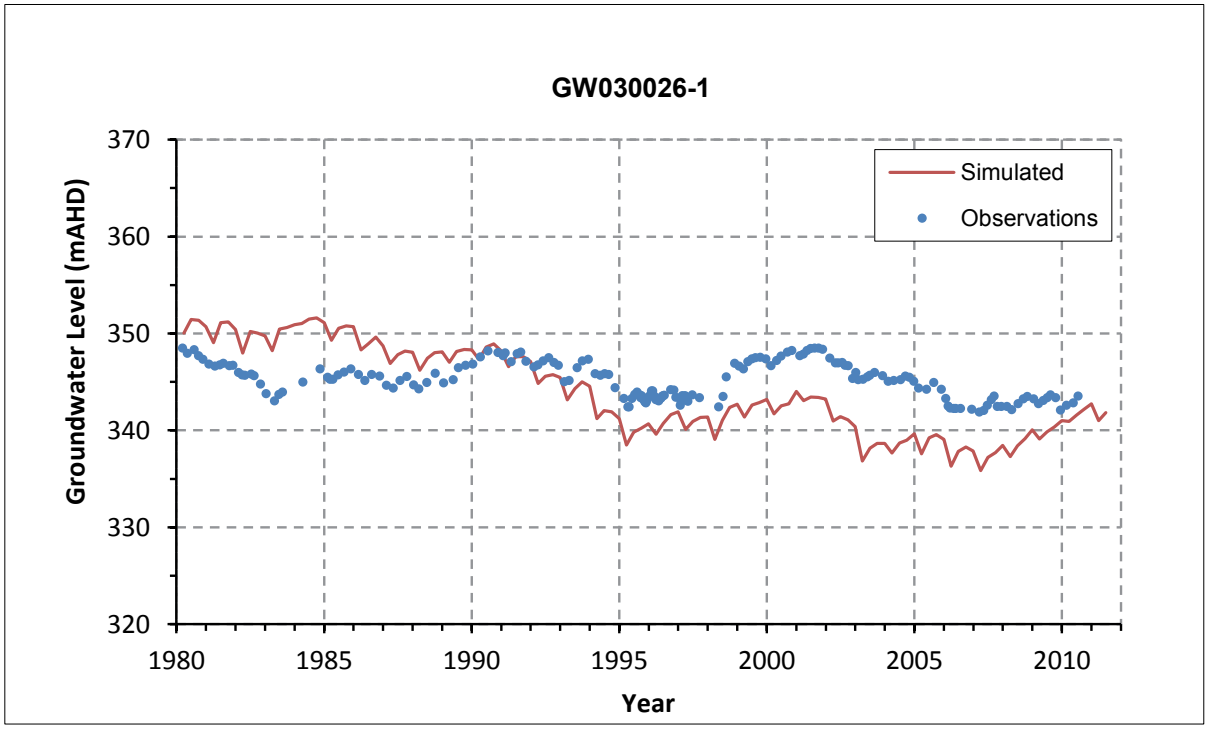
©2012 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

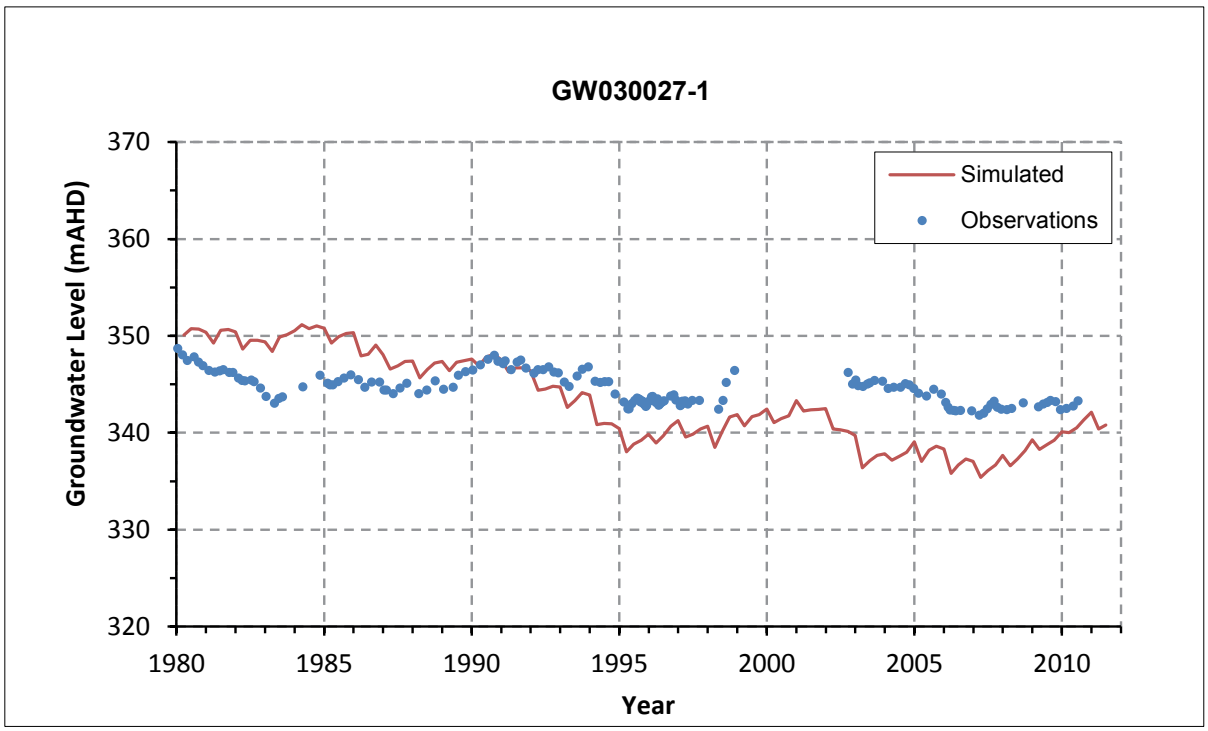

GW025485-1
Groundwater Level (mAHD)
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360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

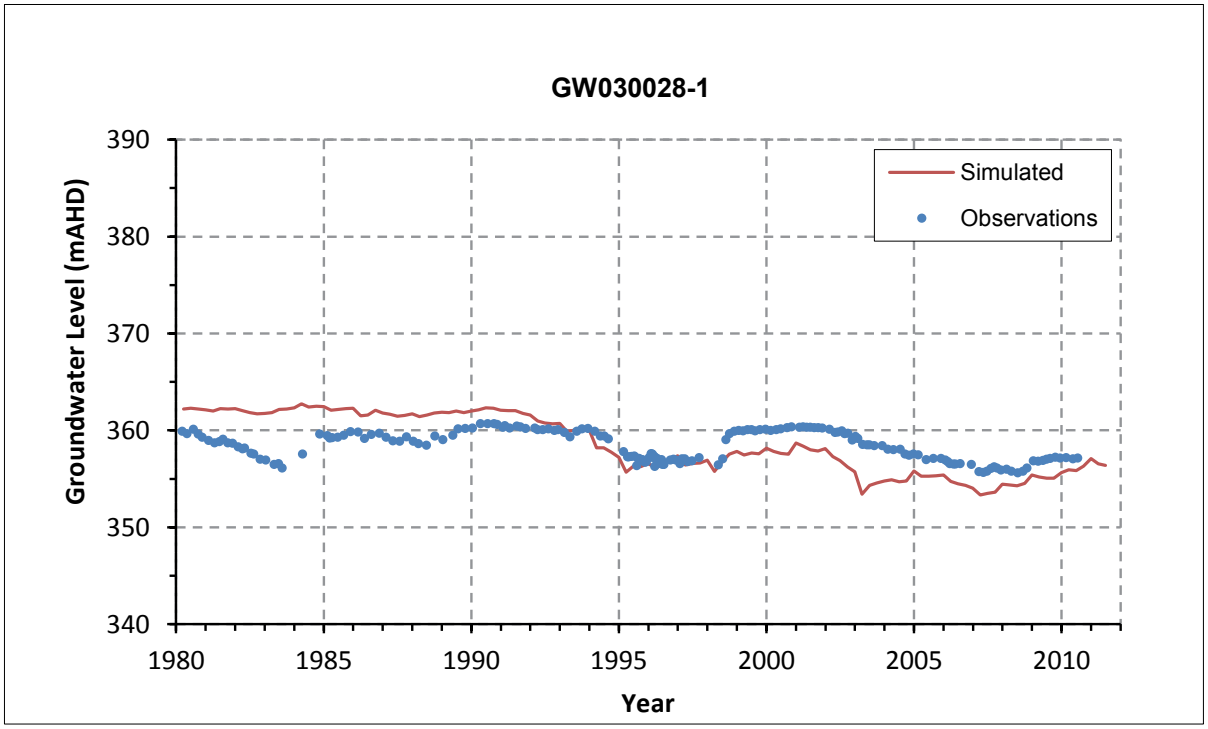

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Groundwater Level (mAHD)
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360
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340
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320
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1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

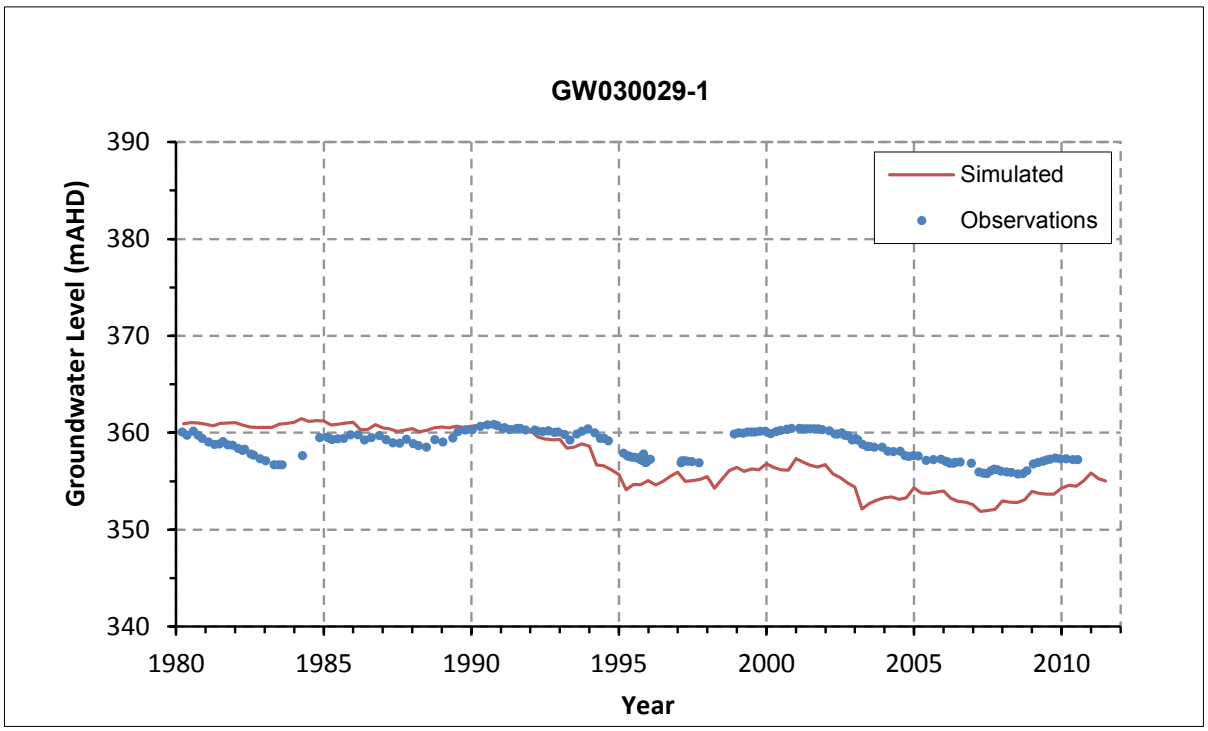

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Year
Simulated
Observations

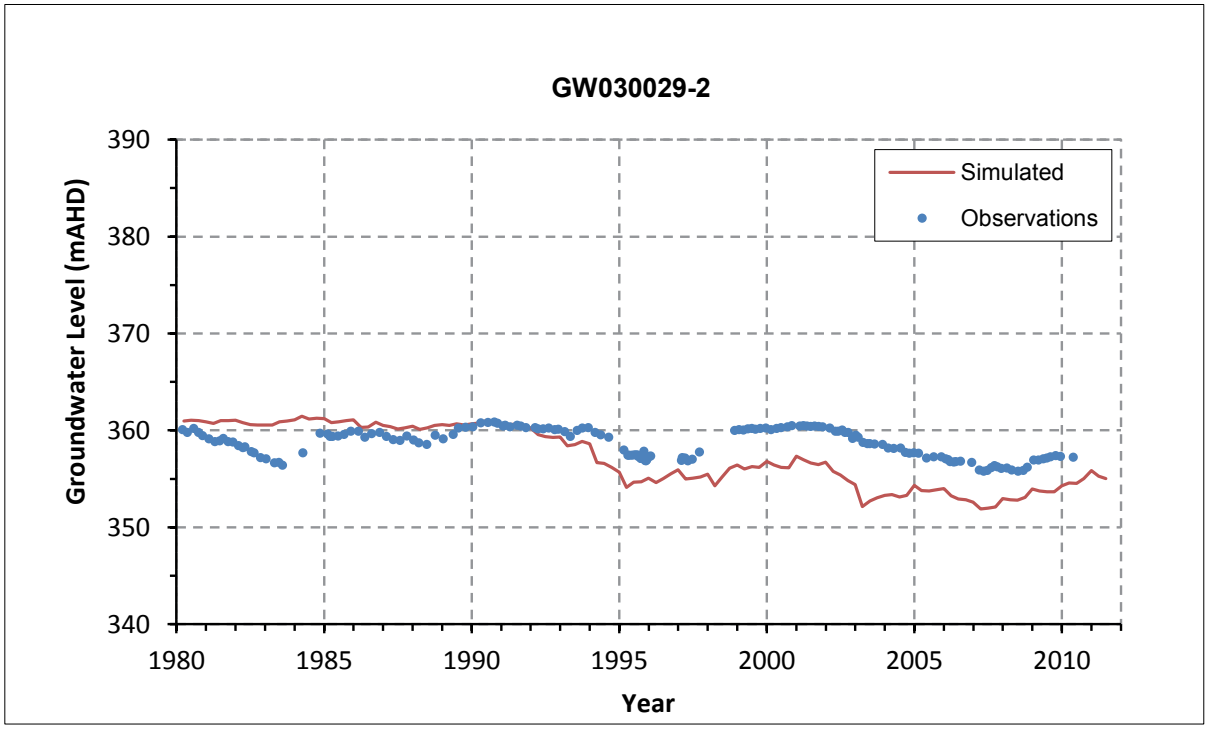

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Year
Simulated
Observations

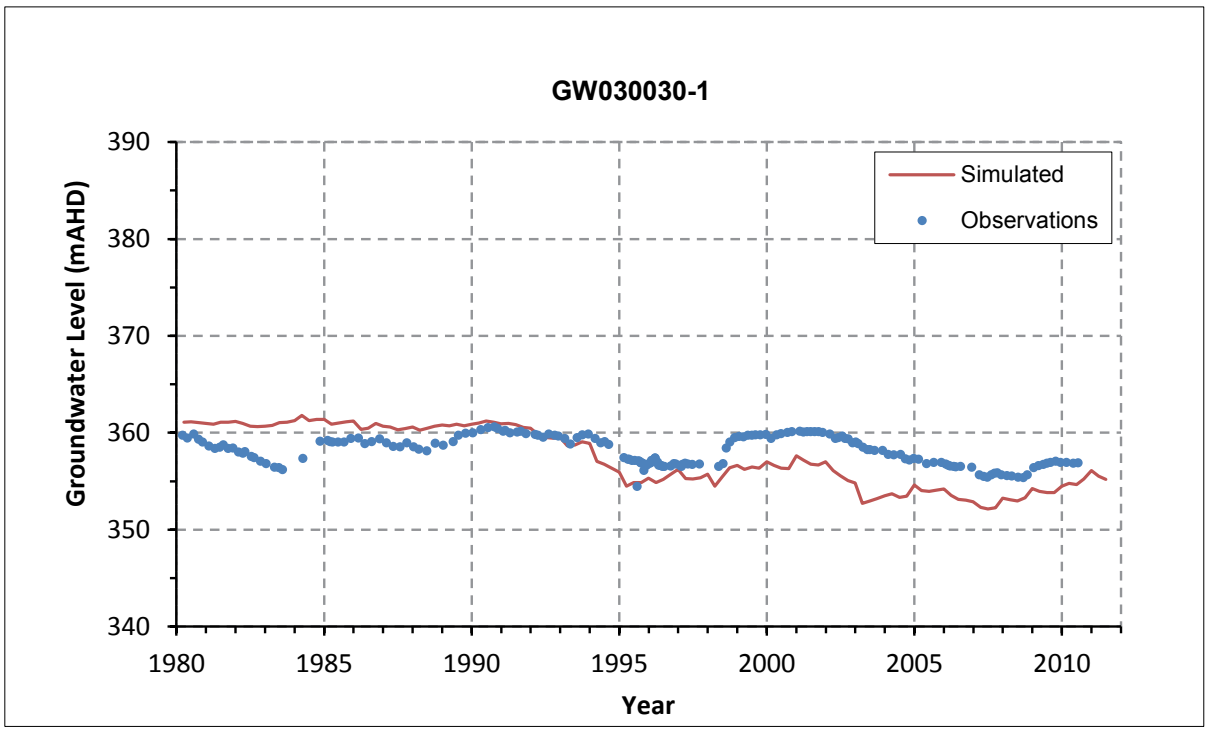

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Groundwater Level (mAHD)
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340
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320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

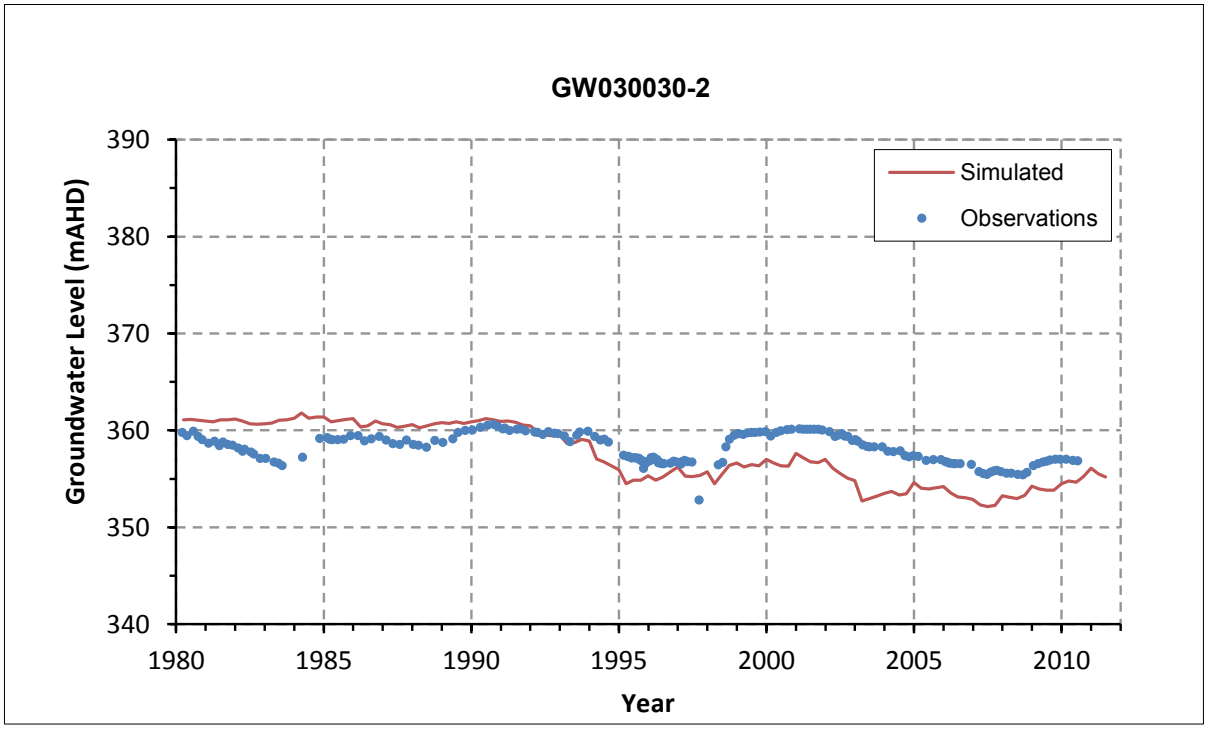

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Year
Simulated
Observations

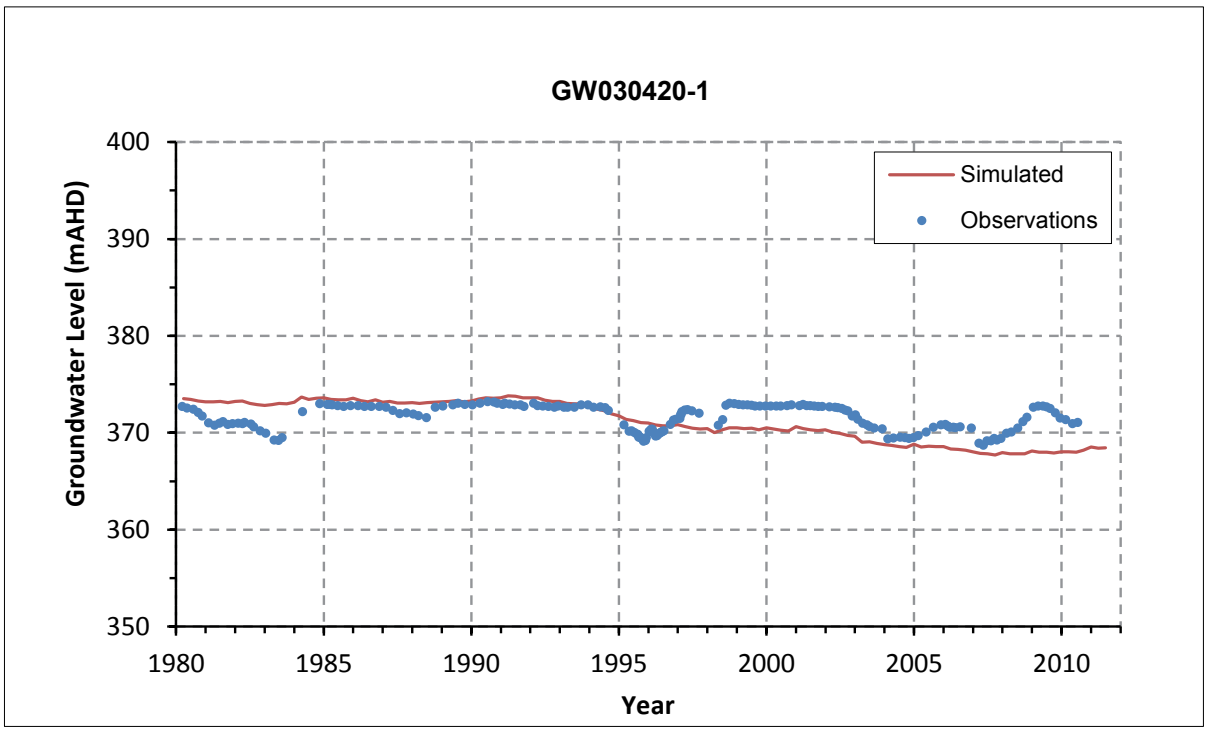

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1990
1995
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2005
2010
Year
Simulated
Observations

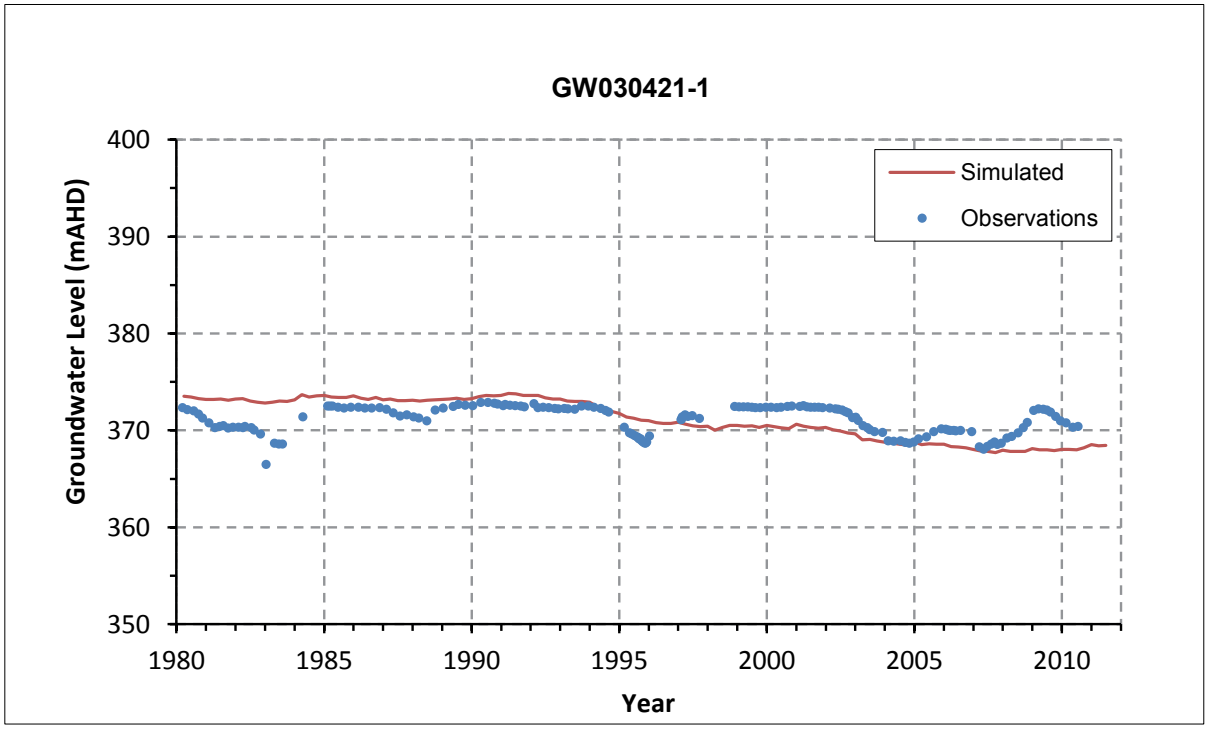

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1995
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2005
2010
Year
Simulated
Observations

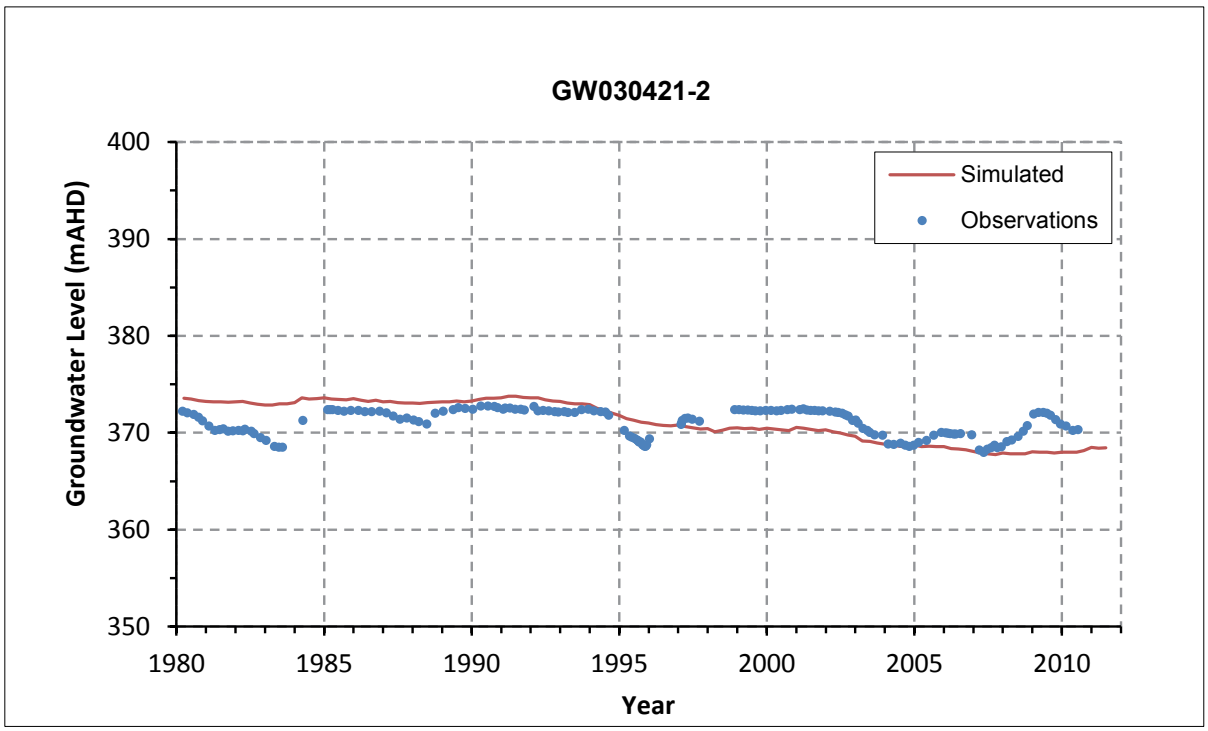

GW030029-2
Groundwater Level (mAHD)
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380
370
360
350
340
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

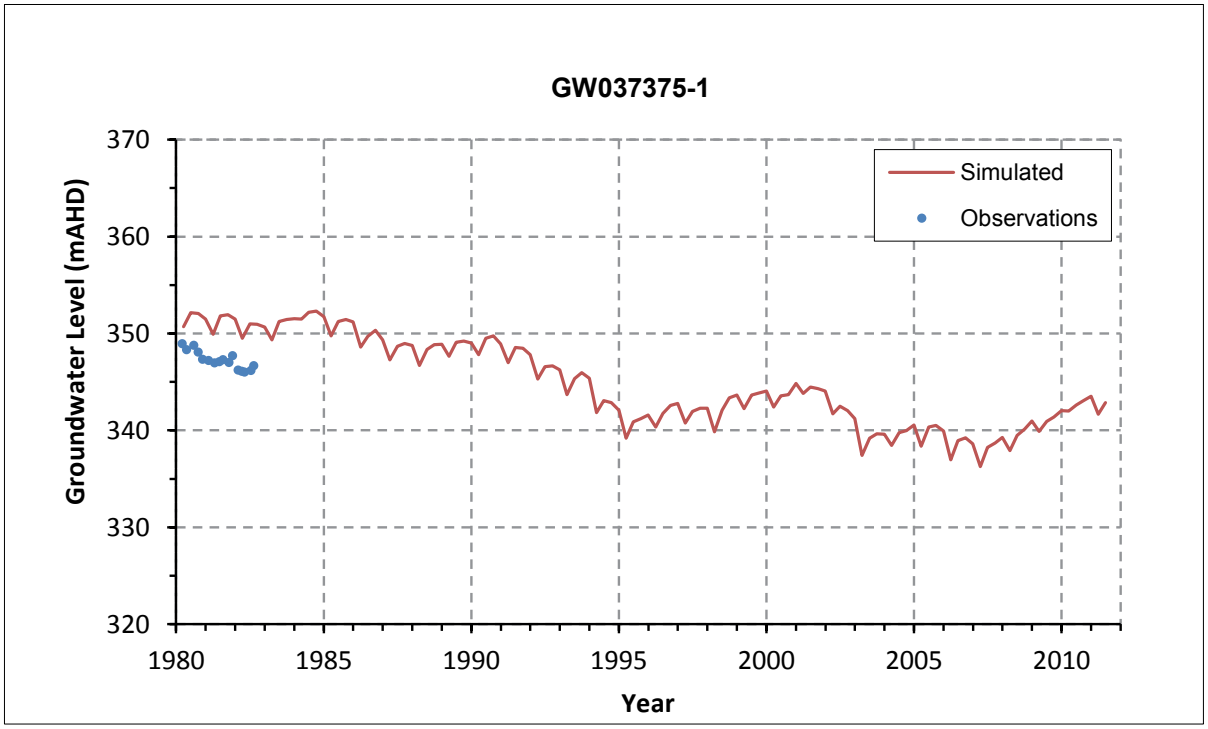

GW030030-1
Groundwater Level (mAHD)
390
380
370
360
350
340
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

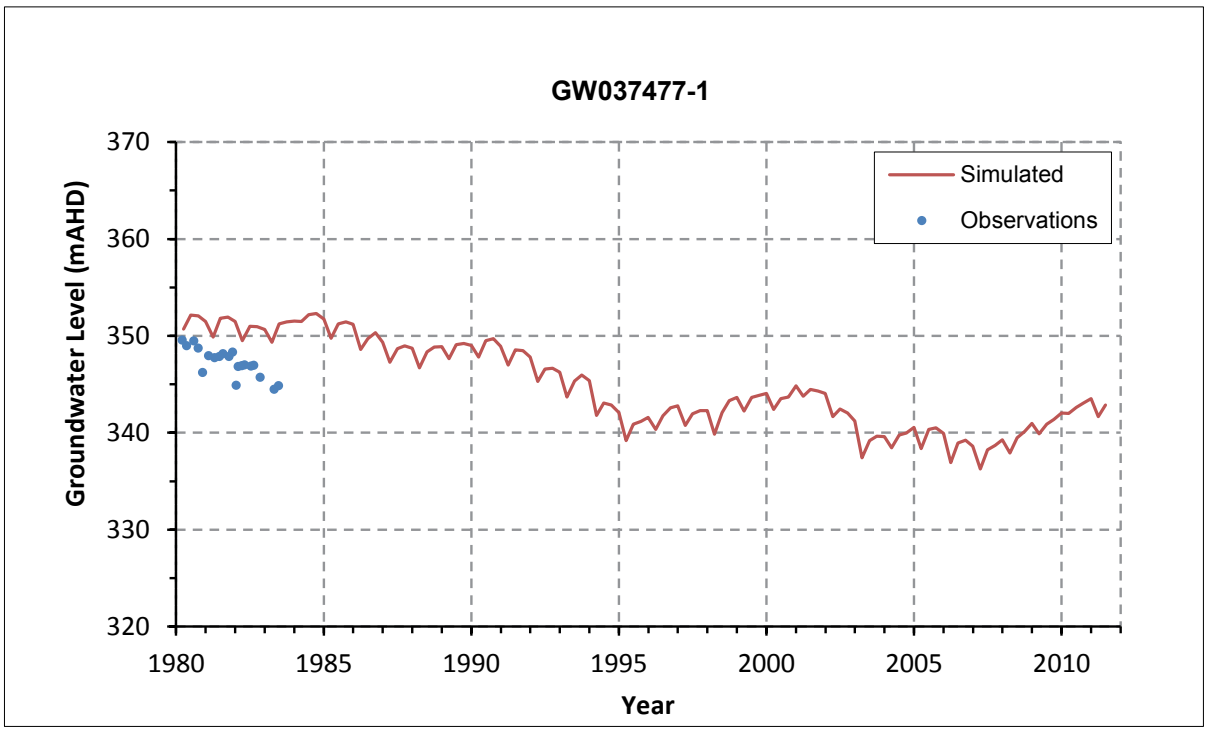

GW030030-2
Groundwater Level (mAHD)
390
380
370
360
350
340
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

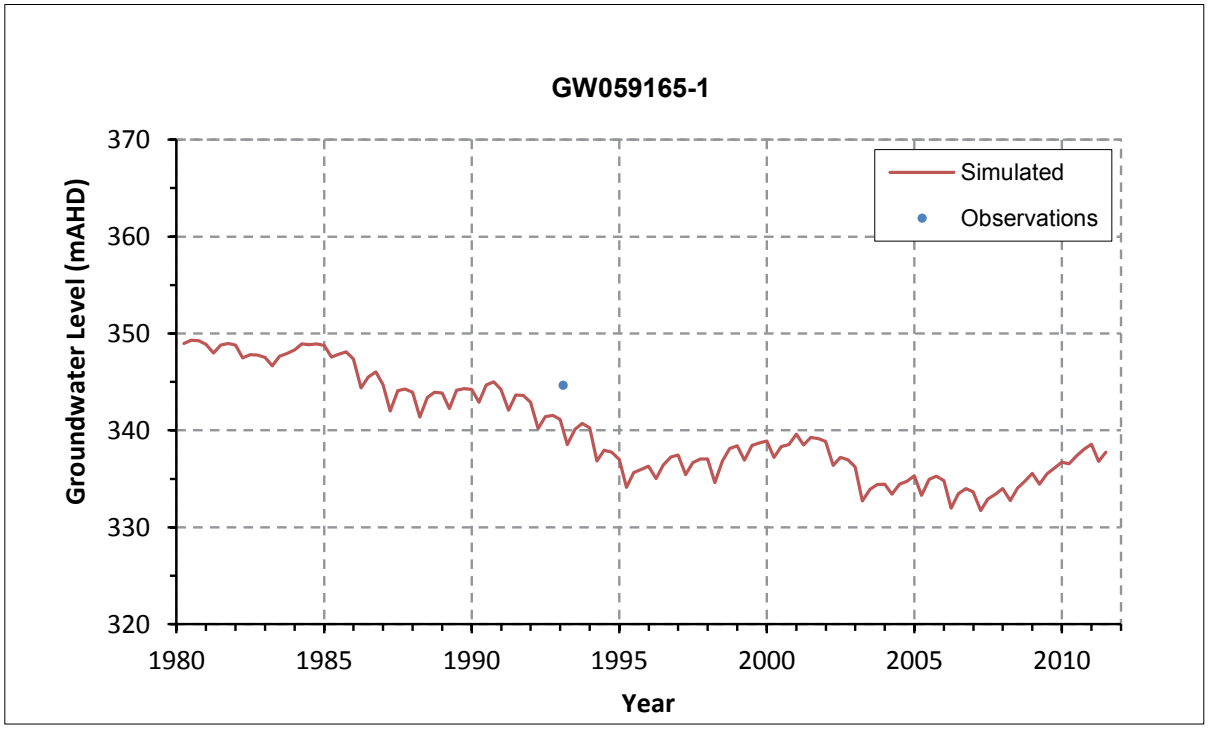

GW030420-1
Groundwater Level (mAHD)
400
390
380
370
360
350
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

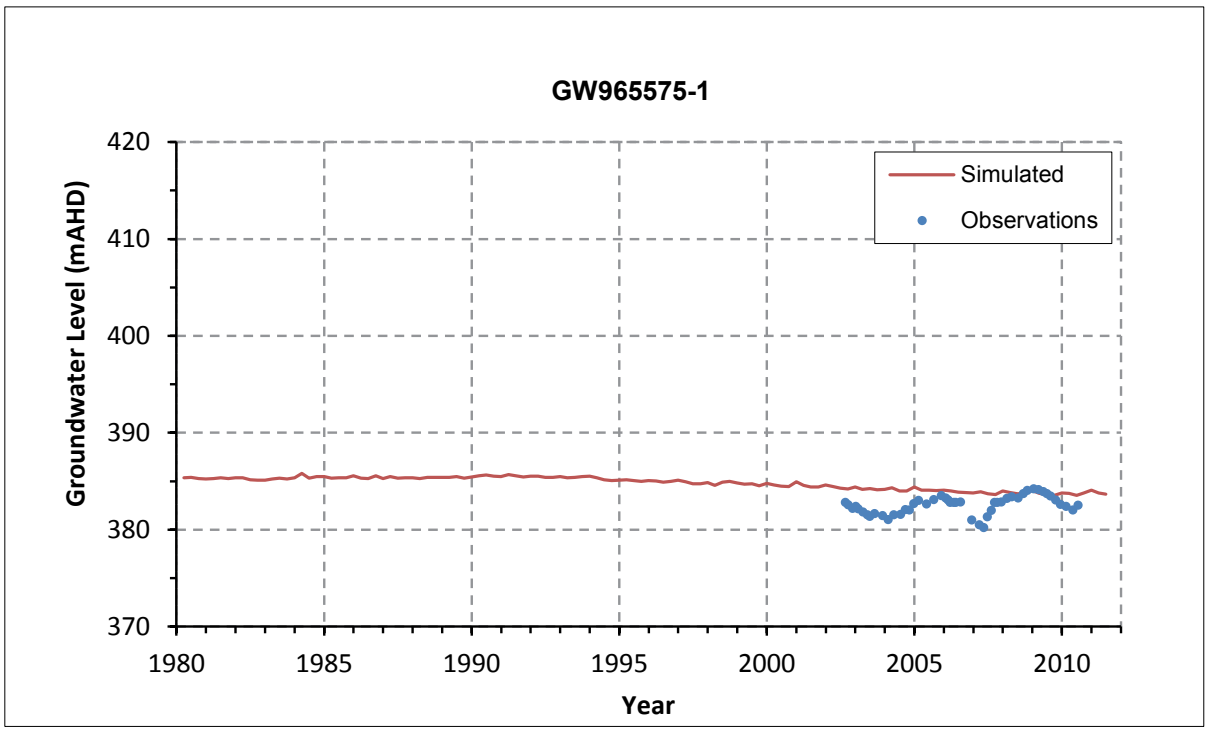

GW030421-1
Groundwater Level (mAHD)
400
390
380
370
360
350
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

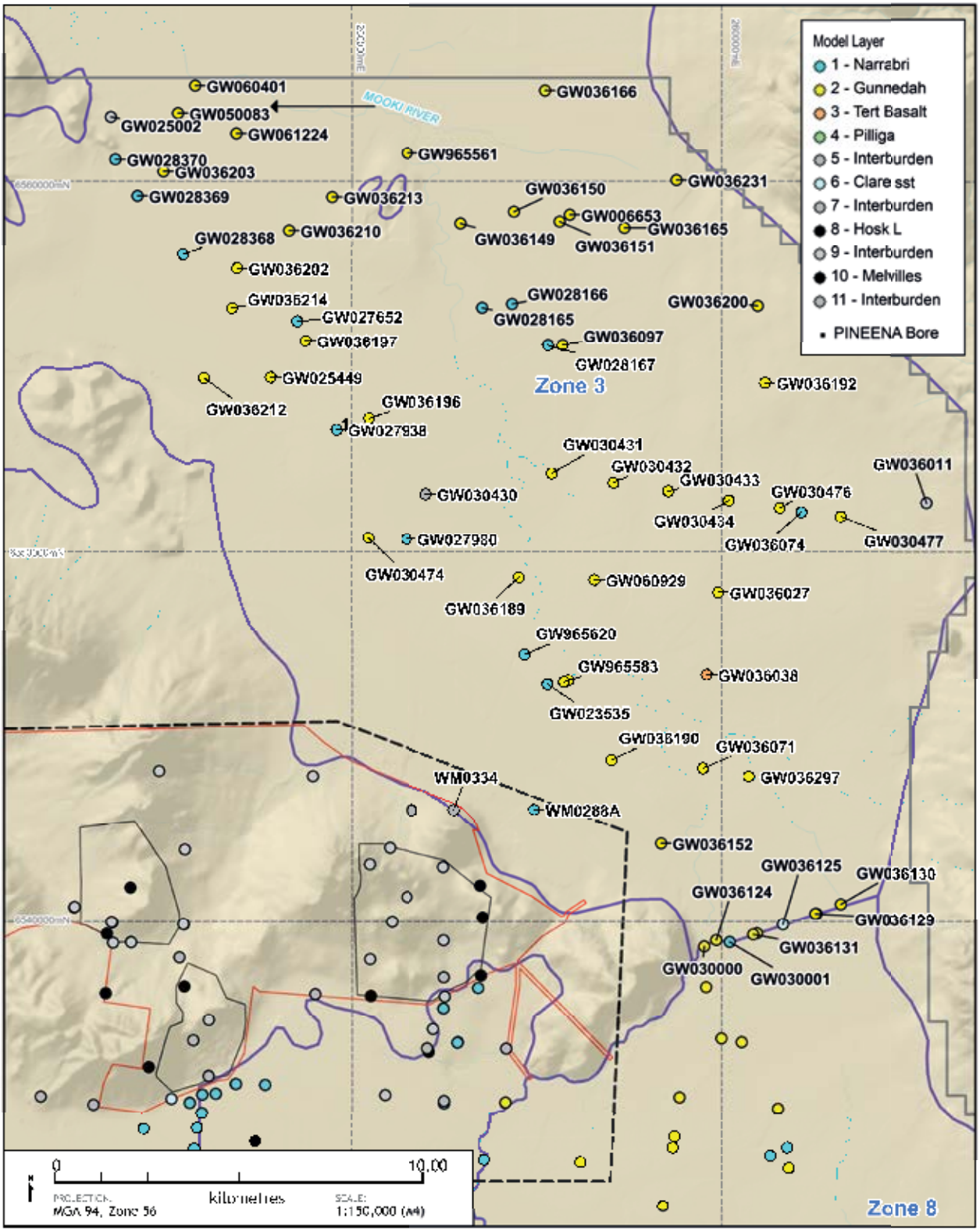

GW030421-2
Groundwater Level (mAHD)
400
390
380
370
360
350
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW037375-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW037477-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW059165-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW965575-1
Groundwater Level (mAHD)
420
410
400
390
380
370
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations



LEGEND

- Groundwater Management Zone
- Proposed Mining Area
- EL 7223
- Project Boundary
- PINEENA Bore

Watermark Coal Project (G1501)
Groundwater Assessment

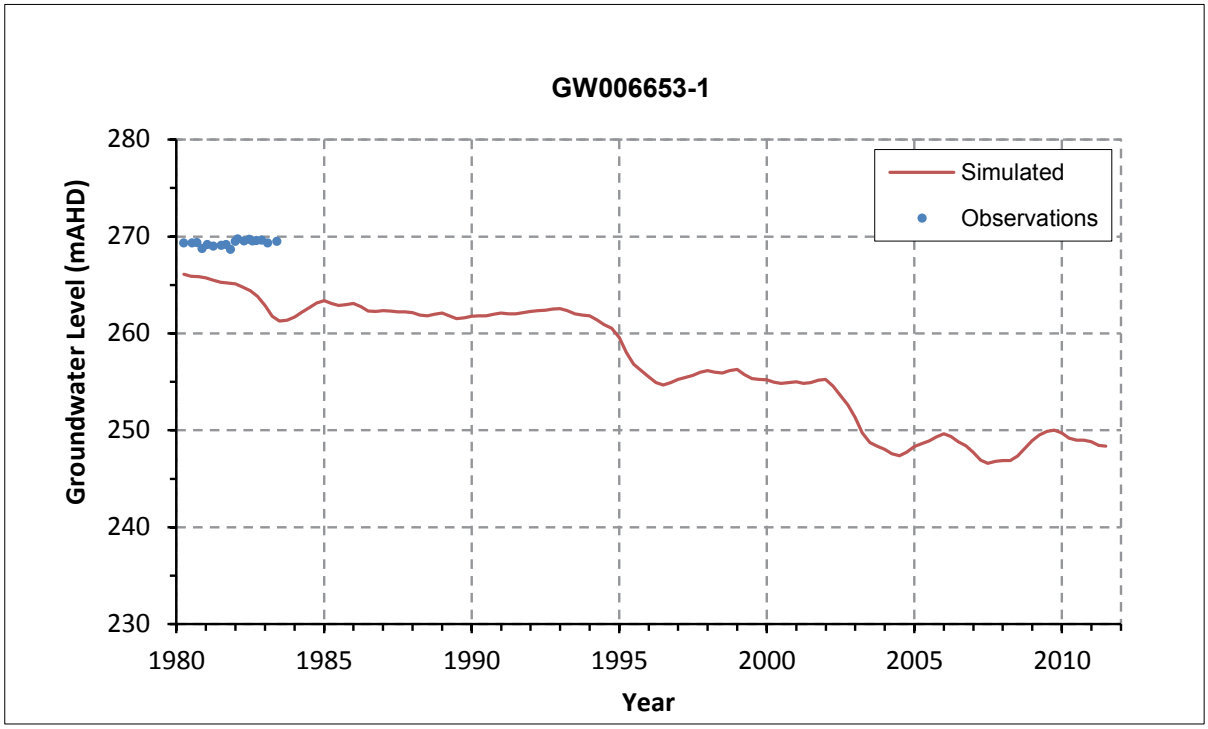
Groundwater Monitoring Bores: Shenhua and Pineena - Zone 3

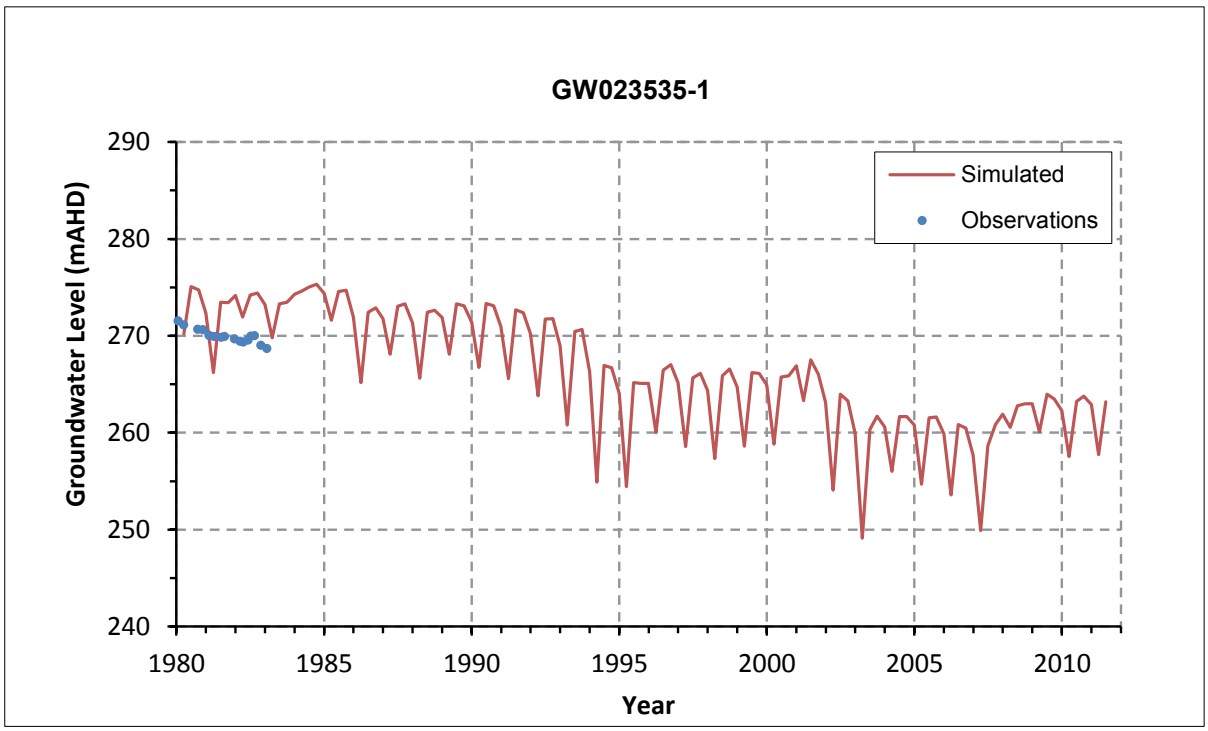
Source: NoW PINEENA Groundwater Database, 2011
GHD Groundwater Monitoring Database, 2011

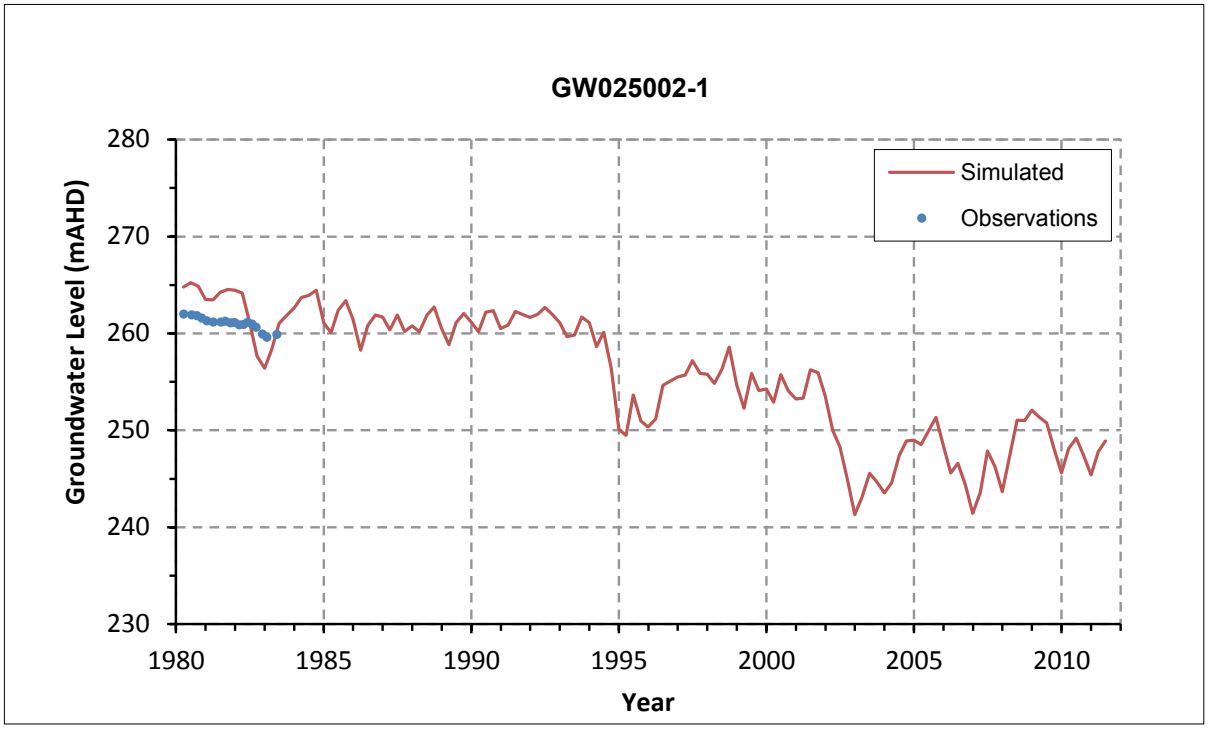
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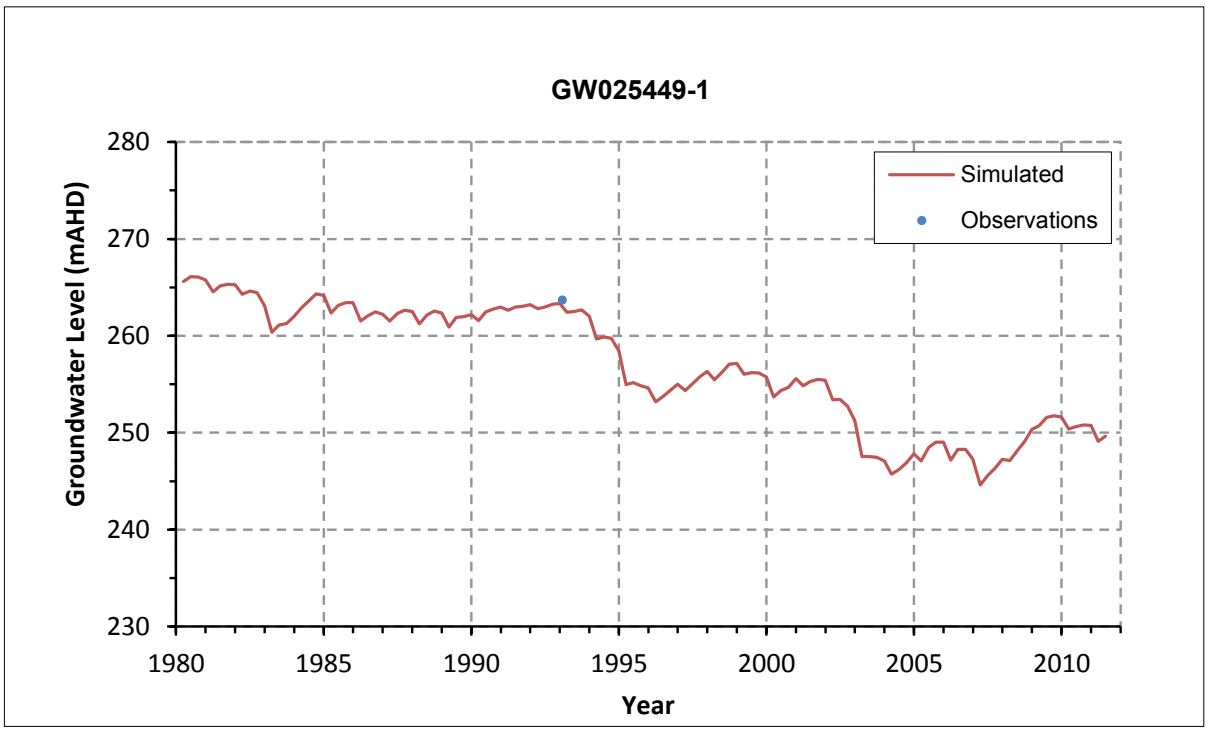
FIGURE No: **A.2**

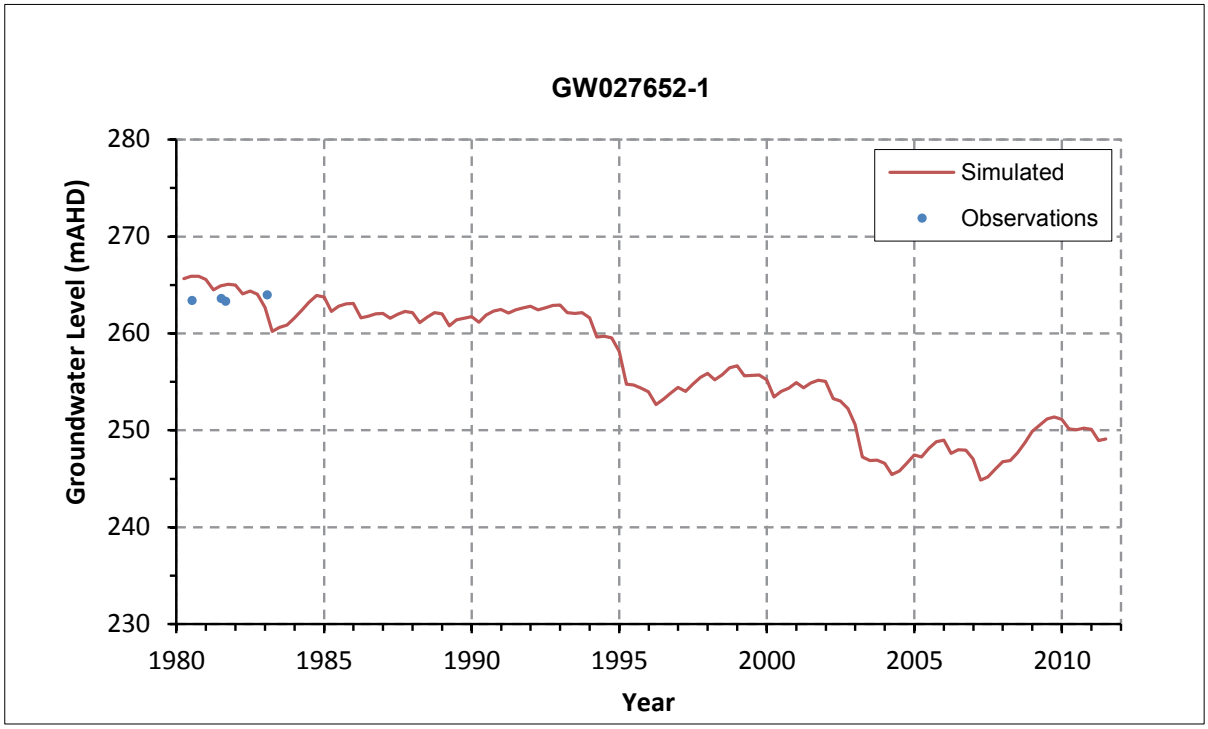
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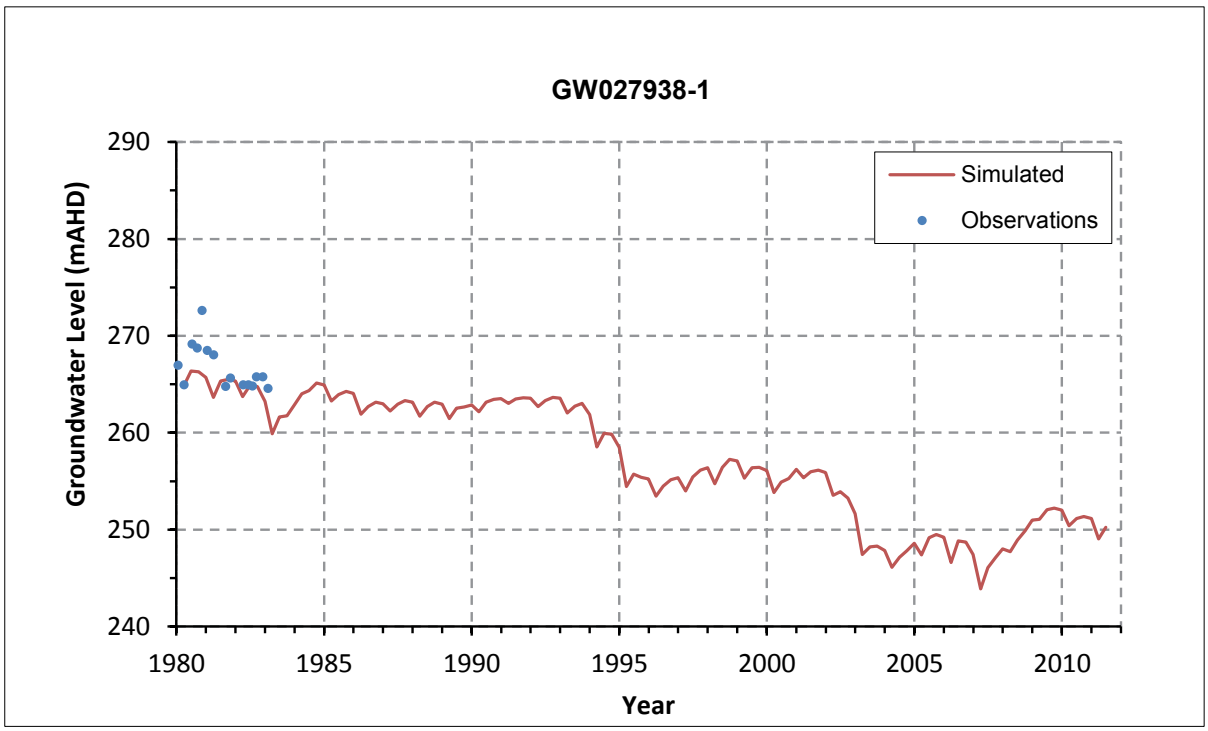

GW006653-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

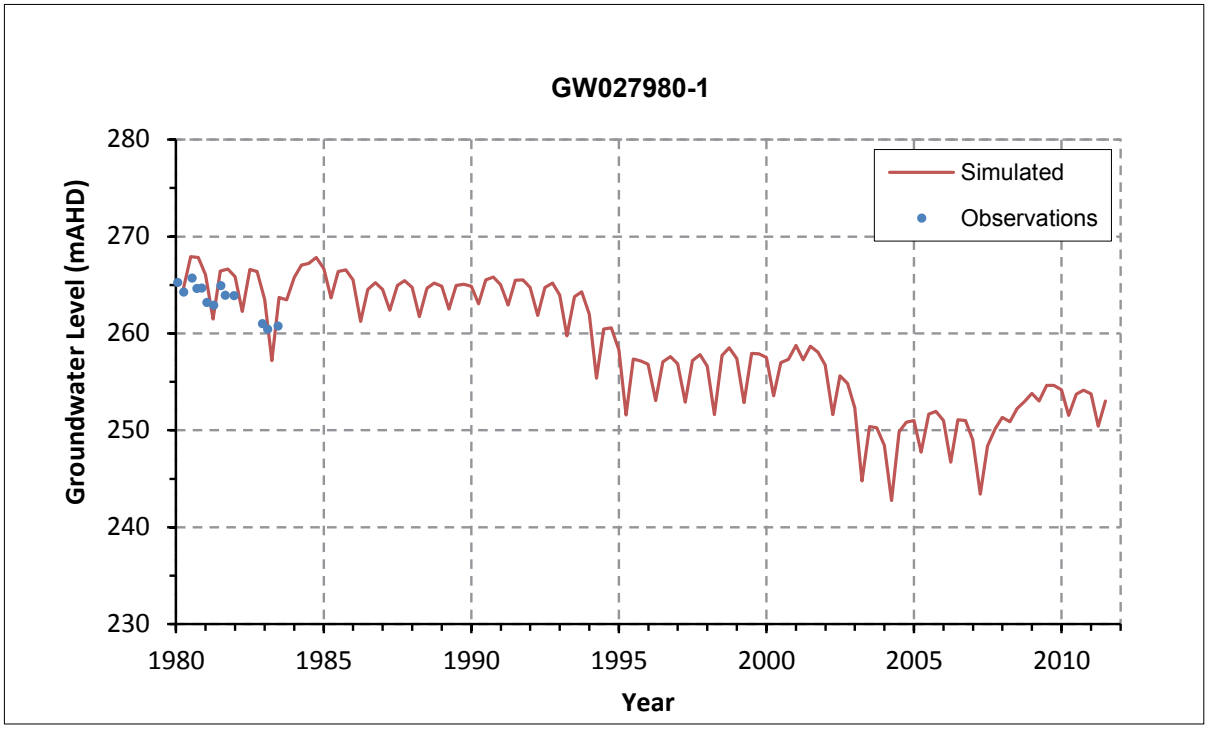

GW023535-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

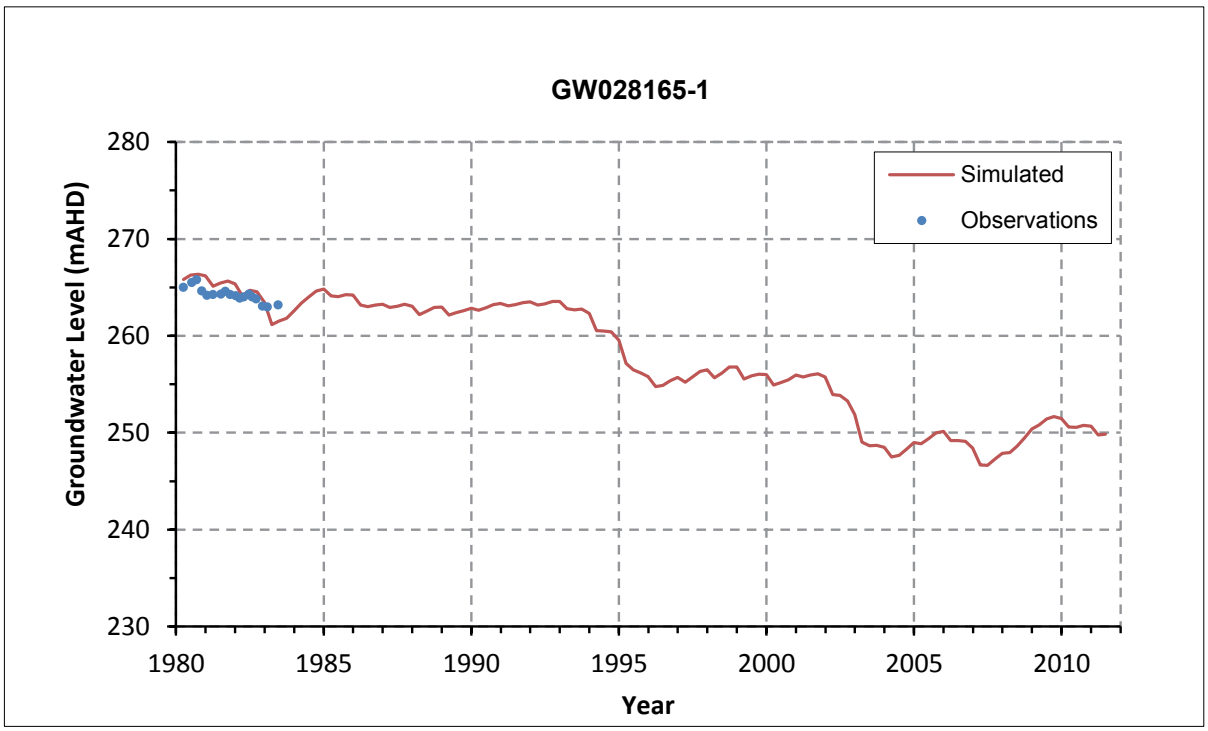

GW025002-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

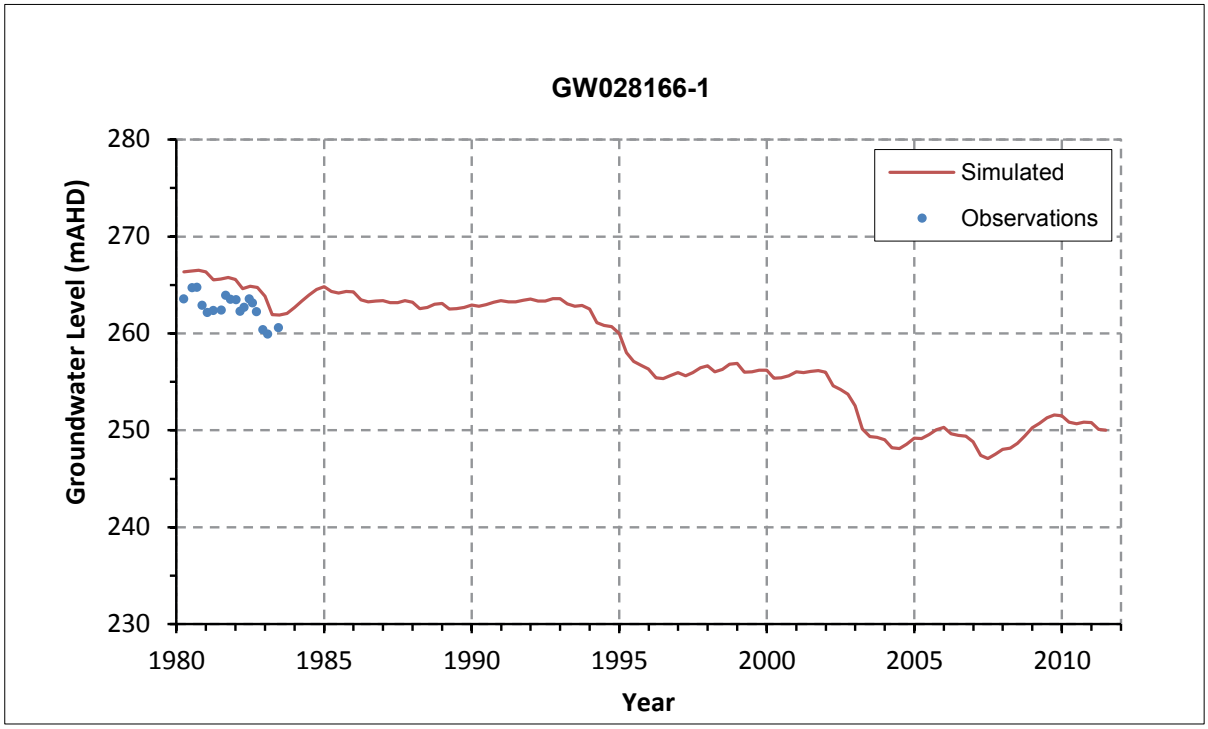

GW025449-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

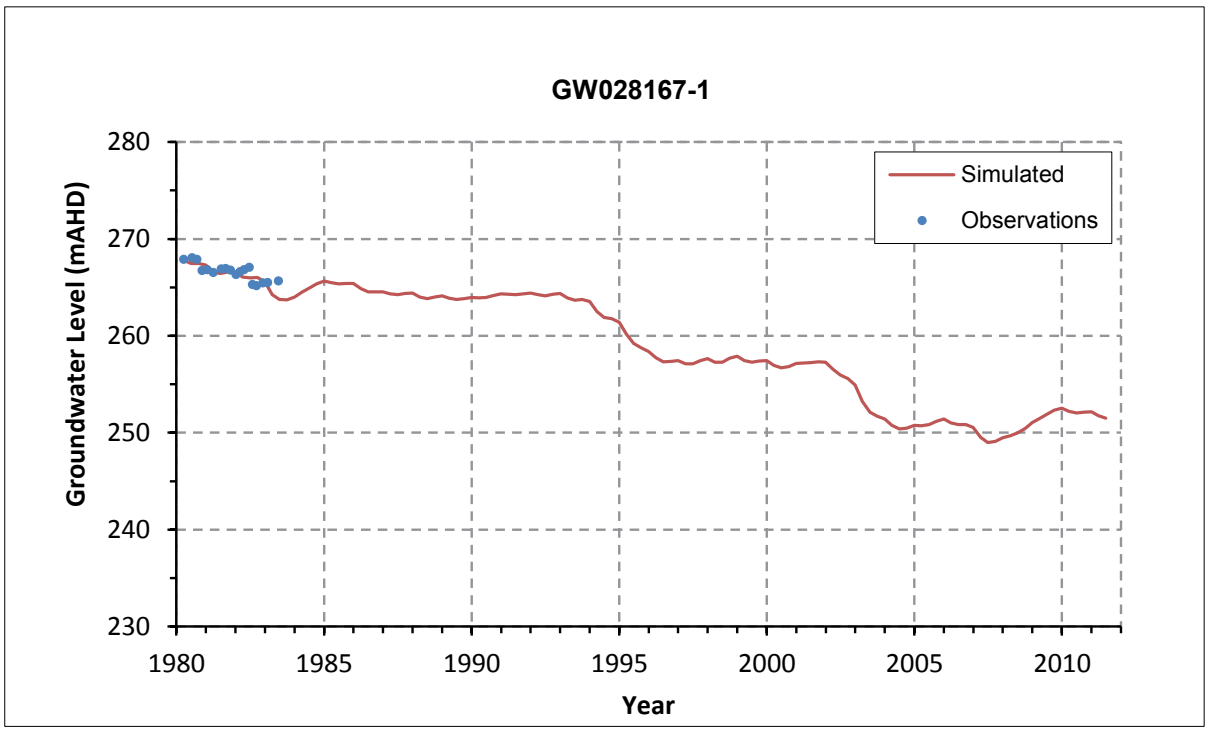

GW027652-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

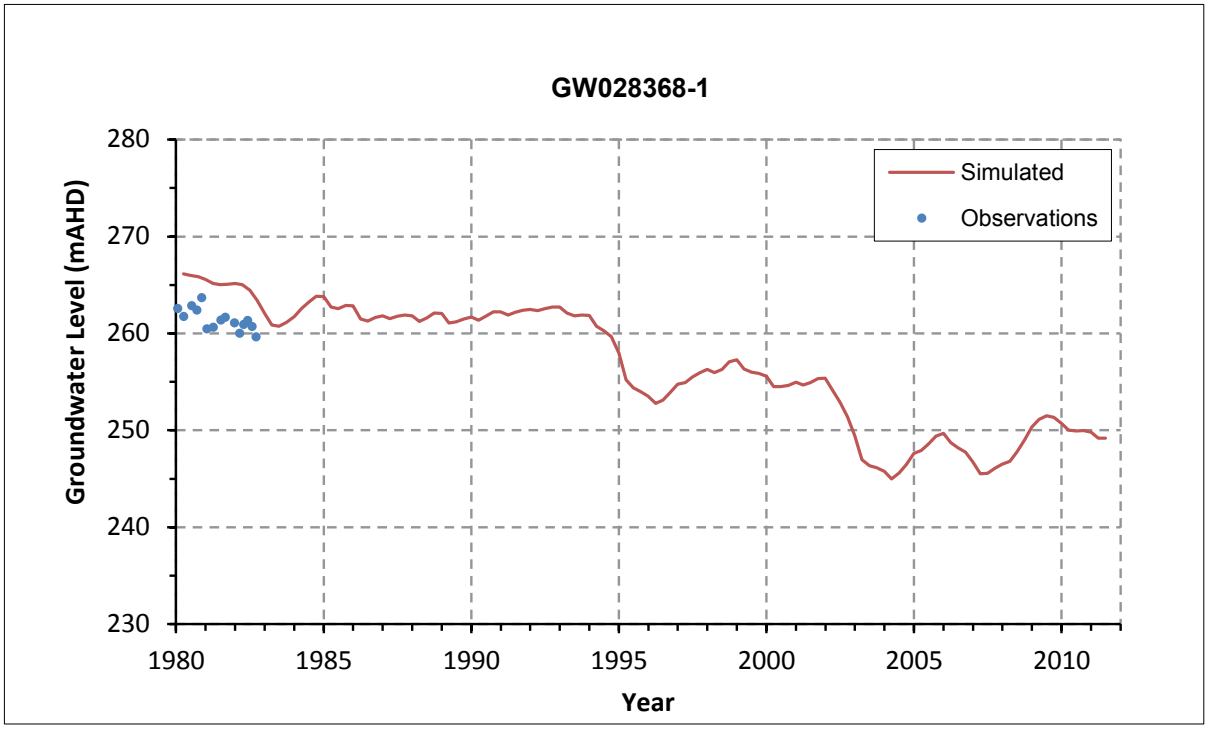

GW027938-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

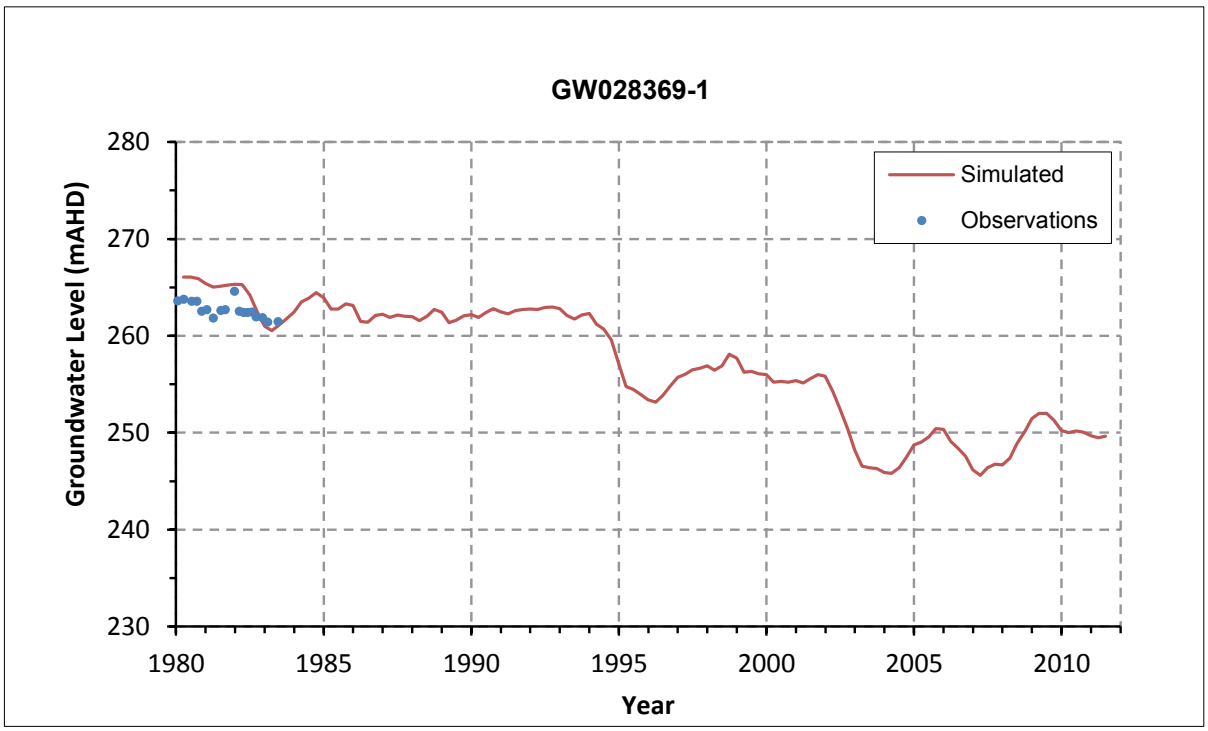

GW027980-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

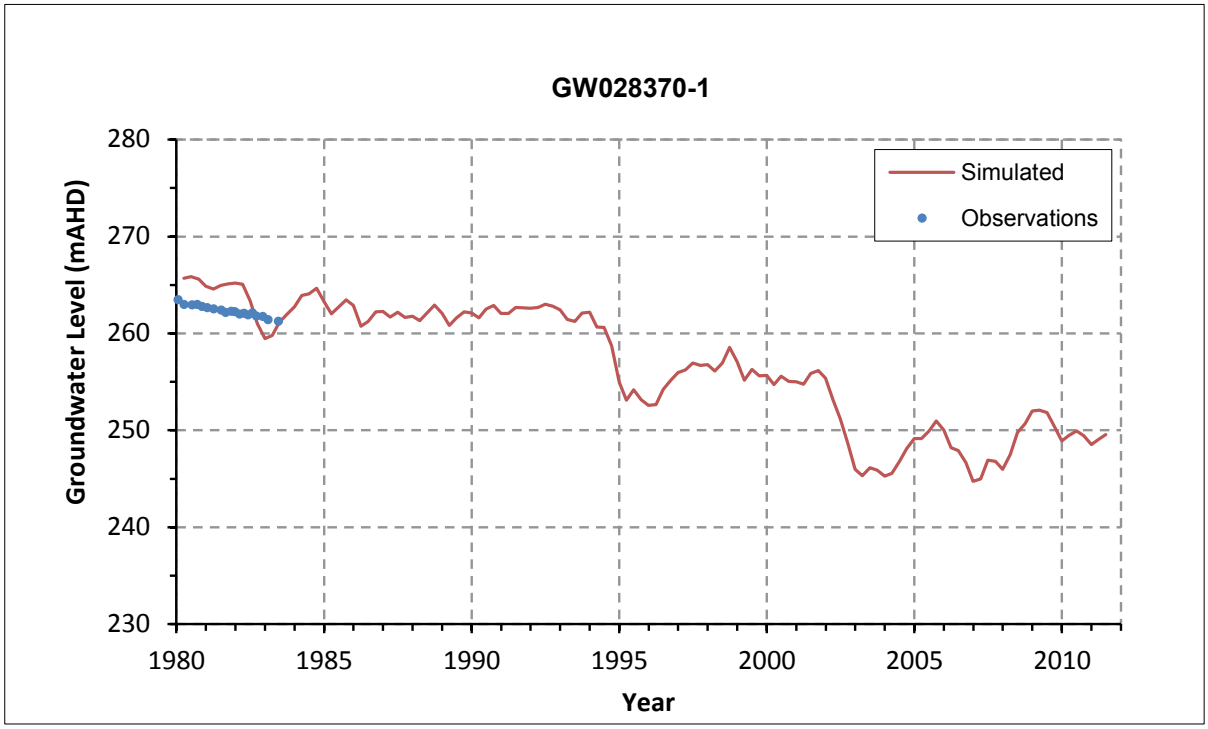

GW028165-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

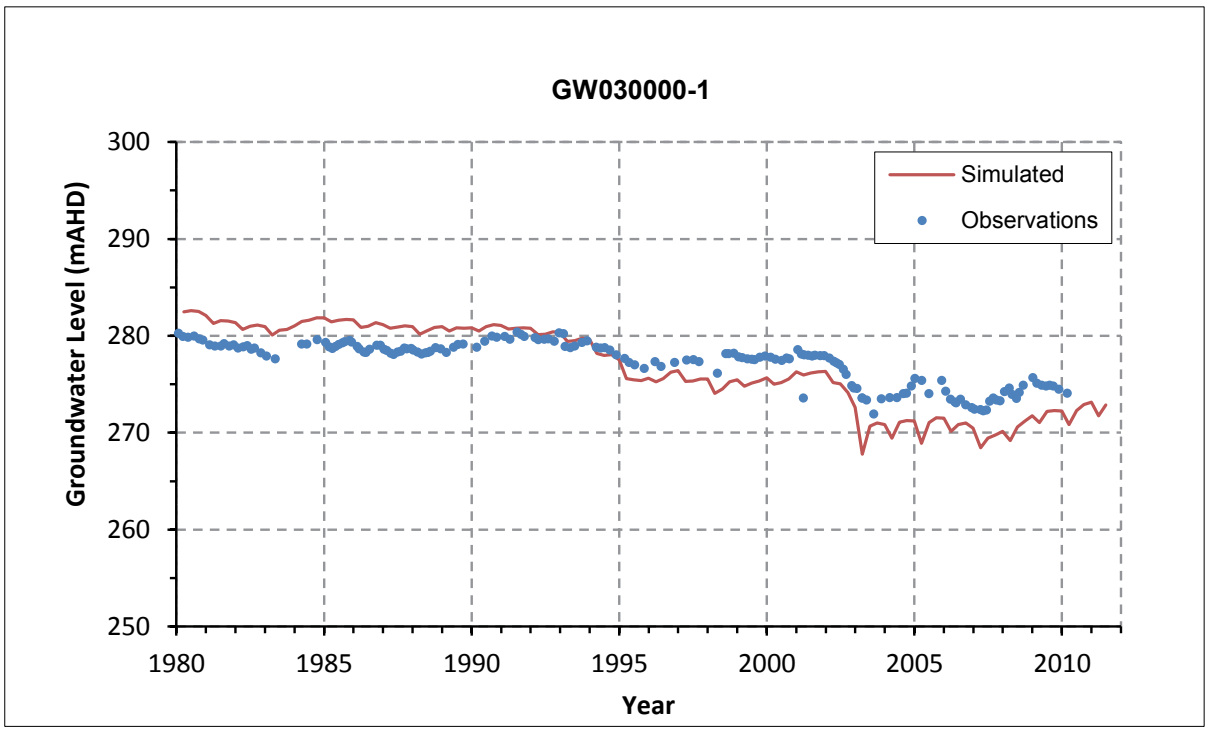

GW028166-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

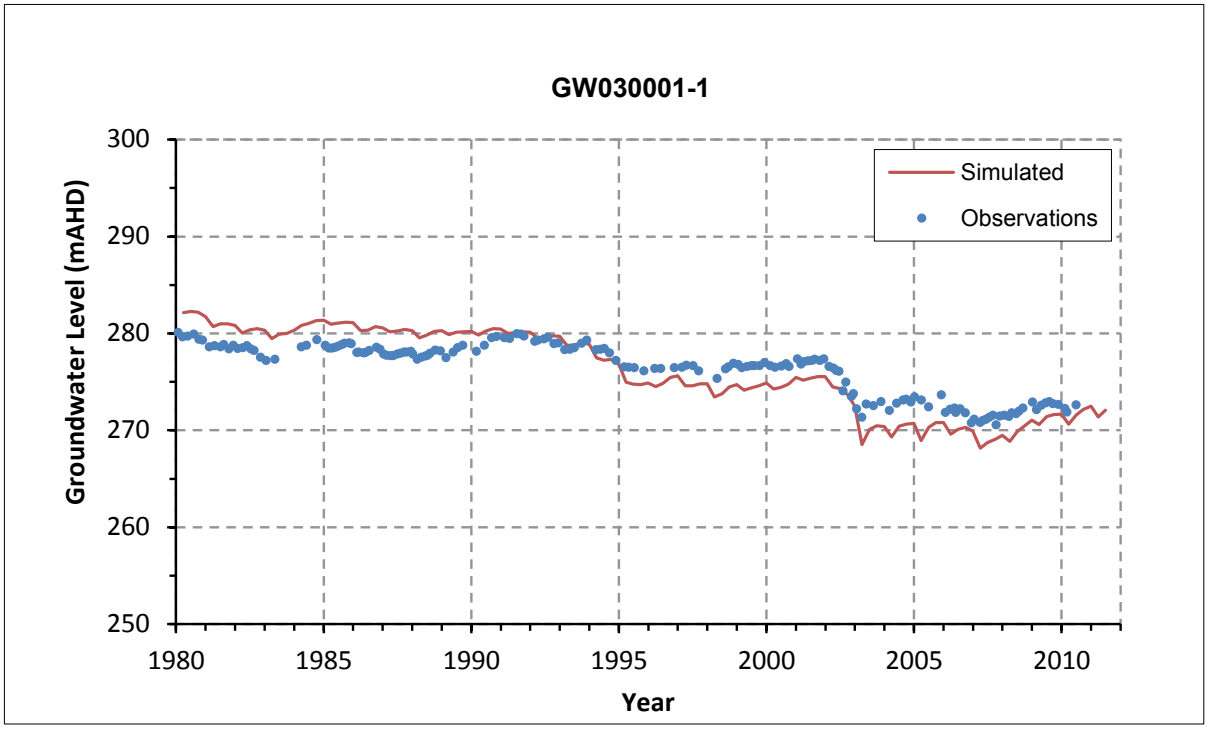

GW028167-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

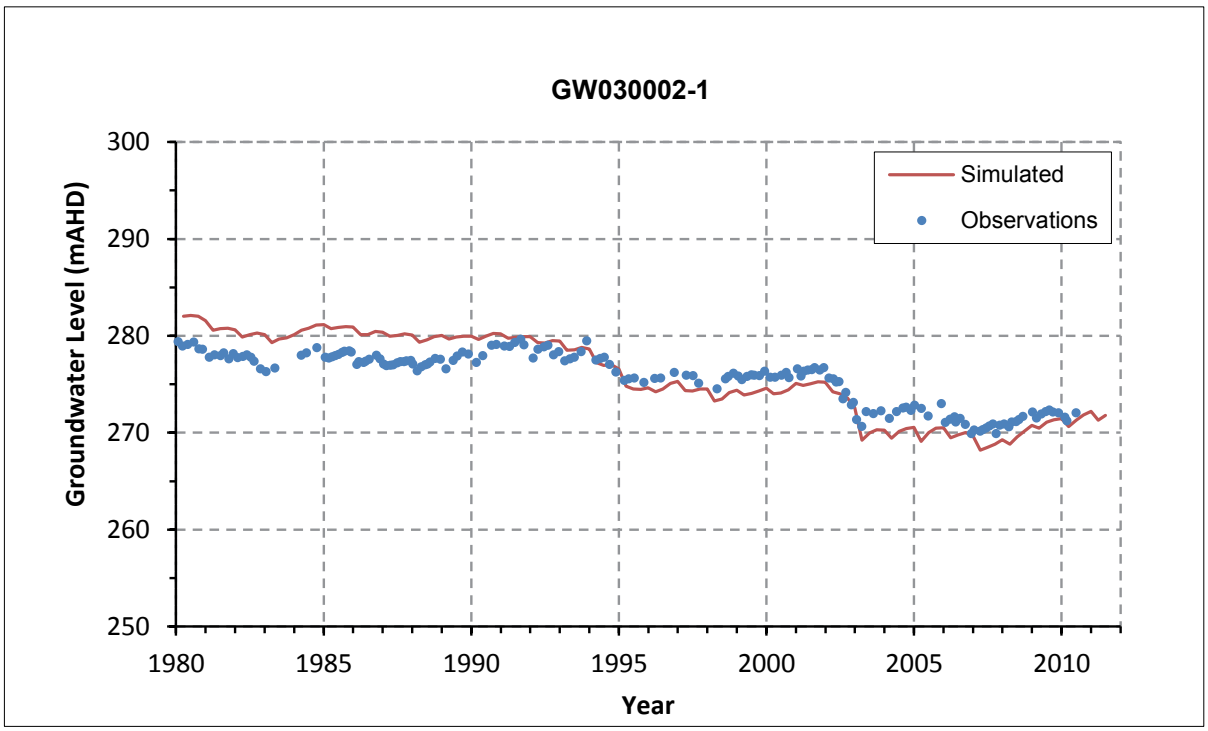

GW028368-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

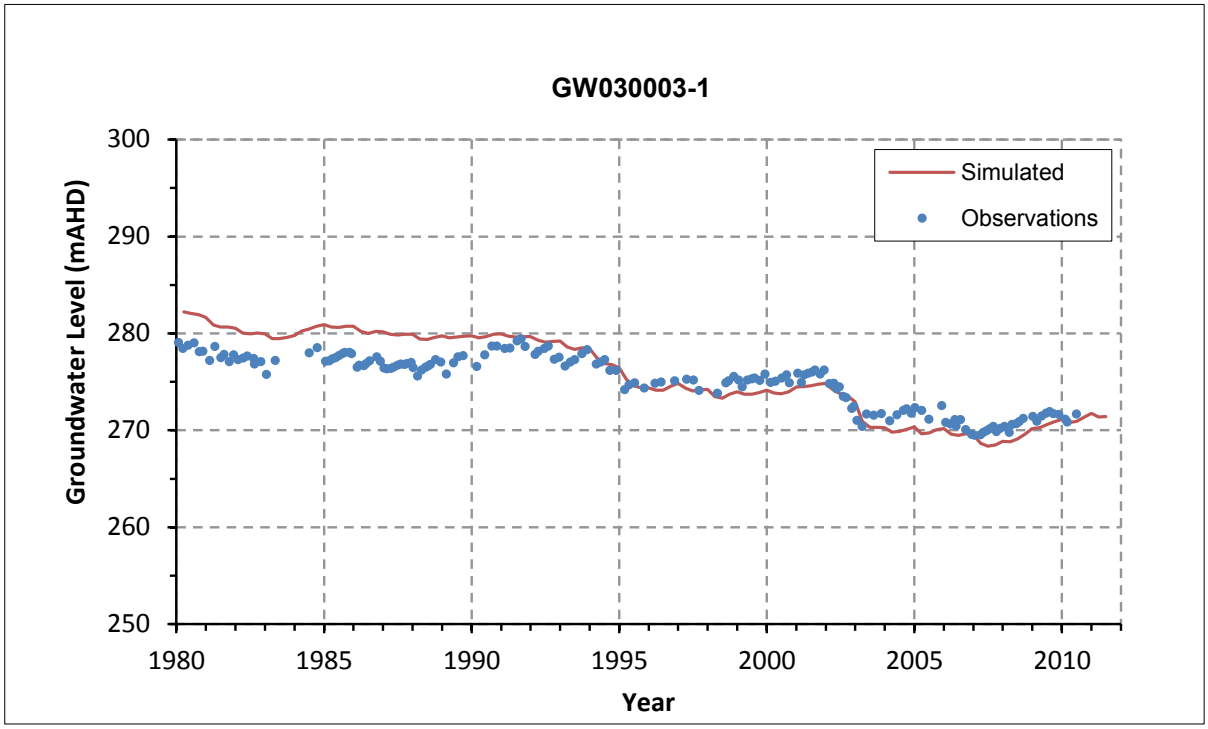

GW028369-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

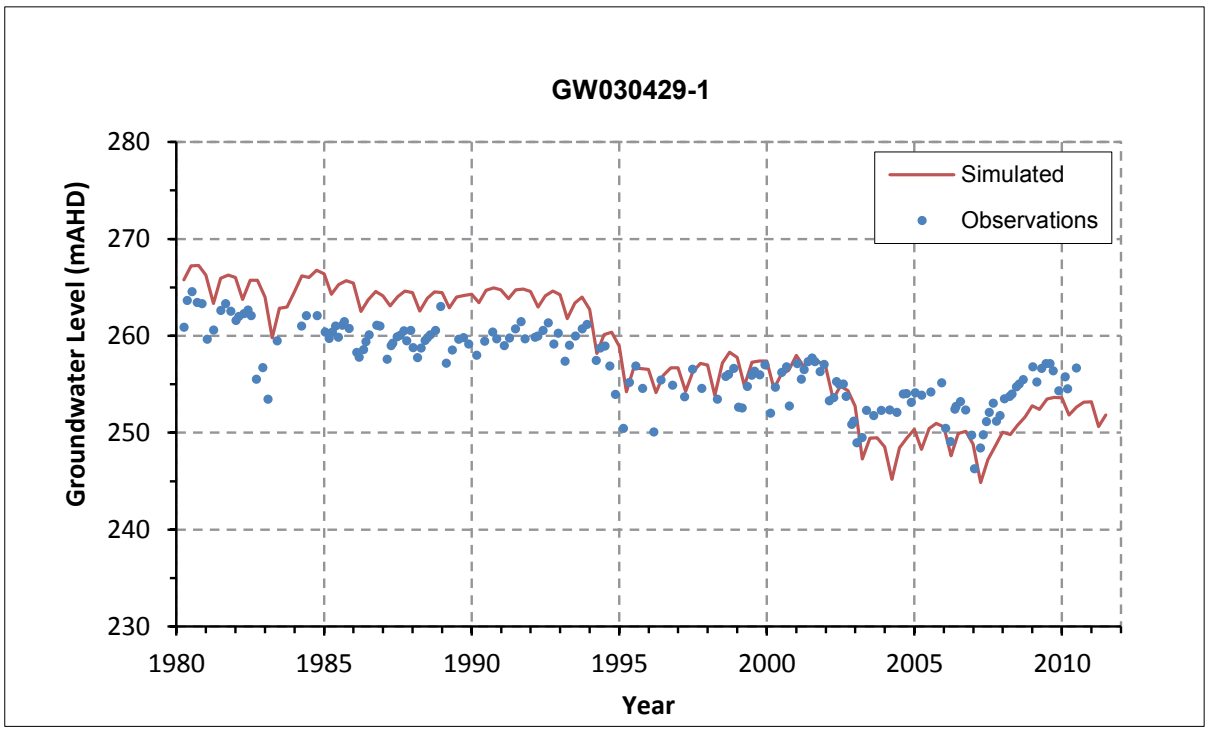

GW028370-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

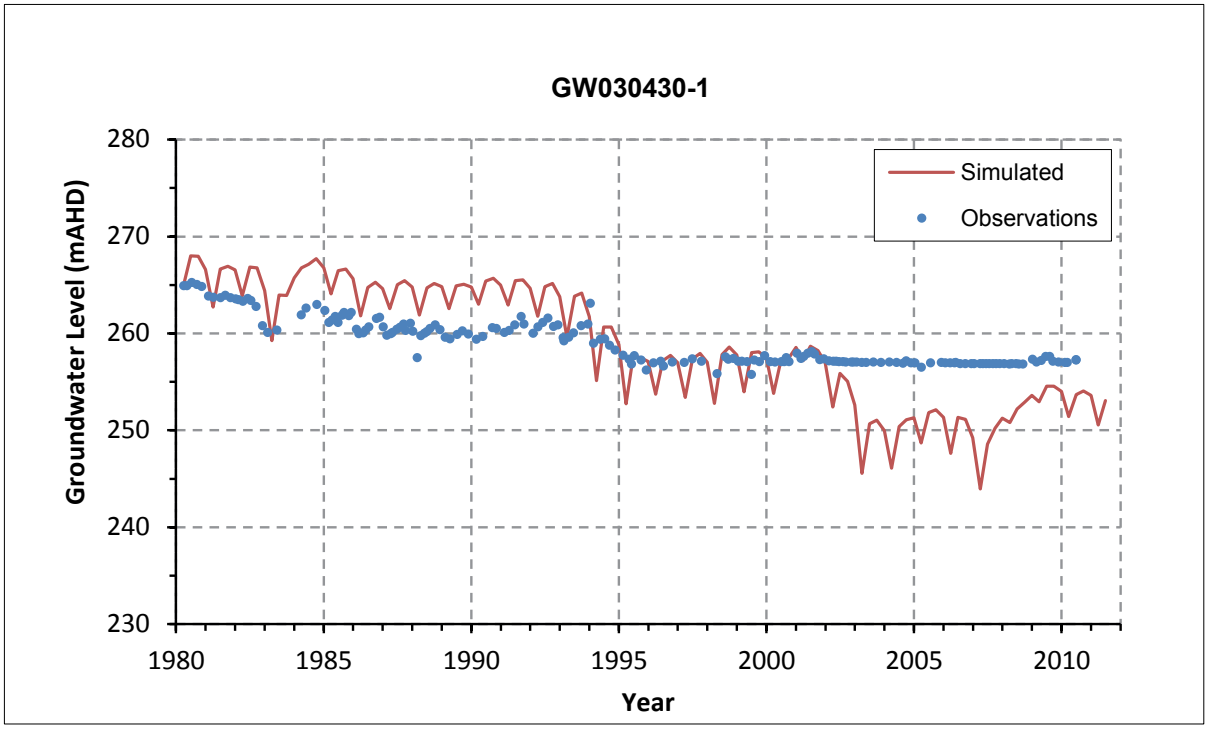

GW030000-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

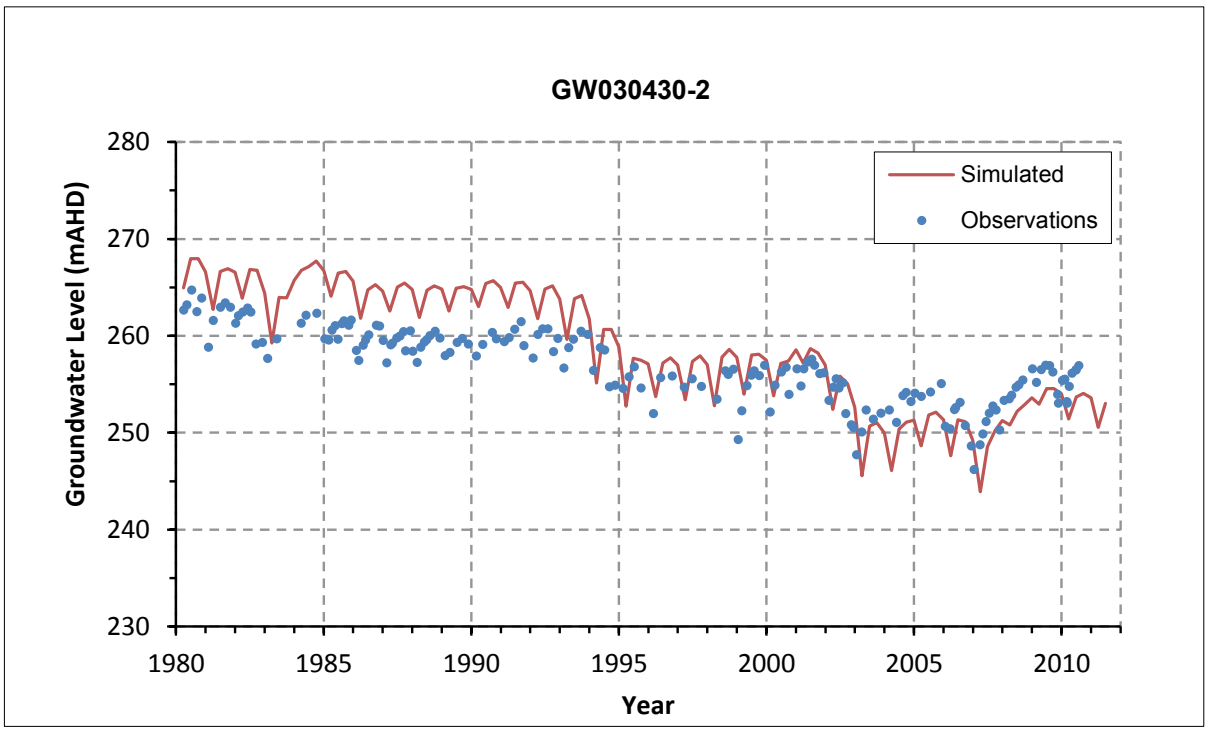

GW030001-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

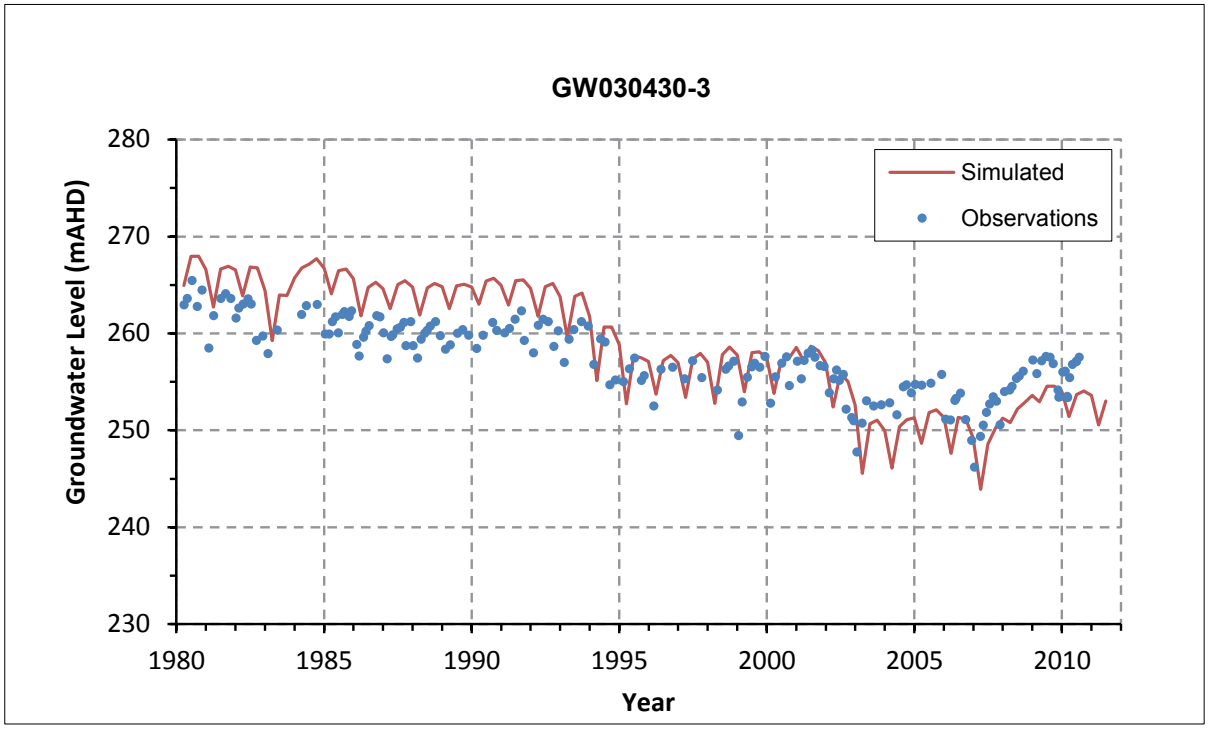

GW030002-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

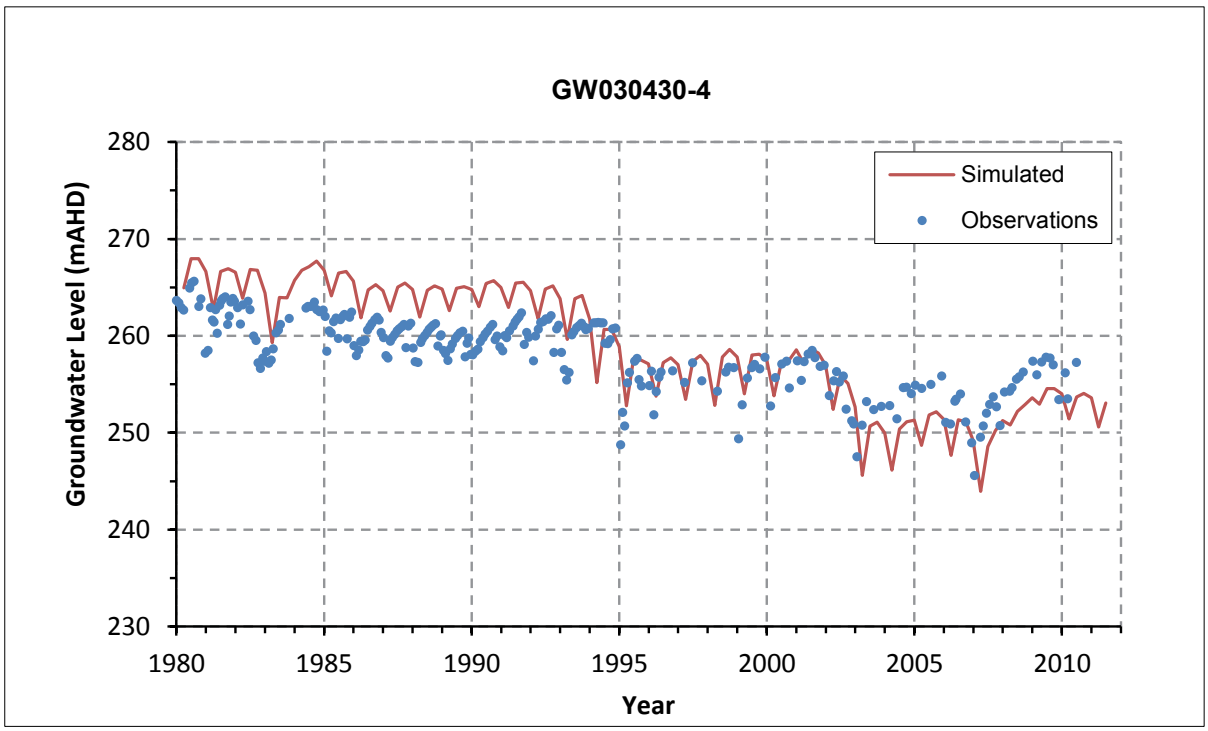

GW030003-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

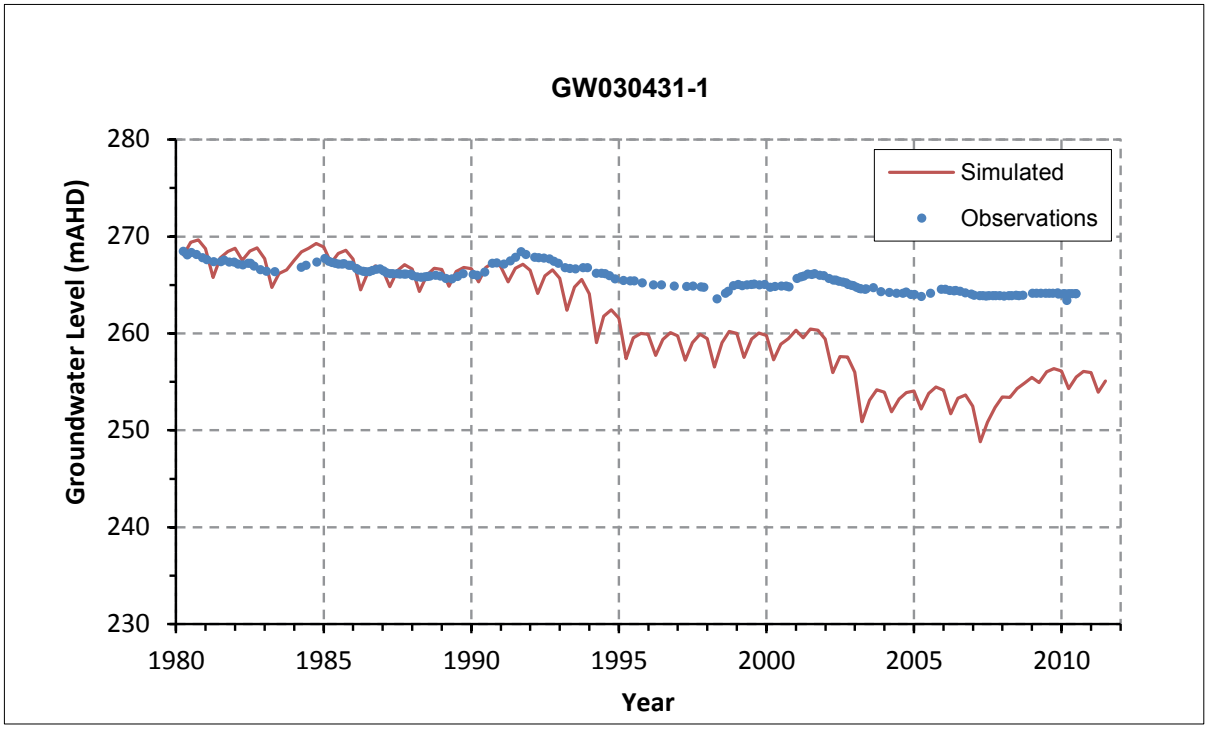

GW030429-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

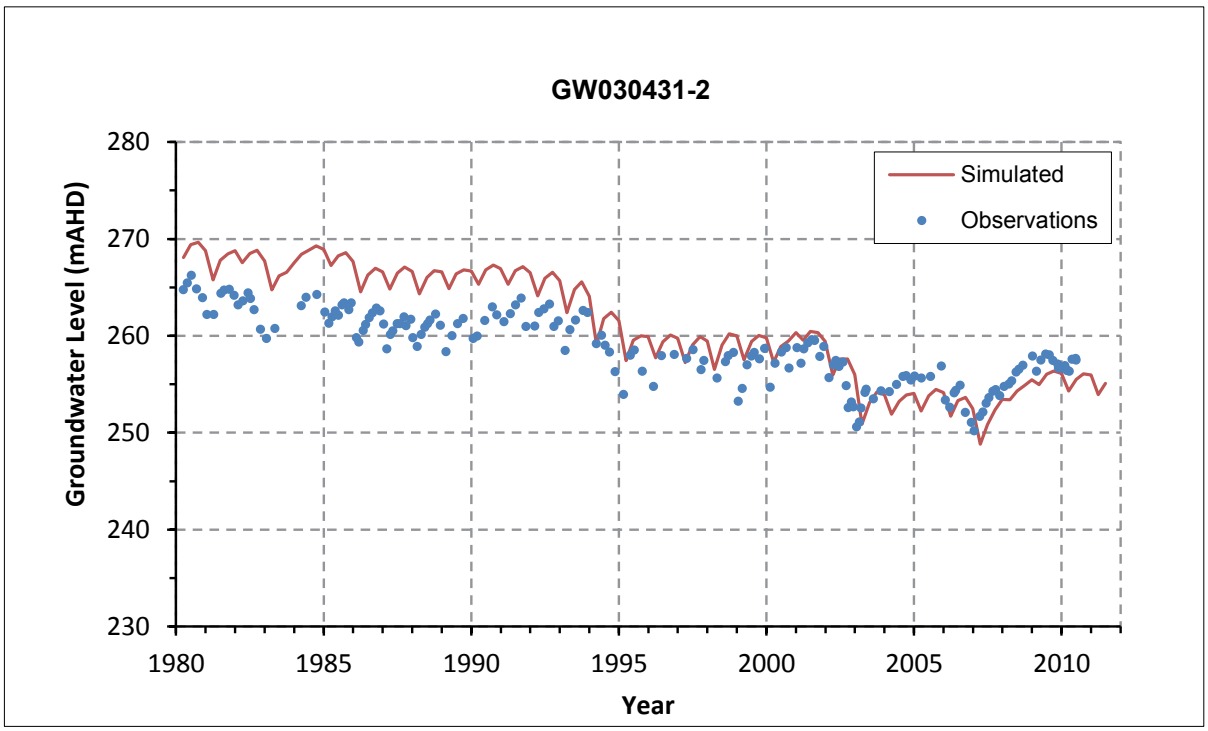

GW030430-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

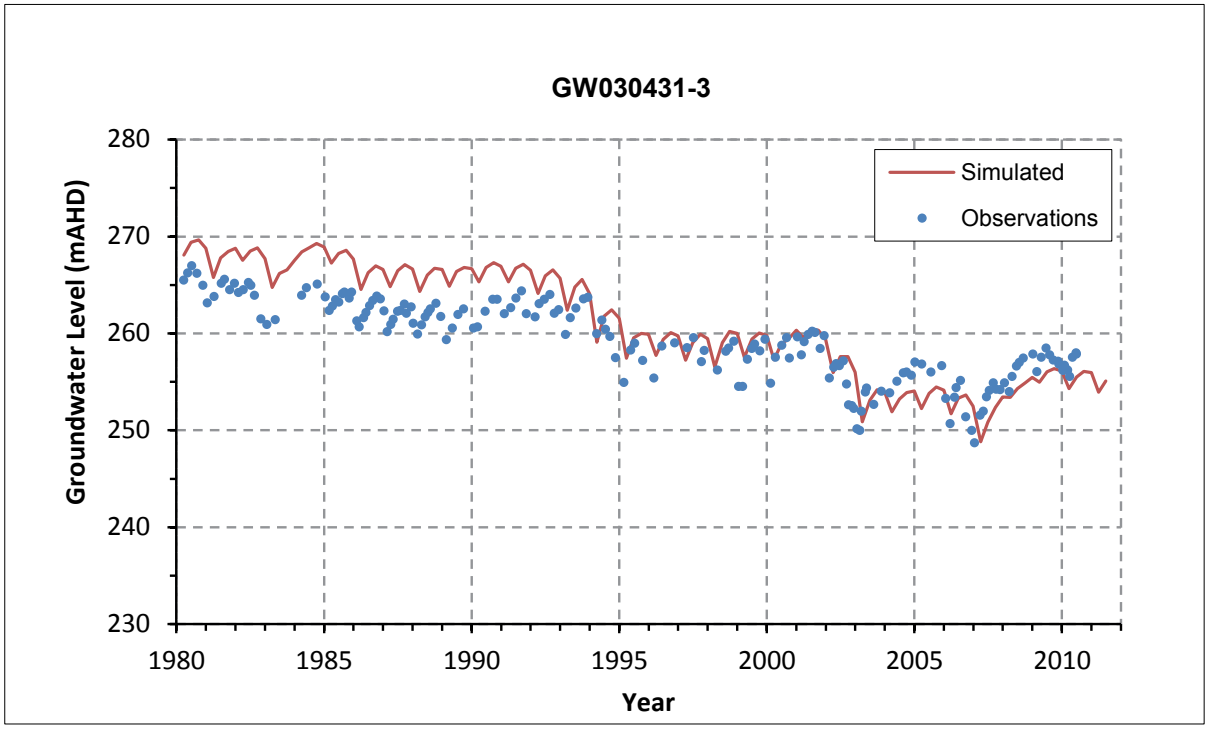

GW030430-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

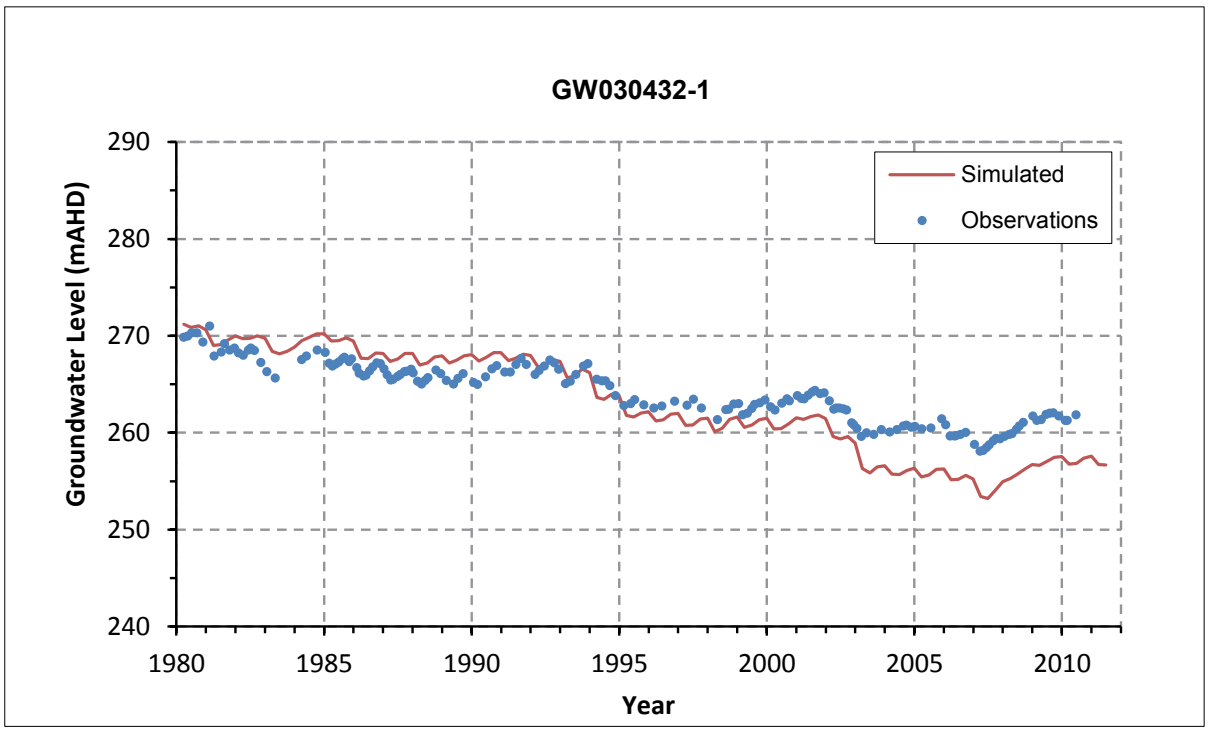

GW030430-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

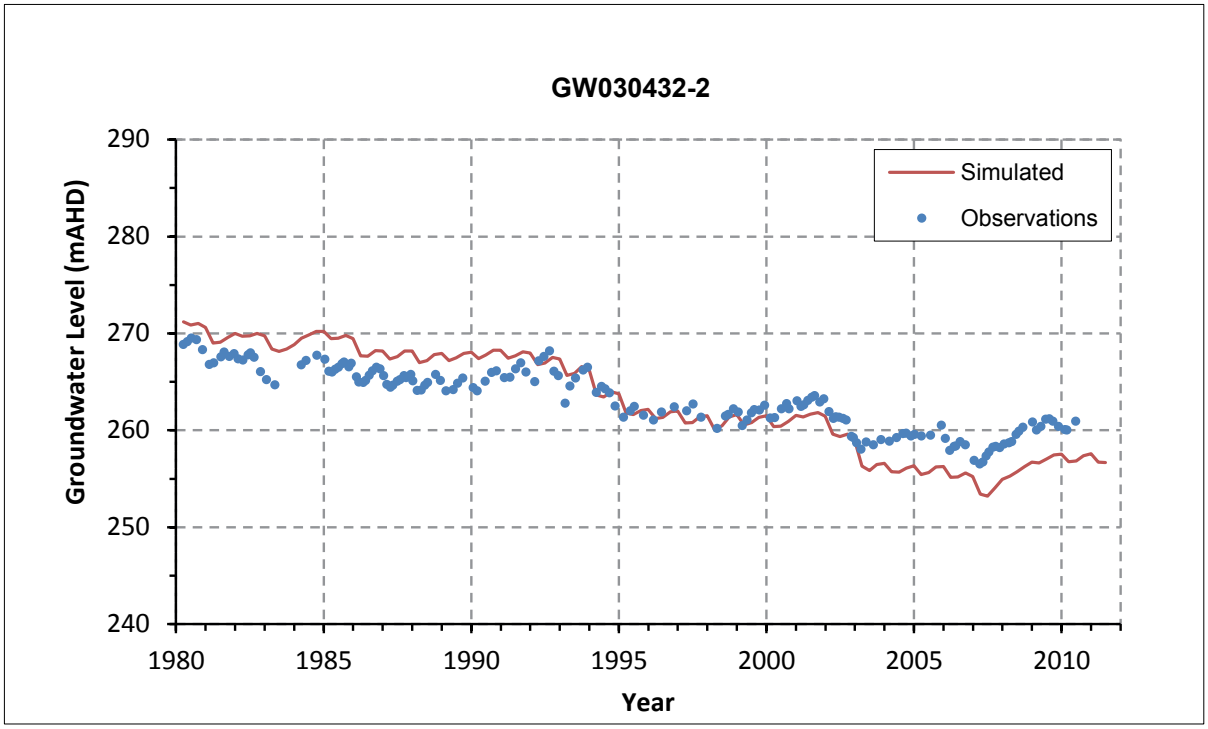

GW030430-4
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

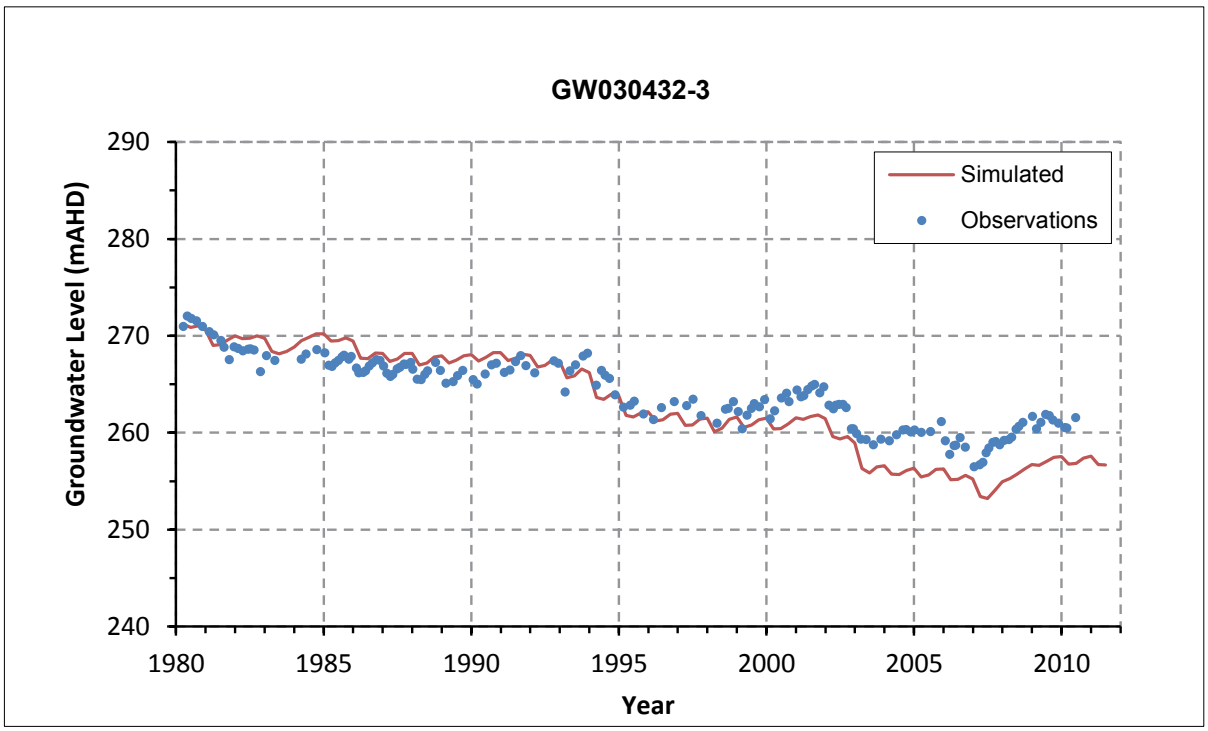

GW030431-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

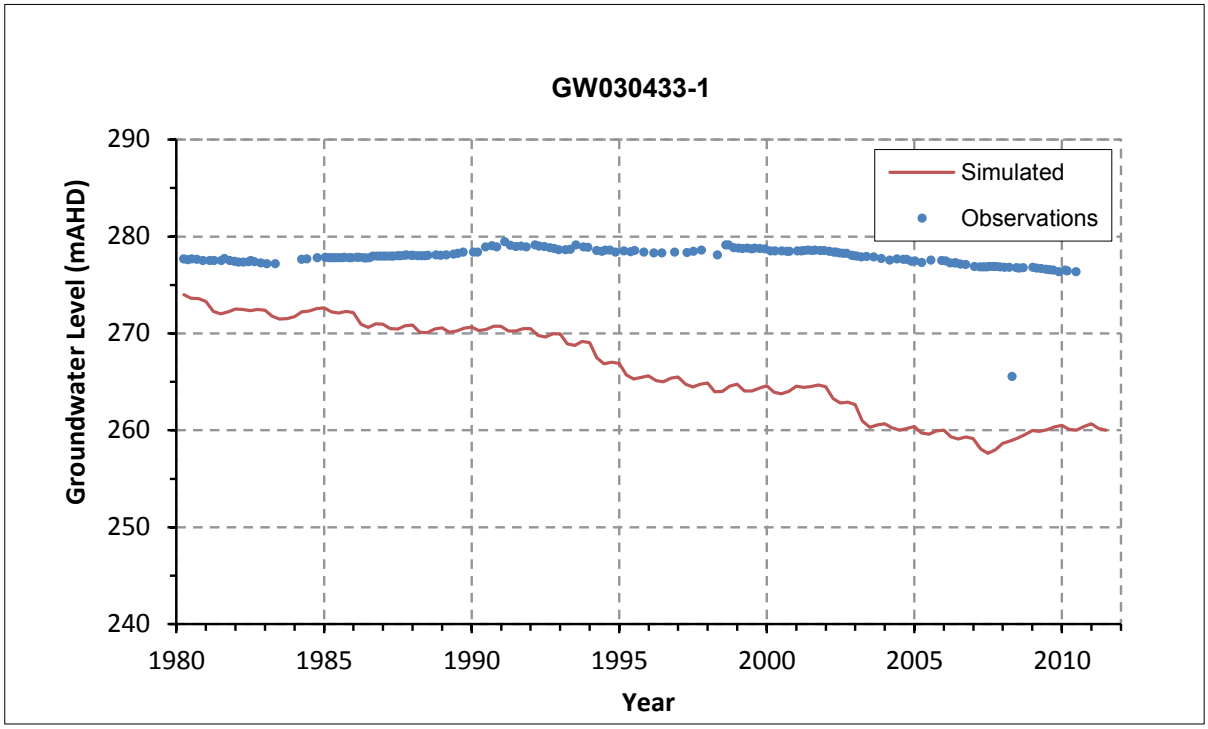

GW030431-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

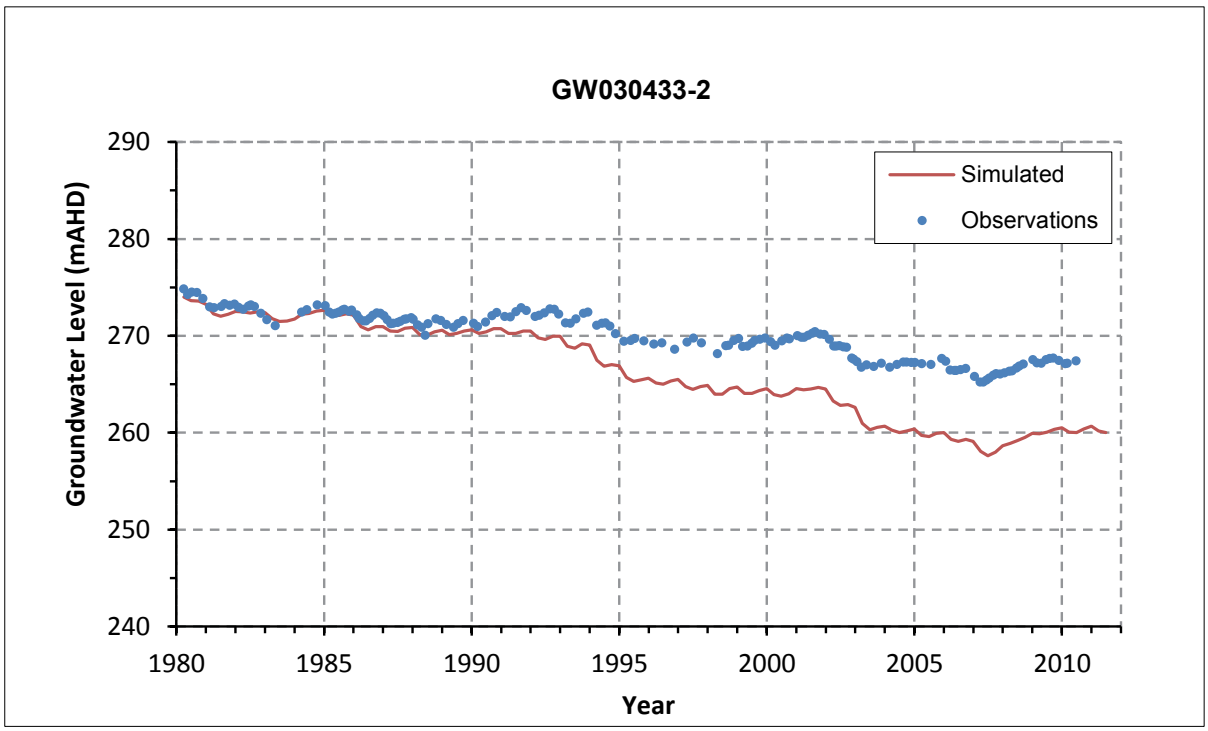

GW030431-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

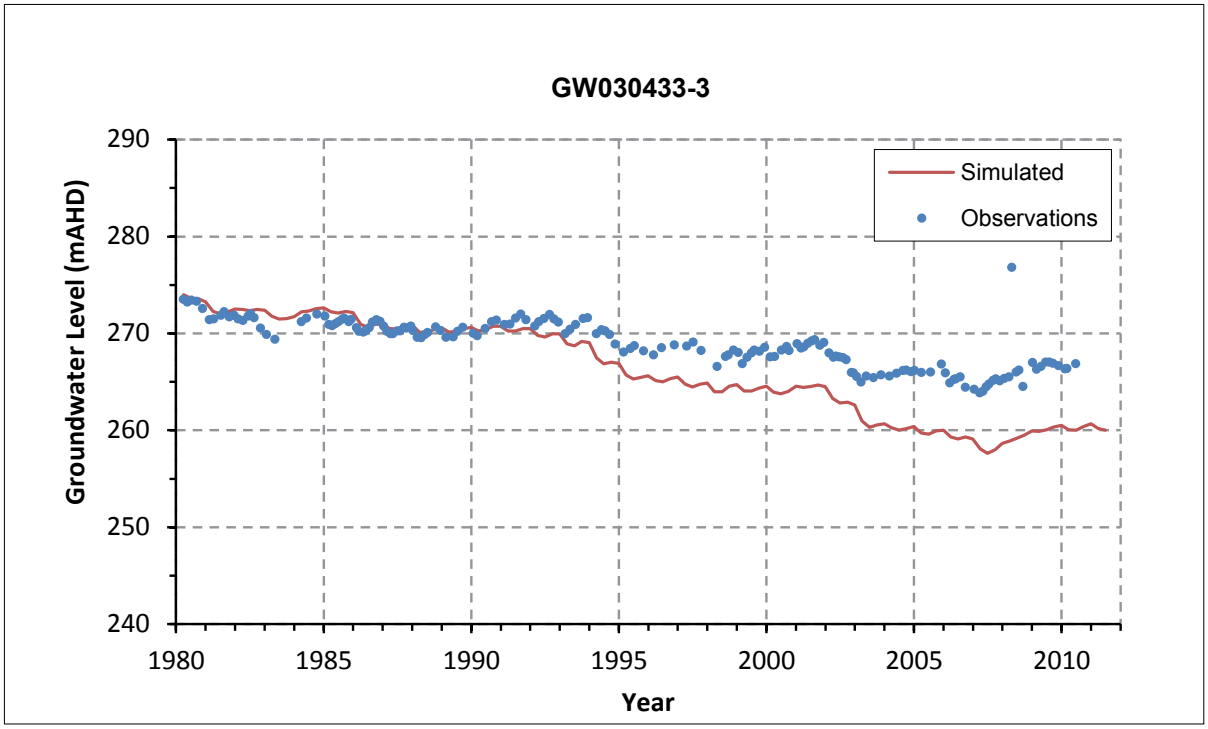

GW030432-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

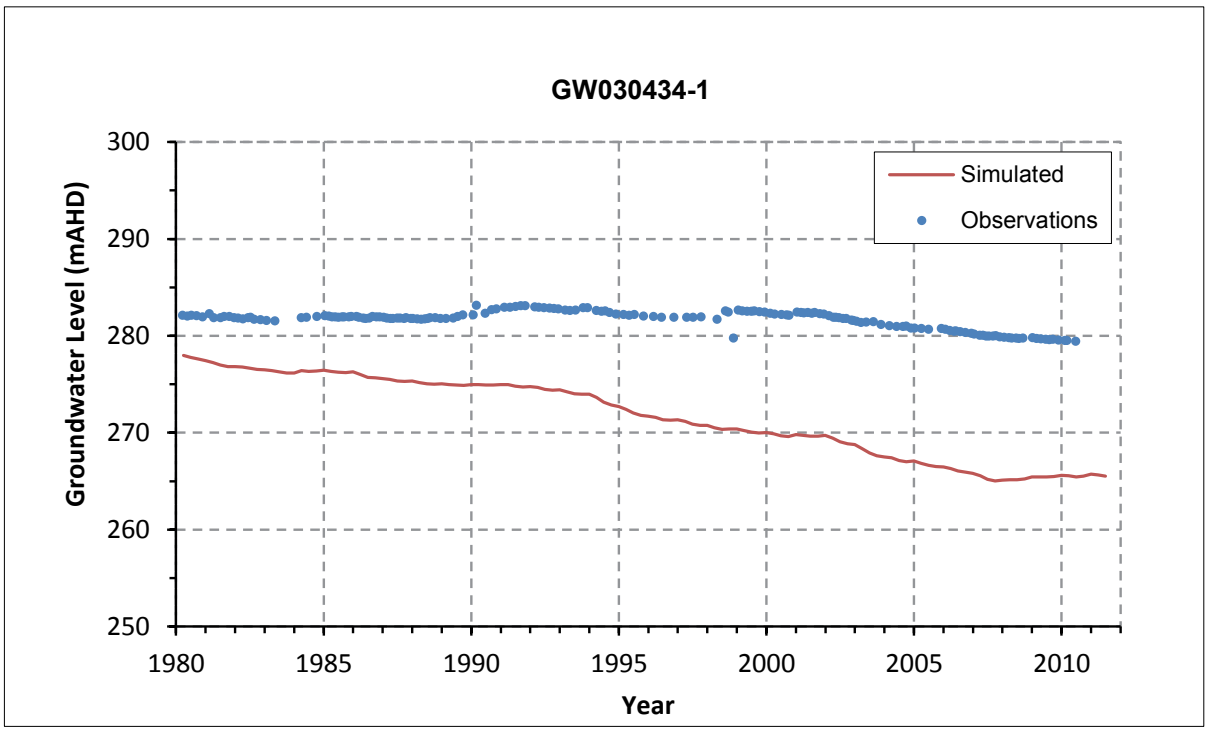

GW030432-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

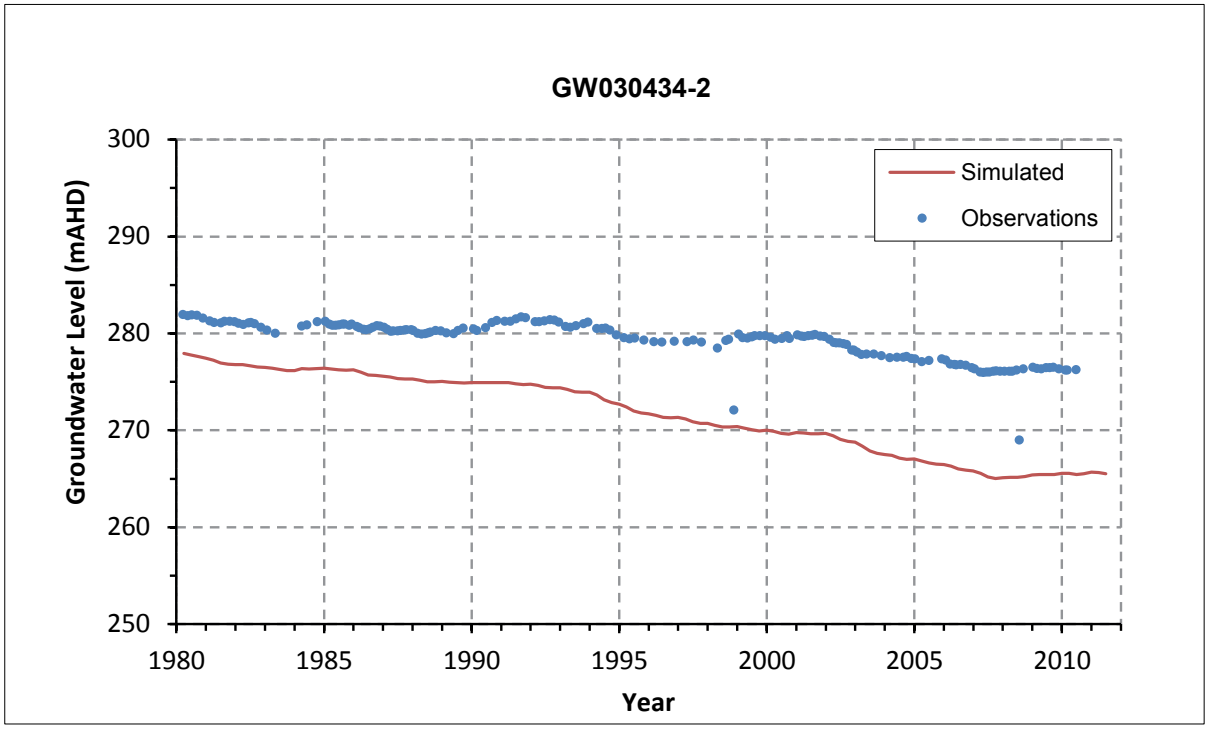

GW030432-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

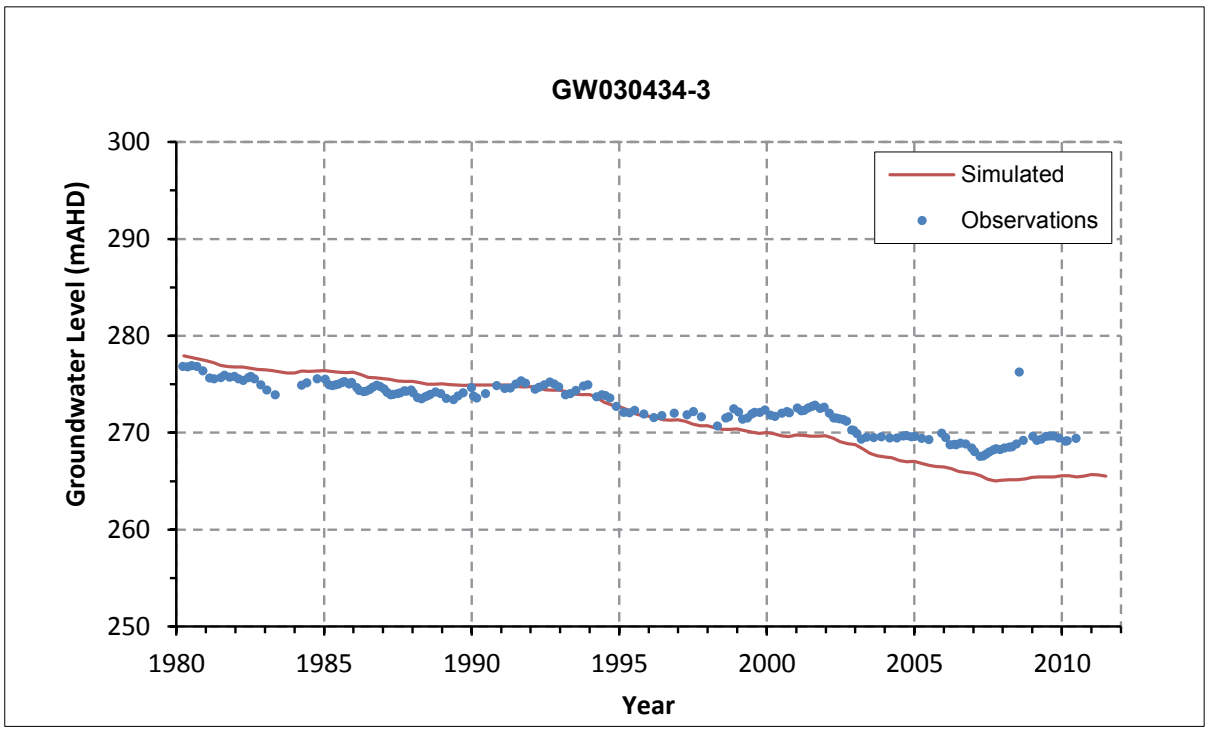

GW030433-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

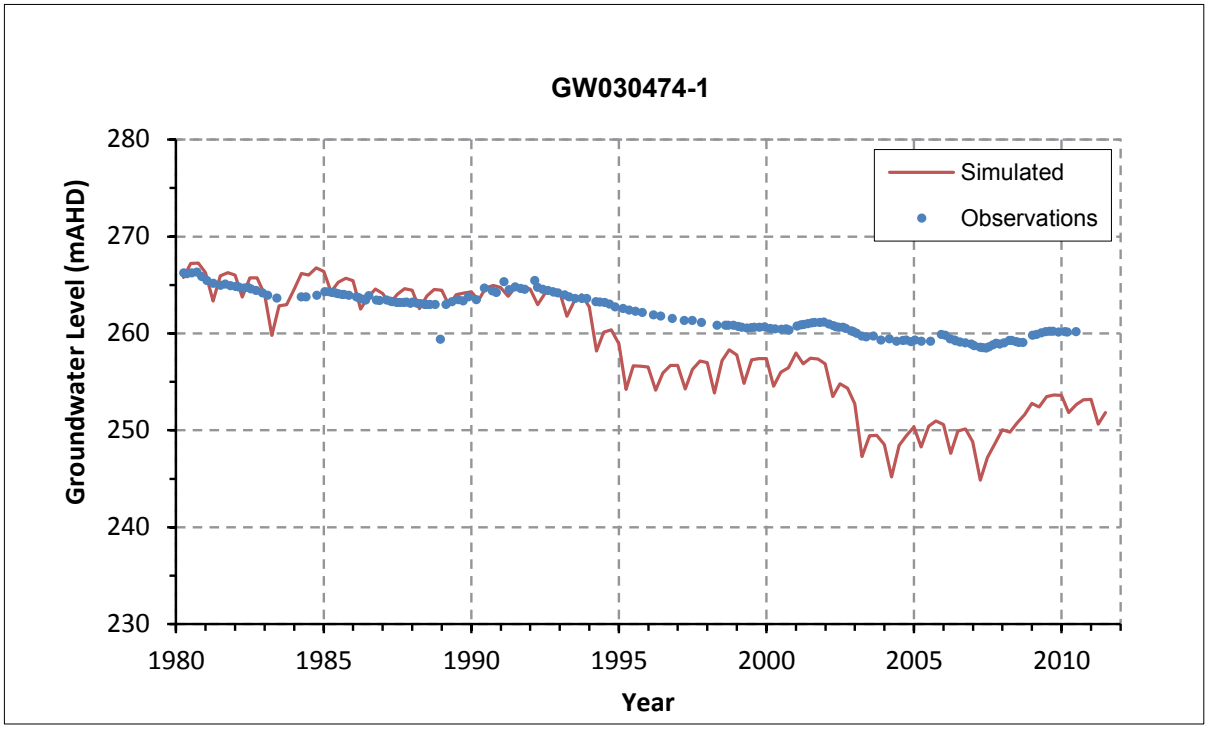

GW030433-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

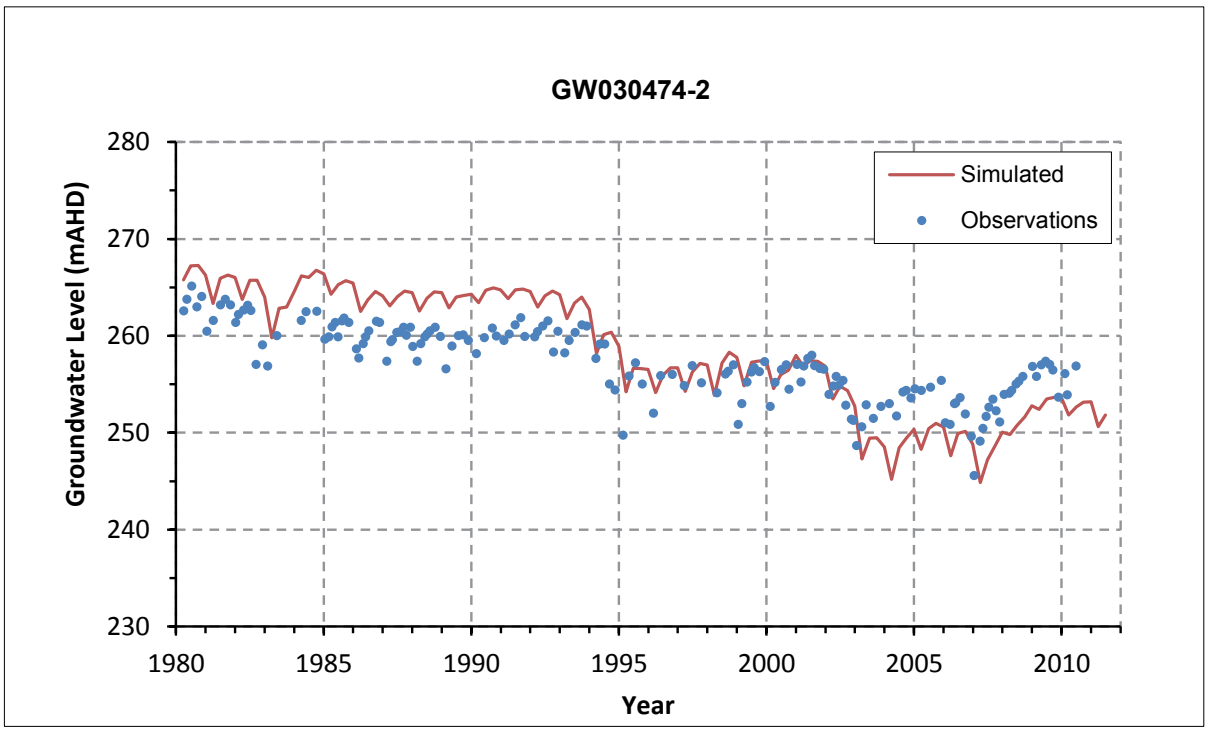

GW030433-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

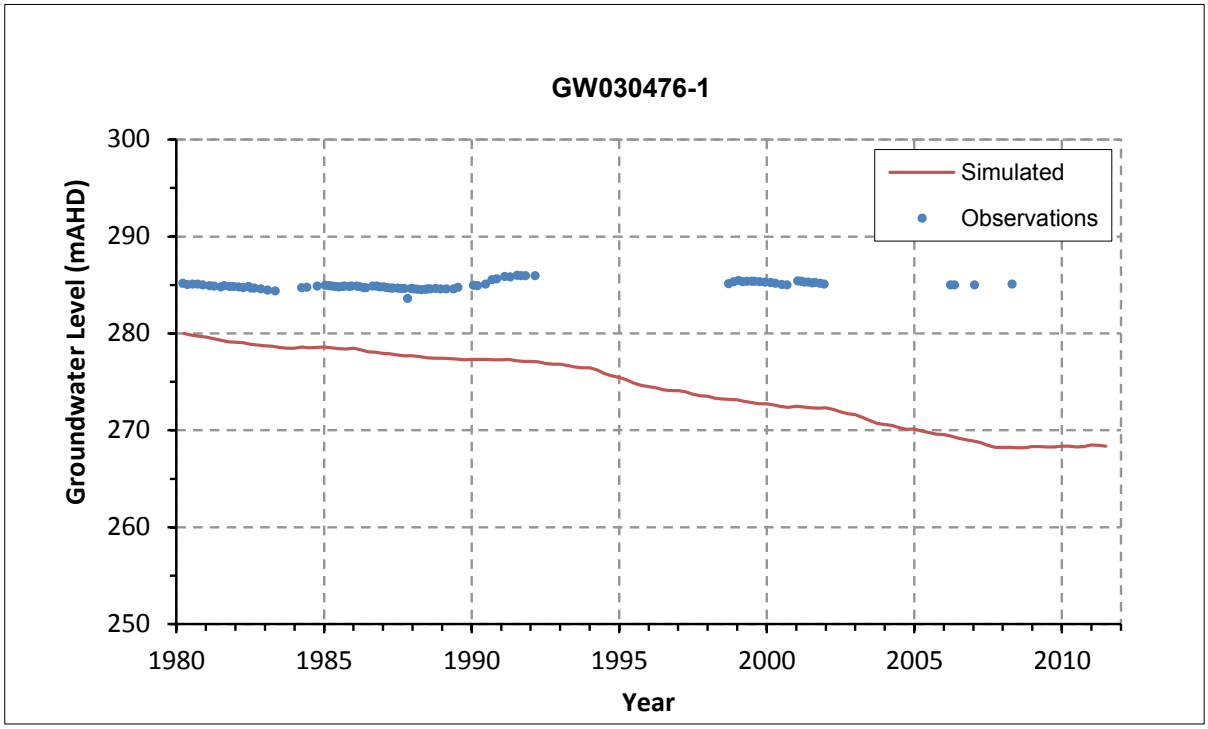

GW030434-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

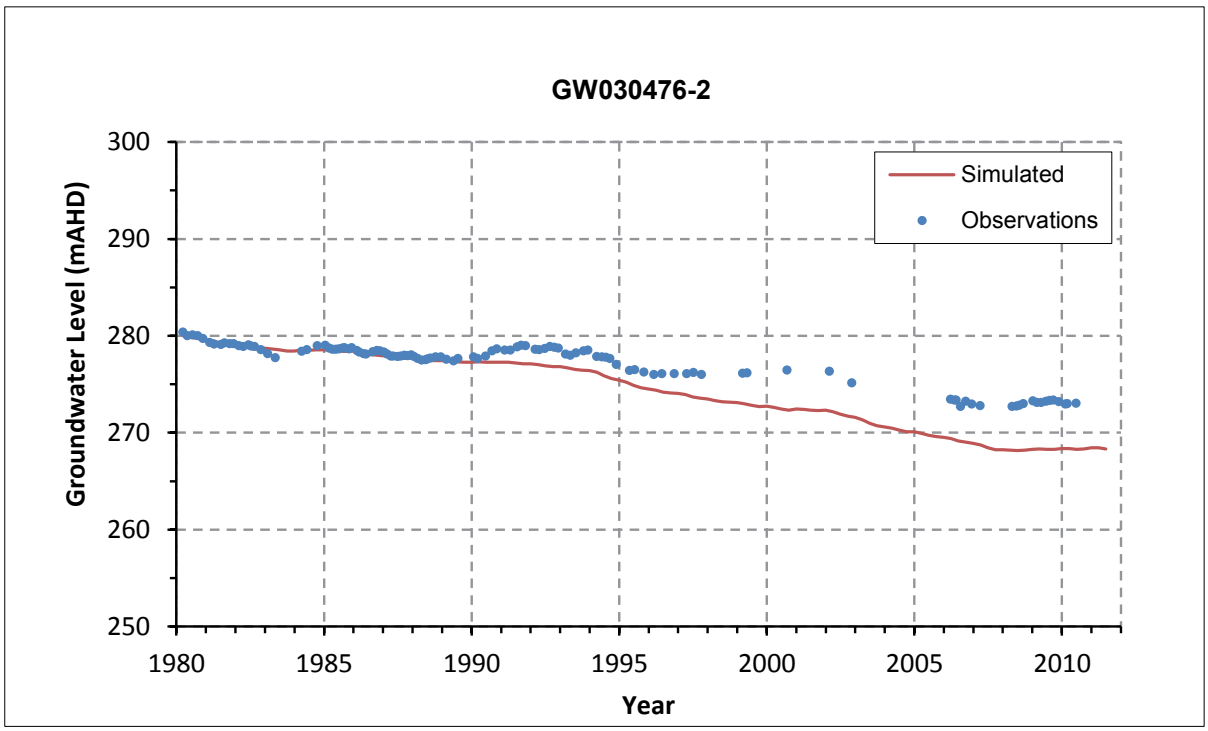

GW030434-2
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

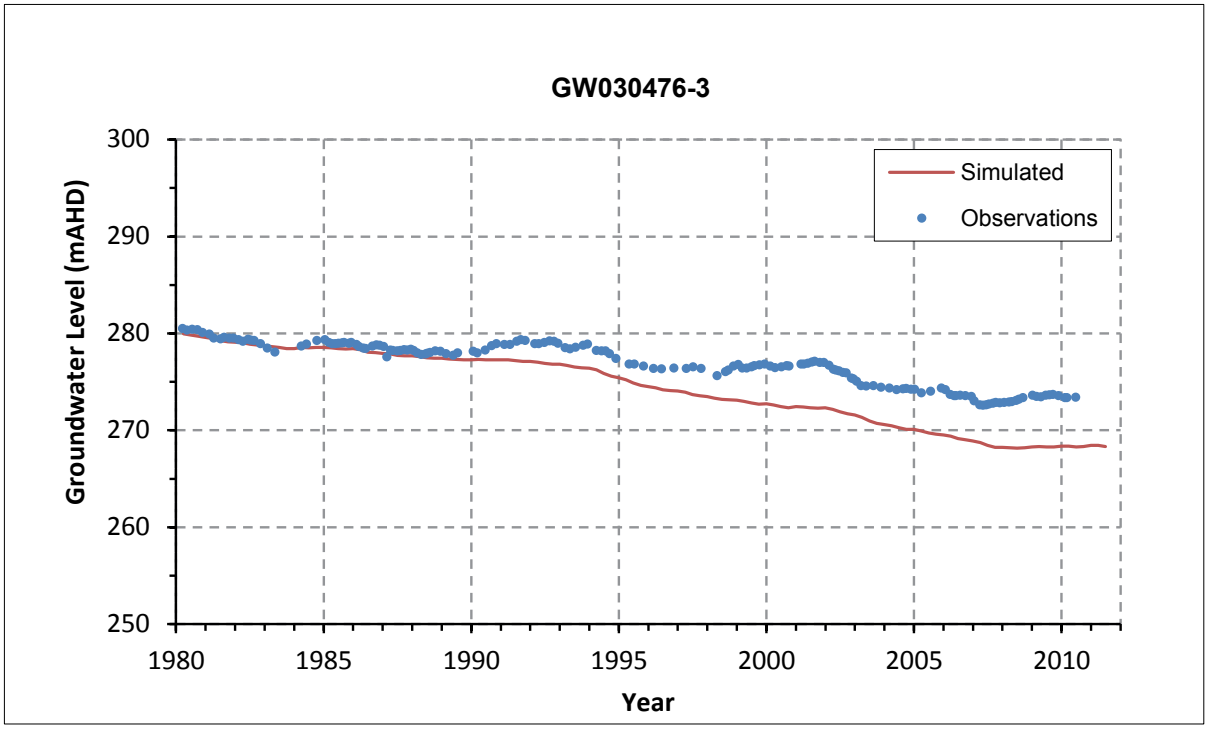

GW030434-3
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

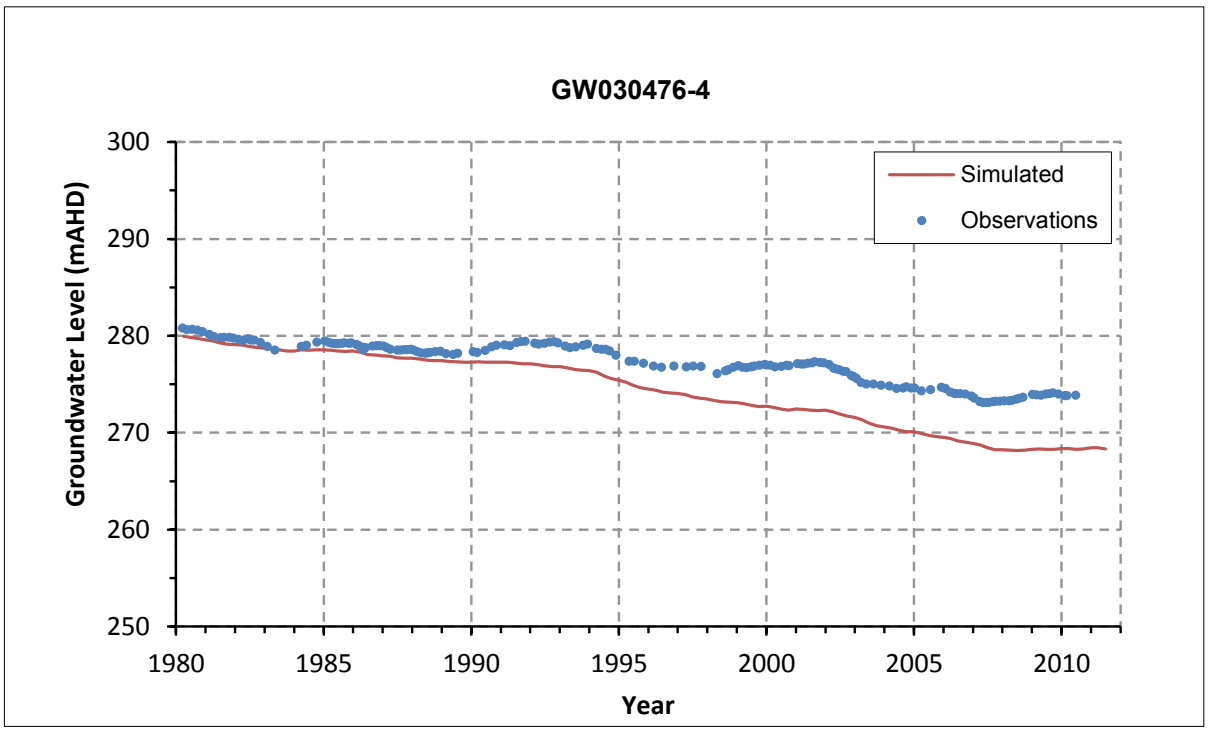

GW030474-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

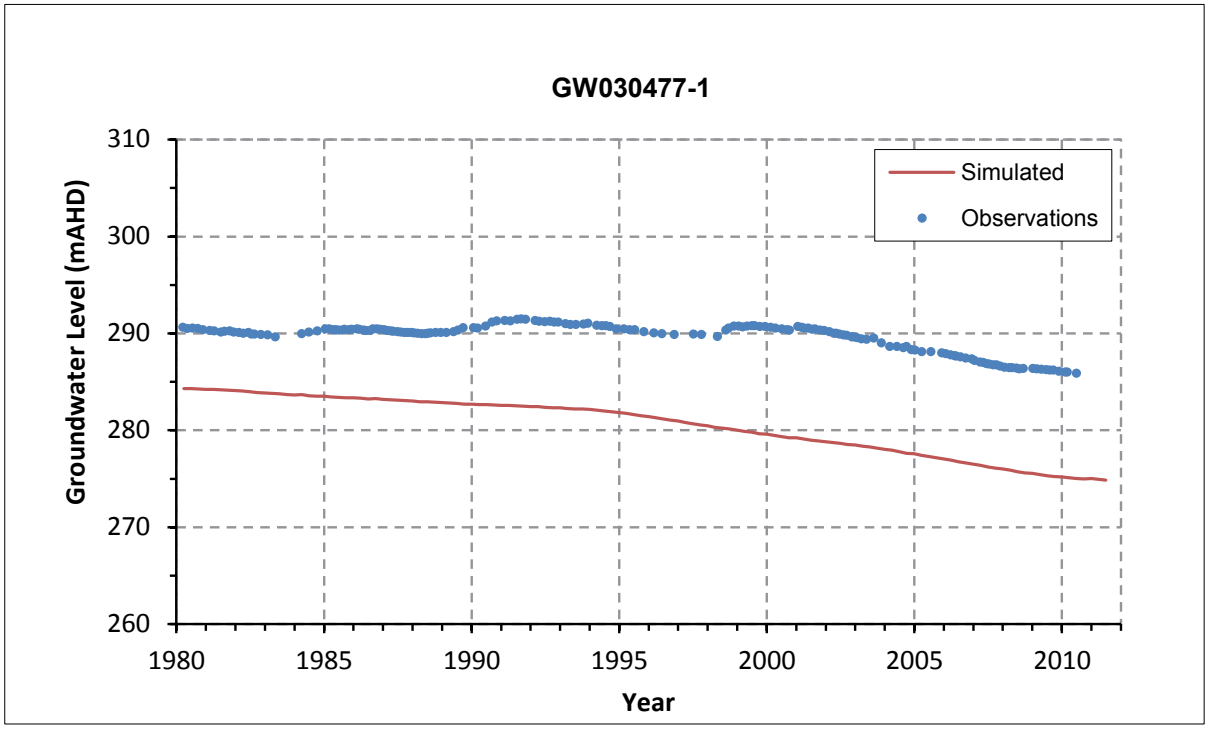

GW030474-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

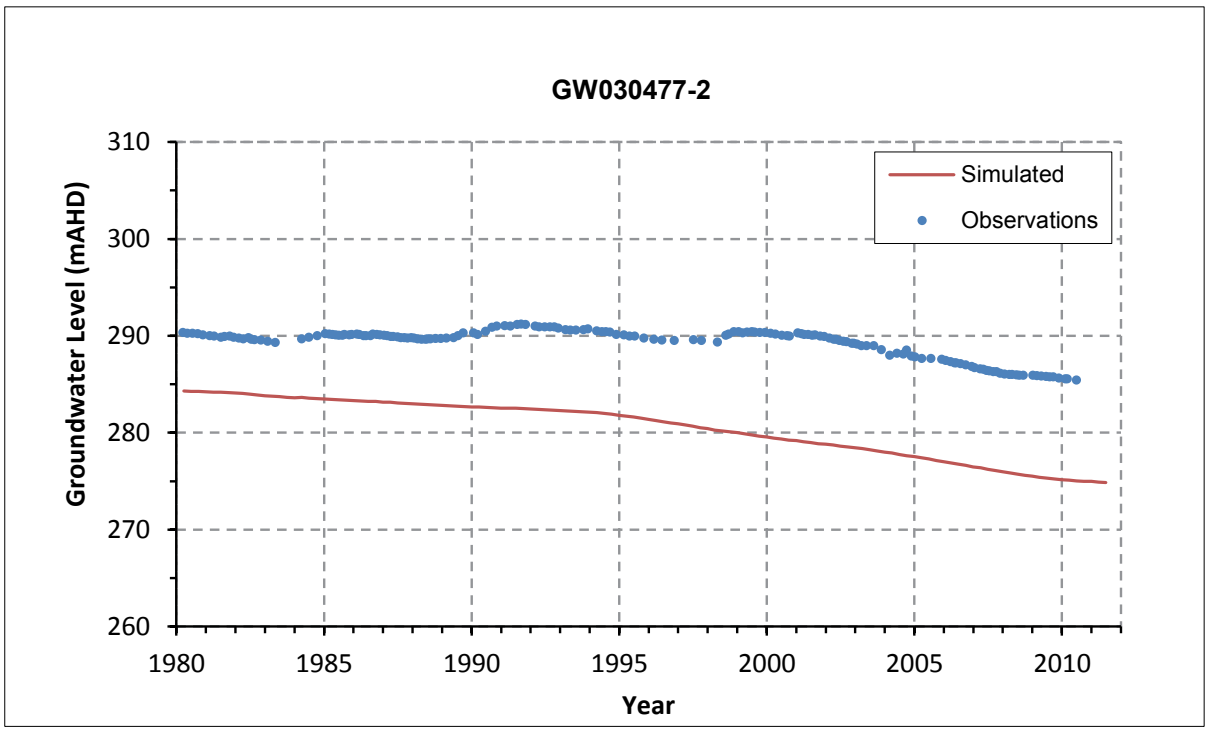

GW030476-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

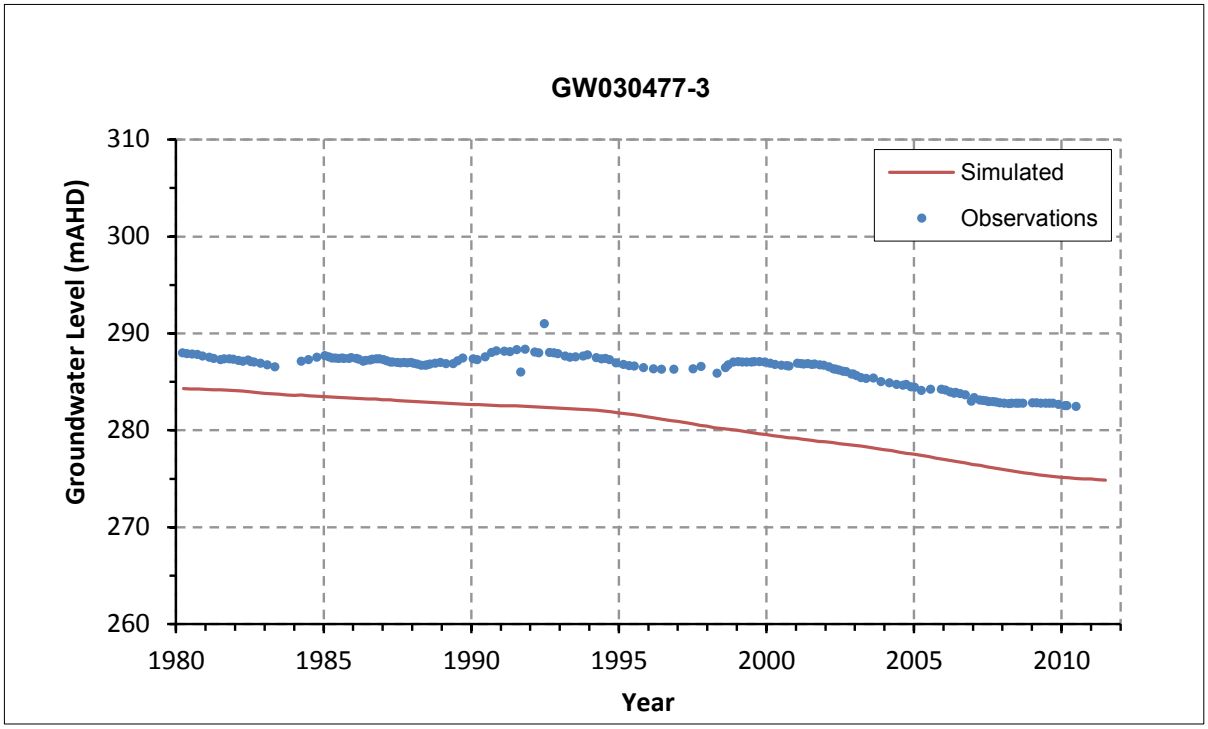

GW030476-2
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

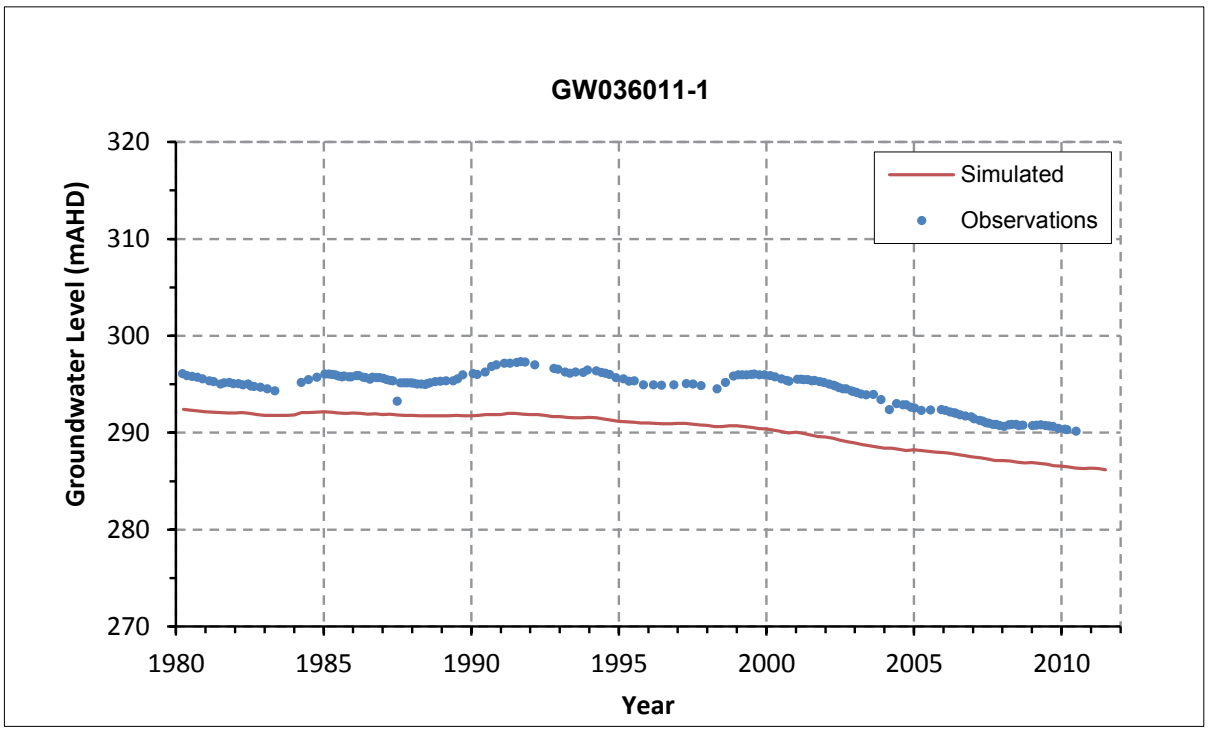

GW030476-3
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

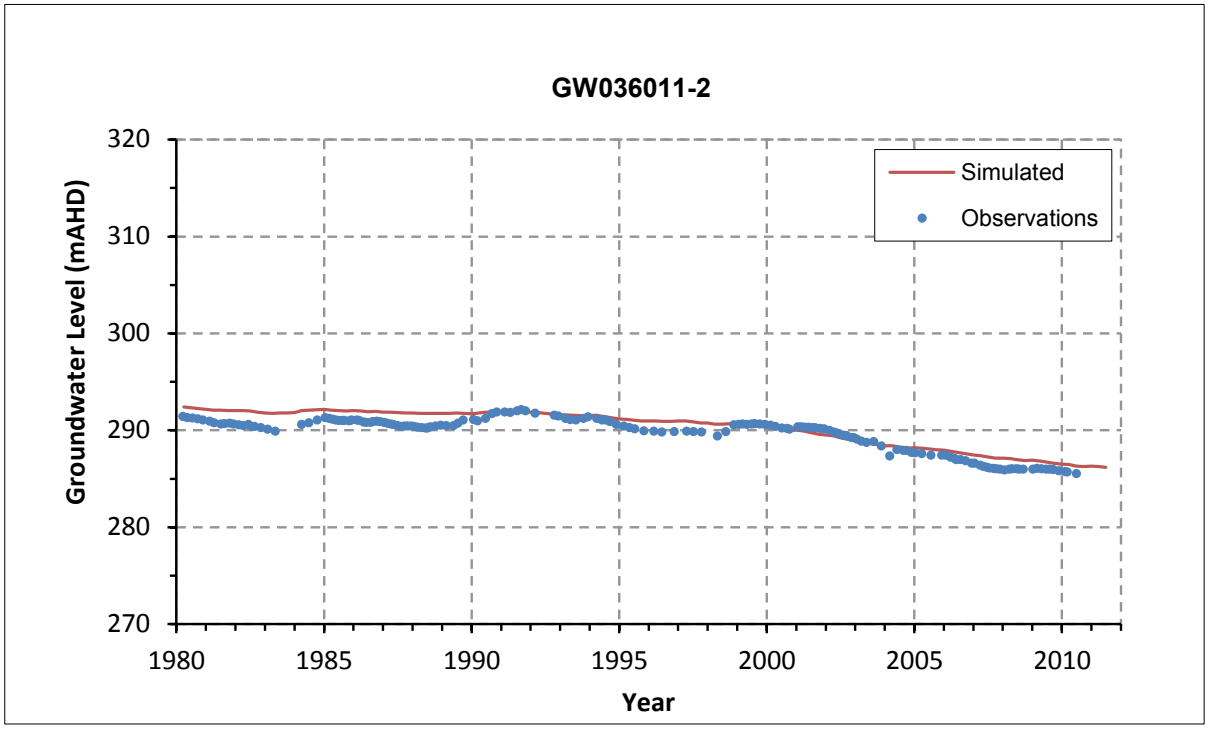

GW030476-4
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

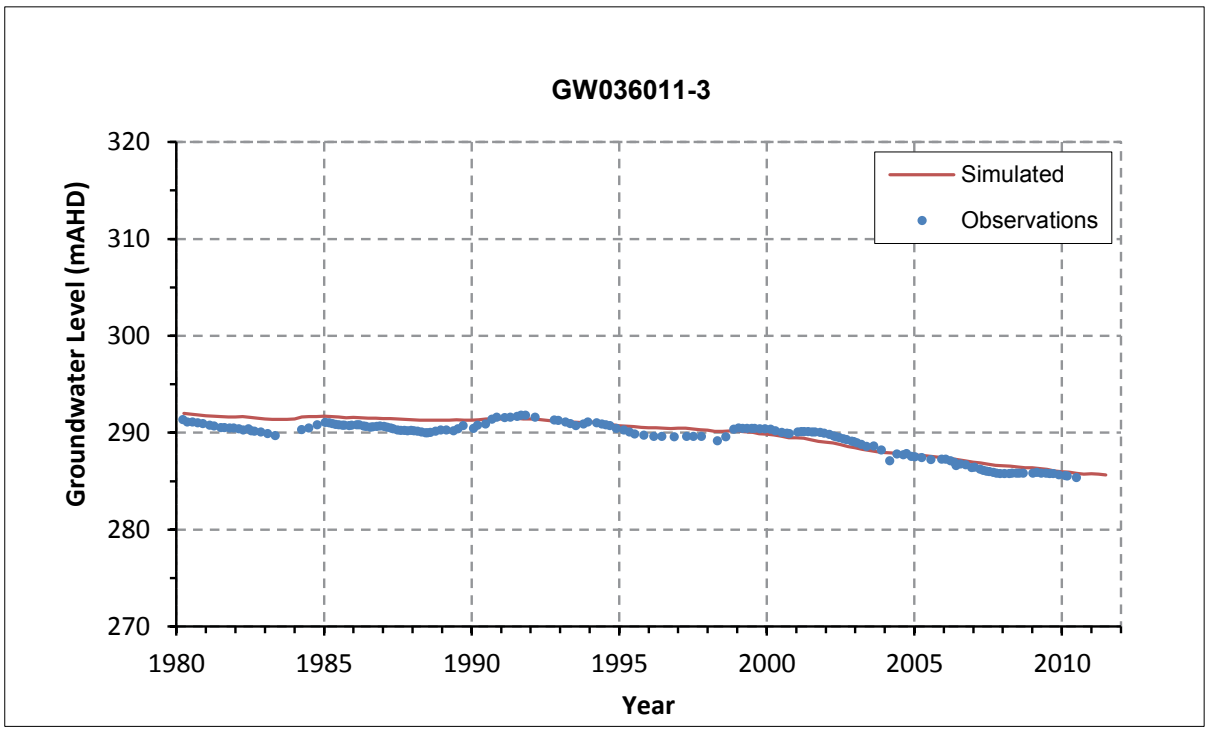

GW030477-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

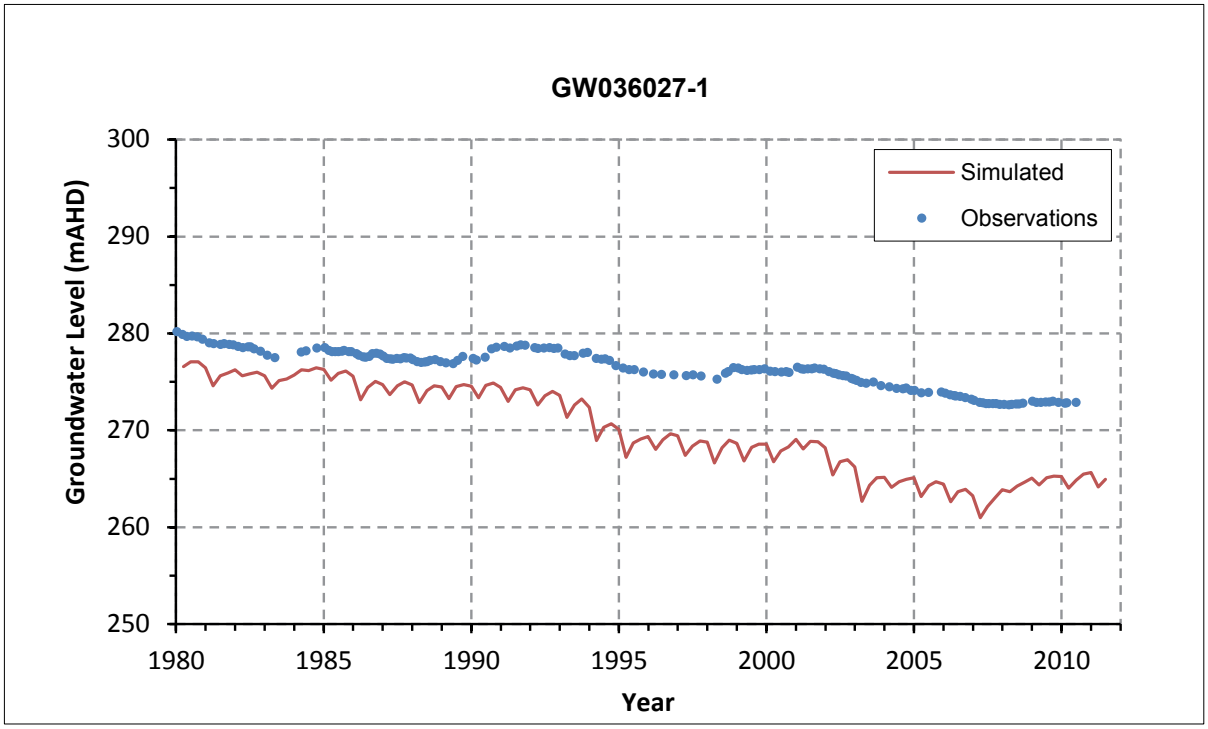

GW030477-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

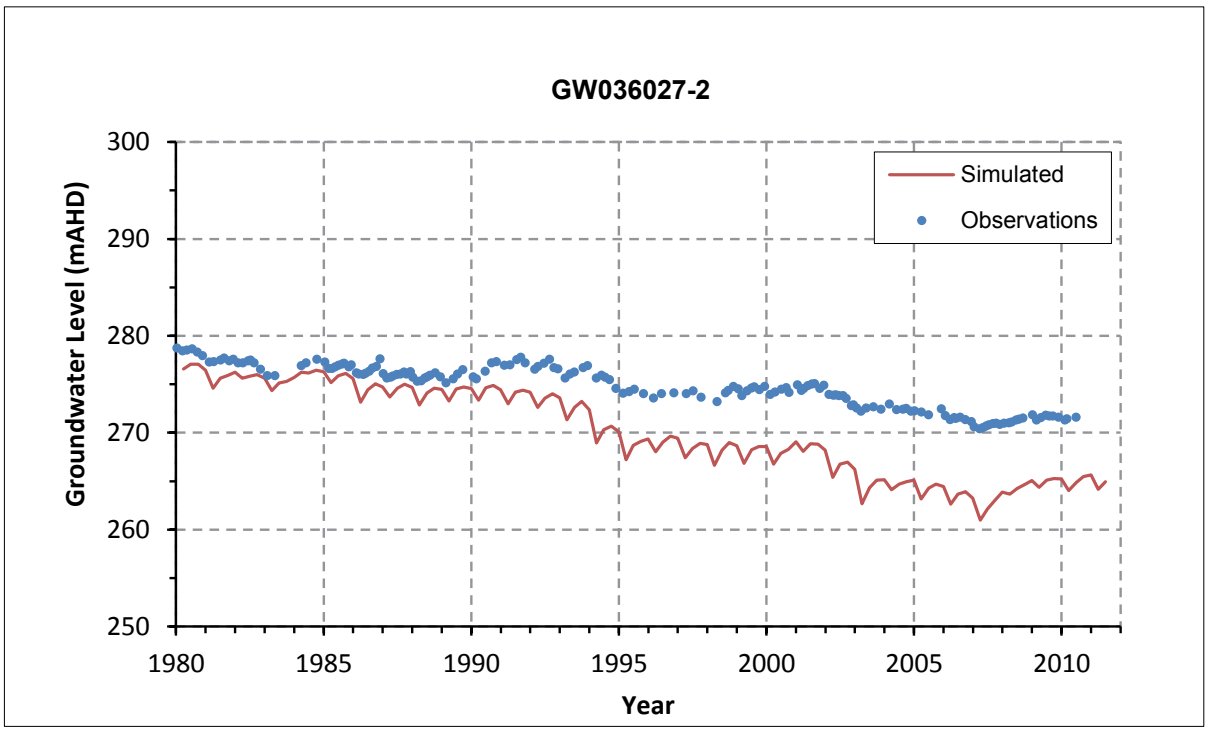

GW030477-3
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

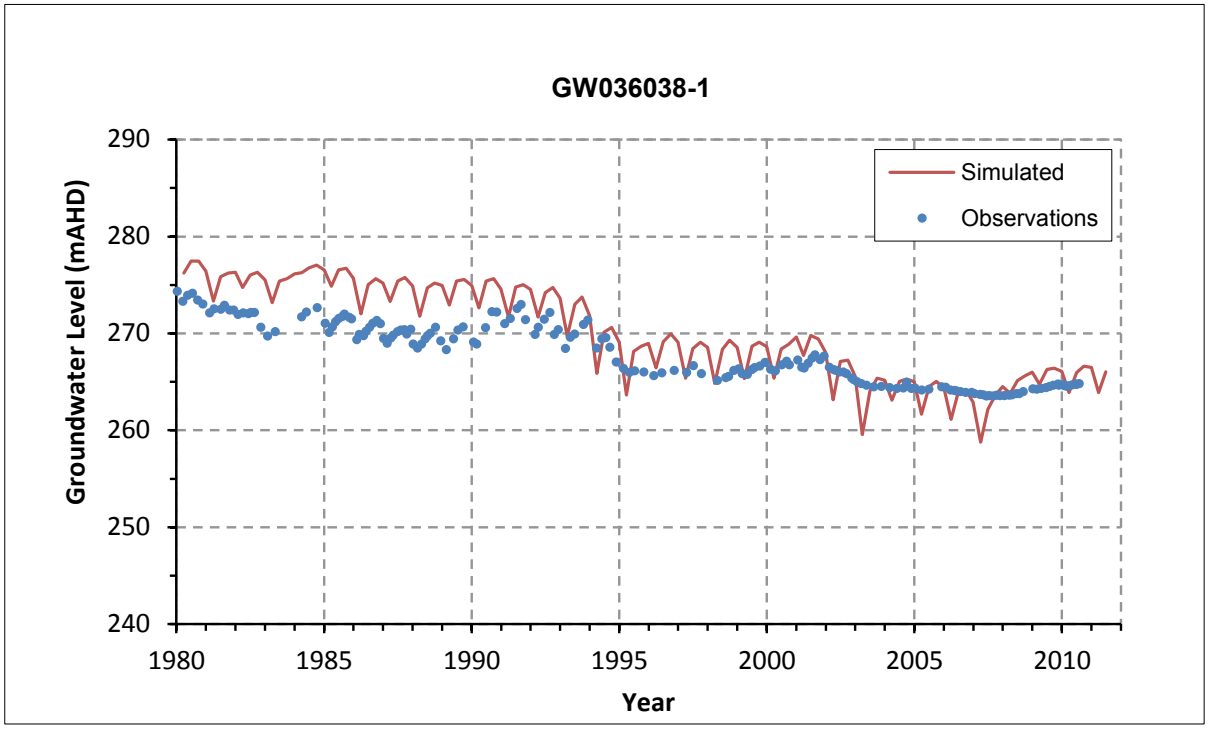

GW036011-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

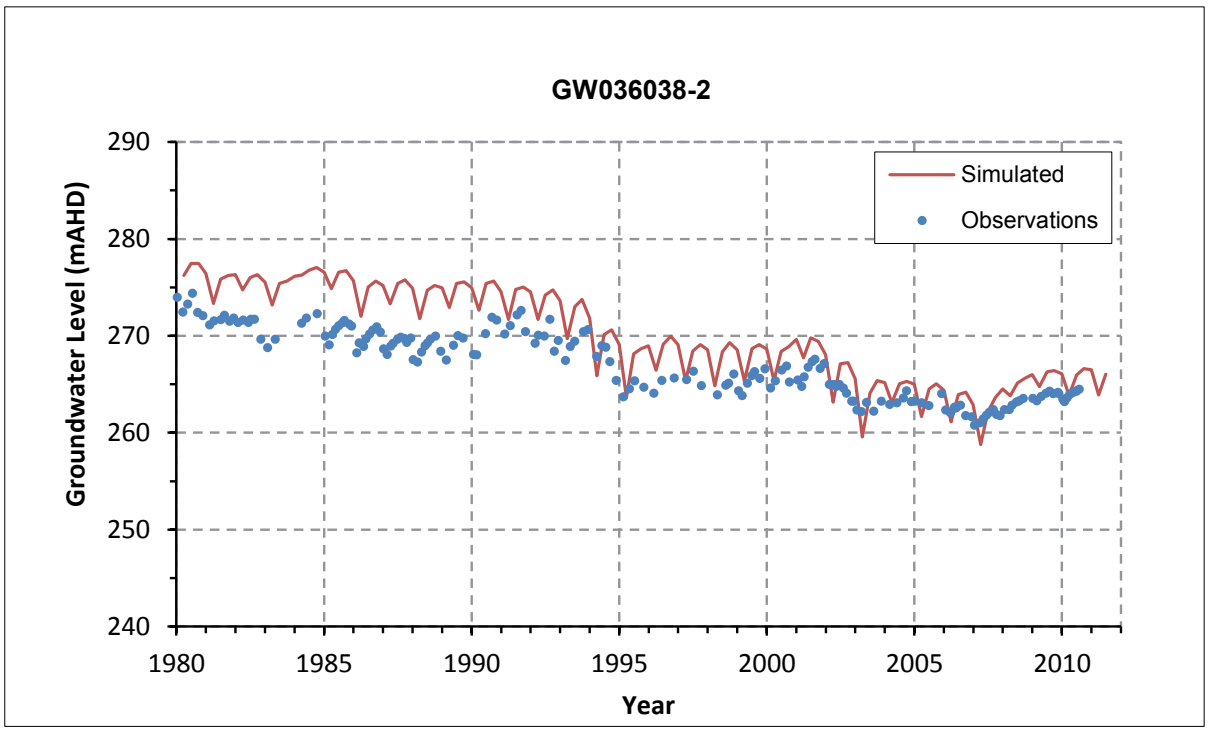

GW036011-2
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

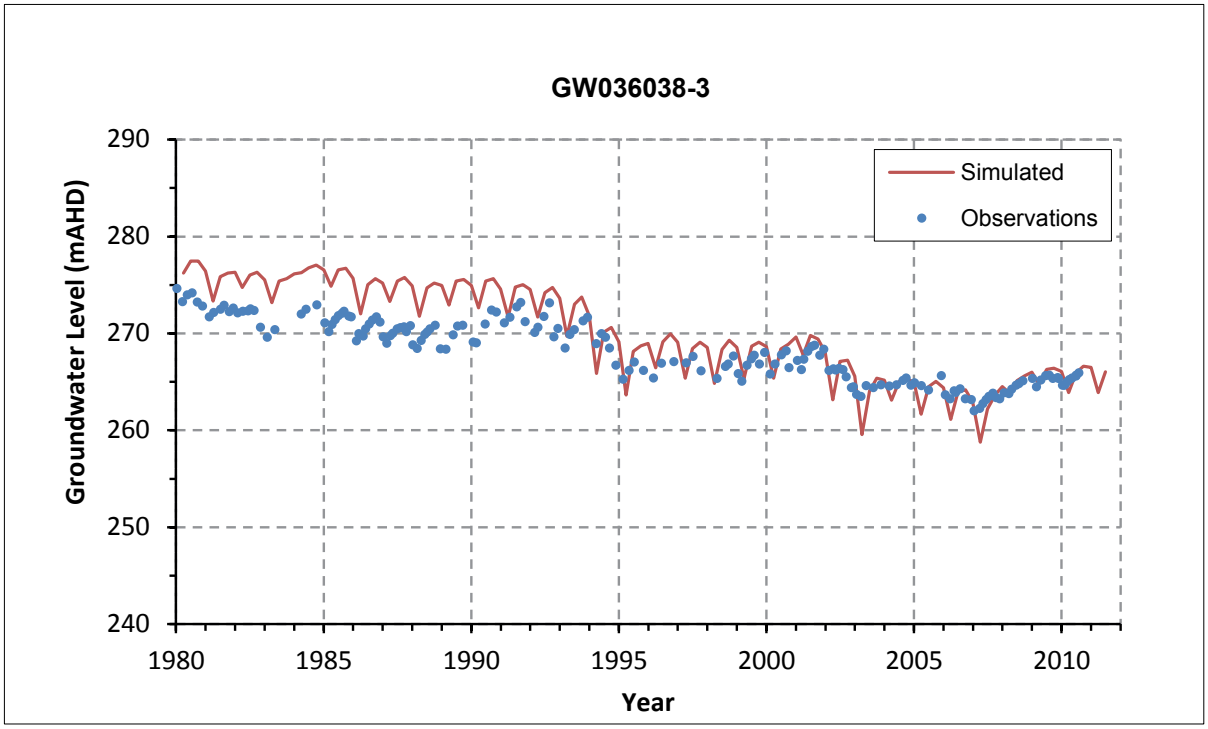

GW036011-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

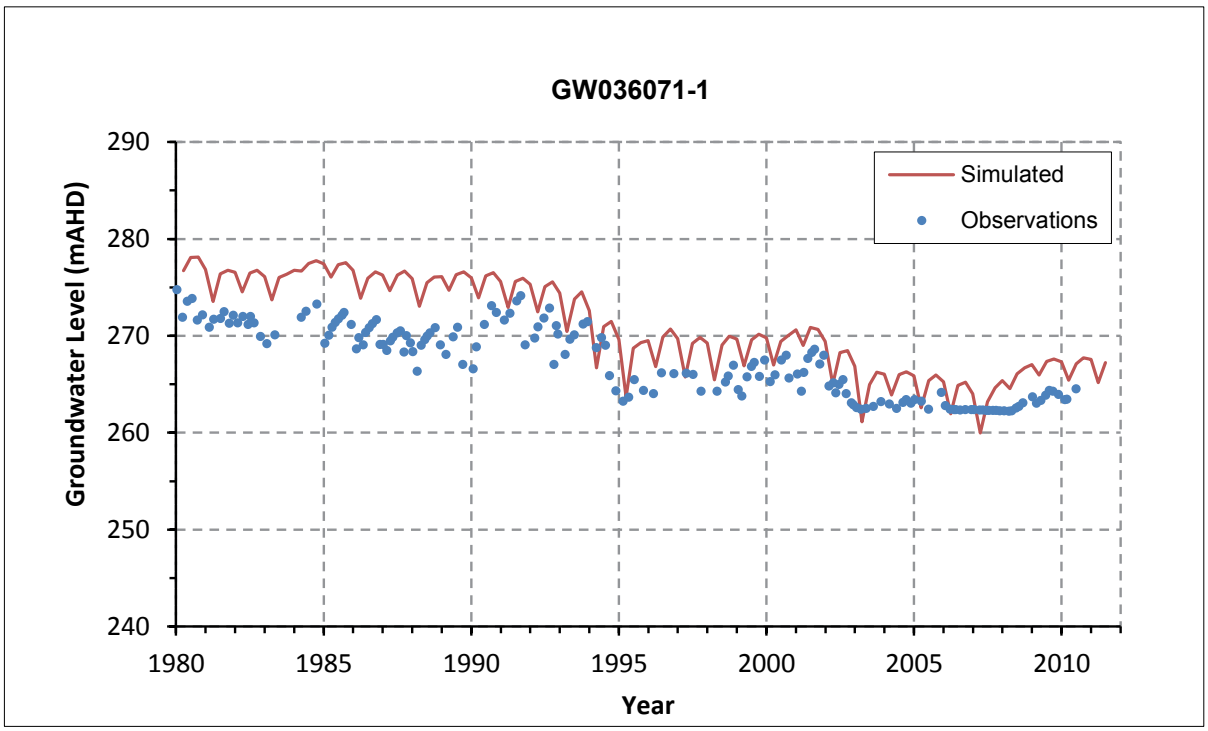

GW036027-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

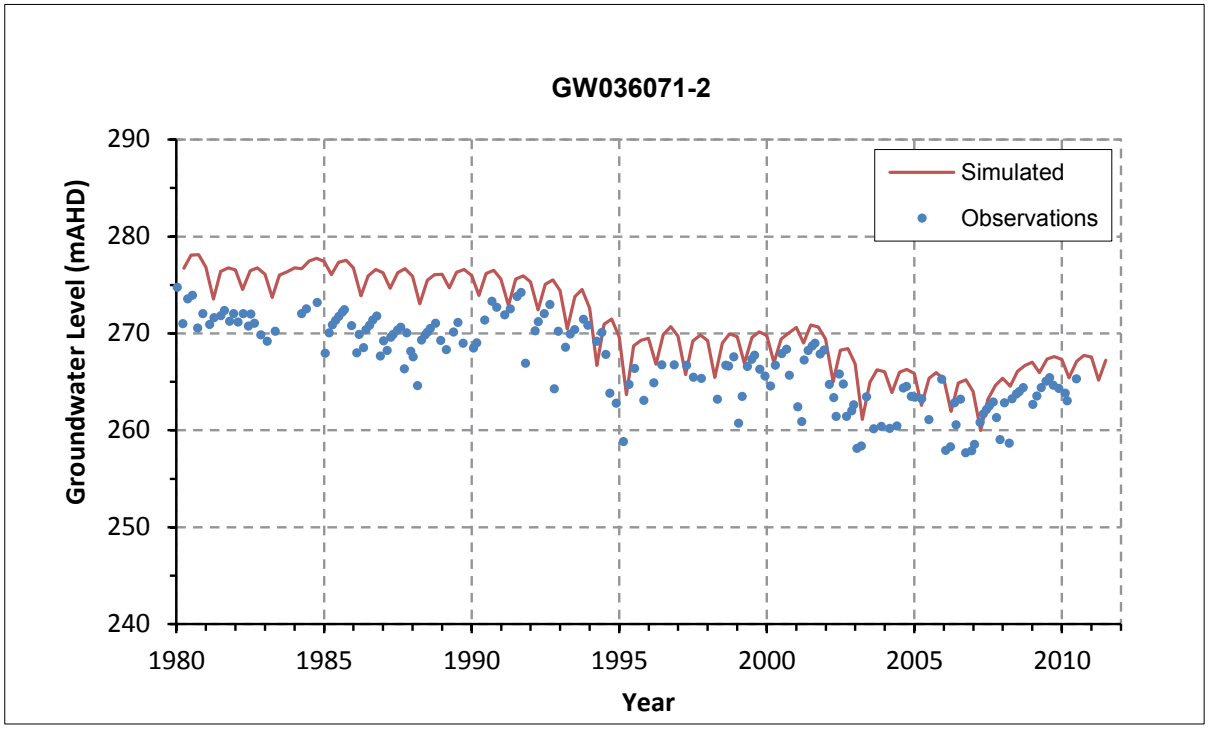

GW036027-2
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

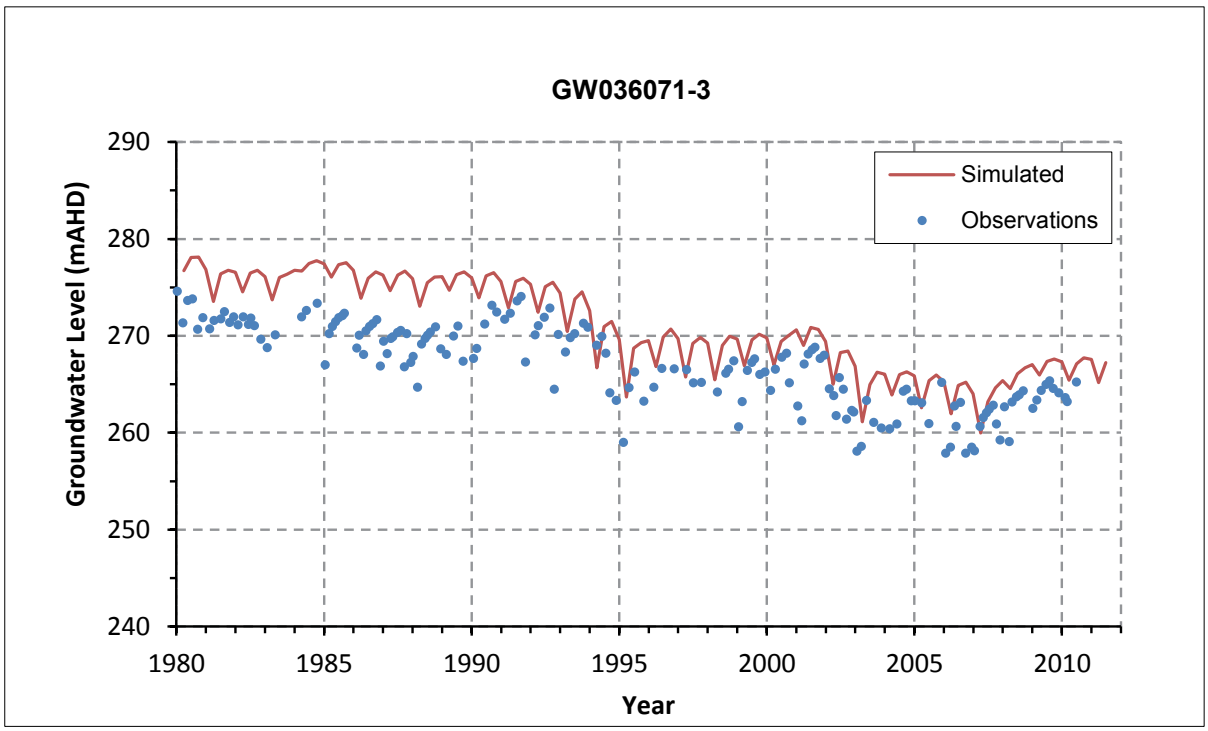

GW036038-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

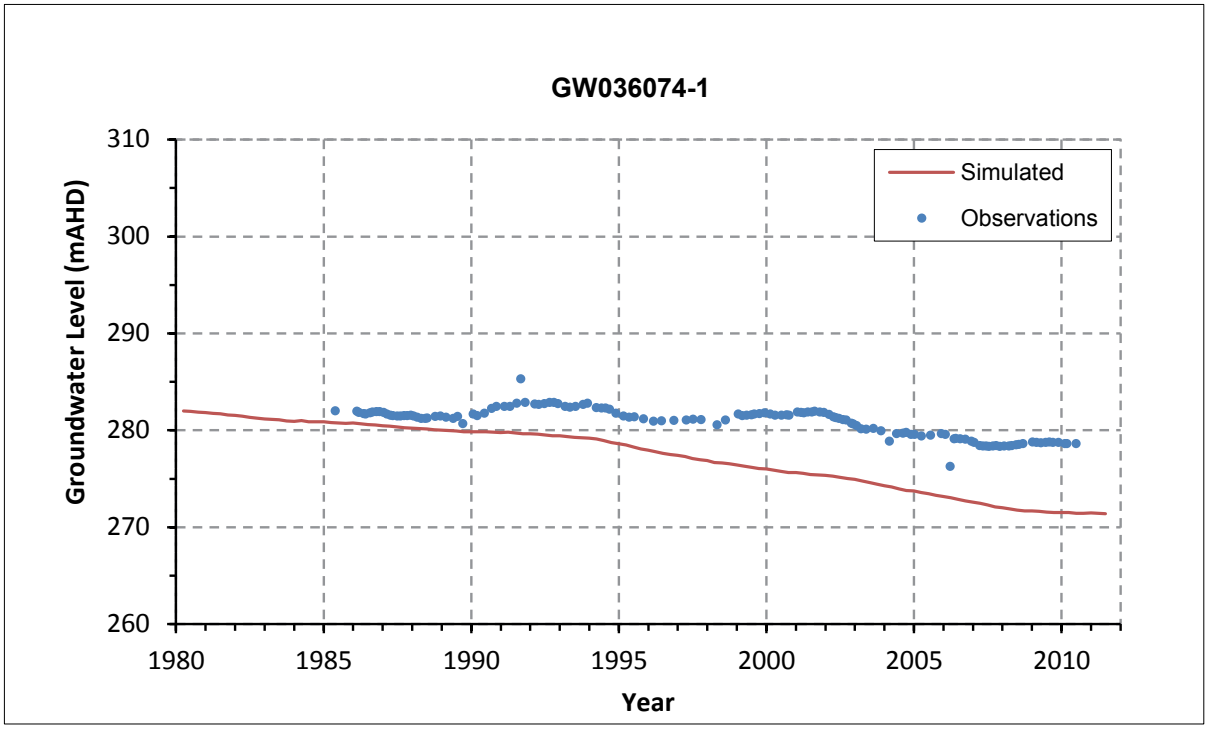

GW036038-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

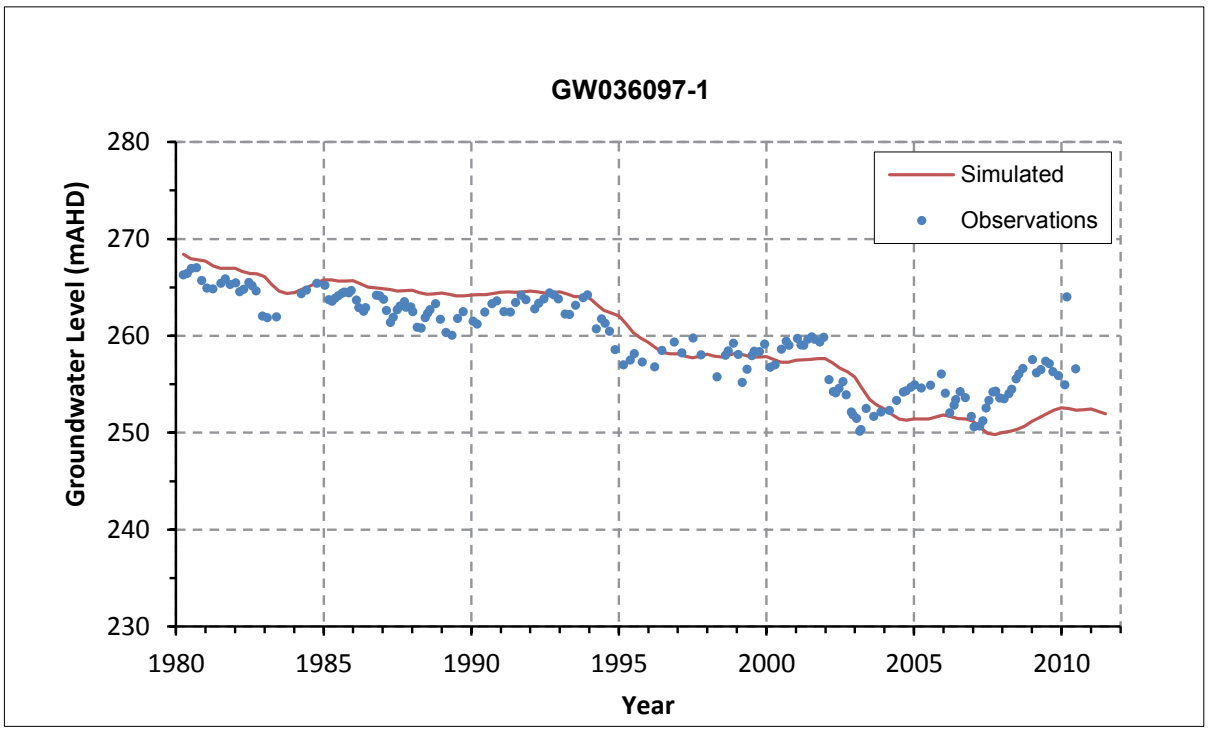

GW036038-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

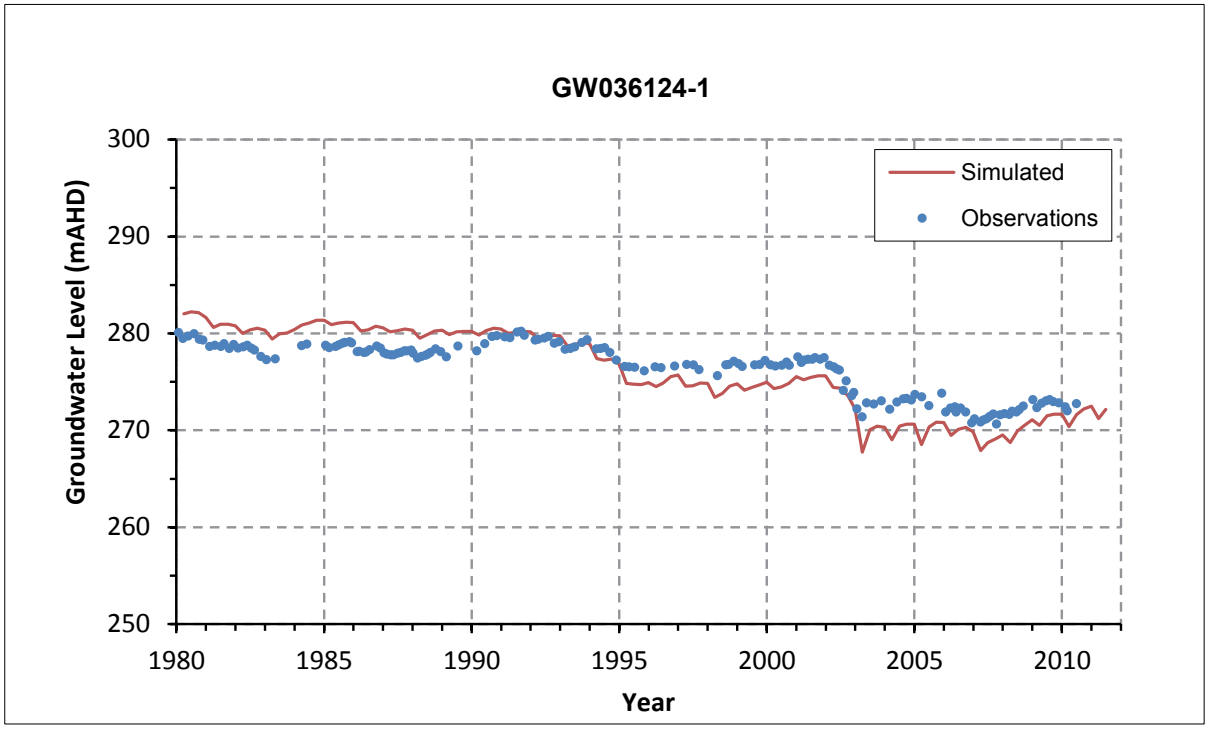

GW036071-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

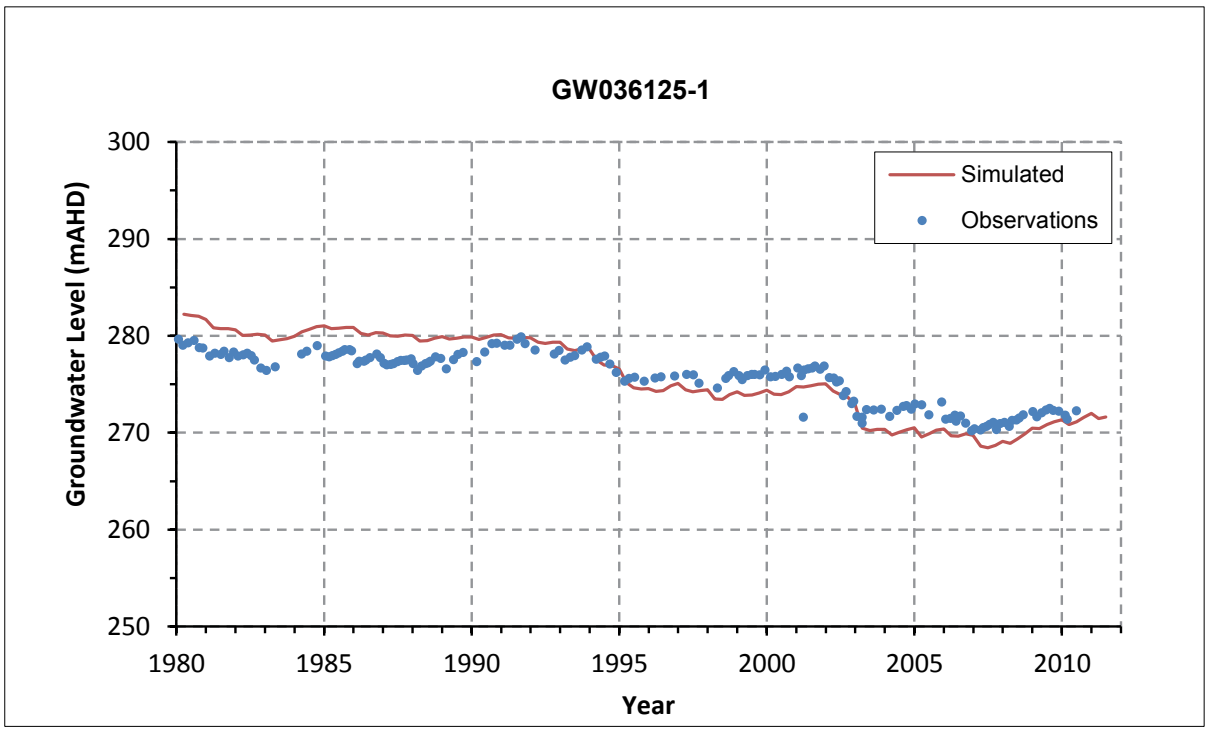

GW036071-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

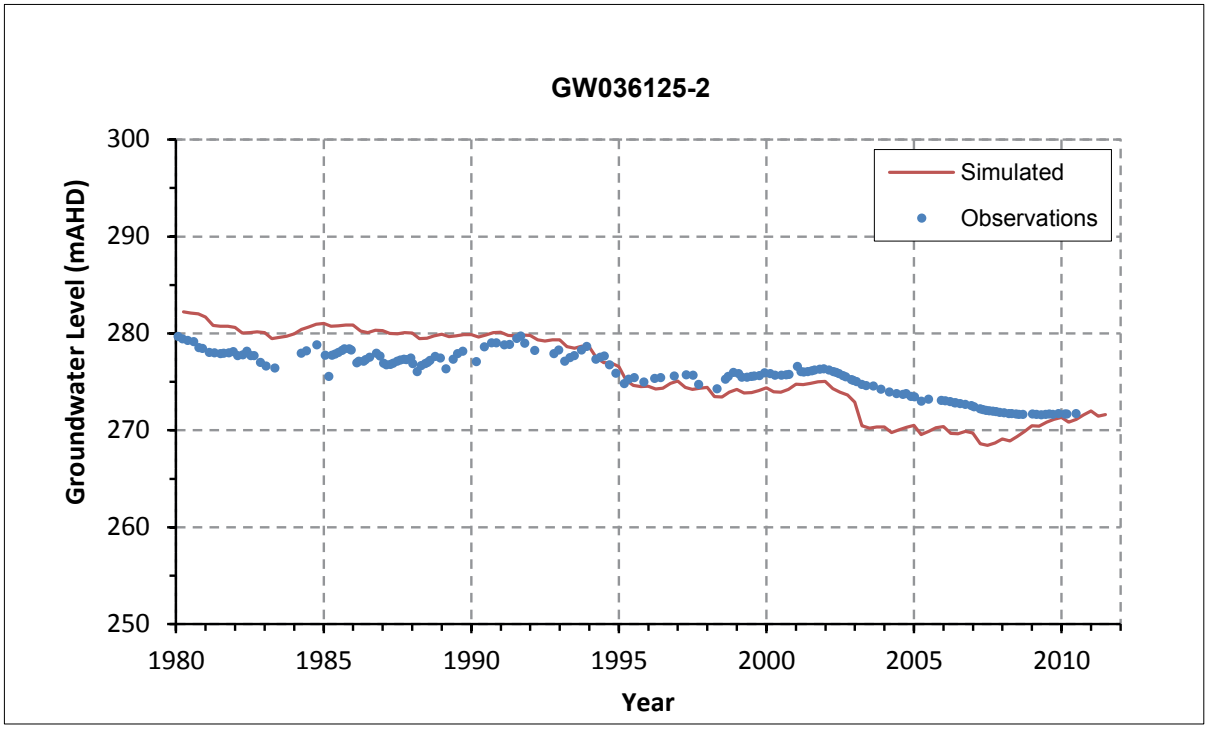

GW036071-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

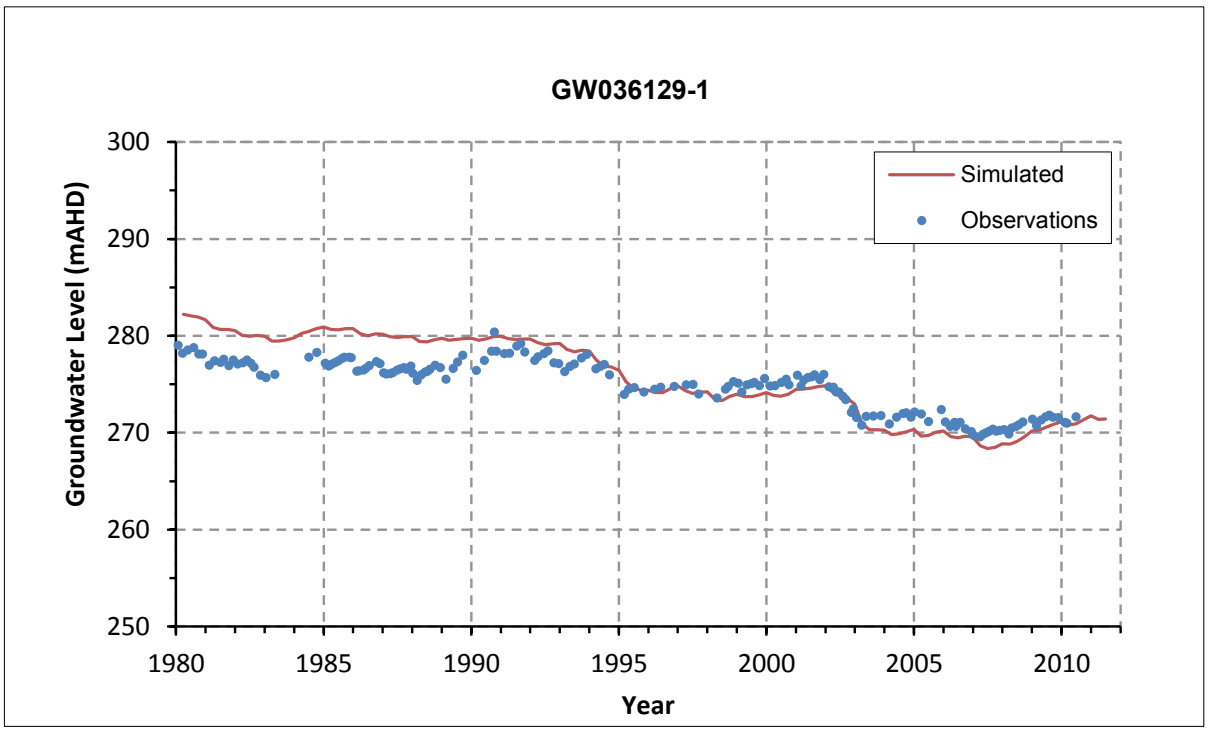

GW036074-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

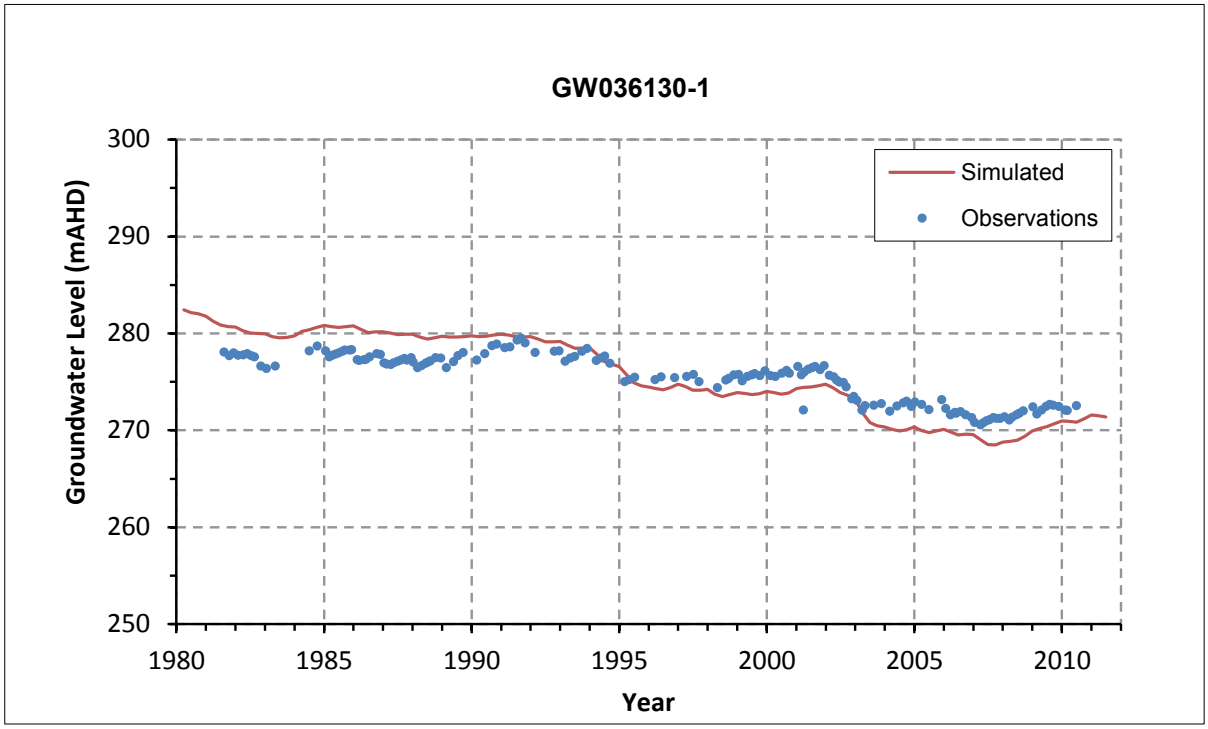

GW036097-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

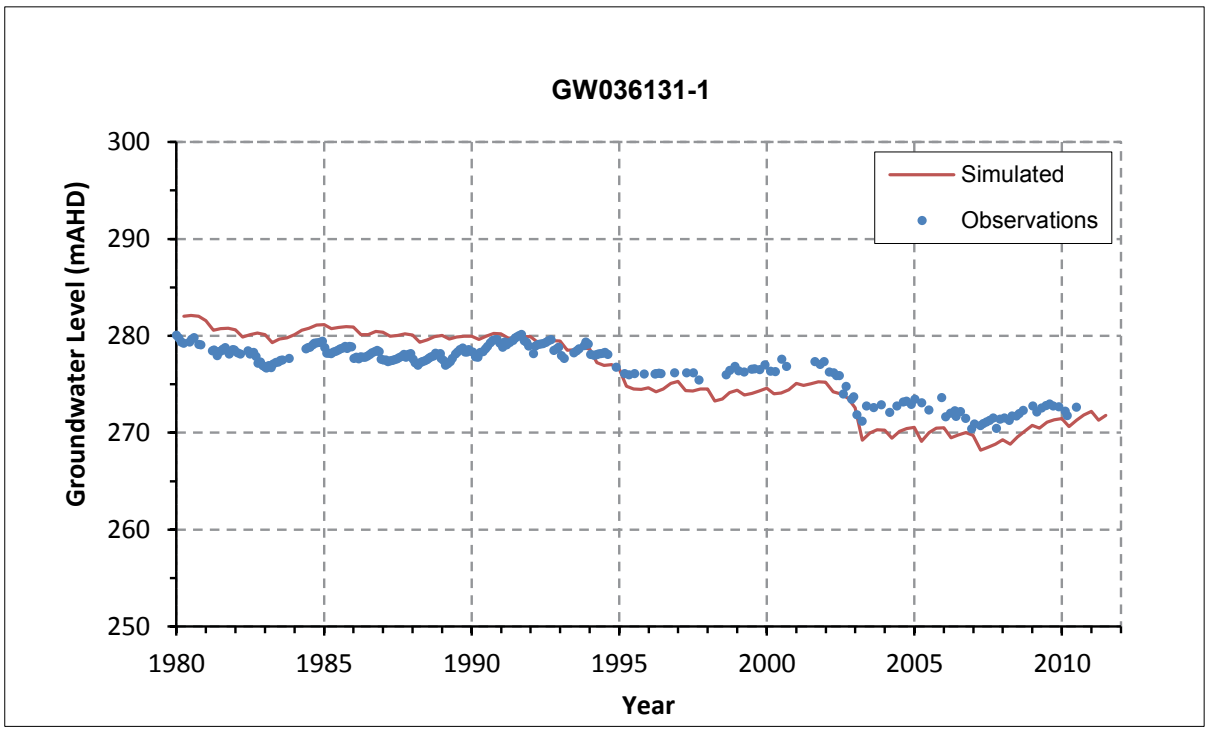

GW036124-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

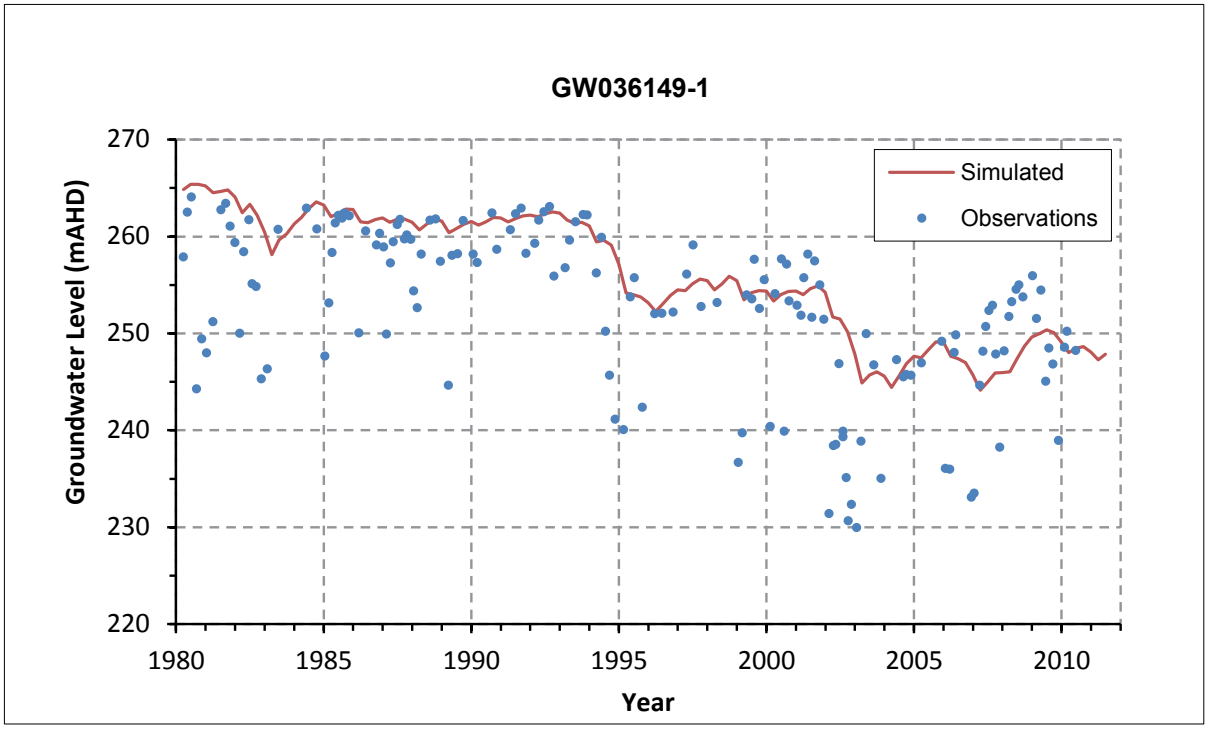

GW036125-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

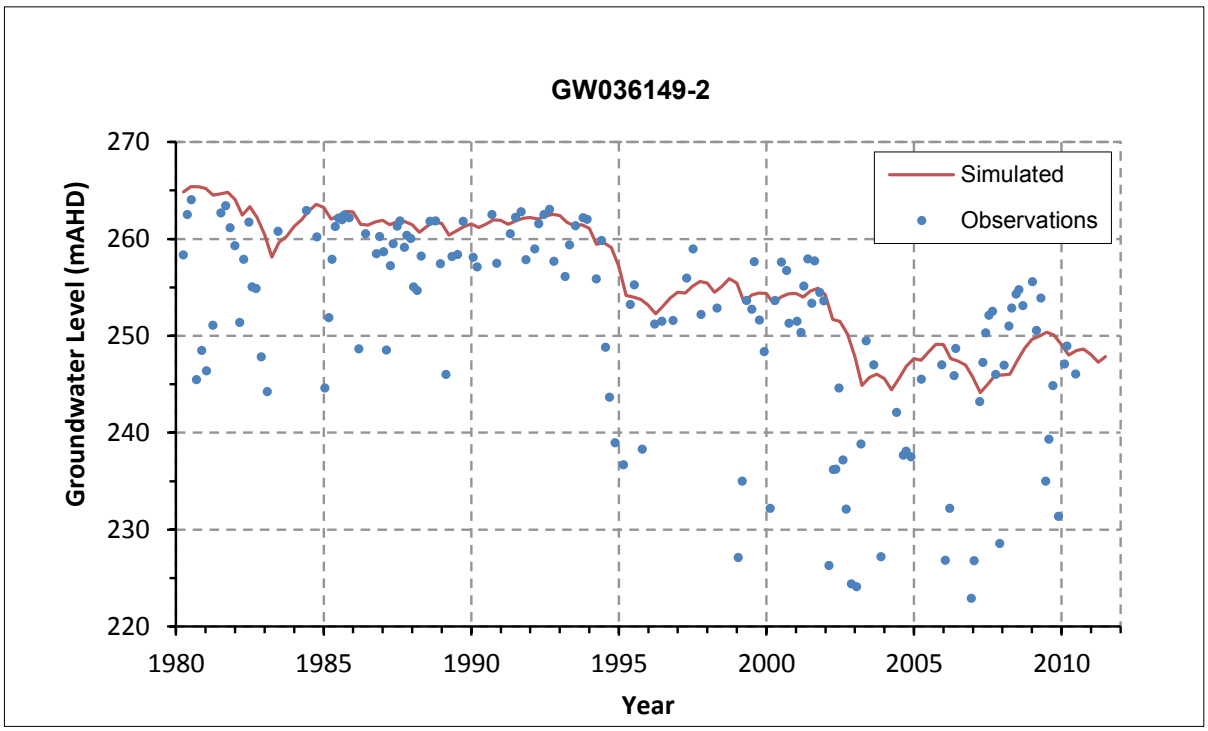

GW036125-2
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

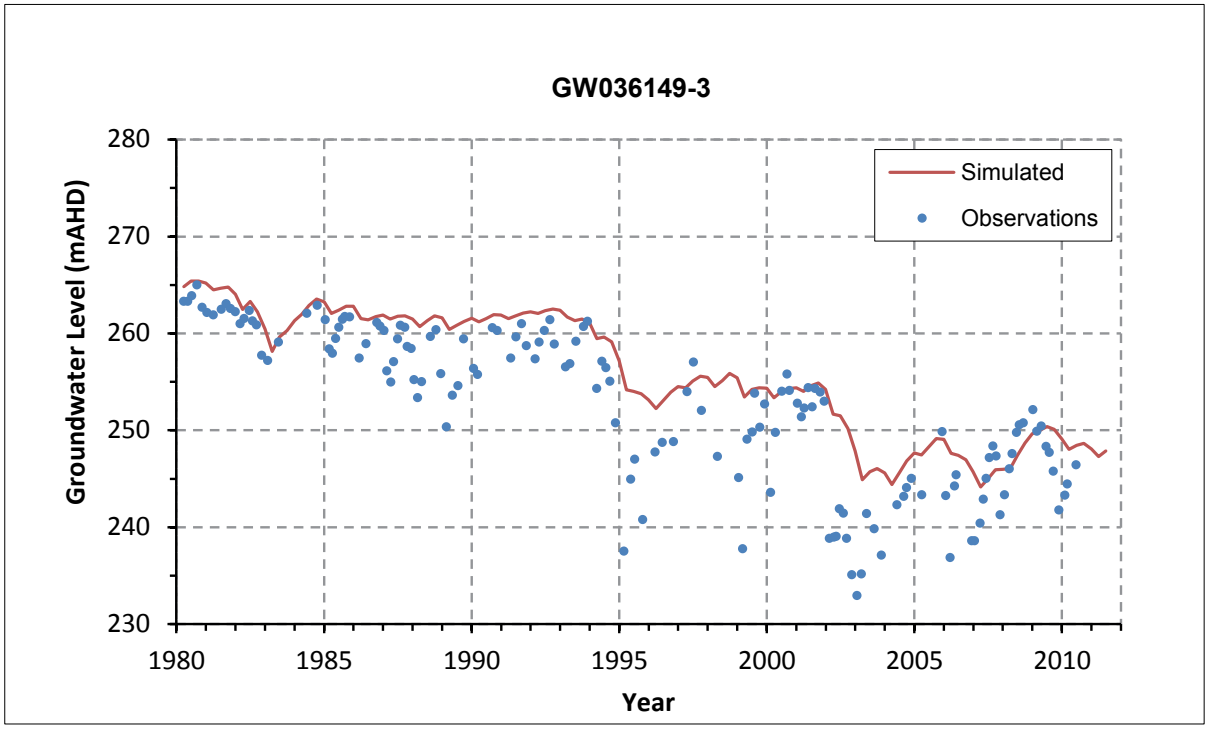

GW036129-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

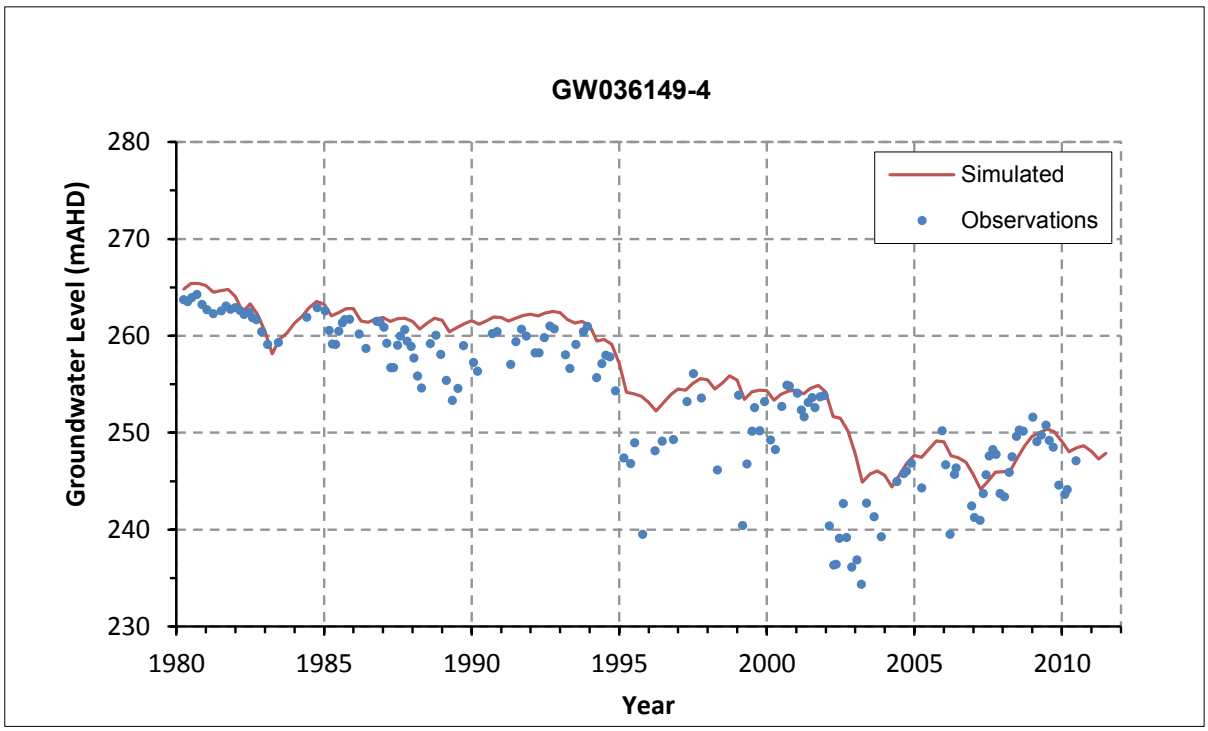

GW036130-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

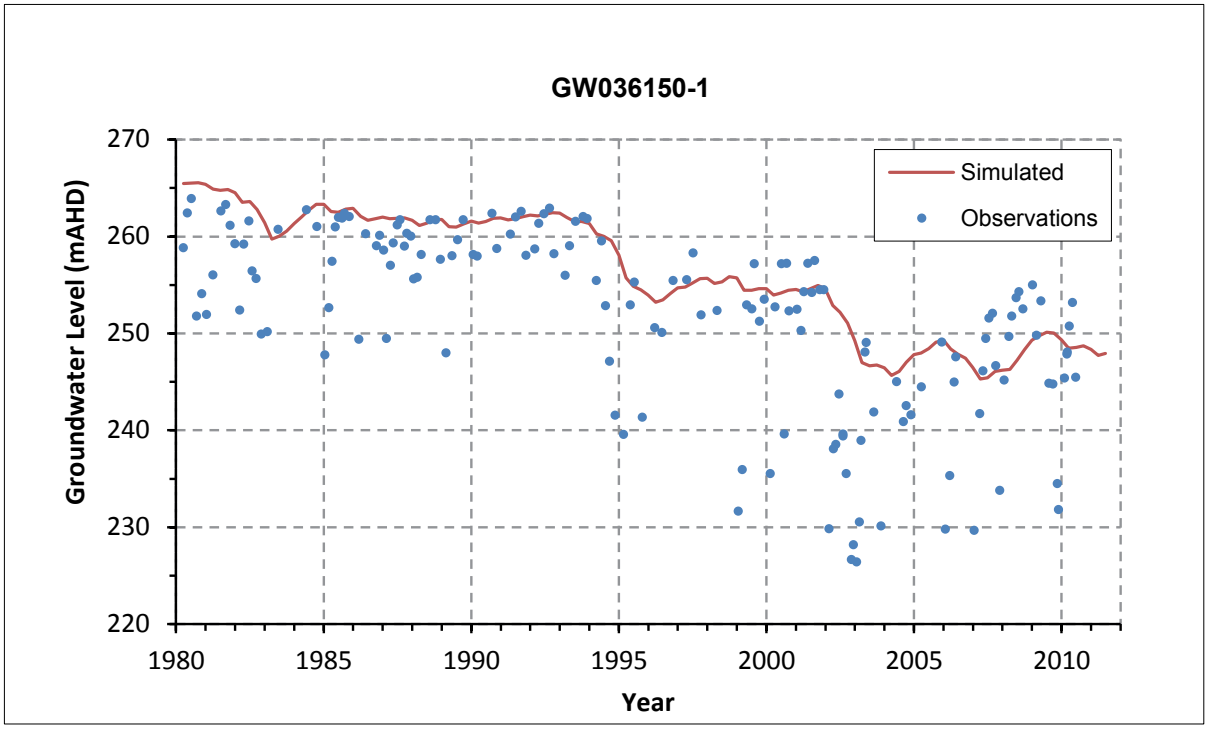

GW036131-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

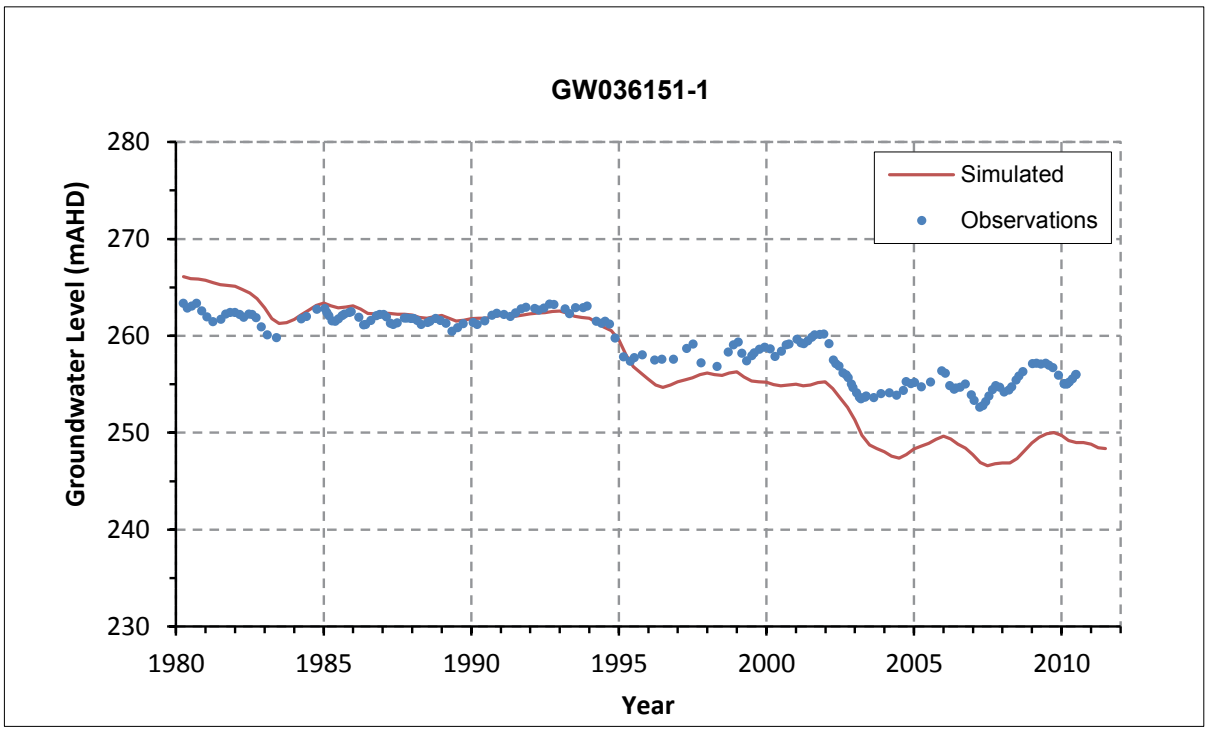

GW036149-1
Groundwater Level (mAHD)
270
260
250
240
230
220
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

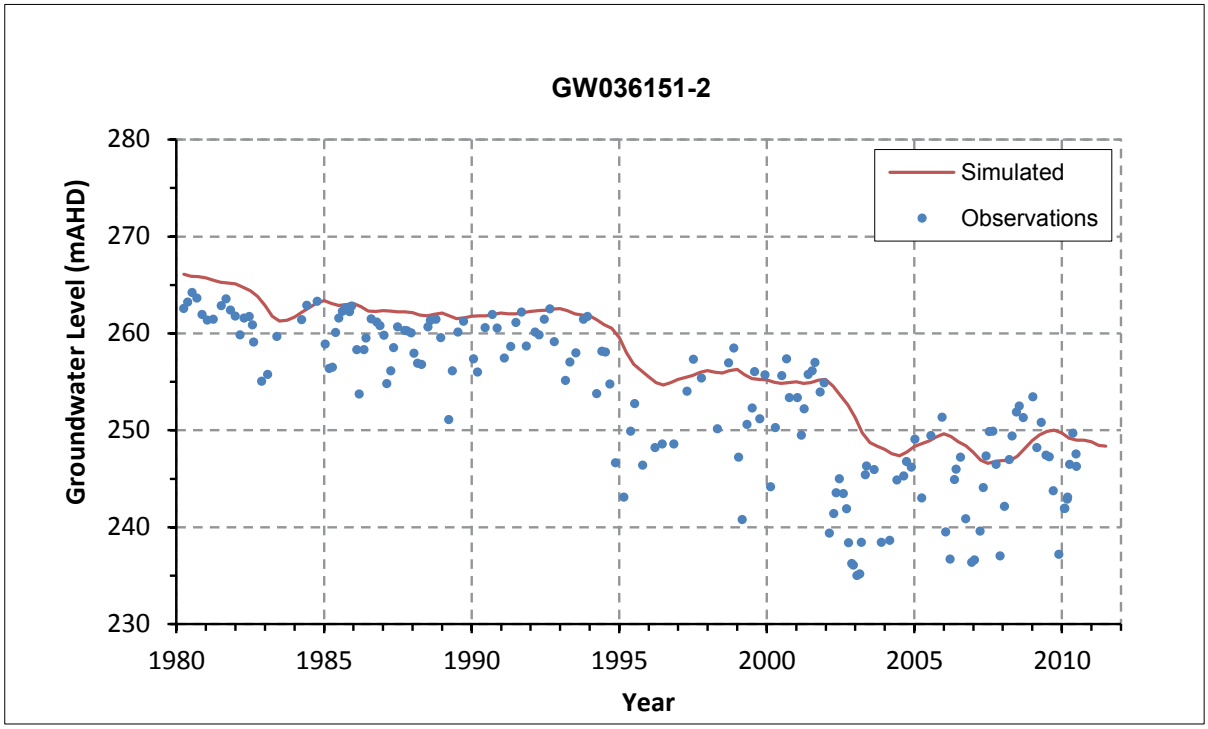

GW036149-2
Groundwater Level (mAHD)
270
260
250
240
230
220
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

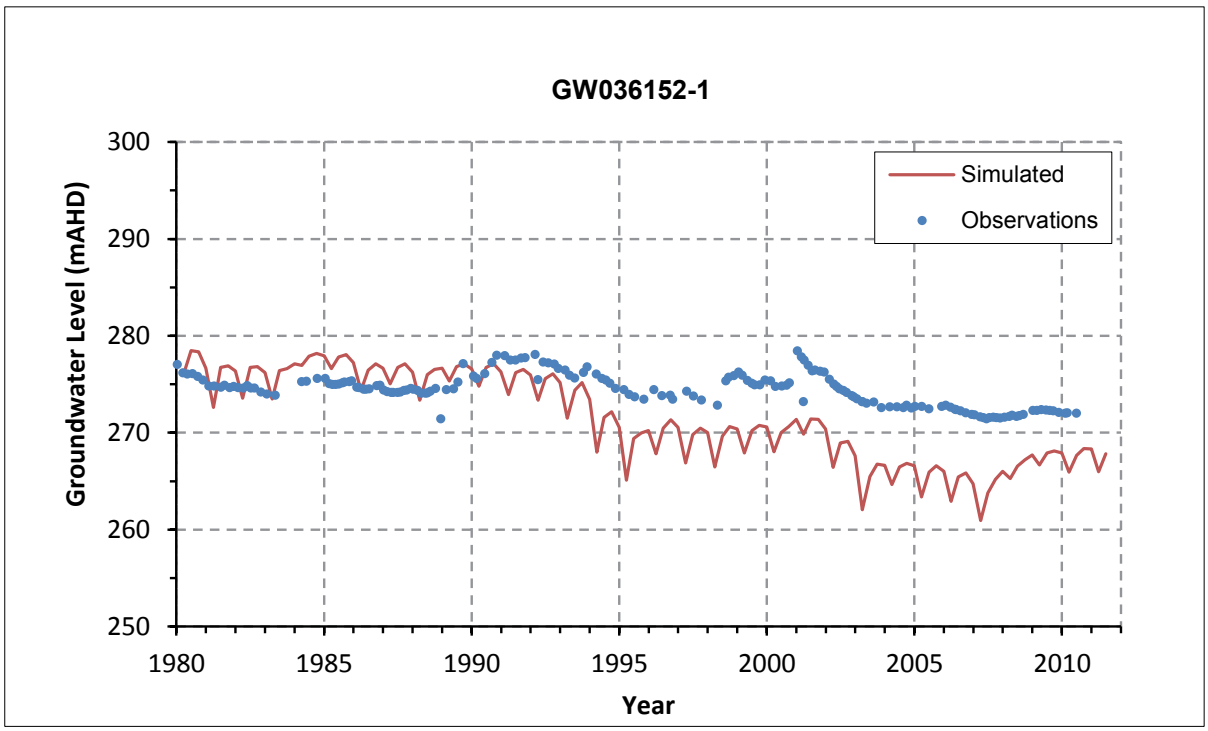

GW036149-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

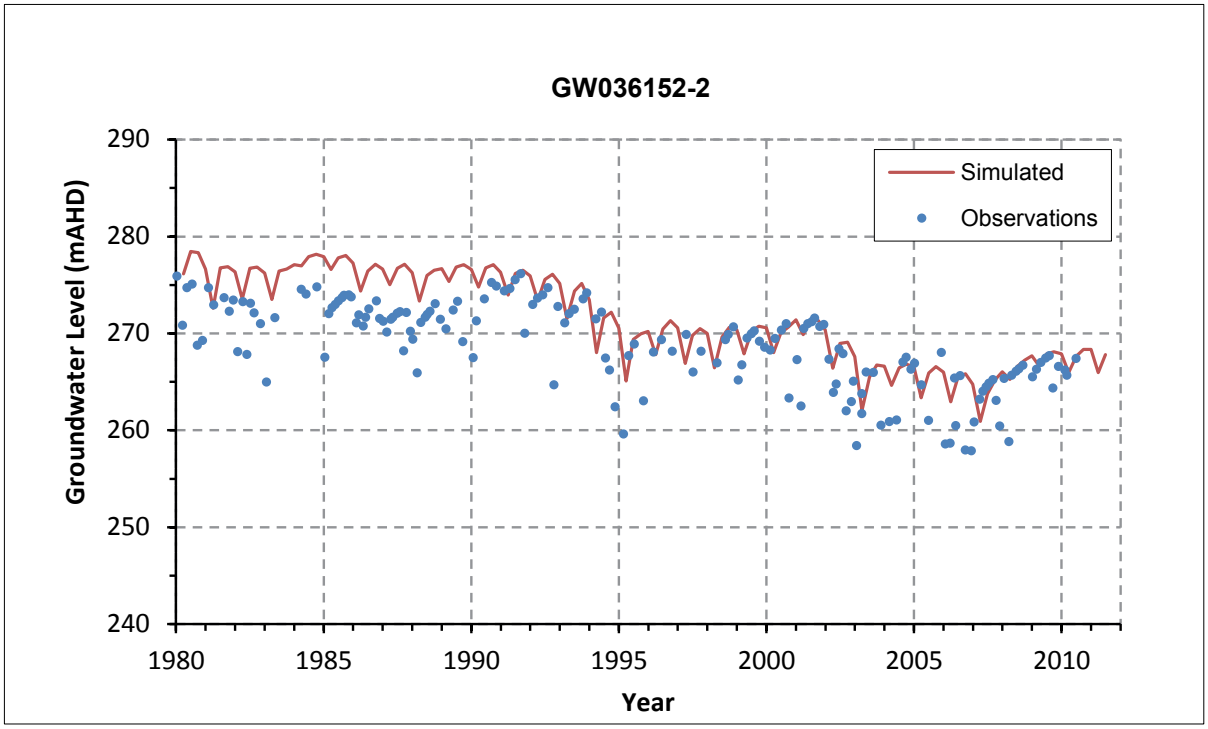

GW036149-4
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

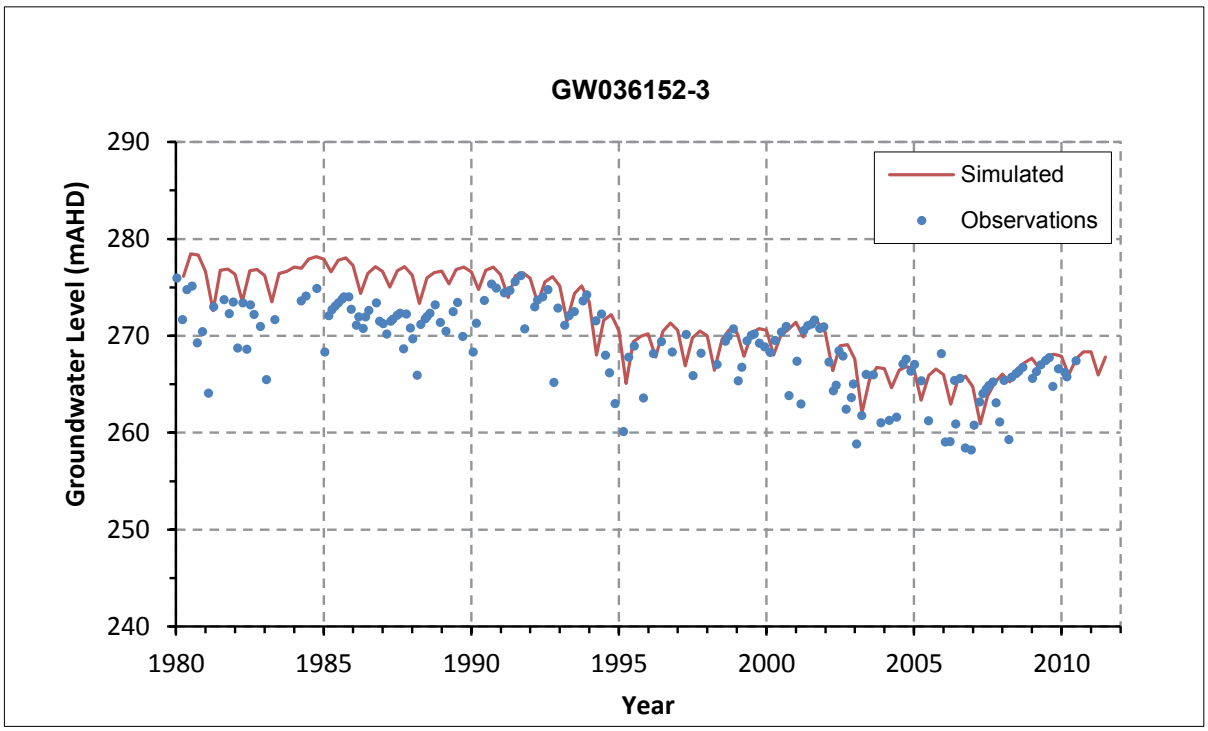

GW036150-1
Groundwater Level (mAHD)
270
260
250
240
230
220
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

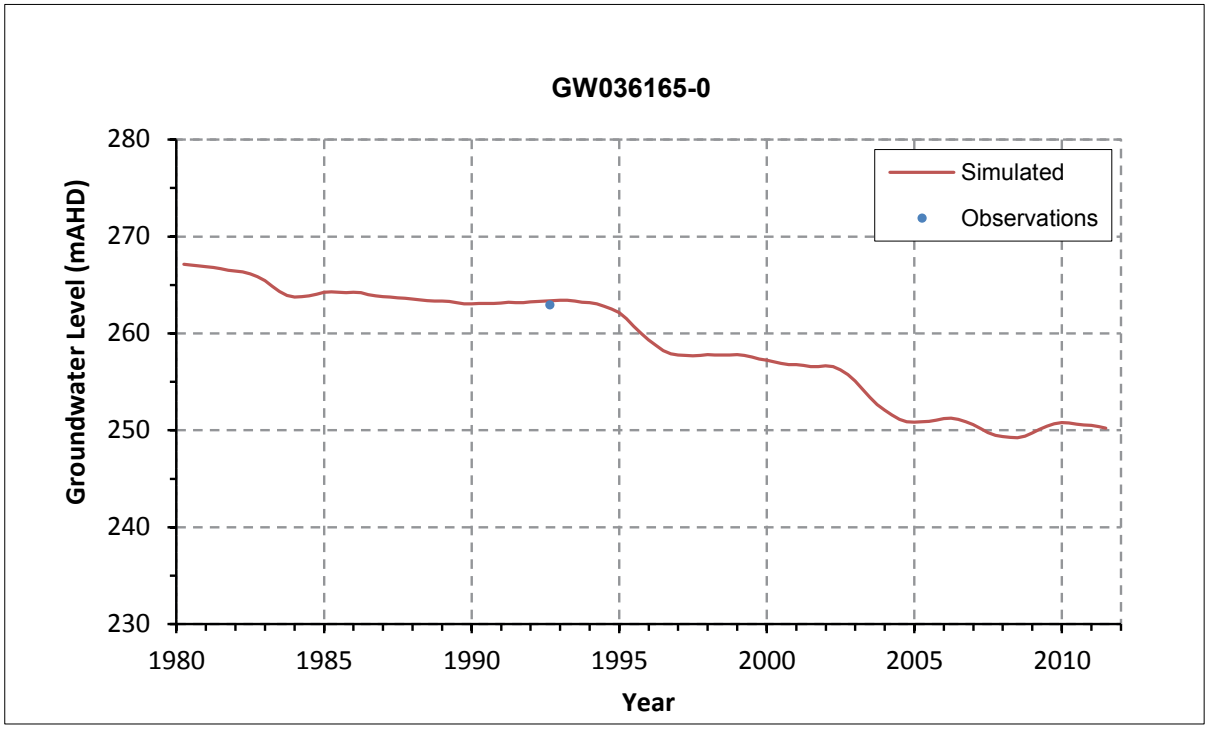

GW036151-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

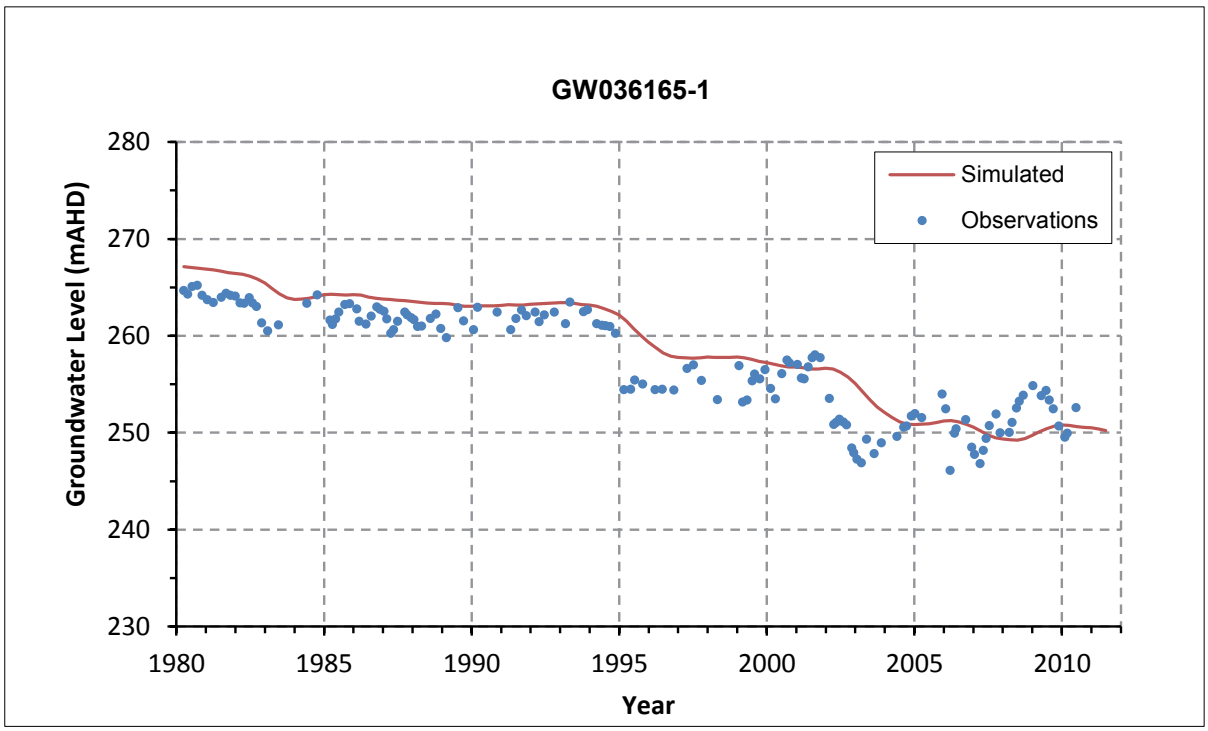

GW036151-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

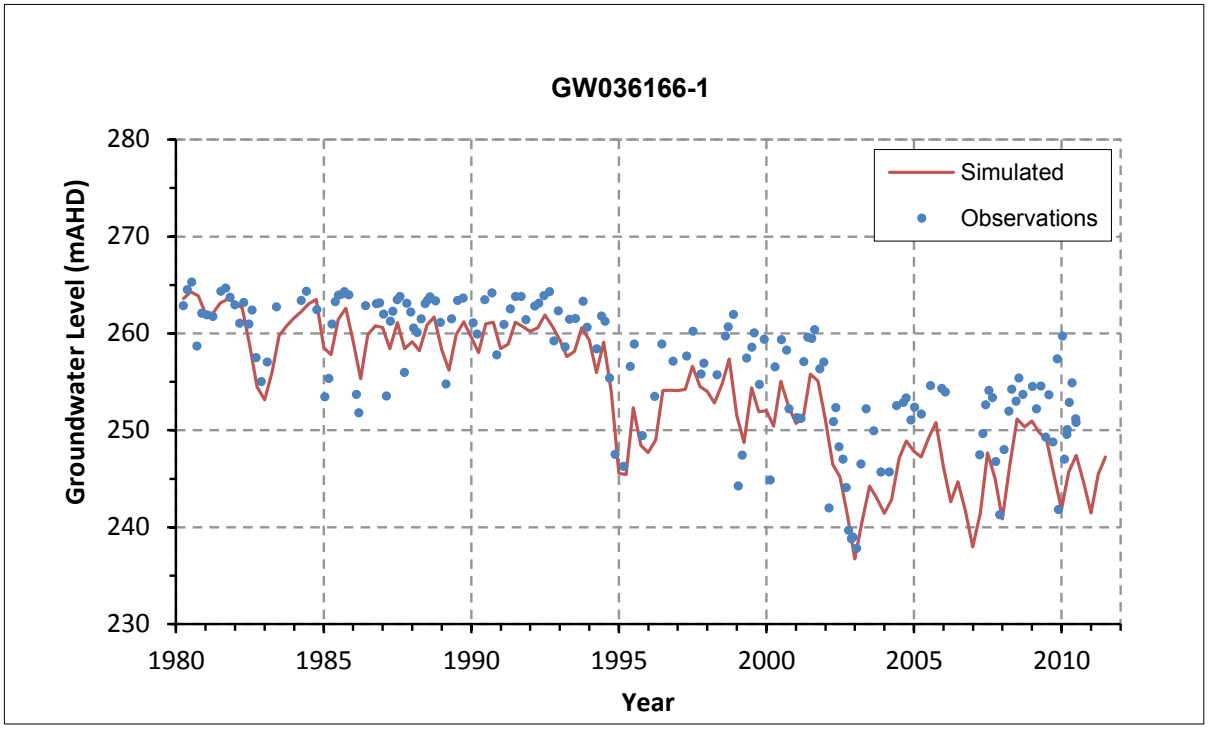

GW036152-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

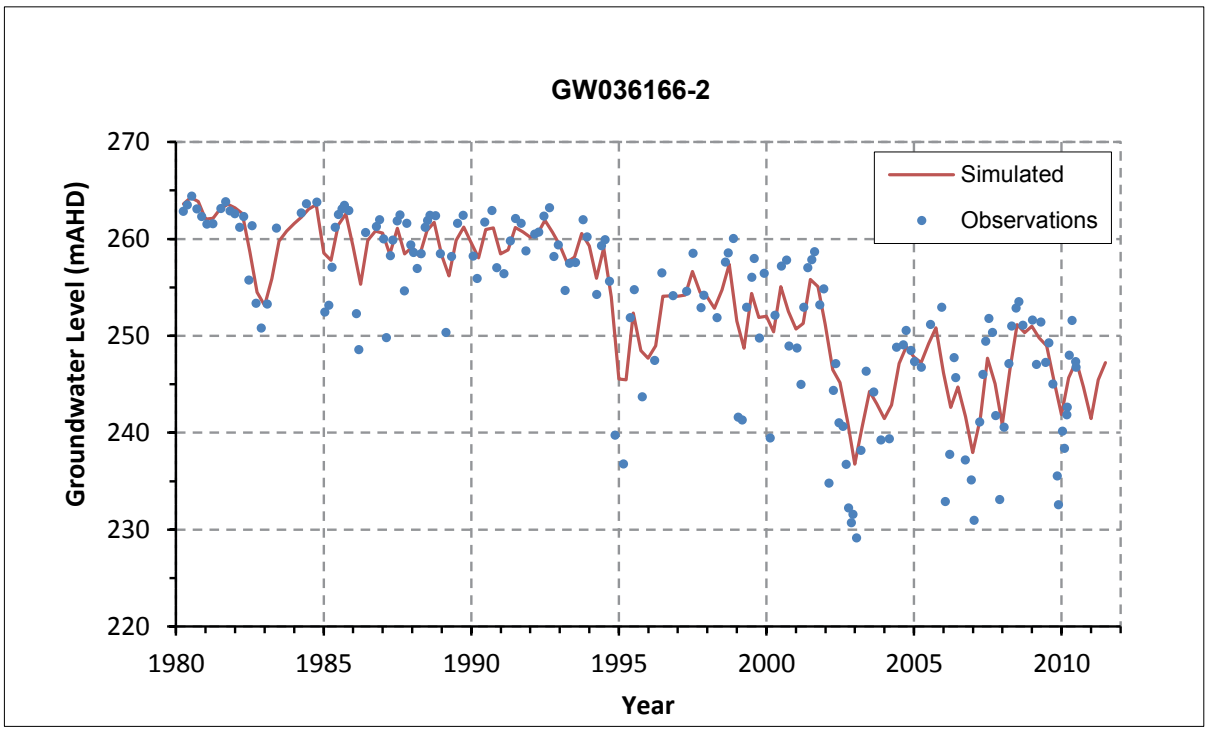

GW036152-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

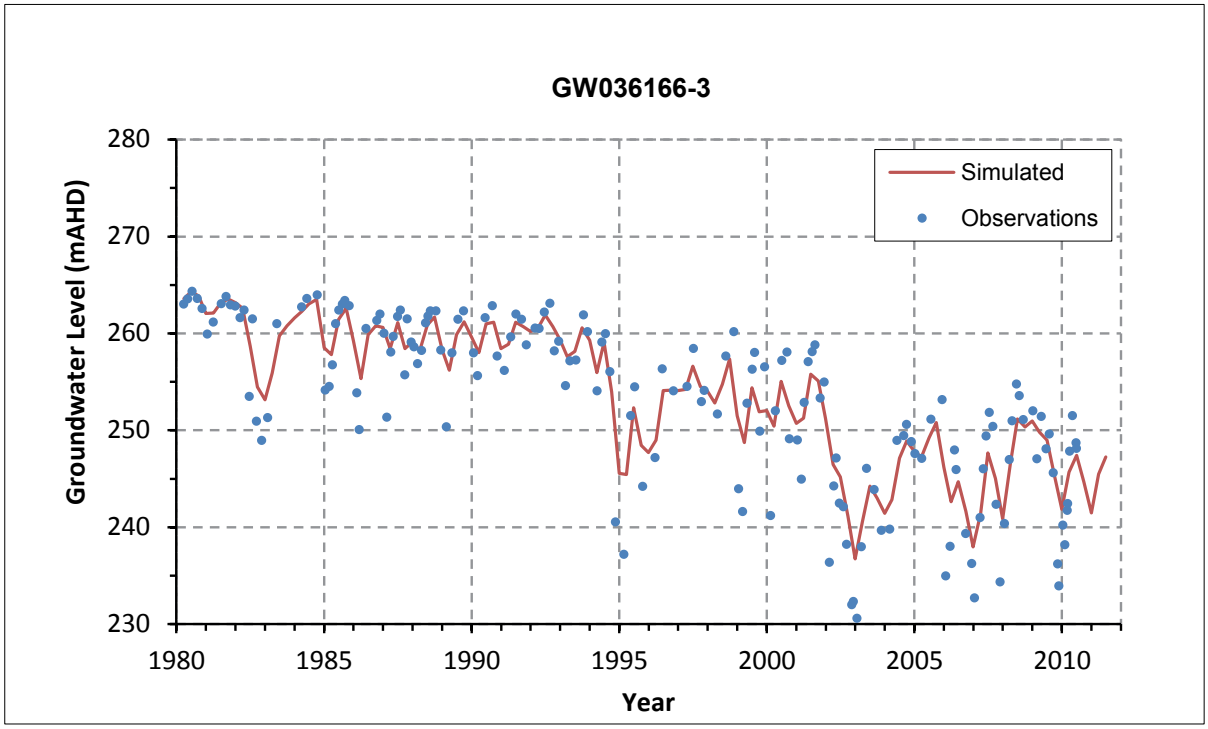

GW036152-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

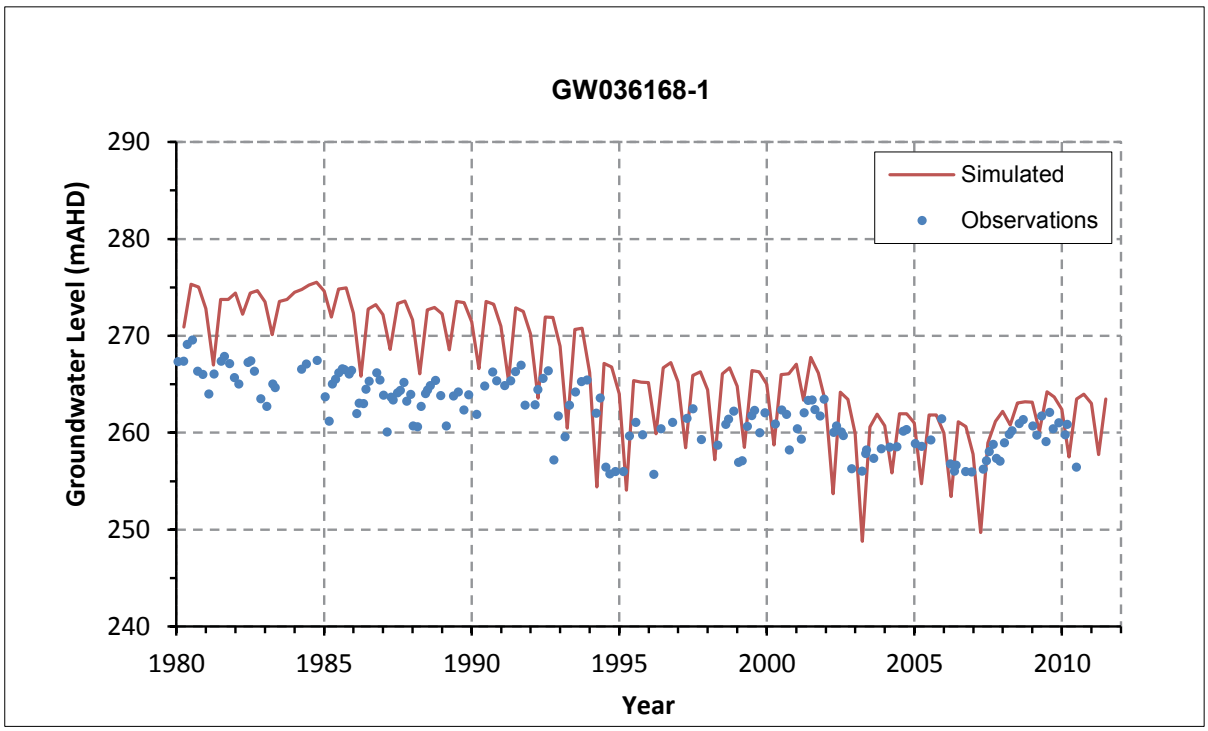

GW036165-0
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

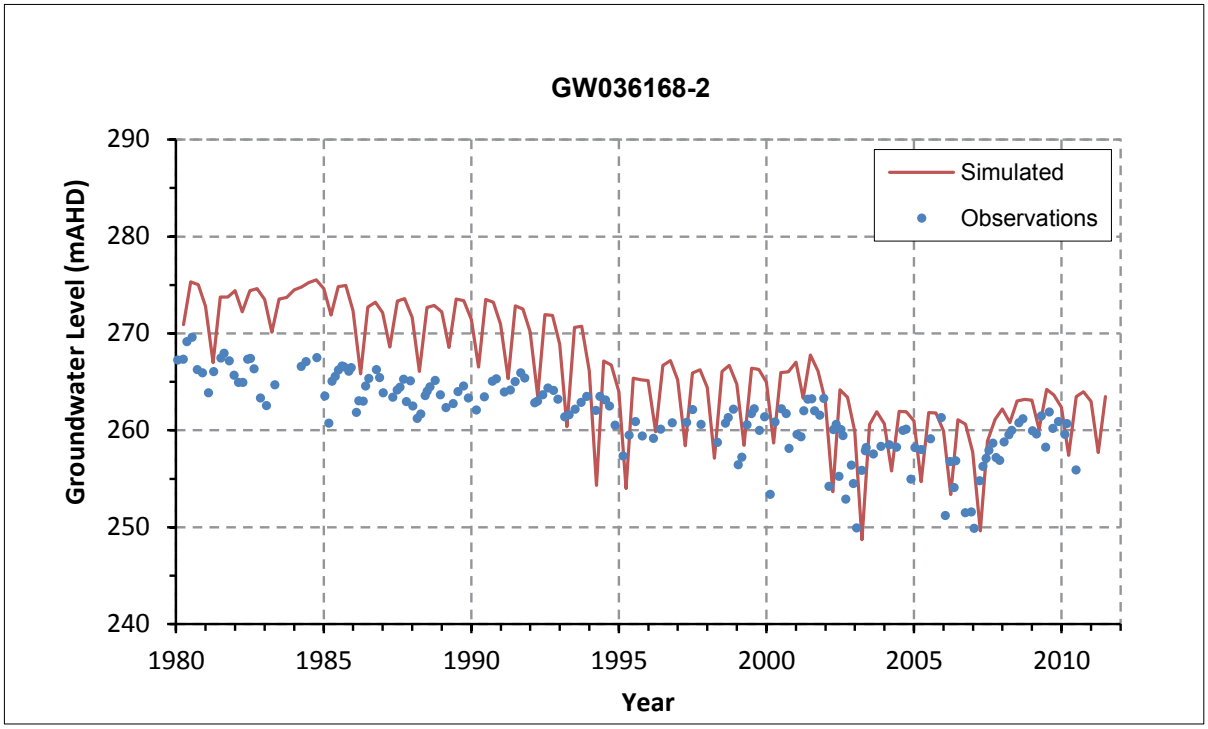

GW036165-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

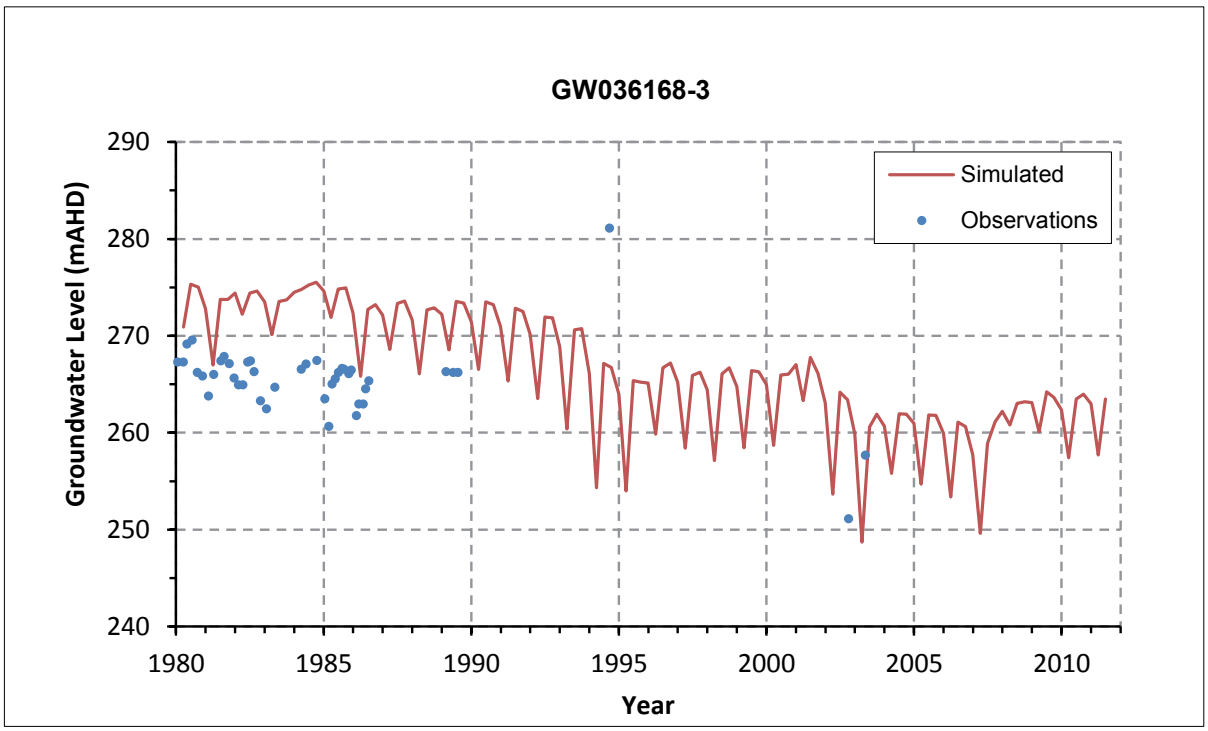

GW036166-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

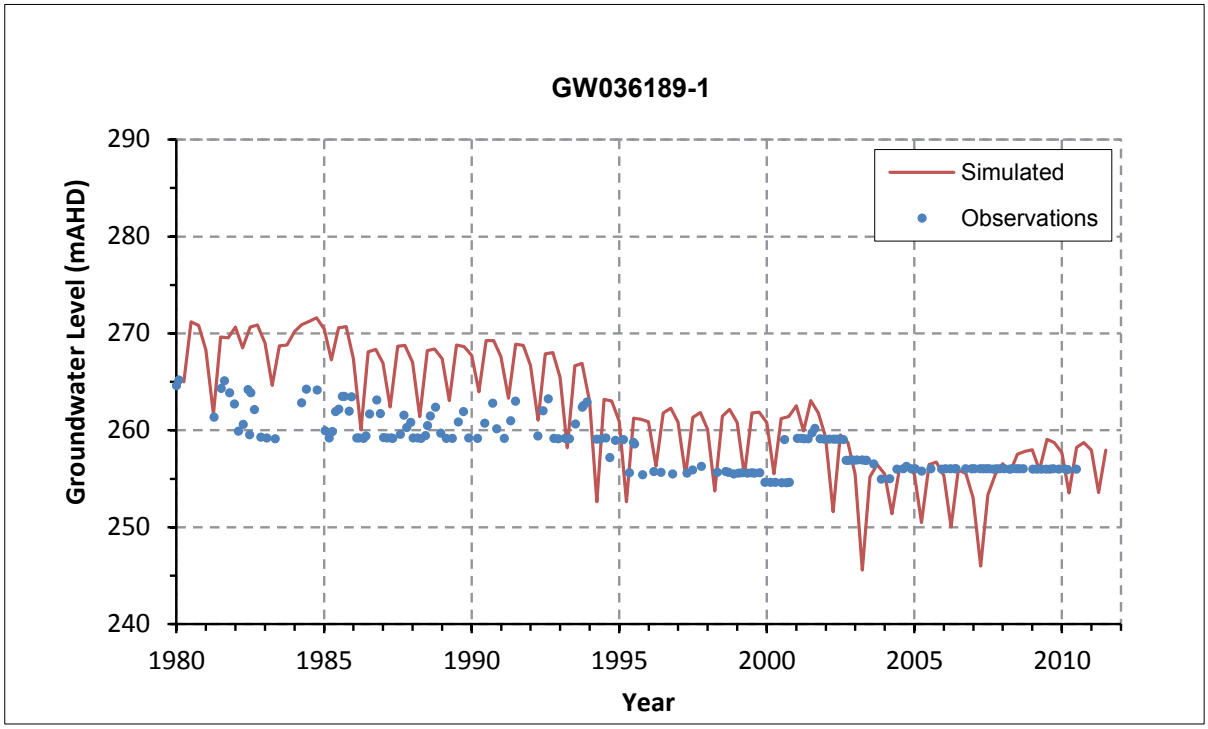

GW036166-2
Groundwater Level (mAHD)
270
260
250
240
230
220
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

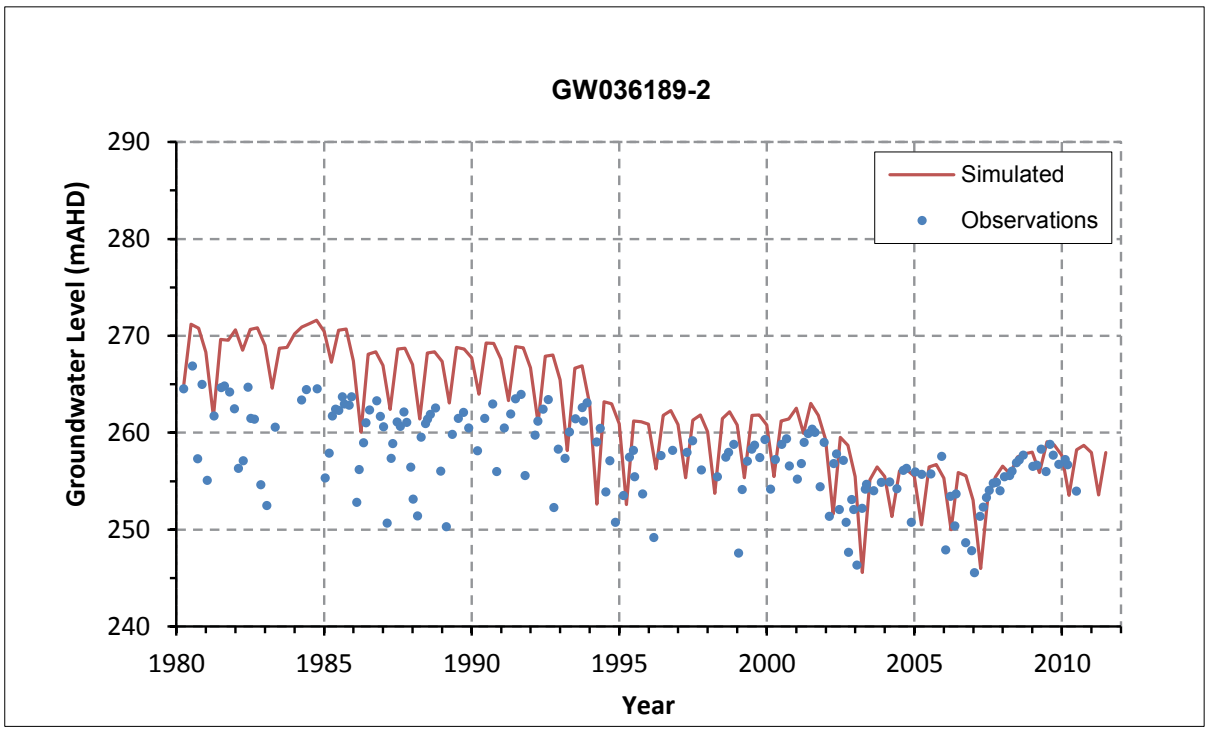

GW036166-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

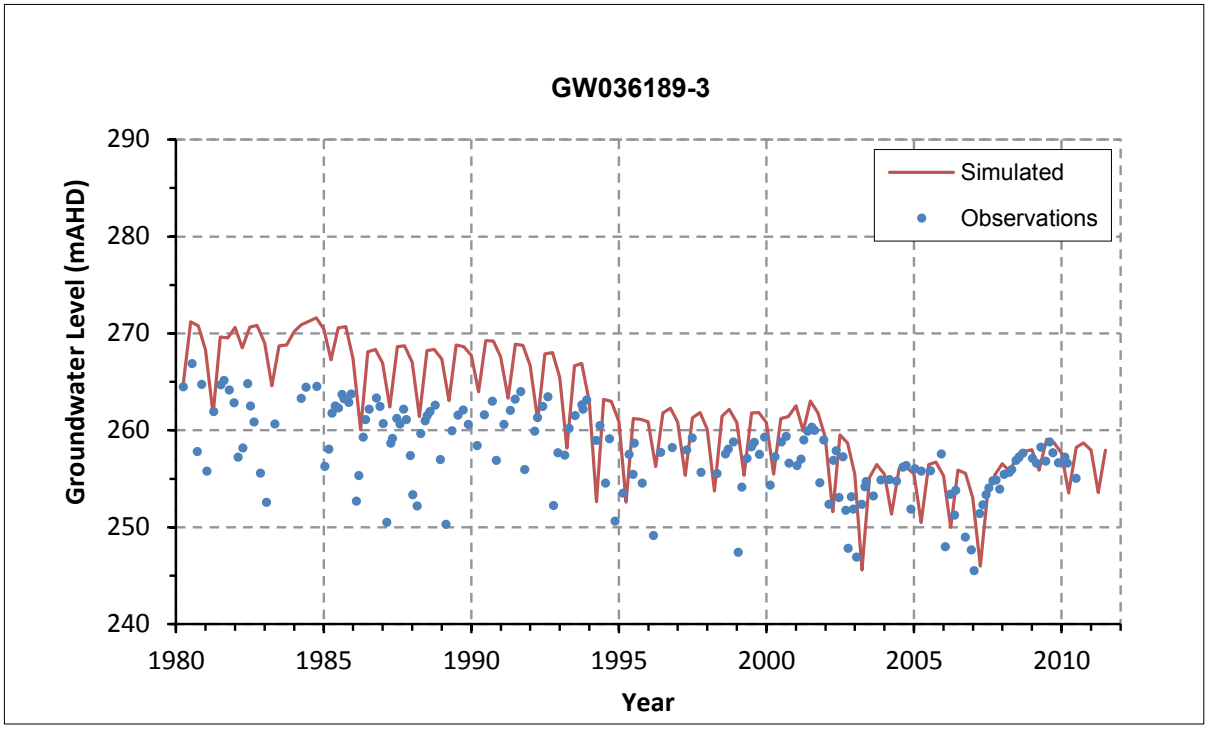

GW036168-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

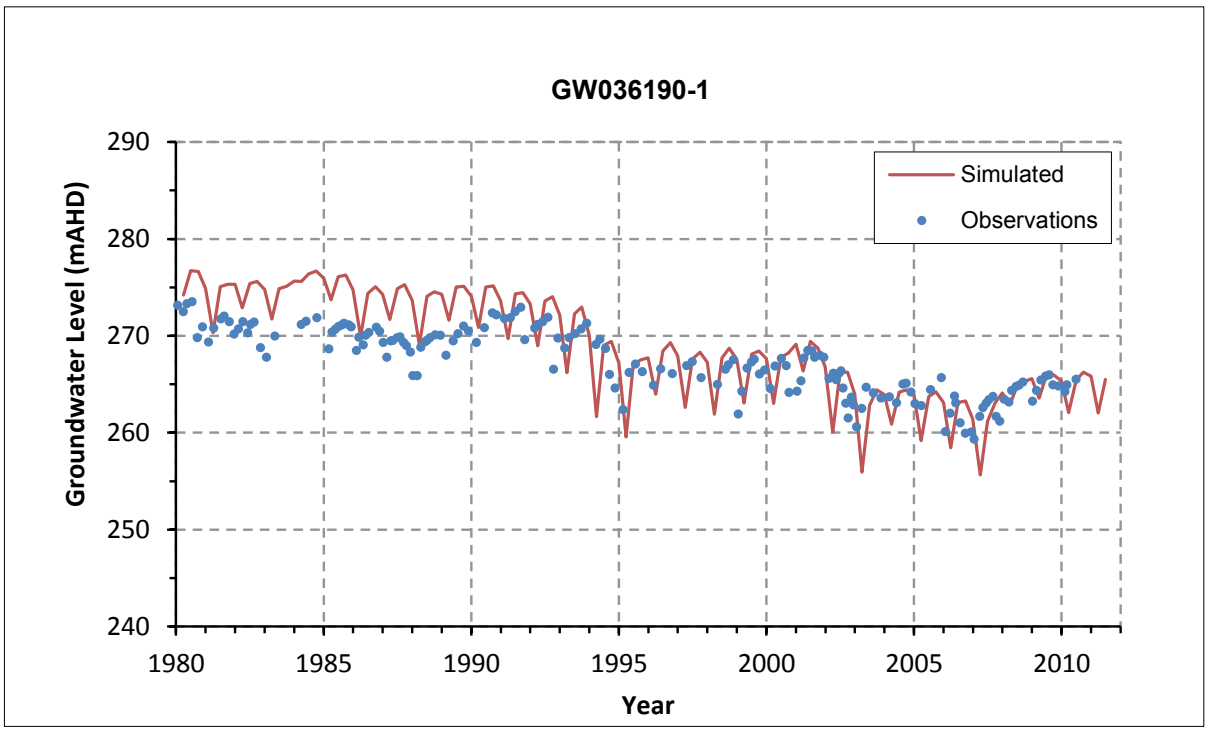

GW036168-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

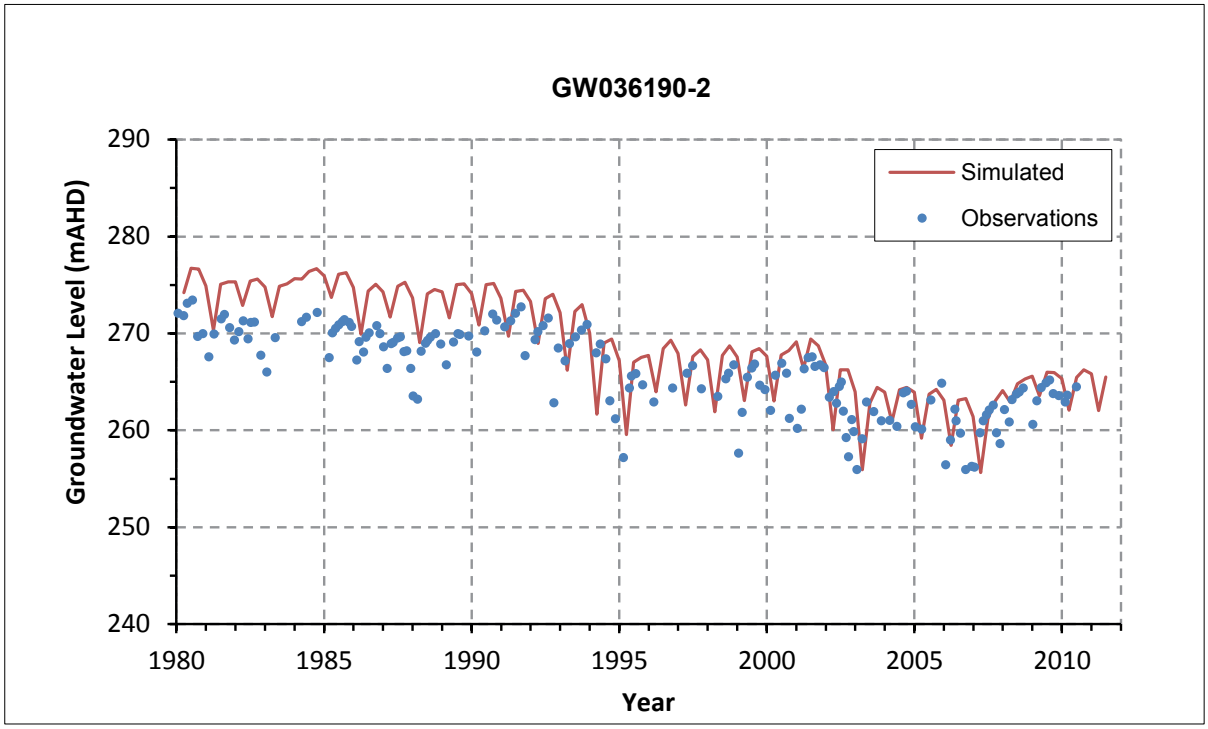

GW036168-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

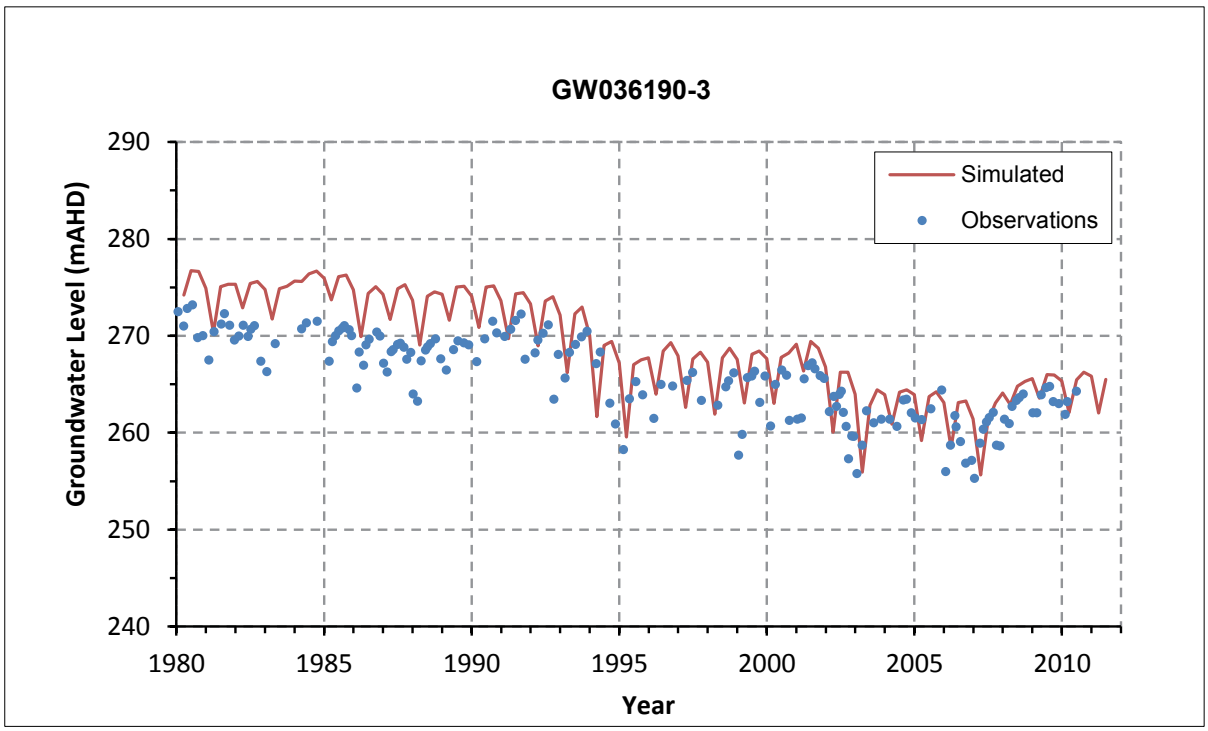

GW036189-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

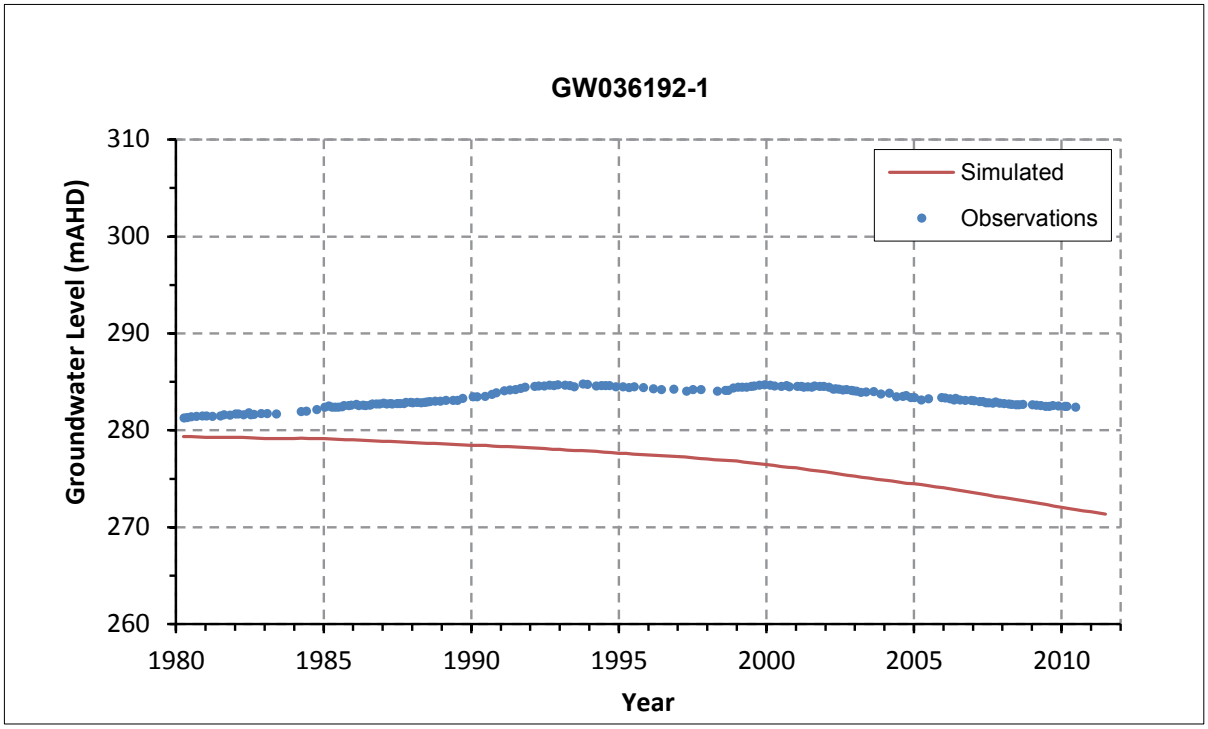

GW036189-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

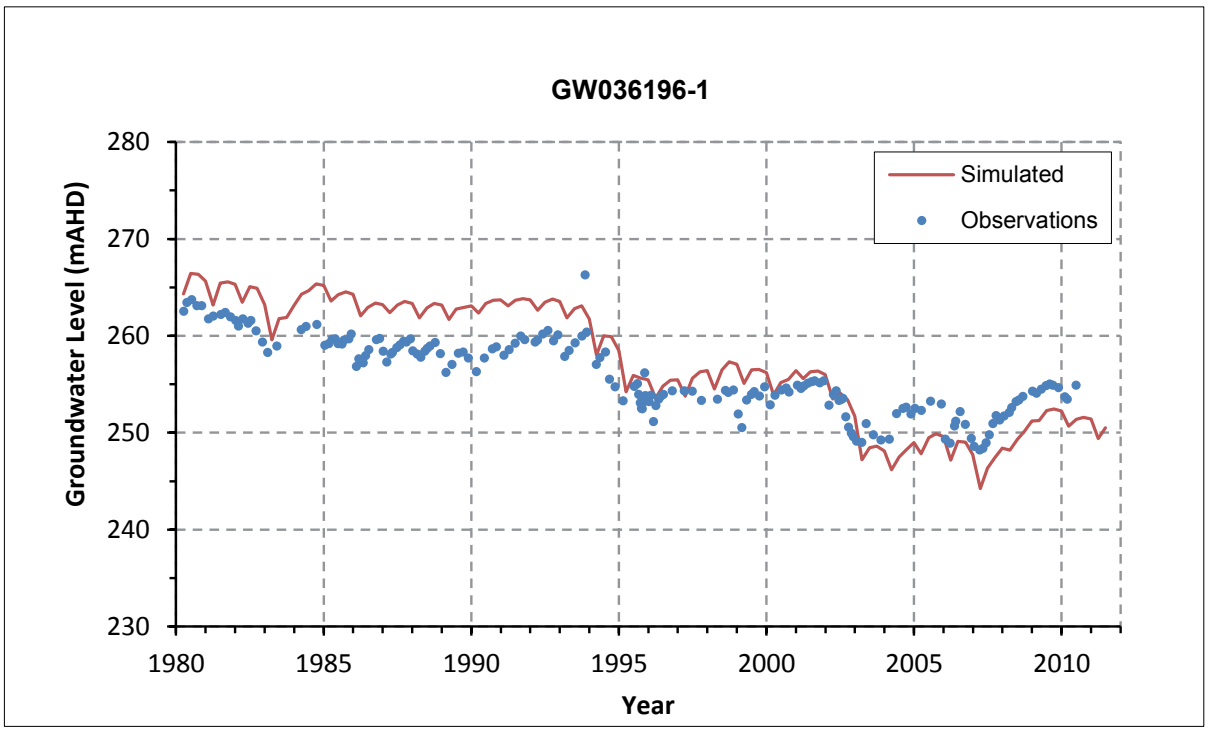

GW036189-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

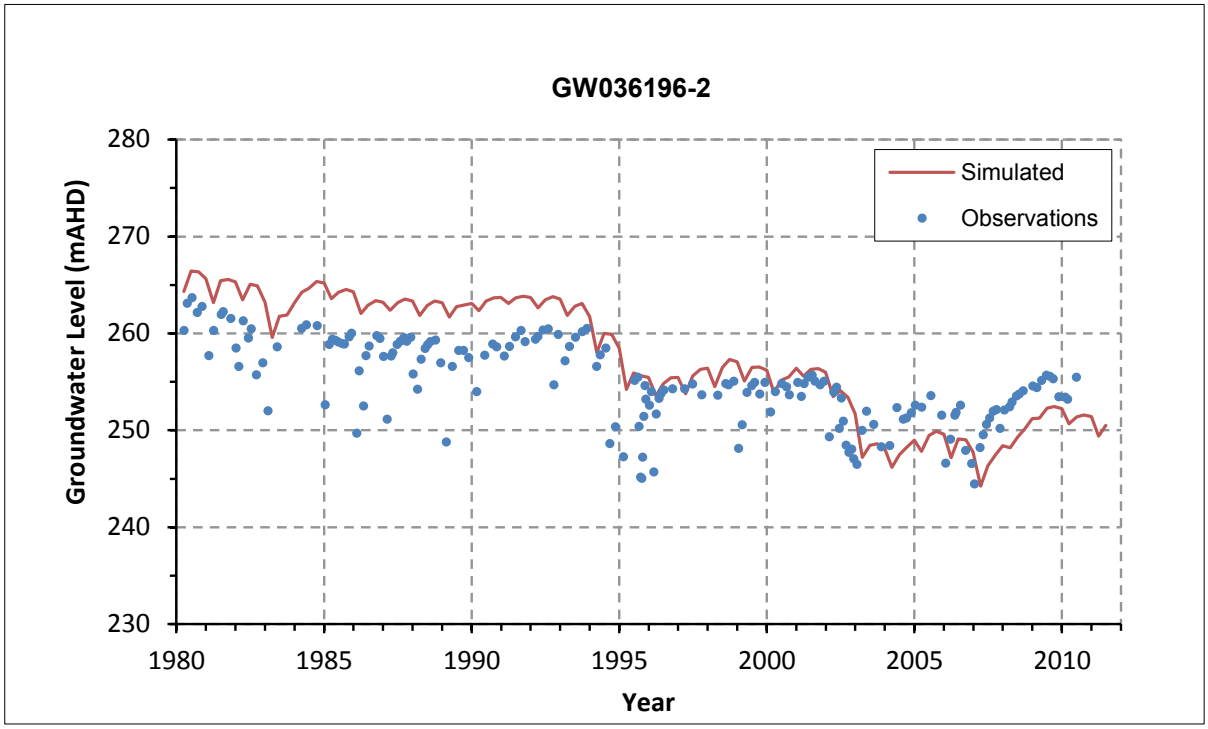

GW036190-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

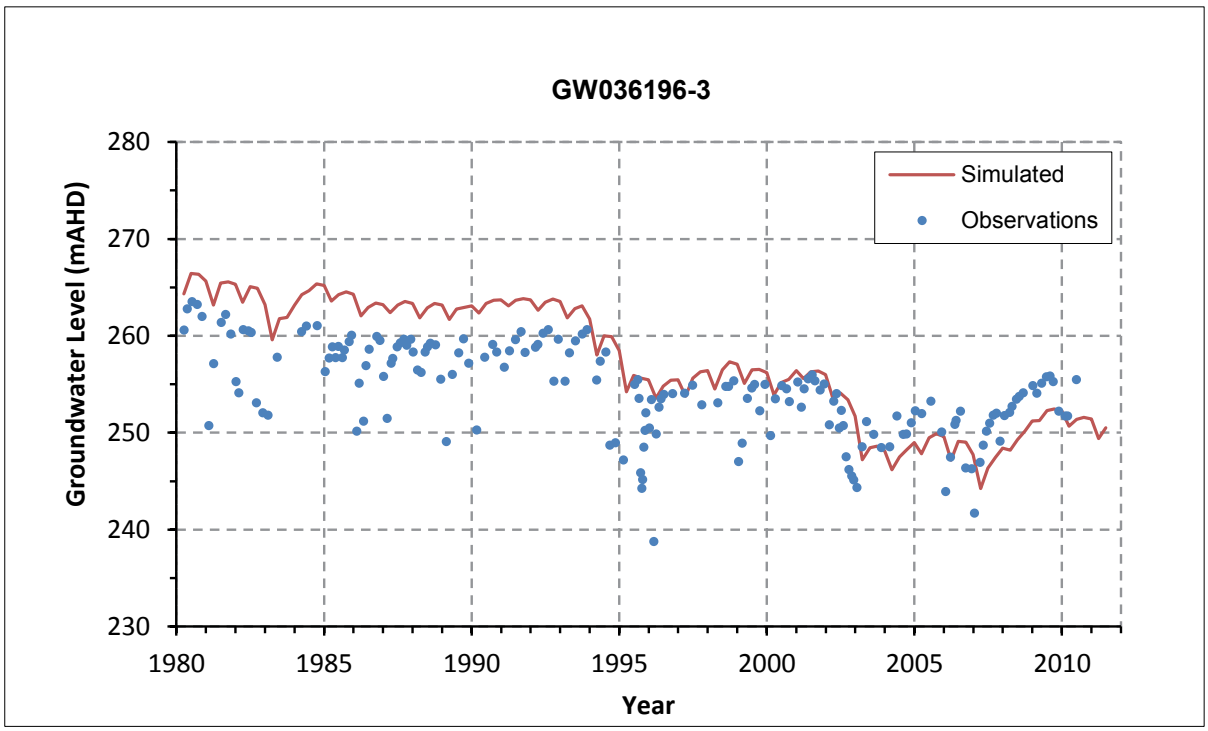

GW036190-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

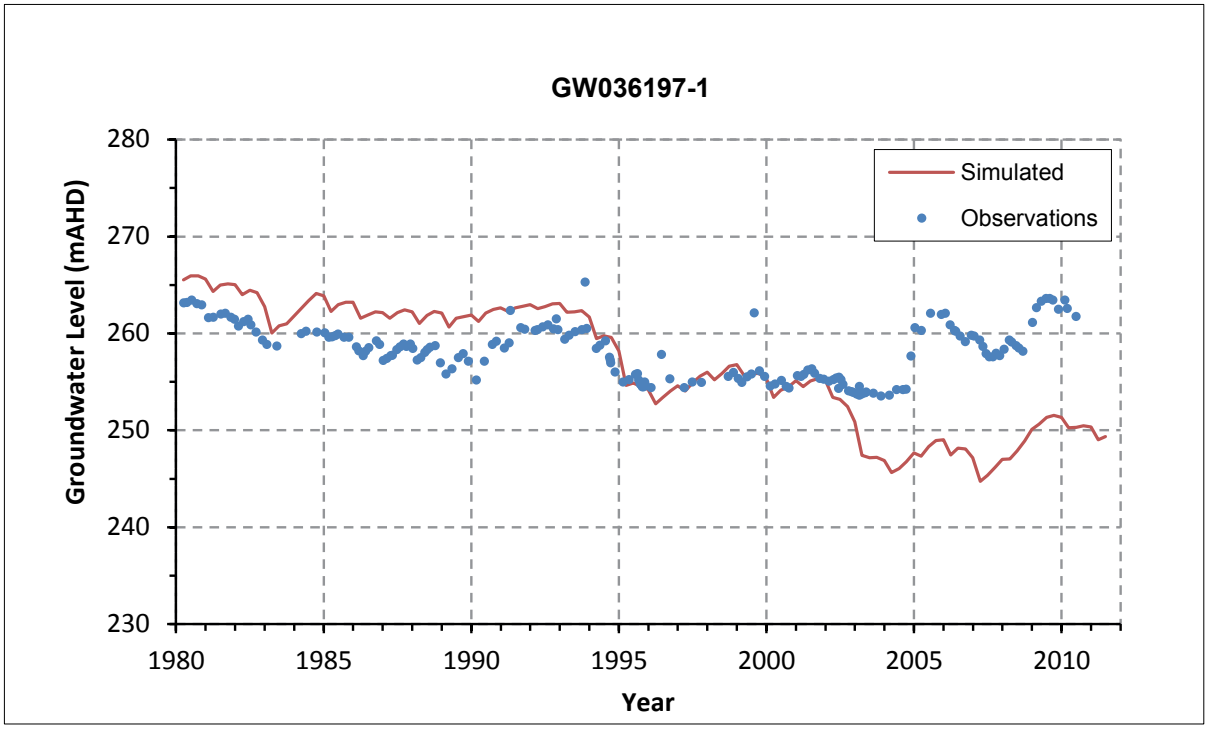

GW036190-3
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

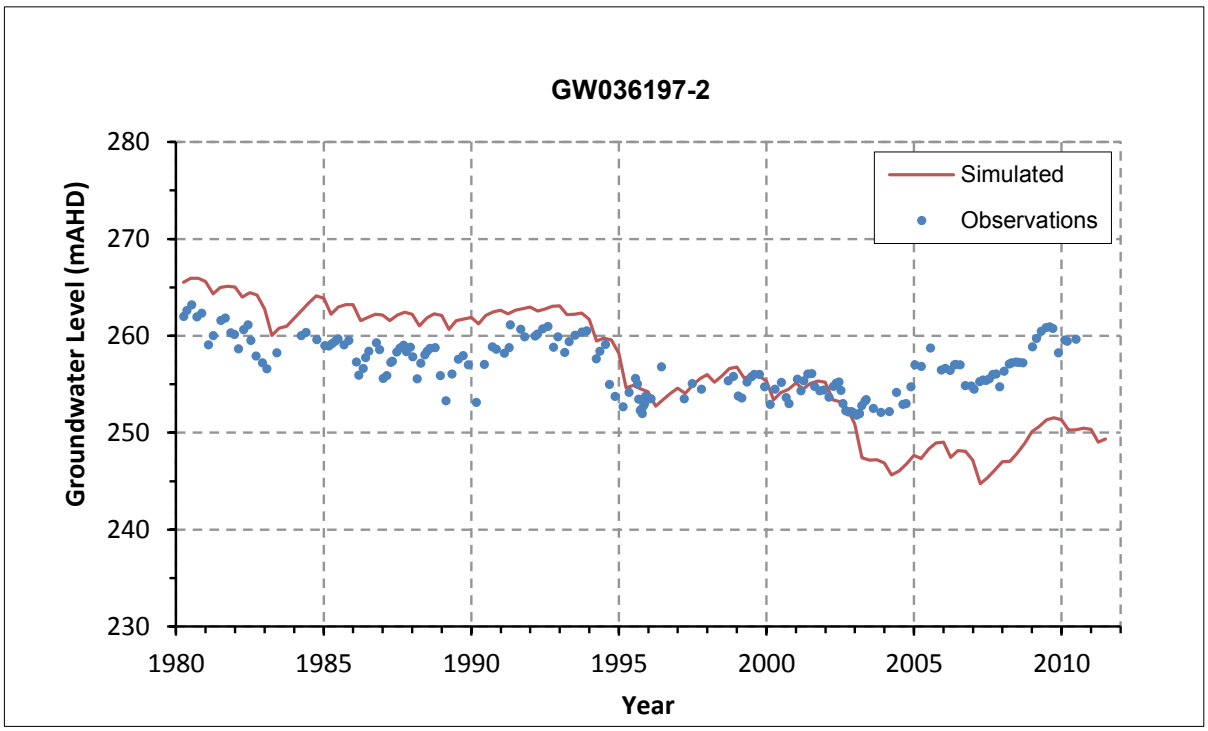

GW036192-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

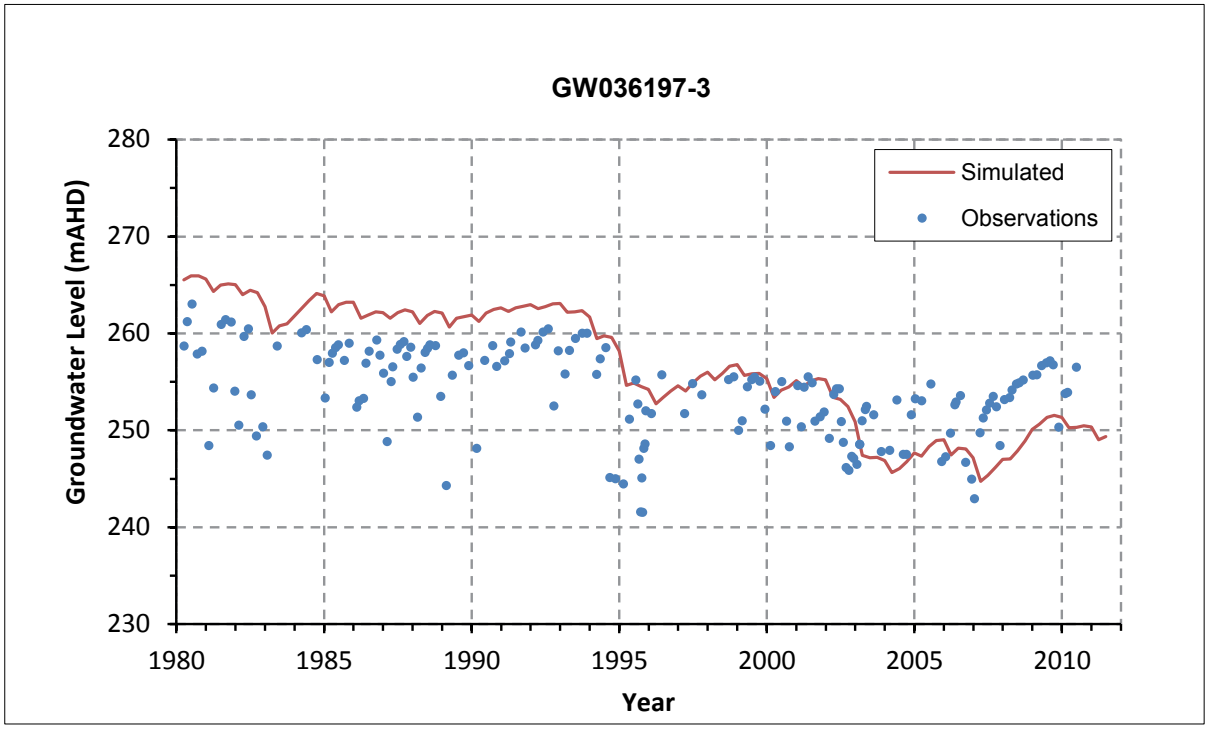

GW036196-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

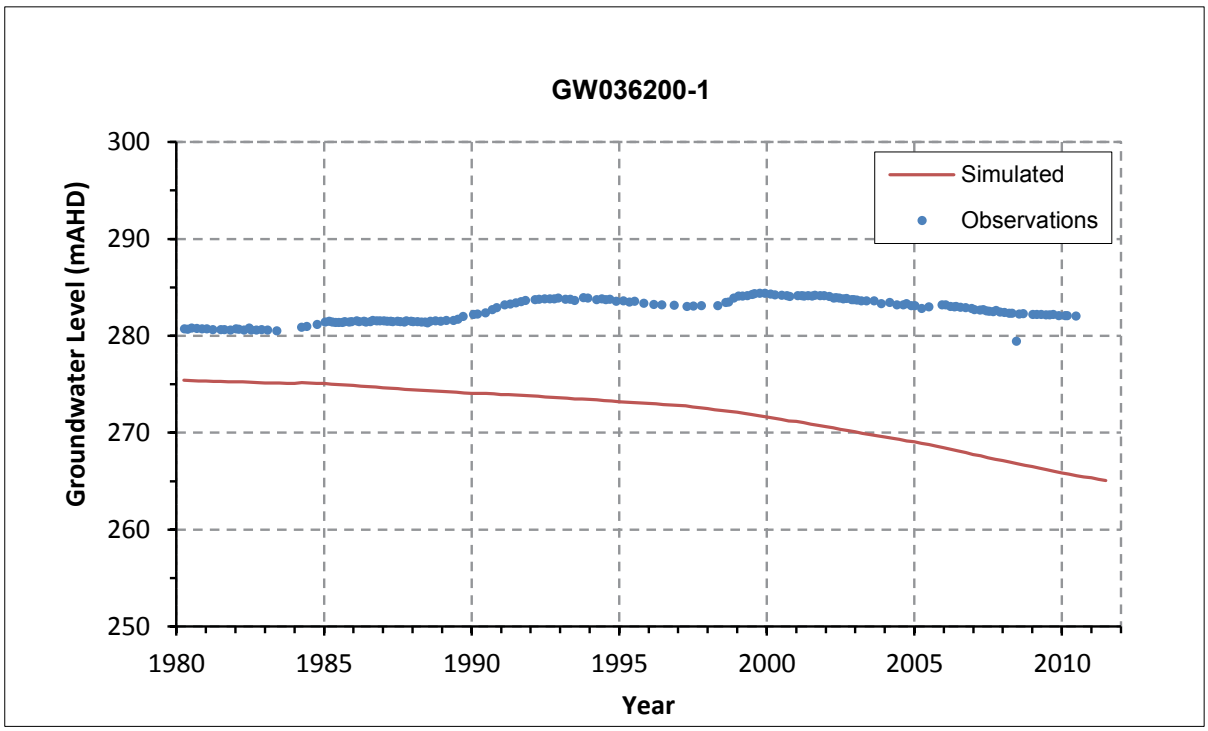

GW036196-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

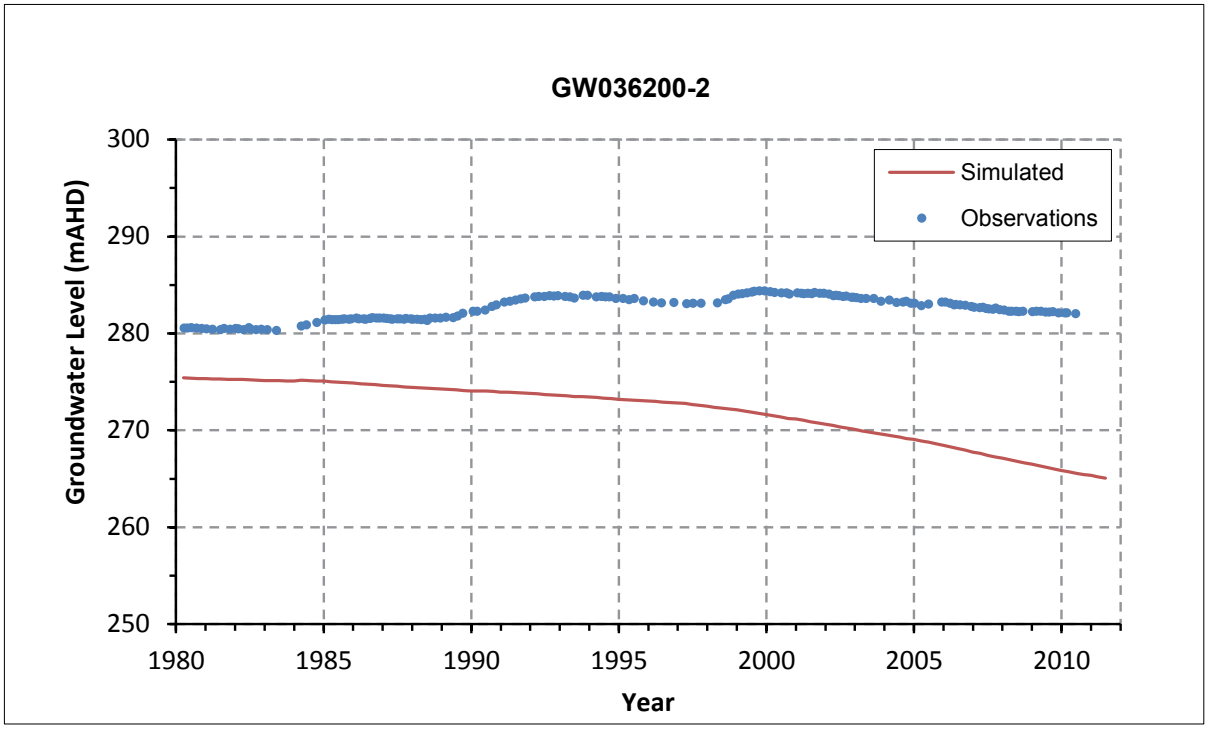

GW036196-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

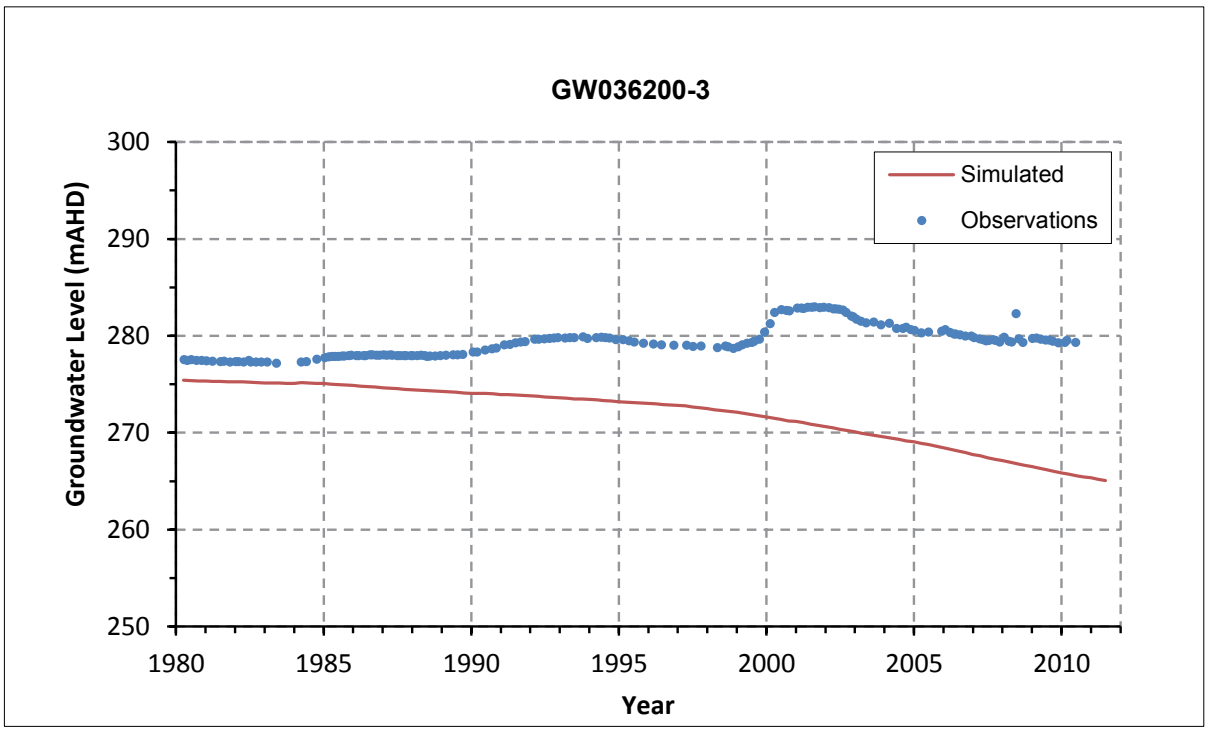

GW036197-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

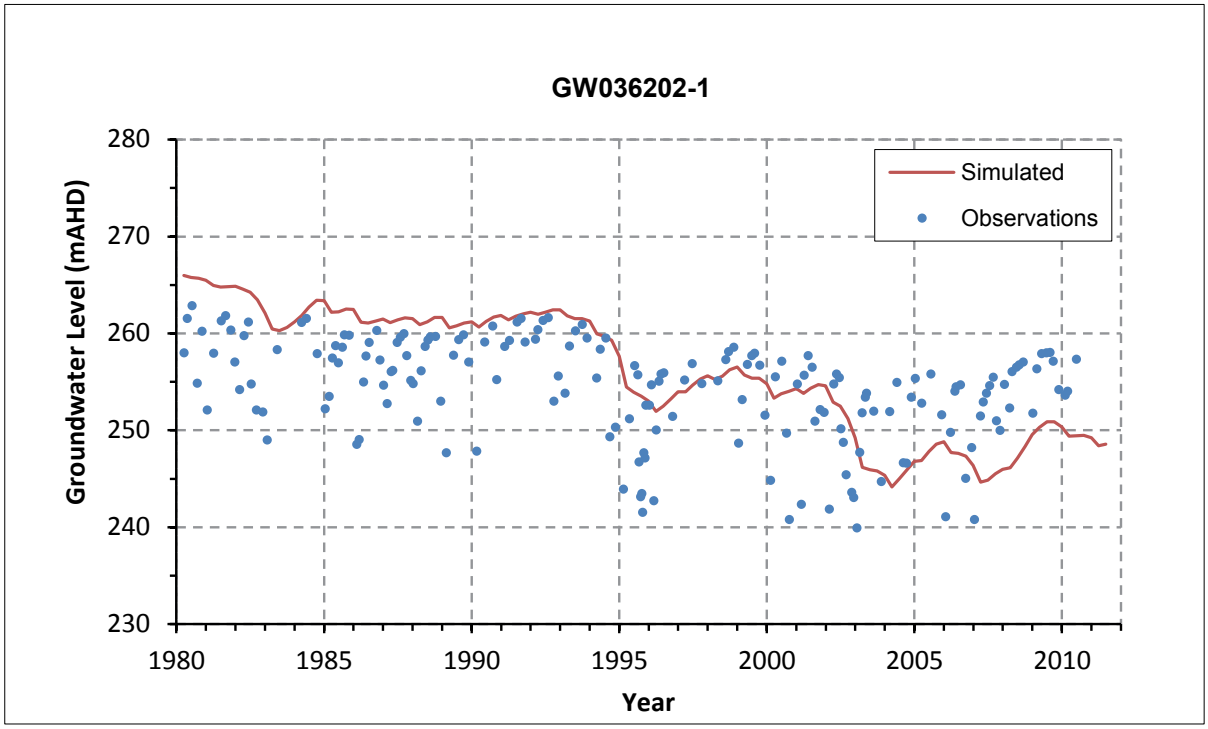

GW036197-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

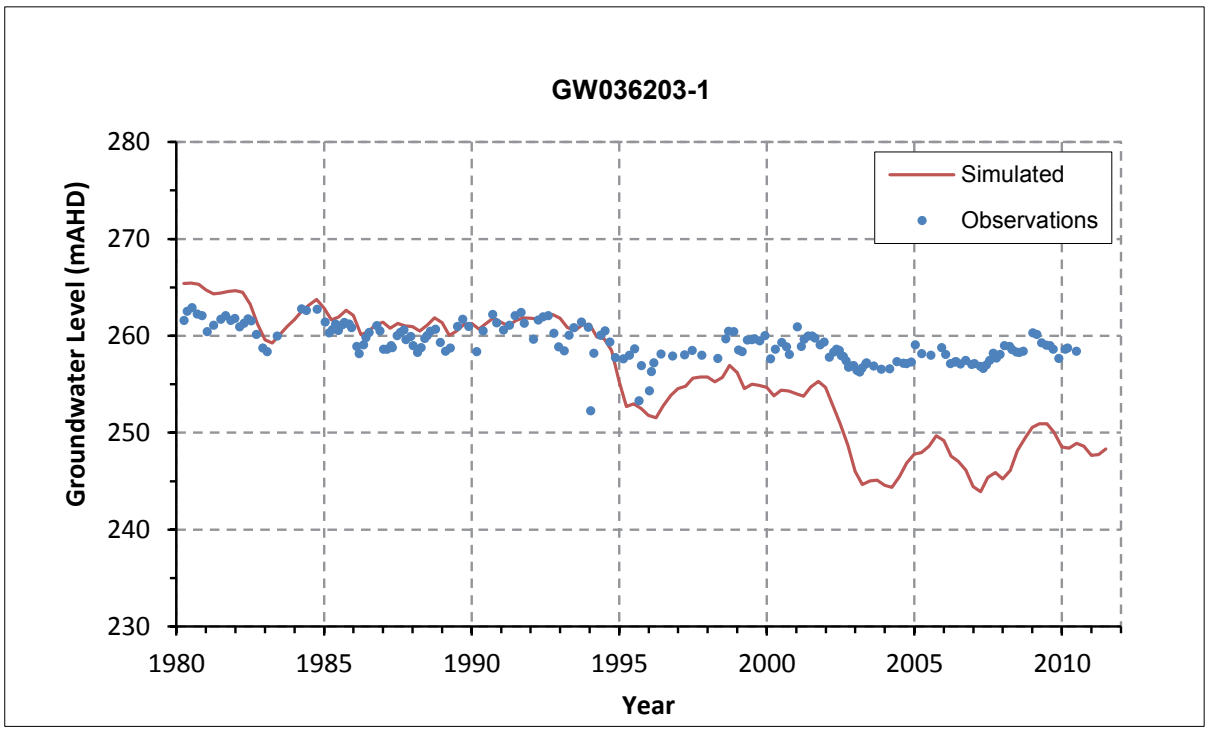

GW036197-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

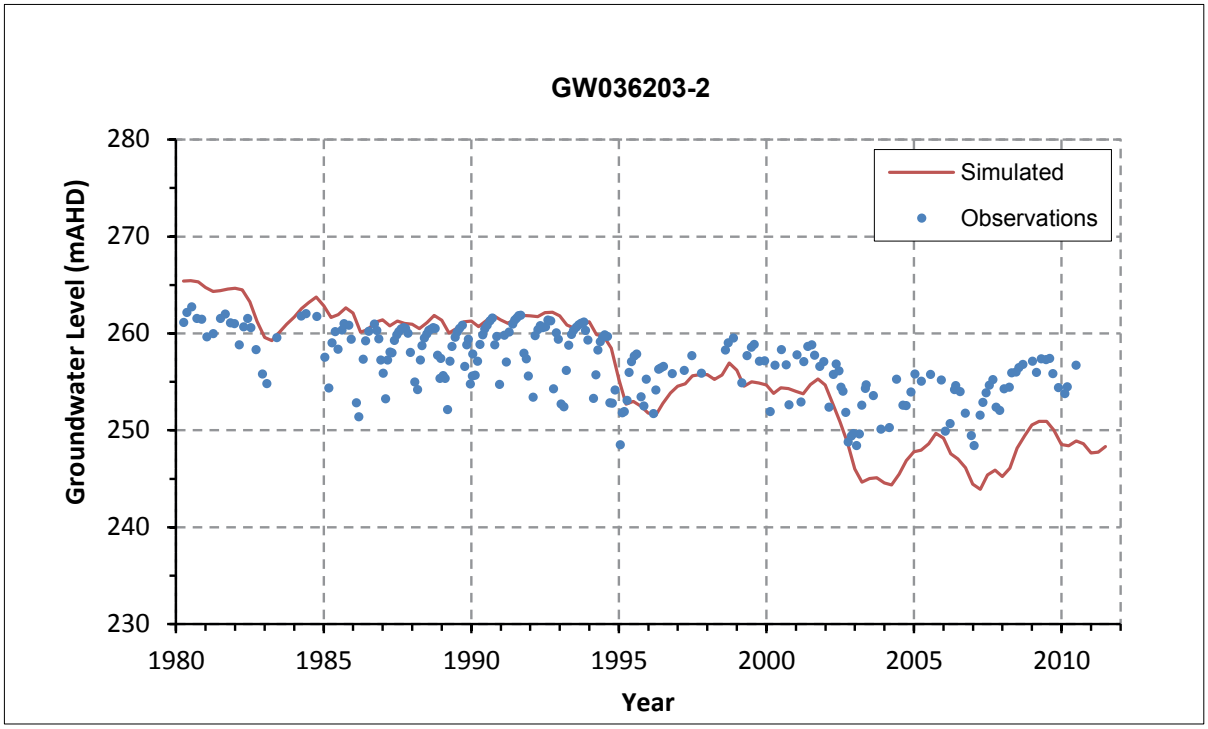

GW036200-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

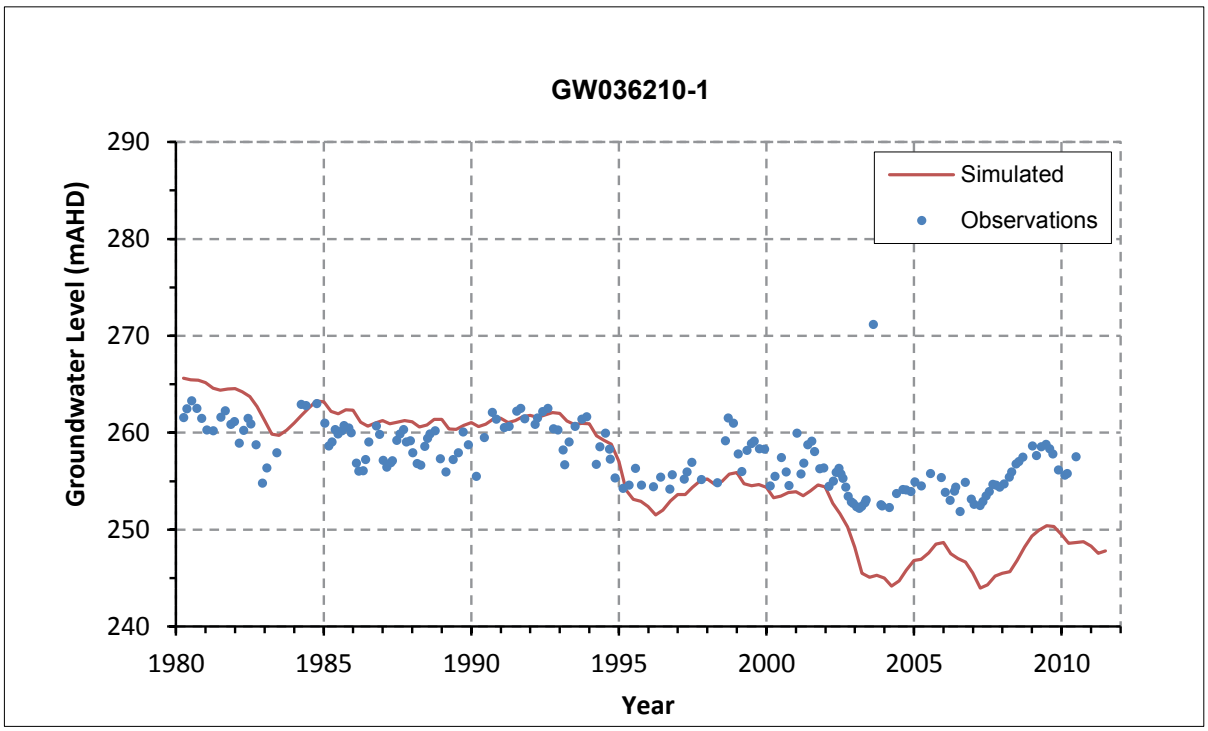

GW036200-2
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

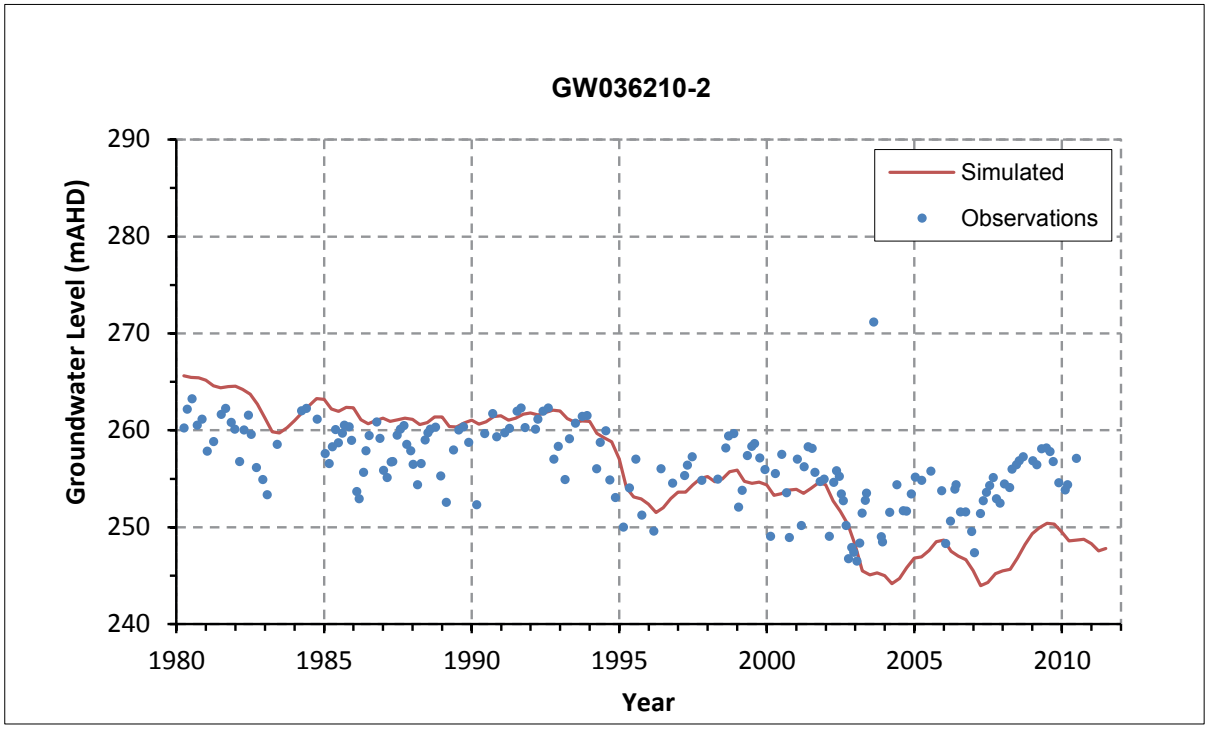

GW036200-3
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

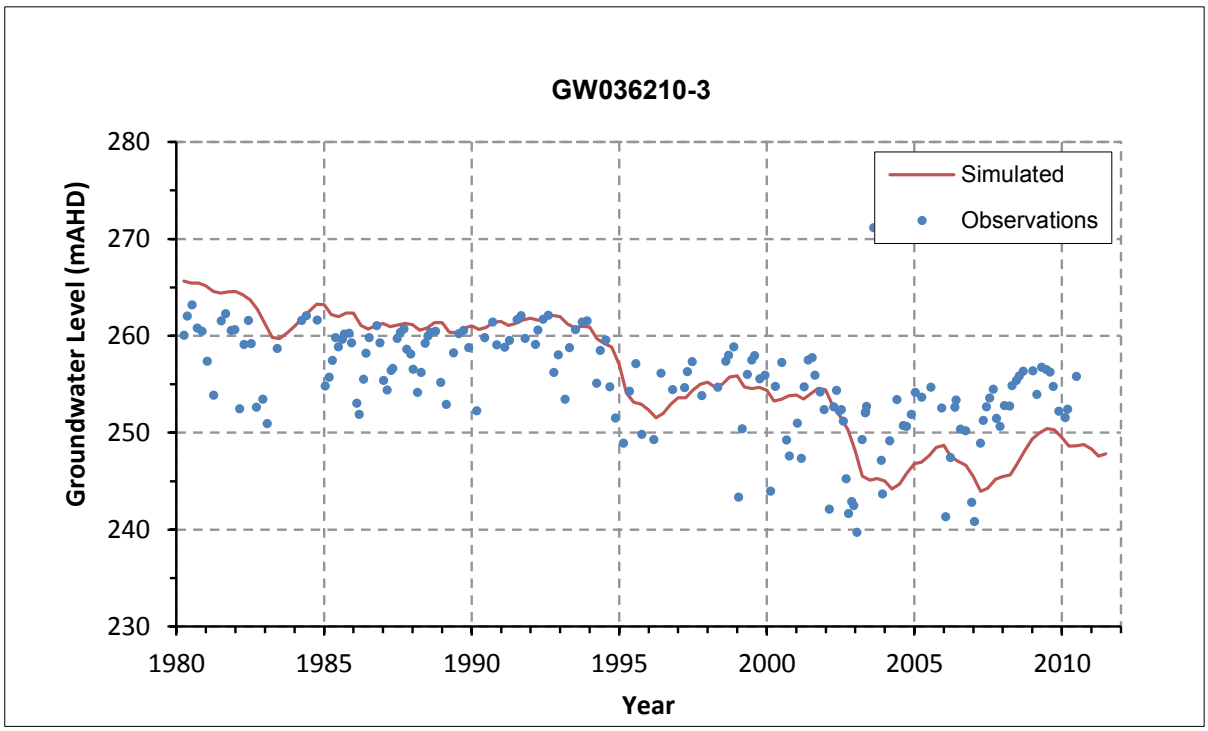

GW036202-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

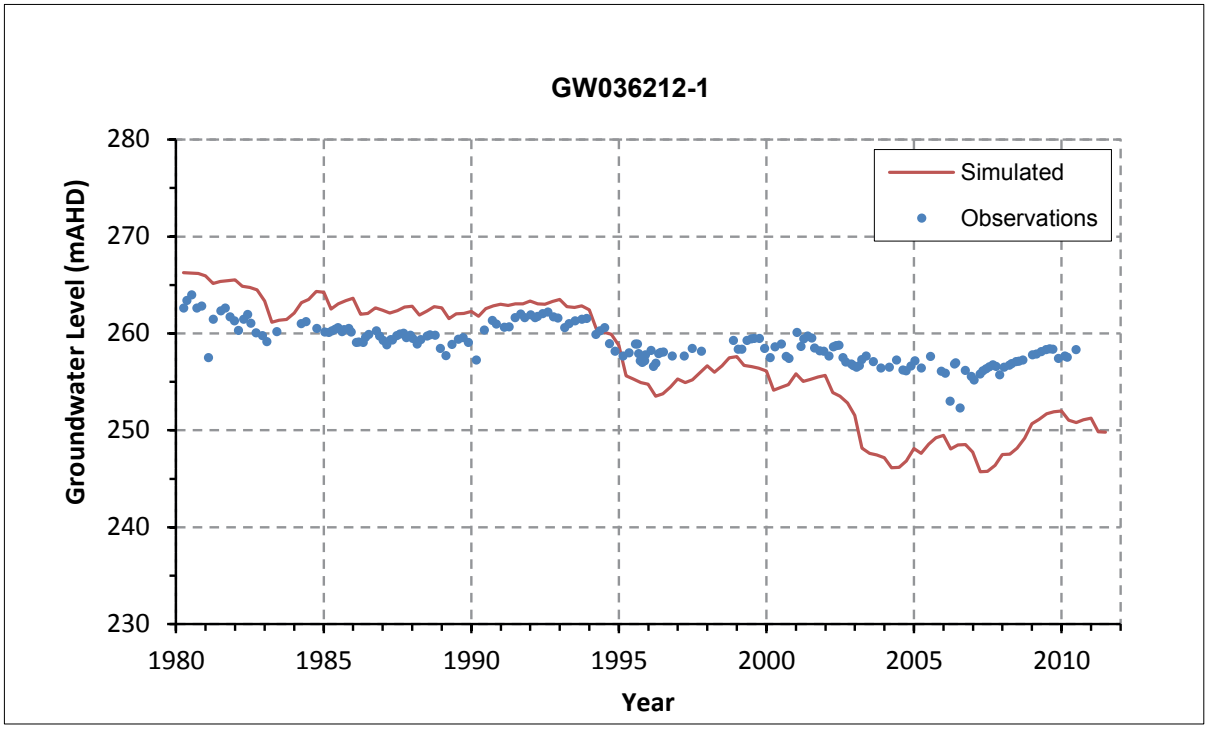

GW036203-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

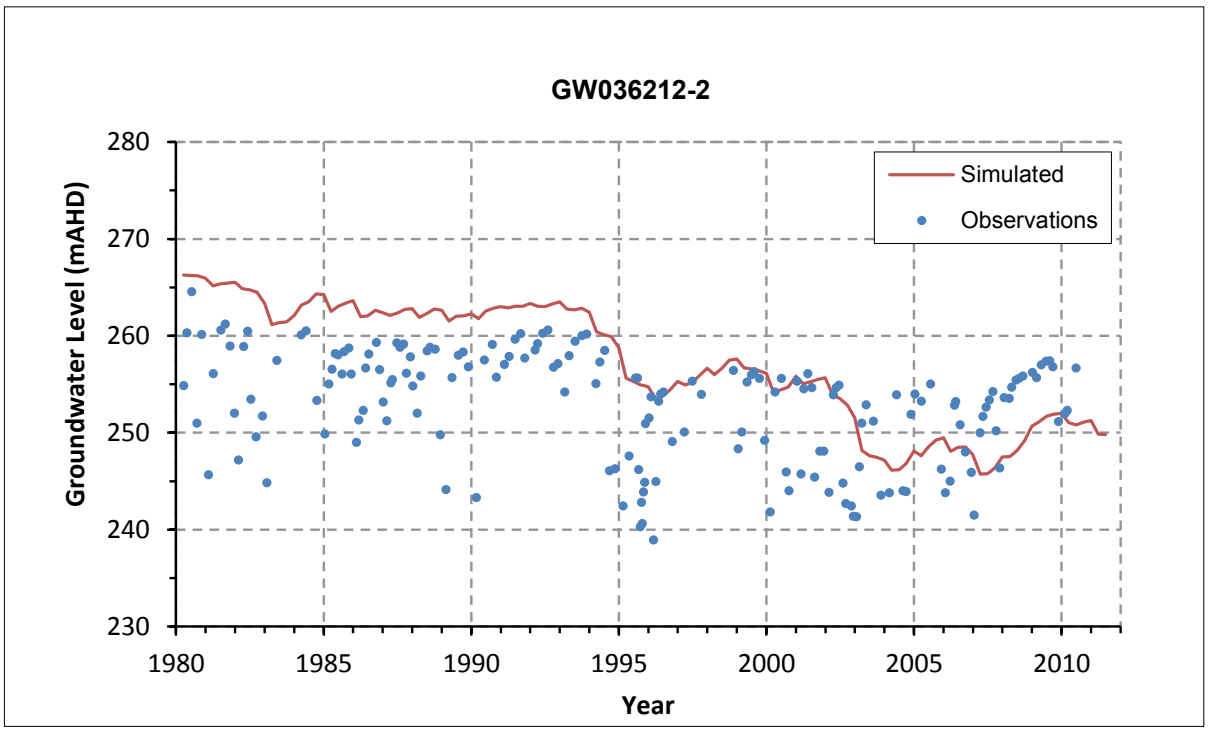

GW036203-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

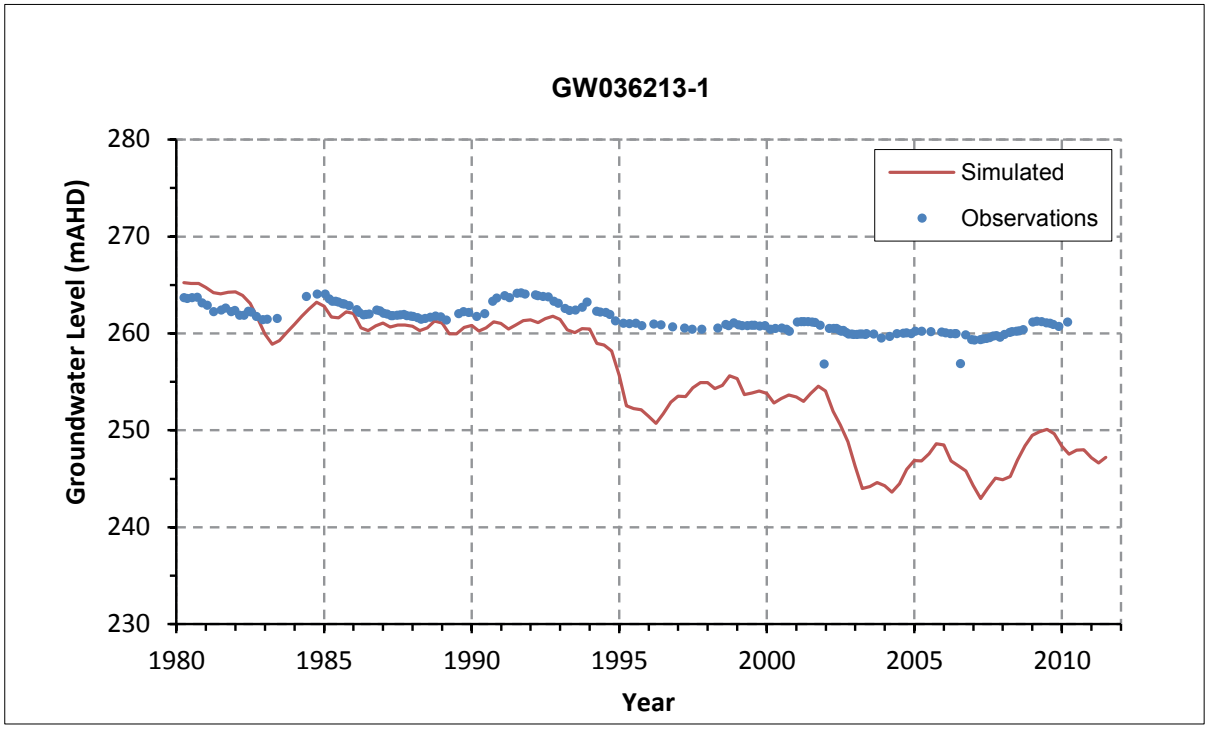

GW036210-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

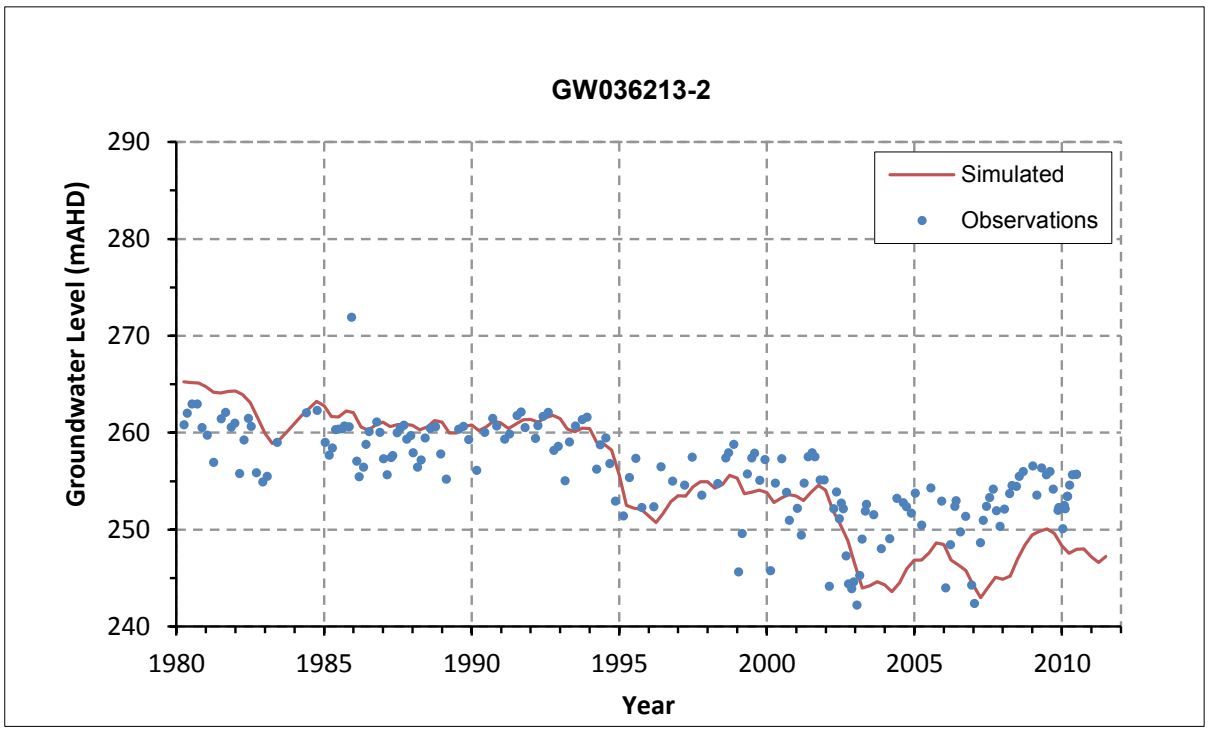

GW036210-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

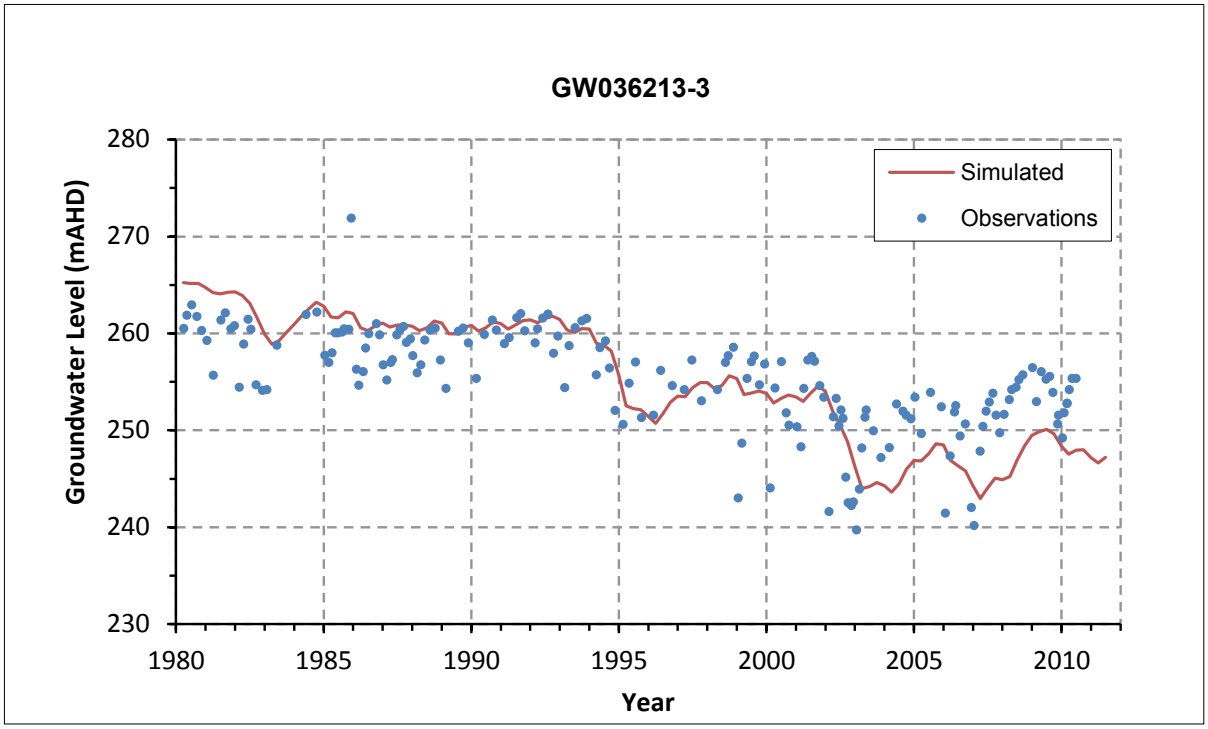

GW036210-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

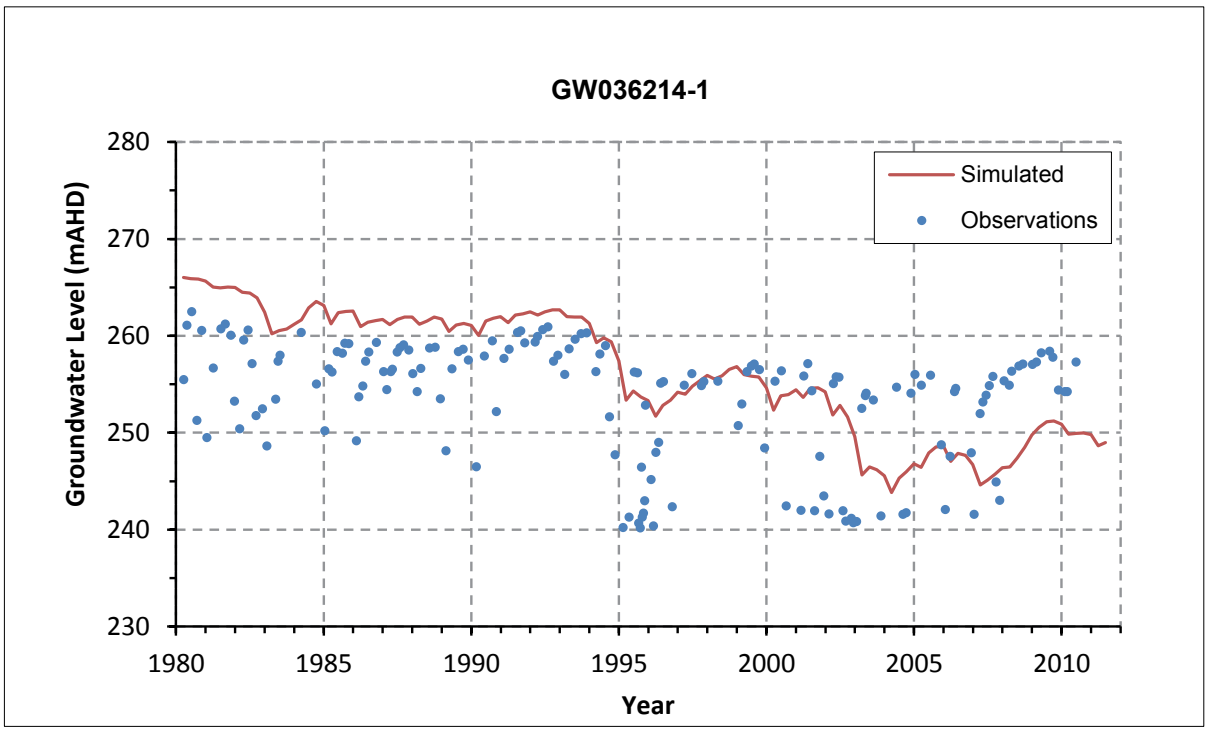

GW036212-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

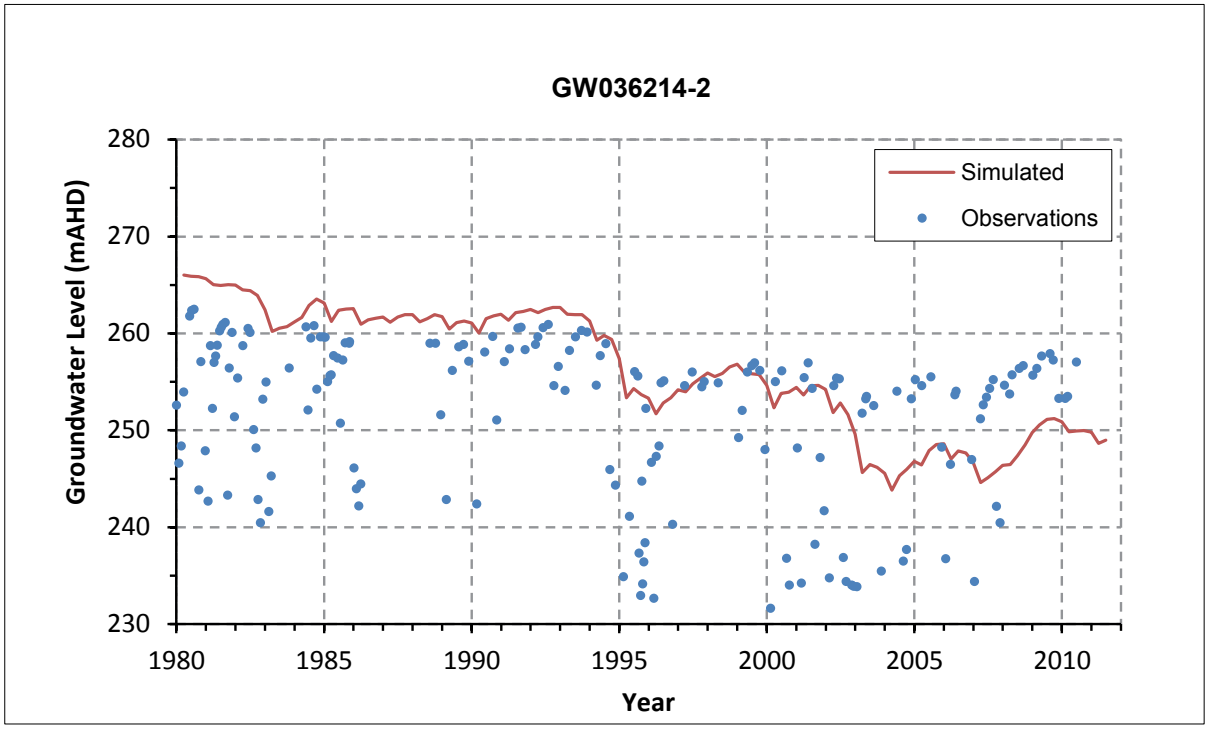

GW036212-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

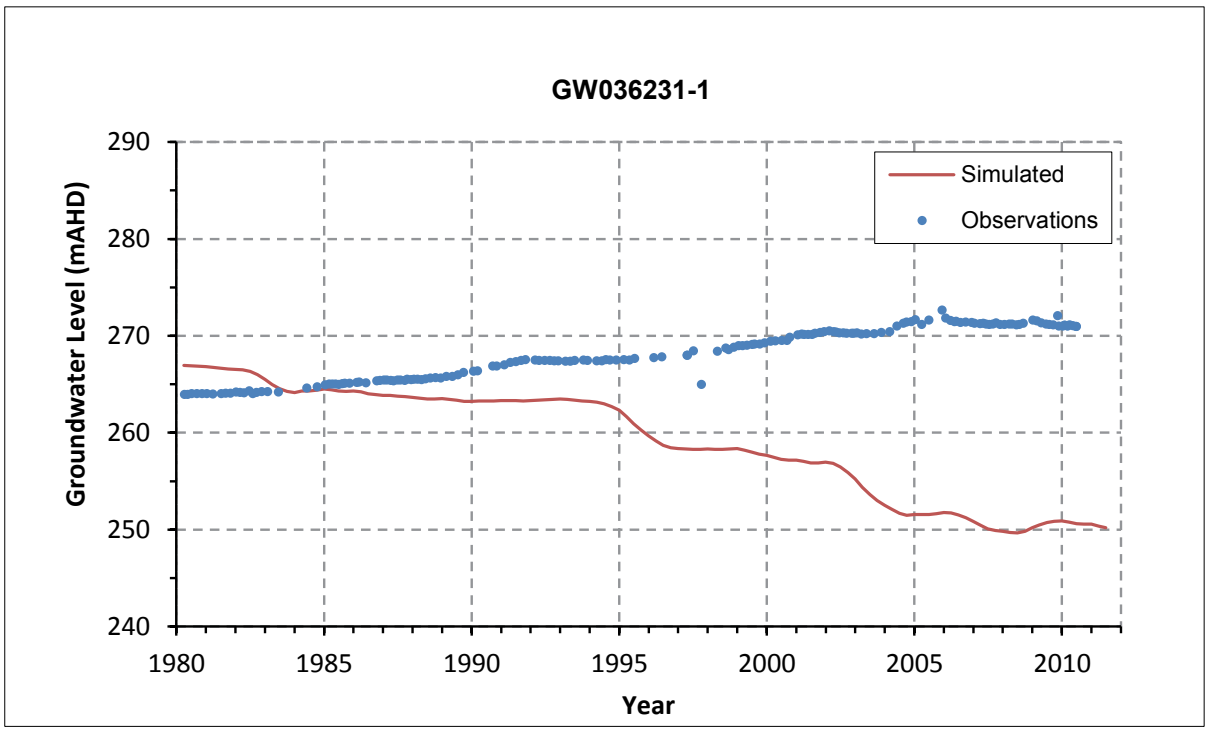

GW036213-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

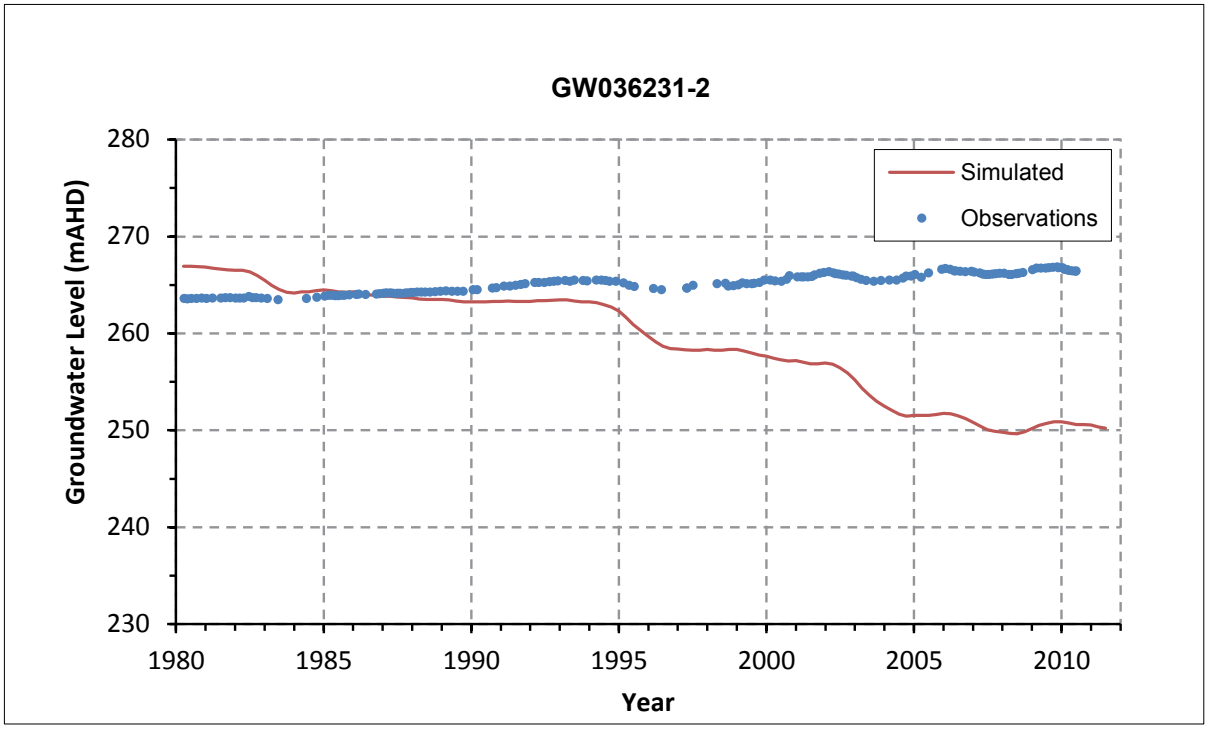

GW036213-2
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

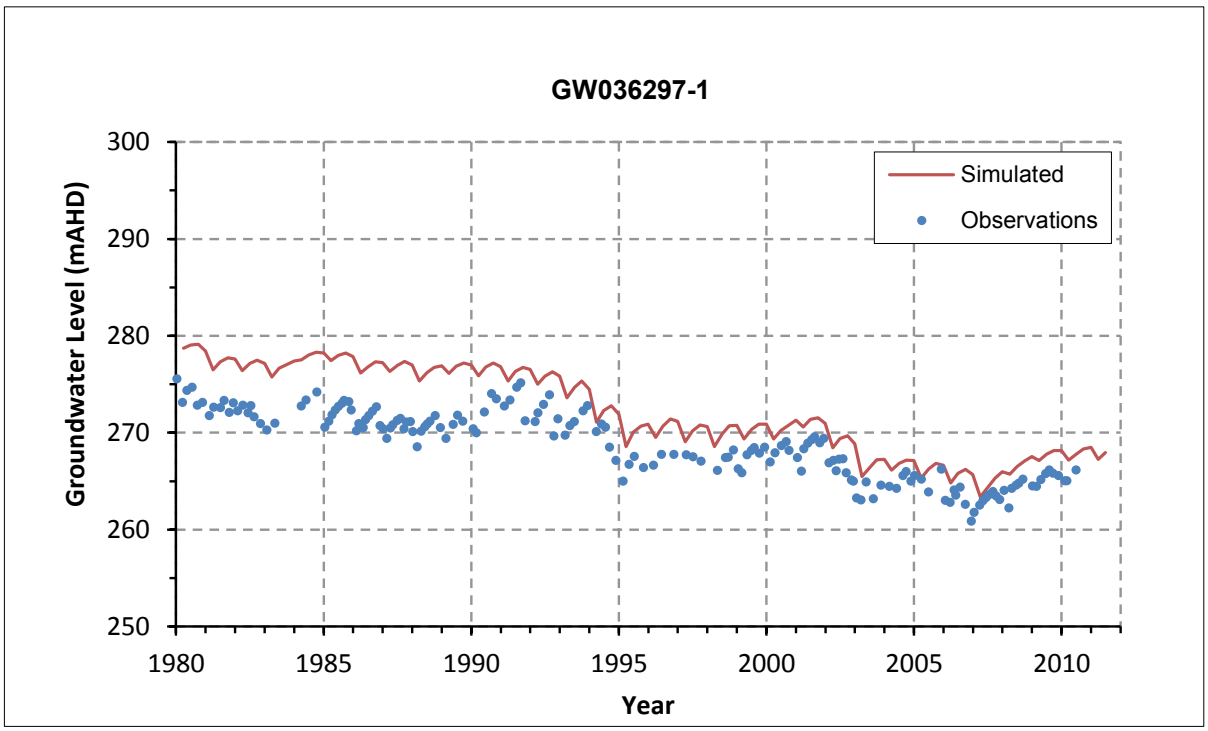

GW036213-3
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

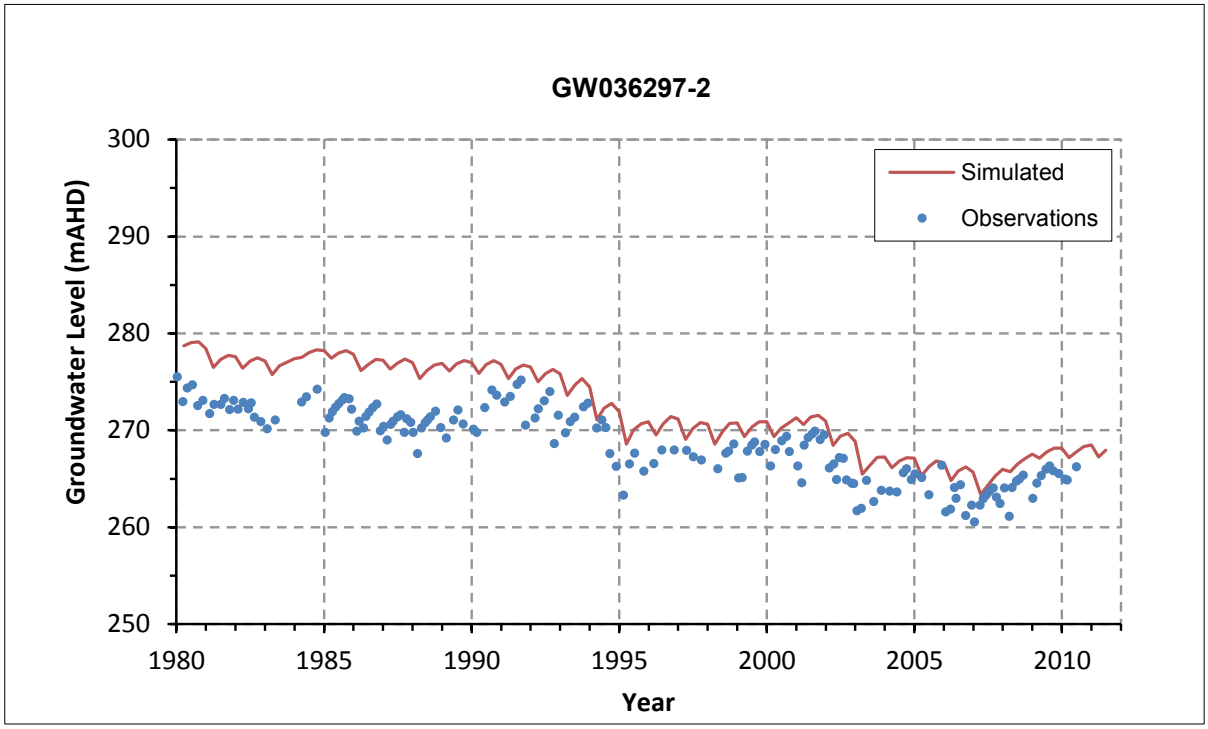

GW036214-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

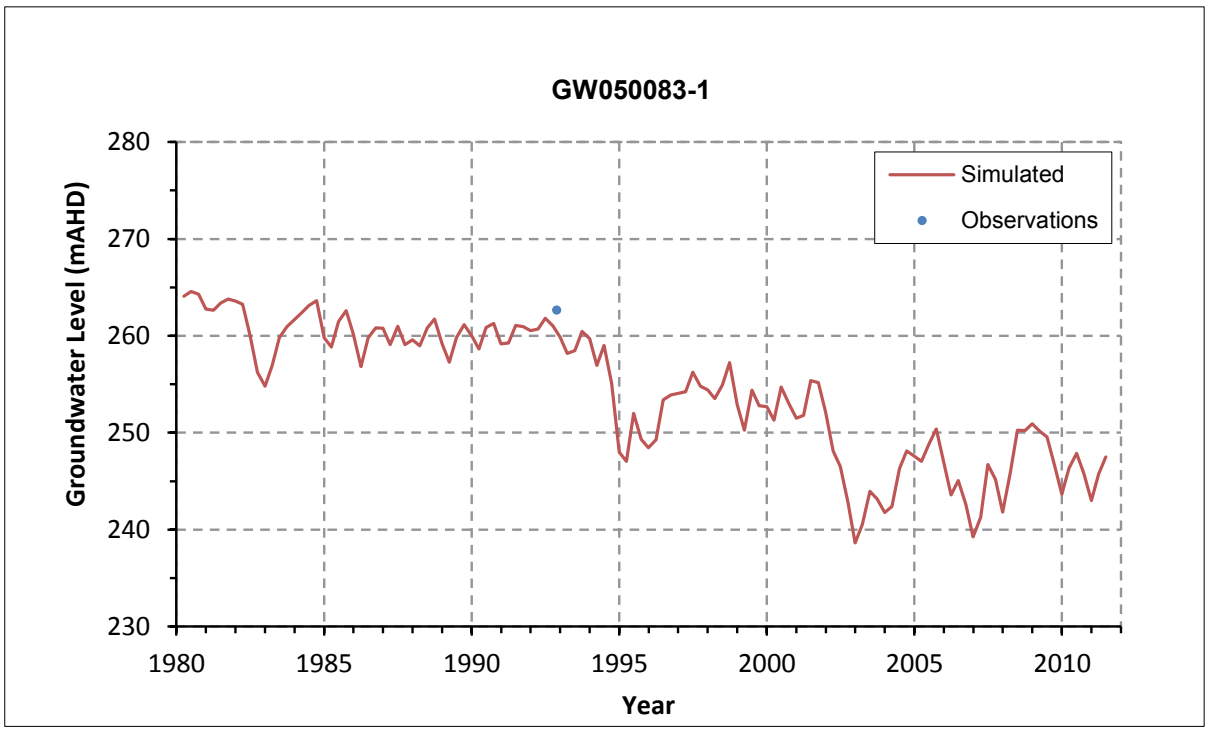

GW036214-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

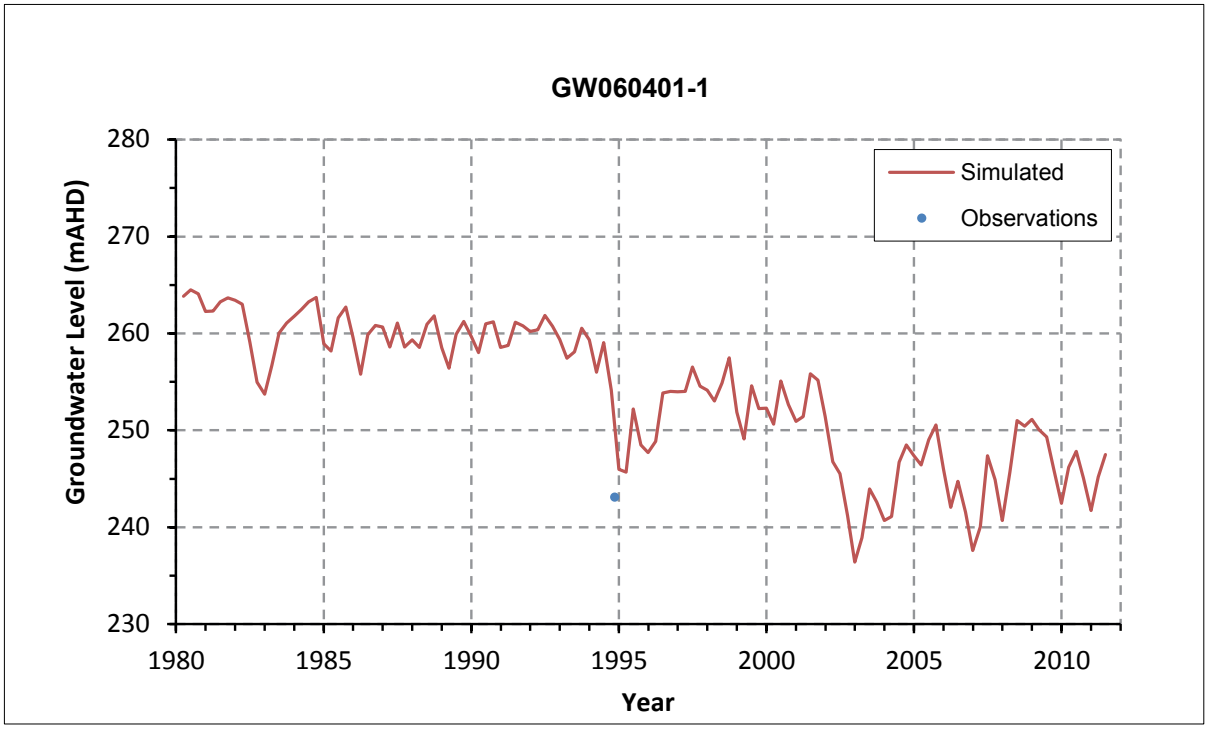

GW036231-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

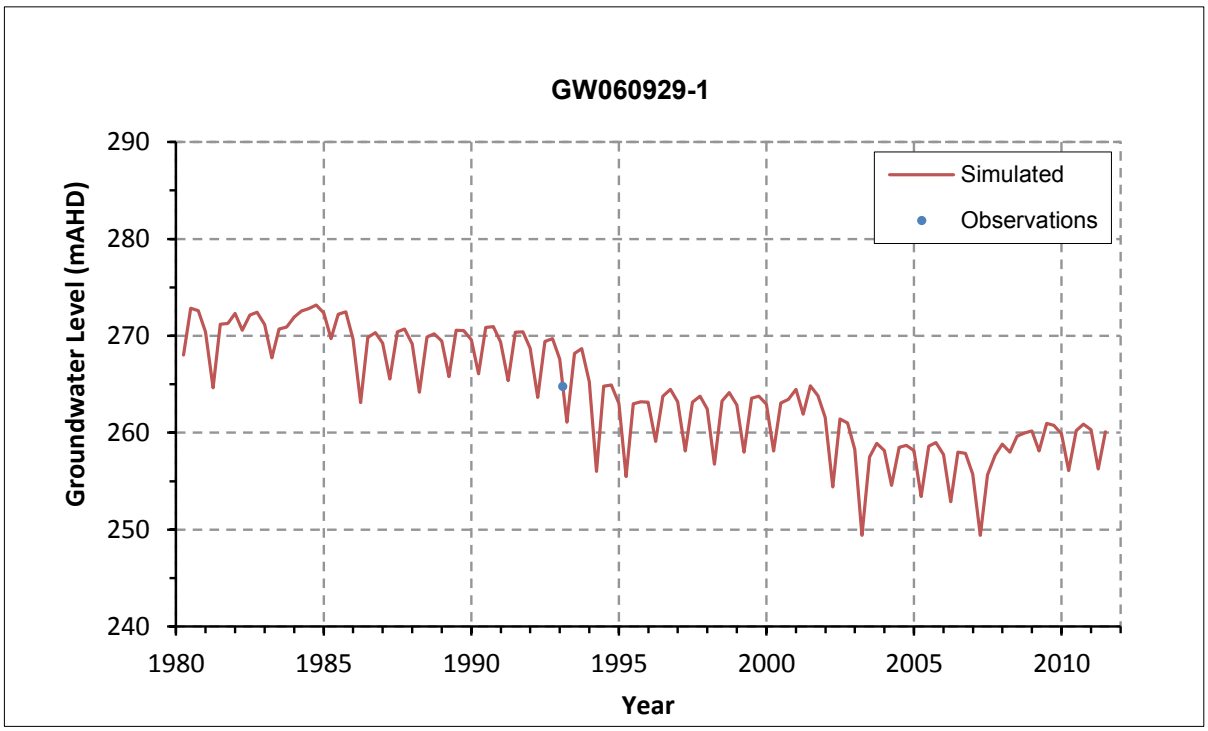

GW036231-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

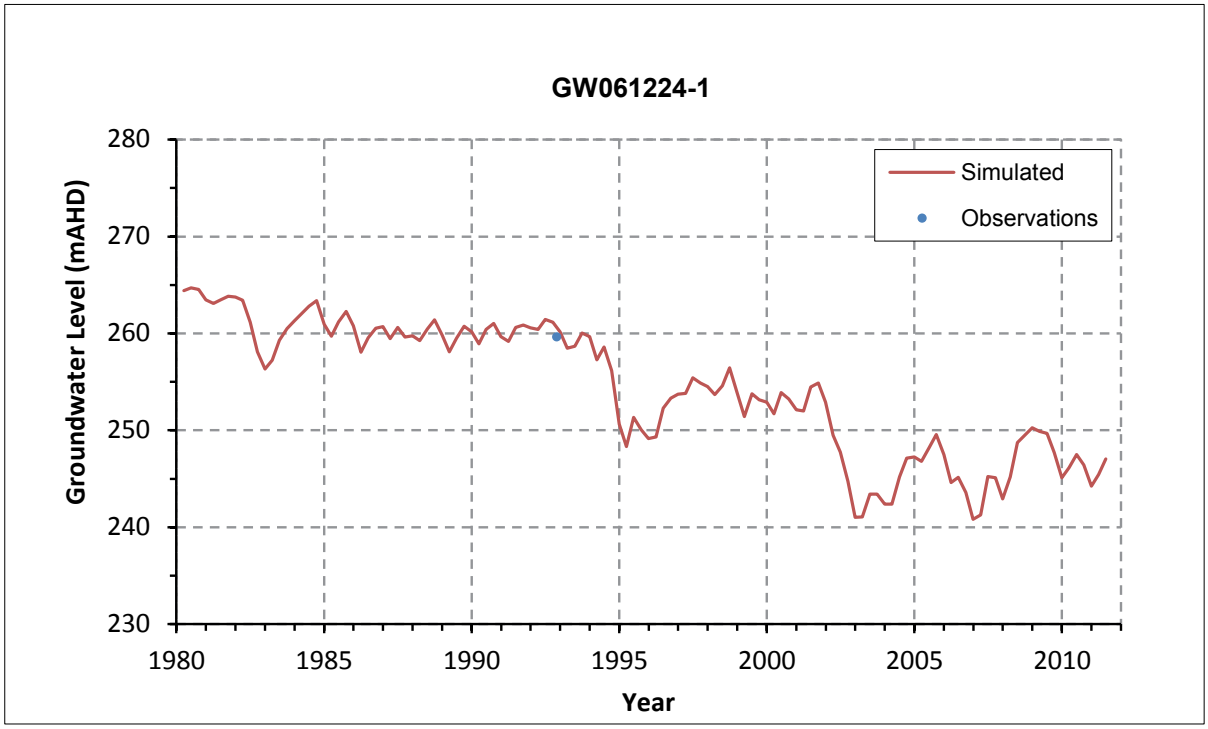

GW036297-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

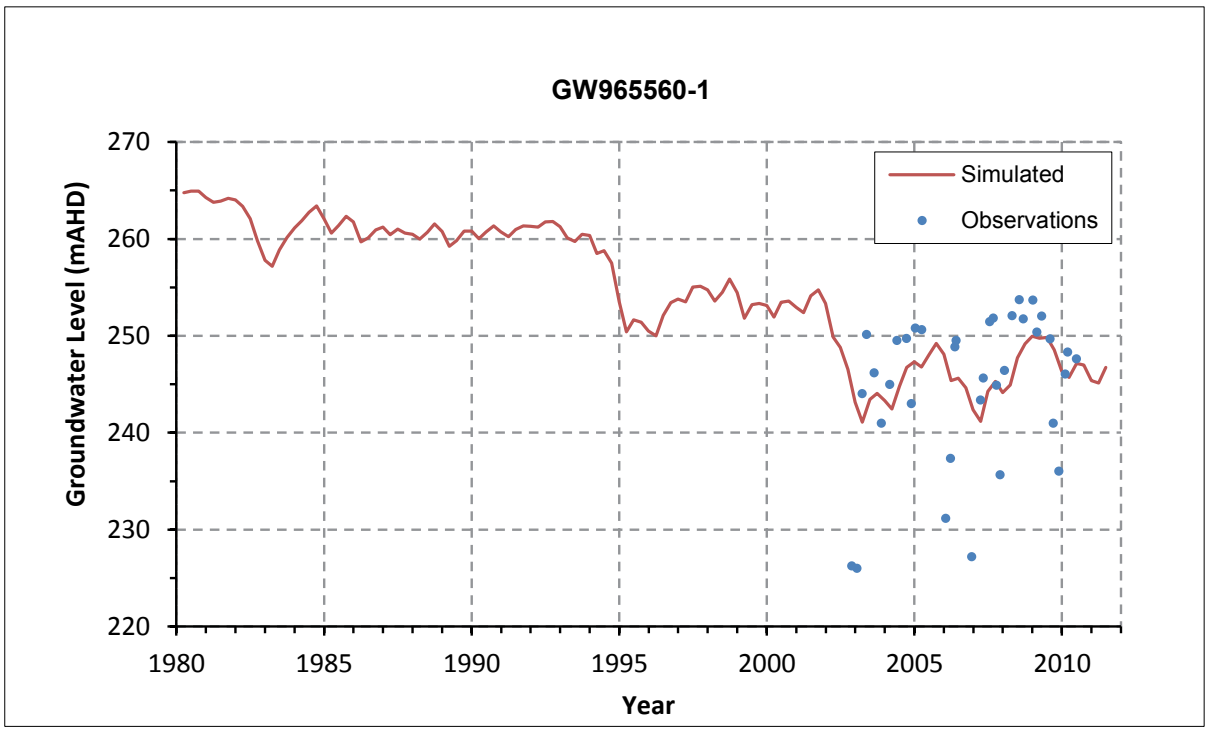

GW036297-2
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

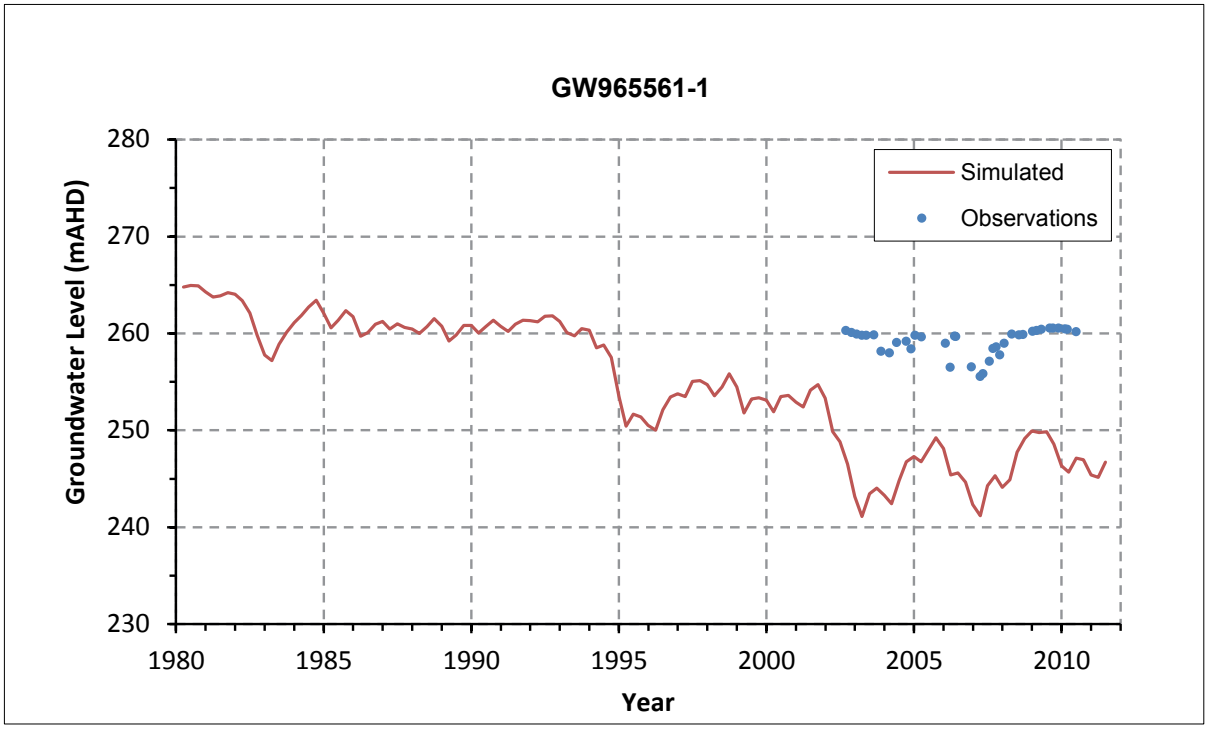

GW050083-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

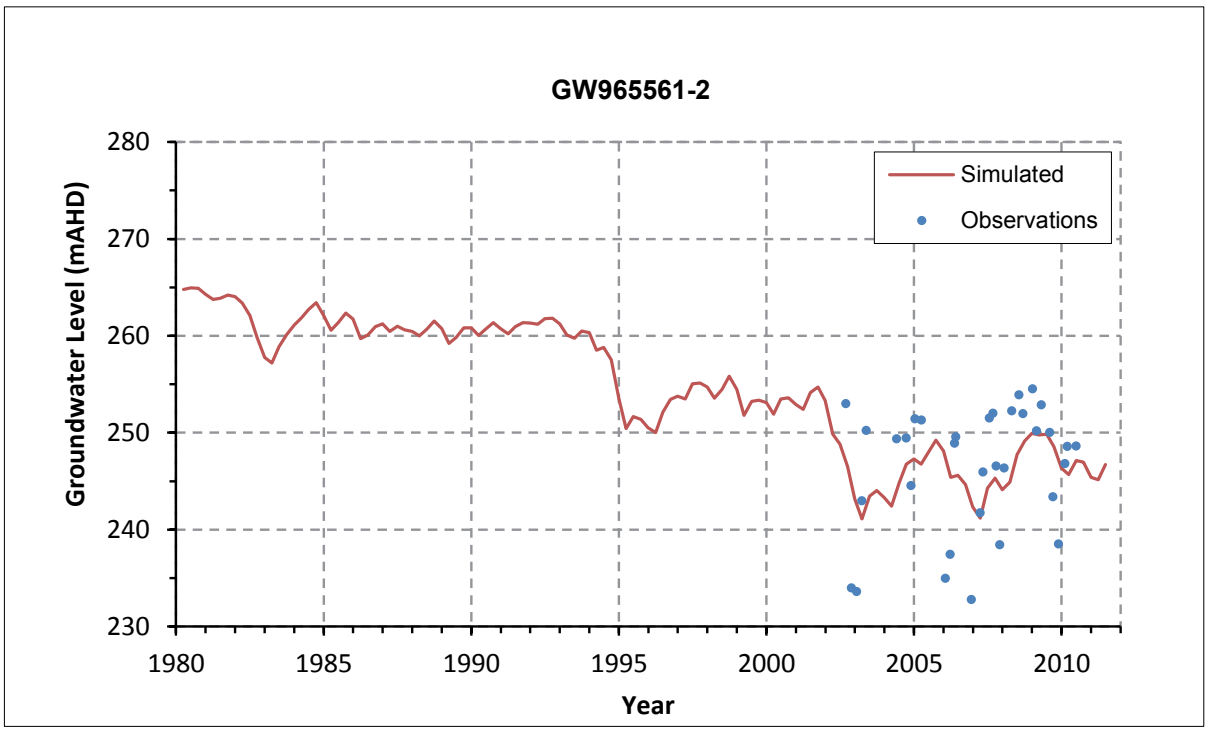

GW060401-1
Groundwater Level (mAHD)
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270
260
250
240
230
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1990
1995
2000
2005
2010
Year
Simulated
Observations

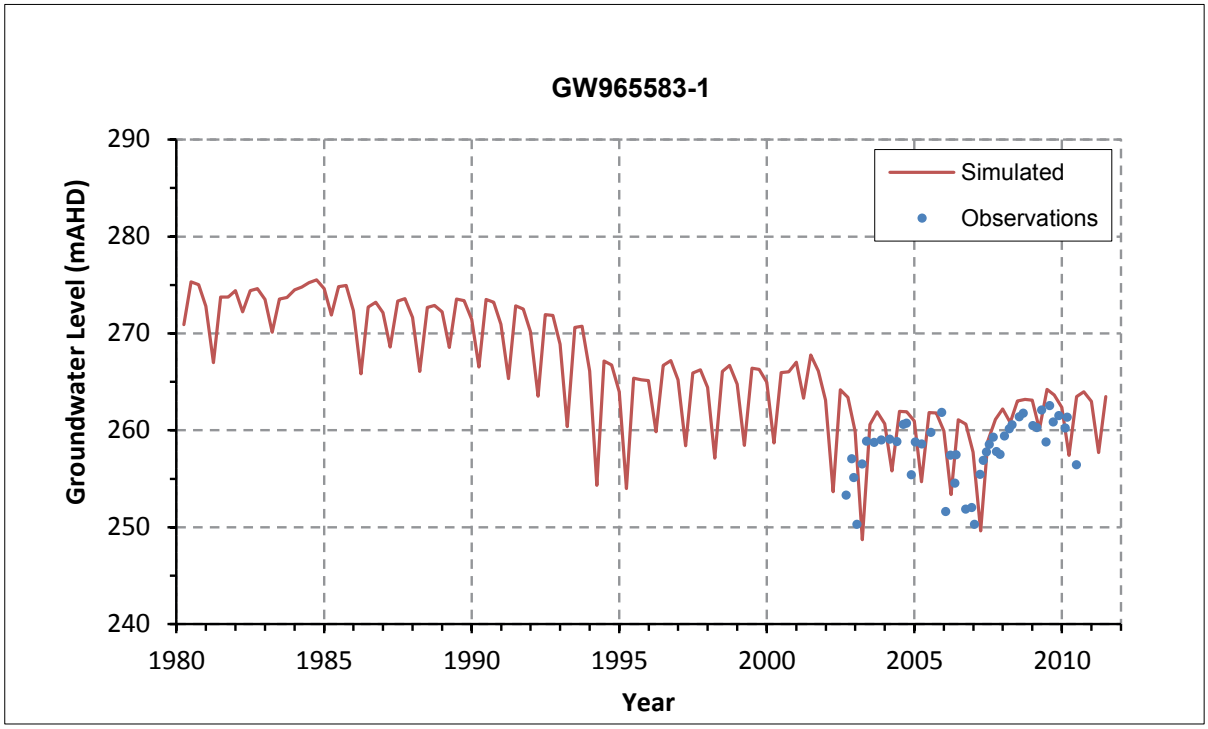

GW060929-1
Groundwater Level (mAHD)
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250
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1980
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1990
1995
2000
2005
2010
Year
Simulated
Observations

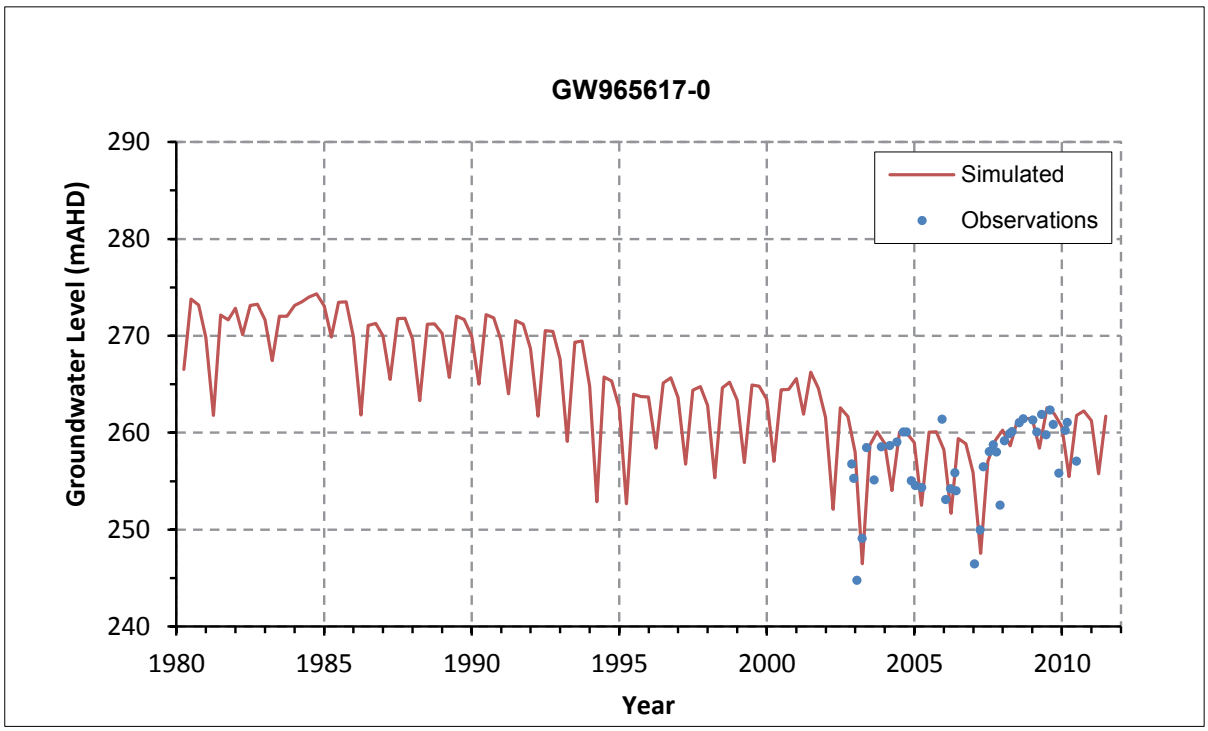

GW061224-1
Groundwater Level (mAHD)
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230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

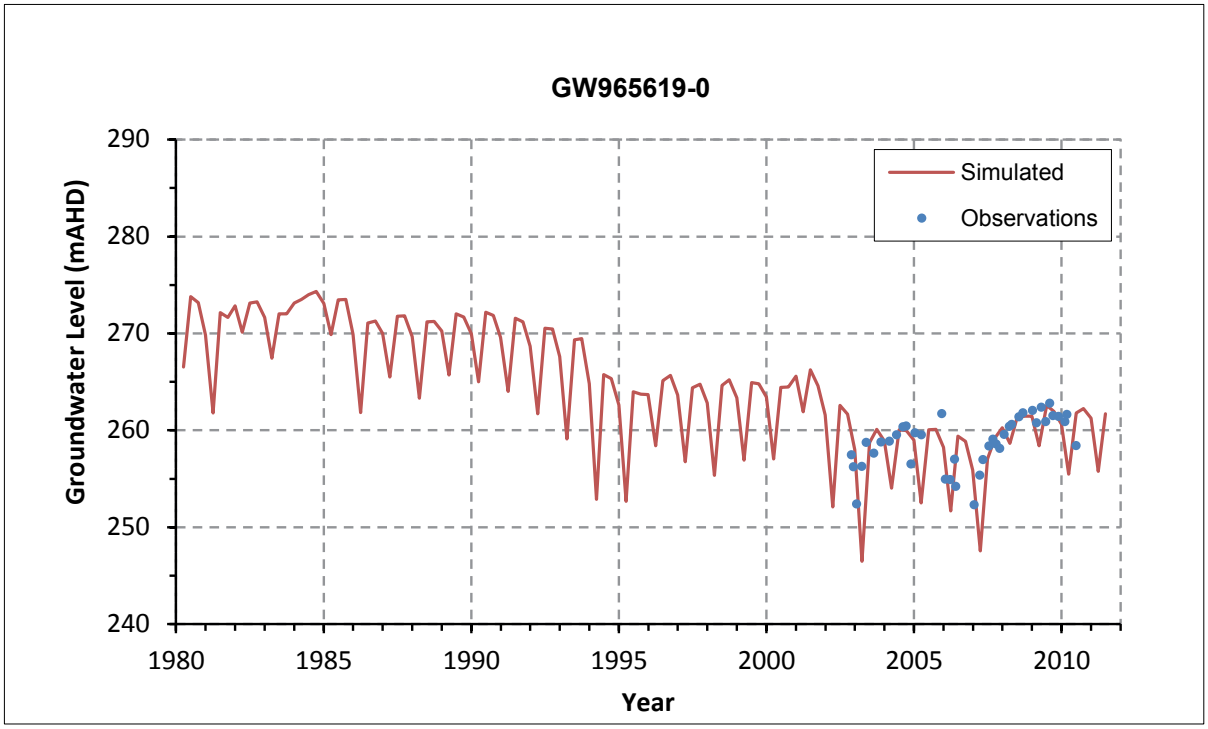

GW965560-1
Groundwater Level (mAHD)
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260
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240
230
220
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

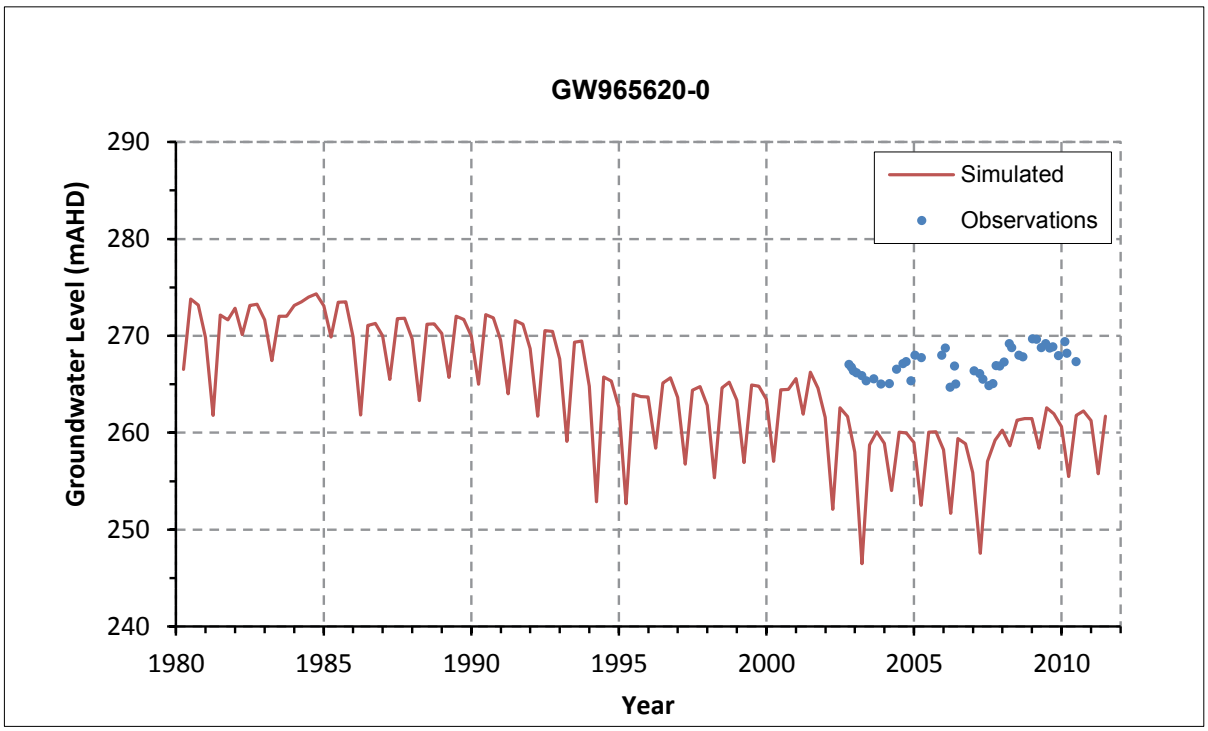

GW965561-1
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

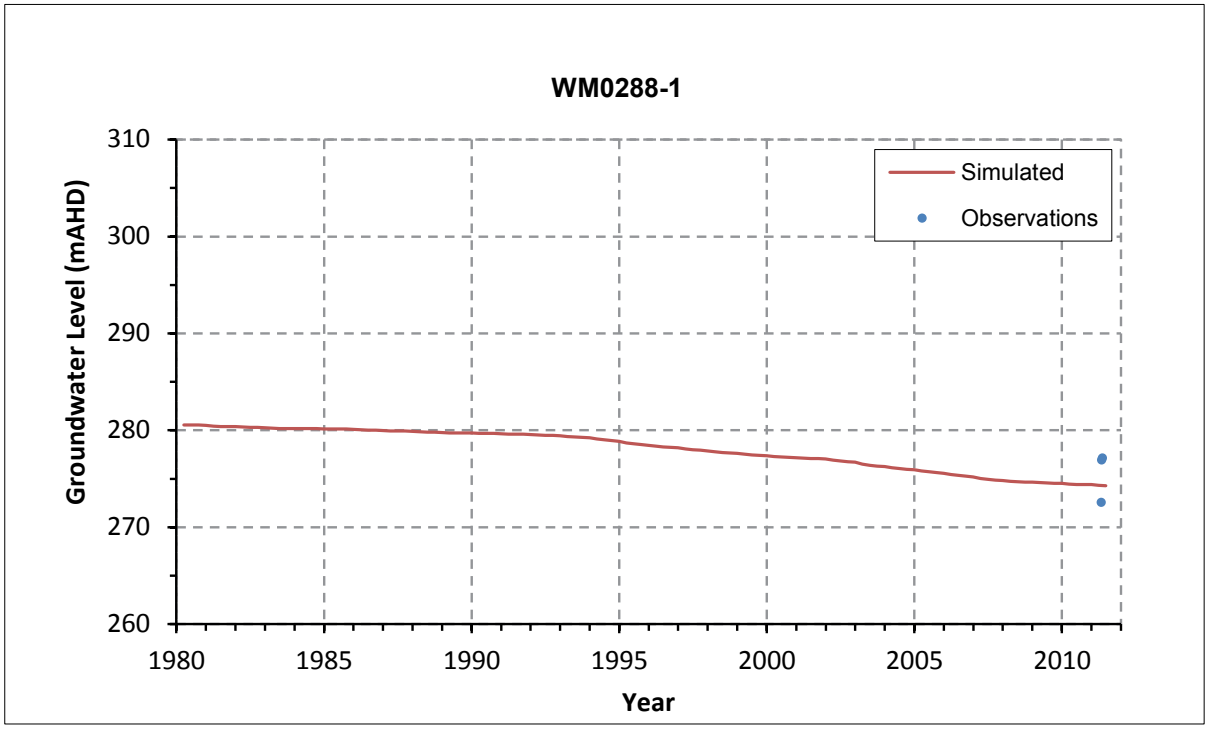

GW965561-2
Groundwater Level (mAHD)
280
270
260
250
240
230
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

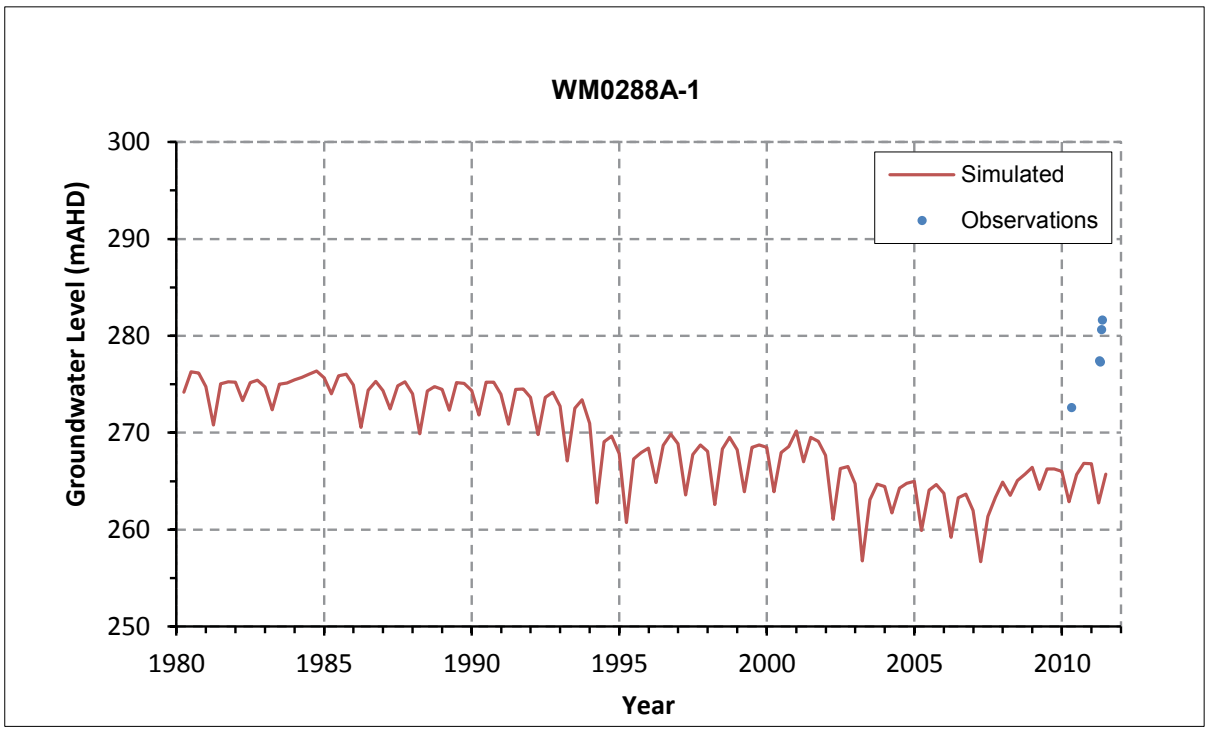

GW965583-1
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

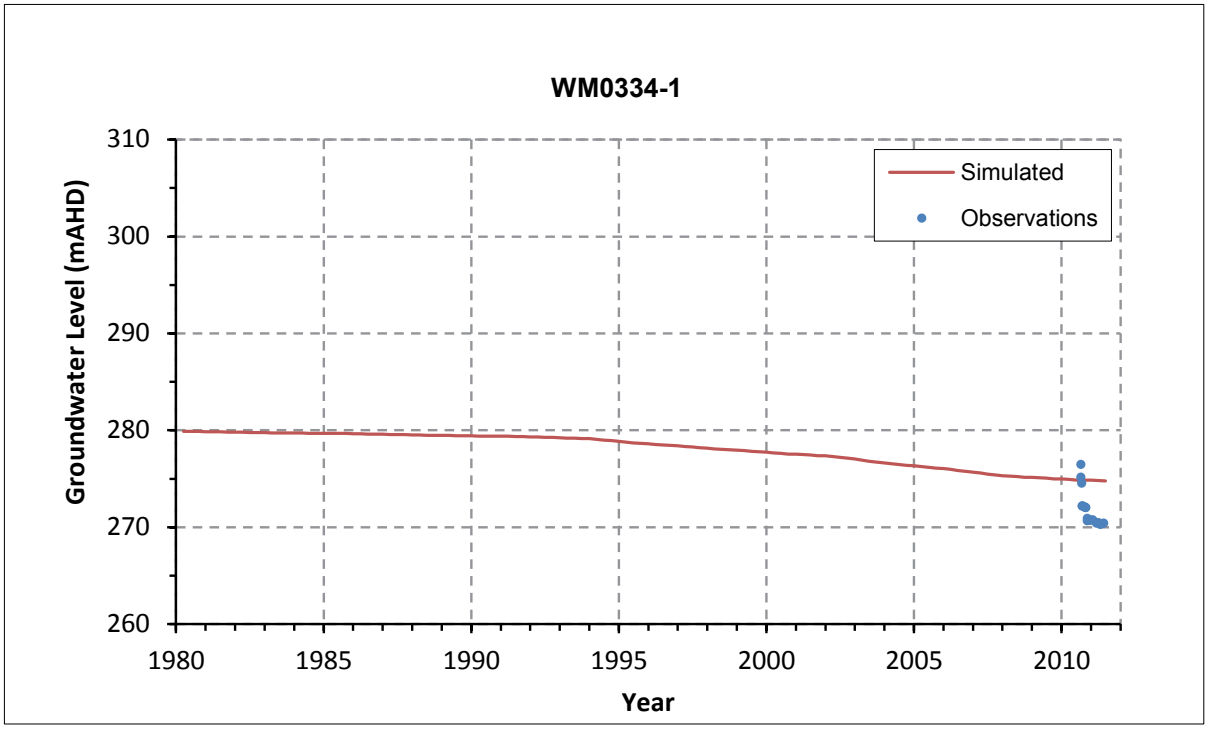

GW965617-0
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

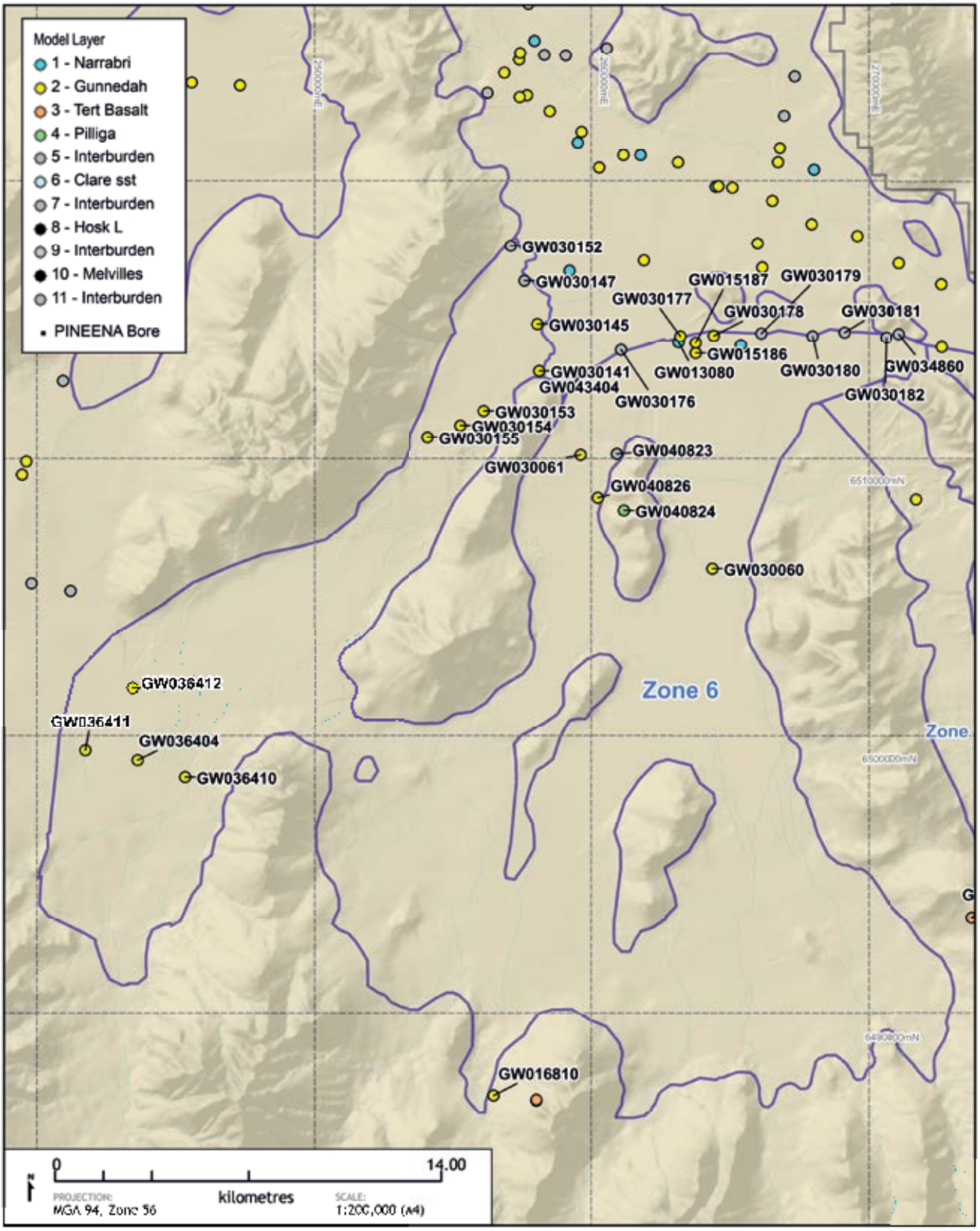

GW965619-0
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW965620-0
Groundwater Level (mAHD)
290
280
270
260
250
240
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0288-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0288A-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0334-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations



LEGEND

- Groundwater Management Zone
- Proposed Mining Area
- EL 7223
- Project Boundary
- PINEENA Bore

Watermark Coal Project (G1501)
Groundwater Assessment

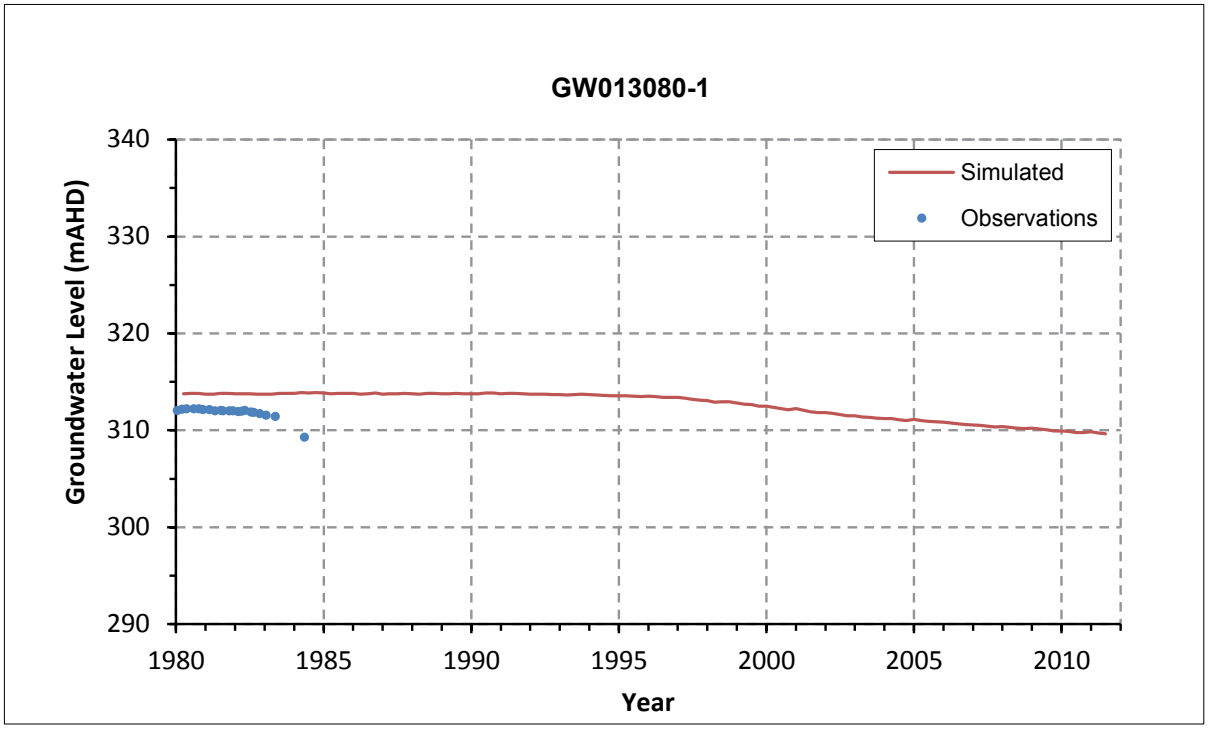
Groundwater Monitoring Bores: Shenhua and Pineena - Zone 6

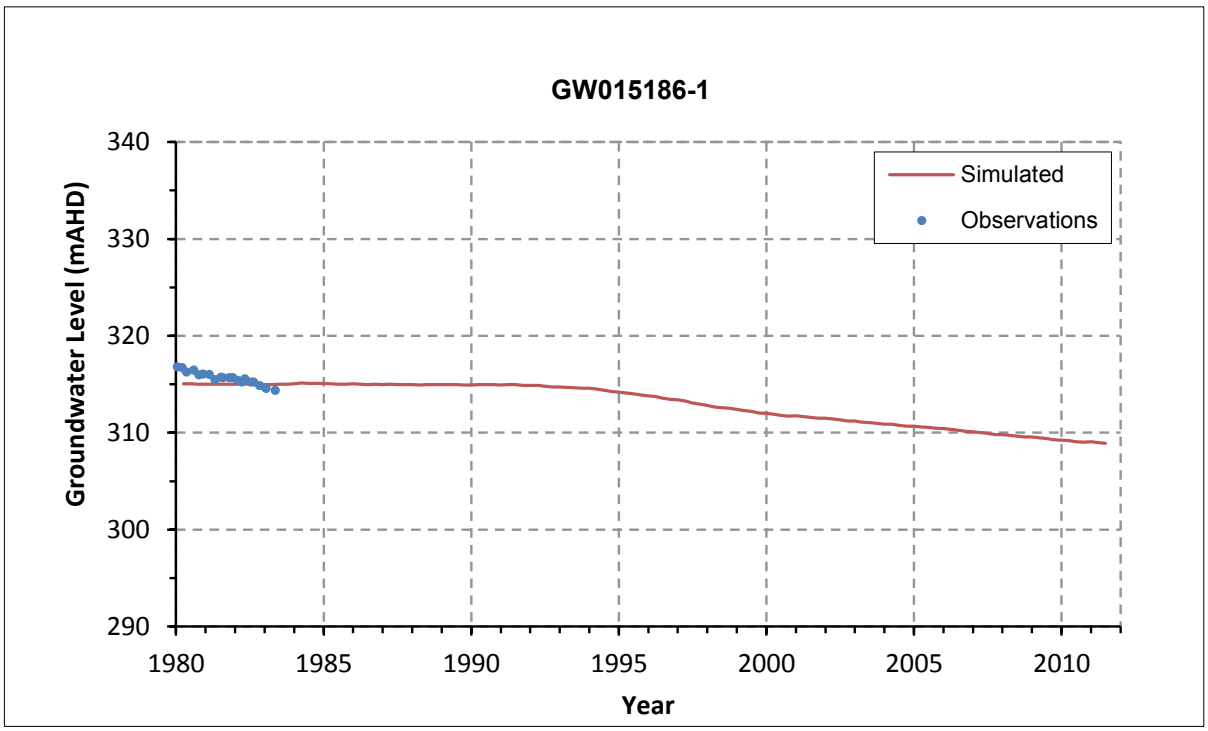
Source: NoW PINEENA Groundwater Database, 2011
GHD Groundwater Monitoring Database, 2011

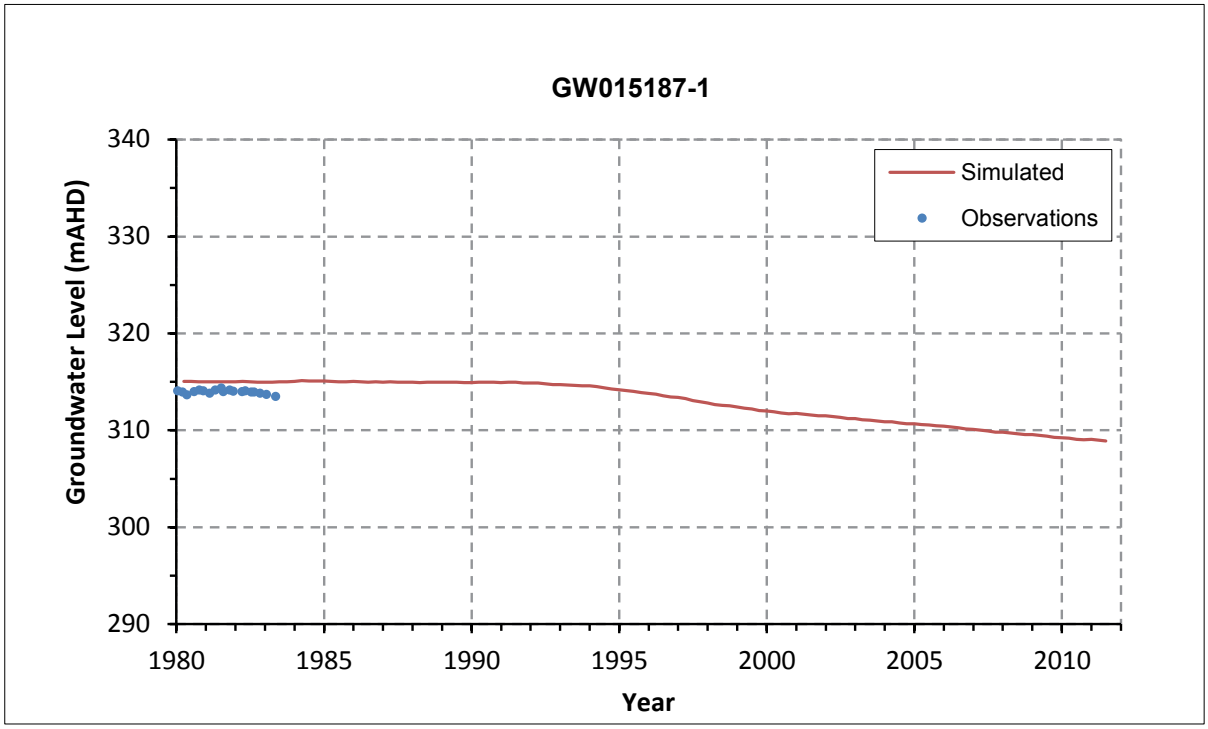
DATE: 25/7/2012

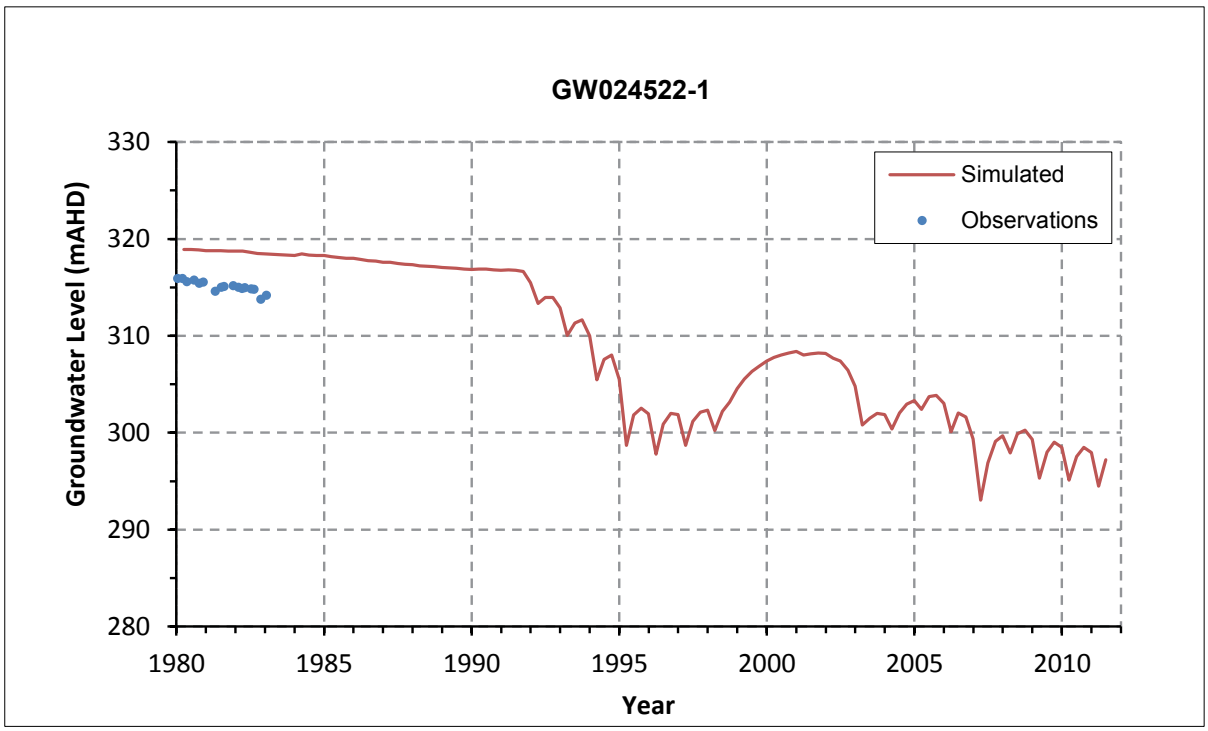
FIGURE No: **A.3**

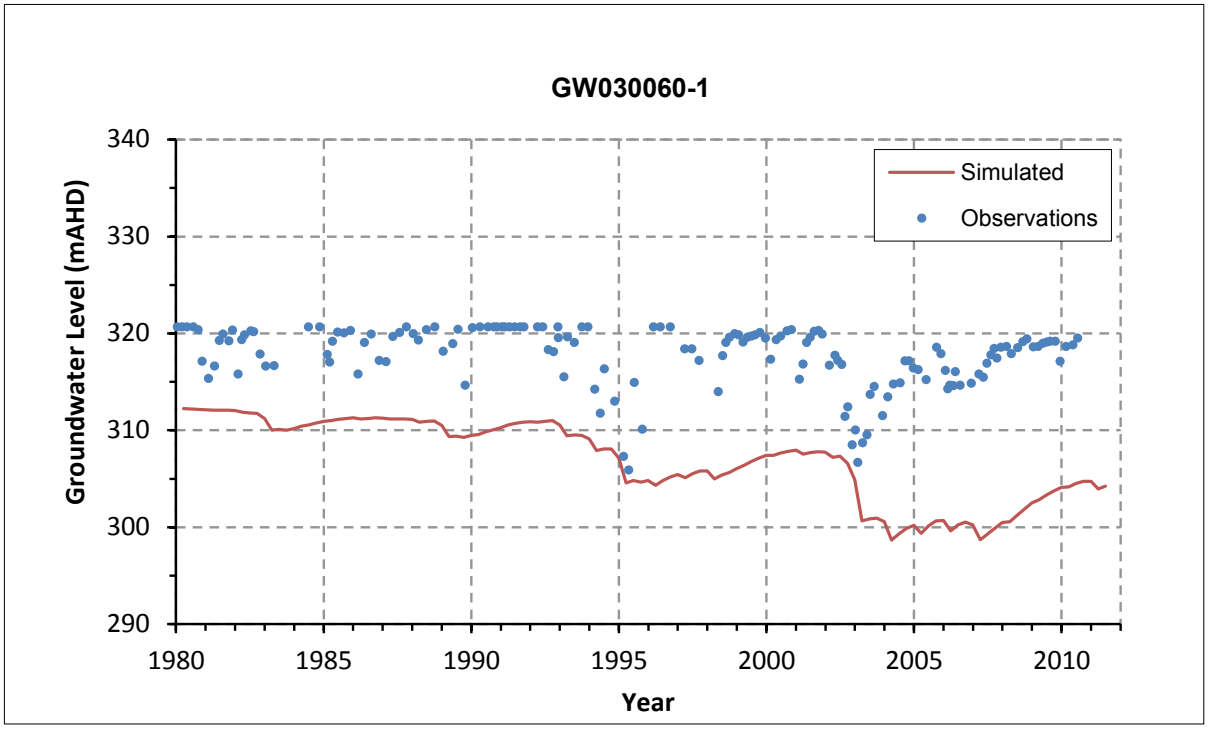
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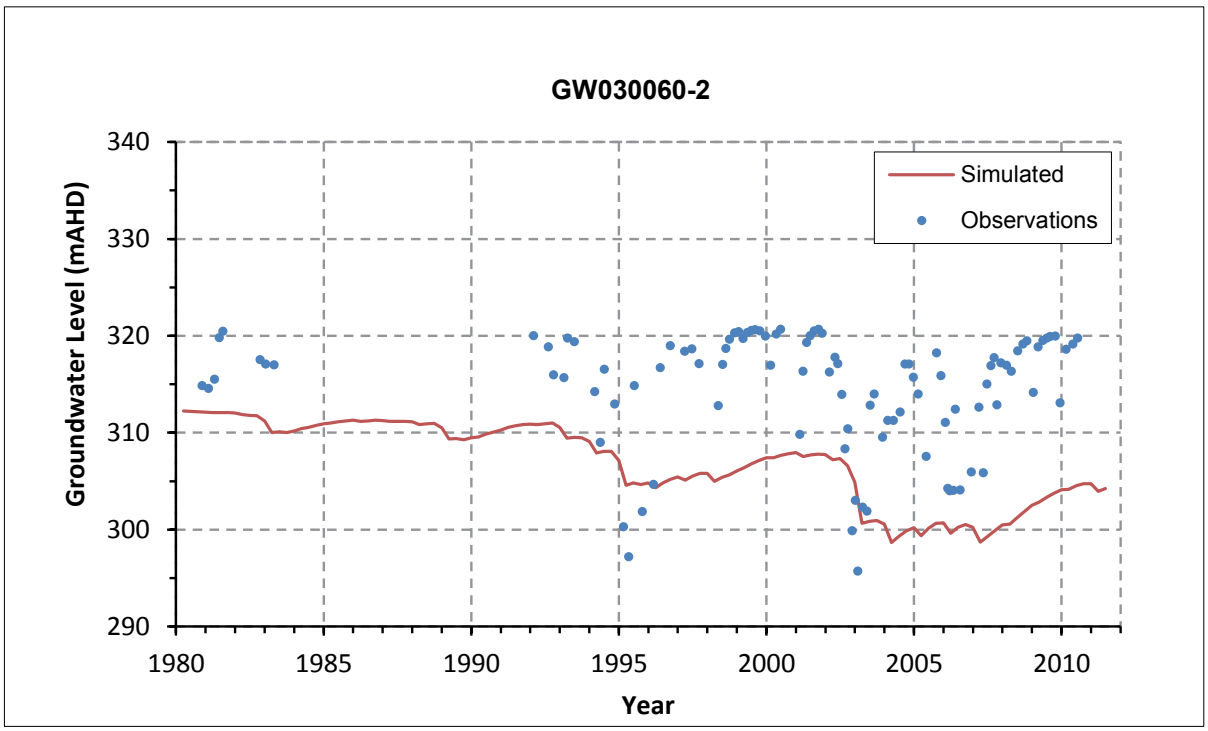

GW013080-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

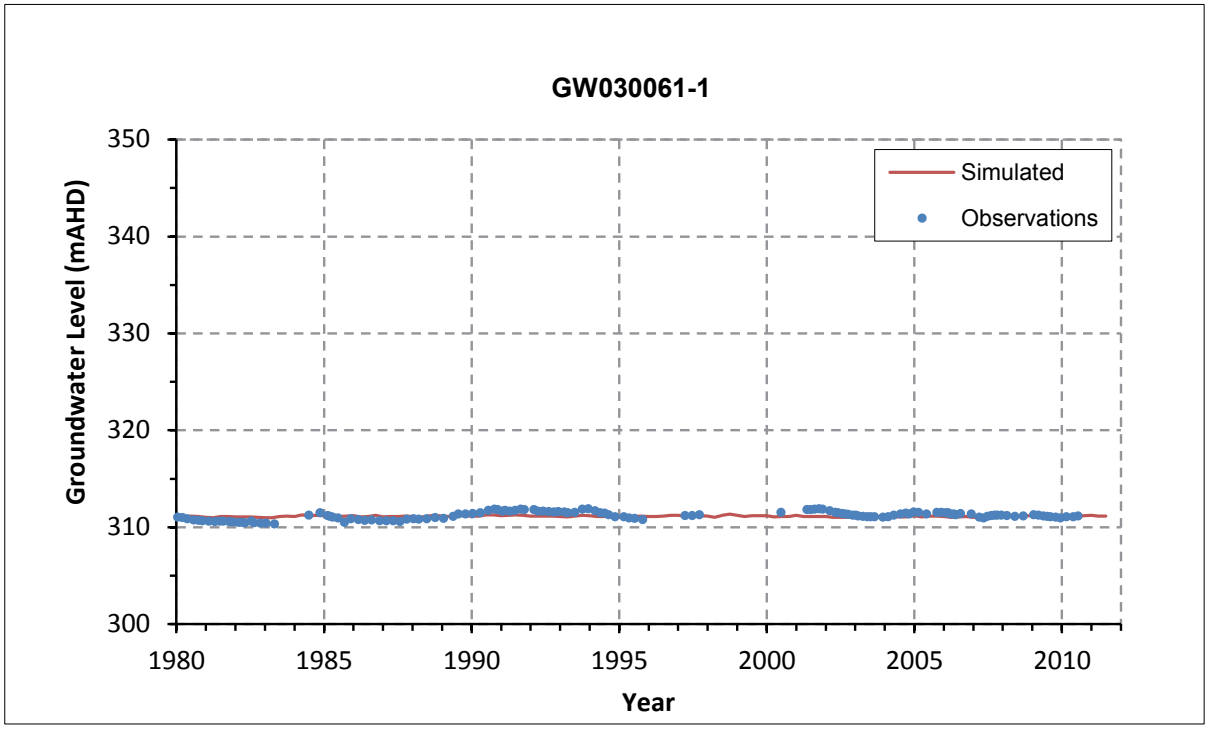

GW015186-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

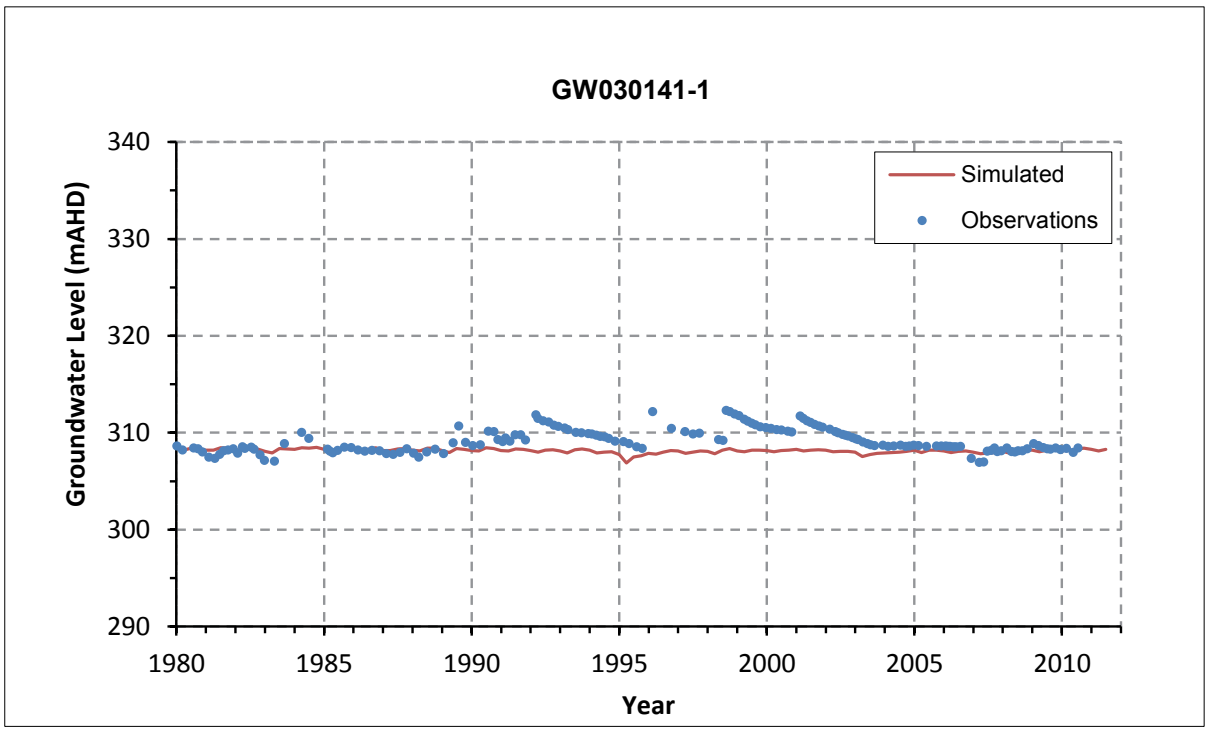

GW015187-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

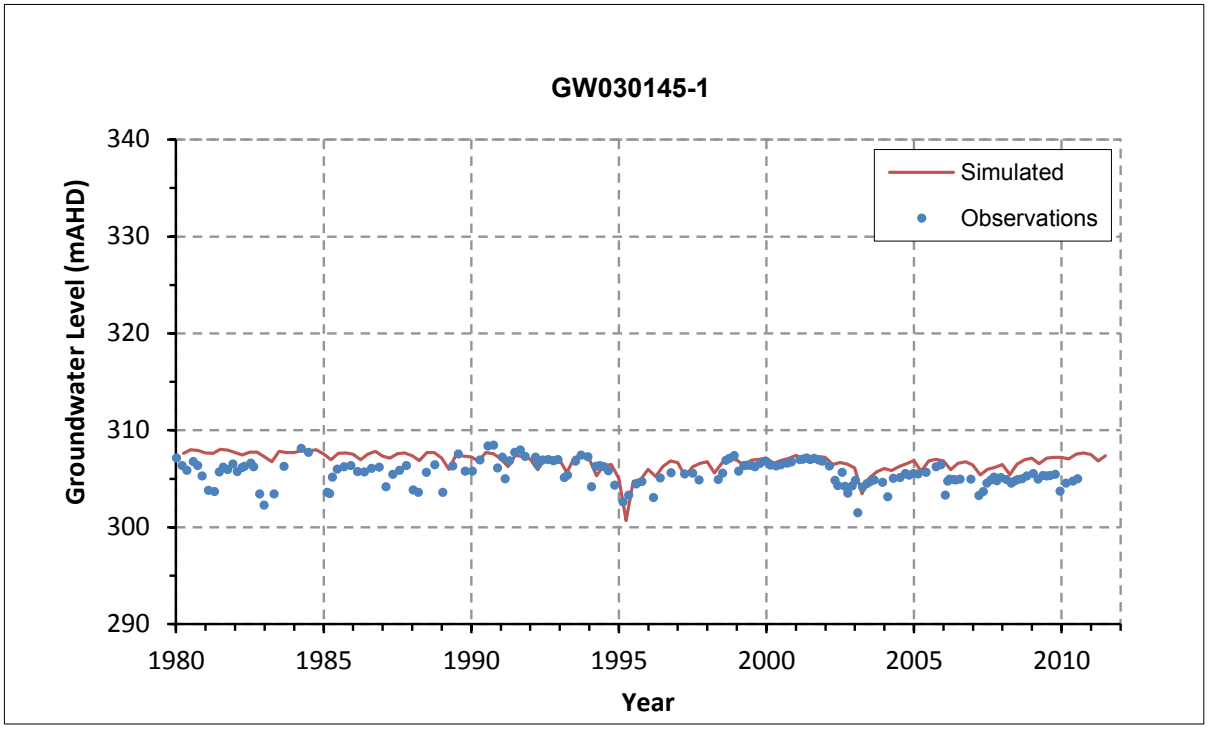

GW024522-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

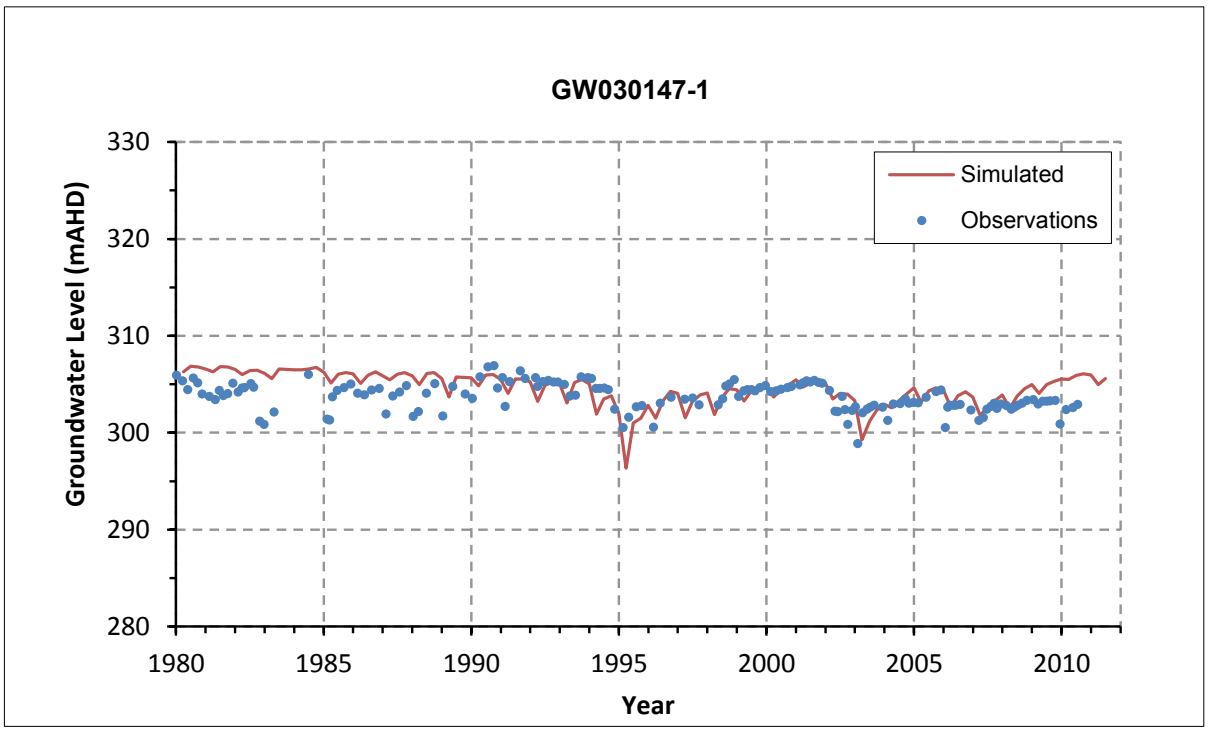

GW030060-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

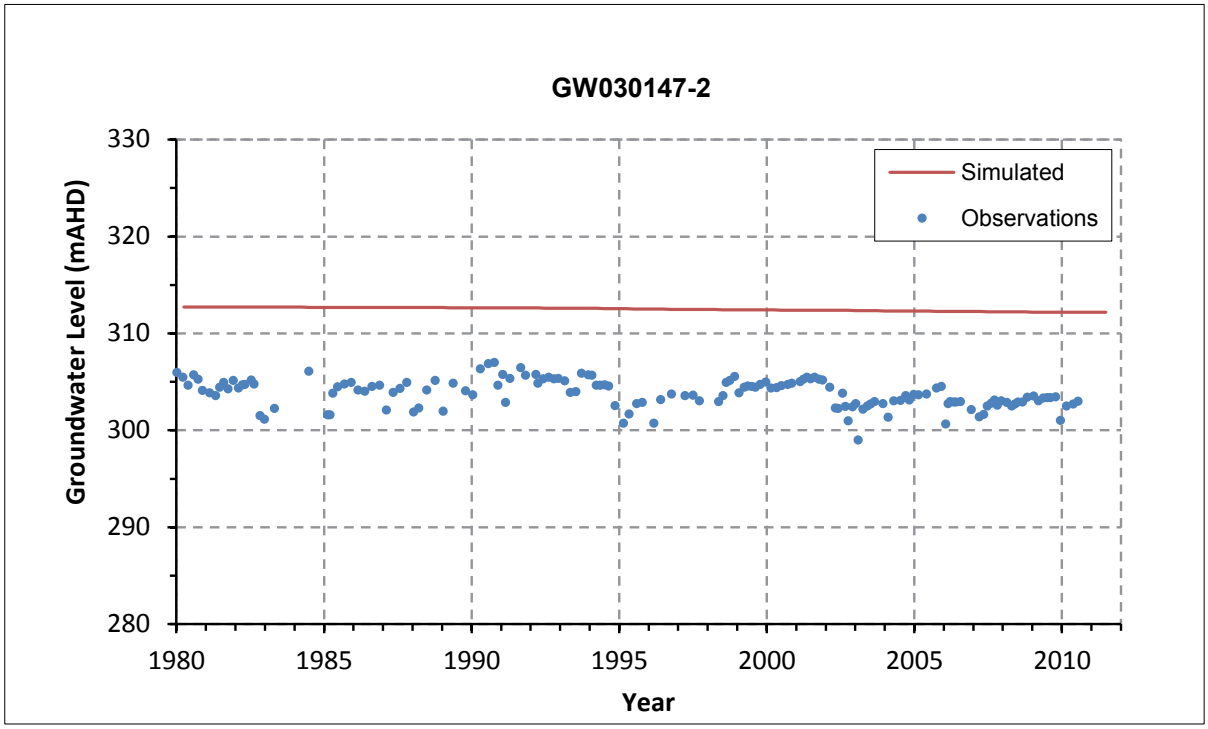

GW030060-2
Groundwater Level (mAHD)
340
330
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310
300
290
1980
1985
1990
1995
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2005
2010
Year
Simulated
Observations

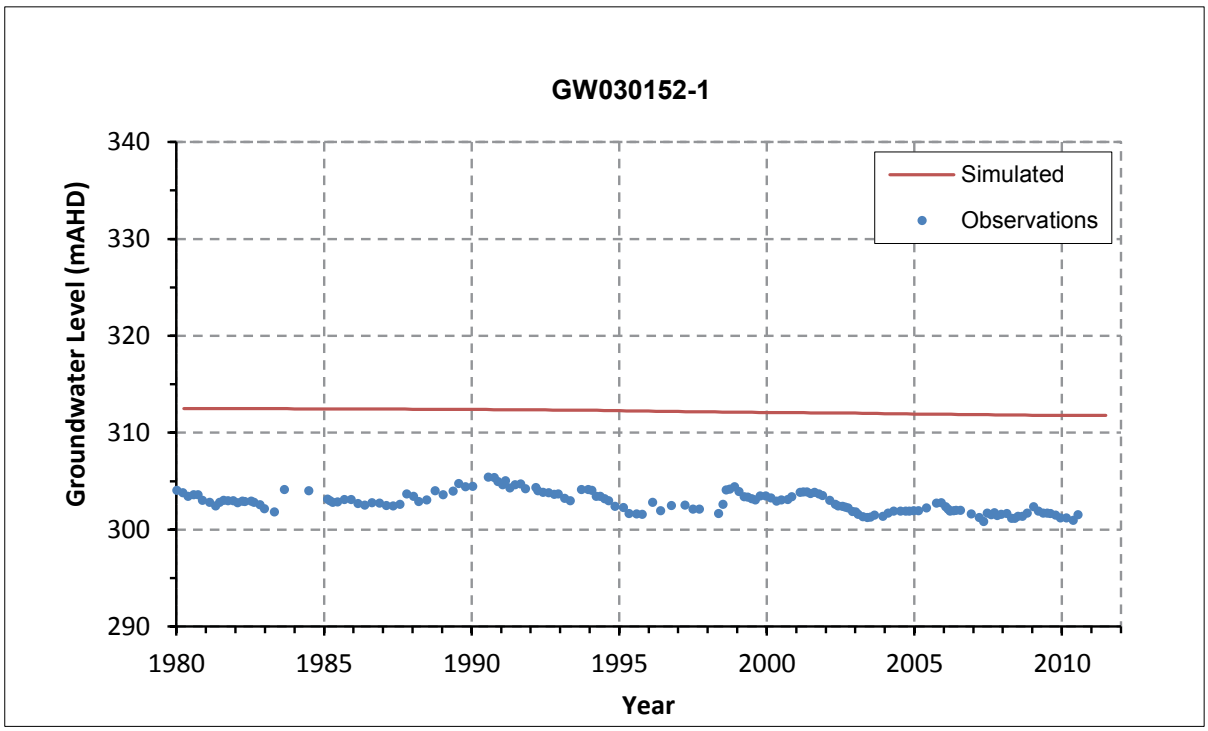

GW030061-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

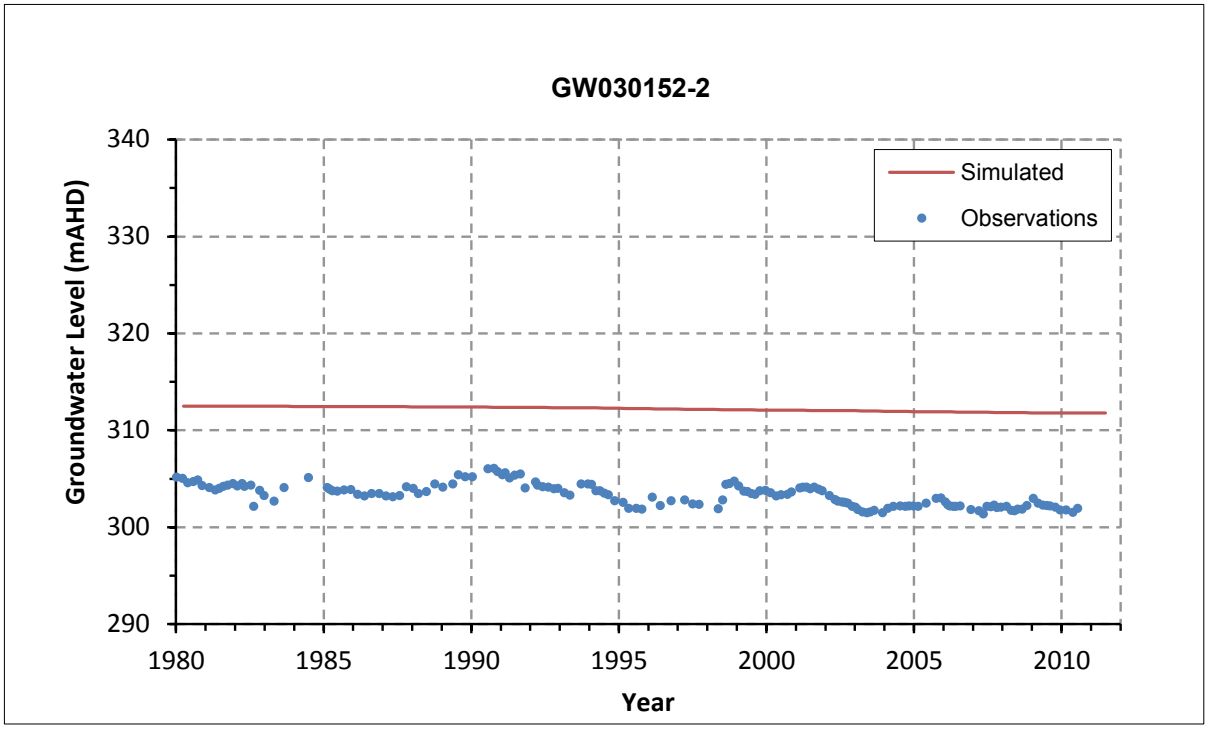

GW030141-1
Groundwater Level (mAHD)
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330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

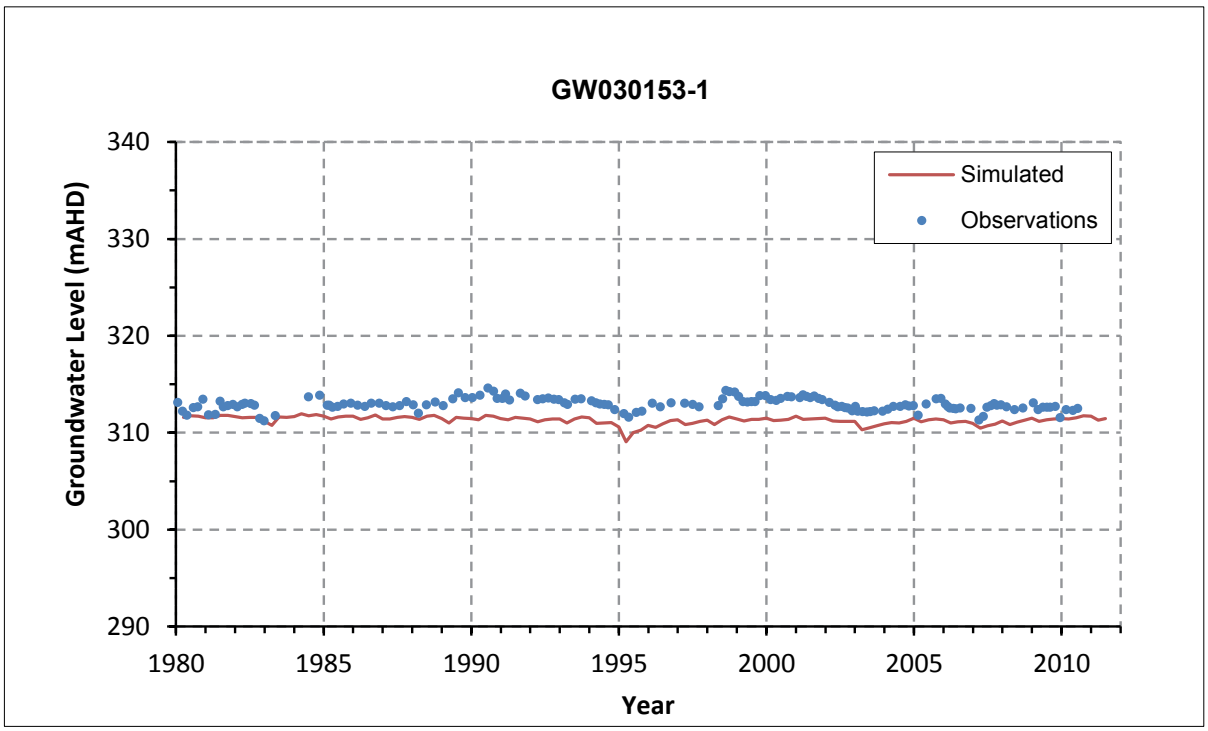

GW030145-1
Groundwater Level (mAHD)
340
330
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300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

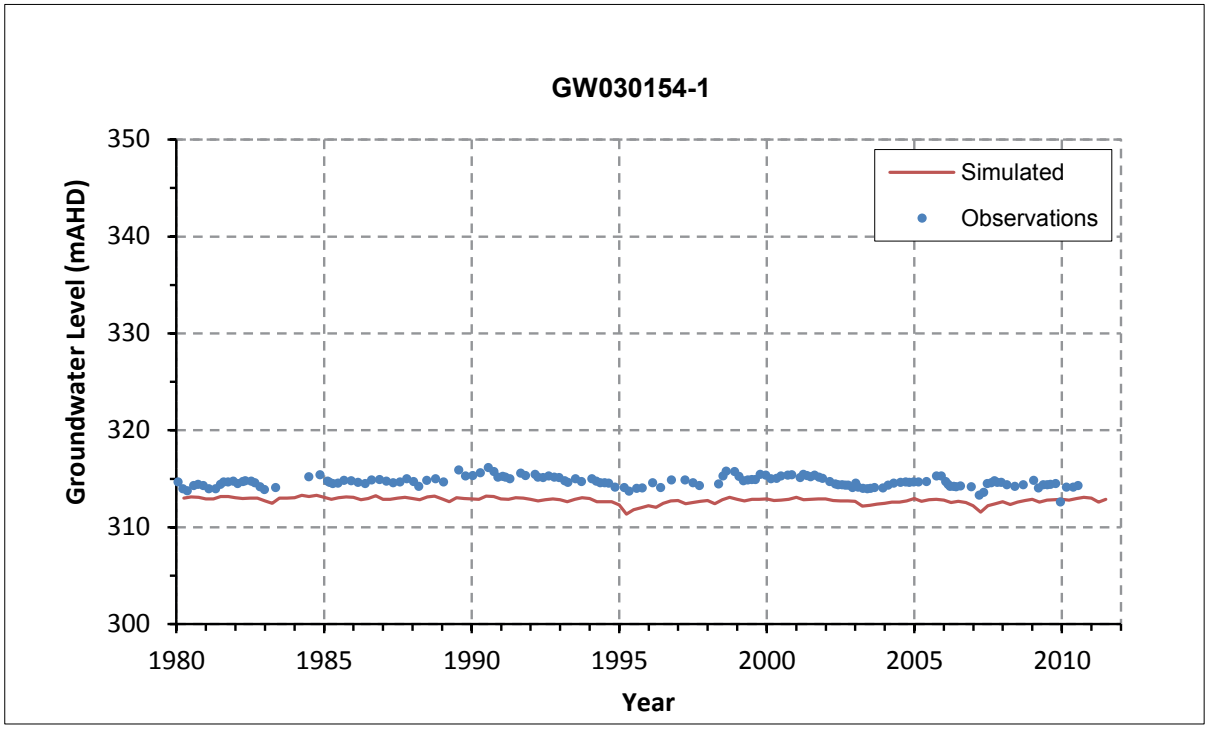

GW030147-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
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2005
2010
Year
Simulated
Observations

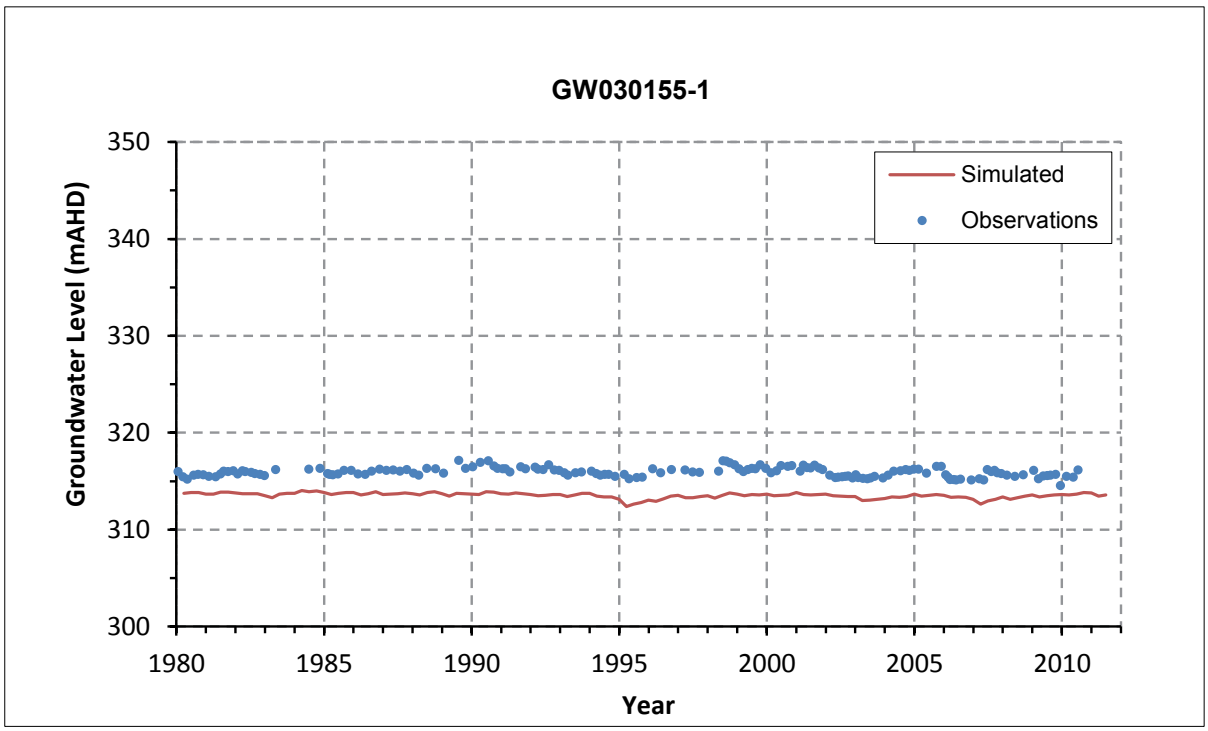

GW030147-2
Groundwater Level (mAHD)
330
320
310
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290
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2005
2010
Year
Simulated
Observations

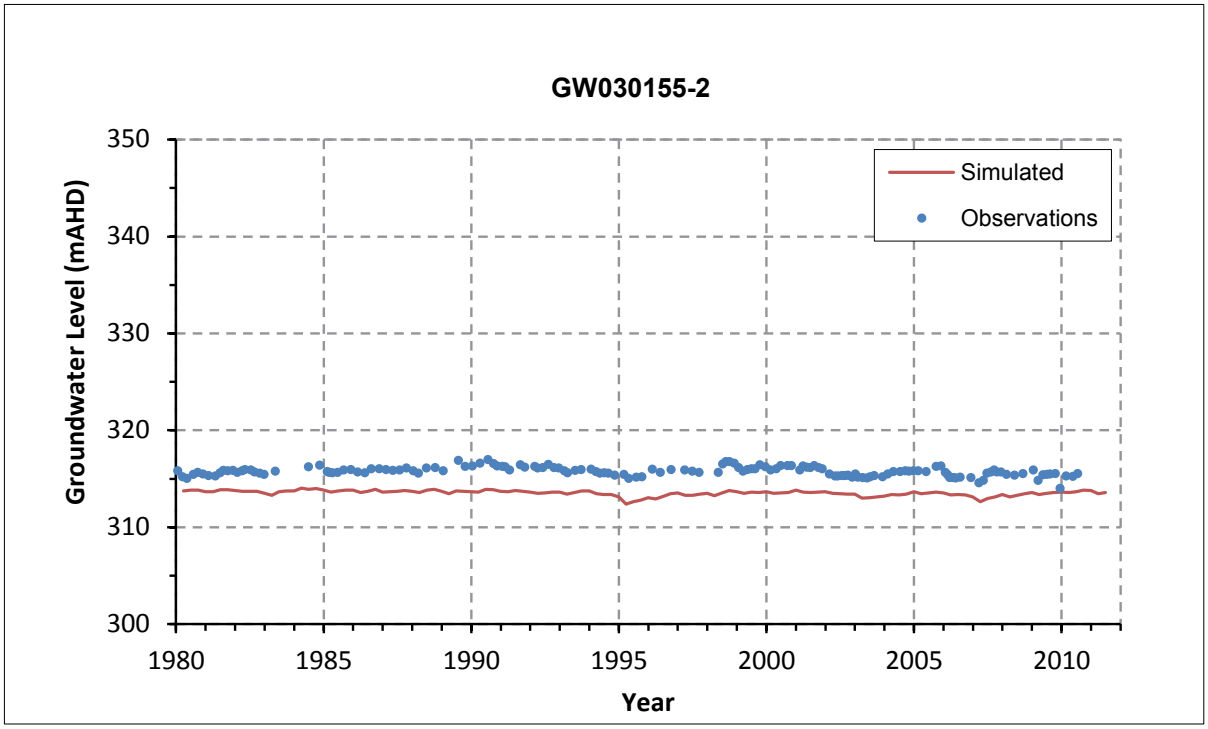

GW030152-1
Groundwater Level (mAHD)
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330
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300
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1990
1995
2000
2005
2010
Year
Simulated
Observations

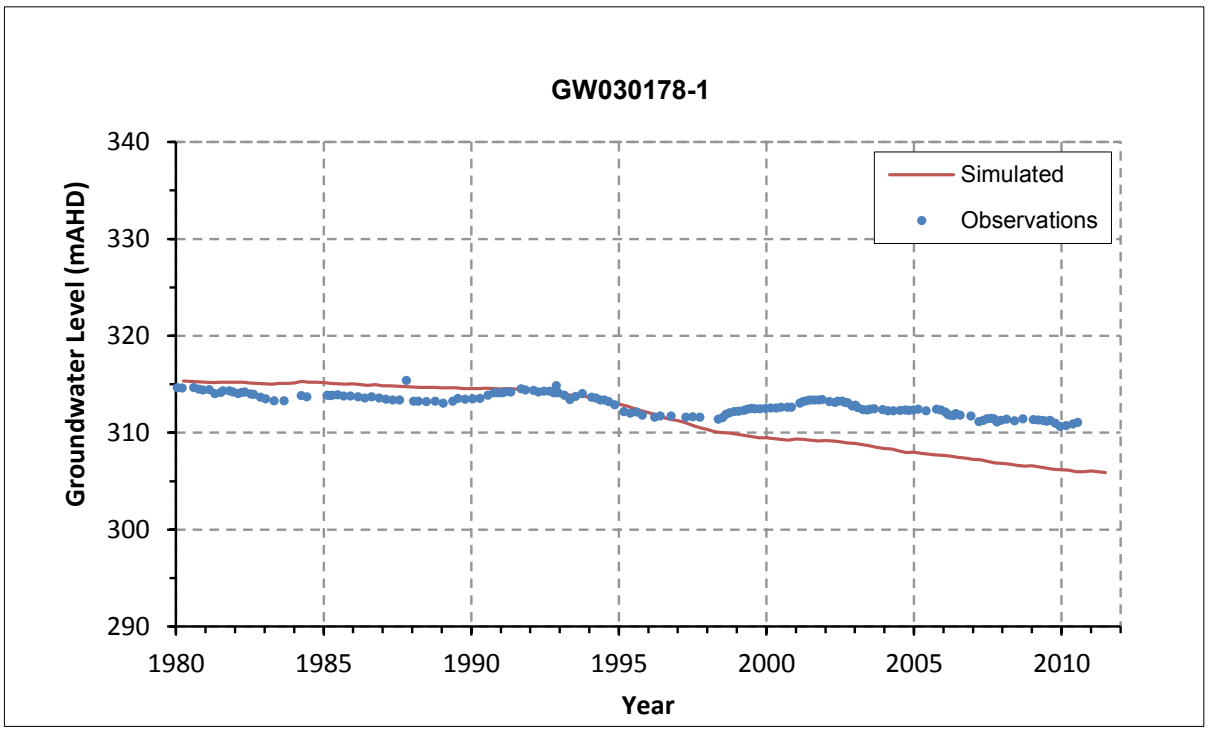

GW030152-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

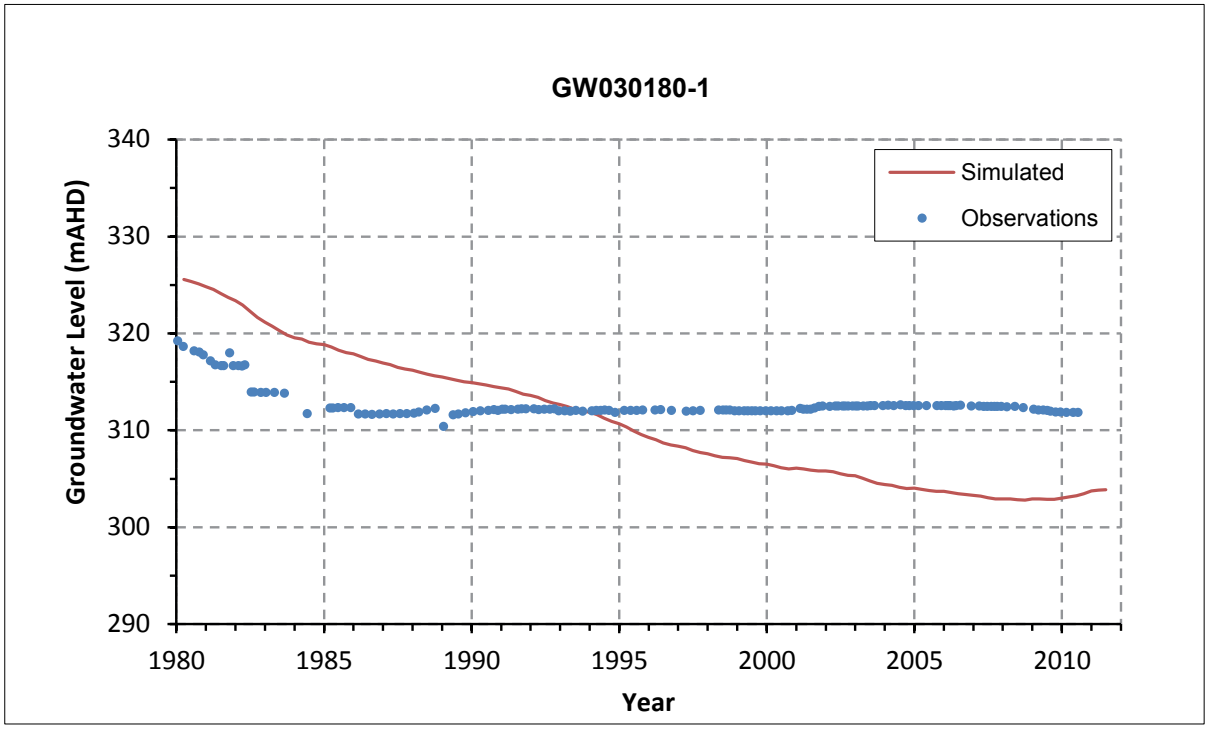

GW030153-1
Groundwater Level (mAHD)
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330
320
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300
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1980
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1990
1995
2000
2005
2010
Year
Simulated
Observations

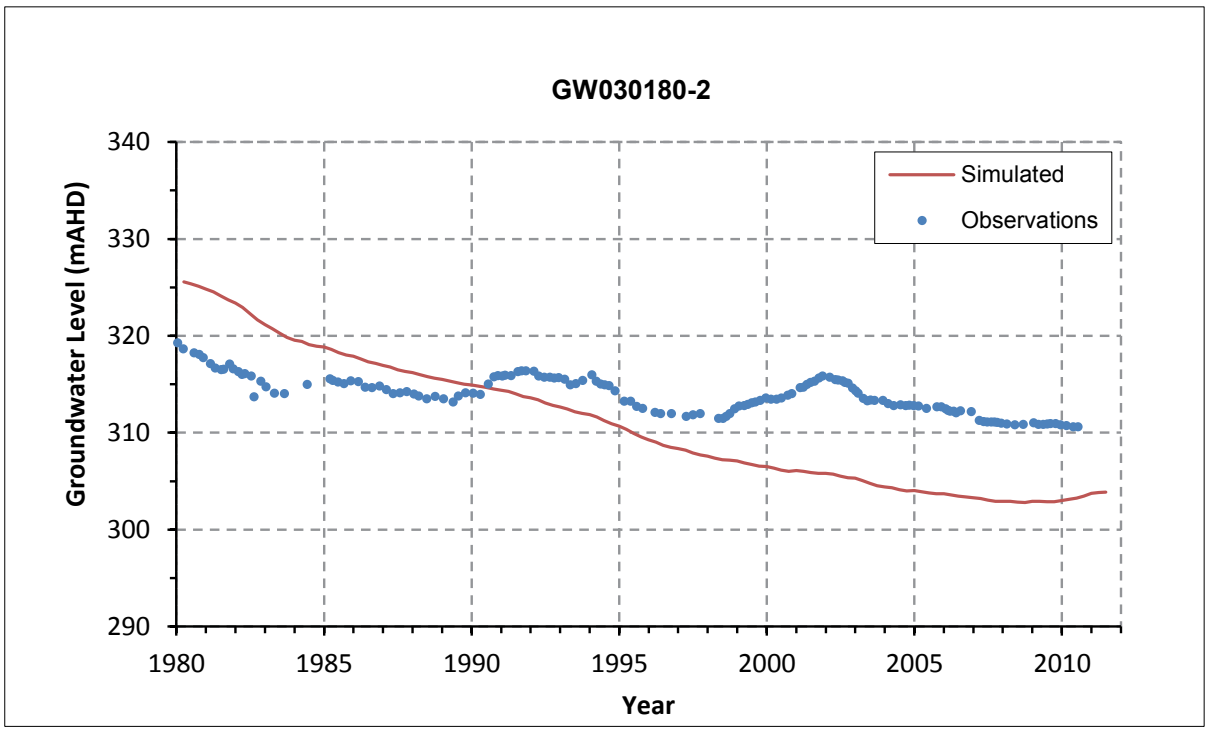

GW030154-1
Groundwater Level (mAHD)
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340
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1980
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1995
2000
2005
2010
Year
Simulated
Observations

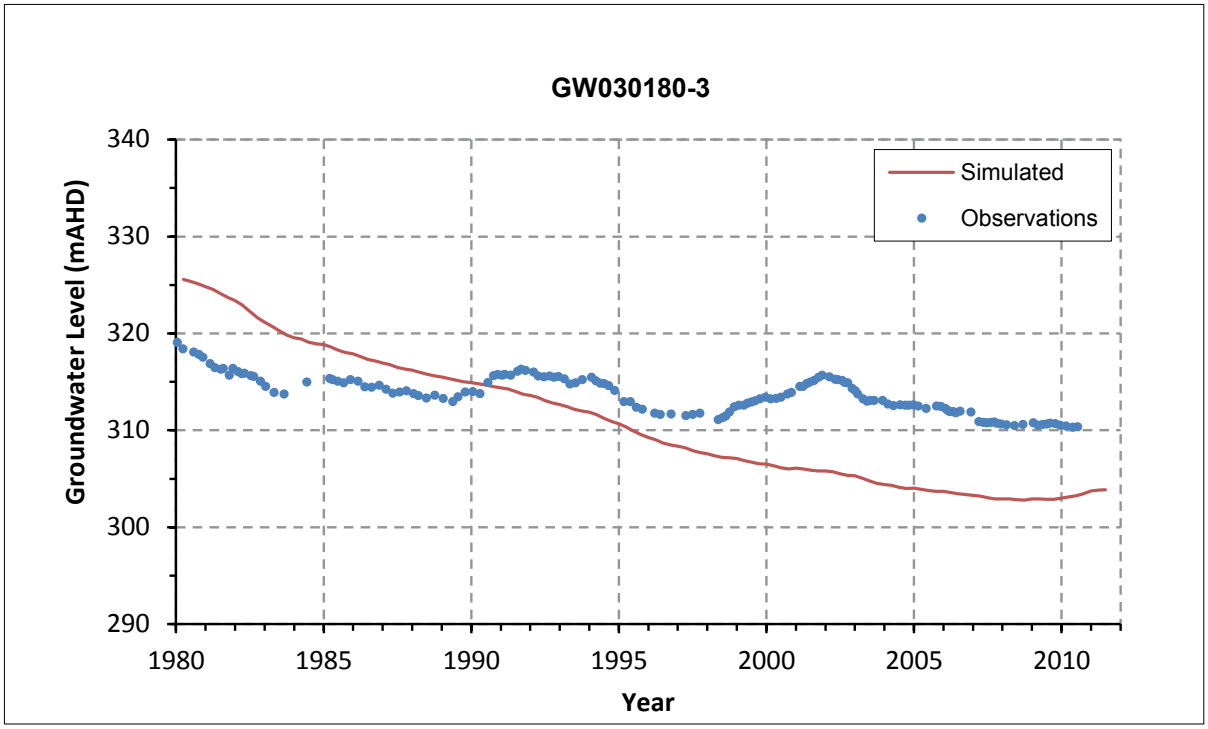

GW030155-1
Groundwater Level (mAHD)
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1995
2000
2005
2010
Year
Simulated
Observations

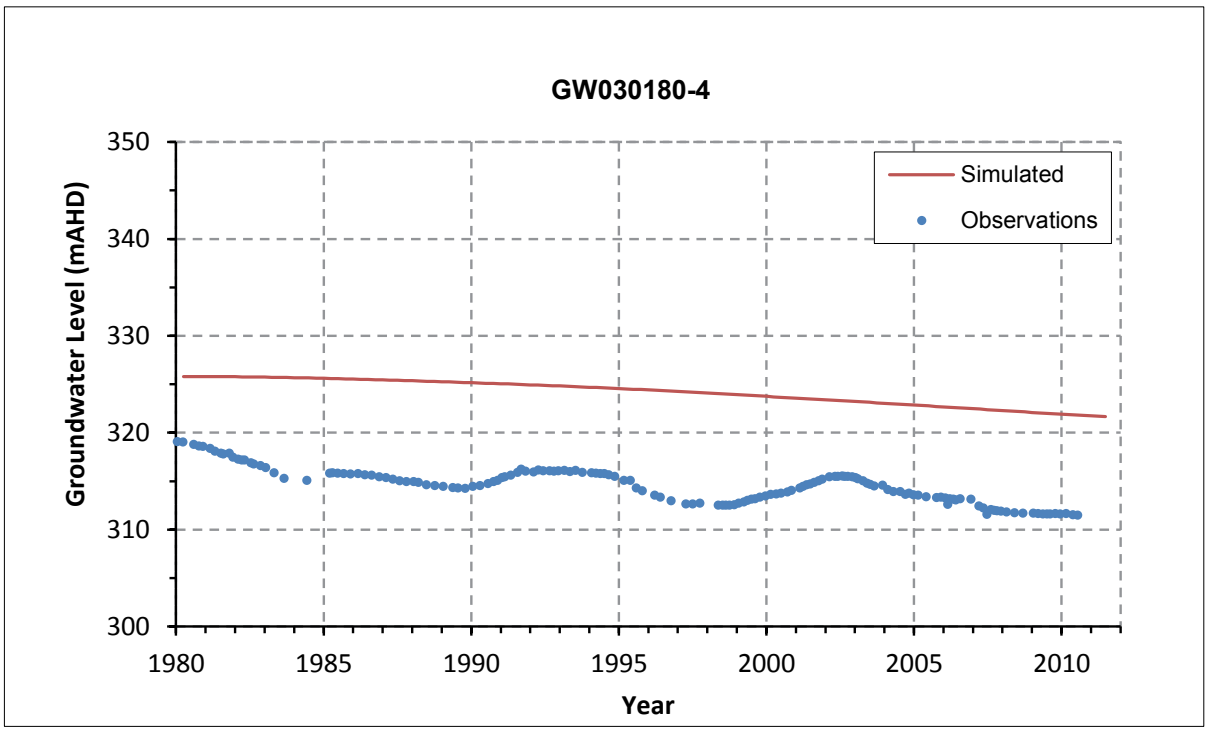

GW030155-2
Groundwater Level (mAHD)
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340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

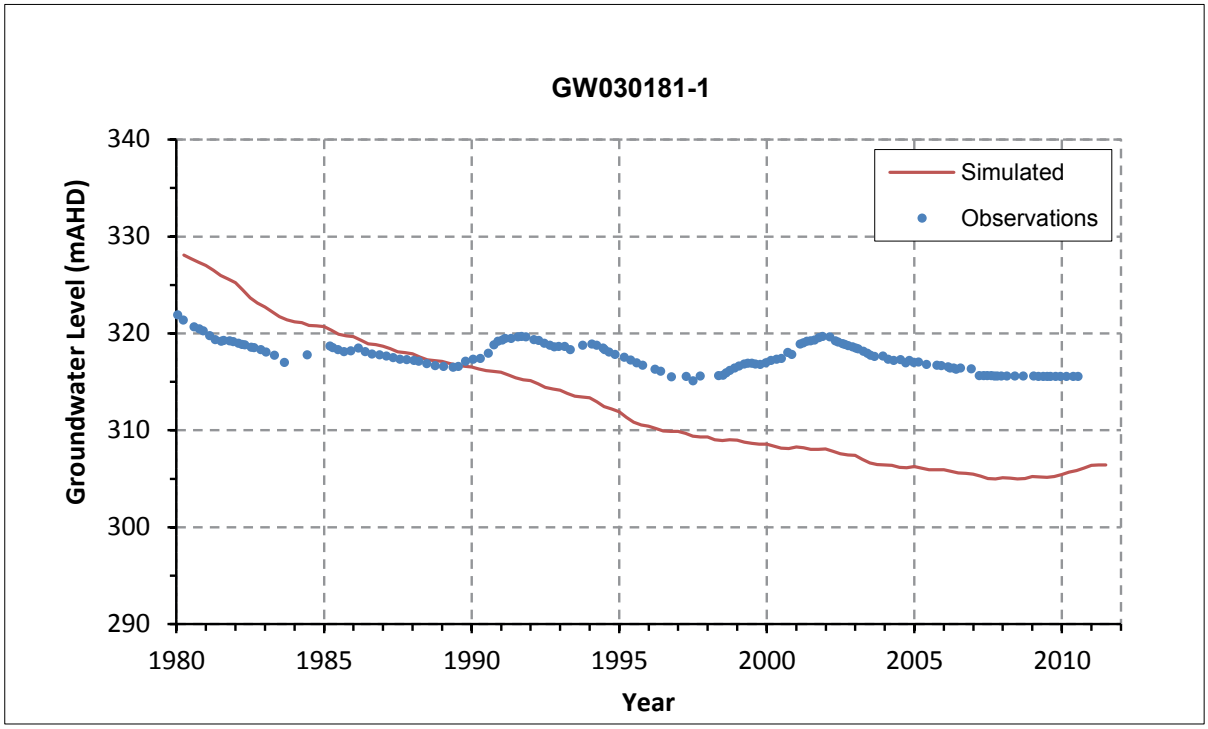

GW030178-1
Groundwater Level (mAHD)
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330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

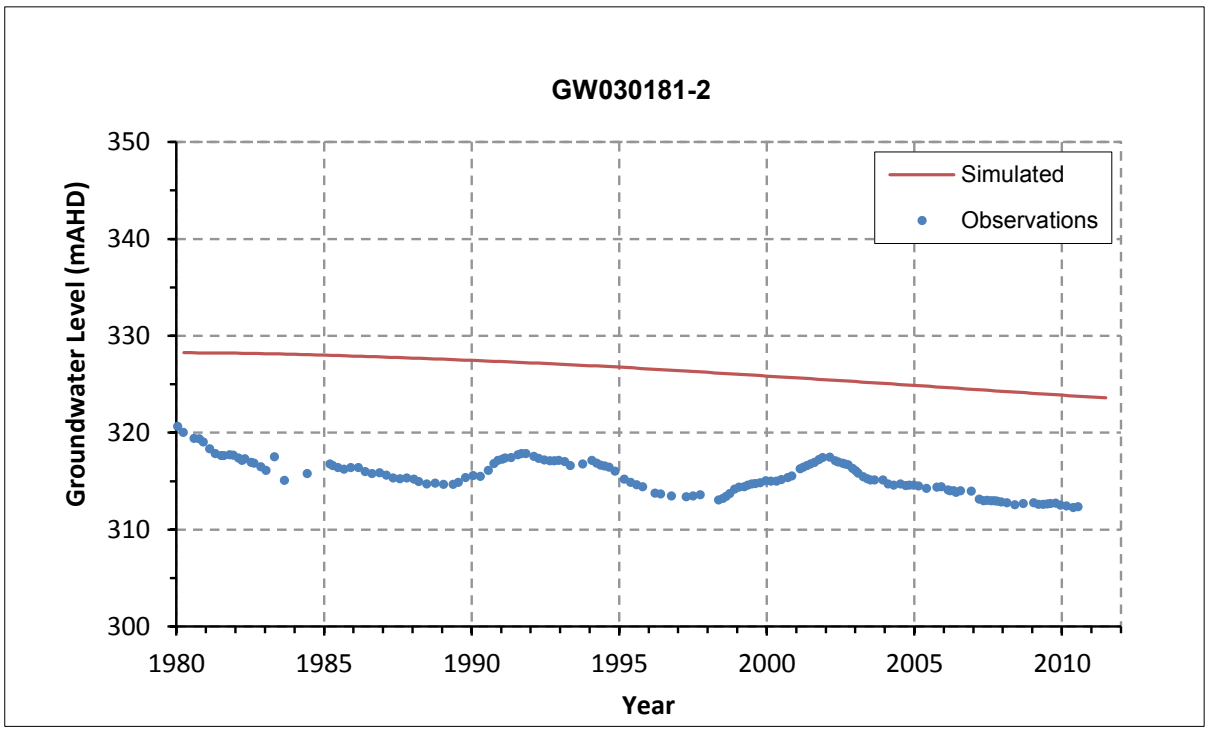

GW030180-1
Groundwater Level (mAHD)
340
330
320
310
300
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1980
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1990
1995
2000
2005
2010
Year
Simulated
Observations

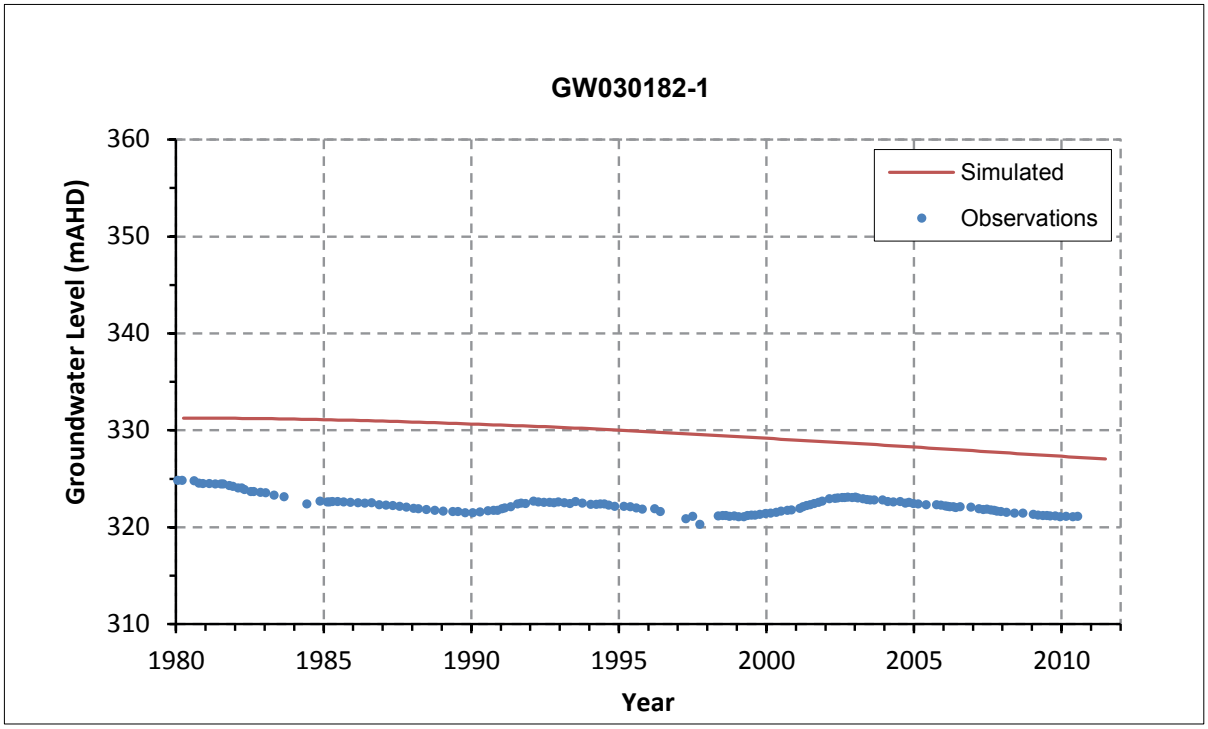

GW030180-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

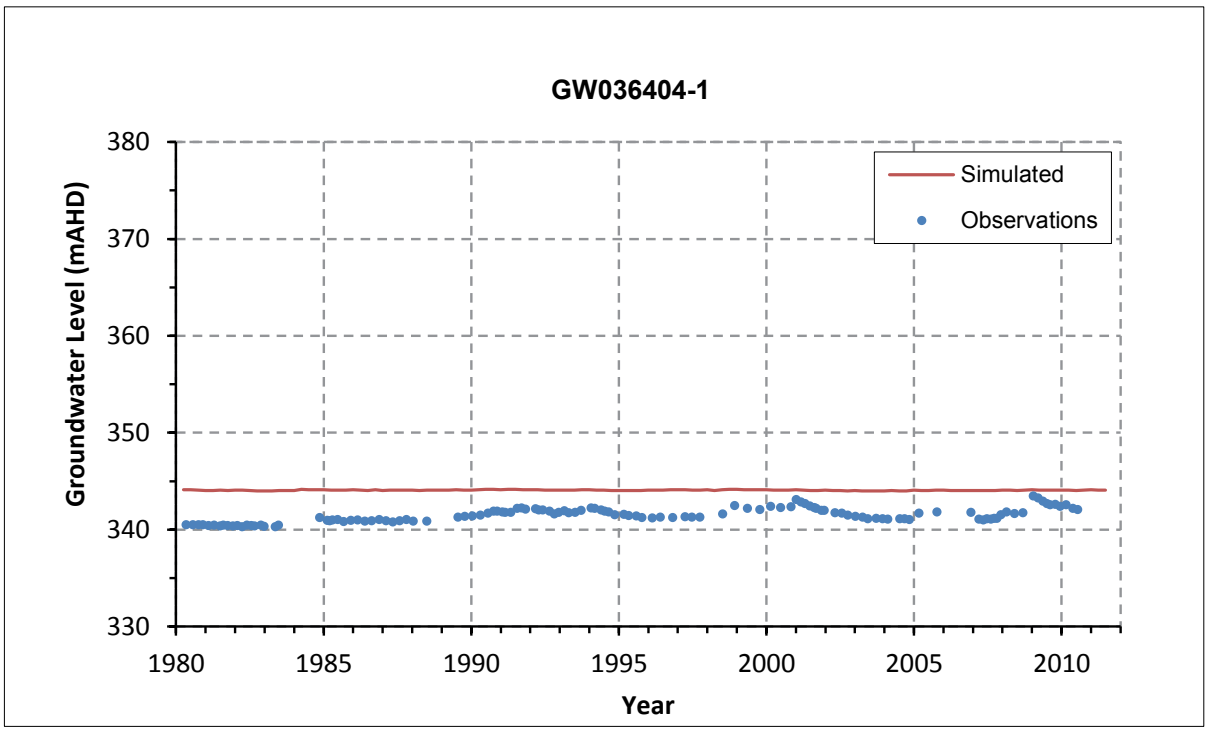

GW030180-3
Groundwater Level (mAHD)
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310
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290
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1995
2000
2005
2010
Year
Simulated
Observations

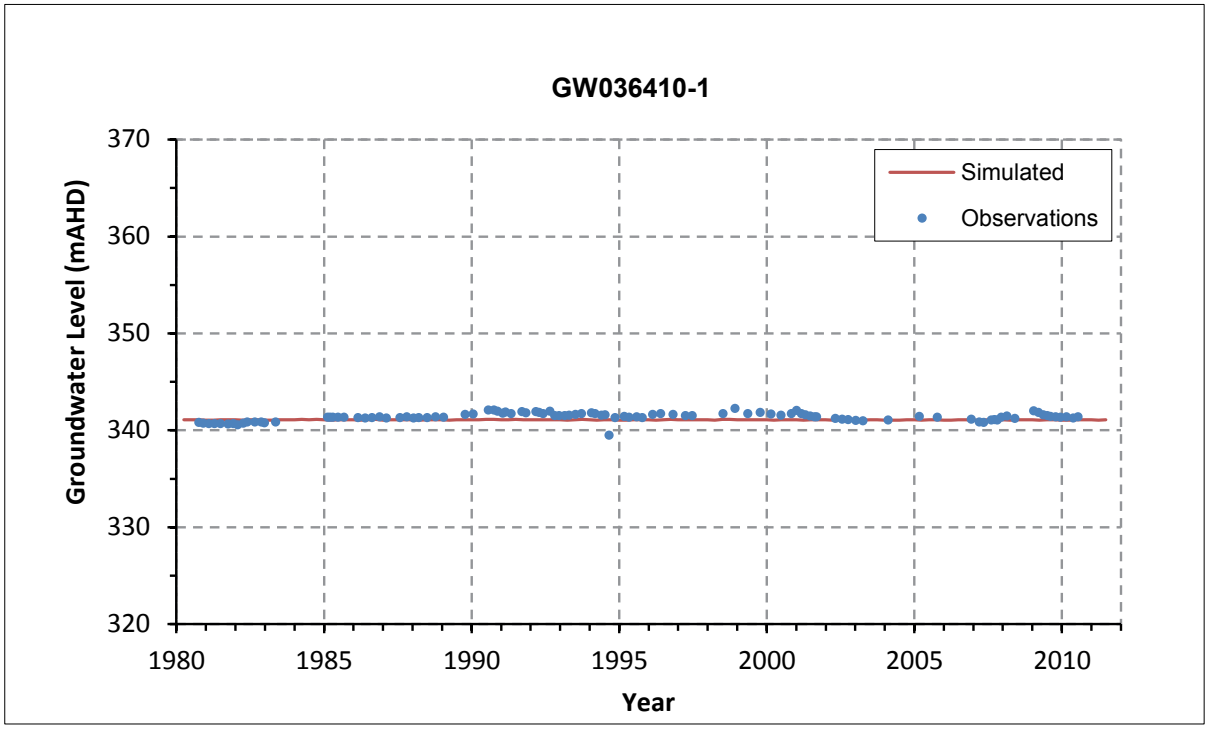

GW030180-4
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
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1990
1995
2000
2005
2010
Year
Simulated
Observations

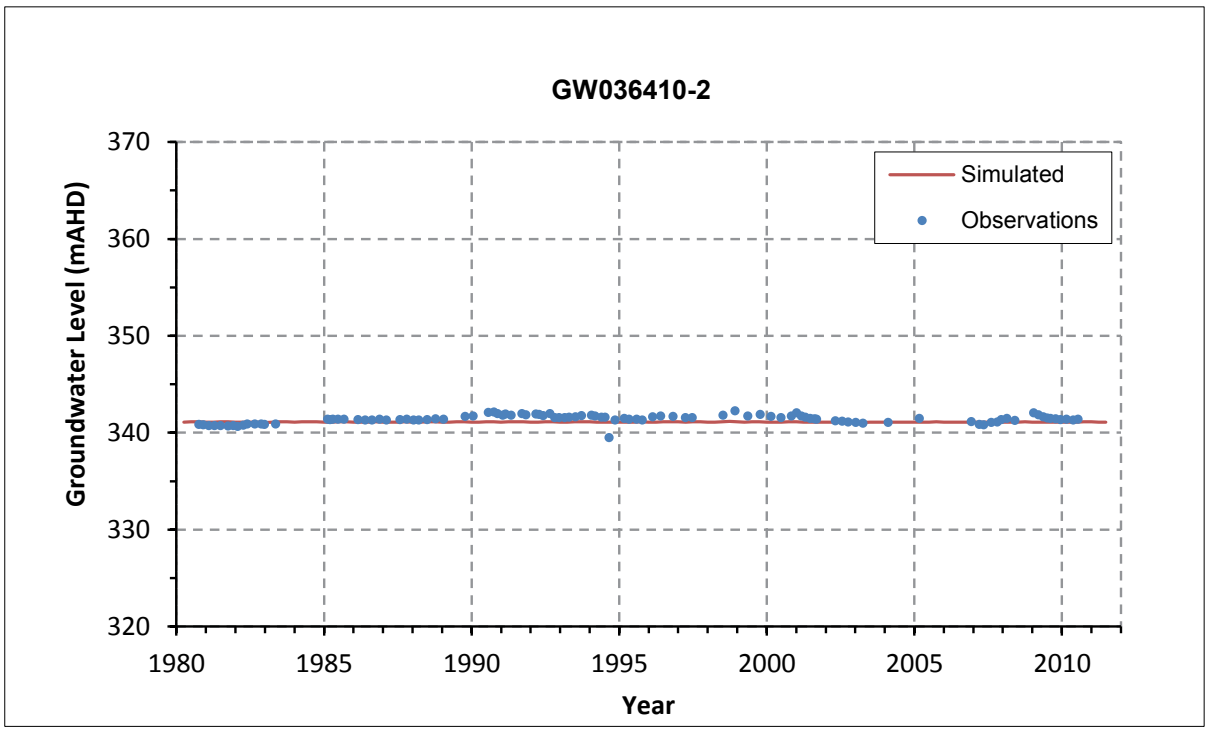

GW030181-1
Groundwater Level (mAHD)
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320
310
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1980
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1995
2000
2005
2010
Year
Simulated
Observations

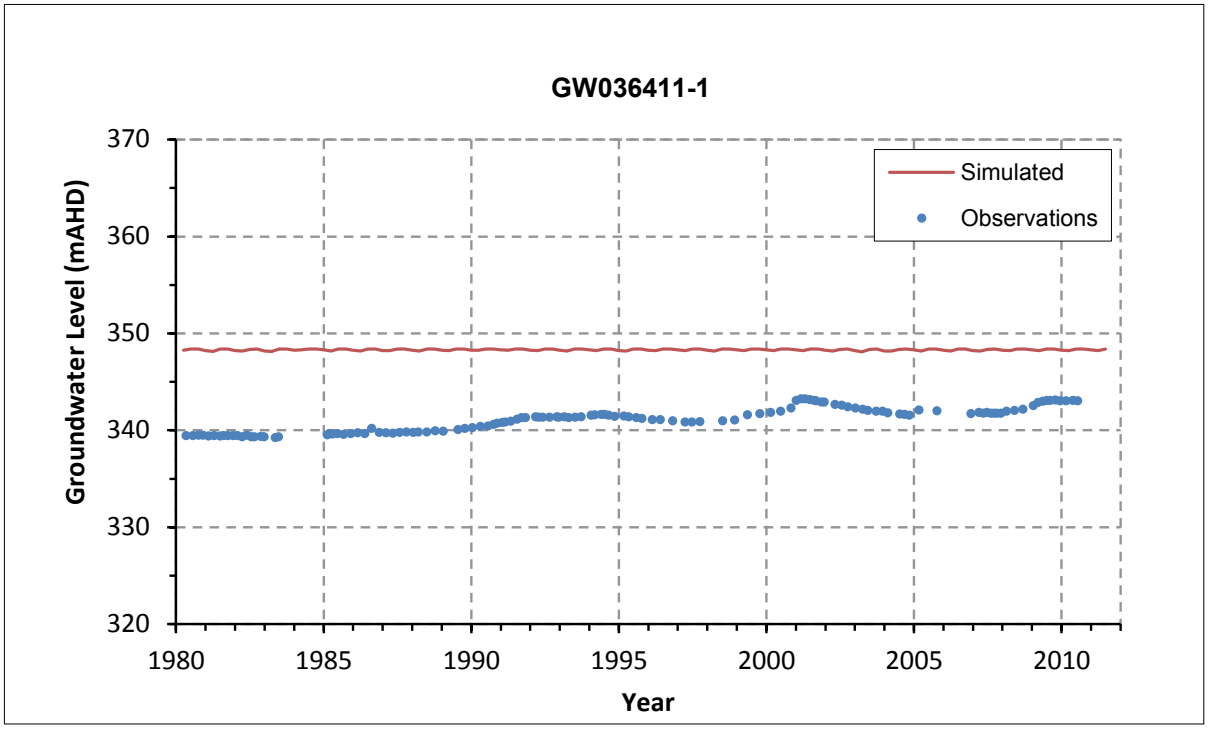

GW030181-2
Groundwater Level (mAHD)
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340
330
320
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300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

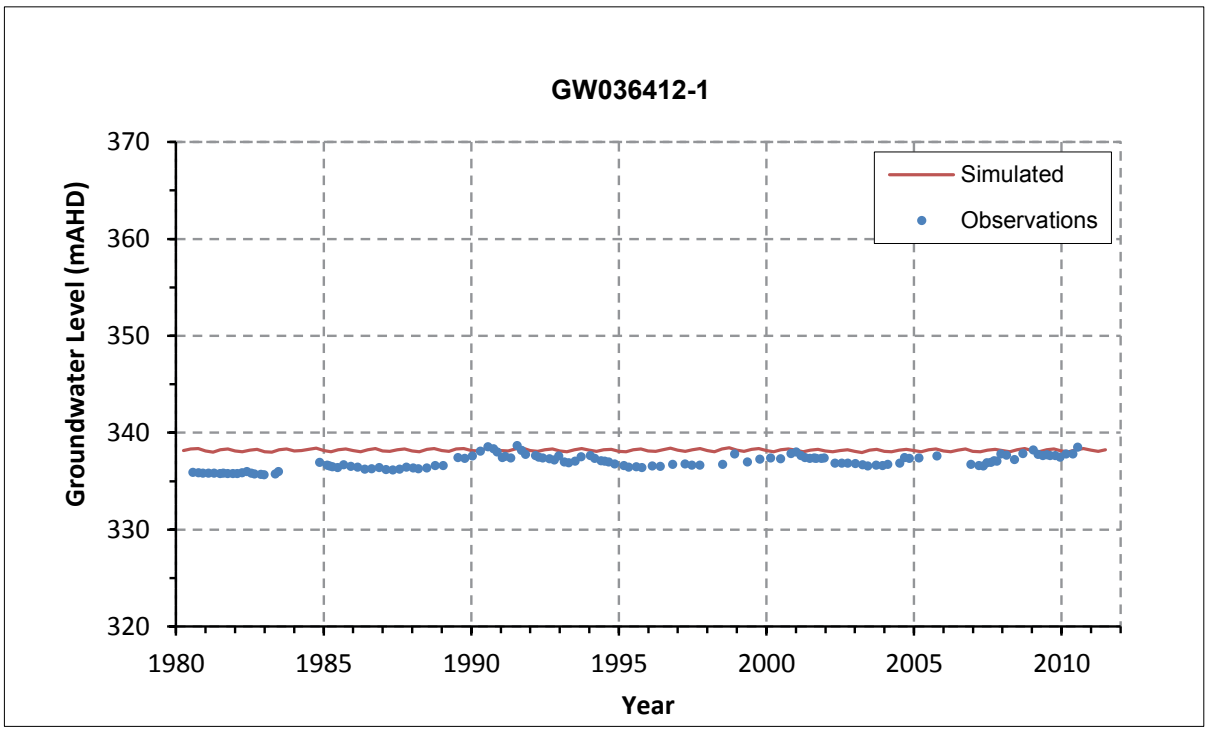

GW030182-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

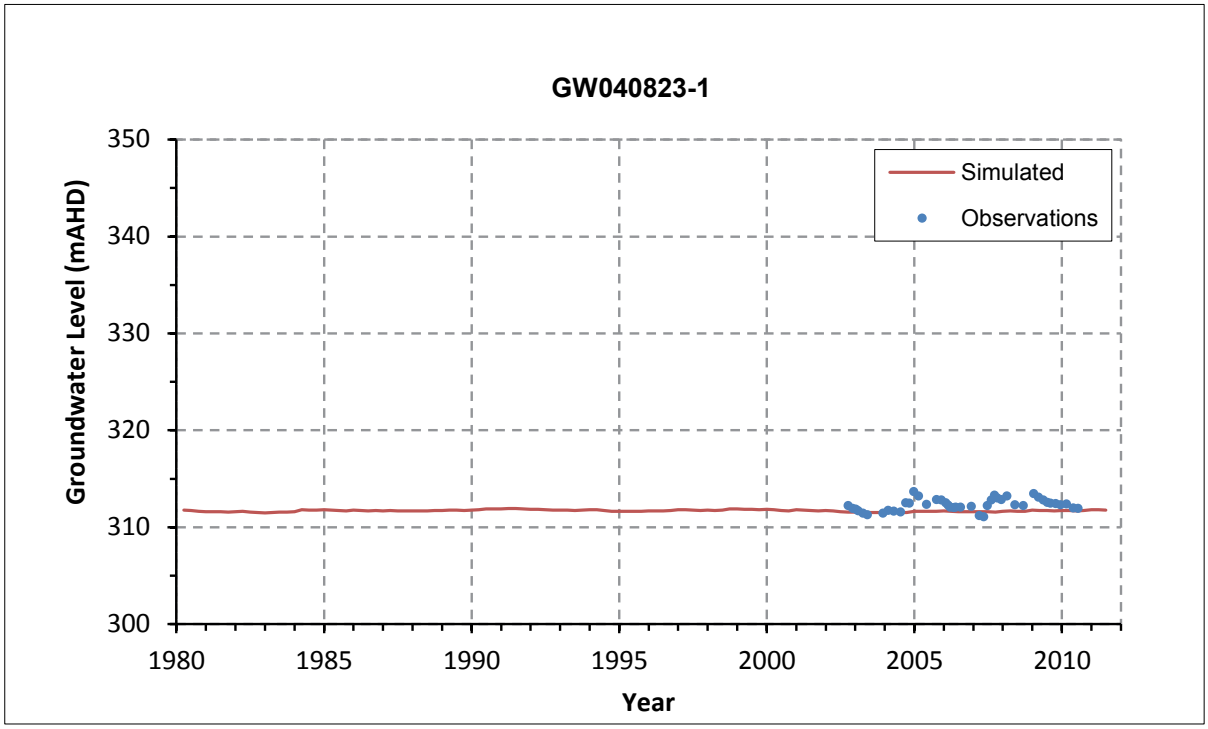

GW036404-1
Groundwater Level (mAHD)
380
370
360
350
340
330
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

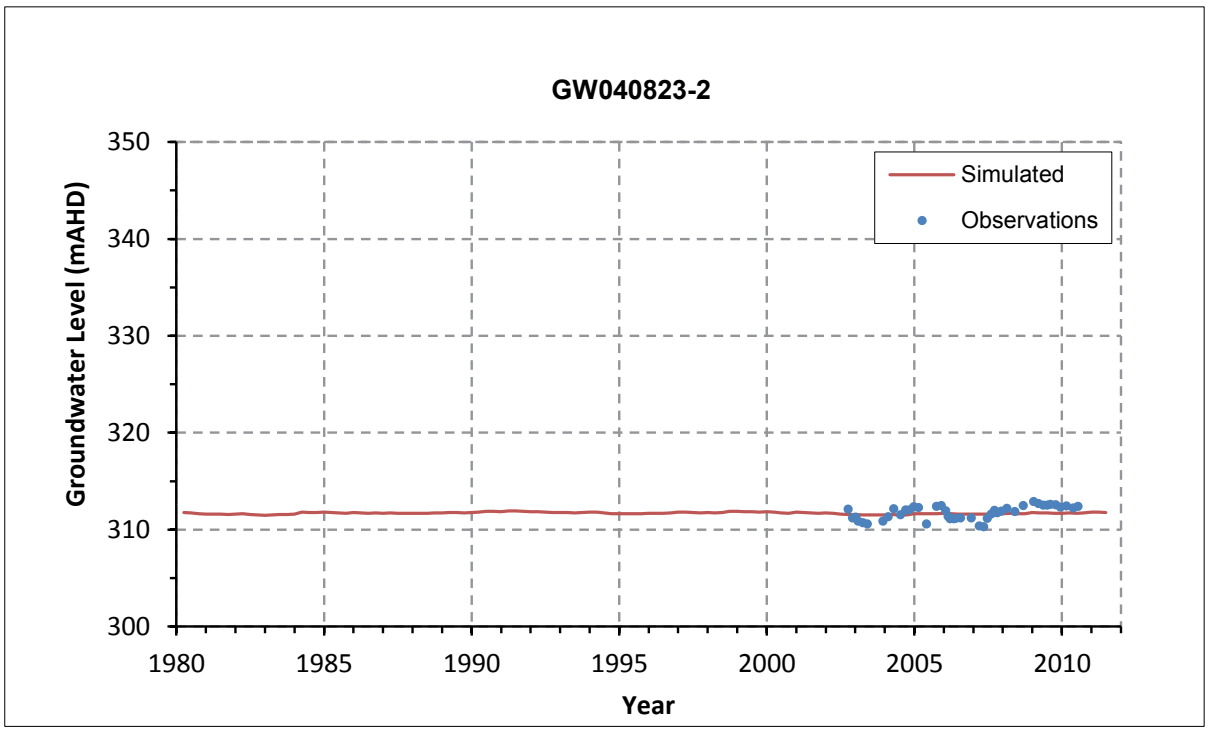

GW036410-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

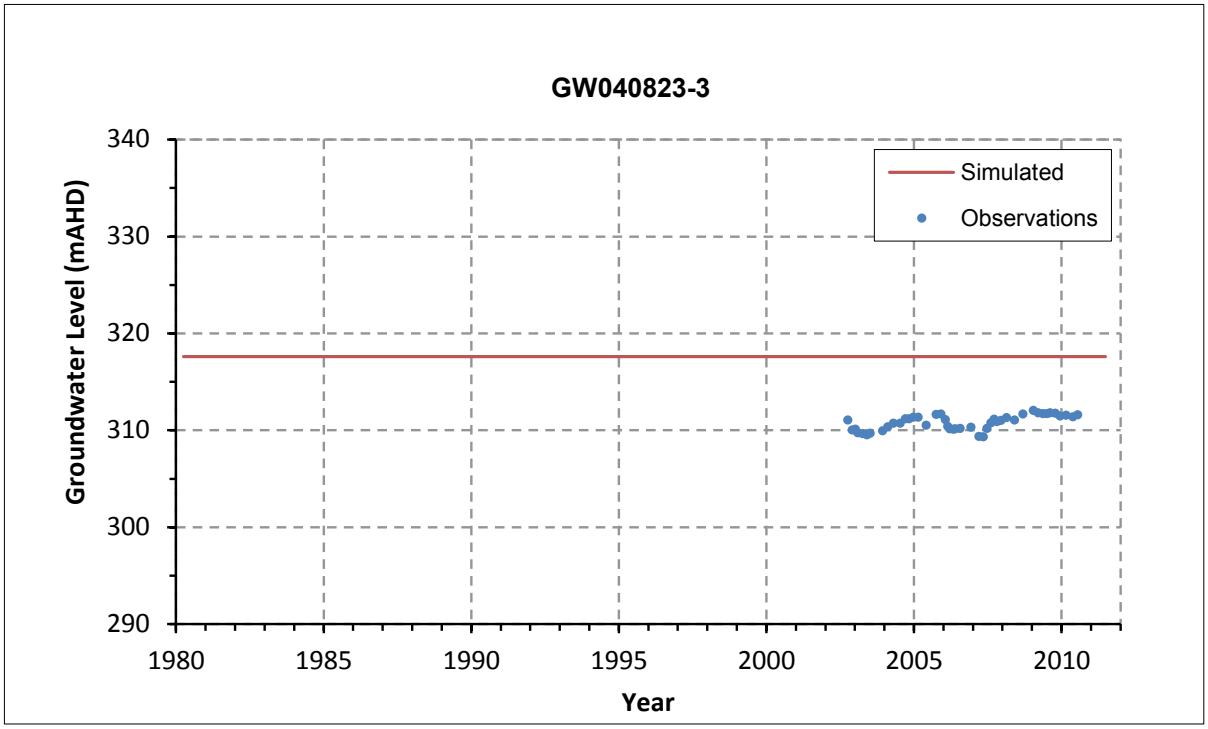

GW036410-2
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

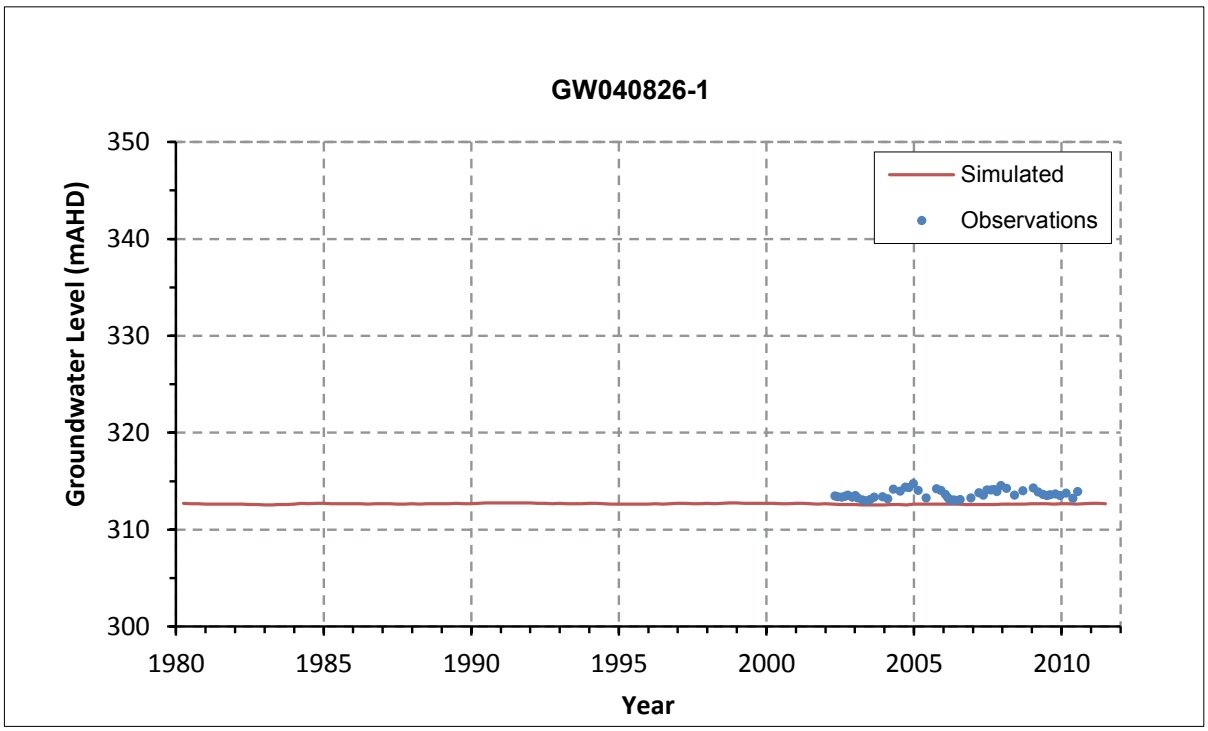

GW036411-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

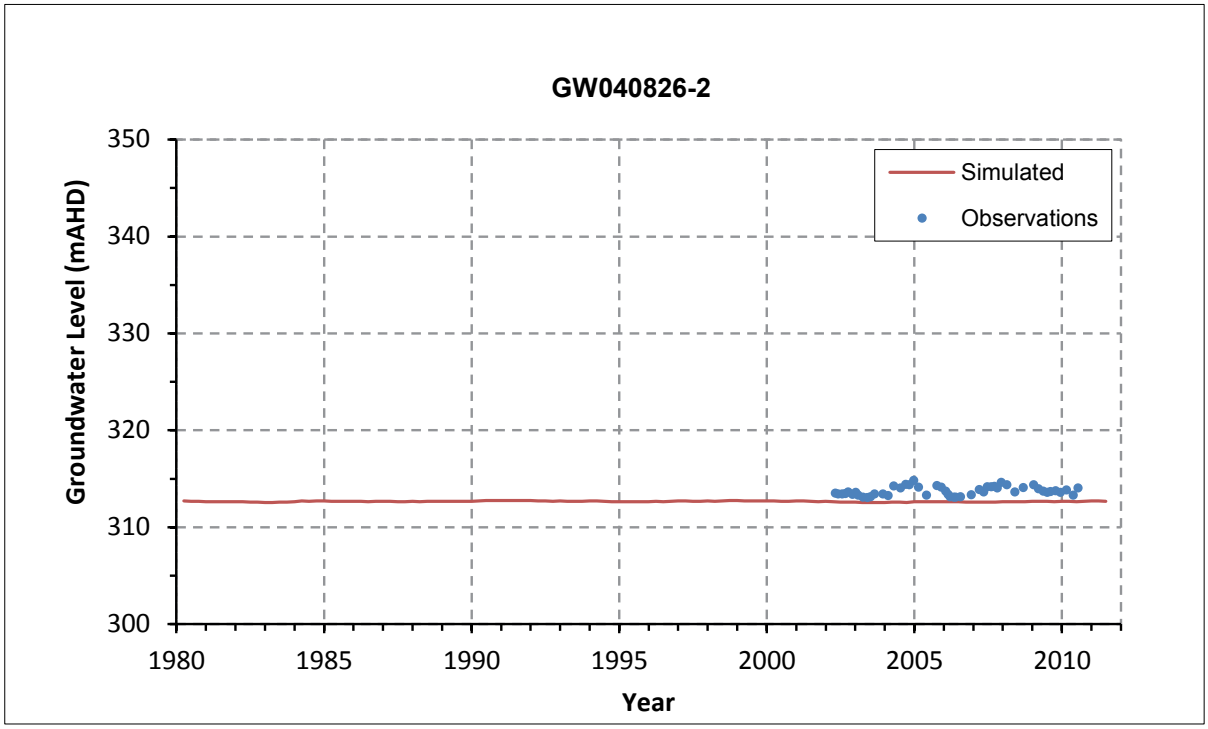

GW036412-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

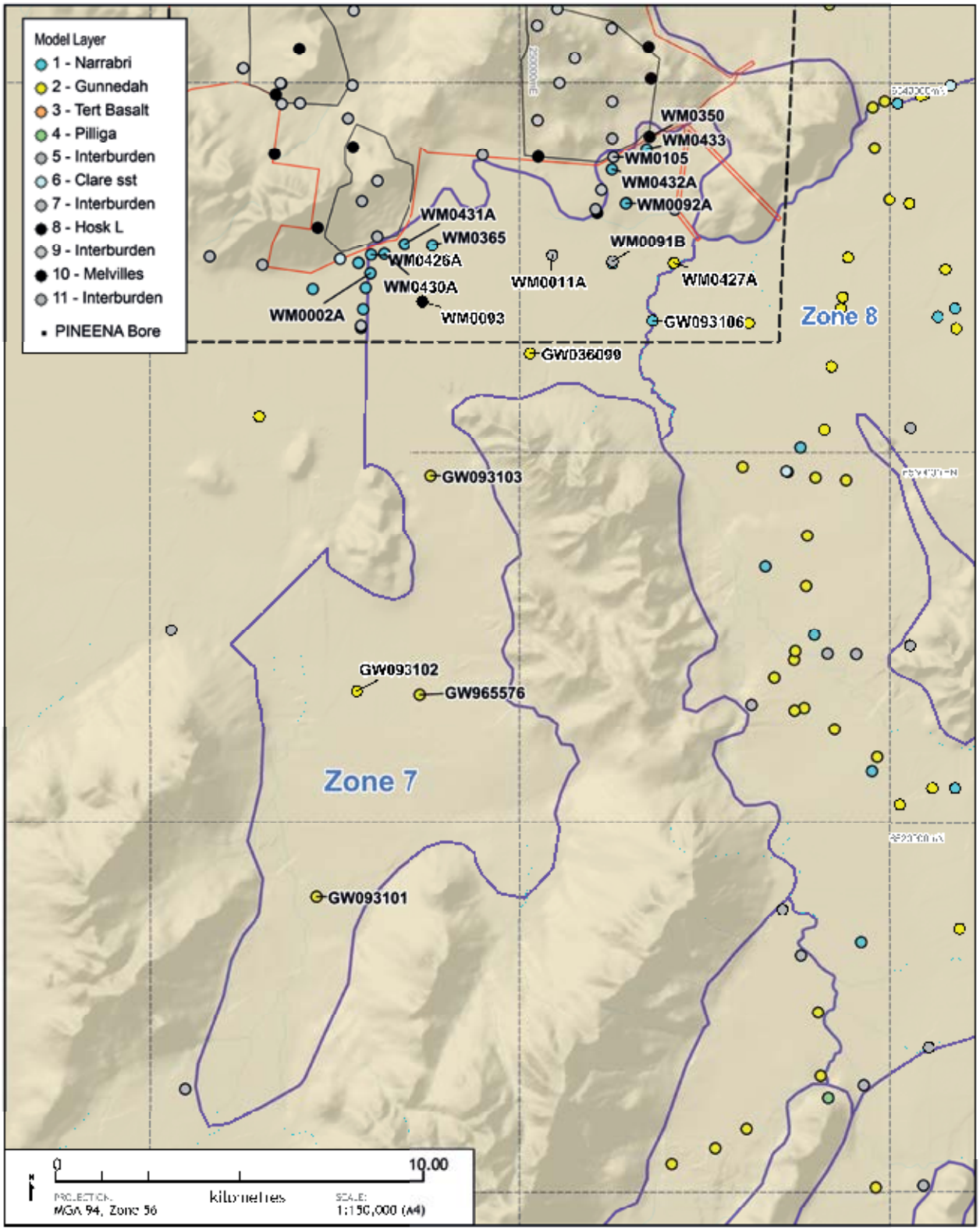

GW040823-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW040823-2
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW040823-3
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW040826-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW040826-2
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations



LEGEND

Groundwater Management Zone

Proposed Mining Area

EL 7223

Project Boundary

PINEENA Bore

Watermark Coal Project (G1501)
Groundwater Assessment

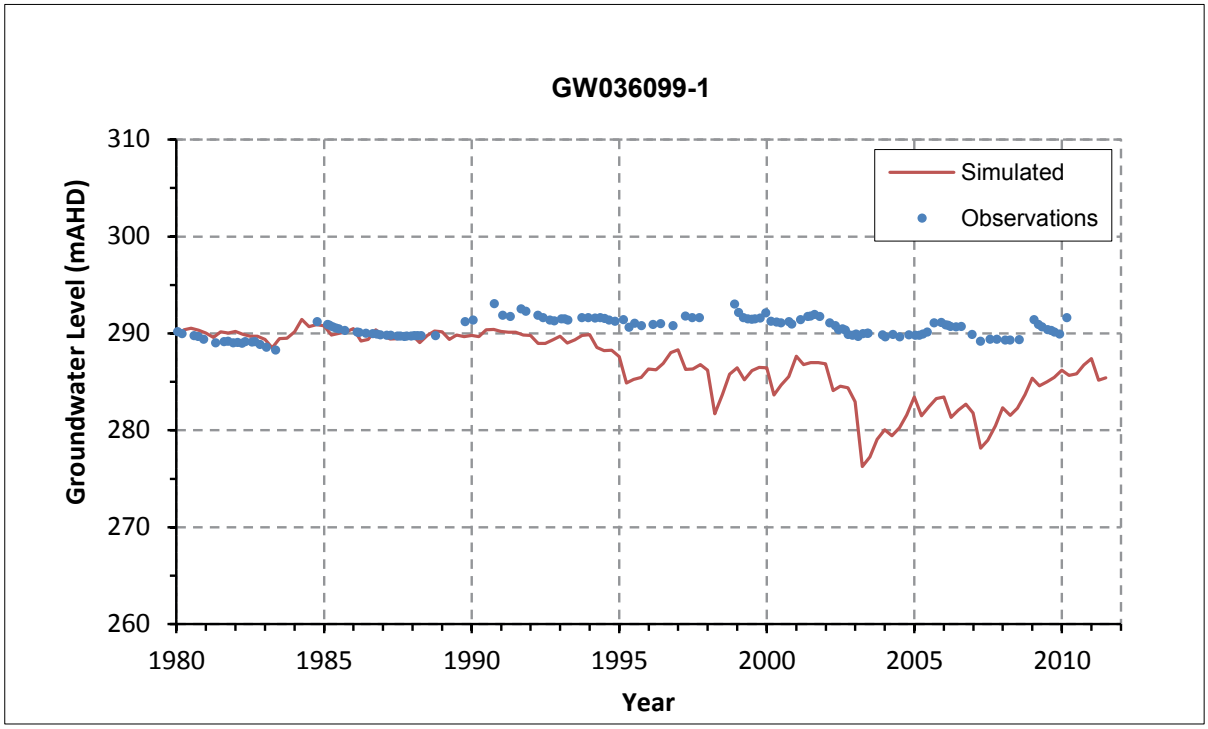
Groundwater Monitoring Bores: Shenhua and Pineena - Zone 7

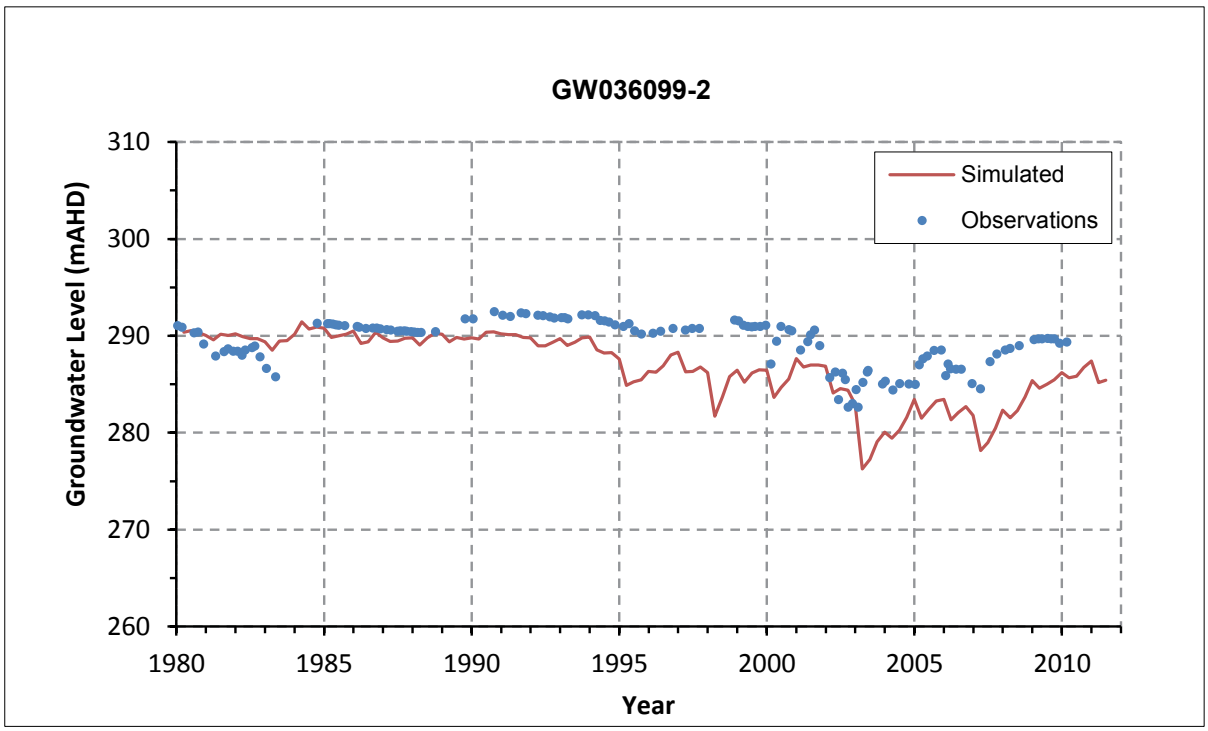
Source: NoW PINEENA Groundwater Database, 2011
GHD Groundwater Monitoring Database, 2011

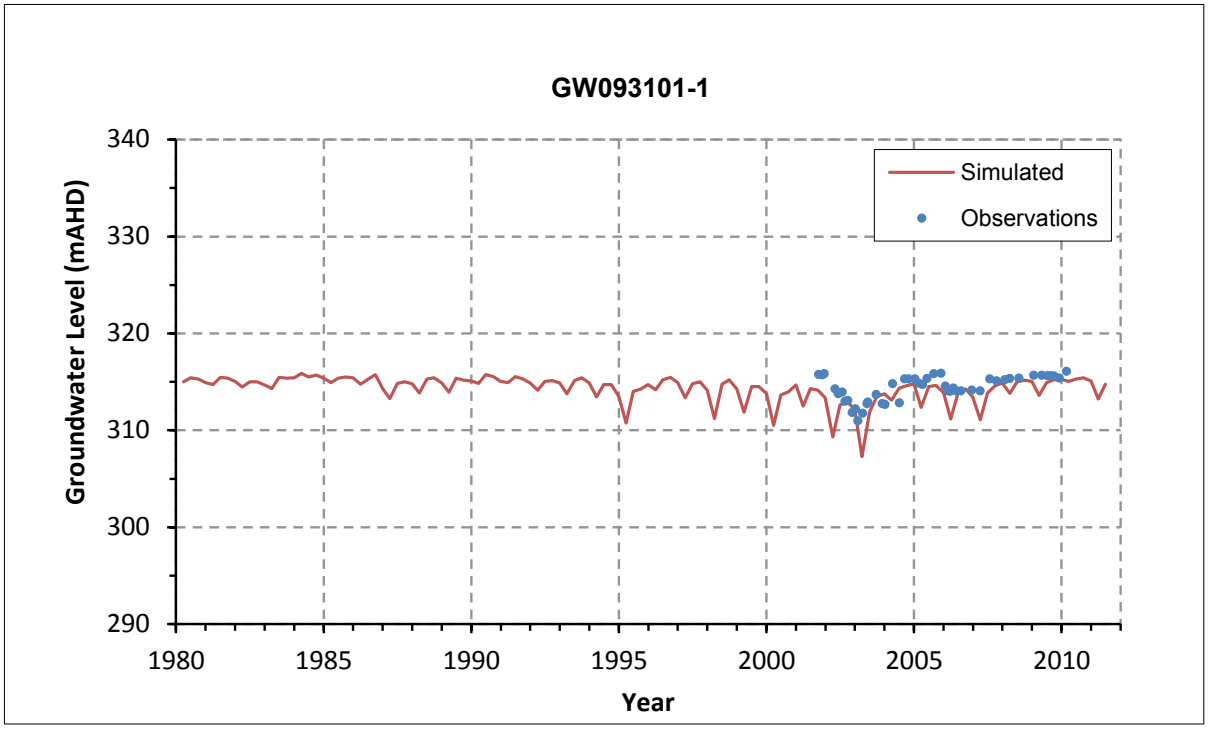
DATE: 25/7/2012

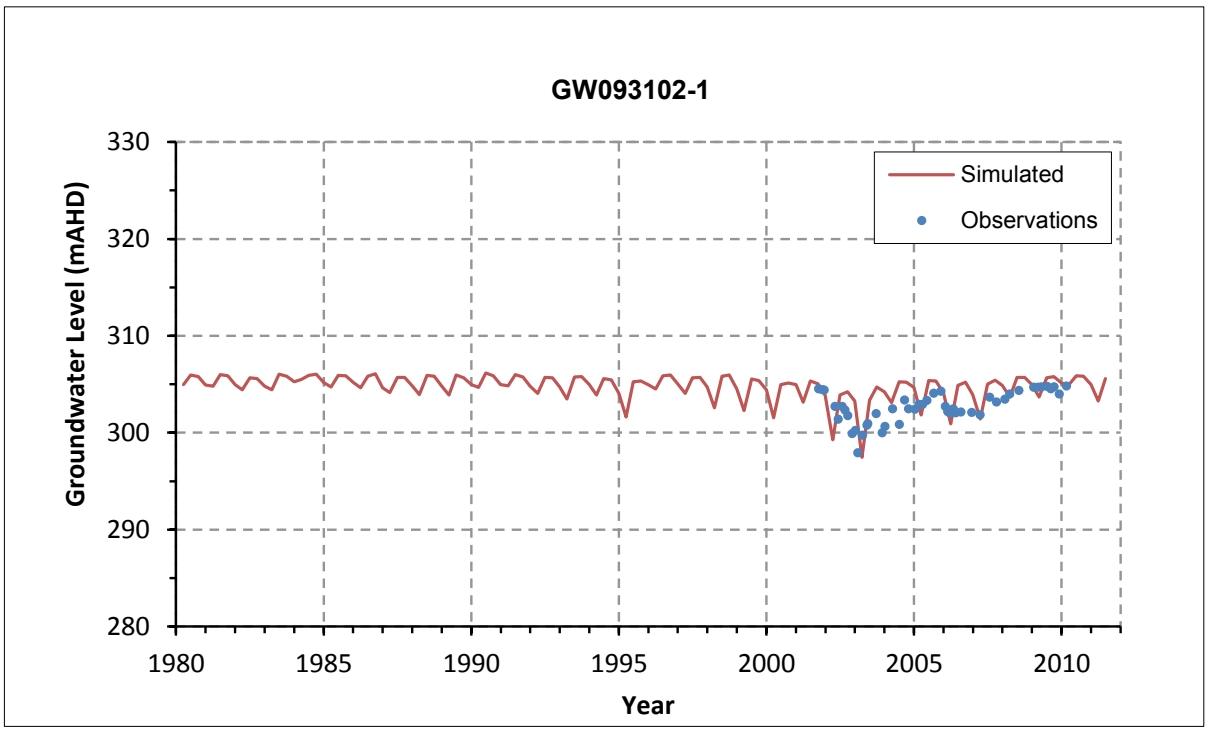
FIGURE No: **A.4**

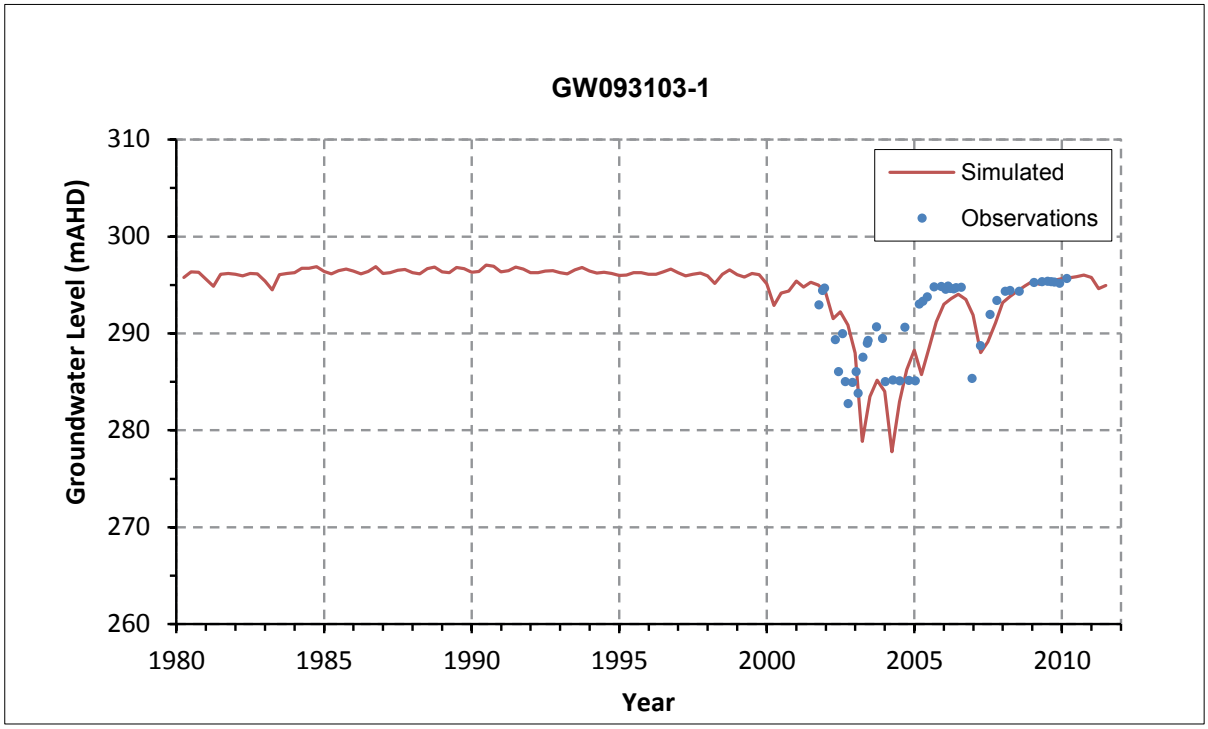
©2012 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

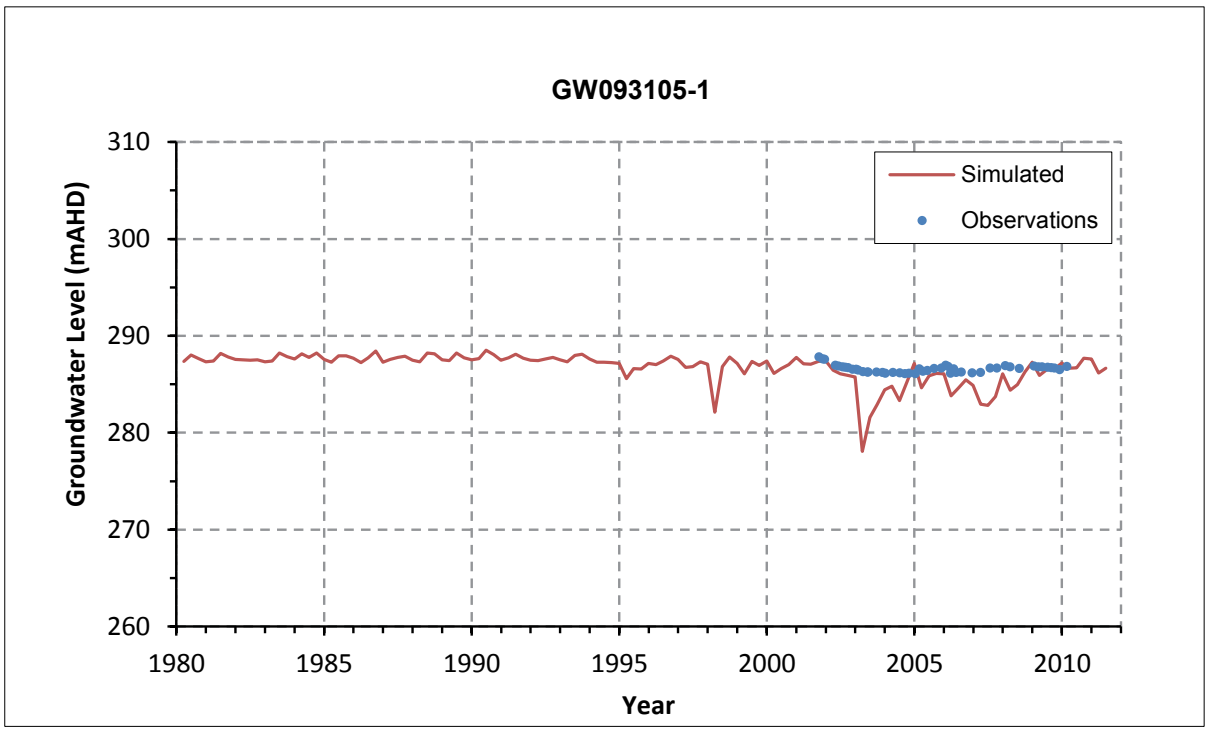

GW036099-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

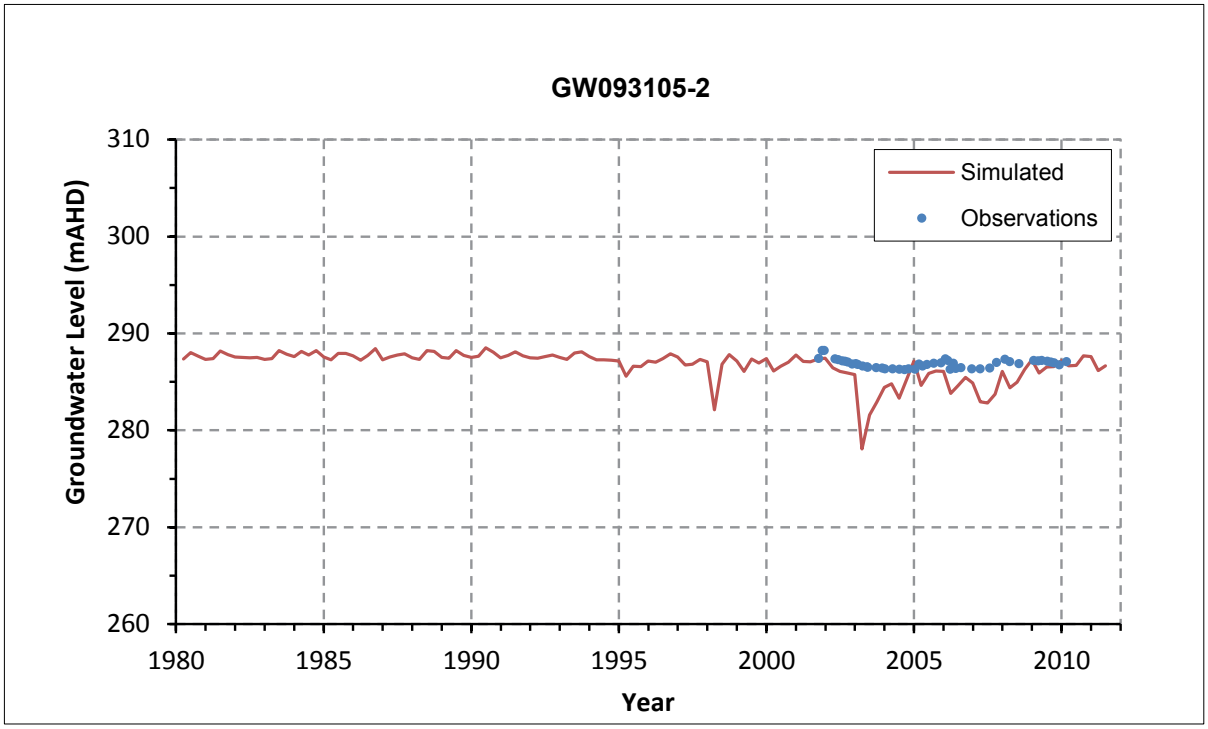

GW036099-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

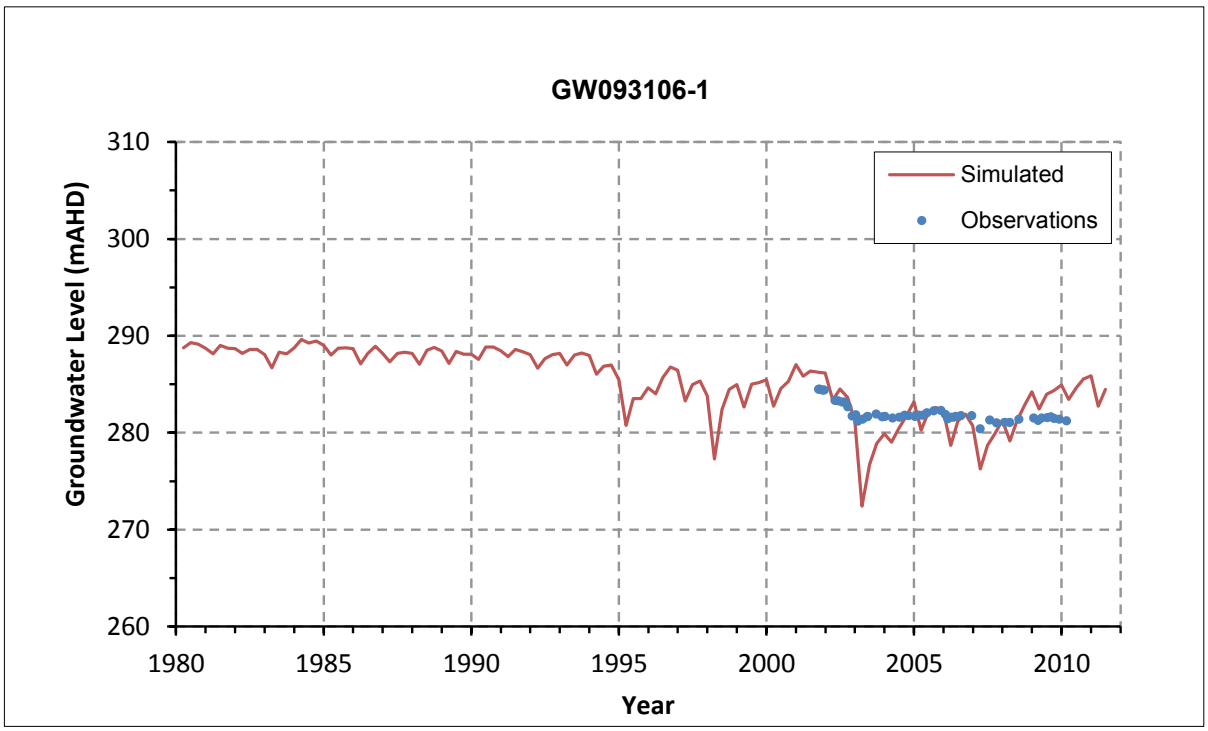

GW093101-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

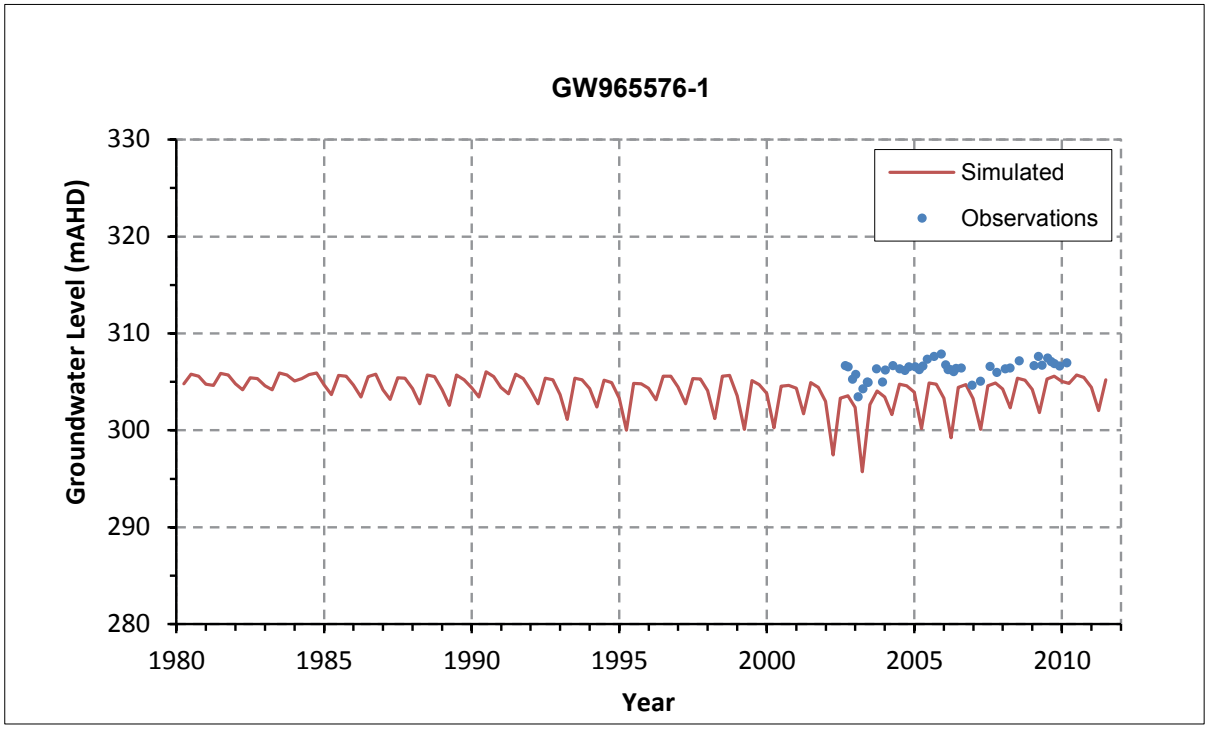

GW093102-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

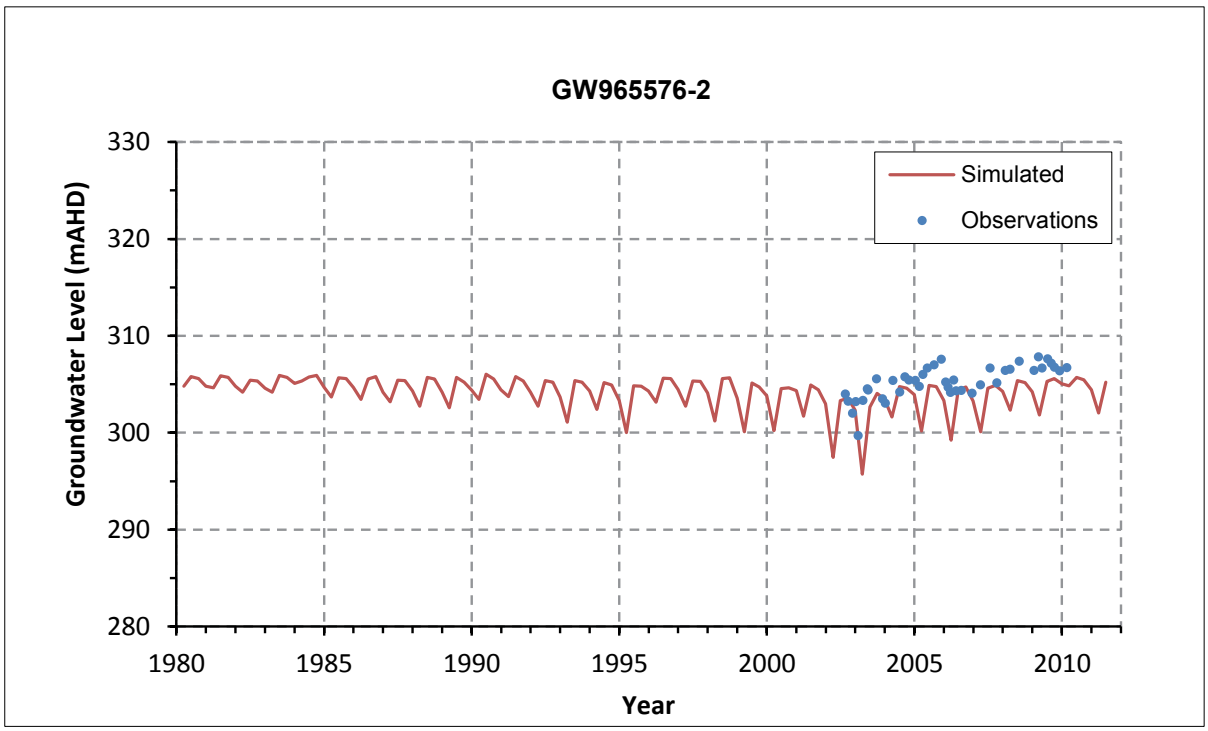

GW093103-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

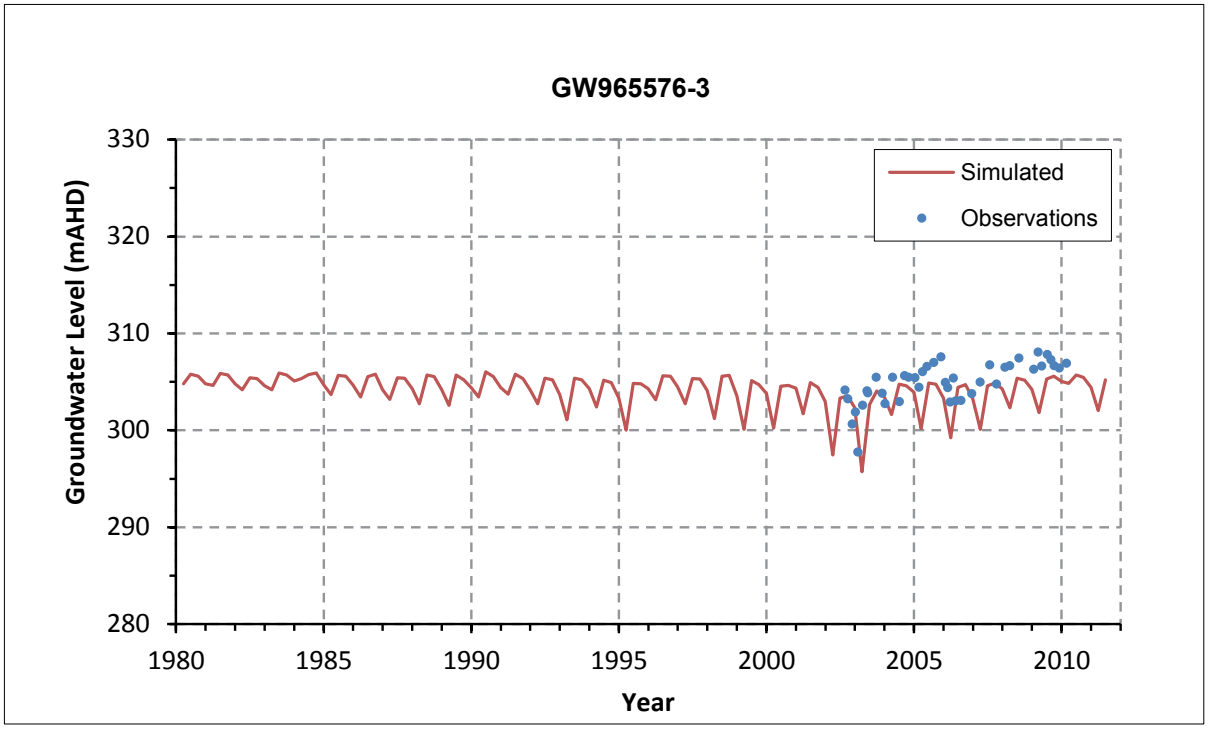

GW093105-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

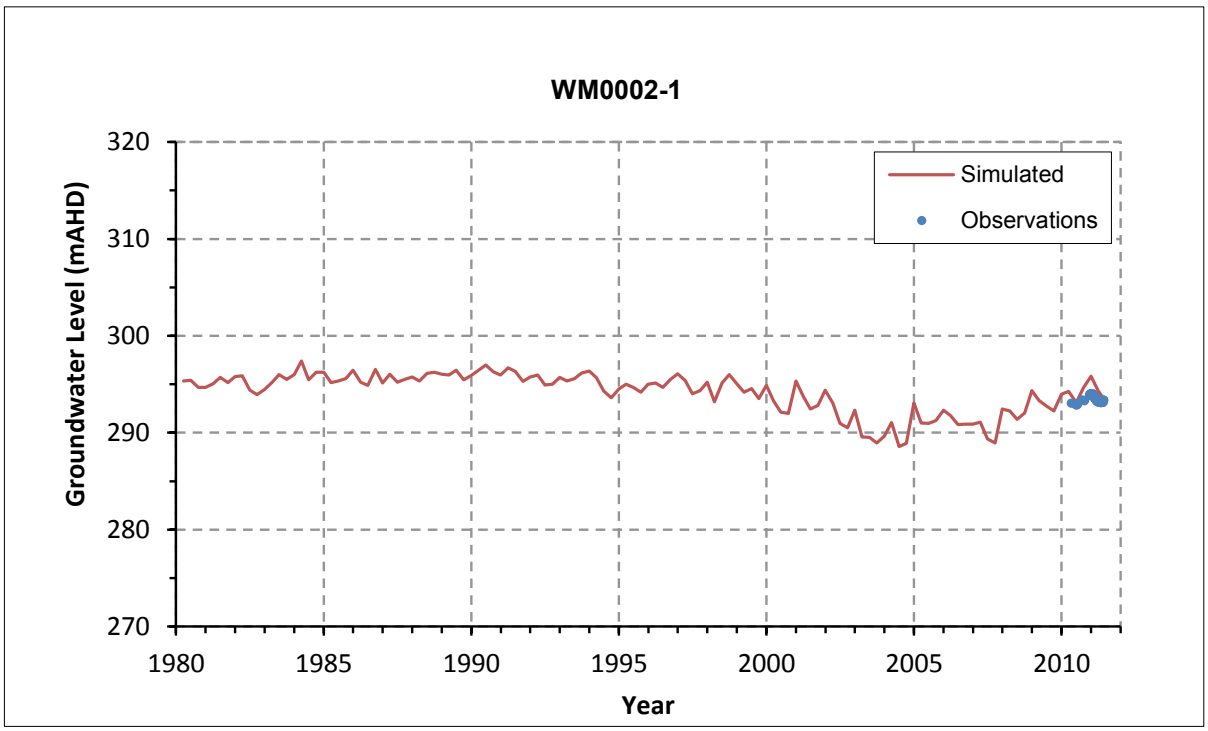

GW093105-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

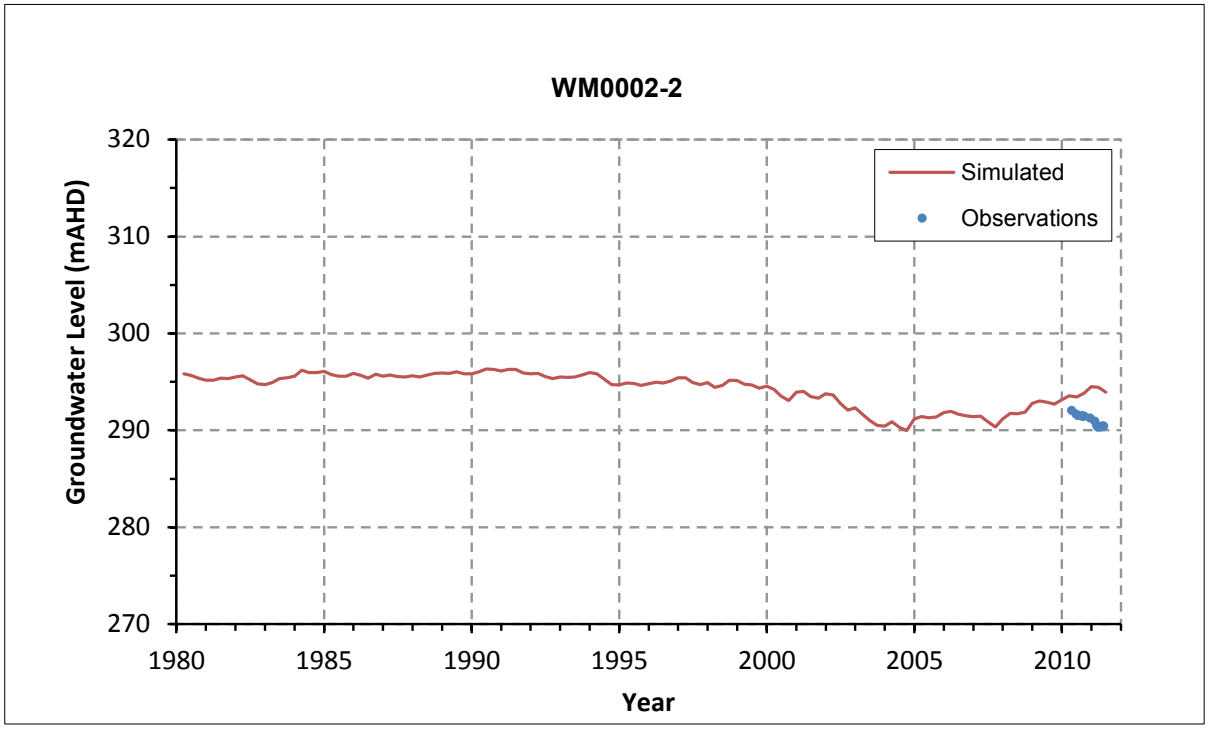

GW093106-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

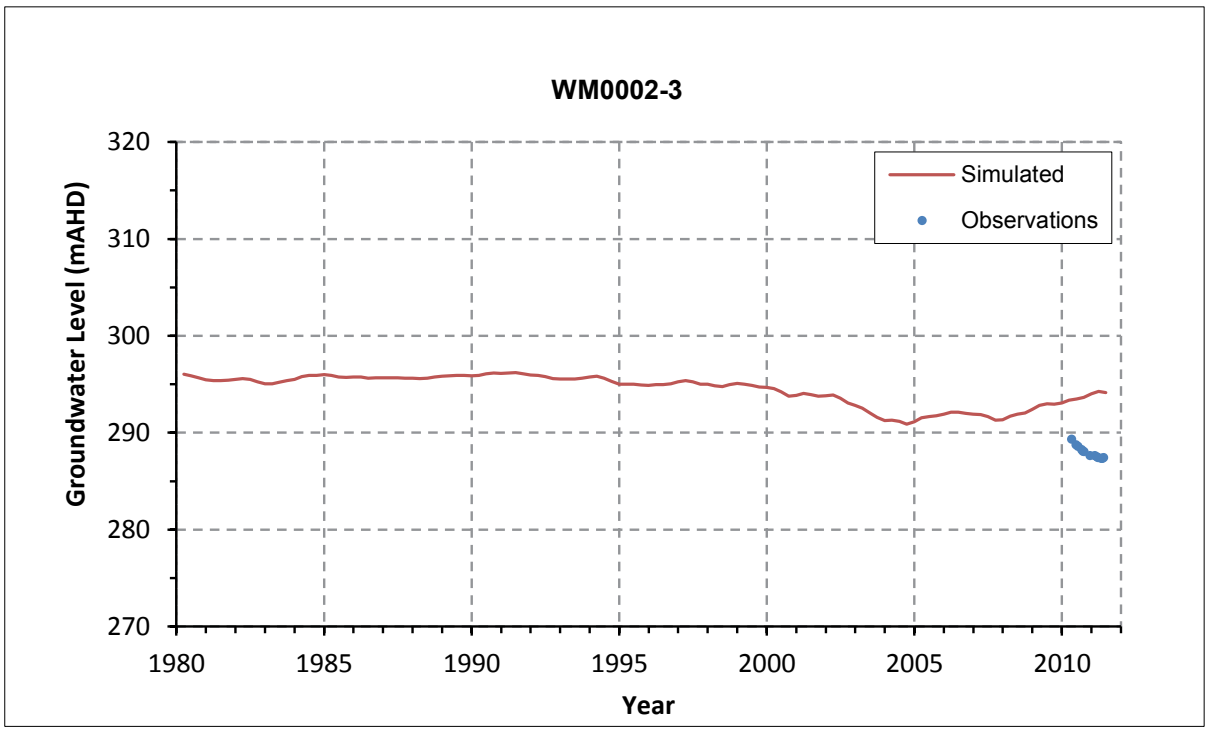

GW965576-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

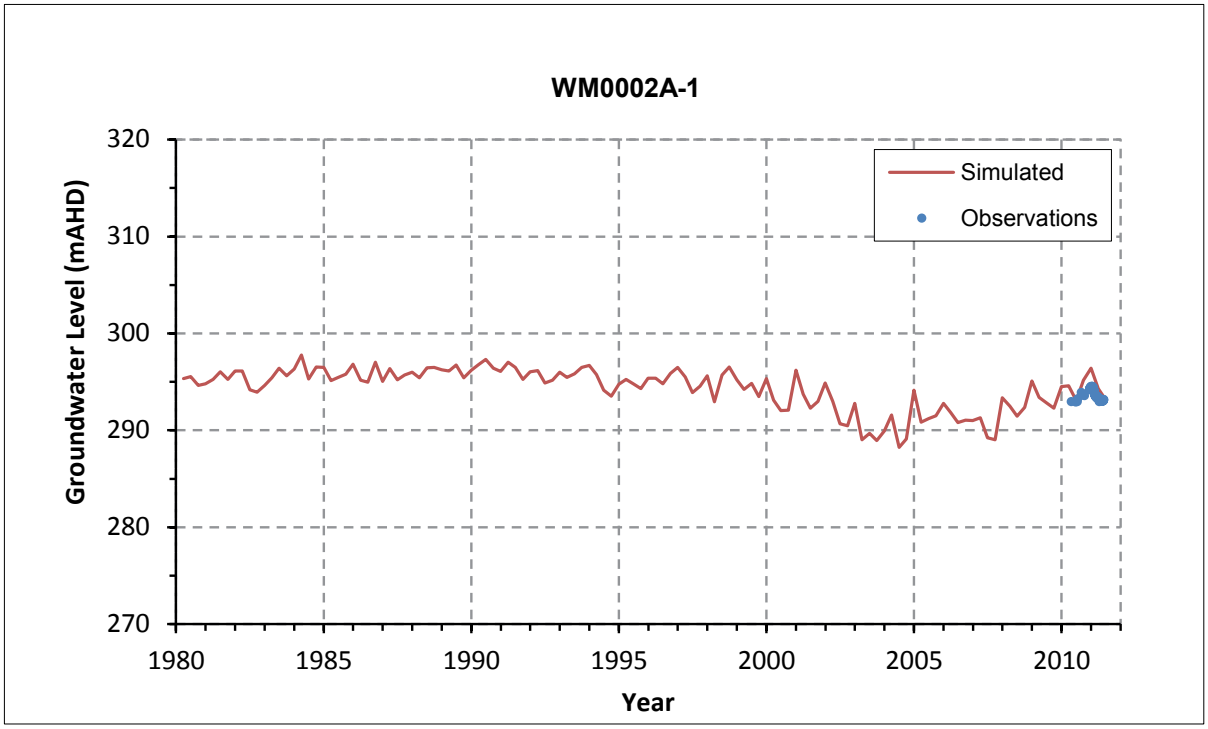

GW965576-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

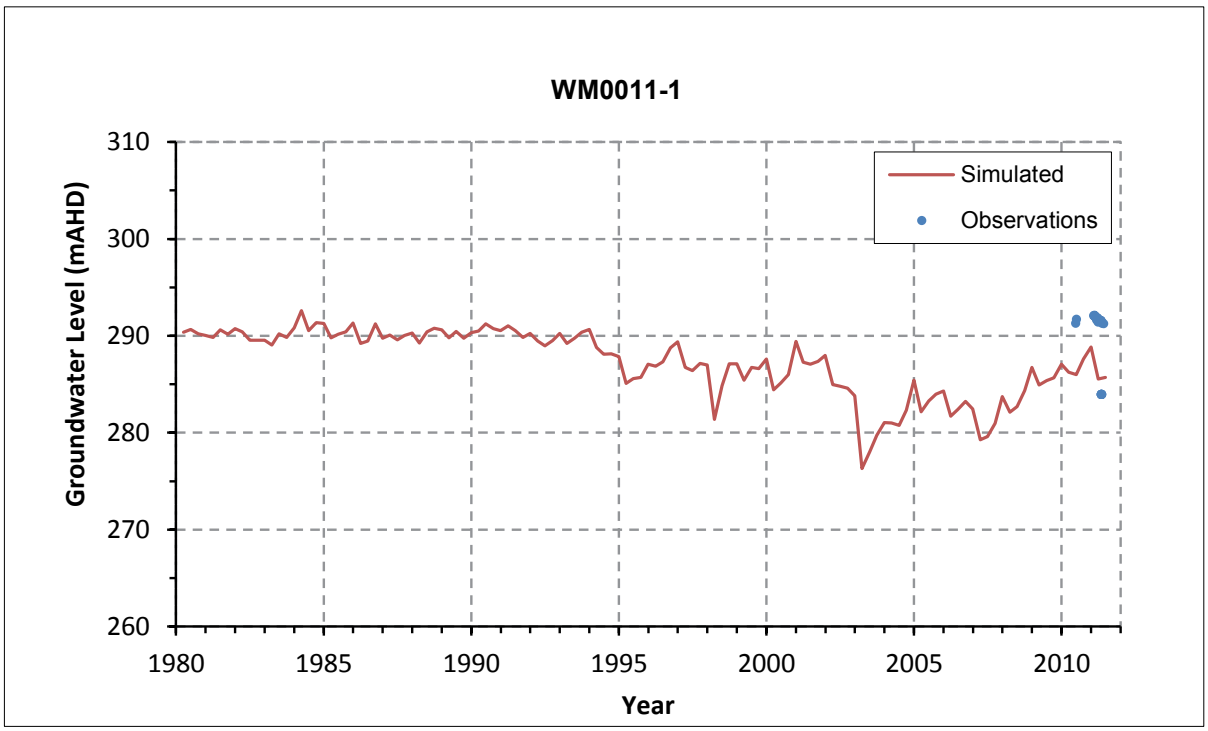

GW965576-3
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

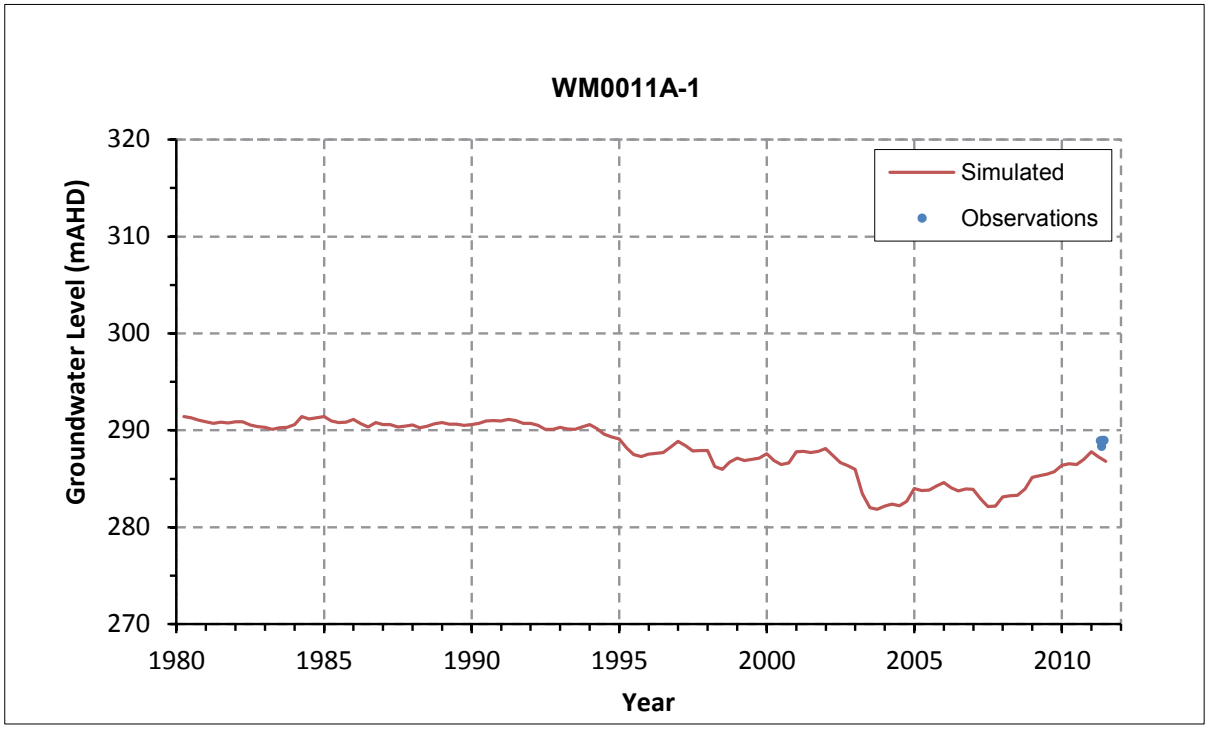

WM0002-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

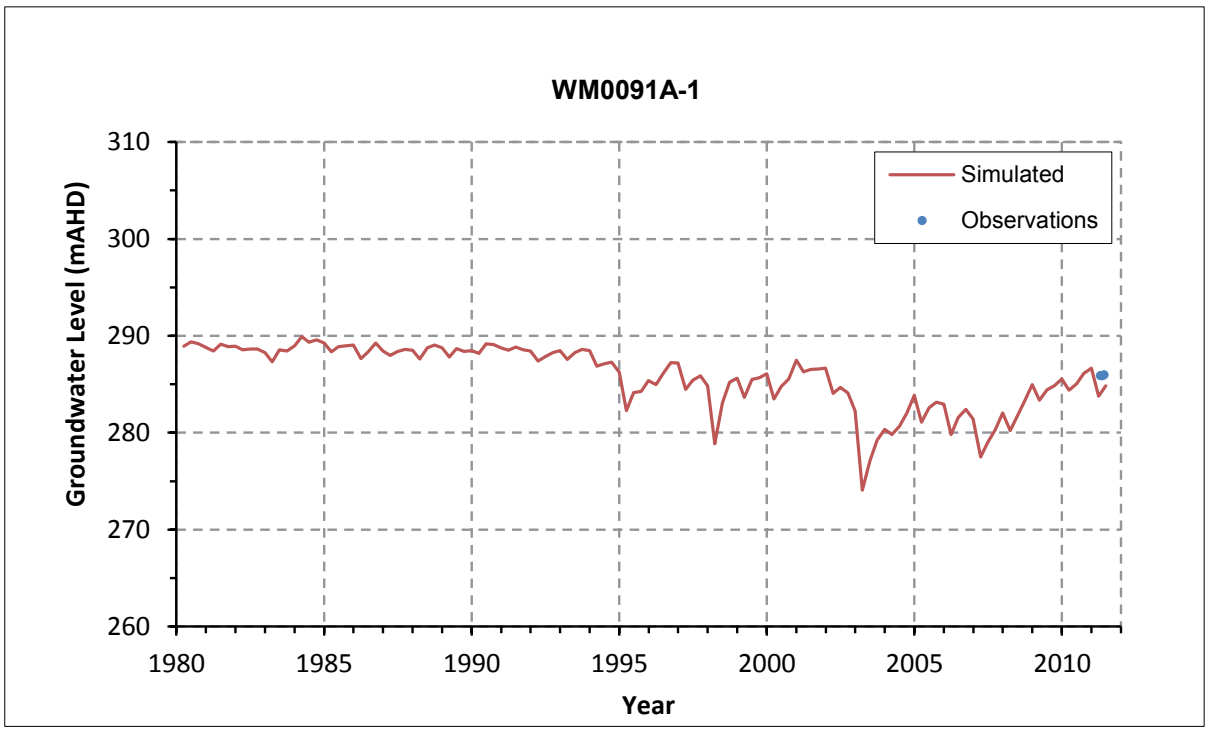

WM0002-2
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

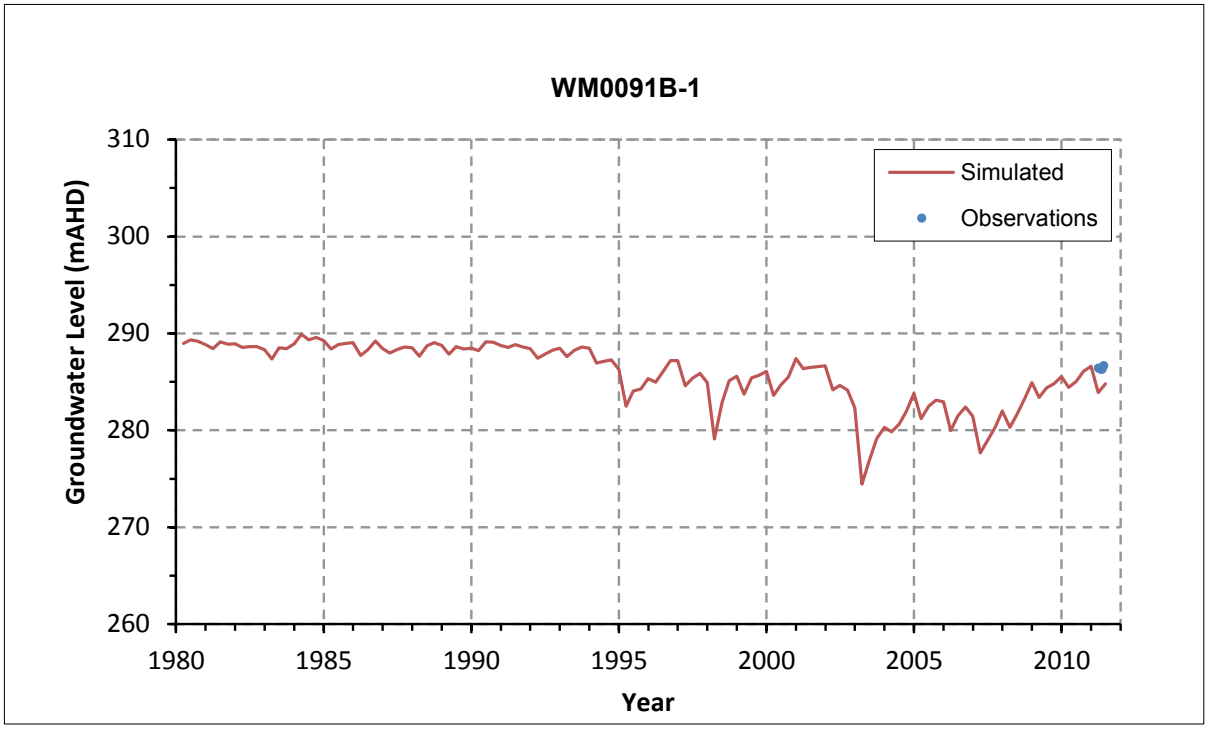

WM0002-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

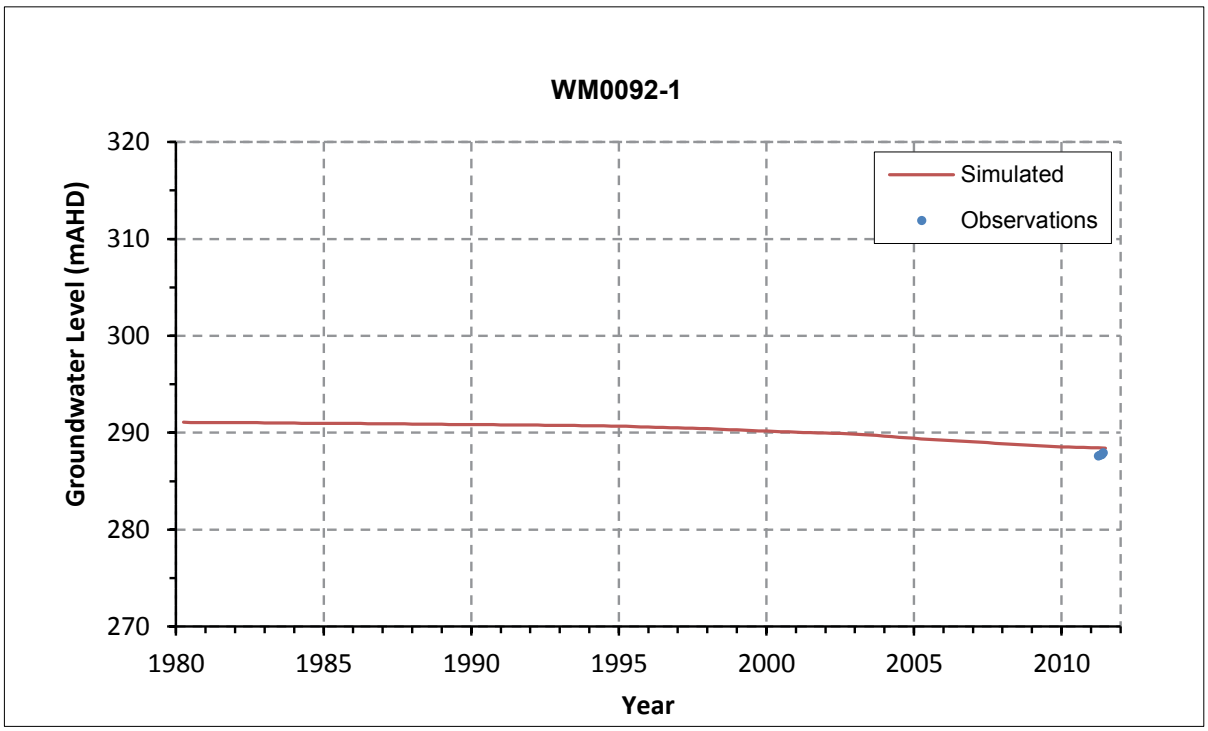

WM0002A-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

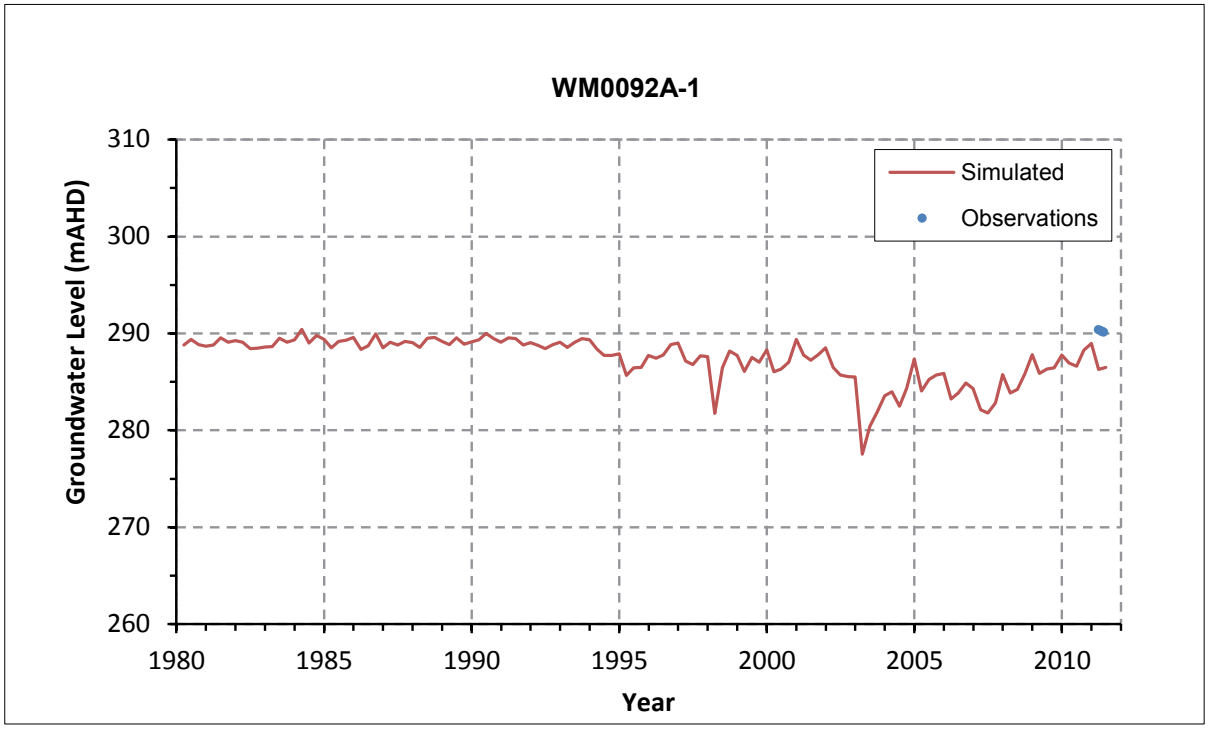

WM0011-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

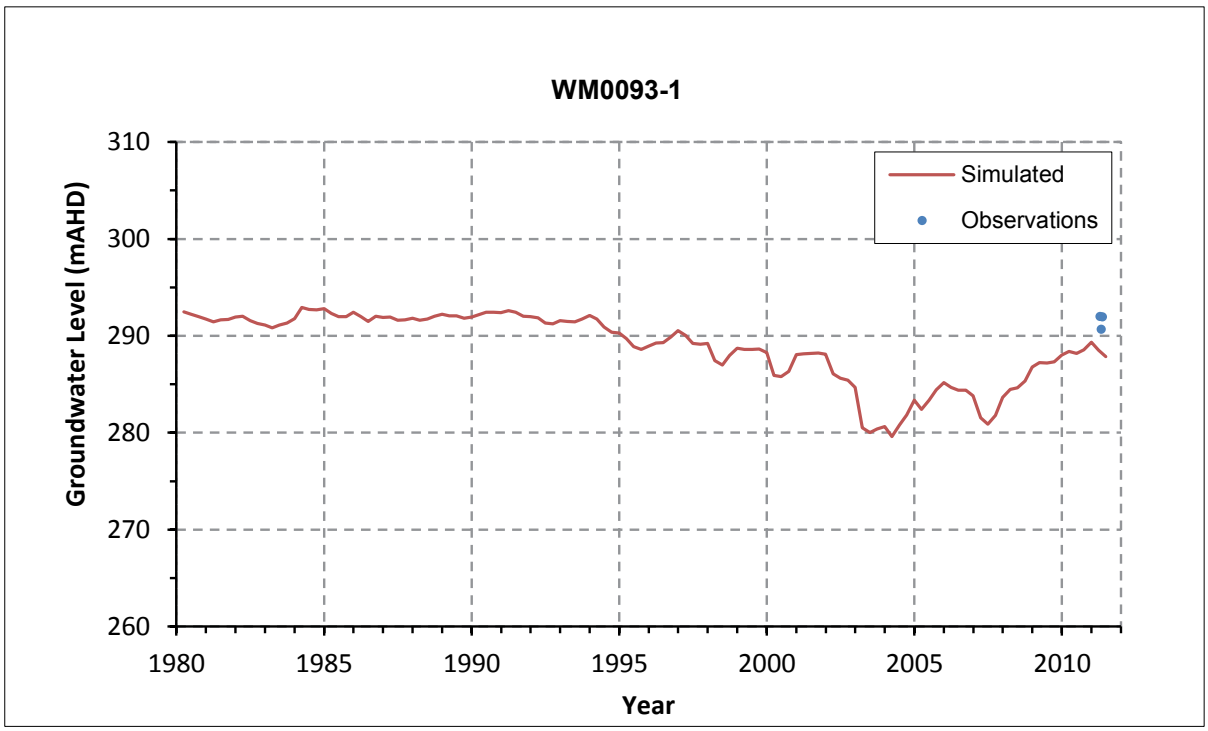

WM0011A-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

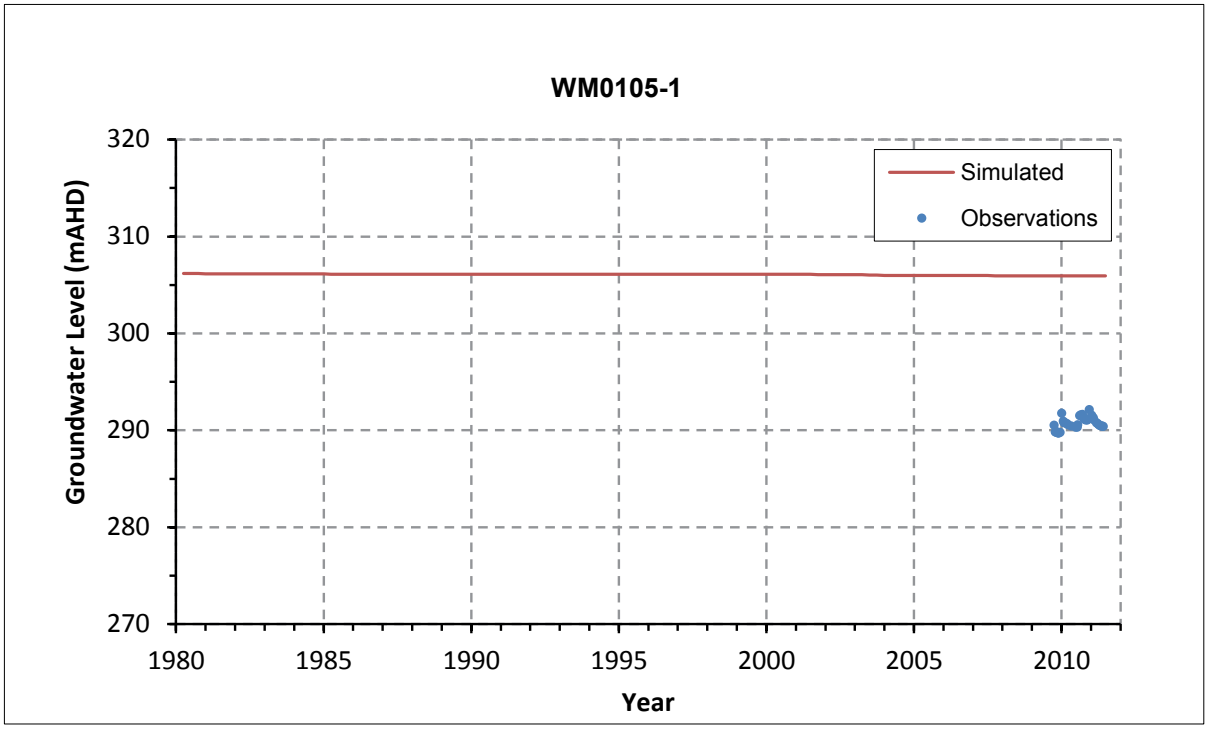

WM0091A-1
Groundwater Level (mAHD)
310
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280
270
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1980
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1990
1995
2000
2005
2010
Year
Simulated
Observations

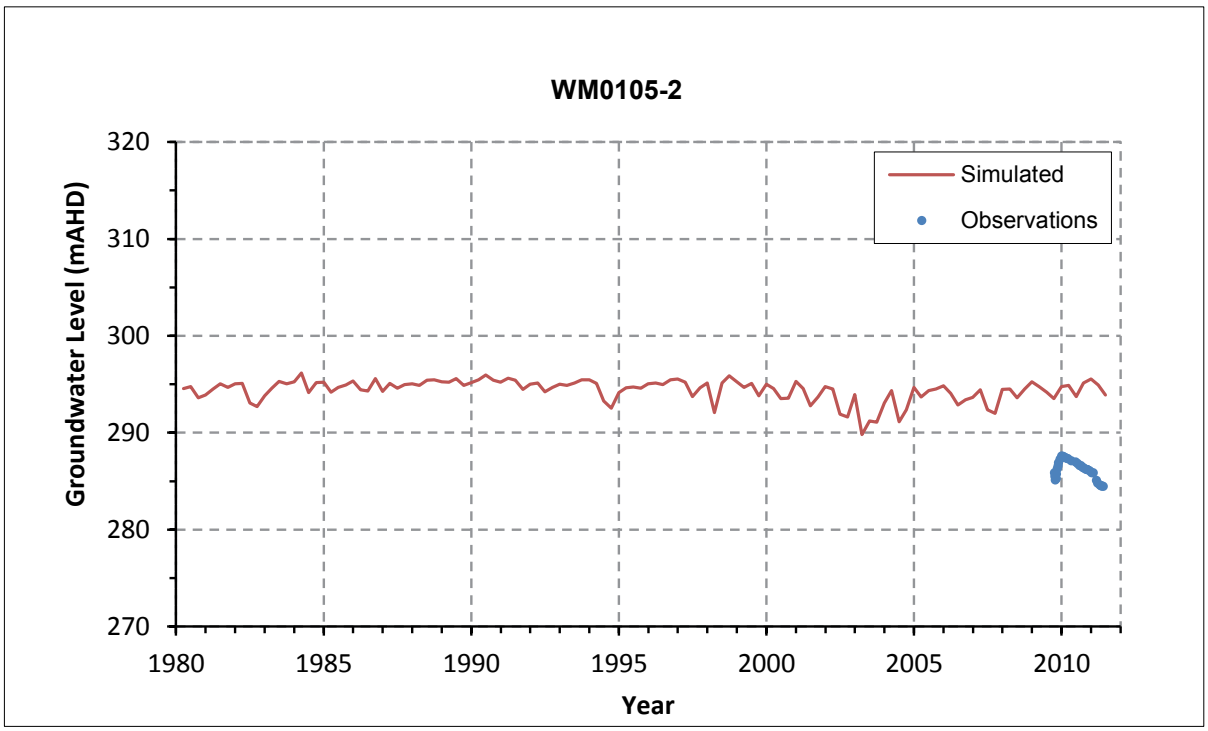

WM0091B-1
Groundwater Level (mAHD)
310
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290
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270
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1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

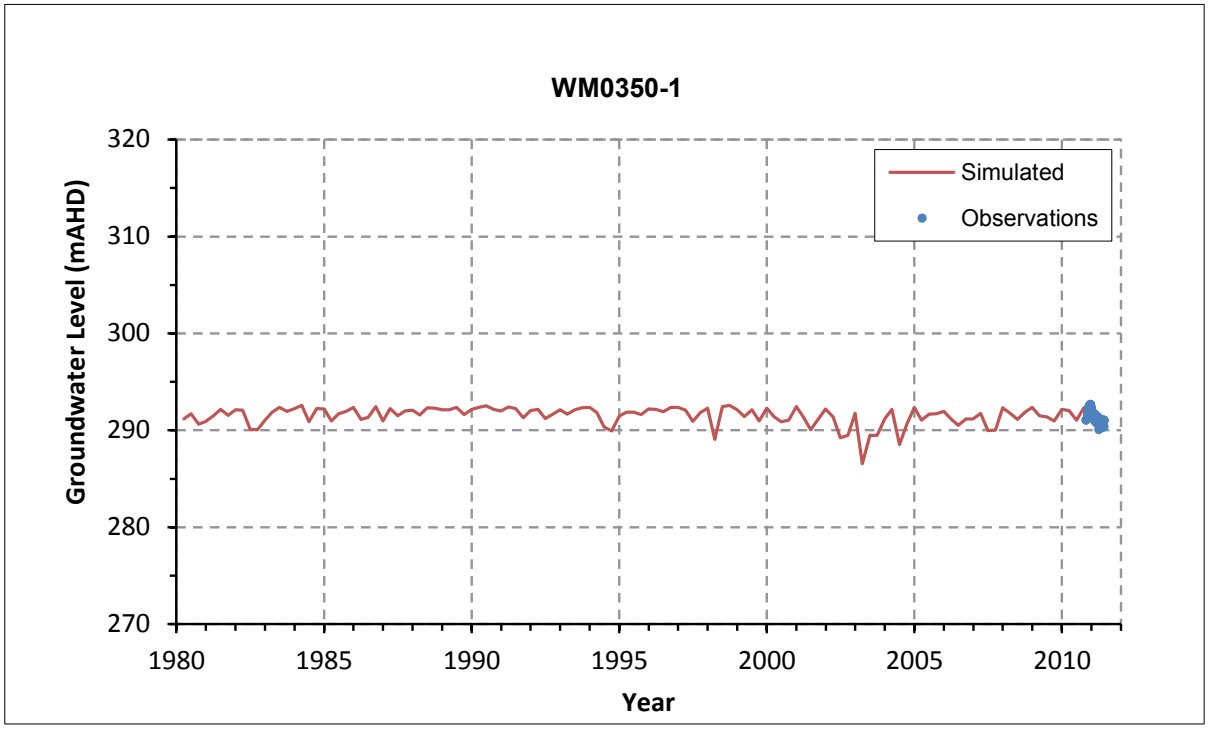

WM0092-1
Groundwater Level (mAHD)
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310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

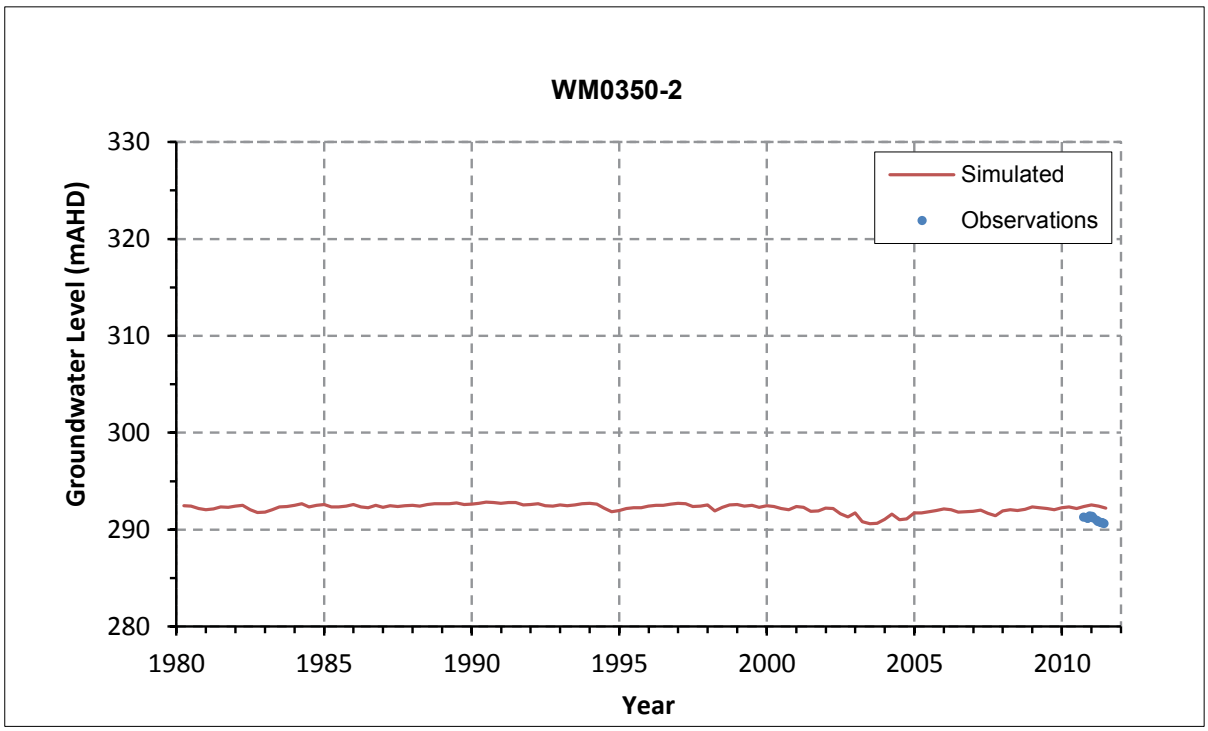

WM0092A-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

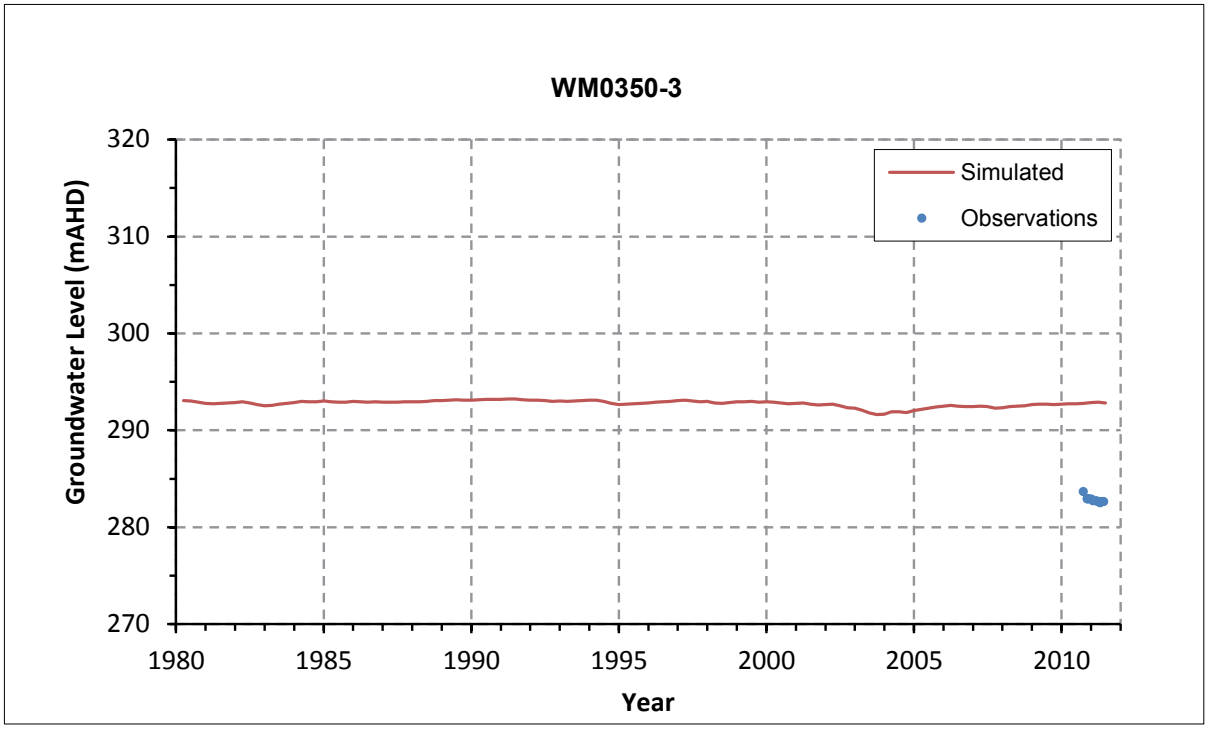

WM0093-1
Groundwater Level (mAHD)
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280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

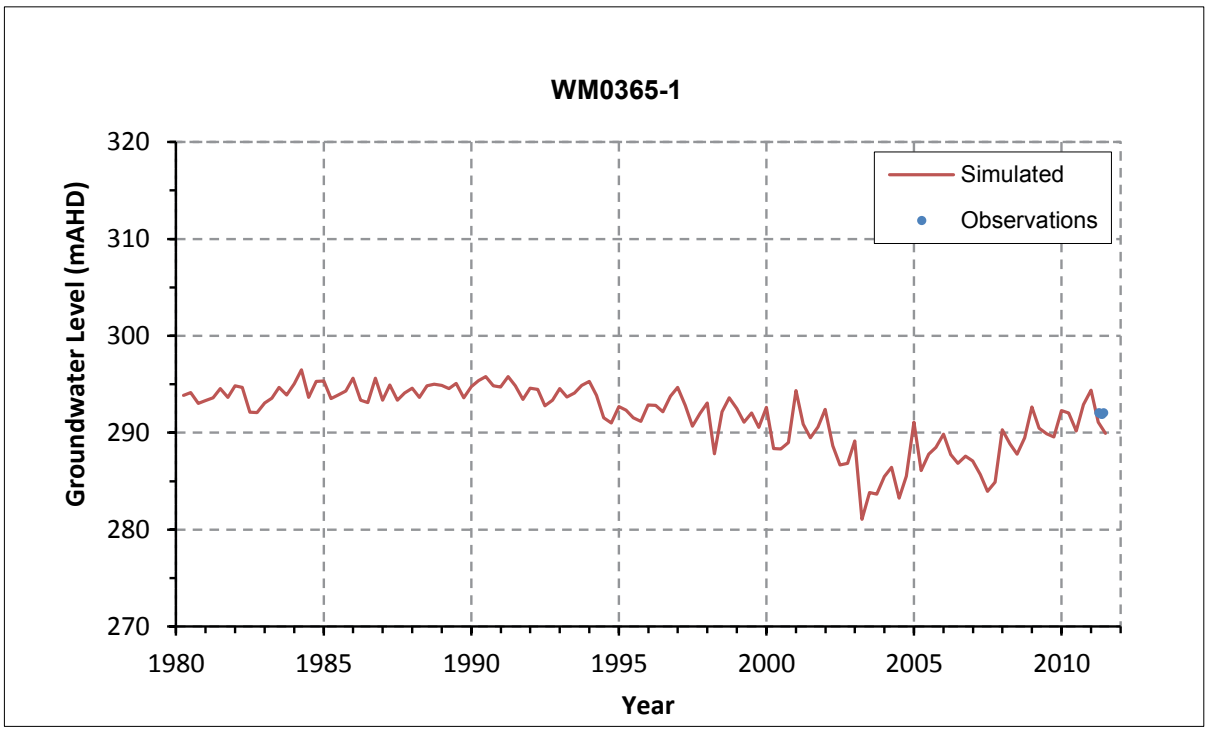

WM0105-1
Groundwater Level (mAHD)
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310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

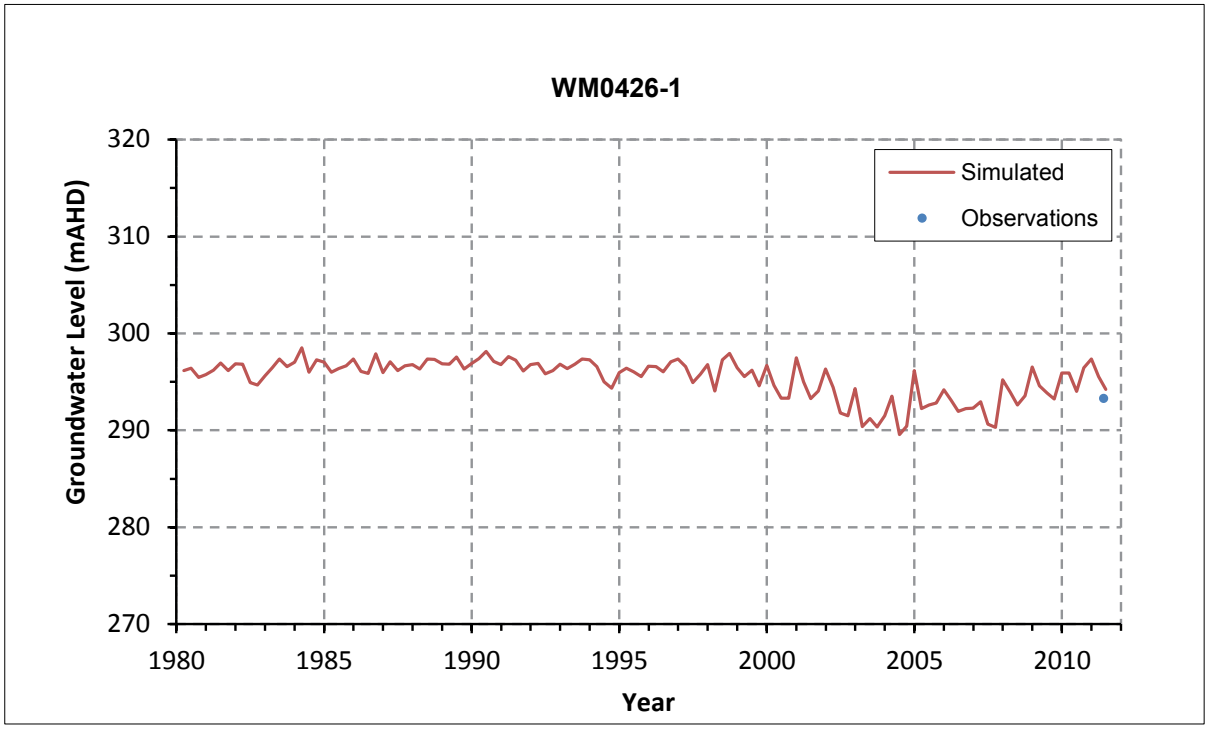

WM0105-2
Groundwater Level (mAHD)
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310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

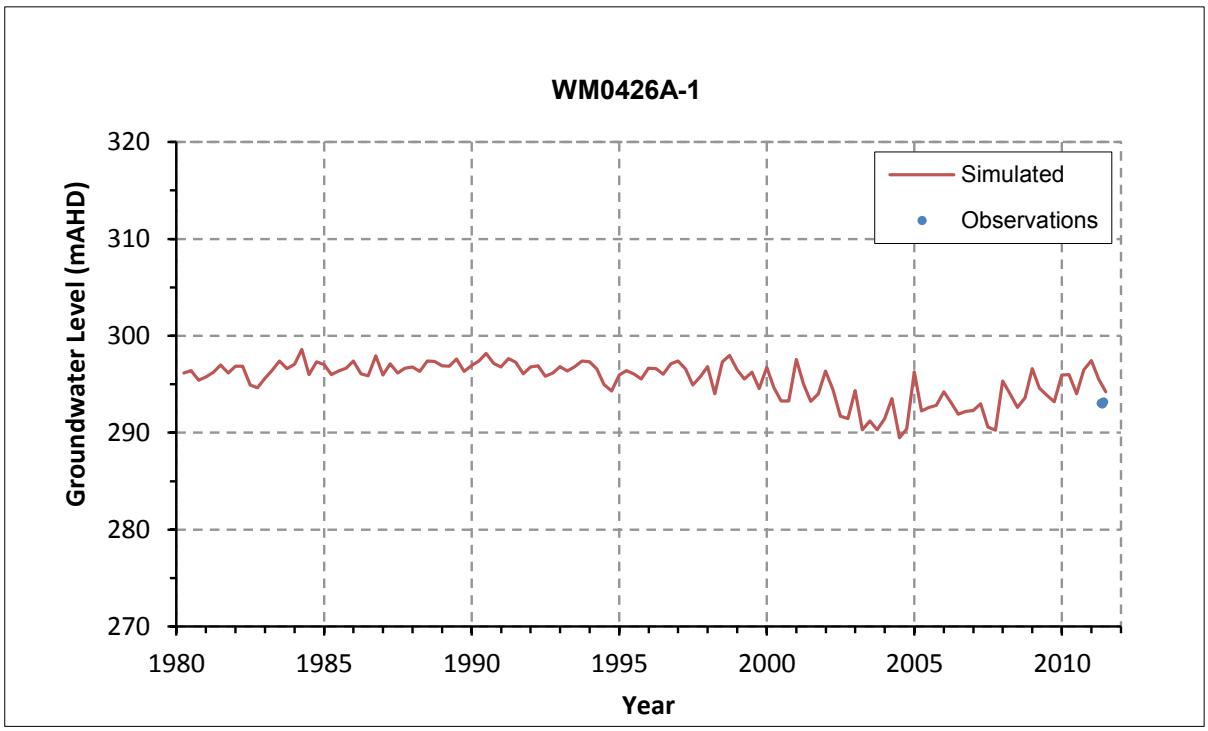

WM0350-1
Groundwater Level (mAHD)
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310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

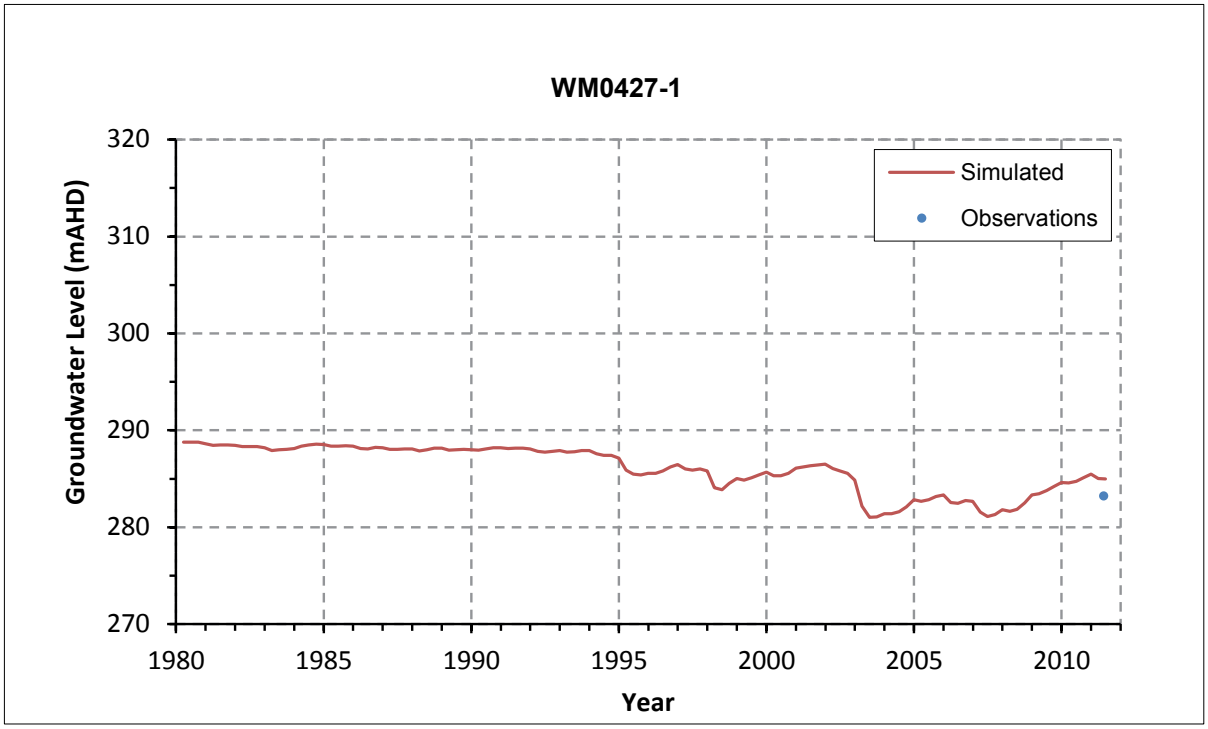

WM0350-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

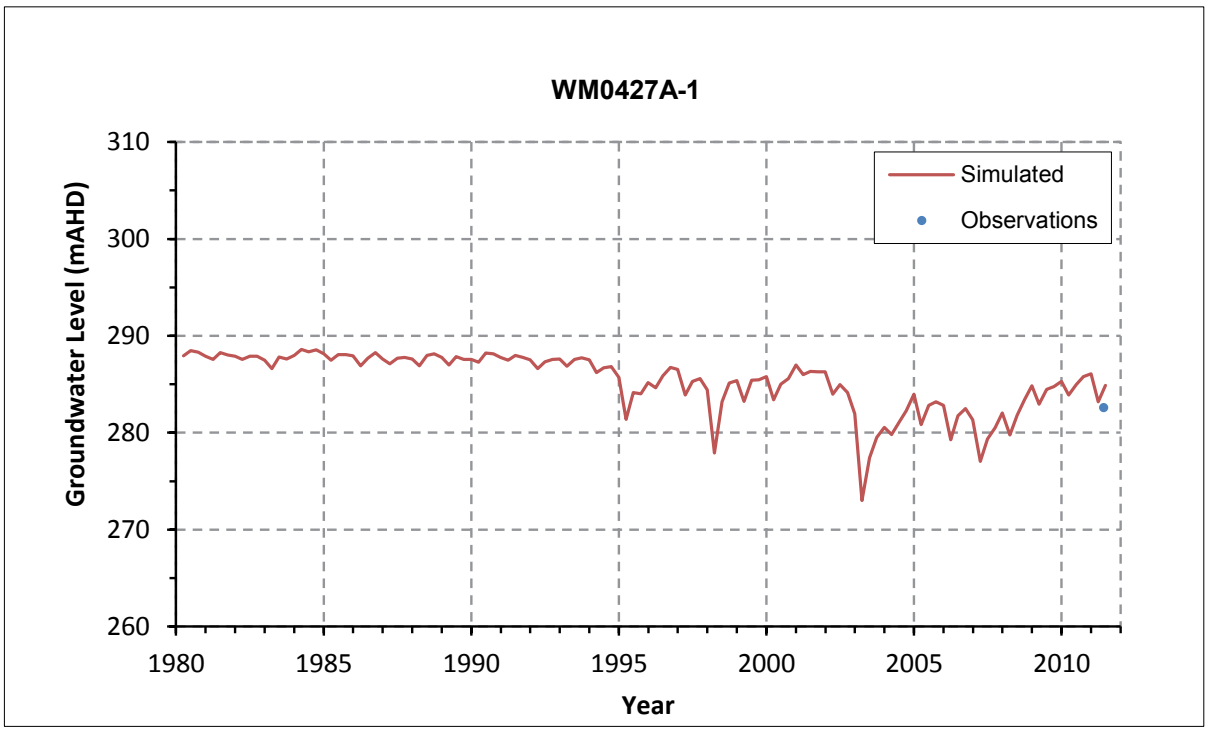

WM0350-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

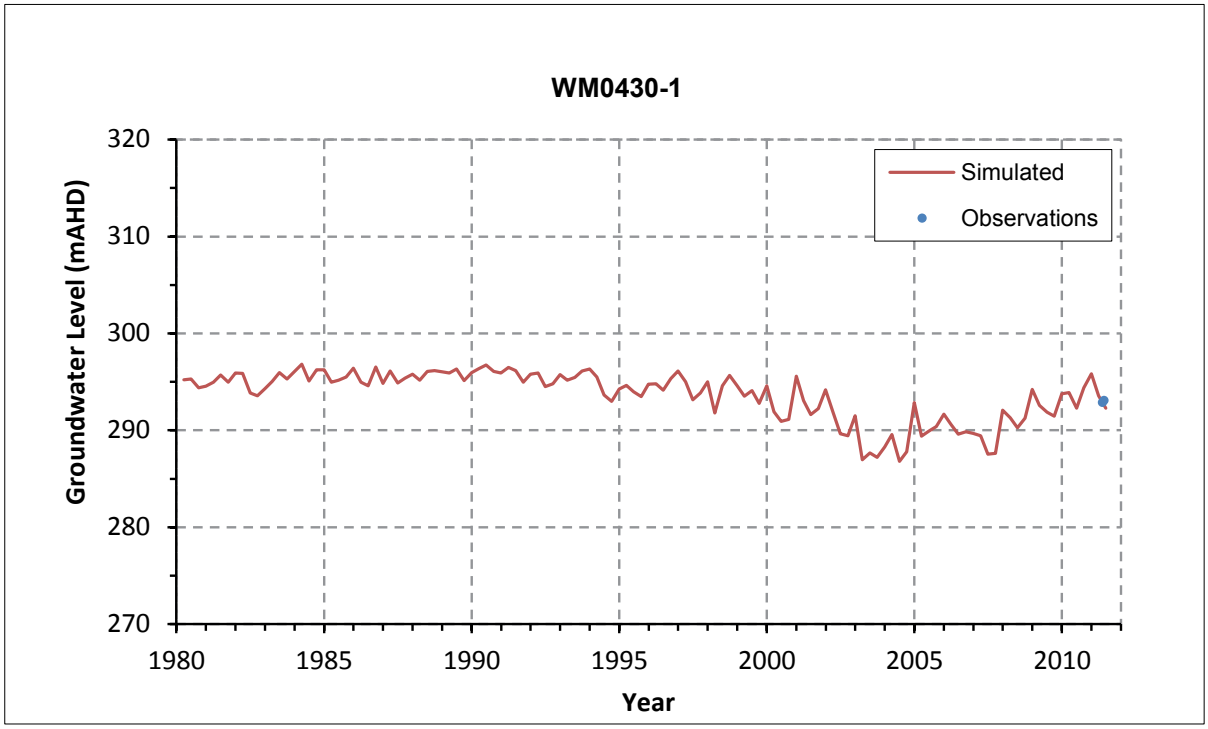

WM0365-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

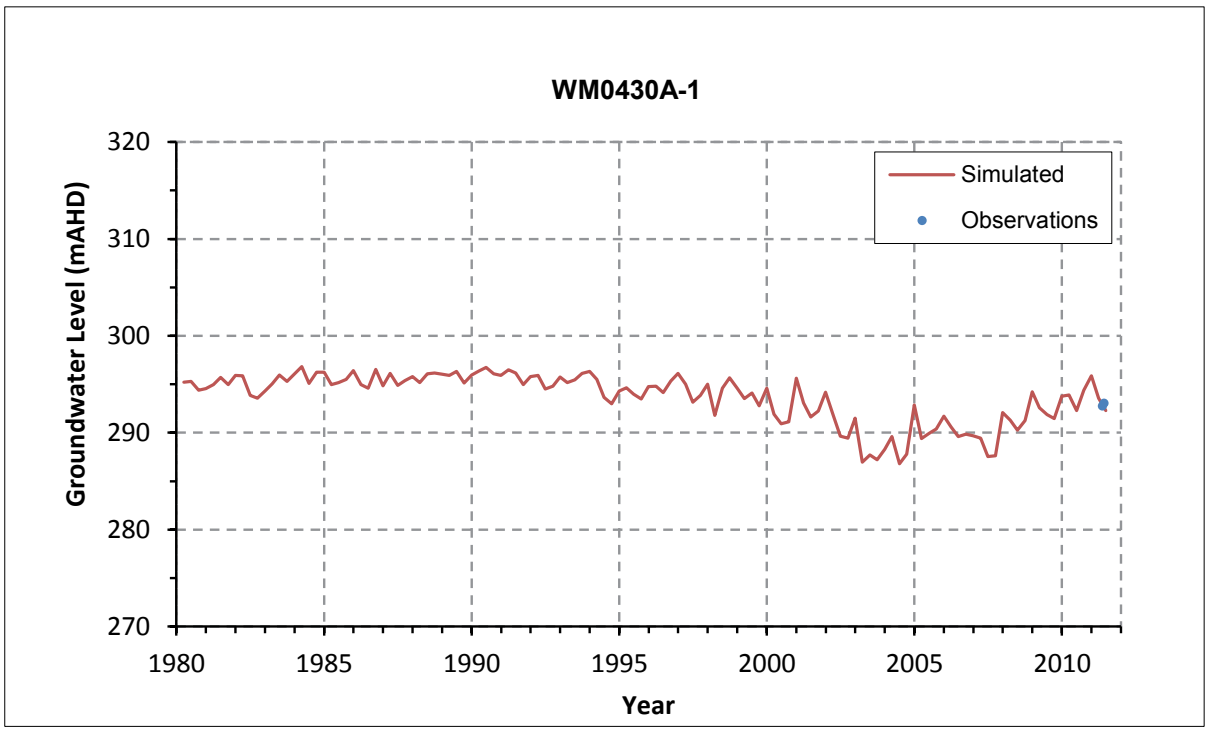

WM0426-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

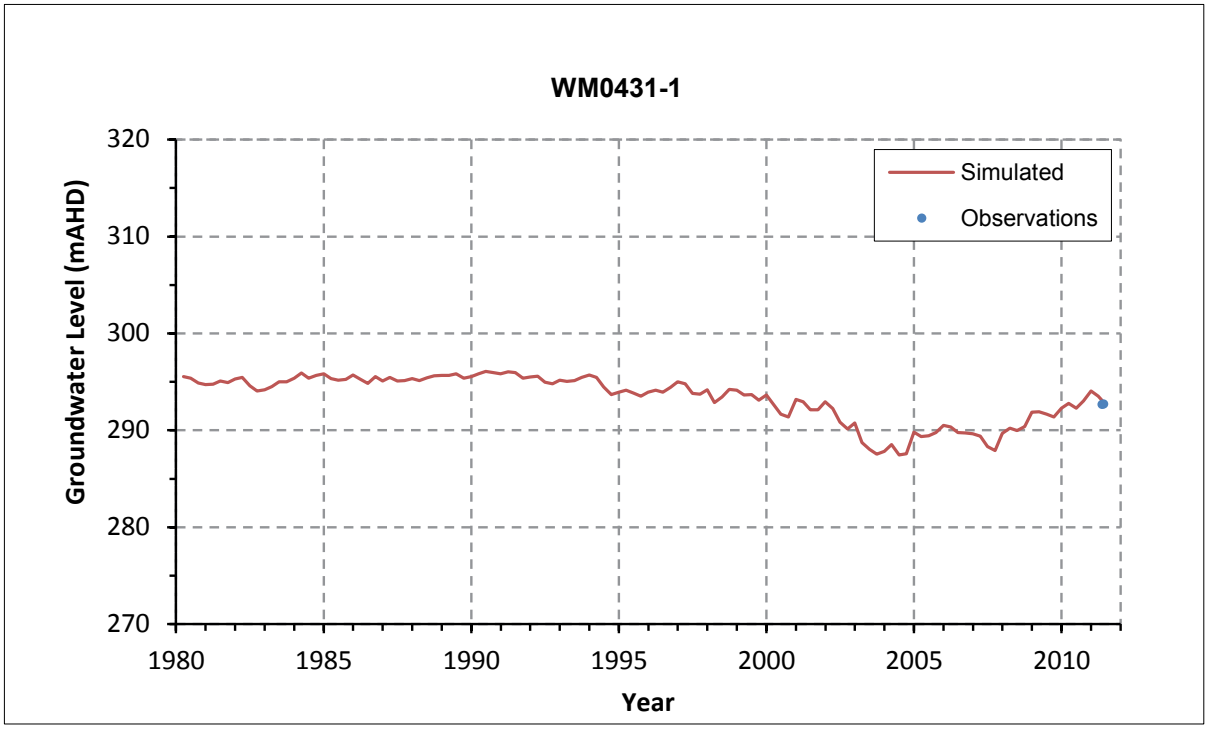

WM0426A-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

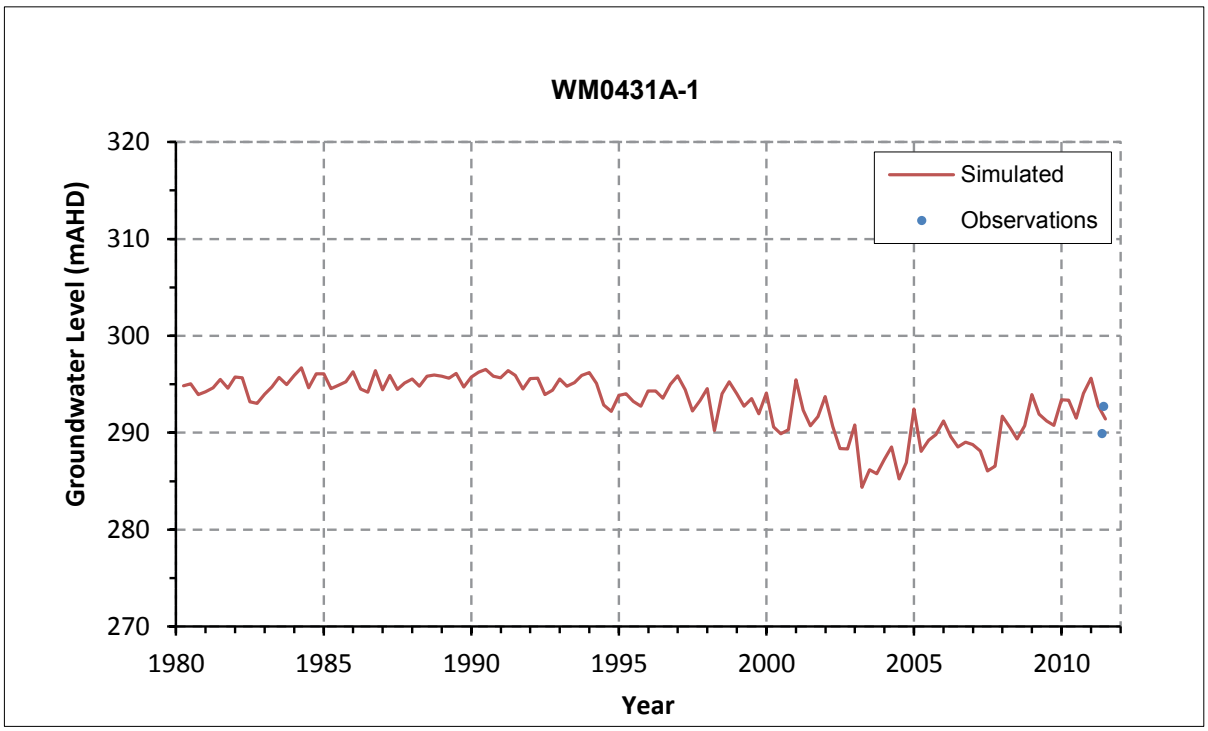

WM0427-1
Groundwater Level (mAHD)
320
310
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290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

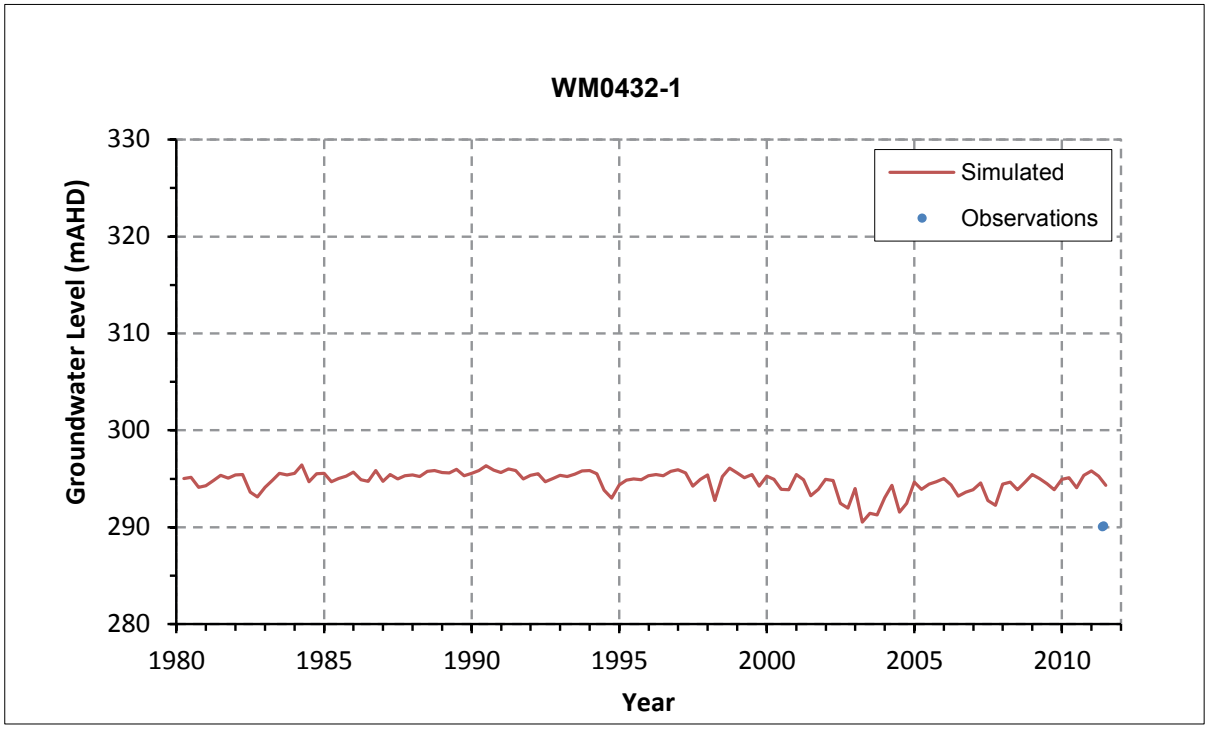

WM0427A-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

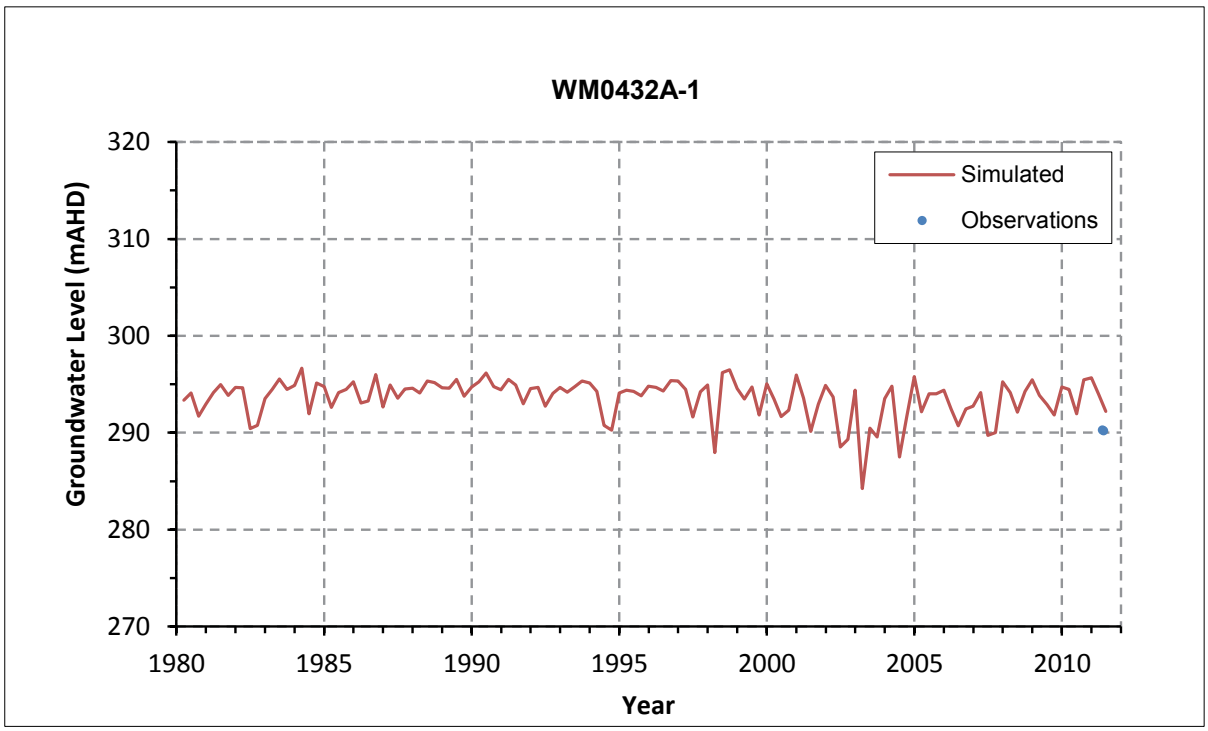

WM0430-1
Groundwater Level (mAHD)
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280
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1980
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2005
2010
Year
Simulated
Observations

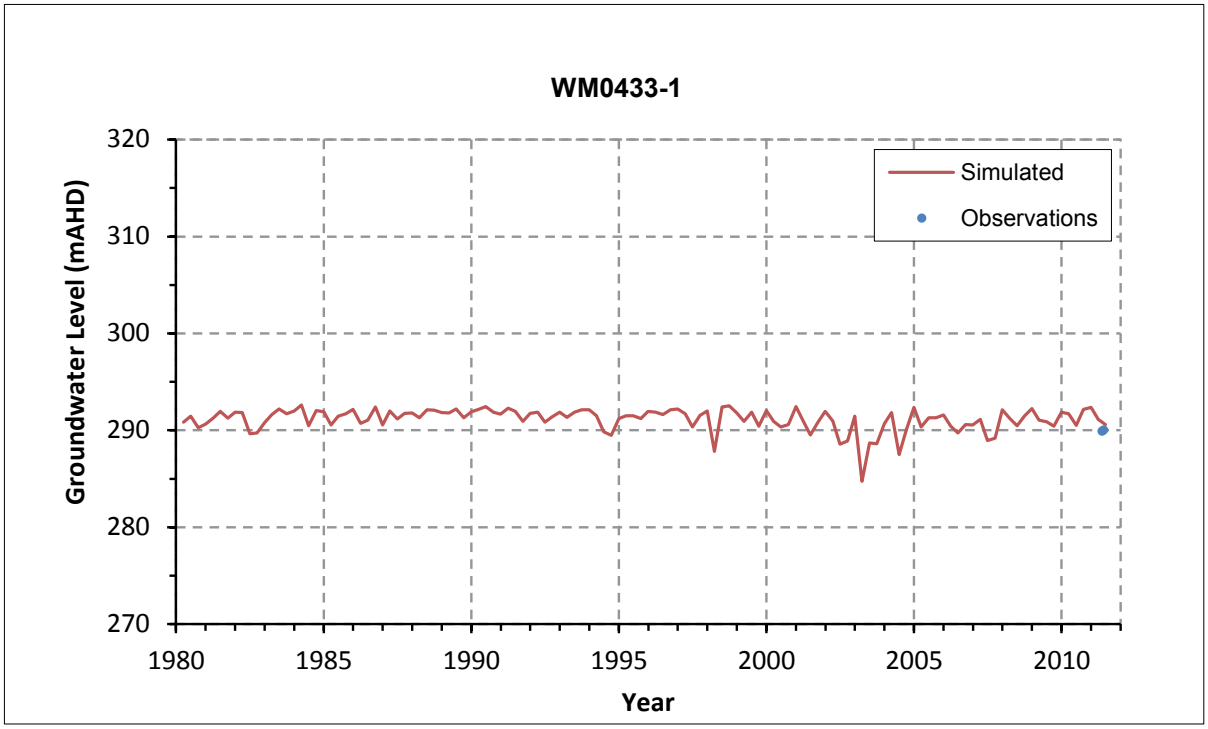

WM0430A-1
Groundwater Level (mAHD)
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2005
2010
Year
Simulated
Observations

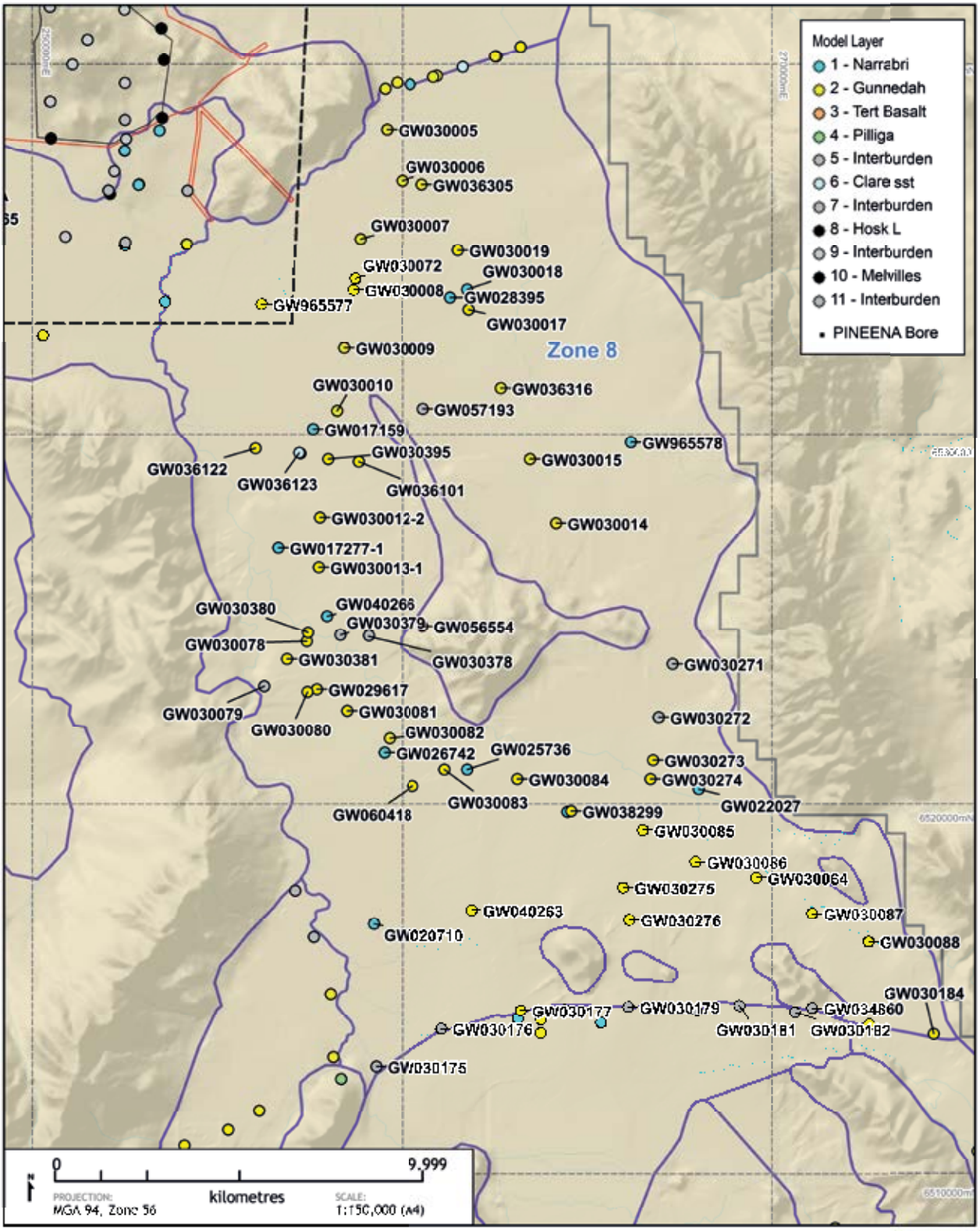

WM0431-1
Groundwater Level (mAHD)
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1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0431A-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0432-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0432A-1
Groundwater Level (mAHD)
320
310
300
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280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0433-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations



LEGEND

- Groundwater Management Zone
- Proposed Mining Area
- EL 7228
- Project Boundary
- PINEENA Bore

Watermark Coal Project (G1501)
Groundwater Assessment

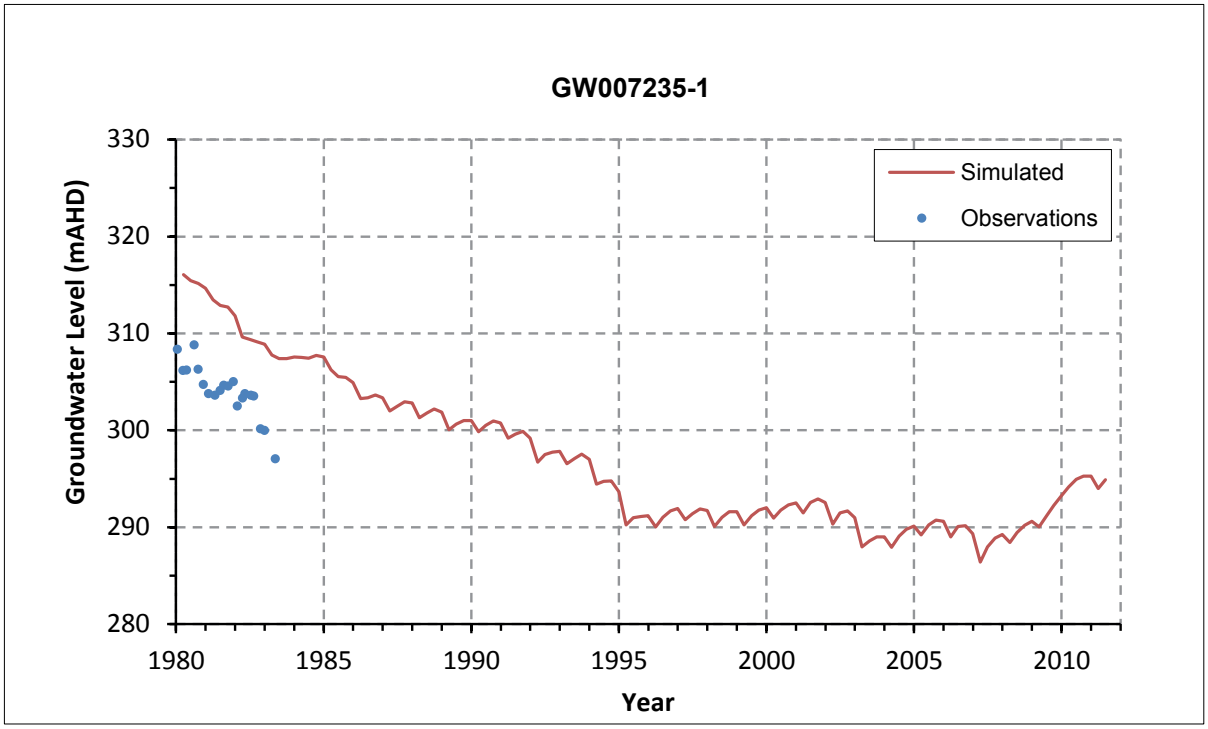
Groundwater Monitoring Bores: Shenhua and Pineena - Zone 8

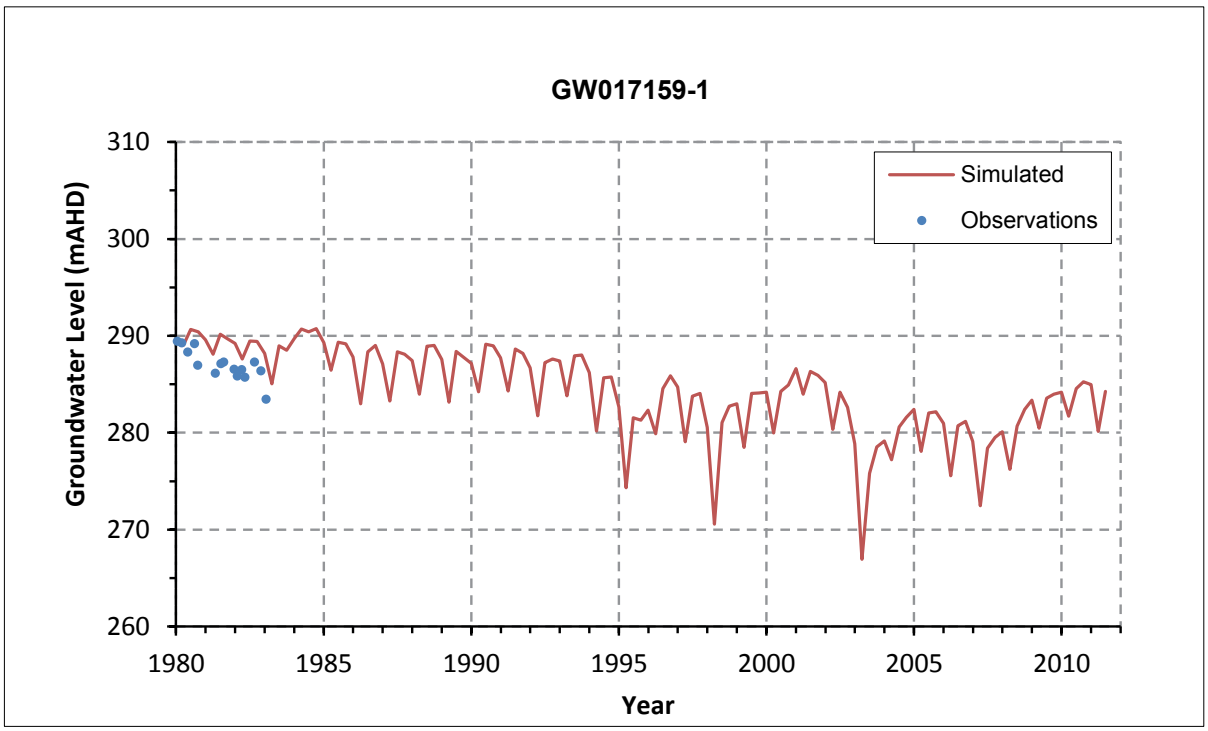
Source: NoW PINEENA Groundwater Database, 2011
GHD Groundwater Monitoring Database, 2011

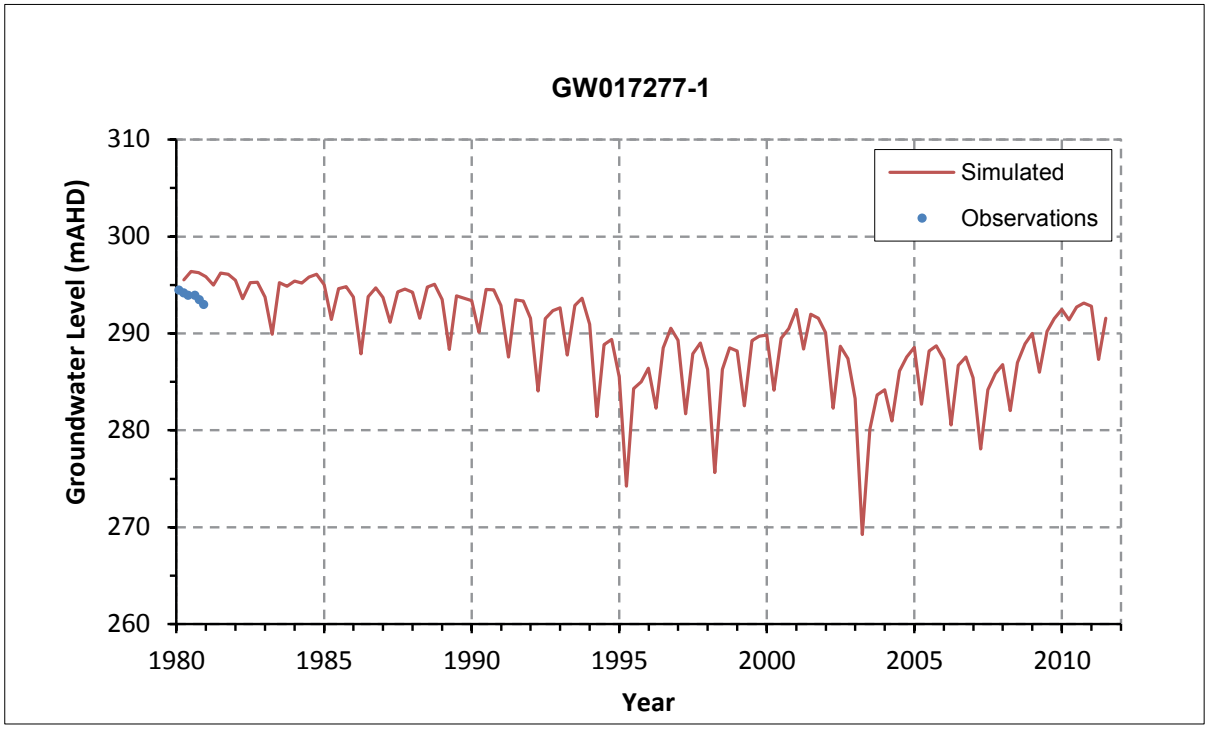
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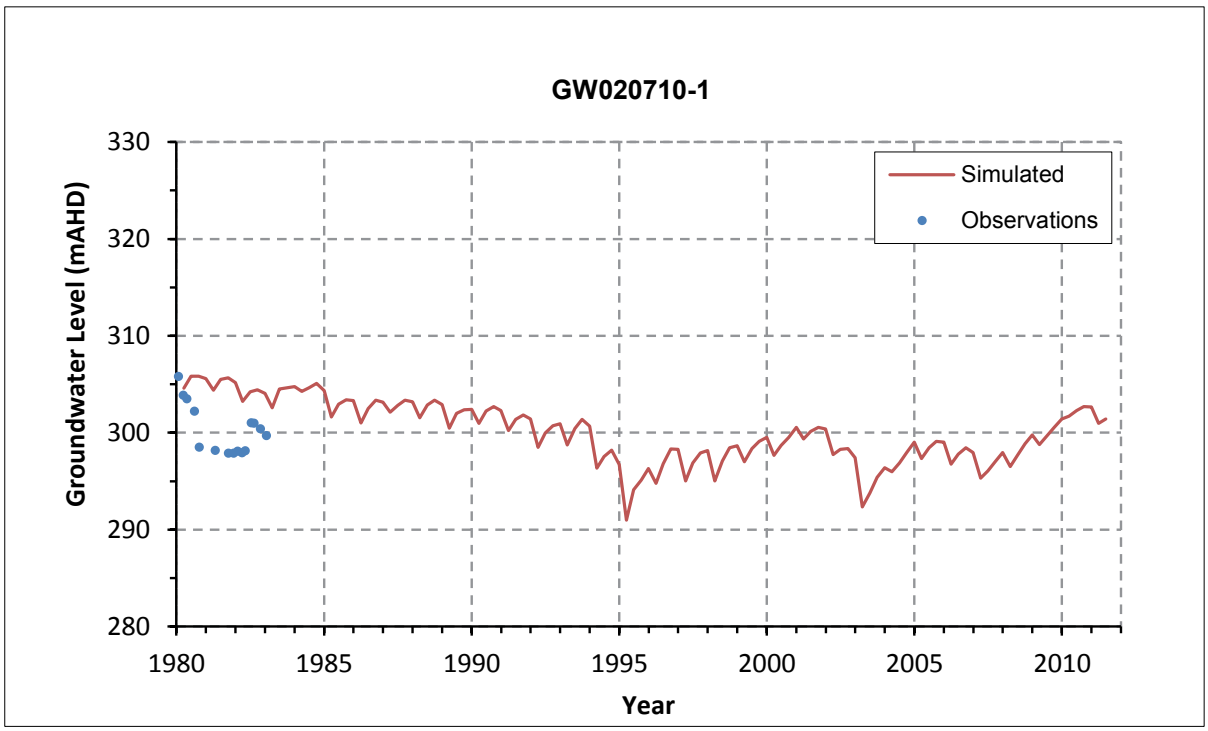
FIGURE No: **A.5**

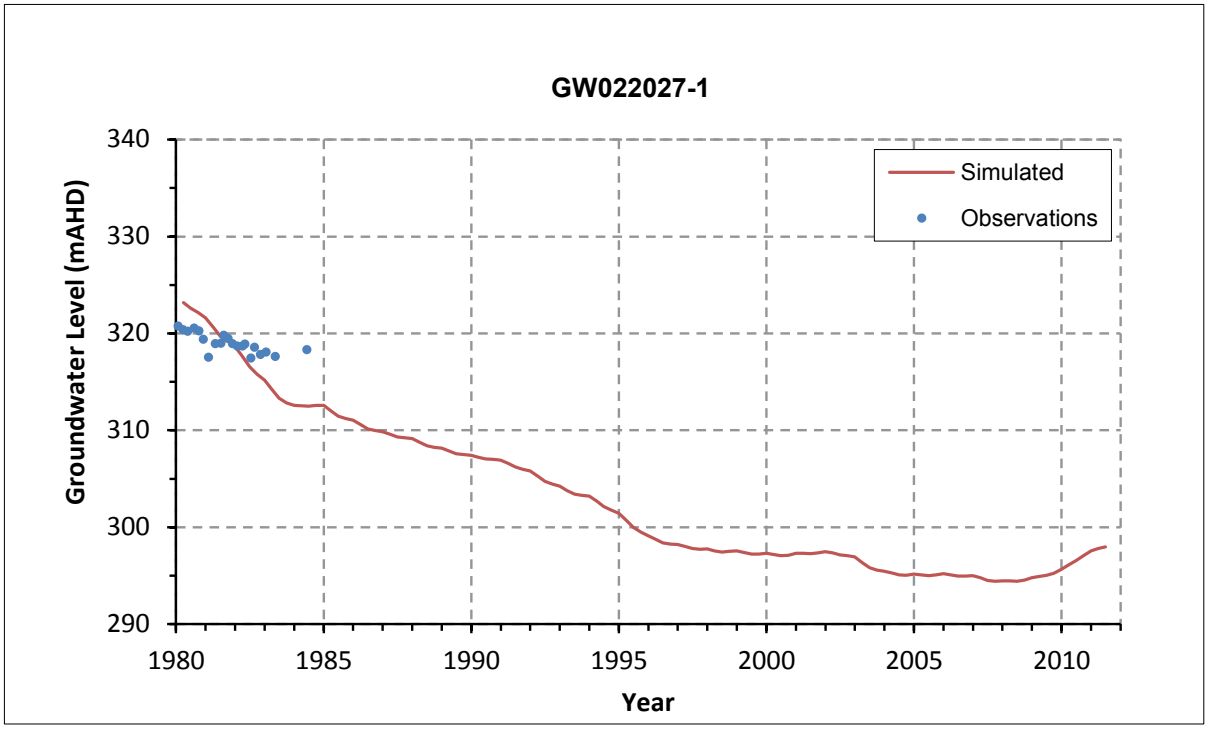
©2012 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

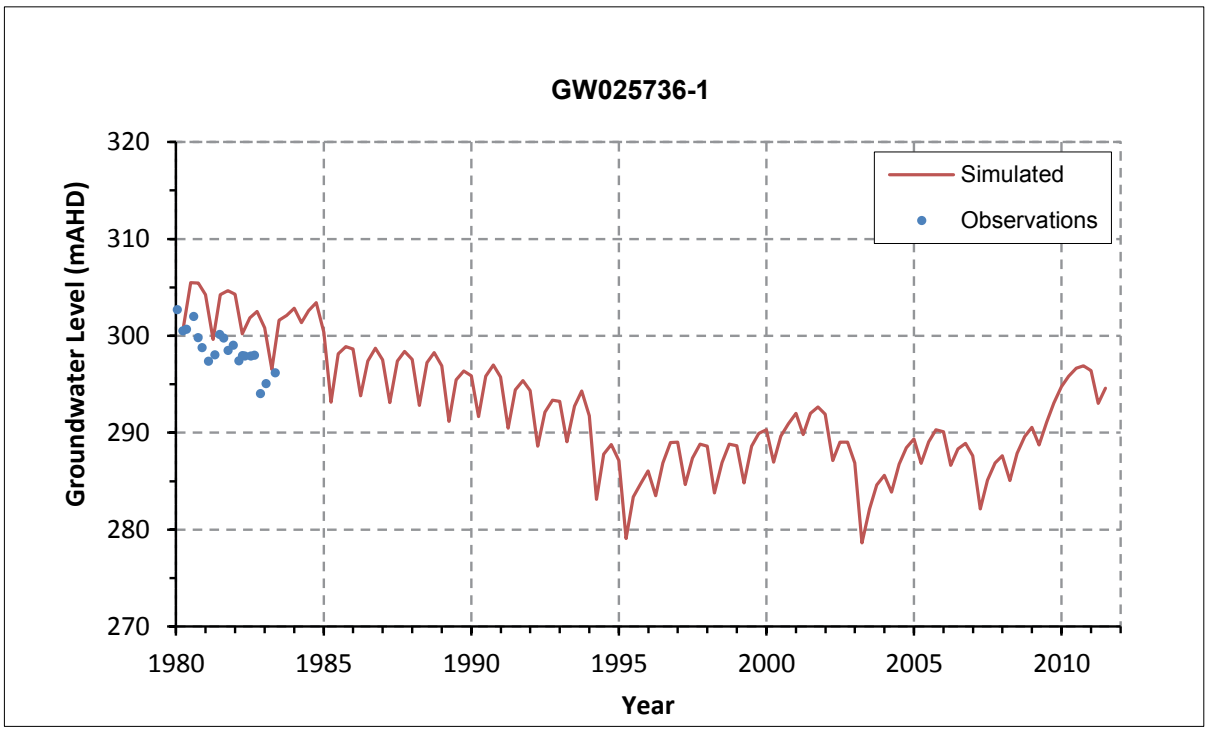

GW007235-1
Groundwater Level (mAHD)
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320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

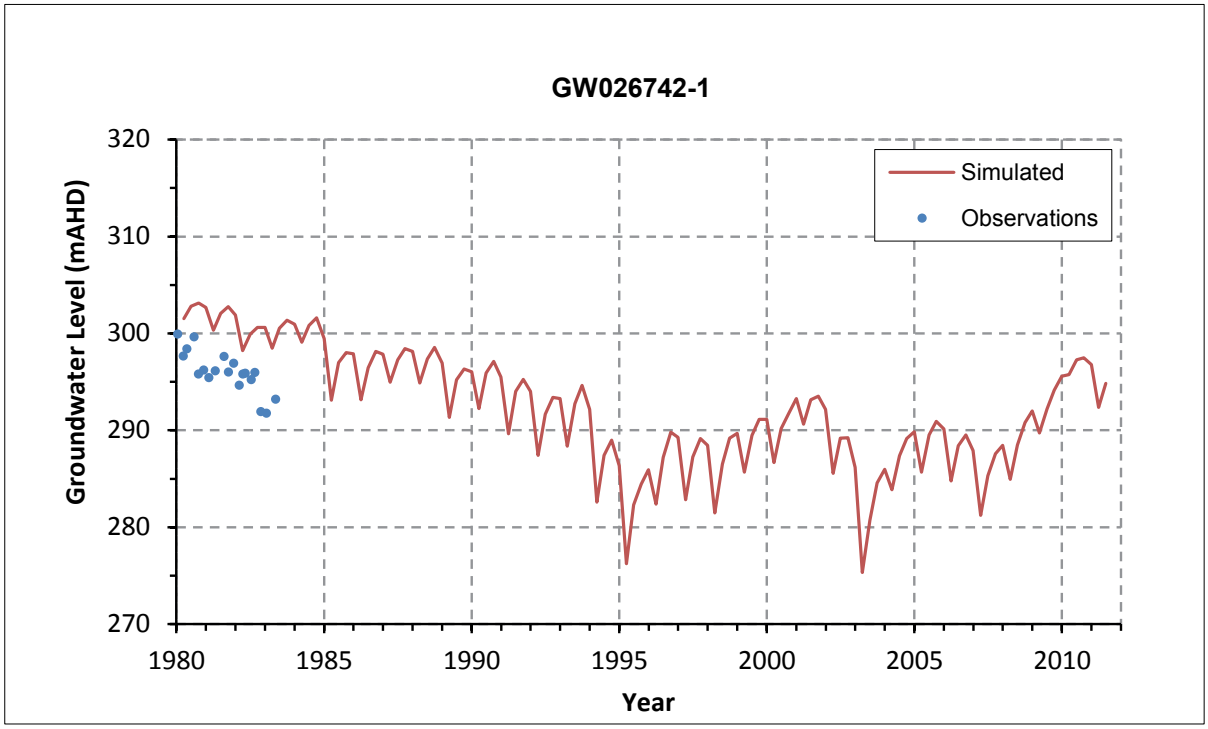

GW017159-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

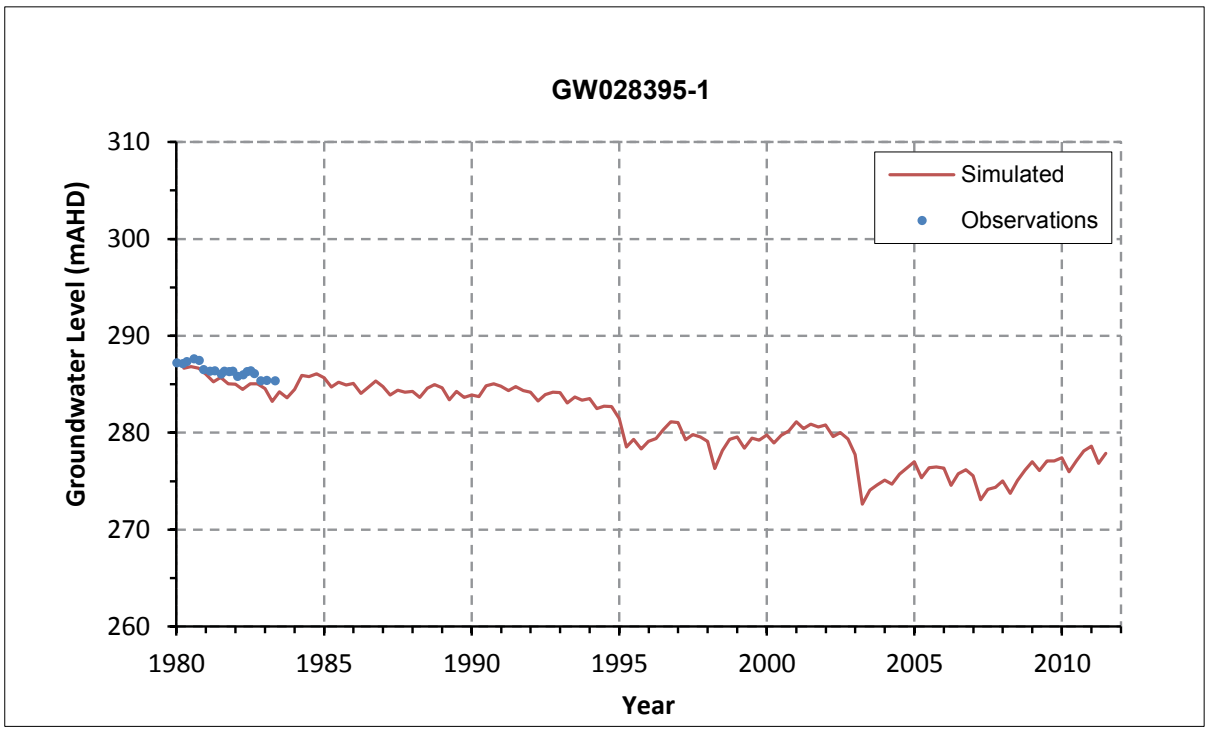

GW017277-1
Groundwater Level (mAHD)
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300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

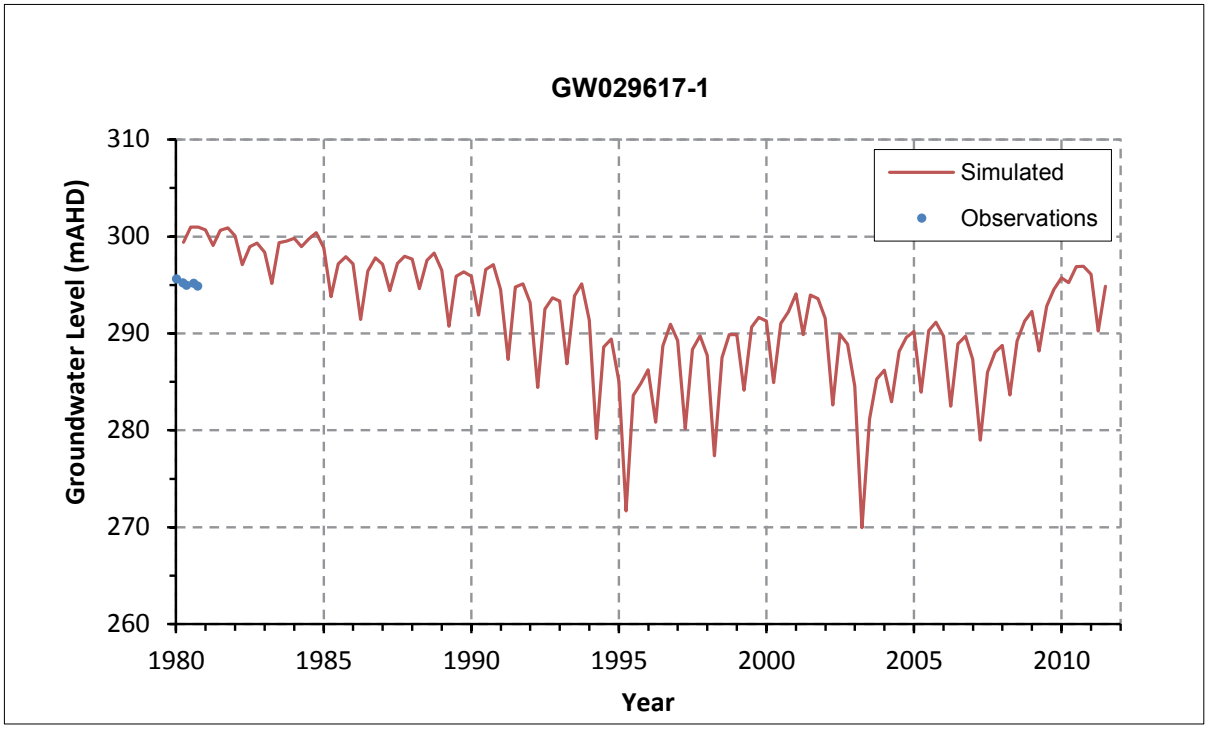

GW020710-1
Groundwater Level (mAHD)
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320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

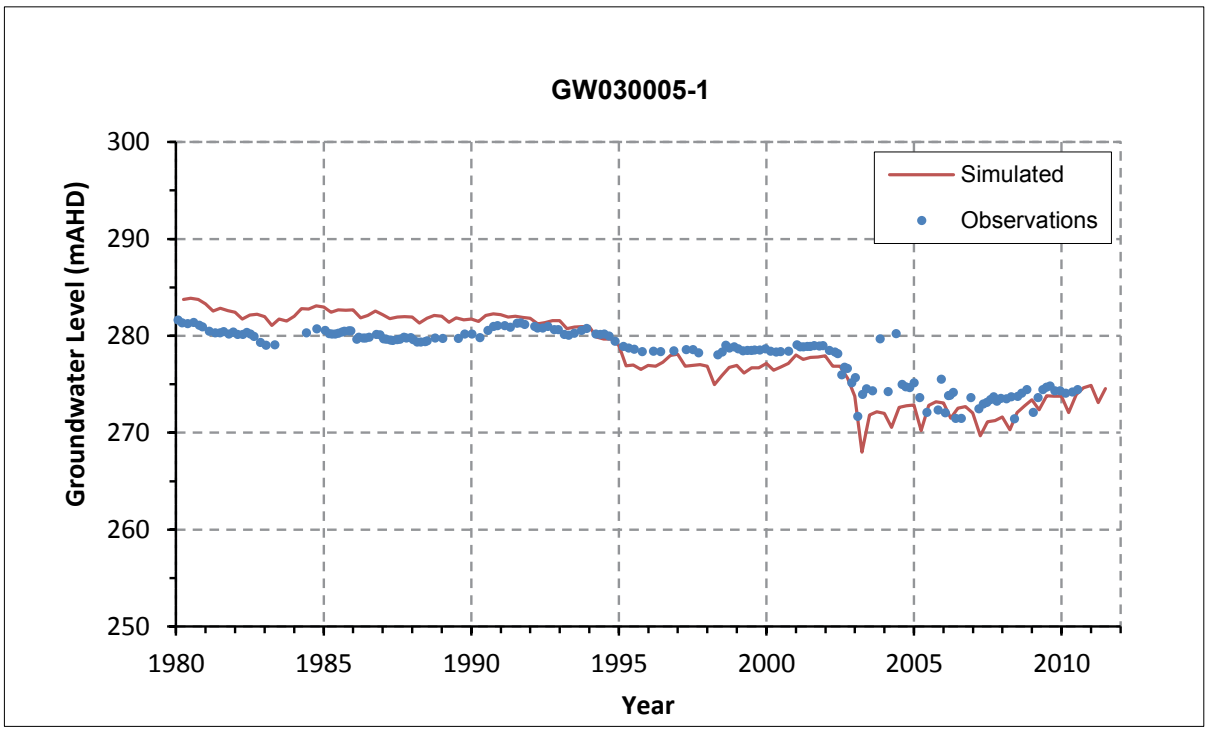

GW022027-1
Groundwater Level (mAHD)
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320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

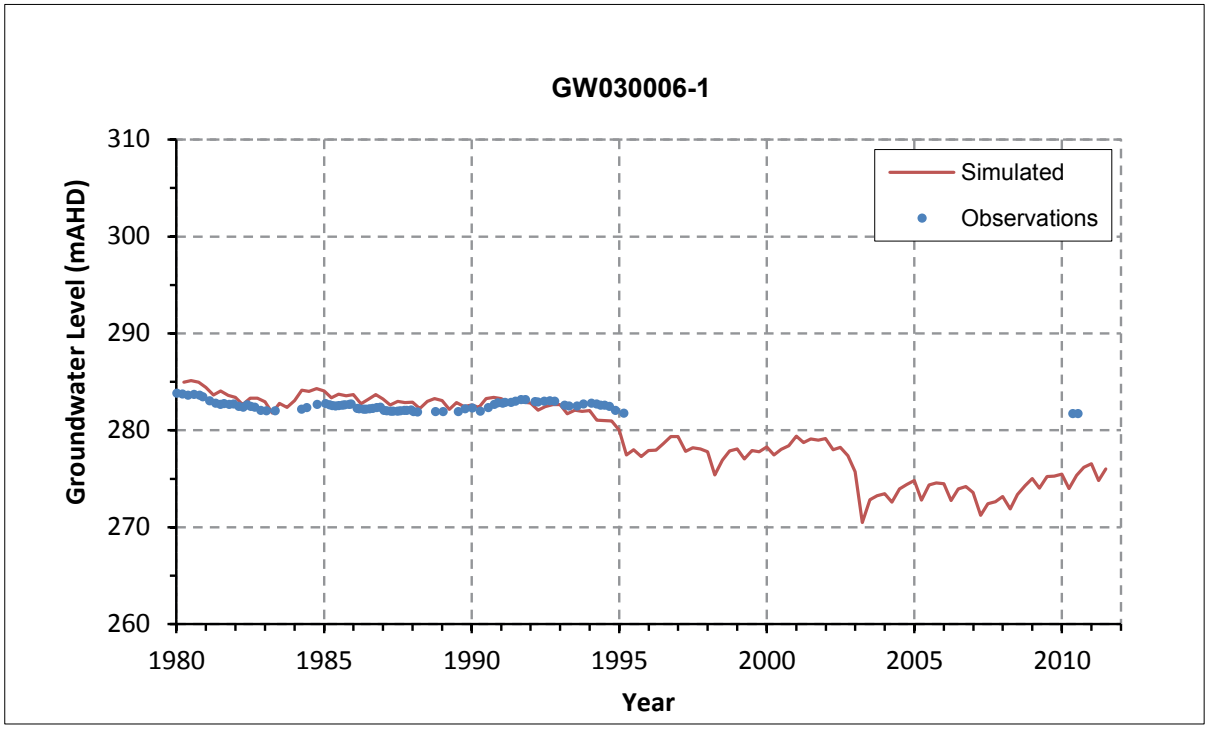

GW025736-1
Groundwater Level (mAHD)
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290
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1995
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2005
2010
Year
Simulated
Observations

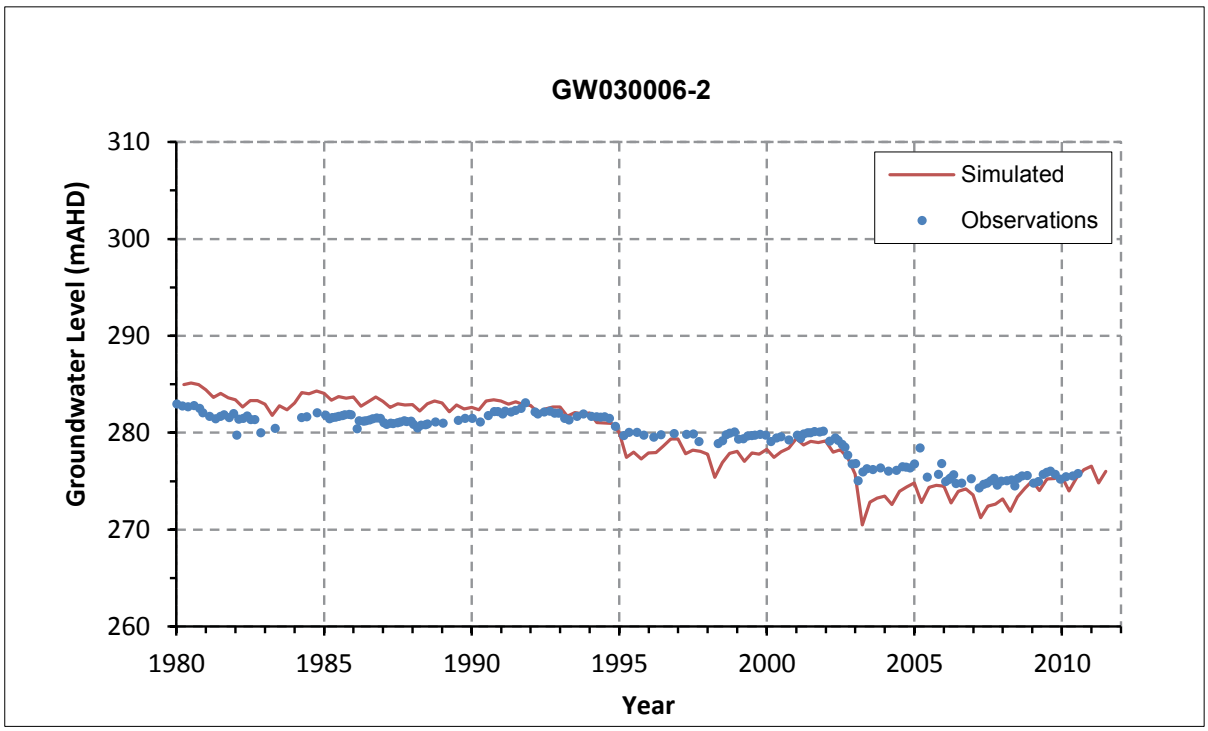

GW026742-1
Groundwater Level (mAHD)
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2005
2010
Year
Simulated
Observations

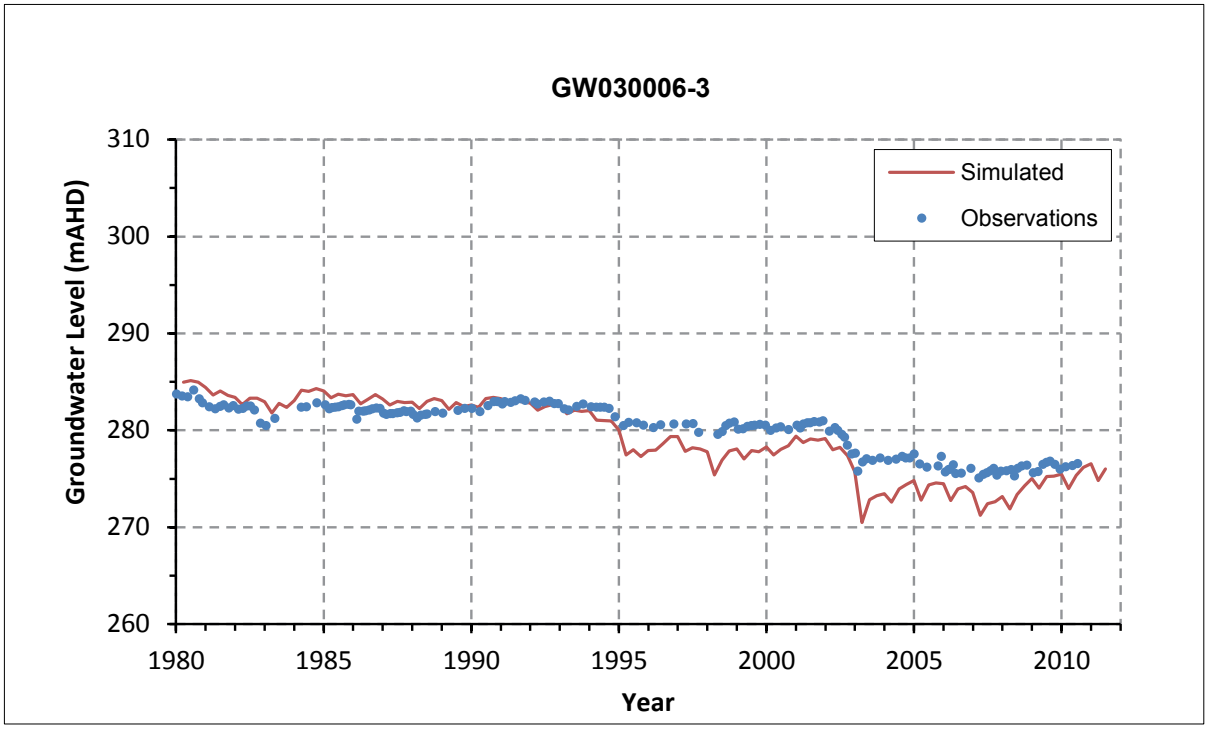

GW028395-1
Groundwater Level (mAHD)
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260
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1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

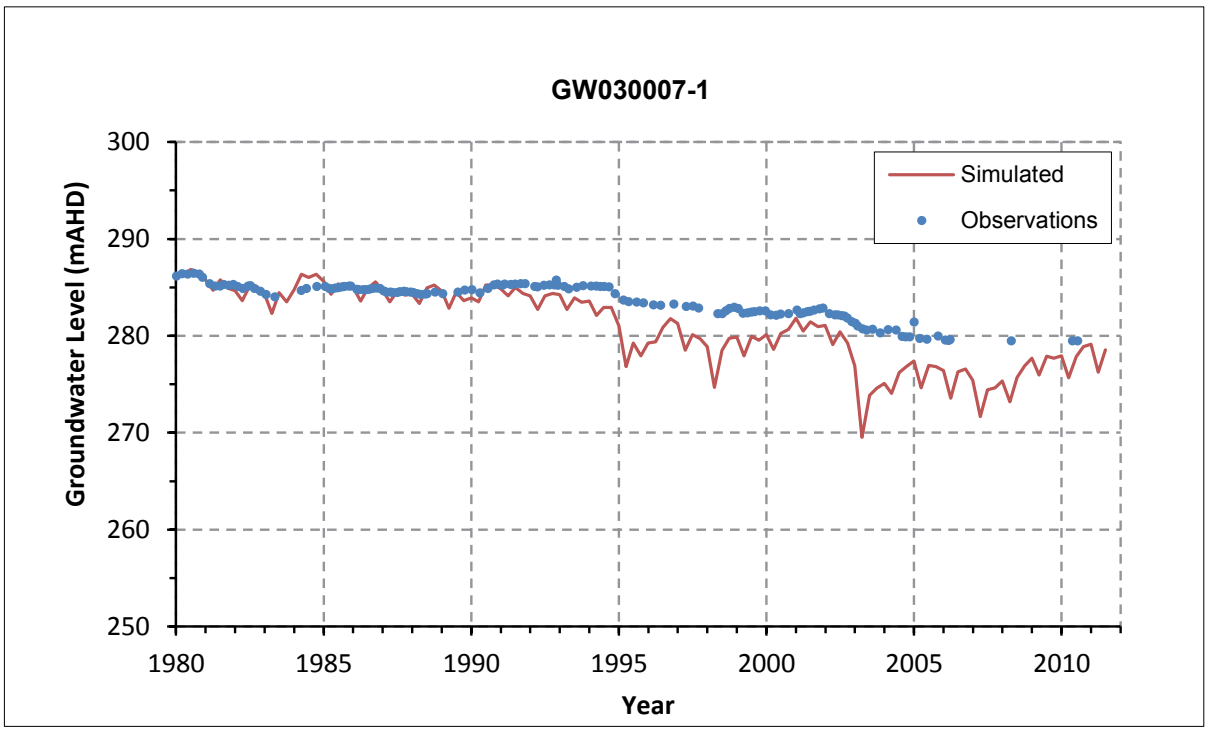

GW029617-1
Groundwater Level (mAHD)
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2000
2005
2010
Year
Simulated
Observations

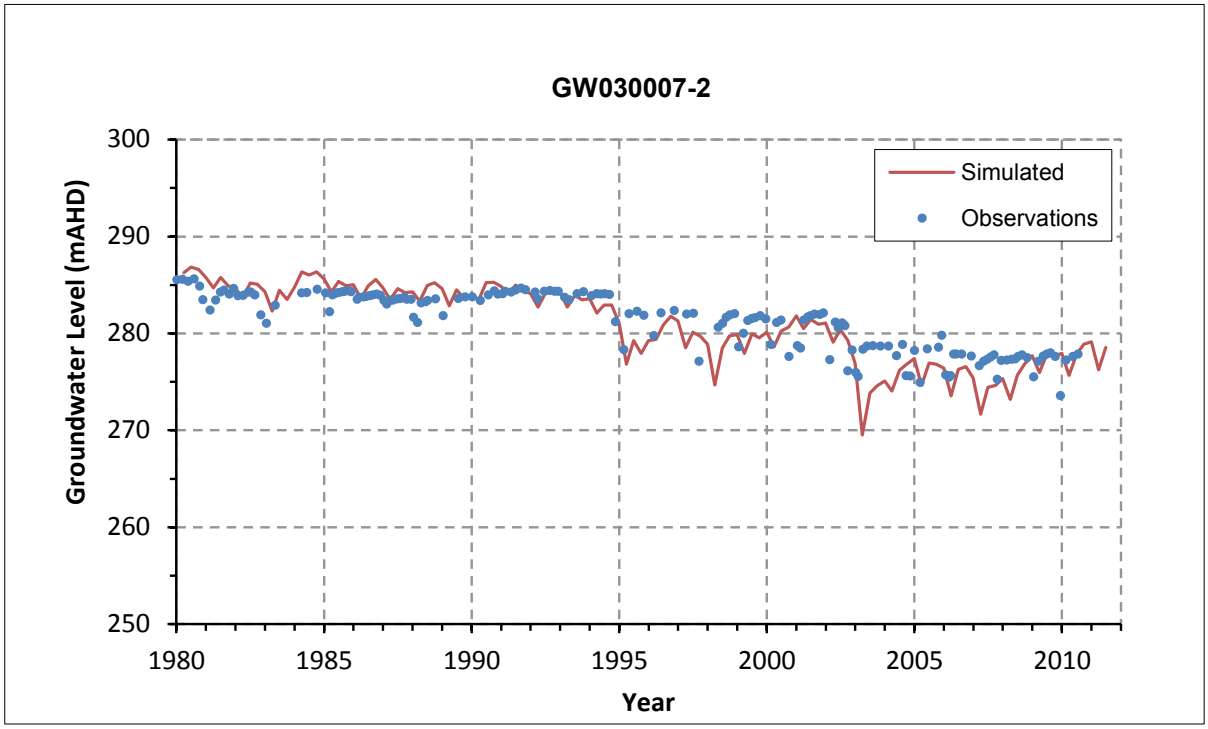

GW030005-1
Groundwater Level (mAHD)
300
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2005
2010
Year
Simulated
Observations

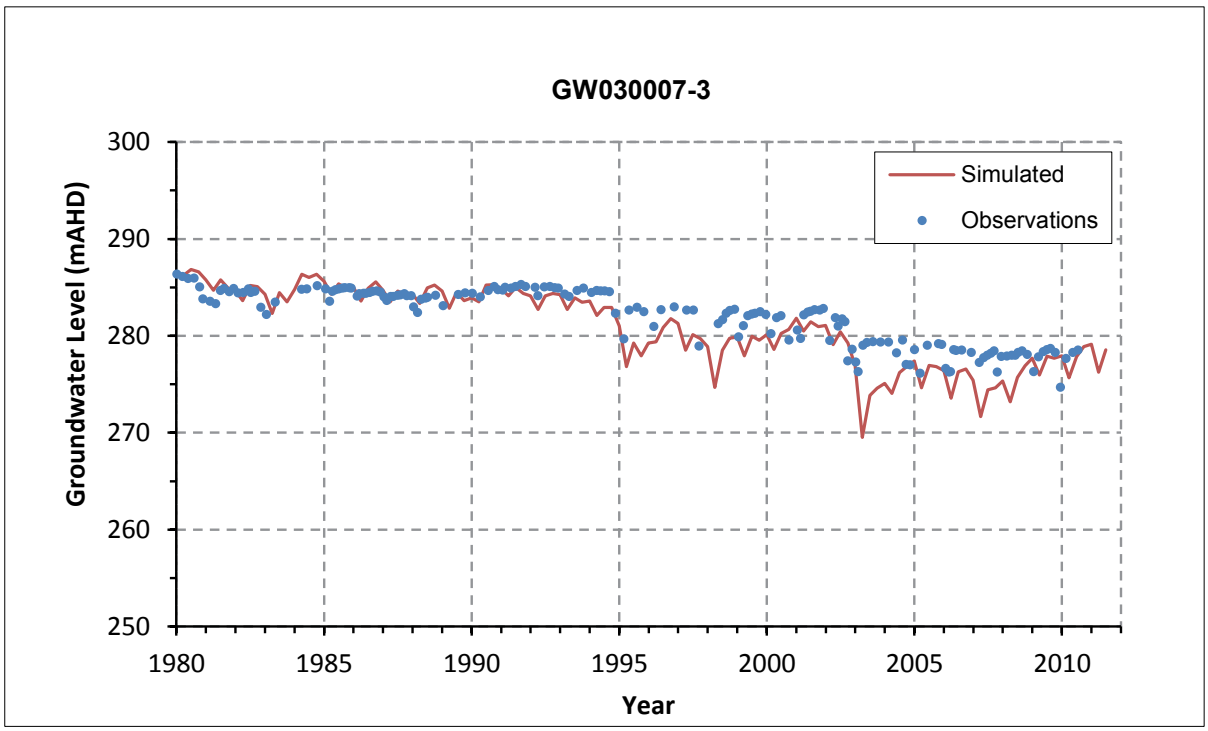

GW030006-1
Groundwater Level (mAHD)
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1980
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2010
Year
Simulated
Observations

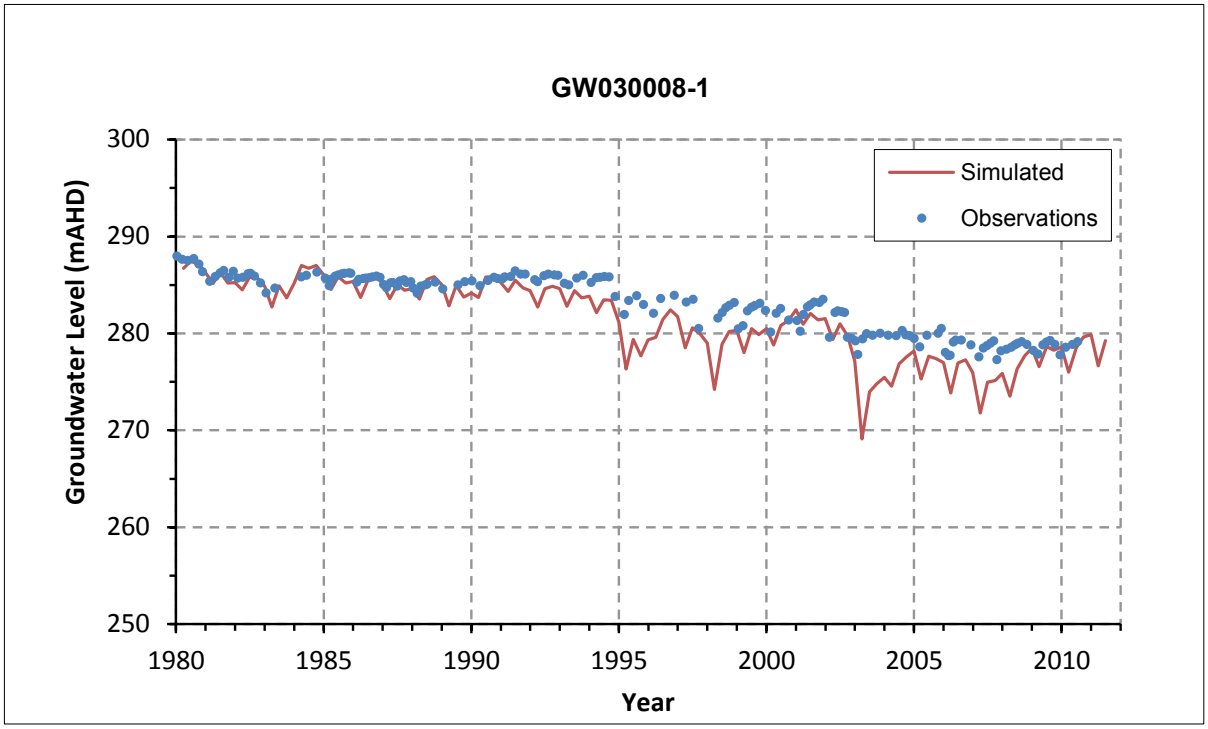

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2010
Year
Simulated
Observations

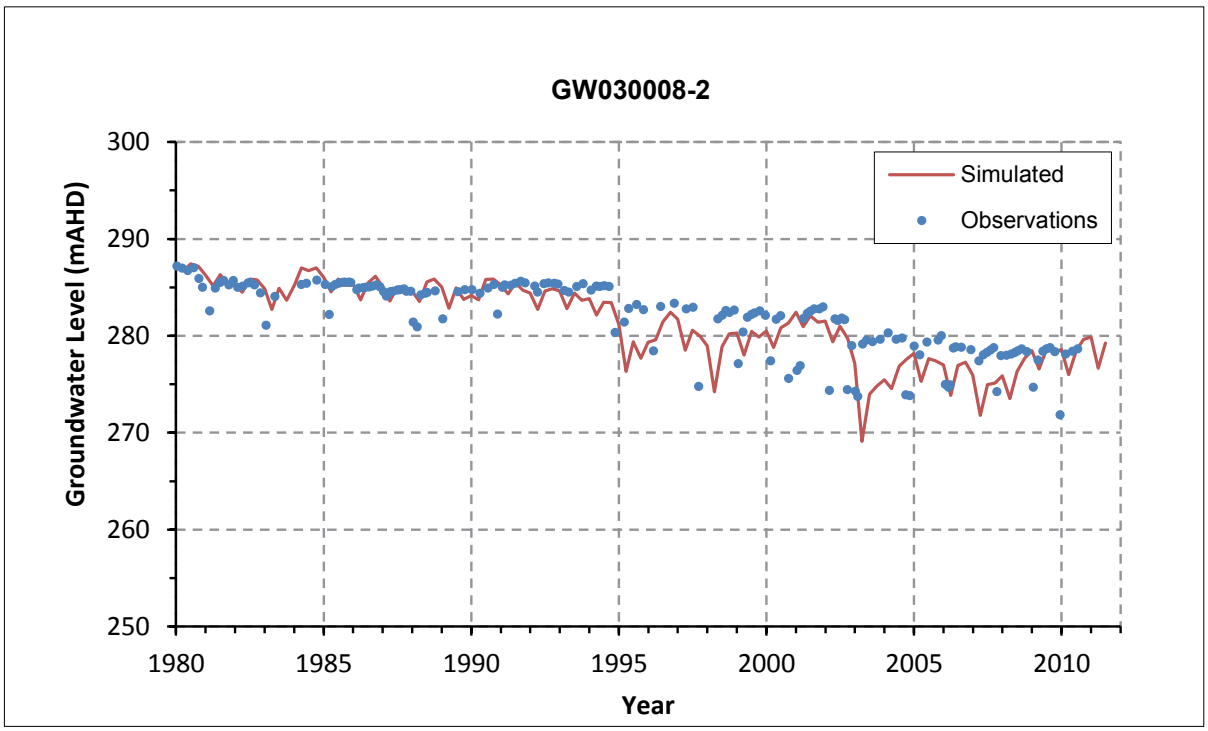

GW030006-3
Groundwater Level (mAHD)
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2010
Year
Simulated
Observations

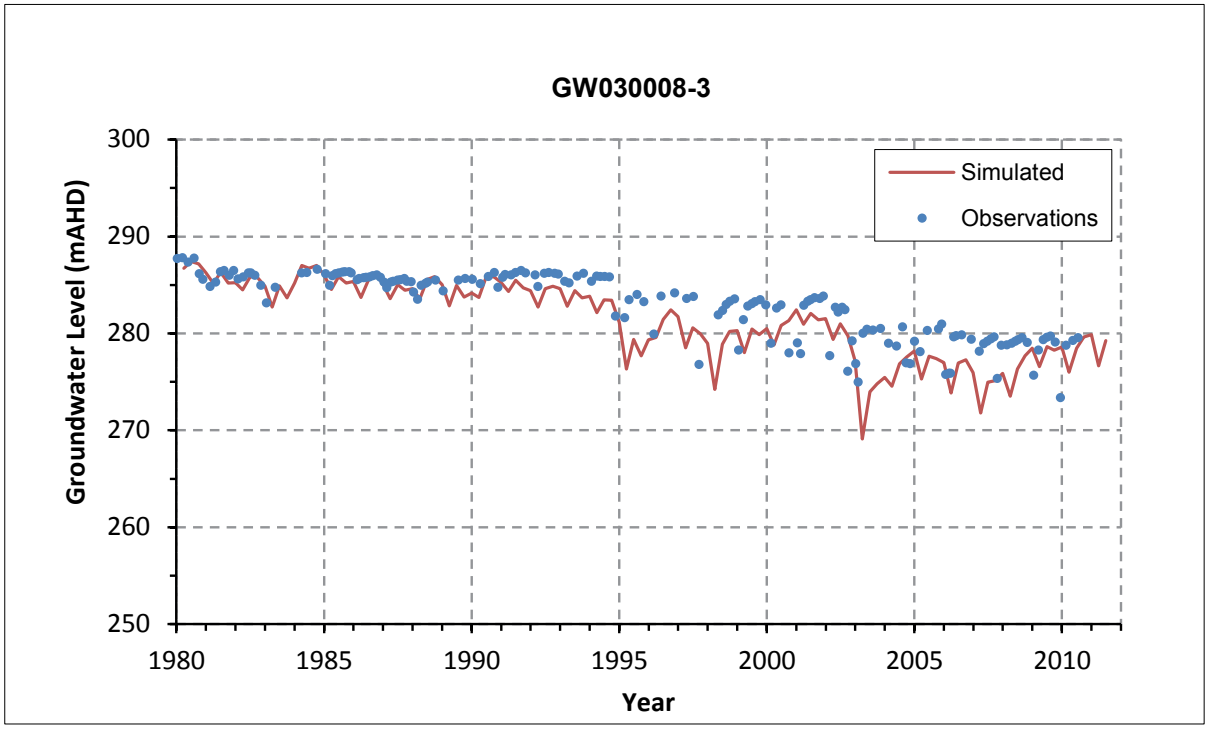

GW030007-1
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Year
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Observations

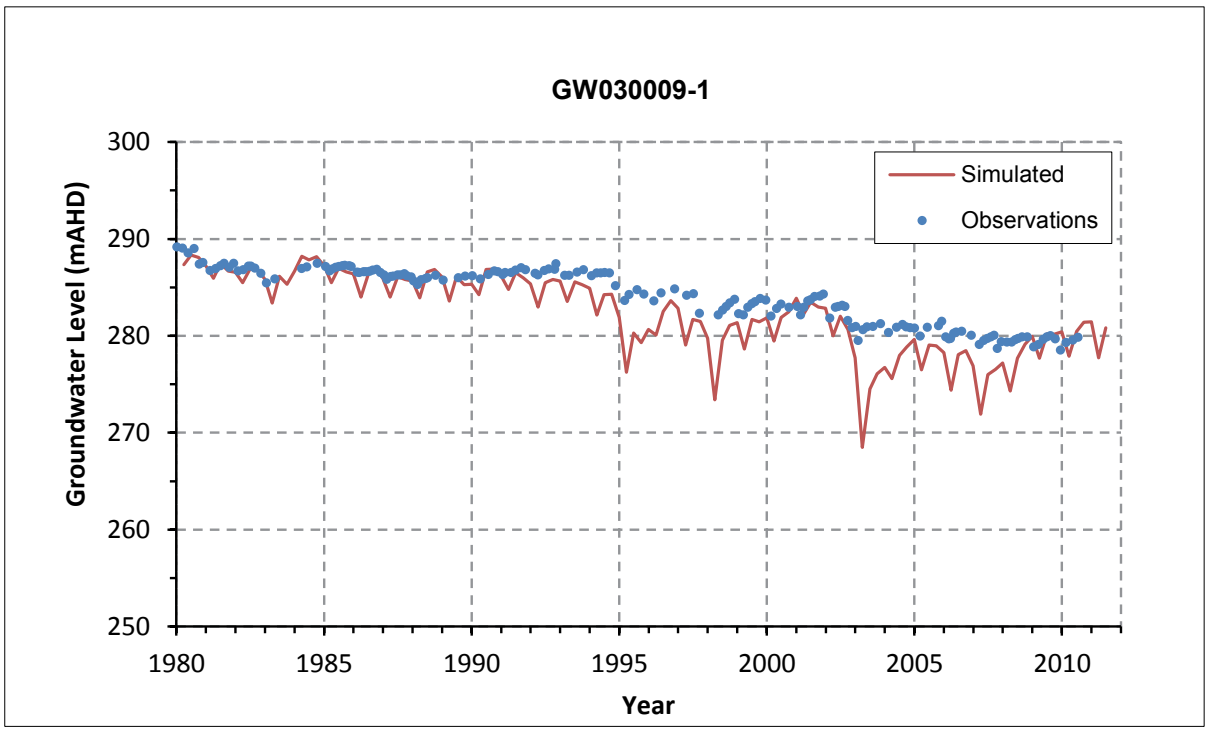

GW030007-2
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2010
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Observations

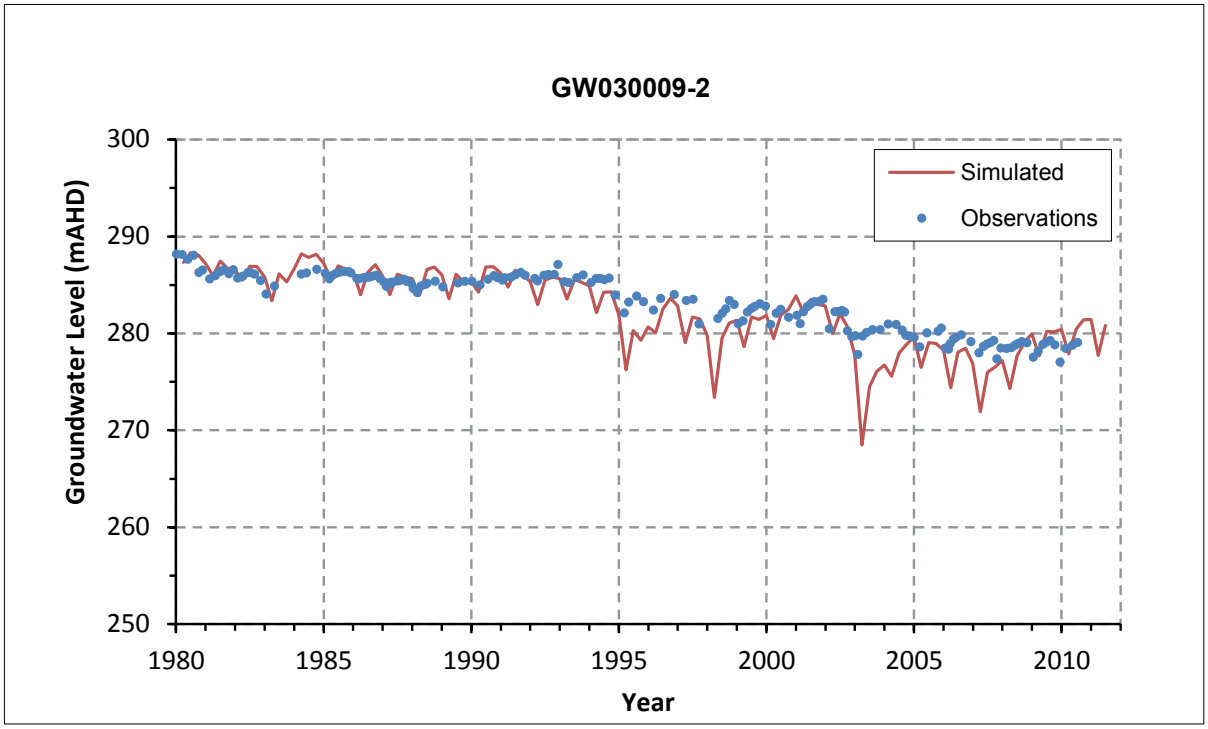

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Groundwater Level (mAHD)
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Year
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Observations

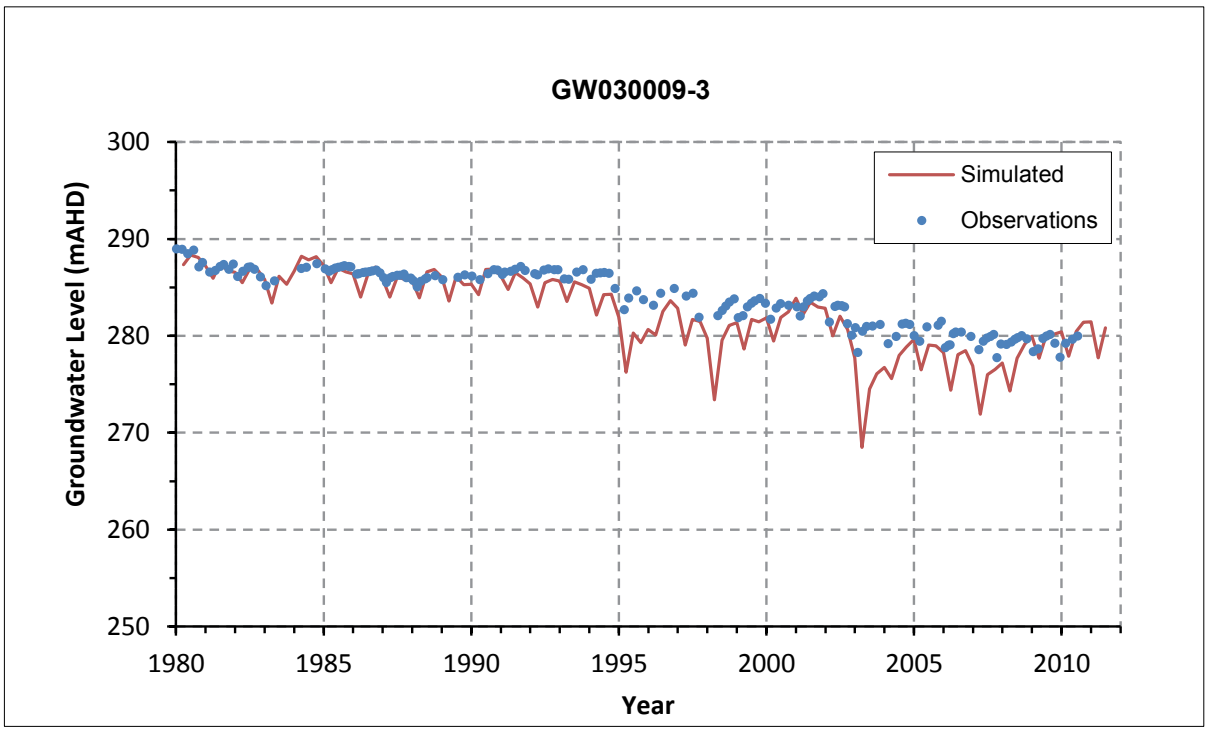

GW030008-1
Groundwater Level (mAHD)
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2000
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2010
Year
Simulated
Observations

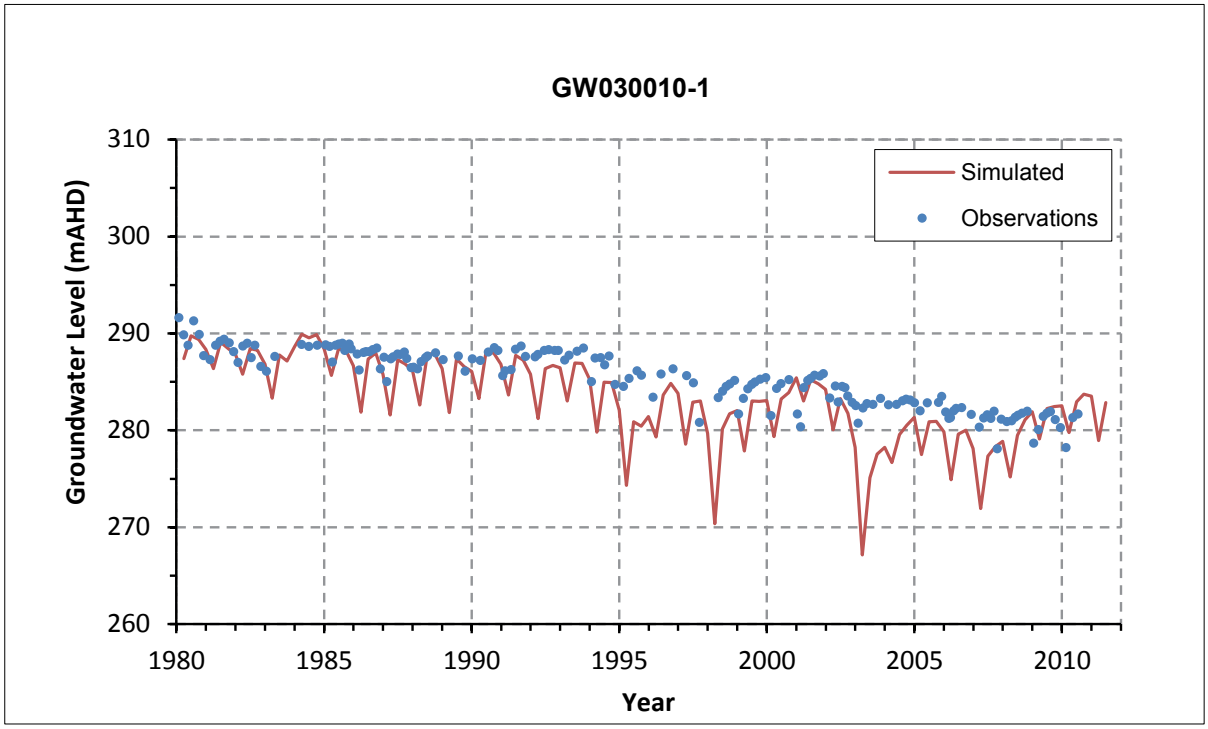

GW030008-2
Groundwater Level (mAHD)
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2010
Year
Simulated
Observations

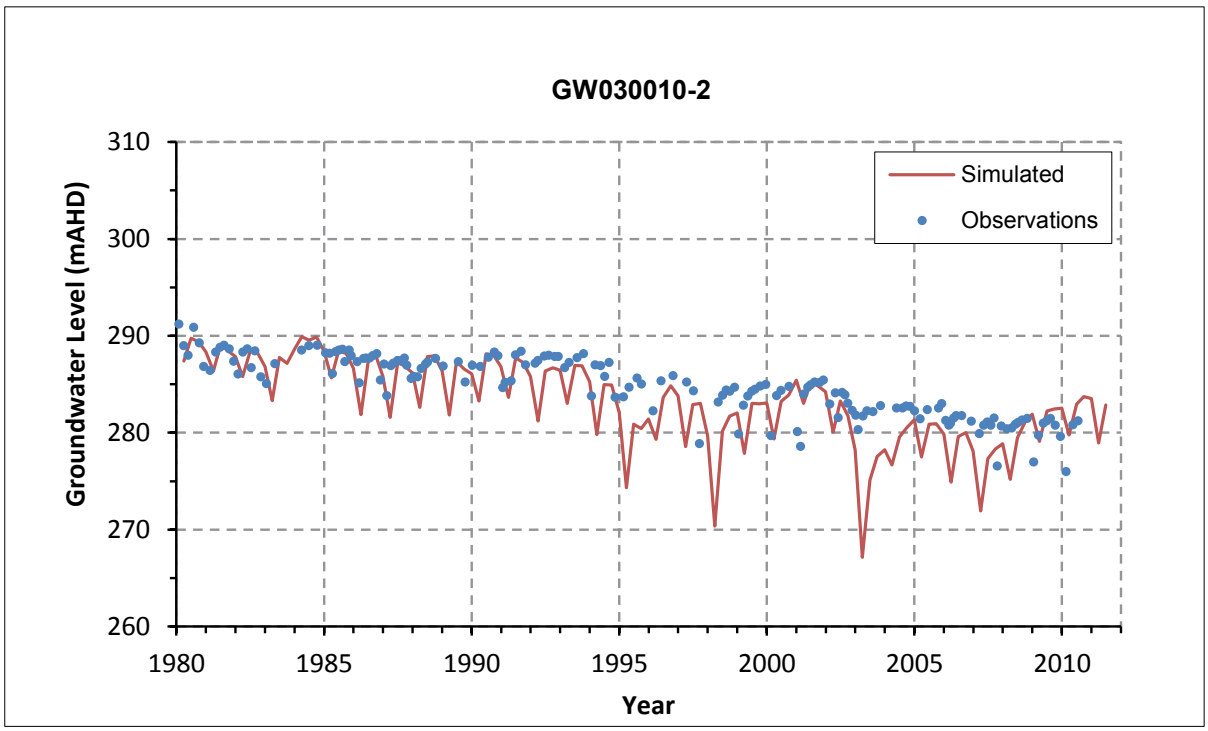

GW030008-3
Groundwater Level (mAHD)
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2010
Year
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Observations

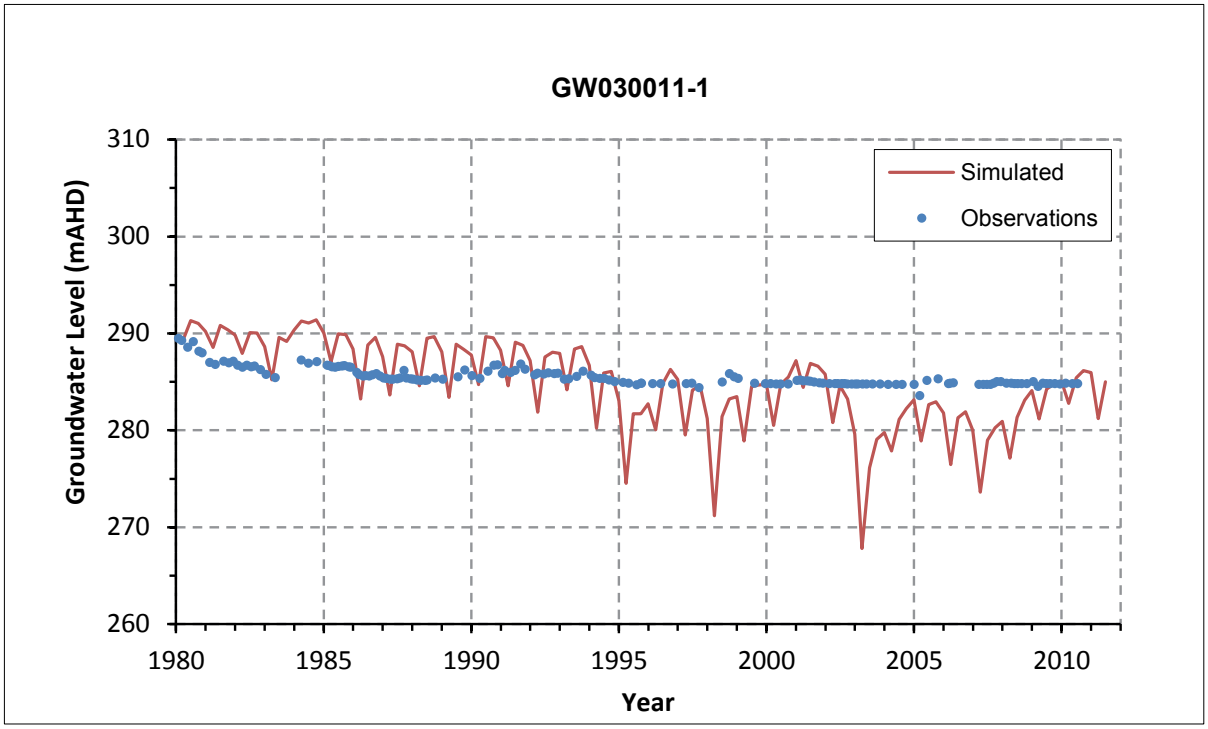

GW030009-1
Groundwater Level (mAHD)
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2000
2005
2010
Year
Simulated
Observations

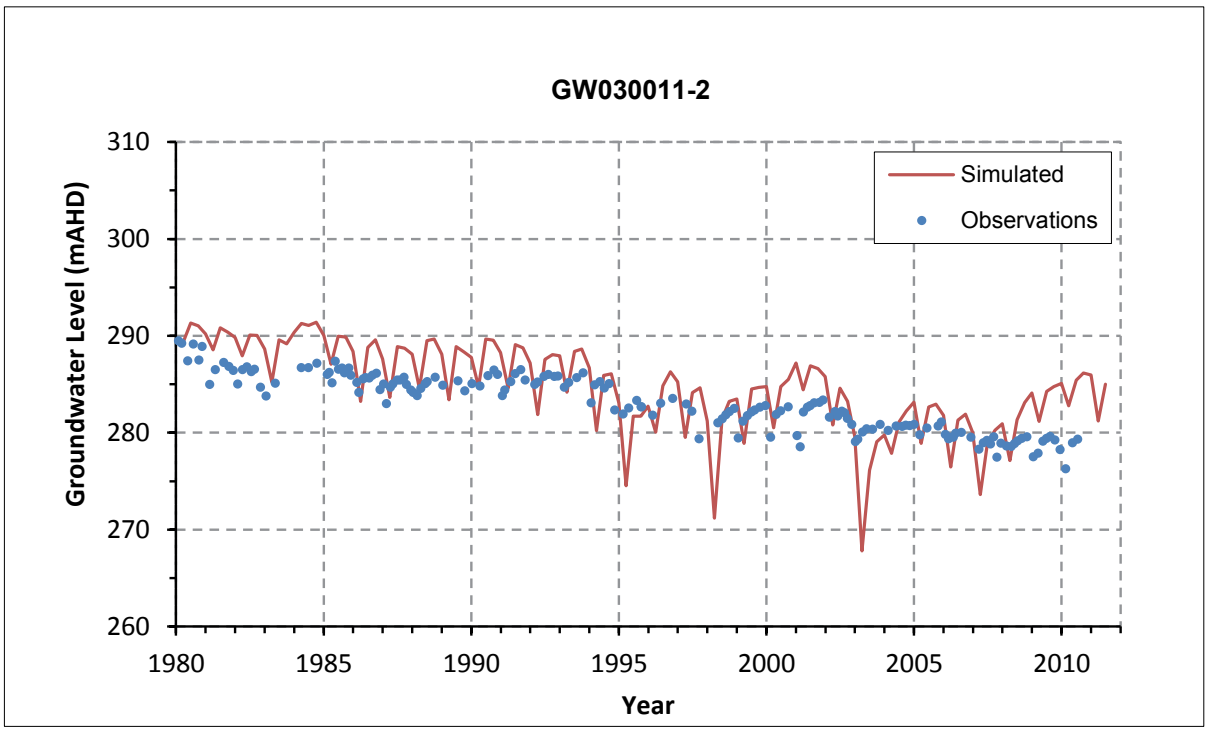

GW030009-2
Groundwater Level (mAHD)
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2005
2010
Year
Simulated
Observations

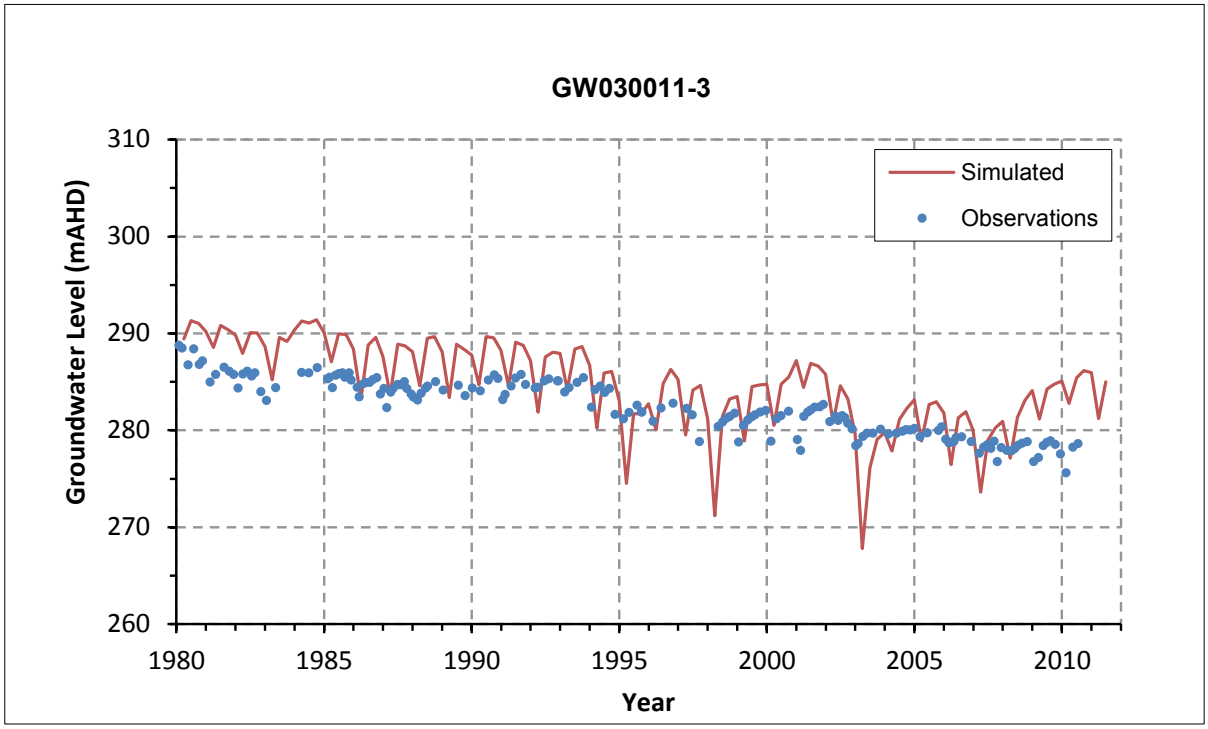

GW030009-3
Groundwater Level (mAHD)
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2005
2010
Year
Simulated
Observations

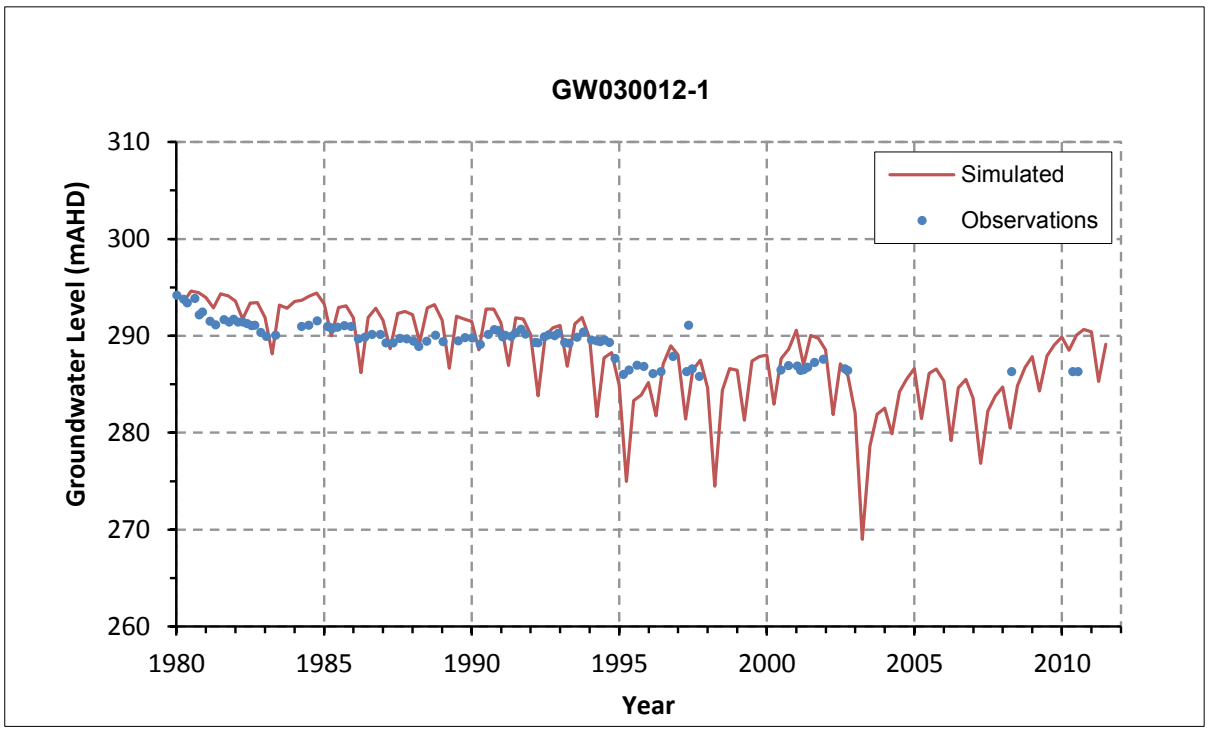

GW030010-1
Groundwater Level (mAHD)
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Simulated
Observations

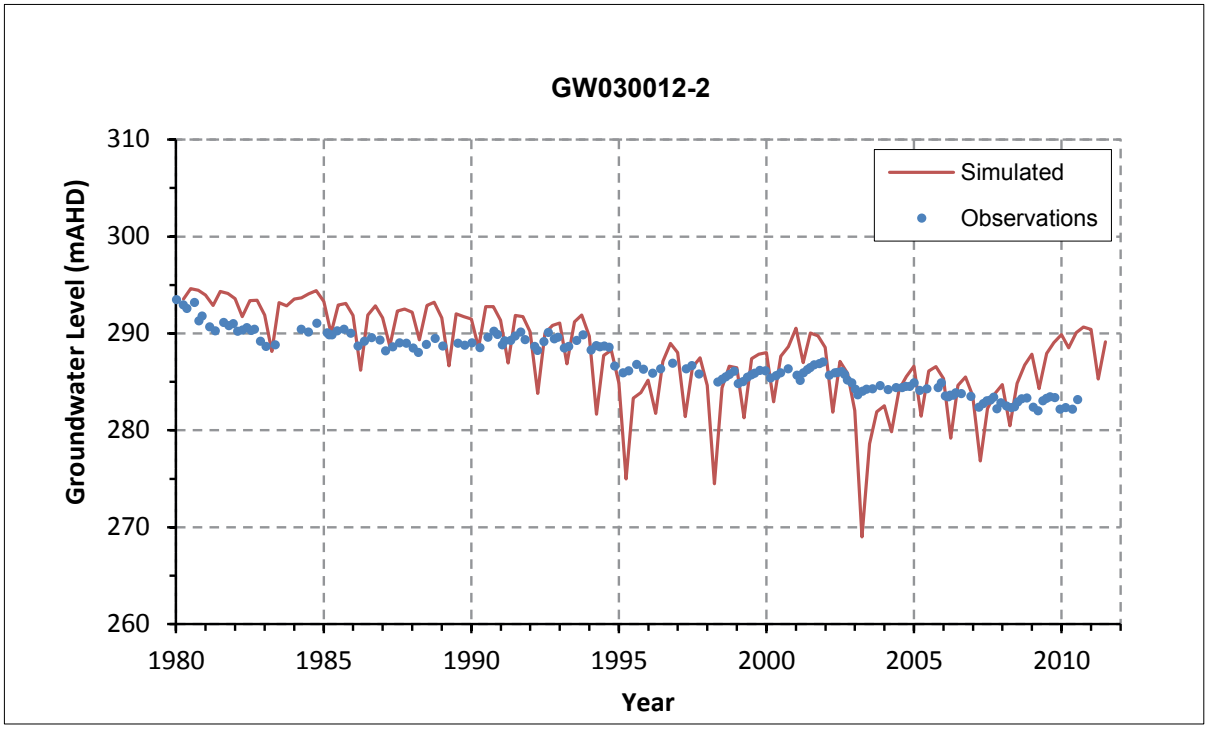

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Groundwater Level (mAHD)
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2010
Year
Simulated
Observations

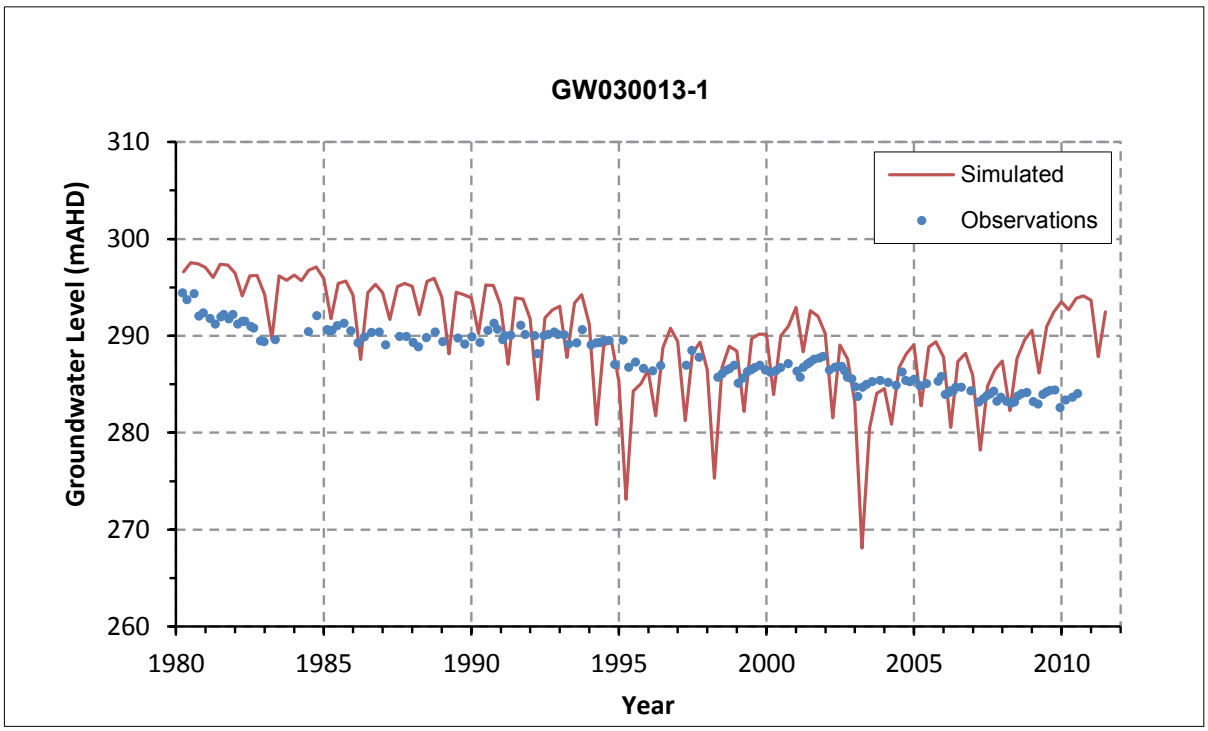

GW030011-1
Groundwater Level (mAHD)
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2005
2010
Year
Simulated
Observations

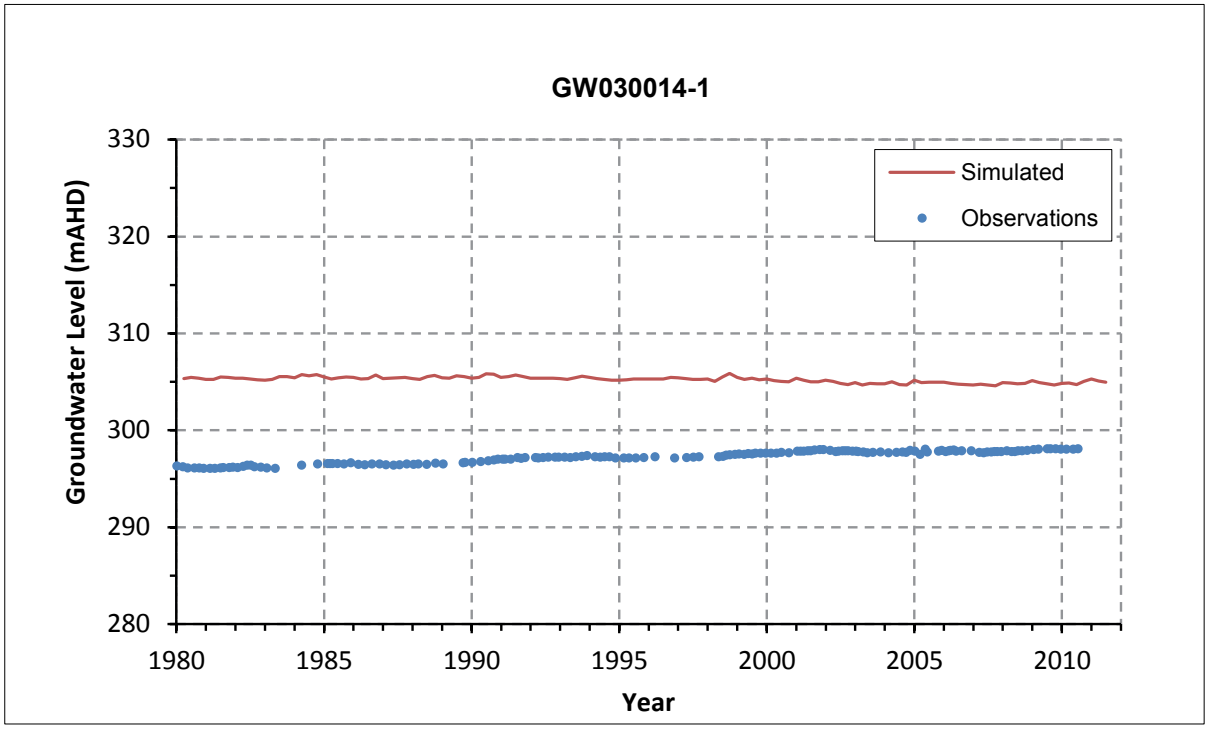

GW030011-2
Groundwater Level (mAHD)
310
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1980
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1995
2000
2005
2010
Year
Simulated
Observations

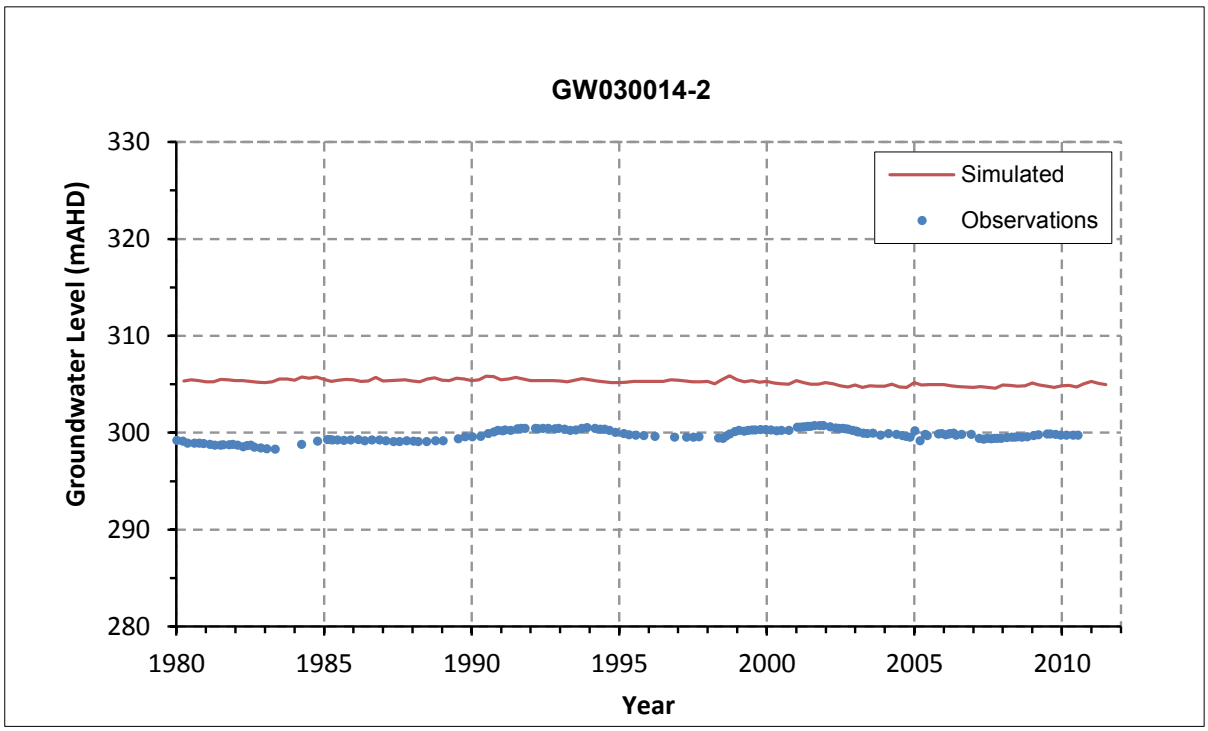

GW030011-3
Groundwater Level (mAHD)
310
300
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280
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1980
1985
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1995
2000
2005
2010
Year
Simulated
Observations

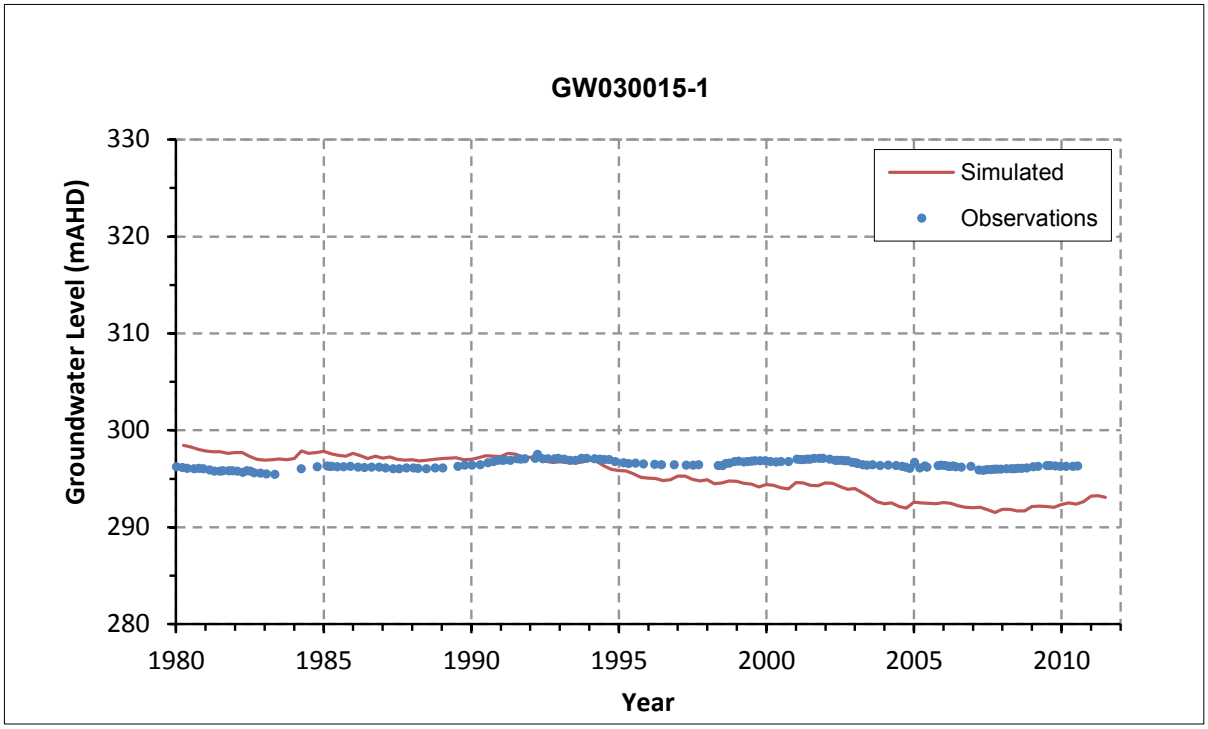

GW030012-1
Groundwater Level (mAHD)
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Year
Simulated
Observations

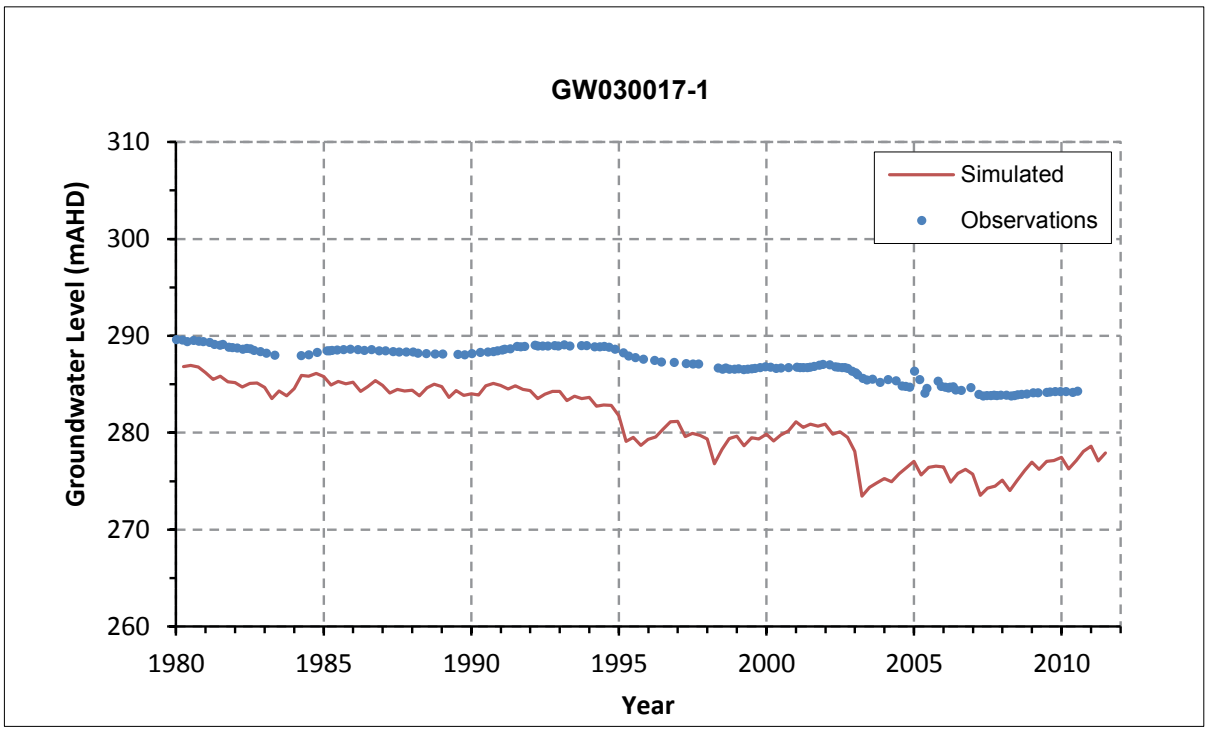

GW030012-2
Groundwater Level (mAHD)
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2005
2010
Year
Simulated
Observations

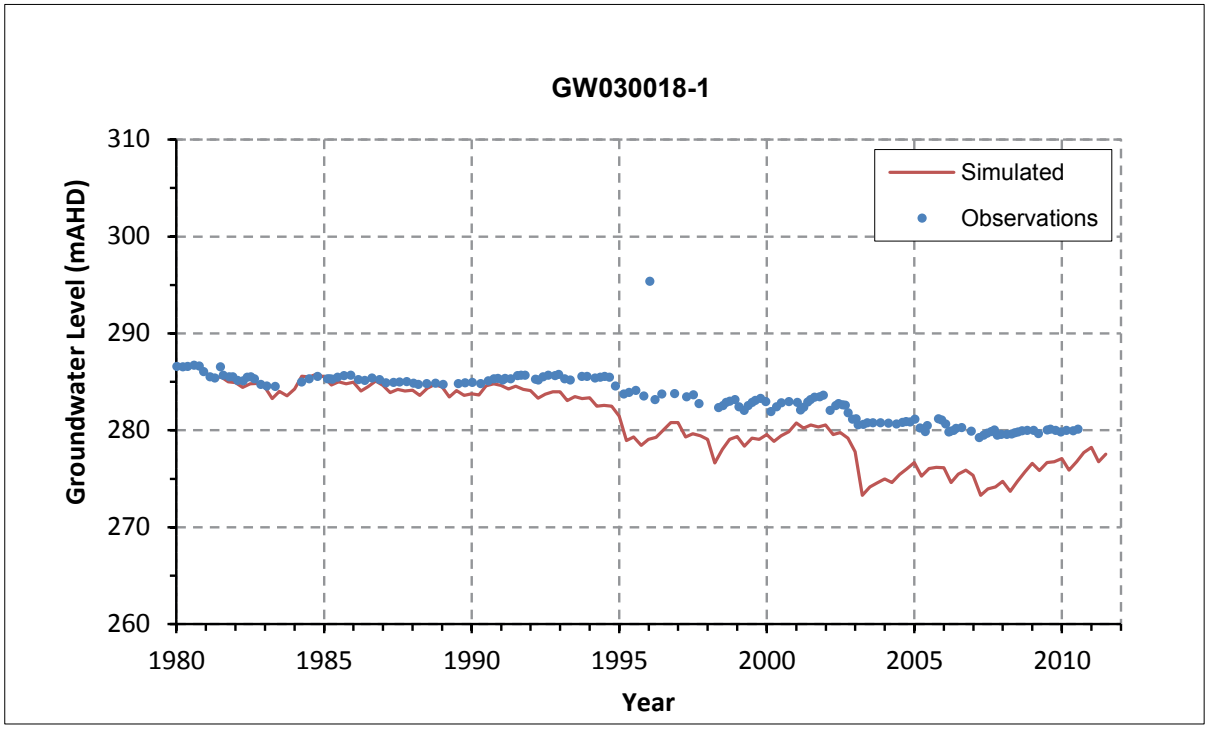

GW030013-1
Groundwater Level (mAHD)
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2005
2010
Year
Simulated
Observations

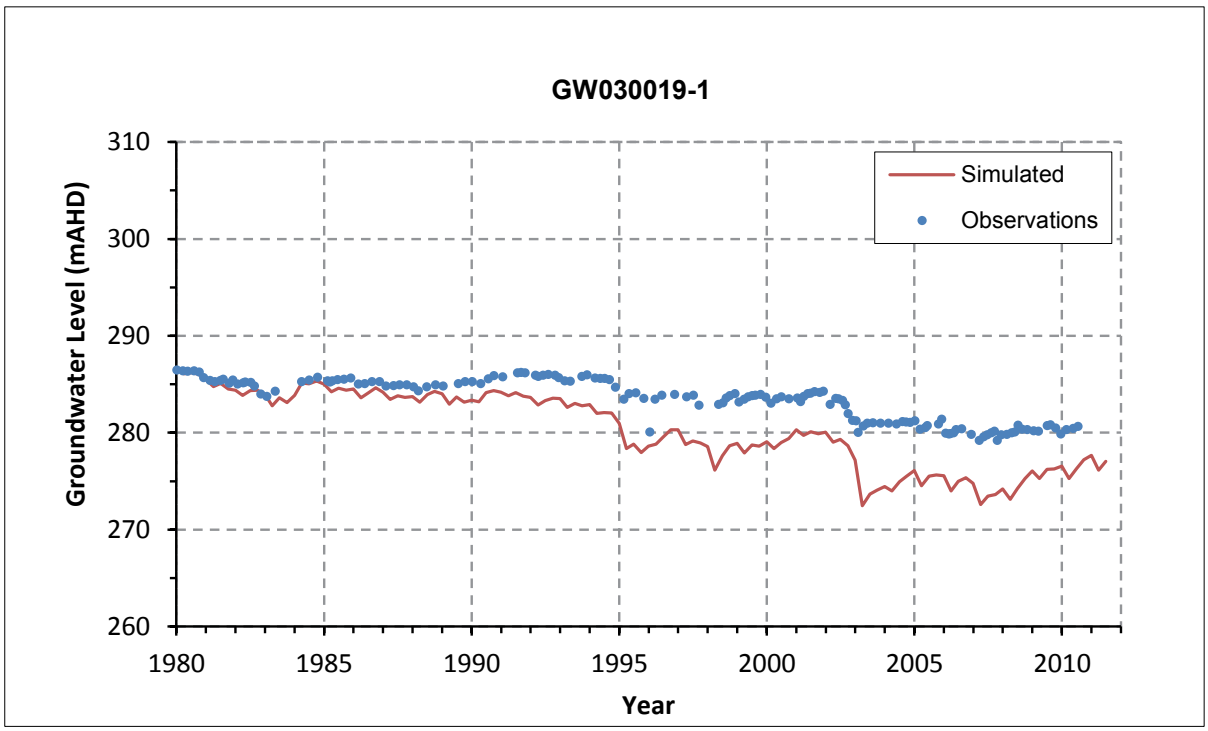

GW030014-1
Groundwater Level (mAHD)
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1995
2000
2005
2010
Year
Simulated
Observations

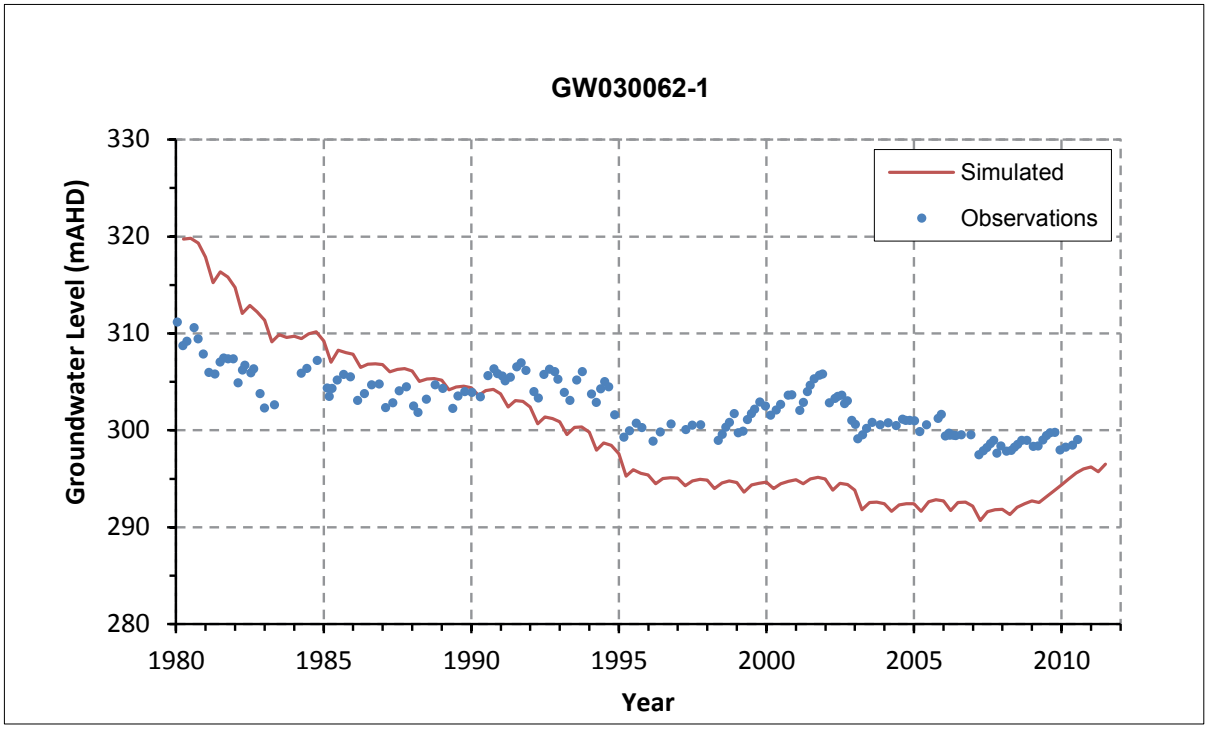

GW030014-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

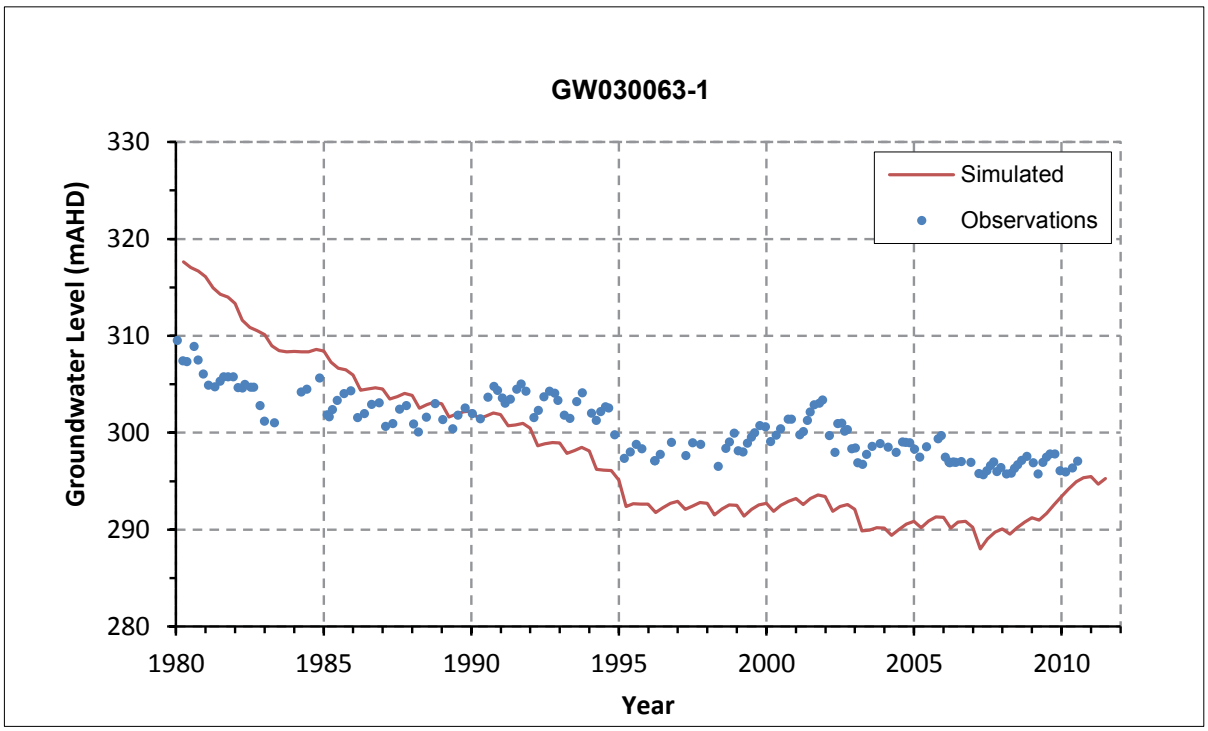

GW030015-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

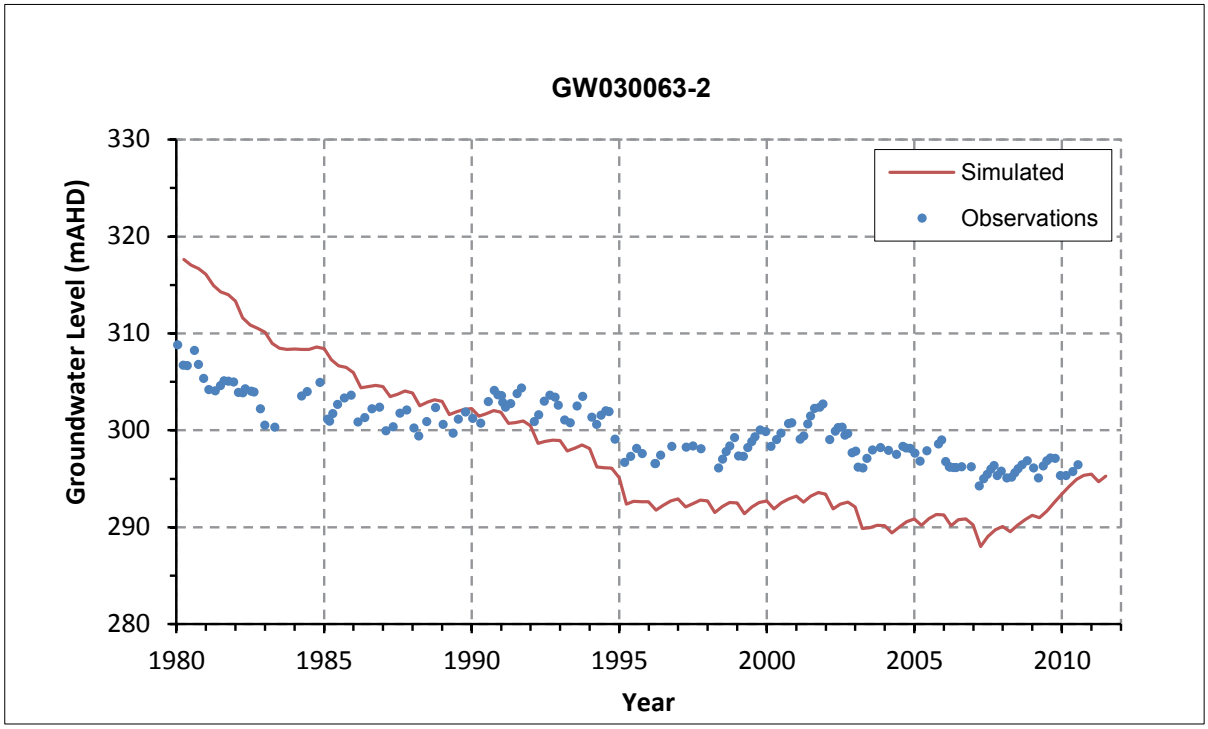

GW030017-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

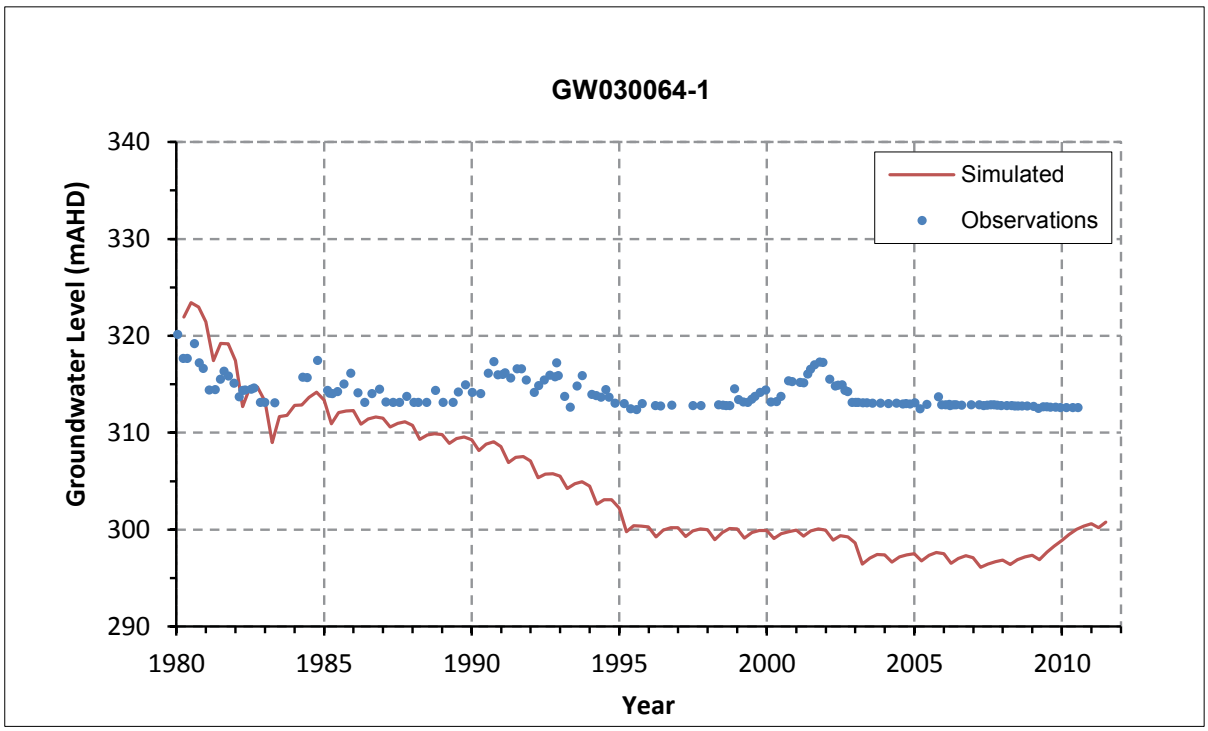

GW030018-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

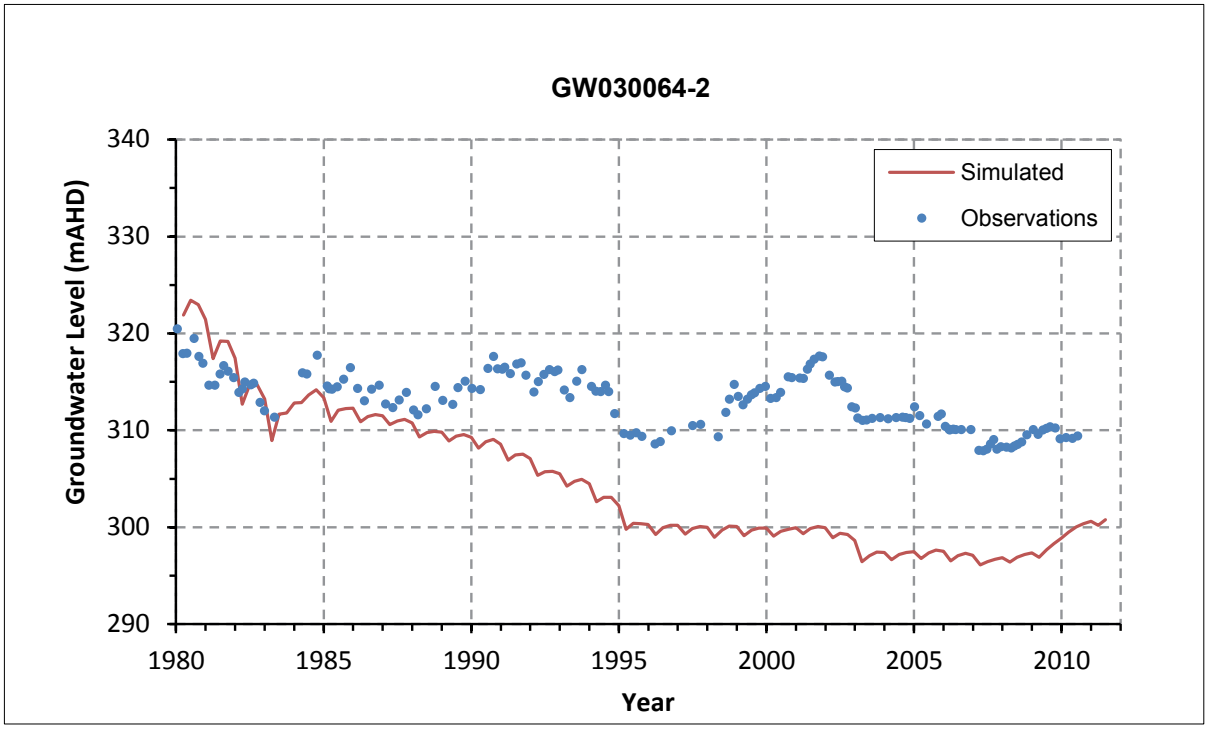

GW030019-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

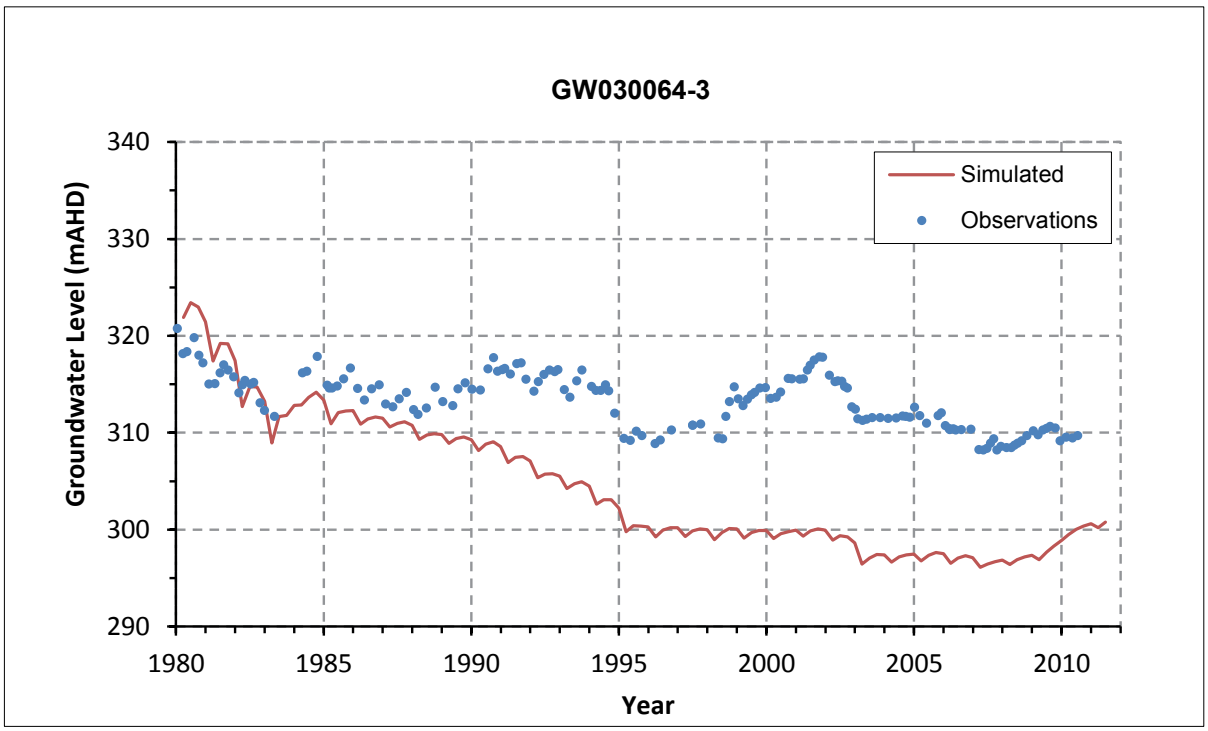

GW030062-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

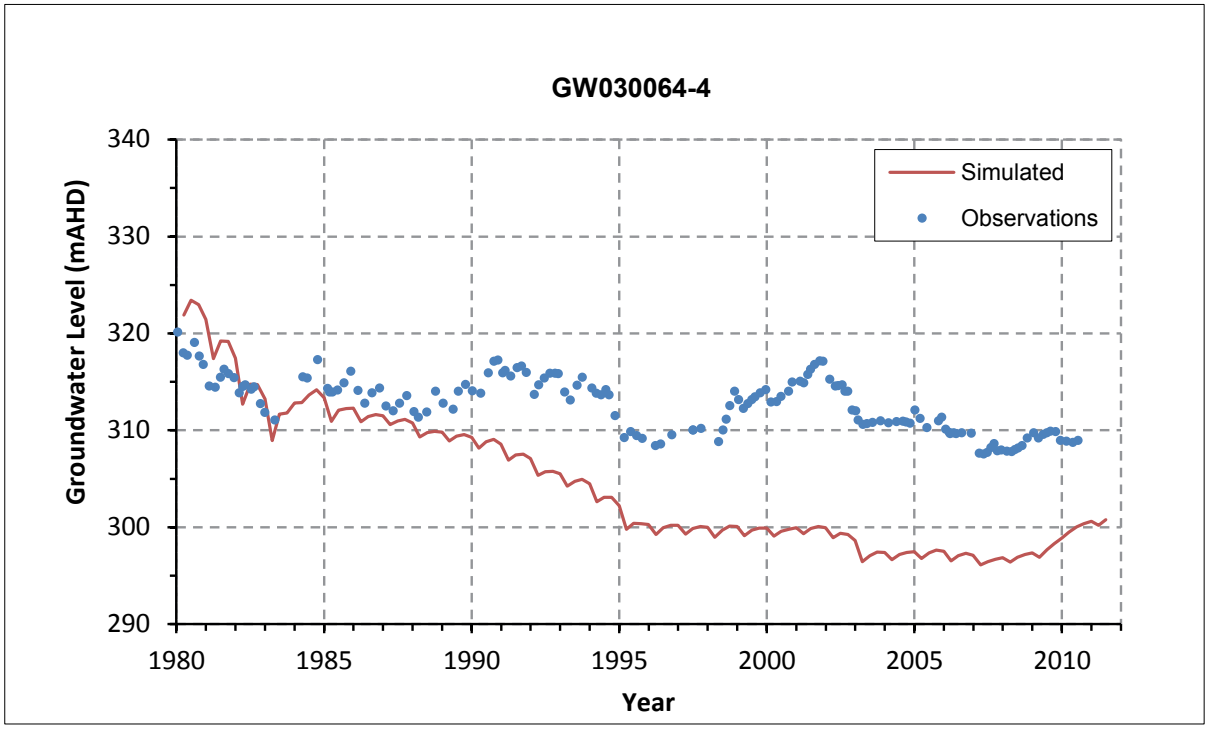

GW030063-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

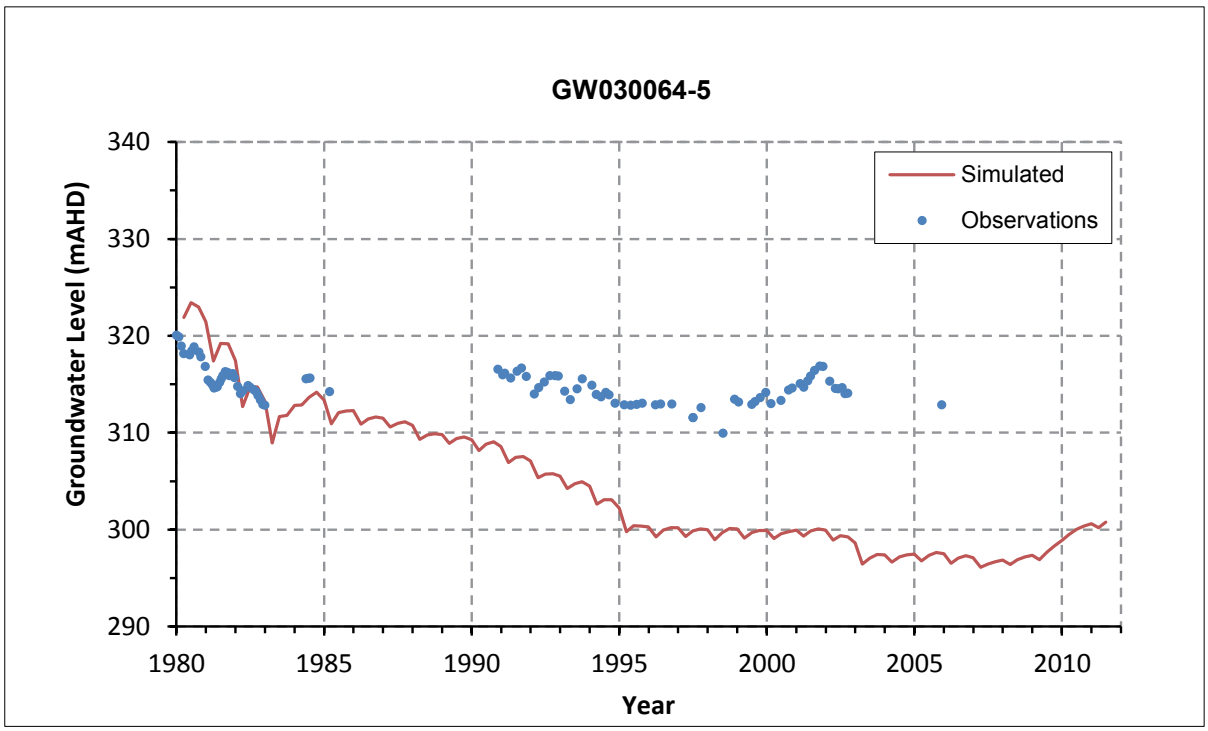

GW030063-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

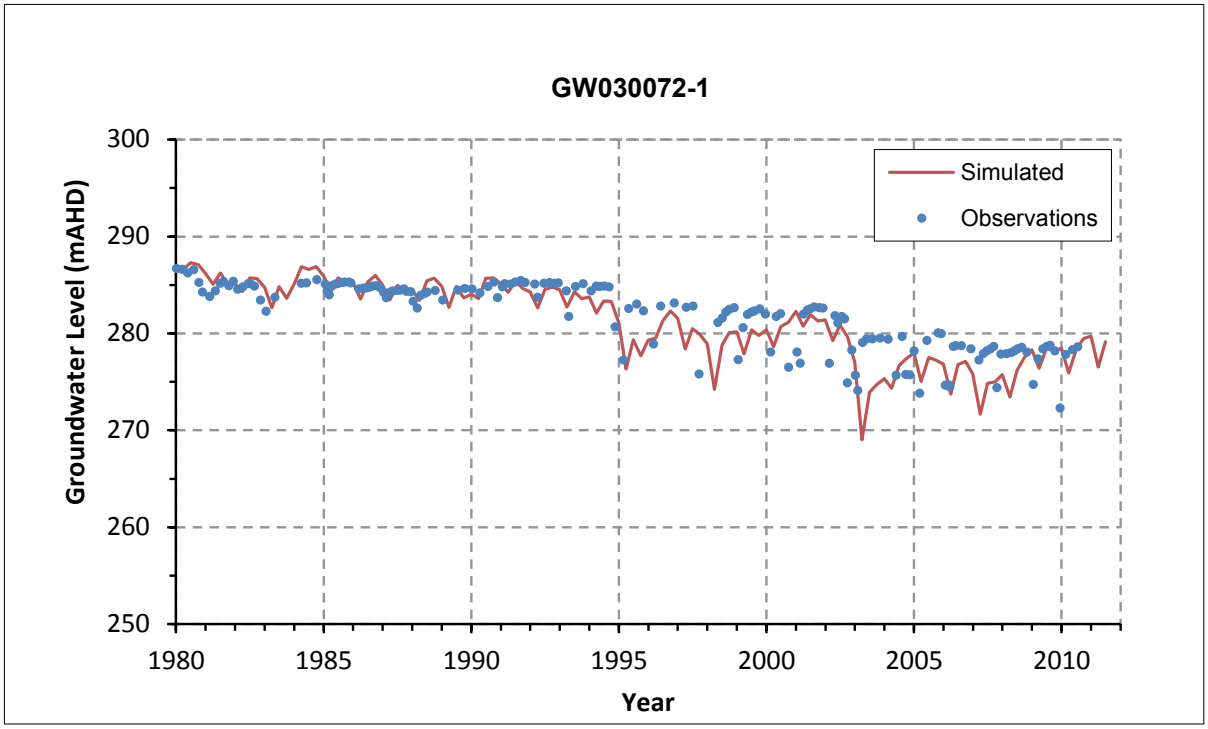

GW030064-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

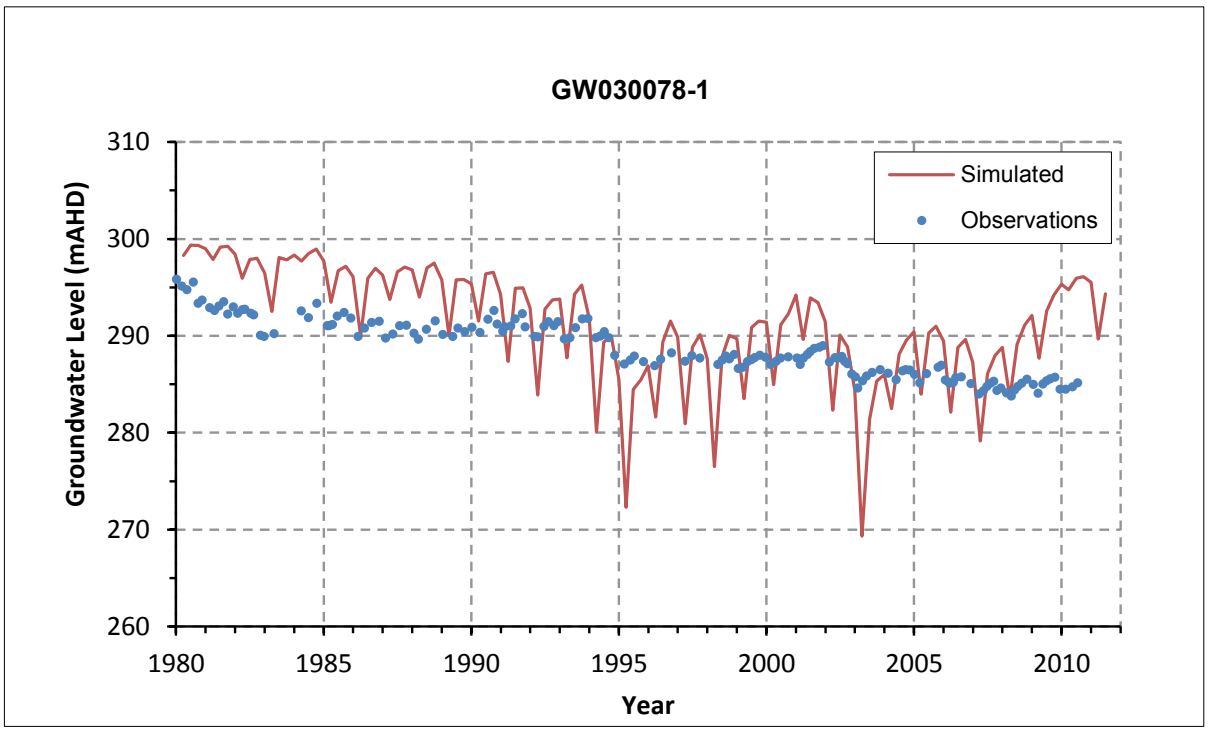

GW030064-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

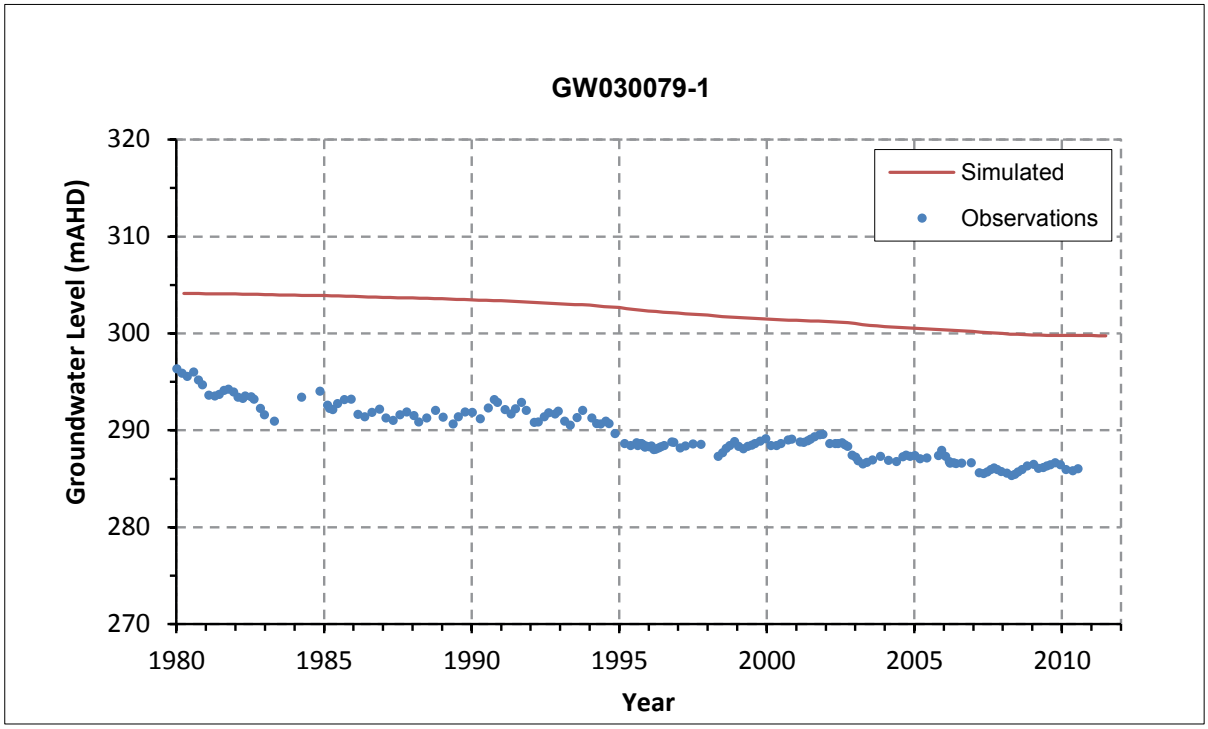

GW030064-3
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

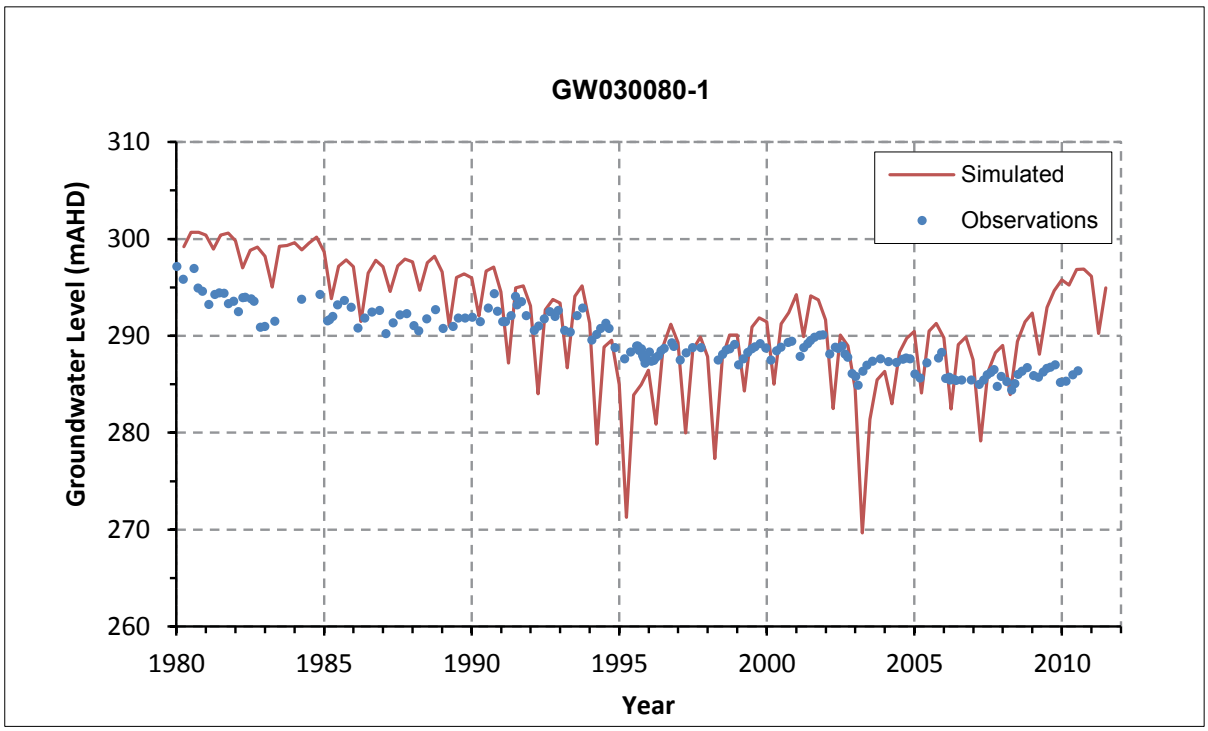

GW030064-4
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

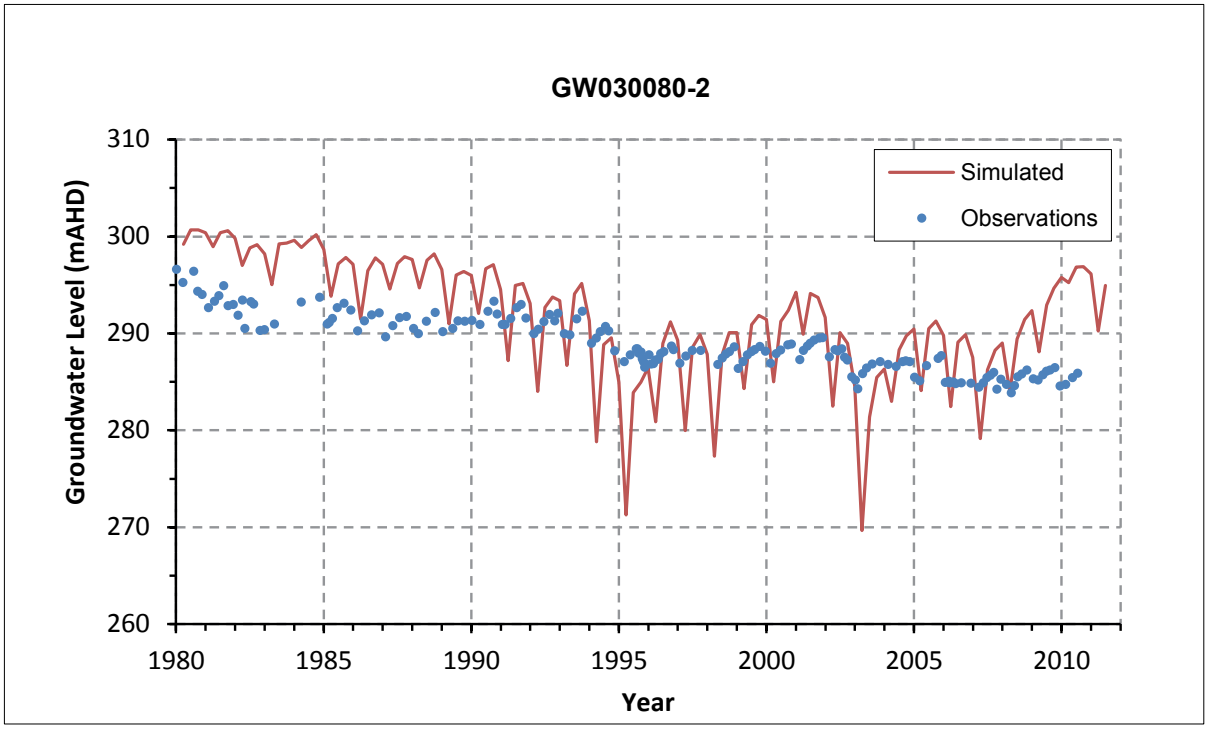

GW030064-5
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

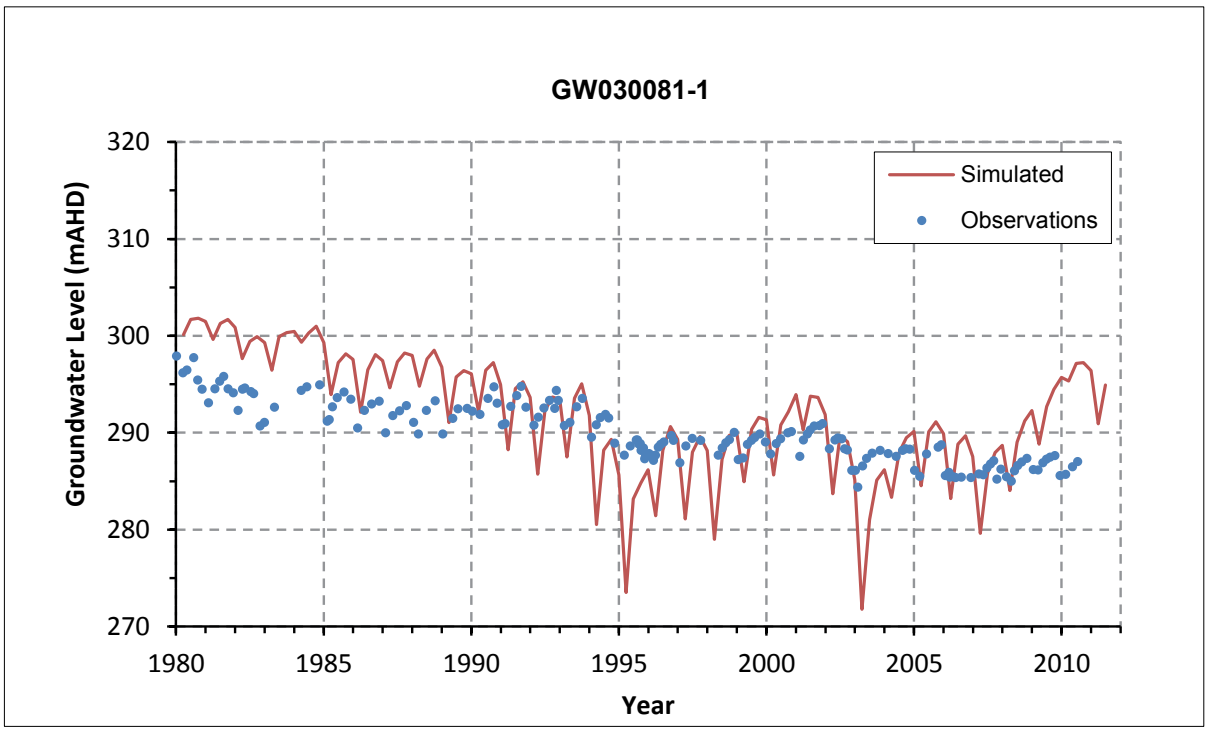

GW030072-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

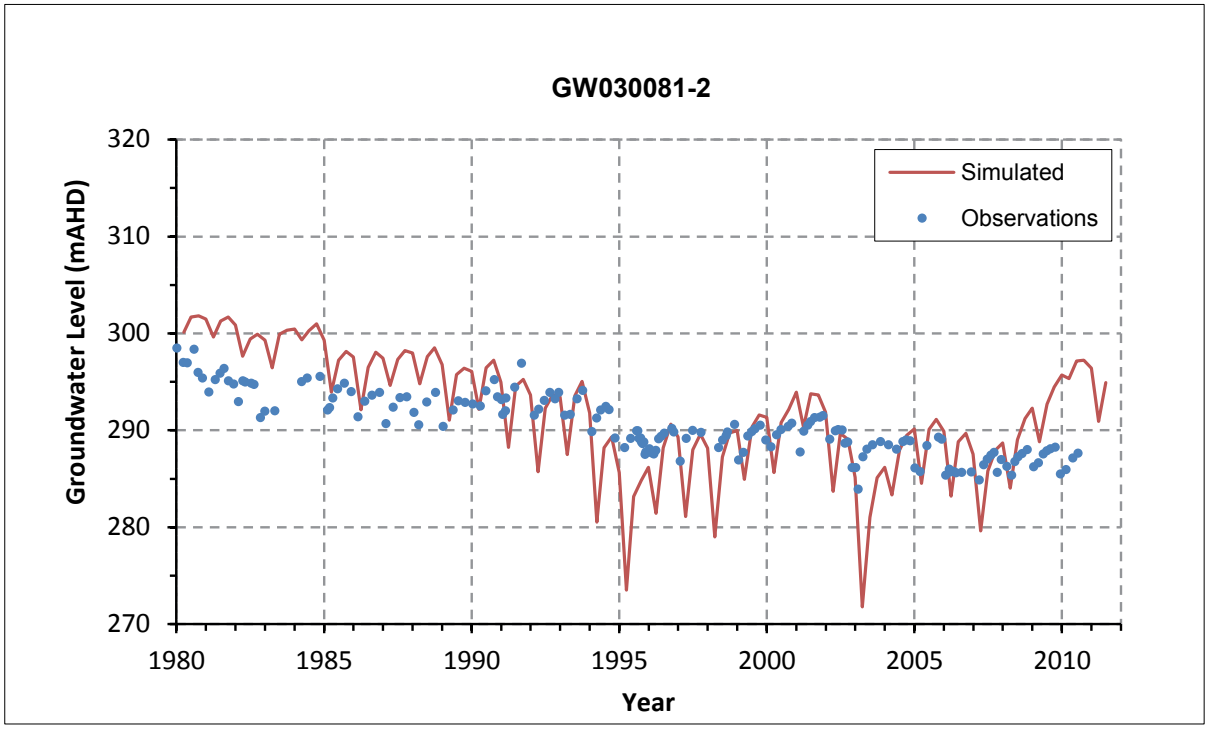

GW030078-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

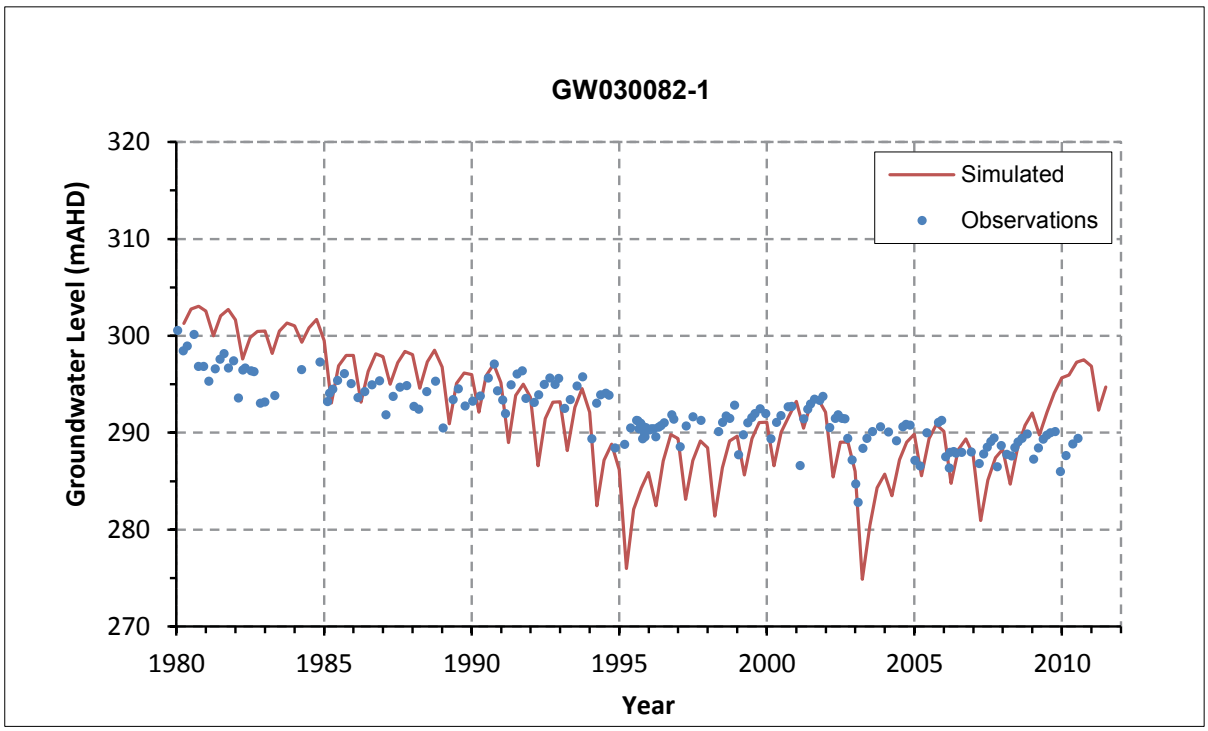

GW030079-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

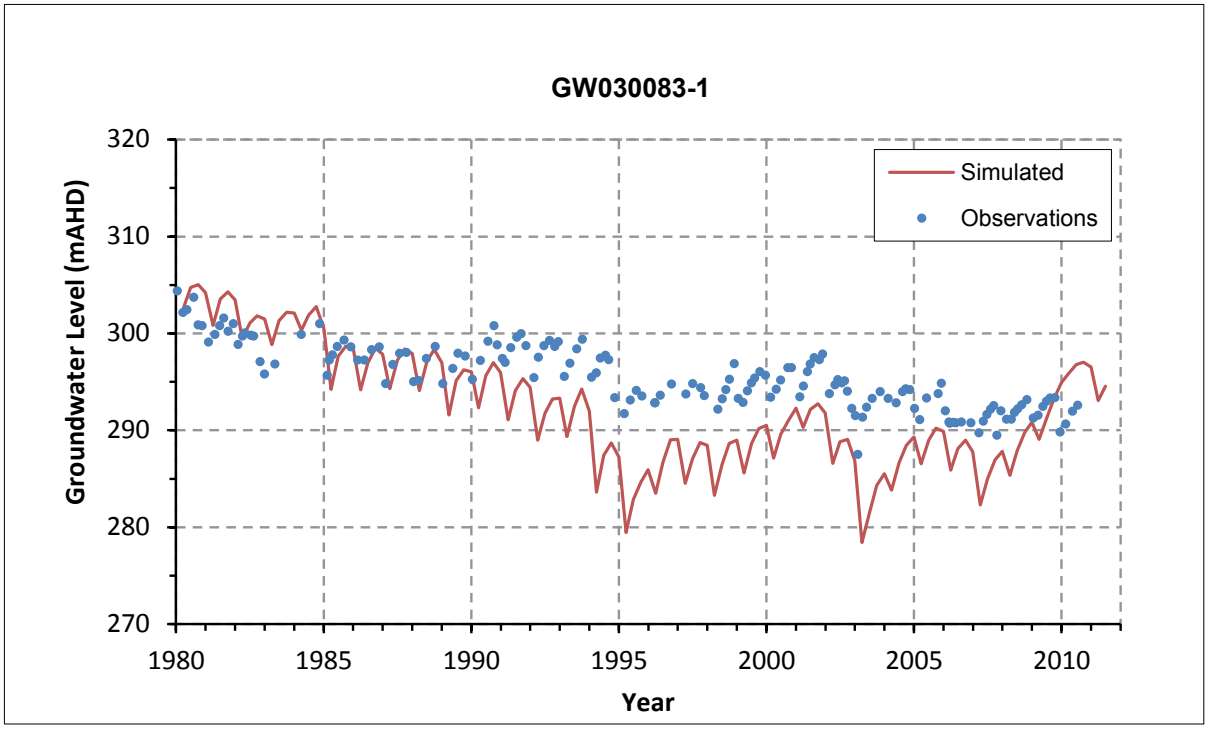

GW030080-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

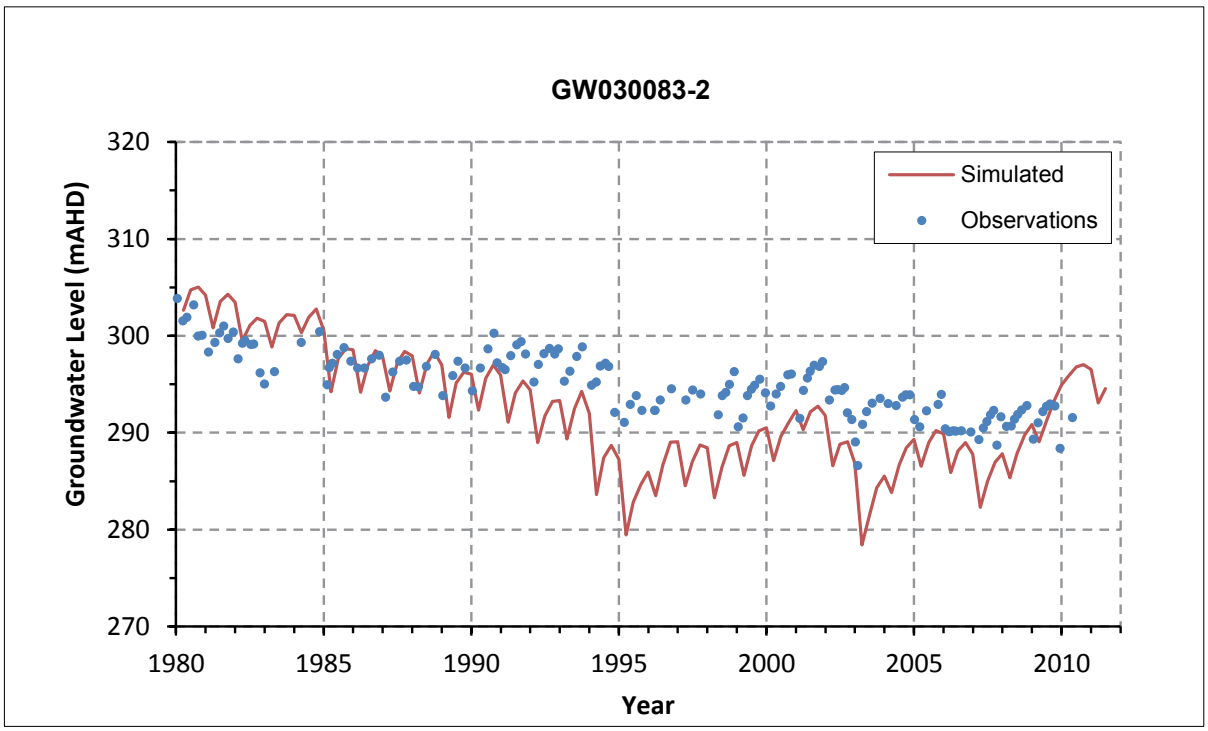

GW030080-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

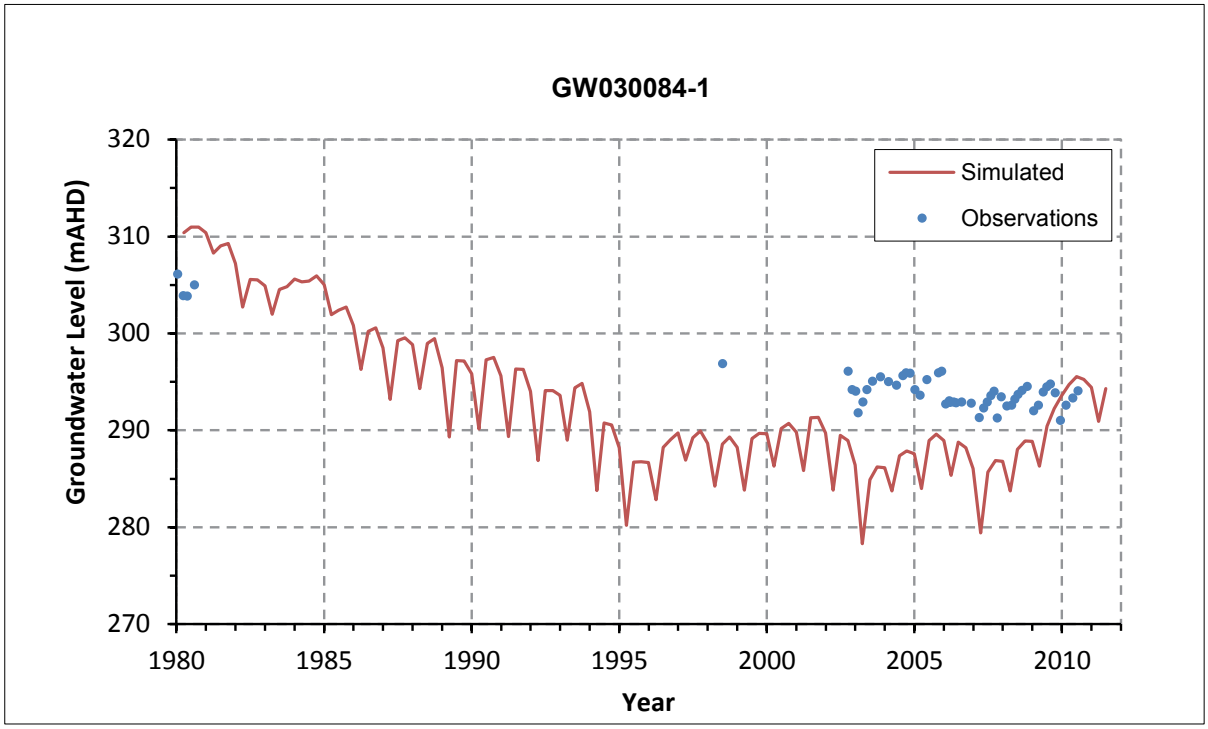

GW030081-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

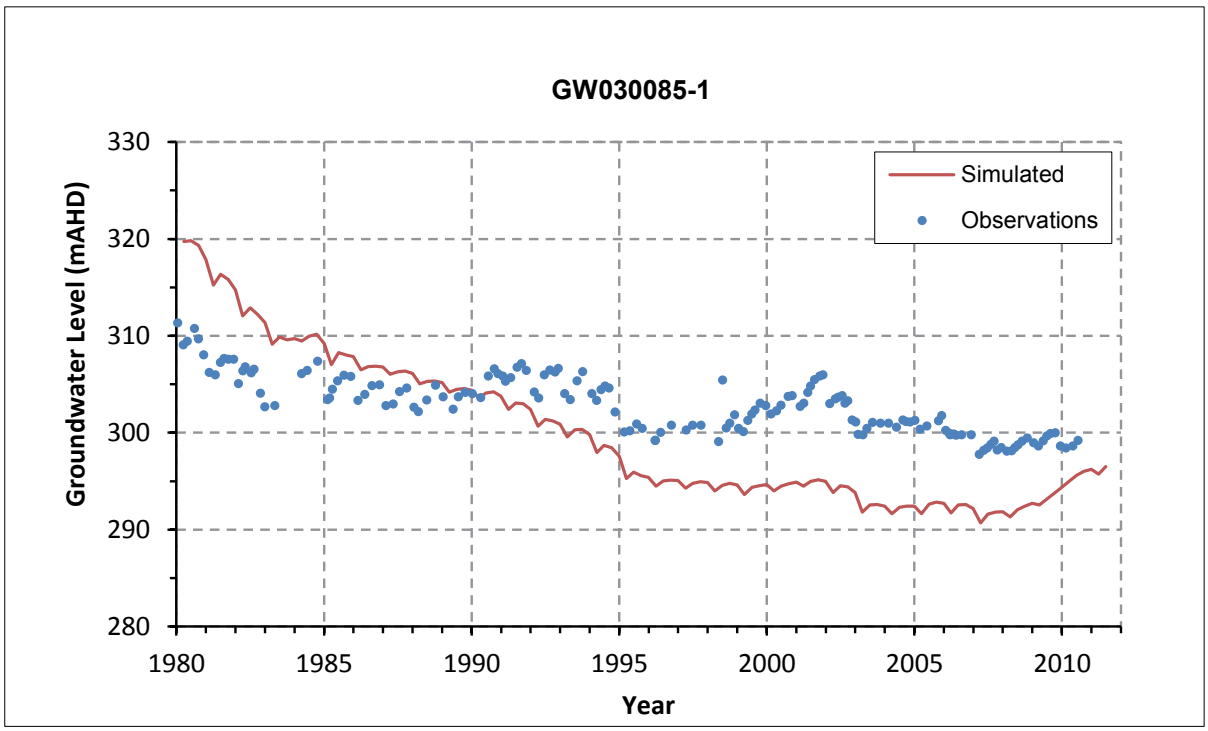

GW030081-2
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

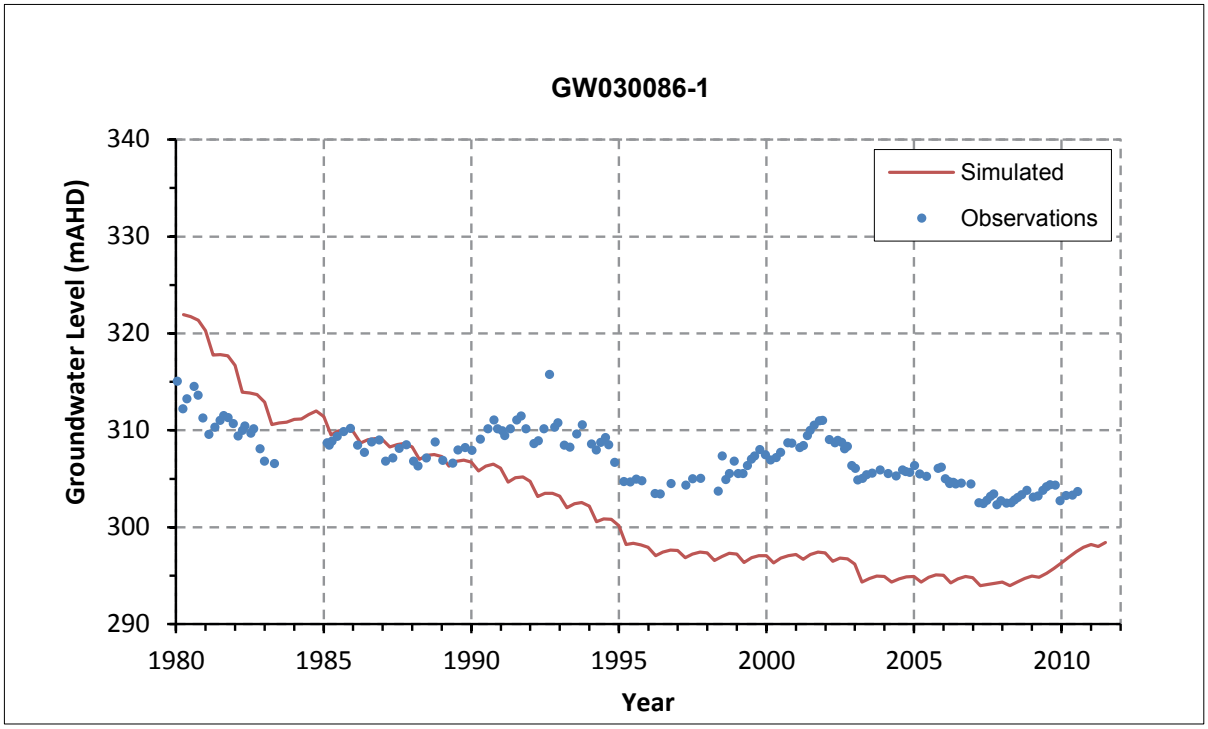

GW030082-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

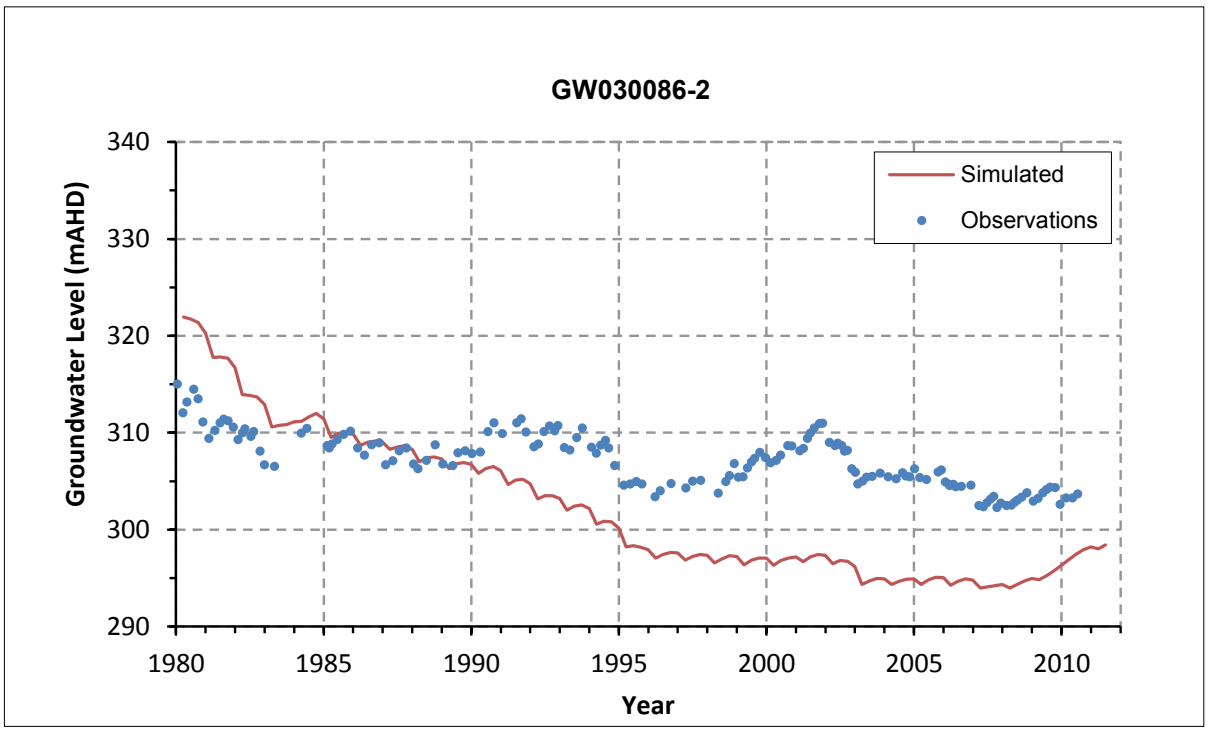

GW030083-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

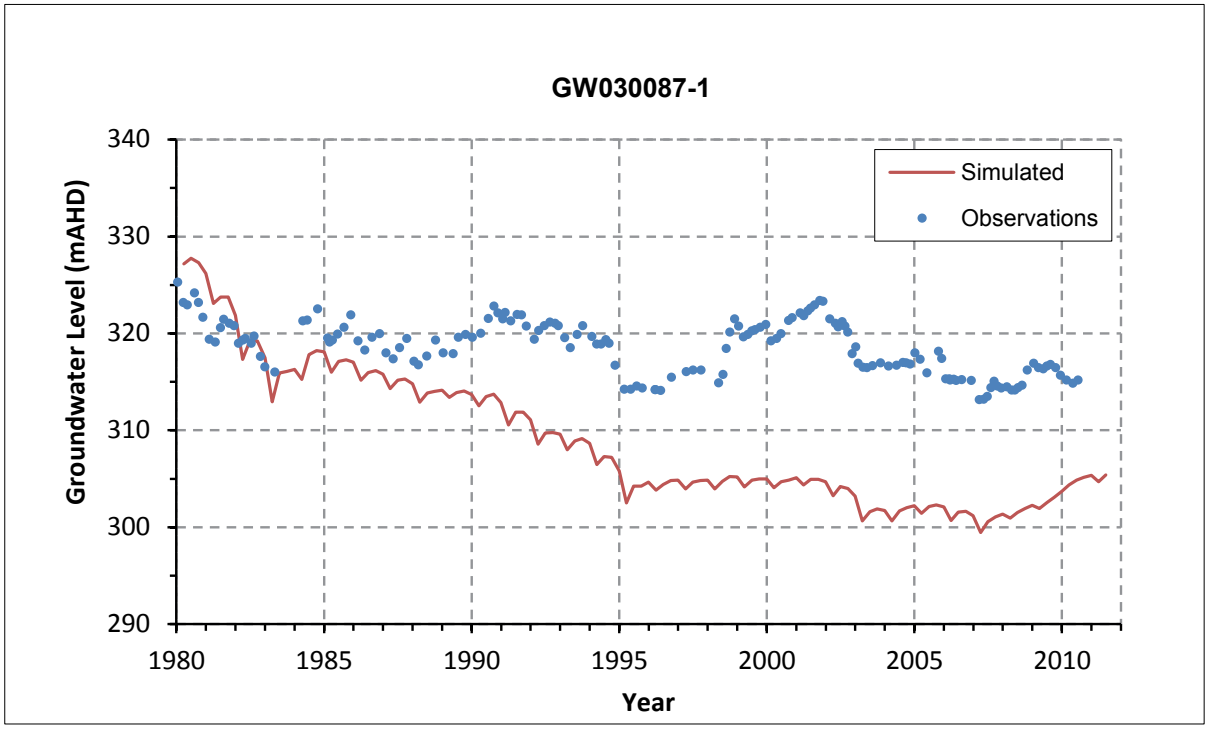

GW030083-2
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

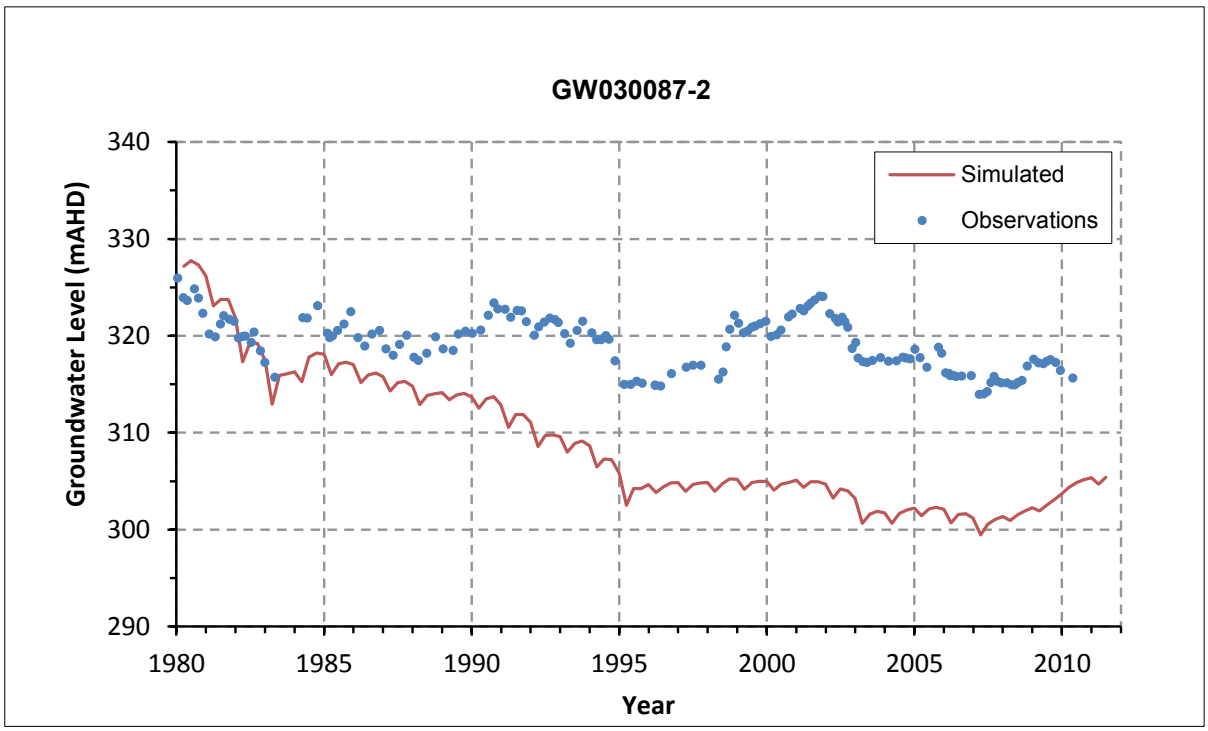

GW030084-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

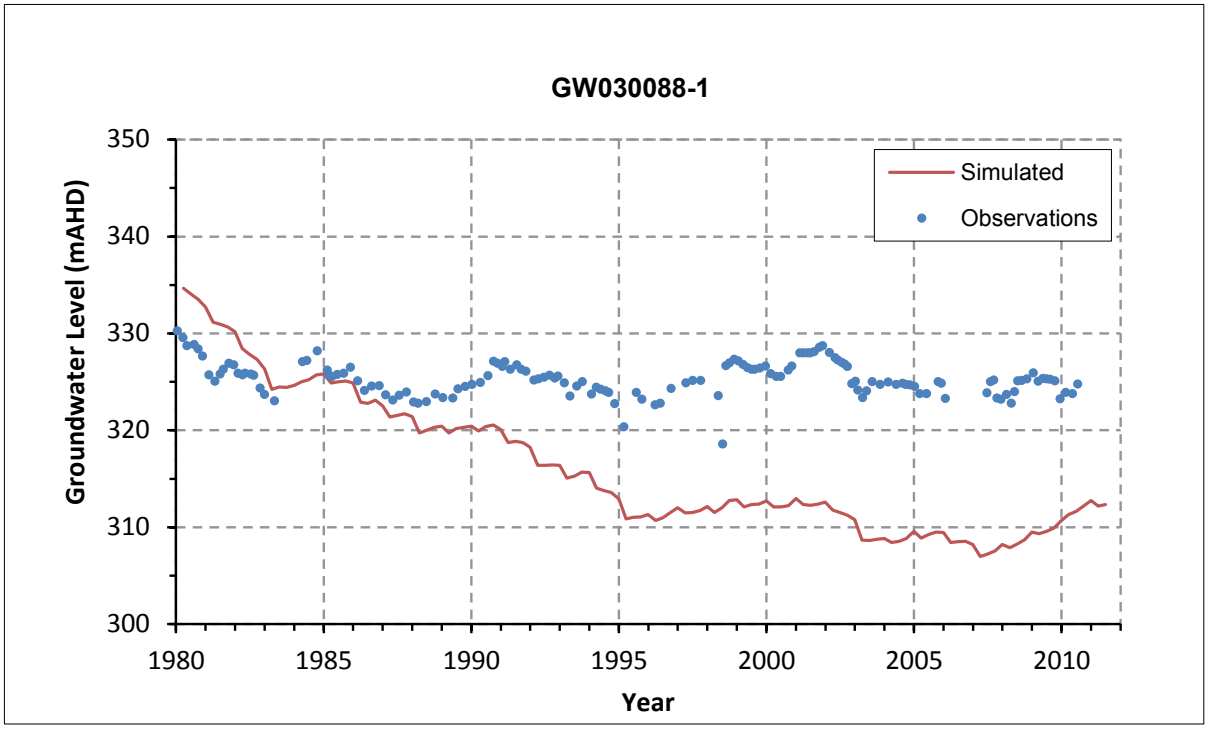

GW030085-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

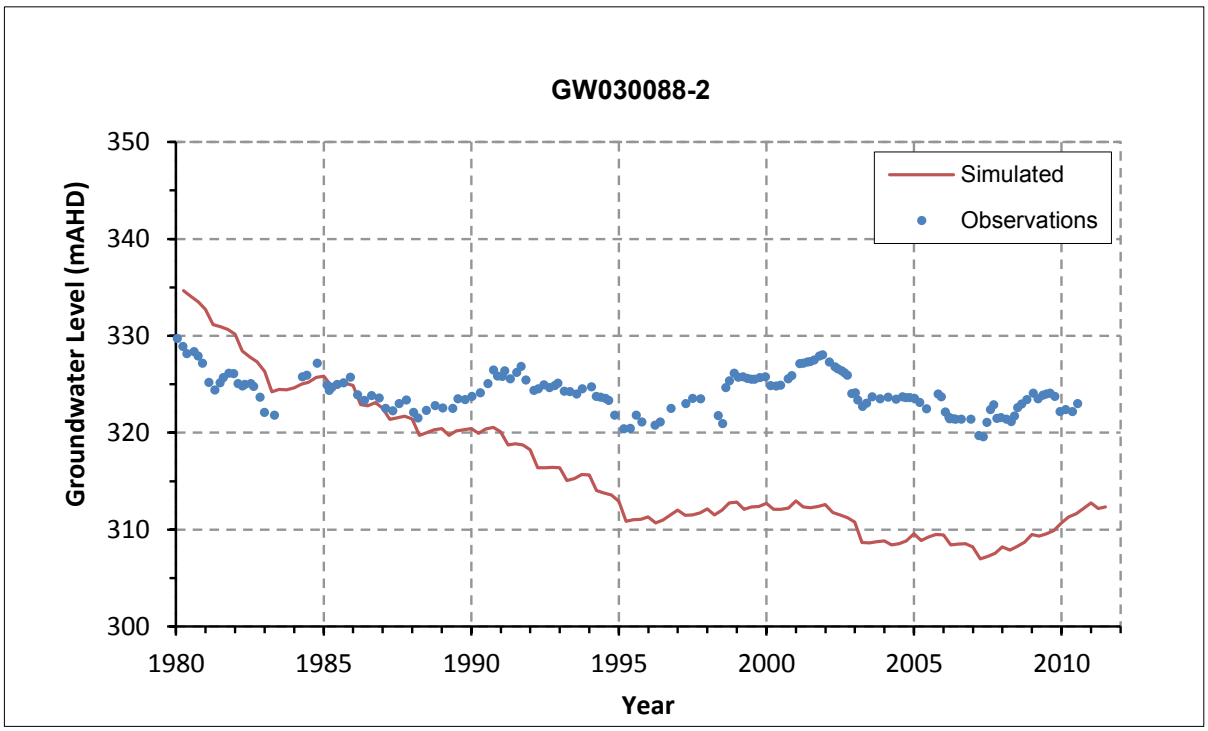

GW030086-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

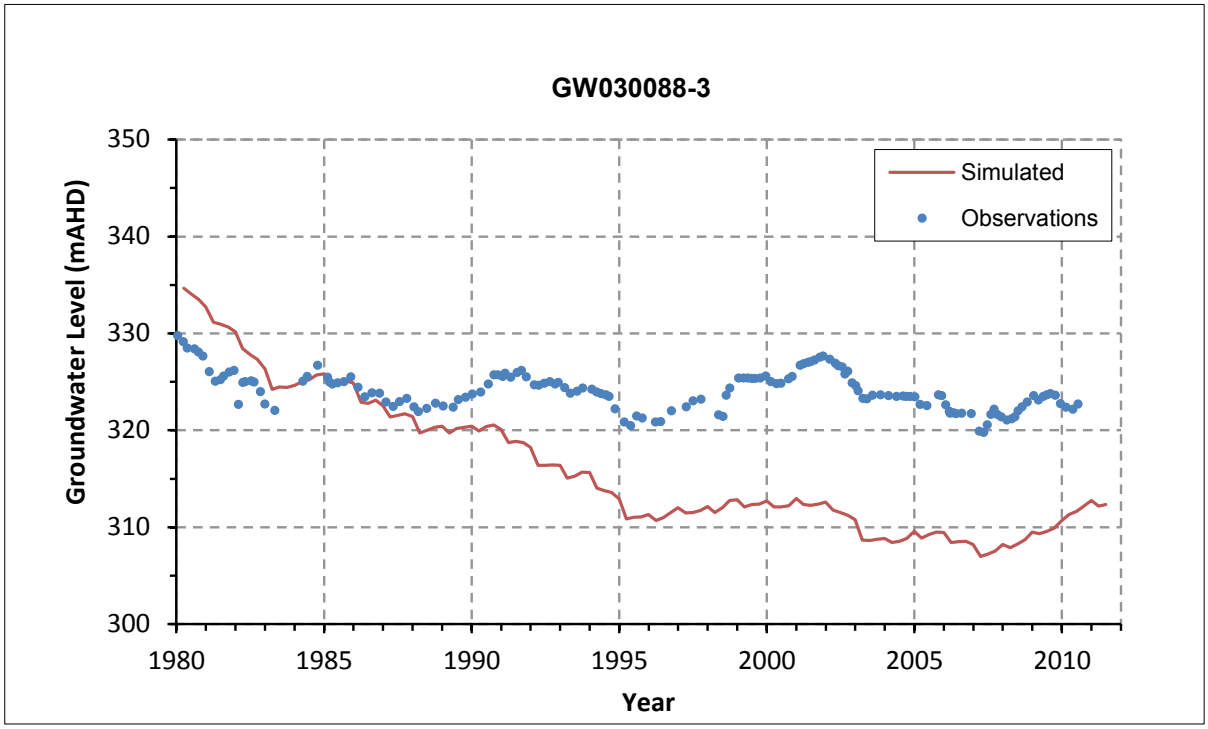

GW030086-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

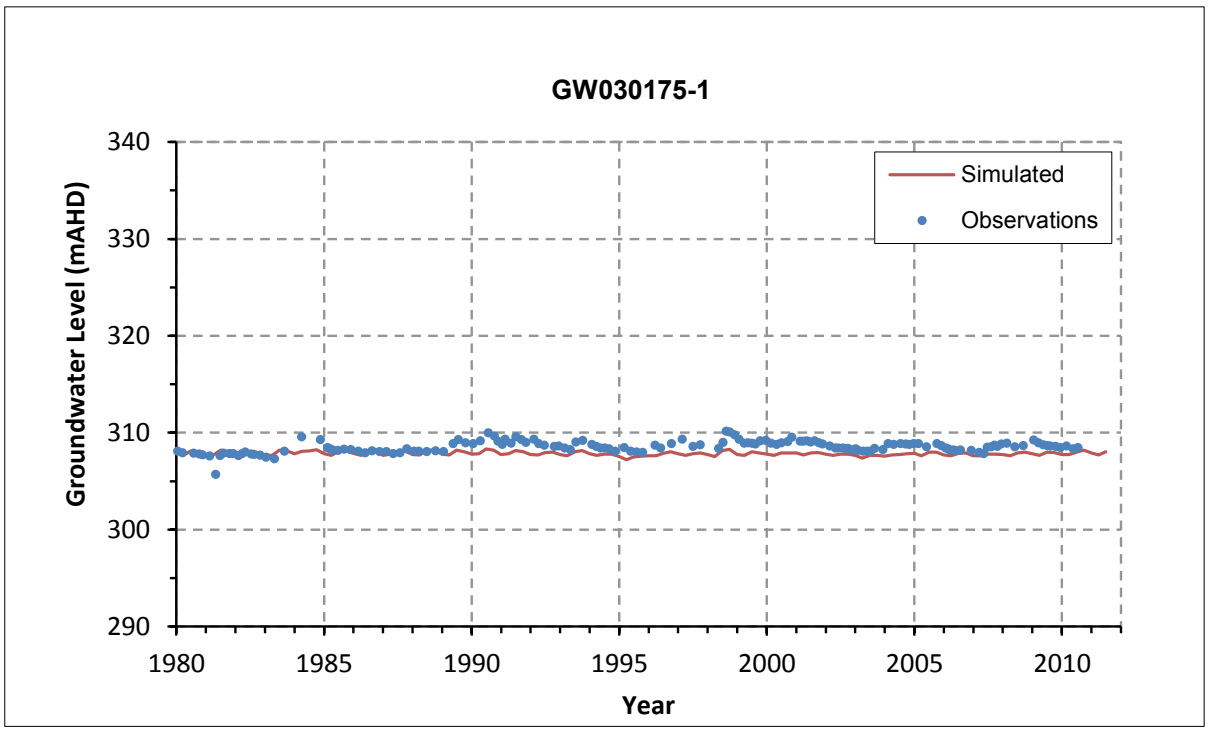

GW030087-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

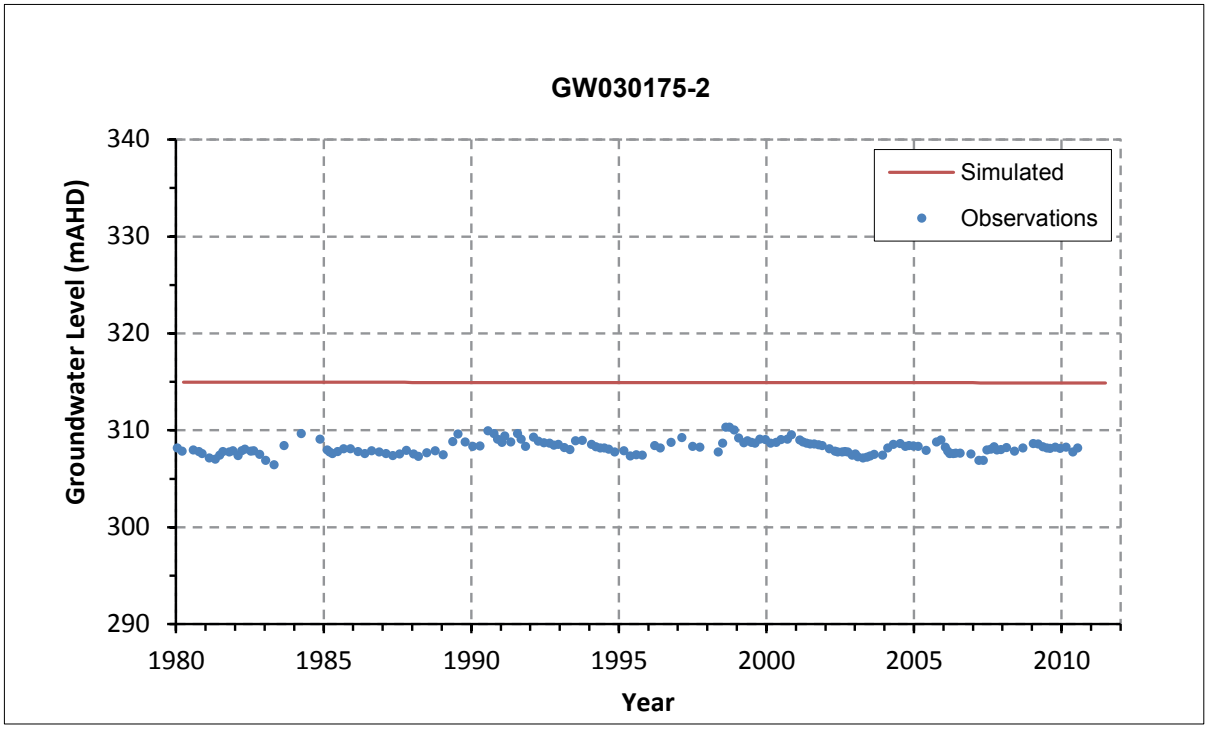

GW030087-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

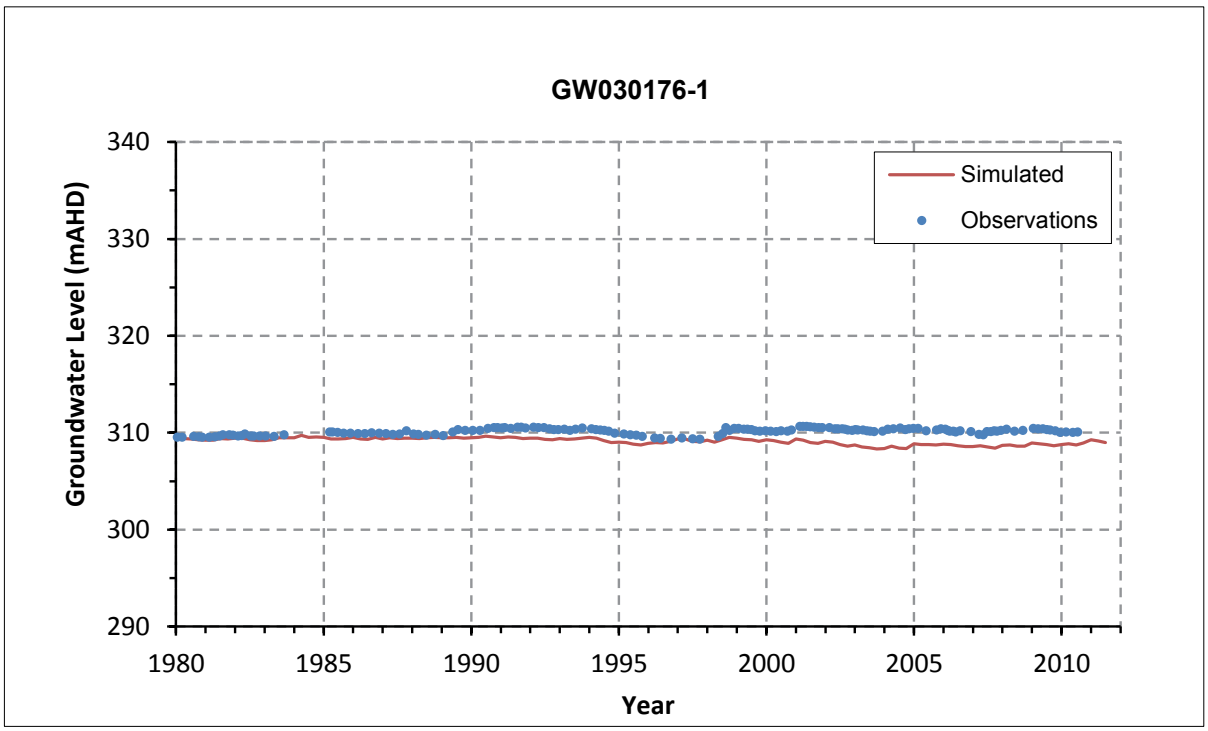

GW030088-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

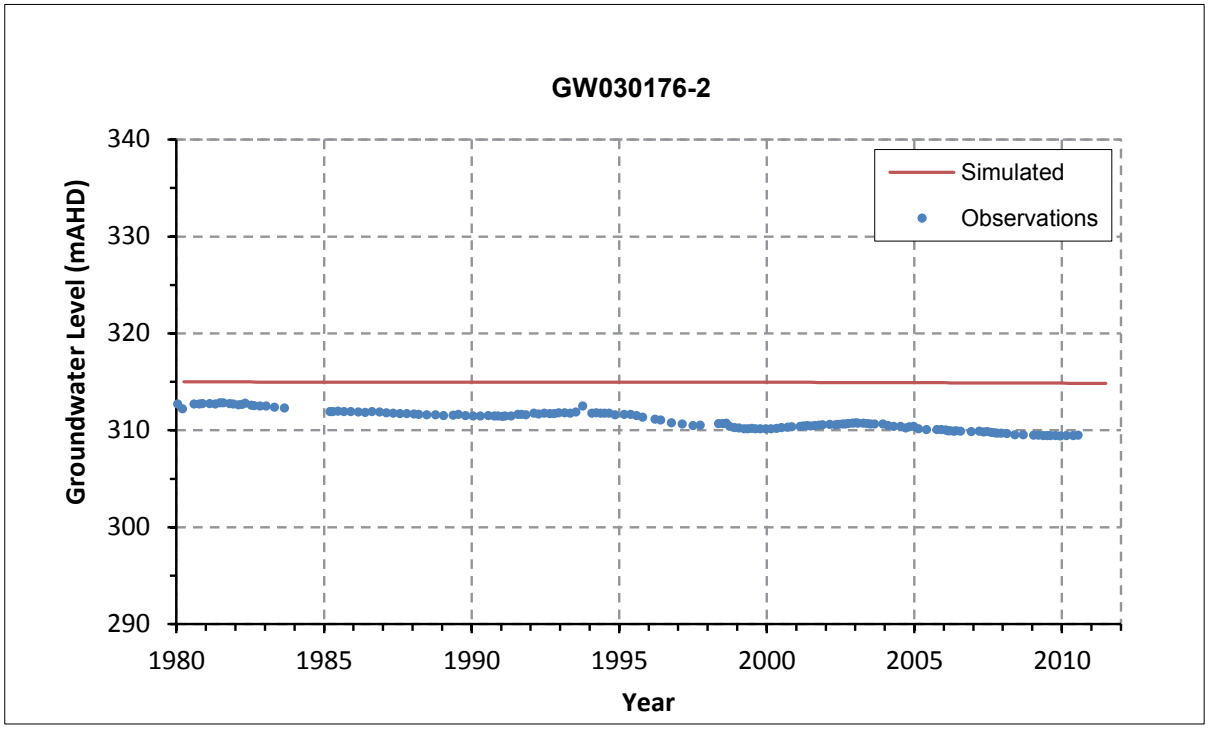

GW030088-2
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

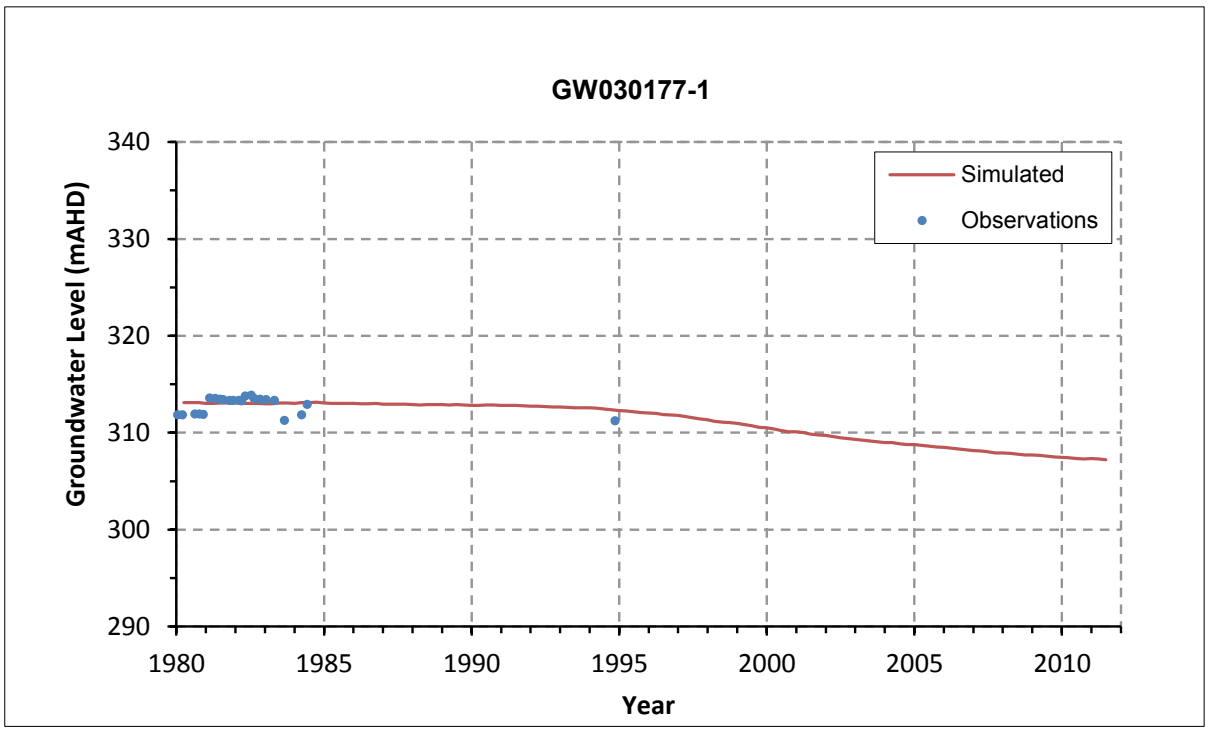

GW030088-3
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

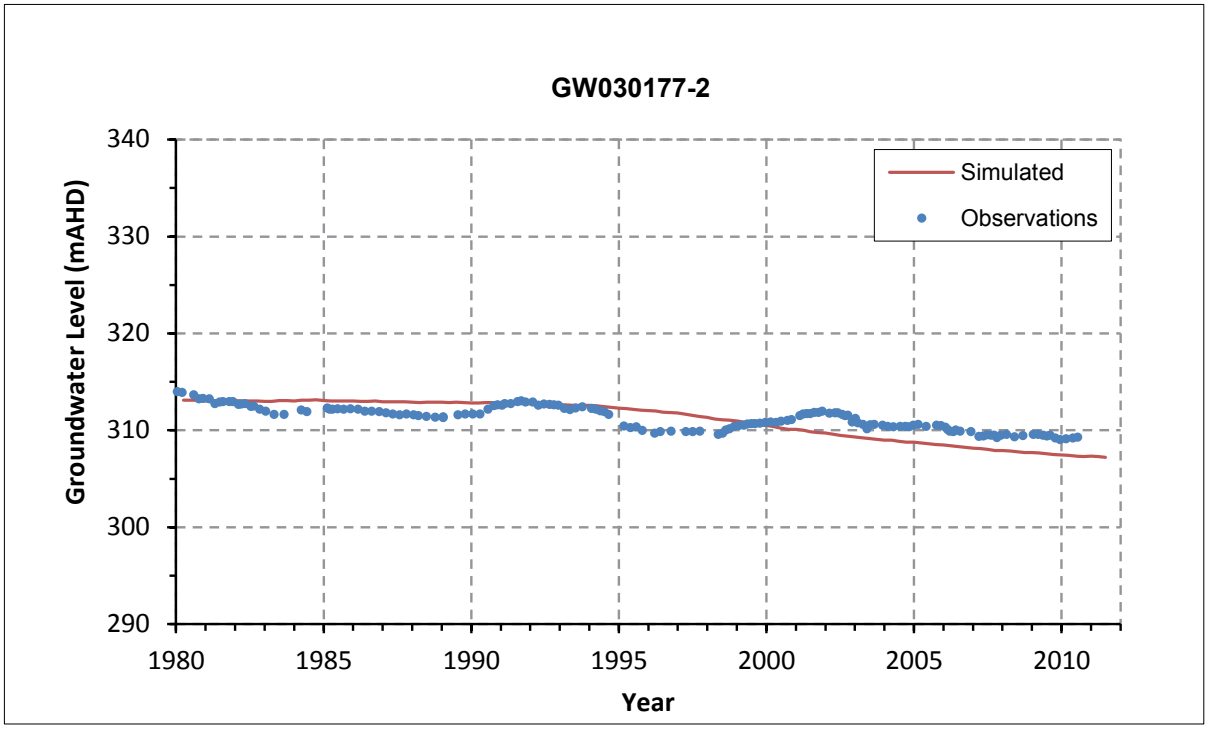

GW030175-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

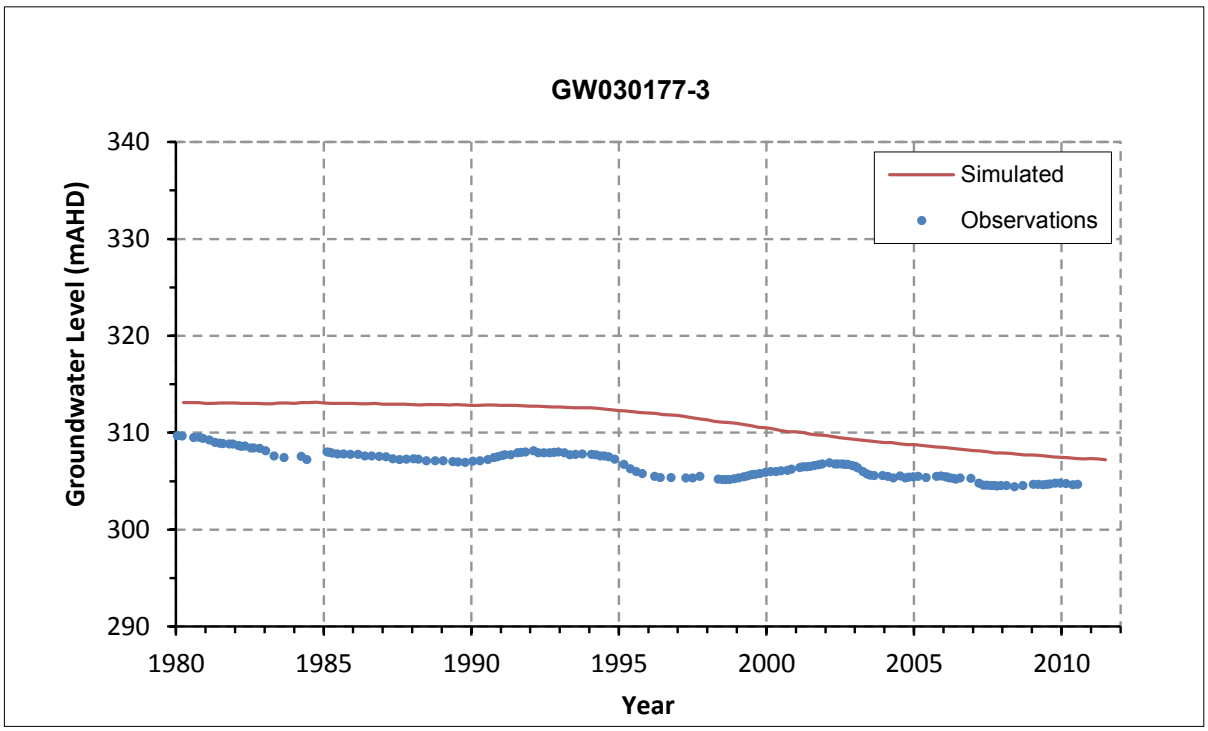

GW030175-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

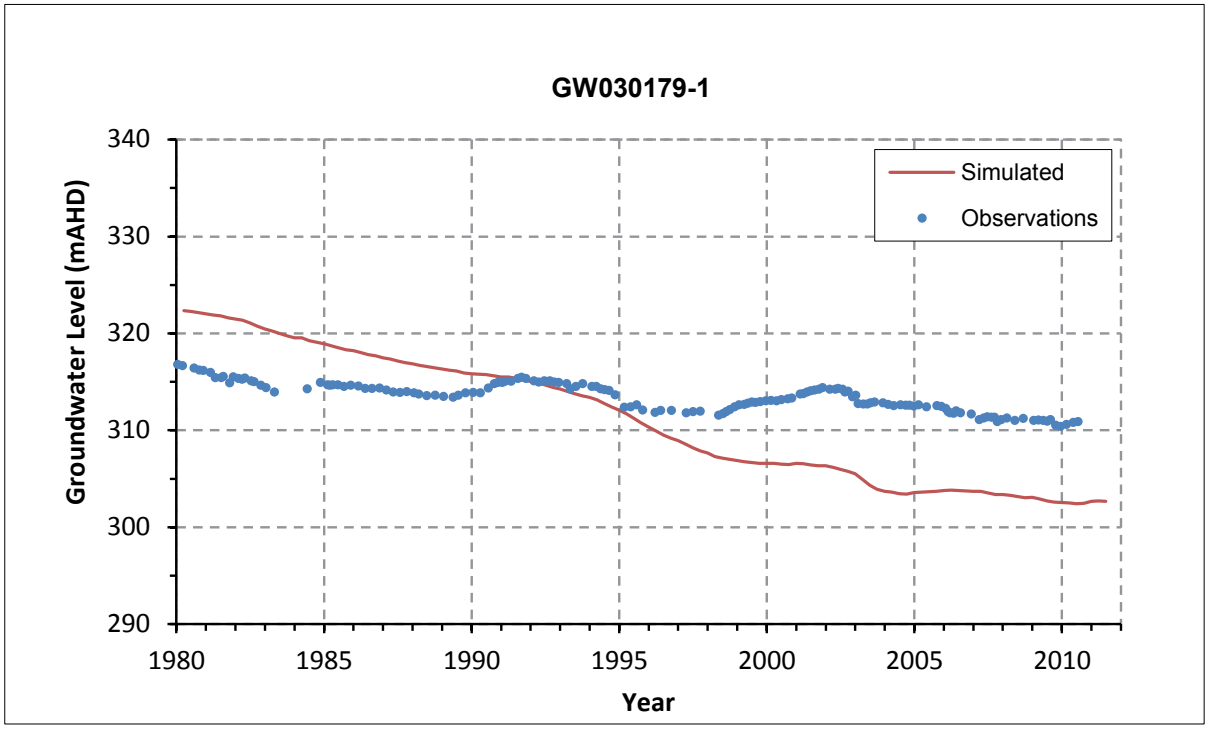

GW030176-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

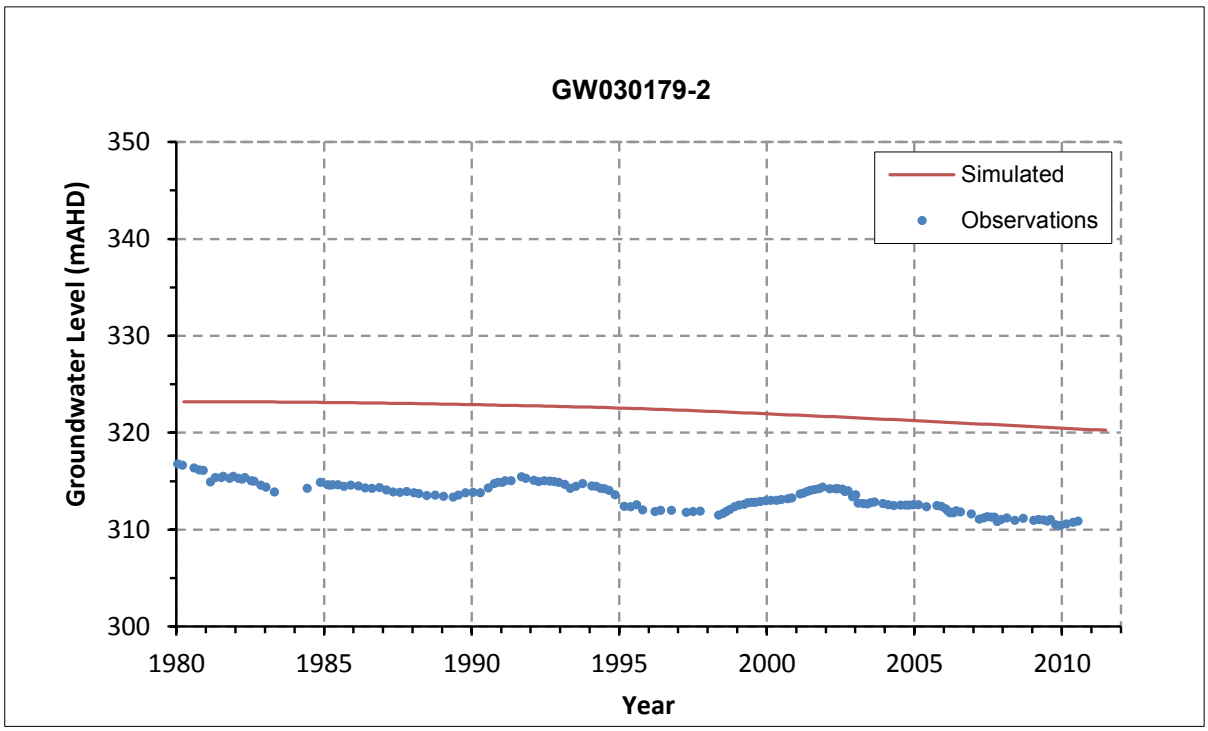

GW030176-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

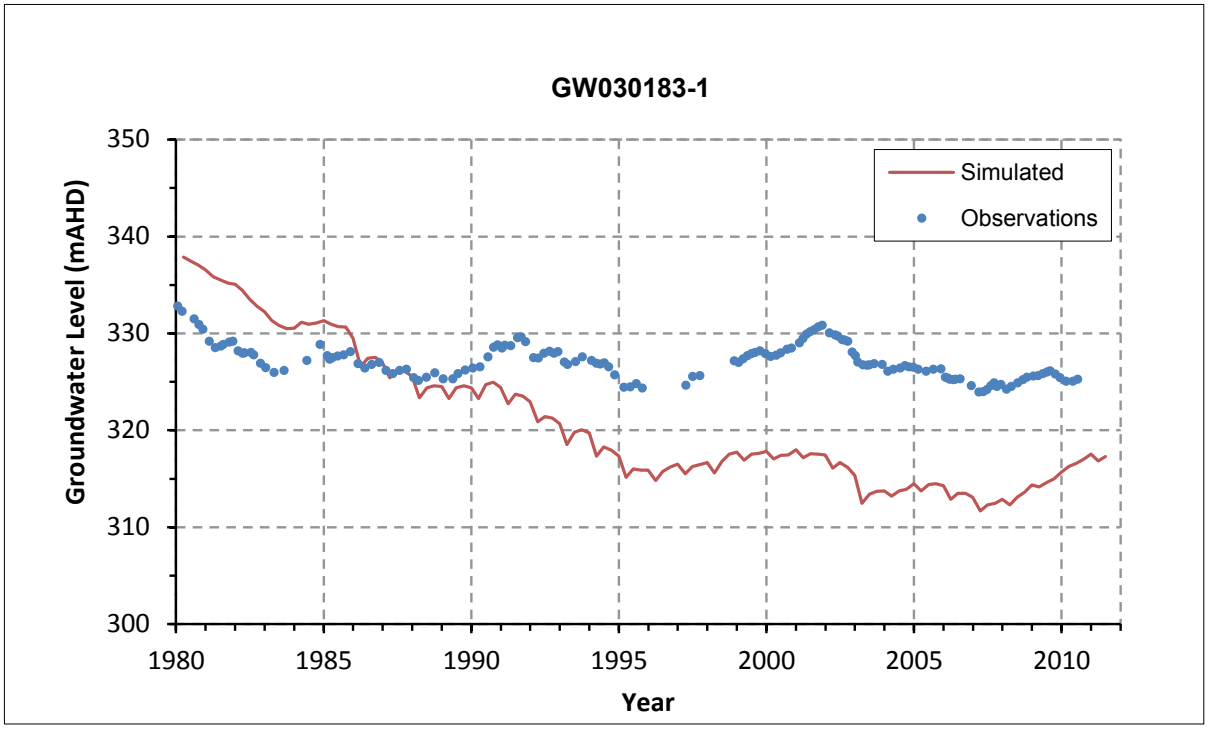

GW030177-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

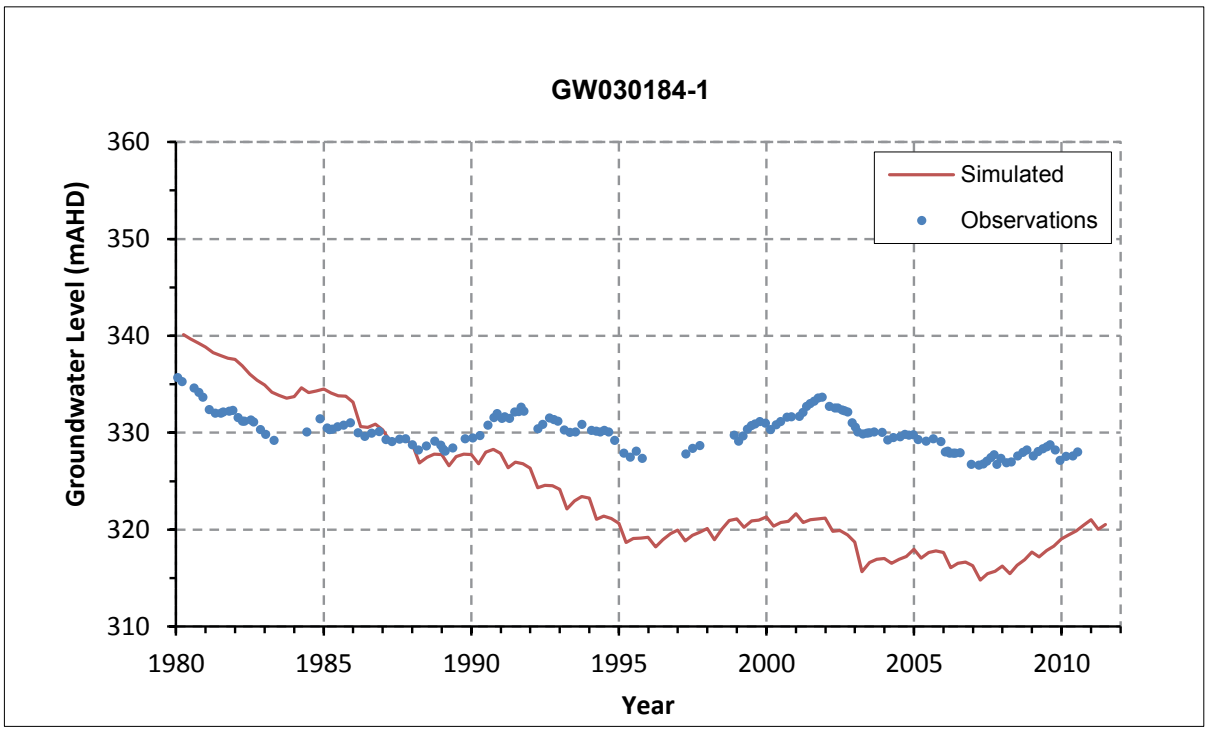

GW030177-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

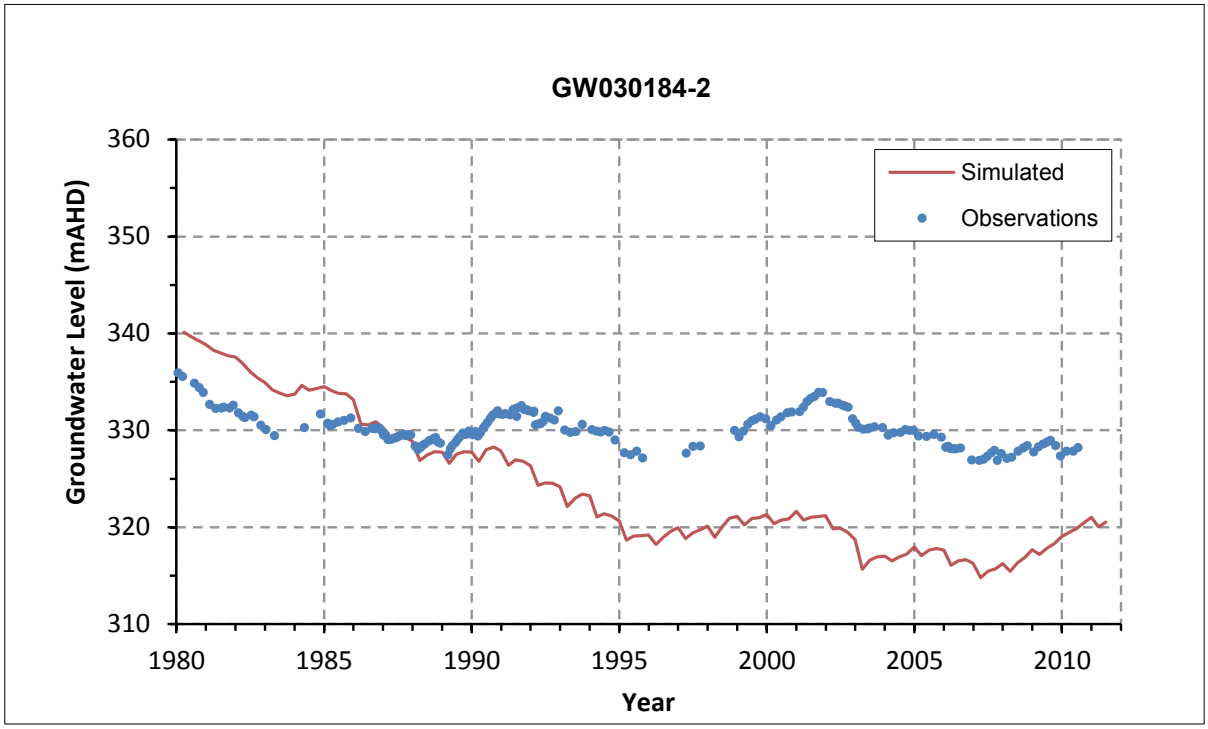

GW030177-3
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

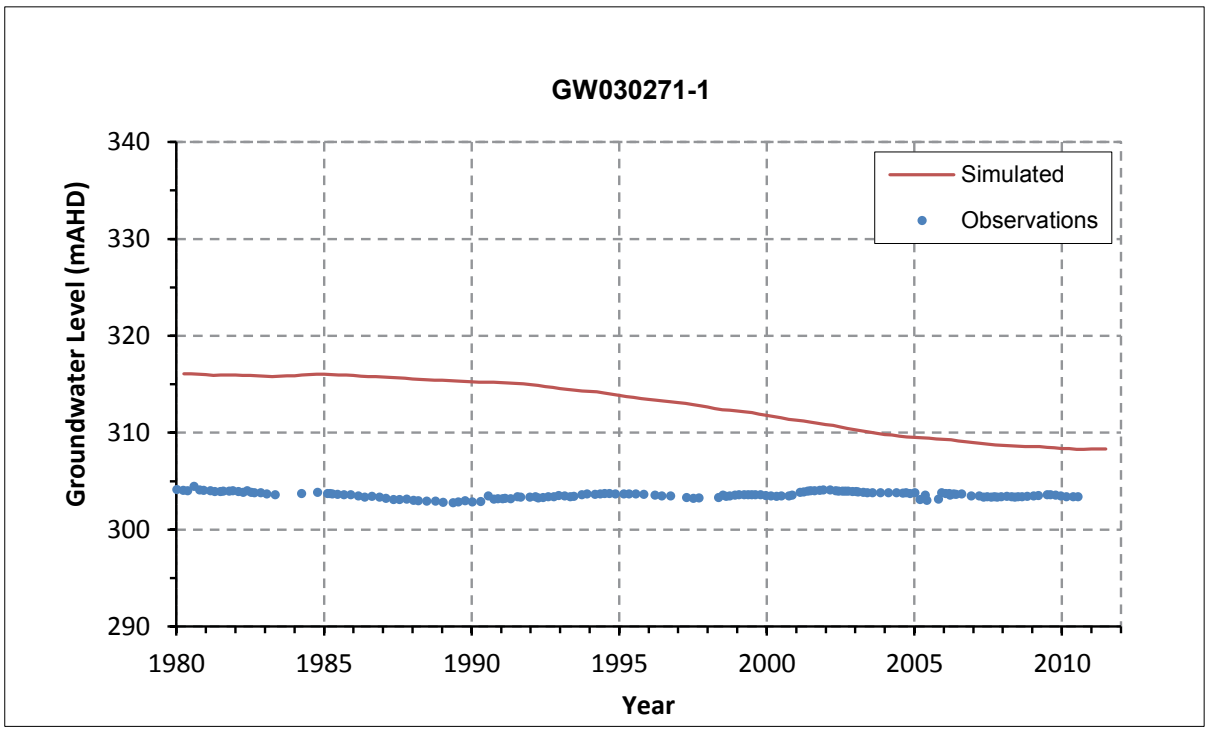

GW030179-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

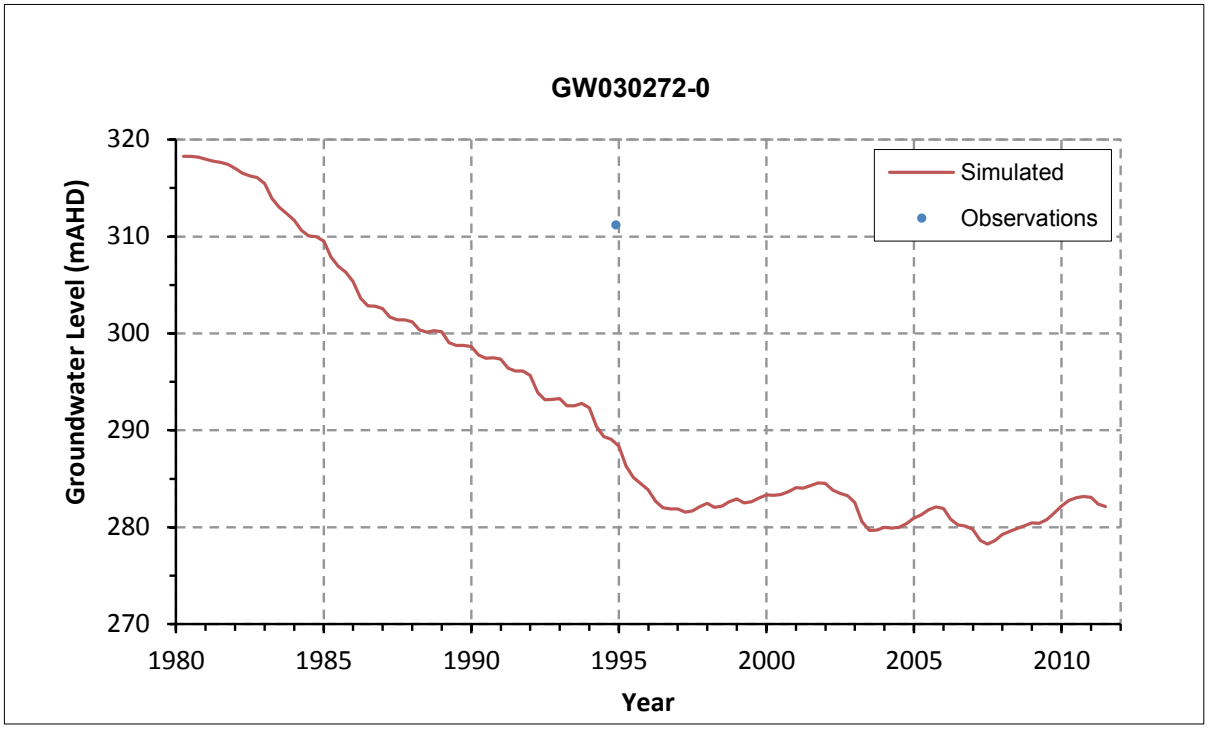

GW030179-2
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

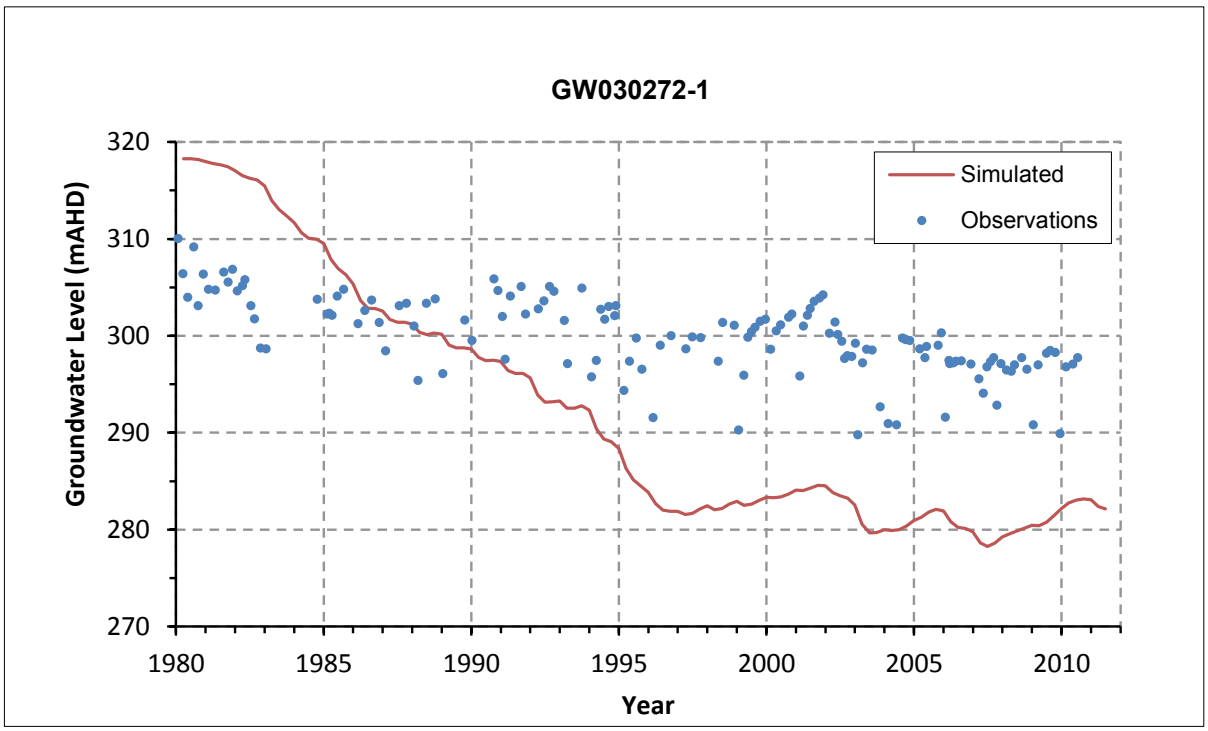

GW030183-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

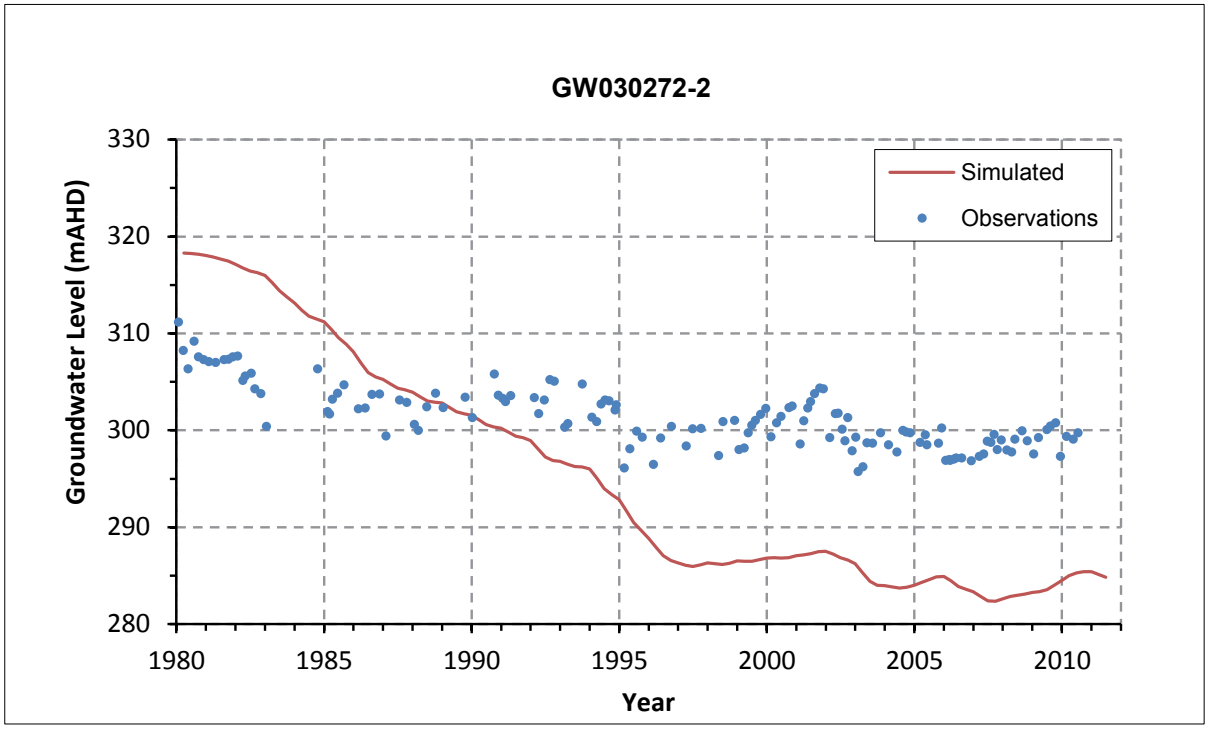

GW030184-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

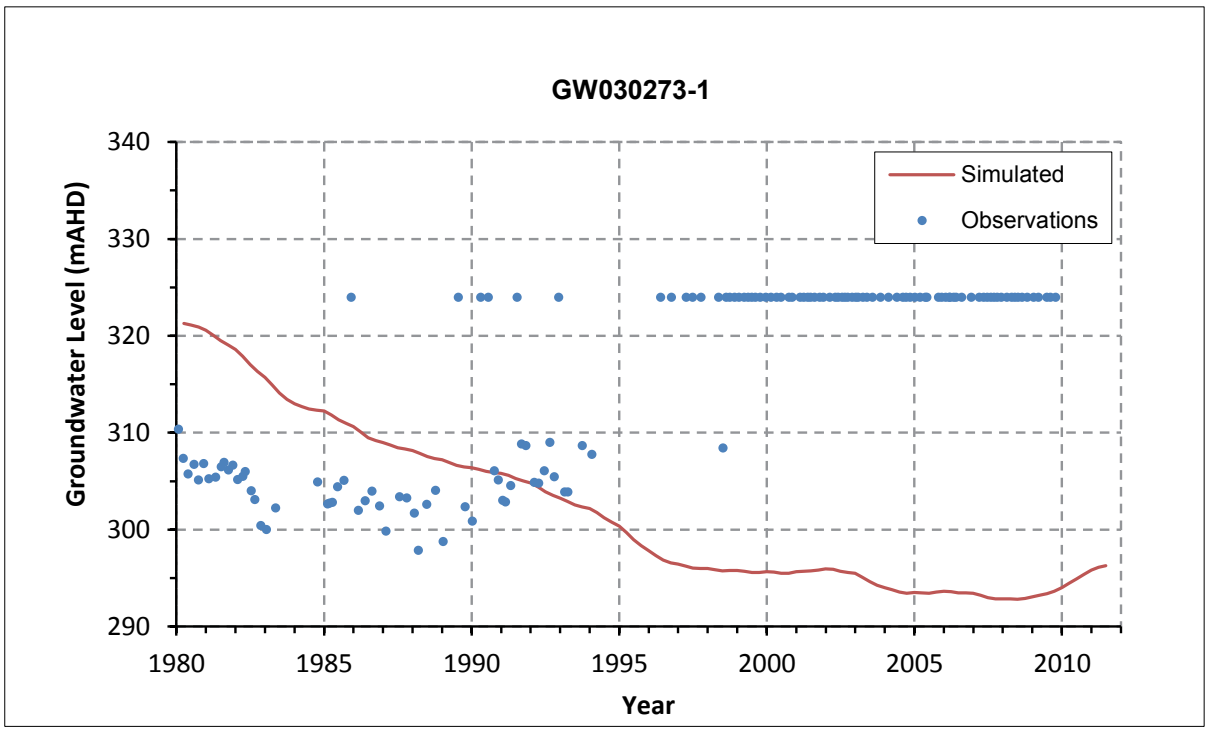

GW030184-2
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

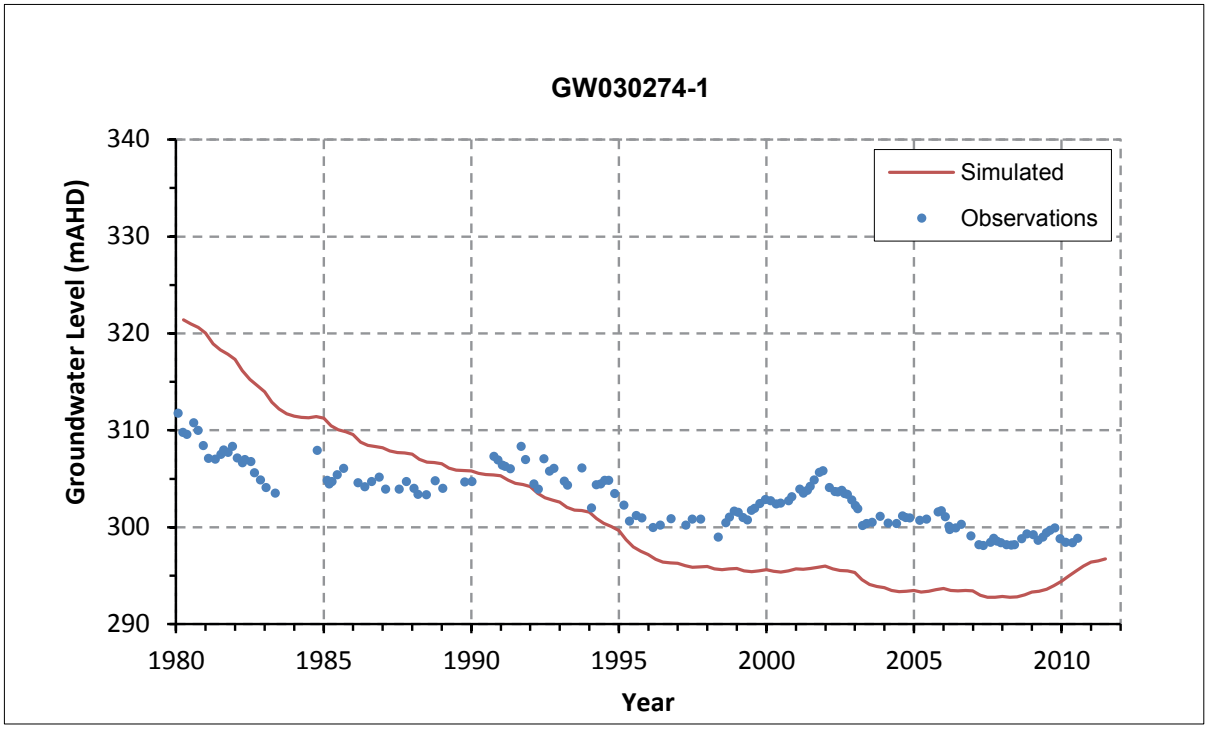

GW030271-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

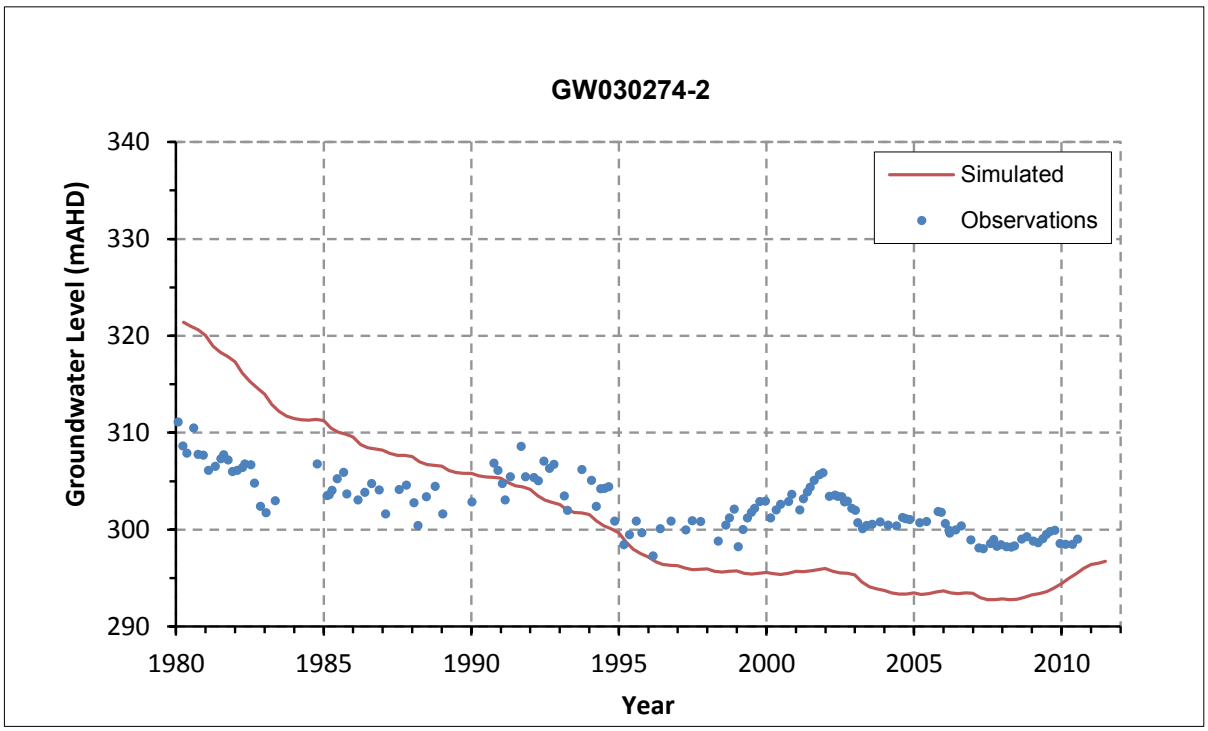

GW030272-0
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

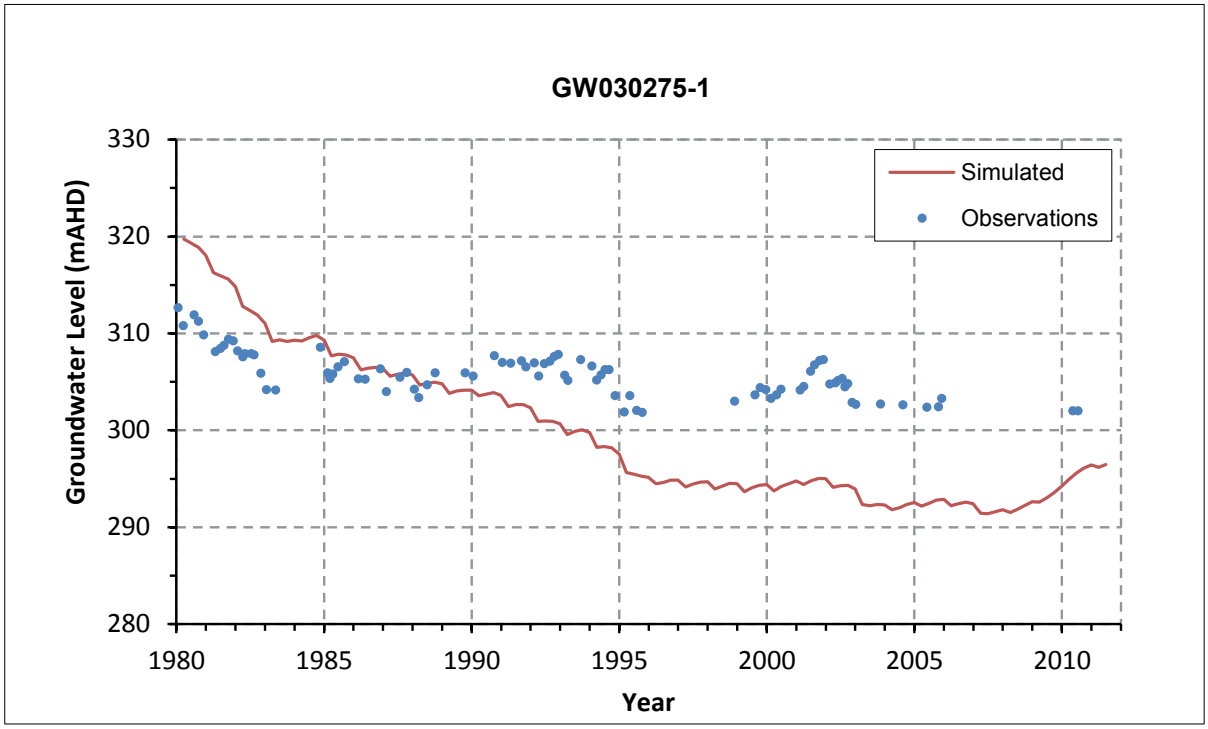

GW030272-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

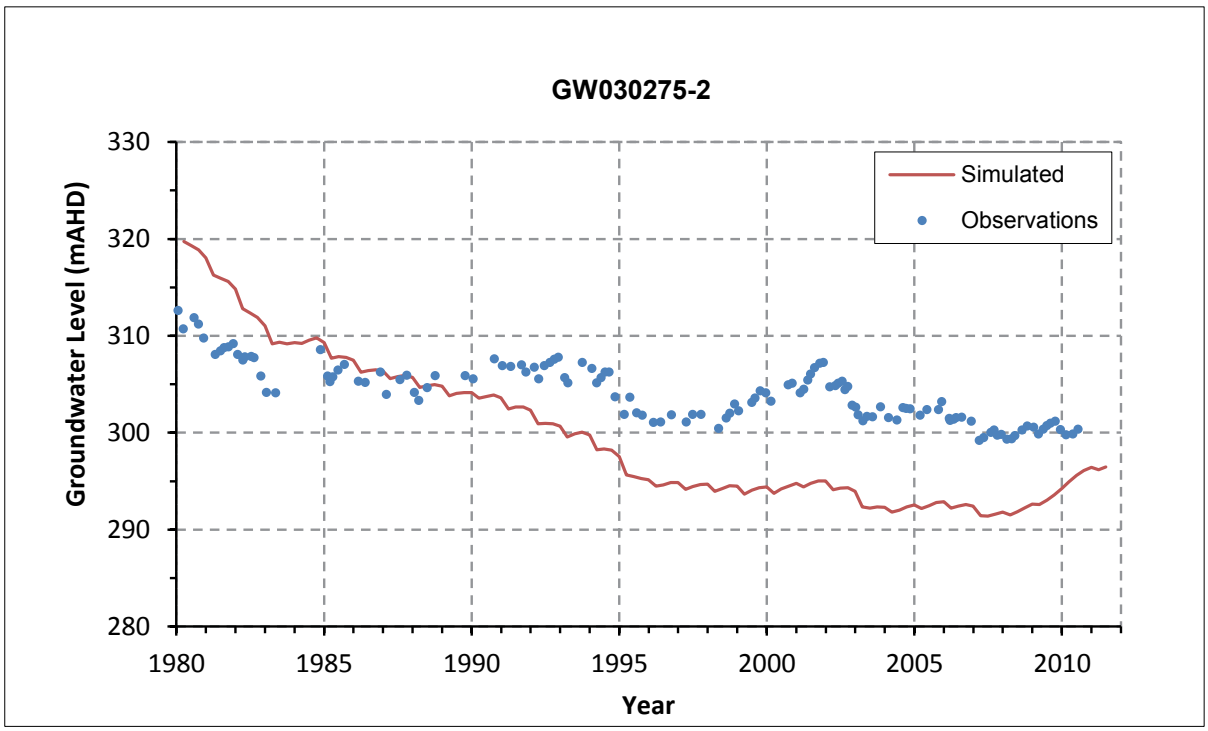

GW030272-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

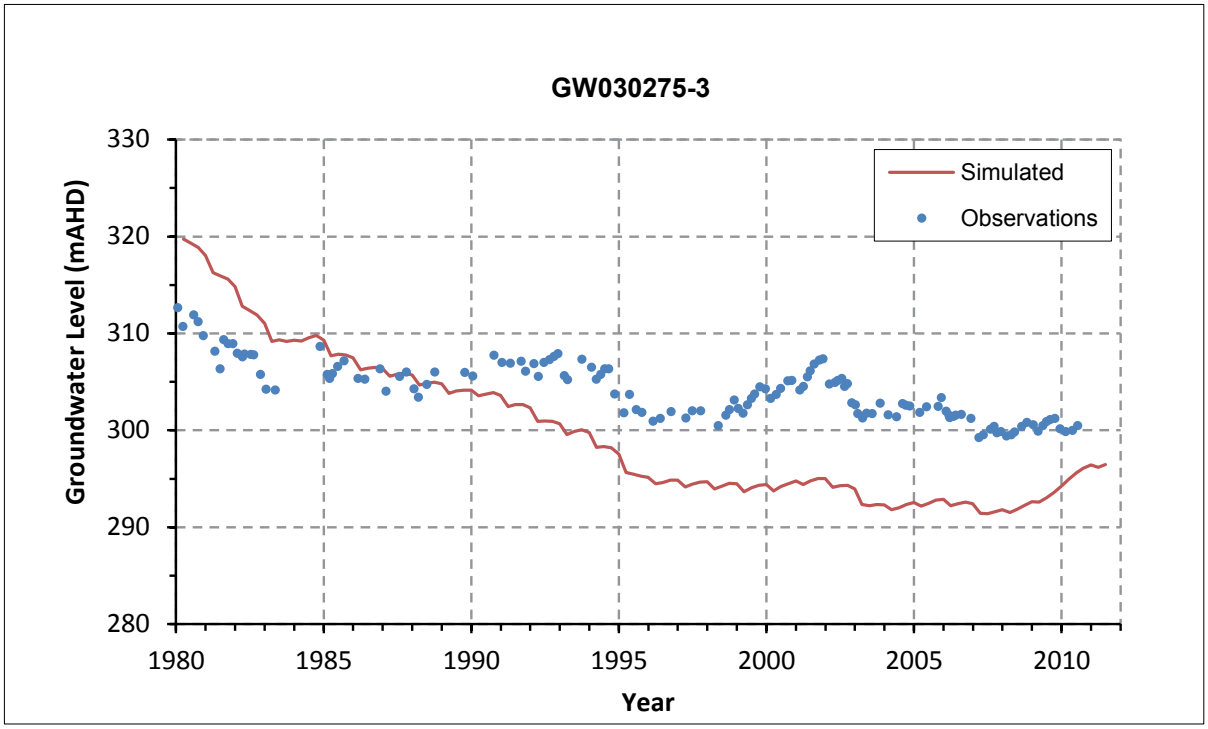

GW030273-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

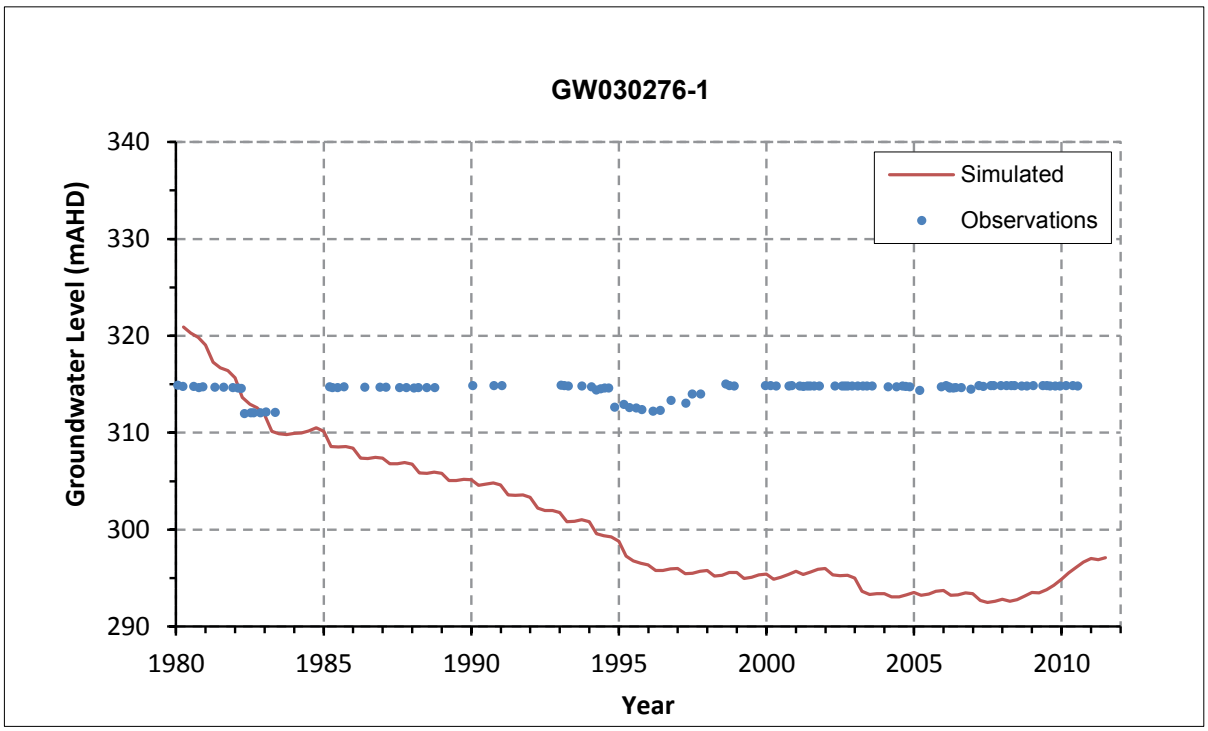

GW030274-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

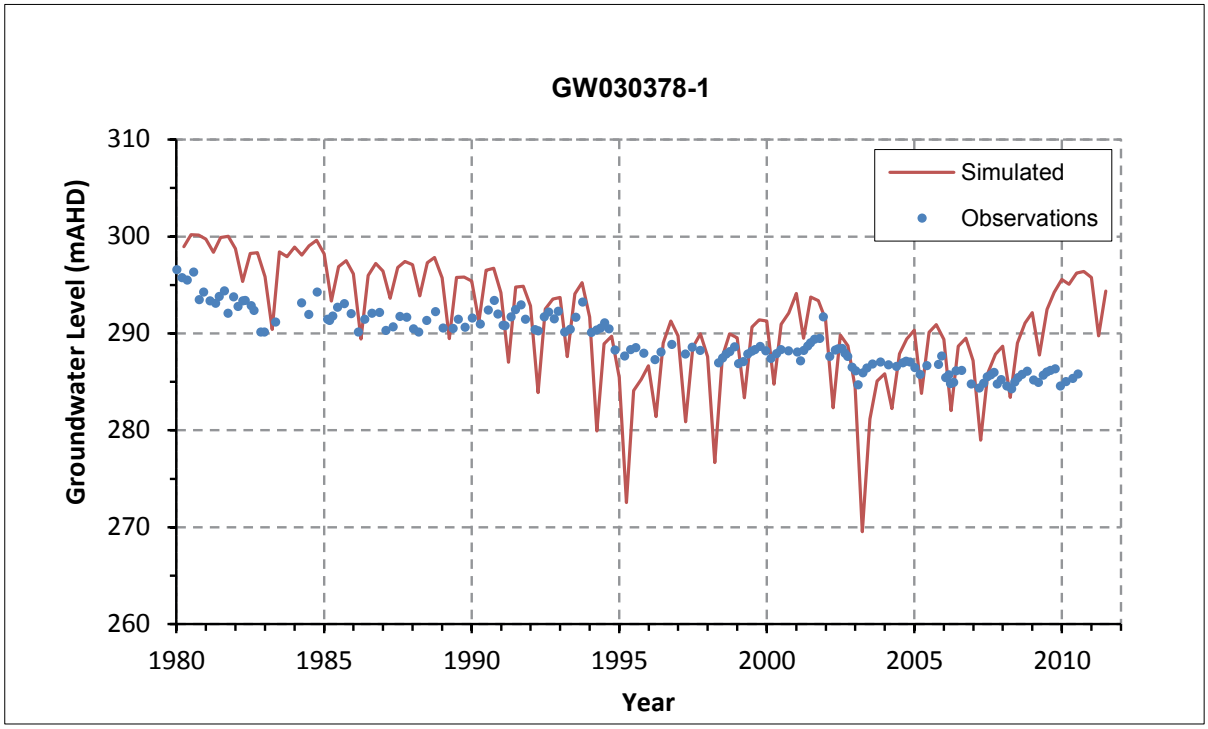

GW030274-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

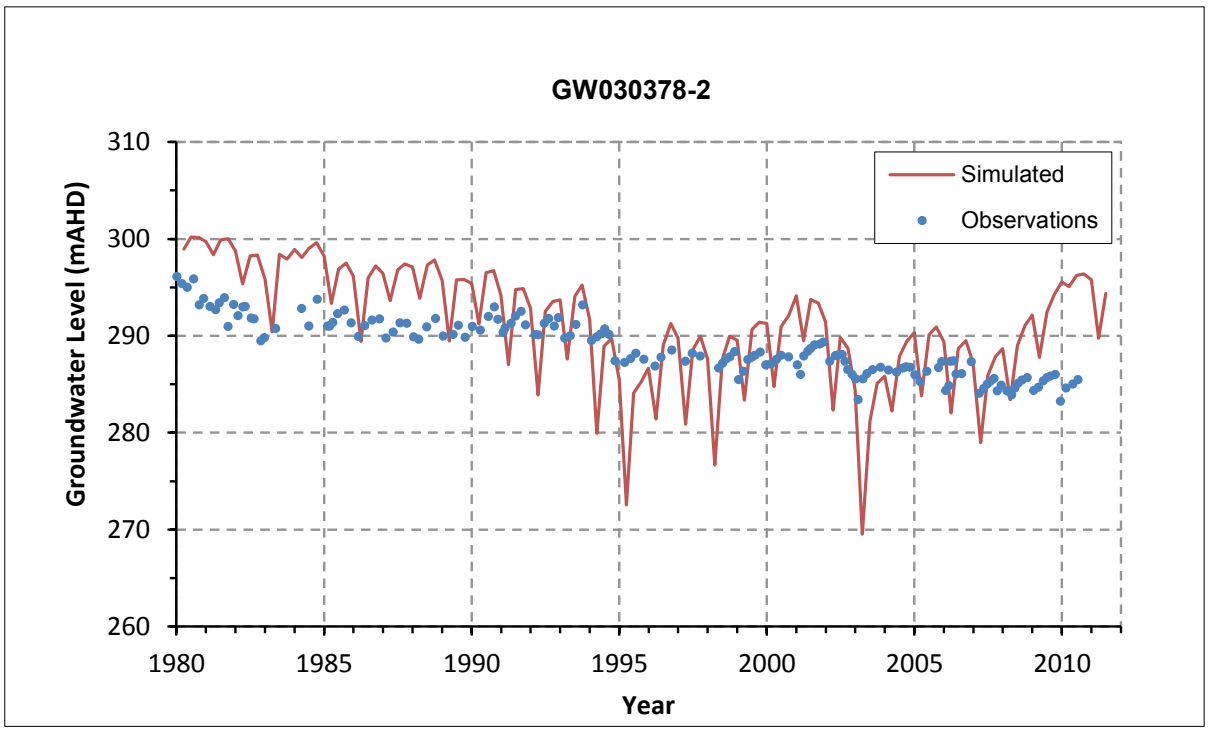

GW030275-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

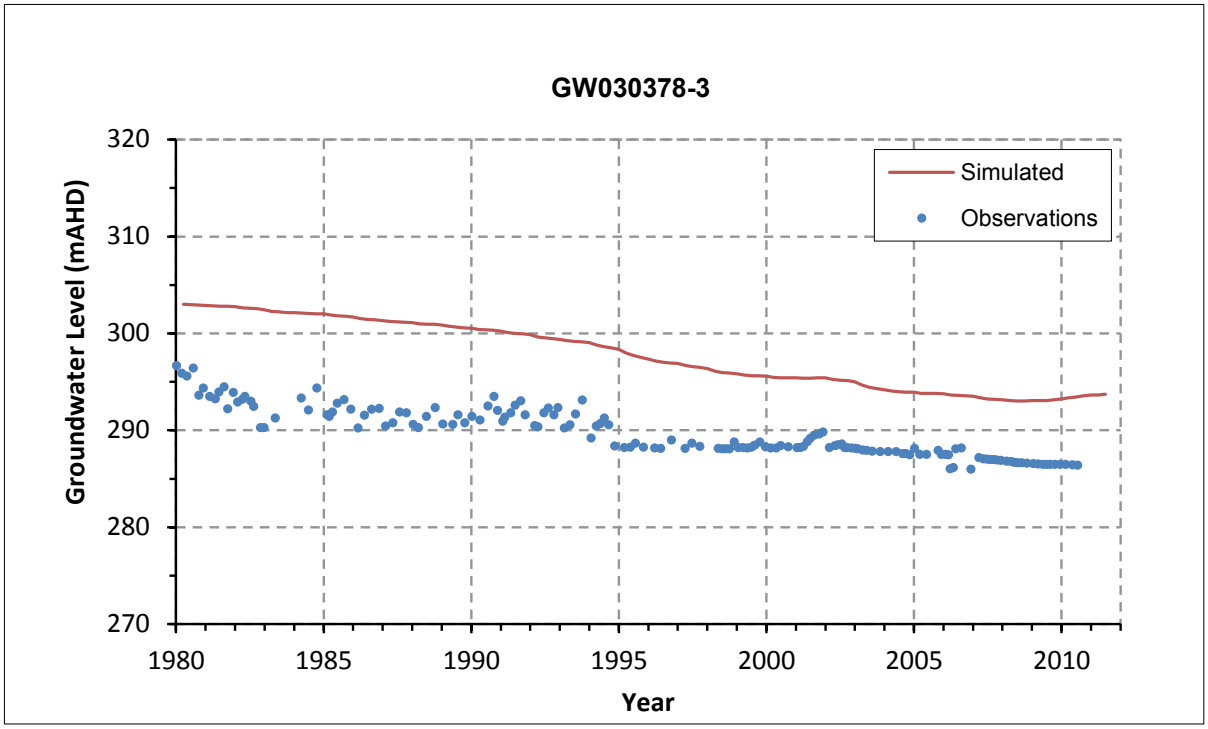

GW030275-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

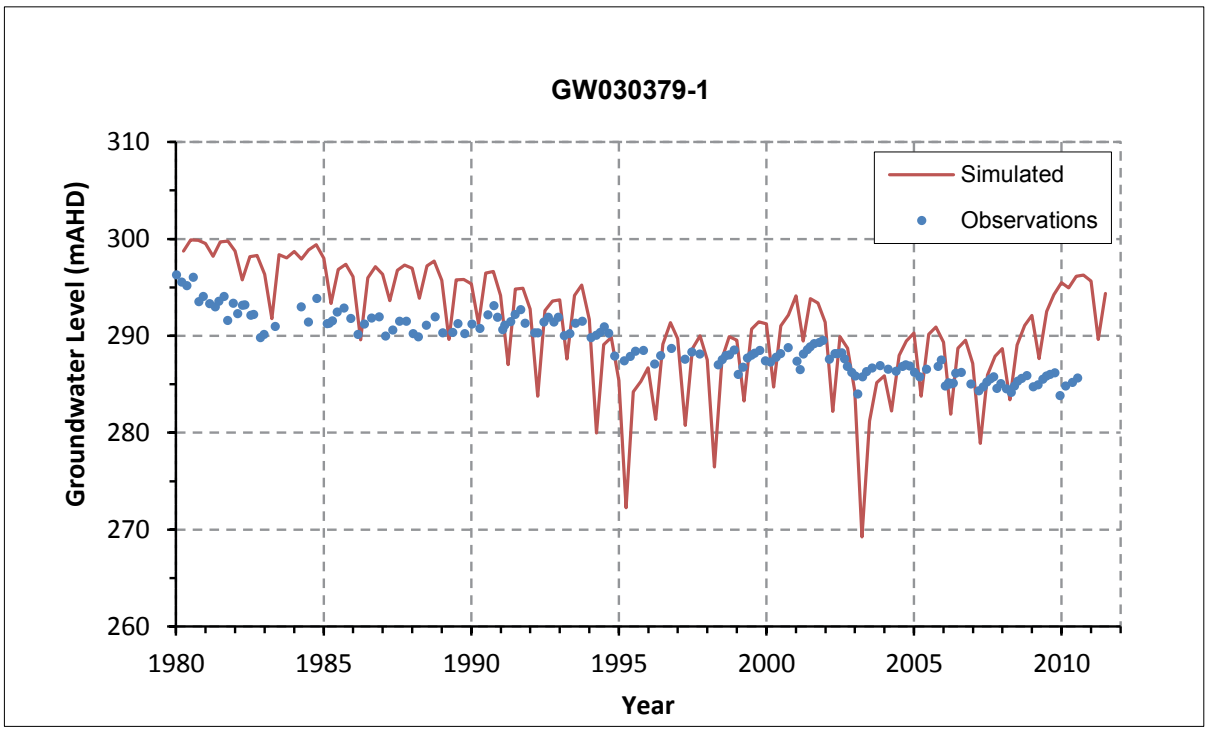

GW030275-3
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

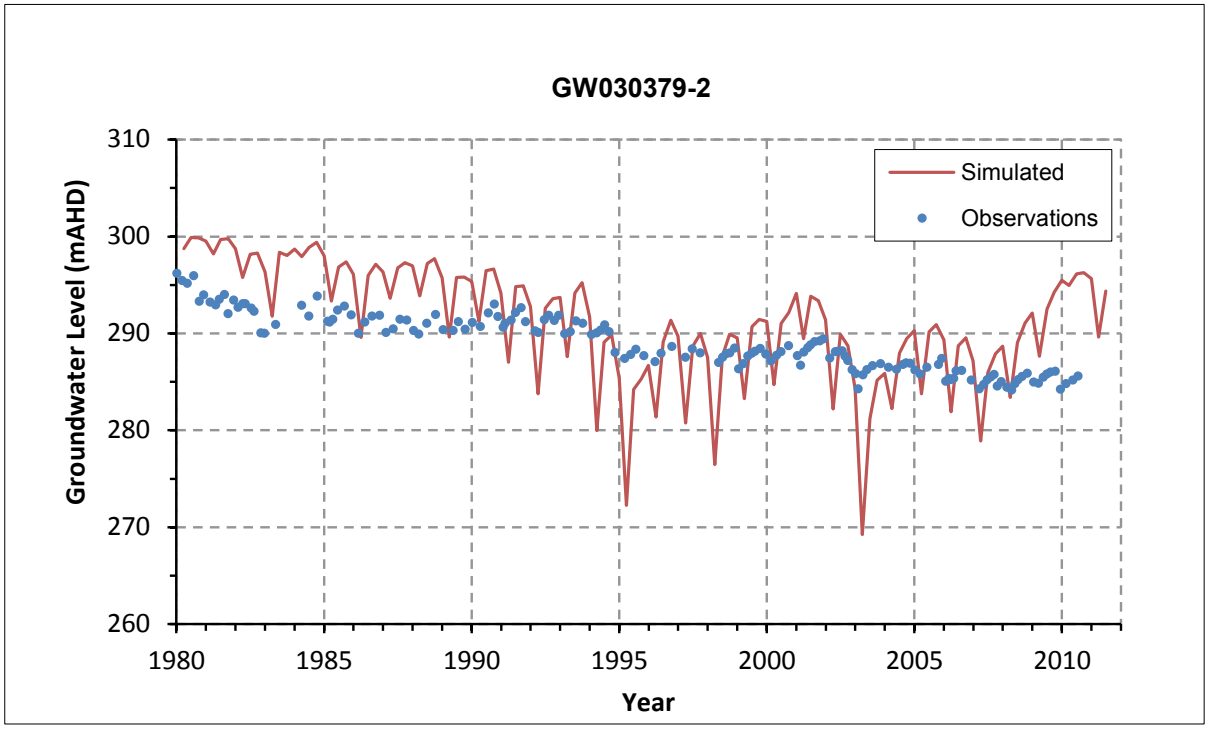

GW030276-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

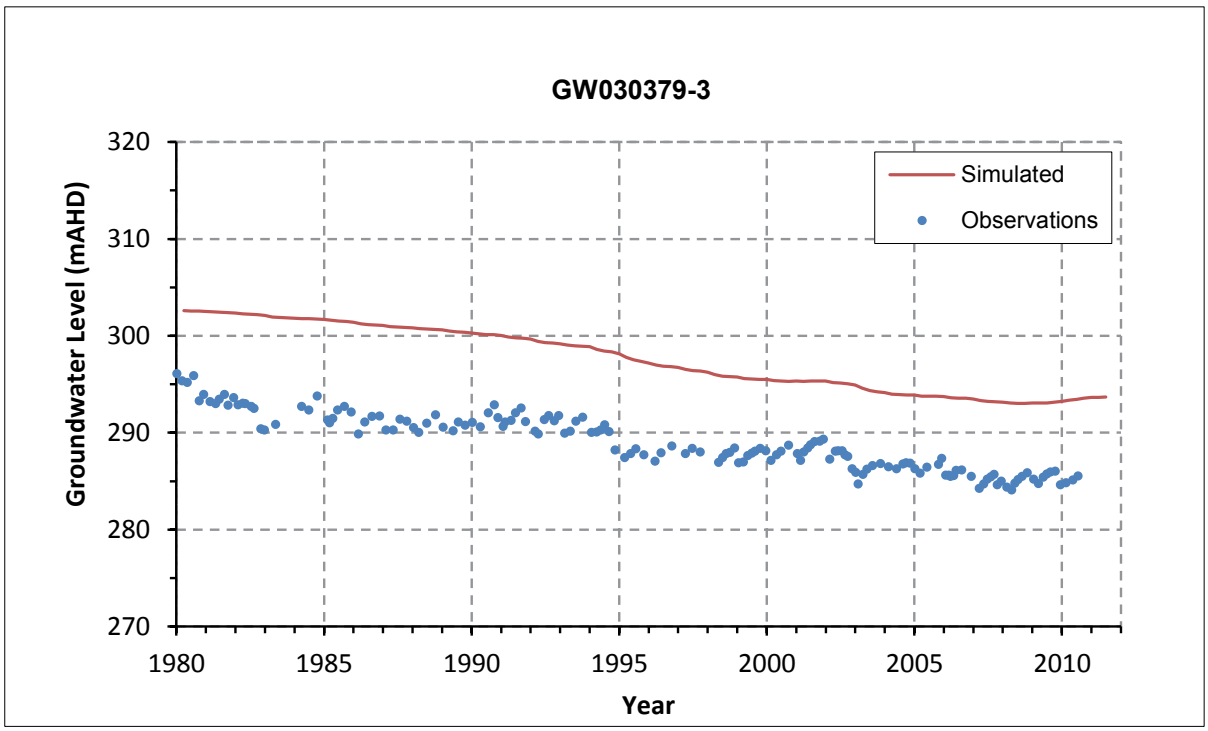

GW030378-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

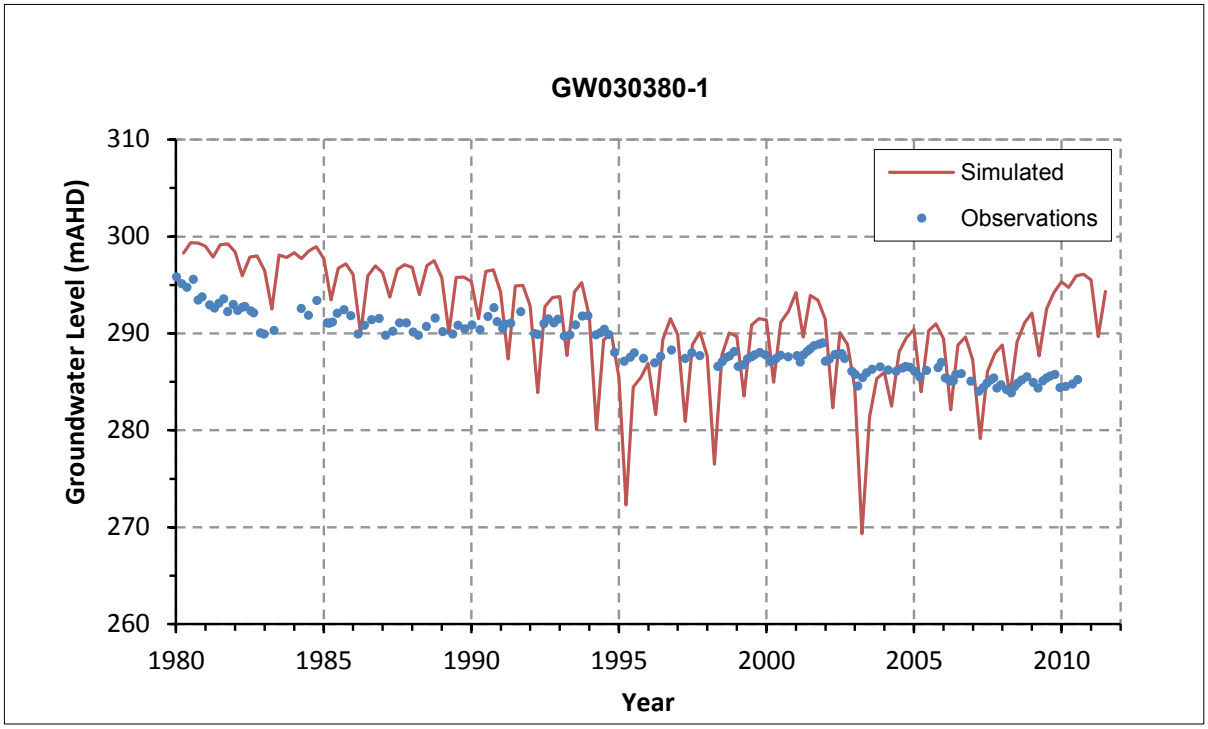

GW030378-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

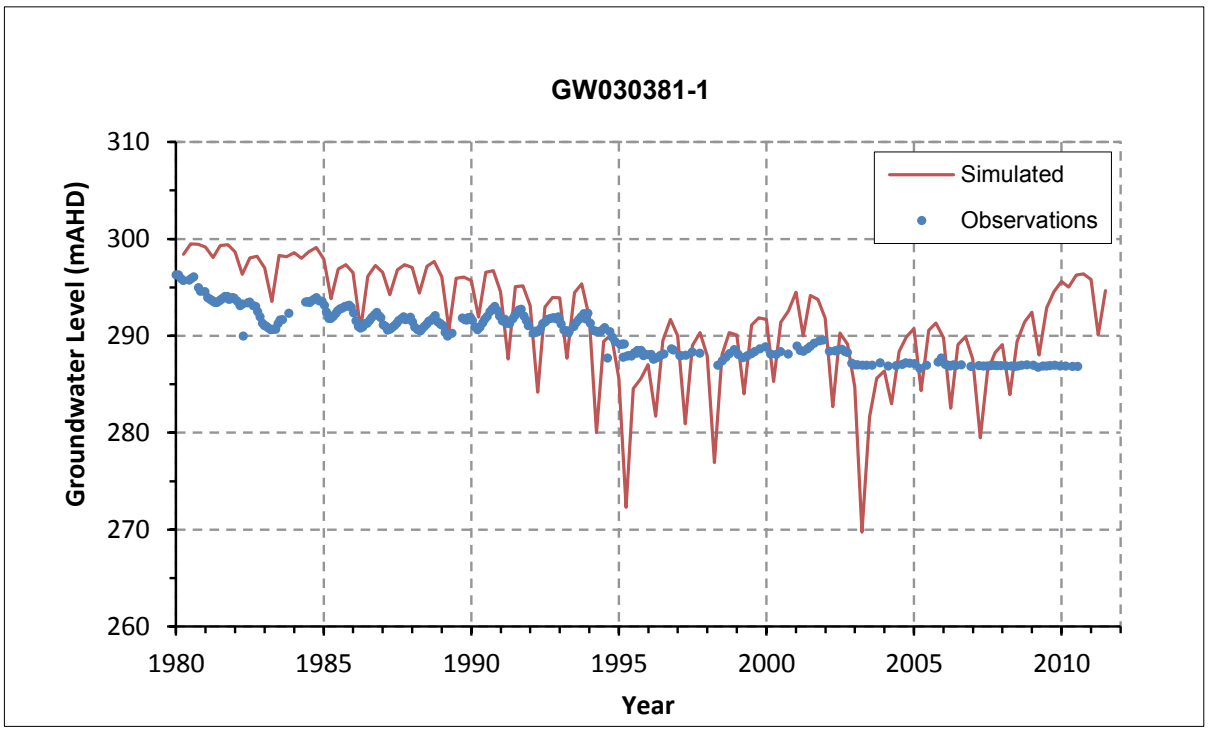

GW030378-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

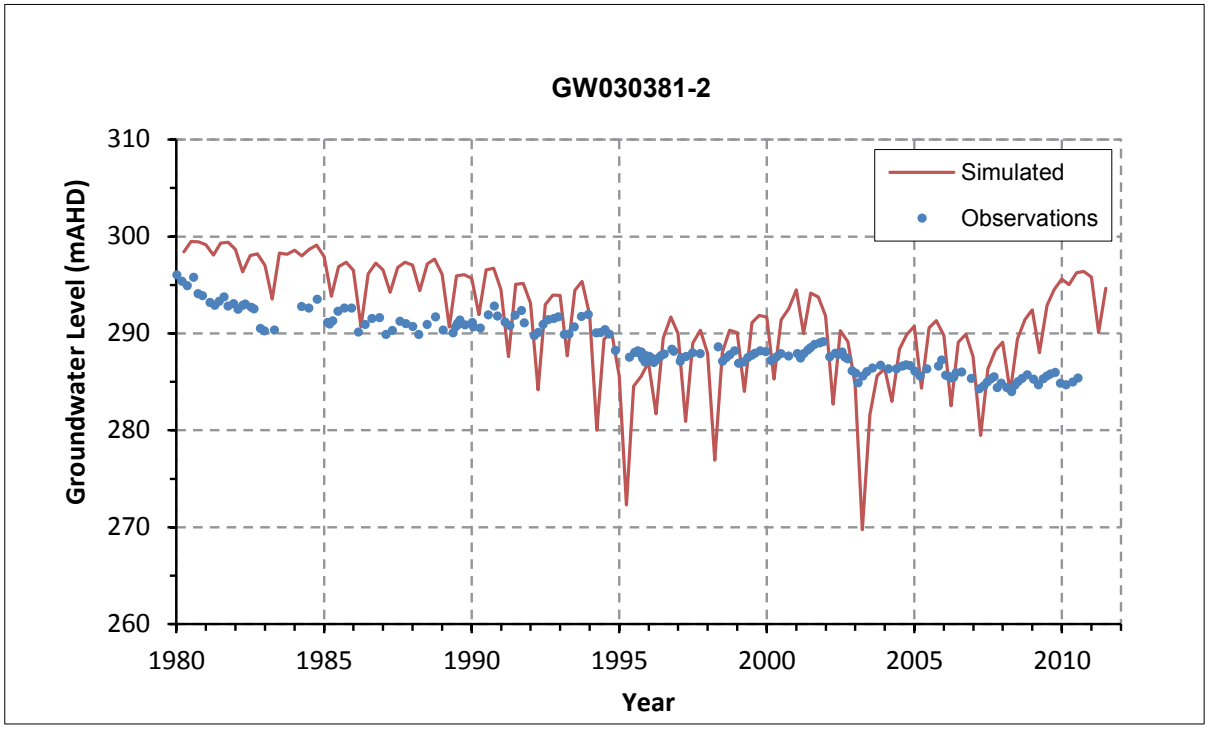

GW030379-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

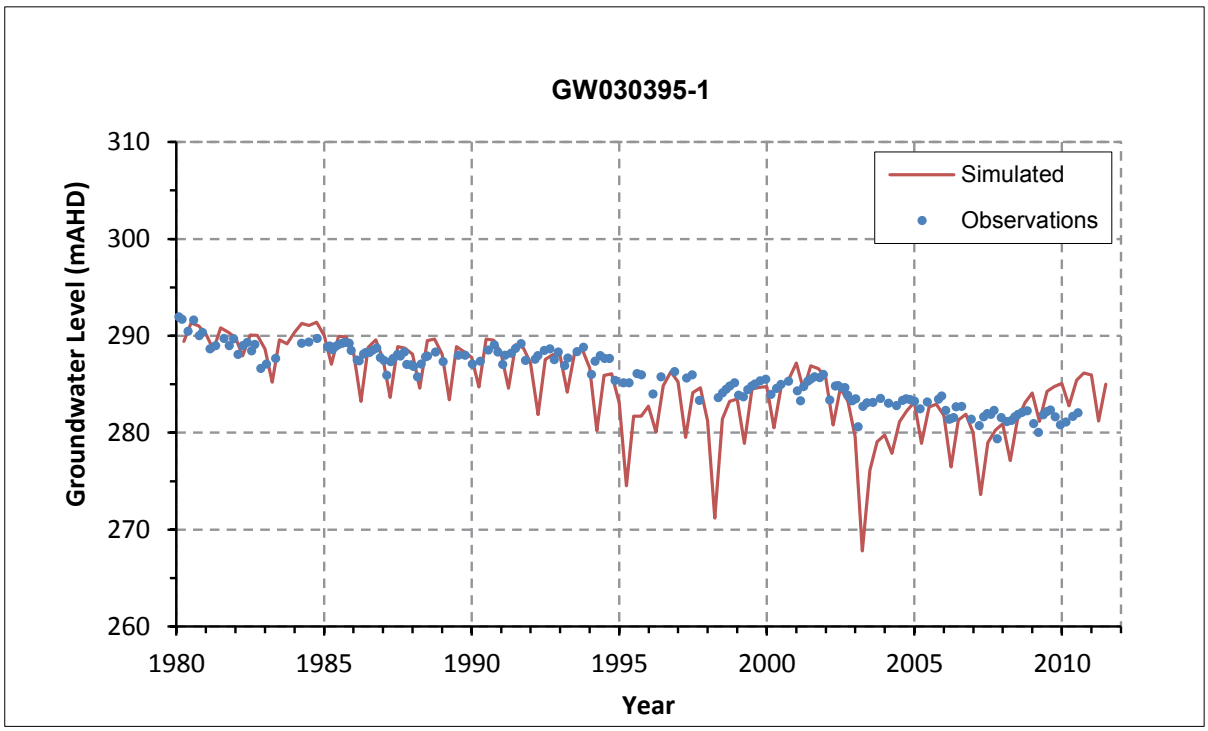

GW030379-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

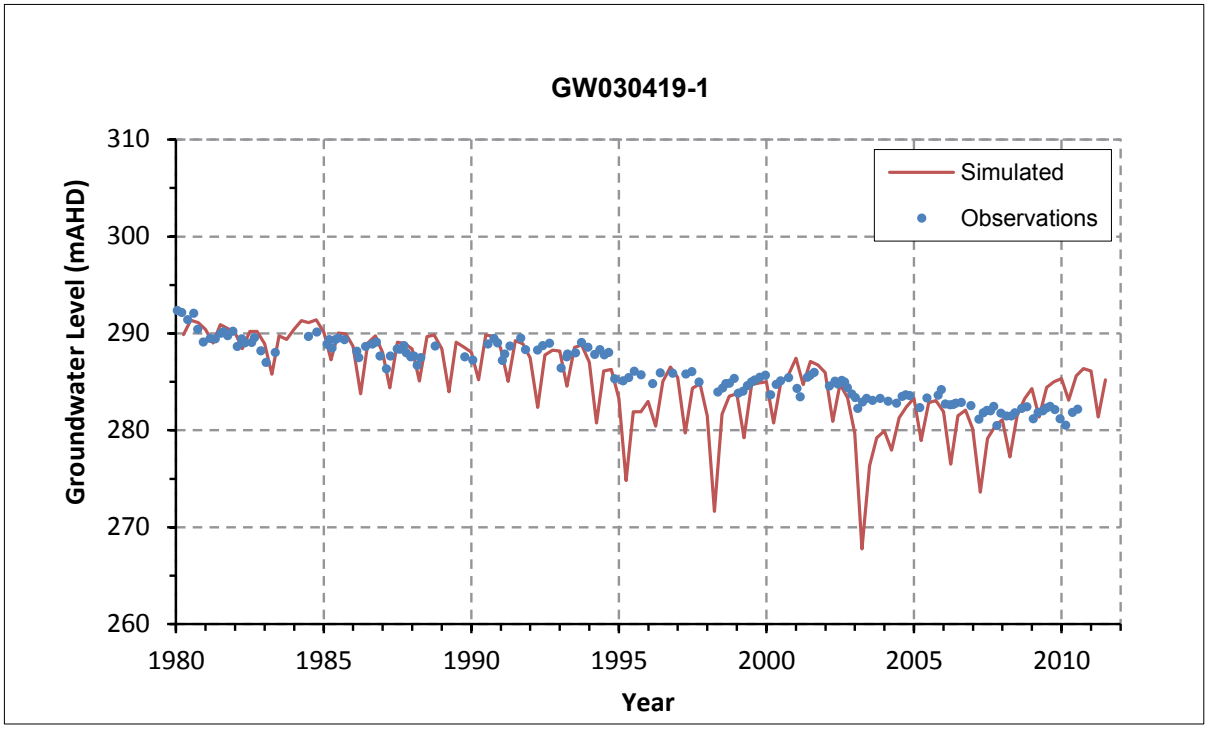

GW030379-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

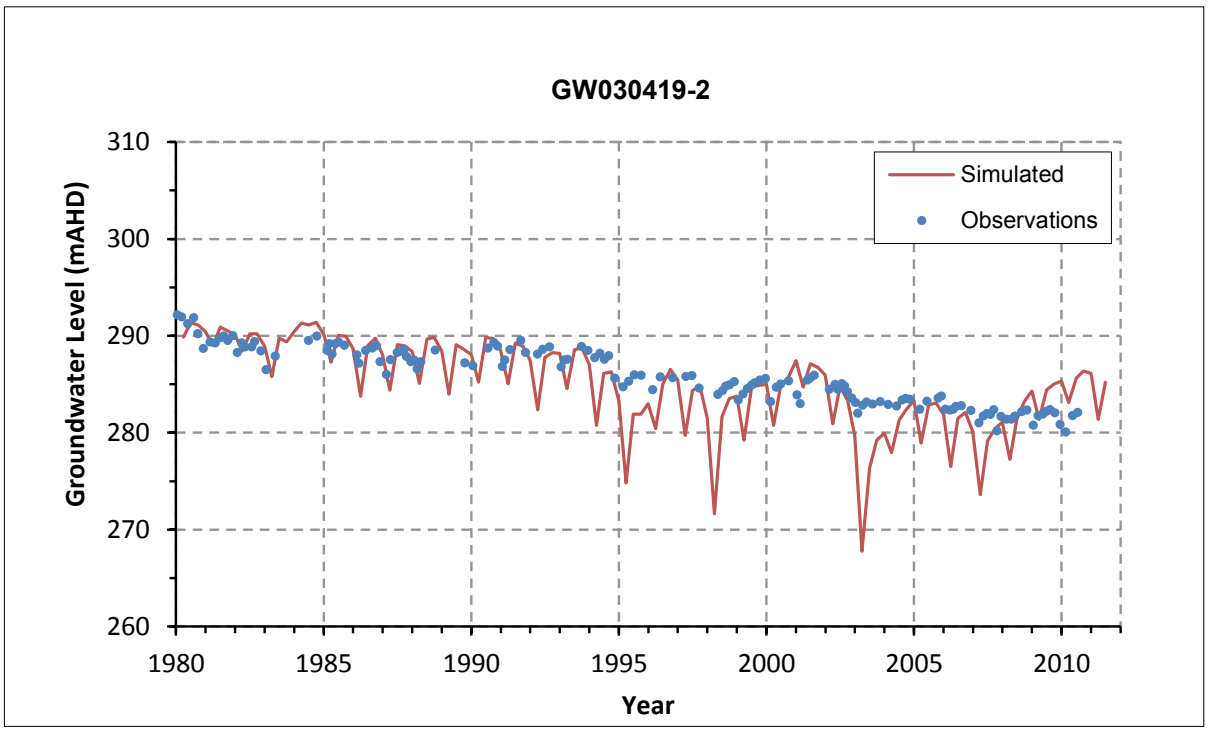

GW030380-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

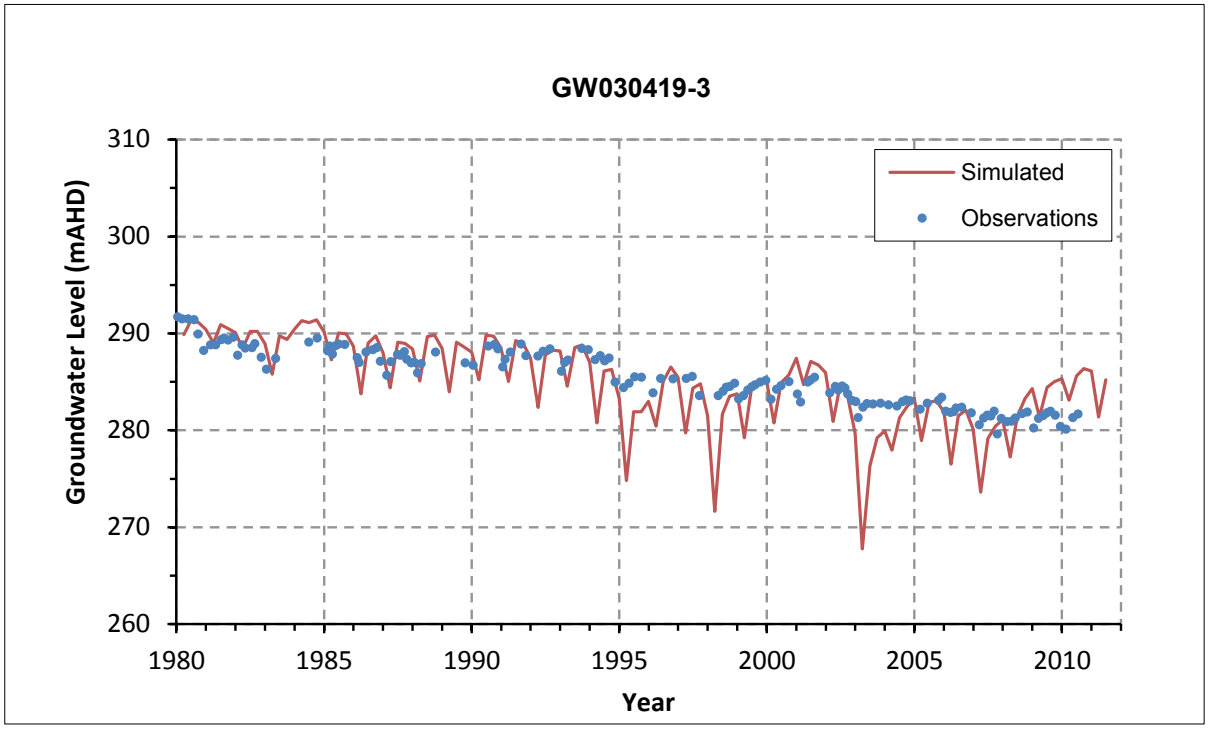

GW030381-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

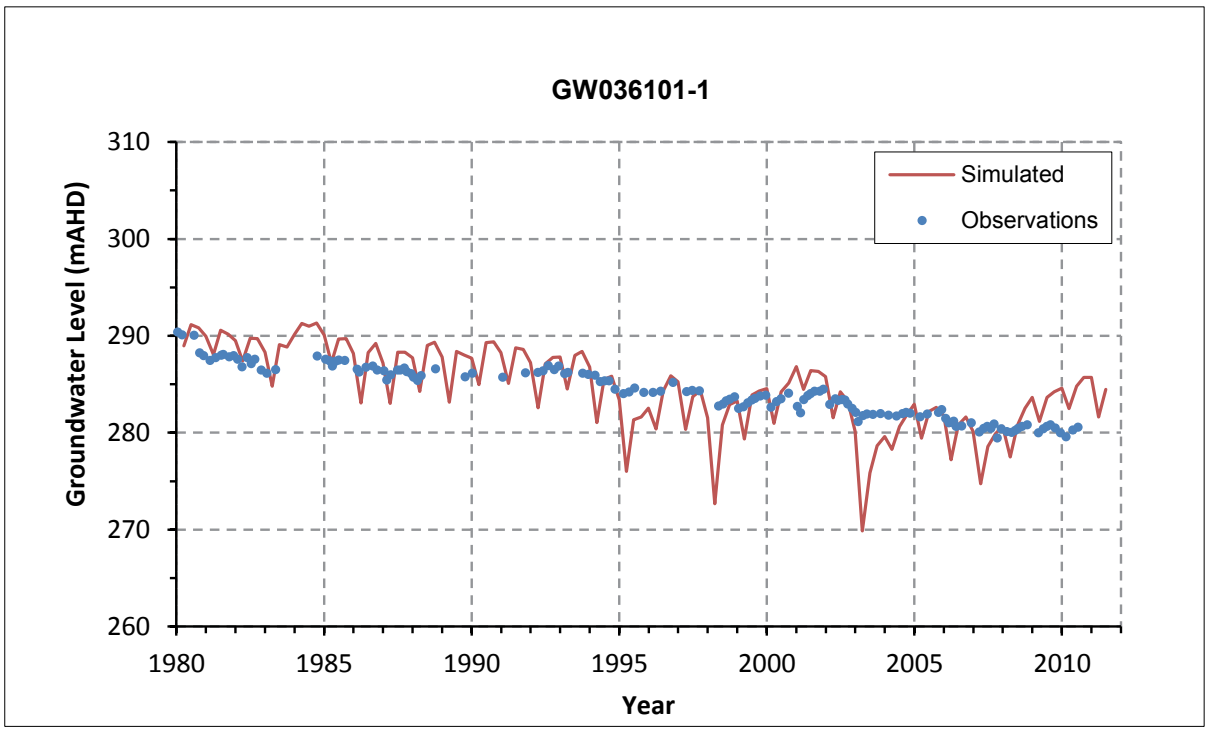

GW030381-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

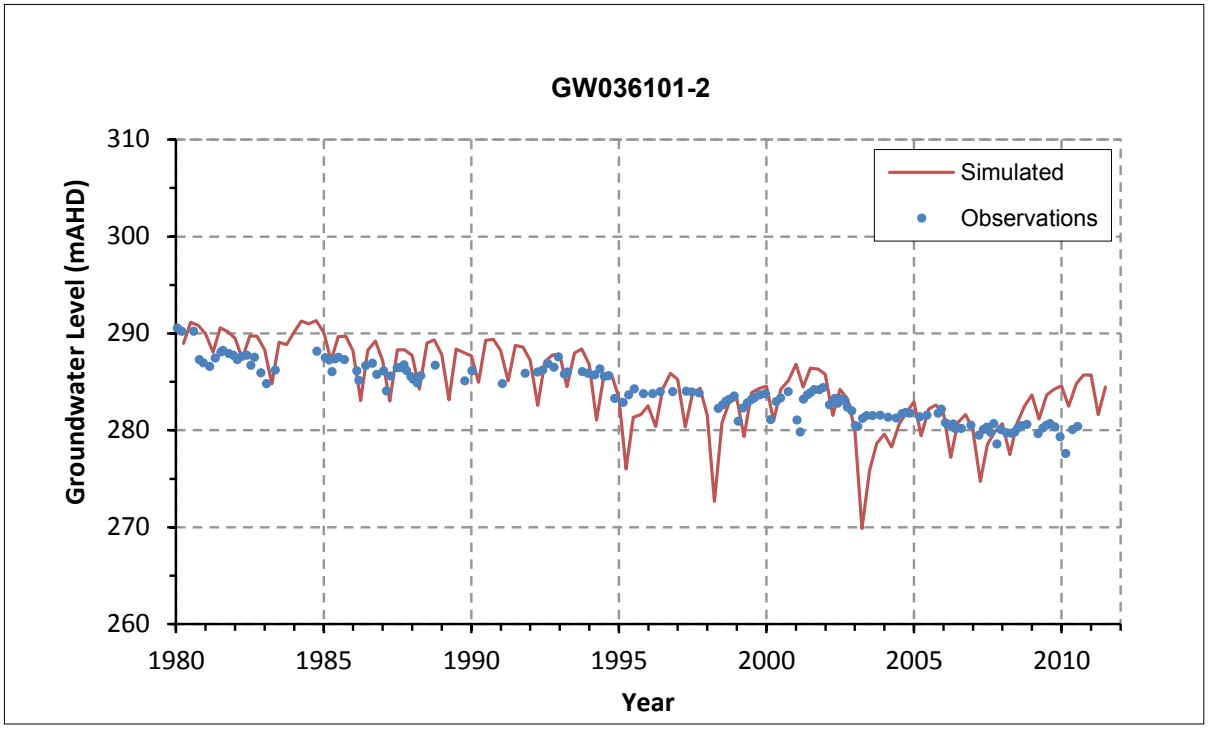

GW030395-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

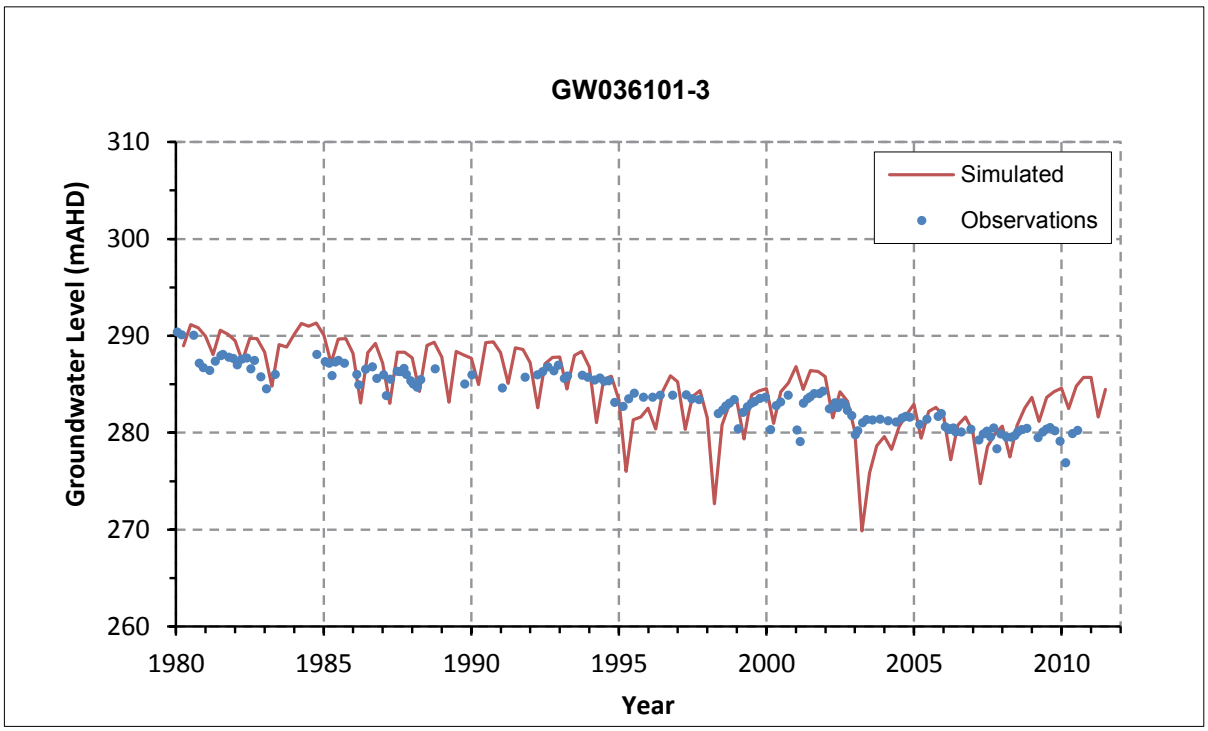

GW030419-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

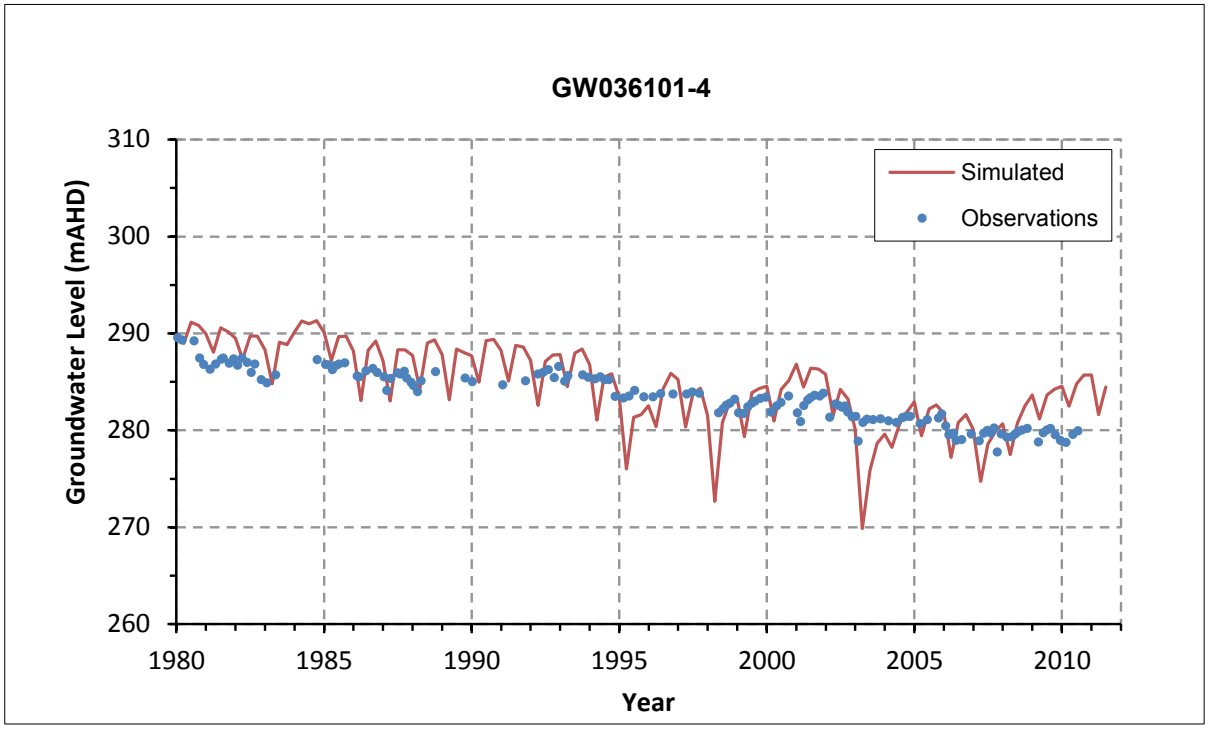

GW030419-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

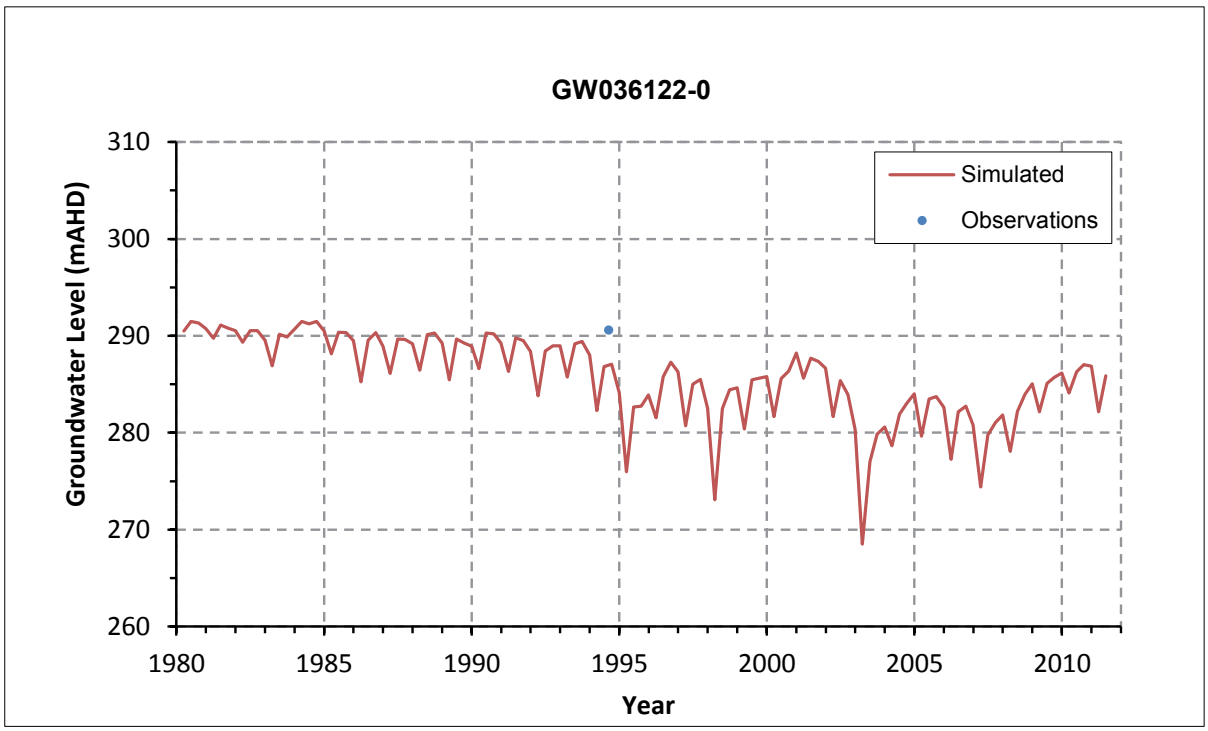

GW030419-3
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

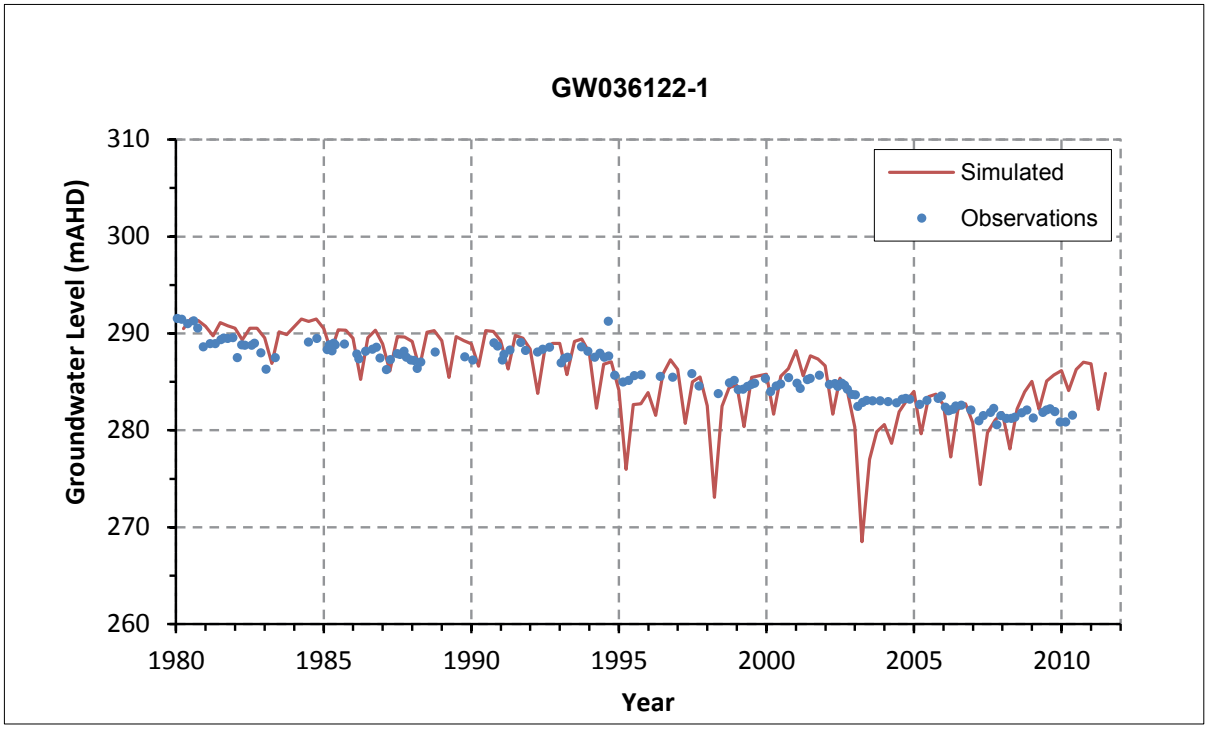

GW036101-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

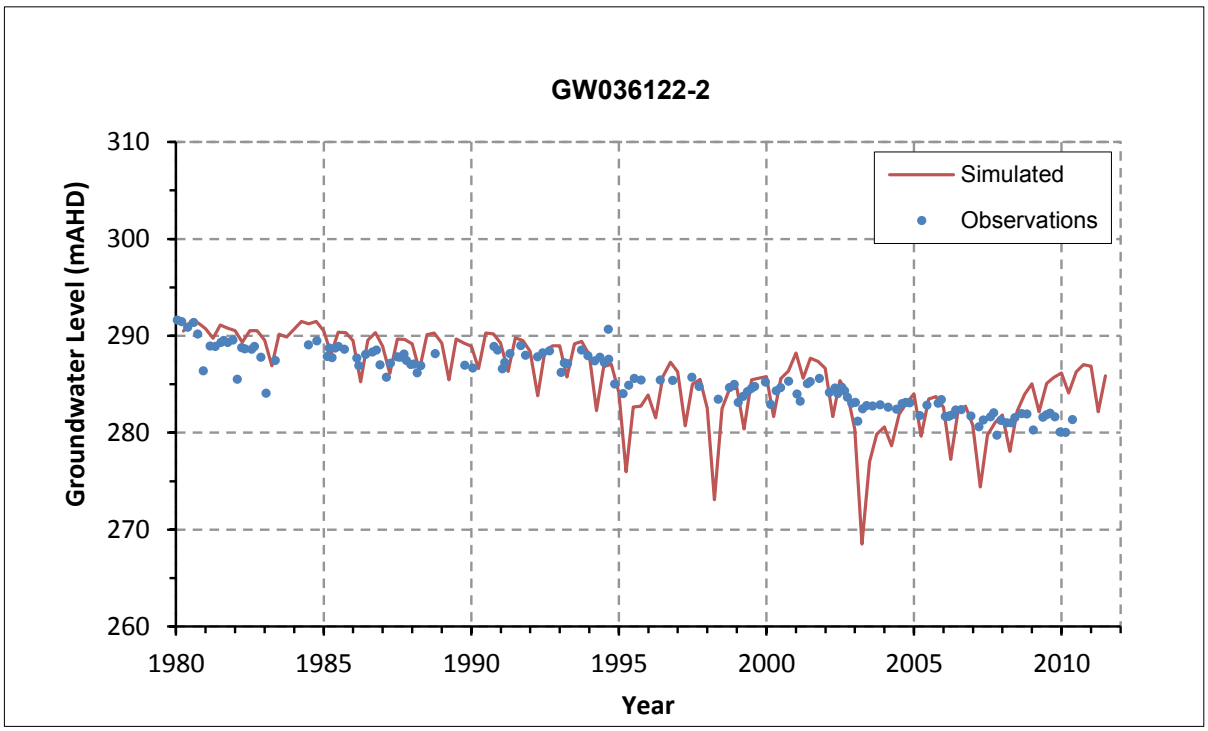

GW036101-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

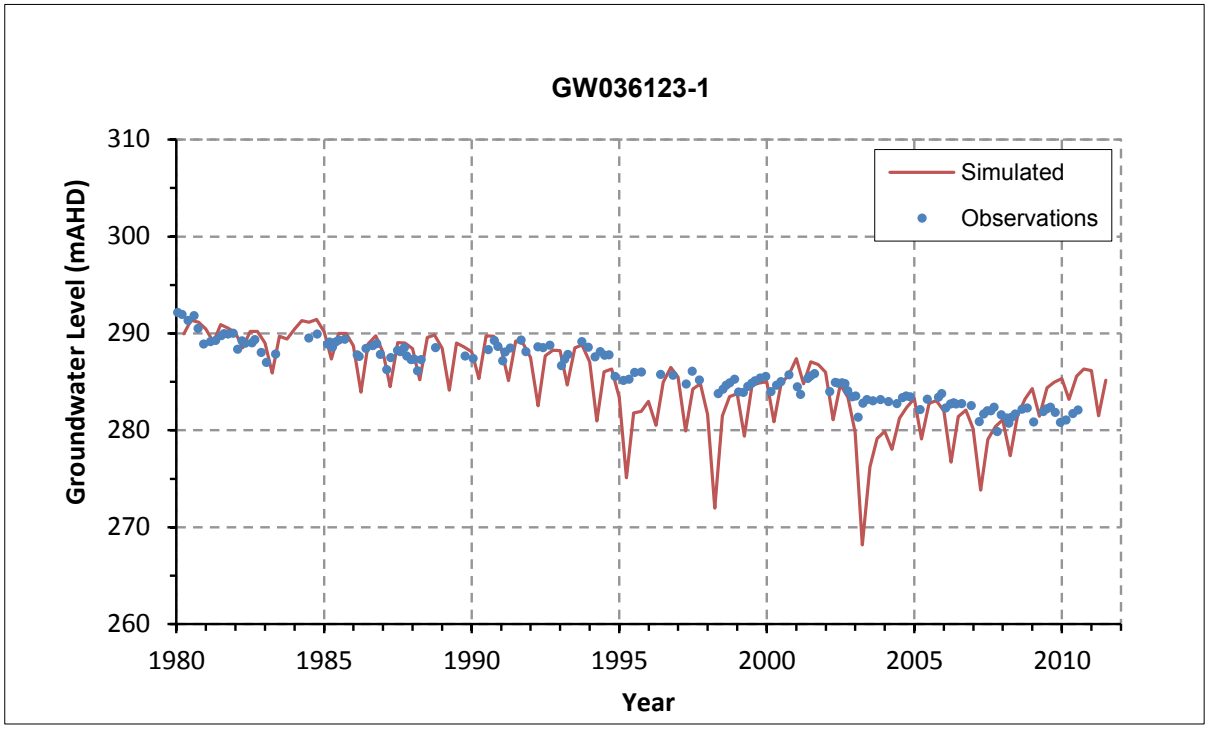

GW036101-3
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

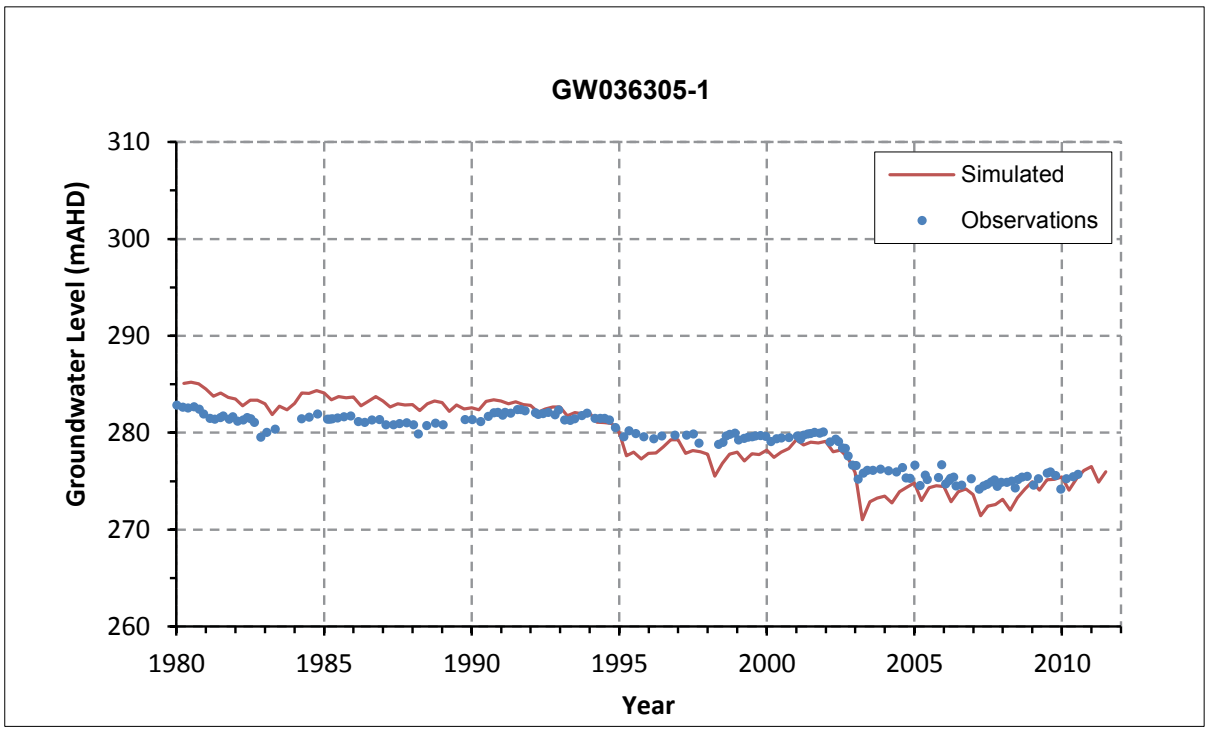

GW036101-4
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

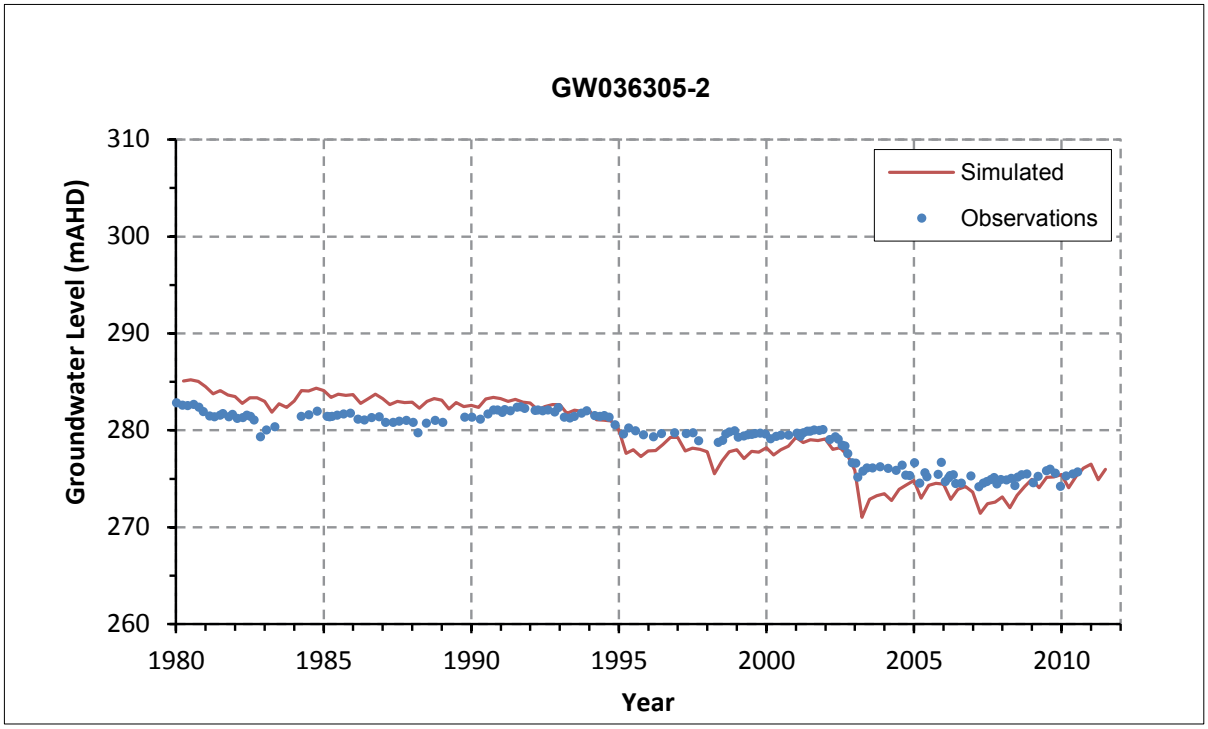

GW036122-0
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

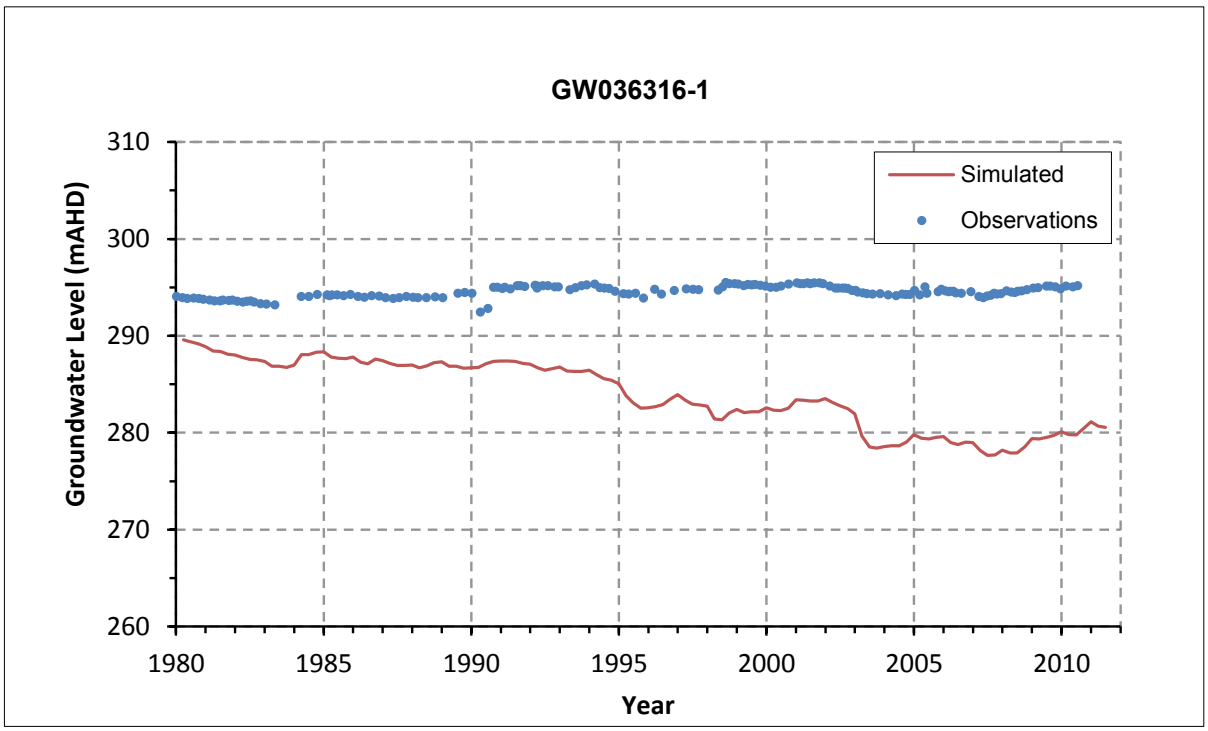

GW036122-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

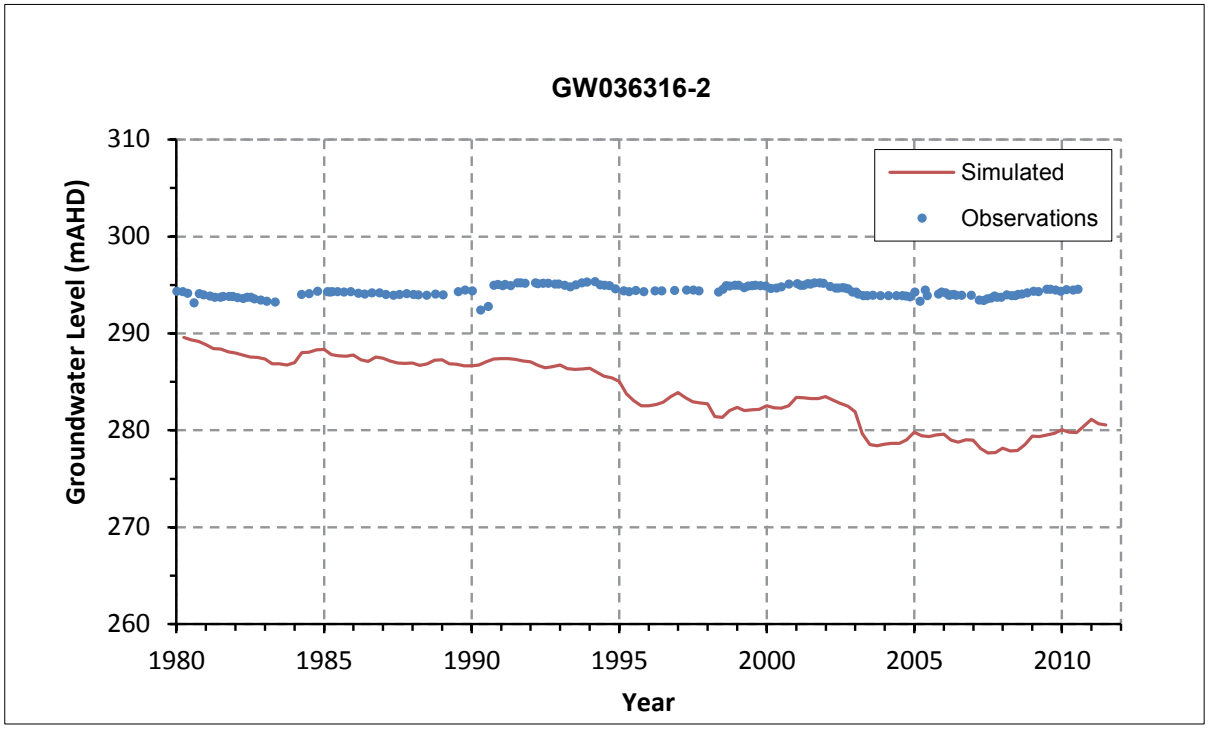

GW036122-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

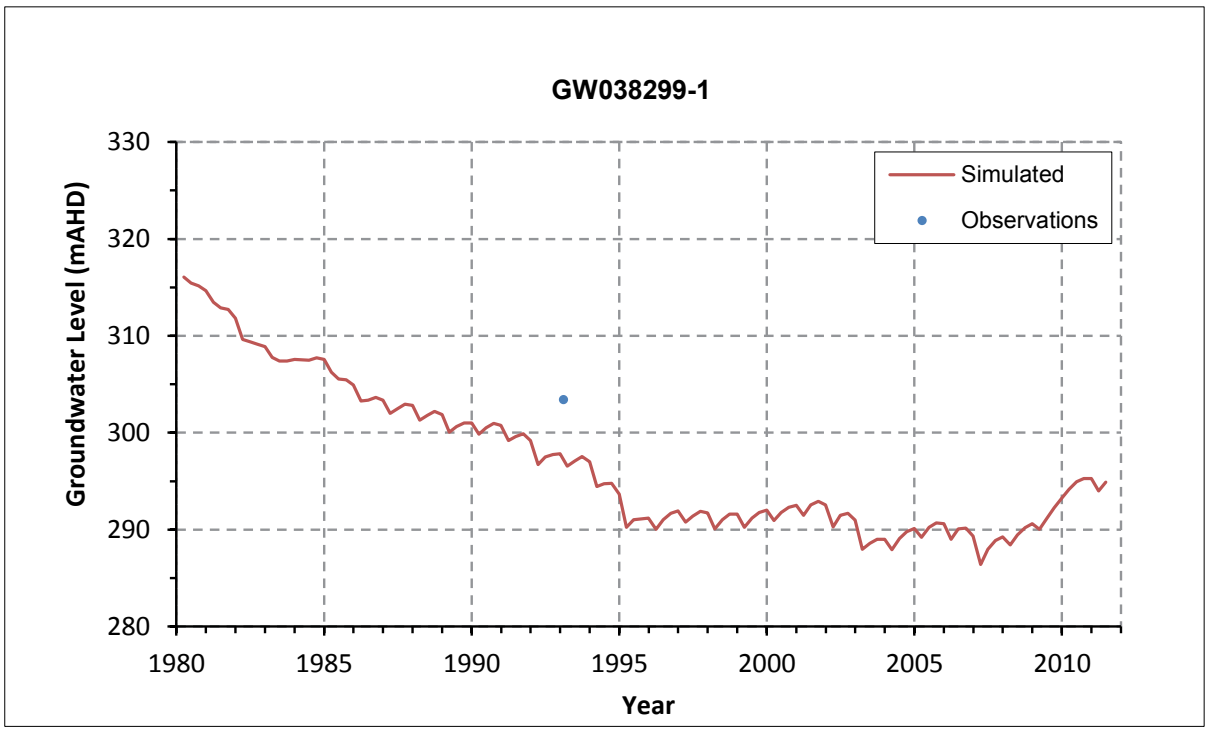

GW036123-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

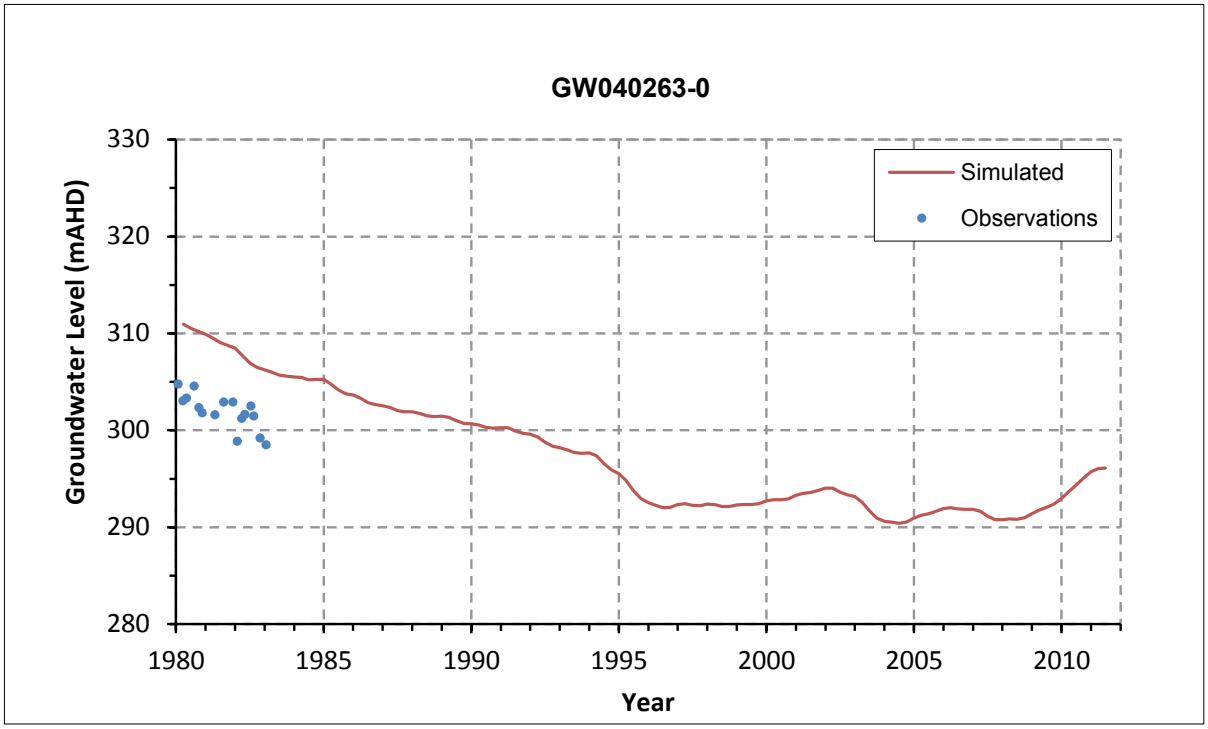

GW036305-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

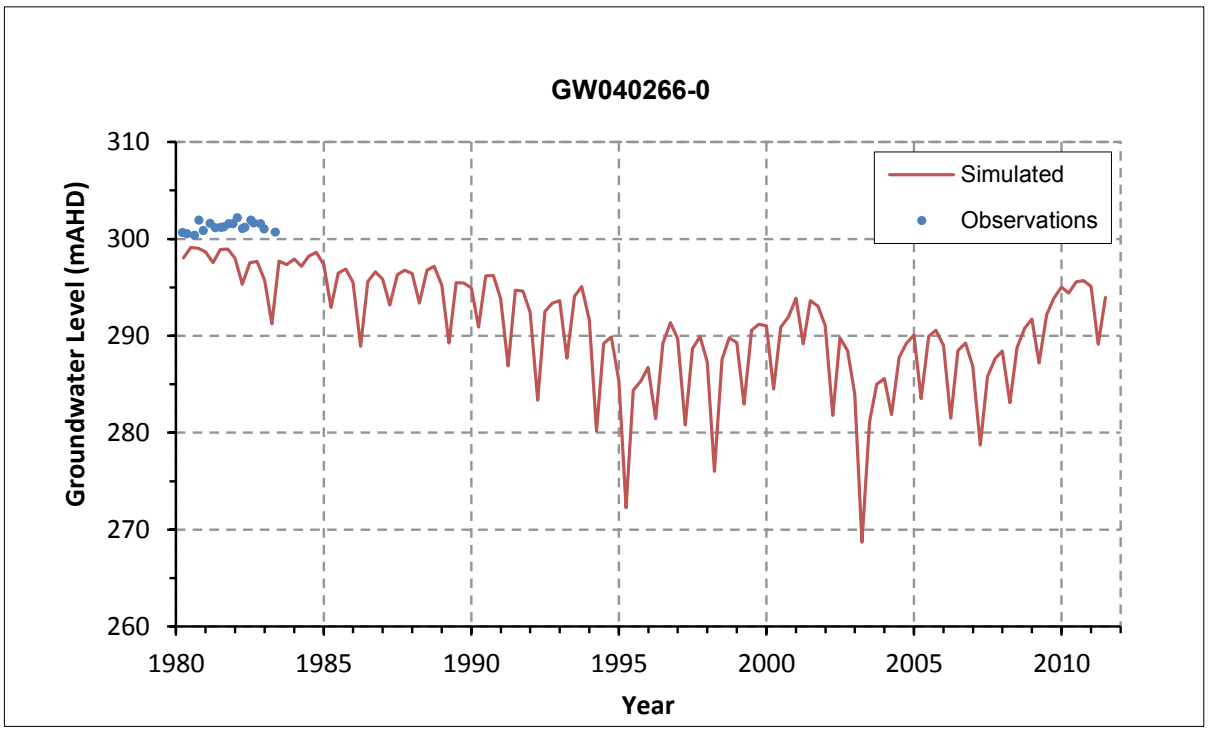

GW036305-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

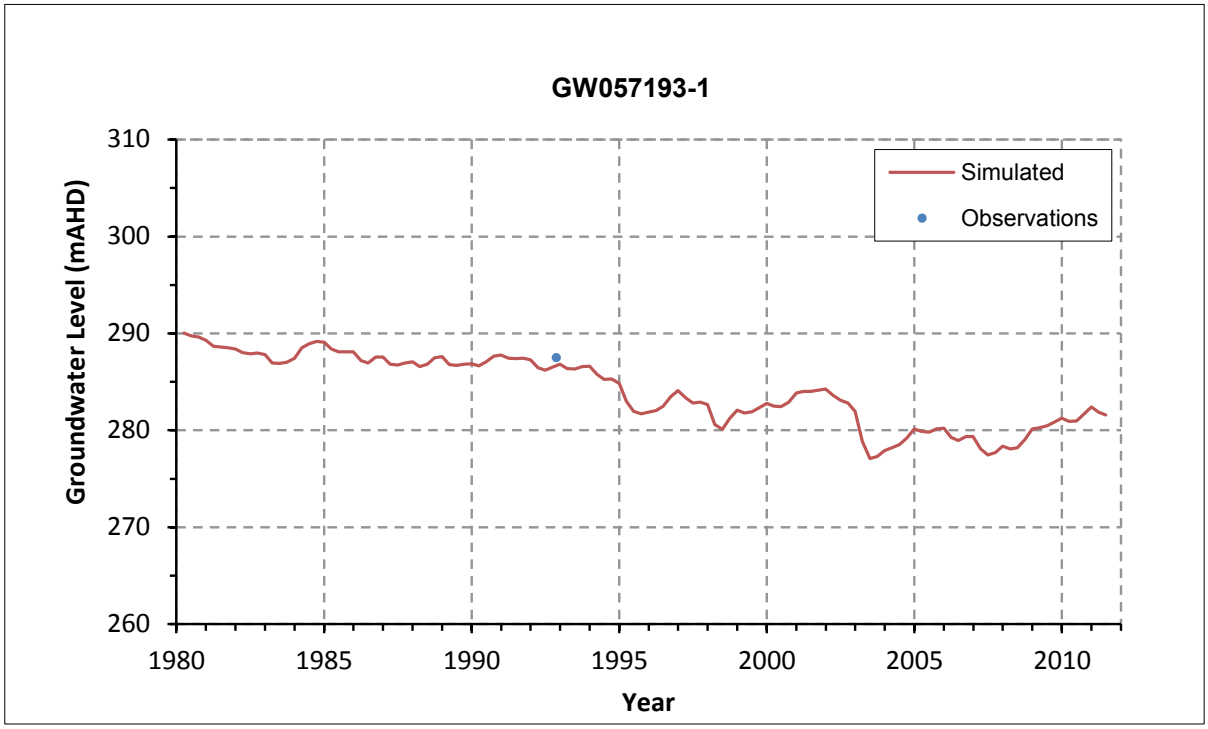

GW036316-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

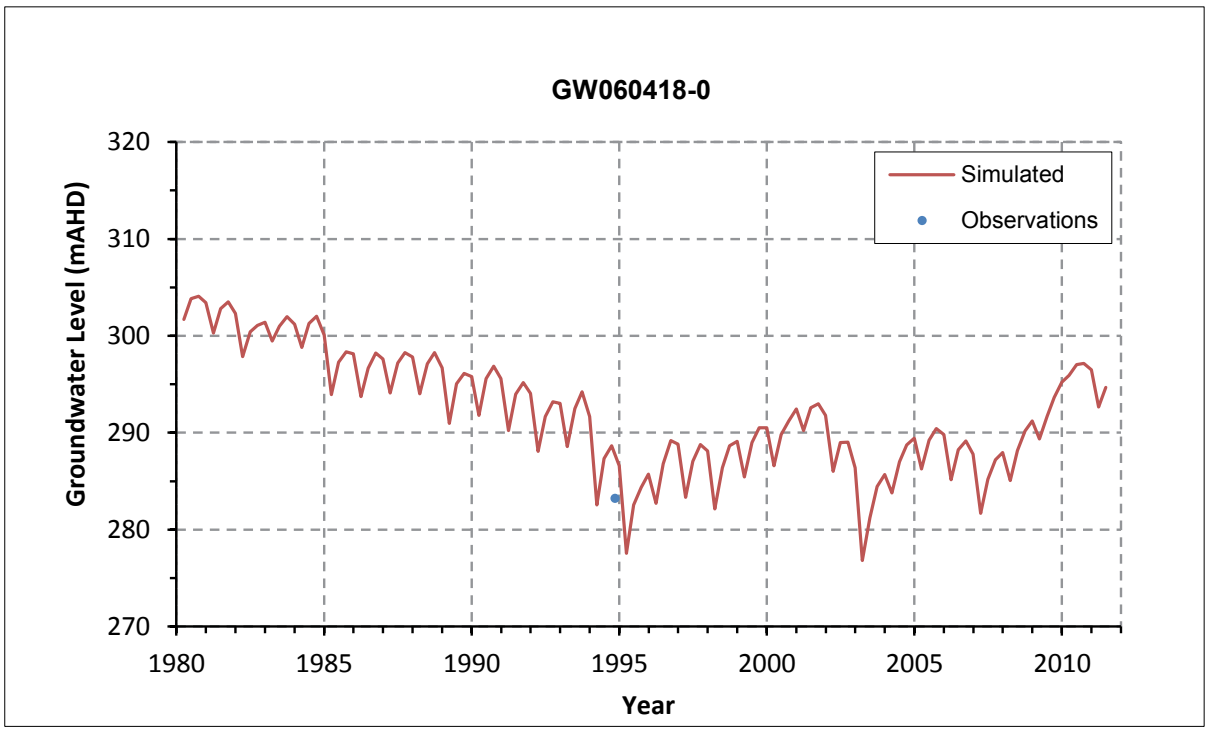

GW036316-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

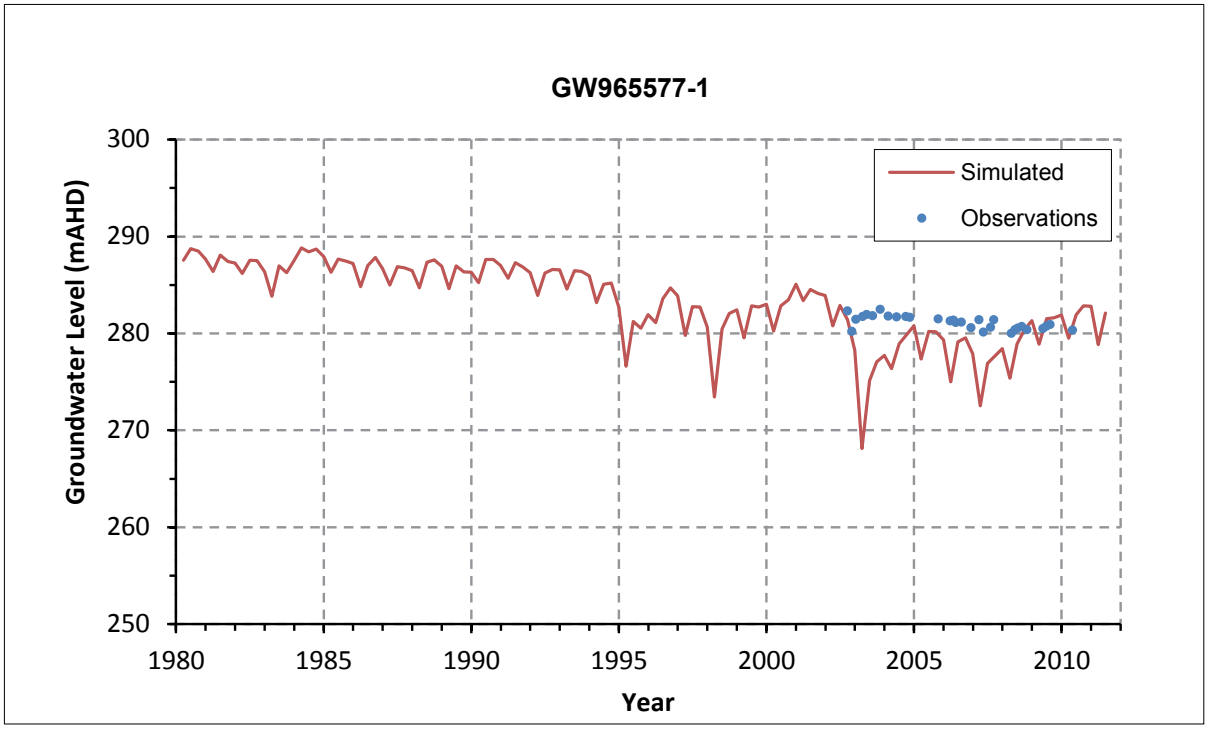

GW038299-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

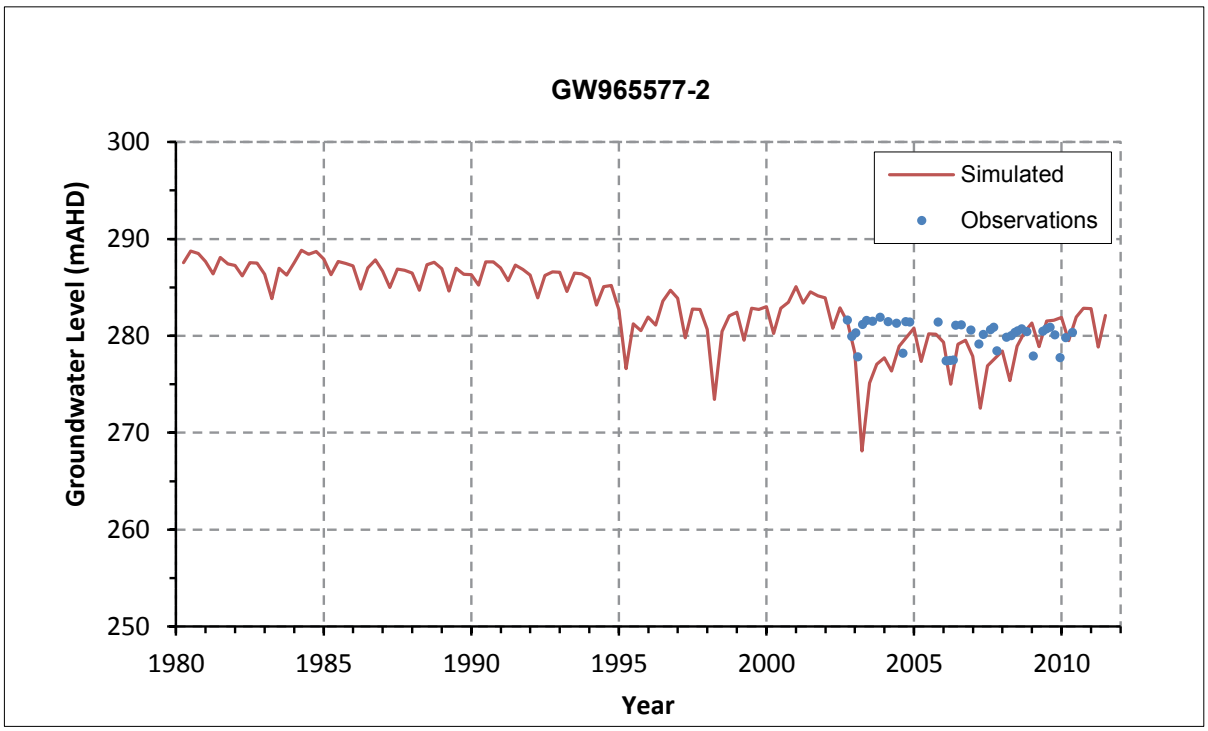

GW040263-0
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

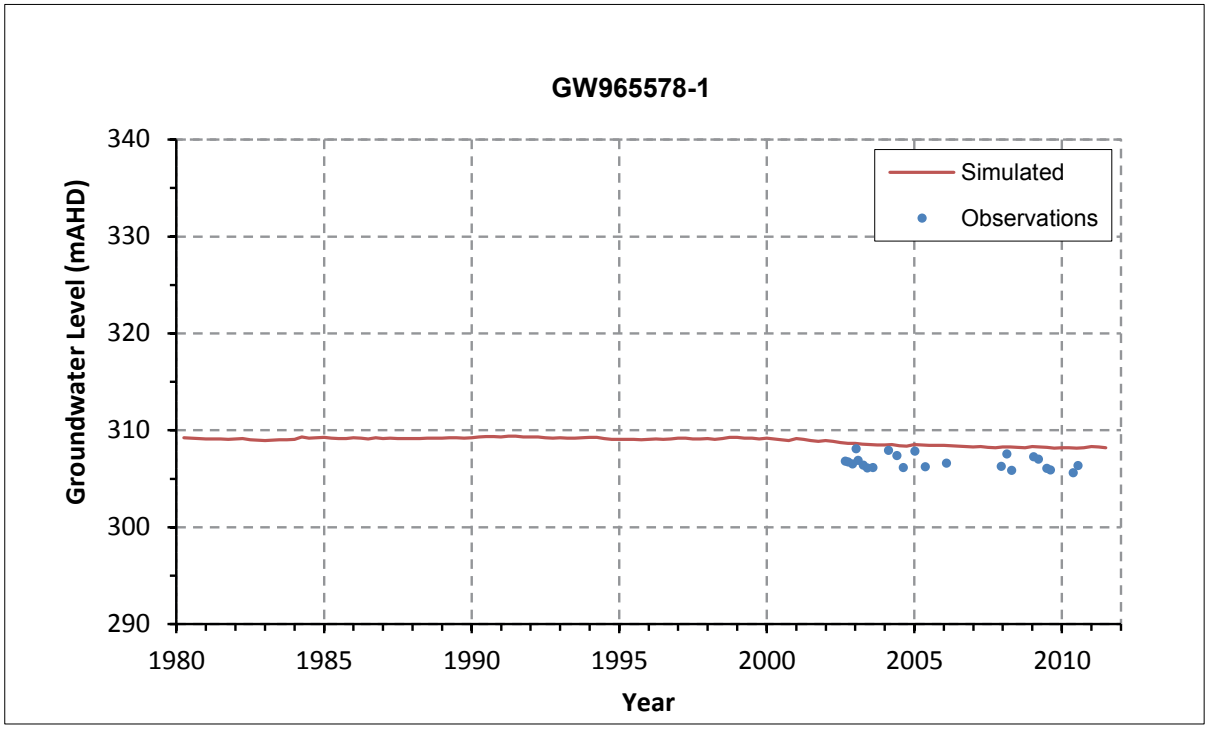

GW040266-0
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

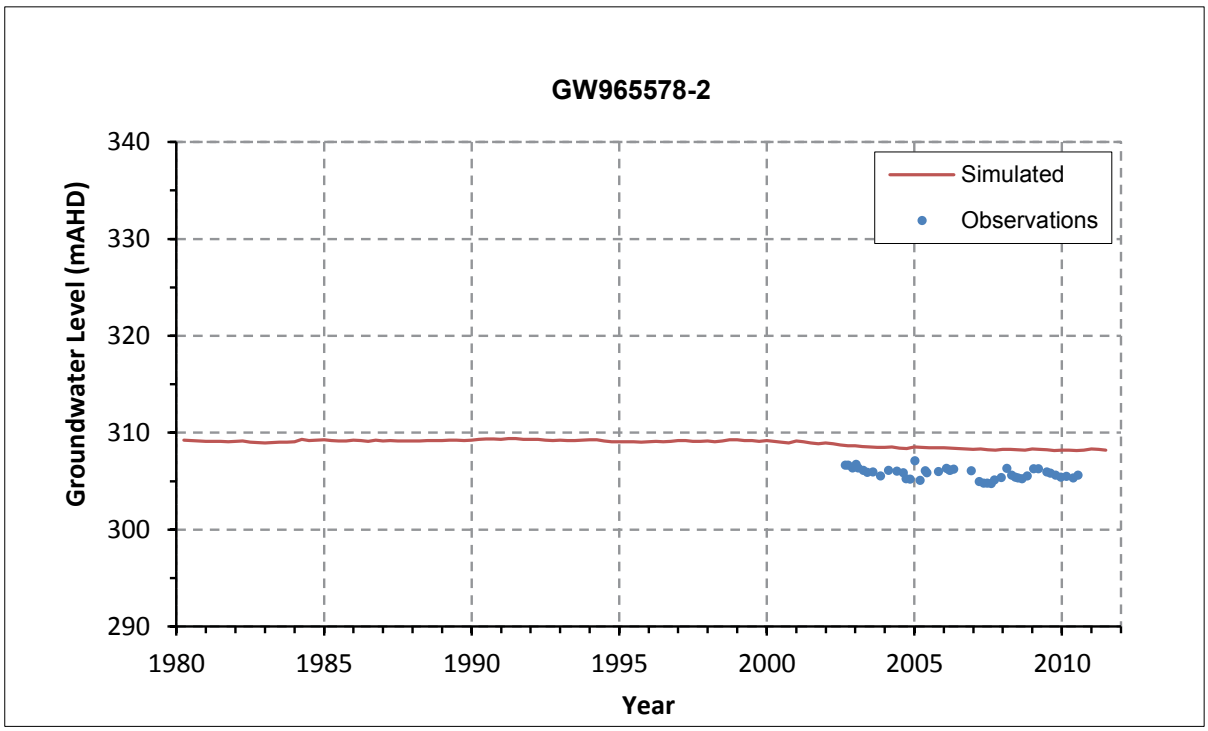

GW057193-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

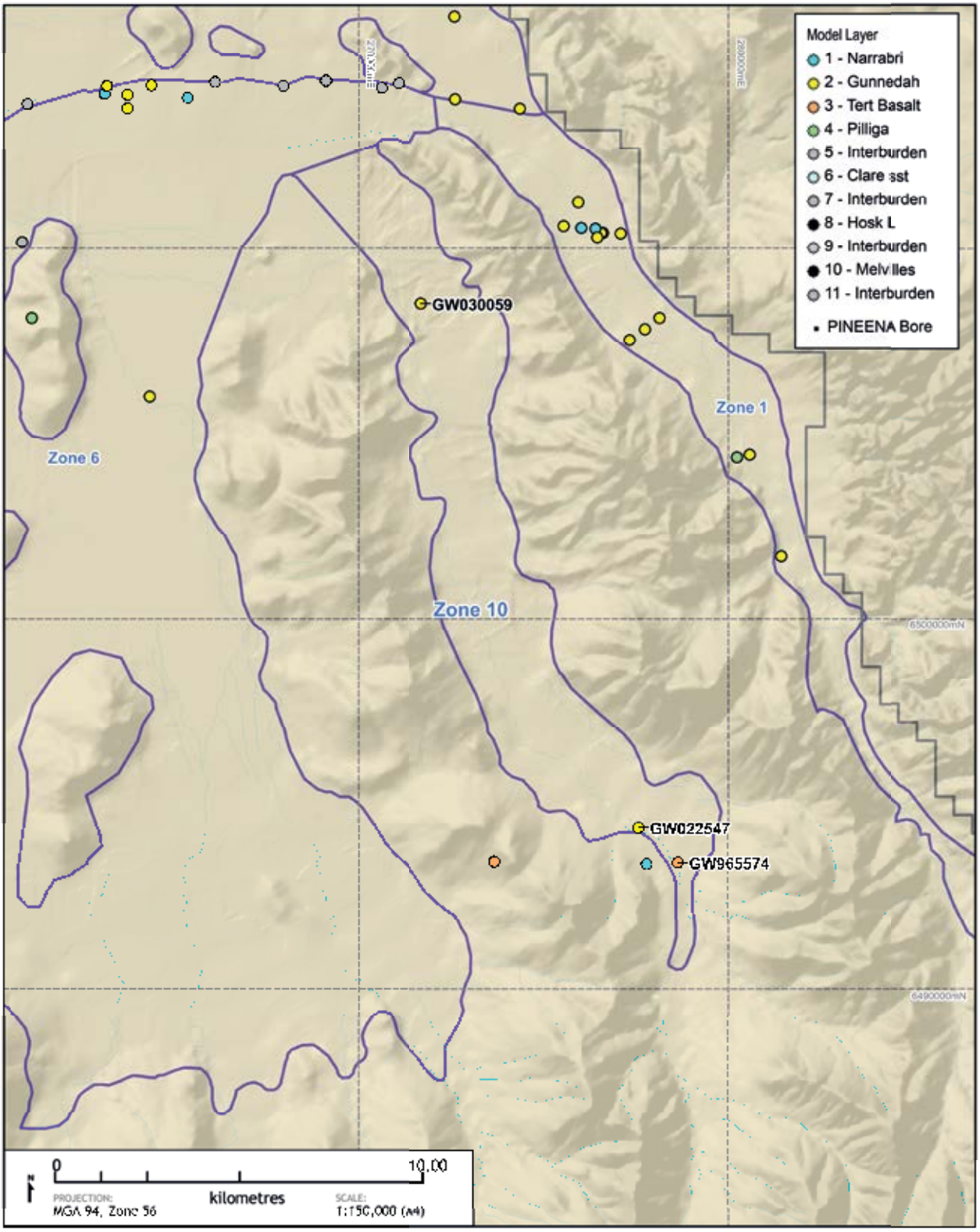

GW060418-0
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW965577-1
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW965577-2
Groundwater Level (mAHD)
300
290
280
270
260
250
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW965578-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW965578-2
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations



LEGEND

- Groundwater Management Zone
- Proposed Mining Area
- EL 7223
- Project Boundary
- PINEENA Bore

Watermark Coal Project (G1501)
Groundwater Assessment

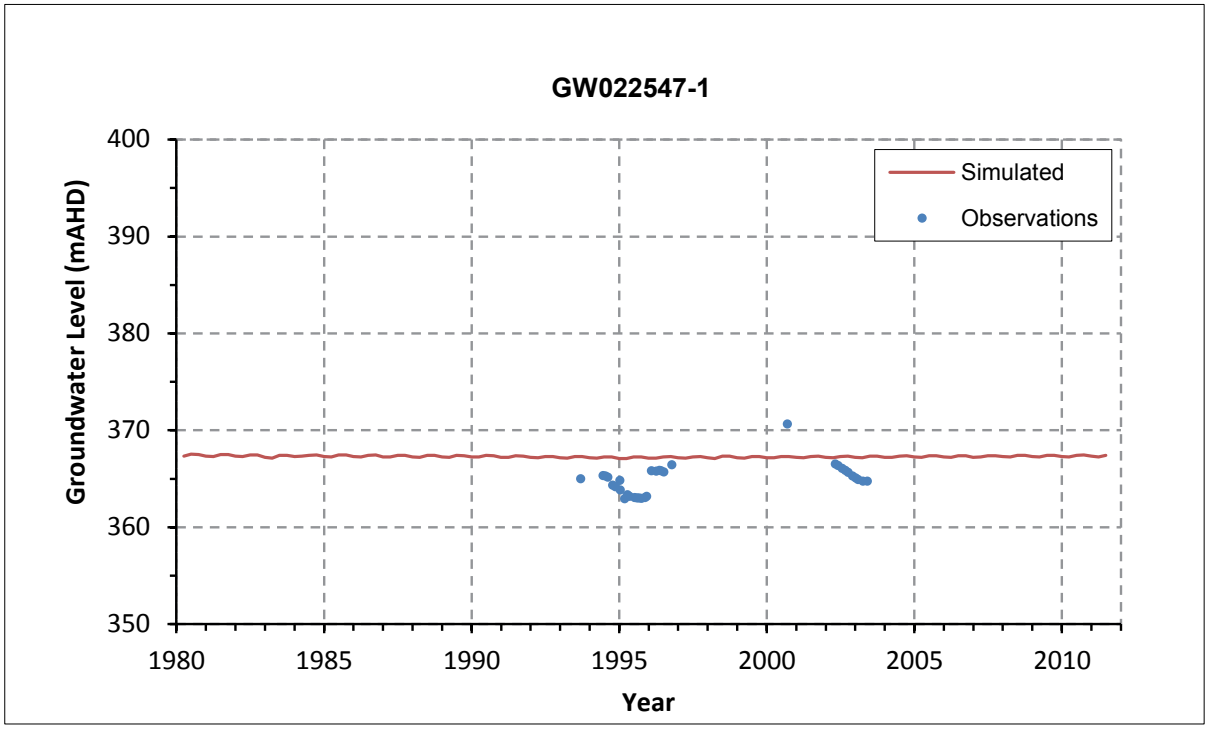
Groundwater Monitoring Bores: Shenhua and Pineena - Zone 10

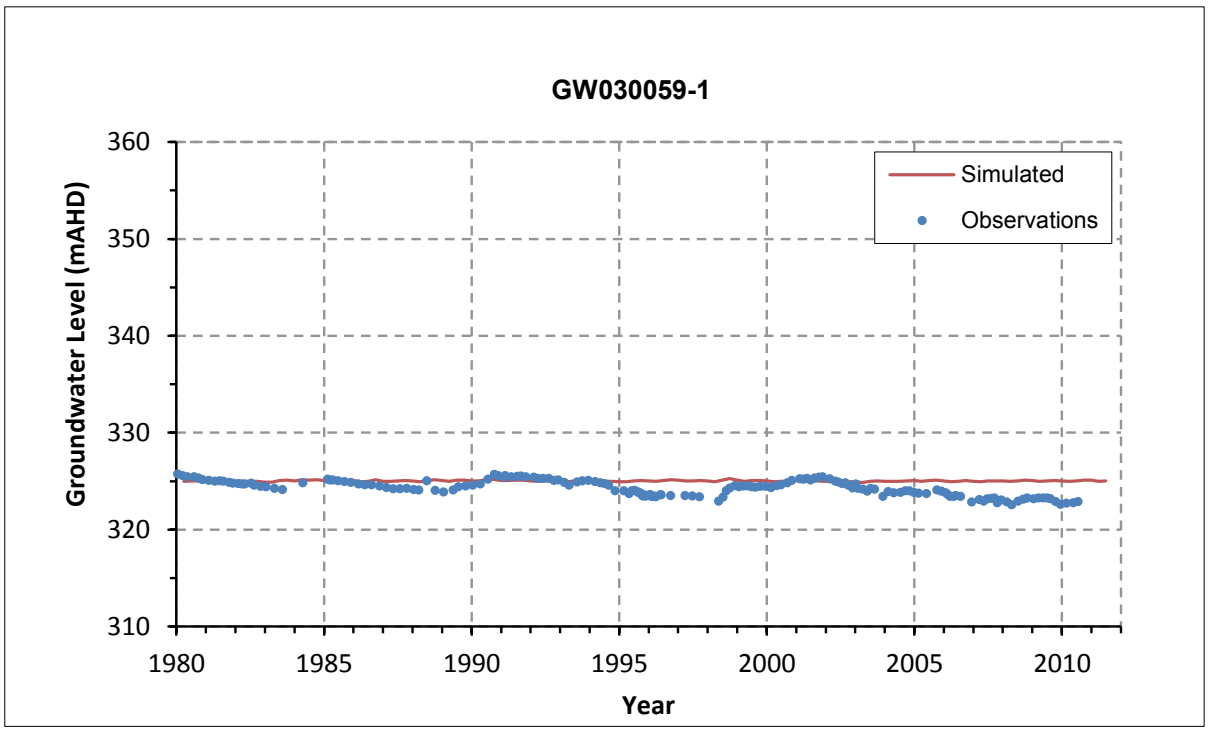
Source: NoW PINEENA Groundwater Database, 2011
GHD Groundwater Monitoring Database, 2011

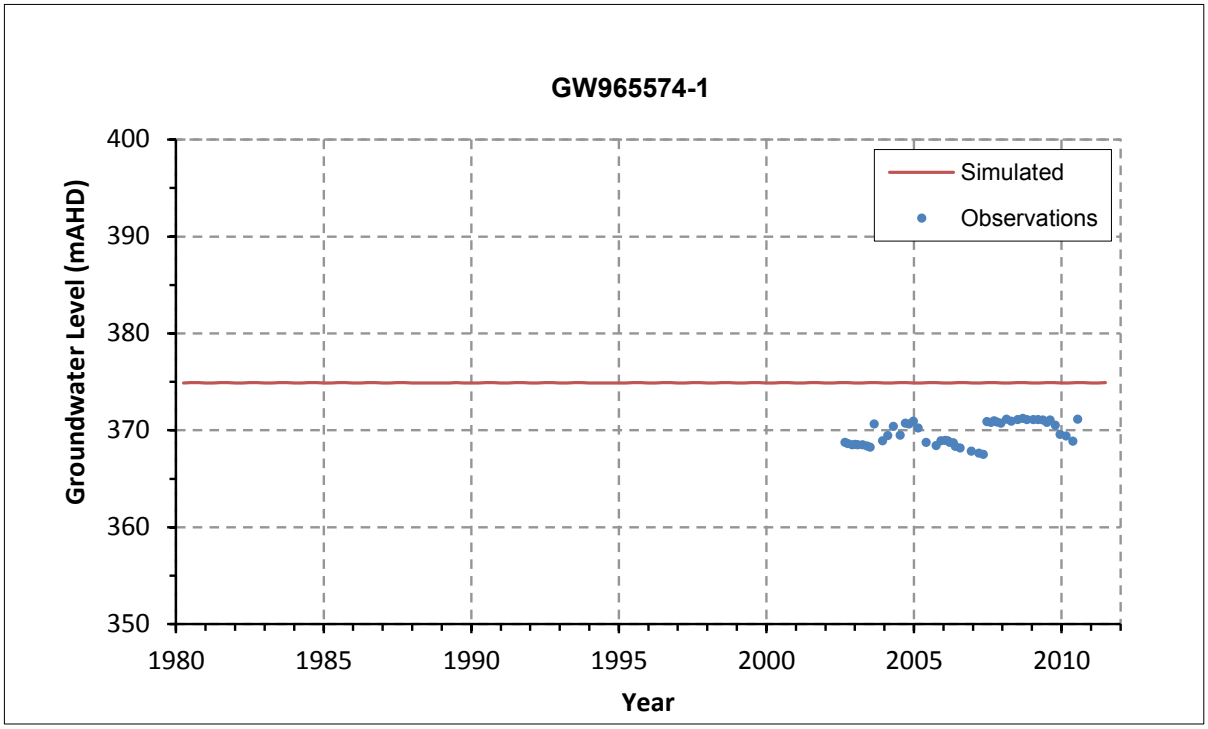
DATE: 25/7/2012

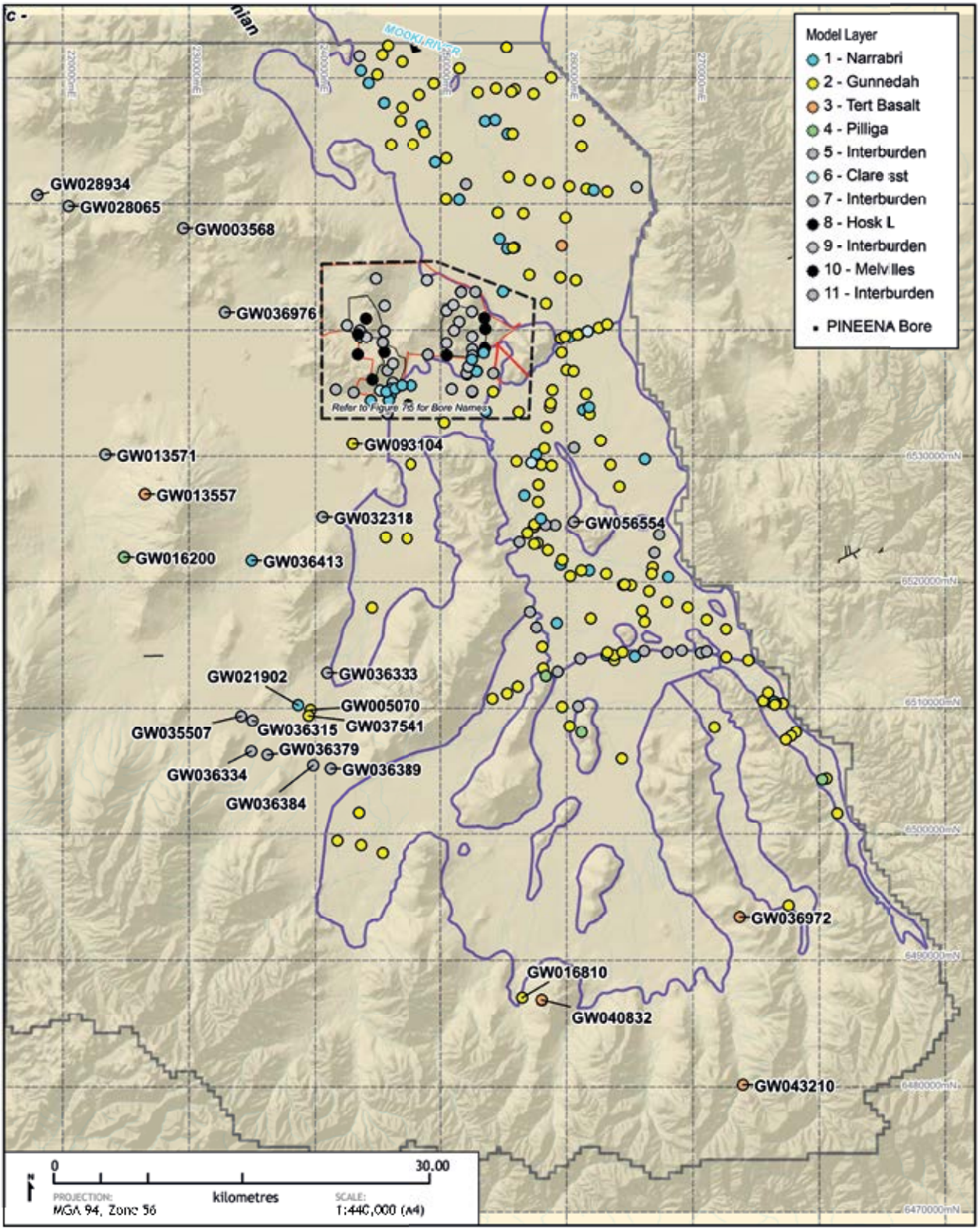
FIGURE No: **A.6**

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GW022547-1
Groundwater Level (mAHD)
400
390
380
370
360
350
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW030059-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


GW965574-1
Groundwater Level (mAHD)
400
390
380
370
360
350
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations



LEGEND

- Groundwater Management Zone
- Proposed Mining Area
- EL 7223
- Project Boundary
- PINEENA Bore

Watermark Coal Project (G1501)
Groundwater Assessment

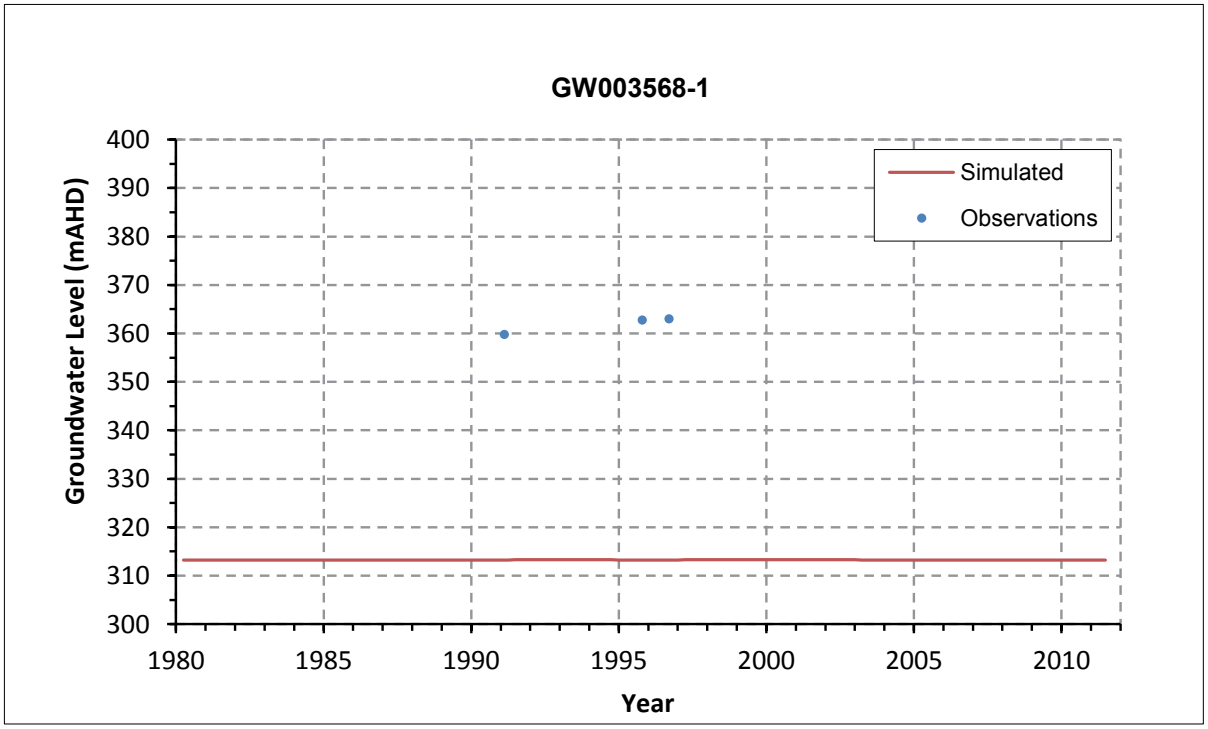
Groundwater Monitoring Bores: Shenhua and Pineena - Unallocated

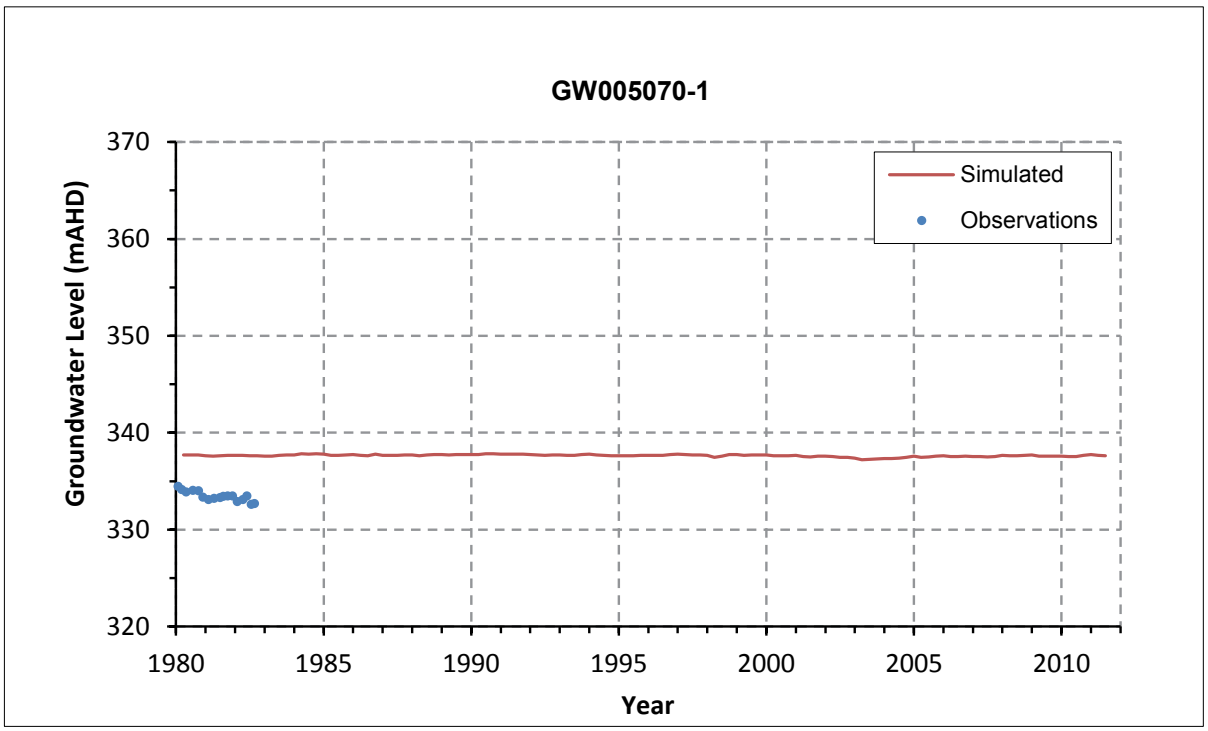
Source: NoW PINEENA Groundwater Database, 2011
GHD Groundwater Monitoring Database, 2011

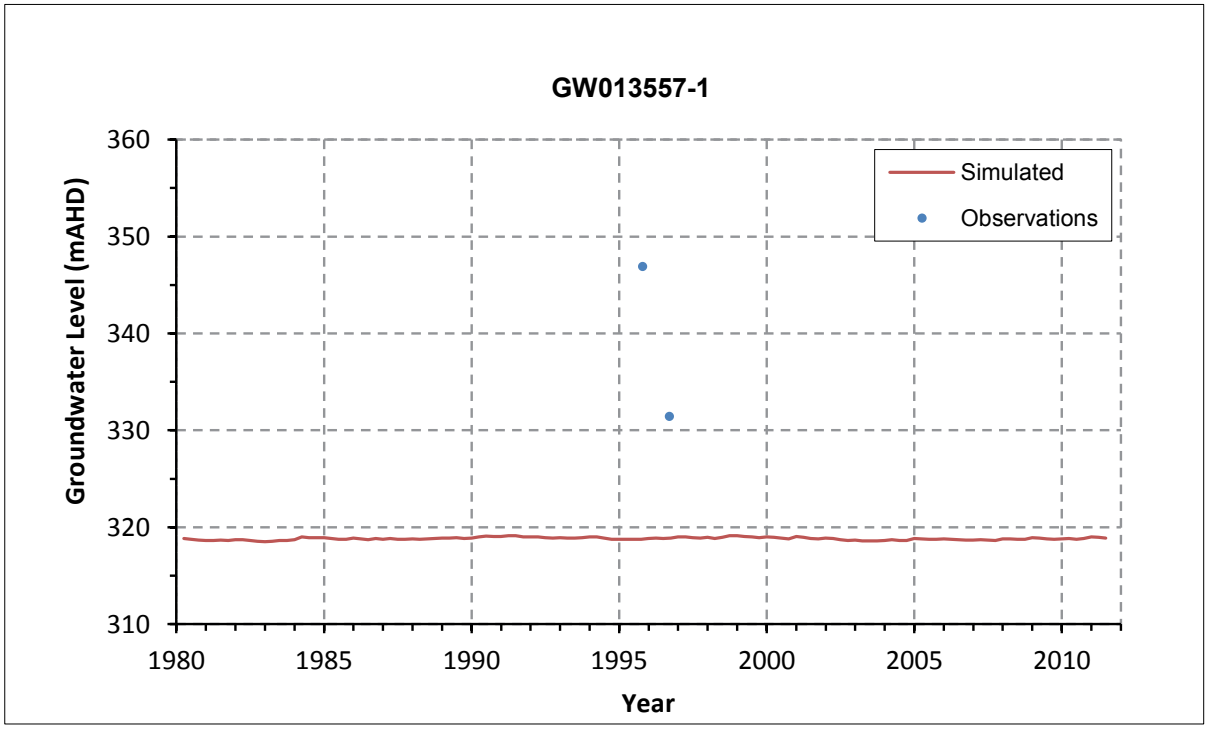
DATE: 25/7/2012

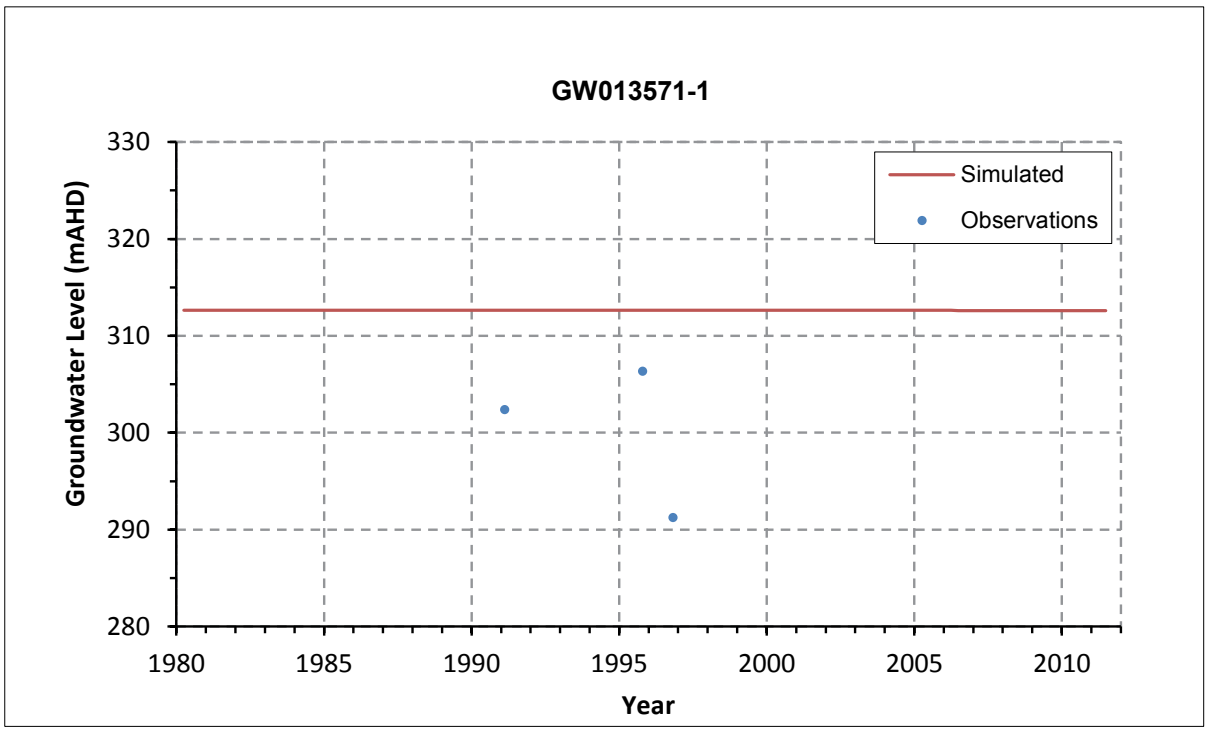
FIGURE No: **A.7**

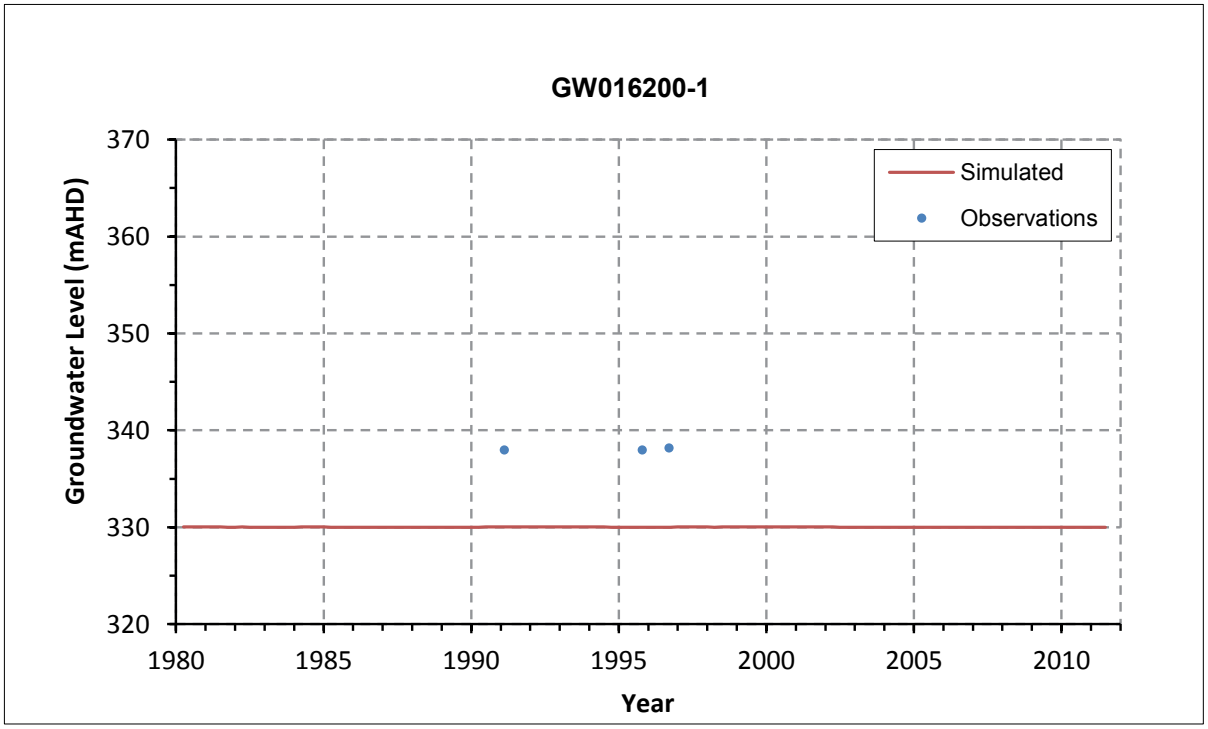
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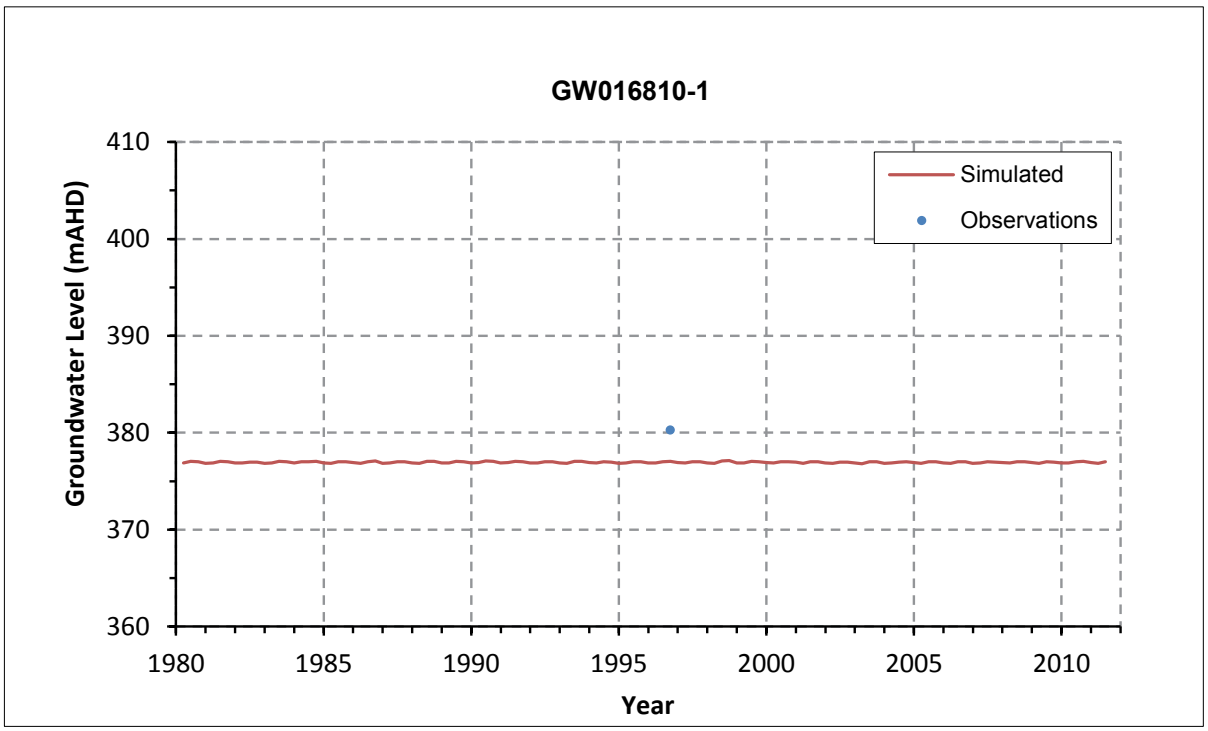

GW003568-1
Groundwater Level (mAHD)
400
390
380
370
360
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

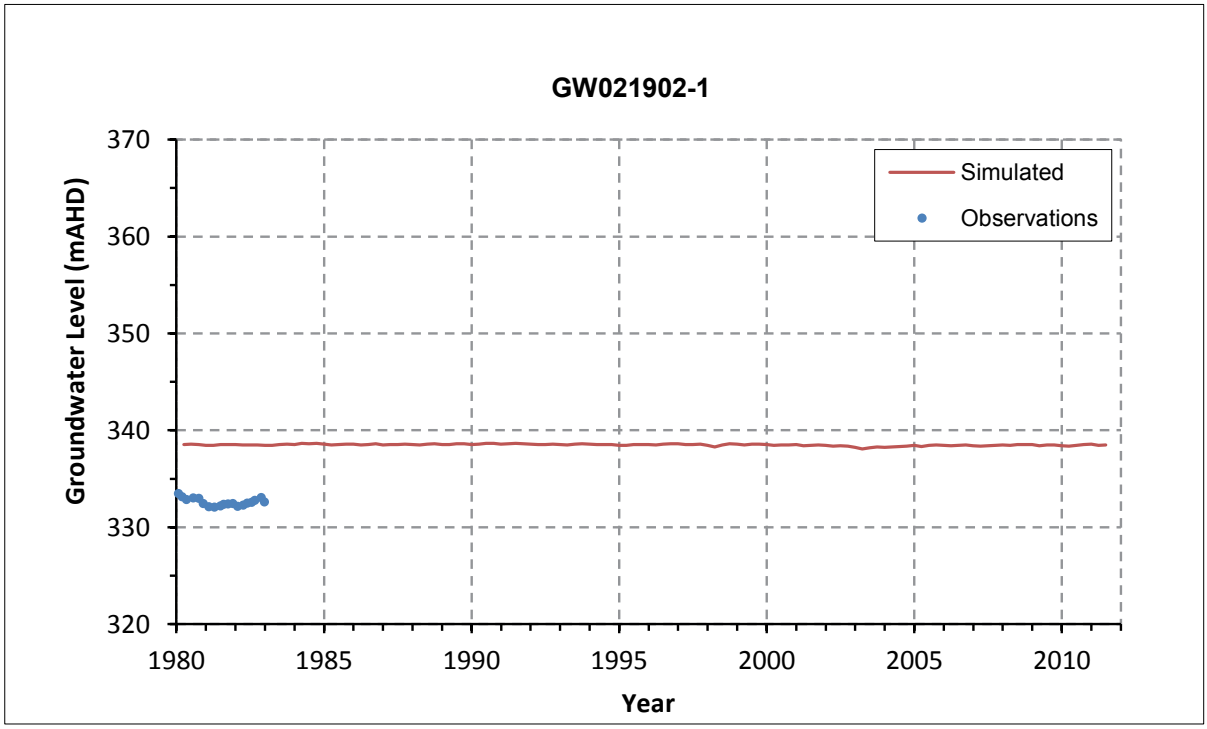

GW005070-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

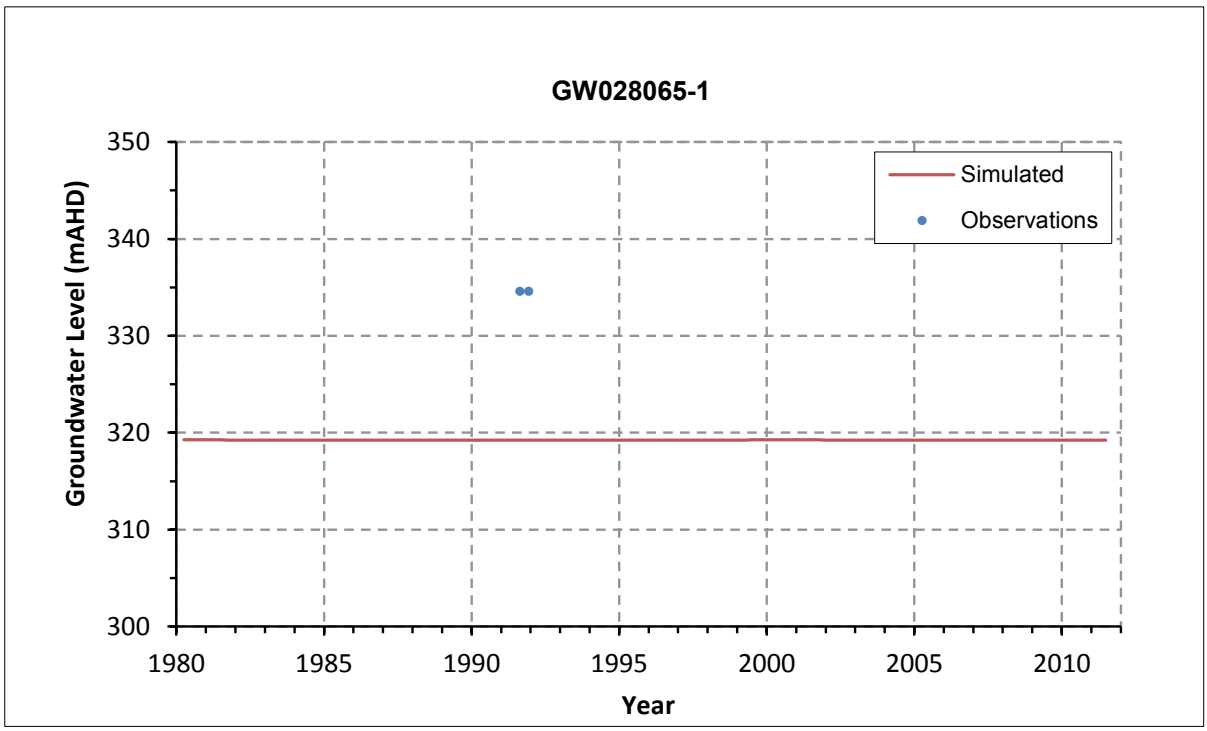

GW013557-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

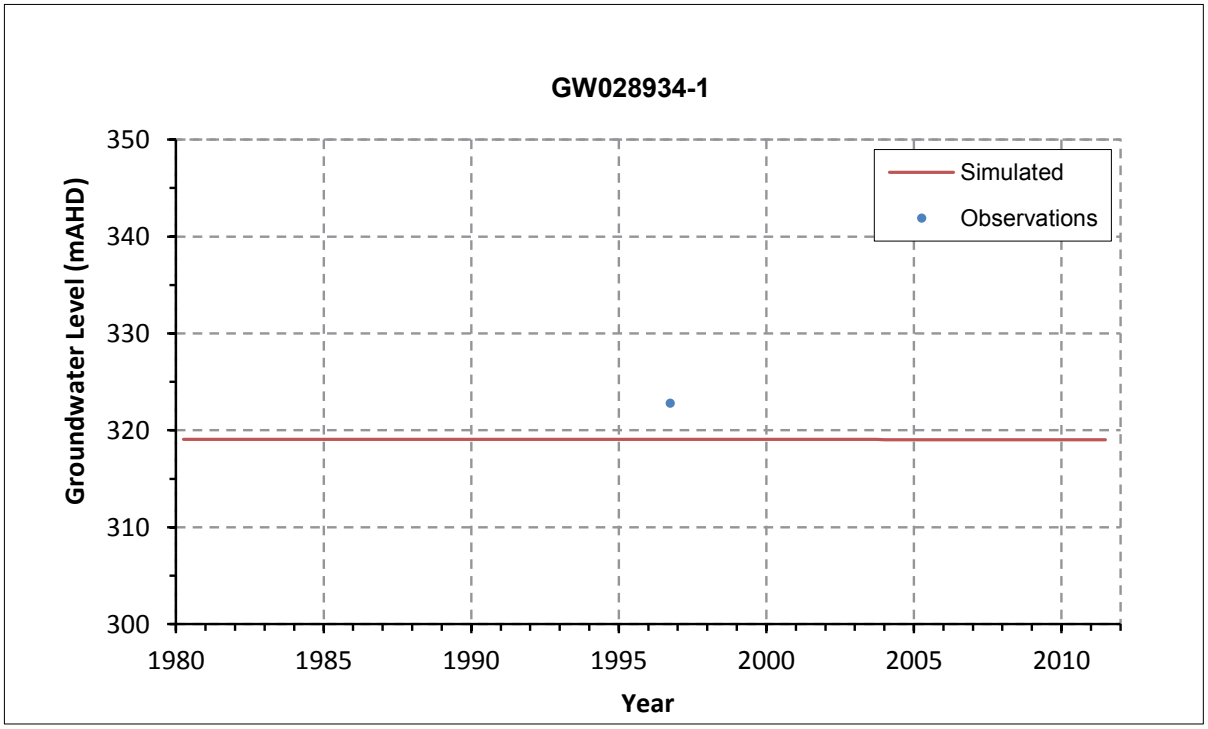

GW013571-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

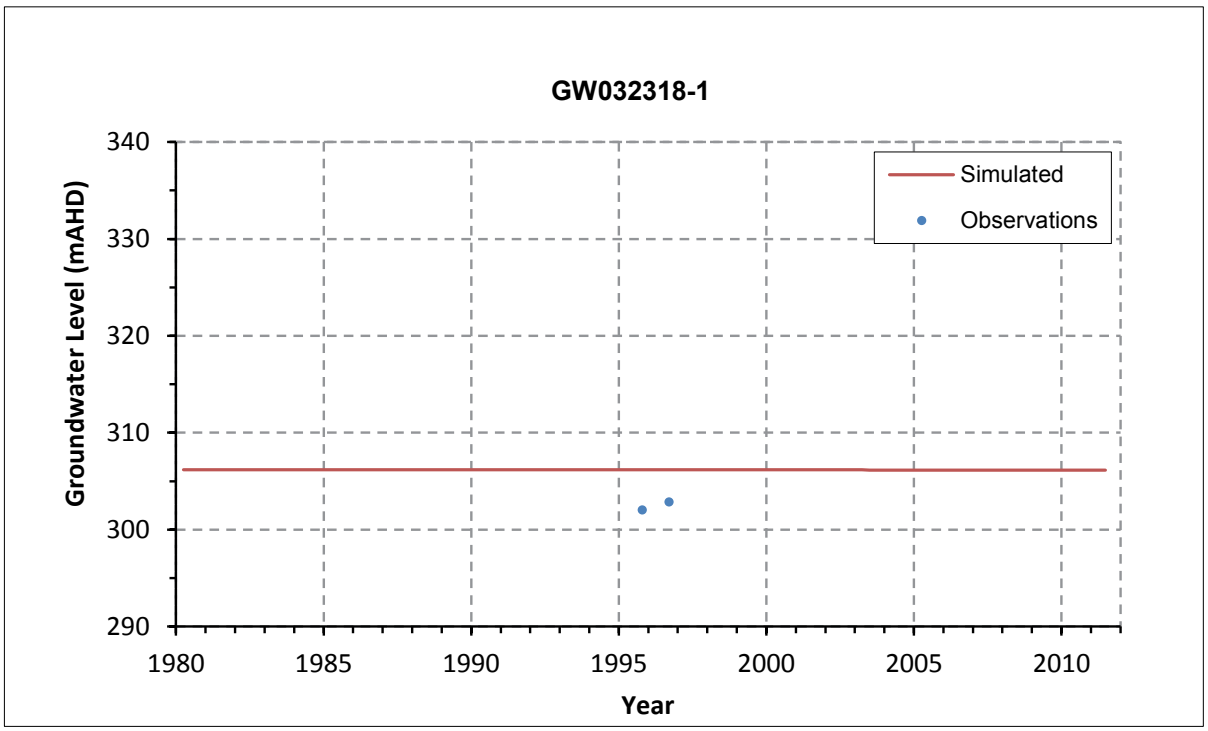

GW016200-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

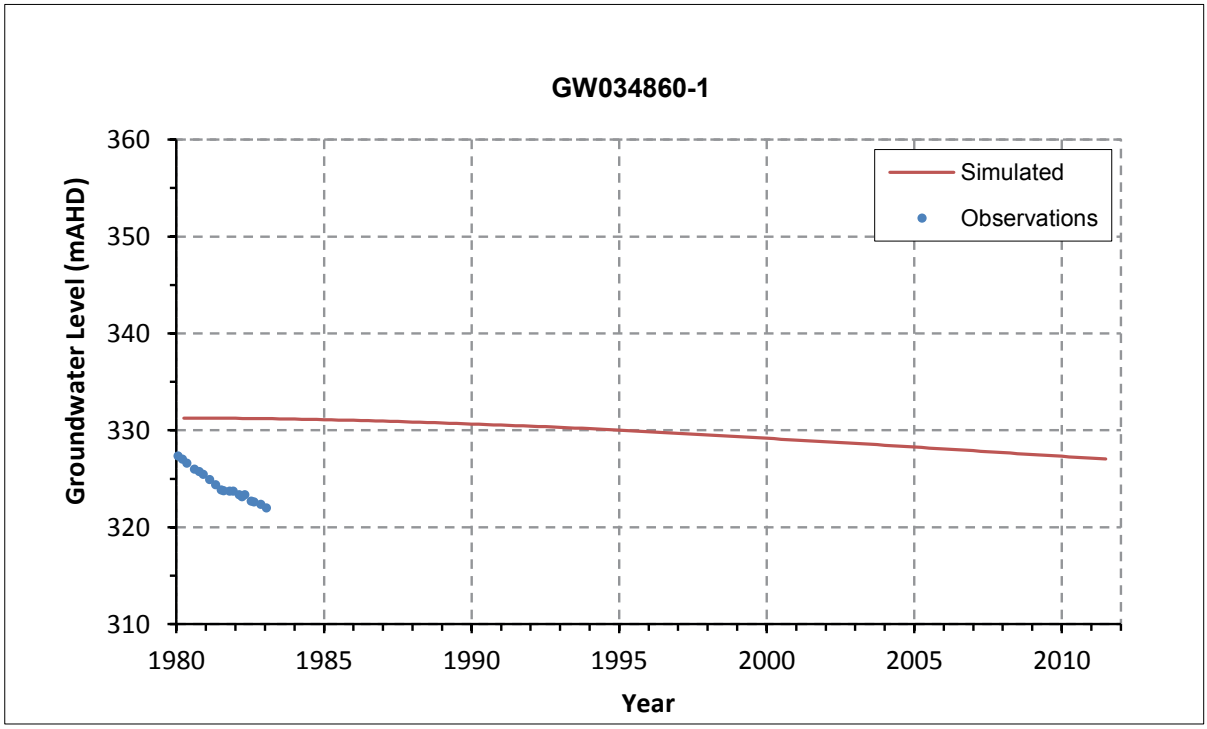

GW016810-1
Groundwater Level (mAHD)
410
400
390
380
370
360
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

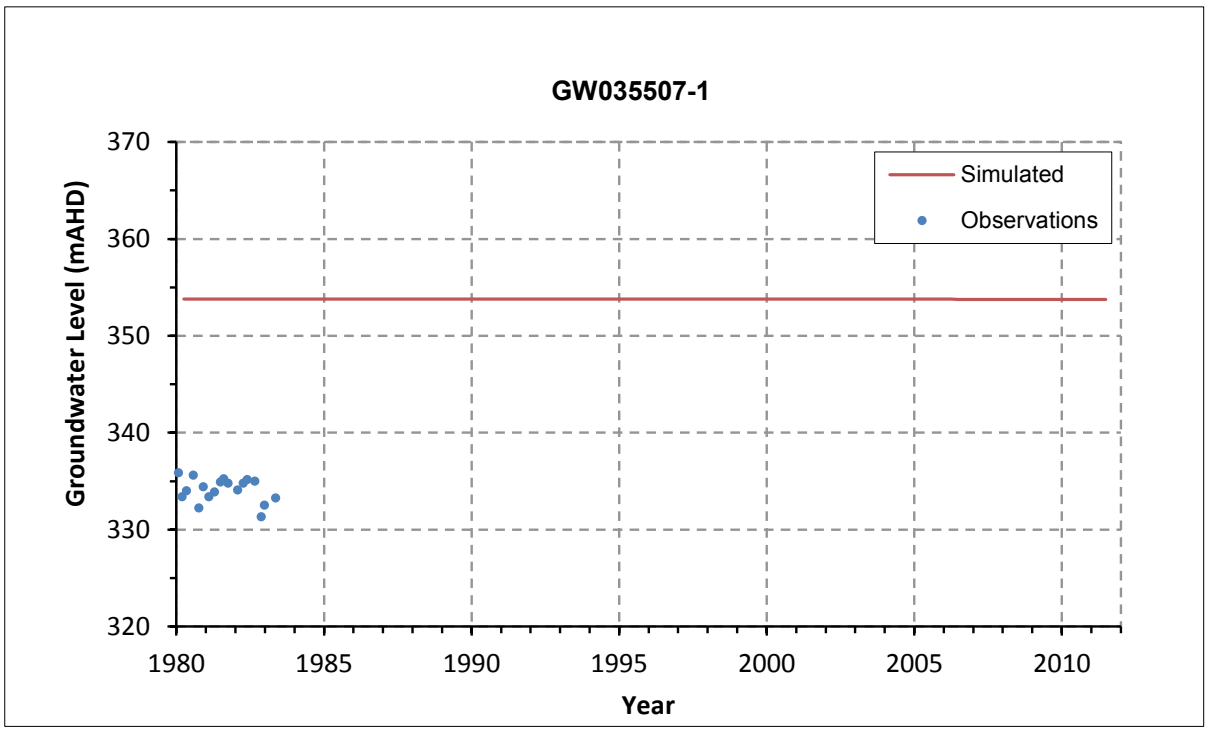

GW021902-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

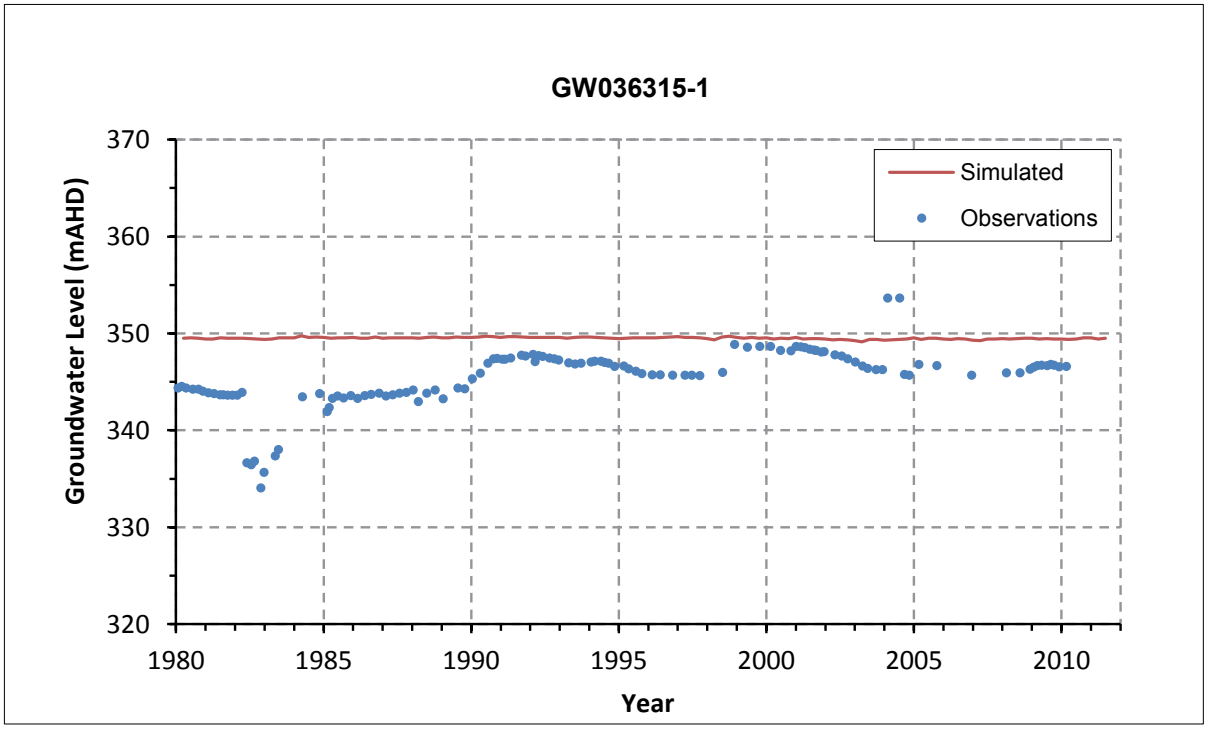

GW028065-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

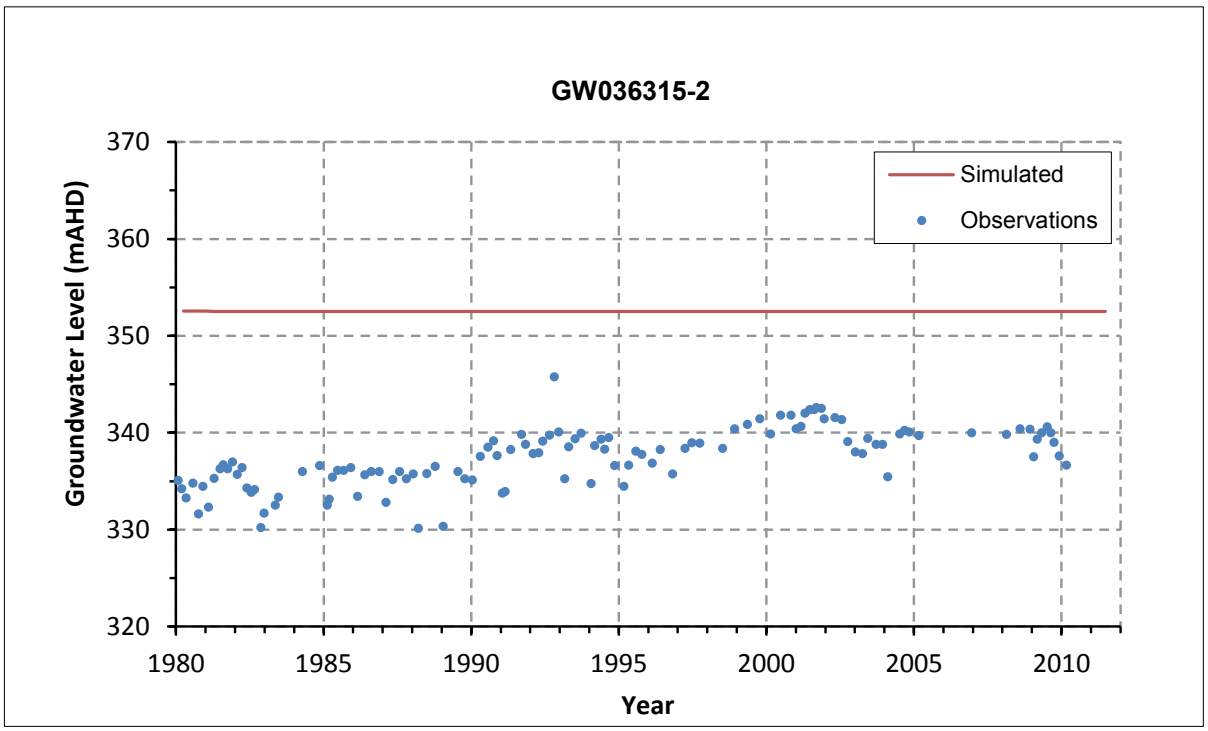

GW028934-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

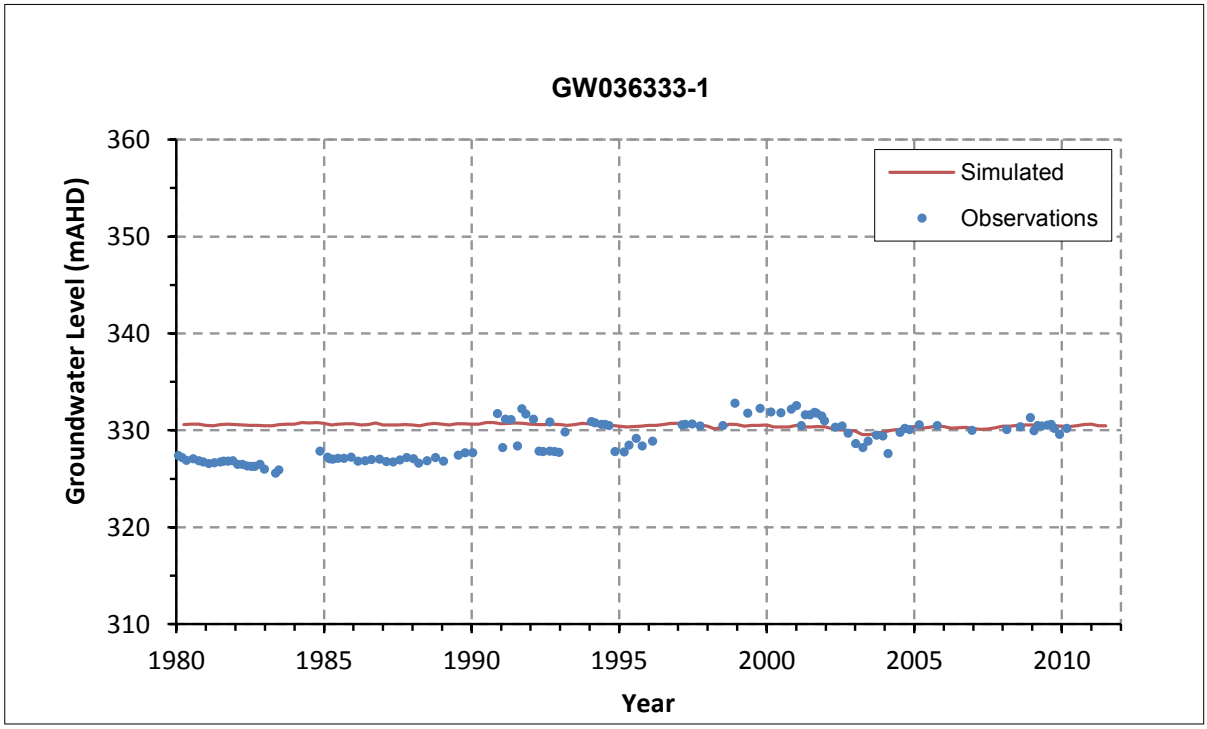

GW032318-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

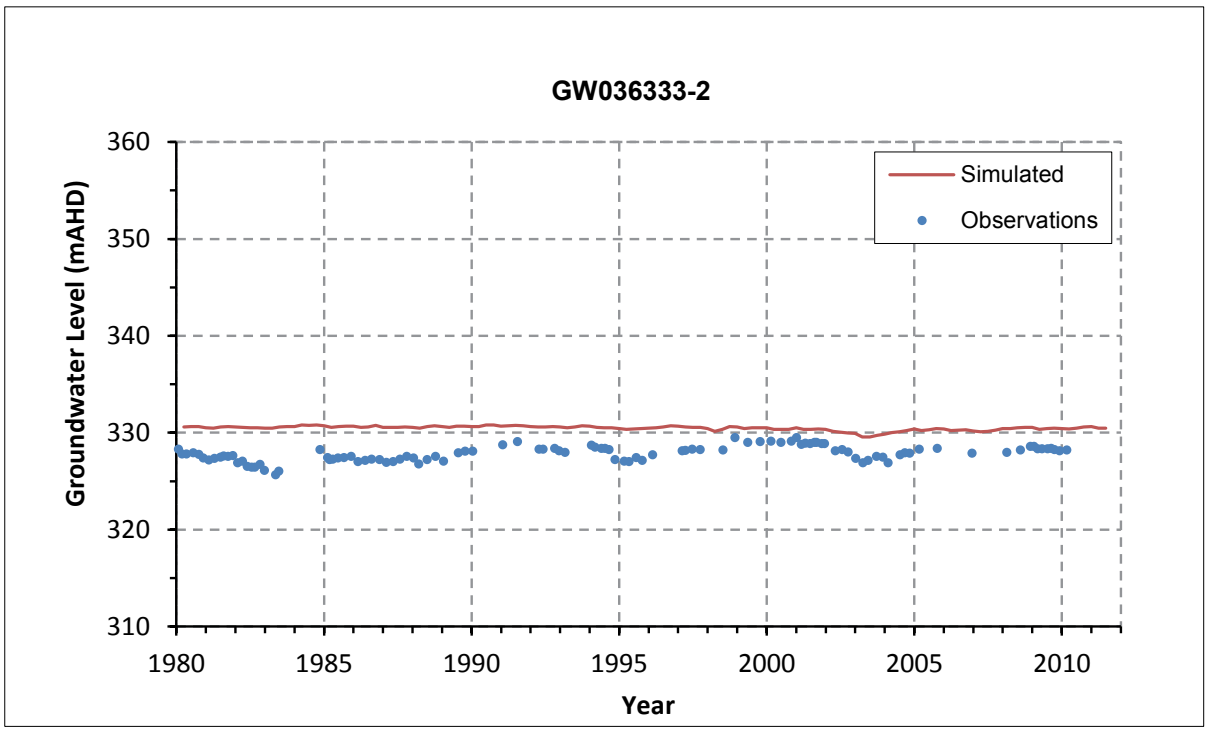

GW034860-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

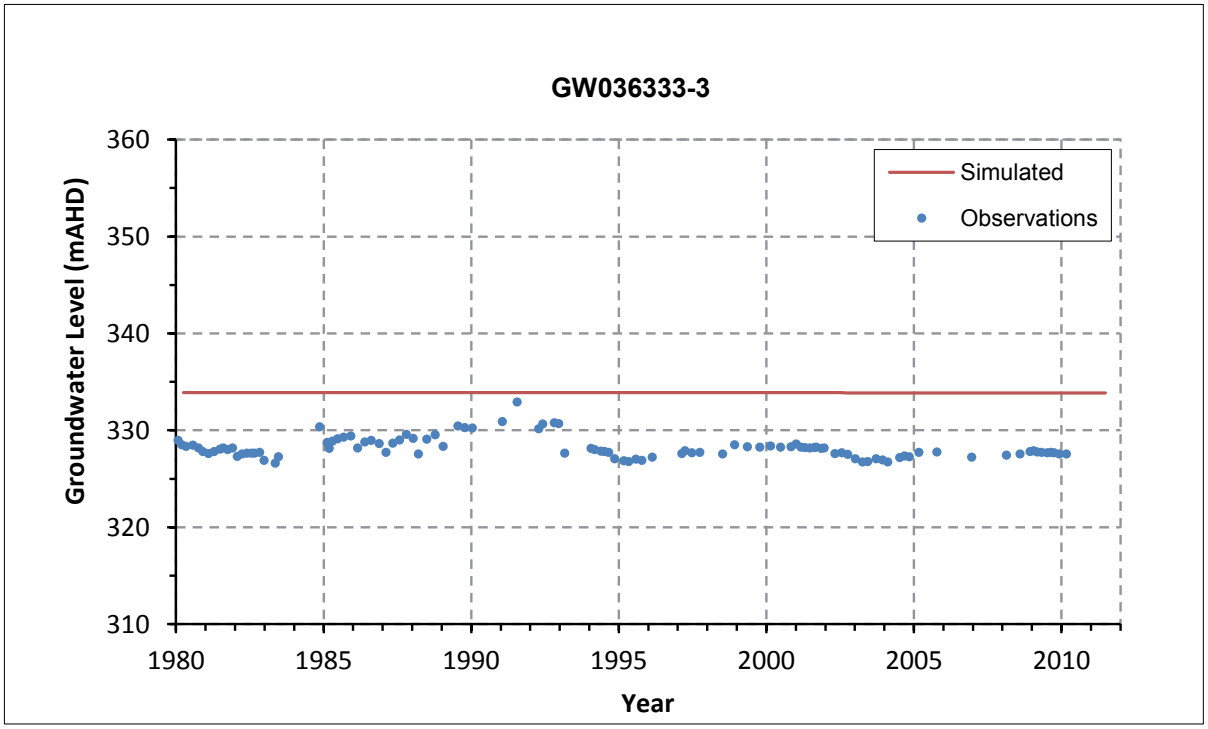

GW035507-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

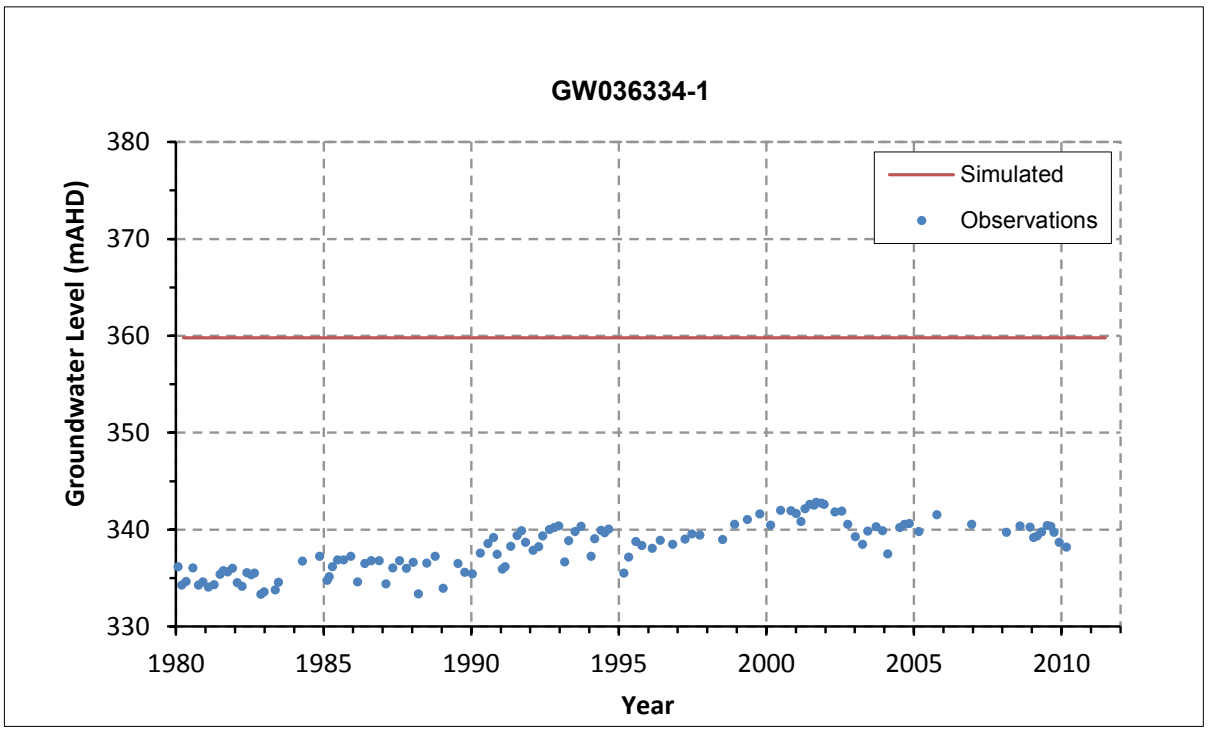

GW036315-1
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

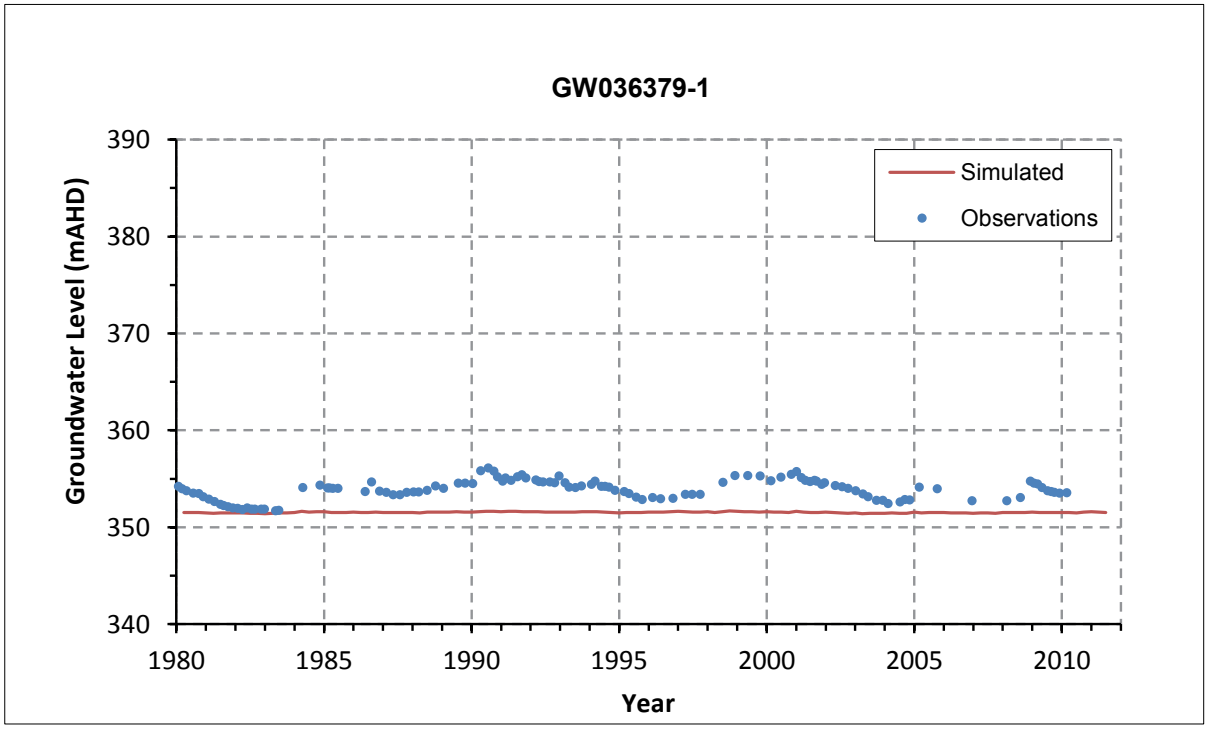

GW036315-2
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

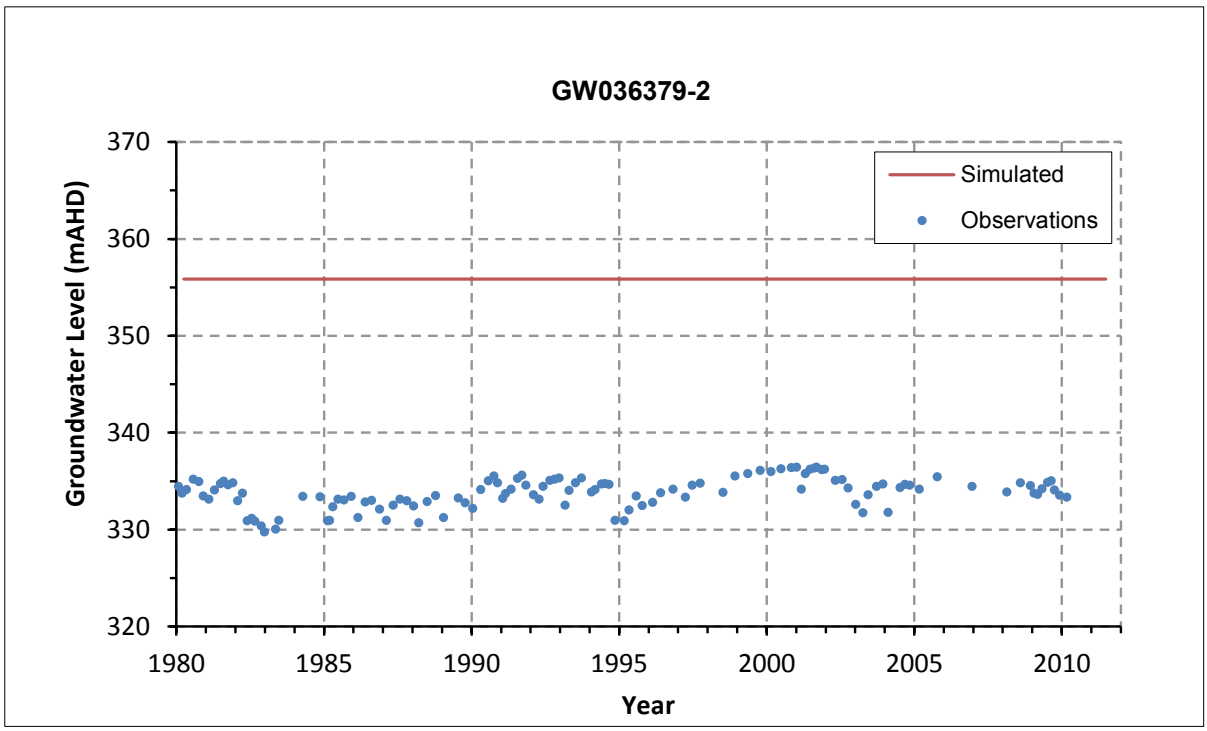

GW036333-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

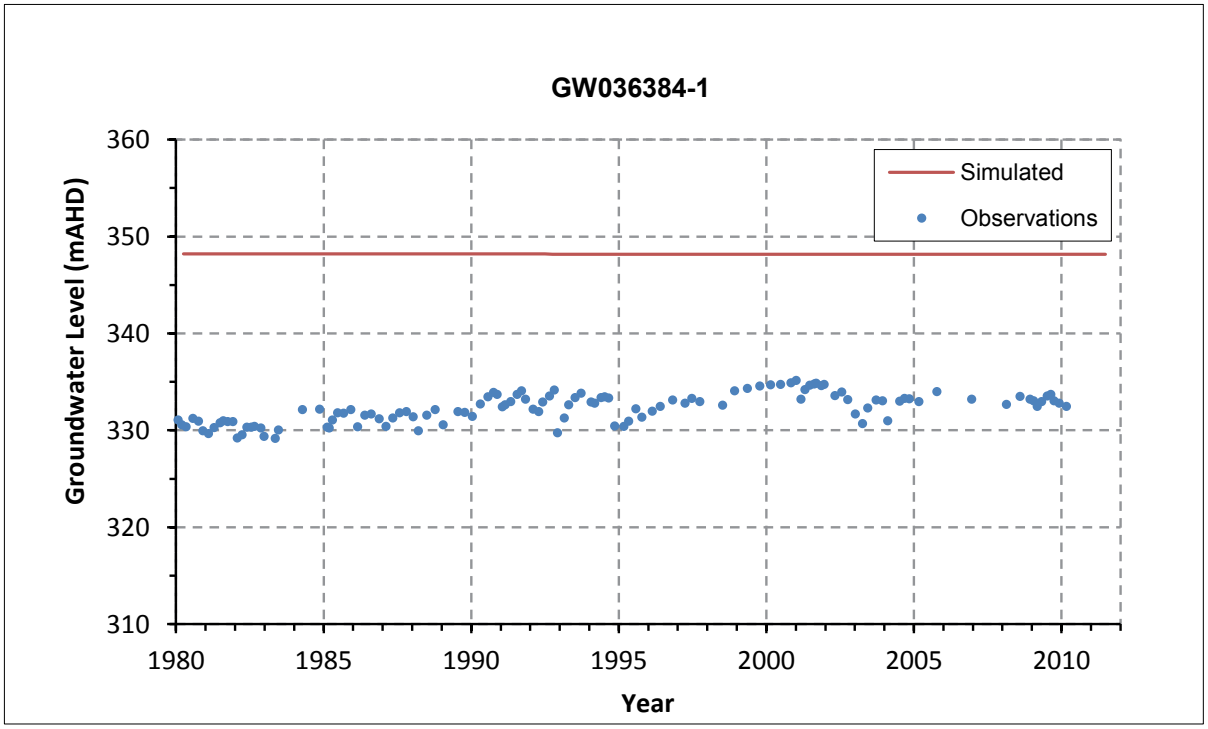

GW036333-2
Groundwater Level (mAHD)
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350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

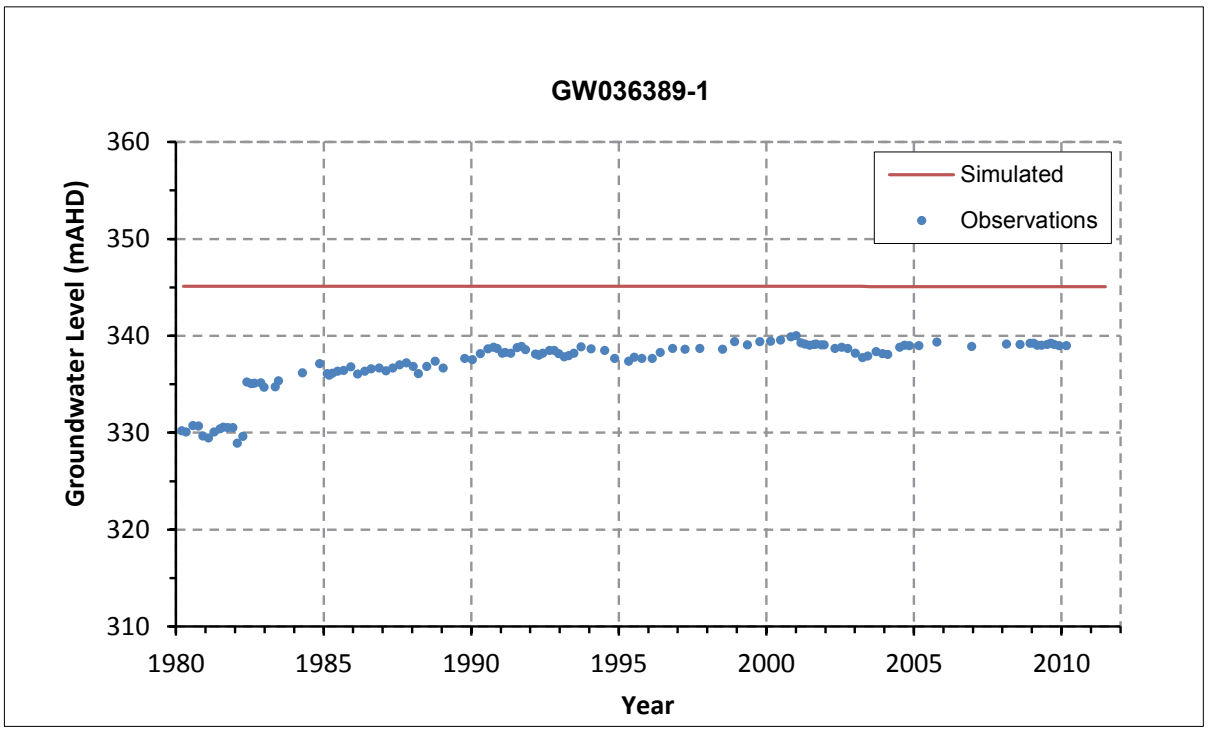

GW036333-3
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

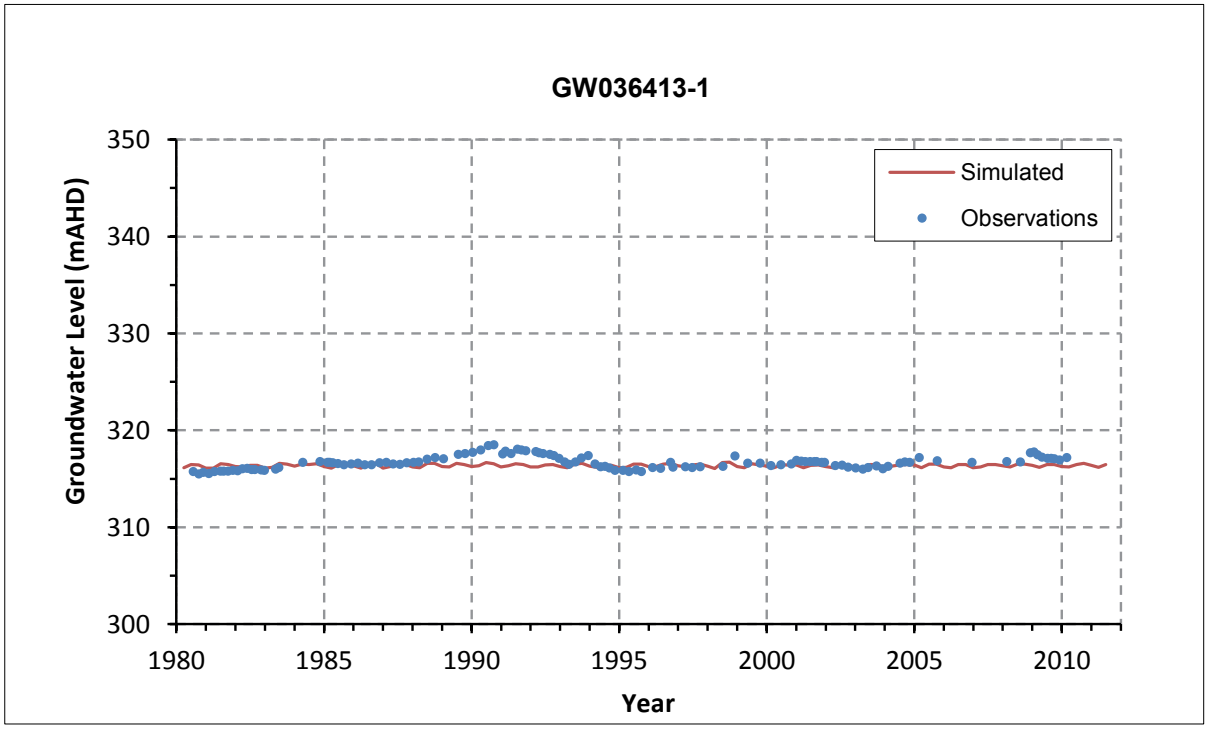

GW036334-1
Groundwater Level (mAHD)
380
370
360
350
340
330
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

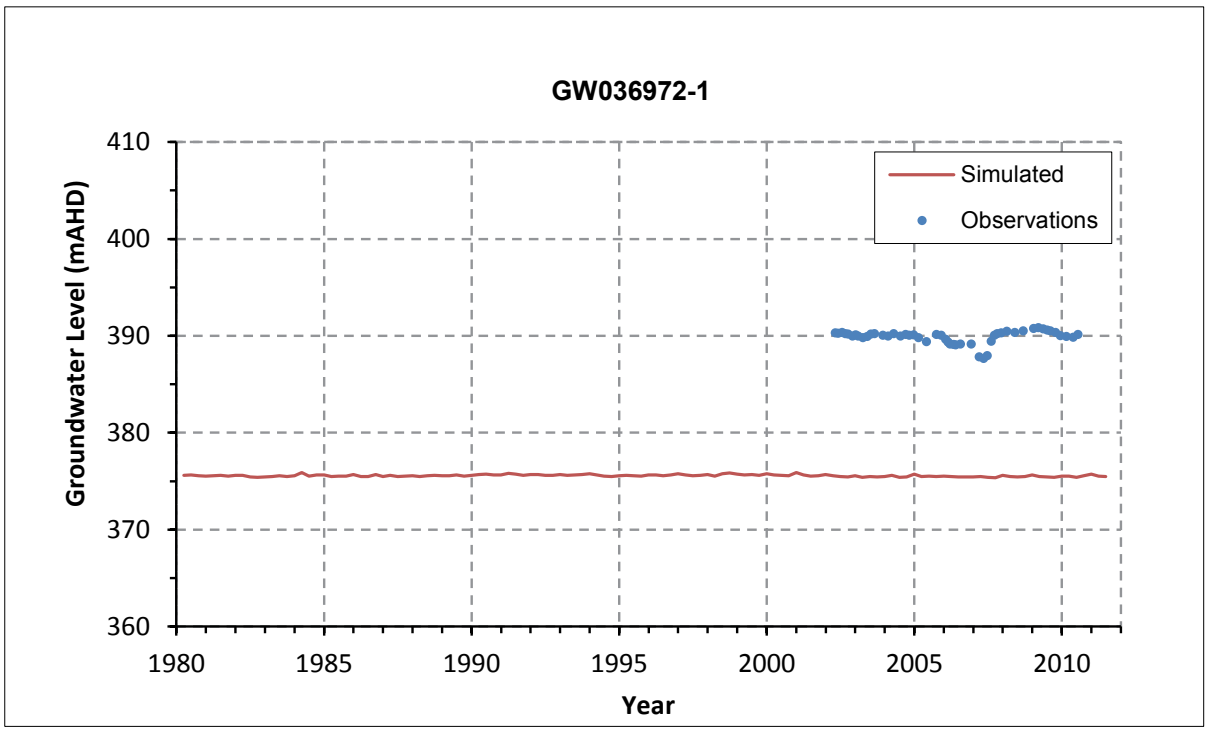

GW036379-1
Groundwater Level (mAHD)
390
380
370
360
350
340
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

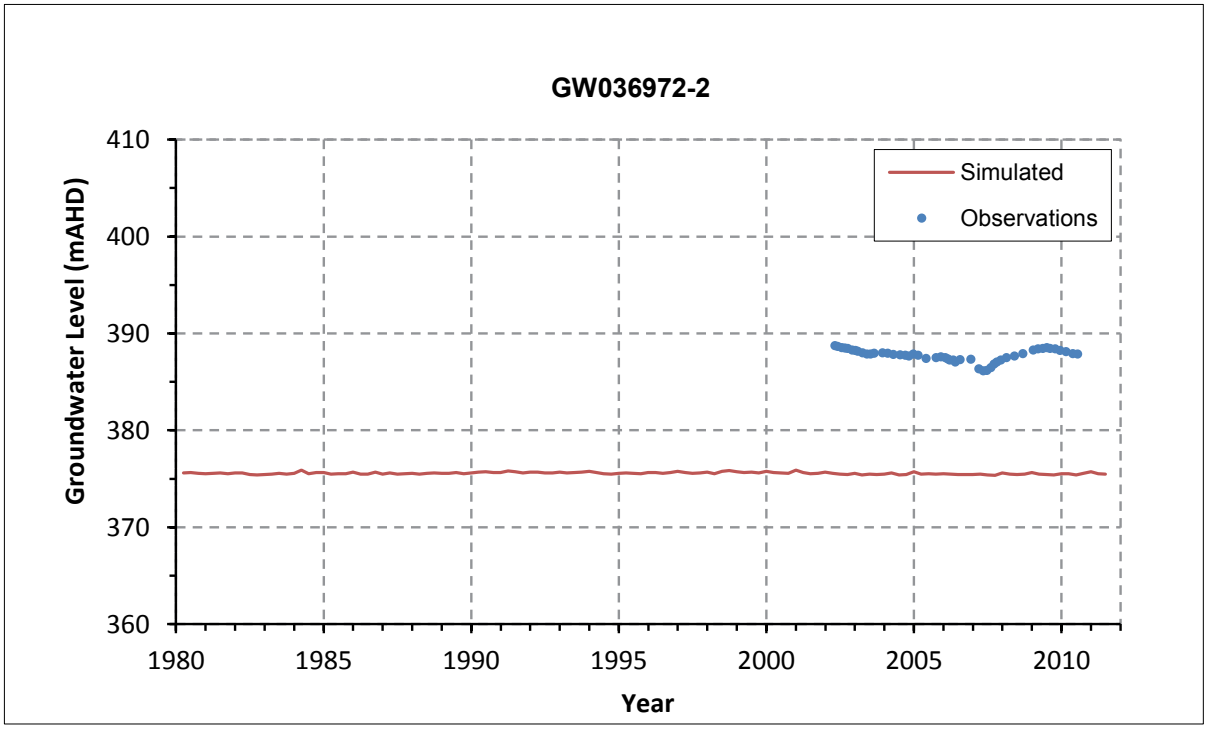

GW036379-2
Groundwater Level (mAHD)
370
360
350
340
330
320
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

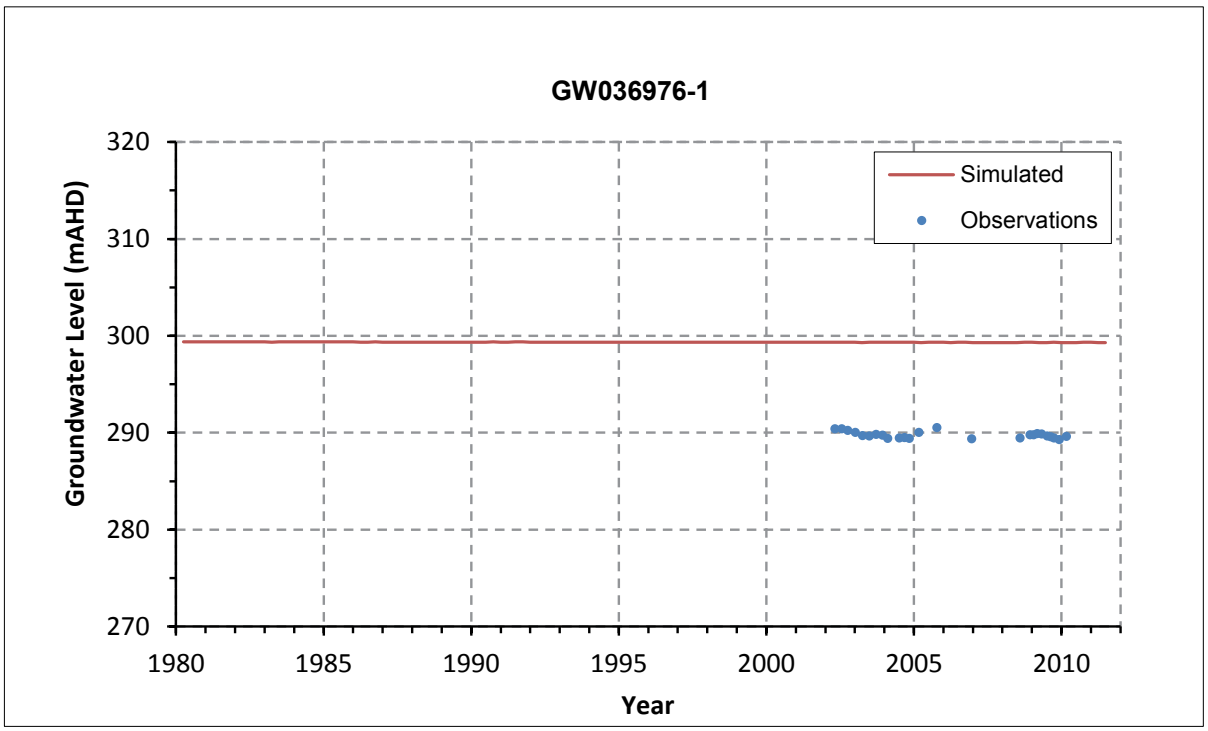

GW036384-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

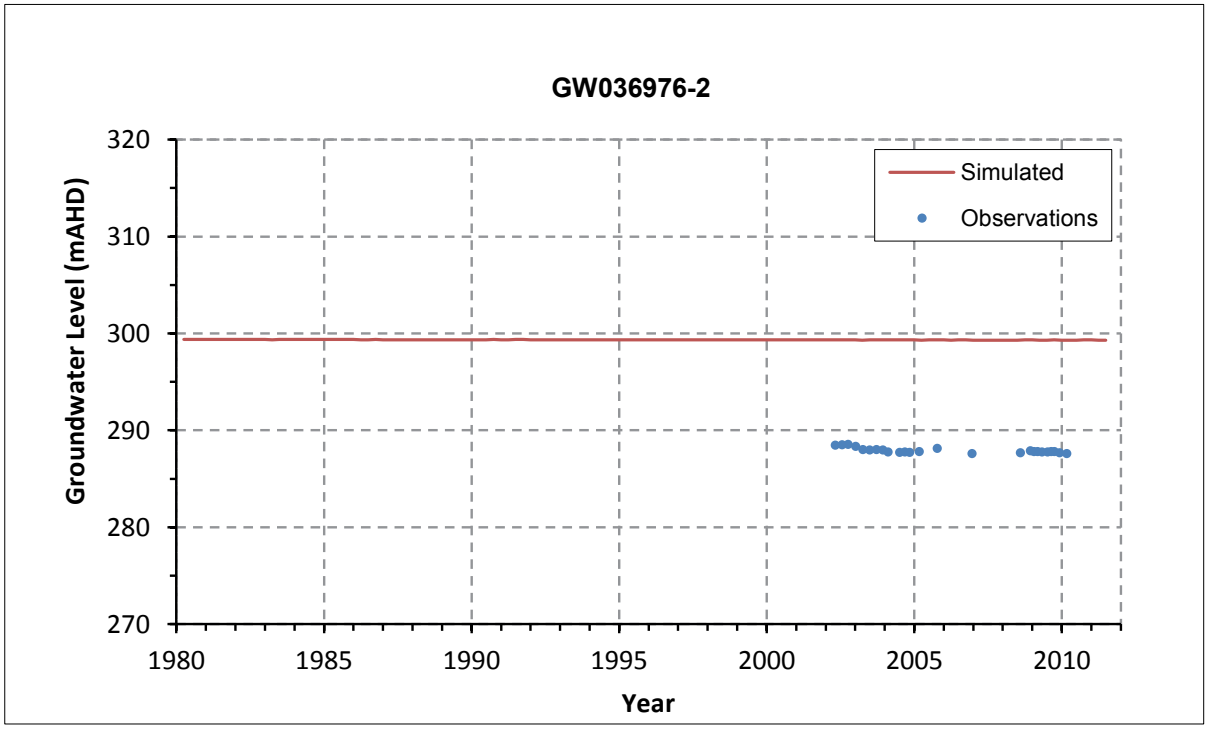

GW036389-1
Groundwater Level (mAHD)
360
350
340
330
320
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1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

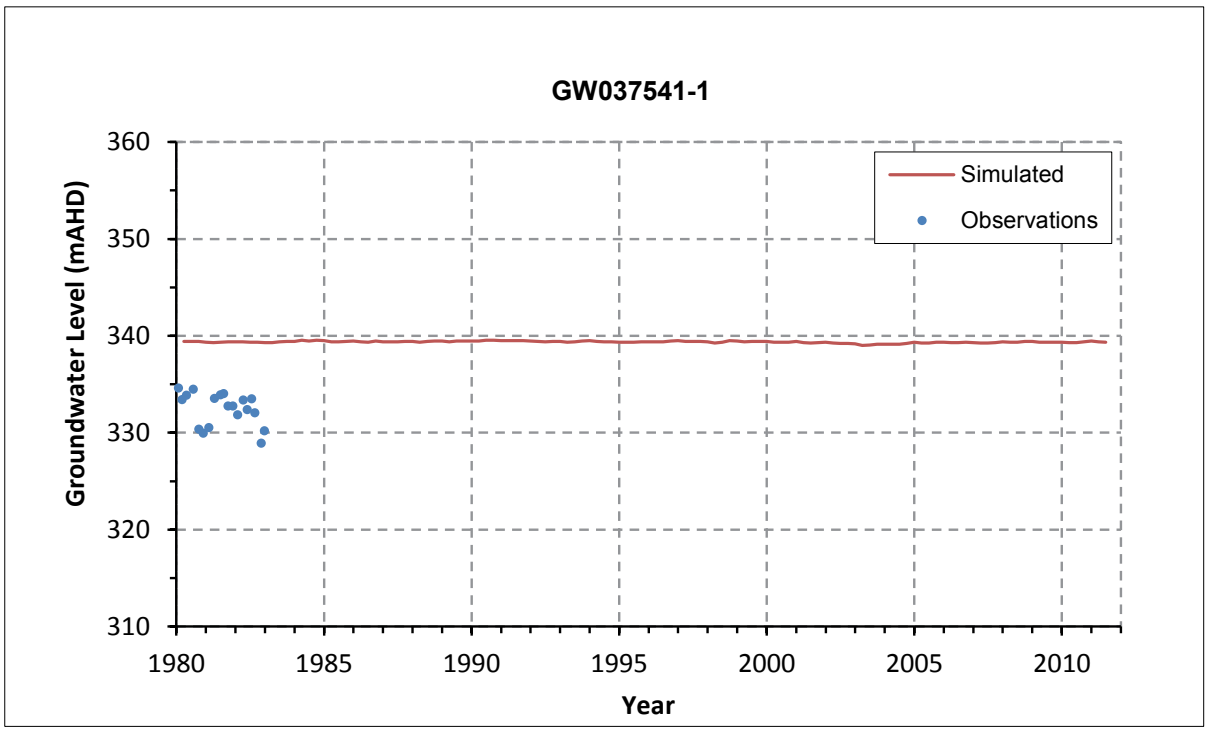

GW036413-1
Groundwater Level (mAHD)
350
340
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1995
2000
2005
2010
Year
Simulated
Observations

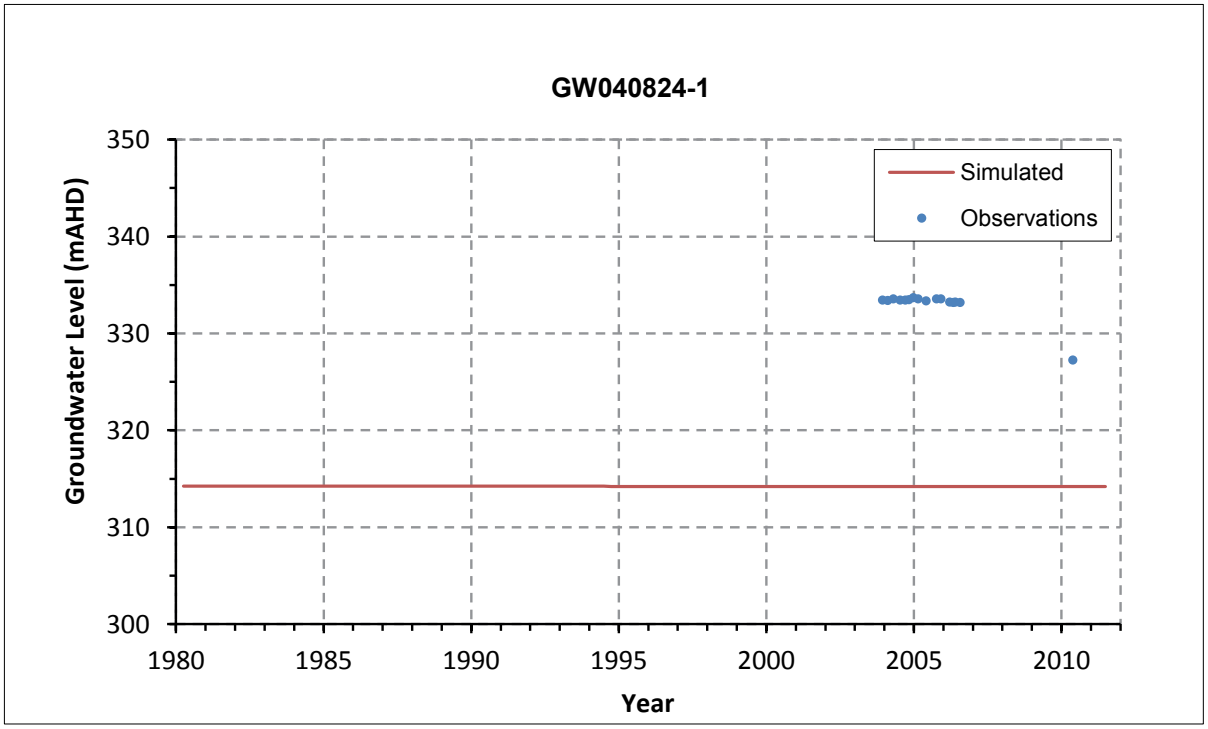

GW036972-1
Groundwater Level (mAHD)
410
400
390
380
370
360
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

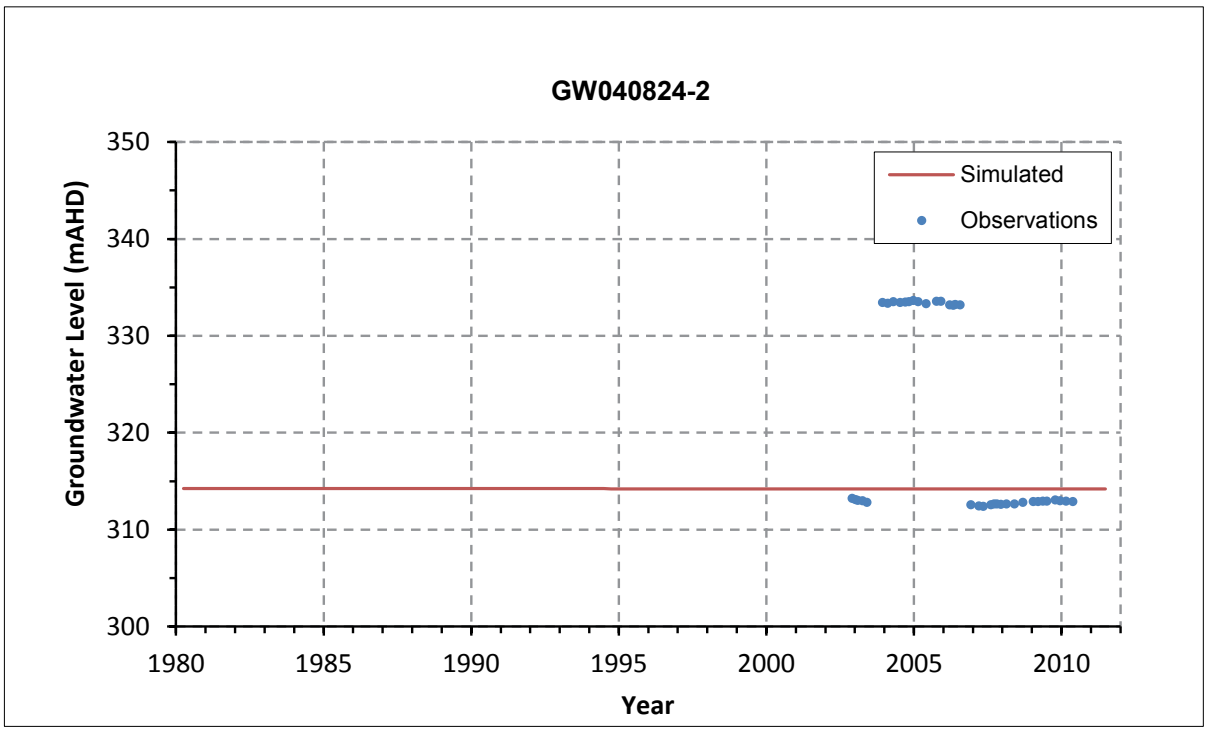

GW036972-2
Groundwater Level (mAHD)
410
400
390
380
370
360
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

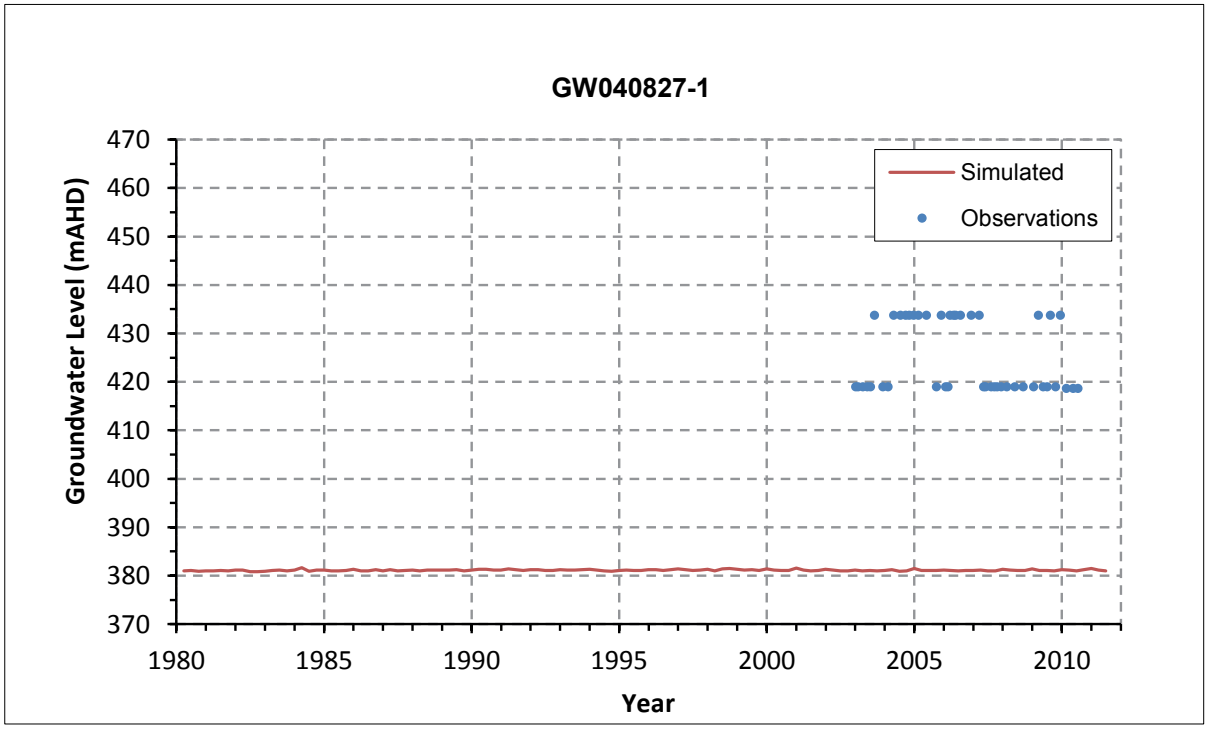

GW036976-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

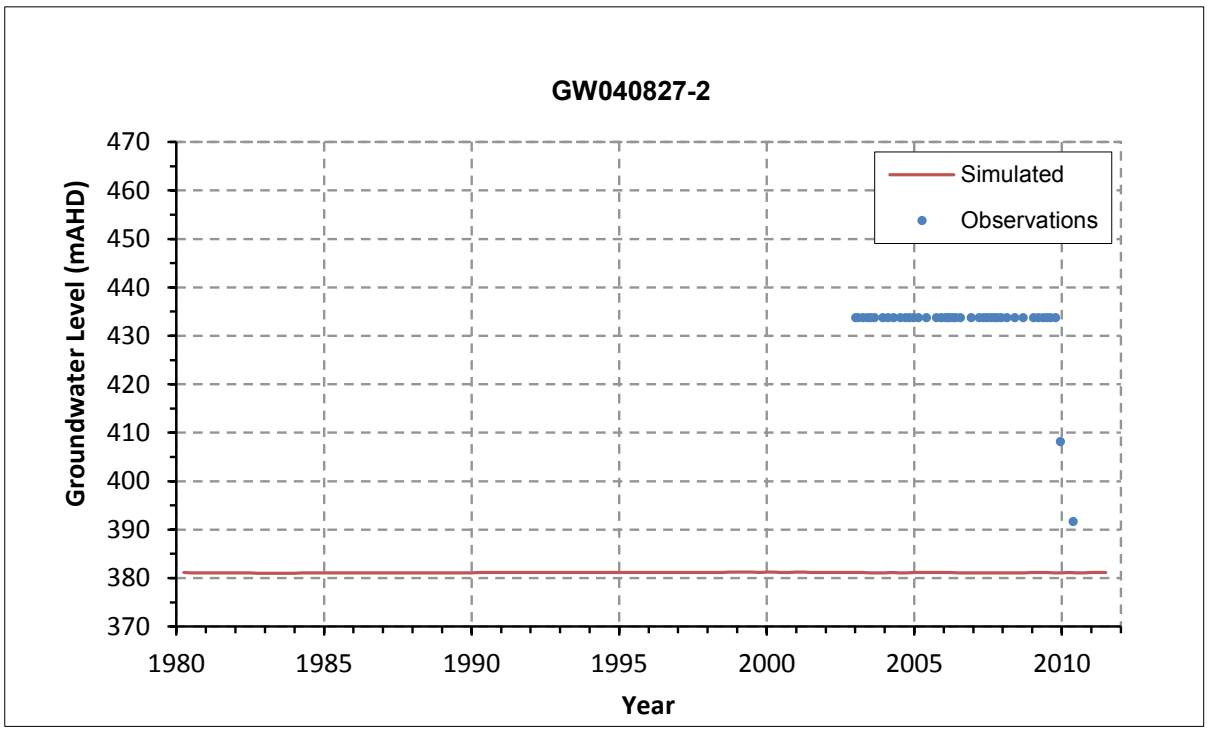

GW036976-2
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

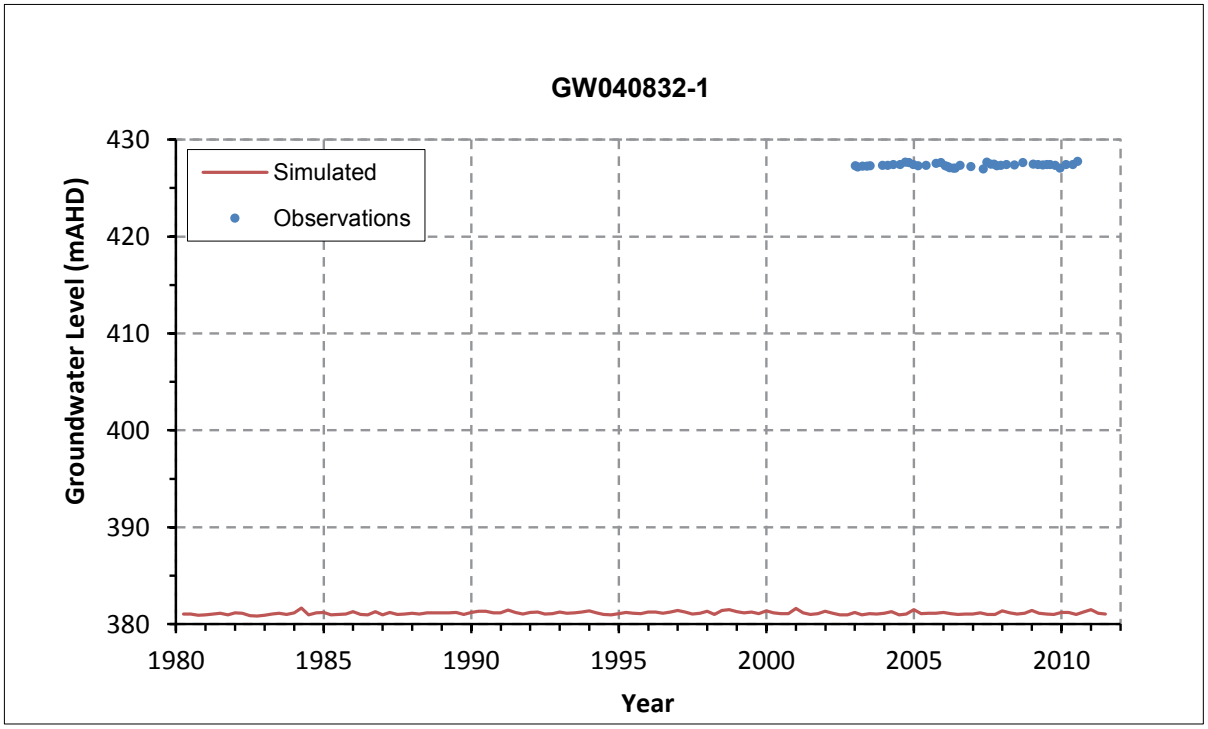

GW037541-1
Groundwater Level (mAHD)
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

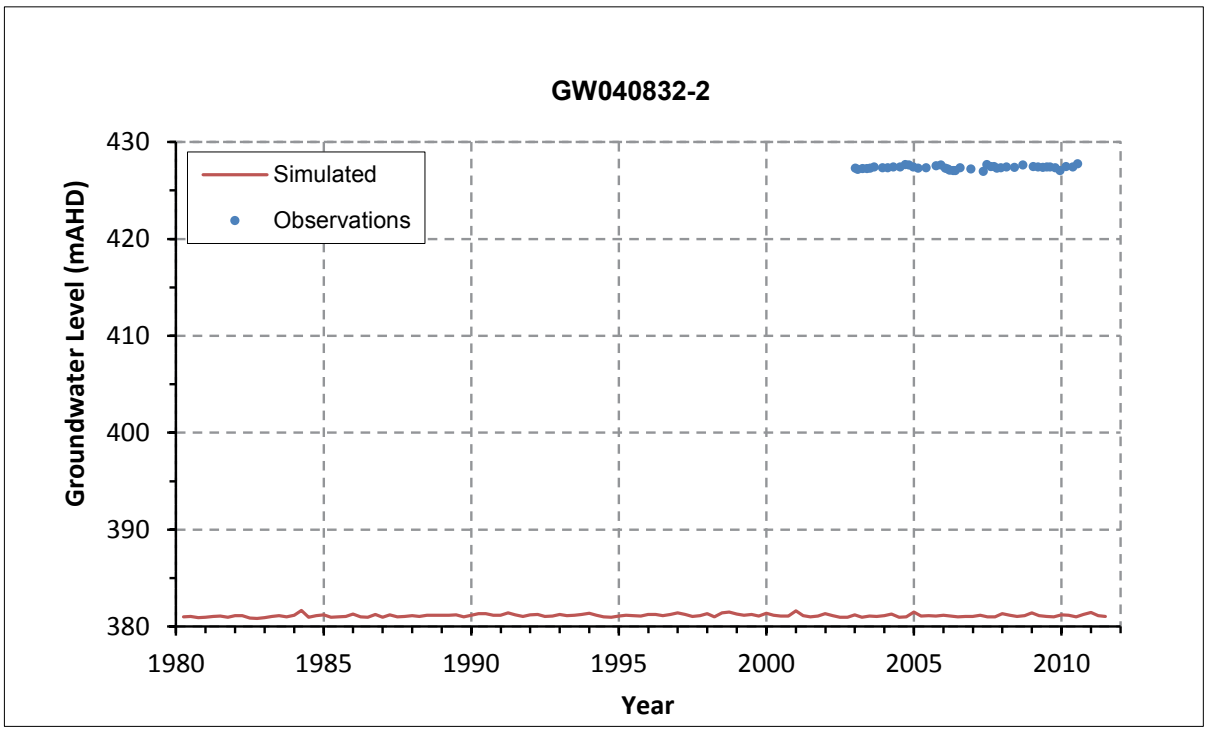

GW040824-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

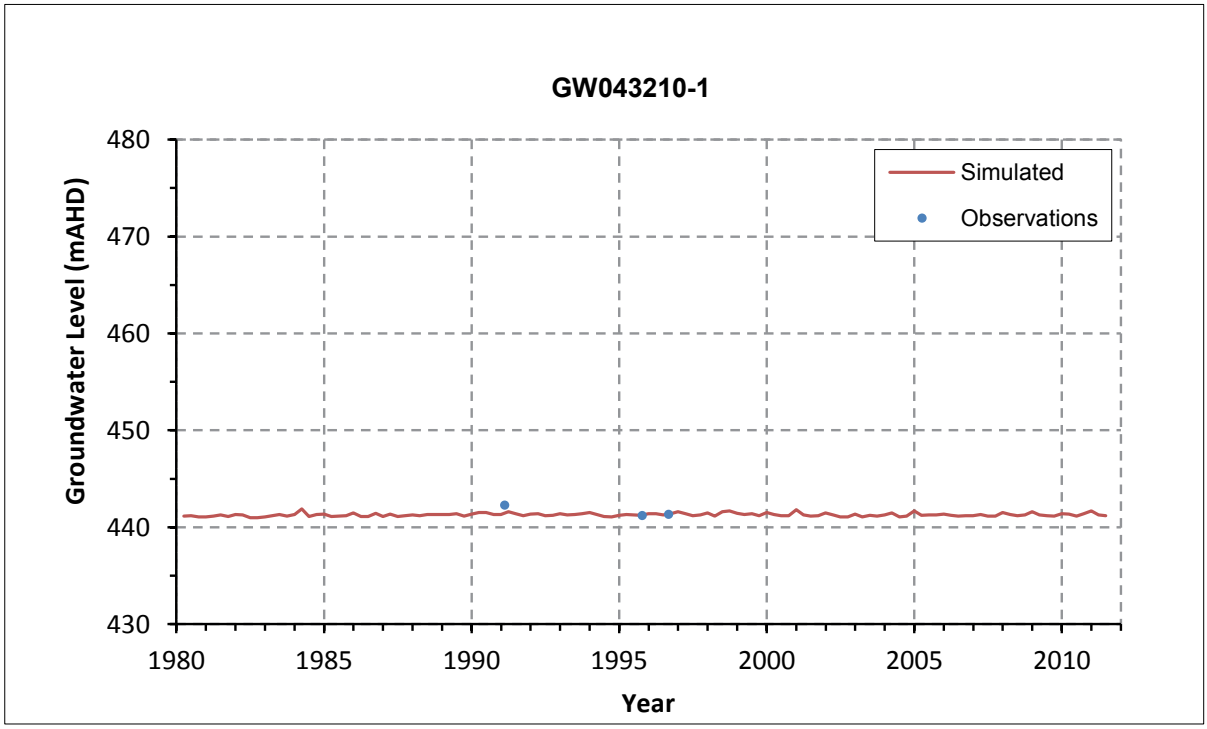

GW040824-2
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

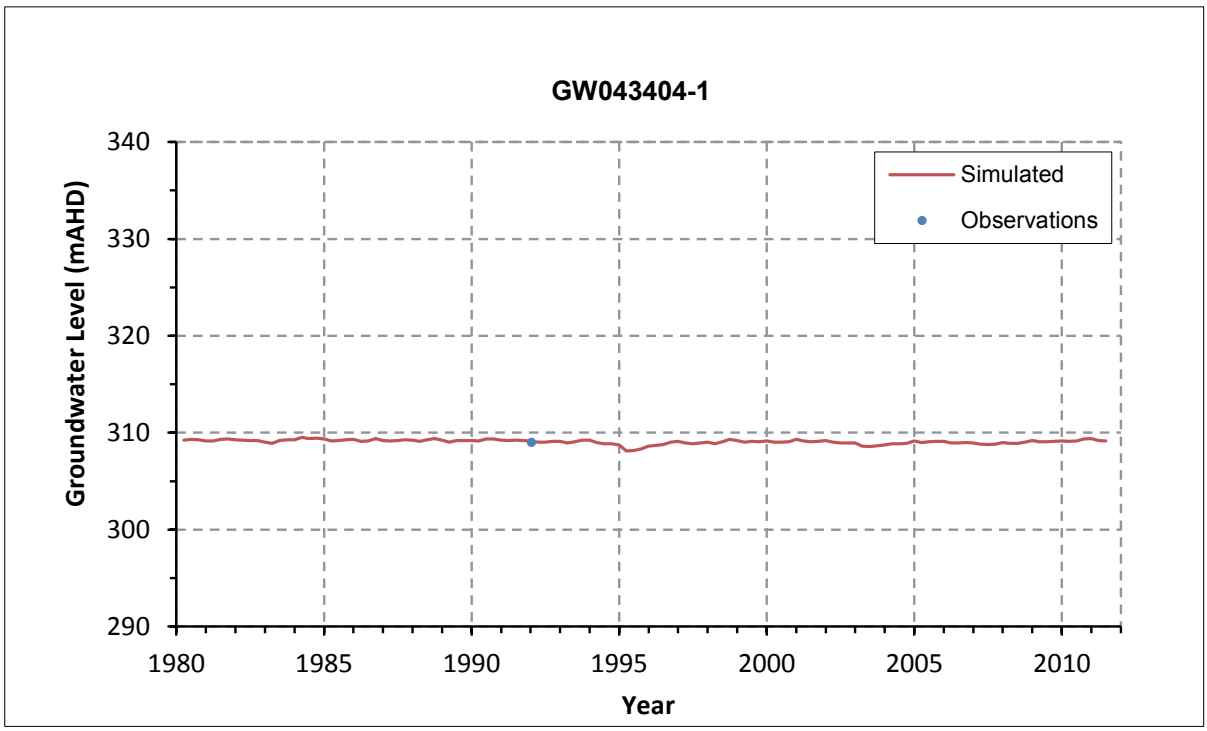

GW040827-1
Groundwater Level (mAHD)
470
460
450
440
430
420
410
400
390
380
370
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

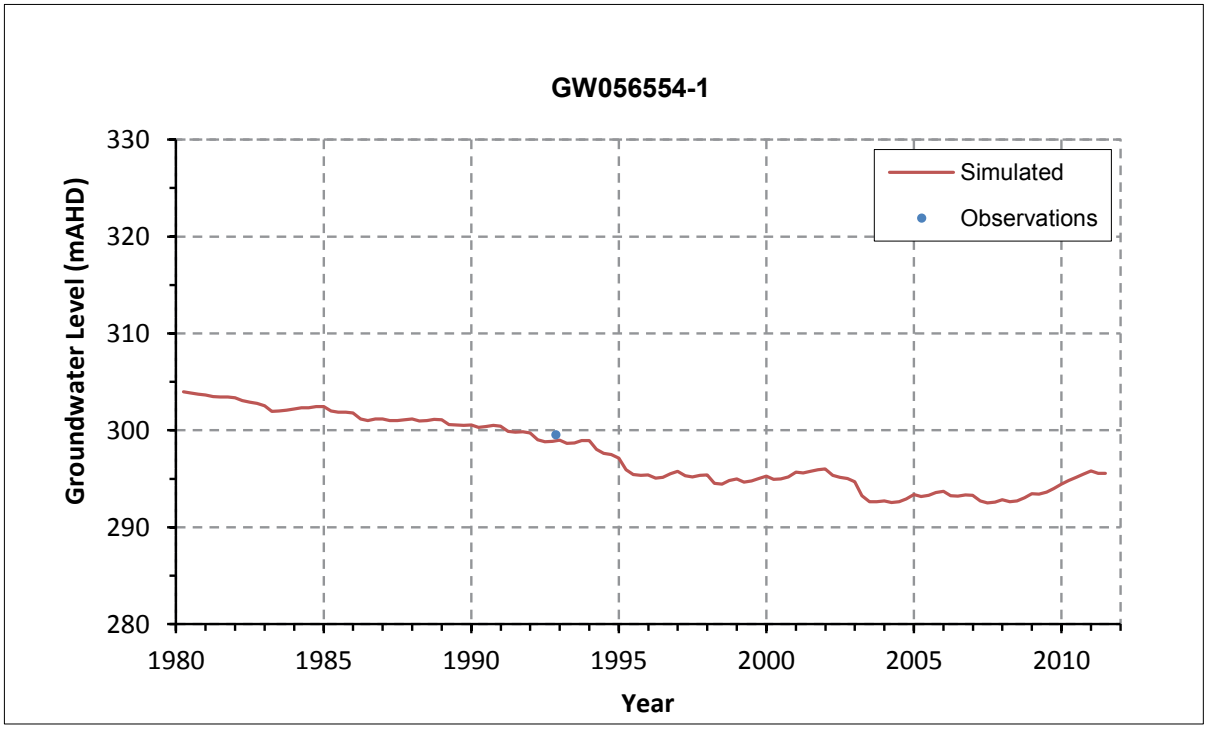

GW040827-2
Groundwater Level (mAHD)
470
460
450
440
430
420
410
400
390
380
370
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

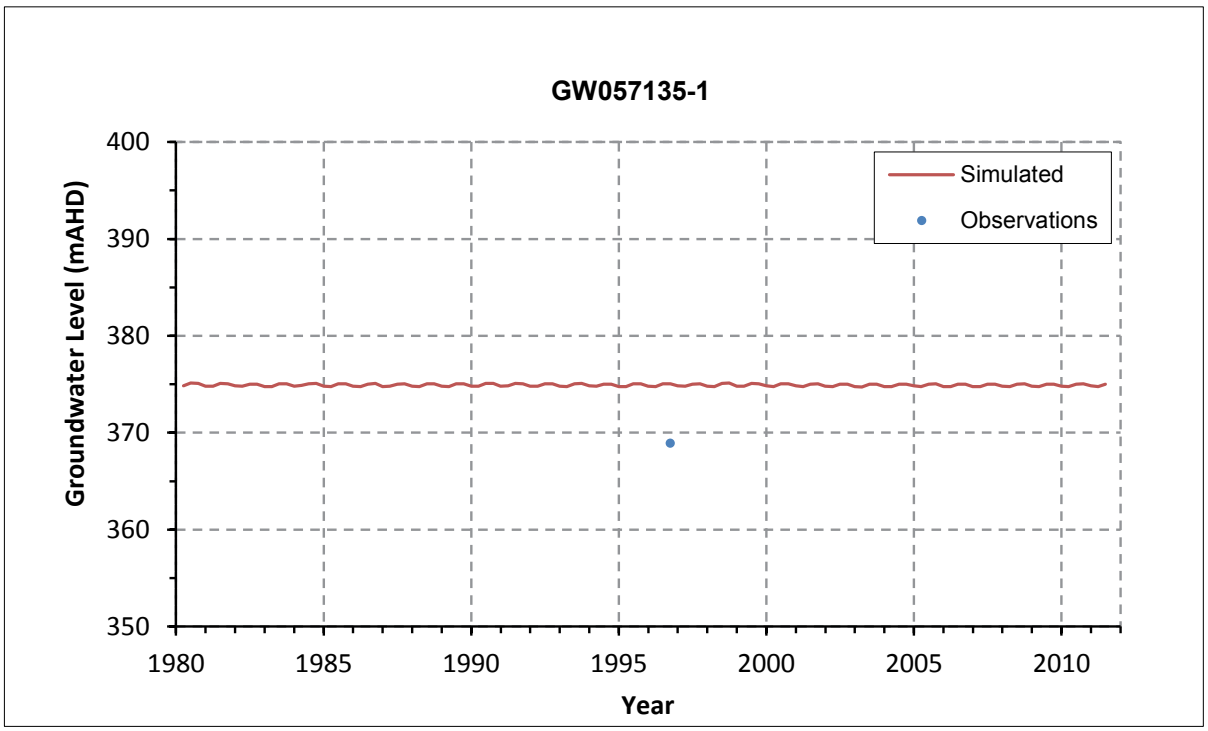

GW040832-1
Simulated
Observations
Groundwater Level (mAHD)
430
420
410
400
390
380
1980
1985
1990
1995
2000
2005
2010
Year

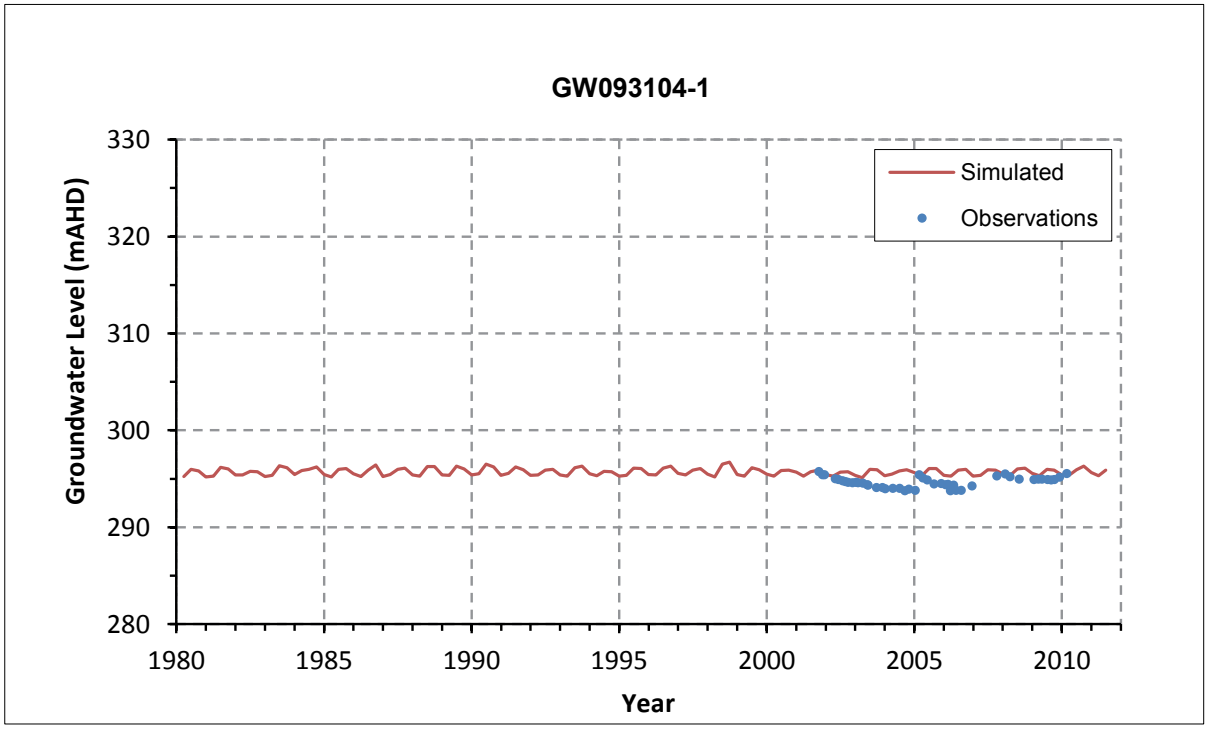

GW040832-2
Simulated
Observations
Groundwater Level (mAHD)
430
420
410
400
390
380
1980
1985
1990
1995
2000
2005
2010
Year

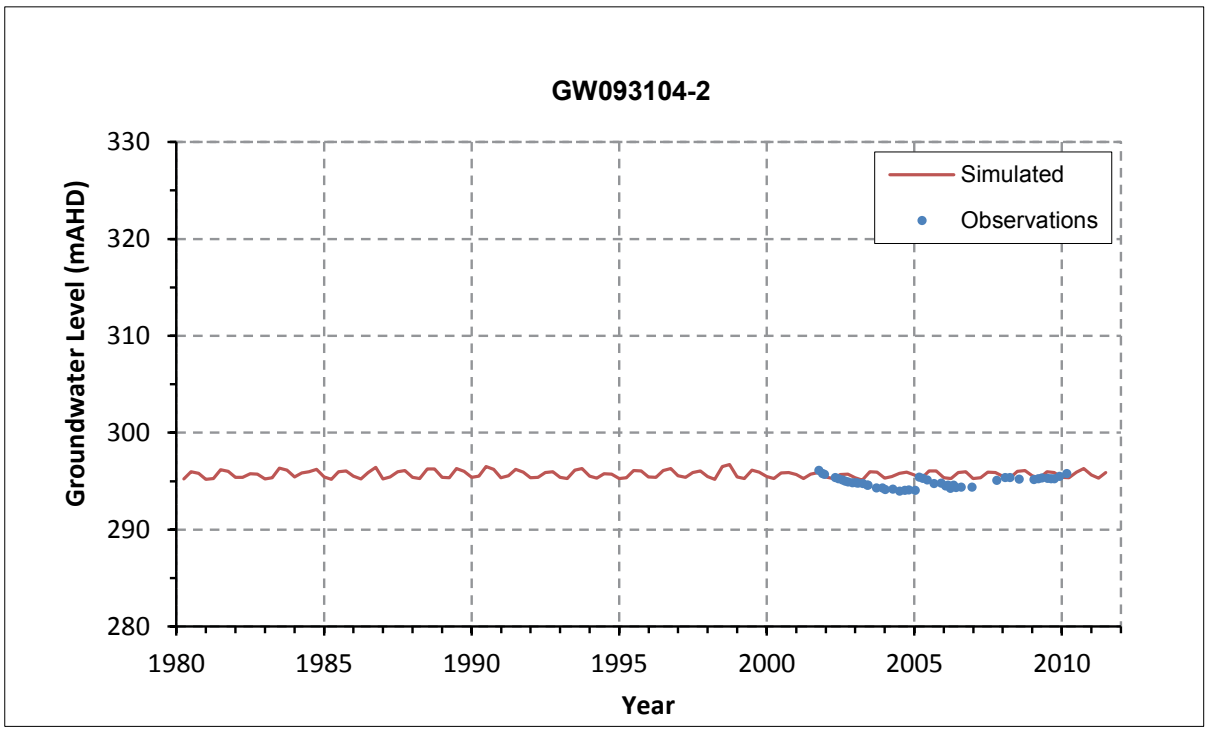

GW043210-1
Groundwater Level (mAHD)
480
470
460
450
440
430
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

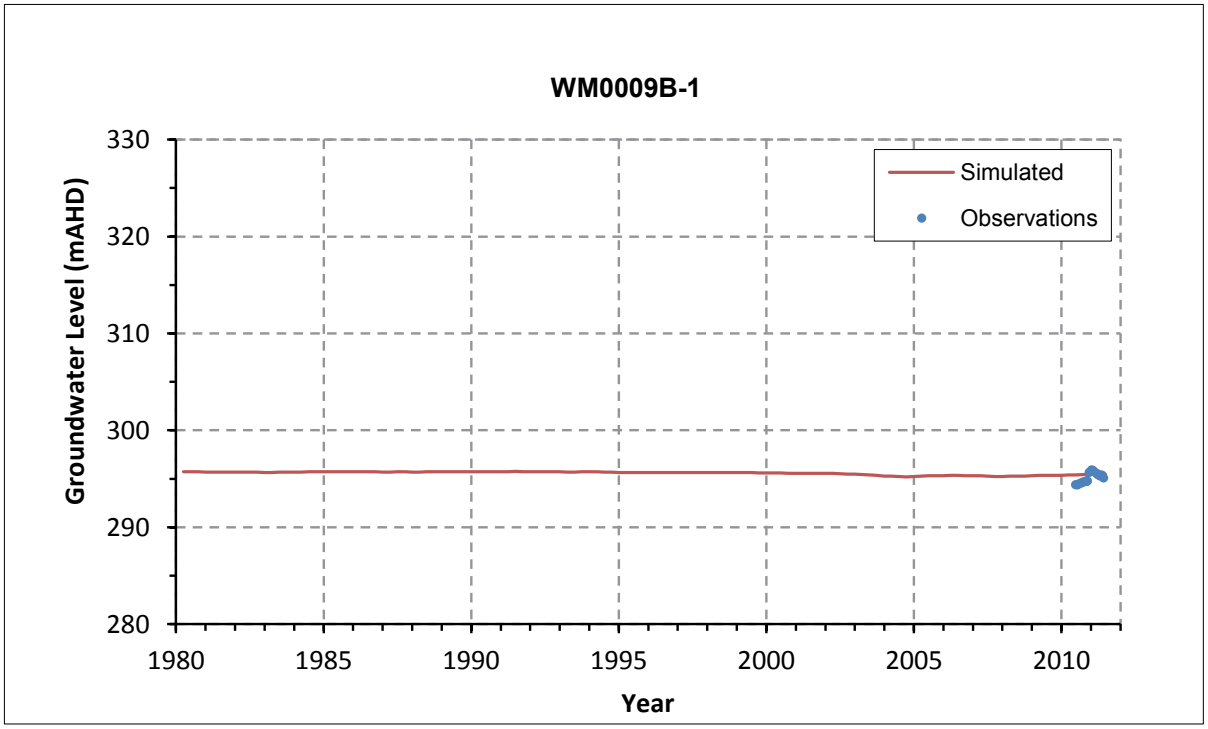

GW043404-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

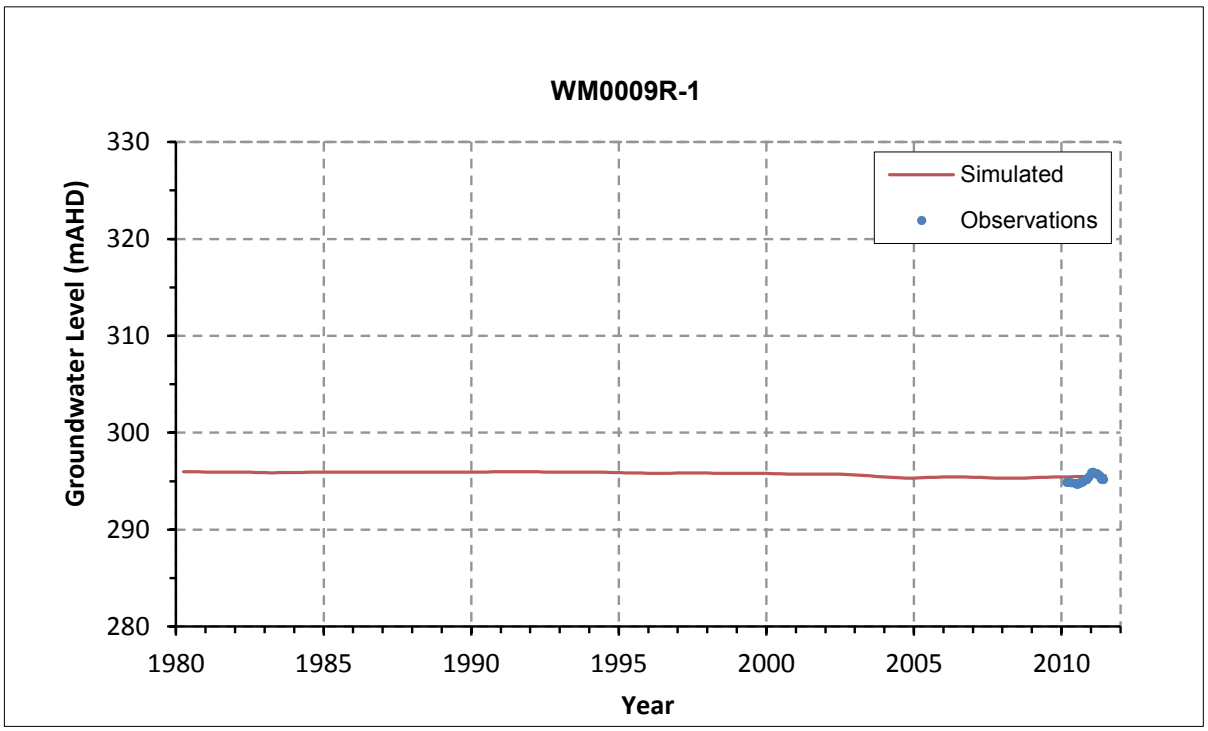

GW056554-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

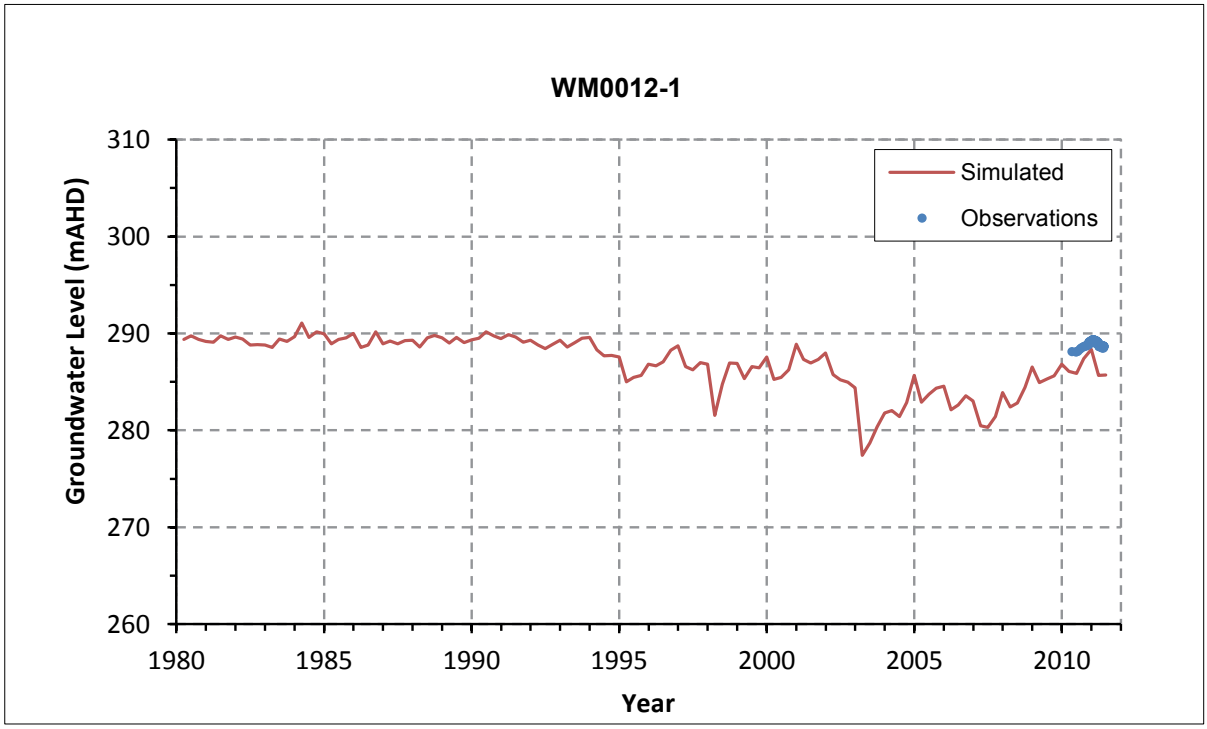

GW057135-1
Groundwater Level (mAHD)
400
390
380
370
360
350
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

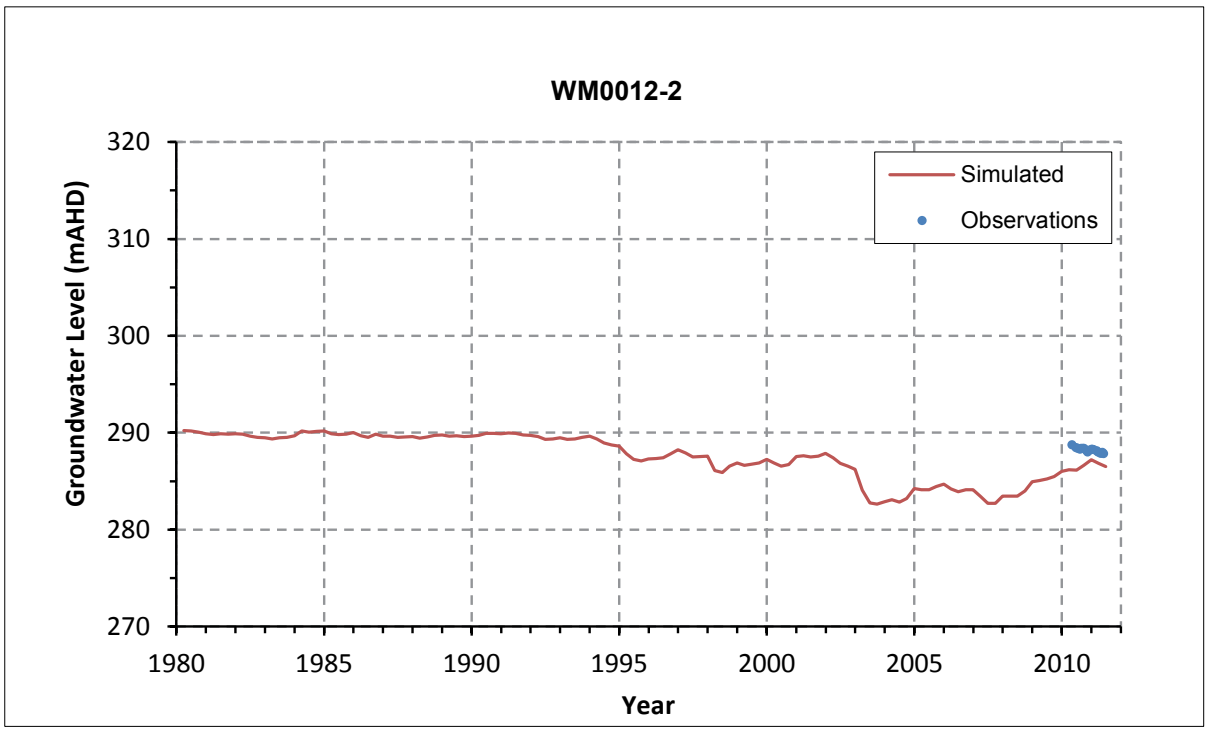

GW093104-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

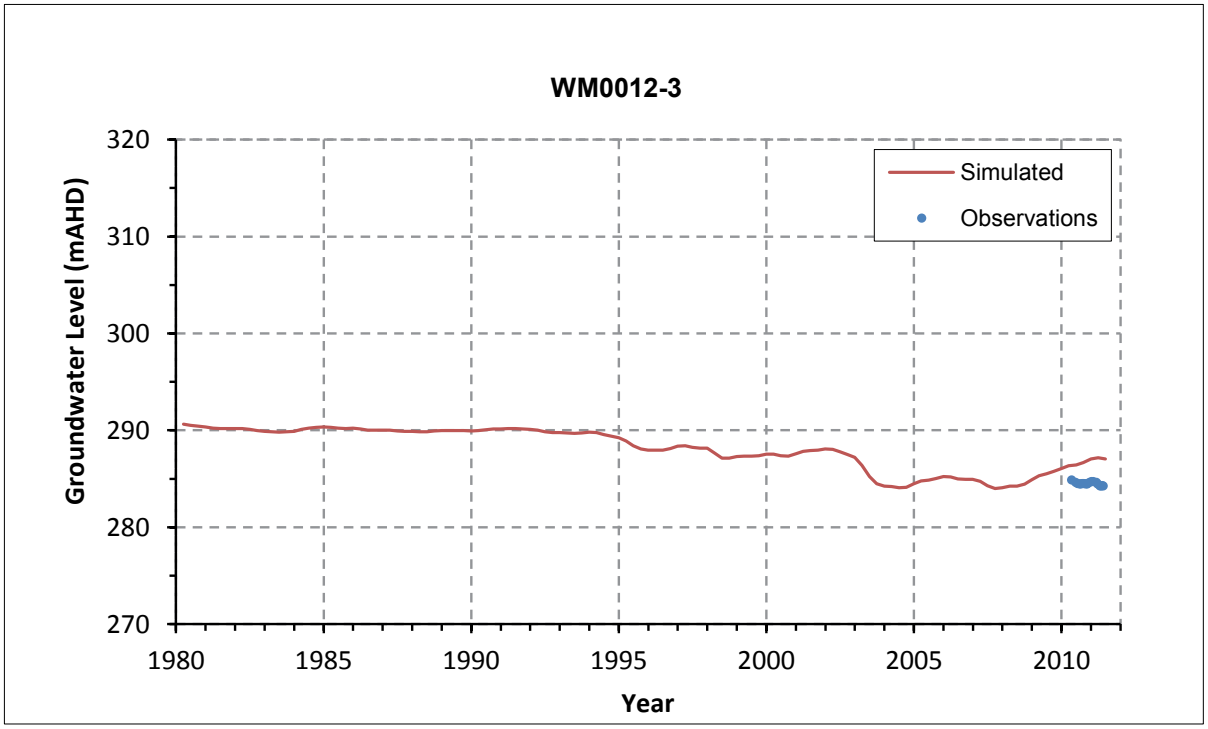

GW093104-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

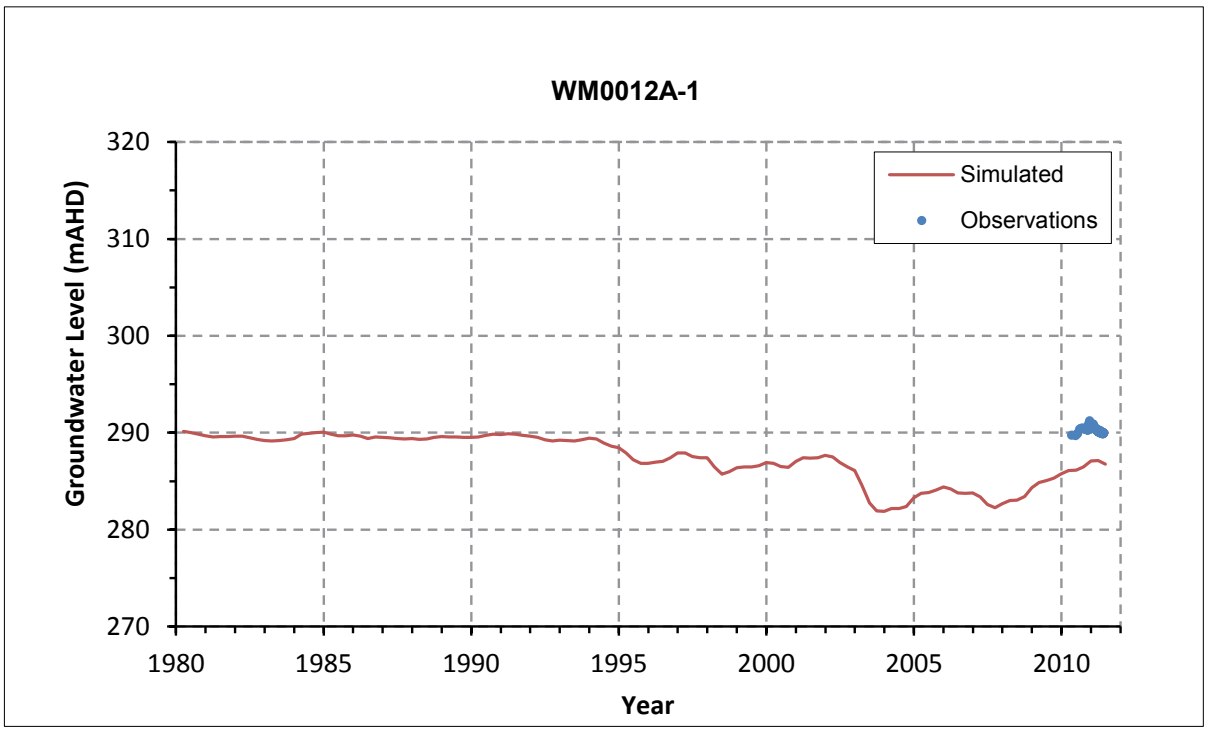

WM0009B-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

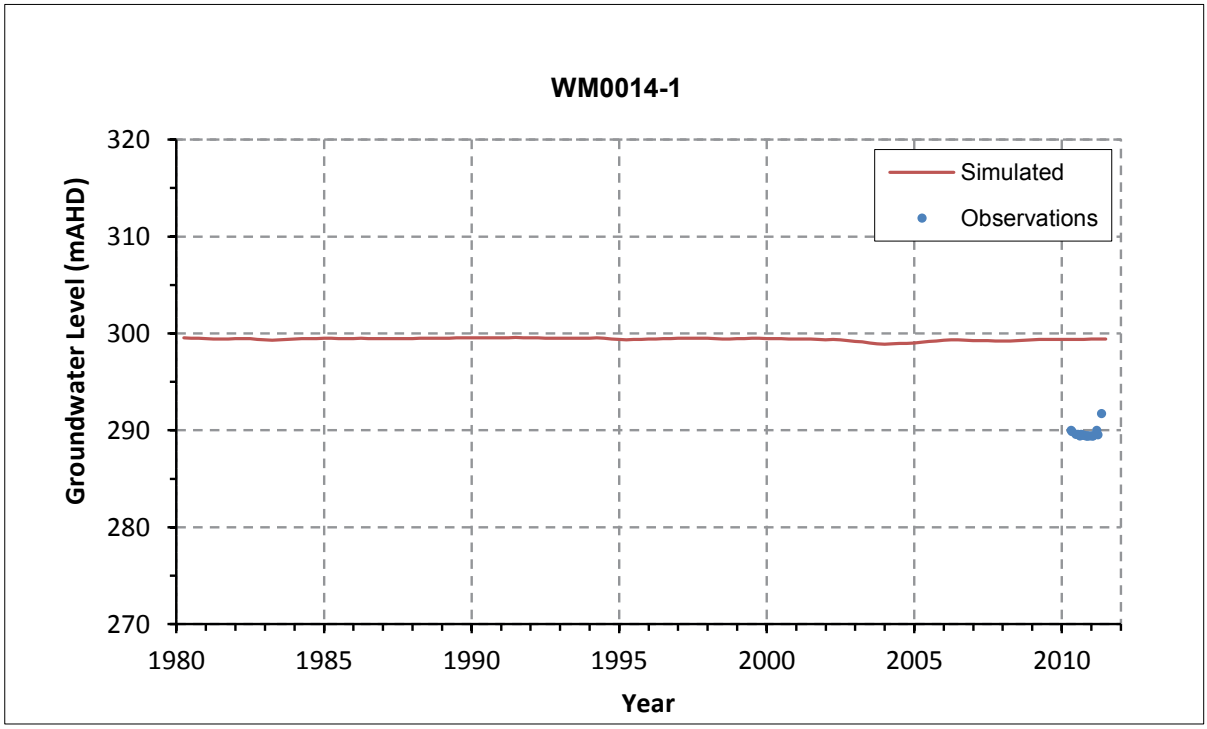

WM0009R-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

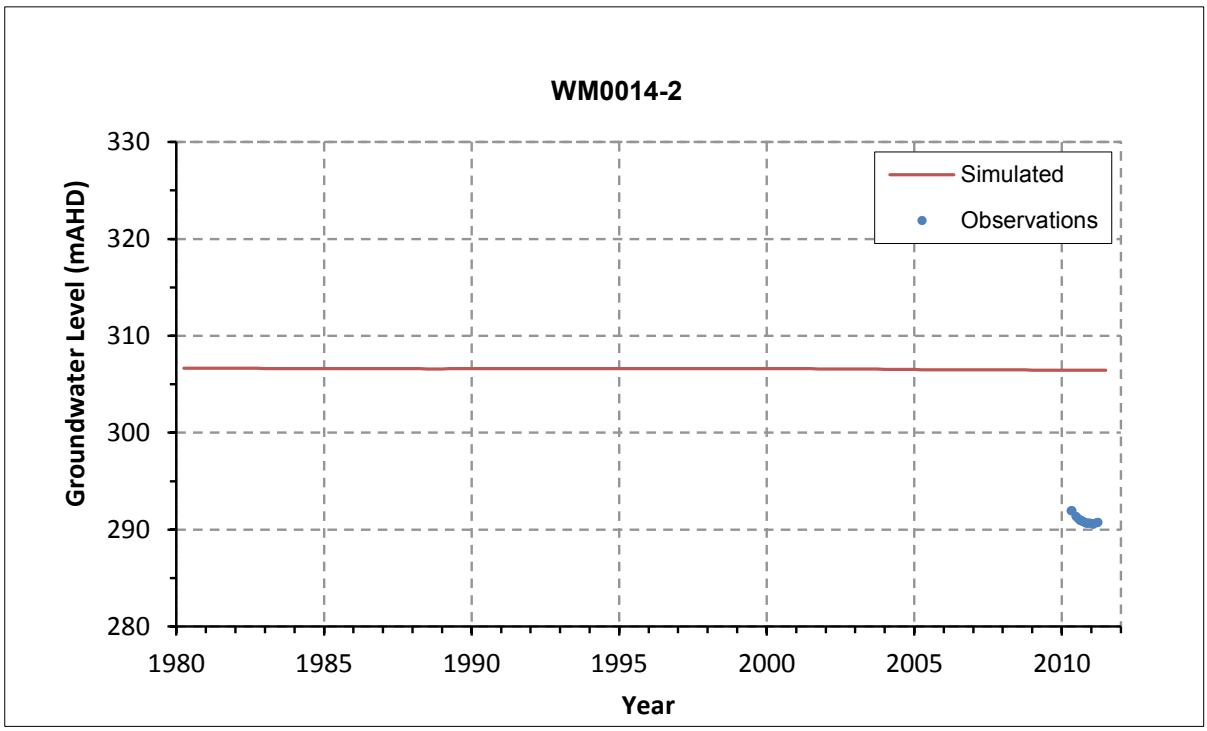

WM0012-1
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

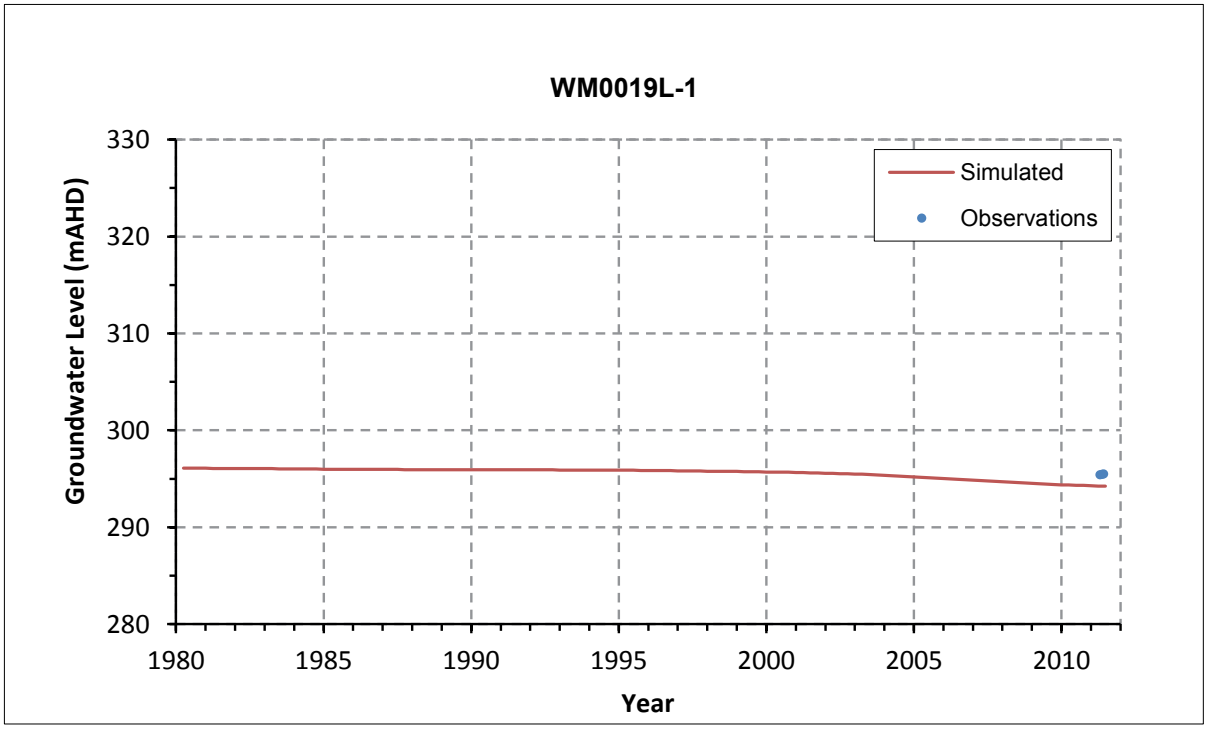

WM0012-2
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

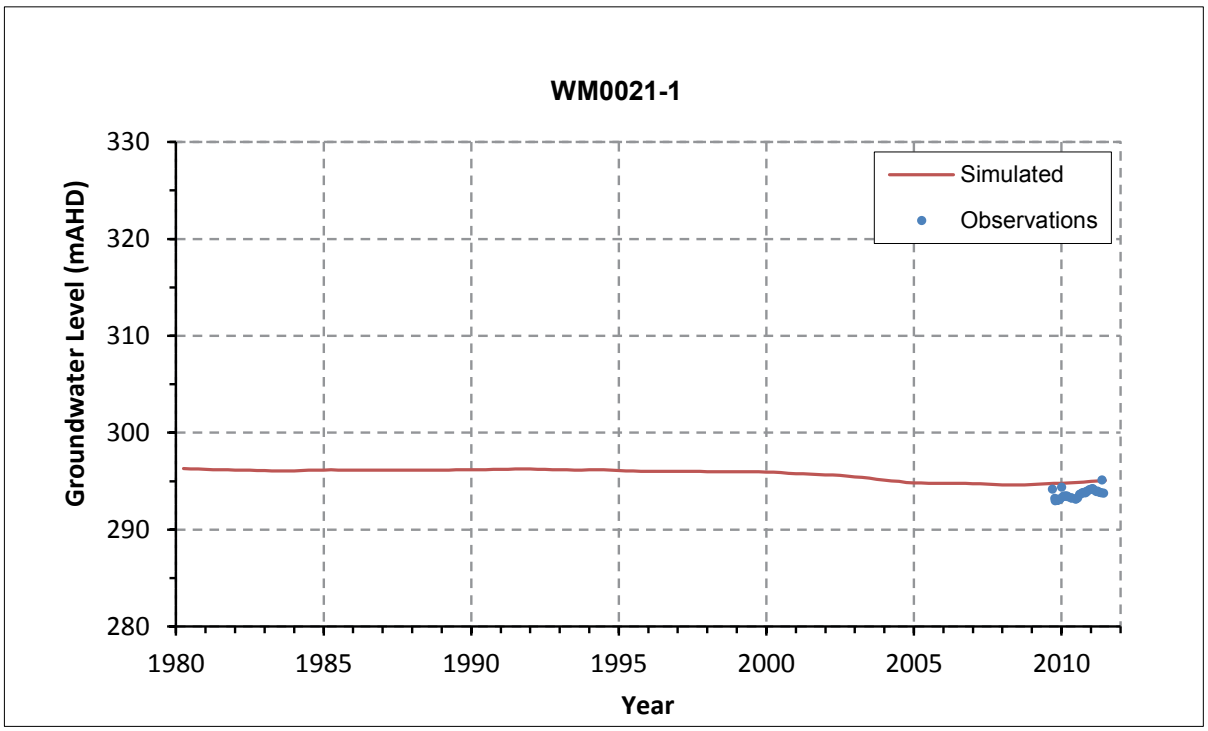

WM0012-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

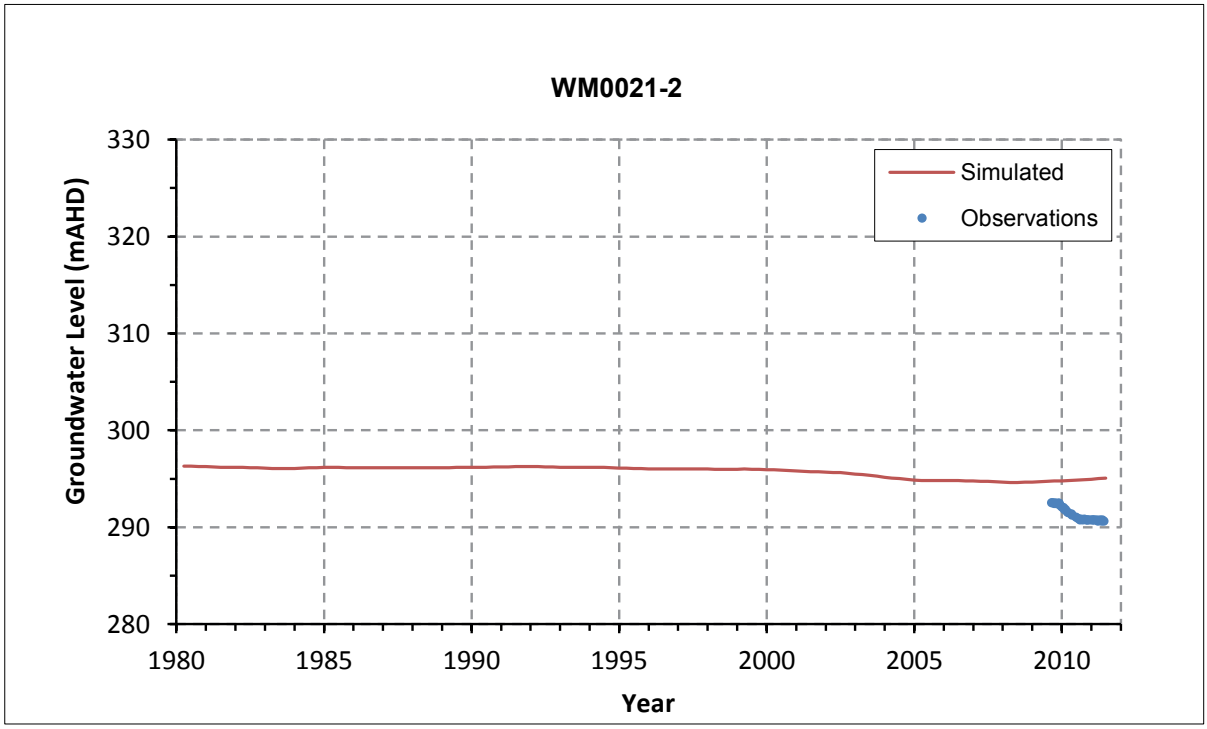

WM0012A-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

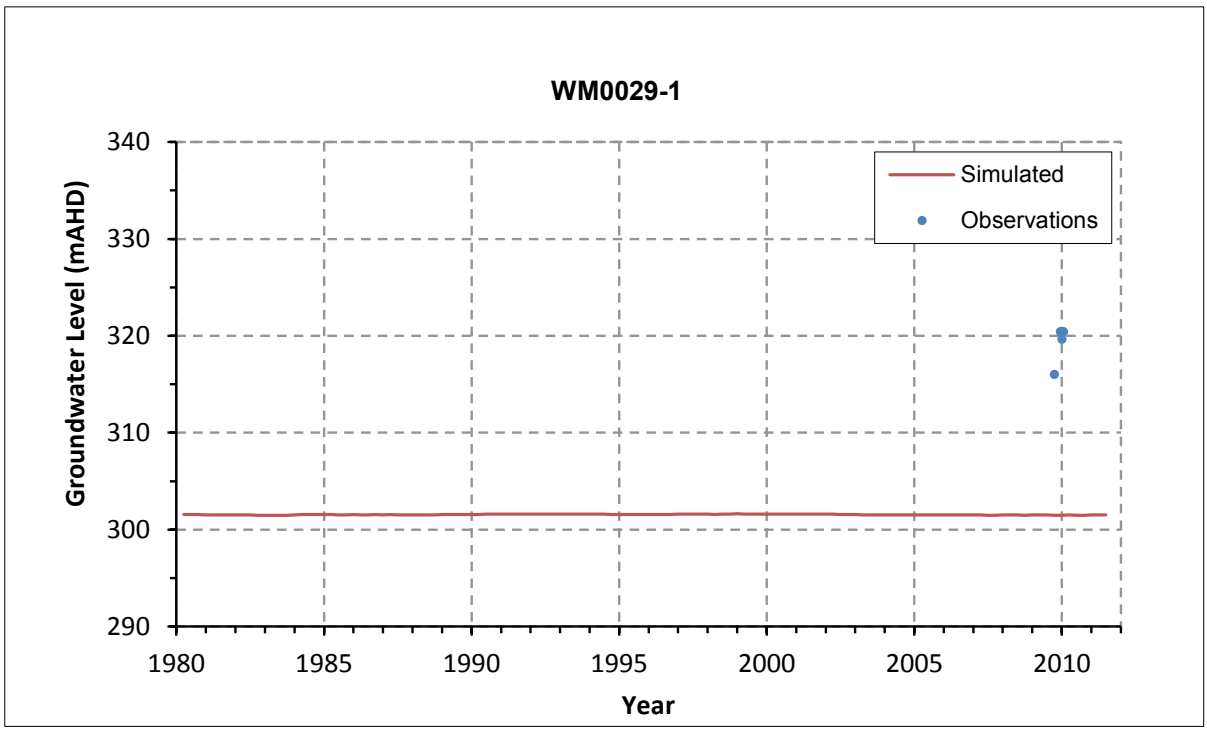

WM0014-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

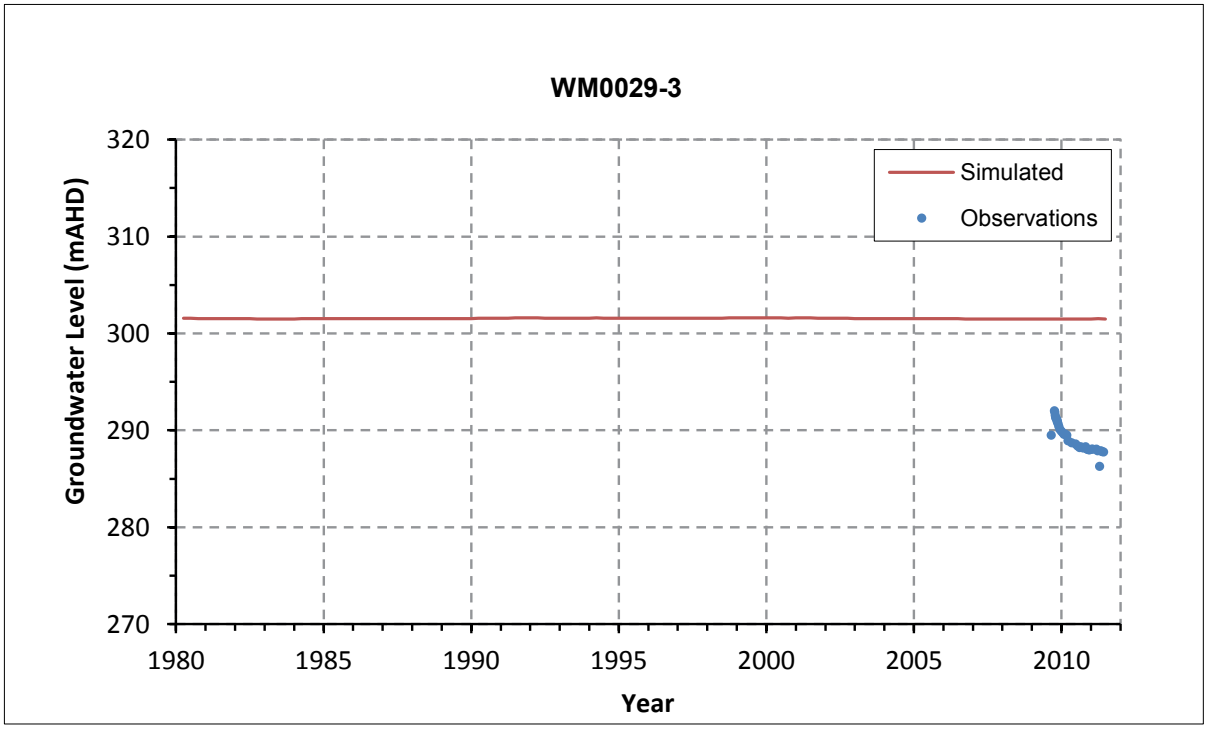

WM0014-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

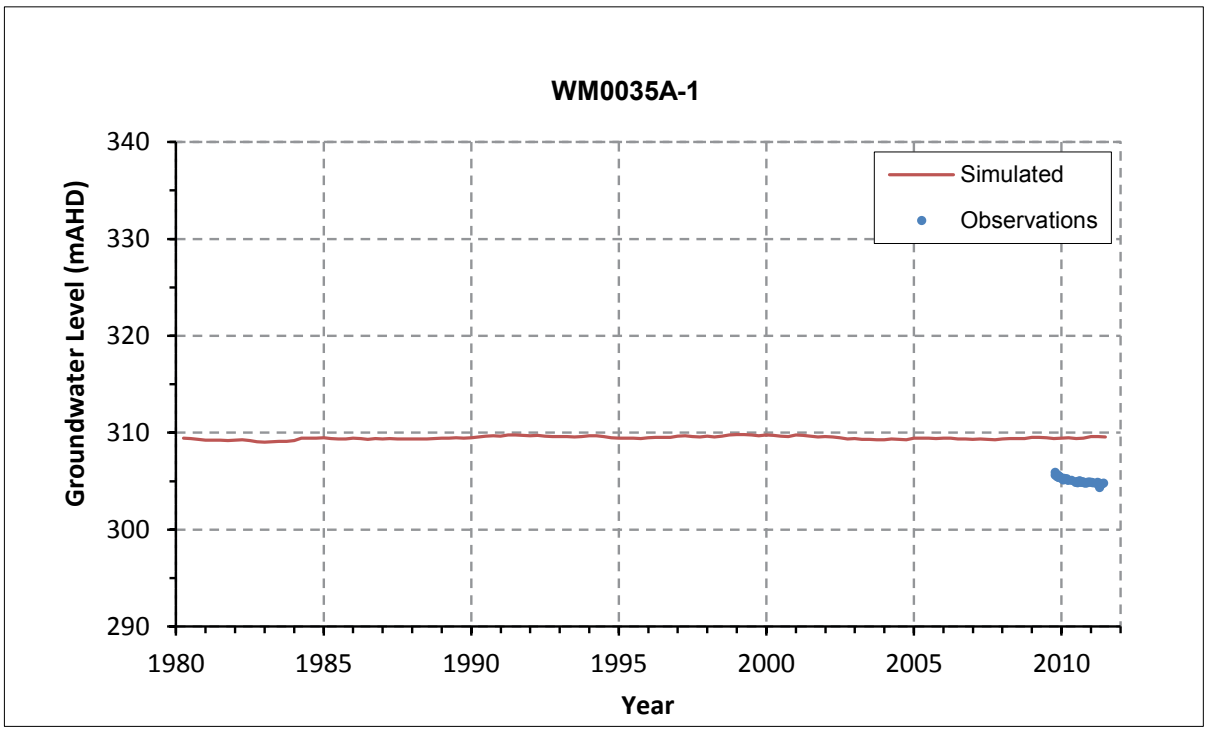

WM0019L-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

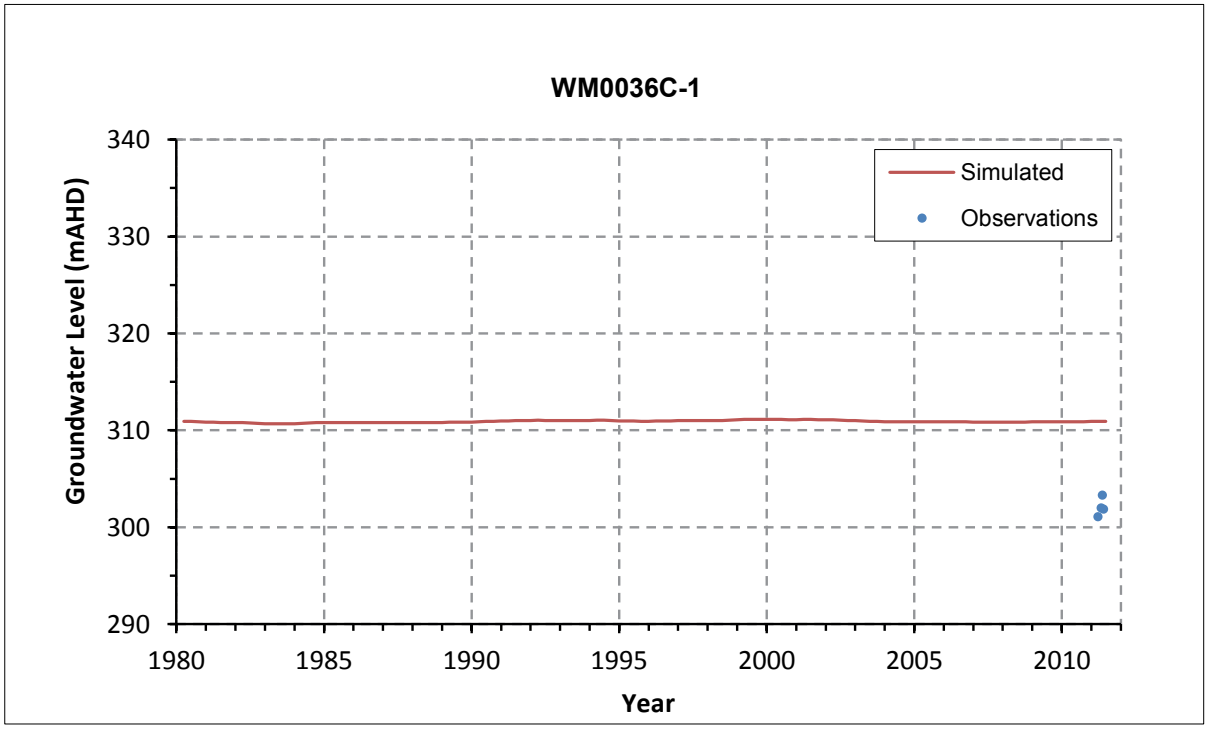

WM0021-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

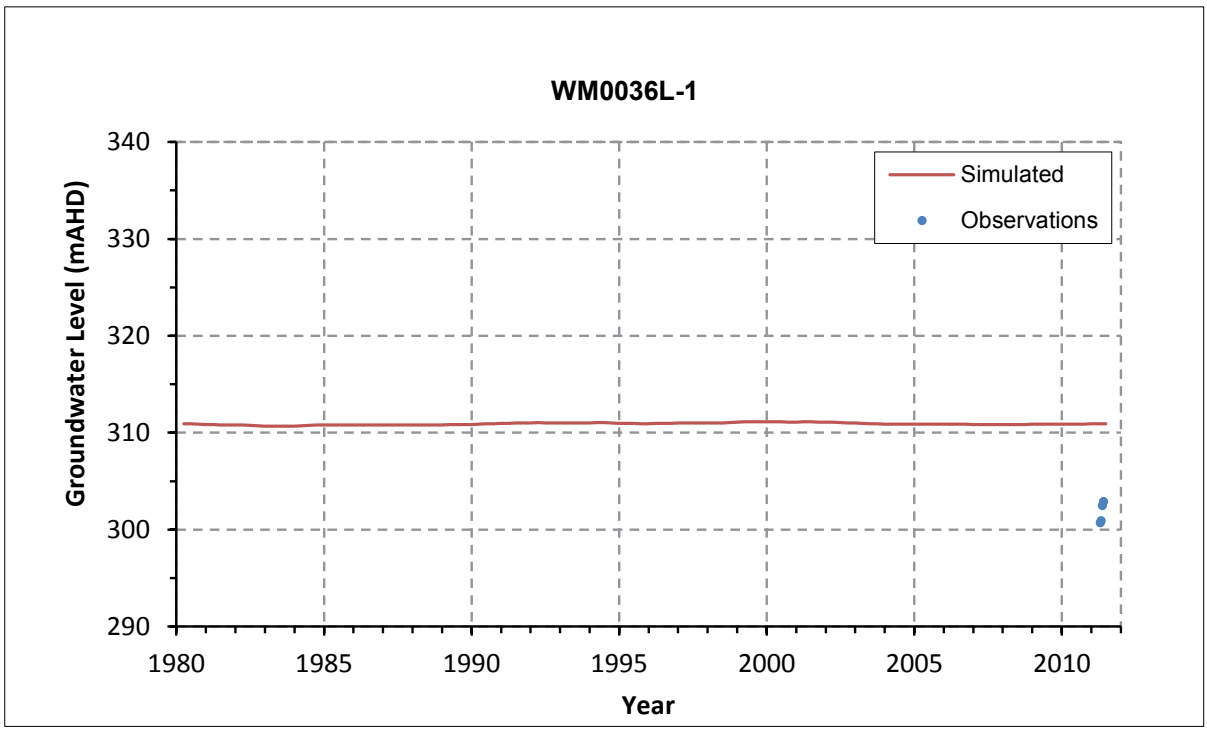

WM0021-2
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

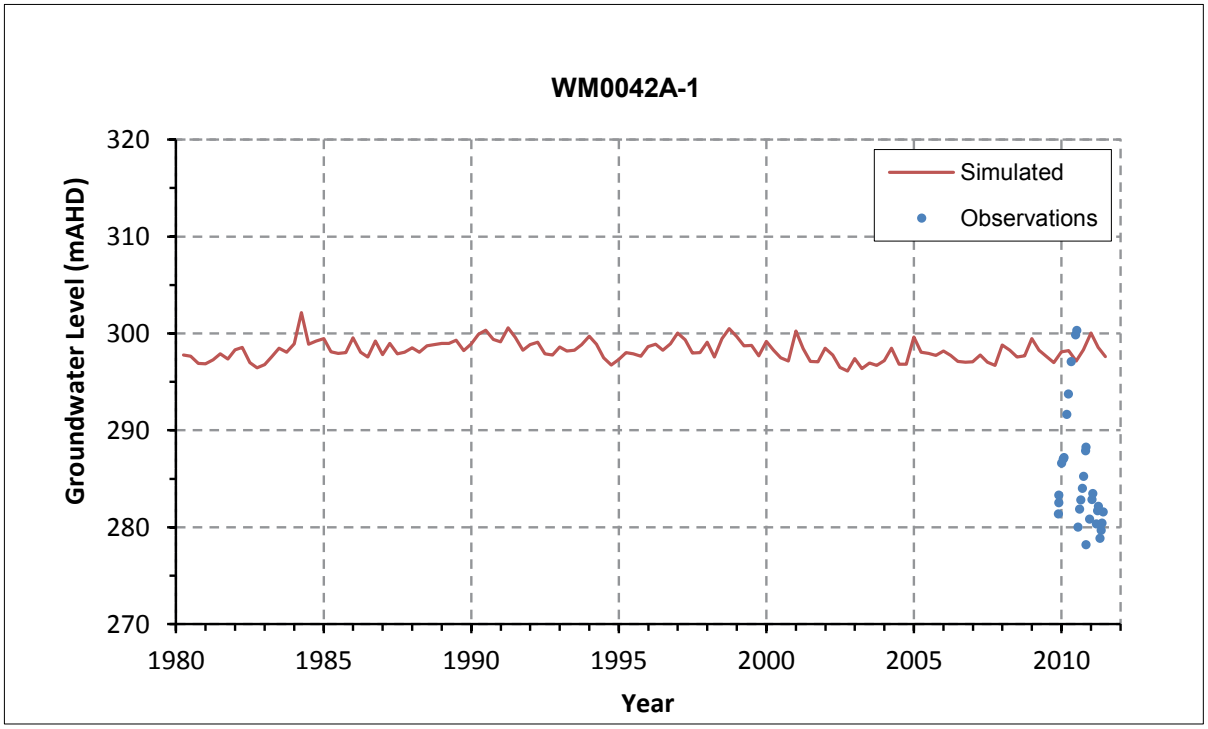

WM0029-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

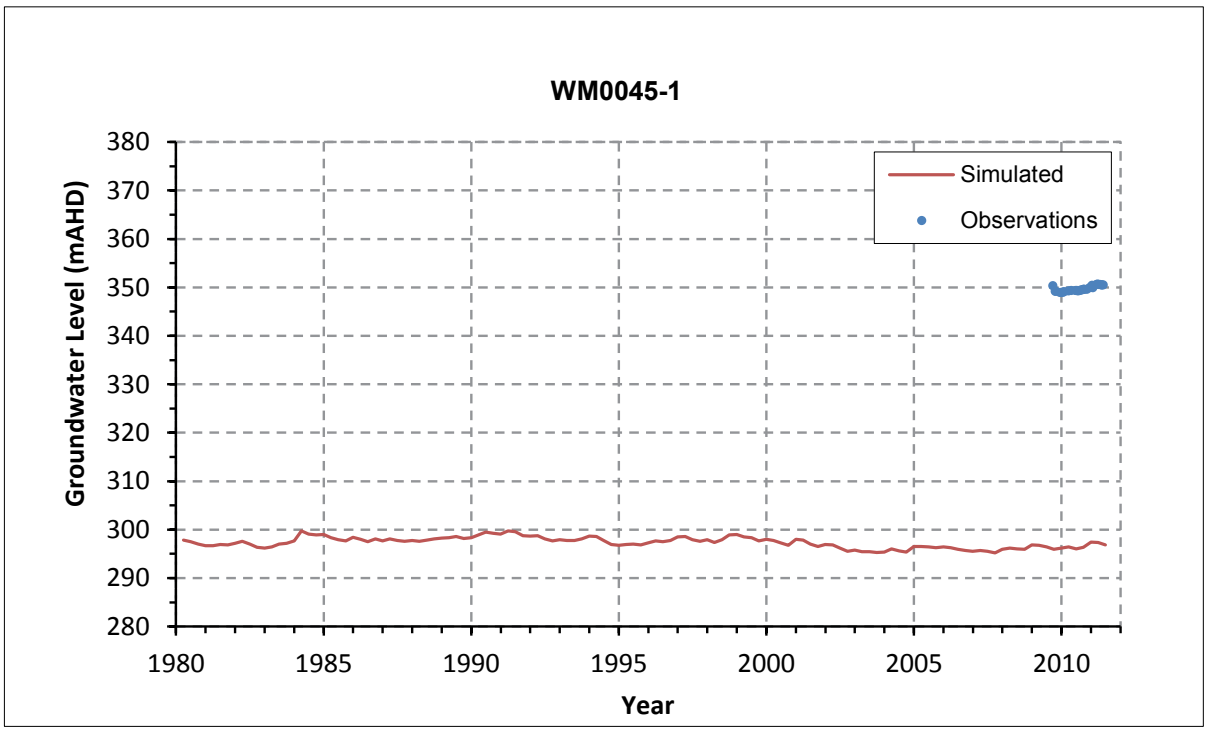

WM0029-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

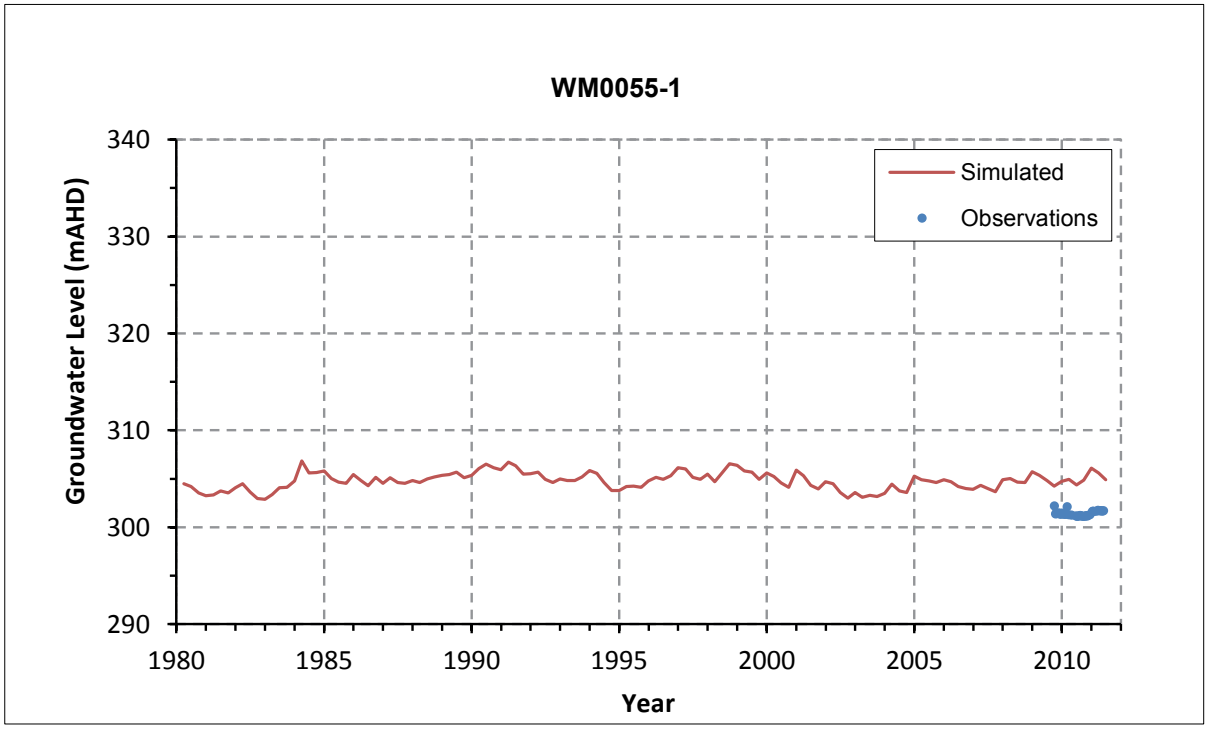

WM0035A-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

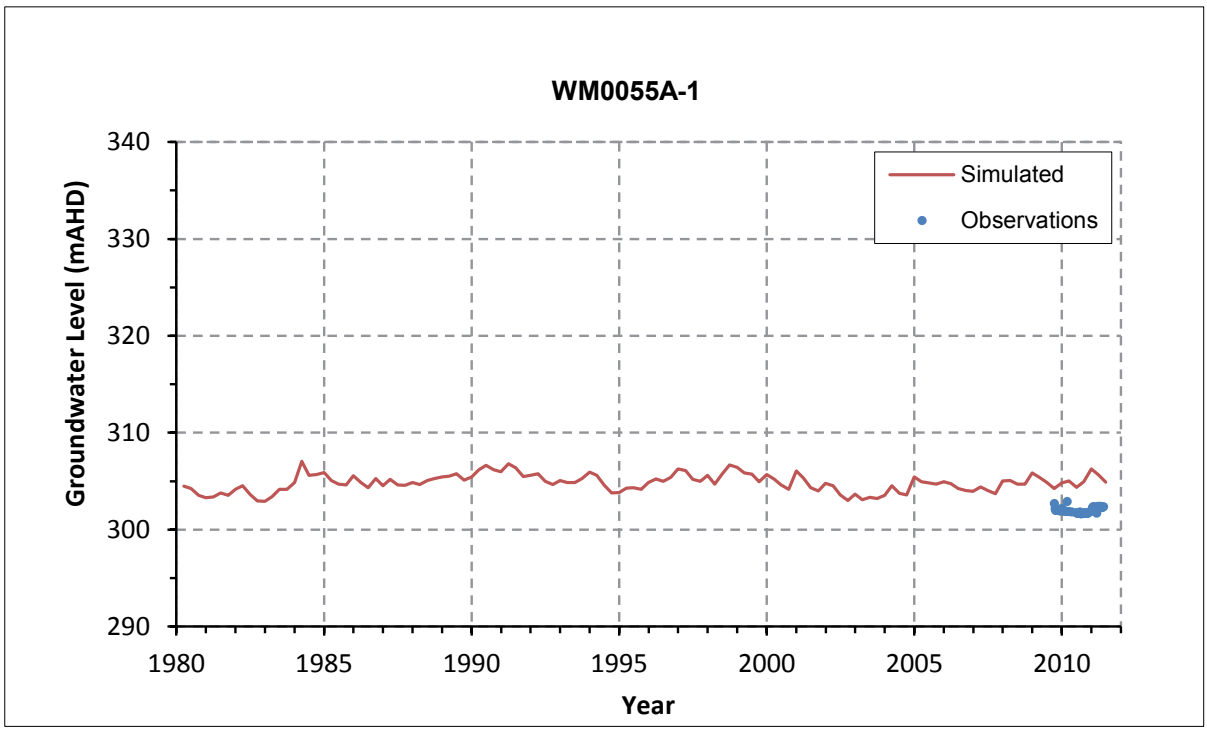

WM0036C-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

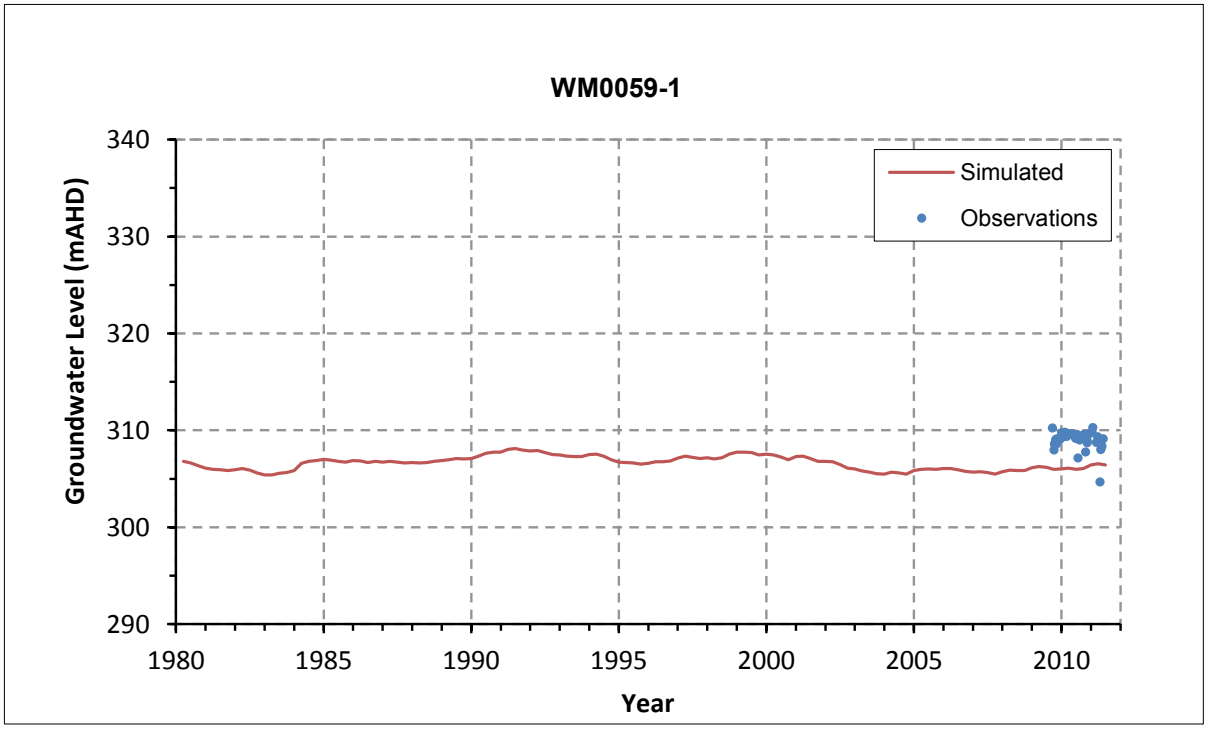

WM0036L-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

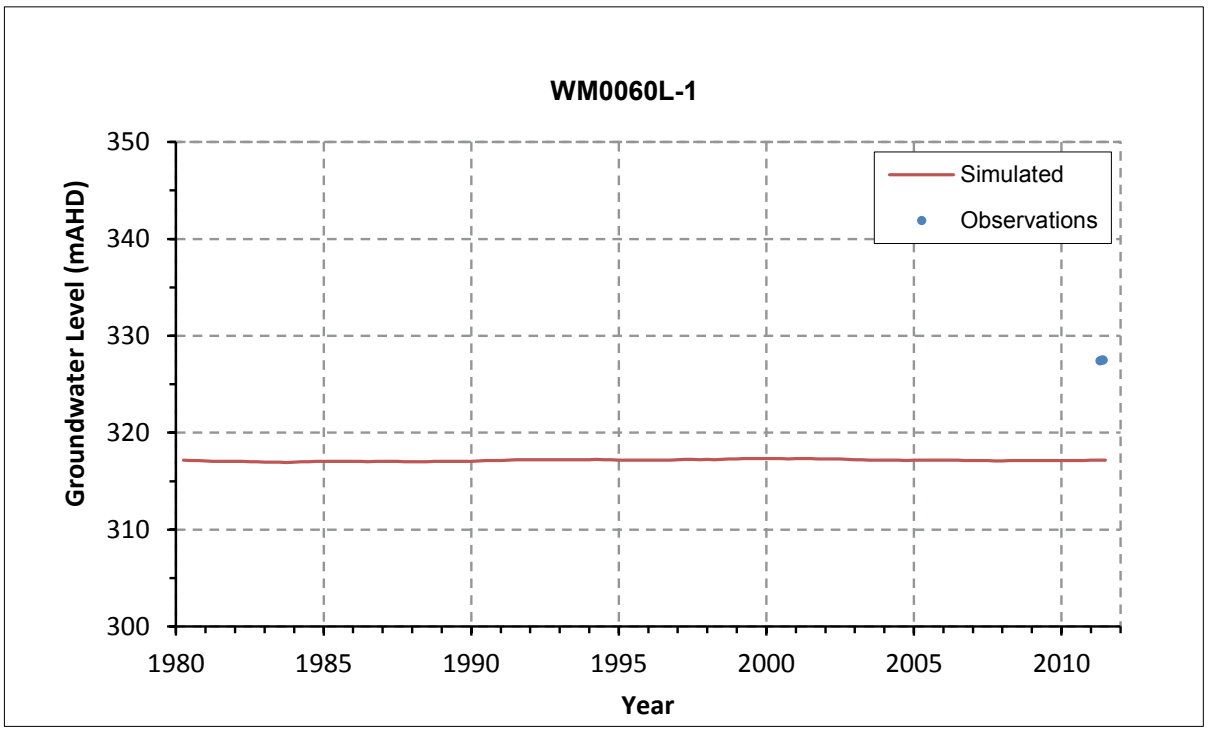

WM0042A-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

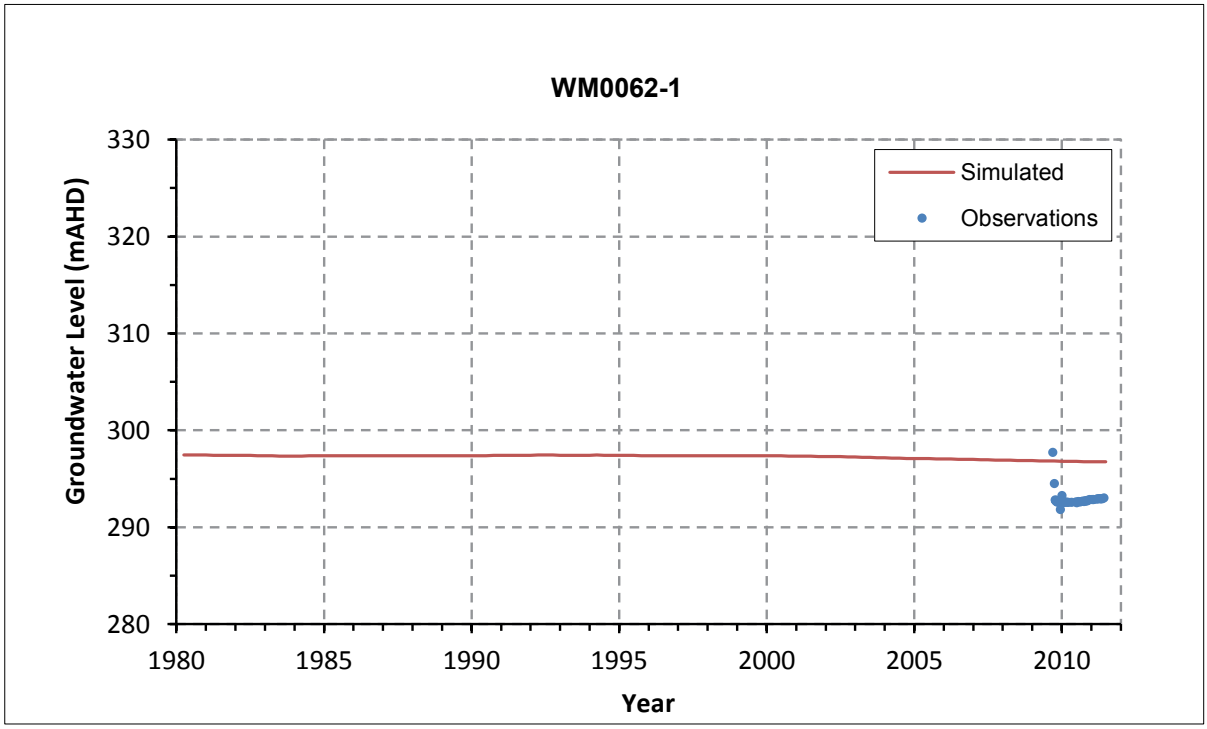

WM0045-1
Groundwater Level (mAHD)
380
370
360
350
340
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

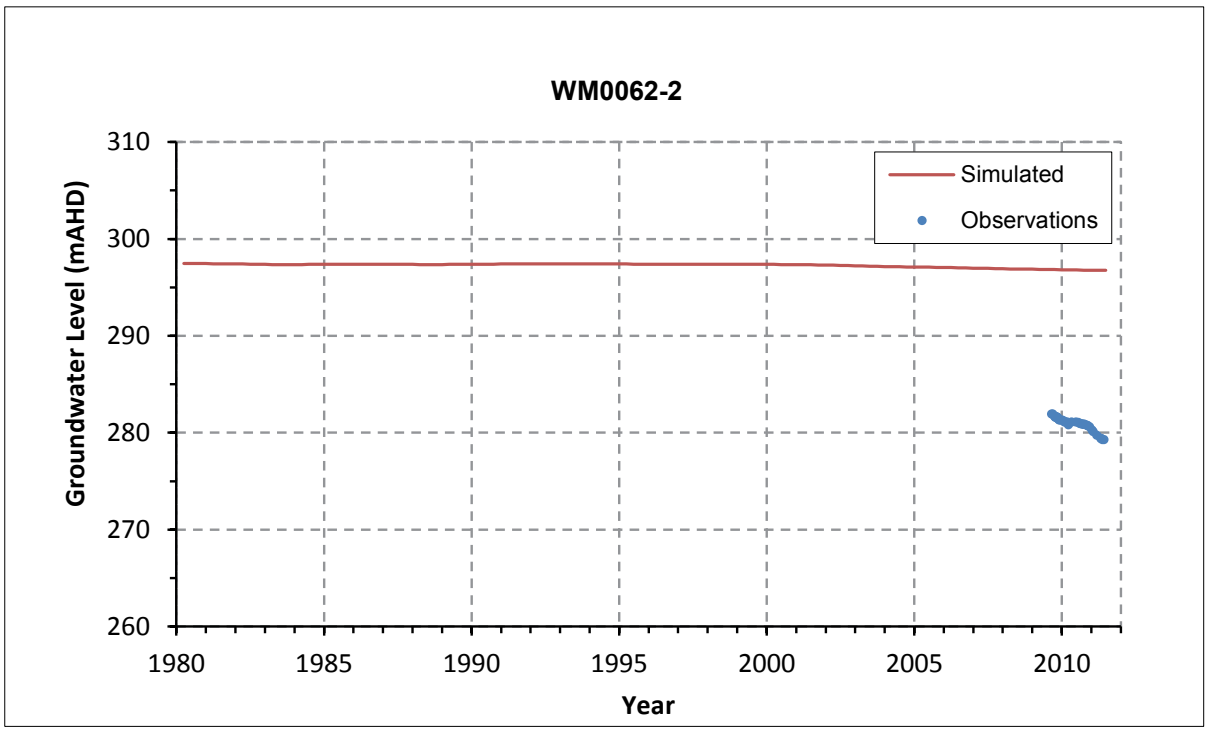

WM0055-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

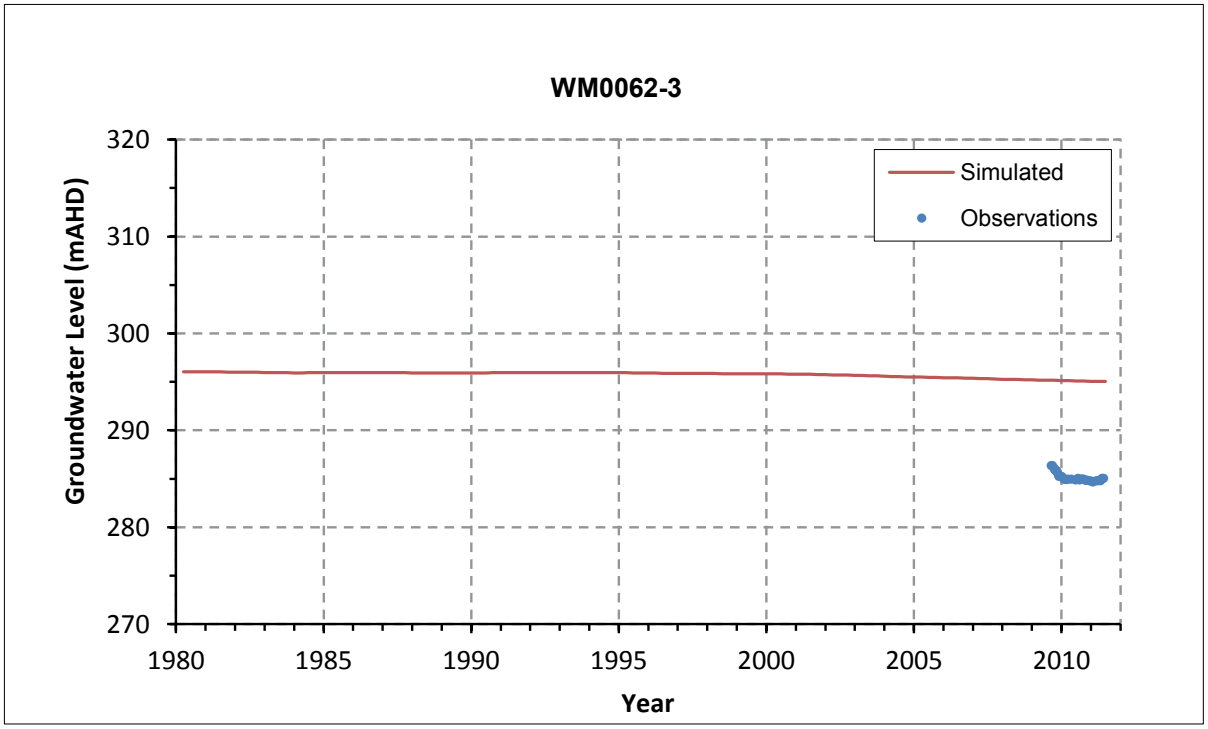

WM0055A-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

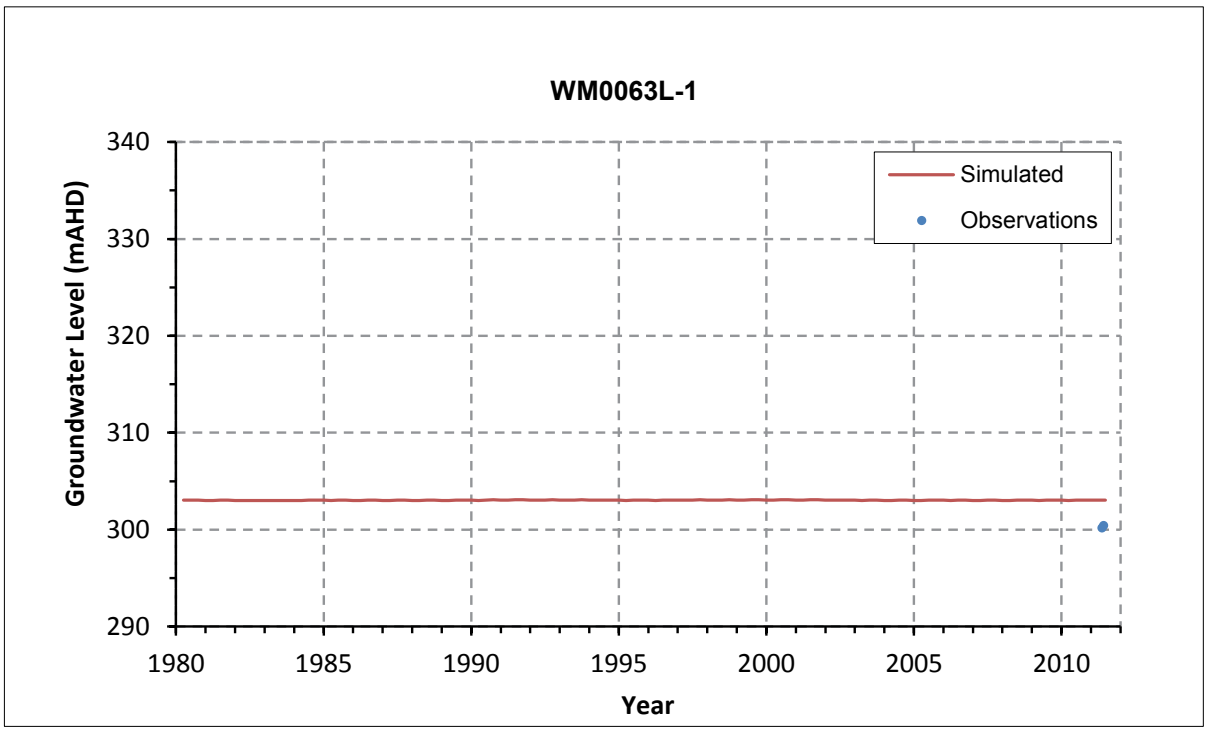

WM0059-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

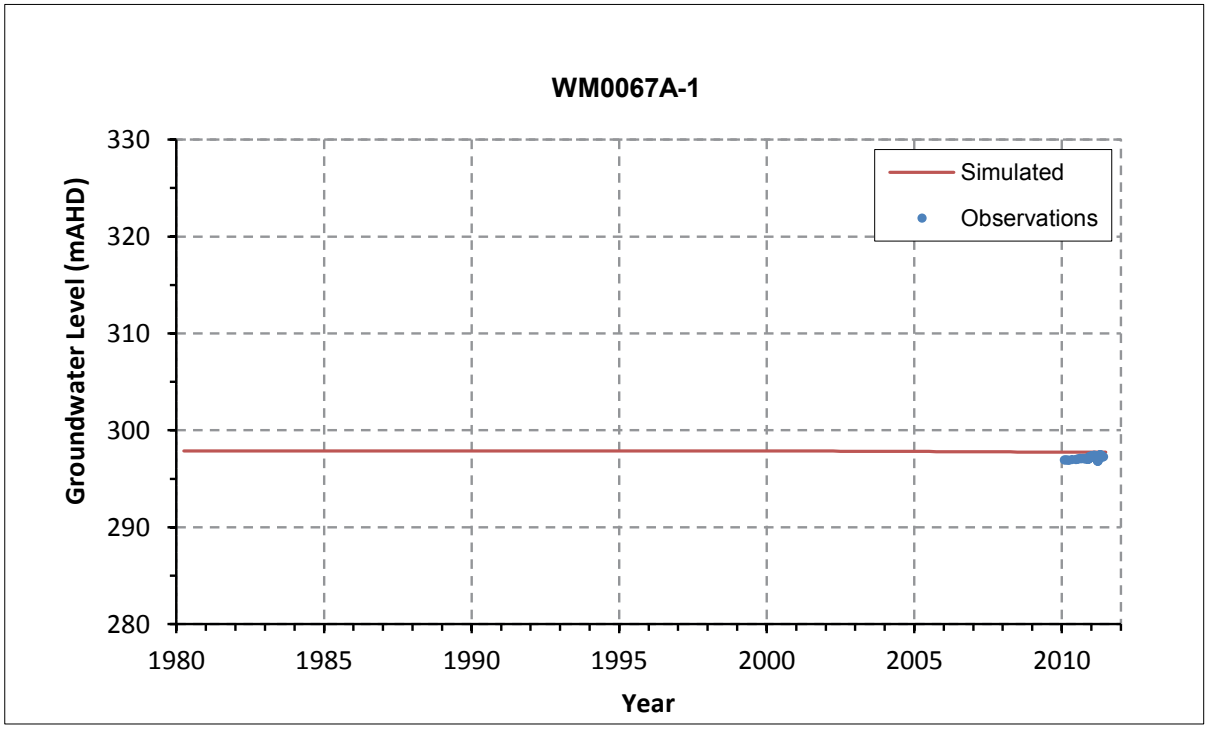

WM0060L-1
Groundwater Level (mAHD)
350
340
330
320
310
300
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

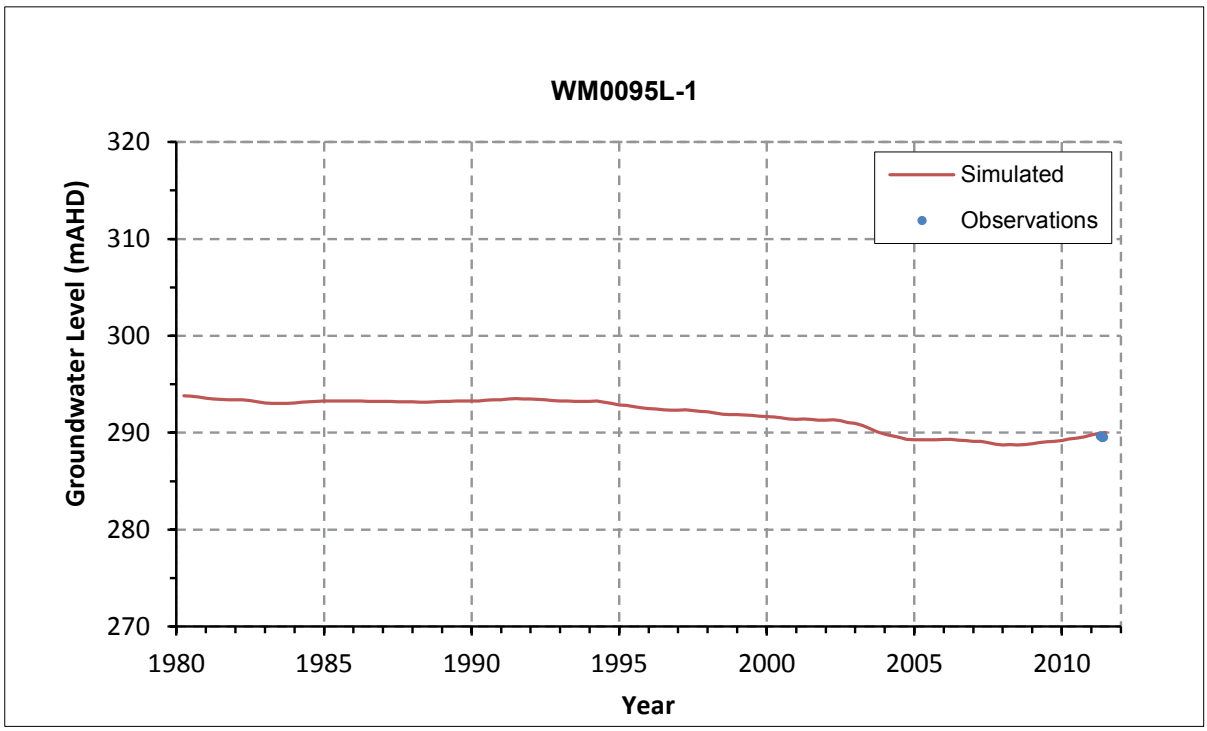

WM0062-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

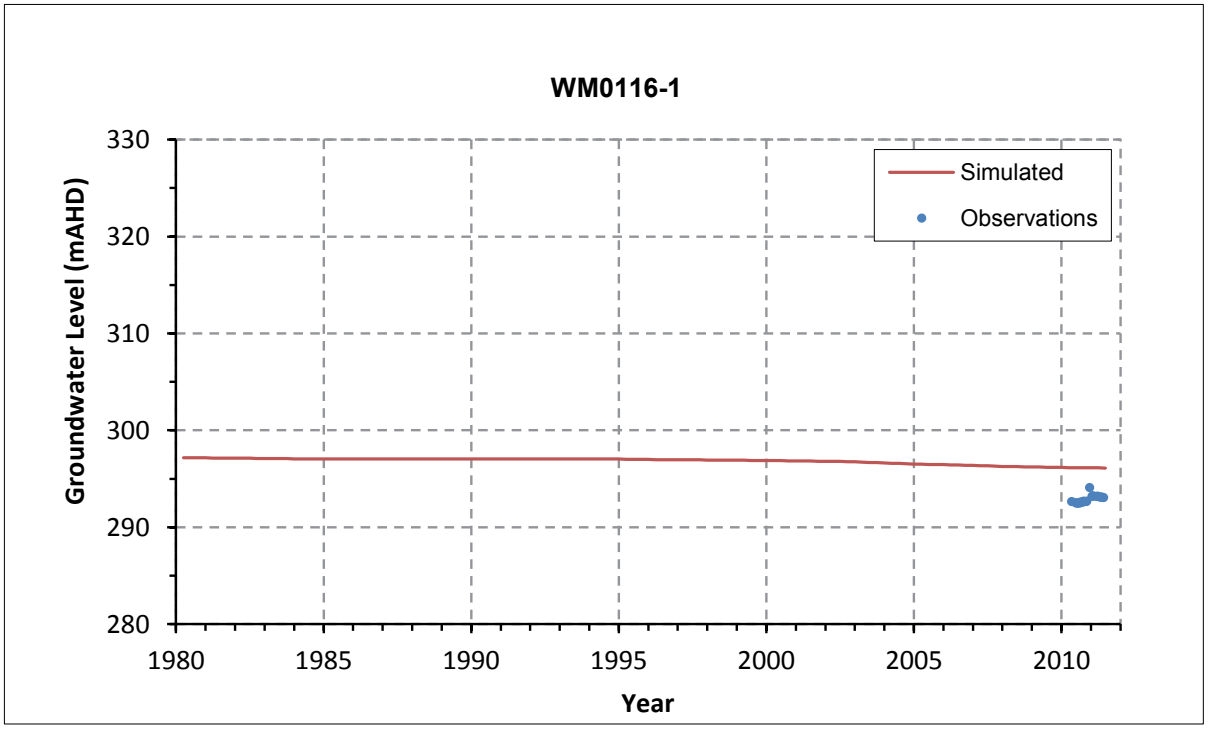

WM0062-2
Groundwater Level (mAHD)
310
300
290
280
270
260
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

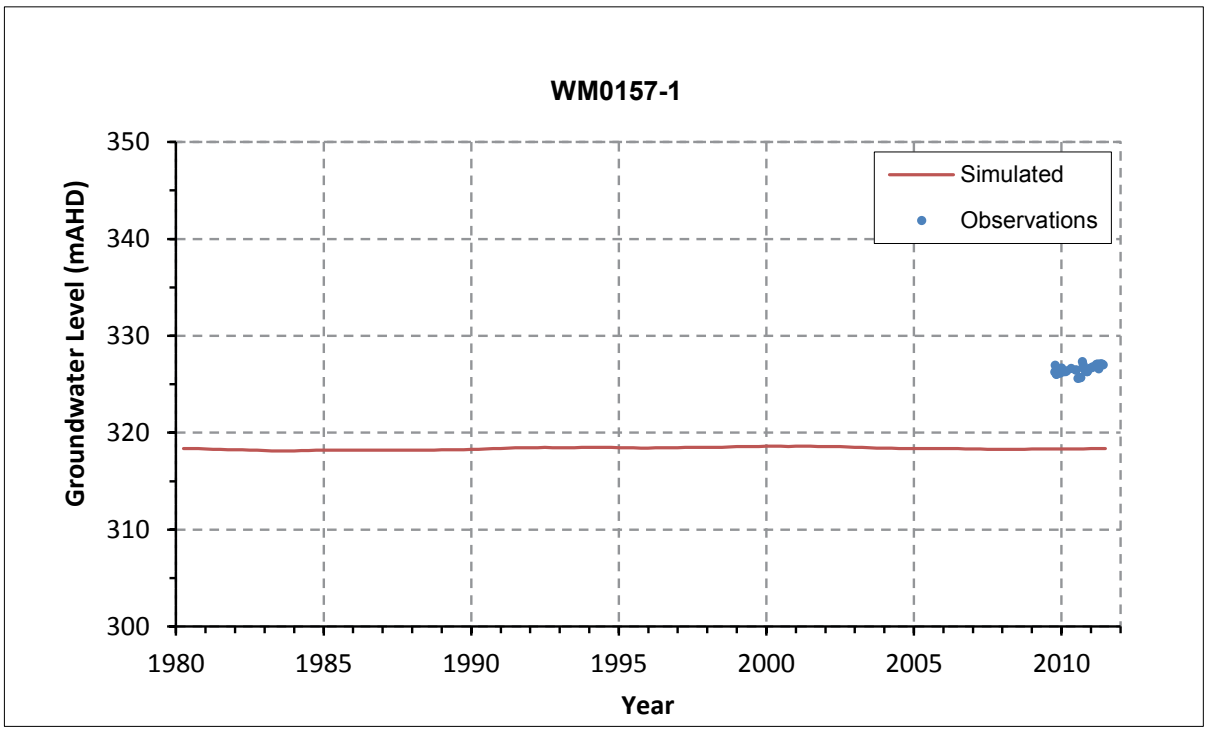

WM0062-3
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

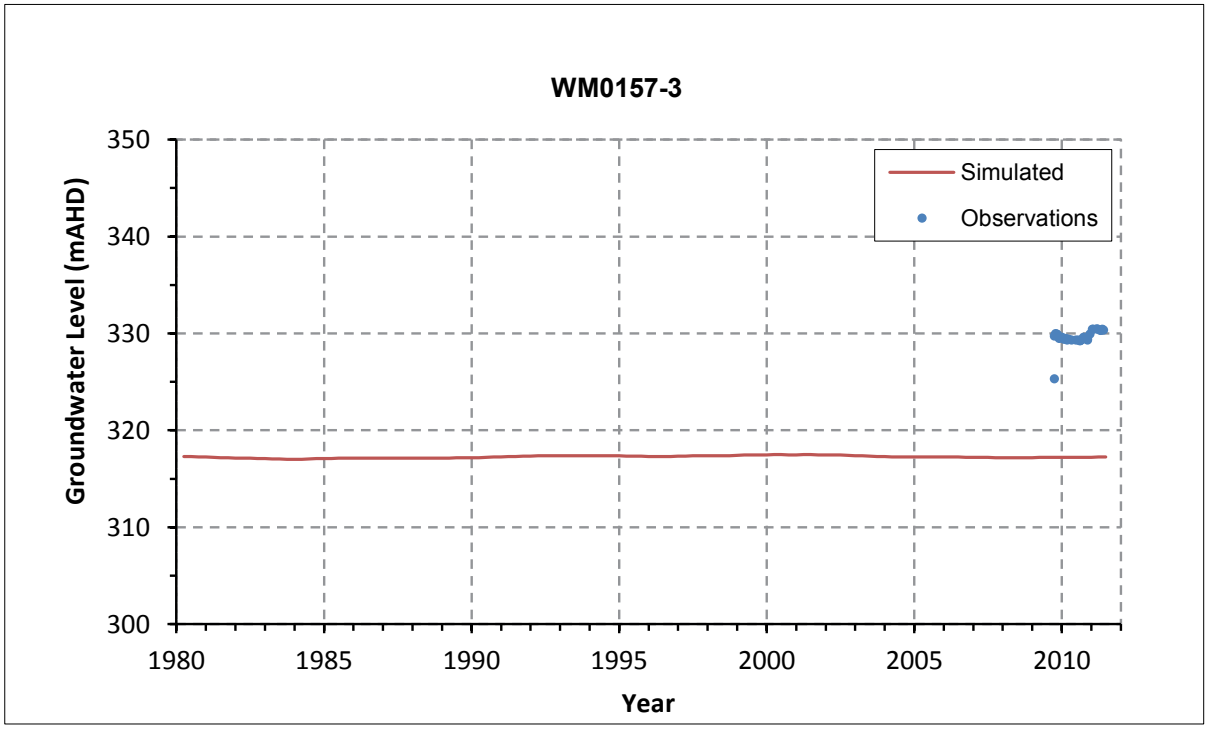

WM0063L-1
Groundwater Level (mAHD)
340
330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

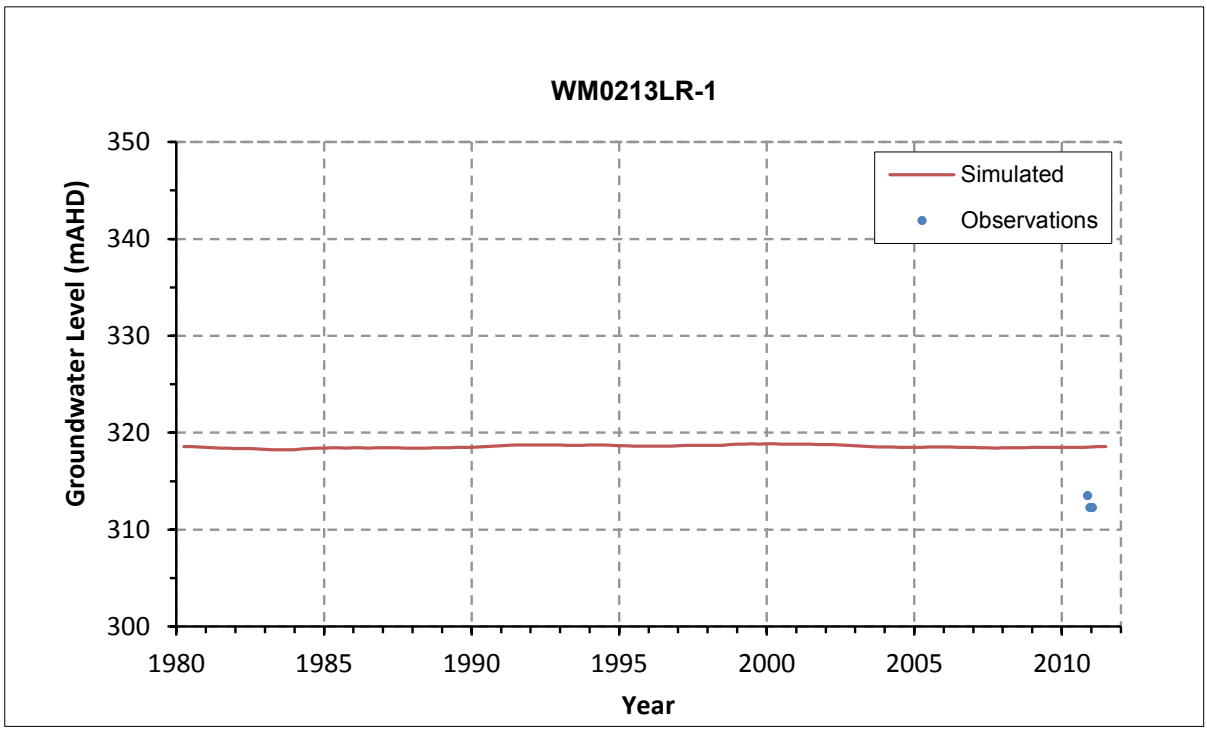

WM0067A-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

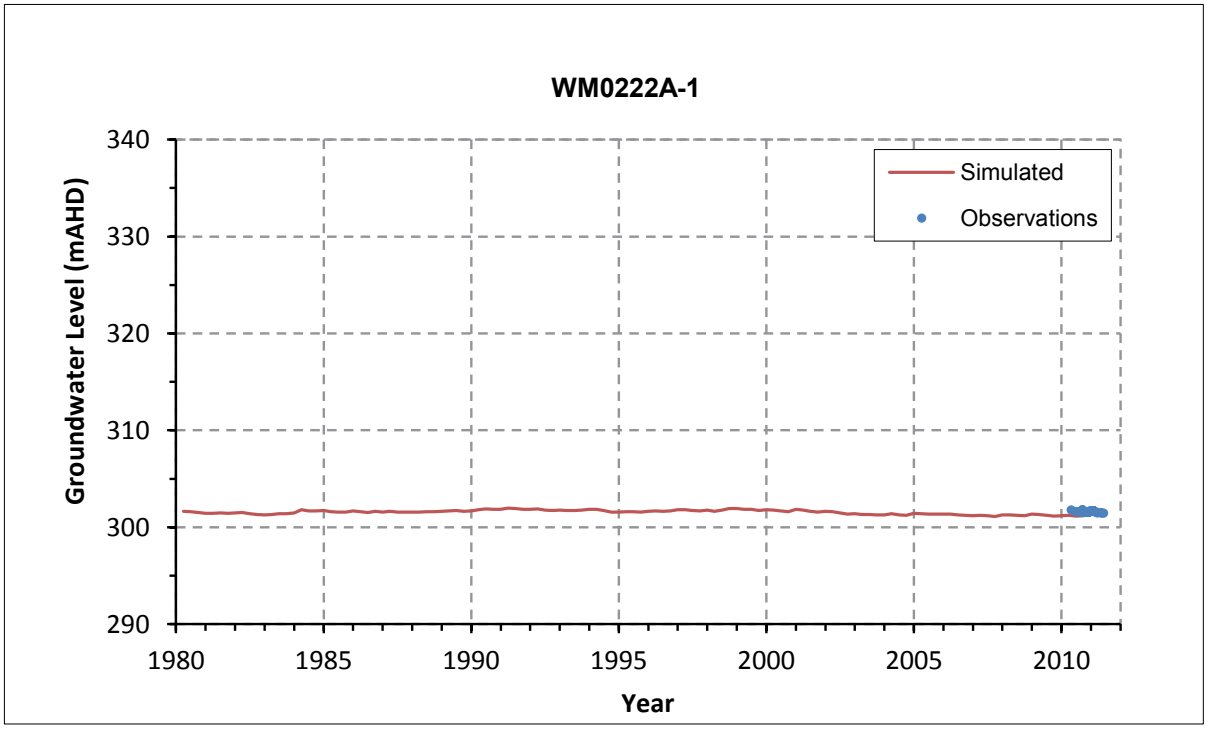

WM0095L-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

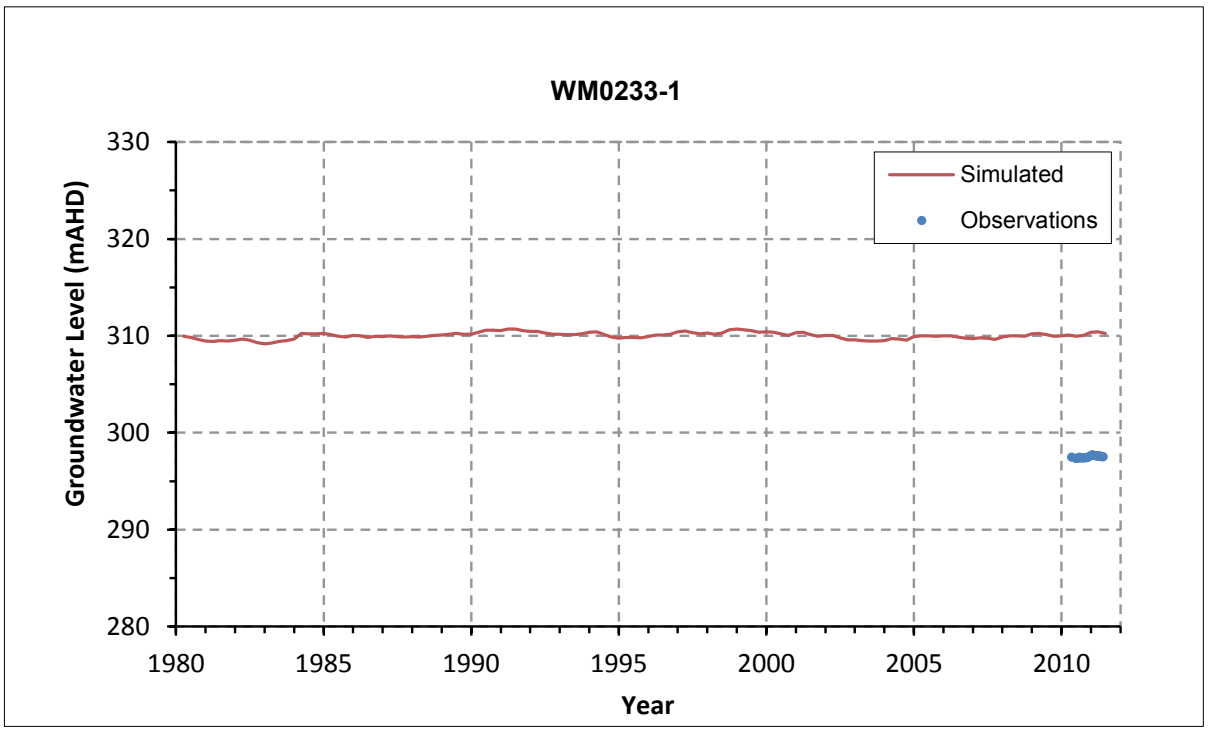

WM0116-1
Groundwater Level (mAHD)
330
320
310
300
290
280
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

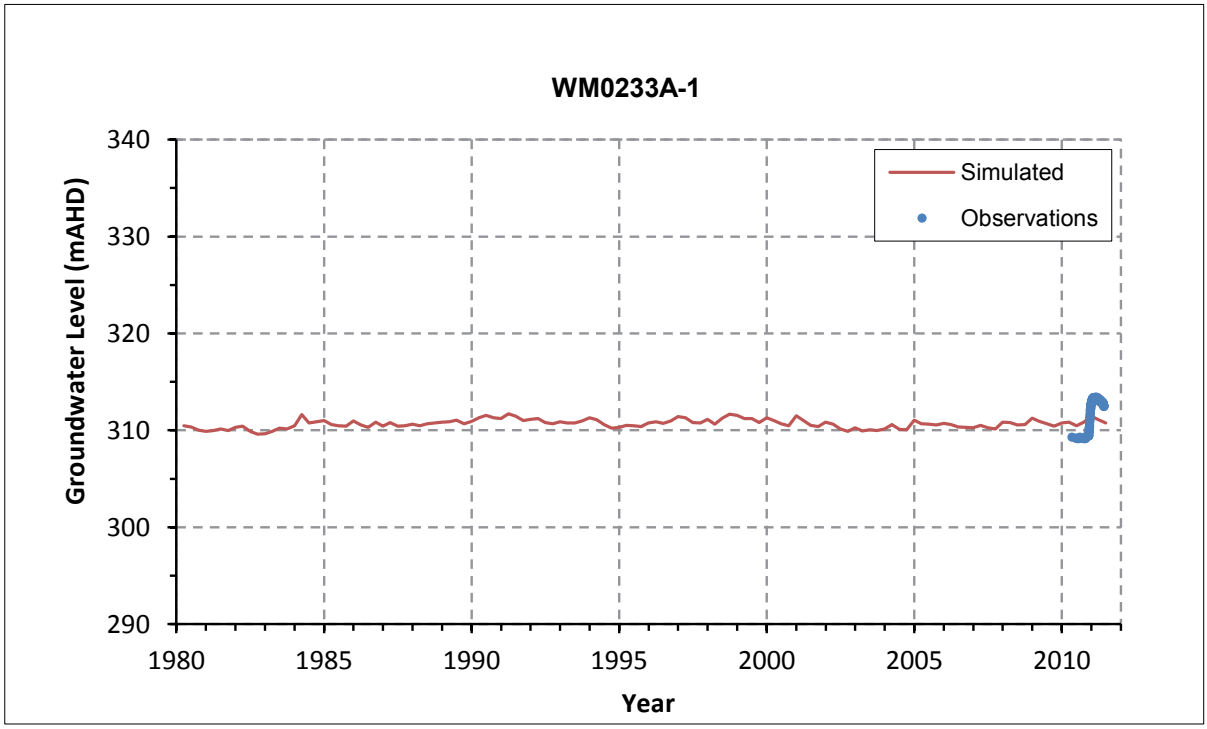

WM0157-1
Groundwater Level (mAHD)
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340
330
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310
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1980
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2000
2005
2010
Year
Simulated
Observations

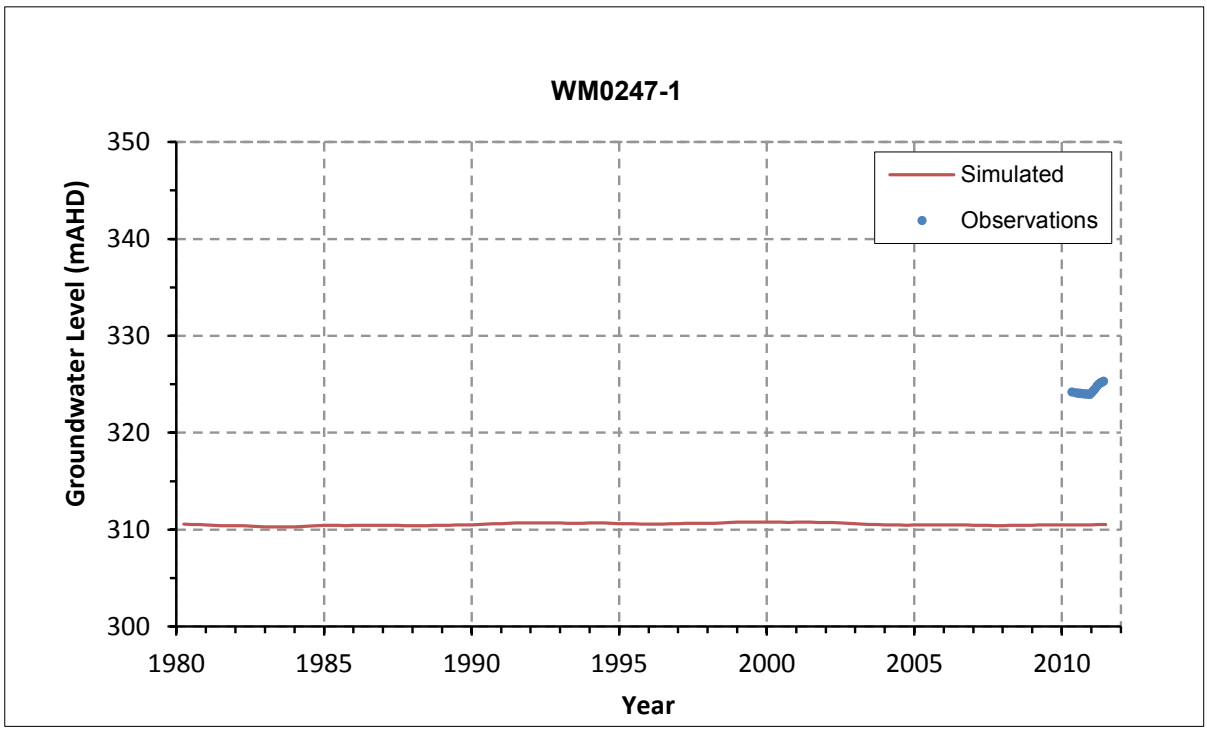

WM0157-3
Groundwater Level (mAHD)
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310
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1980
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1990
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2005
2010
Year
Simulated
Observations

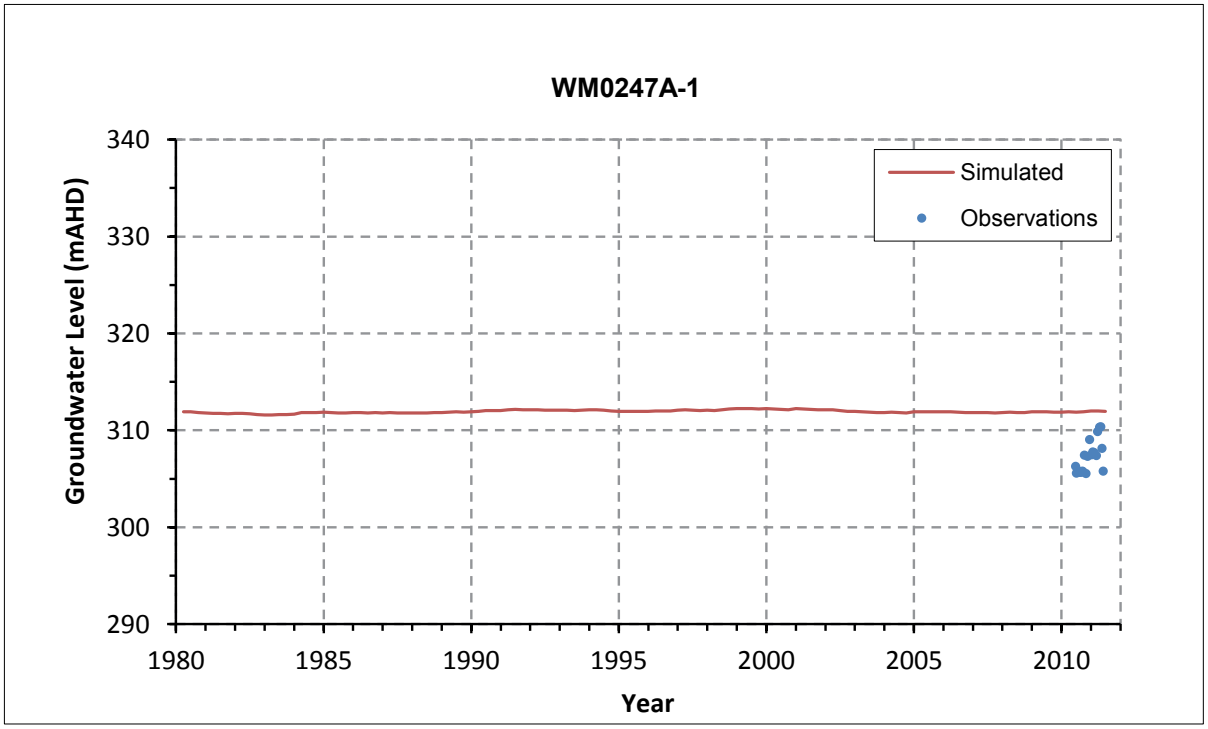

WM0213LR-1
Groundwater Level (mAHD)
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1980
1985
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1995
2000
2005
2010
Year
Simulated
Observations

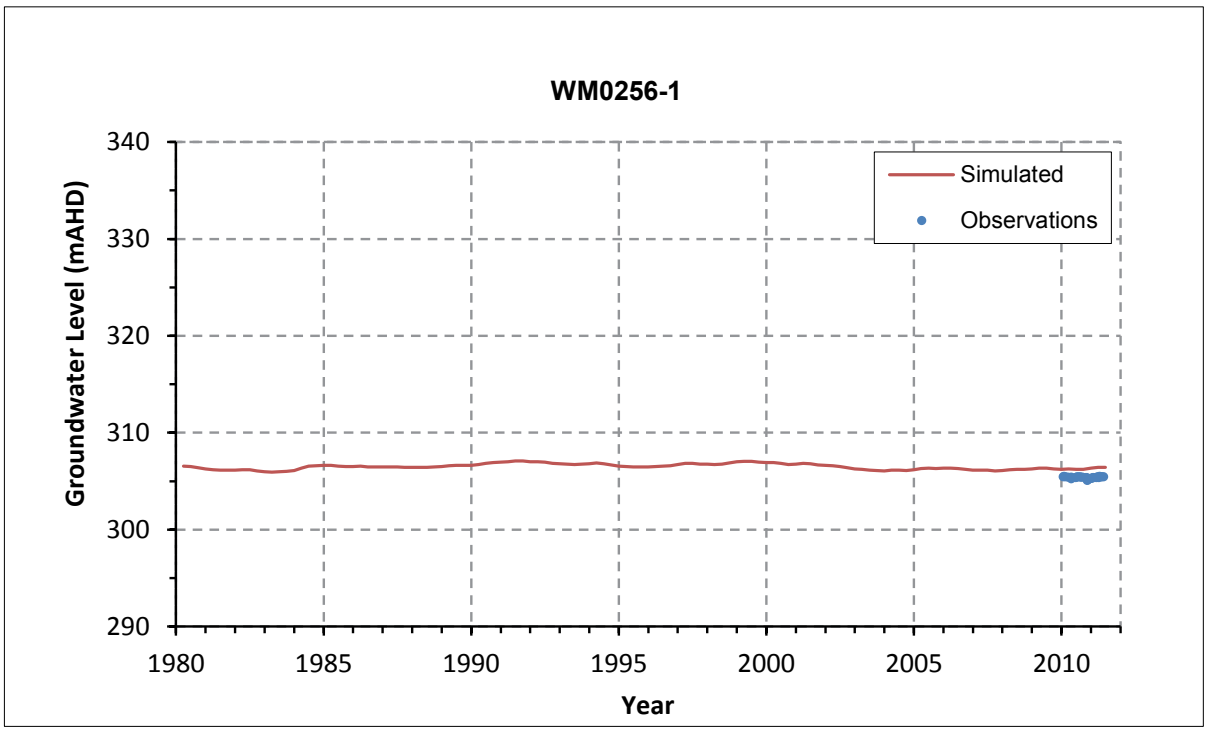

WM0222A-1
Groundwater Level (mAHD)
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330
320
310
300
290
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

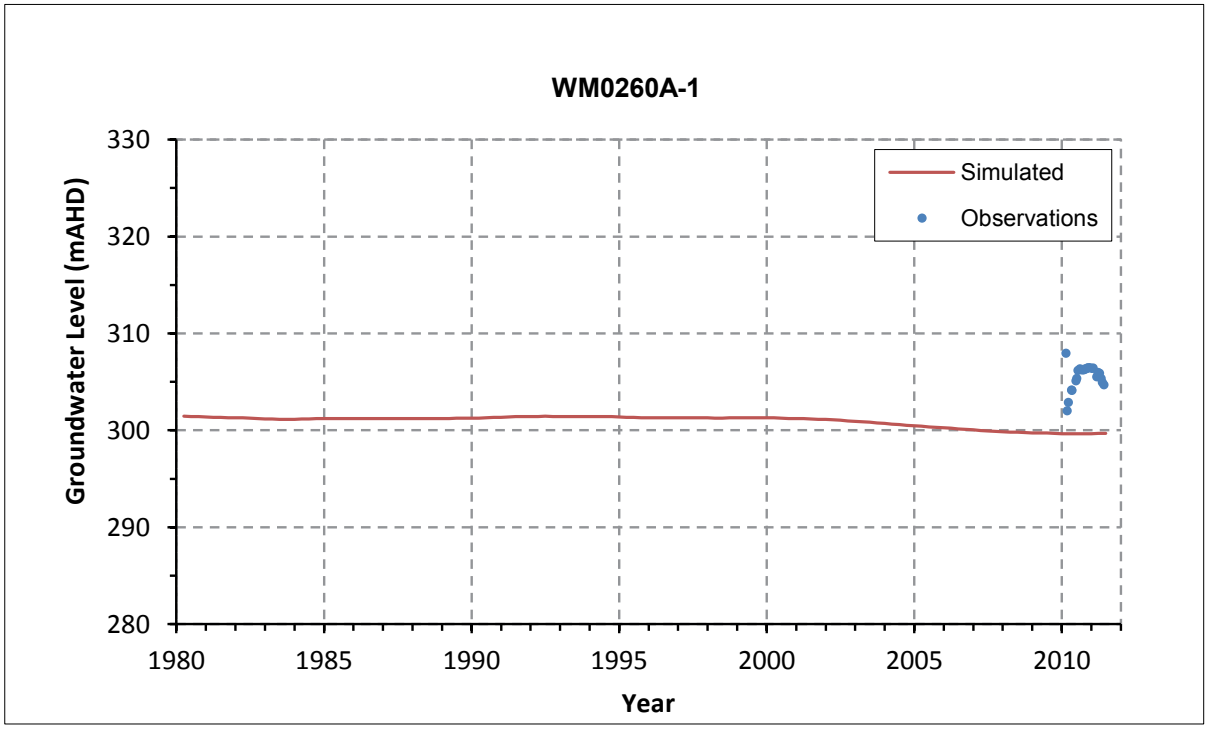

WM0233-1
Groundwater Level (mAHD)
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2010
Year
Simulated
Observations

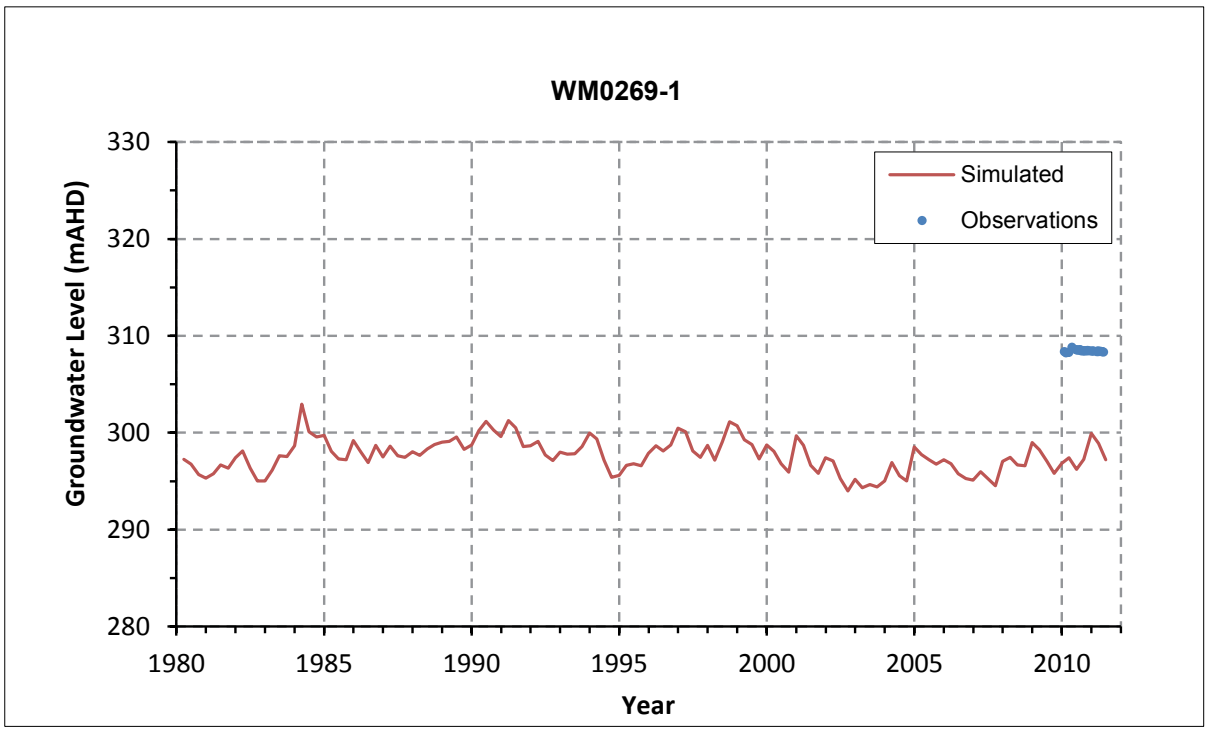

WM0233A-1
Groundwater Level (mAHD)
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330
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1980
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2010
Year
Simulated
Observations

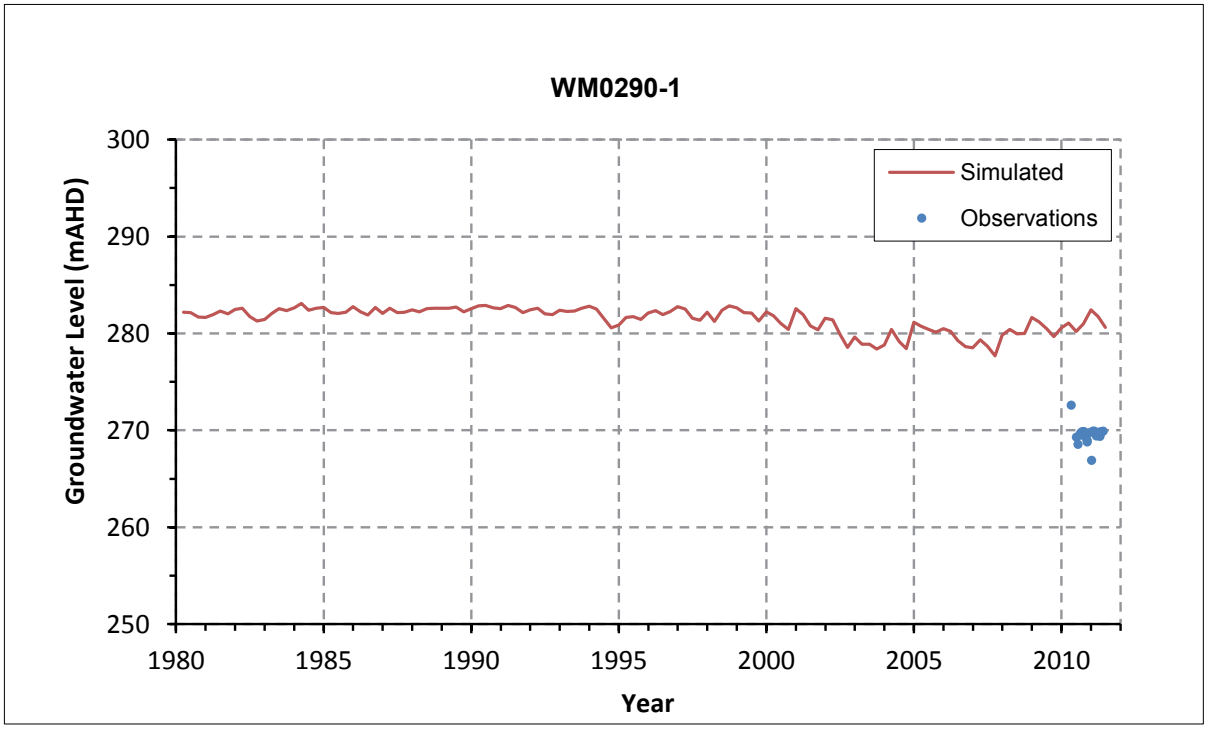

WM0247-1
Groundwater Level (mAHD)
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2010
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Simulated
Observations

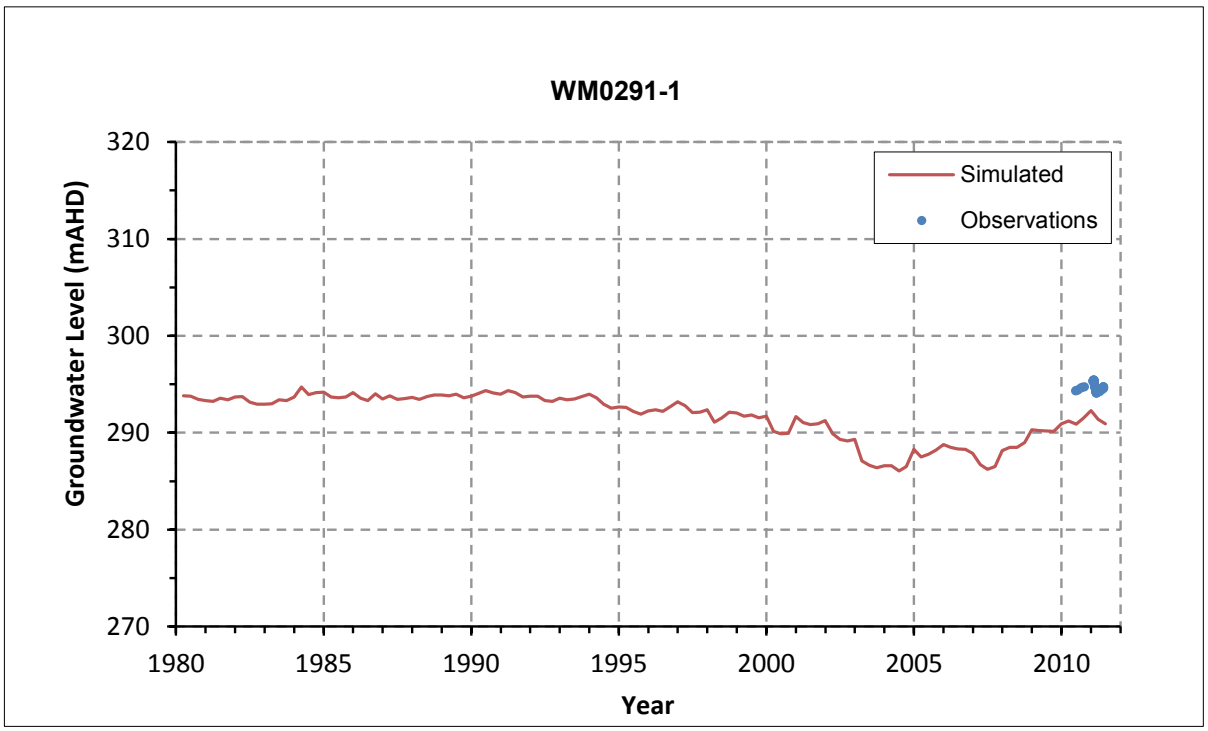

WM0247A-1
Groundwater Level (mAHD)
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Observations

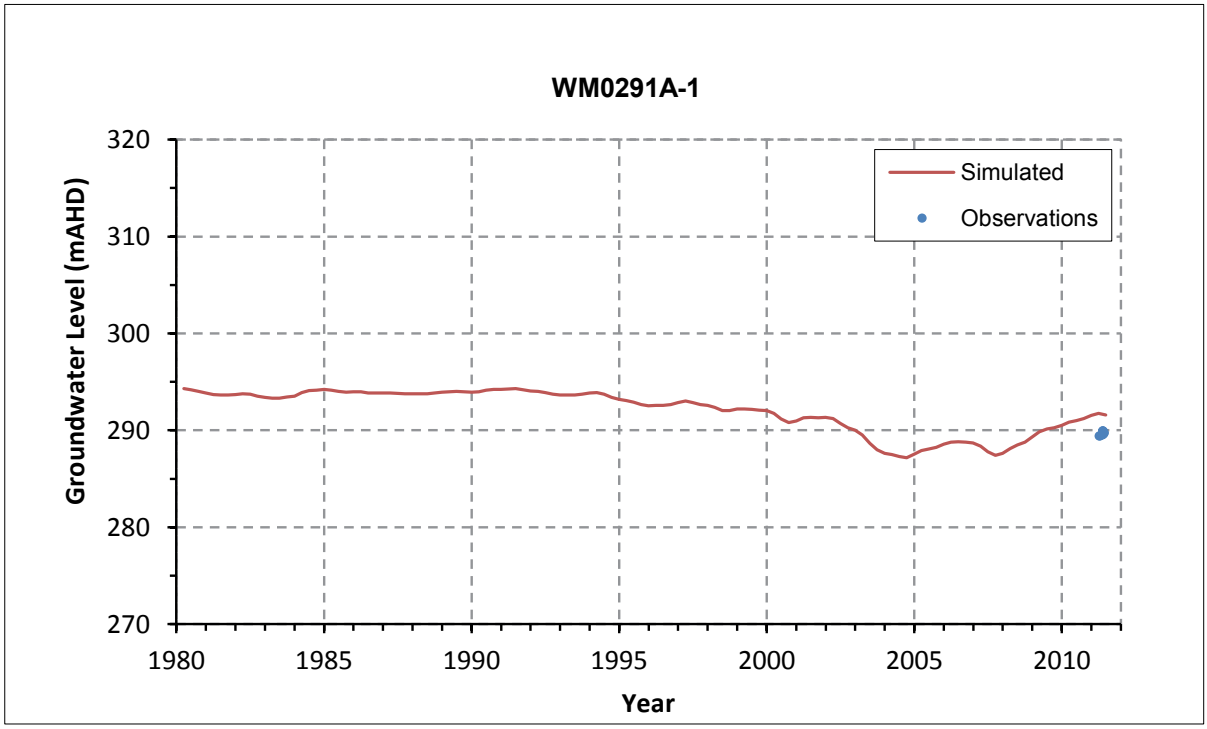

WM0256-1
Groundwater Level (mAHD)
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Simulated
Observations

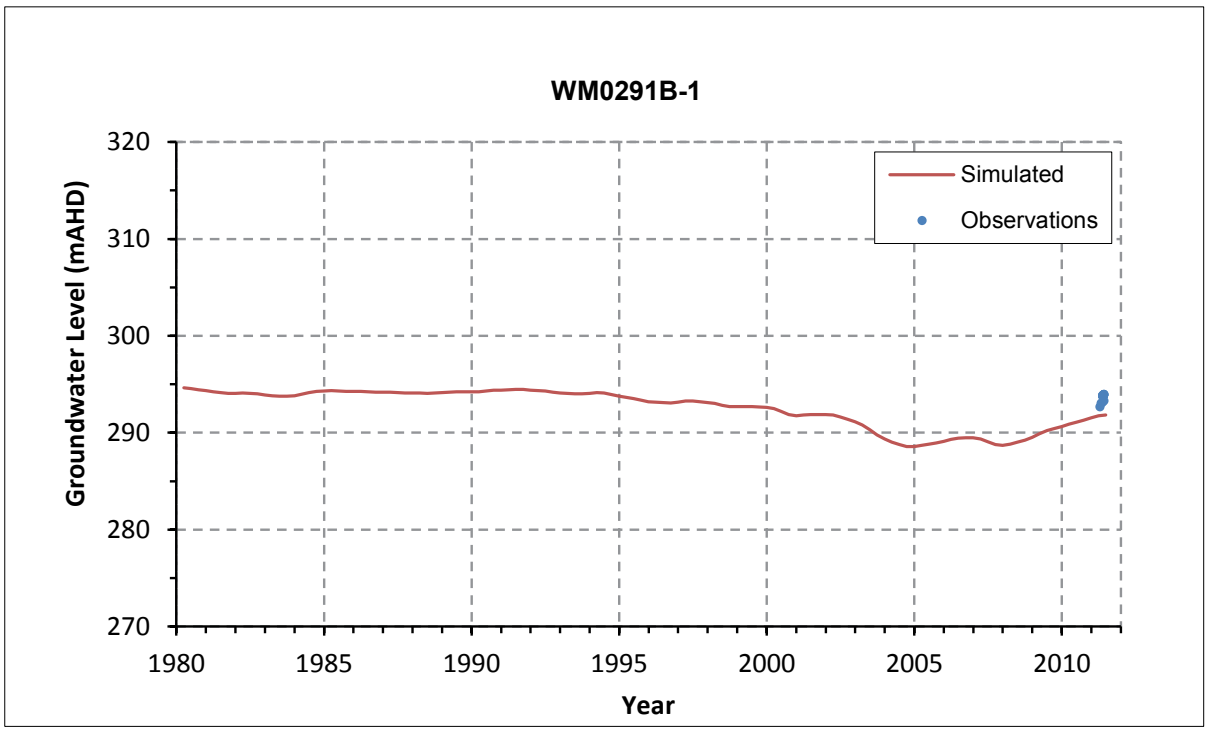

WM0260A-1
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Simulated
Observations

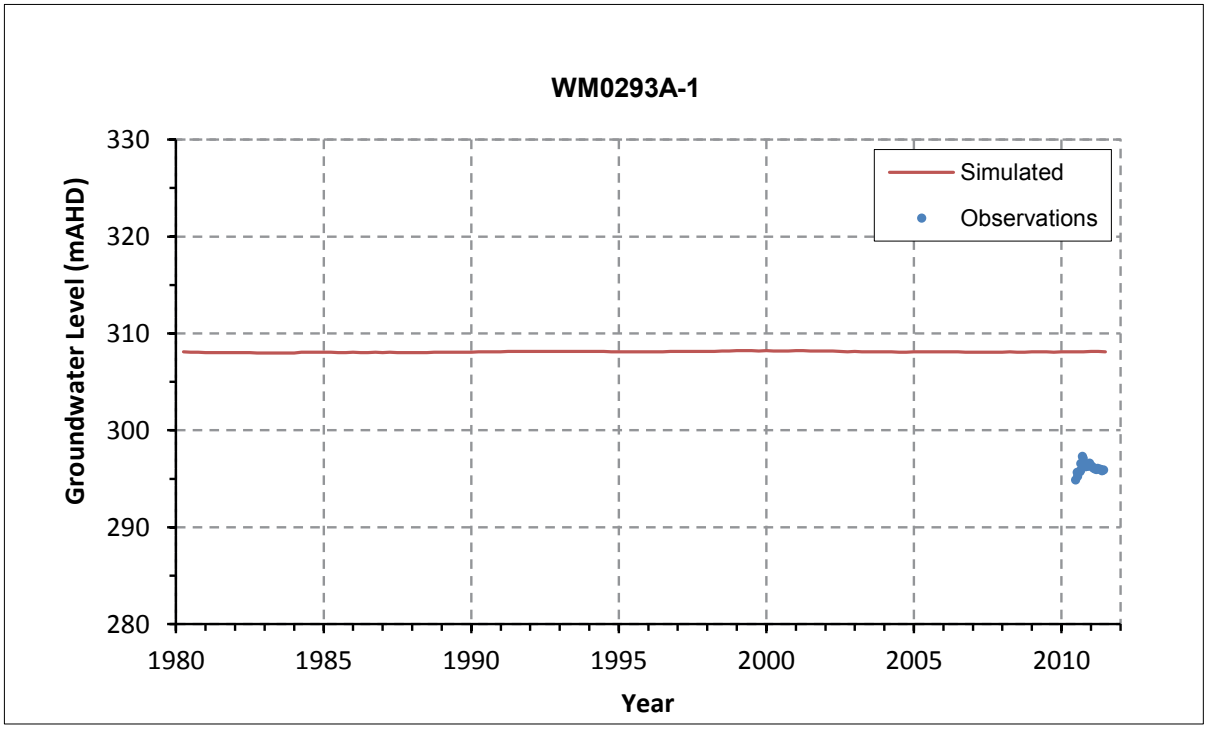

WM0269-1
Groundwater Level (mAHD)
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Year
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Observations

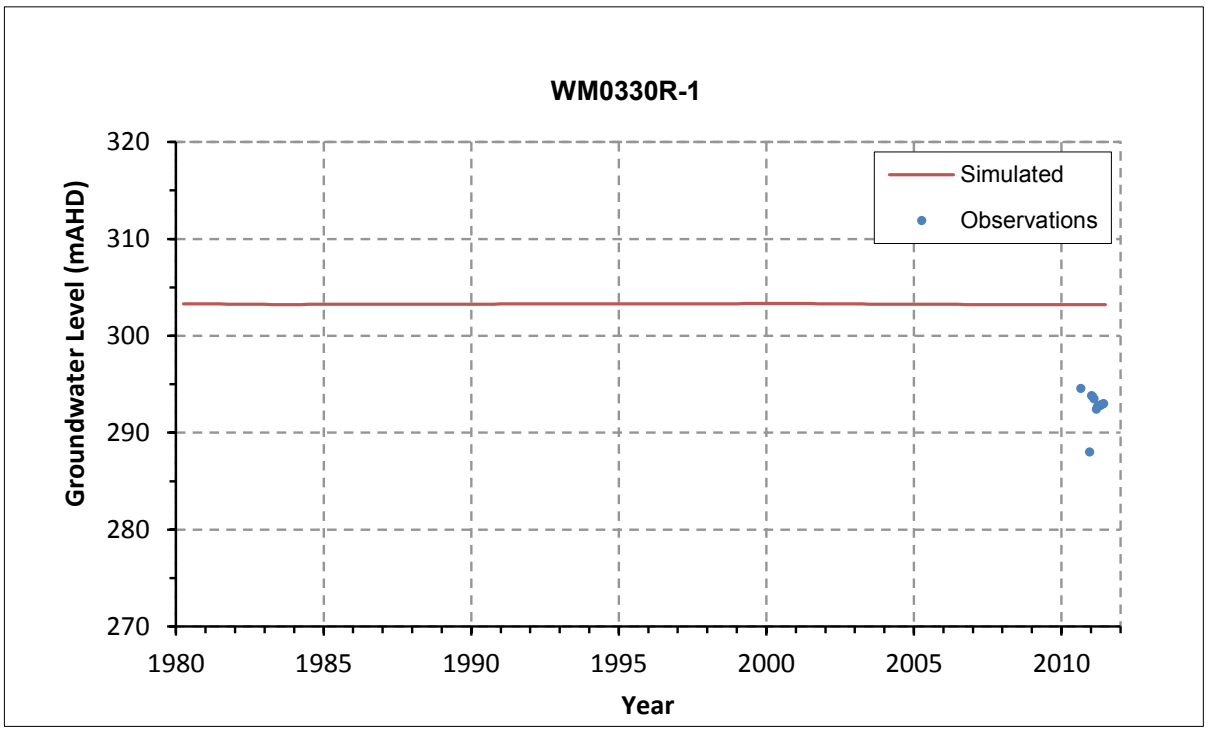

WM0290-1
Groundwater Level (mAHD)
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2010
Year
Simulated
Observations

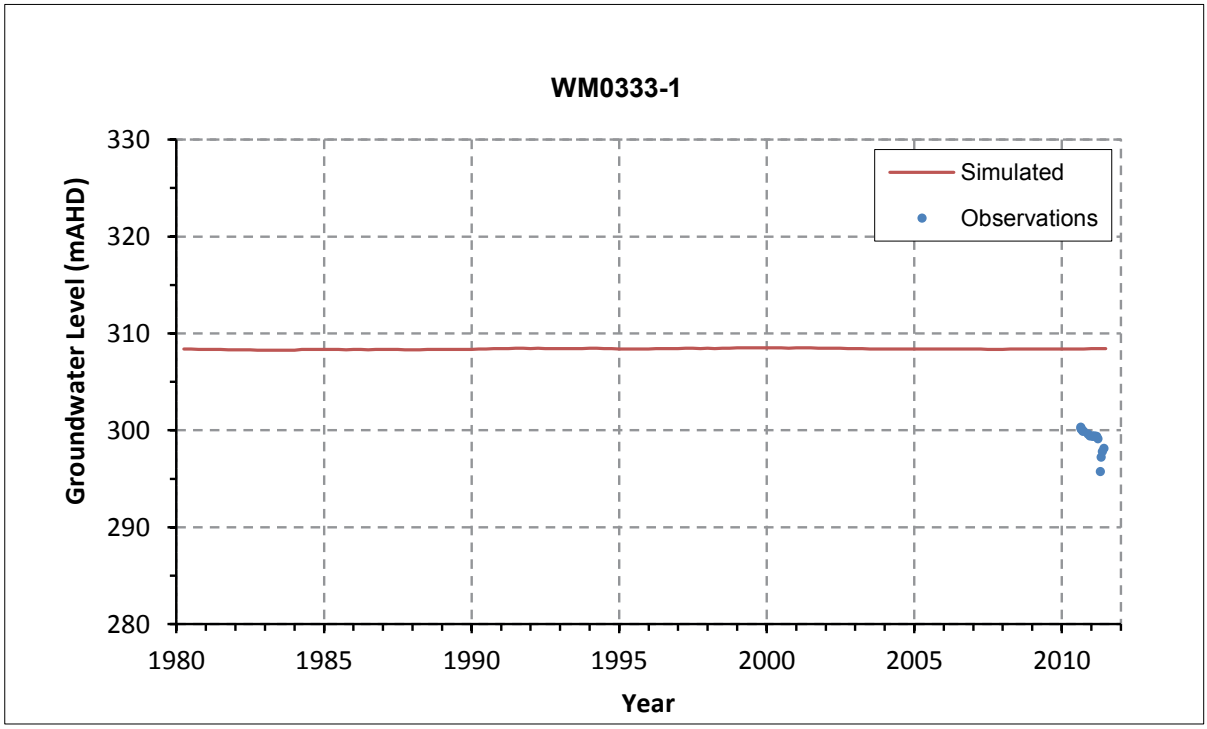

WM0291-1
Groundwater Level (mAHD)
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Year
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Observations

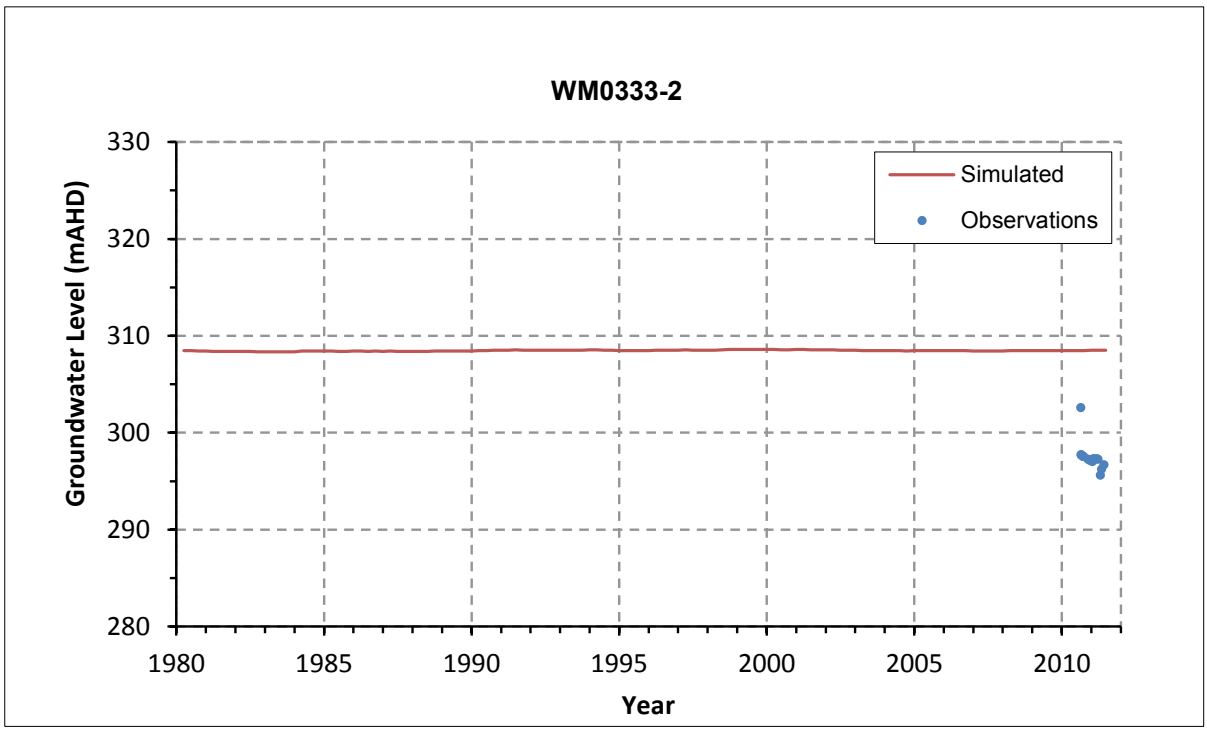

WM0291A-1
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Year
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Observations

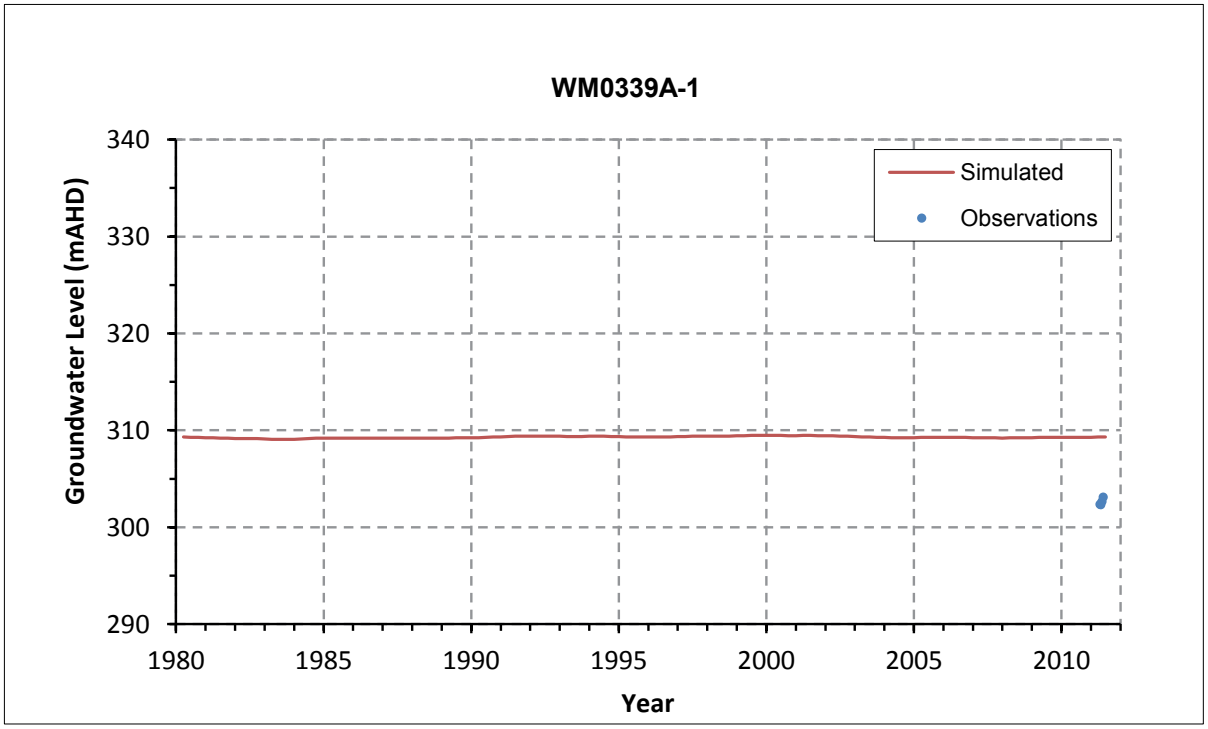

WM0291B-1
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Year
Simulated
Observations

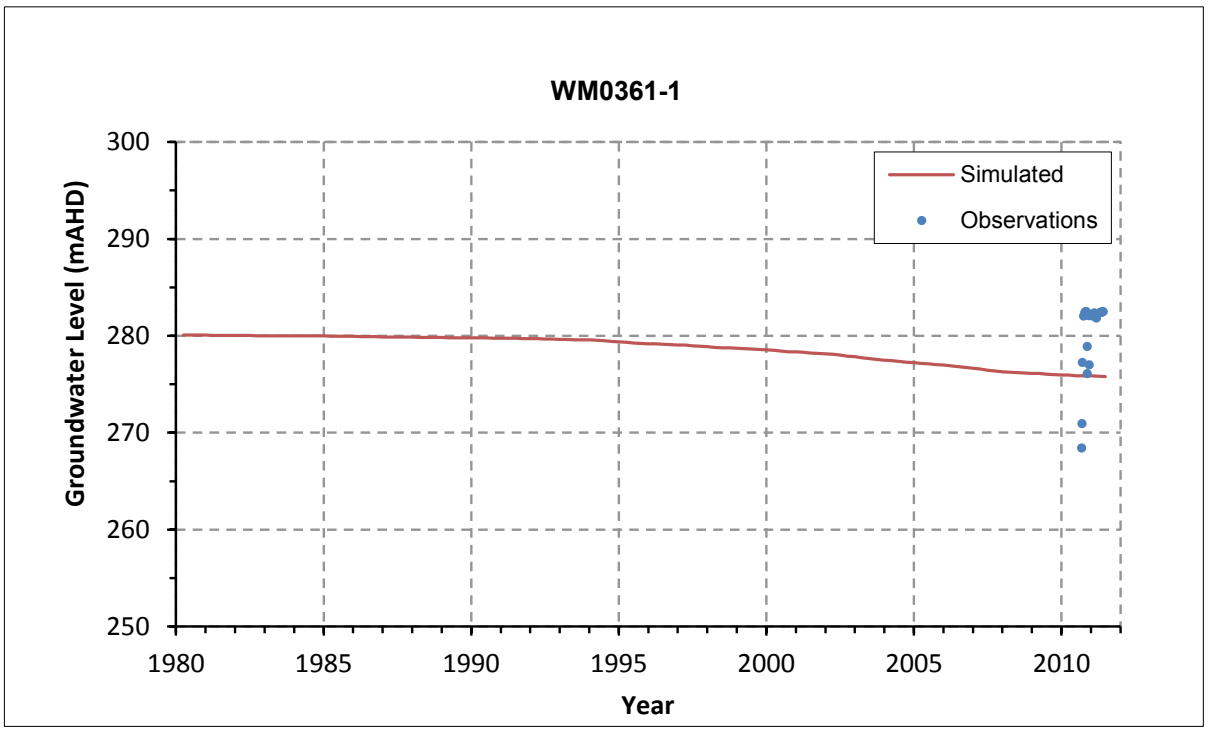

WM0293A-1
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Observations

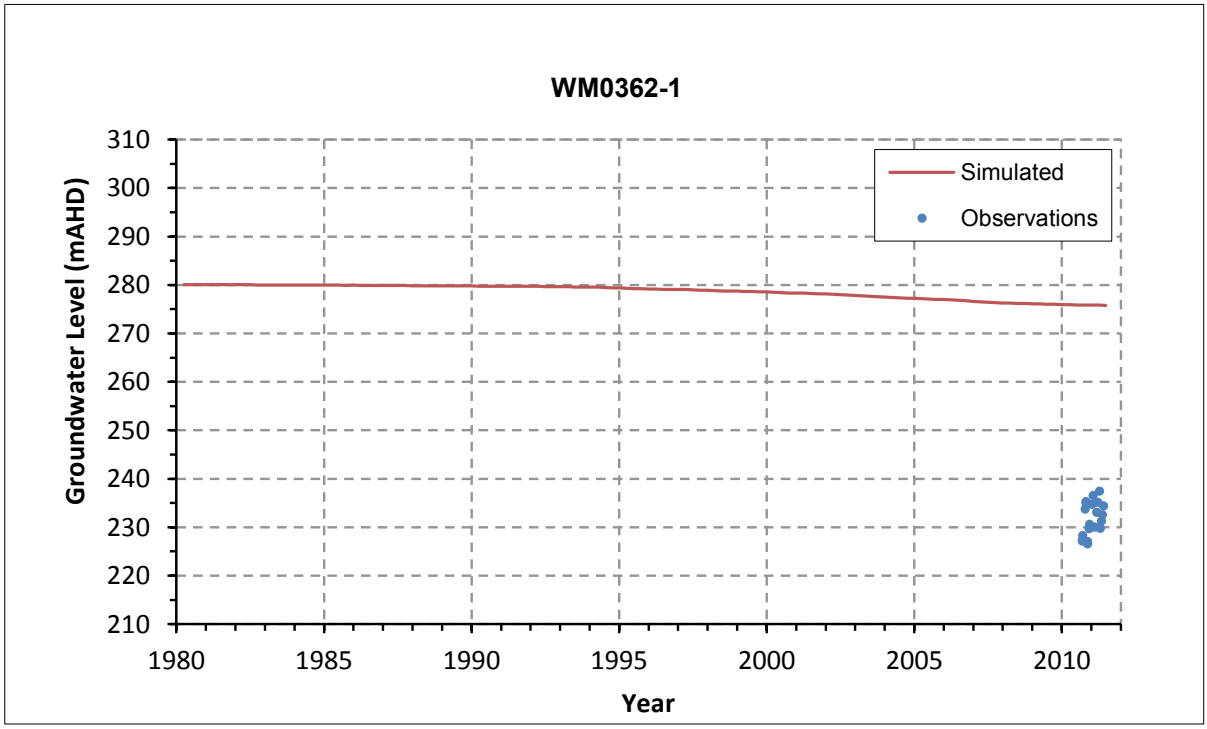

WM0330R-1
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Year
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Observations

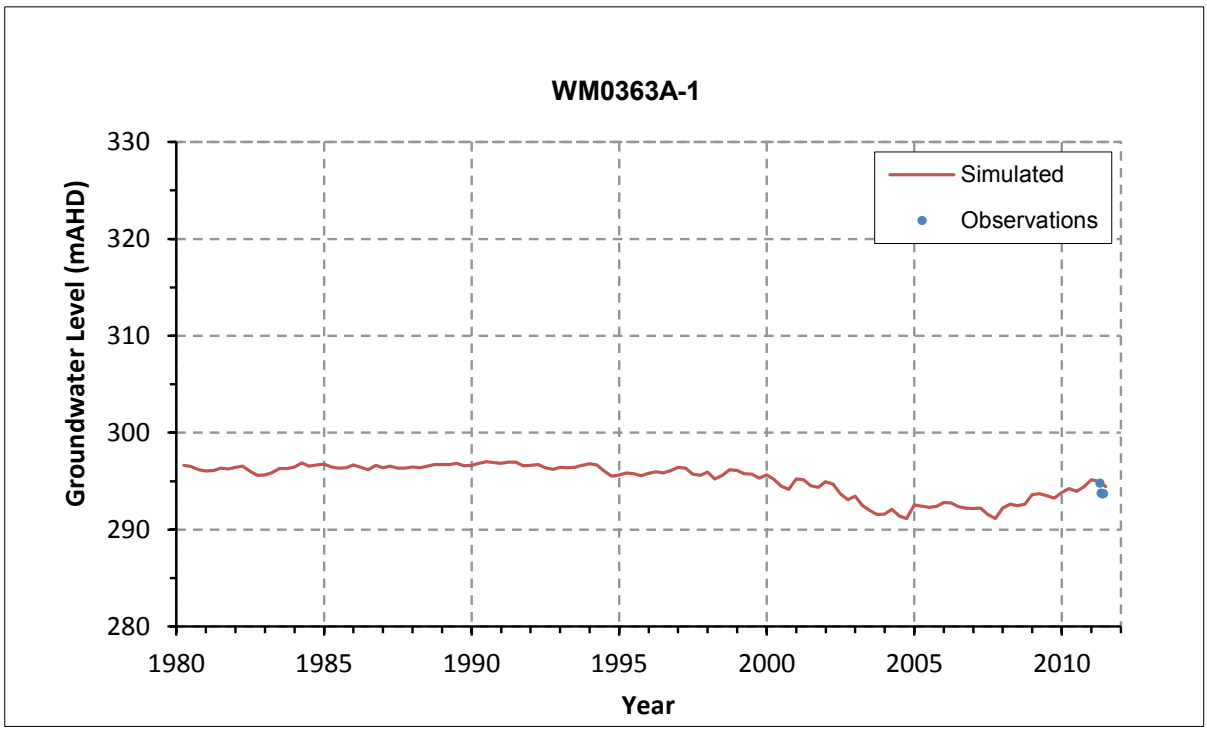

WM0333-1
Groundwater Level (mAHD)
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Year
Simulated
Observations

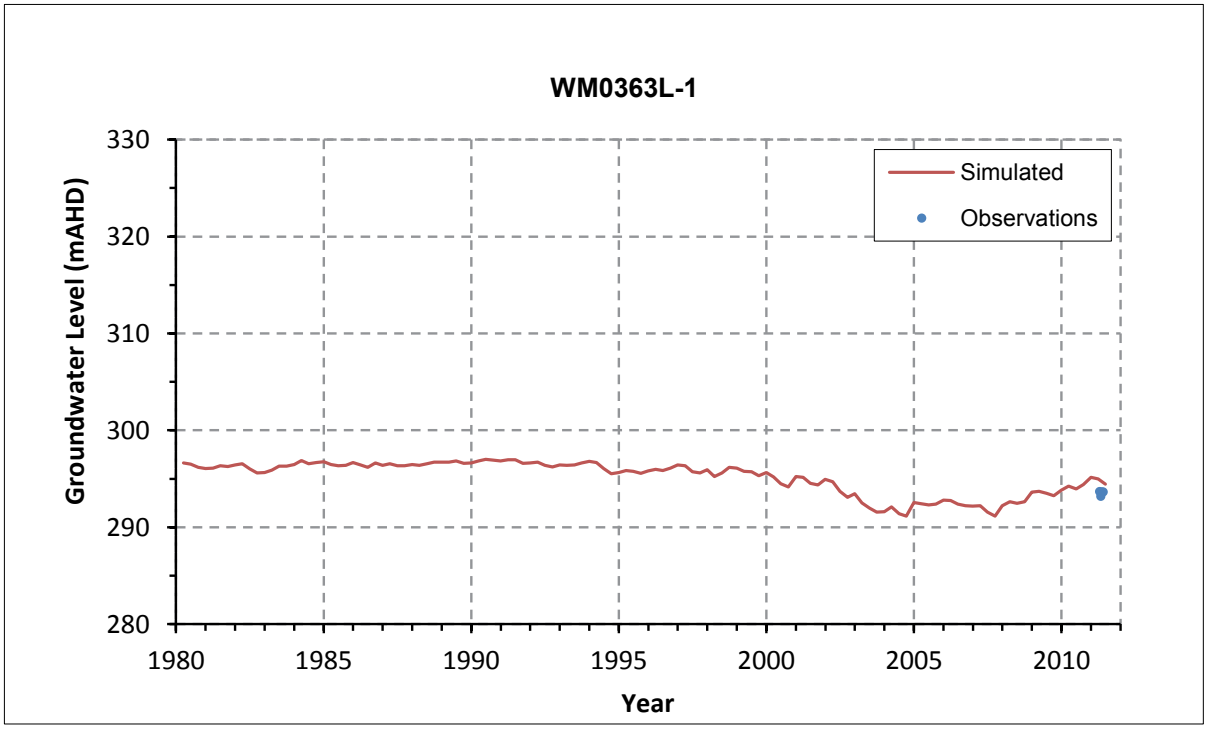

WM0333-2
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Observations

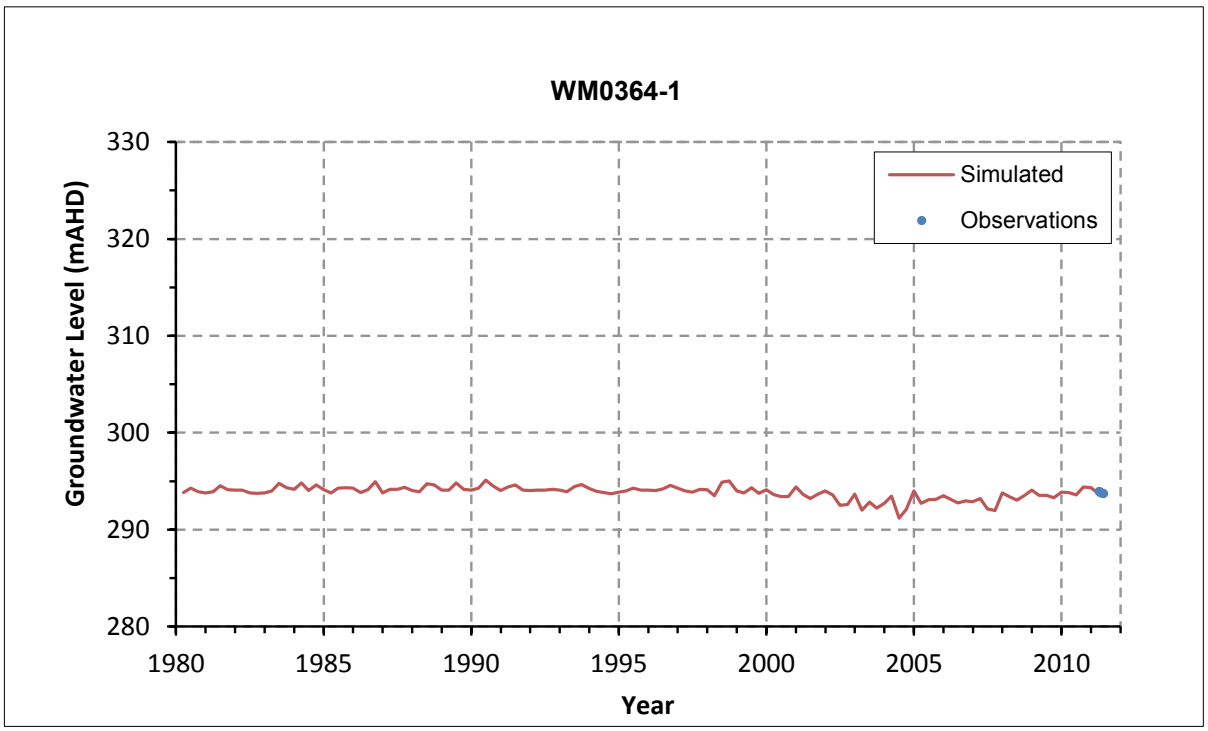

WM0339A-1
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Year
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Observations

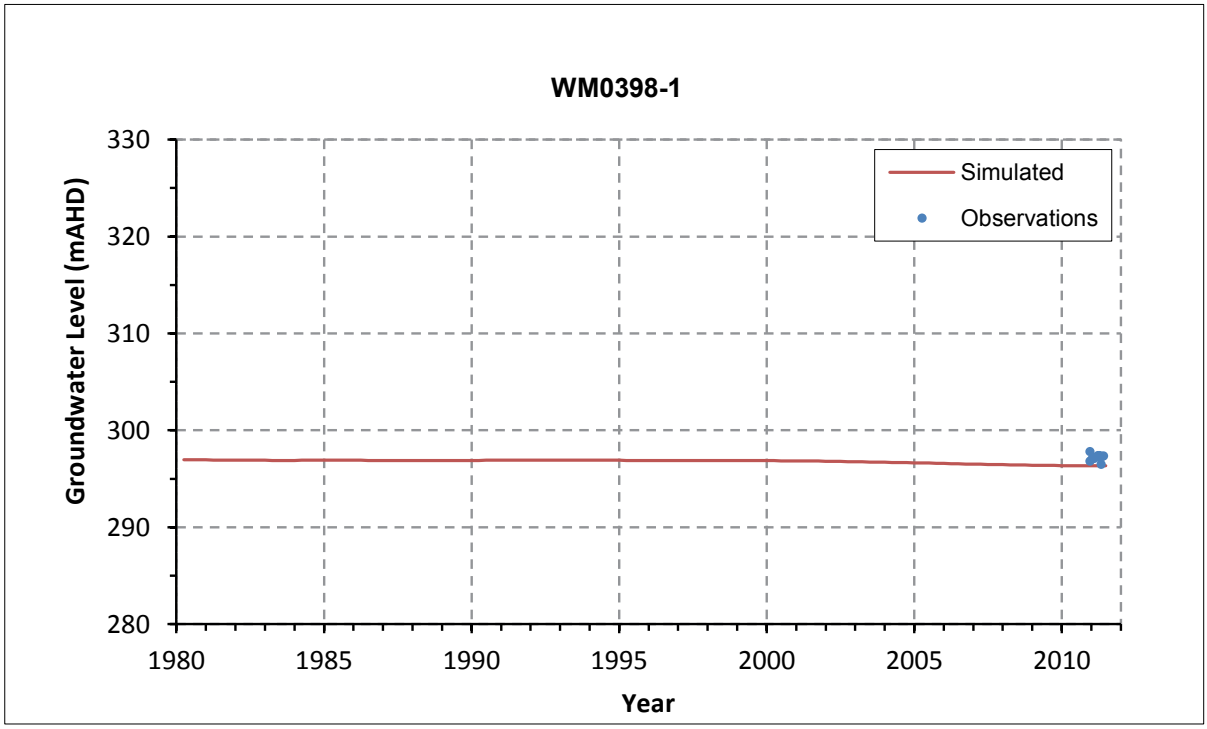

WM0361-1
Groundwater Level (mAHD)
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2010
Year
Simulated
Observations

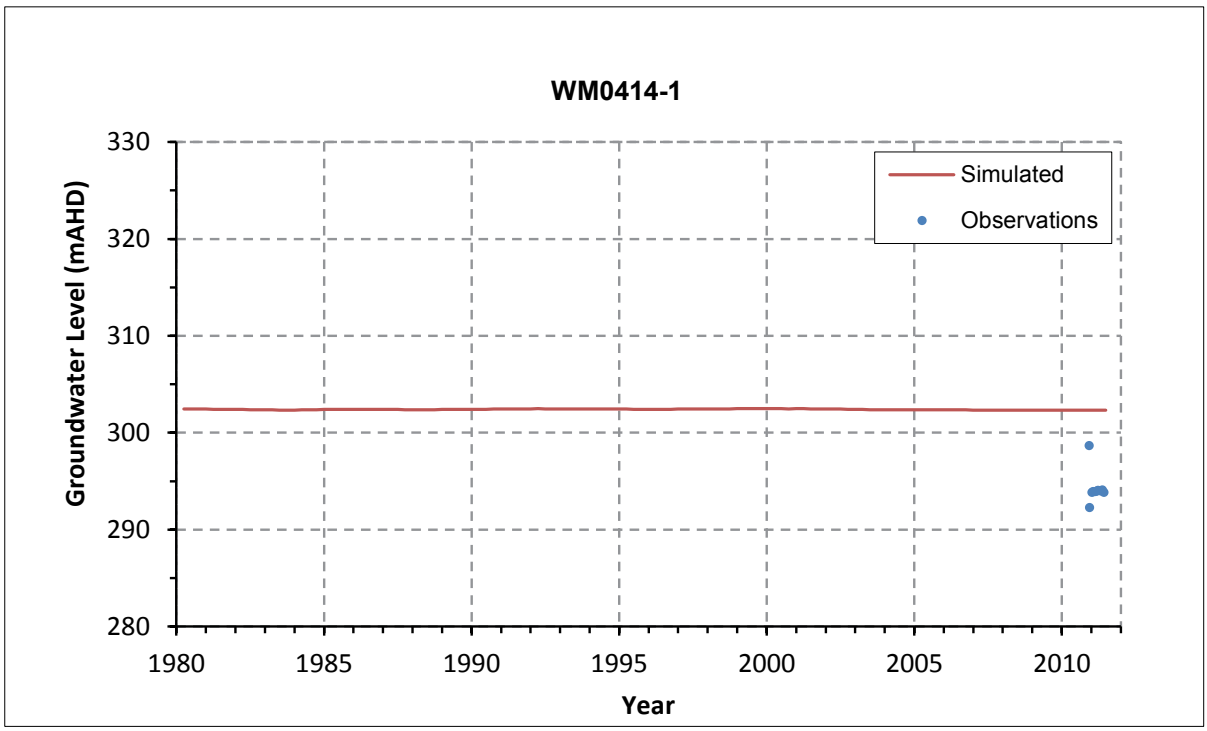

WM0362-1
Groundwater Level (mAHD)
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2010
Year
Simulated
Observations

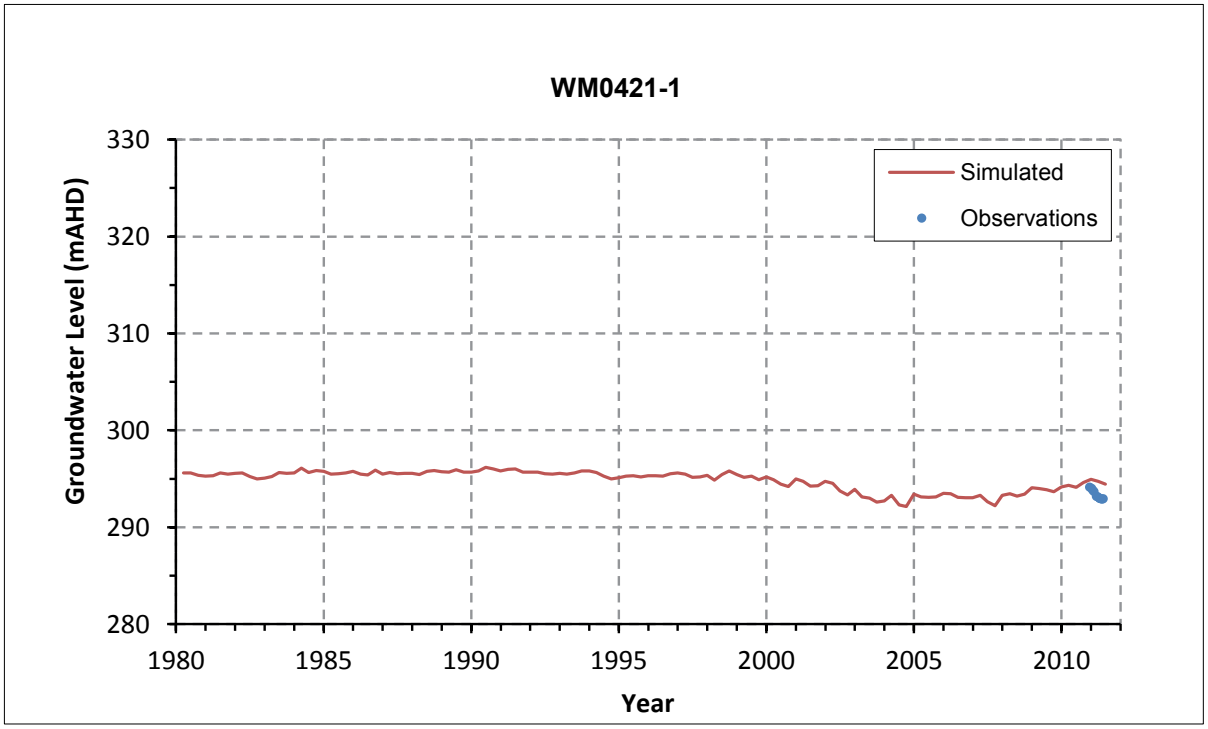

WM0363A-1
Groundwater Level (mAHD)
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2010
Year
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Observations

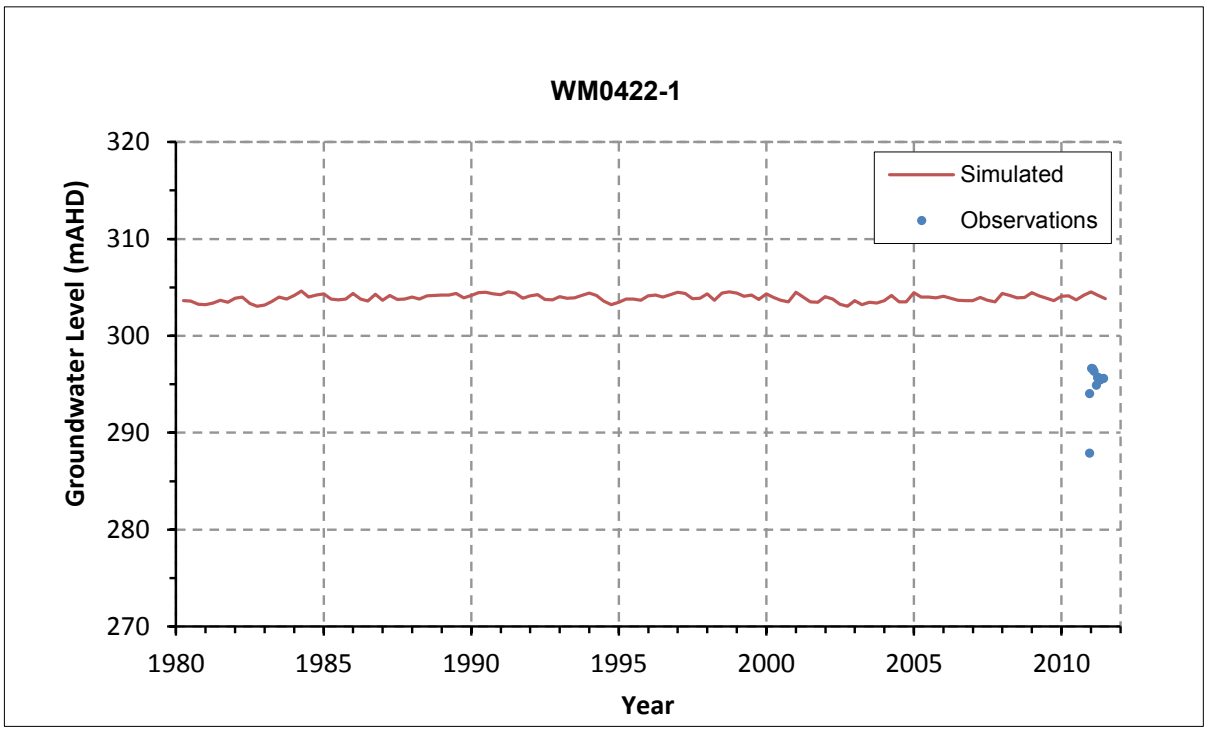

WM0363L-1
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Year
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Observations

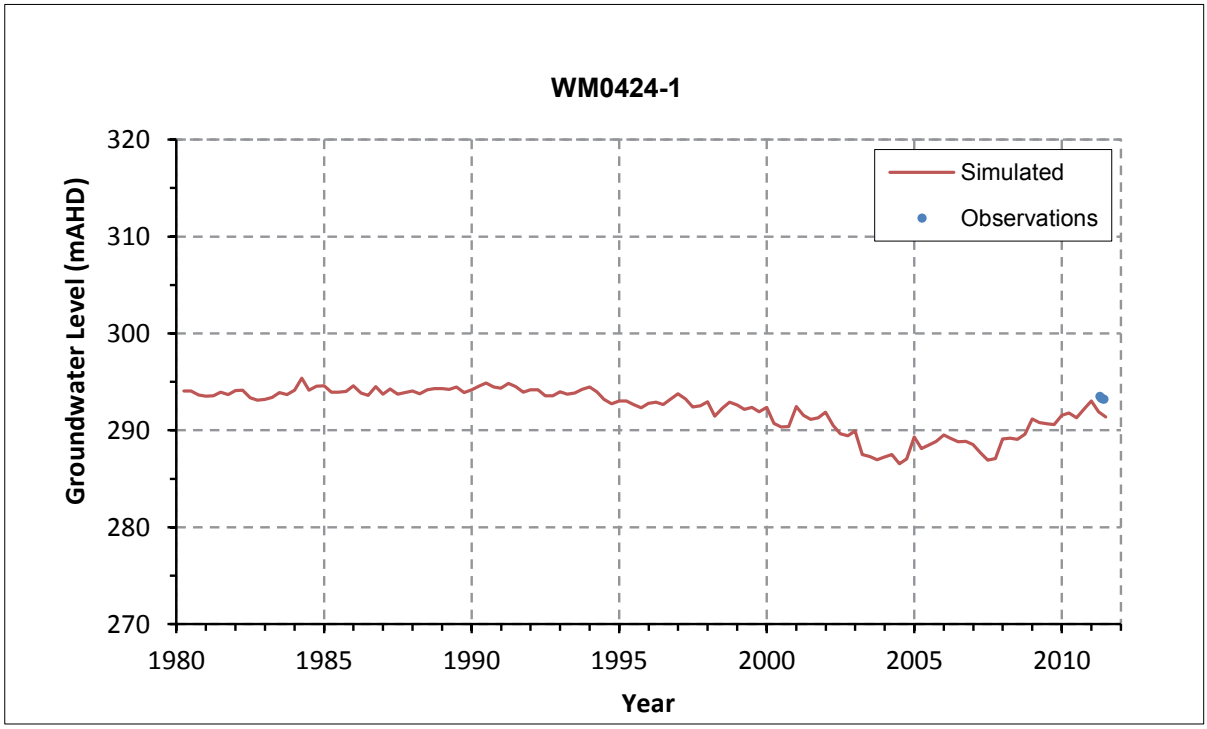

WM0364-1
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Observations

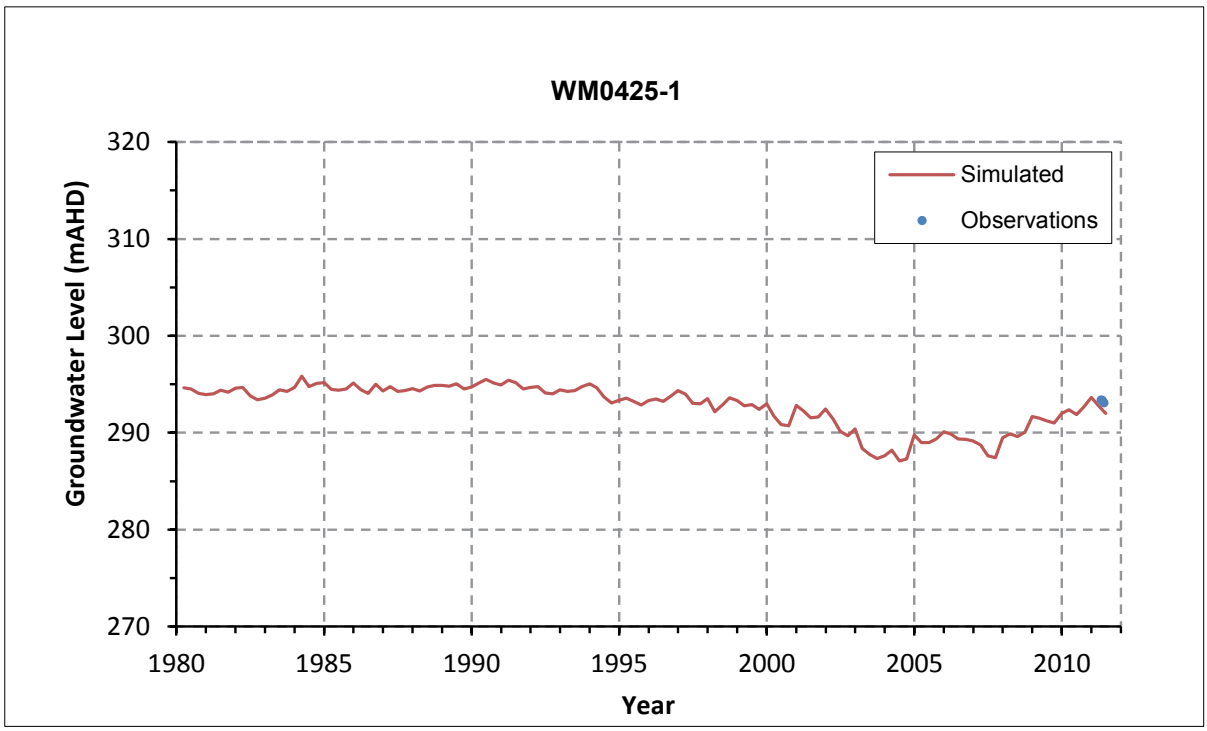

WM0398-1
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Year
Simulated
Observations

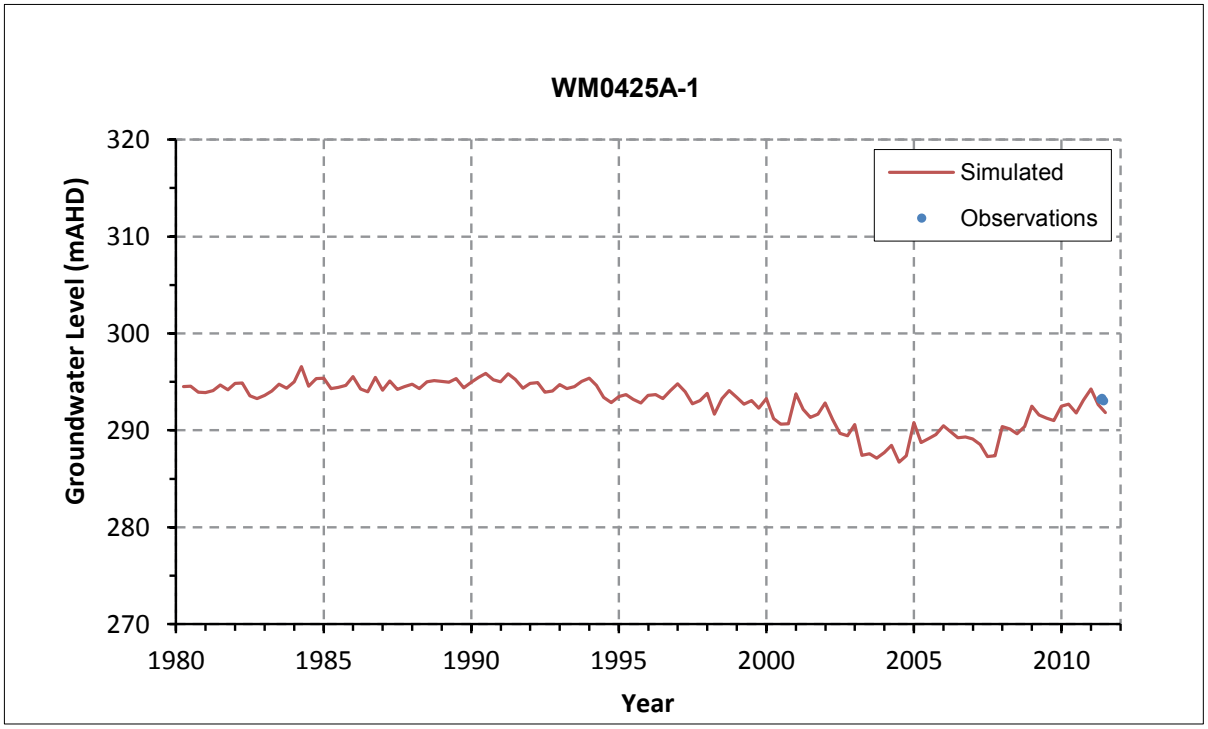

WM0414-1
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Year
Simulated
Observations

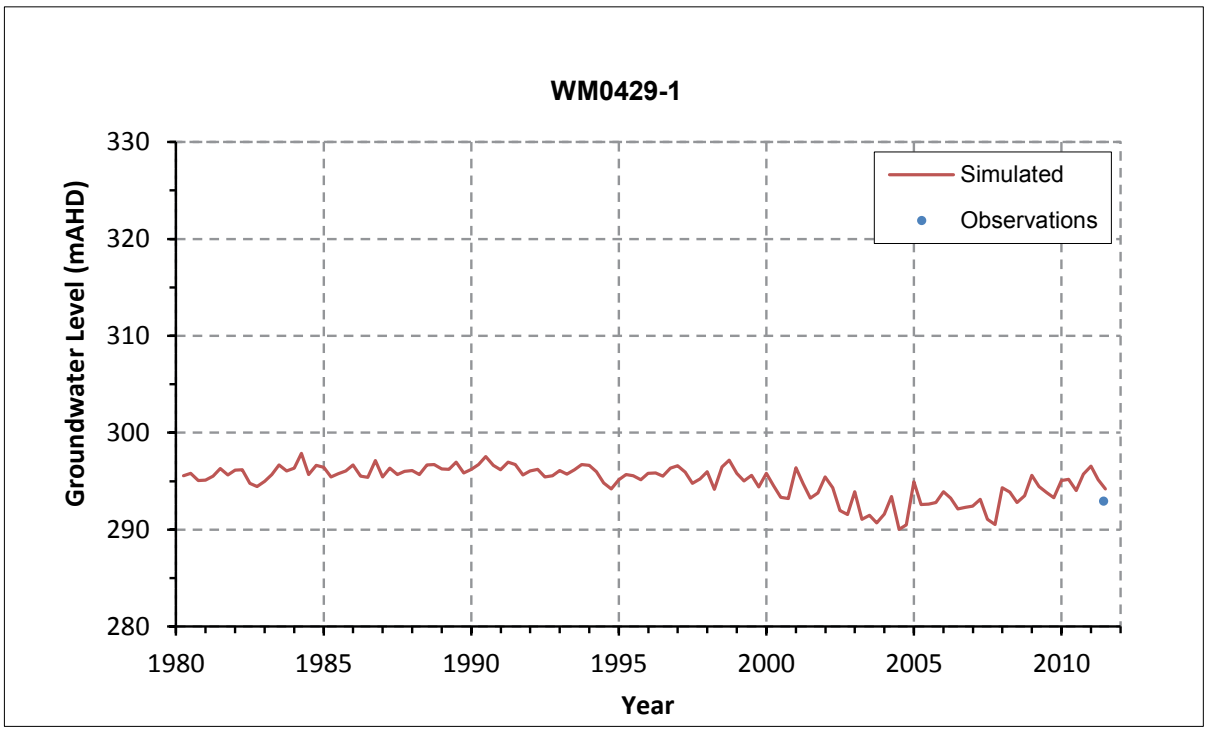

WM0421-1
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Year
Simulated
Observations

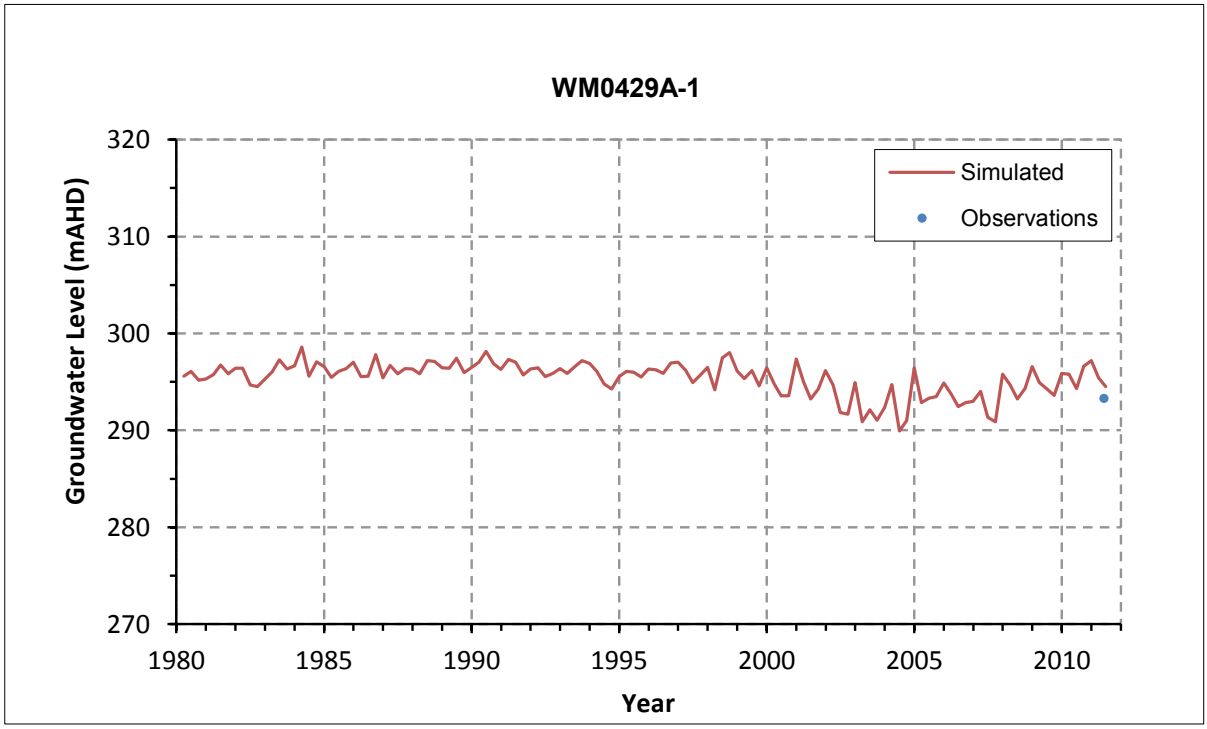

WM0422-1
Groundwater Level (mAHD)
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270
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2005
2010
Year
Simulated
Observations


WM0424-1
Groundwater Level (mAHD)
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310
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270
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1985
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2000
2005
2010
Year
Simulated
Observations


WM0425-1
Groundwater Level (mAHD)
320
310
300
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270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations


WM0425A-1
Groundwater Level (mAHD)
320
310
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270
1980
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2005
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WM0429-1
Groundwater Level (mAHD)
330
320
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2010
Year
Simulated
Observations


WM0429A-1
Groundwater Level (mAHD)
320
310
300
290
280
270
1980
1985
1990
1995
2000
2005
2010
Year
Simulated
Observations

APPENDIX 6

Water Quality Report – Terrenus Earth Sciences

TERRENUS
EARTH SCIENCES

TERRENUS
EARTH SCIENCES

Seepage Water Quality Assessment

WATERMARK COAL PROJECT

January 2013

Prepared for: **Shenhua Watermark Coal and Hansen Bailey**

Seepage Water Quality Assessment

WATERMARK COAL PROJECT

prepared for: **Shenhua Watermark Coal and Hansen Bailey**

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Project Name	Watermark Coal Project		
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Report Number	R001_B		

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EXECUTIVE SUMMARY

Terrenus Earth Sciences (Terrenus) was commissioned by Hansen Bailey Environmental Consultants (Hansen Bailey) on behalf of Shenhua Watermark Coal Pty Ltd (Shenhua Watermark) to undertake an assessment of the water quality associated with seepage from the three proposed mining areas at the Watermark Coal Project (the Project), NSW.

The assessment has been undertaken, primarily, to:

- understand the likely water quality characteristics associated with run-off and seepage from overburden emplacement areas (OEA) after mining ceases and post-closure;
- discuss the potential impacts to surface water and groundwater resulting from run-off and seepage from mining areas; and
- assist Shenhua Watermark with the management of these mining areas with respect to changes in surface water and groundwater quality.

The assessment also forms part of the environmental regulatory approvals process for the Project.

An assessment of potential final void water quality is being undertaken by WRM Water, as part of the final void surface water modelling.

Using groundwater modelling data provided by AGE Consultants, geochemistry data provided by RGS Environmental and groundwater chemistry data provided by GHD, an assessment of the likely (estimated) seepage water quality, and potential impacts to the environment, has been made.

Leachate from mixed overburden emplacement materials, comprising fine- to coarse-grained overburden and interburden and a small proportion of coal rejects, is conservatively estimated to have an initial salt concentration of up to 5000 mg/L. The concentration of seepage / leachate / run-off is expected to decrease over time (as readily available salt is flushed during the early years).

The concentration of soluble metals in leachate from the column leaching tests was low (below or marginally above the laboratory limit of reporting), and seepage would be expected to also have similarly low concentrations of soluble metals. The pH of leachate from the column leaching tests was pH-neutral to alkaline and seepage would be expected to also have similarly pH-neutral to slightly alkaline pH.

Eastern Mining Area

Seepage is predicted by the AGE groundwater model to occur in a zone of about 214 ha along the south and south-eastern boundary of the Eastern Mining Area (EMA), and a smaller zone of about 16 ha along the north-eastern boundary of the EMA. Seepage rates of up to 90,000 litres per day (in total) are predicted to occur from about Year 60 (about 30 years after mining ceases).

Applying the estimated maximum salt concentration (5000 mg/L) to these quantities produces a salt load contribution of about 2 kg of salt per ha of seepage zone per day (on average).

A sensitivity analysis undertaken of the seepage rate (doubling the rate) and seepage area (reducing the area by half) produces a salt load contribution of 8 kg of salt per ha per day (on average), which is regarded as likely to have a low impact on the surrounding environment.

Southern Mining Area

Seepage is predicted by the AGE groundwater model to occur in a zone of about 53 ha along the south and south-eastern boundary of the Southern Mining Area (SMA). Seepage rates of about 30,000 litres per day (in total) are predicted to occur from about Year 60 (about 30 years after mining ceases), and increasing to about 60,000 litres per day by about Year 400.

Applying the estimated maximum salt concentration (5000 mg/L) to these quantities produces a salt load contribution of about 5.6 kg of salt per ha of seepage zone per day.

A sensitivity analysis undertaken of the seepage rate (doubling the rate) and seepage area (reducing the area by half) produces a salt load contribution of 23 kg of salt per ha per day. The impacts of such loads are unclear, and would depend upon the salt receptors. Given that there are no major surface water drainages in the near vicinity (within 100 m) of the SMA it is likely that the salt would accumulate near the toe of the OEA and only be mobilised with significant prolonged rainfall events. The nearest drainage to the SMA is Native Dog Gully (an ephemeral creek), which is approximately 200 m south of the SMA.

Western Mining Area

No seepage (to land surface) is predicted by the AGE groundwater model to occur at the Western Mining Area (WMA), with all seepage from the WMA overburden emplacement area draining into the pit (during mining operations) and final void (at closure and post closure). That is, the final void is predicted to be a seepage and groundwater 'sink' during mining operations and once steady-state (equilibrium) hydrological conditions have been reached (steady-state conditions in the final void are predicted to be met after at least 100 years and potentially as long as 2000 years, depending on the model assumptions made).

Potential Impacts to Groundwater

Groundwater in all aquifers within the Project Boundary has a salt concentration of equal to or significantly greater than (in some aquifers over 10-times) the salinity potentially produced from overburden emplacement area seepage/leachate. Therefore overburden emplacement area seepage/leachate is expected to have a low to negligible impact on local groundwater resources.

Refinement

During mining operations as the Project develops, further assessment of overburden emplacement area seepage and leachate quality will be undertaken by Shenhua Watermark to qualify the above estimates.

TERRENUS EARTH SCIENCES

Seepage Water Quality Assessment

WATERMARK COAL PROJECT

January 2013

Executive Summary iii

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Appendix A. Kinetic leach column test results (from RGS Environmental)

1 Introduction, Background and Objective

Terrenus Earth Sciences (Terrenus) was commissioned by Hansen Bailey Environmental Consultants (Hansen Bailey) on behalf of Shenhua Watermark Coal Pty Ltd (Shenhua Watermark) to undertake an assessment of the water quality associated with seepage from the three proposed open cut mining areas at the Watermark Coal Project (the Project), NSW.

In October 2008, Shenhua Watermark was granted Exploration Licence (EL) 7223. Shenhua Watermark is a subsidiary of the Shenhua Corporation.

The Project is located within EL 7223, approximately 35 km south south-east of the township of Gunnedah and to the immediate west of the village of Breeza, within the Gunnedah Local Government Area (LGA). The Project is approximately 282 km by rail from the export Port of Newcastle.

Shenhua Watermark is seeking State Significant Development Consent under Division 4.1 of Part 4 of the *Environmental Planning & Assessment Act 1979* (EP&A Act) for the Project. The Project Application Boundary (Project Boundary) is shown on **Figure 1**.

The Project generally comprises:

- The construction and operation of an open cut mining operation extracting up to 10 Million tonnes per annum (Mtpa) of Run of Mine (ROM) coal for a 30 year period;
- An open cut mining fleet of excavators and shovels, supported by haul trucks, dozers, graders, drill rigs and water carts;
- Progressive rehabilitation of all disturbed areas;
- The construction and operation of a Coal Handling and Preparation Plant (CHPP) with a throughput of 10 Mtpa ROM coal;
- The co-disposal of tailings and coarse reject within the Overburden Emplacement Areas (OEA);
- The construction and operation of a rail spur, rail loop, Kamilaroi Highway rail overpass, associated load out facility and connection to the Werris Creek - Moree Railway Line;
- The construction and operation of a Mine Access Road;
- The construction and operation of administration, workshop and related facilities;
- The construction and operation of ground and surface water management and reticulation infrastructure including pipelines, pumping stations and associated infrastructure for access to water from groundwater aquifers, the Mooki River and private dams to the north-east of the Project Boundary;
- The installation of communications and electricity reticulation infrastructure; and
- A workforce of up to approximately 600 full-time equivalent employees during construction and up to 600 full-time equivalent employees during the operation of the Project.

The conceptual layout of the Project is shown in **Figure 1.**

The water quality assessment has been undertaken, primarily, to:

- understand the likely water quality characteristics associated with run-off and seepage from overburden emplacement areas after mining ceases and post-closure;
- discuss the potential impacts to surface water and groundwater resulting from run-off and seepage from mining areas; and
- assist Shenhua Watermark with the management of these mining areas with respect to changes in surface water and groundwater quality.

This assessment also includes a brief 'overview' assessment of potential final void water quality associated with the Western Mining Area (WMA), however the full assessment of WMA final void water quality forms part of the final void surface water modelling undertaken by WRM Water & Environment Pty Ltd (WRM), and reported separately by WRM in a *Surface Water Impact Assessment* (WRM, 2012).

1.1 Context

Assessments related to mine waste geochemistry, groundwater quality, groundwater flow modelling and surface water flow have been undertaken for the Project by others, and the data from these assessments forms the basis of the information used by Terrenus. That is, this water quality assessment undertaken by Terrenus related to run-off and seepage from mining areas relies on key information provided by others about the geochemical characteristics of mine waste materials, existing groundwater quality and modelled groundwater flow characteristics for the Project. These related aspects are reported separately by the organisations below as part of the Environmental Impact Statement (EIS) for the Project, which is being prepared by Hansen Bailey. The main sources of information for this assessment included:

- Geochemistry Impact Assessment prepared by RGS Environmental Pty Ltd (RGS) (2012);
- Shenhua Watermark Coal Pty Ltd, Hydrogeological Investigations, Stage 3 Bore Completion Report prepared by GHD (2011);
- Groundwater Impact Assessment prepared by Australasian Groundwater and Environment Consultants Pty Ltd (AGE) (2013); and
- Surface Water Impact Assessment prepared by WRM (2012).

1.2 Objective

The overall objective of this assessment was to:

Evaluate the water quality likely to be associated with OEA run-off and seepage and identify potential environmental issues that may be associated with run-off and seepage from OEA material.

1.3 Key Project Information Relative to this Assessment

With respect to this assessment, the key components of the Project are:

- Three open cut mining areas:
  - Eastern Mining Area (EMA);
  - Southern Mining Area (SMA); and

- Western Mining Area (WMA).

- 30 year mine life. Mining commences in the EMA (Years 1 to 17), then moves to the SMA (Years 17 to 24), then moves to the WMA (Years 24 to 30). The EMA is the largest of the three mining areas.
- Overburden / Interburden materials from the early stages of mining the SMA will be used to backfill the final stage of the EMA, thus leaving no final void in the EMA. By Year 21 the EMA will be completely backfilled and rehabilitated (*ie*. at mine closure the EMA will comprise a mounded rehabilitated landform).
- Overburden / Interburden materials from the early stages of mining the WMA will be used to backfill the final stage of the SMA, thus leaving no final void in the SMA. By Year 26 the SMA will be completely backfilled and rehabilitated (*ie*. at mine closure the SMA will comprise a mounded rehabilitated landform).
- Overburden / Interburden materials from the WMA (once the SMA is backfilled) will be placed behind the WMA active mining area. By Year 30 the WMA will be completed, leaving a relatively small final void.
- The final void in the WMA will be small, relative to final voids for similar open-cut coal projects in NSW and Queensland. The final void will be about 1.9 km long (oriented approximately north-south), by about 600 m wide at the surface (narrower at the mining area floor) by about 60 m deep.

Overburden and interburden – characteristics and quantities

- The EMA, SMA and WMA will contain about 1156, 482 and 495 million cubic metres (Mm^3) (dumped volume) of mine waste, respectively, comprising overburden / interburden and coal rejects.
- The geochemistry assessment (refer to RGS geochemistry report) indicates that almost all (95%) of the overburden and interburden is expected to be non-acid-forming (NAF), with a high factor of safety with respect to not developing acid drainage (*ie*. the materials have considerable excess neutralising capacity relative to acid-generating capacity).
- About 5% of overburden/interburden was classified as potentially acid-forming (PAF) or had an 'uncertain' classification. This PAF and 'uncertain' material was mainly from interburden material close to the Hoskissons Seam. This interburden material close to the Hoskissons Seam will be selectively handled to be placed into the internal zones of the OEAs, well away from final surfaces.

Coal rejects - processing, quantities and disposal

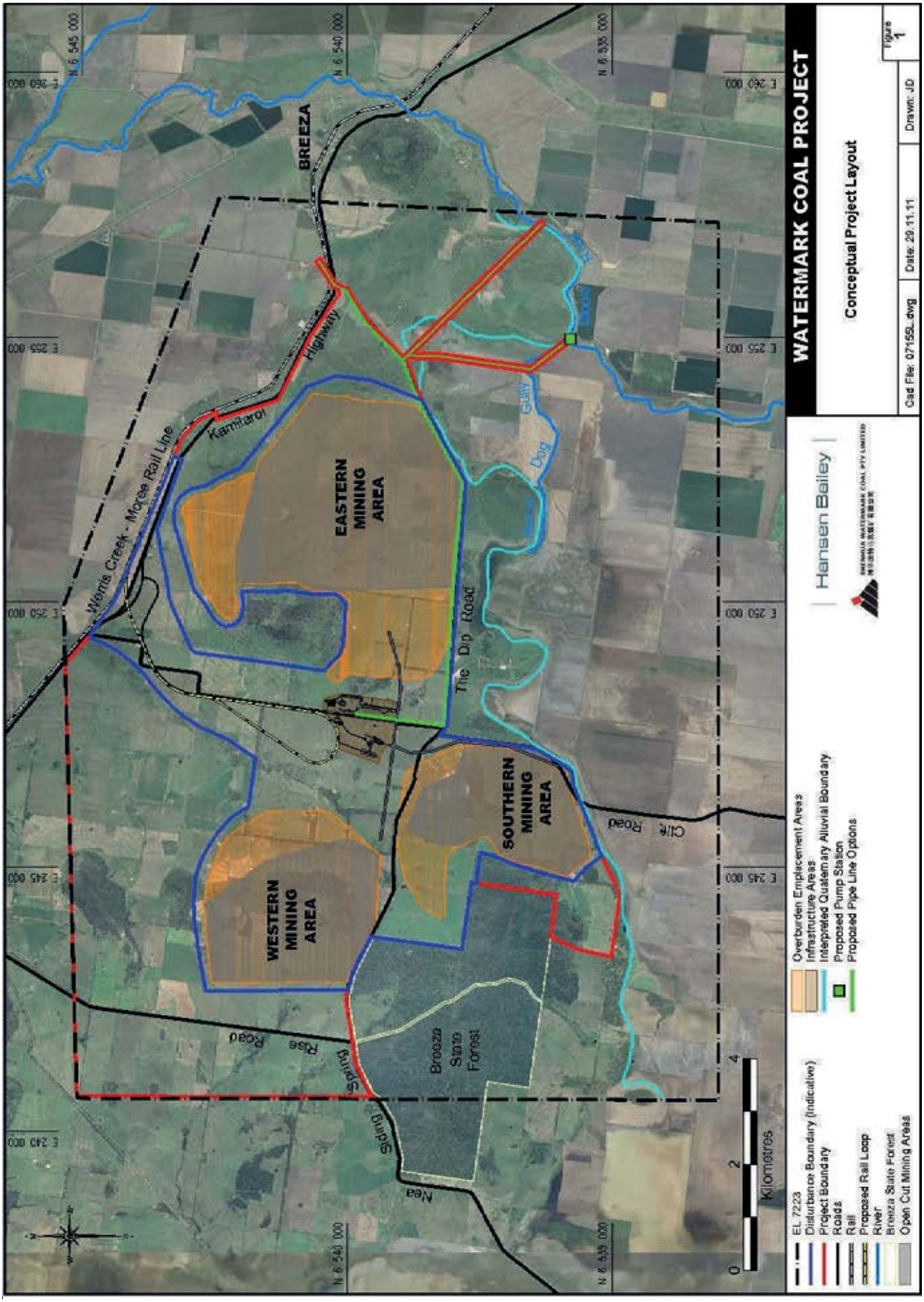
- ROM coal will be processed to produce product coal, coarse rejects and fine tailings. Coal rejects will comprise about 4.3% of total mine waste volume (about 70 Mm^3 dumped volume). Of this 4.3%, about half will come from the Hoskissons Seam and half from the Melvilles Seam. A small proportion (indicatively less than 5% of rejects) may come from opportunistic mining of minor coal seams.
- The geochemistry assessment (RGS, 2012) indicates that about 89% of potential coal rejects are expected to be NAF, with a relatively high factor of safety with respect to not developing acid drainage. About 7% of samples tested were classified as 'uncertain' or 'low capacity'

PAF (*ie*. a low capacity to generate significant acidity). Less than 5% of samples tested were classified as PAF, and these were mainly associated with the Hoskissons (Lower) Seam.

- Therefore, about 5% of all coal rejects (potentially 3.5 Mm^3) may have some capacity to generate acid and/or sulfate loads. This equates to about 0.2% (by volume) of all mine waste.

Mine waste disposal strategy and rehabilitation

- Overburden, interburden and coal rejects will be trucked to the disposal locations at the OEAs and end-dumped. Coal rejects (coarse and fines) will be co-disposed into 'cells' amongst overburden / interburden materials (buried well away from final surfaces). Each cell will be capped with compacted overburden / interburden materials (to reduce seepage through-flow) prior to general burial. Coal rejects identified as PAF will be selectively handled to ensure their placement well-within the OEA and encapsulated by overburden / interburden materials soon after placement (to minimise oxidation). As a general rule, all coal rejects will be placed well inside the OEAs.
- During disposal, overburden / interburden and co-disposed coal rejects will be traffic-compacted to reduce permeability.
- Progressive rehabilitation (re-vegetation) of sections of the OEA at each mining area will be undertaken with grasses and native shrubs as soon as practicable once the final landform is complete.



Seepage Water Quality Assessment

2 Conceptual Water Balance and Seepage Zones Associated with the Mining Areas

To estimate the water quality potentially associated with seepage or run-off from an open cut mining area, it is necessary to understand the water balance for the mining area, as water quality is a function of volume – the less water for a given mass of solute, the higher the volumetric concentration. However, equally important, the less water seeping and running-off into the environment, the less total mass of solute (total solute load) entering into the environment.

Groundwater numerical modelling has been undertaken by AGE (2013) (reported separately) to model (estimate) the predicted water movement (exchange) between the open cut mining areas, groundwater aquifers, rainfall and evaporation until 1400 years after mining (Year 0 to Year 1500) – for each of the three mining areas. The groundwater model makes a number of assumptions, which are not discussed in this report. A key model assumption is that rainfall recharge is 5.5% of average annual rainfall. Average annual rainfall is about 640 mm (AGE, 2013), therefore recharge was estimated to be approximately 35 mm/year.

Additionally, a surface water model has been created for the final void by WRM (2012) (and reported separately), which models (estimates) the rate of water infiltration into the mining areas from rainfall, groundwater and overburden / interburden recharge sources and evaporative losses from the mining area being backfilled.

2.1 Water balance for the Eastern Mining Area

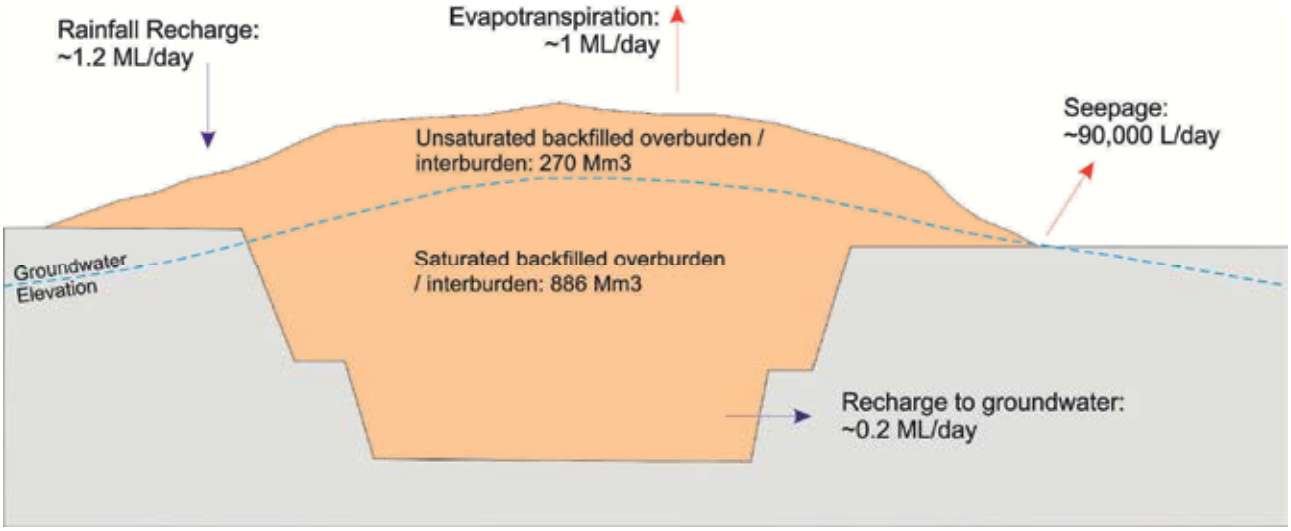
By approximately Year 21, the EMA will be completely backfilled and rehabilitation will be largely (or totally) complete. At this stage the EMA will occupy an area of about 1925 ha, and will be a mounded landform providing topographic relief.

The AGE groundwater model shows that during mining, there is a near transient state between groundwater inflow, rainfall recharge into the EMA and evaporation. Once the EMA is backfilled there is a small net recharge of water from overburden / interburden into the groundwater environment, at a rate of about 0.2 ML per day (about 140 litres per minute). The water is sourced from rainfall, which contributes about 1.5 ML/day recharge. About 1 ML/day is lost from overburden / interburden as evaporation. Groundwater level in the backfilled EMA will become slightly raised above natural ground level (raised phreatic surface). At this point, seepage may occur where the phreatic surface in the EMA meets the natural land surface at the toe of the OEA – and small springs may develop. The seepage rate from the backfilled EMA to the surface, in total for the entire EMA, is predicted to be 90,000 litres per day (33 ML per year; 63 litres per minute). A conceptual water balance for the EMA is shown in **Figure 2**.

2.2 Eastern Mining Area seepage zones after closure

The AGE groundwater model predicts that seepage (discharge) will occur at the EMA at a rate of up to 90,000 litres per day (63 litres per minute) over a total area of about 230 ha. This seepage area is comprised of one main seepage zone along the southern boundary of the EMA (an area of about 214 ha) and one smaller seepage zone along the north-eastern boundary of the EMA (about 16 ha). The predicted seepage zones for the EMA are shown in **Figure 4**. A seepage rate of up to 90,000 litres per day, over a total area of 230 ha (*ie*. about 390 litres per day per ha), is equal to 0.04 litres (40 mL) per square metre per day.

Figure 2. Conceptual water balance for the Eastern Mining Area at Year 60



Predicted recharge and discharge values shown in **Figure 2** are from Year 60 onwards. At closure (Year 30) evapotranspiration rates are slightly less until vegetation establishes, groundwater exchange with the EMA is near-neutral and seepage is about 30,000 L/day (about one-third the value shown).

2.3 Water balance for the Southern Mining Area

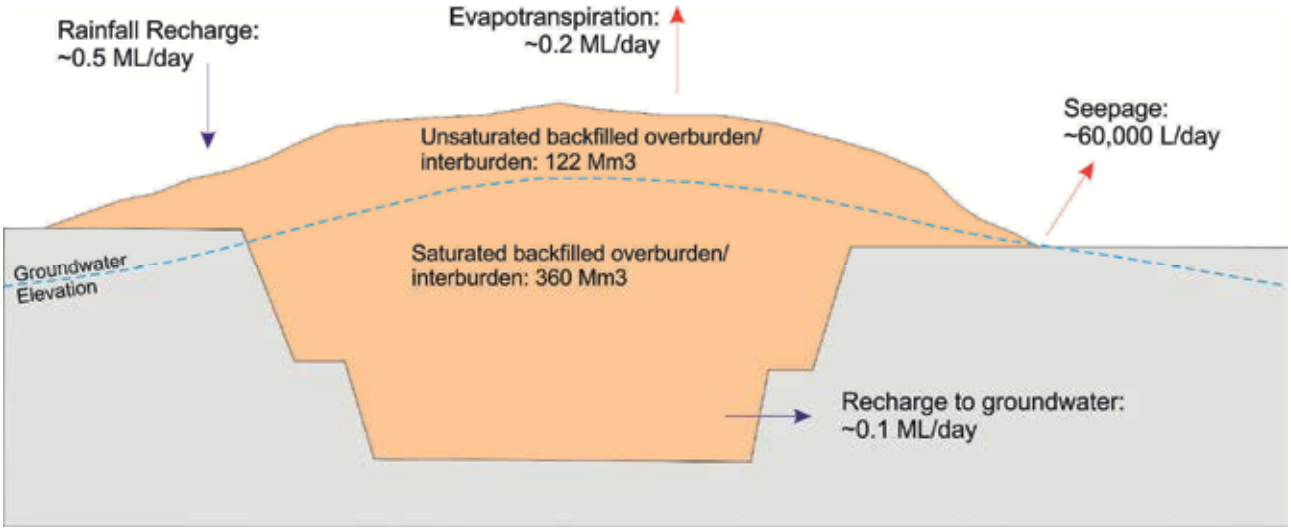
By approximately Year 26, the EMA will be completely backfilled and rehabilitation will be largely (or totally) complete. At this stage the SMA will occupy an area of about 800 ha, and will be a mounded landform providing topographic relief.

The AGE groundwater model shows that during mining, there is a groundwater inflow rate of about 0.4 ML/day (about 278 litres per minute). Once the SMA is backfilled the hydraulic regime reverses, and there is a small net inflow of water from overburden / interburden materials into the groundwater environment, at a rate of about 0.1 ML per day (about 70 litres per minute). The water is sourced from rainfall, which contributes about 0.5 ML/day recharge. About 0.2 ML/day is lost from overburden / interburden materials as evaporation. Groundwater level in the backfilled SMA will become slightly raised above natural ground level (raised phreatic surface). At this point, seepage may occur where the phreatic surface in SMA meets the natural land surface at the toe of the OEA – and small springs may develop. The seepage rate at the toe, in total for the entire SMA, is predicted to be 60,000 litres per day (42 litres per minute; 22 ML per year). A conceptual water balance for the SMA is shown in **Figure 3**.

2.4 Southern Mining Area seepage zones after closure

The AGE groundwater model predicts that seepage (discharge) will occur over an area of about 53 ha, along the south and south-eastern SMA boundary (**Figure 4**) at a rate of up to 60,000 litres per day (42 litres per minute). At this location the seepage front is predicted to be about 3.2 km long. A seepage rate of up to 60,000 litres per day, over an area of 53 ha (*ie*. about 1130 litres per day per ha), is equal to about 0.11 litres (110 mL) per square metre per day.

Figure 3. Conceptual water balance for the Southern Mining Area at Year 400



Predicted recharge and discharge values shown in **Figure 3** are from Year 400 onwards. The rainfall recharge rate remains the same from closure (Year 30) through the modelled period to Year 1500. Seepage is not predicted from the SMA until Year 60, at which point the seepage rate is predicted to be about half (30,000 L/day) of the indicated final rate shown. The SMA is predicted to be a groundwater sink from closure until Year 60.

2.5 Water balance for the Western Mining Area

By Year 30 (end of mining), the WMA will be partially backfilled. At this stage the WMA will occupy an area of about 980 ha, and will comprise a mounded landform providing topographic relief on the eastern side of the WMA, and a small final void.

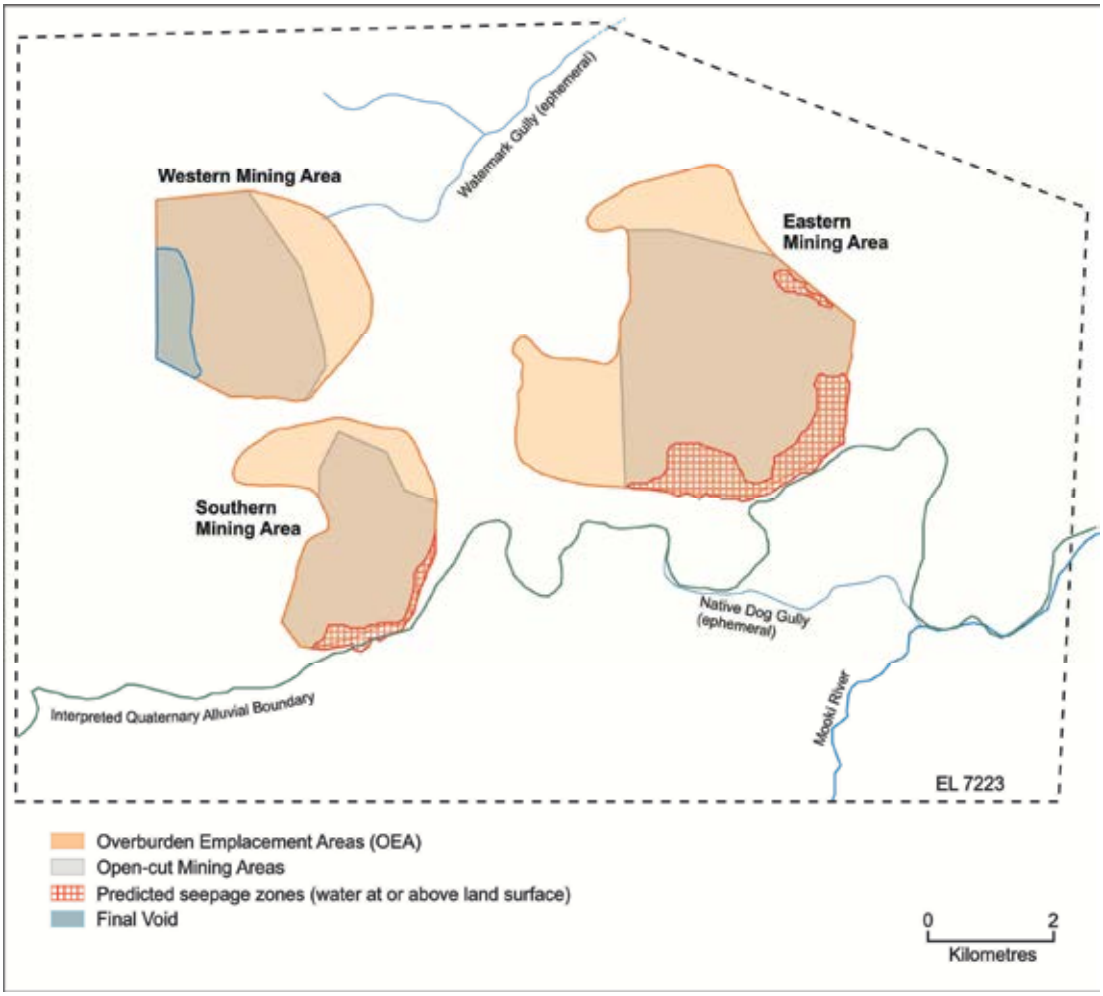
Modelling of the final void by AGE (2013) and WRM (2012) predicts that the final void is expected to reach steady-state (equilibrium) after at least 100 years, and potentially as long at 2000 years (depending on the model assumptions made, including flooding frequency and duration). At steady-state, there is a small discharge of groundwater and seepage water from the OEA into the final void. The water in the final void is sourced primarily from rainfall, which contributes about 5.5 ML/day recharge. The contribution of water from overburden / interburden recharge to the final void is approximately 0.35 ML/day. The groundwater contribution to the pit at the end of mining (before closure) is approximately 0.7 Ml/day, which decreases to less than 0.1 ML/day once the final void has reached steady-state. The evaporation rate from the final void increases as the final void fills and the lake surface area increases. Evaporation rate loss from the final void ranges from 0 ML/day at Year 30 to about 5.5 ML/day (equal to rainfall recharge) at steady-state. The final void volume, when full (steady-state), is approximately 25,000 ML, with a surface area of about 100 ha.

As the final void is a sink for seepage from the OEA and groundwater, both the AGE (2013) and WRM (2012) models do not predict any seepage from the OEA at the WMA away from the WMA, even when steady-state conditions are reached. The detailed water balance for the final void is reported by WRM (2012).

2.6 Western Mining Area seepage zones after closure

The AGE groundwater model predicts that no seepage (discharge) will occur from the WMA at any time during mining operations or post-closure.

Figure 4. Predicted seepage zones at the mining areas



2.7 Seepage behaviour

The above seepage scenarios presented for each of the three mining areas are based on 'average' flow rates. However, it is recognised that at any given time the actual seepage rate from each mining area will vary, depending upon the rainfall patterns at that time. For example, during drier periods seepage can be expected to slow, or potentially cease, whereas during large and prolonged rainfall events the OEAs may be expected to seep greater volumes of water. During drier periods when seepage is slow the concentration of salts within the OEAs can increase. Conversely, during and shortly after wet periods greater concentrations of salt can be released with the greater seepage flux.

3 Overburden / Interburden Water Quality

A geochemical assessment of all likely mined materials, comprising overburden, interburden and potential coal rejects has been undertaken by RGS Environmental using samples obtained from drill-core. The RGS geochemical assessment is not summarised herein (refer to the RGS geochemistry report in the EIS), but comprised static geochemical test methods to determine the acid-base characteristics of the materials and determination of total and water-soluble multi-element concentrations. The assessment also included a number of free-draining kinetic column leaching tests.

RGS undertook static geochemical testing on 104 overburden / interburden samples and 76 coal seam roof and floor samples (potential coal reject samples). The key data and findings from the RGS geochemical assessment, relevant to this seepage assessment, is summarised in **Table 1**.

Table 1. Summary 'static test' water quality results for overburden / interburden and potential coal reject samples

Parameter	Units	No. of Samples	Minimum	Percentiles			Maximum
				50th	75th	90th	
Overburden / Interburden samples							
pH	-	104 individual	2.8	8.4	8.9	9.4	9.9
Electrical Conductivity	µS/cm	104 individual	33	277	481	746	5760
pH	-	6 composites	6.9	7.6	8.3	8.5	8.5
Electrical Conductivity	µS/cm	6 composites	147	210	224	467	708
Aluminium	mg/L	6 composites	<0.2	<0.2	-	-	0.4
Arsenic	mg/L	6 composites	<0.02	<0.02	-	-	0.06
Manganese	mg/L	6 composites	<0.02	<0.02	-	-	0.02
Molybdenum	mg/L	6 composites	<0.02	<0.02	-	-	0.04
Selenium	mg/L	6 composites	<0.02	0.02	-	-	0.04
Concentrations of Sb, B, Cd, Cr, Co, Cu, Fe, Pb, Ni and Zn were all below the laboratory limit of reporting (detection limit) for all overburden / interburden composite samples.							
Potential Coal Reject (roof and floor) samples							
pH	-	76 individual	3.1	8.0	8.8	9.1	9.6
Electrical Conductivity	µS/cm	76 individual	65	198	355	527	3050
pH	-	7 composites	4.5	7.4	8.0	8.5	8.5
Electrical Conductivity	µS/cm	7 composites	168	204	225	464	811
Aluminium	mg/L	7 composites	<0.2	<0.2	-	-	0.4
Arsenic	mg/L	7 composites	<0.02	<0.02	-	-	0.04
Cobalt	mg/L	7 composites	<0.02	<0.02	-	-	0.26
Manganese	mg/L	7 composites	<0.02	<0.02	-	-	1.94
Molybdenum	mg/L	7 composites	<0.02	0.04	0.04	0.05	0.06
Nickel	mg/L	7 composites	<0.02	<0.02	-	-	0.5
Selenium	mg/L	7 composites	<0.02	0.04	-	-	0.04
Concentrations of Sb, B, Cd, Cr, Cu, Fe, Pb and Zn were all below the laboratory limit of reporting (detection limit) for all potential reject composite samples.							

Testing was also undertaken by RGS on 15 coal samples from minor seams (*ie*. other than the target Melville and Hoskissons seams), as coal from minor seams may report either as overburden / interburden or ROM coal, depending on mining production. Coal samples had similar static geochemical test characteristics to overburden / interburden and potential coal reject samples.

The results in **Table 1** show that overburden / interburden water quality is expected to have low salinity (generally less than 500 µS/cm) with low metals concentrations. The electrical conductivity values are determined on the basis of a 1:5 solid:water solution using sample pulps (particle size of less than 75 µm). Therefore, the samples are diluted. However, the large surface area of the very fine grain size typically allows for increased dissolution of readily soluble salts (and increased possibility for ion exchange) compared to a larger size fraction. Hence, the results can be regarded as 'representative' and potentially could be 'maximum' solubility values.

Using electrical conductivity as a proxy for salinity, and converting to total dissolved solids (TDS) using a multiplication factor of 0.63 (typical value), these overburden / interburden samples have a $TDS_{(1:5)}$ concentration of generally below 300 mg/L (TDS). Concentrating this value by a factor of 5 to allow for the 1:5 dilution factor results in a likely maximum concentration of 1500 mg/L.

Kinetic leaching tests on overburden / interburden and coal reject materials

Kinetic column leaching was undertaken by RGS on drill-core composite samples (overburden, interburden and potential coal rejects) and coal rejects obtained from a bench pilot process (coarse rejects and tailings). The drill-core composite samples had been crushed to passing 10 mm diameter. The pilot process coarse reject samples had similar size fractions to the crushed drill-core samples. The pilot process tailings samples were relatively fine-grained – less than 1 mm. Therefore, the column samples had a range of grain sizes from very fine silt/sand to about 8-9 mm diameter. On average, the grain-size in each of the 'non tailings' columns was between 1 to 3 mm.

It is recognised that in an OEA grain sizes will vary from silt/clay fraction through to boulders, depending on the rock type (hardness) and mining methods. As water moves through unconsolidated overburden / interburden materials, solutes are dissolved to varying degrees depending on the interaction with the percolating water. It is also recognised that during truck-dumping of overburden / interburden materials that very coarse (cobbles and boulders) materials naturally segregate towards the base of each lift, with finer-grained materials tending to occupy the upper zones of each lift. This upward fining grading creates a natural impediment to slow the rate of downwards percolation/infiltration.

In sections of the OEA dominated by fine-grained materials the flow rates may be slower and dissolution of solutes may be higher (due to greater residence time and increased particle surface area allowing for increased dissolution and ion exchange). Where larger size fractions exist (*eg.* cobbles or boulders) there is likely to be greater primary porosity (larger pore spaces) and water may flow through these areas faster, leading to more dilute (less concentrated) solution. These higher porosity zones are typically pathways for preferential flow and salts are flushed from these high-porosity zones faster than from fine-grained compacted zones. Therefore, water quality can be expected to vary to some degree at small scales within an OEA. Regardless, the overall water quality in an OEA (comprised of sedimentary materials) will generally be more concentrated when flowing through smaller size fractions.

Therefore, the small size fractions used in the leaching columns would encourage solute dissolution, ion exchange (in the very fine grained materials), oxidation (though this is reduced with finer grain sizes) and thus allow for salts and metals to be appropriately flushed through with the

leachate – thereby producing leachate that is expected to be 'representative' of leachate from these mined materials (once calibrated for dilution).

Free-draining kinetic column leaching undertaken by RGS on selected composite samples of overburden / interburden and coal reject materials produced comparable results to the static geochemical test results. The results are included in **Appendix A** (and also refer to RGS geochemical report). Leaching was undertaken over 7 leaching events over a 13 week period. During this time, each sample (column) was subjected to between 7.0 to 7.1 litres of 'rainwater' (deionised water). This equates to approximately 330 mm of rain, which is about half of the average annual rainfall for the Project Boundary. Samples masses ranged from 1 kg for tailings samples to 1.5 -1.8 kg for coarse reject and roof/floor samples to 2 kg for overburden / interburden samples.

Leachate was analysed for pH, EC, alkalinity, major ions and metals/metalloids. The salt concentration in leachate was not measured (as TDS), but has been calculated using EC values and major ion values.

Overburden / interburden samples produced pH-neutral to slightly alkaline leachate with calculated TDS values ranging from 43 to 1310 mg/L. The mixed fine-grained overburden / interburden sample produced leachate with a median TDS value of 663 mg/L, whereas the coarser-grained overburden / interburden samples produced leachate with median TDS values of 63 and 50 mg/L, respectively. The coarse reject and tailings samples produced leachate with median TDS values of generally between 200 to 350 mg/L. The salt release rate (mg/kg) from the column samples is plotted in **Figure 5**.

The medium and coarse-grained overburden / interburden materials have leached significantly less salt compared to the fine-grained overburden / interburden material (**Figure 5**: top). The mixed fine-grained sample released just under 2000 mg (total) of 'salt' per kg of sample with the application of 330 mm of 'rain' – which is equivalent to about 6-months of average annual rainfall at the Project. Simple extrapolation of this rate out to one year of average annual rainfall produces a release rate of 4 kg (total) of salt per tonne of rock per year of average annual rainfall. Comparatively, the conglomerate and sandstone overburden / interburden samples produced salt release rates of about 0.5 kg of salt per tonne of sandstone rock per year of average annual rainfall.

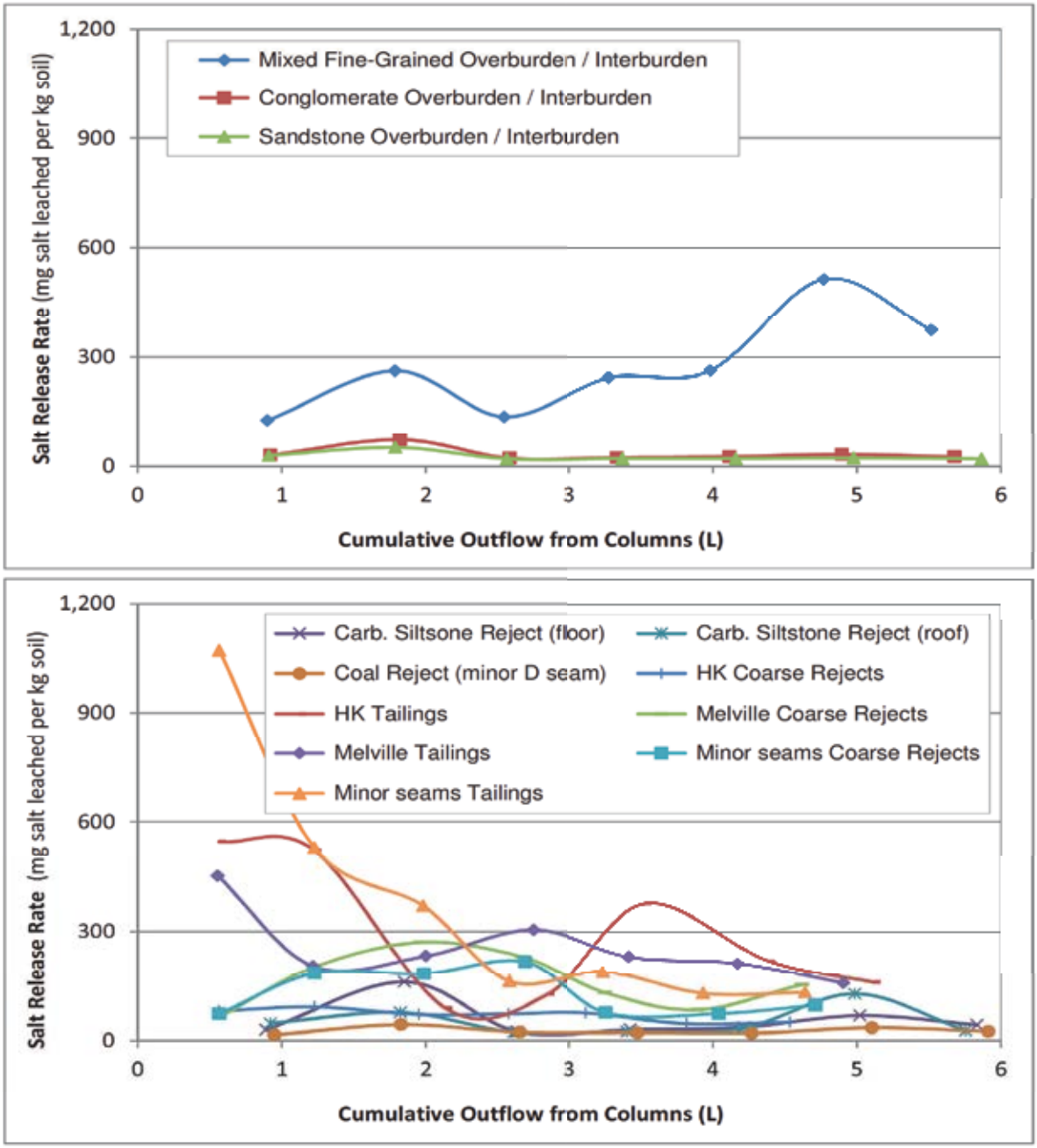
The tailings potential coal reject samples (**Figure 5**: bottom) generally released salt at between 450 and 1000 mg/kg in the first-flush event, which reduced significantly (in all reject samples) to generally below 300 mg/kg thereafter. The cumulative salt release rates per kg of sample per application of 330 mm of 'rain' ranged from 187 mg to approximately 2600 mg of salt. Extrapolating these results to one year of rainfall produces release rates of 0.4 to 5.2 kg of salt per tonne of rock per year of average annual rainfall. The tailings samples had the greatest cumulative salt release of all coal reject samples – likely as a result of their fine-grain-size.

It is acknowledged that it is difficult to directly apply leachate results (salt loads) from column leaching to full-size OEAs, and scaling and correction factors can be calculated. The kinetic leaching columns released between 65 and 83% (average 75%) of the water added; *ie*. the average 'rainfall recharge' rate for the kinetic leaching columns was 75%. This means that the leachate from each column was significantly diluted relative to the predicted rainfall recharge rate at the Project. To correct for this, the salt load in leachate from each column was 'concentrated' by between 12 and 15-times (average 14 times). The resulting salt loads from each material type are shown in **Table 2**, and range between 765 mg/L and 9730 mg/L (as TDS).

It must be recognised that these 're-concentrated' salt release rates taking into account column dilution factors are likely initial (early stage leaching) maximums, for in reality a significant reduction in seepage flux (from 75% rainfall recharge to 5.5% rainfall recharge) would also result in a commensurate reduction in the mass of solute released.

The applied leaching methodology of using fine grained-crush size for the samples enhances the surface area to leaching fluid ratio, and combined with the encouraged oxidation in the columns, should produce leachate which is reasonably 'representative' of overburden / interburden leachate when subjected to rainfall infiltration – as is the case for the Project. As outlined in **Section 2**, groundwater inflow into the mined areas ceases as soon as the open cut mining areas are backfilled, therefore all seepage (discharge) is expected to be a direct combination of rainwater leaching through overburden / interburden materials.

Figure 5. Salt load from overburden / interburden and potential coal rejects from column leaching tests



Seepage Water Quality Assessment

Table 2. Salt release rates from kinetic leaching columns

Column Description		Salt released from column	Leachate recovery rate from column (simulated rainfall recharge rate)	Concentration factor to reduce recharge to 5.5%	Estimated maximum initial salt release rate at 5.5% rainfall recharge
Overburden / Interburden					
KLC1	Mixed carbonaceous siltstone/sandstone interburden	3837 mg of salt in 5.52 litres = 695 mg/L	78%	14 times	9730 mg /L
KLC2	Conglomerate interburden	450 mg of salt in 5.68 litres = 79 mg/L	80%	15 times	1185 mg /L
KLC3	Sandstone interburden	355 mg of salt in 5.87 litres = 61 mg/L	83%	14 times	854 mg/L
Potential Coal Rejects (drill-core)					
KLC4	Carbonaceous siltstone (floor)	635 mg of salt in 5.84 litres = 109 mg/L	82%	15 times	1635 mg/L
KLC5	Carbonaceous siltstone (roof)	601 mg of salt in 5.75 litres = 105 mg/L	81%	15 times	1575 mg/L
Potential Coal Rejects (pilot process)					
KLC7	Hoskissons Seam coarse rejects	890 mg of salt in 4.54 litres = 196 mg/L	65%	12 times	2352 mg/L
KLC9	Melvilles Seam coarse rejects	1713 mg of salt in 4.62 litres = 371 mg/L	66%	12 times	4452 mg/L
KLC11	Minor seams coarse rejects	1367 mg of salt in 4.71 litres = 290 mg/L	67%	12 times	3480 mg/L
KLC8	Hoskissons Seam tailings	2022 mg of salt in 5.12 litres = 395 mg/L	73%	13 times	5135 mg/L
KLC10	Melvilles Seam tailings	1781 mg of salt in 4.91 litres = 363 mg/L	70%	13 times	4719 mg/L
KLC12	Minor seams tailings	2562 mg of salt in 4.64 litres = 552 mg/L	66%	12 times	6624 mg/L
Potential ROM Coal (drill-core)					
KLC6	Coal	300 mg of salt in 5.91 litres = 51 mg/L	83%	15 times	765 mg/L

Based on the calculated salt loads from **Table 2**, which are highly conservative, overburden / interburden materials are assumed to be capable of producing leachate initially with a salt concentration of up to 9730 mg/L (in the early years of exposure), however the actual value is likely to be significantly less (potentially about one quarter of this value, or less) and is expected to decrease over time as salts are flushed from the system. The average salt concentration calculated for the three overburden / interburden materials was 3923 mg/L. Therefore, it is reasonable to assume that overburden / interburden comprised of sandstone, conglomerate and carbonaceous sediments may produce leachate, initially, at concentrations of approximately 5000 mg/L. Coal reject materials have average salt release rates (3747 mg/L) that are similar to the overburden and interburden materials. Rejects comprise less than 5% of all mine waste materials.

The geochemical assessment by RGS determined that almost all materials are expected to be strongly non-acid forming; with most materials having low total sulfur concentrations (median 0.02%). The low sulfur concentrations also suggests that sulfate concentrations in leachate, generally, should also be low.

A small number of potential coal reject samples were shown to have low capacity to generate acid, however these are expected to comprise a small percentage of all rejects. All rejects only comprise 4.3% of all mine materials. Therefore, the very small proportion of potentially acid forming reject materials are not expected to have a significant influence, if any, on the overall leachate (seepage) water quality from the mining areas.

Leachate from coarse-grained overburden and interburden materials (conglomerate and sandstone) can be expected to be strongly sodium-sulfate (Na-SO_4) dominated, as shown in the Piper tri-linear plot in **Figure 6**. Fine-grained carbonaceous overburden/interburden is also strongly SO_4-dominated, but the major cation is magnesium (Mg), with some calcium (Ca) influence. Leachate from potential coal reject materials is more varied compared to overburden / interburden materials. All material types are strongly SO_4 dominated (**Figure 7**), however for most materials there is no dominant cation – with leachate from most materials having mixed Ca-Mg-Na influence. The exceptions are the minor seam coarse reject sample and the Melville seam coarse reject sample, which are dominated by Na (**Figure 7**).

The overburden and interburden column leaching suggests that fine-grained overburden / interburden materials may produce Mg-SO_4 type leachate and coarser-grained overburden / interburden materials will produce Na-SO_4 type leachate. Coal rejects are expected to comprise about 4.3% of the total mine waste quantities, and the coal rejects, generally, have produced Ca-Mg-Na (mixed)-SO_4 type leachate. Therefore, it is expected that leachate from overburden / interburden, subjected to rainfall infiltration can also be expected to be dominated by SO_4, but with a mixed cationic signature.

Figure 6. Piper plot of column leachate chemistry for overburden / interburden materials

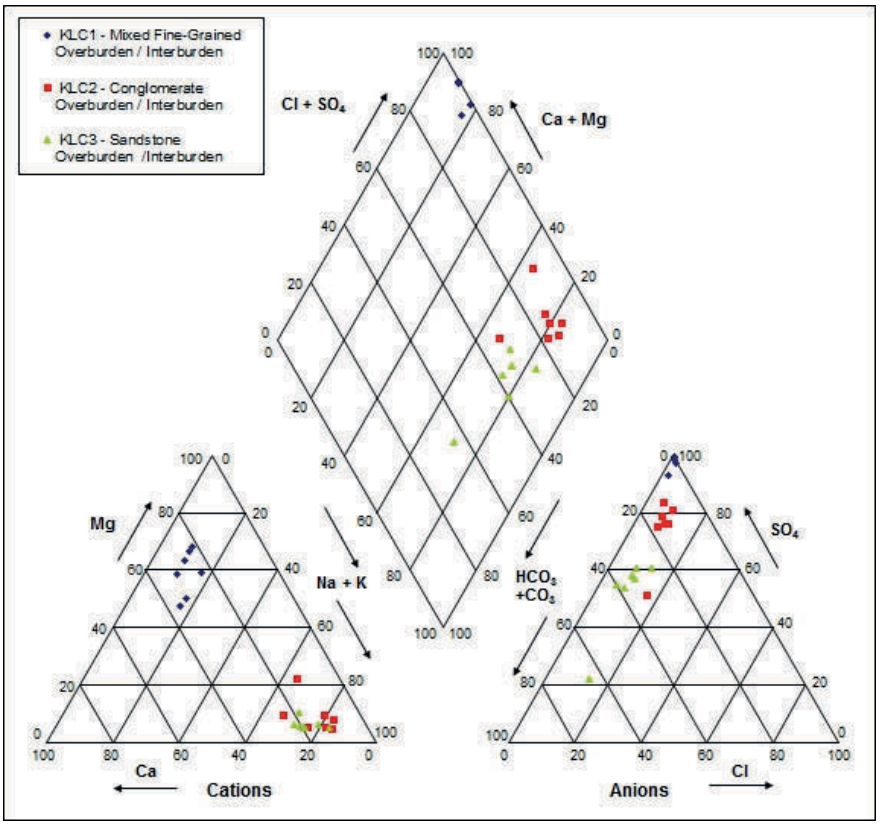
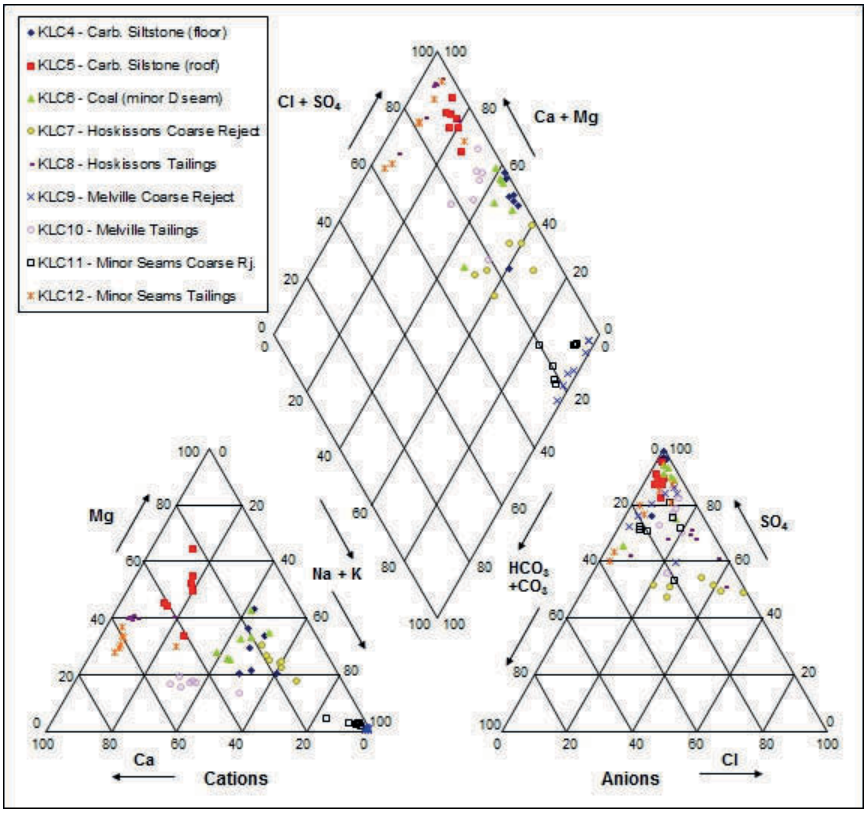


Figure 7. Piper plot of column leachate chemistry for potential coal reject materials



Seepage Water Quality Assessment

4 Groundwater Quality

Groundwater quality for the Project is addressed by GHD (2011) and AGE (2013). However, a brief outline is provided here to place the seepage water quality information into context.

Groundwater exists in several aquifers in the region, ranging from the unconfined Quaternary and alluvial aquifers of the Gunnedah and Narrabri Formations, through to the confined aquifers associated with the Benalabri Formation (and Clare Sandstone), Hoskissons Member (and Hoskissons Coal Seam), Arkarula Formation (and Melville Coal Seam), Pambula Formation and deeper Watermark Formation. The dipping nature (downwards from north to south) of the stratigraphy leads to not all aquifers being present in all mined areas. The limited groundwater interaction that each open cut mining area has with each aquifer varies.

The groundwater model undertaken by AGE has identified the key aquifers and groundwater interaction (sources/sinks) associated with each mining area, as outlined below.

Eastern mining area

During mining the EMA is predicted to receive groundwater inflow initially from the Benalabri Formation (and Clare Sandstone), then as the EMA deepens the Hoskissons Member and the Arkarula Formation. The groundwater model predicts that over 81% of the total groundwater inflow (into the EMA during mining) will be from the Hoskissons Member; 7% from the Arkarula Formation; 4.5% from the weathered Benalabri Formation; 3% from the Clare Sandstone; 2.5% from the Melville Coal Seam and 1.5% from the Hoskissons Coal Seam.

The groundwater salinity (as TDS) of these intersected aquifers, from 16 groundwater monitoring bores in the immediate vicinity of the EMA ranges from 610 to 25,100 mg/L (average = 8042 mg/L). Generally, the less saline groundwater (less than 1500 mg/L) is associated with minor basalt flows from the Tertiary volcanics, which exist at shallow depth in the area. The interburden associated with the Arkarula Formation in the vicinity of the EMA has a median groundwater salinity of 2500 mg/L. No groundwater chemistry data is available from the Hoskissons Interburden in the EMA, however the geology and lithology are very similar to the Arkarula Interburden, therefore most groundwater in the EMA is expected to have a salinity (TDS) of approximately 1000 to 3000 mg/L.

Southern mining area

During mining the SMA is predicted to receive about 85% of its groundwater inflow from the Clare Sandstone aquifer. The groundwater model predicts that weathered Benalabri interburden and weathered Hoskissons interburden will comprise about 6% and 5%, respectively to total groundwater inflow into the SMA. The remaining 4% is predicted to come from a number of other minor aquifer sources.

The groundwater salinity (as TDS) of these intersected aquifers, from 20 groundwater monitoring bores in the immediate vicinity of the SMA ranges from 2190 to 29,600 mg/L (median = 11,700 mg/L and average = 12,744 mg/L). The less saline groundwater (less than 3000 mg/L) is associated with the Melville Coal and with a fault zone in the Arkarula Interburden. The Clare Sandstone aquifer, which is the groundwater aquifer principally intersected, has a median and average salinity of 11,450 and 13,370 mg/L, respectively. Therefore, most groundwater

intersected by the SMA is expected to have a salinity (TDS) of approximately 10,000 to 14,000 mg/L.

Western mining area

During mining the WMA is predicted to receive about 65% of its total groundwater inflow from the Clare Sandstone aquifer and about 28% of its total groundwater inflow from the Hoskissons Formation (Interburden). The groundwater model predicts that weathered Benalabri interburden will discharge (into the WMA) about 3% of the total groundwater inflow. The remaining 4% is predicted to come from the Arkarula Formation (2.5%) and the Melville Seam (1.5%).

The groundwater salinity (as TDS) of these intersected aquifers, from 12 groundwater monitoring bores in the immediate vicinity of the WMA ranges from 1390 to 11,000 mg/L (median = 3420 mg/L and average = 4445 mg/L). The more saline groundwater (greater than 9000 mg/L) is associated with a colluvial weathered zone of Arkarula Formation (interburden). No groundwater chemistry data is currently available from the Hoskissons Interburden or the Clare Sandstone in the WMA. The Clare Sandstone is relatively saline in the SMA (10,000 to 14,000 mg/L), but the Arkarula Formation generally has a lower salinity where it has been intersected in the EMA and SMA (~1000 to 3000 mg/L). Therefore, conservatively, groundwater intersected whilst mining the WMA is assumed to have a salinity (TDS) of approximately 3000 mg/L.

5 Potential Impacts from Seepage and Run-off from Overburden / Interburden

Given the very low, essentially negligible, seepage flow rates (to land) predicted from the EMA and SMA (40 to 110 mL per square metre of seepage-effected area per day), and no seepage discharge from the WMA, the impacts to soil and surface water systems in the vicinity of the mining areas is minimal at worst. The seepage predictions by AGE (modelled) are sensitive to rainfall recharge and evaporation, as these are the dominant inputs and outputs at each mining area. Groundwater inflow is a key input during mining, but once mining ceases and the open cut mining areas are filled with overburden / interburden (in the case of the EMA and SMA) and overburden / interburden plus rainwater (in the case of the WMA), groundwater inflow is reversed and the saturated overburden / interburden becomes a source of water to the aquifers and, as modelled, seepage to land at the EMA and SMA.

The geochemical impact assessment undertaken by RGS has identified that overburden / interburden and reject materials are likely to produce leachate with relatively low concentrations of salt (and low metals concentrations) in the long term. However, the salt concentration predicted from overburden / interburden materials (seepage), at least in the early stages of leaching (first few years, for example) may potentially be in the vicinity of 5000 mg/L TDS – although this value is regarded as conservative. The salt load in seepage/leachate would be expected to diminish rapidly over time as readily available salt is flushed from the system. Salt would be expected to be present mainly as sulfate-salts, such as gypsum.

Eastern mining area

Assume seepage (leachate) is generated with a highly conservative salt concentration of 5000 mg/L and the annual volume of seepage is very low – up to 90,000 litres per day over a 230 ha zone at the EMA (the mining area with the largest predicted seepage zone). This equates to 450 kg of salt leached per day (about 164 tonnes per year, on average) over a 230 ha seepage zone, which equals a salt load contributed of approximately 2 kg of salt per ha per day from the EMA.

If a sensitivity analysis is applied to these numbers by doubling the EMA seepage rate to 180,000 litres per day and halving the EMA seepage area from 230 ha to 115 ha (thus increasing and concentrating the salt load), we calculate a total salt load contributed (from the given seepage area) of 900 kg per day (about 329 tonnes per year, on average). This is equivalent to about 8 kg of salt per ha per day from the EMA, which is a relatively low impact scenario, and salt loads would be expected to diminish with time.

Southern mining area

Assume seepage (leachate) is generated with a conservative salt concentration of 5000 mg/L and the volume of seepage is very low – up to 60,000 litres per day over a 53 ha zone at the SMA. This equates to 300 kg of salt leached per day (about 110 tonnes per year, on average) over a 53 ha seepage zone, which equals a salt load contributed of approximately 5.6 kg of salt per ha per day from the SMA.

If a sensitivity analysis is applied to these numbers by doubling the SMA seepage rate to 120,000 litres per day and halving the SMA seepage area from 53 ha to about 26 ha, we calculate a total salt load contributed (from the given seepage area) of 600 kg per day (219 tonnes per year, on average). This is equivalent to about 23 kg of salt per ha per day from the SMA. The impacts of

such loads are unclear, and would depend upon the salt receptors. Given that there are no major surface water drainages in the near vicinity (within 100 m) of the SMA it is likely that the salt would accumulate near the toe of the OEA and only be mobilised with significant prolonged rainfall events. The nearest drainage to the SMA is Native Dog Gully (an ephemeral creek), which is approximately 200 m south of the SMA.

Western mining area

All seepage from the WMA OEA drains back into the pit and final void, with no seepage reporting to land. The final void is a 'sink' with no drainage reporting outside of the final void walls.

Changes to groundwater quality

As discussed in **Section 4**, groundwater quality varies between aquifers, but ranges from over 25,000 mg/L in the shallow unconfined Narrabri and Gunnedah Formations (close to the EMA) through to about 1500 to 3000 mg in some interburden aquifers. Seepage from the EMA and SMA could potentially enter shallow aquifers (more so than deeper aquifers) due to salt build-up at the toe of mining area OEA that could flush into local watercourses (with rain events) and recharge local aquifers. These shallow (and deeper) aquifers already have salinity concentrations generally the same or greater than the likely seepage salinity (and quality) from overburden / interburden, therefore impacts to groundwater systems would be expected to be negligible.

6 Refinement of This Assessment

This assessment is based, primarily, on the results of short-term bench-scale kinetic leaching columns. Although the assessment has adopted a conservative approach with respect to calculating potential salt concentrations, Shenhua Watermark will undertake monitoring and further assessment of seepage and run-off characteristics from overburden / interburden and coal reject materials as the Project develops. Such continued monitoring and assessment will enable the estimates in this assessment to be refined, which in turn will enable management measures to be refined.

7 References

AGE (2013). *Report On Watermark Coal Project, Groundwater Assessment*. Consultants report G1501 prepared by Australasian Groundwater Environments Pty Ltd for Hansen Bailey Pty Ltd, January 2013.

GHD (2011). *Hydrogeological Investigations, Stage 3 Bore Completion Report*. Consultants report prepared for Shenhua Watermark Coal Pty Ltd, March 2011.

GHD (2012). *Hydrogeological Investigations Stages 1 – 4*. Consultants report by GHD prepared for Shenhua Watermark Coal Pty Ltd, August 2012.

GHD. Groundwater chemistry database for Watermark Coal Project (raw data unreported). Provided May-July 2012.

RGS (2012). *Geochemistry Assessment of Overburden / Interburden and Potential Coal Reject Materials*. Consultants report 091031 prepared by RGS Environmental Pty Ltd for Hansen Bailey Environmental Consultants, August 2012.

WRM (2012). *Shenhua Watermark Project - Surface Water Impact Assessment*. Consultants report 0762-01-C prepared by WRM Water & Environment Pty Ltd for Hansen Bailey Pty Ltd, 12 September 2012.

Appendix A

Kinetic Leach Column Test Results
(RGS Environmental)

Table KLC1

KLC1 Test Results: Mixed Overburden

Sample Weight (kg)	2.0	Total S (%)		0.85	ANC (kg H2SO4/t)		58	
pH(1:5)	6.9	SCR (%)		0.65	NAPP (kg H2SO4/t)		-38.0	
EC(1:5) (µS/cm)	684	MPA (kg H2SO4/t)		19.9	ANC:MPA ratio		16.0	
Date	13-May-11	27-May-11	10-Jun-11	29-Jun-11	14-Jul-11	28-Jul-11	10-Aug-11	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.9	0.888	0.758	0.733	0.707	0.786	0.748	
Cum. Volume (L)	0.90	1.79	2.55	3.28	3.99	4.77	5.52	
Pore Volumes	0.7	1.3	1.9	2.4	3.0	3.5	4.1	
pH	7.28	6.74	6.28	5.97	5.57	7.17	6.76	
EC (mS/cm)	446	863	538	967	1130	1702	1389	
Acidity (mg/L)*	4	5	3	4	21	4	4	
Alkalinity (mg/L)*	13	3	2	<1	<1	3	5	
Net Alkalinity (mg/L)*	11	-2	-1	-4	-21	-1	1	
Dissolved elements (mg/L)								Guideline Levels[1]
Al	<0.01	<0.01	0.01	0.01	0.04	0.01	0.03	5
As	<0.001	<0.001	<0.001	0.00	<0.001	<0.001	<0.001	0.5
B	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	5
Ca	30	48	38	53	55	127	108	1000
Cd	0.0002	0.0002	<0.0001	0.0003	0.0002	0.0006	0.0006	0.01
Cl	3.00	8.00	2.00	2.00	2.00	4.00	3	-
Co	0.02	0.03	0.01	0.02	0.02	0.04	0.034	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	<0.001	<0.001	<0.001	0.006	0.001	0.002	0.006	1 / 0.5
Fe	<0.05	<0.05	<0.05	0.07	0.10	0.10	0.16	-
K	5	7	5	5	6	9	8	-
Mg	24	72	35	92	104	184	123	-
Mn	0.56	0.83	0.38	0.78	0.99	2.09	1.88	-
Mo	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.15
Na	13	36	20	23	25	50	36	-
Ni	0.04	0.04	0.02	0.03	0.04	0.07	0.053	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO4	191	461	276	542	582	1,170	845	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.01	0.03	<0.01	0.02	0.02	0.03	0.02	0.02
Zn	0.03	0.04	0.02	0.04	0.04	0.06	0.085	20
RESULTS**								
SO4 Release Rate	86	205	105	199	206	460	316	
Cumulative SO4 Release	86	291	395	594	800	1259	1575	
Ca Release Rate	14	21	14	19	19	50	40	
Cumulative Ca Release	14	35	49	69	88	138	178	
Mg Release Rate	10.8	32.0	13.3	34	37	72	46	
Cumulative Mg Release	10.8	42.8	56	90	127	199	245	
Residual ANC (%)	99.9	99.6	99.4	99.1	98.7	98.0	97.5	
Residual Sulfur (%)	99.7	98.9	98.4	97.7	96.9	95.1	93.8	
SO4/(Ca+Mg) molar ratio	1.1	1.2	1.2	1.1	1.1	1.1	1.1	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg CaCO3 /L ** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, SCR = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

RGS Environmental

Table KLC2

KLC2 Test Results: Overburden (Conglomerate)

Sample Weight (kg)	2.0	**Total S (%)**		0.02	**ANC (kg H_2SO_4/t)**		26	
pH(1:5)	8.5	**S_{CR} (%)**		0.02	**NAPP (kg H_2SO_4/t)**		-25.4	
EC(1:5) (µS/cm)	227	**MPA (kg H_2SO_4/t)**		0.6	**ANC:MPA ratio**		42.4	
Date	13-May-11	27-May-11	10-Jun-11	29-Jun-11	14-Jul-11	28-Jul-11	10-Aug-11	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.92	0.9	0.763	0.75	0.783	0.78	0.78	
Cum. Volume (L)	0.92	1.82	2.58	3.33	4.12	4.90	5.68	
Pore Volumes	0.7	1.3	1.9	2.5	3.0	3.6	4.2	
pH	9.02	7.93	7.47	7.07	6.92	8.33	8.17	
EC (µS/cm)	103	232	87	95	107	137	107	
Acidity (mg/L)*	<1	<1	2	2	8	2	2	
Alkalinity (mg/L)*	17	15	8	8	7	7	7	
Net Alkalinity (mg/L)*	17	15	6	6	-1	5	5	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	0.14	0.04	0.21	0.25	0.58	0.35	0.61	5
As	0.003	0.005	0.002	0.002	0.002	0.003	0.002	0.5
B	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	5
Ca	4.0	7.0	2.0	3.0	2.0	2.0	2.0	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	5.00	8.00	2.00	3.00	3.00	2.00	2	-
Co	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	1 / -
Cu	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	0.07	-
K	2.0	2.0	1.0	<1	1.0	<1	<1	-
Mg	1.0	7.0	0.5	0.5	0.5	1.0	1.0	-
Mn	<0.001	0.004	0.001	0.003	0.003	0.002	0.002	-
Mo	0.003	0.011	0.003	0.005	0.005	0.008	0.005	0.15
Na	12	38	14	14	17	20	16	-
Ni	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	21	95	27	33	30	42	30	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO_4 Release Rate	9.7	42.8	10.3	12.4	11.7	16.4	11.7	
Cumulative SO_4 Release	9.7	52.4	62.7	75.1	86.8	103.2	114.9	
Ca Release Rate	1.8	3.2	0.8	1.1	0.8	0.8	0.8	
Cumulative Ca Release	1.8	5.0	5.8	6.9	7.7	8.4	9.2	
Mg Release Rate	0.5	3.2	0.2	0.2	0.2	0.4	0.4	
Cumulative Mg Release	0.5	3.6	3.8	4.0	4.2	4.6	5.0	
Residual ANC (%)	100.0	99.9	99.9	99.9	99.9	99.8	99.8	
Residual Sulfur (%)	98.4	91.3	89.5	87.5	85.5	82.8	80.8	
SO_4/(Ca+Mg) molar ratio	1.6	2.1	4.0	3.6	4.4	4.8	3.4	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$ /L ** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC3

KLC3 Test Results: Overburden (Sandstone)

Sample Weight (kg)	2.0	**Total S (%)**		0.02	**ANC (kg H_2SO_4/t)**		48.9	
pH(1:5)	8.6	**S_{CR} (%)**		0.02	**NAPP (kg H_2SO_4/t)**		-48.3	
EC(1:5) (µS/cm)	216	**MPA (kg H_2SO_4/t)**		0.6	**ANC:MPA ratio**		79.8	
Date	13-May-11	27-May-11	10-Jun-11	29-Jun-11	14-Jul-11	28-Jul-11	10-Aug-11	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.91	0.88	0.774	0.808	0.788	0.819	0.886	
Cum. Volume (L)	0.91	1.79	2.56	3.37	4.16	4.98	5.87	
Pore Volumes	0.8	1.6	2.2	2.9	3.6	4.3	5.1	
pH	9.39	8.72	8.86	8.44	8.35	9.38	9.2	
EC (µS/cm)	93	182	74.9	75.7	84	83.5	66.4	
Acidity (mg/L)*	<1	<1	<1	<1	<1	<1	<1	
Alkalinity (mg/L)*	33	25	16	13	12	14	13	
Net Alkalinity (mg/L)*	33	25	16	13	12	14	13	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	0.23	0.09	0.33	0.31	1.01	0.63	0.94	5
As	0.009	0.008	0.005	0.004	0.004	0.006	0.004	0.5
B	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	5
Ca	3.00	4.00	3.00	3.00	3.00	3.00	2	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	4.0	7.0	2.0	2.0	2.0	2.0	1.0	-
Co	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Cr	<0.001	0.00	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	<0.001	<0.001	<0.001	0.00	<0.001	<0.001	<0.001	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	0.08	0.05	0.09	-
K	2.0	2.0	1.0	0.5	1.0	0.5	1.0	-
Mg	1.0	1.0	0.5	0.5	0.5	0.5	0.5	-
Mn	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Mo	0.005	0.02	0.004	0.004	0.006	0.009	0.006	0.15
Na	12.00	31.00	12.00	11.00	13.00	13.00	12	-
Ni	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	9	45	18	20	16	19	14	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO_4 Release Rate	4	20	7	8	6	8	6	
Cumulative SO_4 Release	4	24	31	39	45	53	59	
Ca Release Rate	1.4	1.8	1.2	1.2	1.2	1.2	0.9	
Cumulative Ca Release	1	3	4	5	7	8	9	
Mg Release Rate	0.5	0.4	0.2	0.2	0.2	0.2	0.2	
Cumulative Mg Release	0.5	0.9	1.1	1.3	1.5	1.7	1.9	
Residual ANC (%)	100.0	100.0	100.0	100.0	100.0	99.9	99.9	
Residual Sulfur (%)	99.3	96.0	94.9	93.5	92.4	91.2	90.1	
SO_4/(Ca+Mg) molar ratio	0.8	3.3	2.0	2.2	1.7	2.1	2.1	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$/L

** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC4

KLC4 Test Results: Coal Reject (Carbonaceous Siltstone Floor)

Sample Weight (kg)	1.6	**Total S (%)**		0.16	**ANC (kg H_2SO_4/t)**		7.6	
pH(1:5)	6.4	**S_{CR} (%)**		0.07	**NAPP (kg H_2SO_4/t)**		-5.3	
EC(1:5) (µS/cm)	217	**MPA (kg H_2SO_4/t)**		2.3	**ANC:MPA ratio**		3.3	
Date	13-May-11	27-May-11	10-Jun-11	29-Jun-11	14-Jul-11	28-Jul-11	10-Aug-11	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.89	0.962	0.782	0.793	0.789	0.806	0.813	
Cum. Volume (L)	0.89	1.85	2.63	3.43	4.22	5.02	5.84	
Pore Volumes	0.7	1.4	2.0	2.5	3.1	3.7	4.3	
pH	7.32	7.8	7.63	7.97	6.31	8.15	7.12	
EC (µS/cm)	89	425	830	101	128	213	141.8	
Acidity (mg/L)*	2	3	2	2	2	4	2	
Alkalinity (mg/L)*	7	3	1	1	2	1	2	
Net Alkalinity (mg/L)*	5	0	-1	-1	0	-3	0	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	0.05	<0.01	0.02	0.02	0.02	<0.01	0.02	5
As	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.5
B	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	5
Ca	3	16	4	5	5	6	4	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	2.00	4.00	<1	<1	<1	<1	<1	-
Co	<0.001	0.007	0.001	0.002	0.002	0.003	0.002	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	2	5	2	2	2	2	2	-
Mg	2	18	2	2	4	11	5	-
Mn	0.02	0.19	0.02	0.03	0.04	0.07	0.043	-
Mo	0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	0.15
Na	10	38	8	8	11	19	13	-
Ni	0.002	0.016	0.003	0.004	0.004	0.007	0.005	1
Pb	<0.001	<0.001	0.02	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	26	186	33	41	46	101	55	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.01	0.05	<0.01	<0.01	<0.01	0.02	<0.01	0.02
Zn	<0.005	0.01	<0.005	<0.005	<0.005	0.01	<0.005	20
RESULTS**								
SO_4 Release Rate	14	112	16	20	23	51	28	
Cumulative SO_4 Release	14	126	142	163	185	236	264	
Ca Release Rate	1.7	9.6	2.0	2.5	2.5	3.0	2.0	
Cumulative Ca Release	1.7	11.3	13.2	15.7	18.2	21.2	23.2	
Mg Release Rate	1.1	10.8	1.0	1.0	2.0	5.5	2.5	
Cumulative Mg Release	1.1	11.9	12.9	13.9	15.9	21.4	24.0	
Residual ANC (%)	99.9	99.0	98.9	98.8	98.6	98.2	98.0	
Residual Sulfur (%)	99.7	97.4	97.0	96.6	96.1	95.1	94.5	
SO_4/(Ca+Mg) molar ratio	1.7	1.7	1.9	2.1	1.7	1.7	1.9	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$/L

** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC5

KLC5 Test Results: Coal Reject (Carbonaceous Siltstone Roof)

Sample Weight (kg)	1.7	**Total S (%)**		0.12	**ANC (kg H_2SO_4/t)**		120.4	
pH(1:5)	7.4	**S_{CR} (%)**		0.02	**NAPP (kg H_2SO_4/t)**		-116.7	
EC(1:5) (µS/cm)	205	**MPA (kg H_2SO_4/t)**		3.7	**ANC:MPA ratio**		32.8	
Date	13-May-11	27-May-11	10-Jun-11	29-Jun-11	14-Jul-11	28-Jul-11	10-Aug-11	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.92	0.904	0.789	0.792	0.789	0.792	0.768	
Cum. Volume (L)	0.92	1.82	2.61	3.41	4.19	4.99	5.75	
Pore Volumes	0.8	1.6	2.3	3.0	3.6	4.3	5.0	
pH	6.98	7.55	7.06	7.83	6.70	7.94	7.29	
EC (µS/cm)	148	231	83	84	120	693	100	
Acidity (mg/L)*	2	3	2	2	2	2	2	
Alkalinity (mg/L)*	7	7	3	4	4	3	5	
Net Alkalinity (mg/L)*	5	4	1	2	2	1	3	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	<0.01	<0.01	0.01	0.02	0.01	<0.01	0.02	5
As	<0.001	0.00	<0.001	0.001	0.001	<0.001	0.001	0.5
B	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	5
Ca	10	13	6	6	6	7	5	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	3.00	4.00	<1	1.00	2.00	1.00	1	-
Co	0.11	0.10	0.01	0.01	0.01	0.02	0.01	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	0.005	0.004	0.002	0.006	0.002	0.004	0.002	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	2	2	1	<1	1	1	1	-
Mg	5	14	4	4	6	12	6	-
Mn	0.026	0.027	0.007	0.008	0.009	0.009	0.006	-
Mo	0.001	0.008	0.002	0.004	0.004	0.012	0.007	0.15
Na	6	8	2	2	4	4	3	-
Ni	0.075	0.055	0.007	0.006	0.008	0.009	0.005	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	45	91	31	36	40	71	36	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.01	0.04	<0.01	0.01	0.02	0.02	0.01	0.02
Zn	0.07	0.07	0.02	0.02	0.03	0.03	0.02	20
RESULTS**								
SO_4 Release Rate	25	50	15	17	19	34	17	
Cumulative SO_4 Release	25	75	90	107	126	160	177	
Ca Release Rate	6	7.1	2.9	2.9	2.9	3.4	2.3	
Cumulative Ca Release	6	13	16	18	21	25	27	
Mg Release Rate	2.8	7.7	1.9	1.9	2.9	5.8	2.8	
Cumulative Mg Release	2.8	10.5	12.4	14.3	17.2	22.9	25.7	
Residual ANC (%)	100.0	99.9	99.9	99.9	99.9	99.9	99.9	
Residual Sulfur (%)	99.3	97.9	97.5	97.0	96.5	95.5	95.1	
SO_4/(Ca+Mg) molar ratio	1.0	1.1	1.0	1.2	1.1	1.1	1.0	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$/L ** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC6

KLC6 Test Results: Coal Reject (Coal)

Sample Weight (kg)	1.6	**Total S (%)**		0.58	**ANC ($kg H_2SO_4/t$)**		6.7	
pH(1:5)	7.2	**S_{CR} (%)**		0.04	**NAPP ($kg H_2SO_4/t$)**		-5.5	
EC(1:5) (µS/cm)	98	**MPA ($kg H_2SO_4/t$)**		1.2	**ANC:MPA ratio**		5.5	
Date	13-May-11	27-May-11	10-Jun-11	29-Jun-11	14-Jul-11	28-Jul-11	10-Aug-11	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.95	0.879	0.826	0.821	0.794	0.835	0.808	
Cum. Volume (L)	0.95	1.83	2.66	3.48	4.27	5.11	5.91	
Pore Volumes	0.8	1.6	2.3	3.0	5.5	4.4	5.1	
pH	6.19	7.57	6.65	7.74	5.47	7.96	7.13	
EC (µS/cm)	49	129	75	72	68	111	86	
Acidity (mg/L)*	2	3	1	2	2	1	2	
Alkalinity (mg/L)*	2	2	1	1	11	2	2	
Net Alkalinity (mg/L)*	0	-1	0	-1	9	1	0	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	0.03	<0.01	0.01	0.04	0.07	0.03	0.07	5
As	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.5
B	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	5
Ca	2	6	4	4	2	3	2	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	2	3	2	1	1	1	1	-
Co	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	<0.001	<0.001	<0.001	0.00	<0.001	<0.001	<0.001	1 / 0.5
Fe	0.17	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	<1	1	<1	<1	<1	<1	<1	-
Mg	1	5	2	2	2	5	3	-
Mn	0.02	0.02	0.01	0.01	0.01	0.01	0.008	-
Mo	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.15
Na	3	12	6	5	5	9	8	-
Ni	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	13	51	28	28	19	47	30	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	0.02
Zn	0.01	0.01	<0.005	0.01	0.01	0.01	0.006	20
RESULTS**								
SO_4 Release Rate	8	28	14	14	9	25	15	
Cumulative SO_4 Release	8	36	50	65	74	99	114	
Ca Release Rate	1	3.3	2.1	2.1	1.0	1.6	1.0	
Cumulative Ca Release	1	4	7	9	10	11	12	
Mg Release Rate	0.6	2.7	1.0	1.0	1.0	2.6	1.5	
Cumulative Mg Release	0.6	3.3	4.4	5.4	6.4	9.0	10.5	
Residual ANC (%)	99.9	99.6	99.5	99.4	99.3	99.1	98.9	
Residual Sulfur (%)	100.0	99.8	99.7	99.6	99.6	99.4	99.3	
SO_4/(Ca+Mg) molar ratio	1.5	1.5	1.6	1.6	1.5	1.7	1.8	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$/L ** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC7

KLC7 Test Results: HK Upper Composite Coal Reject

Sample Weight (kg)	1.8	**Total S (%)**		0.22	**ANC (kg H_2SO_4/t)**		13.3	
pH(1:5)	718.0	**S_{CR} (%)**		0.04	**NAPP (kg H_2SO_4/t)**		-12.1	
EC(1:5) (µS/cm)	247	**MPA (kg H_2SO_4/t)**		1.2	**ANC:MPA ratio**		10.9	
Date	10-Feb-12	24-Feb-12	09-Mar-12	22-Mar-12	02-Apr-12	20-Apr-12	03-May-12	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.566	0.662	0.726	0.622	0.54	0.702	0.718	
Cum. Volume (L)	0.57	1.23	1.95	2.58	3.12	3.82	4.54	
Pore Volumes	0.5	1.1	1.7	2.2	2.7	3.3	3.9	
pH	7.36	7.19	7.27	7.7	7.17	7.08	7.26	
EC (µS/cm)	303	408	310	348	442	182	197	
Acidity (mg/L)*	2	4	4	3	1	<1	2	
Alkalinity (mg/L)*	26	3	12	22	46	28	32	
Net Alkalinity (mg/L)*	24	-1	8	19	45	28	30	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	<0.01	<0.01	<0.01	0.01	<0.01	0.02	0.02	5
As	<0.001	<0.001	0.00	0.011	<0.001	0.004	<0.001	0.5
B	<0.05	<0.05	<0.05	0.08	0.06	<0.05	<0.05	5
Ca	16	13	8	12	14	6	7	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	66	69	37	38	30	17	14	-
Co	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	<0.001	<0.001	<0.001	0.001	0.002	0.002	0.001	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	9	7	4	6	6	4	4	-
Mg	12	12	8	10	12	5	7	-
Mn	0.014	0.014	0.011	0.014	0.02	0.006	0.011	-
Mo	0.018	0.021	0.022	0.033	0.049	0.016	0.019	0.15
Na	82	52	34	38	42	23	20	-
Ni	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	118	93	59	82	80	41	47	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	0.06	0.14	0.09	0.12	0.09	0.05	0.03	0.02
Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO_4 Release Rate	37	34	24	28	24	16	19	
Cumulative SO_4 Release	37	71	95	123	147	163	182	
Ca Release Rate	5	4.8	3.2	4.1	4.2	2.3	2.8	
Cumulative Ca Release	5	10	13	17	21	24	27	
Mg Release Rate	3.8	4.4	3.2	3.5	3.6	2.0	2.8	
Cumulative Mg Release	3.8	8.2	11.4	14.9	18.5	20.4	23.2	
Residual ANC (%)	99.8	99.6	99.4	99.2	99.0	98.9	98.8	
Residual Sulfur (%)	99.4	98.9	98.6	98.1	97.8	97.5	97.2	
SO_4/(Ca+Mg) molar ratio	1.4	1.2	1.2	1.2	1.0	1.2	1.1	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$ /L

** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

KLC8 Test Results: HK Composite Tailings

Sample Weight (kg)	0.99	Total S (%)		0.52	ANC (kg H2SO4/t)		20.37	
pH(1:5)	6.1	SCR (%)		0.24	NAPP (kg H2SO4/t)		-38.0	
EC(1:5) (µS/cm)	517	MPA (kg H2SO4/t)		7.4	ANC:MPA ratio		16.0	
Date	10-Feb-12	24-Feb-12	09-Mar-12	22-Mar-12	02-Apr-12	20-Apr-12	03-May-12	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.566	0.662	0.908	0.712	0.684	0.854	0.732	
Cum. Volume (L)	0.57	1.23	2.14	2.85	3.53	4.39	5.12	
Pore Volumes	0.4	0.9	1.6	2.1	2.6	3.2	3.8	
pH	7.62	7.35	7.13	7.45	7.44	7.21	7.34	
EC (mS/cm)	1220	1050	33	281	913	305	305	
Acidity (mg/L)*	10	3	2	3	2	3	2	
Alkalinity (mg/L)*	64	28	12	11	31	38	65	
Net Alkalinity (mg/L)*	54	25	10	8	29	35	63	
Dissolved elements (mg/L)								Guideline Levels[1]
Al	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5
As	0.004	0.02	<0.001	0.004	0.002	0.009	0.002	0.5
B	0.13	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	5
Ca	151	156	31	32	92	43	36	1000
Cd	0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	286	186	22	22	73	24	10	-
Co	0.034	0.002	<0.001	<0.001	0.001	<0.001	<0.001	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	0.003	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	21	10	2	2	5	4	3	-
Mg	91	69	14	14	42	20	17	-
Mn	0.276	0.083	0.024	0.018	0.057	0.025	0.023	-
Mo	0.008	0.010	0.00	0.003	0.014	0.01	0.011	0.15
Na	68	15	2	2	8	5	3	-
Ni	0.045	0.003	<0.001	<0.001	0.002	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO4	461	436	91	95	266	134	107	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	0.09	0.09	0.01	0.02	0.04	0.05	0.02	0.02
Zn	0.106	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO4 Release Rate	264	292	83	68	184	116	79	
Cumulative SO4 Release	264	555	639	707	891	1006	1085	
Ca Release Rate	86	104	28	23	64	37	27	
Cumulative Ca Release	86	191	219	242	306	343	369	
Mg Release Rate	52.0	46.1	12.8	10	29	17	13	
Cumulative Mg Release	52.0	98.2	111	121	150	167	180	
Residual ANC (%)	97.9	95.8	95.2	94.7	93.4	92.6	92.0	
Residual Sulfur (%)	98.3	96.4	95.9	95.5	94.3	93.5	93.0	
SO4/(Ca+Mg) molar ratio	0.6	0.7	0.7	0.7	0.7	0.7	0.7	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg CaCO3 /L ** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, SCR = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC9

KLC9 Test Results: Composite Melvilles Coal Reject

Sample Weight (kg)	1.5	**Total S (%)**		0.55	**ANC (kg H_2SO_4/t)**		16.6	
pH(1:5)	8.6	**S_{CR} (%)**		0.31	**NAPP (kg H_2SO_4/t)**		-7.1	
EC(1:5) (µS/cm)	574	**MPA (kg H_2SO_4/t)**		9.5	**ANC:MPA ratio**		1.7	
Date	**10-Feb-12**	**24-Feb-12**	**09-Mar-12**	22-Mar-12	02-Apr-12	20-Apr-12	03-May-12	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.566	0.662	0.734	0.706	0.582	0.646	0.722	
Cum. Volume (L)	0.57	1.23	1.96	2.67	3.25	3.90	4.62	
Pore Volumes	0.4	0.9	1.5	2.0	2.4	2.9	3.4	
pH	8.85	7.43	7.48	8.32	8.41	8.5	8.53	
EC (µS/cm)	194	726	866	719	576	472	472	
Acidity (mg/L)*	<1	3	2	3	4	<1	<1	
Alkalinity (mg/L)*	31	17	20	34	37	35	68	
Net Alkalinity (mg/L)*	31	14	18	31	33	35	68	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	0.14	<0.01	<0.01	0.03	0.07	0.28	0.05	5
As	0.002	0.016	0.002	0.006	0.002	0.003	0.005	0.5
B	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	0.07	5
Ca	1	2	2	1	<1	<1	<1	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	26	23	33	22	9	4	5	-
Co	<0.001	0.006	0.009	0.001	<0.001	0.001	<0.001	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	<0.001	<0.001	0.002	0.001	0.002	0.003	0.002	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	2	2	2	2	1	<1	1	-
Mg	<1	<1	1	<1	<1	<1	<1	-
Mn	<0.001	0.003	0.024	<0.001	<0.001	<0.001	<0.001	-
Mo	0.014	0.117	0.158	0.193	0.166	0.078	0.125	0.15
Na	72	148	183	172	102	65	110	-
Ni	<0.001	0.002	0.004	<0.001	<0.001	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	88	273	321	300	168	104	159	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.01	0.08	0.09	0.08	0.05	0.04	0.05	0.02
Zn	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO_4 Release Rate	33.2	120.5	157.1	141.2	65.2	44.8	76.5	
Cumulative SO_4 Release	33.2	153.7	310.8	452.0	517.1	561.9	638.5	
Ca Release Rate	0.4	0.9	1.0	0.5	0.2	0.2	0.2	
Cumulative Ca Release	0.4	1.3	2.2	2.7	2.9	3.1	3.4	
Mg Release Rate	0.2	0.2	0.5	0.2	0.2	0.2	0.2	
Cumulative Mg Release	0.2	0.4	0.9	1.1	1.3	1.5	1.8	
Residual ANC (%)	100.0	100.0	99.9	99.9	99.9	99.9	99.9	
Residual Sulfur (%)	99.8	99.1	98.1	97.3	96.9	96.6	96.1	
SO_4/(Ca+Mg) molar ratio	20.1	40.3	36.7	68.6	52.9	32.8	50.1	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$/L

** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC10
KLC10 Test Results: Composite Melvilles Tailings

Sample Weight (kg)	0.99	**Total S (%)**		0.75	**ANC (kg H_2SO_4/t)**		42.8	
pH(1:5)	7.6	**S_{CR} (%)**		0.28	**NAPP (kg H_2SO_4/t)**		-34.2	
EC(1:5) (µS/cm)	553	**MPA (kg H_2SO_4/t)**		8.6	**ANC:MPA ratio**		5.0	
Date	10-Feb-12	24-Feb-12	09-Mar-12	22-Mar-12	02-Apr-12	20-Apr-12	04-May-12	
Leach Number	1	2	3	4	5	6	7	
Volume Collected (L)	0.556	0.662	0.782	0.75	0.668	0.756	0.732	
Cum. Volume (L)	0.56	1.22	2.00	2.75	3.42	4.17	4.91	
Pore Volumes	0.5	1.1	1.7	2.4	3.0	3.6	4.3	
pH	8.23	7.31	7.15	7.5	7.02	7.57	7.39	
EC (µS/cm)	1170	492	480	613	560	421	319	
Acidity (mg/L)*	5	3	2	2	3	<1	4	
Alkalinity (mg/L)*	163	24	12	28	29	39	44	
Net Alkalinity (mg/L)*	158	21	10	26	26	39	40	
Dissolved elements (mg/L)								Guideline Levels[1]
Al	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5
As	0.001	0.002	<0.001	0.005	<0.001	0.002	<0.001	0.5
B	0.13	<0.05	<0.05	0.08	0.07	<0.05	0.06	5
Ca	88	47	47	58	46	39	34	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	101	22	20	31	35	18	7	-
Co	0.014	0.002	0.003	0.003	0.002	0.002	0.002	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	0.001	0.001	0.002	0.001	0.001	0.002	0.001	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	11	3	2	4	4	4	3	-
Mg	22	9	9	13	11	9	8	-
Mn	0.012	0.008	0.012	0.014	0.013	0.01	0.008	-
Mo	0.05	0.01	0.010	0.023	0.025	0.022	0.022	0.15
Na	151	34	29	48	39	34	23	-
Ni	0.01	0.002	0.003	0.002	0.002	0.002	0.002	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	340	165	170	238	167	149	109	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	0.02	0.01	0.01	0.03	0.02	0.02	<0.01	0.02
Zn	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO_4 Release Rate	191	110	134	180	113	114	81	
Cumulative SO_4 Release	191	301	436	616	729	842	923	
Ca Release Rate	49.4	31.4	37.1	43.9	31.0	29.8	25.1	
Cumulative Ca Release	49	81	118	162	193	223	248	
Mg Release Rate	12.4	6.0	7.1	9.8	7.4	6.9	5.9	
Cumulative Mg Release	12.4	18.4	25.5	35.3	42.8	49.6	55.5	
Residual ANC (%)	99.6	99.4	99.1	98.7	98.5	98.3	98.1	
Residual Sulfur (%)	99.2	98.7	98.1	97.3	96.8	96.3	95.9	
SO_4/(Ca+Mg) molar ratio	1.1	1.1	1.1	1.3	1.1	1.2	1.0	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$/L

** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC11

KLC11 Test Results: Coal Seam Reject

Sample Weight (kg)	1.5	**Total S (%)**		0.34	**ANC ($kg H_2SO_4/t$)**		67	
pH(1:5)	8.1	**S_{CR} (%)**		0.11	**NAPP ($kg H_2SO_4/t$)**		-63.6	
EC(1:5) (µS/cm)	518	**MPA ($kg H_2SO_4/t$)**		3.4	**ANC:MPA ratio**		19.9	
Date	10-Feb-12	24-Feb-12	09-Mar-12	22-Mar-12	02-Apr-12	20-Apr-12	03-May-12	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.566	0.662	0.758	0.706	0.562	0.788	0.678	
Cum. Volume (L)	0.57	1.23	1.99	2.69	3.25	4.04	4.72	
Pore Volumes	0.4	0.9	1.5	2.0	2.4	3.0	3.5	
pH	8.64	8.31	8.02	8.84	8.93	8.75	8.46	
EC (µS/cm)	255	680	571	791	339	213	385	
Acidity (mg/L)*	<1	<1	<1	<1	<1	<1	<1	
Alkalinity (mg/L)*	41	29	30	36	34	27	41	
Net Alkalinity (mg/L)*	41	29	30	36	34	27	41	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	0.02	0.02	0.01	0.04	0.08	0.42	0.05	5
As	0.002	0.009	0.006	0.013	0.006	0.008	0.007	0.5
B	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	0.06	5
Ca	8	3	3	4	3	1	2	1000
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	31	23	35	32	9	5	7	-
Co	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	<0.001	<0.001	0.002	0.001	<0.001	0.003	0.001	1 / 0.5
Fe	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	-
K	2	3	2	3	2	1	2	-
Mg	2	2	2	2	1	<1	1	-
Mn	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	-
Mo	0.02	0.042	0.026	0.038	0.025	0.014	0.021	0.15
Na	64	127	117	129	55	44	66	-
Ni	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	85	225	182	218	95	69	108	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	0.01	0.08	0.06	0.06	0.02	0.02	0.02	0.02
Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO_4 Release Rate	32	99	92	103	36	36	49	
Cumulative SO_4 Release	32	131	223	326	362	398	447	
Ca Release Rate	3.0	1.3	1.5	1.9	1.1	0.5	0.9	
Cumulative Ca Release	3.0	4.3	5.9	7.7	8.9	9.4	10.3	
Mg Release Rate	0.8	0.9	1.0	0.9	0.4	0.3	0.5	
Cumulative Mg Release	0.8	1.6	2.6	3.6	4.0	4.2	4.7	
Residual ANC (%)	100.0	100.0	100.0	100.0	99.9	99.9	99.9	
Residual Sulfur (%)	99.7	98.7	97.8	96.8	96.5	96.1	95.6	
SO_4/(Ca+Mg) molar ratio	3.1	14.9	12.1	12.5	8.5	15.8	12.4	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$/L

** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

Table KLC12

KLC12 Test Results: Coal Seam tailings

Sample Weight (kg)	0.99	**Total S (%)**		0.66	**ANC (kg H_2SO_4/t)**		94.8	
pH(1:5)	7.5	**S_{CR} (%)**		0.31	**NAPP (kg H_2SO_4/t)**		-85.3	
EC(1:5) (µS/cm)	658	**MPA (kg H_2SO_4/t)**		9.5	**ANC:MPA ratio**		10.0	
Date	**10-Feb-12**	**24-Feb-12**	**09-Mar-12**	**22-Mar-12**	**02-Apr-12**	**20-Apr-12**	**03-May-12**	
Leach Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume Collected (L)	0.566	0.662	0.754	0.6	0.654	0.696	0.708	
Cum. Volume (L)	0.57	1.23	1.98	2.58	3.24	3.93	4.64	
Pore Volumes	0.5	1.1	1.7	2.2	2.8	3.4	4.0	
pH	7.85	7.62	7.68	8.12	8.02	7.86	7.82	
EC (µS/cm)	2620	1160	747	400	416	280	280	
Acidity (mg/L)*	14	3	2	4	2	3	2	
Alkalinity (mg/L)*	139	30	42	47	53	56	61	
Net Alkalinity (mg/L)*	125	27	40	43	51	53	59	
Dissolved elements (mg/L)								**Guideline Levels[1]**
Al	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5
As	0.008	0.003	0.001	0.002	<0.001	0.002	<0.001	0.5
B	0.33	0.12	0.15	0.15	0.15	0.05	0.07	5
Ca	295	175	95	53	44	35	34	1000
Cd	0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Cl	130	41	16	8	5	3	3	-
Co	0.142	0.003	0.002	<0.001	<0.001	<0.001	<0.001	1
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1 / -
Cu	0.002	0.001	0.002	<0.001	<0.001	<0.001	<0.001	1 / 0.5
Fe	0.13	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
K	18	6	4	2	2	2	2	-
Mg	120	46	27	16	15	12	13	-
Mn	0.647	0.022	0.014	0.006	0.006	0.004	0.005	-
Mo	0.007	0.008	0.009	0.009	0.011	0.006	0.006	0.15
Na	174	18	11	6	5	3	2	-
Ni	0.195	0.005	0.003	0.001	0.001	<0.001	<0.001	1
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.1
SO_4	1220	537	308	156	188	83	79	1,000
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	0.08	0.02	0.01	<0.01	<0.01	<0.01	<0.01	0.02
Zn	0.155	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	20
RESULTS**								
SO_4 Release Rate	697	359	235	95	124	58	56	
Cumulative SO_4 Release	697	1057	1291	1386	1510	1568	1625	
Ca Release Rate	169	117.0	72.4	32.1	29.1	24.6	24.3	
Cumulative Ca Release	169	286	358	390	419	444	468	
Mg Release Rate	68.6	30.8	20.6	9.7	9.9	8.4	9.3	
Cumulative Mg Release	68.6	99.4	119.9	129.6	139.5	148.0	157.3	
Residual ANC (%)	99.3	98.8	98.6	98.4	98.3	98.2	98.1	
Residual Sulfur (%)	96.5	94.7	93.5	93.0	92.4	92.1	91.8	
SO_4/(Ca+Mg) molar ratio	1.0	0.9	0.9	0.8	1.1	0.6	0.6	

< indicates less than the analytical detection limit.

* Acidity and Alkalinity data calculated in mg $CaCO_3$ /L ** SO4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur, S_{CR} = Chromium Reducible Sulfur, MPA = Maximum Potential Acidity, ANC = Acid Neutralising Capacity, and NAPP = Net Acid Producing Potential

1. The first guideline level shown refers to ANZECC (2000) and the second to NEPC (1999) . Where the two guidelines limits for a given element are in agreement, only one value is shown. A 'dash' represents no trigger value provided for this element.

APPENDIX 7

Settlement Report - SRK

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5 July 2012

Project No: HAN002

Mr Mark Howes
Shenhua Watermark Coal Pty Ltd
368 Conadilly Street
Gunnedah NSW 2380

Attention: Mark Howes

Dear Mark

Re: Groundwater Drawdown Induced Settlement

1 Introduction and Terms of Reference

This letter report has been prepared further to instructions from Mark Howes of Shenhua Watermark Coal Pty Ltd. The scope of the study is as generally detailed in the SRK email correspondence dated 29 June 2012.

A significant thickness of alluvial soils, known locally as the Narrabri and Gunnedah formations, are known to be present within and adjacent to the exploration lease and these soils have been the subject of recent investigation works. As a consequence of in-pit seepage associated with mining activities a drawdown of groundwater levels in the Narrabri formation is anticipated within and outside of the exploration lease. The magnitude of the anticipated drawdown has been modelled by others.

Where groundwater drawdown occurs in compressible soils an increase in effective stress occurs and an associated consolidation settlement would be expected. The purpose of this study is to make a high level assessment of the likely magnitude of consolidation settlement associated with the predicted change in groundwater level based on the currently available borehole and groundwater information.

Some discussion on other external effects that might influence the apparent settlements in the area of interest is also provided to give some context to the predicted settlements.

2 Available Information

SRK was provided with the following relevant background information:

- Monitoring bore location plans (GHD 2012)
- Monitoring bore borehole logs (GHD 2011)
- Monitoring bore groundwater level charts (GHD 2011)
- Modelled groundwater drawdown contours plan (AGE 2012).

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The classification descriptions of the soil profile recorded in the GHD borehole logs are not in accordance with the soil classification description guidelines provided in the Australian Standard for site investigations (AS1726). In particular non-standard terminology is used to describe the soil consistency and in some instances the borehole logs contain no record of the soil consistency. As a result there is some uncertainty in our interpretation. We would note that this level of detail in the logging of soils is not uncommon in exploration drilling.

3 Settlement Analysis Methodology

3.1 Analysis Methodology

The settlement analysis undertaken has comprised the calculation by traditional methods (hand calc and spreadsheet) of simple one dimensional consolidation of the soil at each borehole location in response to the anticipated groundwater drawdown. The analysis assumed that the effective depth limit of settlement would be the shallower of the following two levels:

Bedrock level; or

- The level within the soil profile where the stress induced by the groundwater drawdown is less than 20% of the effective overburden stress following drawdown.

3.2 Sections

Settlement calculations have been undertaken at each borehole intersected by the two sections shown in Figure 3-1 below.

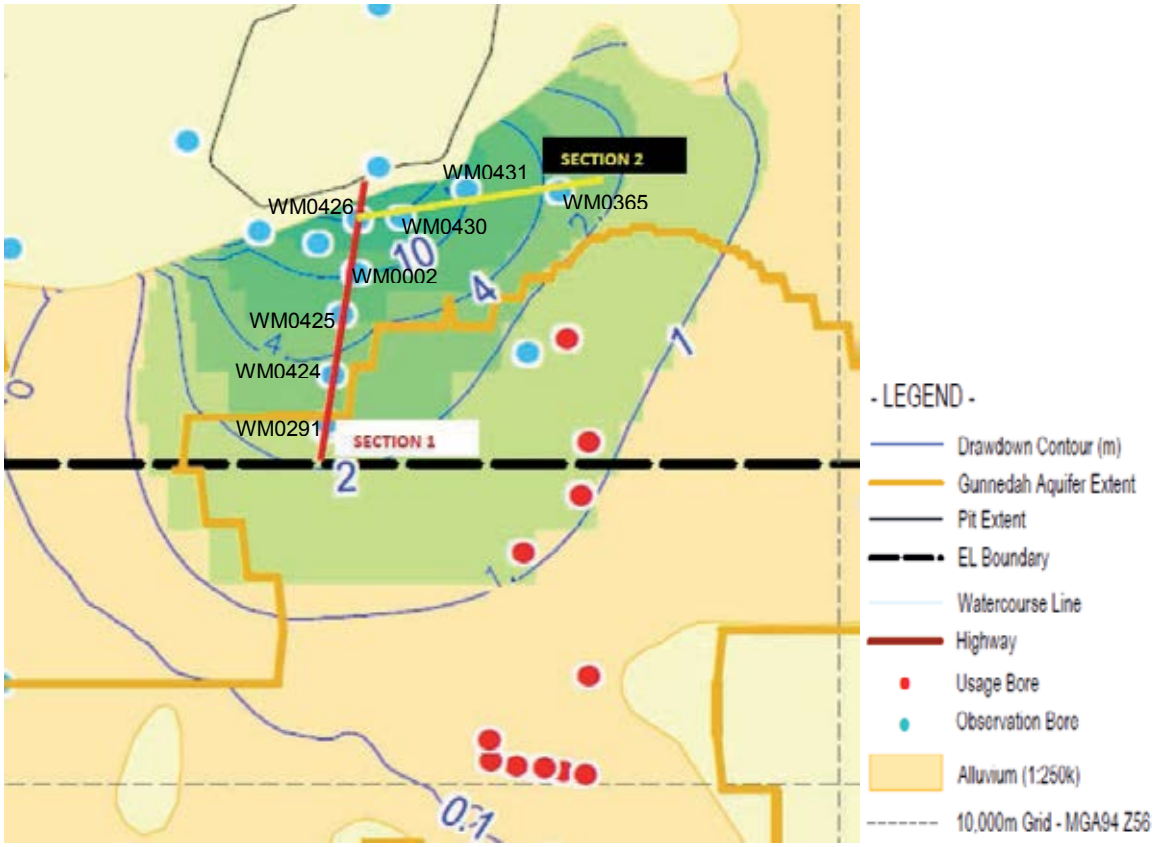


Figure 3-1: Section Locations Overlain on Groundwater Drawdown Contours (AGE 2012)

Section 1 runs from the southern extent of the open pit, where 15 m of groundwater drawdown is anticipated, to the southern mine lease boundary, where 2 m of groundwater drawdown is anticipated, and intersects the following five boreholes:

Borehole reference	Initial GWL	Drawdown
WM0426	3 m bgl	15 m
WM002	1 m bgl	10 m
WM0425	2 m bgl	6 m
WM0424	2 m bgl	3.75 m
WM0291	2 m bgl	3 m

Section 2 runs from the southern extent of the open pit, where 15 m of groundwater drawdown is anticipated, to the southeast of the pit where only 3.5 m of groundwater drawdown is anticipated. Section 2 intersects the following four boreholes:

Borehole reference	Initial GWL	Drawdown
WM0426	3 m bgl	15 m
WM0430	1 m bgl	15 m
WM0431	1 m bgl	10 m
WM0365	2 m bgl	3.5 m

3.3 Subsurface Profile

For the purposes of the settlement analysis reported here a single representative subsurface soil profile (rather than borehole specific subsurface profiles) has been assumed. This was in part due to the shortcomings identified in Section 2 regarding the description of the soil profile consistency / density contained in the borehole logs in addition to the lack of any in situ testing undertaken to confirm the recorded consistency / density of the soil profile.

The representative subsurface profile was developed based on the information contained in the eight individual borehole logs located along the analysis sections and is summarised below:

- 0 to 1 m CLAY; soft
- 1 to 8 m CLAY; soft to firm
- 8 to 18 m CLAY; firm
- 18 to 26 m CLAY; firm to stiff
- 26 to 34 m SAND; loose to medium dense.

The above representative subsurface profile was altered only where the rockhead level at individual borehole locations was recorded to be shallower than 34 m.

For section 1, analysis was undertaken at the exploration lease boundary (ELB) based on an assumed depth to rockhead as there is no borehole located within close proximity to the ELB.

3.4 Groundwater

The initial groundwater level at each borehole was adopted from the GHD monitoring bore groundwater level charts. The initial groundwater level within the Narrabri formation was typically between 1 and 2 m below ground level.

The groundwater drawdown adopted at each borehole location was based on the AGE groundwater drawdown contour plot, which includes the location of the monitoring bores (see Figure 3-1 above).

3.5 Material Properties

A bulk unit weight of 18 kN/m^3 was adopted for all soil layers within the representative subsurface profile.

Upper and lower bound values of undrained shear strength were assigned to the clay layers of the representative subsurface profile based on the range of values contained in Table A4 of AS1726 reproduced as Figure 3-2 below.

Empirical relationships exist for determining the modulus of elasticity (Es) of clay from the undrained shear strength (cu). This relationship (Es = βCu) is primarily dependent upon the plasticity and over-consolidation ratio of the soil profile (see Figure 3-3 below). The borehole logs indicate that the clay profile is typically recorded to be highly plastic and it has been conservatively assumed that the alluvial clay is not over-consolidated. Accordingly a β value of 250 was adopted for this assessment.

The borehole logs typically contained no record of the density of the underlying sand layer. For the purposes of this assessment it has been assumed that the sand layer is loose to medium dense. Upper and lower bound modulus of elasticity values have been adopted based on typical published values for loose to medium dense sand.

TABLE A4

CONSISTENCY TERMS—COHESIVE SOILS

Term	Undrained shear strength kPa	Field guide to consistency
Very soft	≤12	Exudes between the fingers when squeezed in hand
Soft	>12 ≤25	Can be moulded by light finger pressure
Firm	>25 ≤50	Can be moulded by strong finger pressure
Stiff	>50 ≤100	Cannot be moulded by fingers Can be indented by thumb
Very stiff	>100 ≤200	Can be indented by thumb nail
Hard	>200	Can be indented with difficulty by thumb nail

Figure 3-2: Undrained Shear Strength Values (AS1726-1993)

Plasticity index	β				
	OCR = 1	OCR = 2	OCR = 3	OCR = 4	OCR = 5
< 30	1500–600	1380–500	1200–580	950–380	730–300
30 to 50	600–300	550–270	580–220	380–180	300–150
> 50	300–150	270–120	220–100	180–90	150–75

Figure 3-3: Empirical Relationship between Modulus of Elasticity and Plasticity Index (Das 2007)

4 Results of Settlement Analysis

The results of the settlement analyses for Section 1 and Section 2 are presented below in Figure 4-1 and Figure 4-2 respectively.

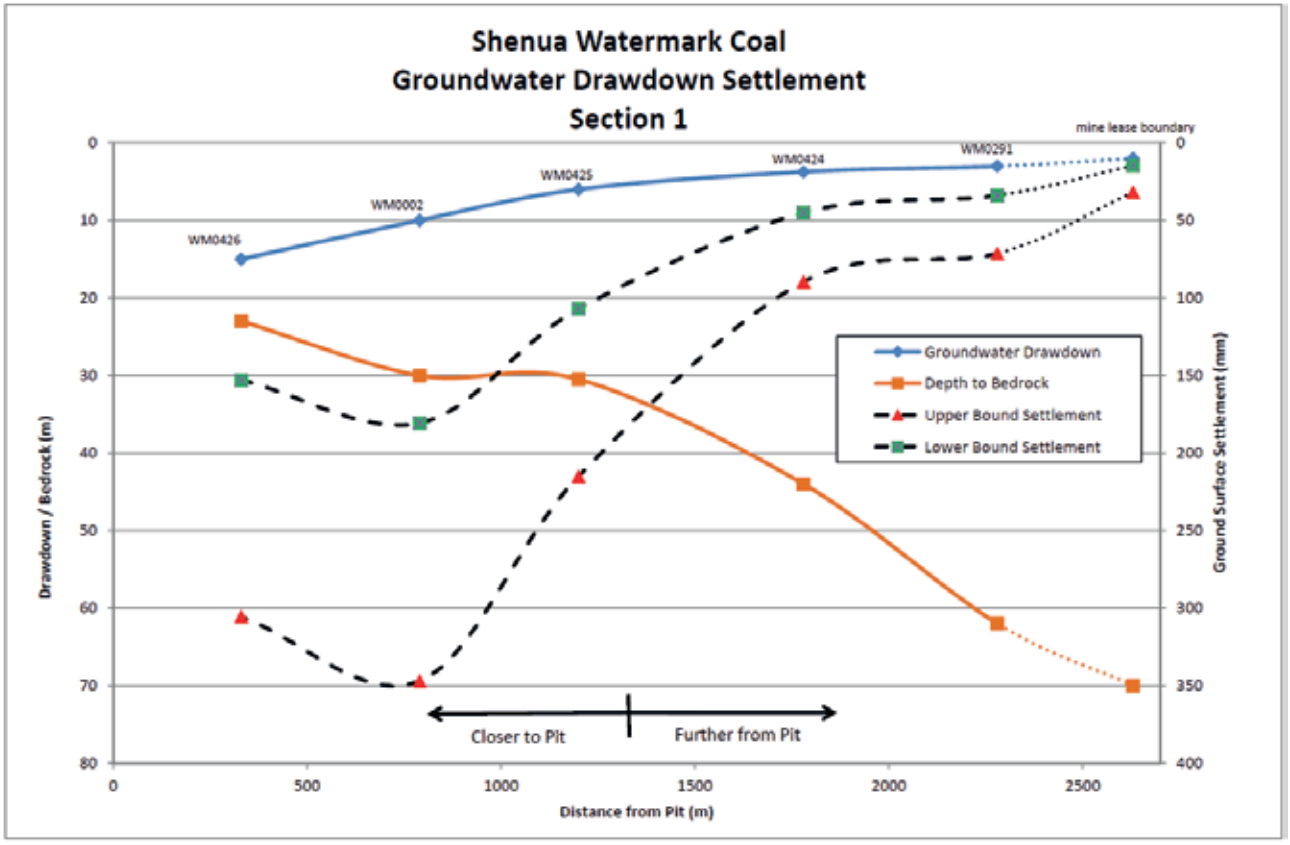


Figure 4-1: Section 1 Settlement Results

The Section 1 analysis predicts ground surface settlements of between 15 and 30 mm at the ELB due to an anticipated 2 m of groundwater drawdown. The results show that the predicted settlement generally increases with increasing groundwater drawdown from the MLB towards the pit with settlements of between 180 and 350 mm anticipated at WM0002.

The depth to bedrock generally decreases from the ELB to the pit and at WM0002 the depth to bedrock becomes a critical factor in the settlement calculation. The predicted settlement decreases between WM0002 and WM0426 despite increasing groundwater drawdown as a result of decreasing depth to rockhead.

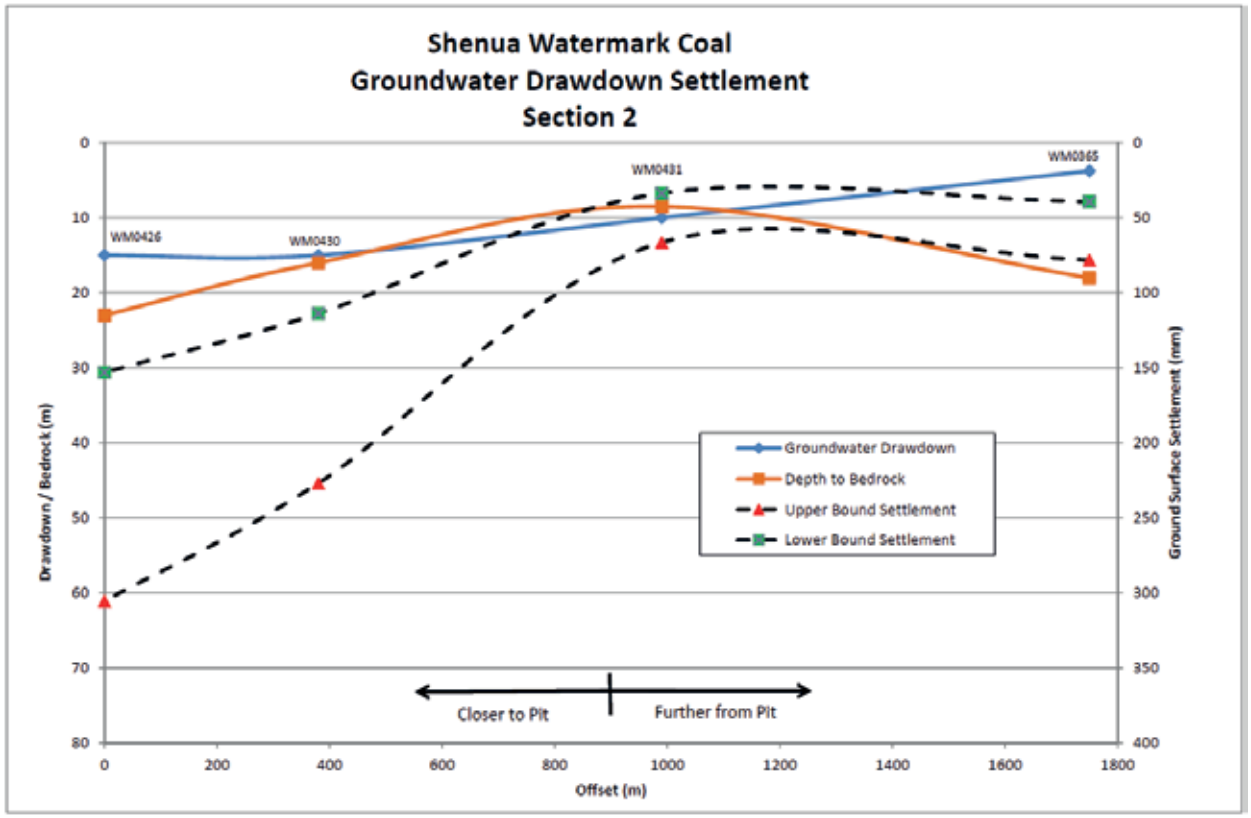


Figure 4-2: Section 2 Settlement Results

The Section 2 analysis predicts ground surface settlements of between approximately 30 mm and 300 mm. The results show that the predicted settlement generally increases as the groundwater drawdown depth increases. The exception to this is at borehole WM0431 where the reduced depth to bedrock becomes critical and the predicted settlement decreases.

The predicted settlement calculated for Section 1 and Section 2 is a total settlement comprising immediate settlement plus consolidation settlement. The time taken for total settlement to occur will be dependent upon the consolidation properties of the soil profile including hydraulic conductivity and drainage path length and for thick layers of high plasticity clays this period may be many tens of years.

5 Discussion

The scope of this study has been limited to the assessment of groundwater drawdown induced settlement only. The borehole information provided contains no in-situ strength testing from which to derive elastic modulus parameters and as such the assumed soils parameters have been based on the inconsistent and non-standard descriptive terms in the borehole logs only. Accordingly there is some doubt about the accuracy of the calculated settlement results and it is recommended that they are considered as indicative only.

In reviewing the magnitudes of settlement reported above, where the drawdown is around 2 m or less then the settlement magnitudes are relatively small, however once the drawdown reaches 3 m then the envelope of potential settlement ranges from around 40 – 80 mm.

In reviewing the settlements reported it is worth considering that the ground within the vicinity of the open cut pit will likely be subject to settlement associated with the ground movements resulting from the excavation of the mine void. In addition it is understood that the alluvial soils at site are overlain at surface by “black soils” which are known to exhibit seasonal shrink swell behaviour as a result of moisture content change not associated with groundwater drawdown. Sites with “black soils” are typically classified as highly to extremely reactive sites in accordance with the definition of site classes in the Australian Standard for Residential slabs

and footings (AS2870 – 1996). AS2870 indicates that highly to extremely reactive sites will experience surface movement of greater than 40mm associated with seasonal shrink swell behaviour.

6 Further Work

The settlement analysis summarised in this letter report has been based on limited geotechnical information and should be considered as an indication of settlement magnitude only. To obtain a more accurate estimate of settlement it is recommended that a geotechnical drilling investigation be undertaken in the area of interest to confirm the assumptions of this analysis.

The geotechnical drilling should comprise Standard Penetrometer Testing (SPT) within the alluvial soil profile to enable determination of actual soil consistency. Disturbed samples should be collected to allow laboratory classification testing of the soil, including testing to determine the plasticity index. The materials encountered should be classified in accordance with a recognised geotechnical classification description standard, preferably AS1726. If it is required to also calculate the potential surface movement associated with the presence of shrink swell soils it is recommended that laboratory testing be undertaken on samples of the "black soils" to determine the shrink-swell index of the soil.

If accurate settlement predictions are required for the area to the south of the ELB then it is recommended that geotechnical information also be obtained for this area.

Yours faithfully

SRK Consulting (Australasia) Pty Ltd



Ben Stark
Senior Geotechnical Consultant

Reviewed by



Sam Paterson
Principal Geotechnical Consultant

APPENDIX 8

Uncertainty Analysis

A8.1 OBJECTIVES

It is widely accepted that any prediction of natural phenomena, particularly those pertaining to the subsurface where direct measurement is logistically challenging, will be endowed with numerous sources of uncertainty. It then follows that a numerical groundwater flow model developed to furnish predictions of subsurface behaviour, such as the model documented in this report, will be confronted with issues including:-

(i) adequacy of physically-based algorithms in representing naturally complex processes;
(ii) gaps in our understanding of hydrogeological system processes;
(iii) measurement "noise" pertaining to the reliability and (in)frequency of observed aquifer response;
(iv) deficiencies in historical data for climate, land-use change, water management practice, groundwater extractions etc, and
(v) paucity of information for aquifer hydraulic characteristics (e.g. test pumping data).

On the assumption that a model possesses the mathematical and numerical ability to appropriately simulate environmental processes (and thus has satisfactorily addressed the issues raised above), its ability to make a prediction of future environmental behaviour with minimum error variance at a particular study site is determined by the integrity of values assigned to the parameters (and source/sink terms) which it employs in simulation of hydraulic processes at that site. In general, the more complex the model, the greater the number of parameters that require assignment. Such a high level of parameterisation detail is not warranted when a model needs to make predictions only on a coarse scale. However where it must make predictions on a fine scale or at a similar scale to that at which spatial and temporal discretisation of the model domain takes place, then parameterisation detail at this scale may be important, for this is the level of parameterisation detail on which such a prediction may depend.

Unfortunately, there are both practical and theoretical limits to the detail with which parameter values can be uniquely ascribed to a model. Parameter values are normally assigned through a combination of expert knowledge and calibration against historical measurements of system state. Due to limitations in each of these aspects (especially in the case of a relatively complex aquifer system in the environs of the Watermark Coal Project), parameter assignment can only be approximate. Fortunately, the degree of approximation decreases as the scale of parameter assignment increases, for it is easily shown that the calibration process can yield good estimates of spatially averaged parameter values where averaging takes place on a scale similar to that of the available data. Conversely the finer the scale on which parameters are considered, the more likely are they to be locally in error, (notwithstanding a model's ability to replicate a comprehensive measurement dataset well or even perfectly) because of the inability of the calibration process to provide estimates at a finer scale than that determined by the spatial averaging that is necessary to obtain a unique solution to the inverse problem of model calibration based on the current calibration dataset.

The ability of a model to make a prediction with integrity is thus determined by sensitivity of that prediction to hydraulic property detail, and by the degree to which aquifer properties can be inferred at that scale either by direct measurement or through calibration against historical measurements of system state. To the extent that either are lacking in furnishing unique estimates of hydraulic properties at the scale required by the prediction, the model's ability to make that prediction is compromised. In general, the finer the resolution (both spatially and temporally) at which a prediction is required, the greater its sensitivity is likely to be to parameterisation detail, and the greater is the propensity for error in that prediction. The exact size of this error cannot be

known in any specific instance (for otherwise it could be corrected). For these reasons, it is important that the statistical properties of model predictive uncertainty are estimated.

The primary objectives of this investigation are thus:-

(i) describe a numerically-tractable approach for quantification of uncertainty for this model, and

(ii) report the results of applying the methodology to estimate the potential uncertainty associated with the 30-year development of the open-cut pits as described in Section 10.3 of the main report.

Such an analysis is unfortunately, rarely performed in such contexts. Thus, this investigation offers a valuable insight into model predictive uncertainty, and which extends the sensitivity analyses provided in Section 11. On the basis of efforts already undertaken and described herein, if desired, the methodology can be readily applied to an analysis of the uncertainties of predictions other than those documented here.

A8.2 METHODOLOGY

A8.2.1 Uncertainty Analysis versus Predictive Analysis

Even before a model is calibrated, something is known of the values which model parameters will assume. For example, hydraulic conductivity can be estimated on the basis of test pumping analyses in aquifer material; groundwater interaction with streams may be estimated through an understanding of regional recharge processes and consideration of topography, etc. Conceptually, on the basis of such knowledge, a “pre-calibration probability distribution” can be constructed for model parameters. In some cases the pre-calibration probability distribution will be simple, being comprised, for example, of a set of mutually independent uniform probability distributions between respective parameter upper and lower bounds. In other cases correlation between spatially distributed parameters may need to be taken into account (based on a variogram of other geo-statistical descriptor for the pertinent hydraulic property).

If no data were available with which to calibrate a model, the uncertainty associated with any of its predictions could be related directly to the uncertainty pertaining to its parameters. Predictive uncertainty analysis where a model is not subject to the constraints on parameter values imposed by the calibration process is, in fact, a relatively straightforward matter. For example, a Monte-Carlo analysis could be carried out by generating random parameter sets according to the global parameter probability distribution, running the model on the basis of each such parameter realisation, assimilating model predictions into a frequency distribution, and calculating predictive probabilities accordingly. This is, however, a numerically intensive procedure, especially where the number of parameters used by a model is high (as it needs to be to represent spatial heterogeneity or other aspects of model complexity).

Analysis of the uncertainty of model outputs where parameters are not subject to calibration is often referred to as “uncertainty analysis”. This is to be distinguished from the term “predictive analysis” which is often used to describe the process by which model output variability is assessed when parameter values are subject to the constraints imposed by a calibration process. As has been noted above, model calibration does not necessarily result in a unique set of parameter values, especially if the model employs a large number of parameters so that aspects of system complexity to which a prediction may be sensitive are properly represented; hence parameter and predictive variability can still be large.

Calibration-constrained Monte Carlo methods for predictive uncertainty analysis seek to generate many different parameter sets that enable the model to match the observed data within a level of misfit that is commensurate with measurement errors associated with that data (this is commonly referred to as the *posterior* distribution). Classical examples of such approaches include the generalised likelihood uncertainty estimation (GLUE) technique (Beven and Binley, 1992) and Markov Chain Monte Carlo (MCMC). A number of lumped hydrologic model applications have successfully applied GLUE to assess model parameter and predictive uncertainty (e.g. Yu et al, 2001; Arabi et al, 2006). The MCMC methodology is also finding increasing use in environmental modelling for quantification of uncertainty of parameters subject to the constraints of a calibration process. Examples of its use include the works of Harmon and Challenor (1997), Kuczera and Parent (1998), Campbell and Bates (2001) and Vrught et al. (2003). Unfortunately, in a highly-parameterised groundwater modelling context each of these approaches requires a considerable number of model runs (in the order of $10^3 – 10^4$) to adequately sample the posterior distribution. Consequently, reported applications of these methods are normally restricted to simple models.

More recently, approaches with greater numerical efficiency such as null-space Monte Carlo (NSMC) (Tonkin and Doherty, 2009) have been applied successfully in highly-parameterised contexts (refer Section 7.1 for brief details). Keating et al (2010) provide a comparison of the NSMC and MCMC methodologies as applied to highly parameterized groundwater models. Further details of this methodology, as well as examples of its implementation in conjunction with synthetic and real-world models, are described in Tonkin and Doherty (2009), James et al (2009), Doherty et al (2010), Keating et al (2010) and Herckenrath et al (2011).

A8.2.2 General Approach

Models are often built precisely because conditions are about to be changed, or because predictions must be made of a quantity, or at a location, for which little historical hard information is available. It is precisely for this reason that a physically-based model is chosen for environmental simulation, and that a considerable level of numerical complexity may be devoted to the simulation of environmental processes encapsulated in the model. In fact an important design consideration for many models is that a process should not be excluded from the model if a prediction of interest may be sensitive to it. Given that the uncertainty associated with the making of that prediction will probably be high, the same logic must apply to the parameterisation if the uncertainty associated with the prediction is to be properly explored.

In this study, while a formal calibration-constrained approach was attractive, it was considered that predictive analysis would be more suitably applied to a model calibrated to a measurement dataset that reflected groundwater response within all relevant aquifers under stresses consistent with void excavation over time. (It is acknowledged that this was obviously not possible given that pre-development conditions currently prevail). Even in the absence of calibration, if the sensitivity of each such observation to individual parameter perturbations was calculable, a NSMC exercise could still be performed, for example.

Alternatively, a pragmatic approach was sought which balanced the information inherent in the current pre-development calibration dataset with stochastic generation of parameters on the basis of an adopted set of parameter statistical properties that respected current hydrogeological understanding and “professional intuition and experience”. In other words, an acceptable level of “de-calibration” was sought given that only a pre-development measurement dataset was available. To achieve this, a Monte Carlo approach was adopted, whereby prior probability distributions for parameters were treated as multi-Gaussian with means centred on the calibrated parameter values. The form of the multi-normal prior parameter probabilities was defined (in part) using parameter-by-parameter uncertainties and covariance parameter matrices where

appropriate. Additionally, for some parameter types, cell-by-cell variability in the model domain was employed instead of parameter-by-parameter variability. Refer Section 3.1.2 for details. As Tonkin and Doherty (2009) explain, the stochastic parameter generation can be made more sophisticated by allowing random heterogeneity to be represented on a cell-by-cell basis to better represent the type of aquifer variability that exists in the real world. Each spatial parameter field was thereby generated using a cell-by-cell stochastic field generator (e.g. the GSLIB geostatistical suite of Deutsch and Journel, 1998). Cell-by-cell variability of parameters also assumed a log-normal prior probability distribution with means corresponding to optimised parameter values and a variogram sill corresponding to the assumed parameter variance.

For the process of generating stochastic parameters (i.e. random realisations), the bounds used for calibration were to be enforced, whereby the intervals between respective parameter limits correspond roughly to 95% pre-calibration parameter confidence intervals on the basis of hydrogeological interpretation and inference. The acceptance or rejection of random parameter sets for use in uncertainty analysis would be determined using a ranking of the objective function for the transient calibration computed for each realisation. Thus, for a suite of 500 random realisations, a ranking in increasing order of objective function would provide the basis for removal of the most de-calibrated realisations, with the 50th percentile adopted as a cut-off level for acceptance (i.e. 250 realisations). It was anticipated that this manner of stochastic parameter selection would sufficiently probe predictive extremes, although it should be noted that such an approach does not formally take account of predictive noise, rather the predictive variability is primarily a function of parameter variability.

Exploration of the uncertainty of a model prediction could then be accomplished by running the model repeatedly using the suite of 250 random parameter realisations, collecting cell-based and site-specific outputs, and building empirical predictive probability distributions and computing common statistical measures on the basis of these model run outcomes.

A8.3 APPLICATION OF UNCERTAINTY ANALYSIS

A8.3.1 Stochastic Parameter and Field Generation

A8.3.1.1 Parameters of Interest

As described in Section 9 of the main report, there were 105 pilot point parameters common to spatially-distributed aquifer hydraulic parameters in the Narrabri and Gunnedah formations (i.e. model layer 1 and 2 respectively) which were available for adjustment during the calibration process. These entailed horizontal conductivity, specific yield and confined storage coefficient. Vertical hydraulic conductivity was computed through multiplication of the horizontal hydraulic conductivity of a given layer by a layer-wide vertical anisotropy ratio.

The level of parameterisation detail in these alluvium layers was considered acceptable for exploration of predictive uncertainty and thus remained unchanged for stochastic parameter generation. Pilot points and covariance matrices based on one or a number of presumed variograms were used to characterize parameter field variability (refer Section 3.1.2 for further details).

For the other model layers, the original calibration process employed layer-wide parameters to describe aquifer hydraulic characteristics (i.e. horizontal and vertical hydraulic conductivity, specific yield and confined storage coefficient). Fresh and weathered zones were delineated within each layer (excluding the Watermark - Maules Creek Formations of layer 11); the observed

increase in horizontal and vertical hydraulic conductivity in the weathered zones represented via use of a multiplication factor for cells located above the base of weathering. Additionally, for the Hoskissons and Melvilles coal seams (layer 8 and 10 respectively), the reduction of hydraulic conductivity with depth below surface was represented using an exponential decline function determined from measurement data (refer Section 7.5 of the main report). Thus, layer-wide values of horizontal hydraulic conductivity for the Hoskissons or Melvilles coal seams were translated to a spatially distributed hydraulic conductivity fields on the basis of depth of burial. The K_0 (zero depth) coefficient for this function was also considered an adjustable parameter for calibration.

For the purpose of uncertainty analyses, the parameterisation approach adopted for calibration in layers 3 to 11 was adjusted to better incorporate spatial parameter variability for hydraulic characteristics. The layer-wide hydraulic conductivity parameters were "re-constituted" as spatially variable fields by employing stochastic field generation to produce cell-by-cell variability in the fresh and weathered zones of each layer, excluding the coal-seam layers which maintained a layer-wide parameterisation for hydraulic conductivity and weathering factor. Instead, spatial variability in hydraulic conductivity for the coal seam layers was introduced through the agency of pilot point multipliers (totalling 59 and 61 in the Hoskissons and Melvilles coal seams respectively), while the K0 (zero depth) coefficient was also included in the stochastic parameter generation process. This approach was undertaken to better respect the established depth-based relationships for hydraulic conductivity in the coal seam layers. Stochastic field generation to produce cell-by-cell variability for the primary and secondary storage characteristics of layers 3 to 11 was also applied.

General-head boundary (GHB) cells used to represent down-valley flow along the northern boundary were included in the uncertainty analysis. These were originally represented by a single conductance value for the calibration process, but were converted to a set of 10 pilot-point conductance parameters. Given that GHB cells are orientated along a segment of the uppermost model row, linear interpolation between pilot points was used for cell-based parameter assignment. Furthermore, a pilot point based parameterisation scheme was used to facilitate the adjustment of the maximum evapotranspiration rate for the purposes of uncertainty analysis; a suite of 68 pilot point multipliers were created.

Zonal parameters were also included in the uncertainty analyses. Zones of piecewise constancy used for quantification of the recharge rate were not altered, i.e. 3 zones representing percentage of rainfall as recharge in (i) alluvium, (ii) Regolith/Permian outcrop and (iii) Liverpool Range basalt, and the 9 subzones representing percentage of rainfall as recharge for various breaks of slope. Also, the annual rainfall rate was included as an adjustable parameter for uncertainty analyses.

Zonal parameter schemes for riverbed permeability were enhanced for uncertainty analyses. In addition to the 4 zones of cells representing riverbed permeability for Quirindi Creek, minor creeks, drainage lines and Lake Goran, the single zone corresponding to the Mooki River was subdivided into 10 zones for uncertainty analyses. Given its relative importance to this study, this allowed for improved exploration of the influence of parameter variability on predictions in this area. Another modification to the existing model parameterisation was the addition of extraction rate multipliers in each of the six groundwater management zones to evaluate the influence of noise in the licensed bore data on predictions. A zonal approach was preferred over a system wide multiplier given the high variability in both pumping rate and hydraulic properties between the zones.

The original parameterisation of faults involved a system-wide value for their hydraulic characteristic (barrier hydraulic conductivity divided by the width of the horizontal flow barrier). These were ascribed a very low value after calibration, which suggested that faults acted as groundwater barriers to flow. This conclusion was scrutinised for the uncertainty analyses by delineating the faults into 25 zones for assignment of the hydraulic characteristic value.

Finally, lumped parameters related to the hydraulic characteristics of spoil were examined; these were not involved in the calibration process and were only utilised during the predictive simulation of open pit development. Mean values for the purpose of stochastic parameter generation of these spoil parameters corresponded with those used in the predictive base case simulation.

A8.3.1.2 Statistical Representation

The covariance matrix C(**k**) represents information on hydraulic properties available from outside of the calibration process. Thus it presents a mechanism for the incorporation of "expert knowledge" into the model parameterisation process. For example, for a spatially variable property such as hydraulic conductivity, it expresses both the range of values that this property is likely to take for the different aquifer materials prevailing within the study area, as well as the degree of spatial continuity that is likely to exist for this property.

The uncertainty of predictions made by an uncalibrated model is a function of C(**k**). To the extent that such a prediction is reliable, this is a reflection of the fact that it is sensitive to parameters whose variances, as expressed by pertinent elements of C(**k**), are small as a result of expert knowledge brought to bear on model parameterisation in areas of well-known hydrogeological characteristics. To the extent that a particular prediction is unreliable, this is a reflection of its dependence on parameters with large variance and covariance as expressed by pertinent elements of C(**k**), this reflecting limitations in prevailing expert knowledge of that particular aspect of the study area. For a first order stationary field, C(**k**), like γ, is a function only of separation between two points at which a hydraulic property is characterised, and can thus be represented (where there is no anisotropy) as C(*h*). The relationship between C(*h*) and γ(*h*) is given by the equation:-

$$C(h) = C(0) - \gamma(h) \qquad (2.1)$$

In generating random realisations of pilot point based parameters for the model, spatial correlation of parameter values was assumed. Statistical correlation was represented by an exponential variogram, and hence was assumed to be a function only of pilot point separation. Covariance relationships implied by the exponential variogram are described by the equation:

$$C(h) = C(0)[1-e^{-h/a}] \qquad (2.2)$$

where *h* depicts the separation between any two pilot points and C(0) expresses parameter covariance at zero pilot point separation (the so-called variogram "sill"), this being the innate variance of the parameter, and *a* is a length parameter or integral scale, which defines a variogram range of approximately 3*a* (Deutsch and Journel, 1992).

Rarely are enough measurements available within a groundwater model domain to allow construction of a reliable variogram for any hydraulic property; this study is no different. Assignment of values to elements of the C(**k**) matrix was undertaken on the basis of hydrogeological expertise to define realistic ranges or bounds for each parameter over which uncertainty is explored. The standard deviation of each parameter was defined by dividing the difference between its upper and lower bounds on the assumption that the parameter was Gaussian and the parameter range represented the 95% confidence limit. Note that variance is the square of standard deviation. Adjustable parameters were log-transformed in the present study (except where indicated), as assumed in the original calibration process given the relationship between parameter and model output is more likely to approach linearity. Thus, the standard deviations and variances pertain to the log of each parameter.

Information used to assemble the components of the C(**k**) matrix for random parameter generation and cell-by-cell stochastic field generation (where applicable, refer Section 3.1.1) for various parameter types employed by the model are presented in Table 2-1 to Table 2-10. Note that the exponential variogram range (three times the coefficient of distance in the exponent of the variogram equation) was generally based on existing or newly-added pilot point separation distances. All zonal and lumped parameters are assumed to be uncorrelated, thus off-diagonal terms of the submatrix of C(**k**) are zero.

For random parameter generation, one instance of parameter ordering was applied to ensure that the percentage of annual rainfall as alluvium recharge (zone 1) exceeded the percentage of annual rainfall as Regolith recharge (zone 2). Any parameter realisation that did not satisfy this relationship was rejected and a sample was successively generated until this condition was respected. It should be noted that if any random parameter realisation was below or above the bounds of the parameter as stipulated in the original PEST calibration, the parameter was assigned a value equal to the parameter lower or upper bound respectively.

Table A.1: STATISTICS USED FOR HORIZONTAL HYDRAULIC CONDUCTIVITY PILOT POINT PARAMETER AND CELL-BY-CELL FIELD GENERATION

Pilot Point Parameter Type (Number of Pilot Points)	Mean (m/d)	Standard Deviation (log_{10})	Variance (log_{10})	"a" of Exponential Variogram (km)
Horizontal Hydraulic Conductivity - Layer 1 (105) *[1]	0.01 - 25.1	0.67	0.45	15
Horizontal Hydraulic Conductivity - Layer 2 (105) *[1]	0.1 - 46.7	0.67	0.45	15
Horizontal Hydraulic Conductivity - Layer 3 (Fresh)	0.646	0.42	0.18	15
Horizontal Hydraulic Conductivity - Layer 3 (Weathered)	3.23	0.30	0.09	10
Horizontal Hydraulic Conductivity - Layer 4 (Fresh)	1.04e-3	0.75	0.56	15
Horizontal Hydraulic Conductivity - Layer 4 (Weathered)	1.04e-2	0.75	0.56	10
Horizontal Hydraulic Conductivity - Layer 5 (Fresh)	1.0e-3	0.75	0.56	15
Horizontal Hydraulic Conductivity - Layer 5 (Weathered)	1.0e-2	0.75	0.56	10
Horizontal Hydraulic Conductivity - Layer 6 (Fresh)	0.2	0.75	0.56	15
Horizontal Hydraulic Conductivity - Layer 6 (Weathered)	0.3	0.42	0.18	10
Horizontal Hydraulic Conductivity - Layer 7 (Fresh)	1.0e-3	0.50	0.25	15
Horizontal Hydraulic Conductivity - Layer 7 (Weathered)	1.0e-2	0.50	0.25	10
Horizontal Hydraulic Conductivity Multiplier - Layer 8 (59) *[1]	1.0	0.5	0.25	15
Horizontal Hydraulic Conductivity - Layer 9 (Fresh)	1.0e-4	1.00	1.0	15

Table A.1: STATISTICS USED FOR HORIZONTAL HYDRAULIC CONDUCTIVITY PILOT POINT PARAMETER AND CELL-BY-CELL FIELD GENERATION				
Pilot Point Parameter Type (Number of Pilot Points)	**Mean (m/d)**	**Standard Deviation (log_{10})**	**Variance (log_{10})**	**"a" of Exponential Variogram (km)**
Horizontal Hydraulic Conductivity - Layer 9 (Weathered)	1.0e-3	1.00	1.0	10
Horizontal Hydraulic Conductivity Multiplier - Layer 10 (61) *[1]	1.0	0.5	0.25	15
Horizontal Hydraulic Conductivity - Layer 11	1.0e-3	1.00	1.0	15

*[1] *Parameter-by-parameter variability only*

Table A.2: STATISTICS USED FOR VERTICAL HYDRAULIC CONDUCTIVITY PILOT POINT PARAMETER AND CELL-BY-CELL FIELD GENERATION				
Pilot Point Parameter Type (Number of Pilot Points)	**Mean (m/d)**	**Standard Deviation (log_{10})**	**Variance (log_{10})**	**"a" of Exponential Variogram (km)**
Vertical Hydraulic Conductivity - Layer 1 (105) *[1]	0.005 – 12.5	0.50	0.25	15
Vertical Hydraulic Conductivity - Layer 2 (105) *[1]	0.009 – 4.2	0.50	0.25	15
Vertical Hydraulic Conductivity - Layer 3 (Fresh)	0.19	0.50	0.25	15
Vertical Hydraulic Conductivity - Layer 3 (Weathered)	0.96	0.24	0.06	10
Vertical Hydraulic Conductivity - Layer 4	0.1	0.50	0.25	15
Vertical Hydraulic Conductivity - Layer 4 (Weathered)	1.0	0.24	0.06	10
Vertical Hydraulic Conductivity - Layer 5	1.0e-4	0.50	0.25	15
Vertical Hydraulic Conductivity - Layer 5 (Weathered)	1.0e-3	0.50	0.25	10
Vertical Hydraulic Conductivity - Layer 6	1.0e-2	1.00	1.0	15
Vertical Hydraulic Conductivity - Layer 6 (Weathered)	1.5e-2	0.50	0.25	10
Vertical Hydraulic Conductivity - Layer 7	1.0e-4	0.50	0.25	15
Vertical Hydraulic Conductivity - Layer 7 (Weathered)	1.0e-3	0.50	0.25	10
Vertical Hydraulic Conductivity Multiplier - Layer 8 (59) *[1]	1.0	0.5	0.25	15
Vertical Hydraulic Conductivity - Layer 9	1.0e-5	0.75	0.56	15

Table A.2: STATISTICS USED FOR VERTICAL HYDRAULIC CONDUCTIVITY PILOT POINT PARAMETER AND CELL-BY-CELL FIELD GENERATION				
Pilot Point Parameter Type (Number of Pilot Points)	**Mean (m/d)**	**Standard Deviation (log_{10})**	**Variance (log_{10})**	**"a" of Exponential Variogram (km)**
Vertical Hydraulic Conductivity - Layer 9 (Weathered)	1.0e-4	0.75	0.56	10
Vertical Hydraulic Conductivity Multiplier - Layer 10 (61) *[1]	1.0	0.5	0.25	15
Vertical Hydraulic Conductivity - Layer 11	1.59e-5	0.75	0.56	15

*[1] *Parameter-by-parameter variability only*

Table A.3: STATISTICS USED FOR HYDRAULIC CONDUCTIVITY ZONAL PARAMETER AND CELL-BY-CELL FIELD GENERATION			
Zonal Parameter Type	**Mean**	**Standard Deviation**	**Variance**
Horizontal Hydraulic Conductivity - Layer 8	1.0E-3 m/d	0.75 (log10)	0.56 (log10)
Horizontal Hydraulic Conductivity - Layer 10	1.0E-3 m/d	1.00 (log10)	1.00 (log10)
Vertical Hydraulic Conductivity - Layer 8	1.0E-4 m/d	0.75 (log10)	0.56 (log10)
Vertical Hydraulic Conductivity - Layer 10	1.0E-4 m/d	1.00 (log10)	1.00 (log10)
Weathering Factor – Coal Seams	2.0	0.33 (log10)	0.109 (log10)
Ko exponential decline coefficient	-0.007500	0.00125	1.6E-6

Table A.4: STATISTICS USED FOR SPECIFIC YIELD PILOT POINT PARAMETER AND CELL-BY-CELL FIELD GENERATION				
Pilot Point Parameter Type (Number of Pilot Points)	**Mean (m/d)**	**Standard Deviation (log_{10})**	**Variance (log_{10})**	**"a" of Exponential Variogram (km)**
Specific Yield - Layer 1 (105) *[1]	0.03 – 0.2	0.32	0.10	15
Specific Yield - Layer 2 (105) *[1]	0.03 – 0.2	0.32	0.10	15
Specific Yield - Layer 3	1.38E-2	0.50	0.25	15
Specific Yield - Layer 4	1.46E-2	0.42	0.18	15
Specific Yield - Layer 5	2.64E-3	0.24	0.06	15
Specific Yield - Layer 6	1.2E-3	0.24	0.06	15
Specific Yield - Layer 7	1E-3	0.24	0.06	15
Specific Yield - Layer 8	2.19E-3	0.24	0.06	15

Table A.4: STATISTICS USED FOR SPECIFIC YIELD PILOT POINT PARAMETER AND CELL-BY-CELL FIELD GENERATION				
Pilot Point Parameter Type (Number of Pilot Points)	**Mean (m/d)**	**Standard Deviation (log_{10})**	**Variance (log_{10})**	**"a" of Exponential Variogram (km)**
Specific Yield - Layer 9	1E-3	0.24	0.06	15
Specific Yield - Layer 10	2.98E-3	0.24	0.06	15
Specific Yield - Layer 11	2.06E-3	0.24	0.06	15

*[1] *Parameter-by-parameter variability only*

Table A.5: STATISTICS USED FOR SPECIFIC STORAGE PILOT POINT PARAMETER AND CELL-BY-CELL FIELD GENERATION				
Pilot Point Parameter Type (Number of Pilot Points)	**Mean (m/d)**	**Standard Deviation (log_{10})**	**Variance (log_{10})**	**"a" of Exponential Variogram (km)**
Specific Storage - Layer 1 (105) *[1]	1E-5 – 1E-3	0.71	0.50	15
Specific Storage - Layer 2 (105) *[1]	1E-5 – 1E-3	0.71	0.50	15
Specific Storage - Layer 3	5.61E-5	0.50	0.25	15
Specific Storage - Layer 4	5E-4	0.50	0.25	15
Specific Storage - Layer 5	5E-5	0.50	0.25	15
Specific Storage - Layer 6	5E-5	0.50	0.25	15
Specific Storage - Layer 7	5E-5	0.50	0.25	15
Specific Storage - Layer 8	1.67E-5	0.50	0.25	15
Specific Storage - Layer 9	1E-6	0.50	0.25	15
Specific Storage - Layer 10	1.45E-5	0.50	0.25	15
Specific Storage - Layer 11	1E-6	0.50	0.25	15

*[1] *Parameter-by-parameter variability only*

Table A.6: STATISTICS USED FOR EVT AND GHB PILOT POINT PARAMETER GENERATION				
Pilot Point Parameter Type (Number of Pilot Points)	**Mean**	**Standard Deviation (log_{10})**	**Variance (log_{10})**	**"a" of Exponential Variogram (km)**
Evapotranspiration Multiplier (68)	1.0	0.02	0.0004	15
GHB Conductance (10)	500 m^2/d	0.67	0.455	*[2]

*[2] *Linear interpolation used*

Table A.7: STATISTICS USED FOR ZONE-BASED WELL AND HFB PARAMETER GENERATION			
Zonal Parameter Type (Number of Zones)	**Mean**	**Standard Deviation (log_{10})**	**Variance (log_{10})**
Well rate multipliers (6)	1.0	0.12	0.014
HFB hydraulic conductivity / width (25)	1E-8	1.0	1.0

Table A.8: STATISTICS USED FOR ZONE-BASED RECHARGE PARAMETER GENERATION			
Zonal/Lumped Parameter Type	**Mean**	**Standard Deviation (log_{10})**	**Variance (log_{10})**
Annual rainfall (mm)	644.4	0.03	0.001
Alluvium (Zone 1) (%)	1.5	0.83	0.681
Regolith (Zone 2) (%)	0.054	0.69	0.482
Liverpool Range Volcanics / Basalt (Zone 3) (%)	5.0	0.17	0.031
Break of slope alluvium - Southwest (Zone 1) (%)	1.0	0.29	0.086
Break of slope alluvium - Doona Point (Zone 2) (%)	1.0	0.35	0.122
Break of slope alluvium - Watermark East (Zone 3) (%)	7.75	0.35	0.122
Break of slope alluvium - GMZ Zone 8 (Zone 4) (%)	25.0	0.35	0.122
Break of slope alluvium - Northeast (Zone 5) (%)	10.0	0.35	0.122
Break of slope alluvium - GMZ Zone 1 (Zone 6) (%)	25.0	0.35	0.122
Break of slope alluvium - Northwest (Zone 7) (%)	25.0	0.35	0.122
Break of slope alluvium – Watermark West (Zone 8) (%)	15.3	0.35	0.122
Break of slope alluvium - Central West (Zone 9) (%)	19.4	0.35	0.122

Table A.9: STATISTICS USED FOR ZONE-BASED RIVER PARAMETER GENERATION			
Zonal Parameter Type	**Mean (m/d)**	**Standard Deviation (log_{10})**	**Variance (log_{10})**
Riverbed permeability (Zone 1)	1.0	1.0	1.0
Riverbed permeability (Zone 2)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 3)	5.19E-03	1.0	1.0
Riverbed permeability (Zone 4)	1.0	1.0	1.0
Riverbed permeability (Zone 5)	7.48E-03	1.0	1.0
Riverbed permeability (Zone 6)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 7)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 8)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 9)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 10)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 11)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 12)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 13)	1.95E-03	1.0	1.0
Riverbed permeability (Zone 14)	1.95E-03	1.0	1.0

Table A.10: ELEMENTS OF COVARIANCE MATRIX APPLIED TO SPOIL PROPERTIES			
Lumped Parameter Type	**Mean**	**Standard Deviation (log_{10})**	**Variance (log_{10})**
Horizontal Hydraulic Conductivity of Spoil (m/d)	1	0.85	0.72
Vertical Hydraulic Conductivity of Spoil (m/d)	1	0.85	0.72
Specific Yield of Spoil (-)	0.1	0.15	0.023
Specific Storage of Spoil (m^{-1})	1E-3	0.50	0.25
Recharge of Spoil (%)	0.055	0.25	0.063

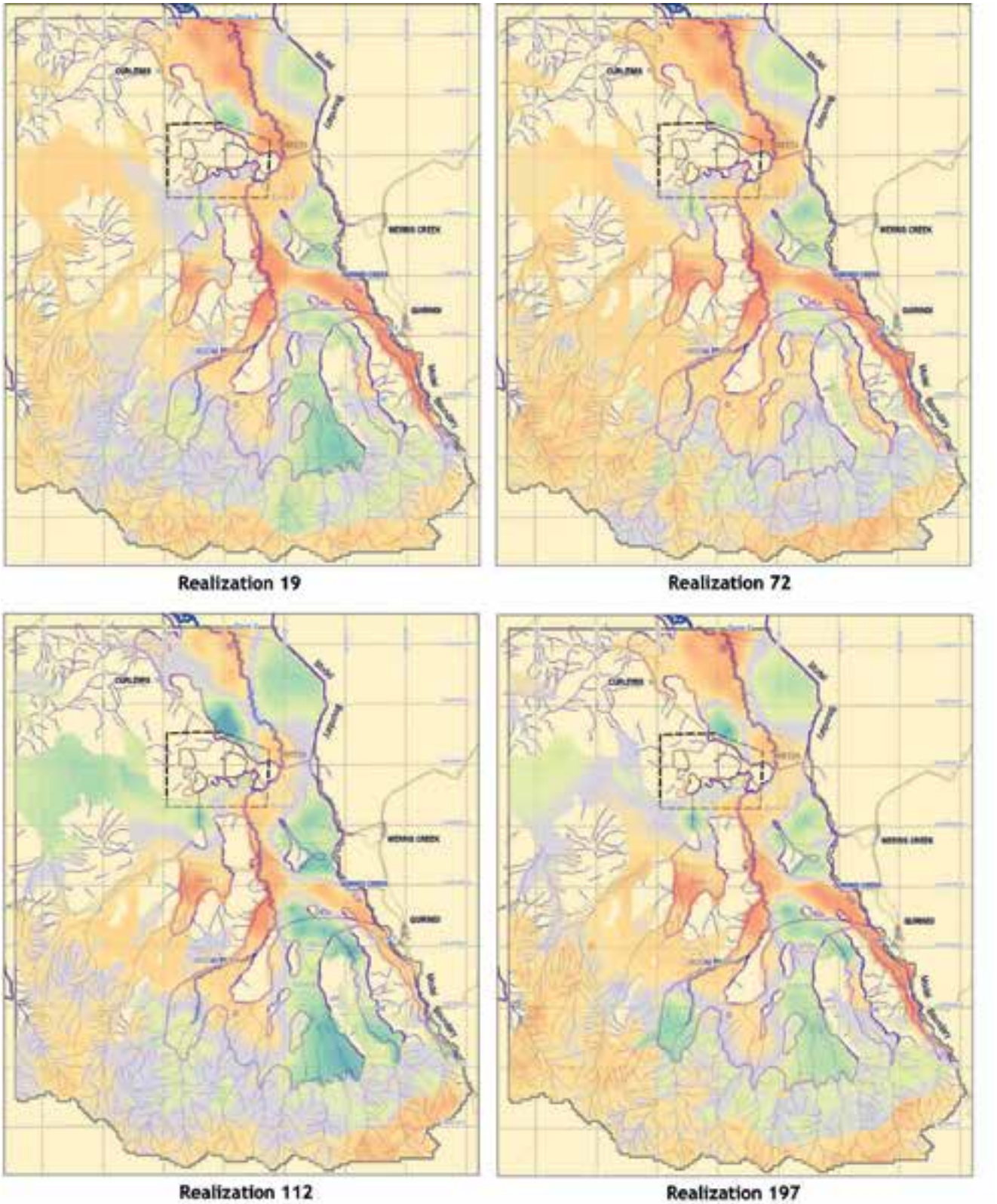
A8.3.2 Implementation

A total of 500 random realisations were generated on the basis of both parameter-by-parameter variability and cell-by-cell parameter variability. Each of these parameter sets were run using the transient calibration simulation. The relative objective function (i.e. the computed objective function for a given realisation normalised by the calibrated objective function of 615) ranged from 1.12 to 35.1; recall that the pre-calibration objective function noted in Section 9.2.1 of the main report was 14,000 (i.e. a relative objective function of 22.8). The average relative objective function was 3.4 with a standard deviation of 2.9 across the 500 parameter sets. As previously noted, the

realisations were ranked in increasing order of relative objective function, and to remove the most de-calibrated realisations, the 50th percentile was adopted as a cut-off level for acceptance (i.e. 250 realisations) for use in uncertainty analysis of the predictive simulations. The maximum relative objective function value for the 250 realisation subsets was 2.07 with a standard deviation of 0.5. This indicates a reasonable degree of conformance to transient calibration performance; in a real-world context such extra variability in these objective functions provides room for the effects of structural noise. Thus a greater level of model-to-measurement misfit than that which would be suggested on the basis of measurement noise alone is tolerated, while maintaining an acceptable level of "de-calibration" given that only pre-development observations were available.

Figure 3.1ab-3.44ab shows a sample (8) of the 250 stochastic parameter fields for the hydraulic conductivity, vertical conductivity, confined aquifer storage coefficient and specific yield in model layers 1-11 respectively. "Notional" cells (i.e. active cells of minimum thickness that allow vertical connectivity between layers to be maintained) are not shown for ease of inspection. Each of these parameter fields pertaining to layer 1 and 2 are based on pilot points, the horizontal and vertical hydraulic conductivity parameter fields for layer 8 and 10 are based on pilot point multipliers in conjunction with layer-wide hydraulic properties, whereas all other parameter fields are based on cell-by-cell stochastic field generation (for hydraulic conductivity, vertical conductivity, confined aquifer storage coefficient and specific yield).

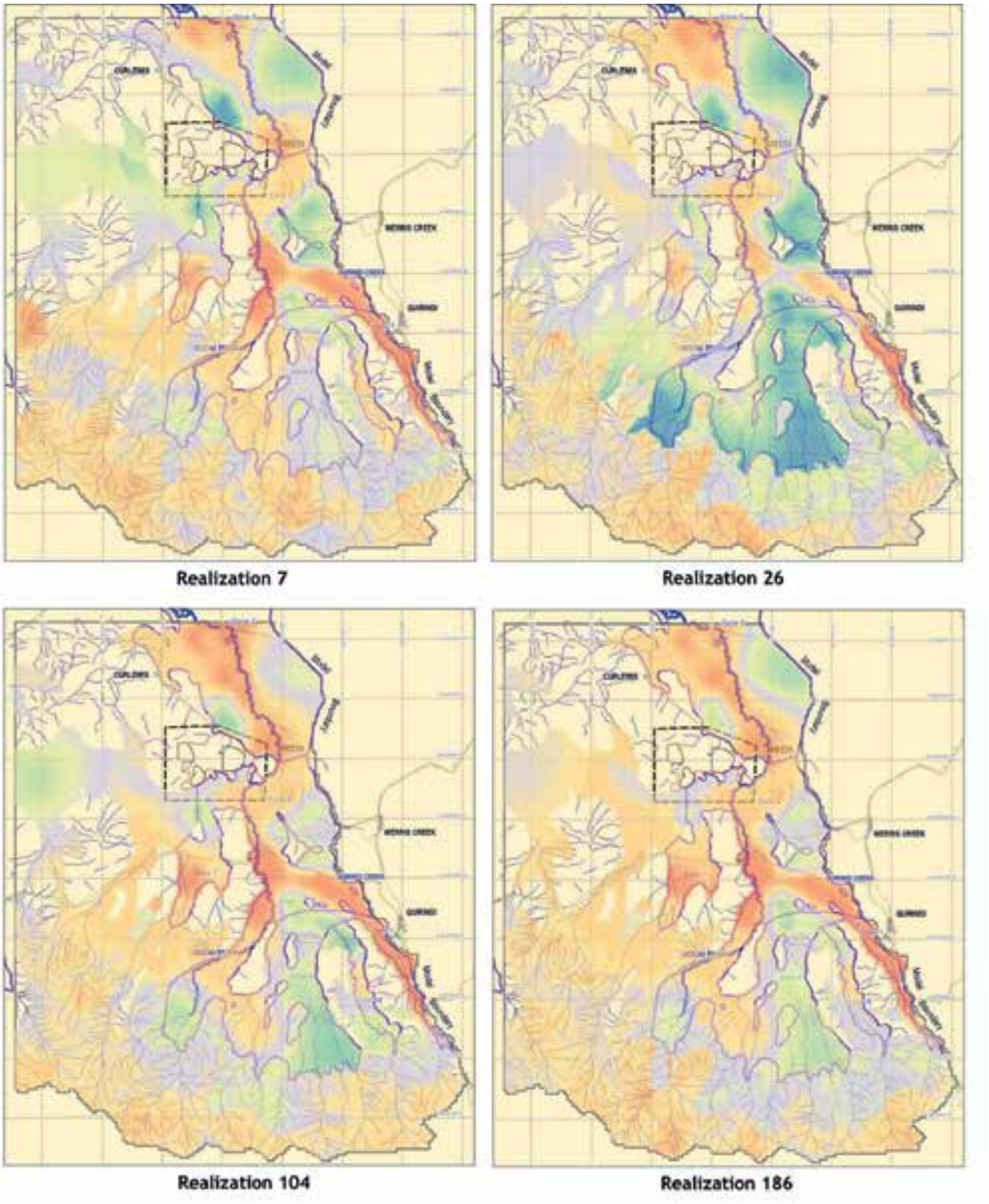
For other parameter fields continuous over the model domain, a cell-based statistical analysis of the realisations was undertaken to provide a visualisation of the variability in actual parameter values across the model domain. Figures 3-45 to 3-46 summarise the cell-based variability in layer-specific parameter variations across 250 realisations for annual average recharge and annual average evapotranspiration, respectively. Cell-by-cell statistics for parameter fields which are discretely represented (i.e. which occupy selected interior regions of the model domain) such as riverbed permeability, general head boundary conductance, groundwater extraction rate and fault permeability per unit width are provided in Figure 3-47 to 3-50 respectively. It should be emphasised that none of these fields represent actual realisations; they merely convey a statistically-derived bandwidth of parameter realisations performed in the stochastic analyses.



Realizations of Horizontal Hydraulic Conductivity (Layer 1)

Figure 3.1a

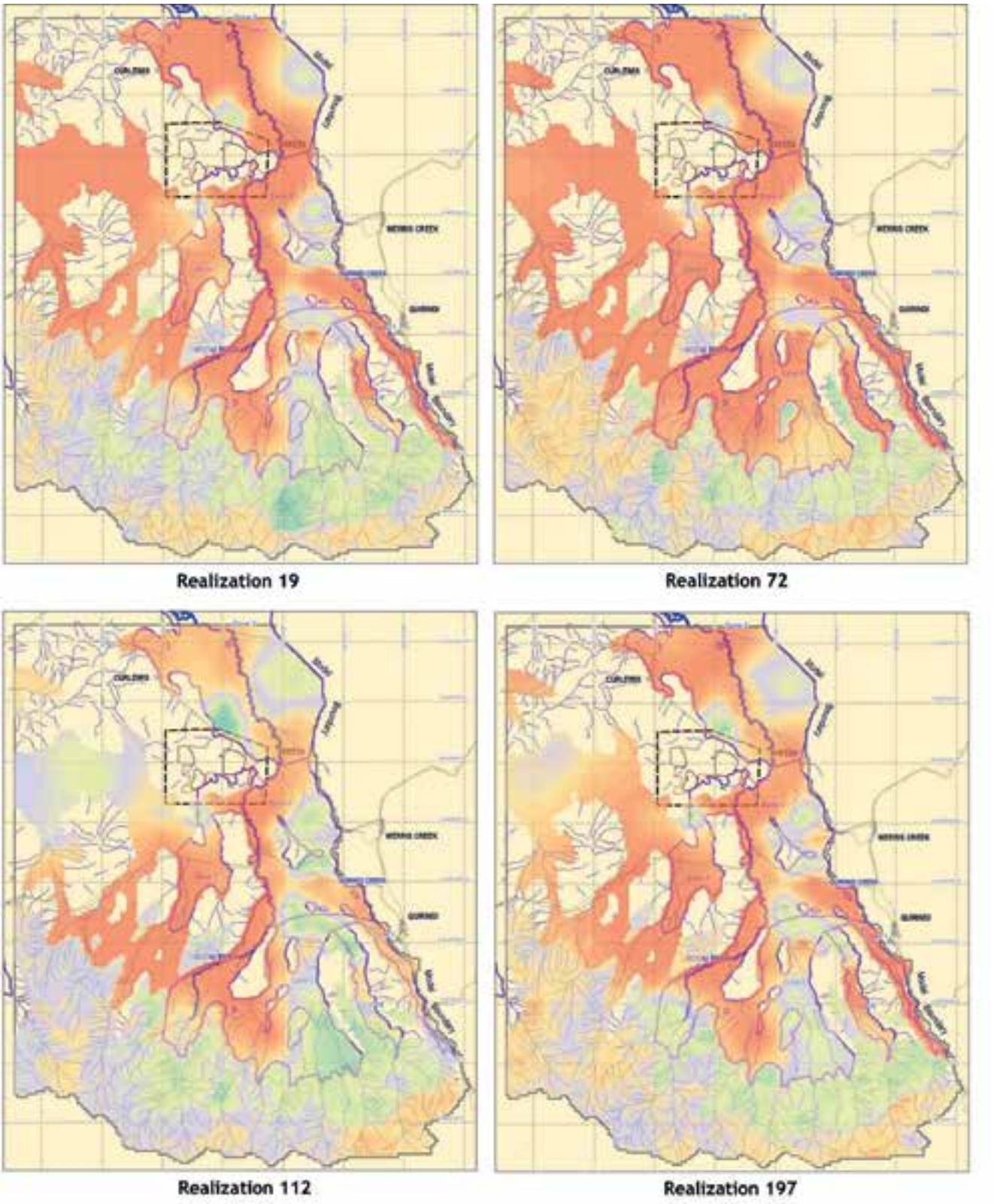
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 1)

Figure 3.1b

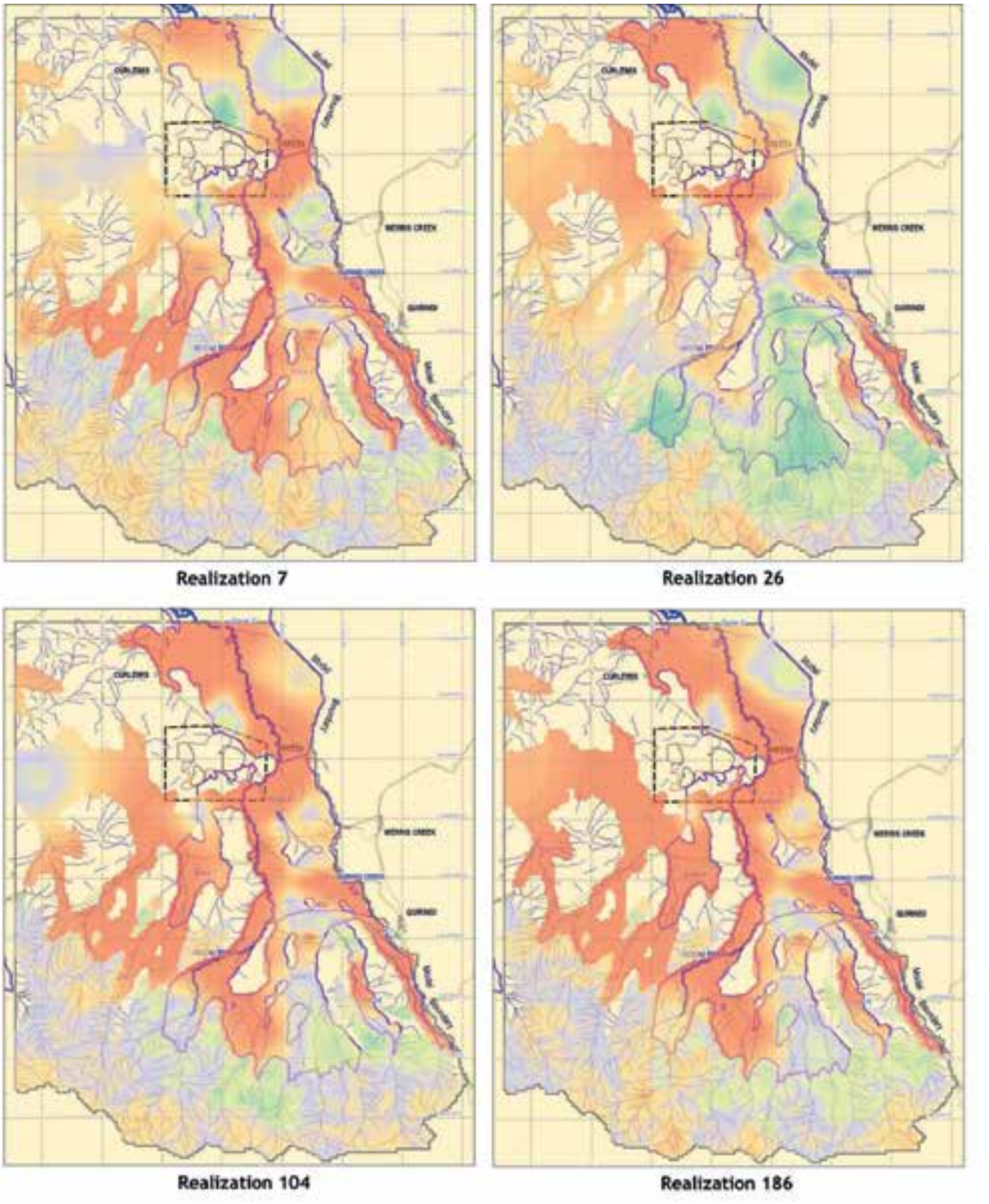
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 2)

Figure 3.2a

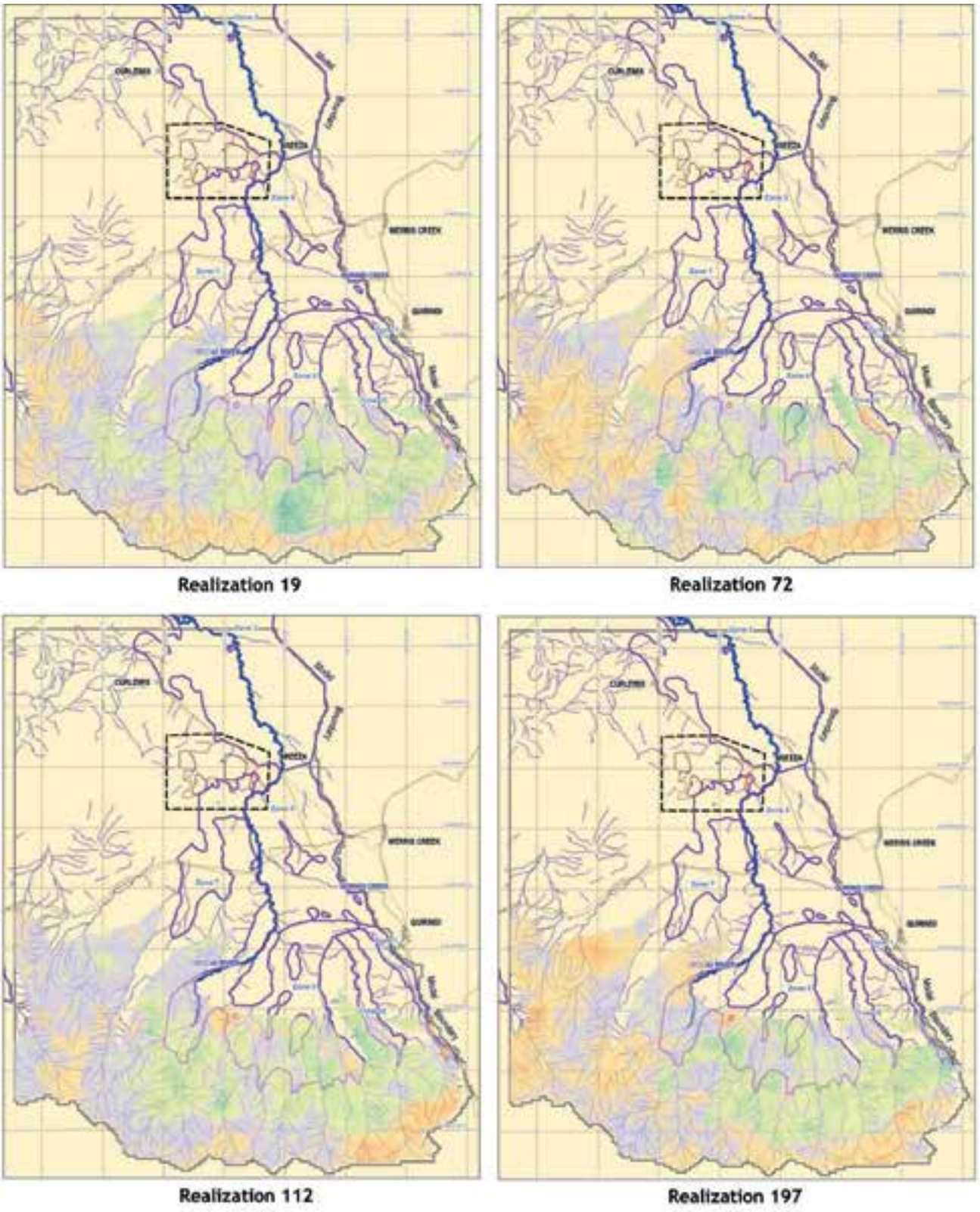
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 2)

Figure 3.2b

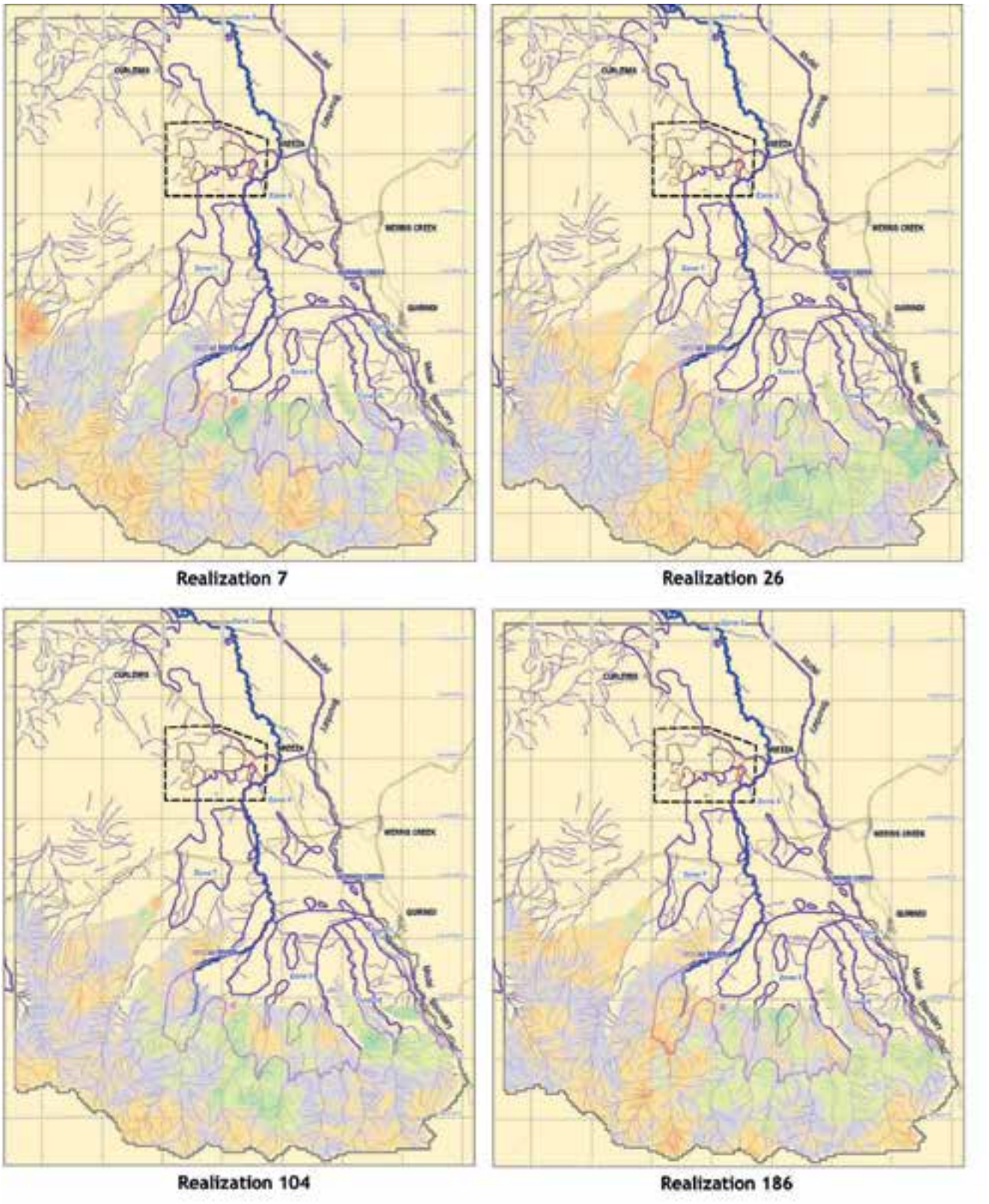
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 3)

Figure 3.3a

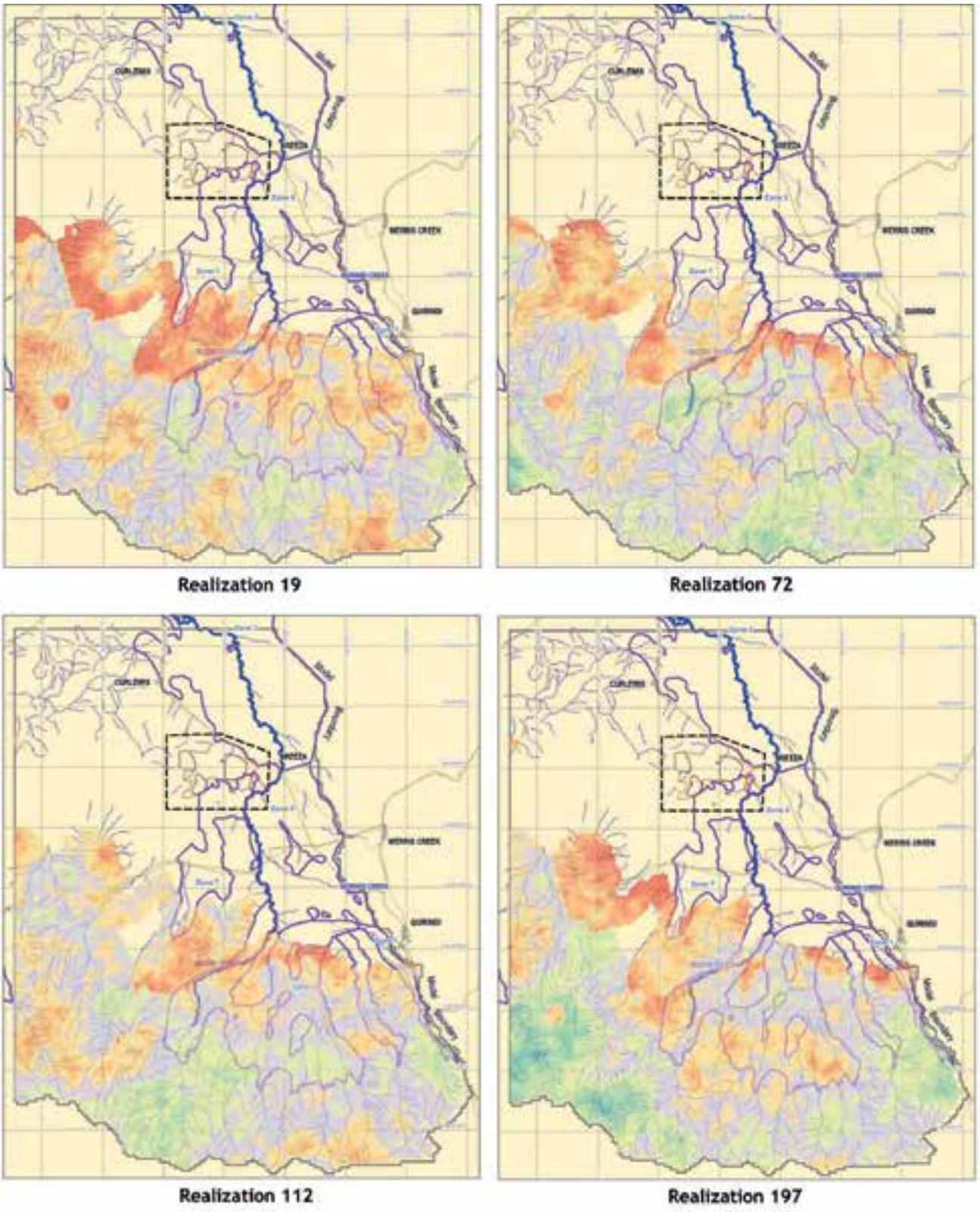
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 3)

Figure 3.3b

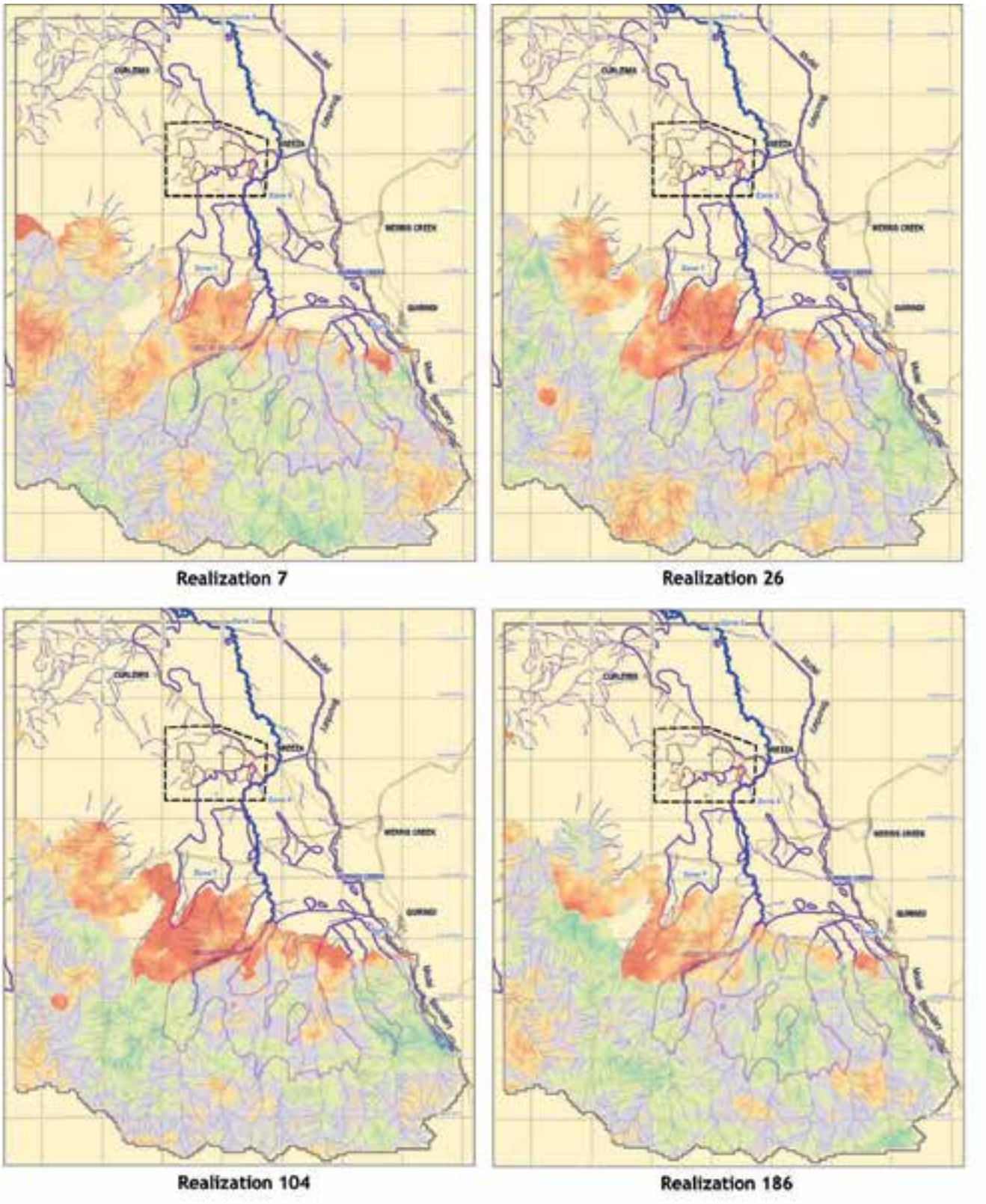
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 4)

Figure 3.4a

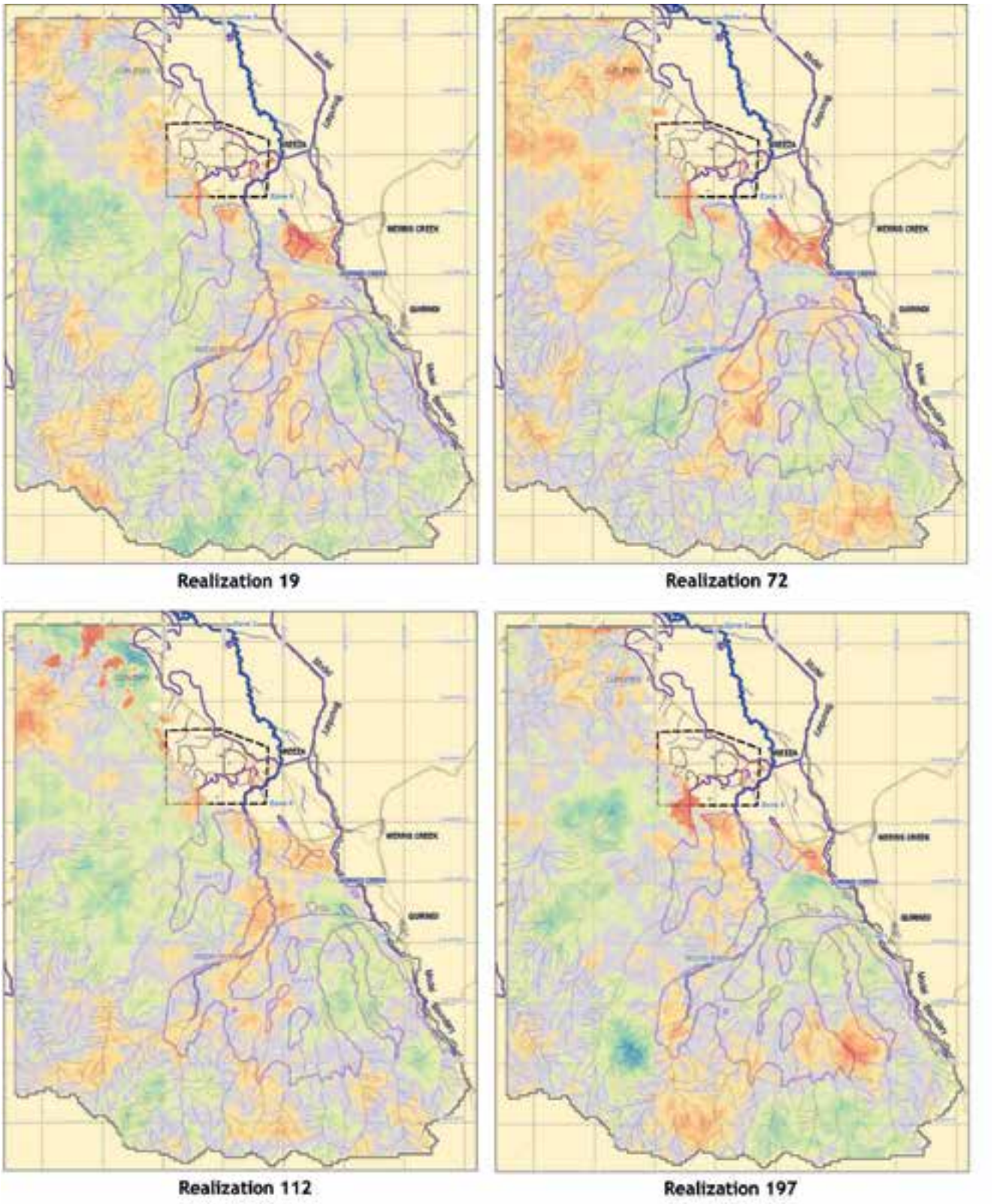
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 4)

Figure 3.4b

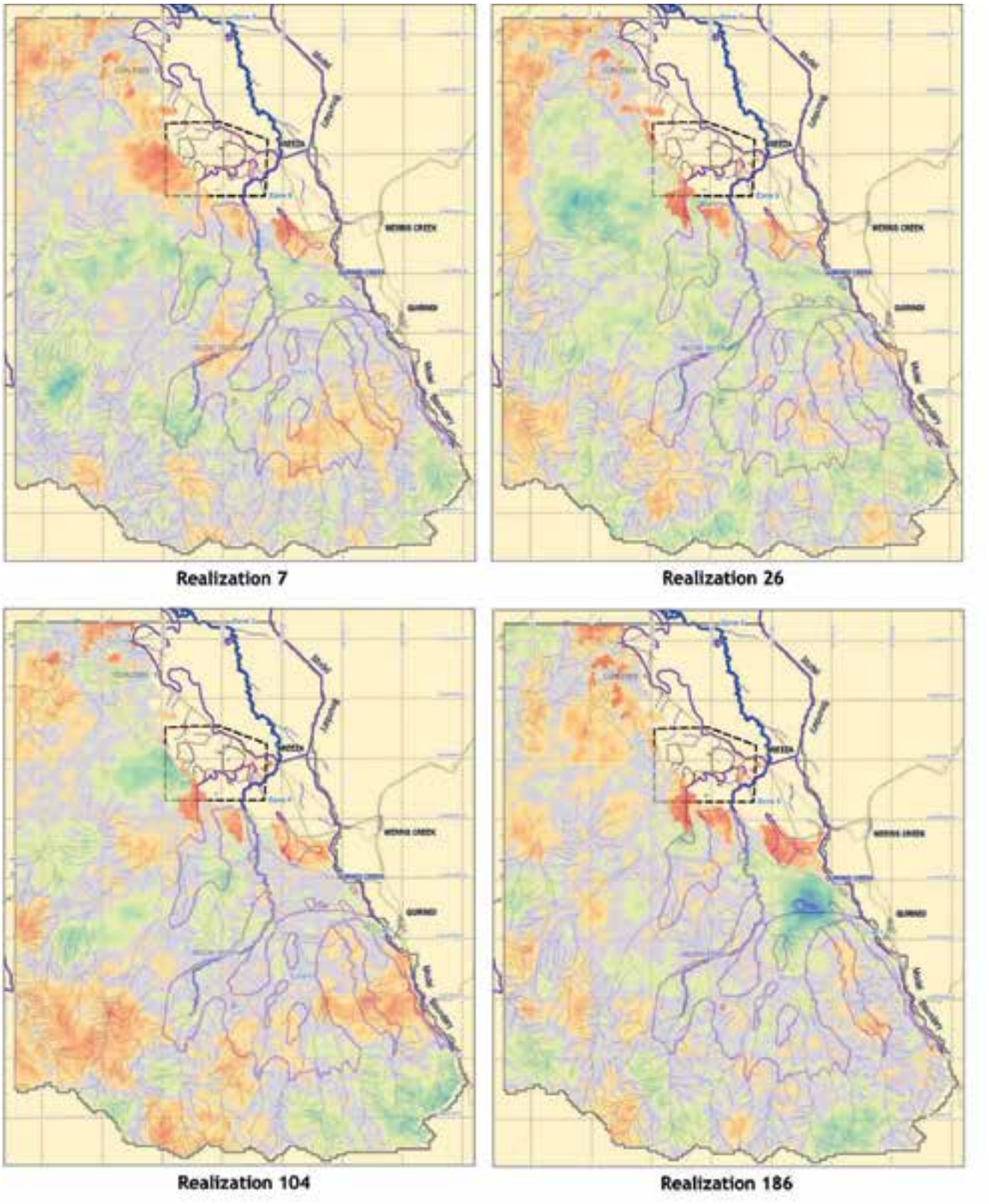
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 5)

Figure 3.5a

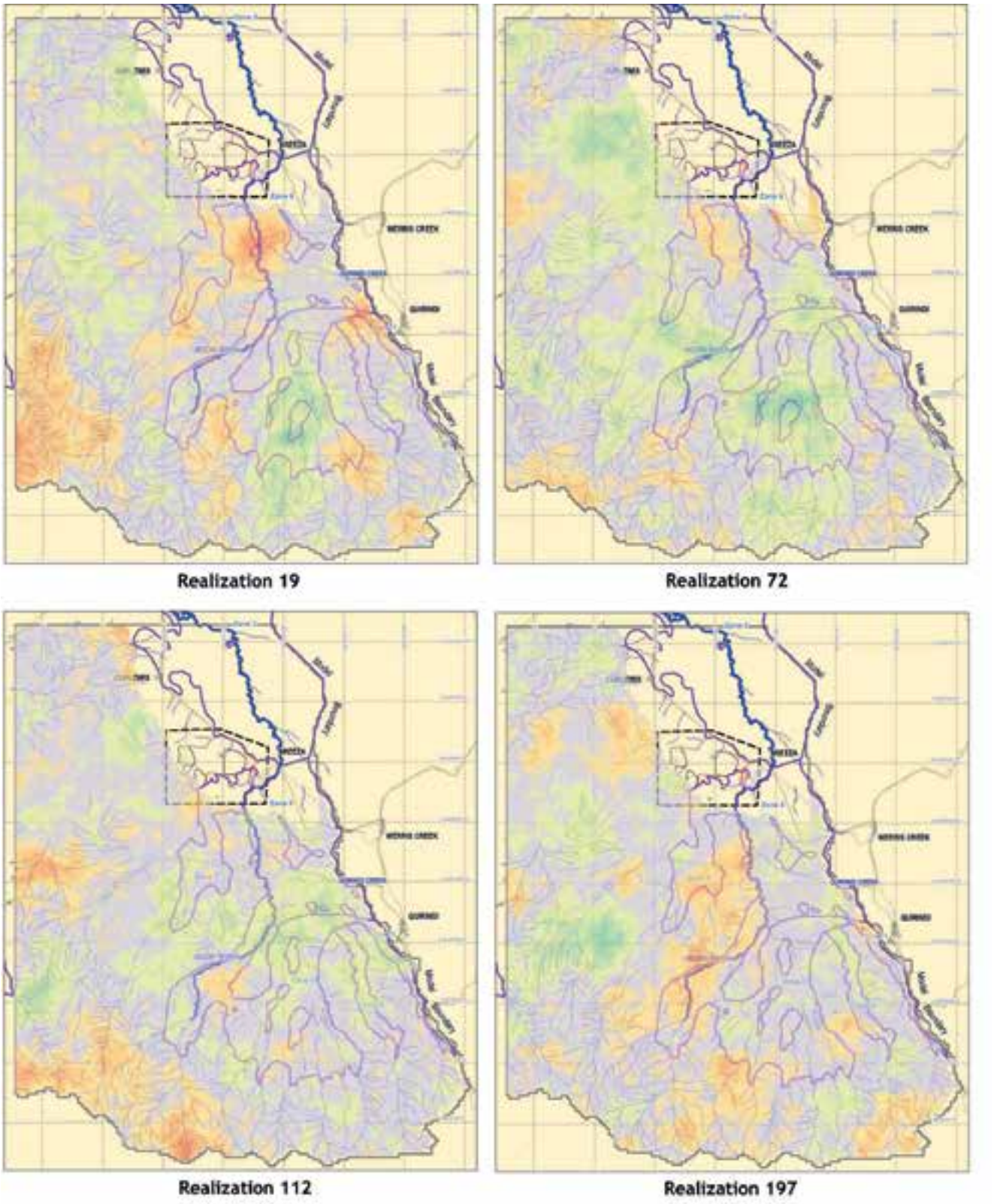
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 5)

Figure 3.5b

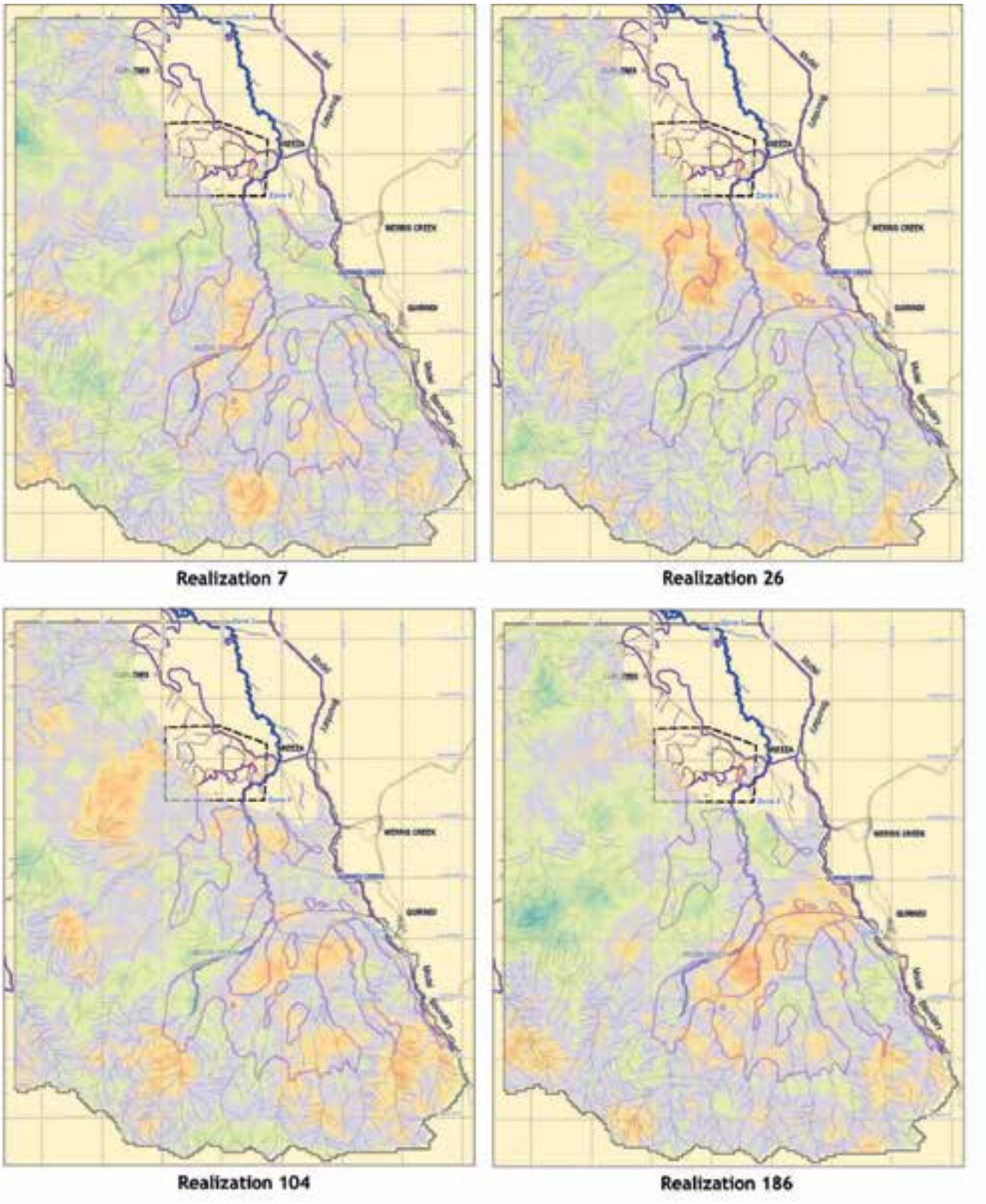
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 6)

Figure 3.6a

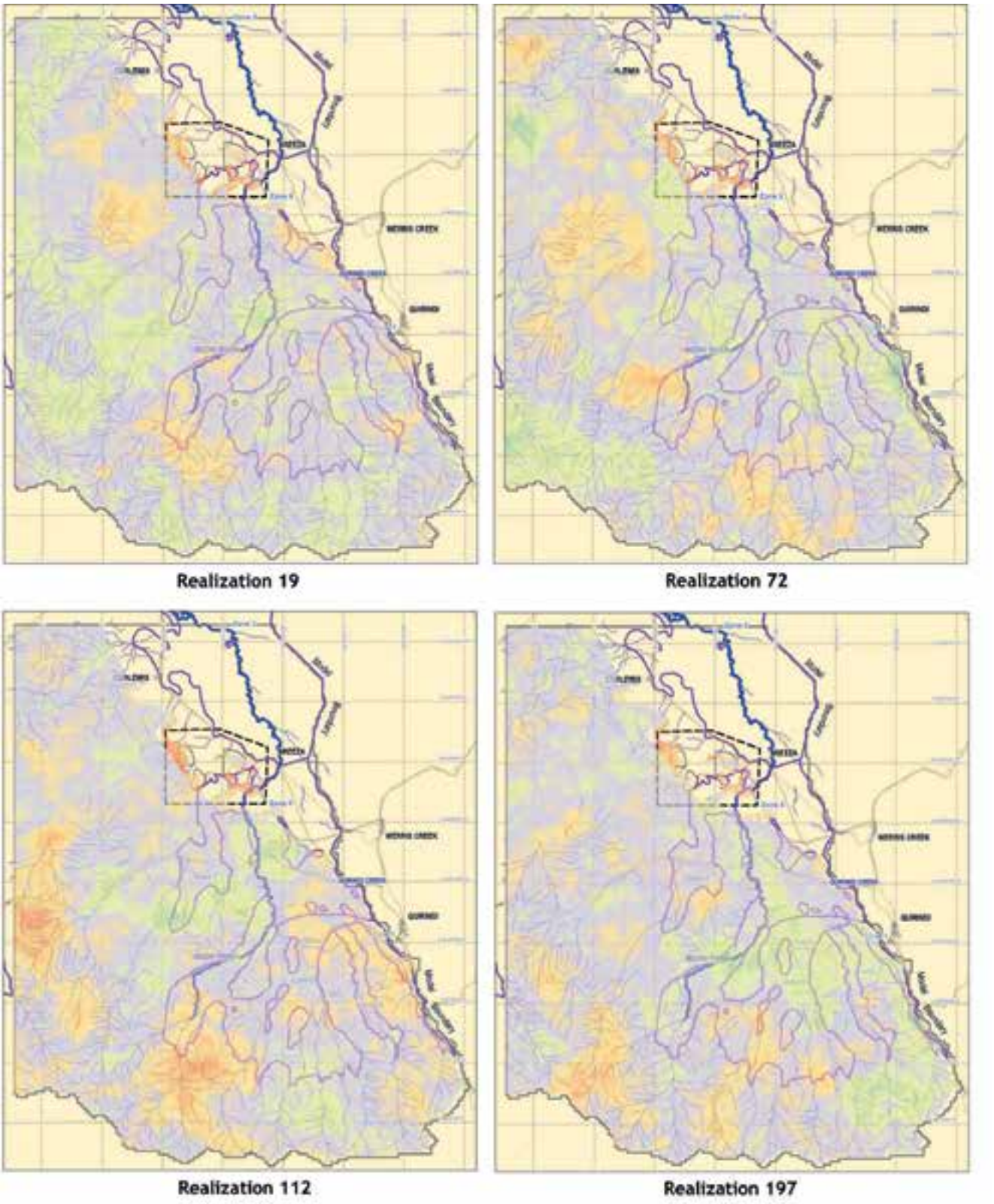
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 6)

Figure 3.6b

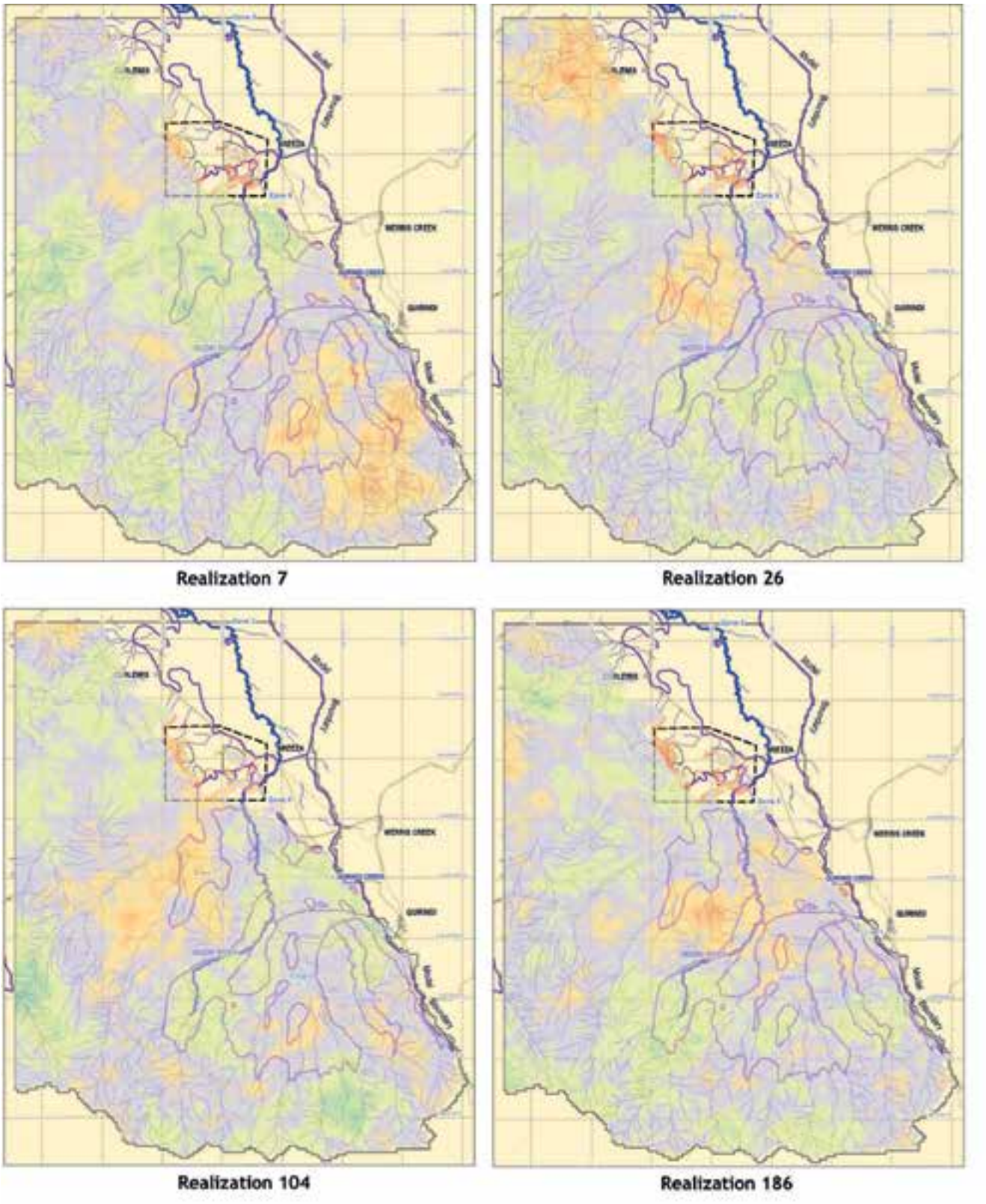
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 7)

Figure 3.7a

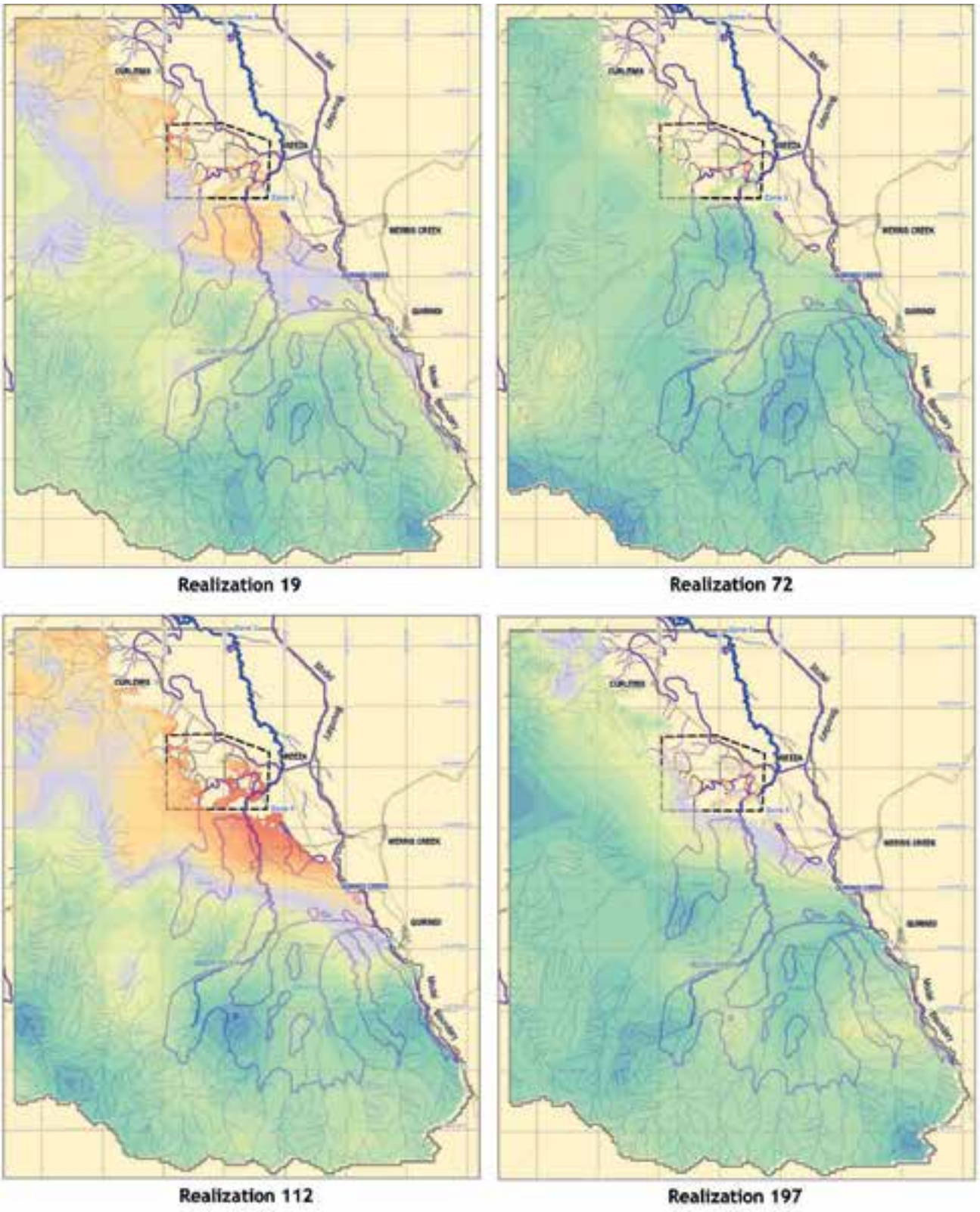
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 7)

Figure 3.7b

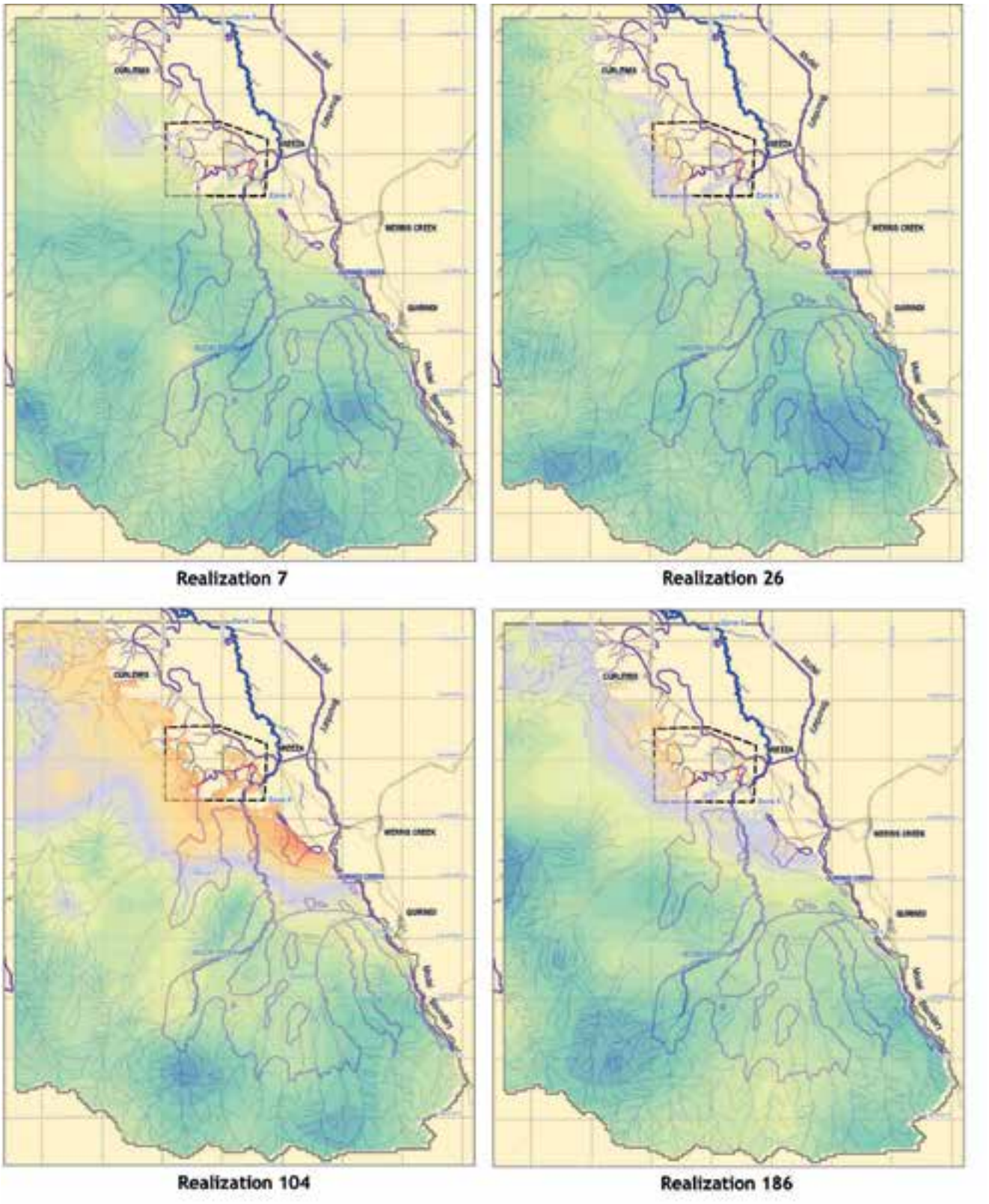
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 8)

Figure 3.8a

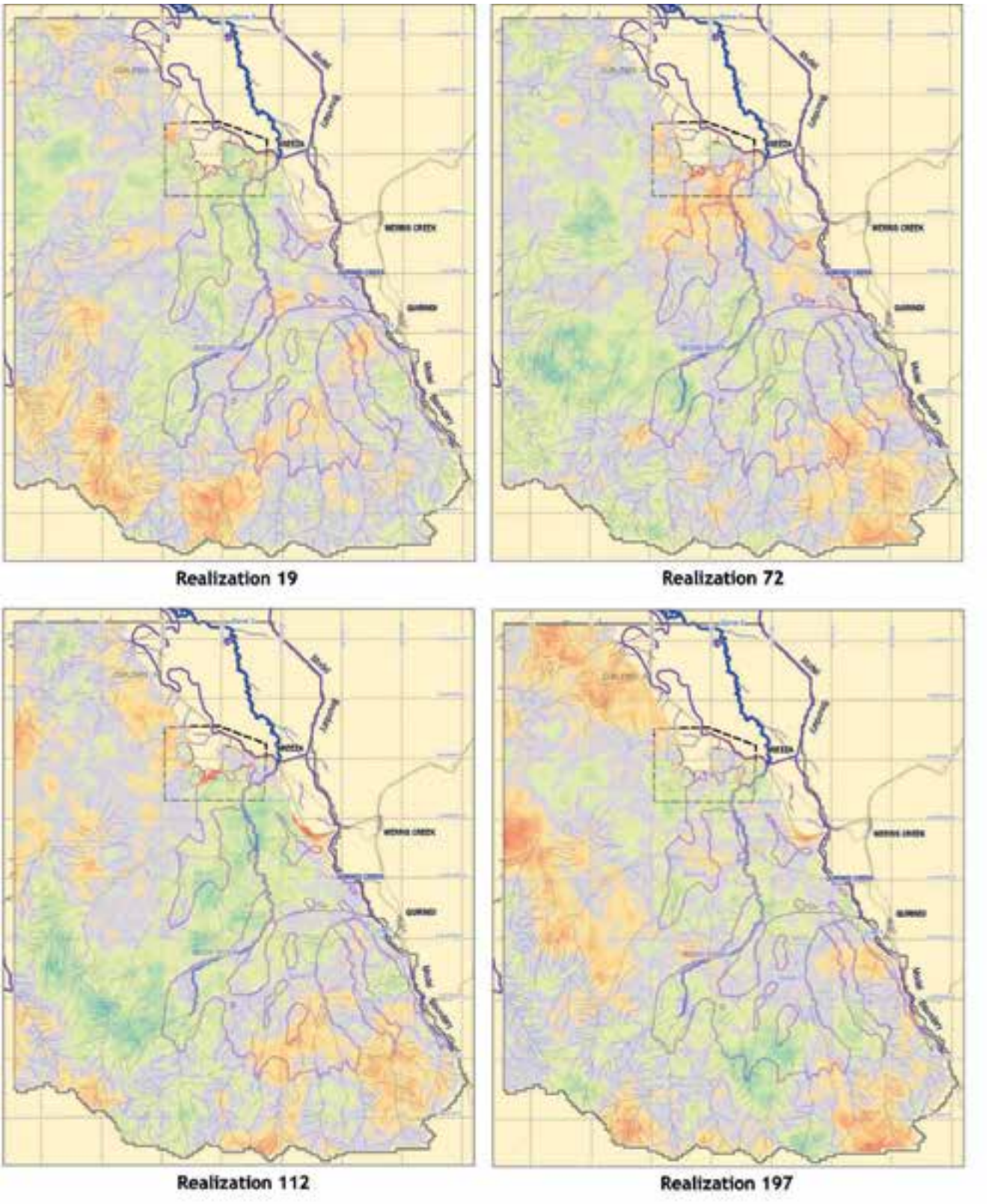
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 8)

Figure 3.8b

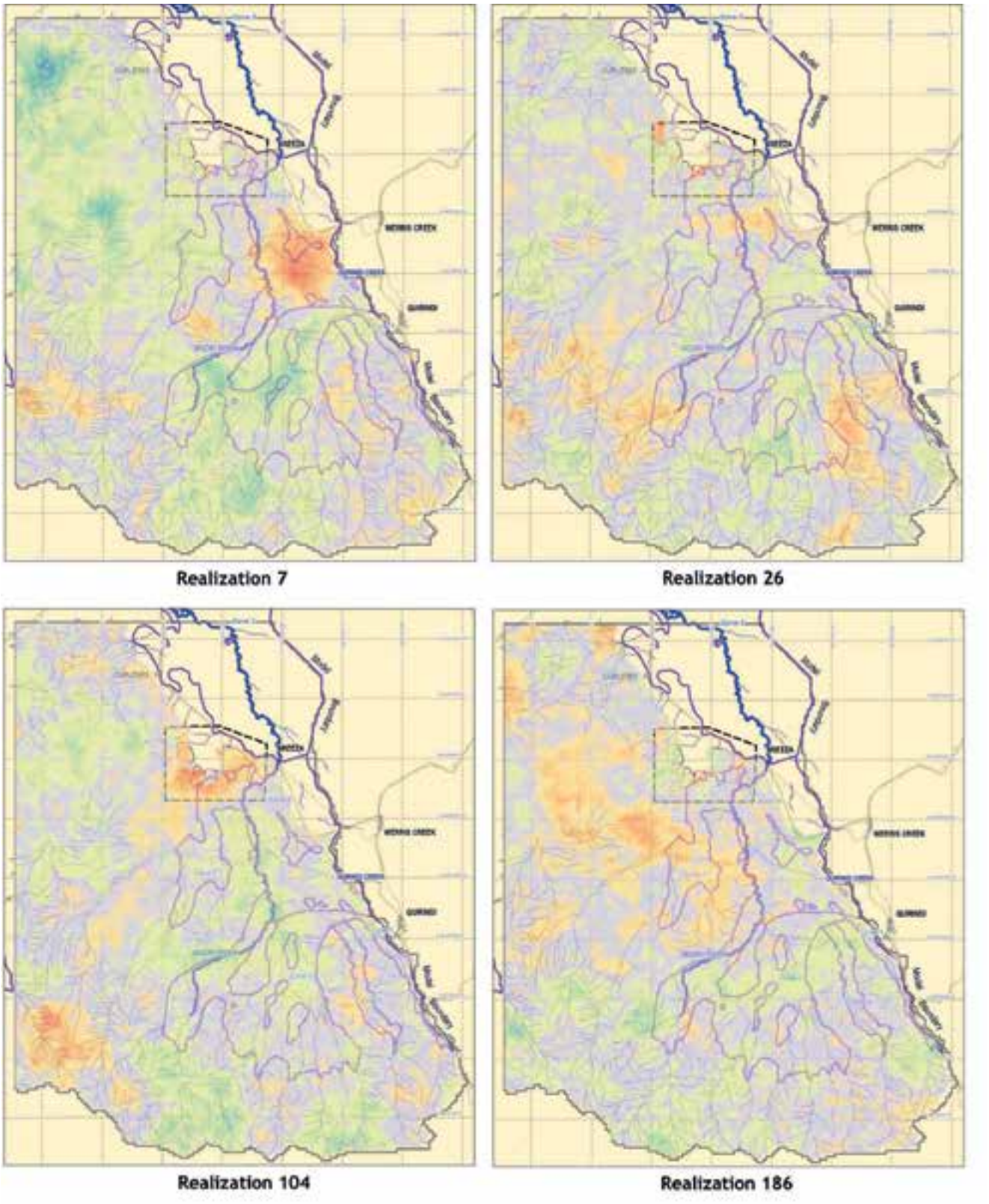
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 9)

Figure 3.9a

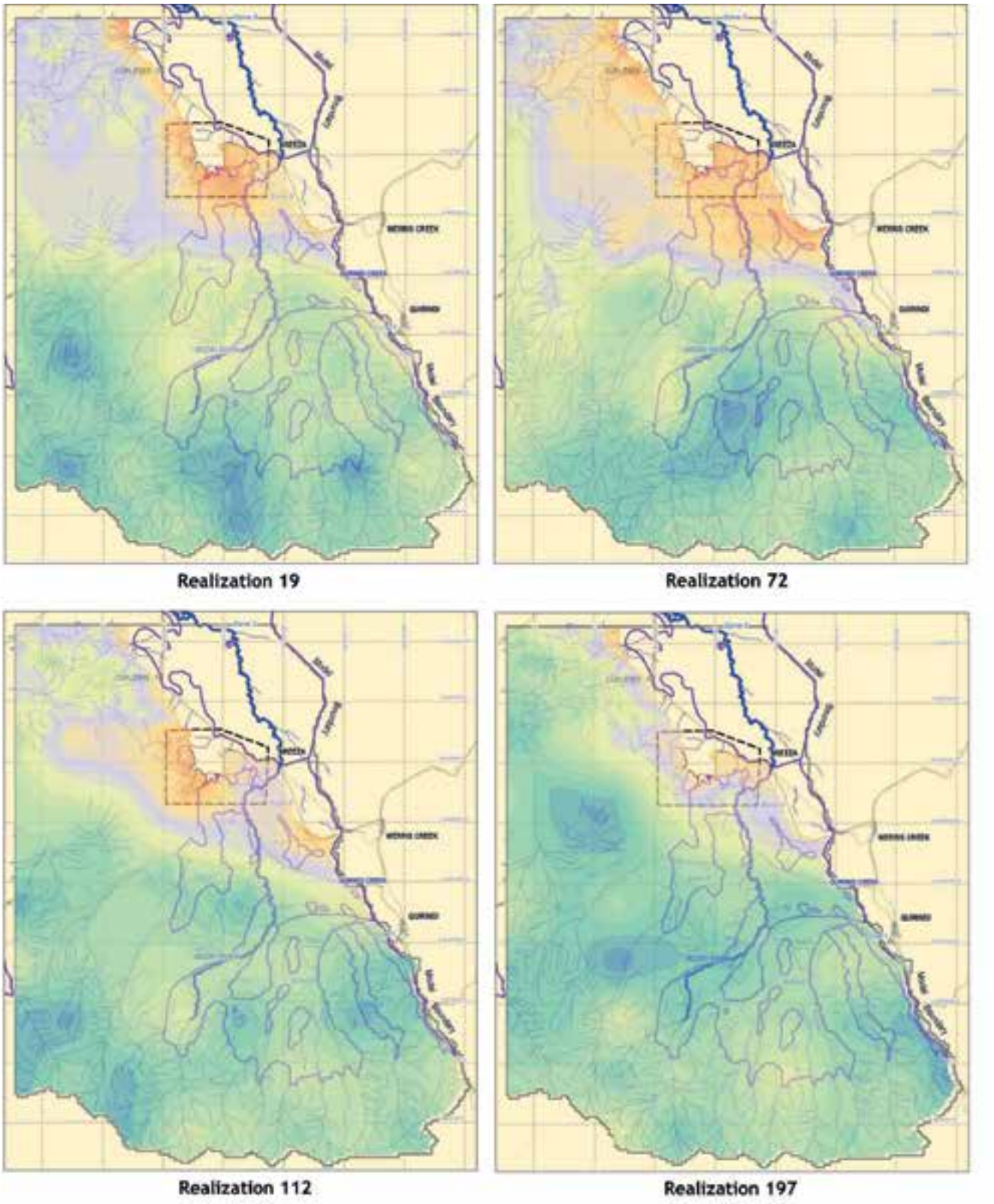
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 9)

Figure 3.9b

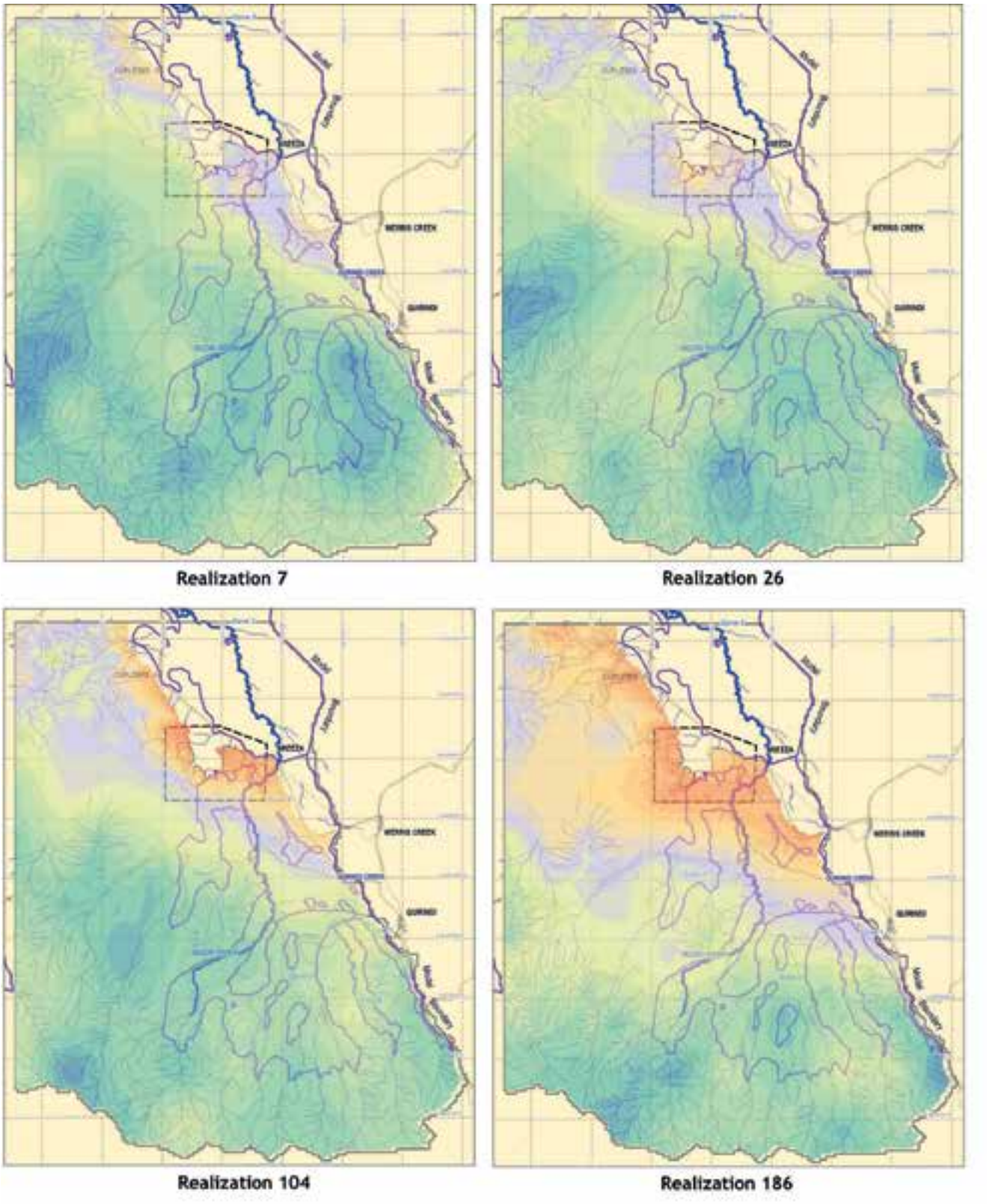
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 10)

Figure 3.10a

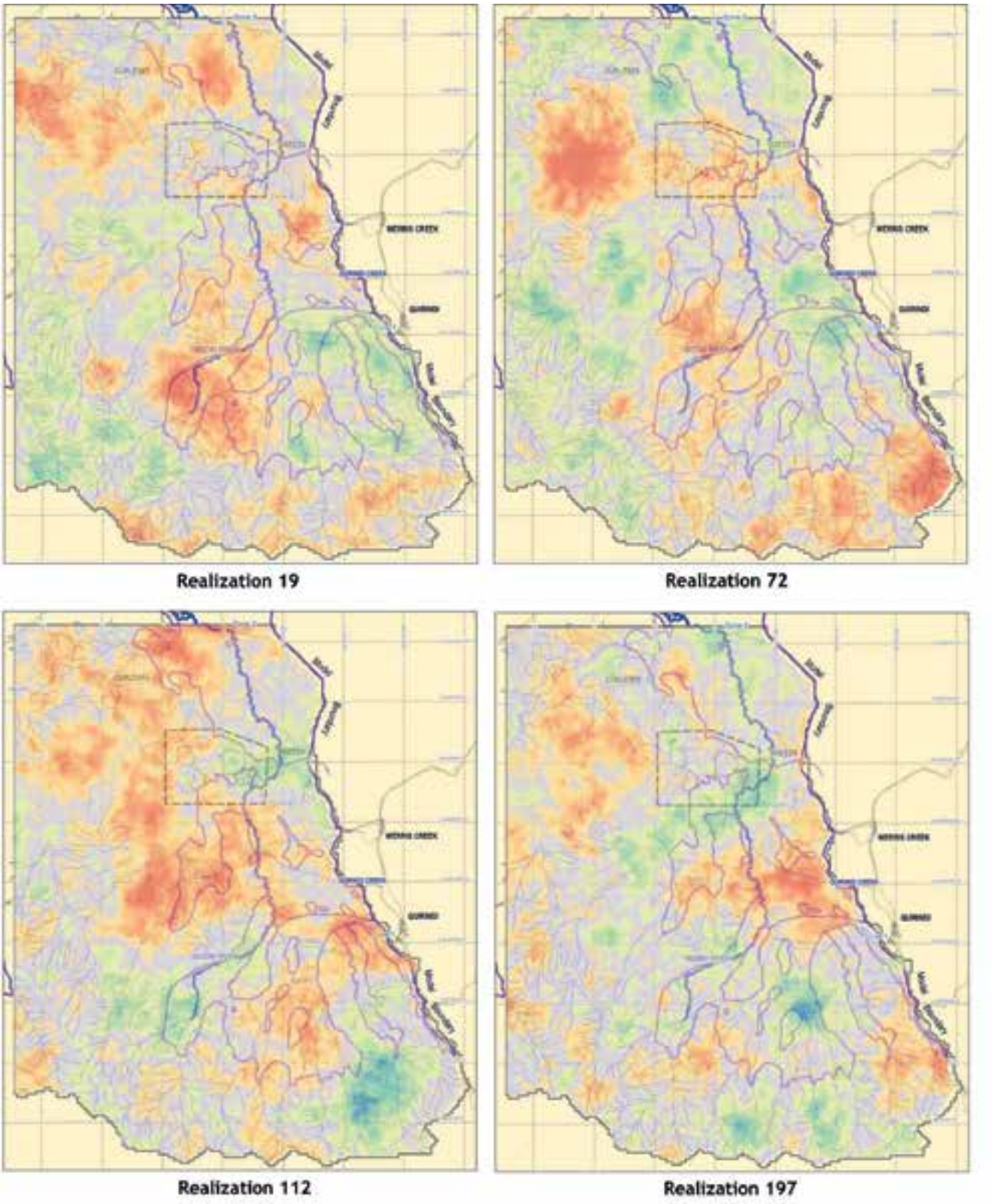
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 10)

Figure 3.10b

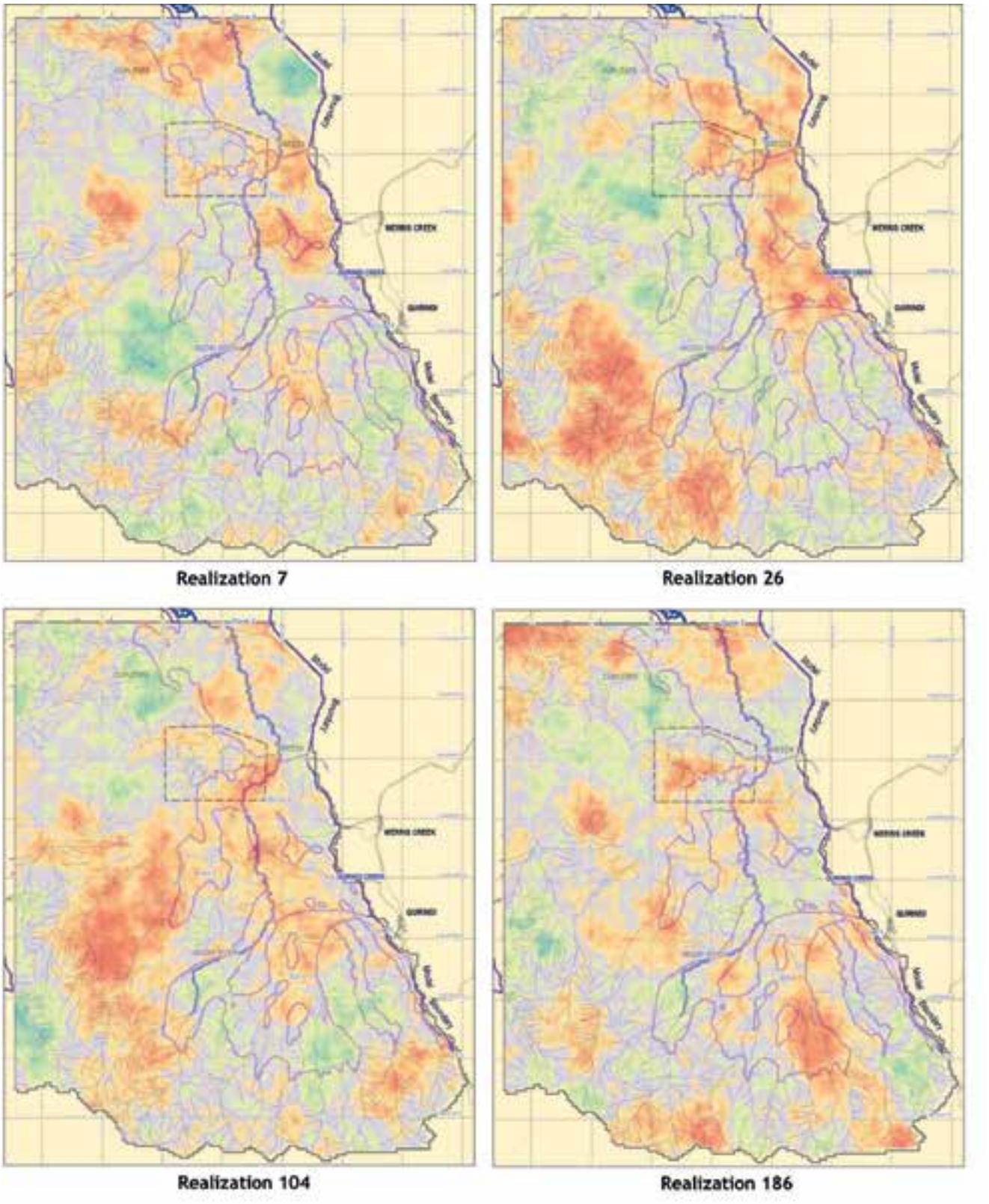
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 11)

Figure 3.11a

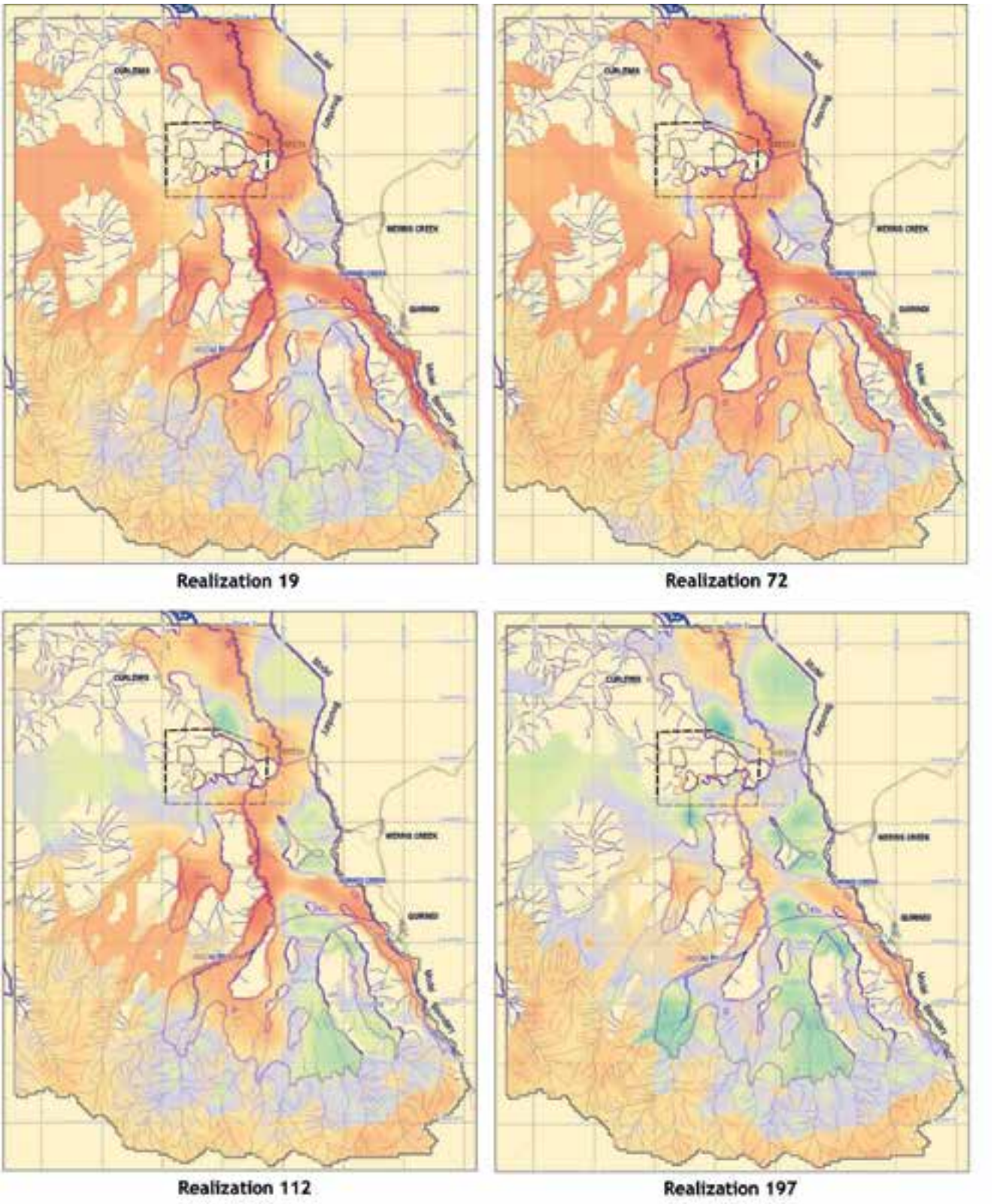
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Horizontal Hydraulic Conductivity (Layer 11)

Figure 3.11b

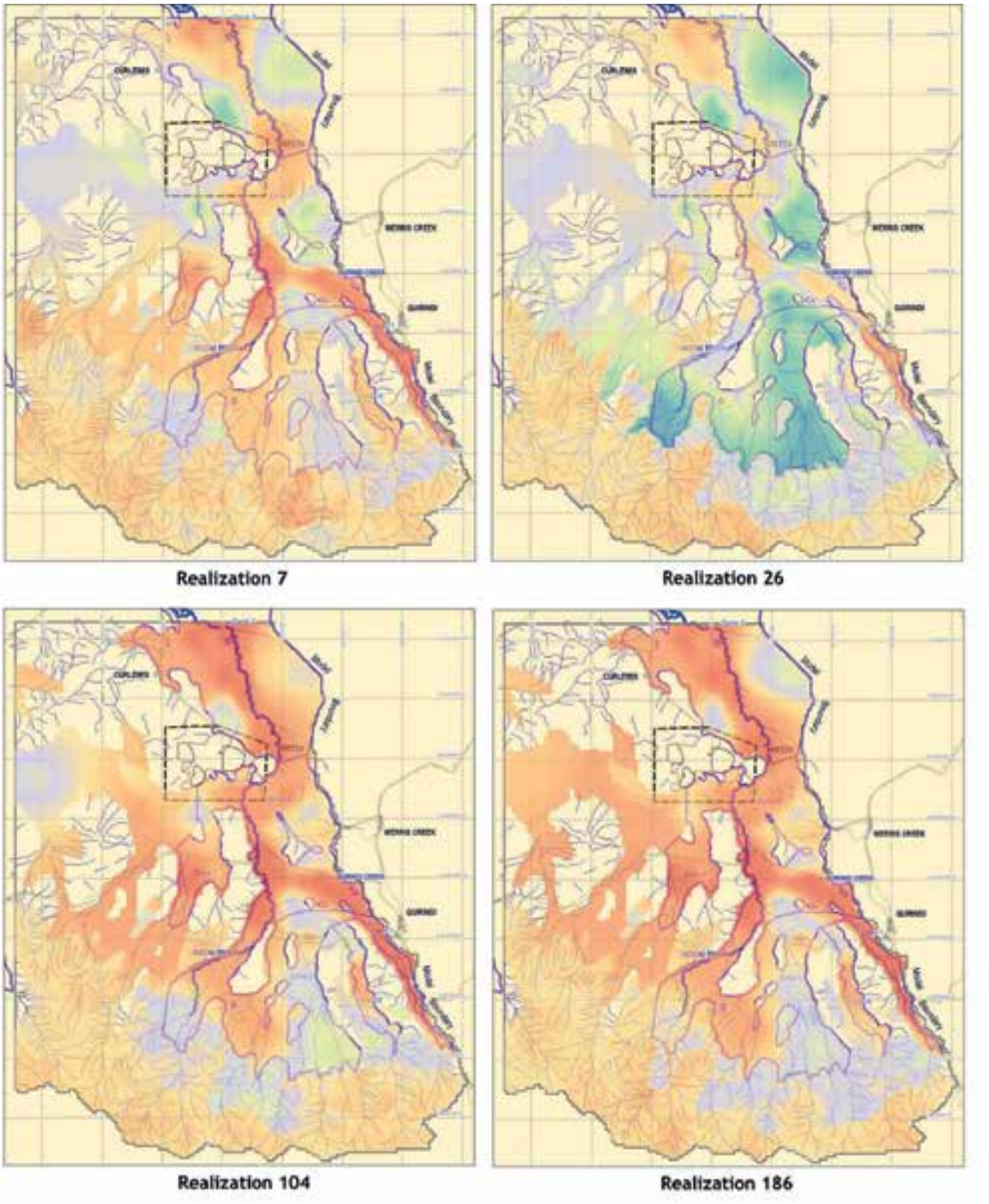
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 1)

Figure 3.12a

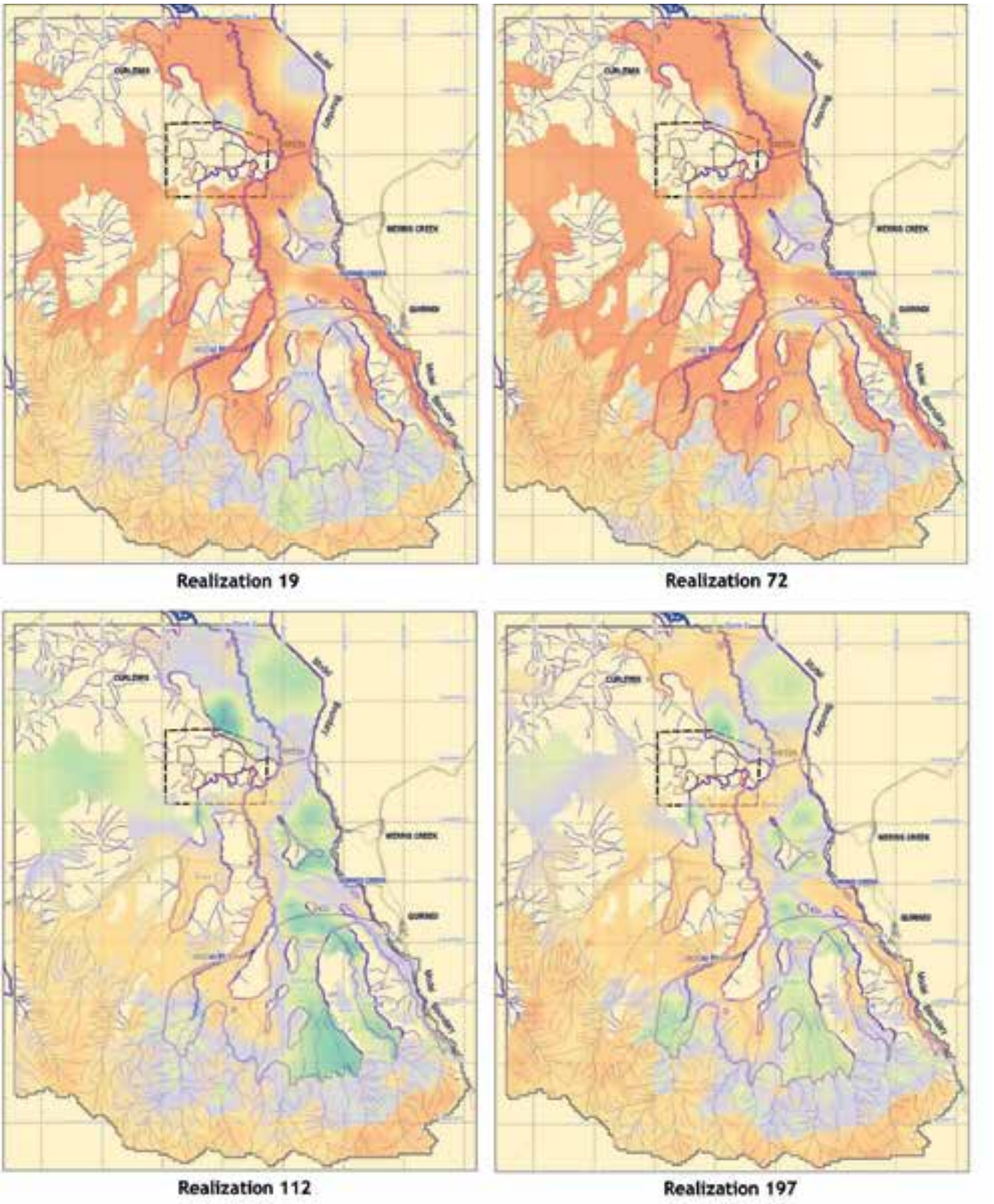
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 1)

Figure 3.12b

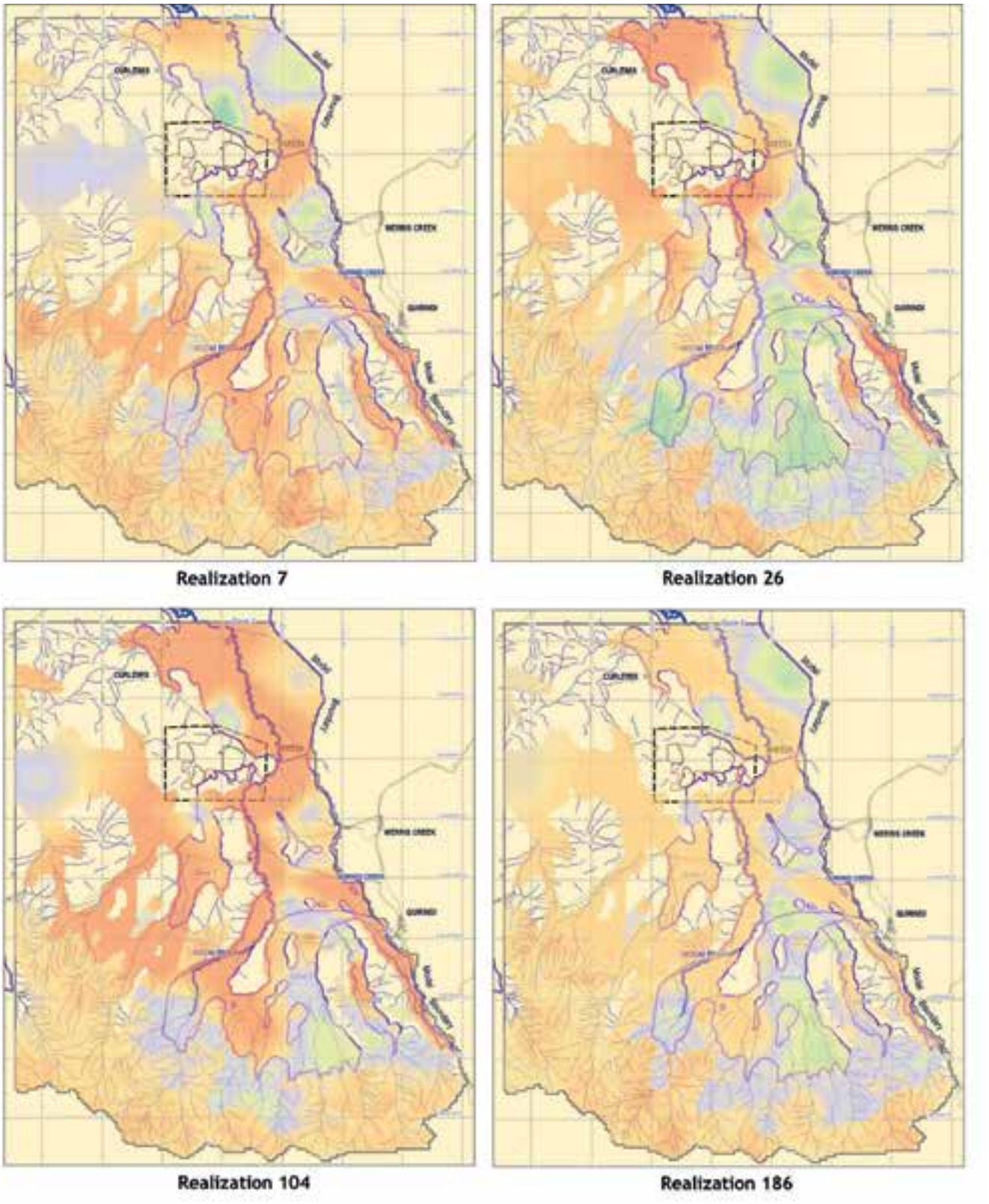
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 2)

Figure 3.13a

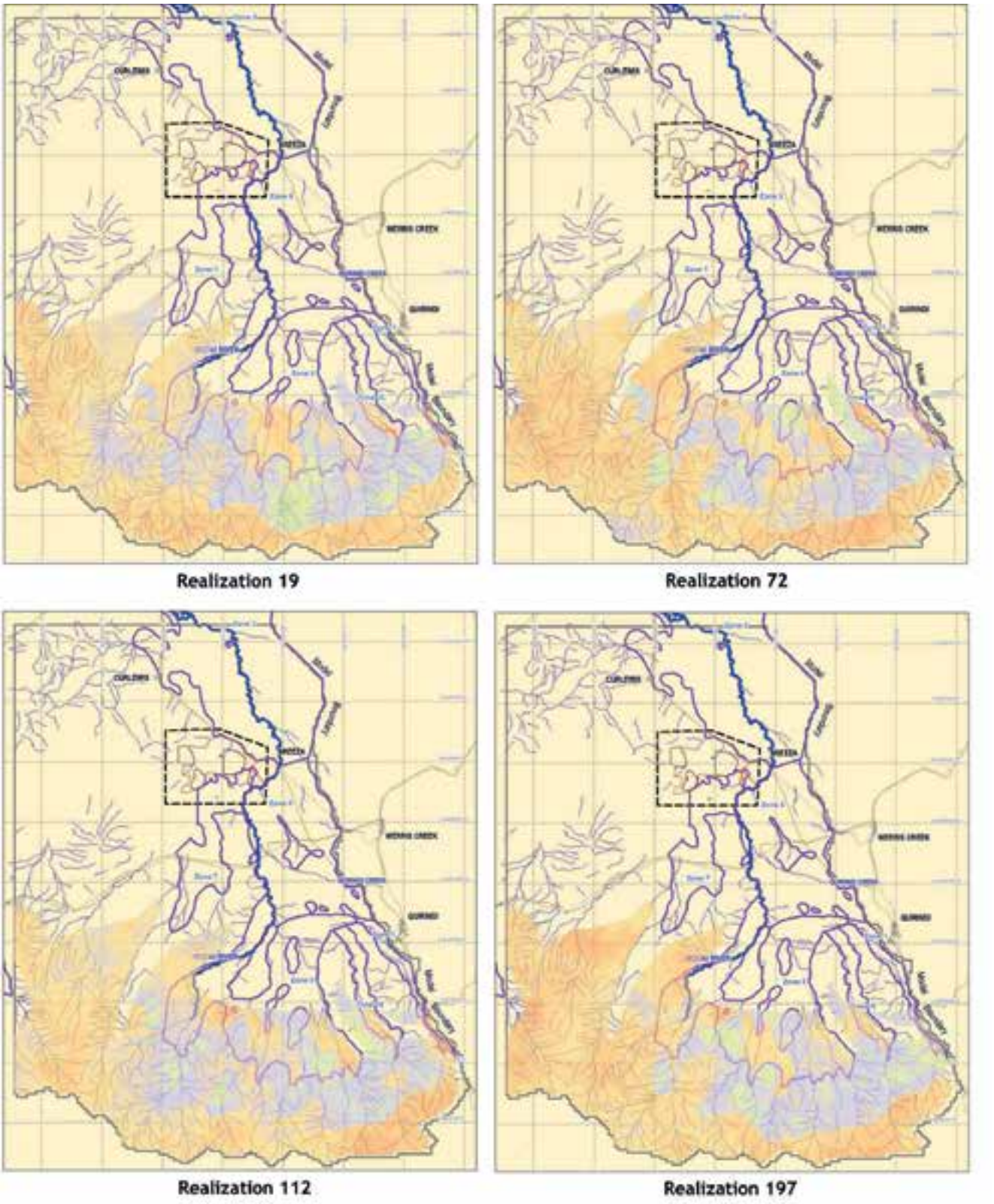
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 2)

Figure 3.13b

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



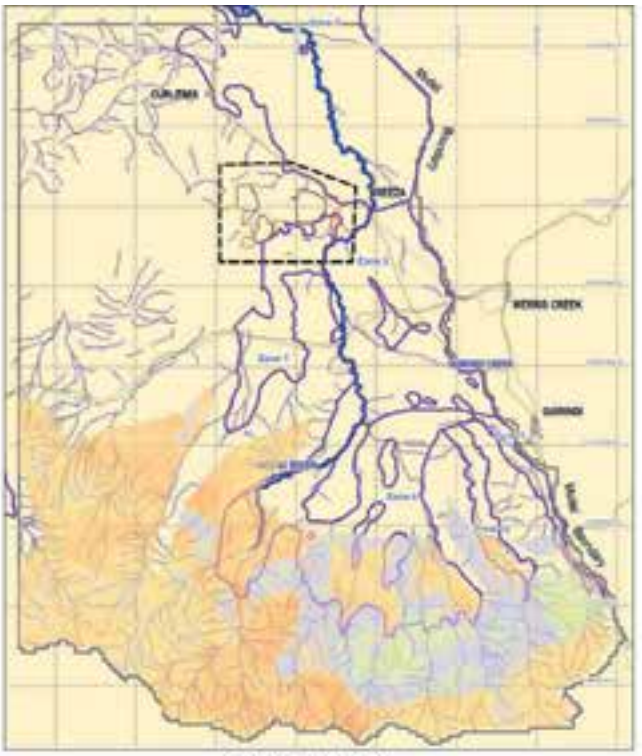
Realizations of Vertical Hydraulic Conductivity (Layer 3)

Figure 3.14a

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realization 7



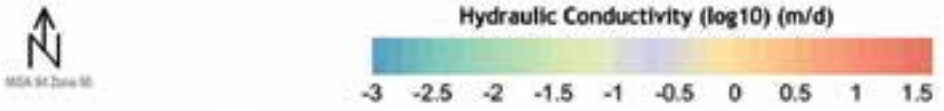
Realization 26



Realization 104



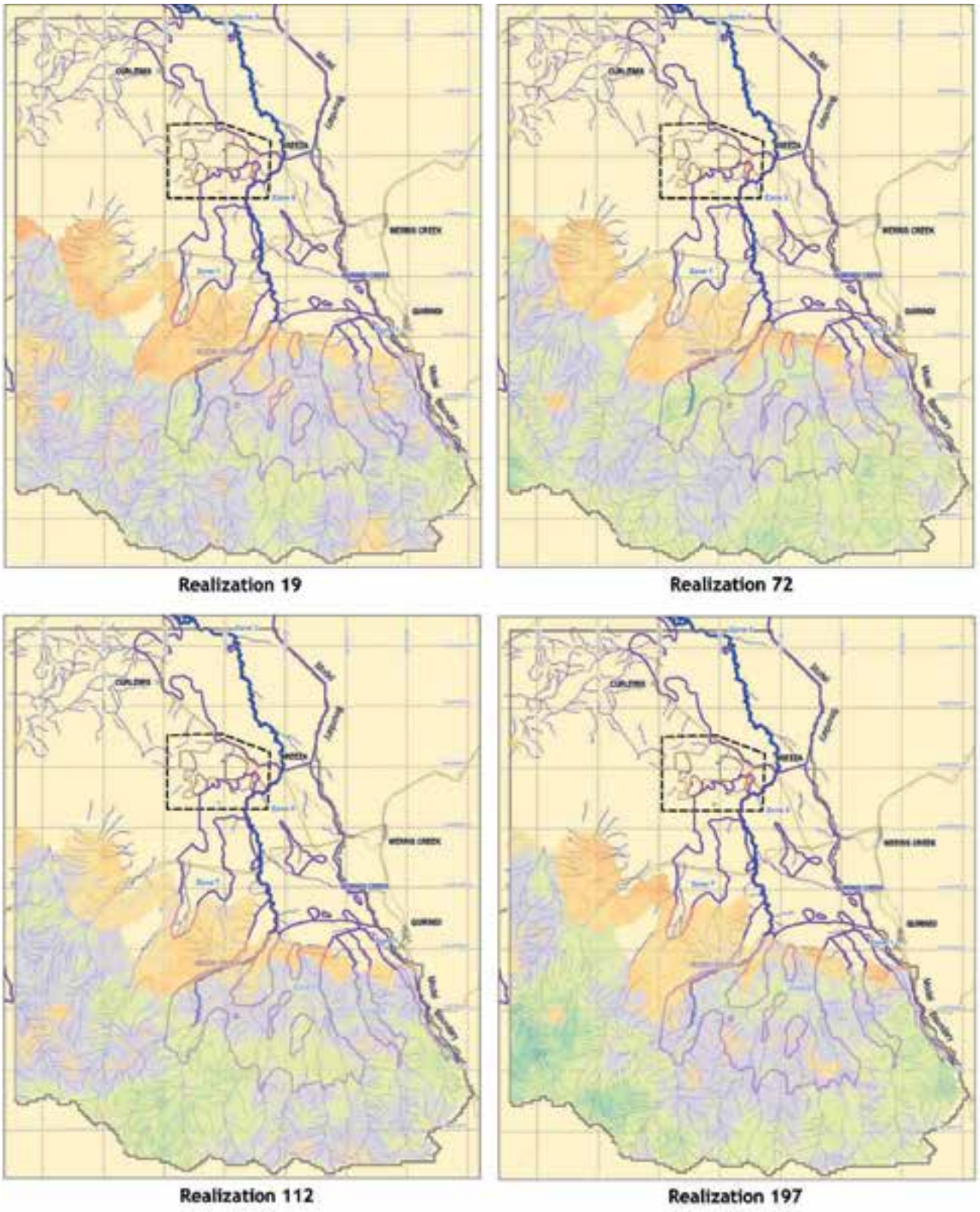
Realization 186



Realizations of Vertical Hydraulic Conductivity (Layer 3)

Figure 3.14b

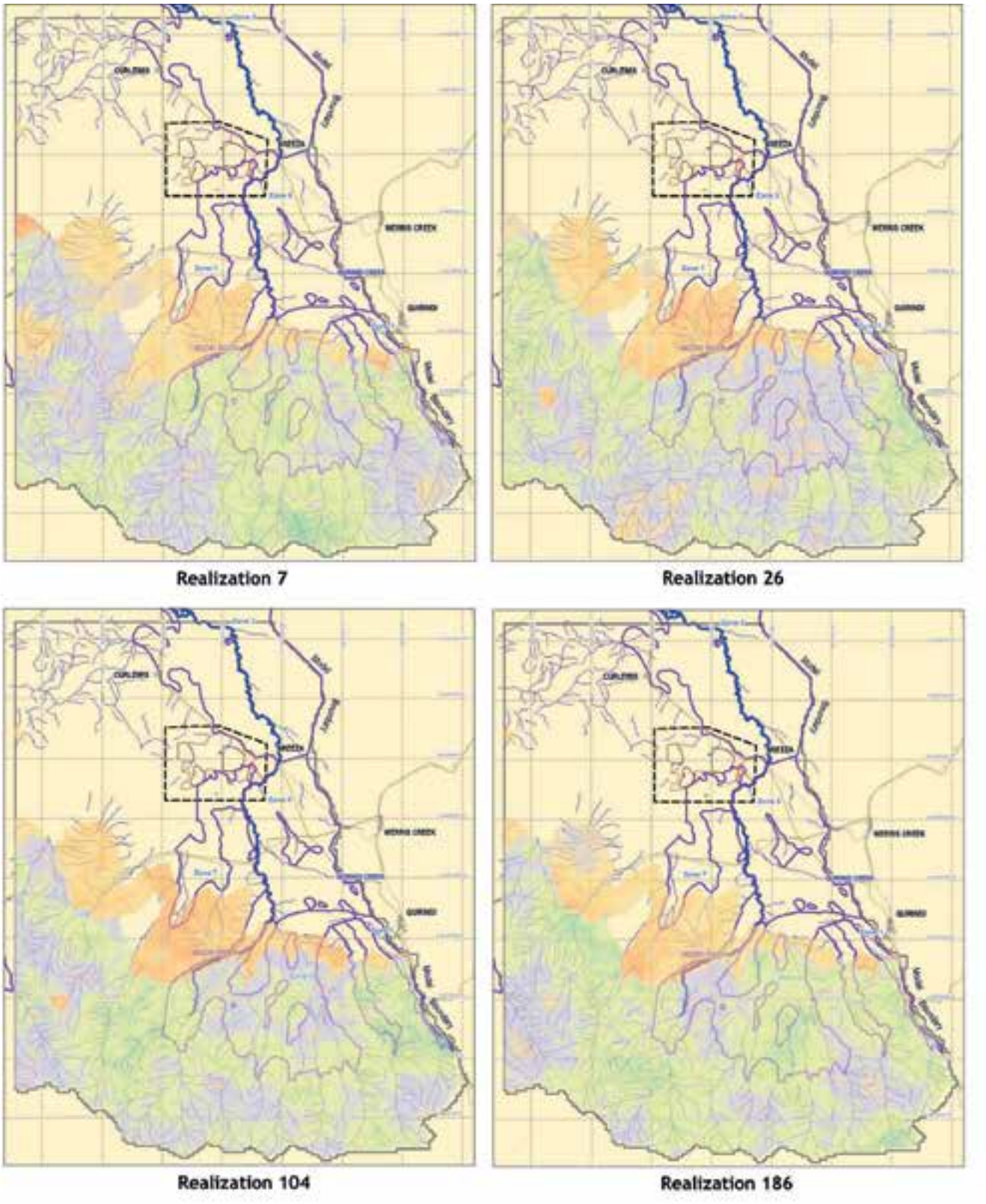
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 4)

Figure 3.15a

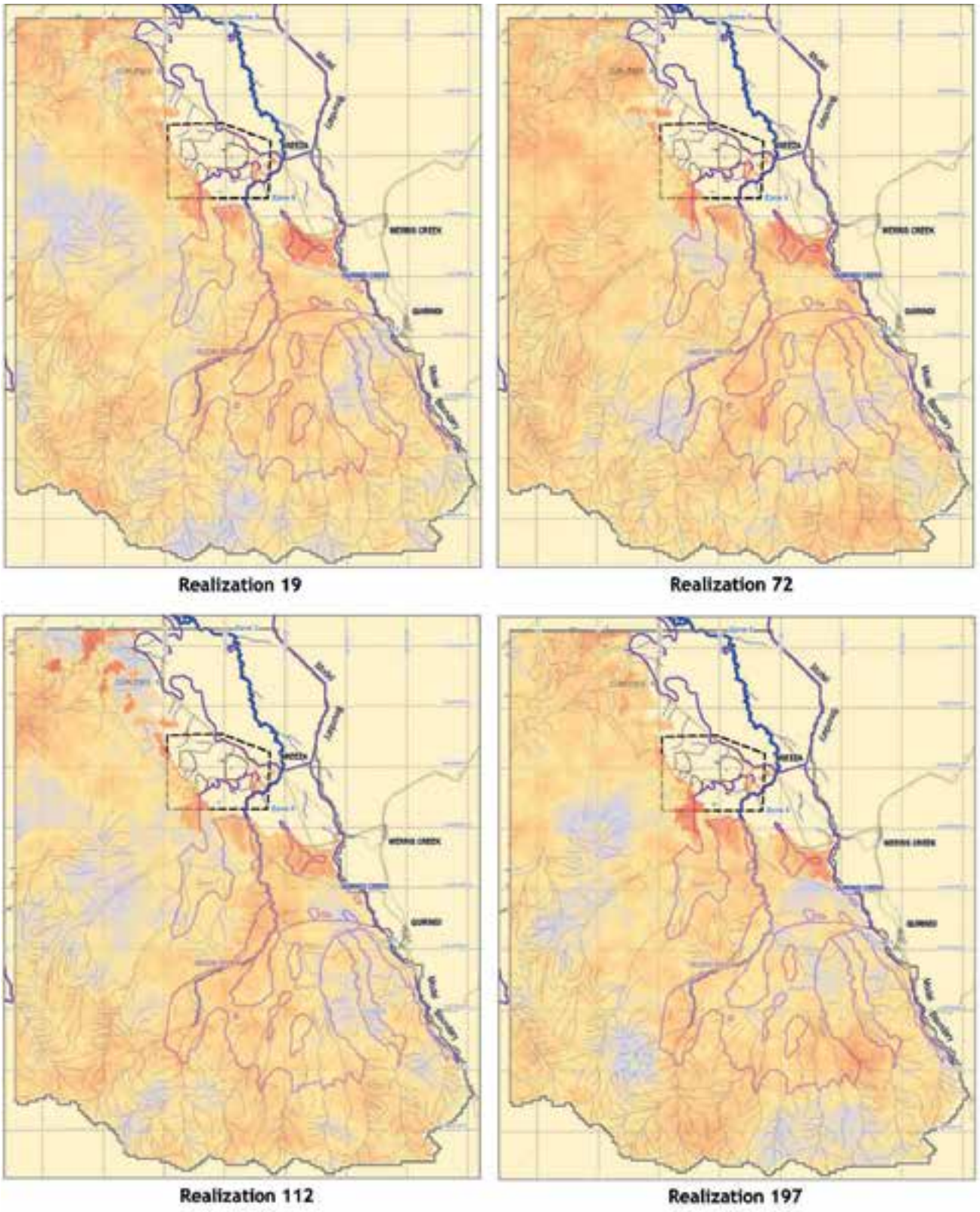
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 4)

Figure 3.15b

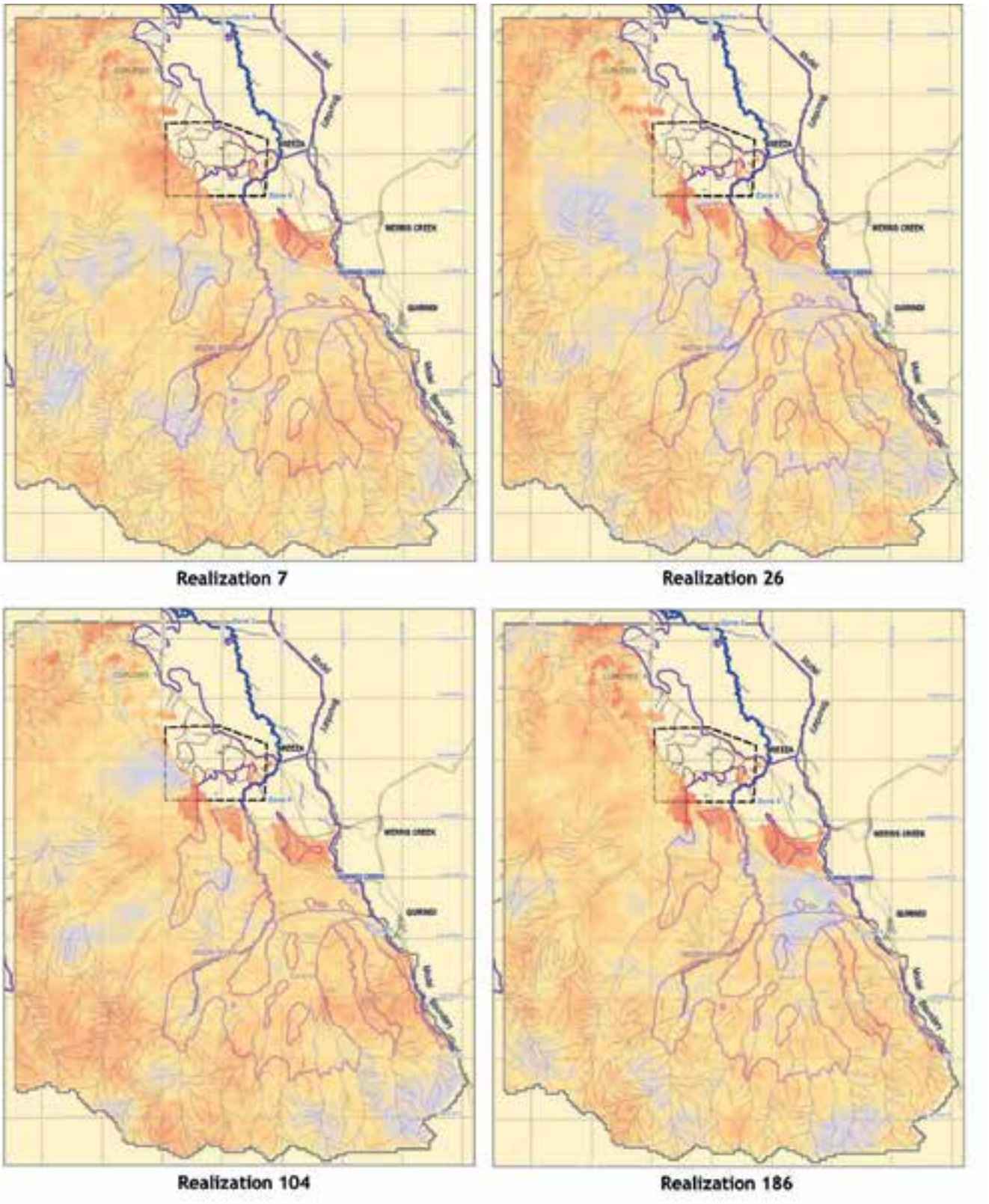
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 5)

Figure 3.16a

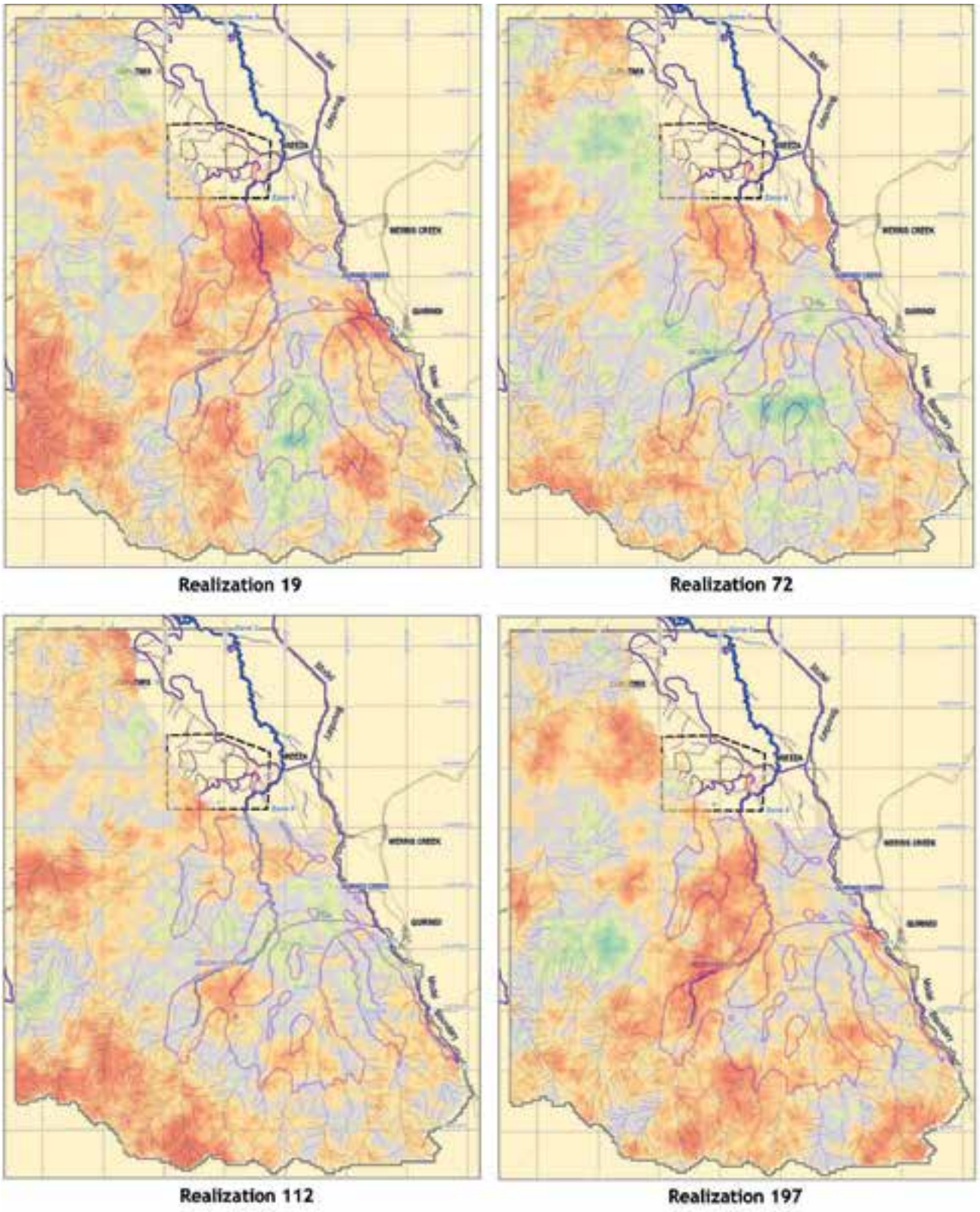
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 5)

Figure 3.16b

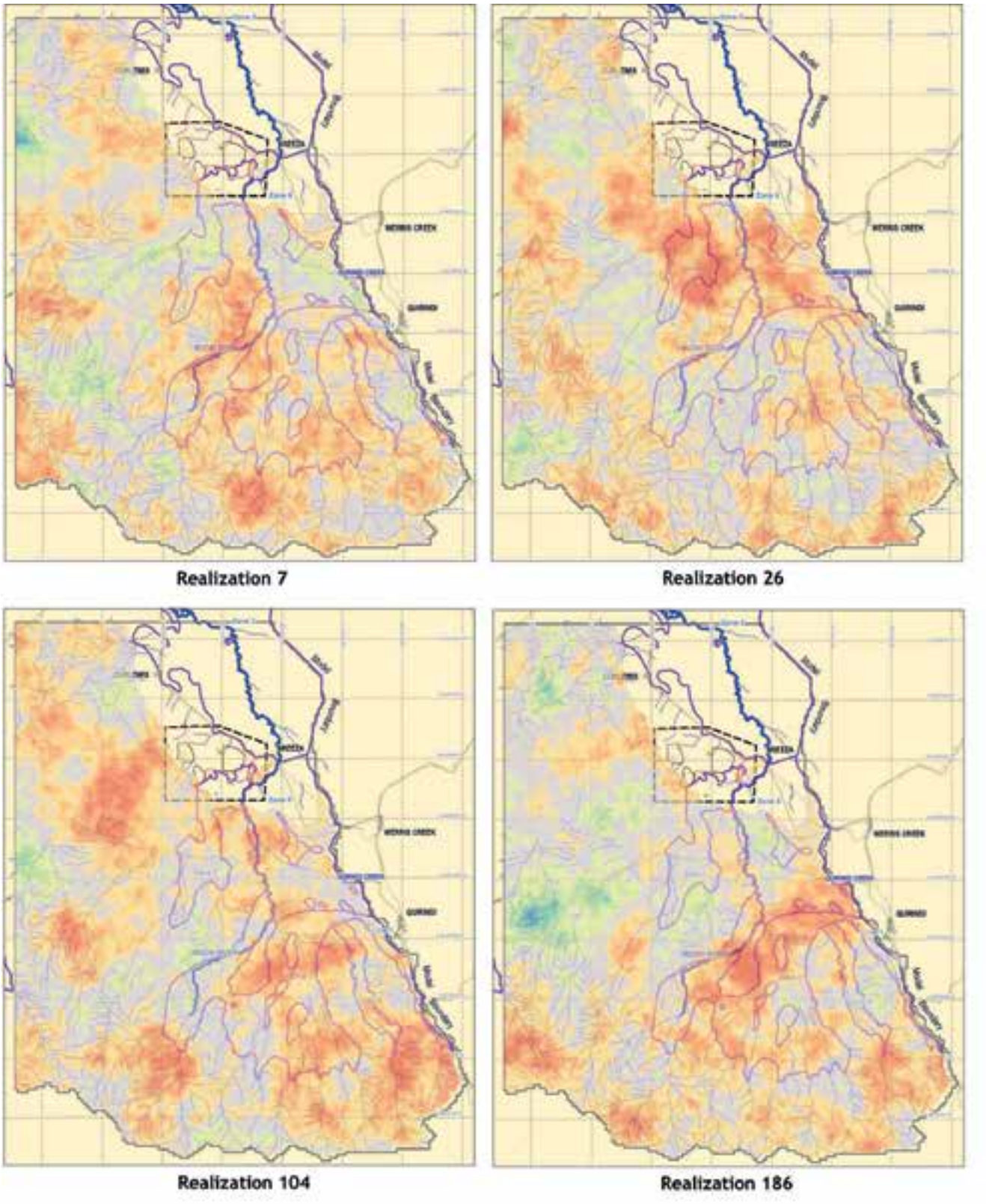
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 6)

Figure 3.17a

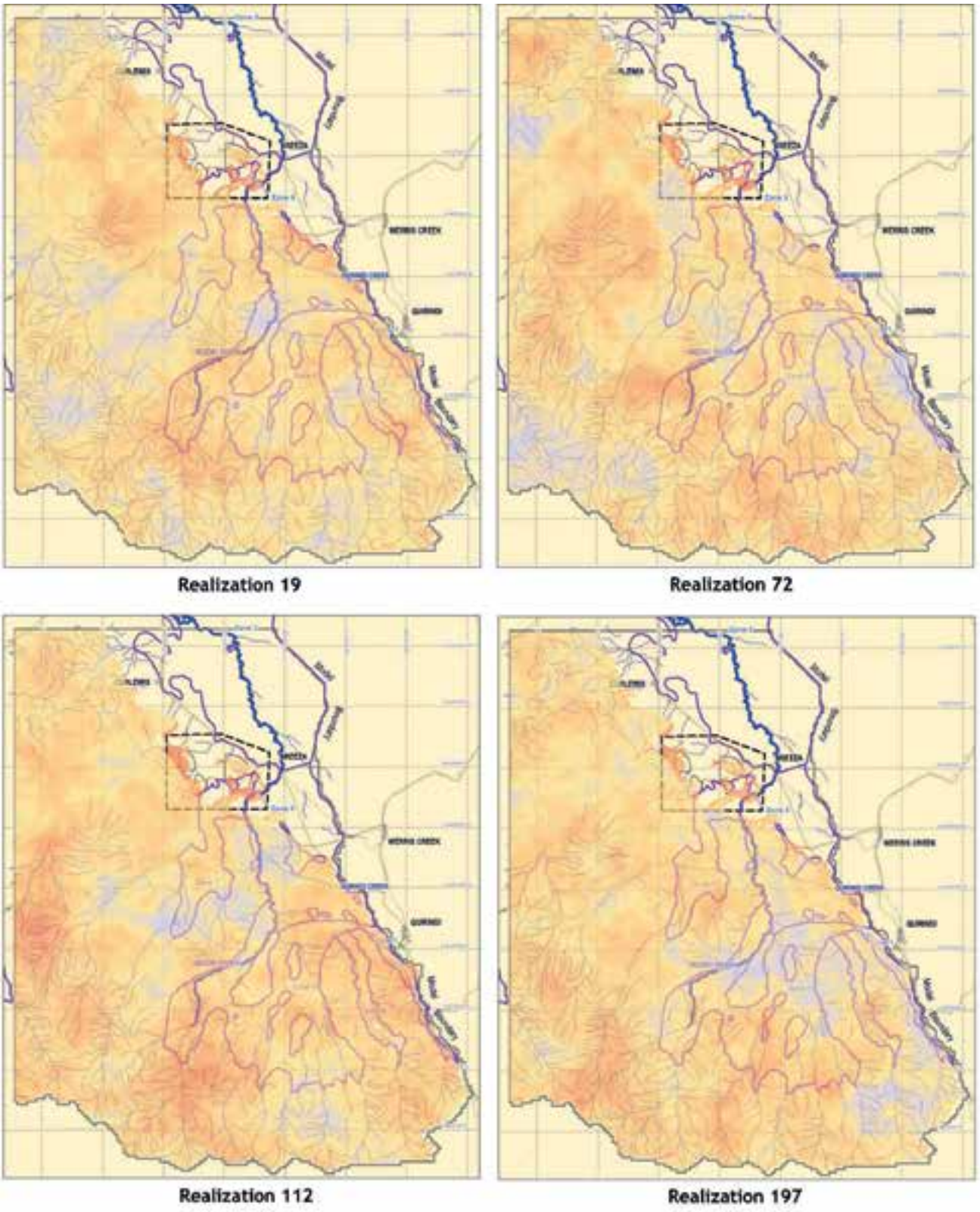
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 6)

Figure 3.17b

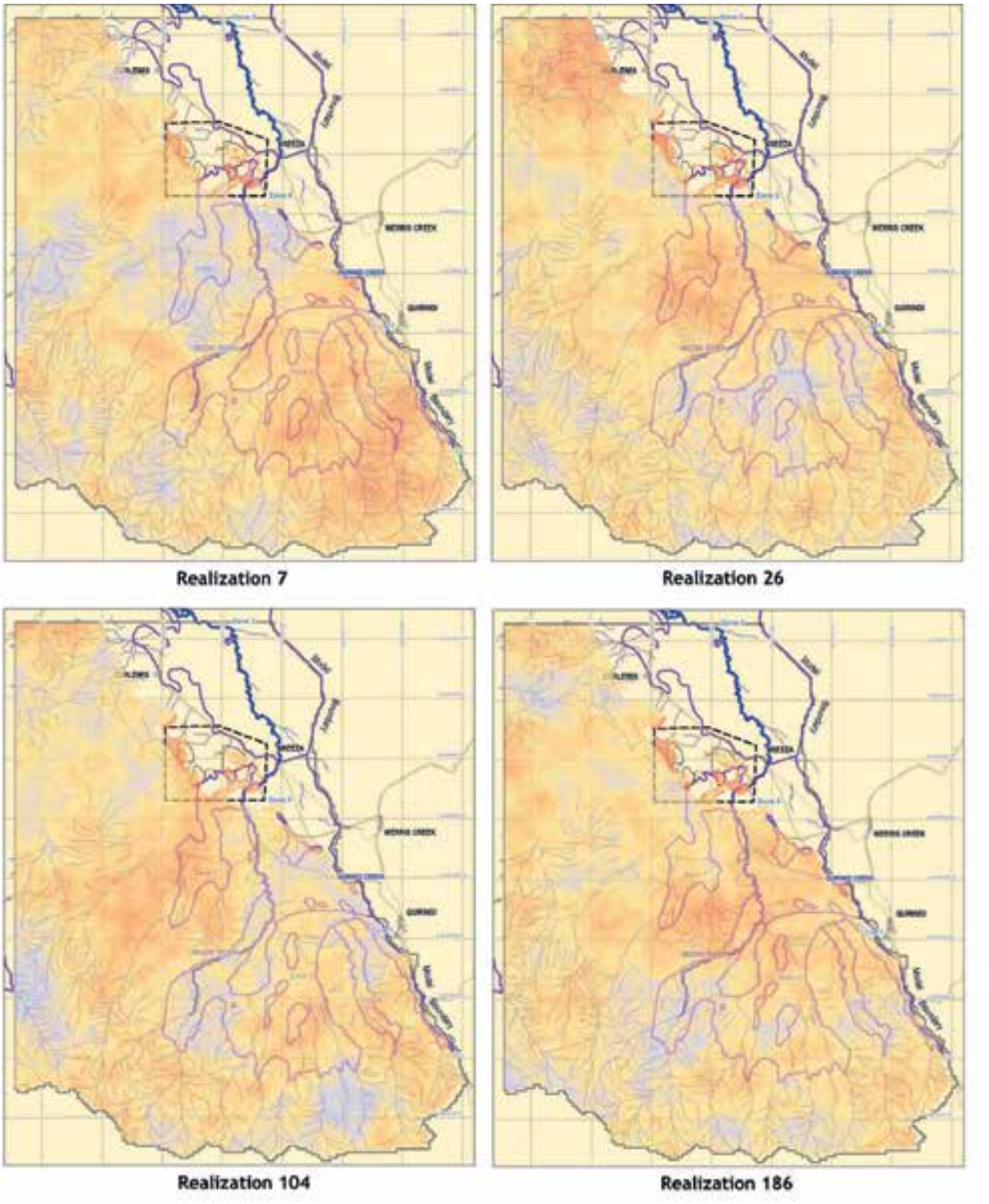
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 7)

Figure 3.18a

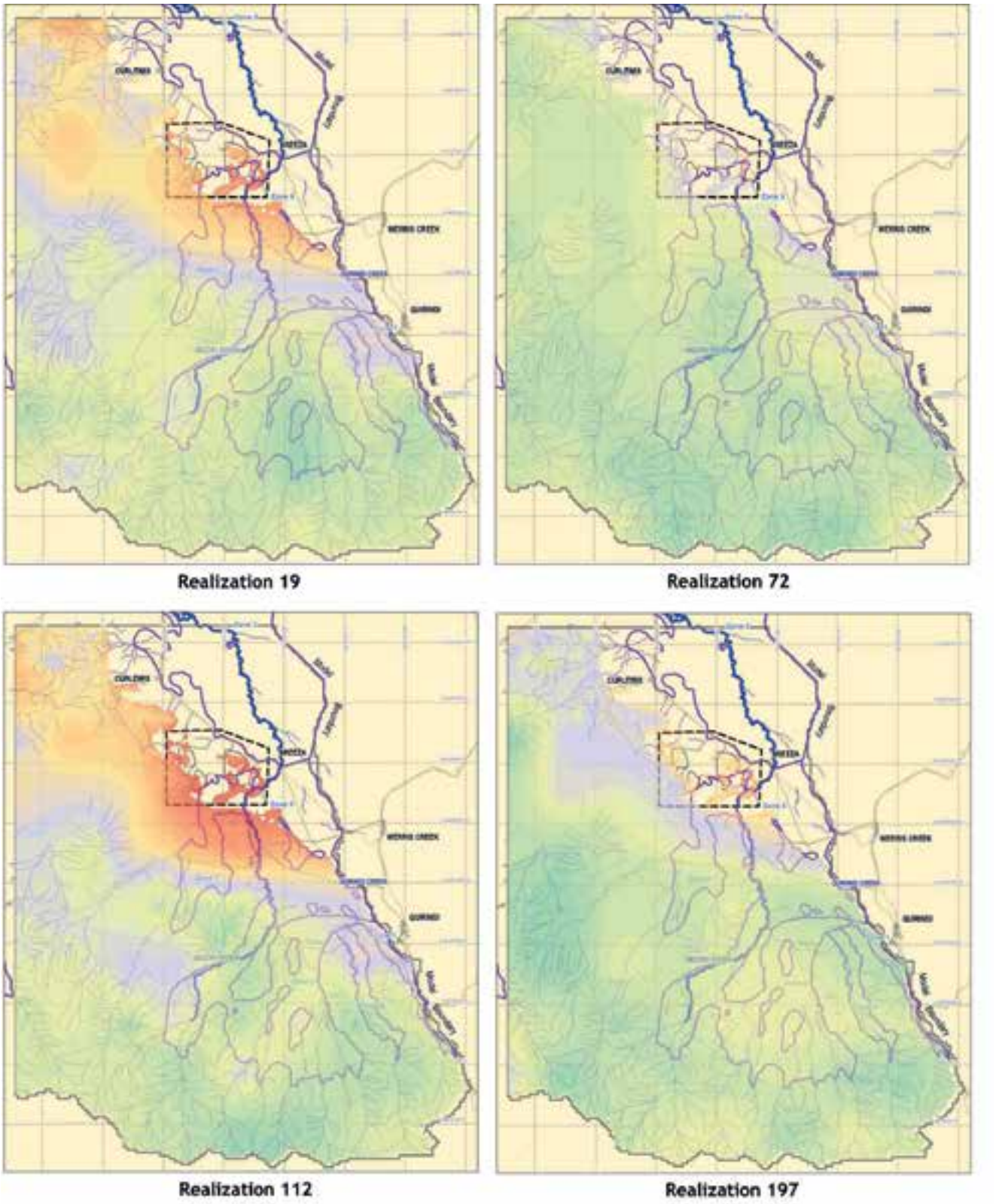
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 7)

Figure 3.18b

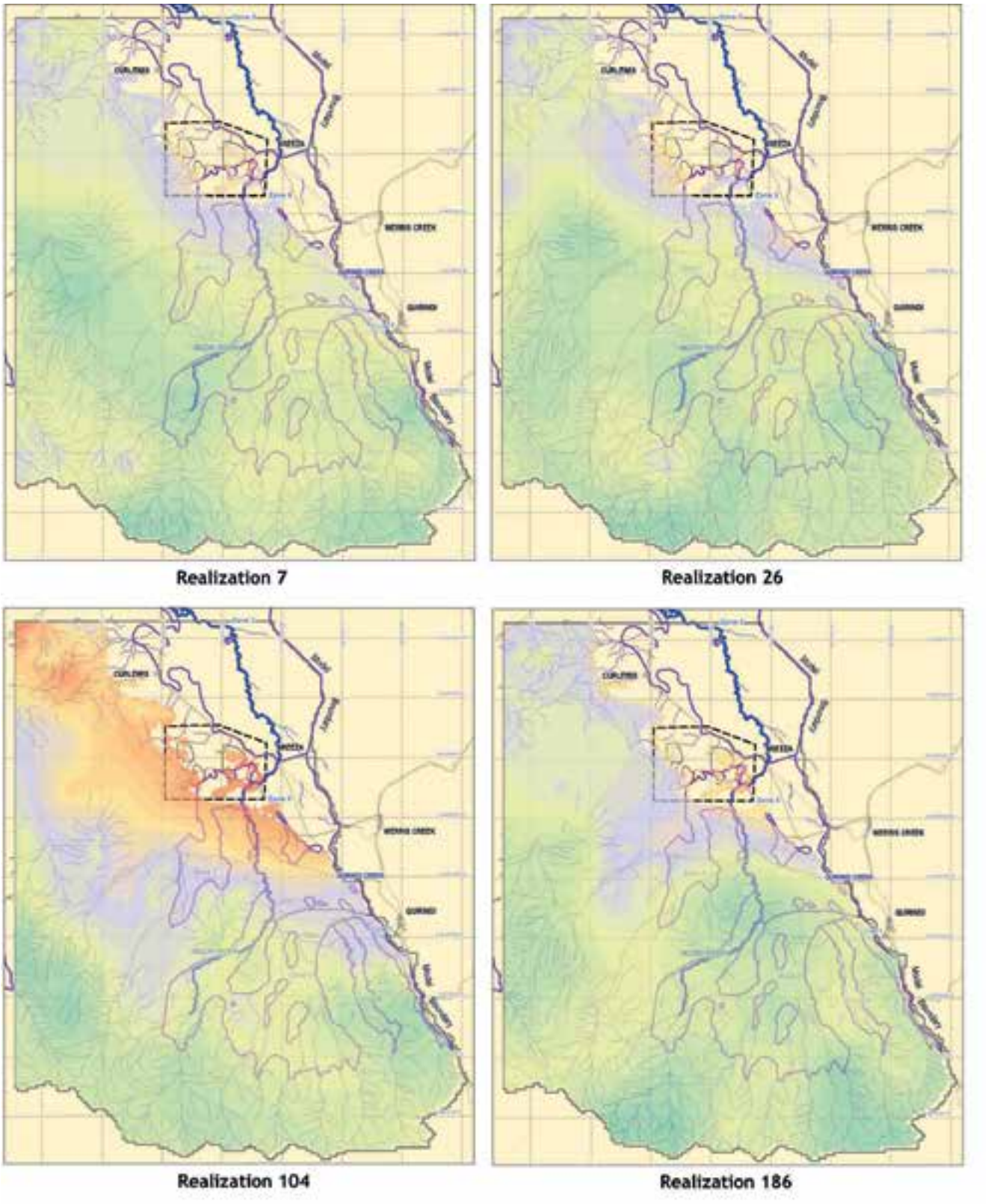
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 8)

Figure 3.19a

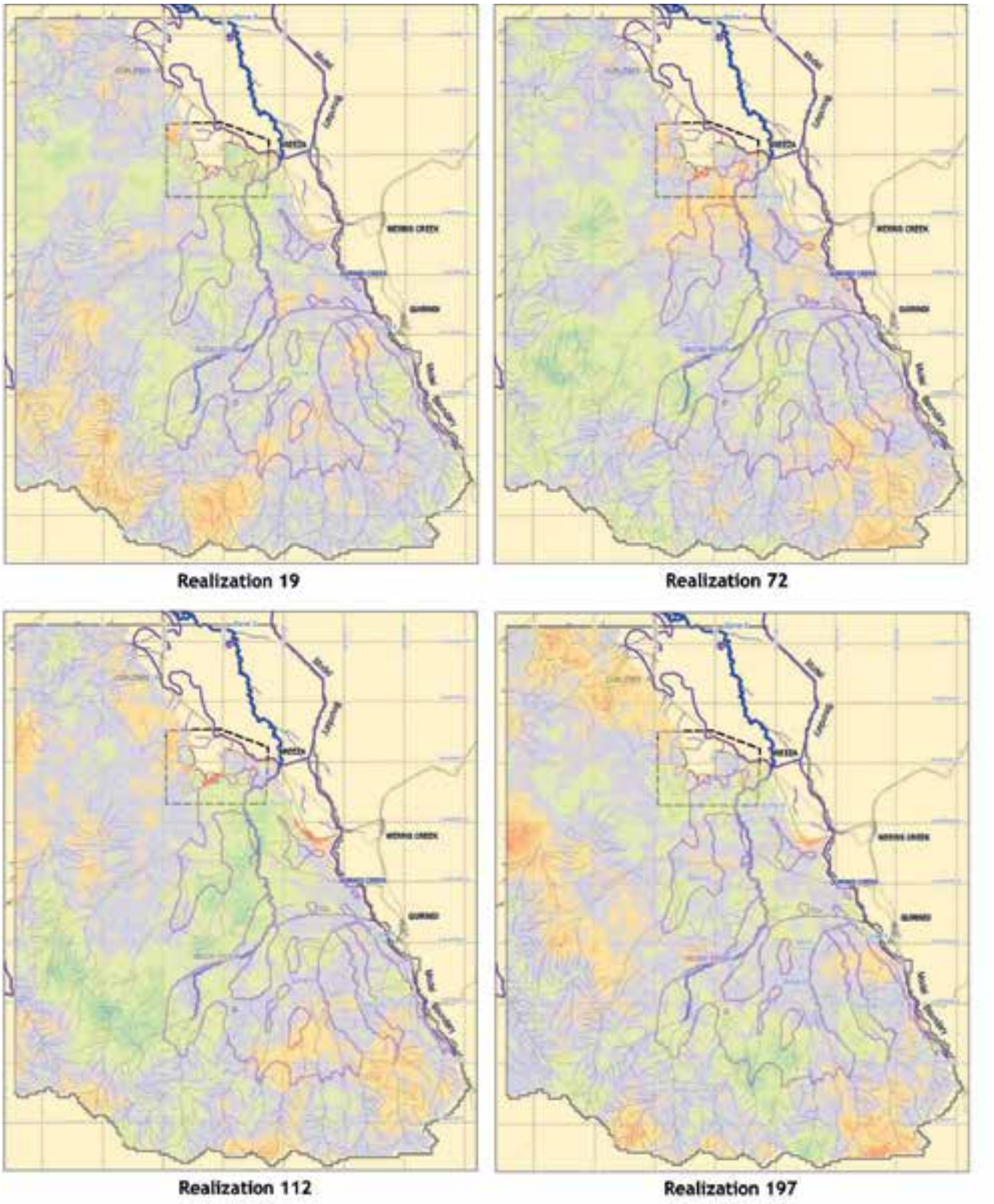
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 8)

Figure 3.19b

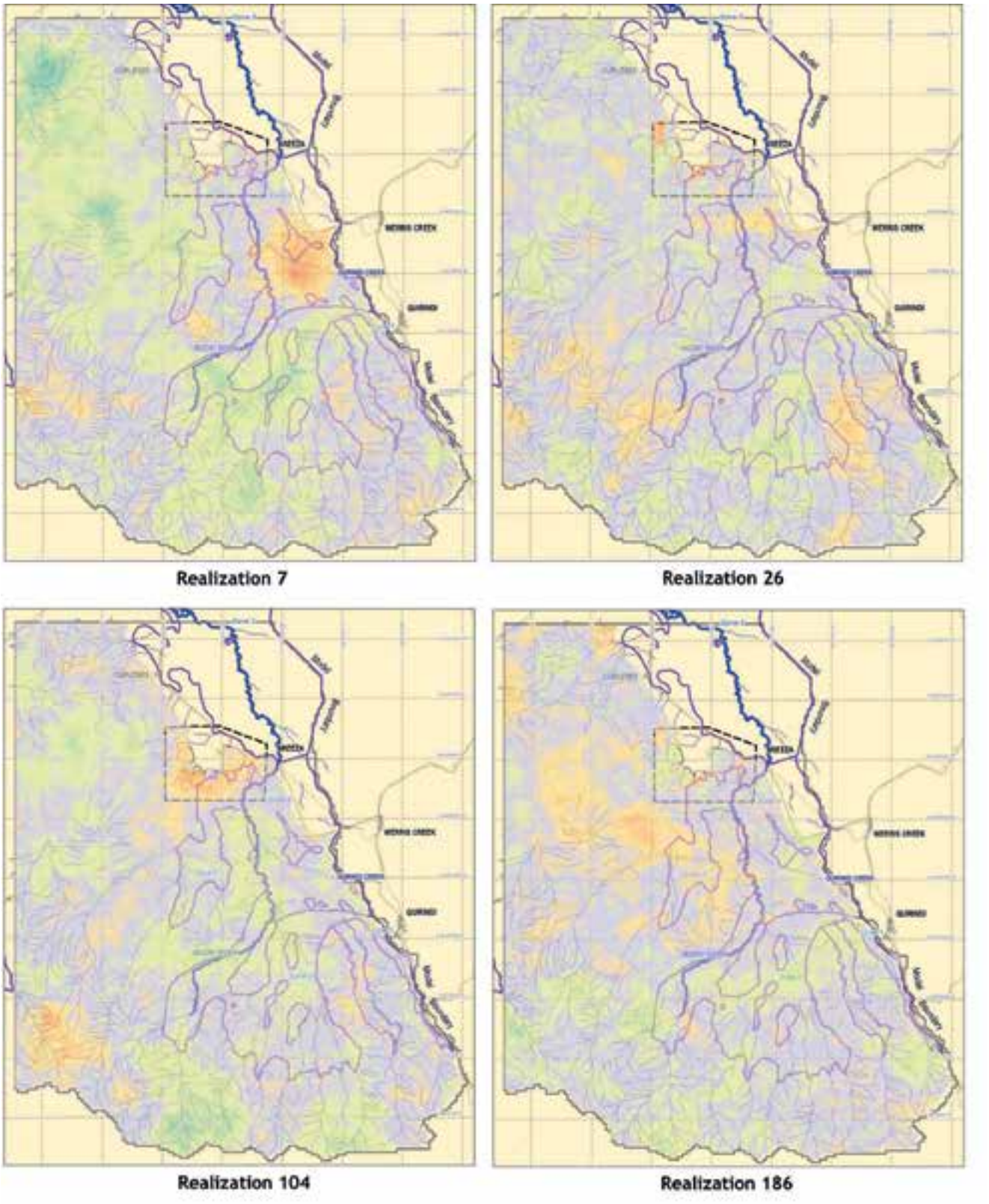
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 9)

Figure 3.20a

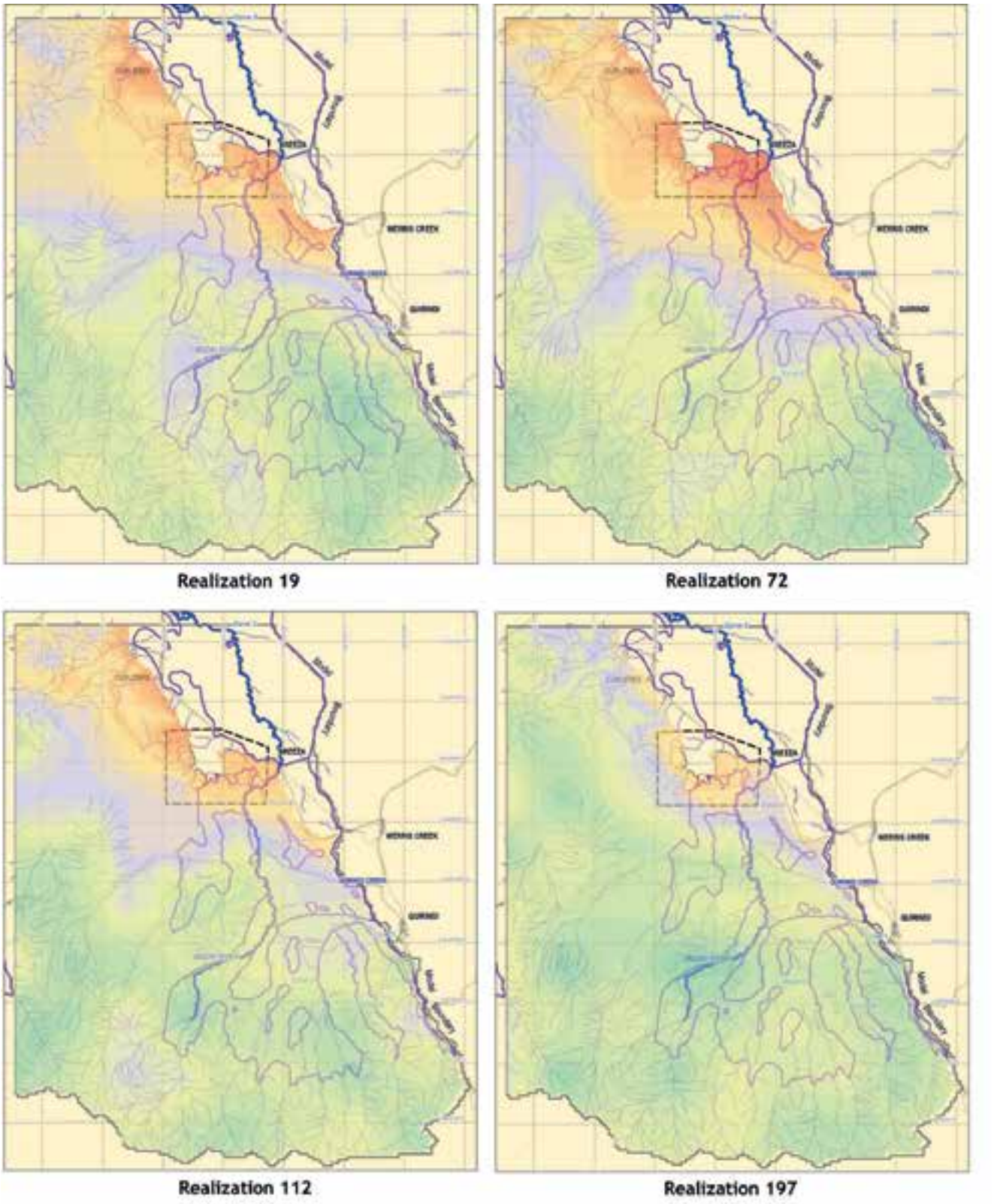
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 9)

Figure 3.20b

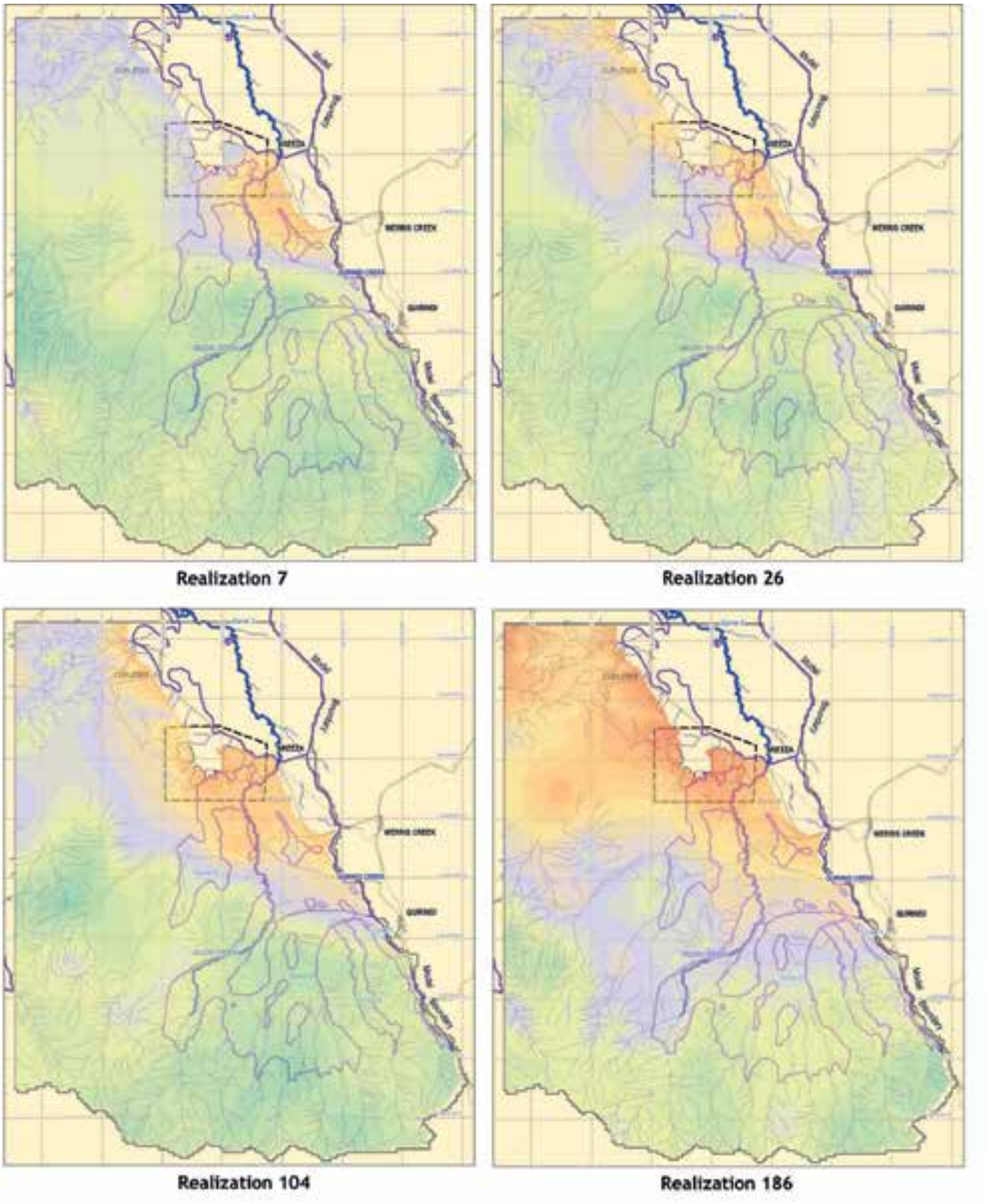
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 10)

Figure 3.21a

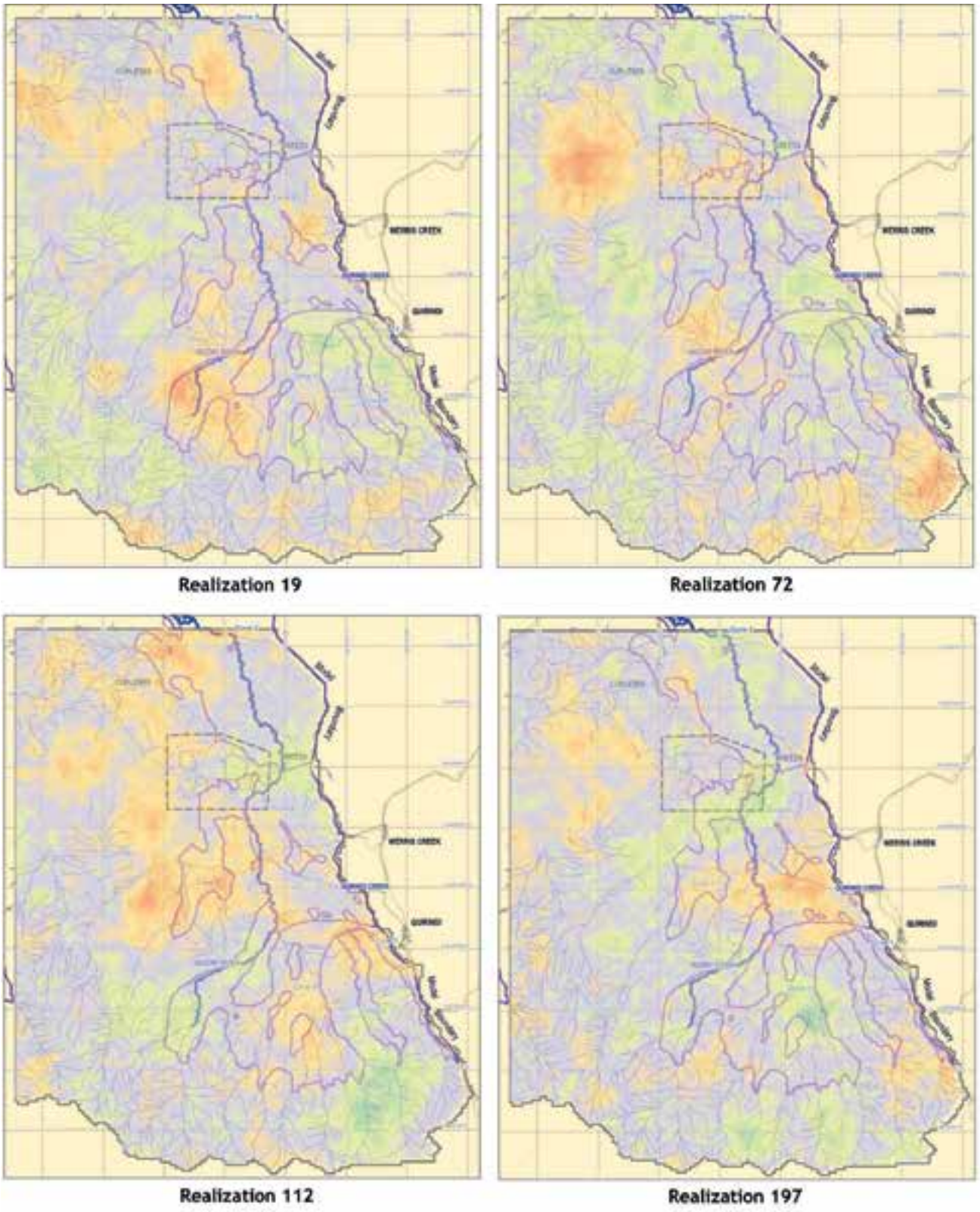
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 10)

Figure 3.21b

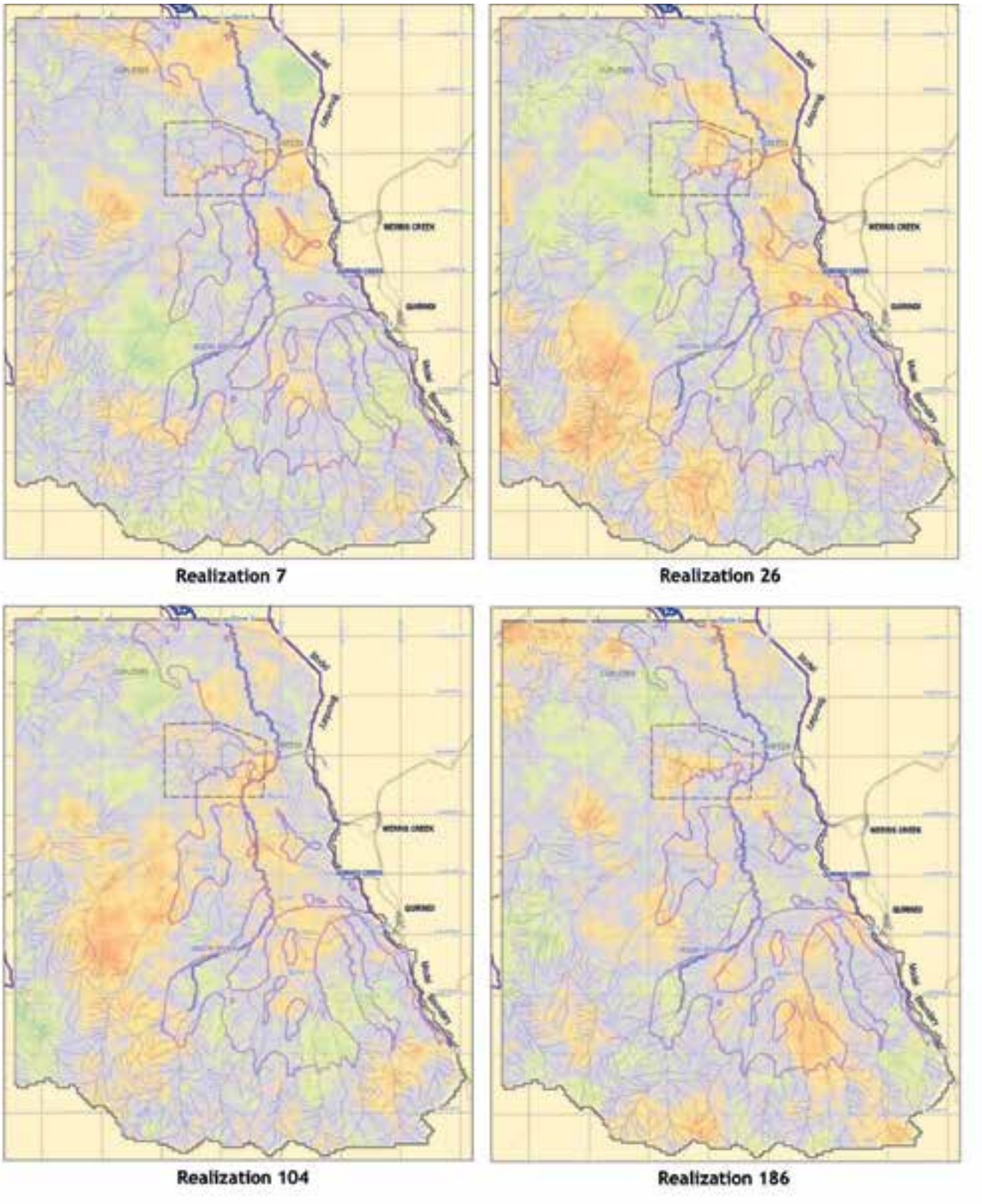
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 11)

Figure 3.22a

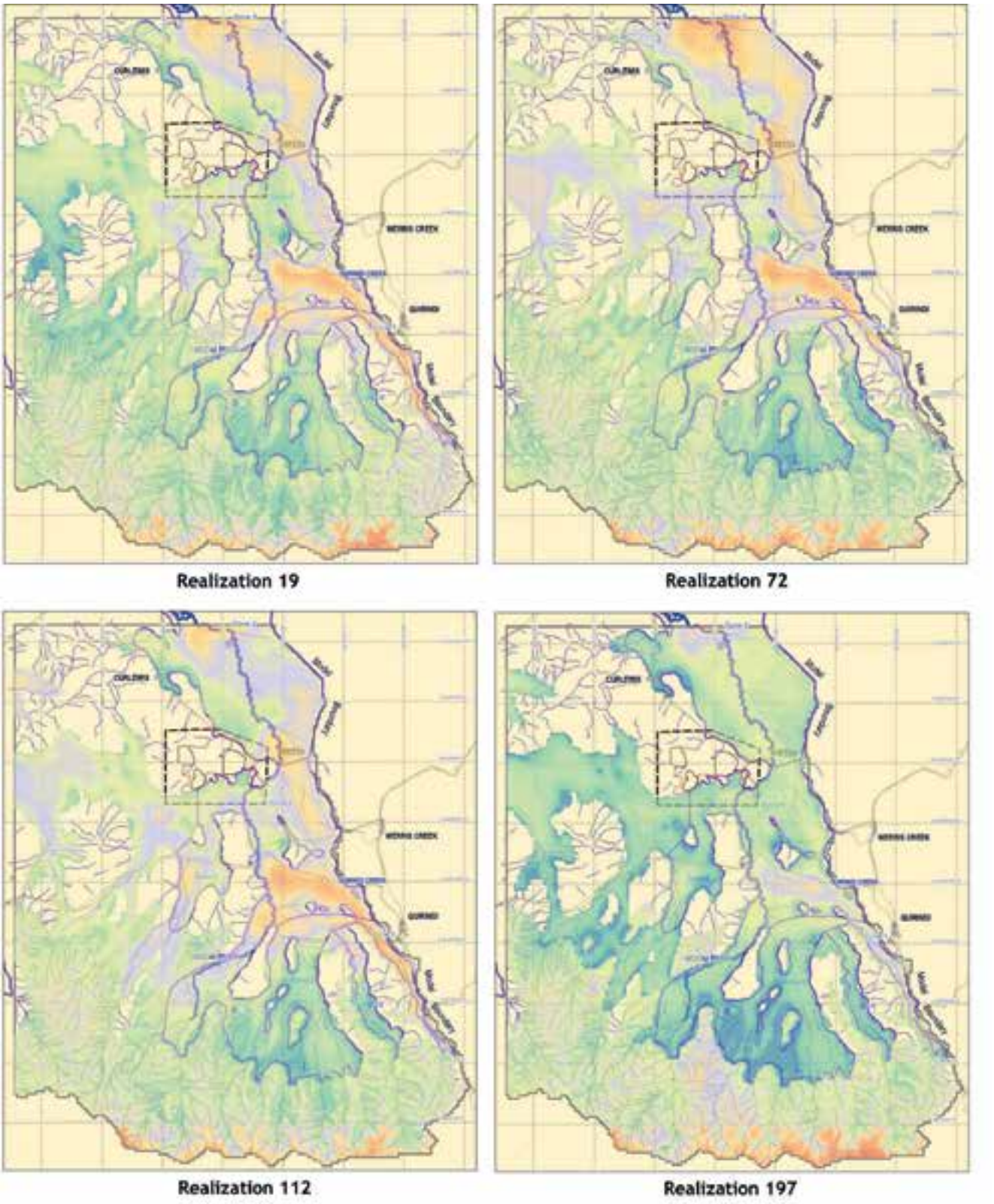
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Vertical Hydraulic Conductivity (Layer 11)

Figure 3.22b

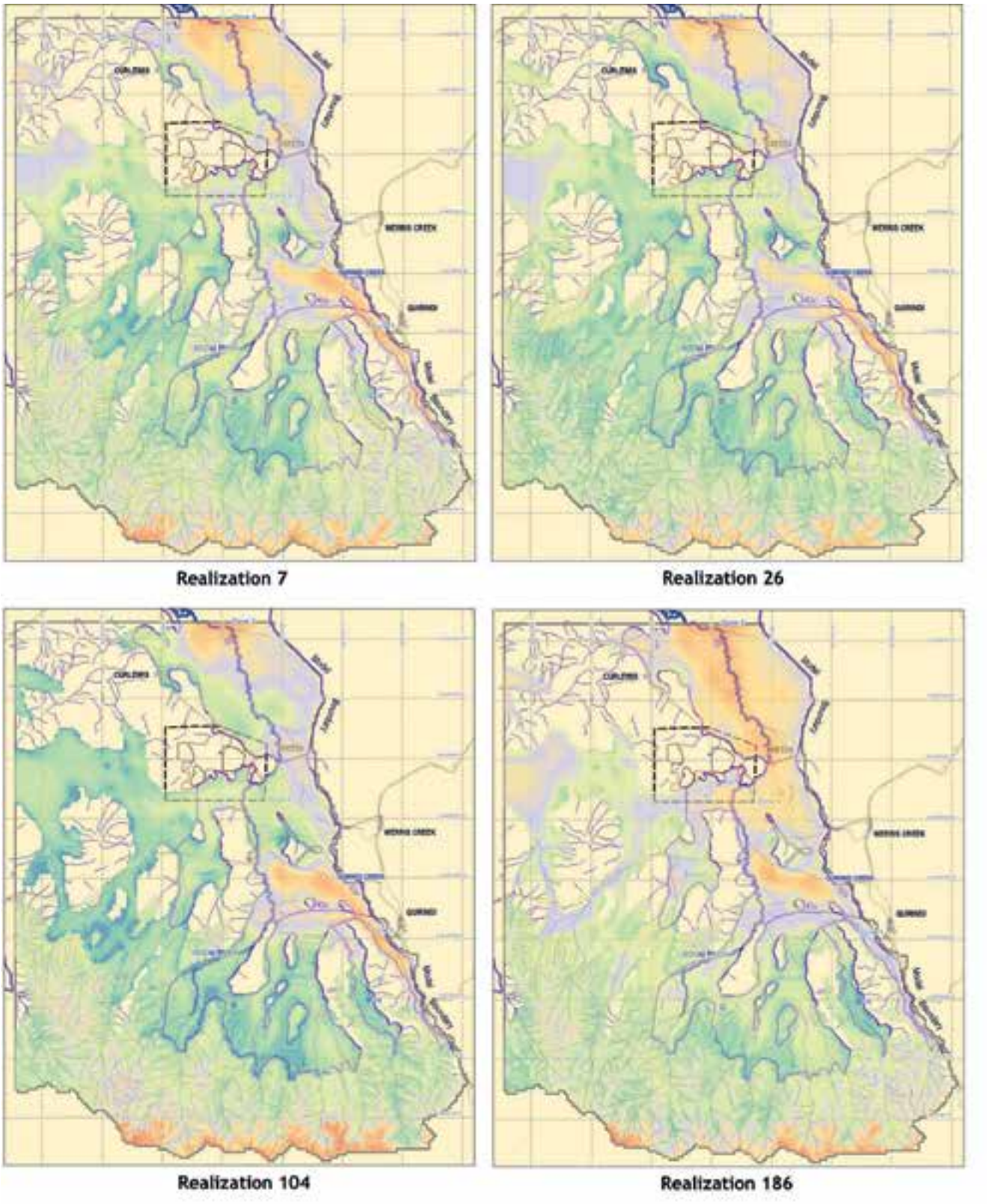
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 1)

Figure 3-23a

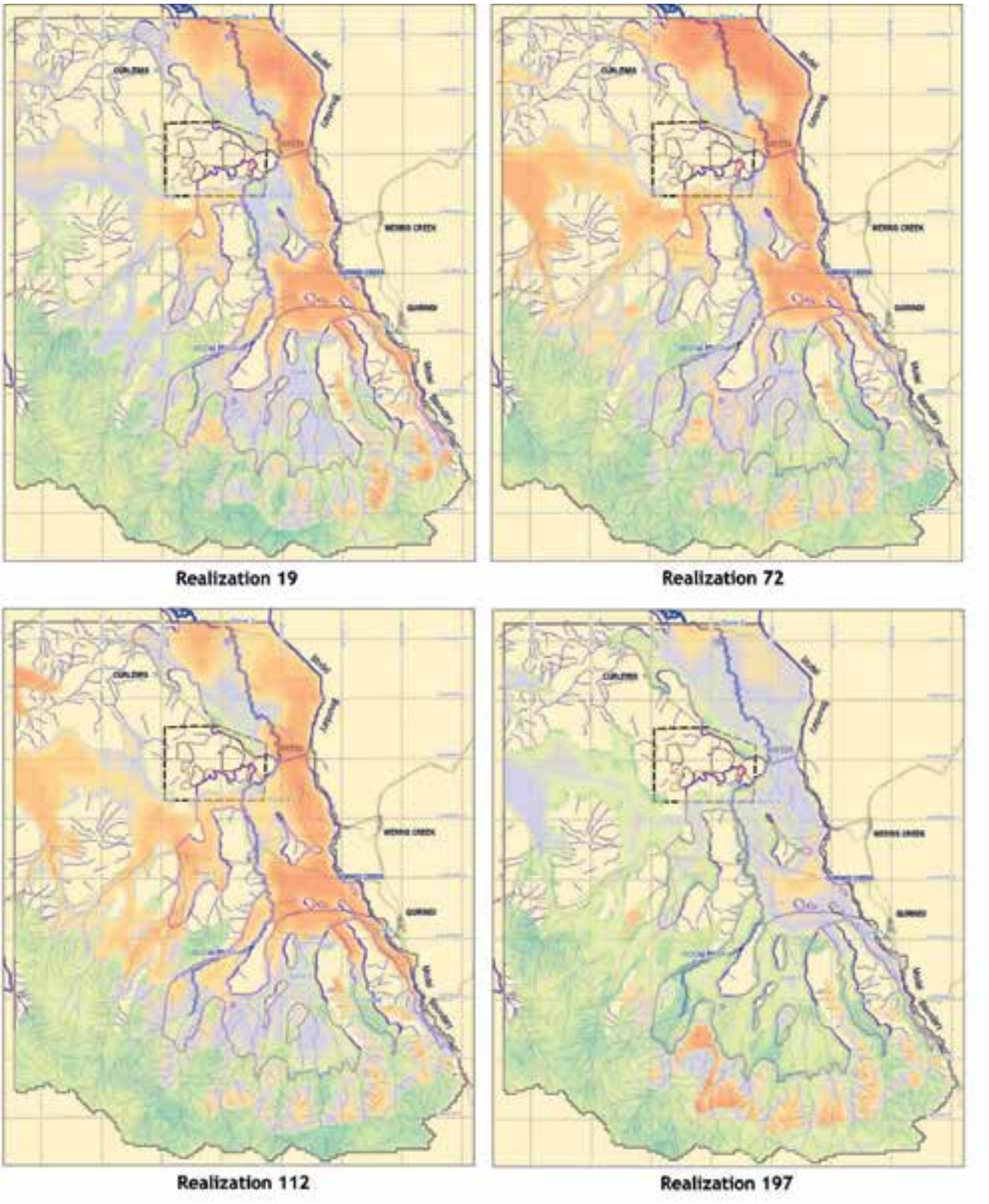
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 1)

Figure 3-23b

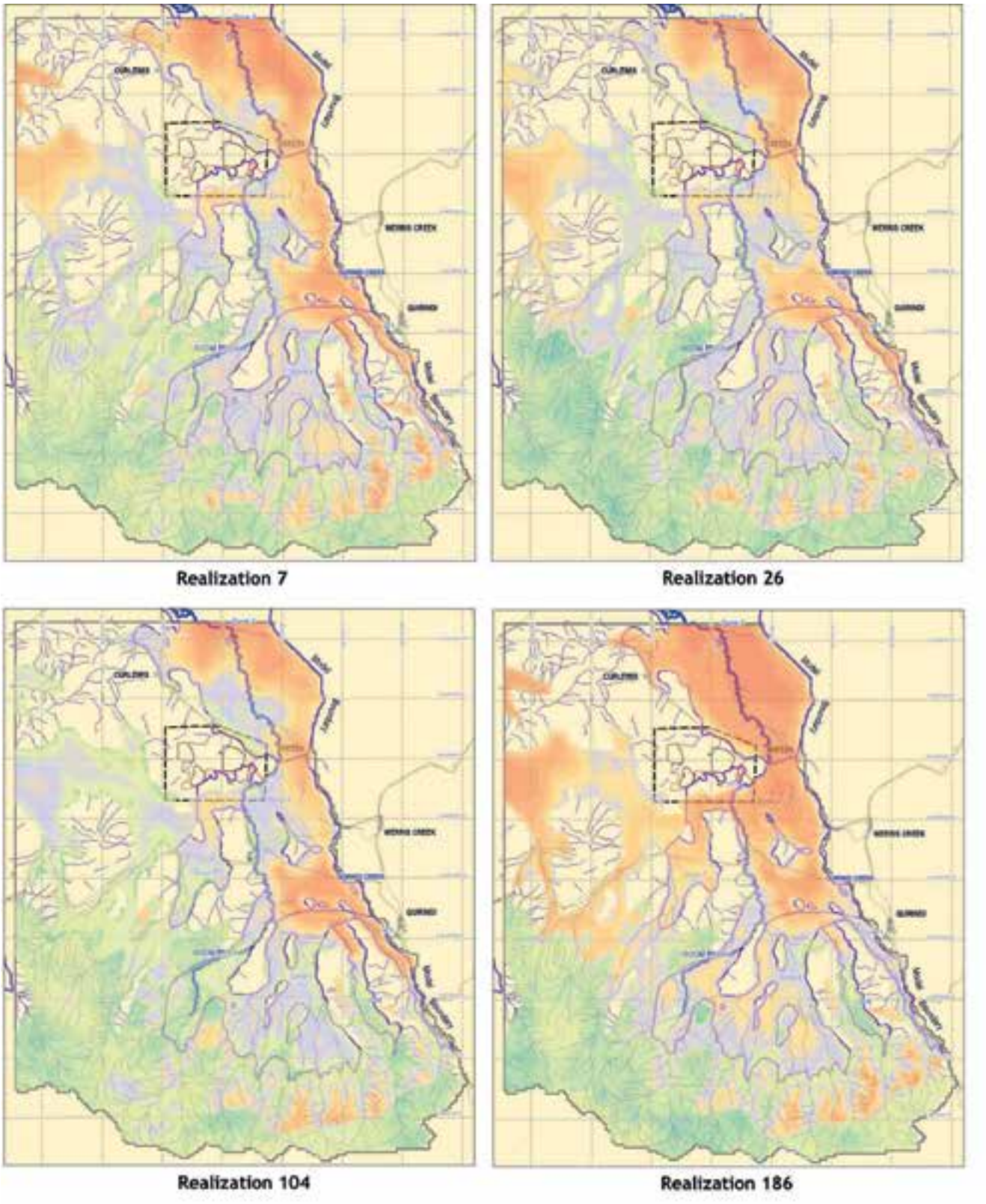
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 2)

Figure 3-24a

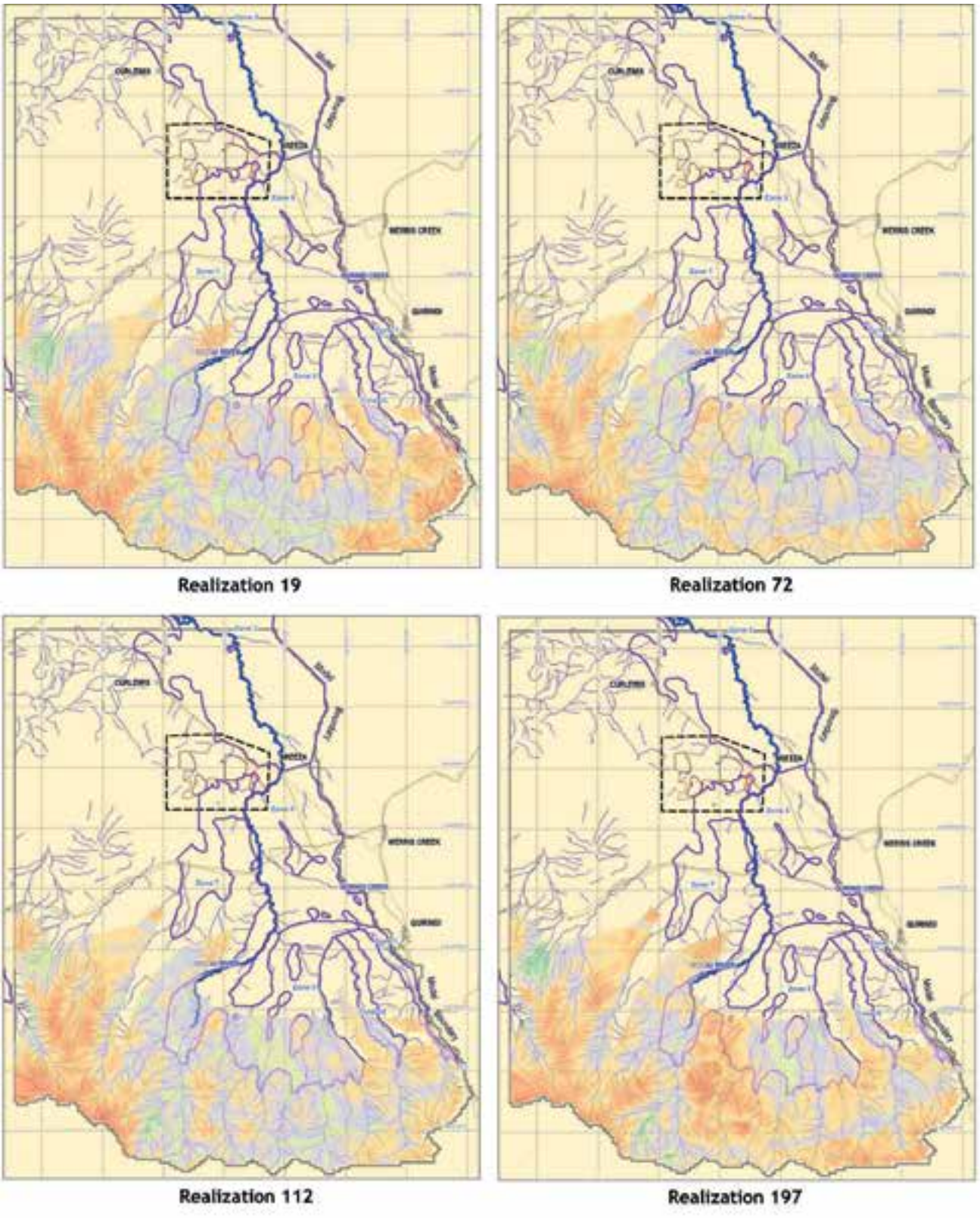
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 2)

Figure 3-24b

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



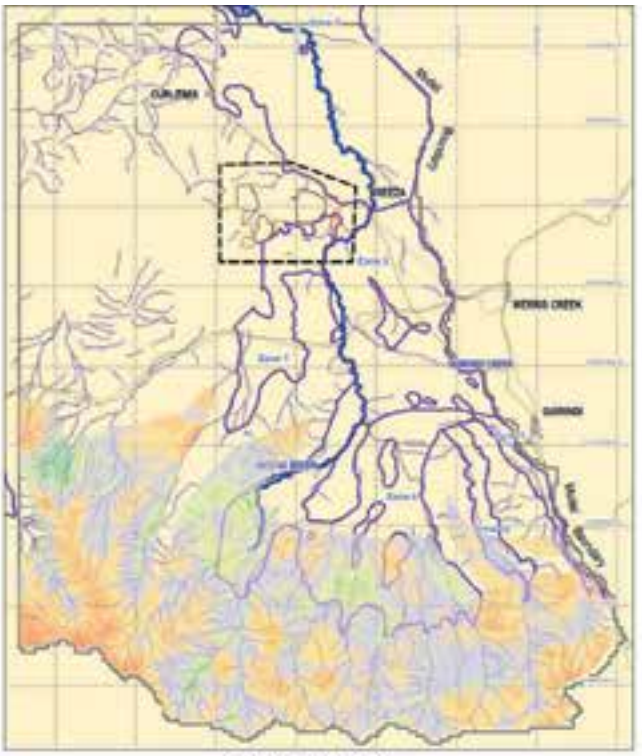
Realizations of Confined Storage Coefficient (Layer 3)

Figure 3-25a

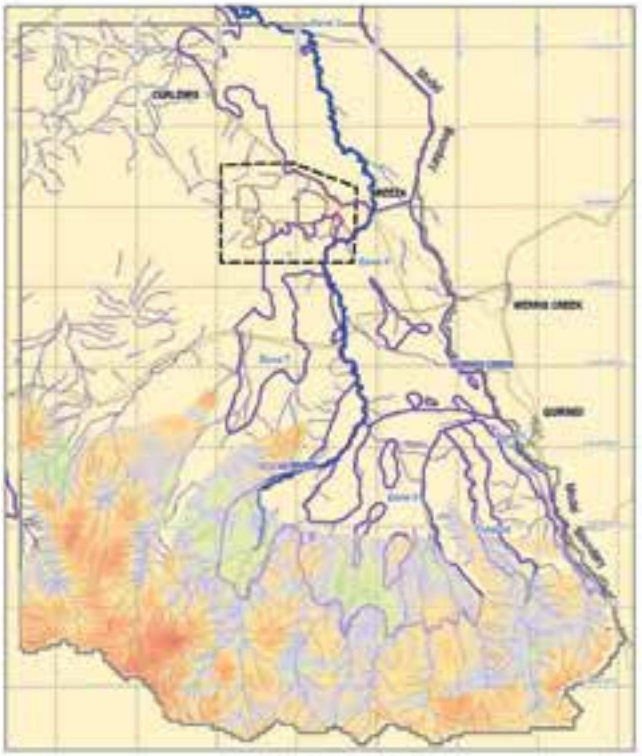
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realization 7



Realization 26



Realization 104



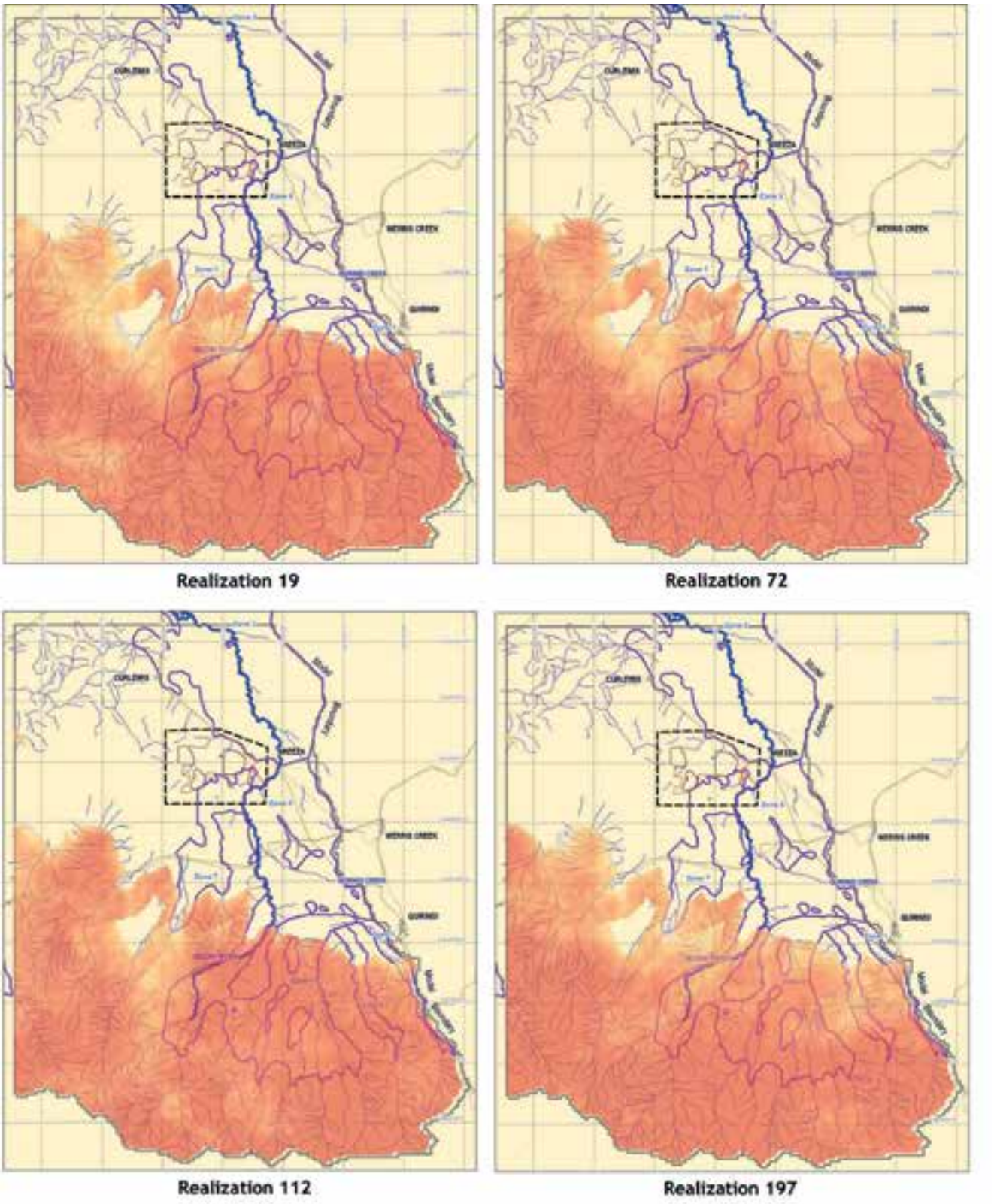
Realization 186



Realizations of Confined Storage Coefficient (Layer 3)

Figure 3-25b

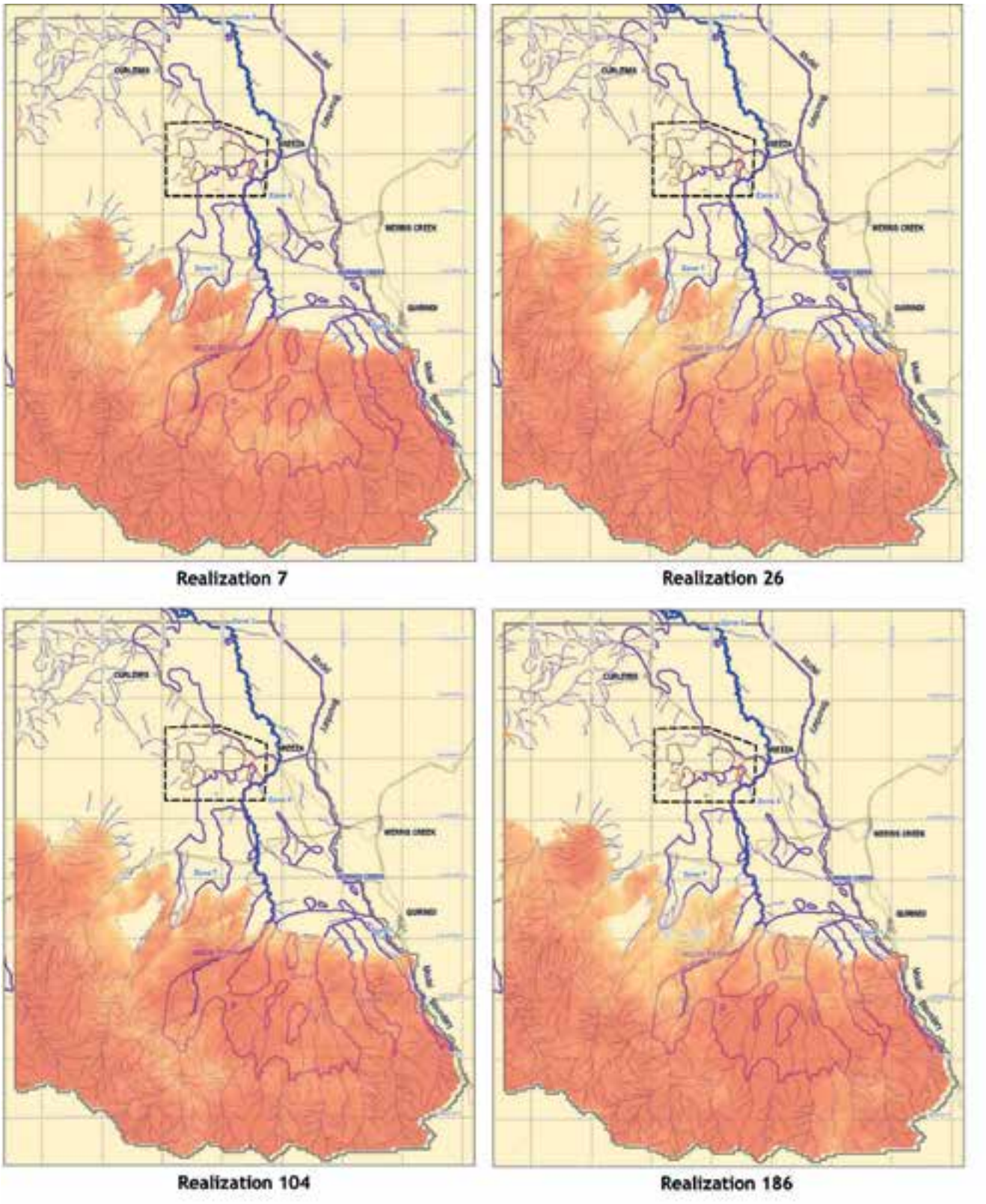
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 4)

Figure 3-26a

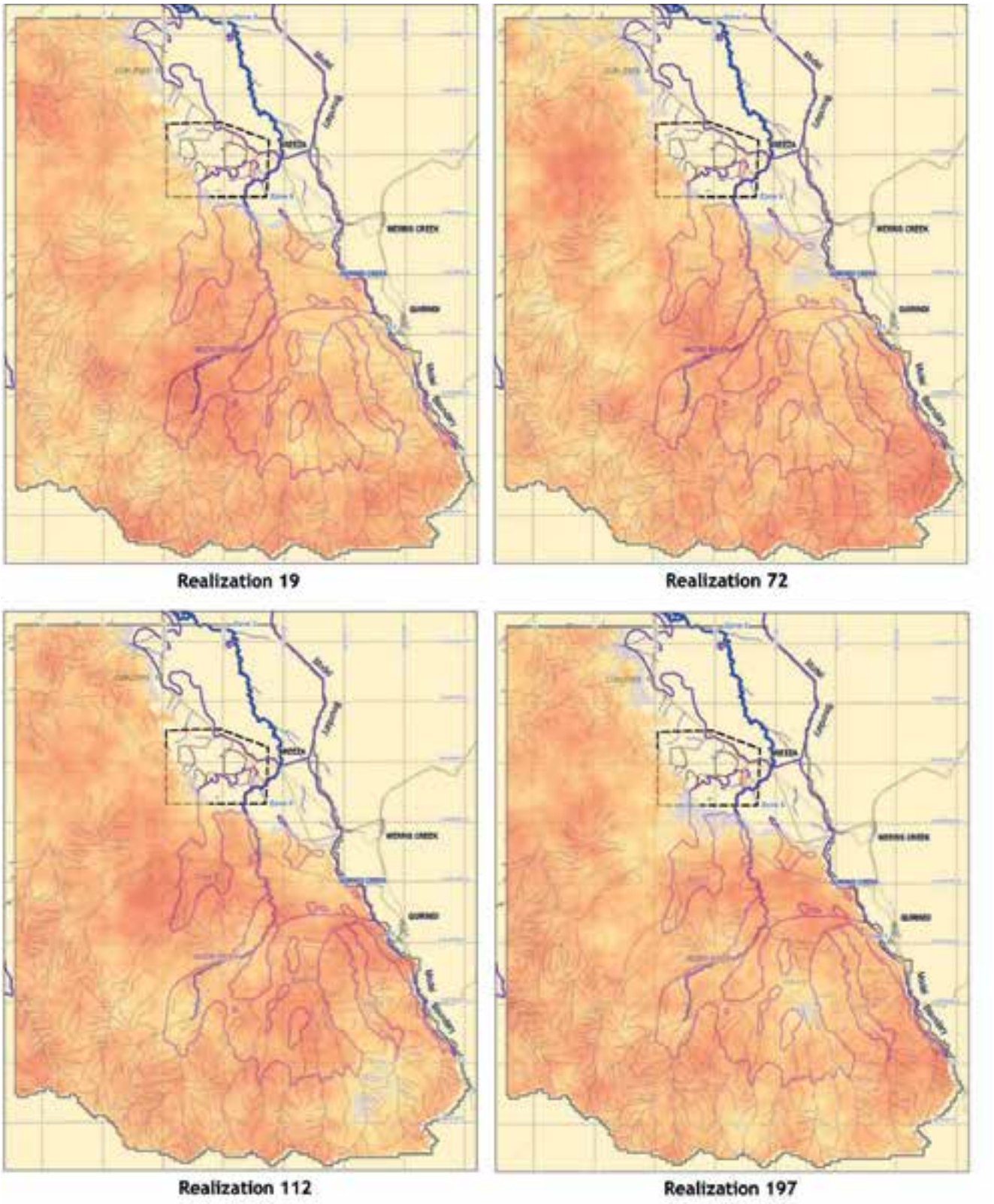
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 4)

Figure 3-26b

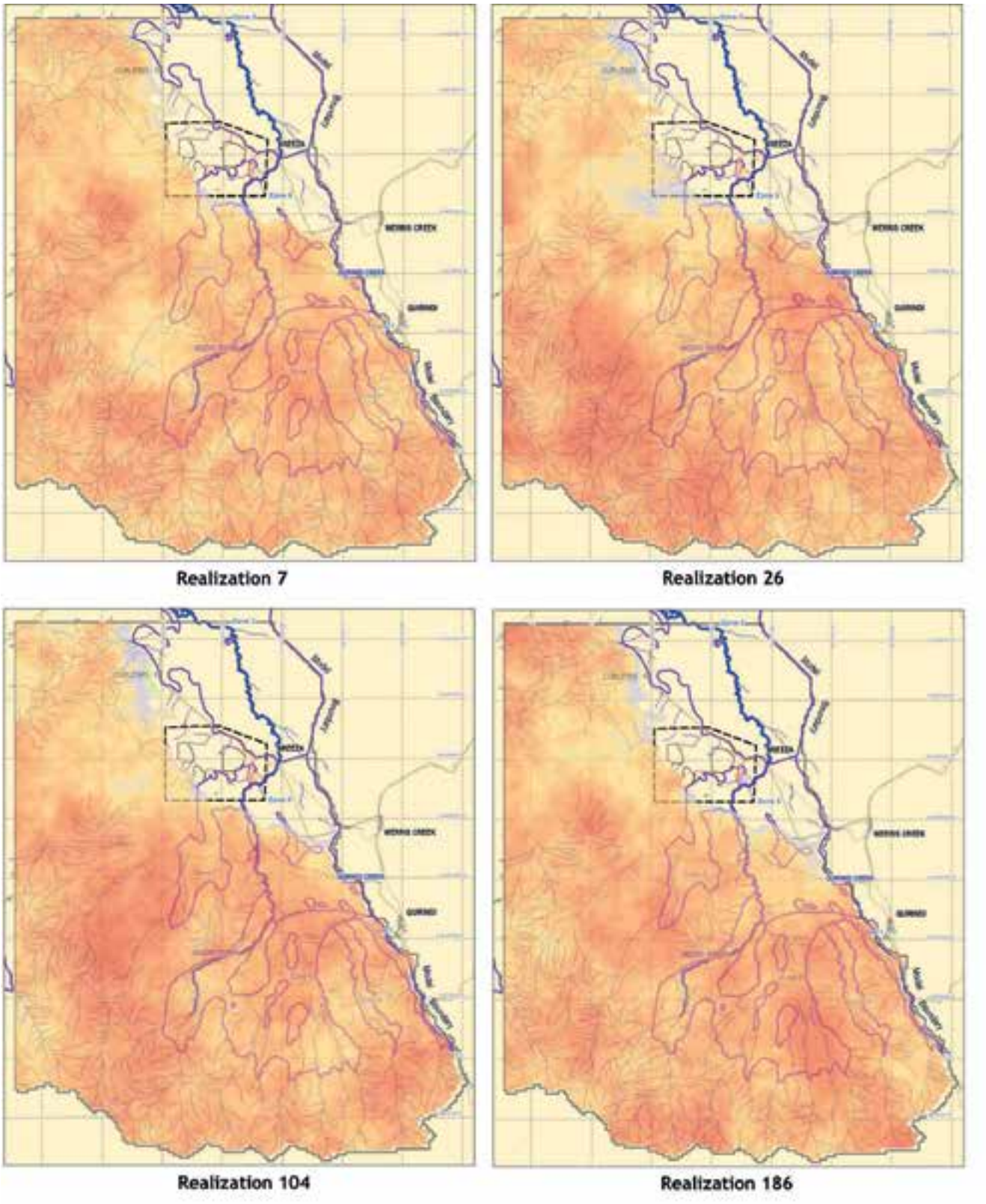
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 5)

Figure 3-27a

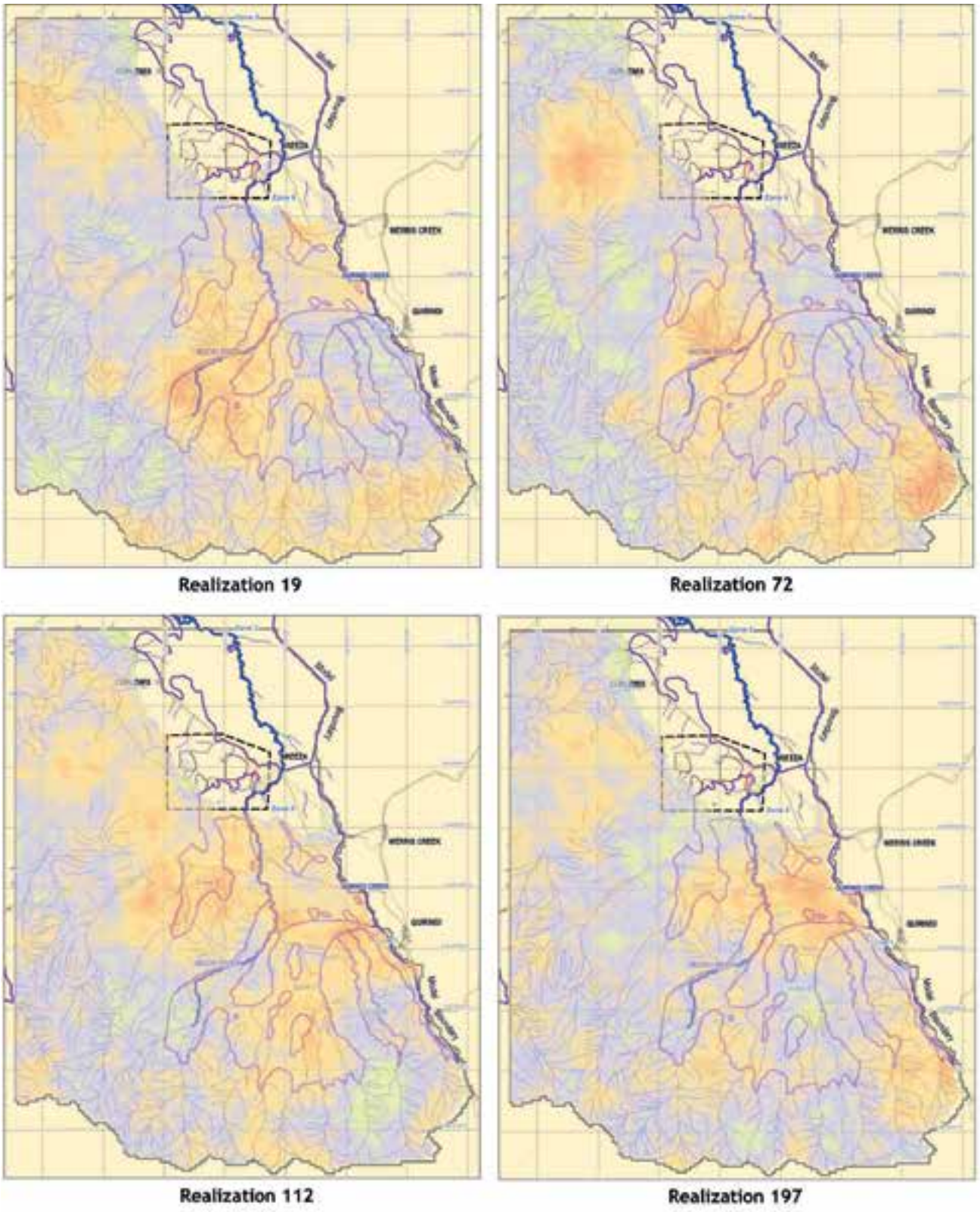
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 5)

Figure 3-27b

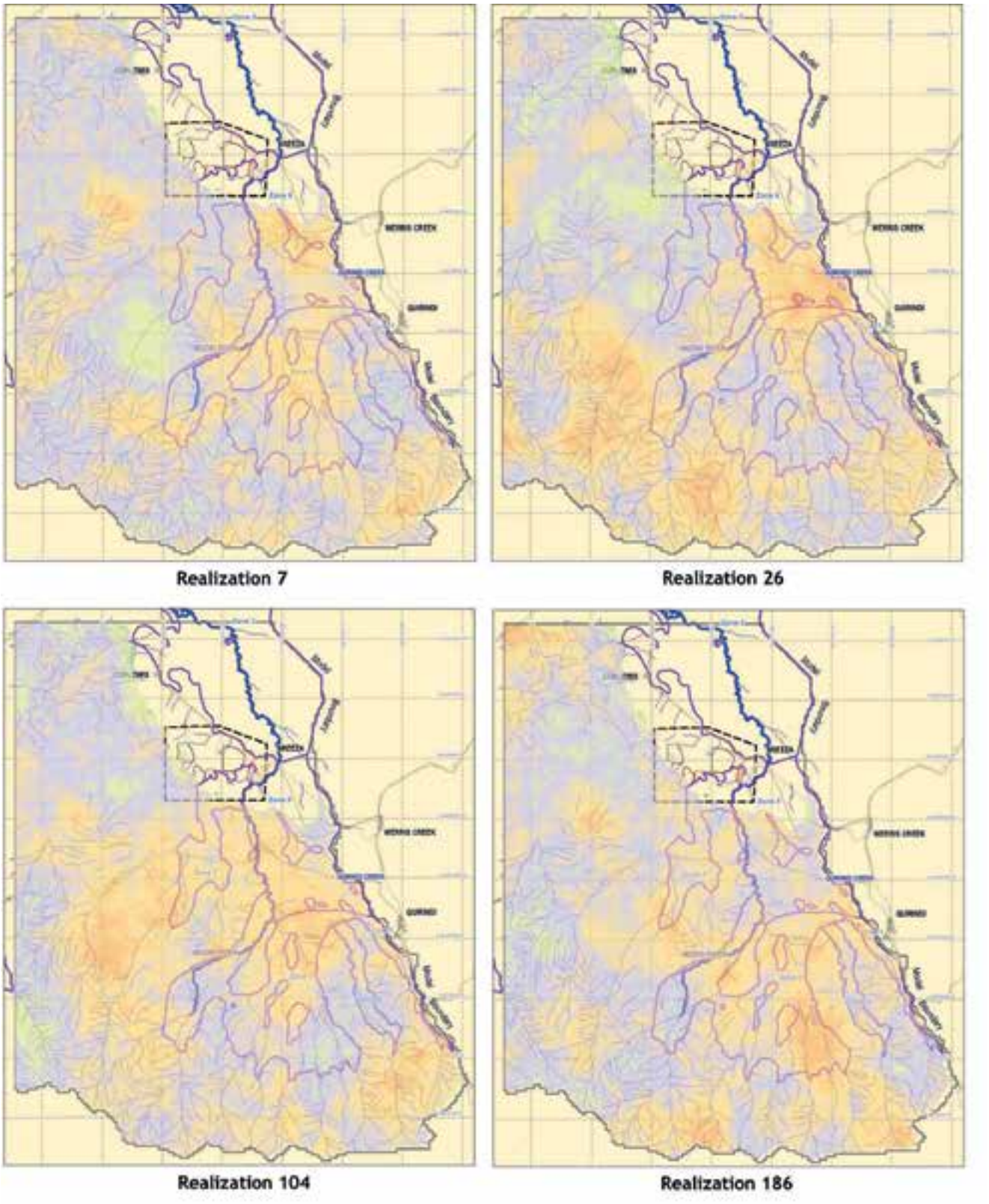
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 6)

Figure 3-28a

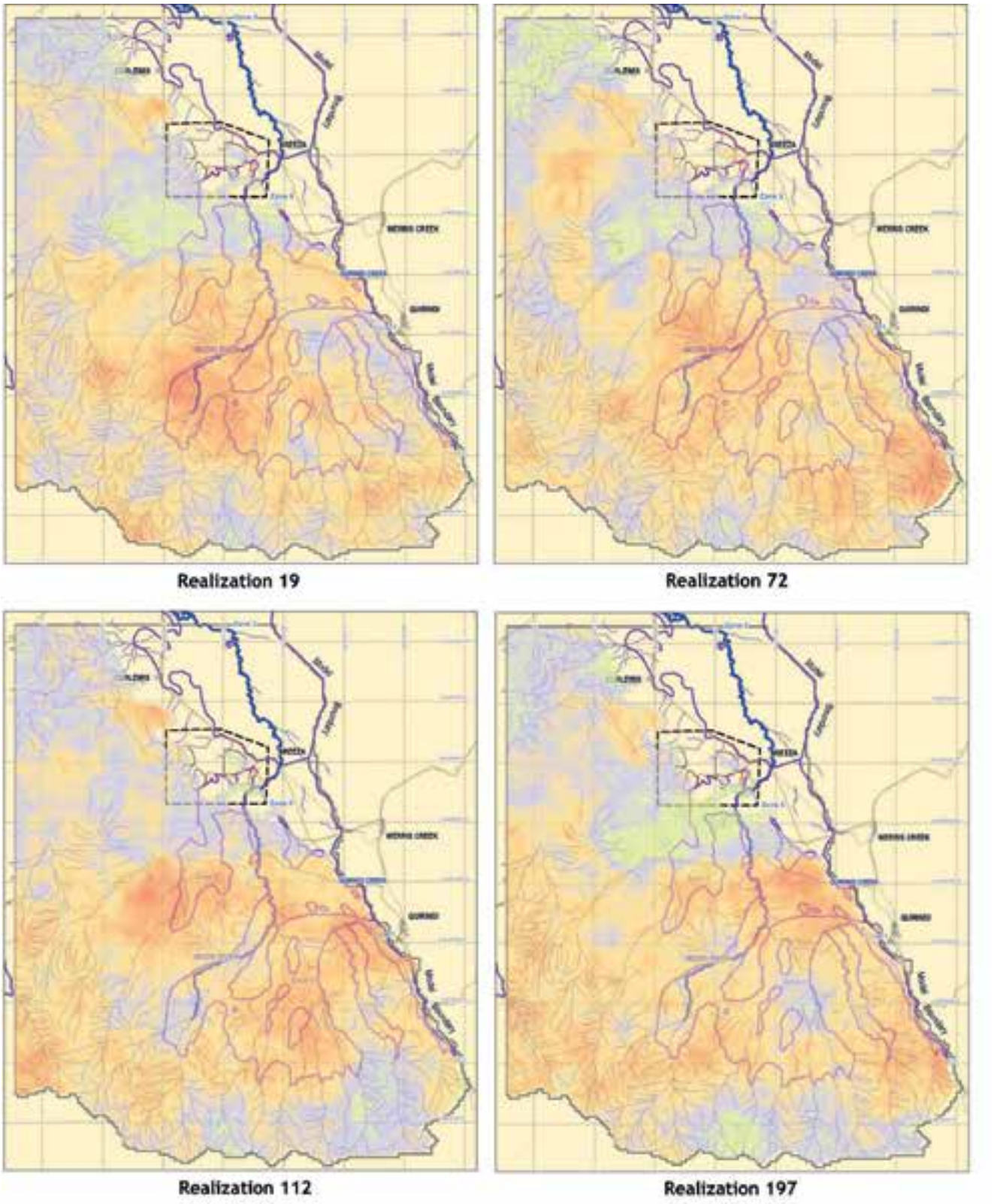
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 6)

Figure 3-28b

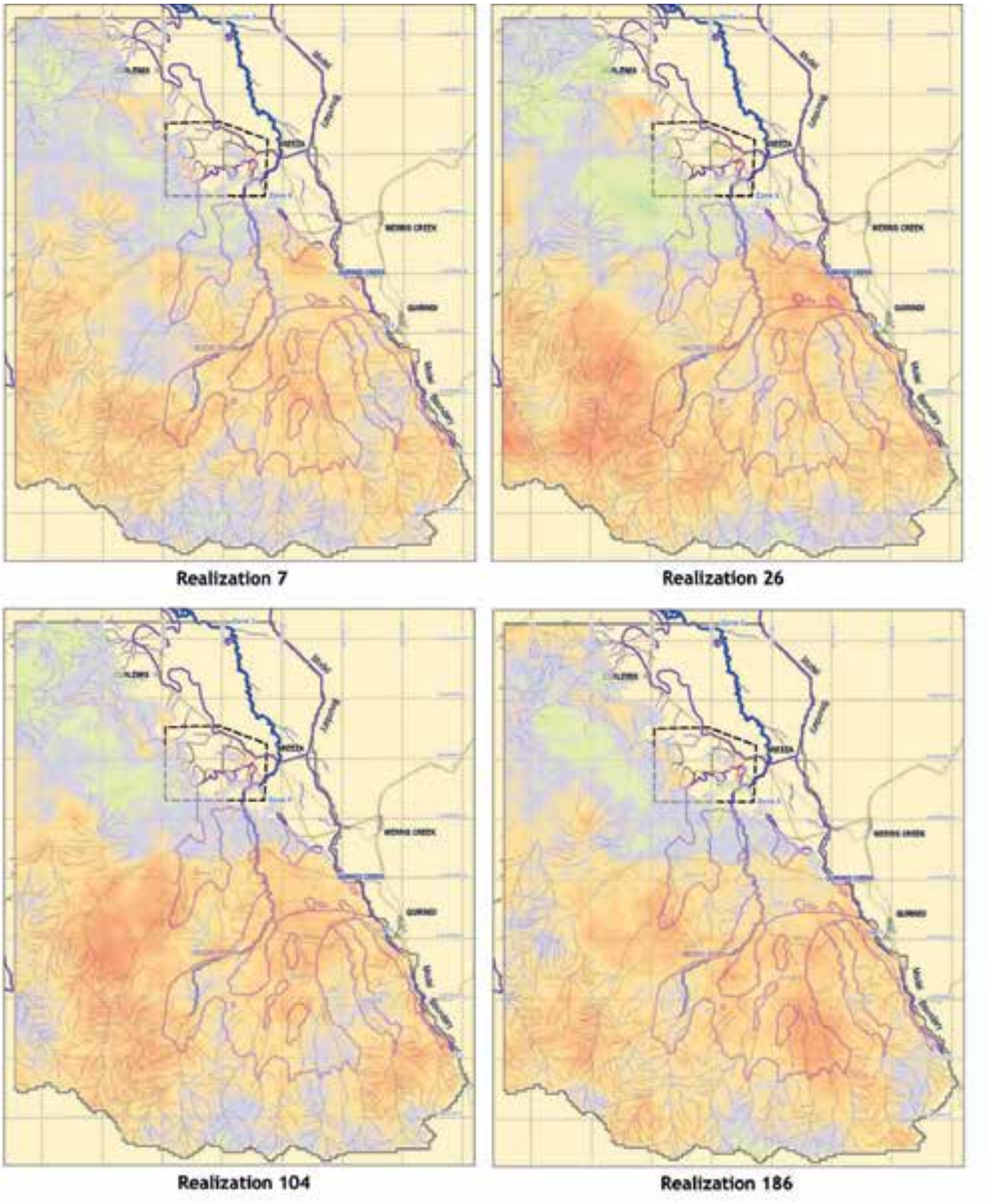
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 7)

Figure 3-29a

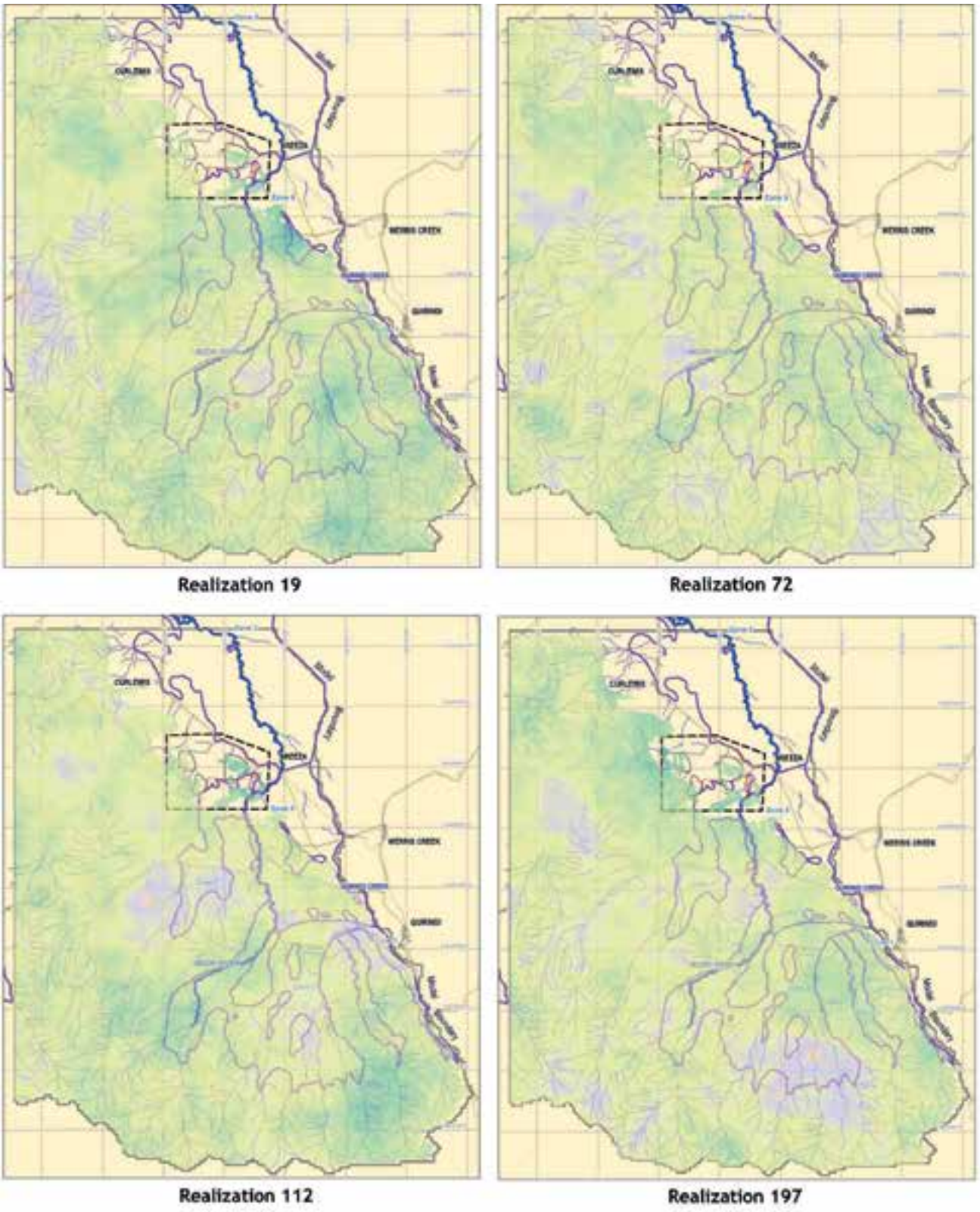
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 7)

Figure 3-29b

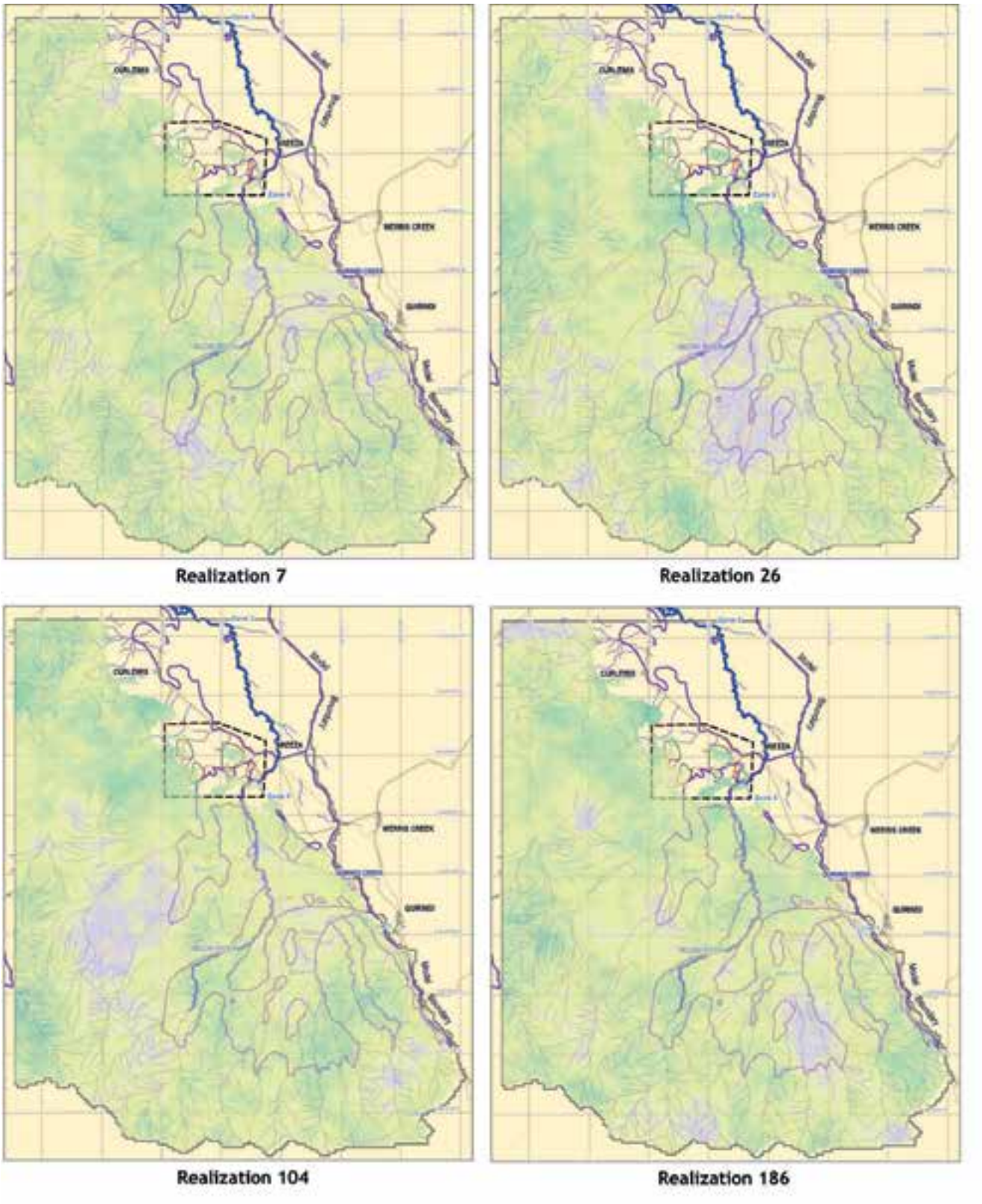
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 8)

Figure 3-30a

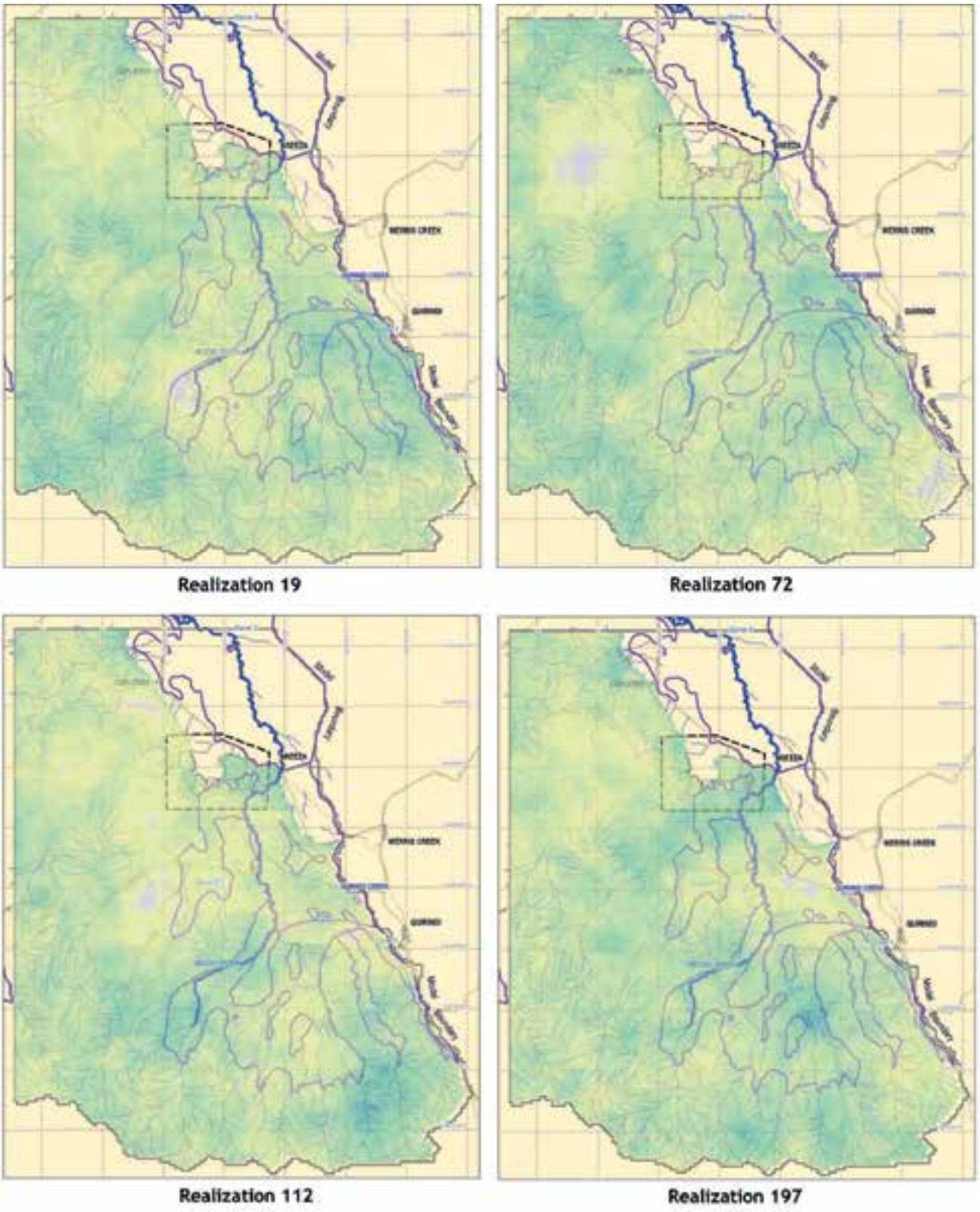
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 8)

Figure 3-30b

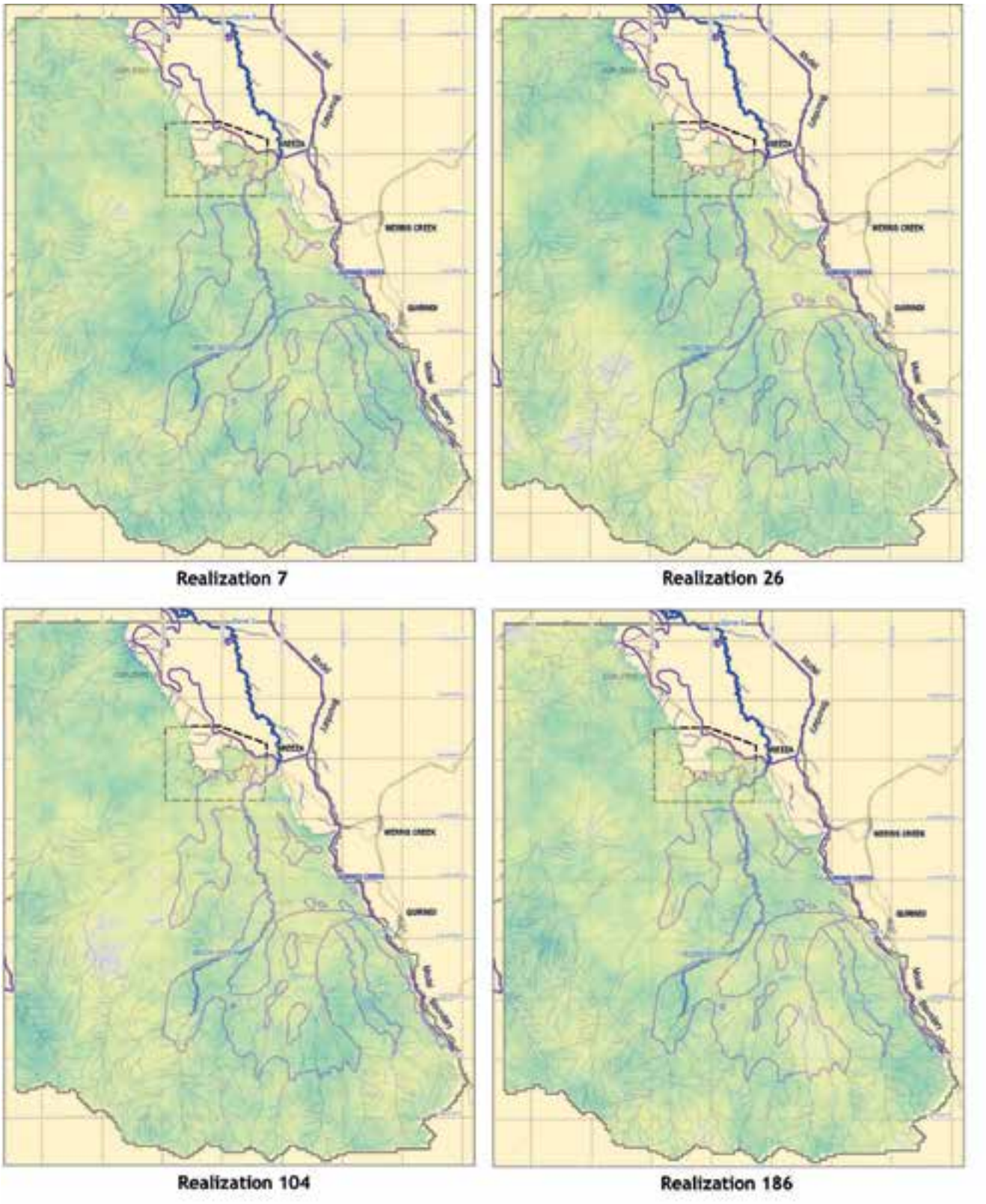
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 9)

Figure 3-31a

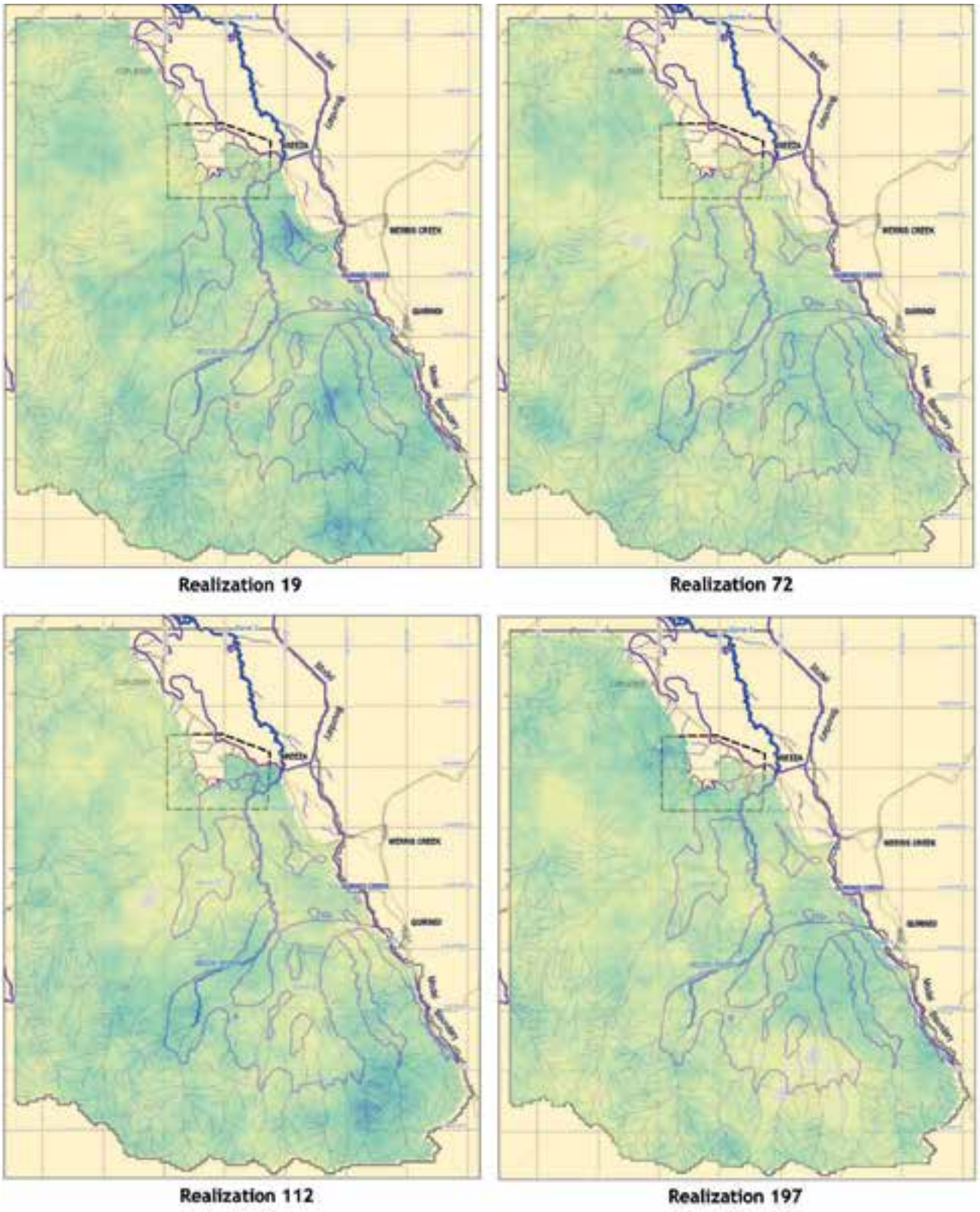
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 9)

Figure 3-31b

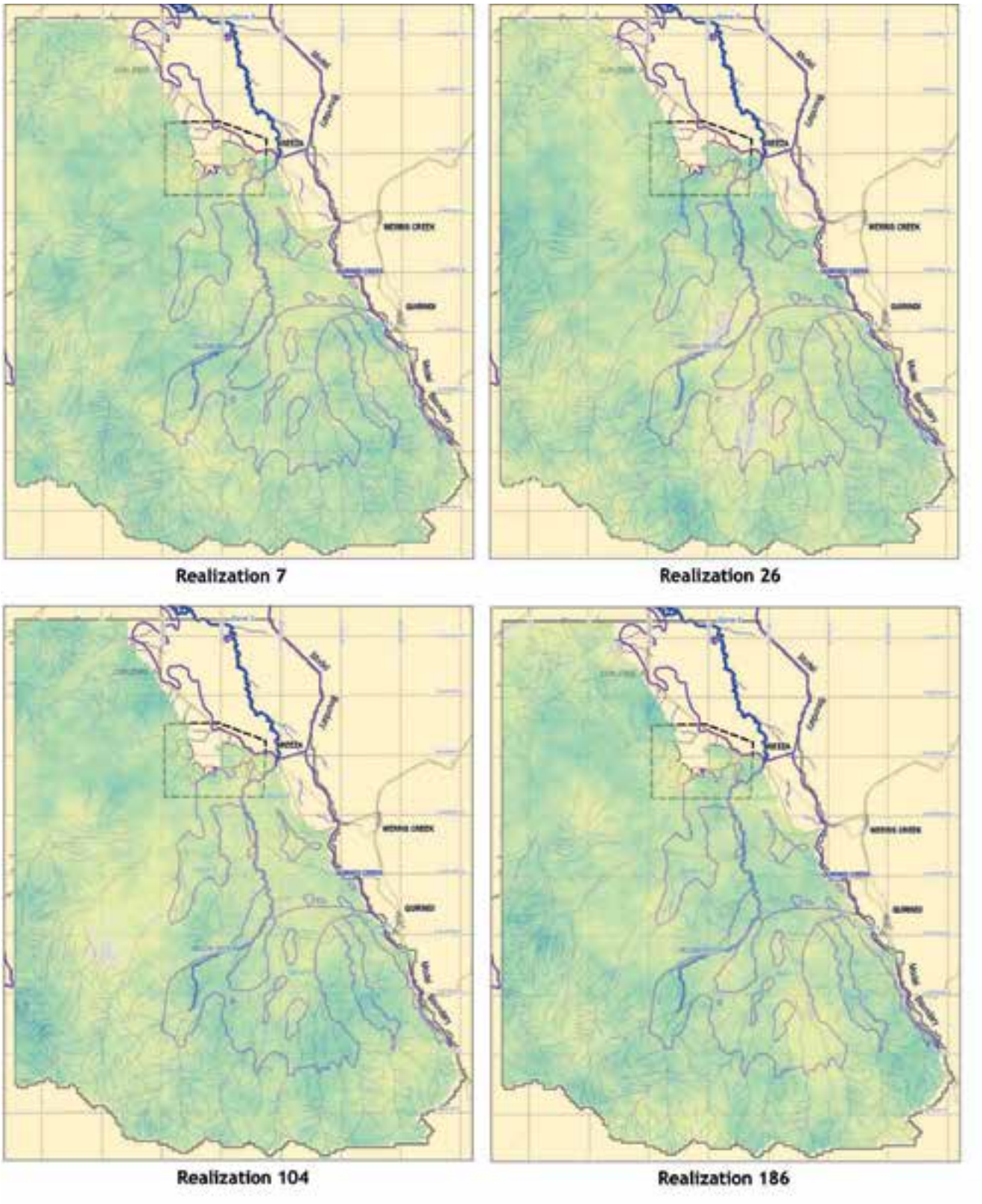
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 10)

Figure 3-32a

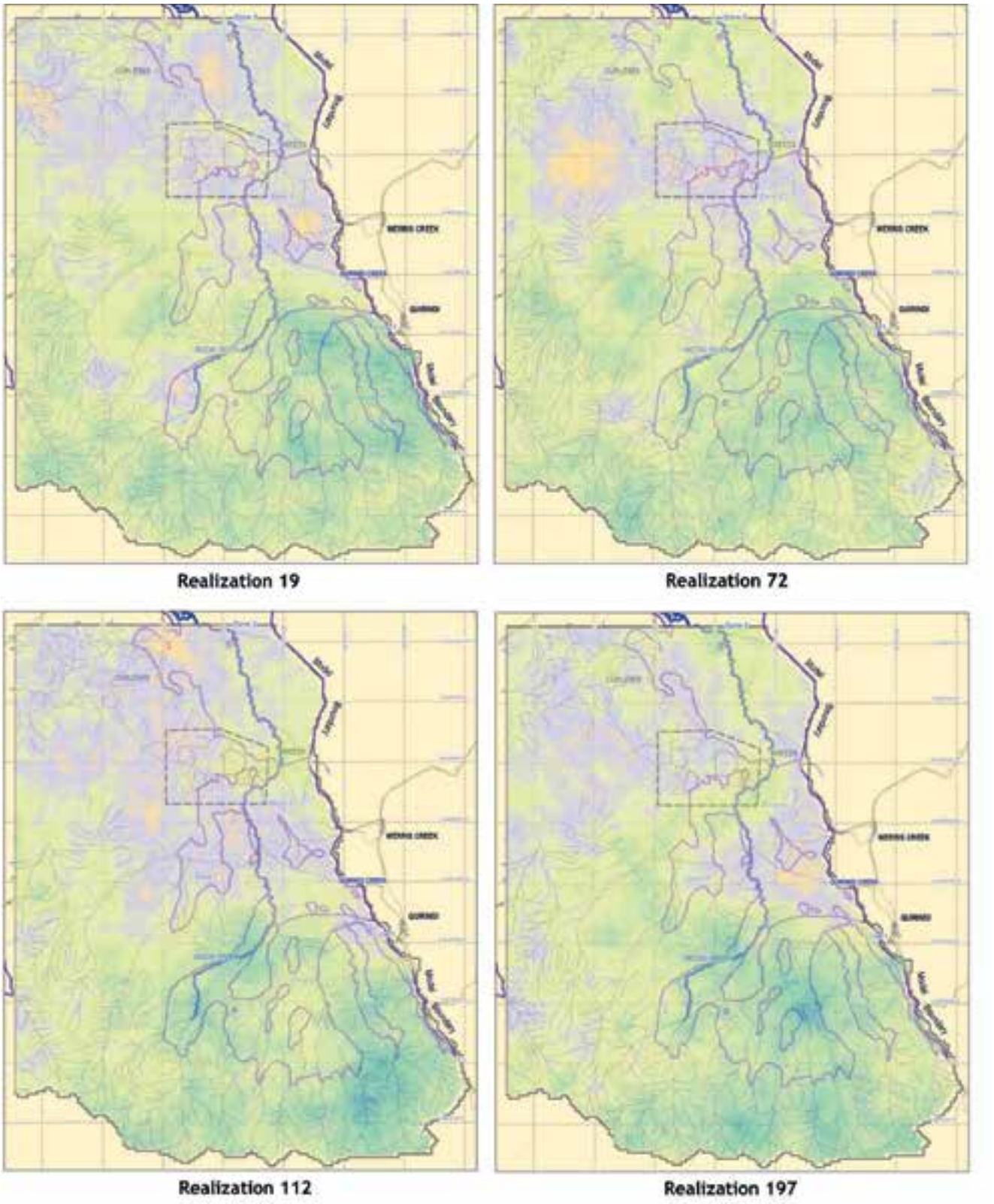
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 10)

Figure 3-32b

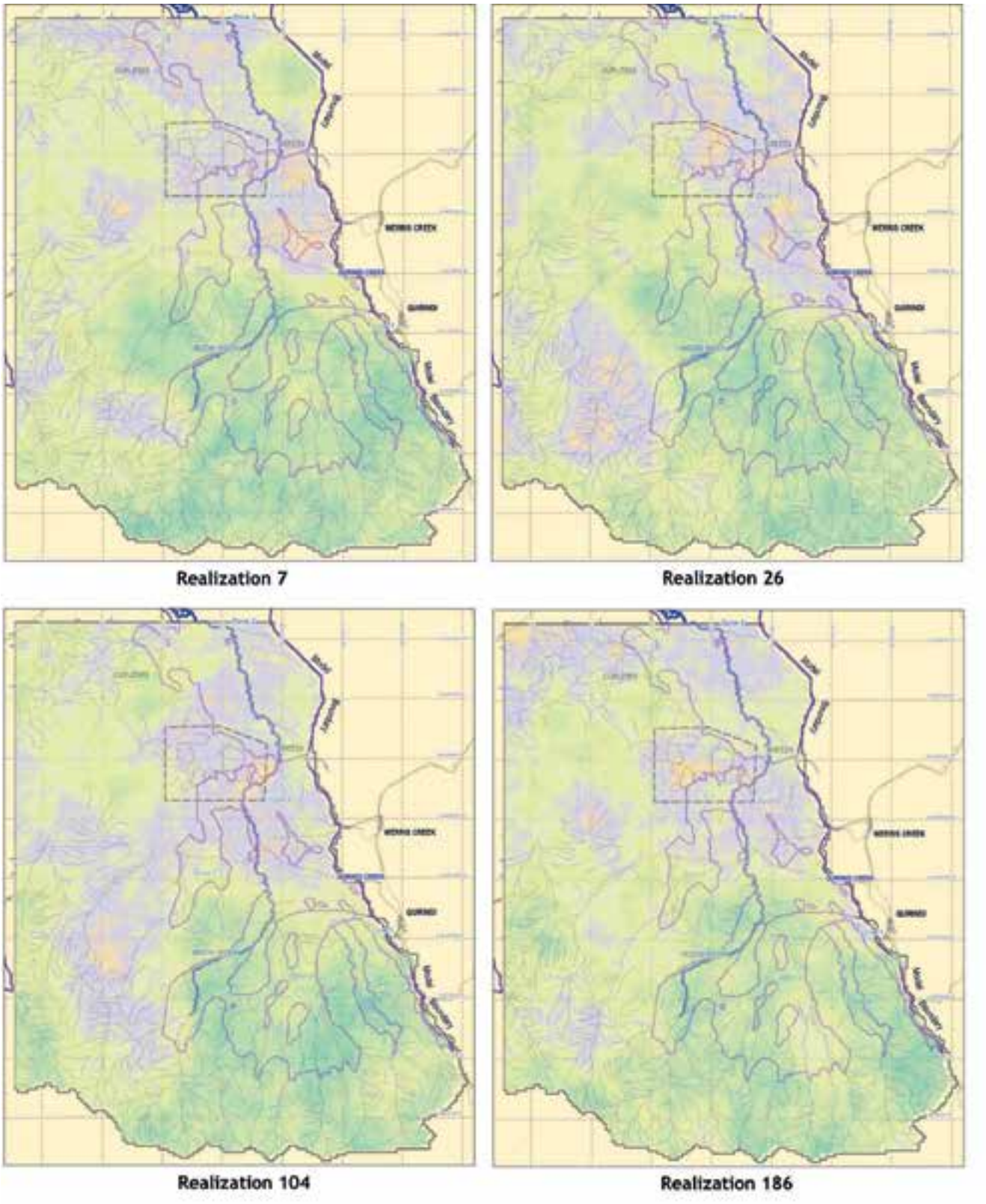
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 11)

Figure 3-33a

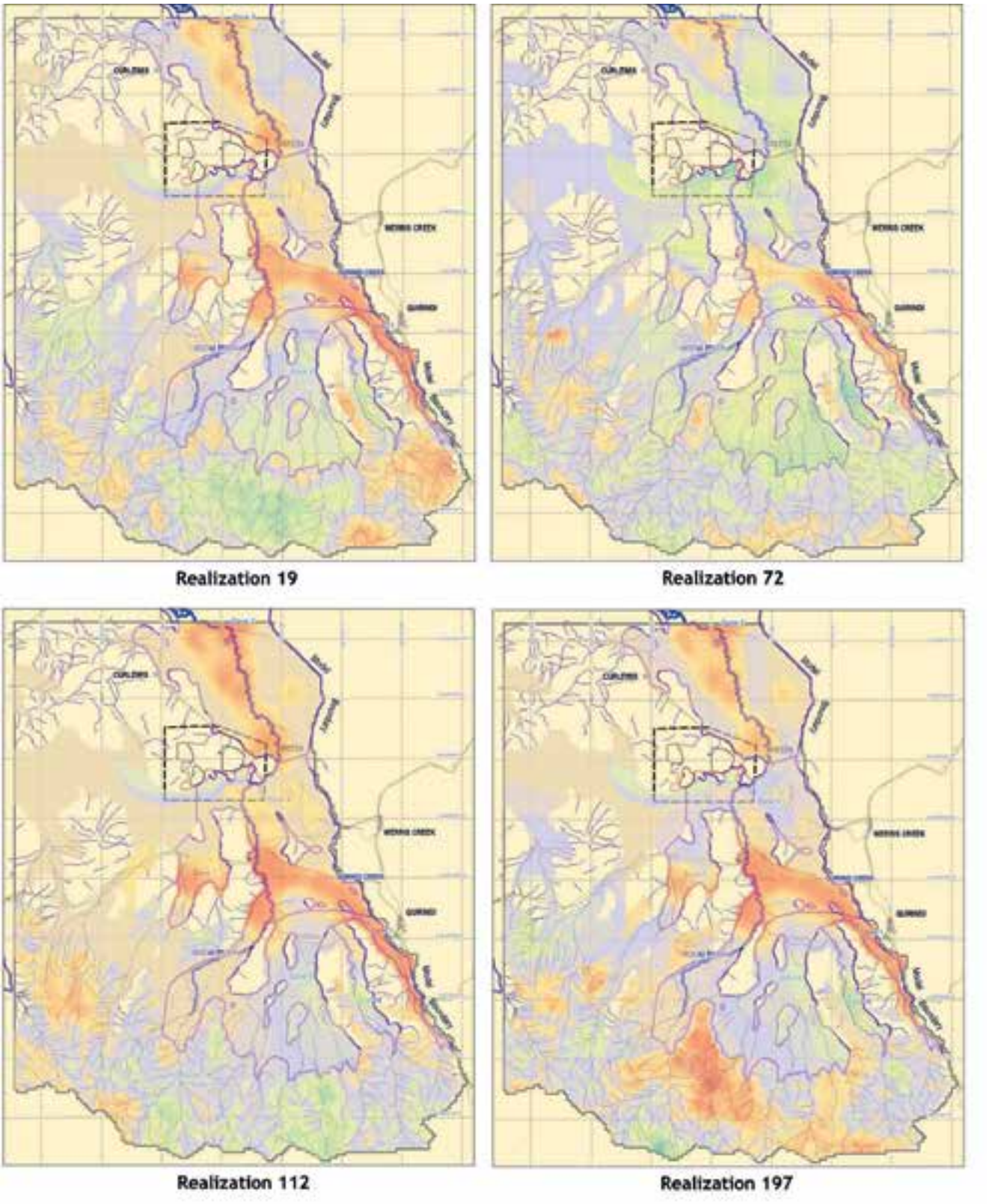
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Confined Storage Coefficient (Layer 11)

Figure 3-33b

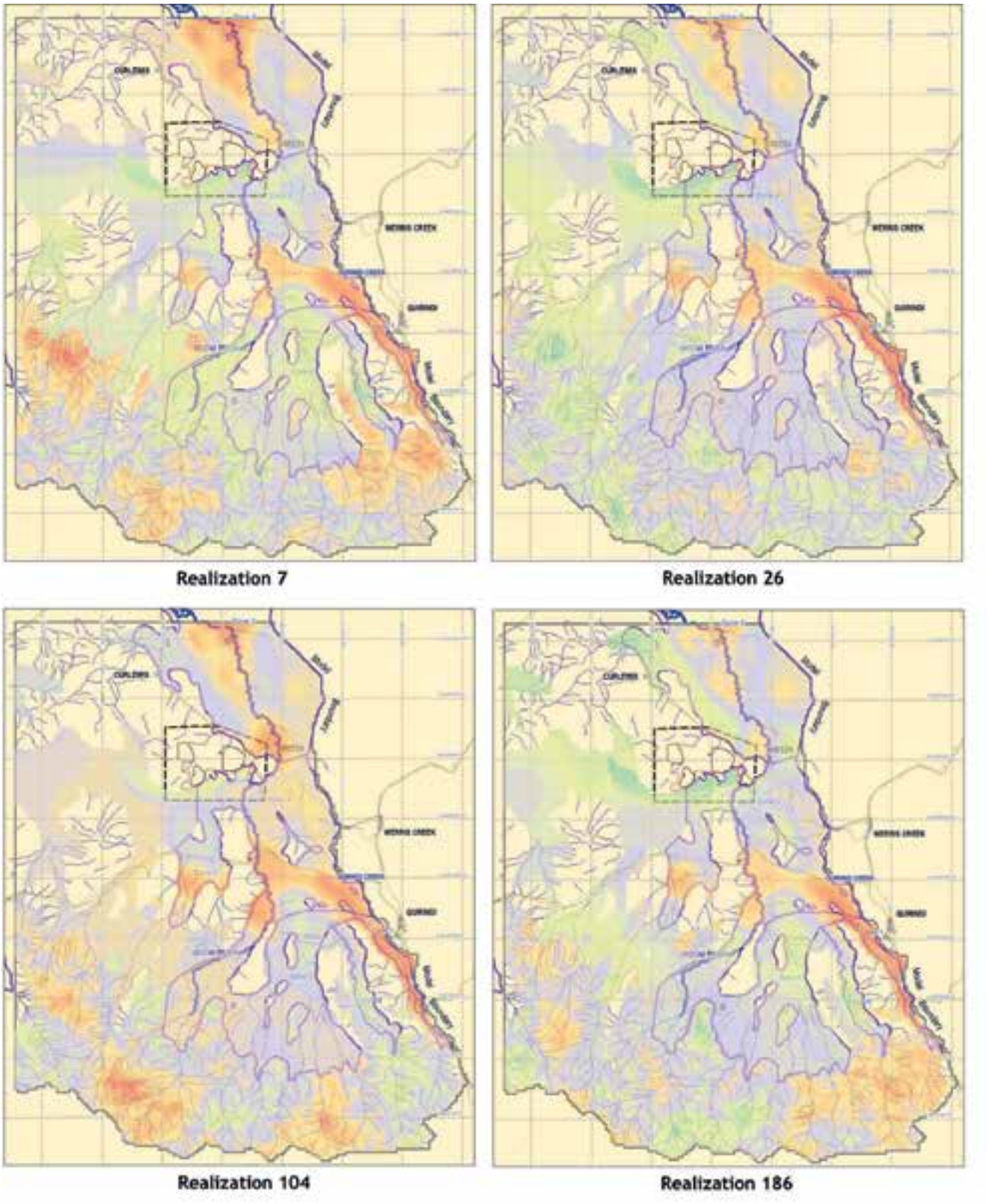
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 1)

Figure 3-34a

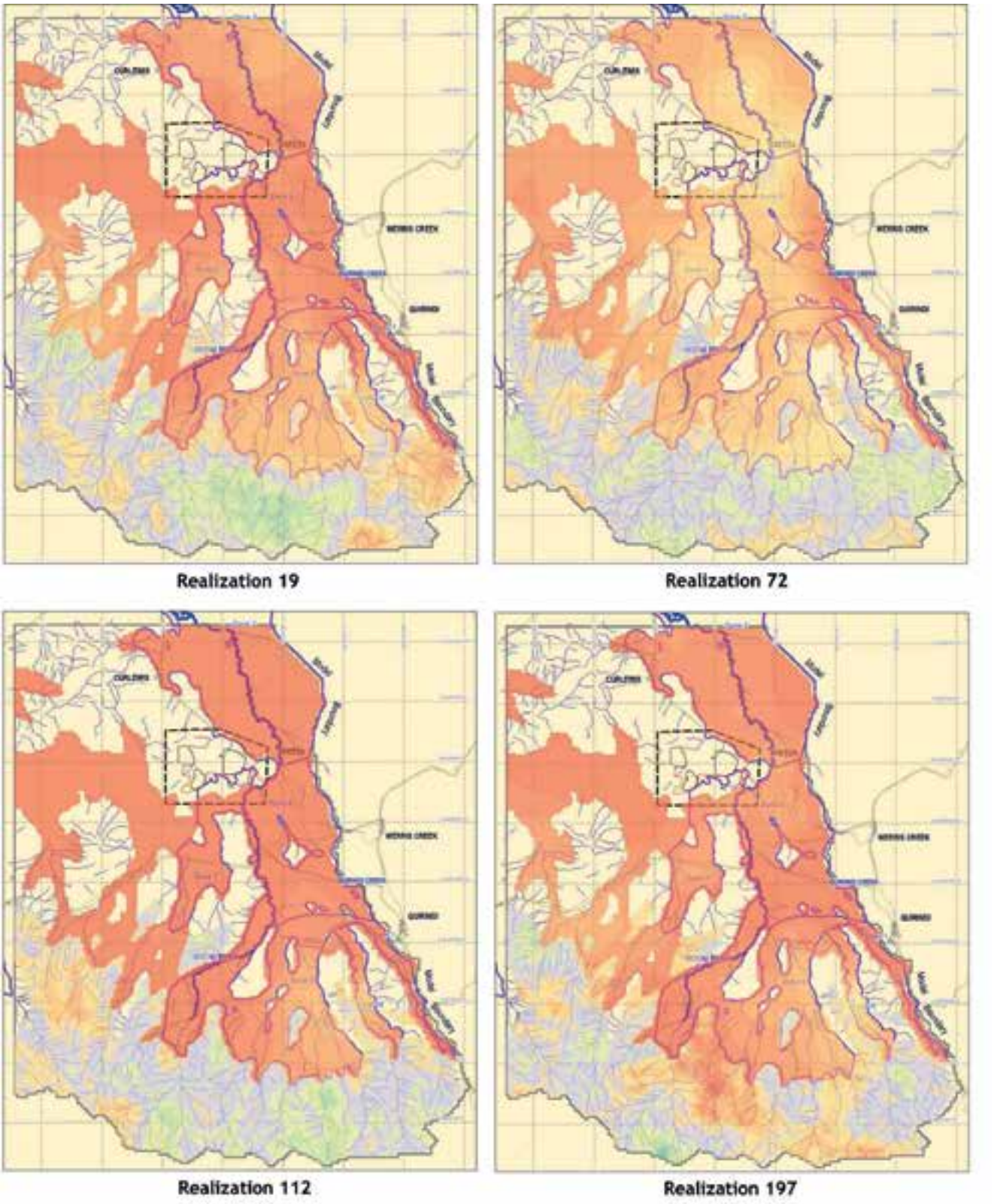
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 1)

Figure 3-34b

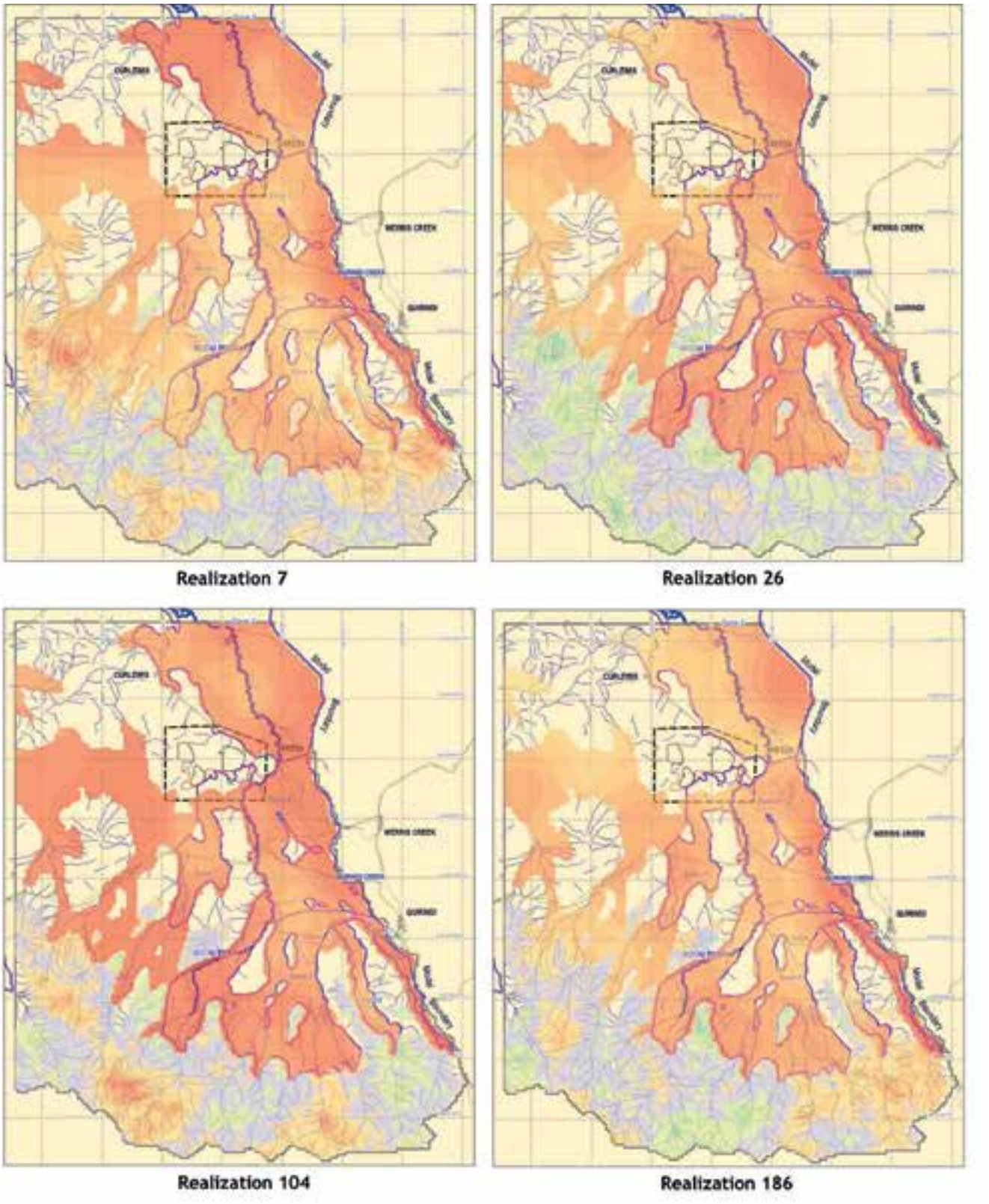
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 2)

Figure 3-35a

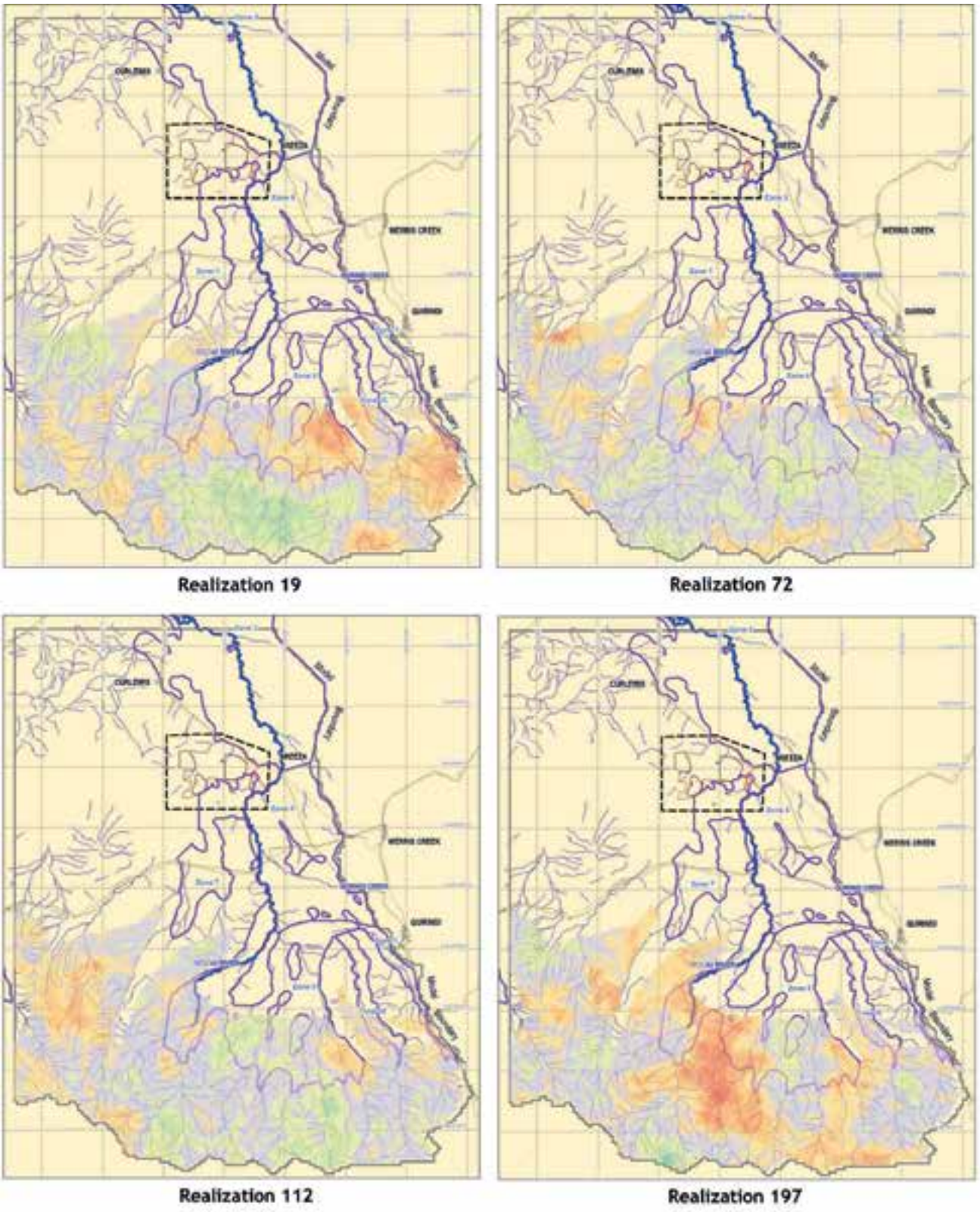
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 2)

Figure 3-35b

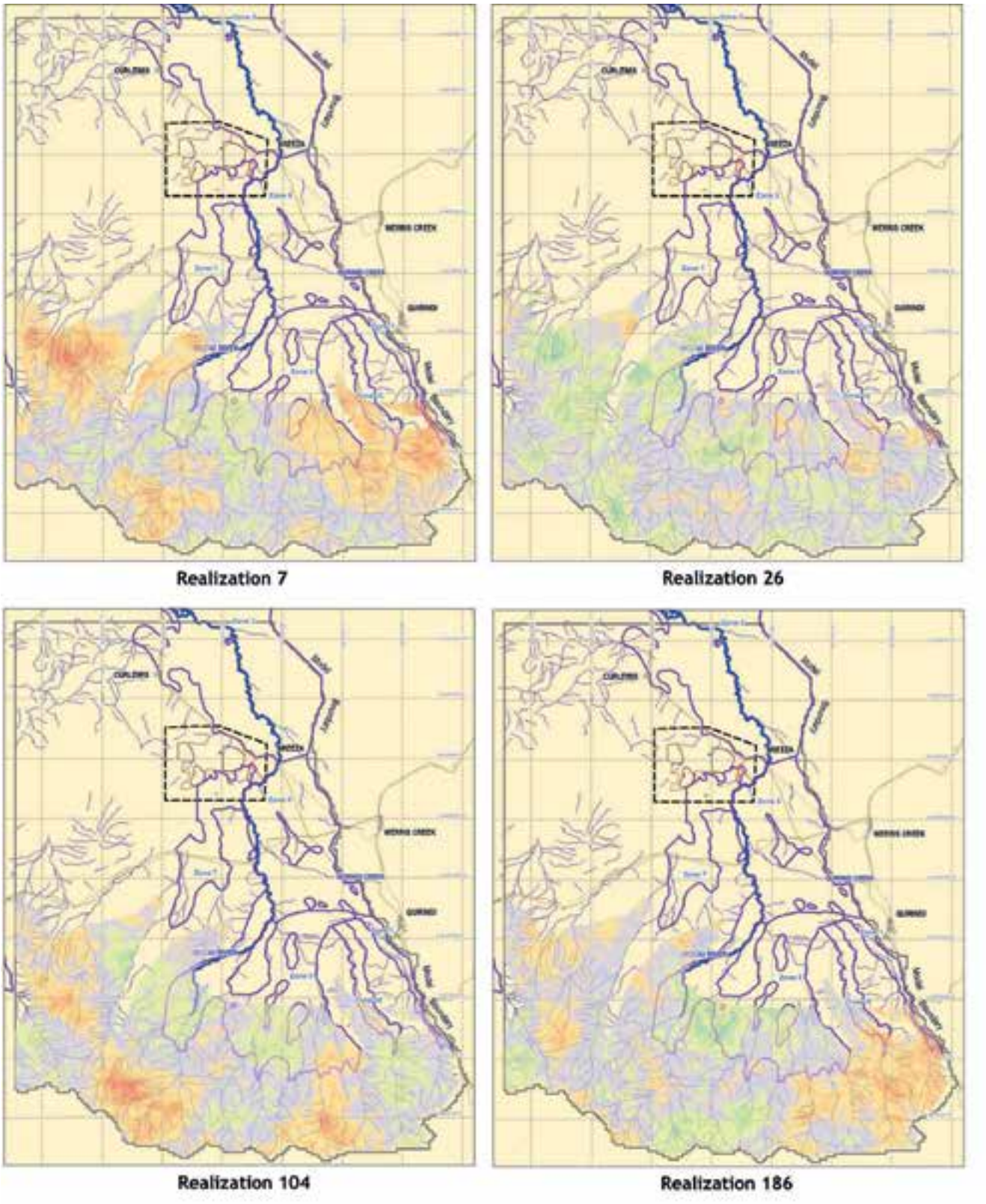
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 3)

Figure 3-36a

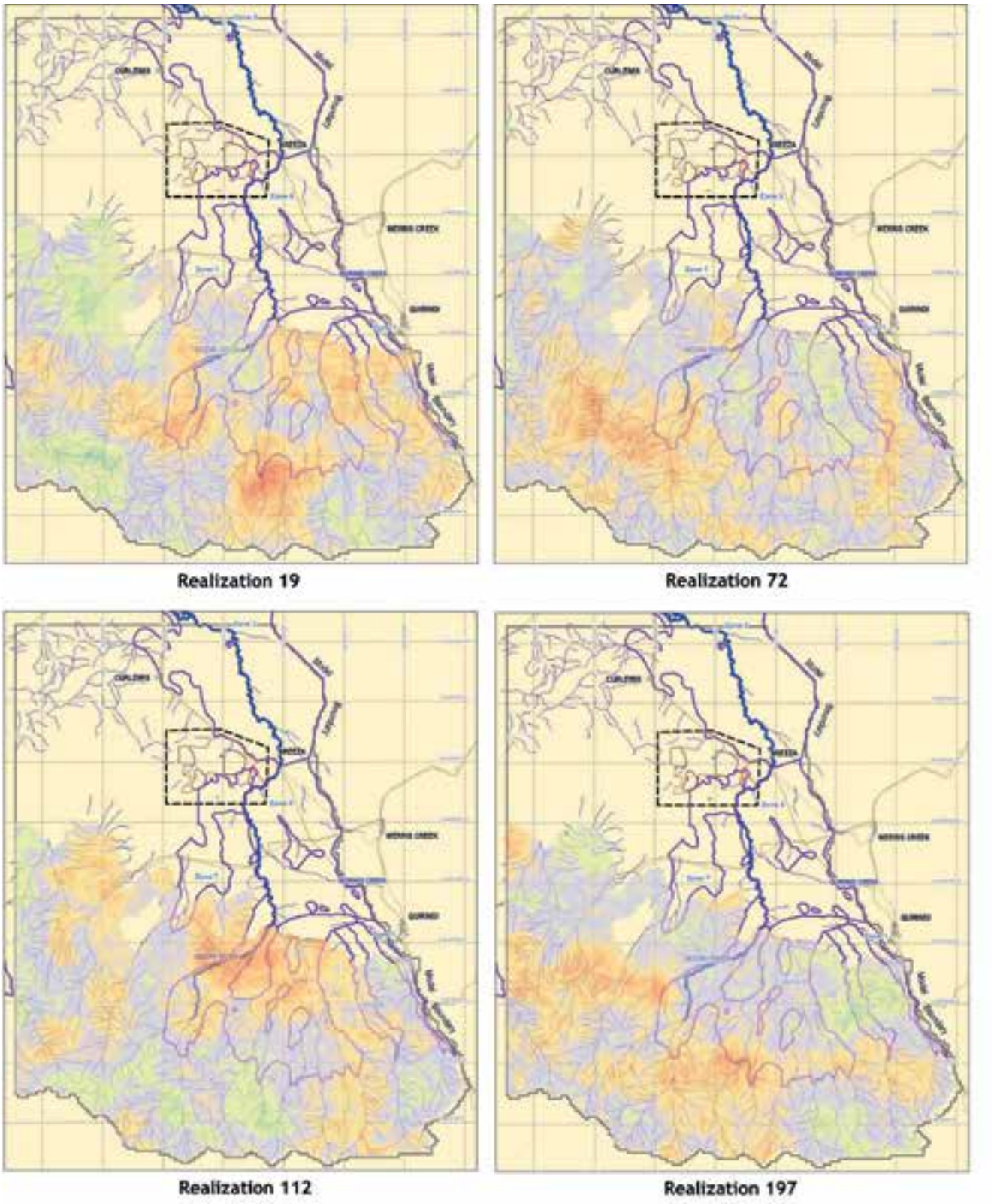
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 3)

Figure 3-36b

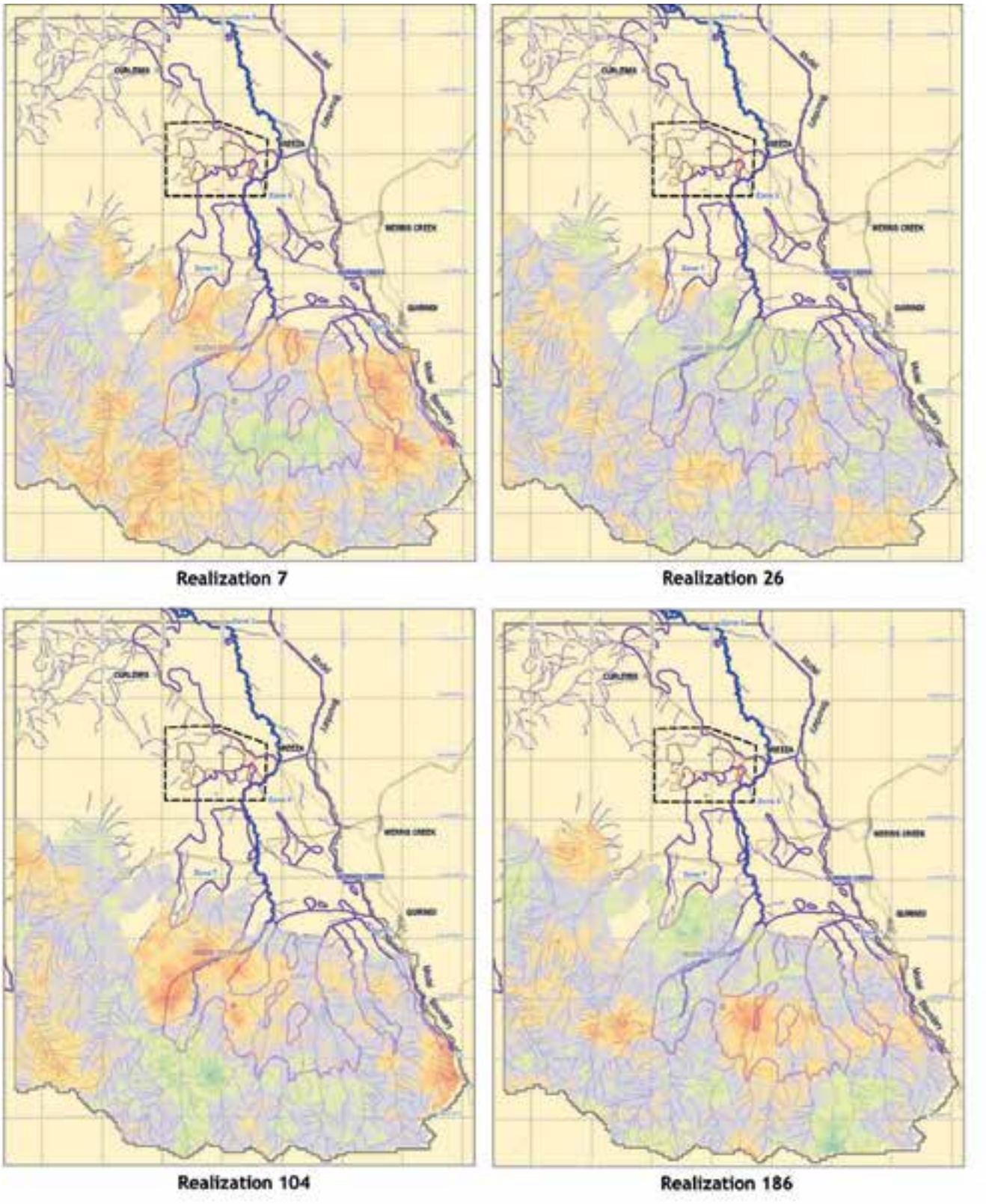
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 4)

Figure 3-37a

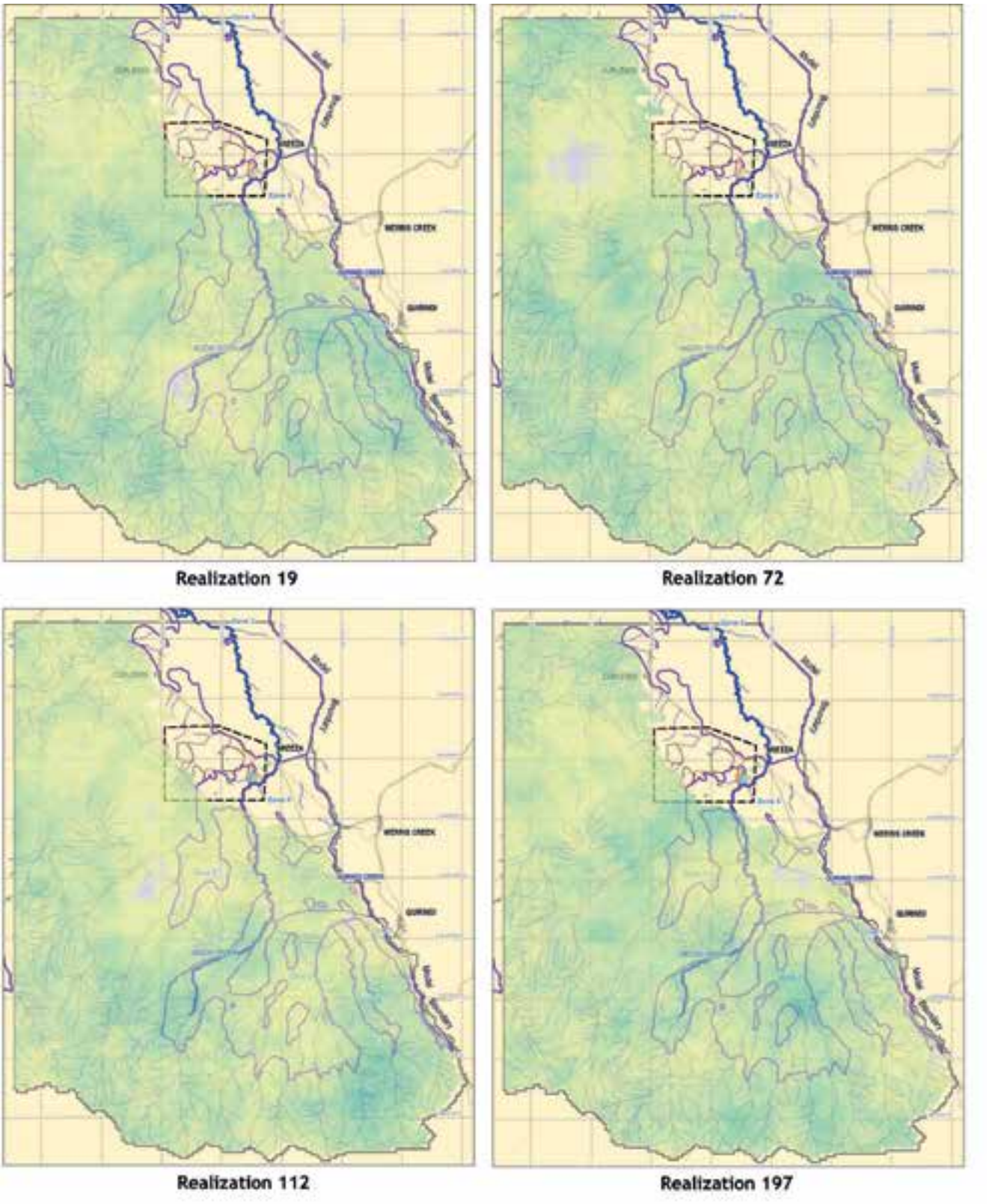
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 4)

Figure 3-37b

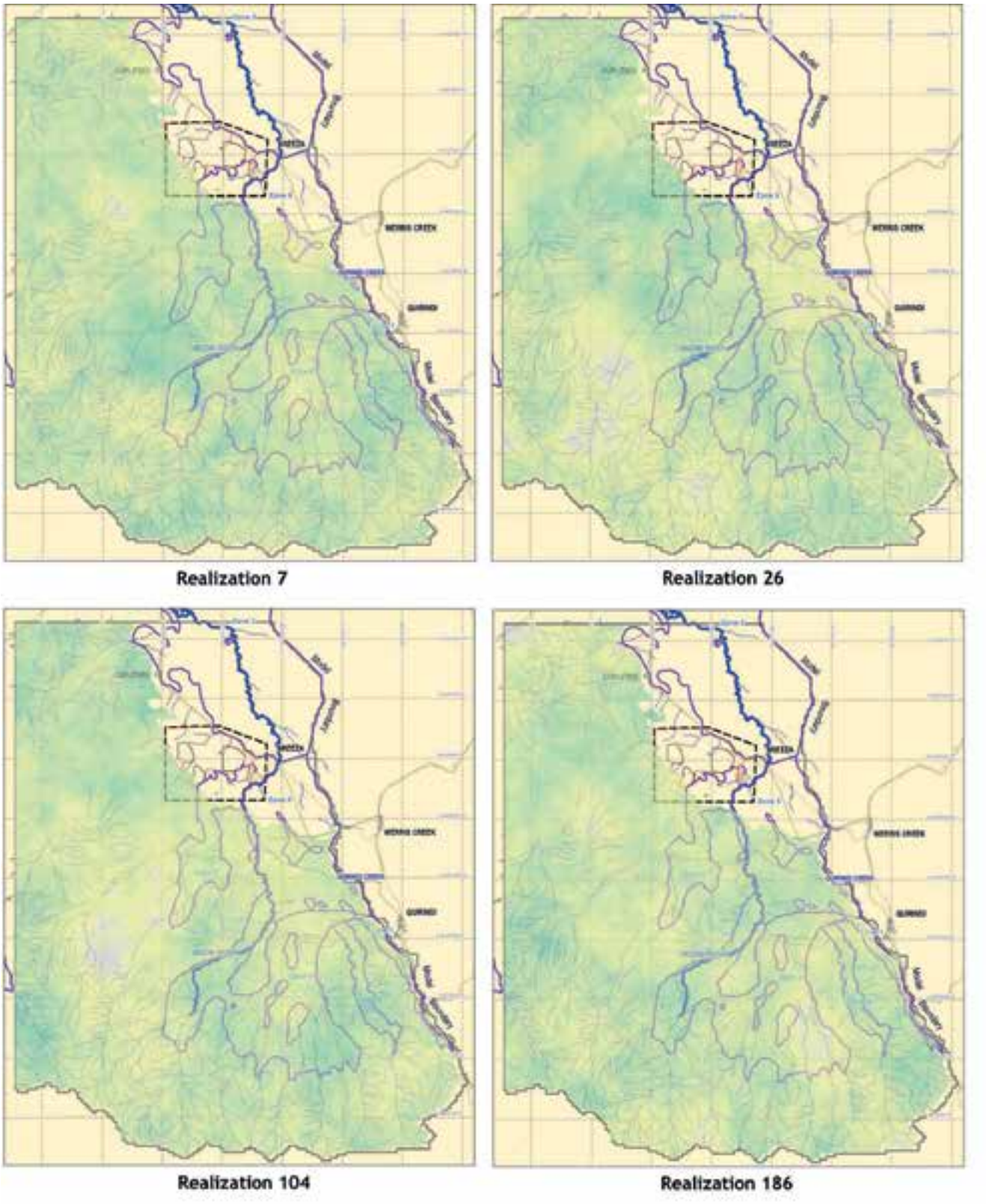
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 5)

Figure 3-38a

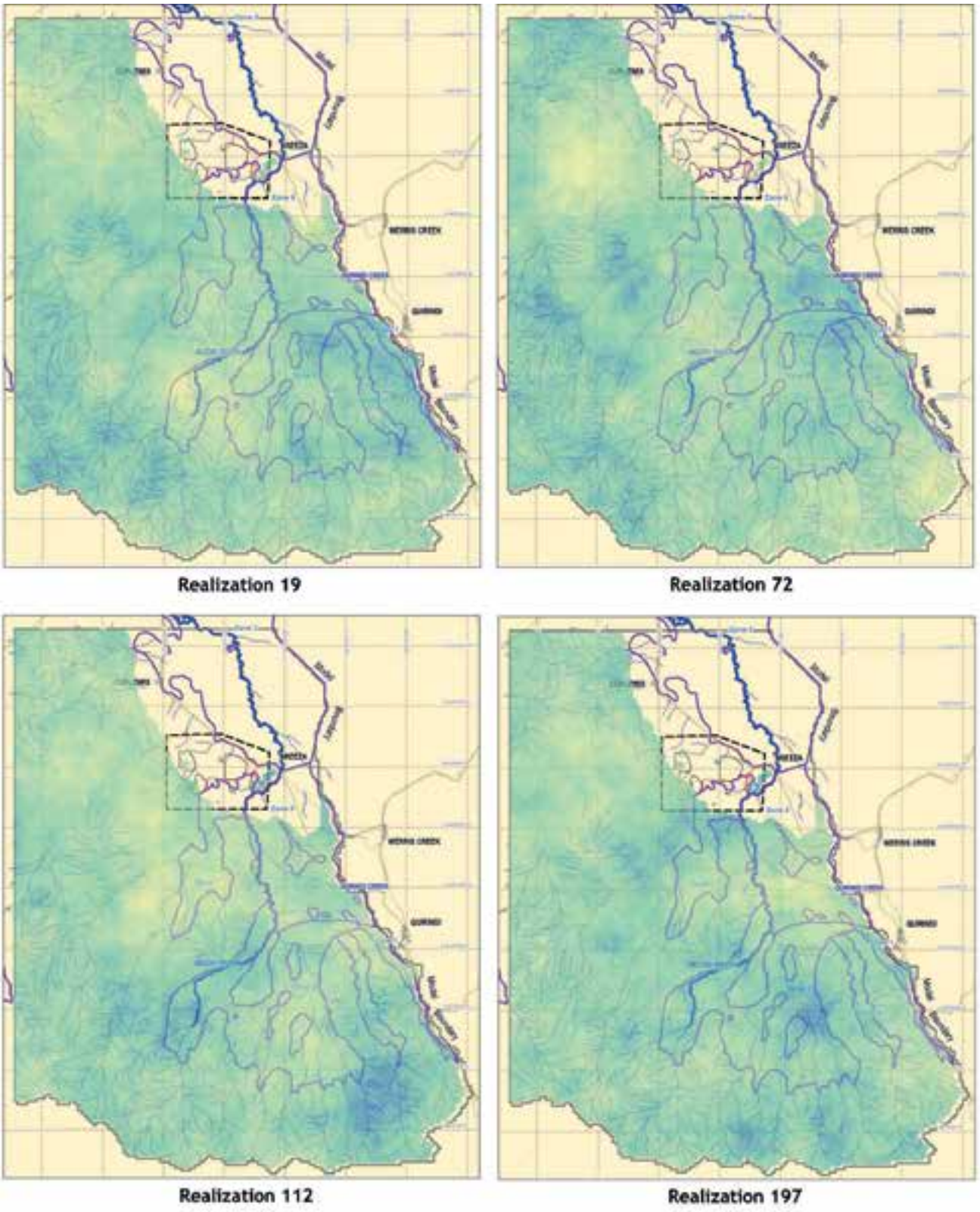
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 5)

Figure 3-38b

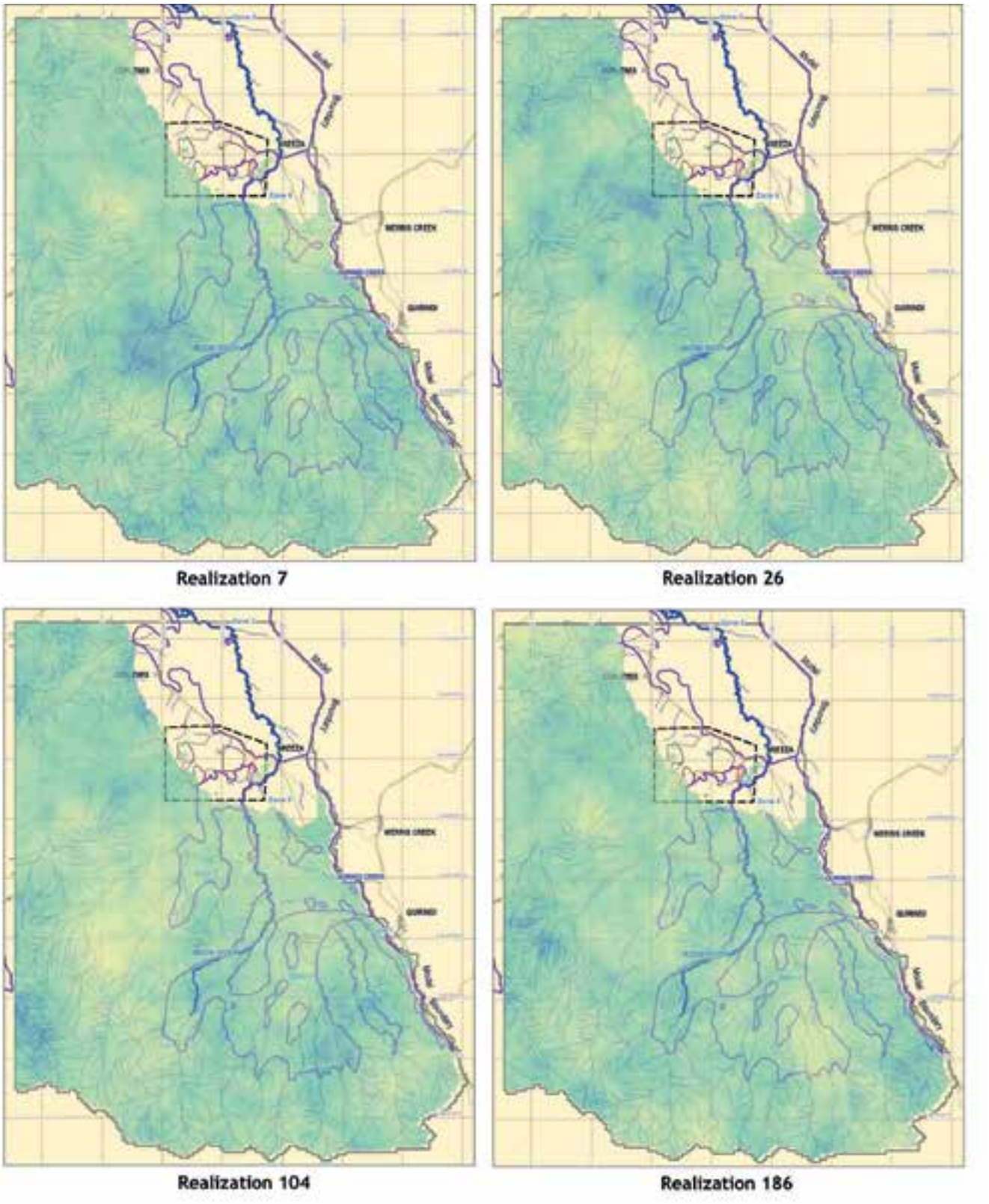
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 6)

Figure 3-39a

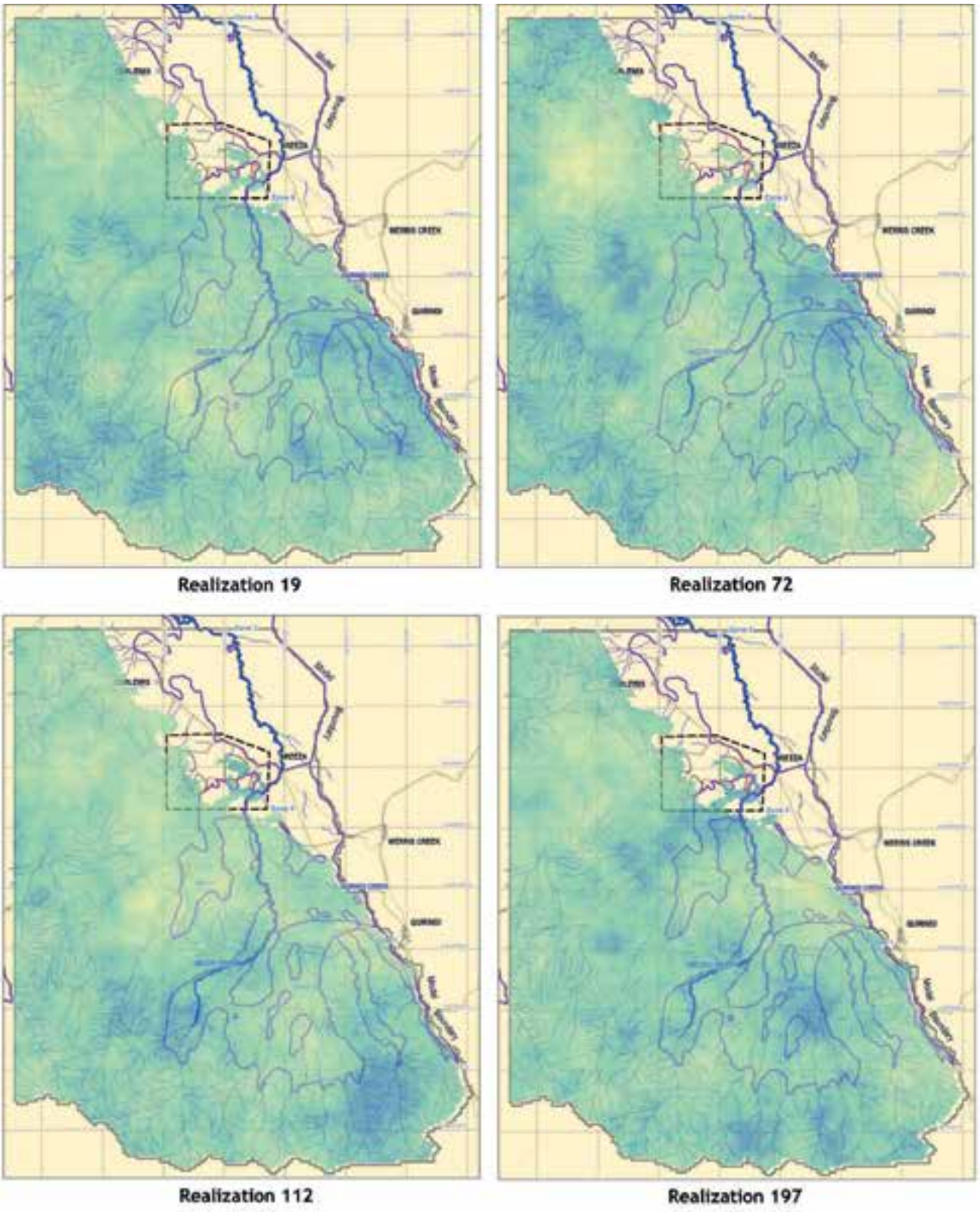
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 6)

Figure 3-39b

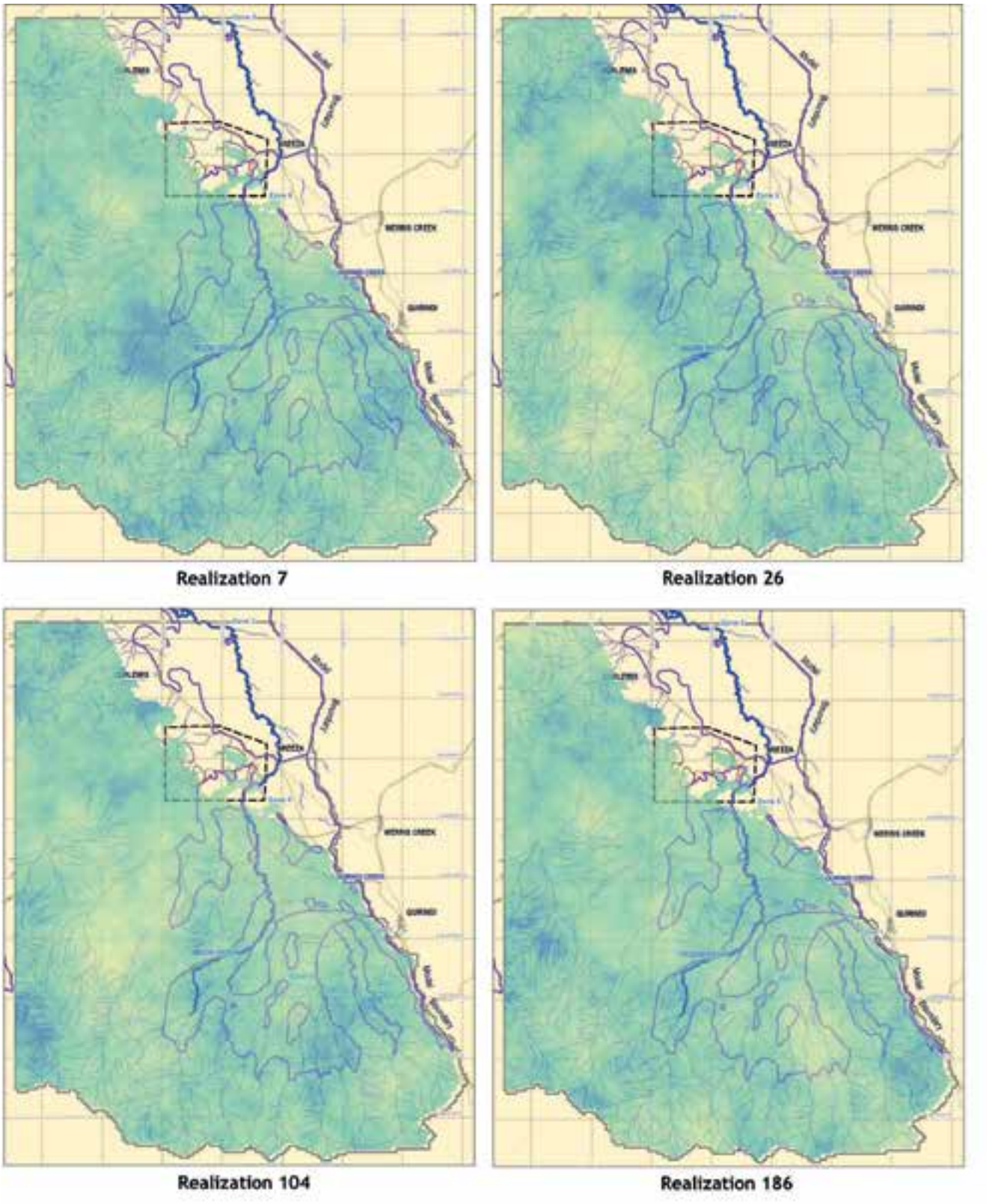
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 7)

Figure 3-40a

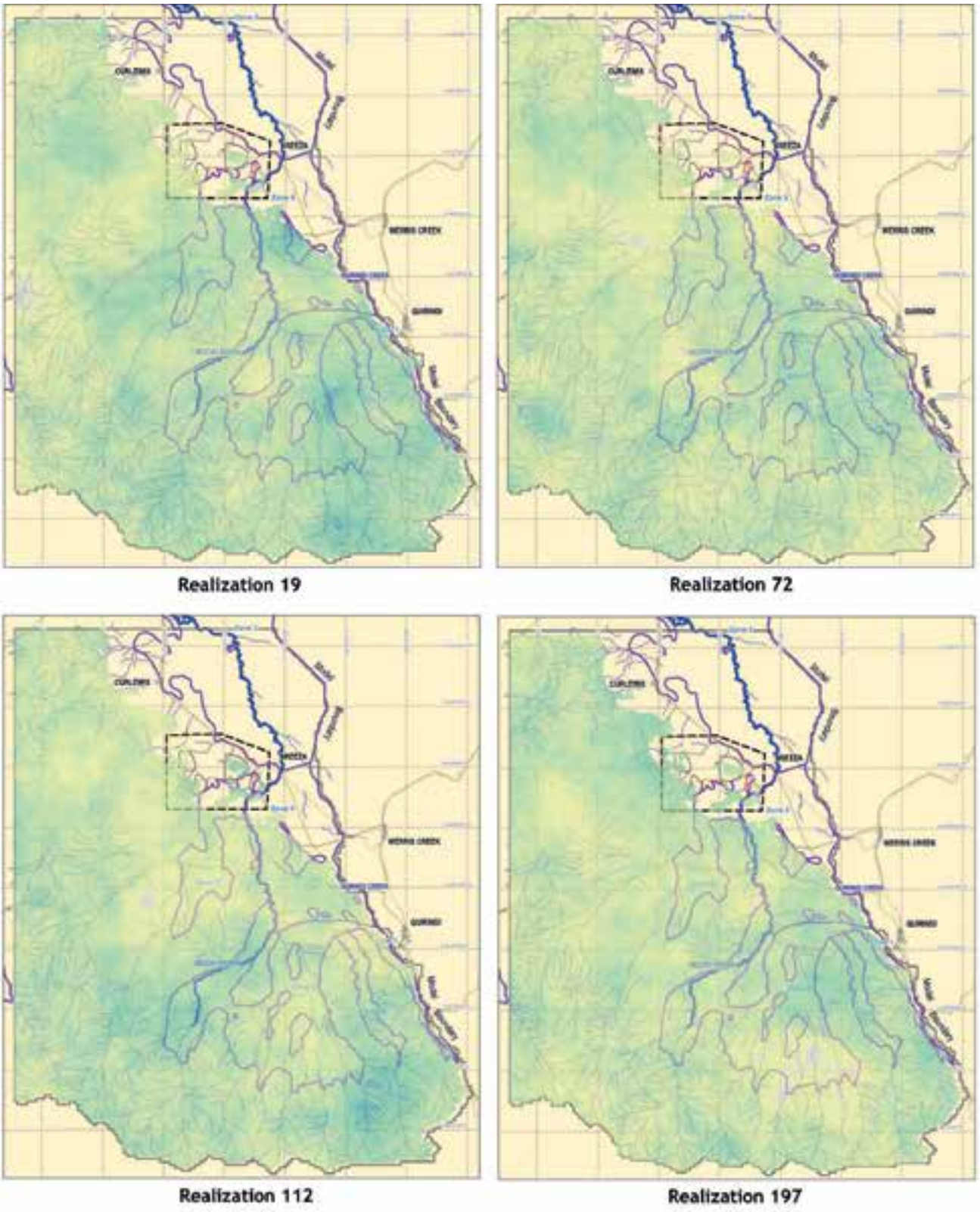
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 7)

Figure 3-40b

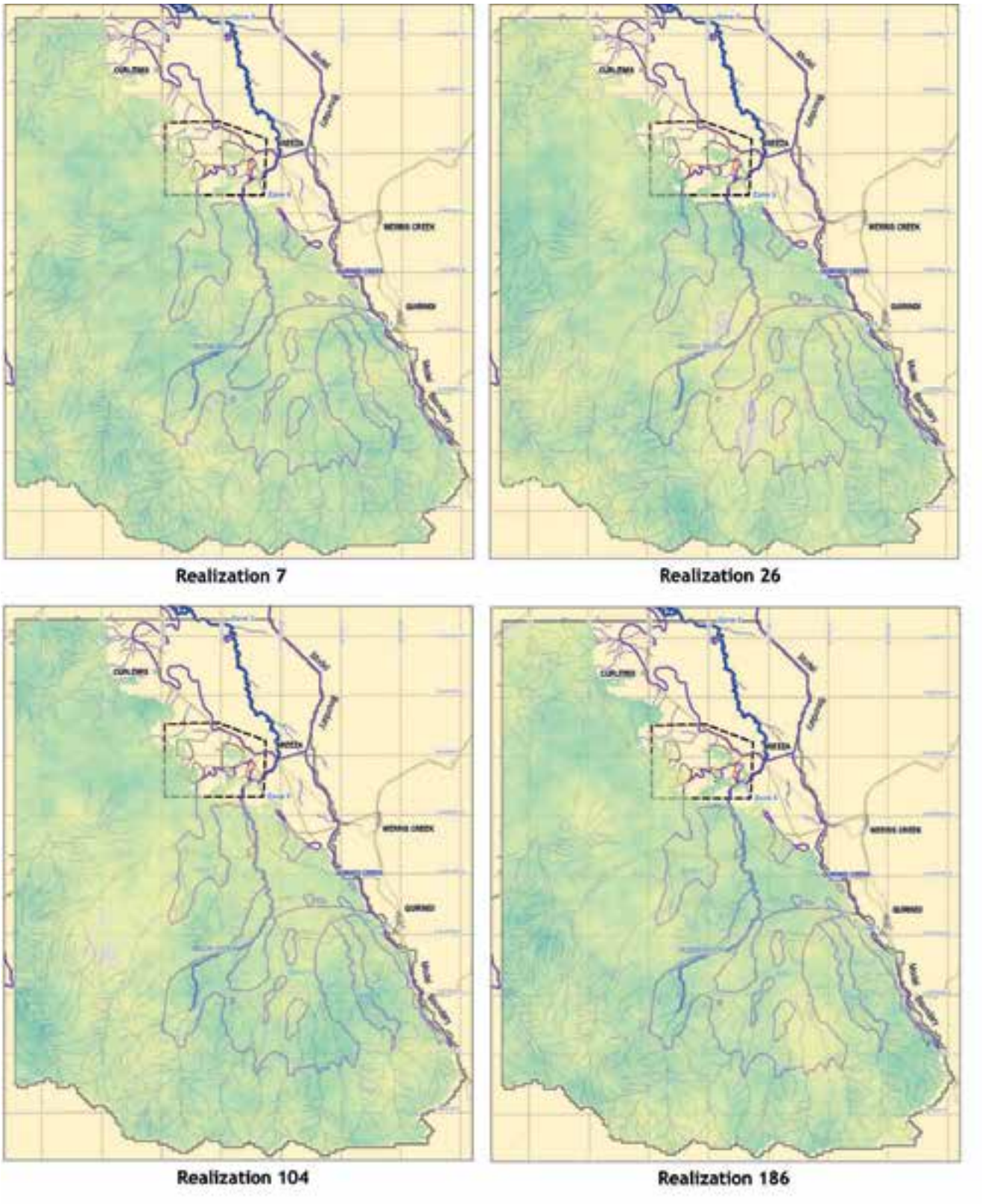
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 8)

Figure 3-41a

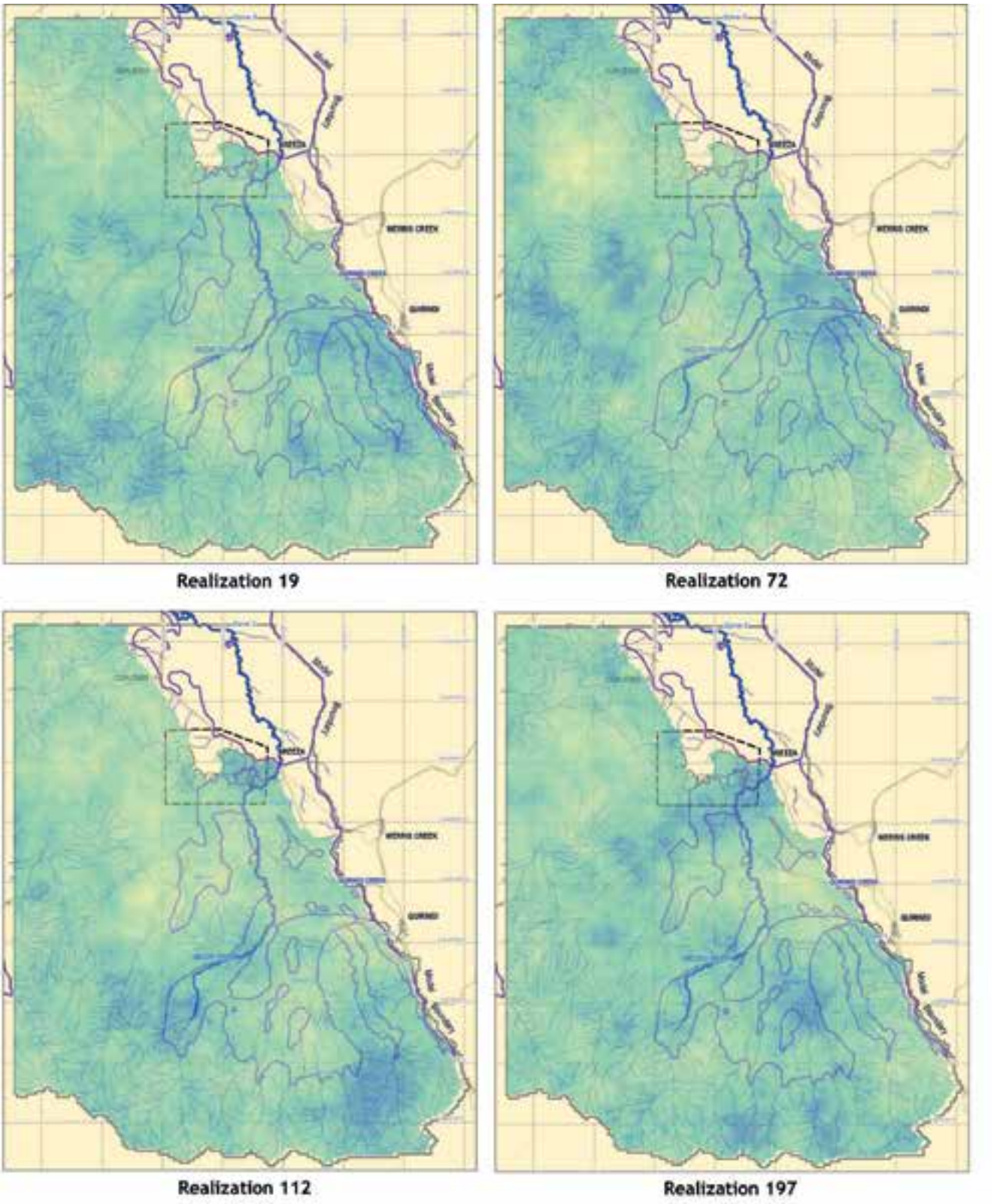
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 8)

Figure 3-41b

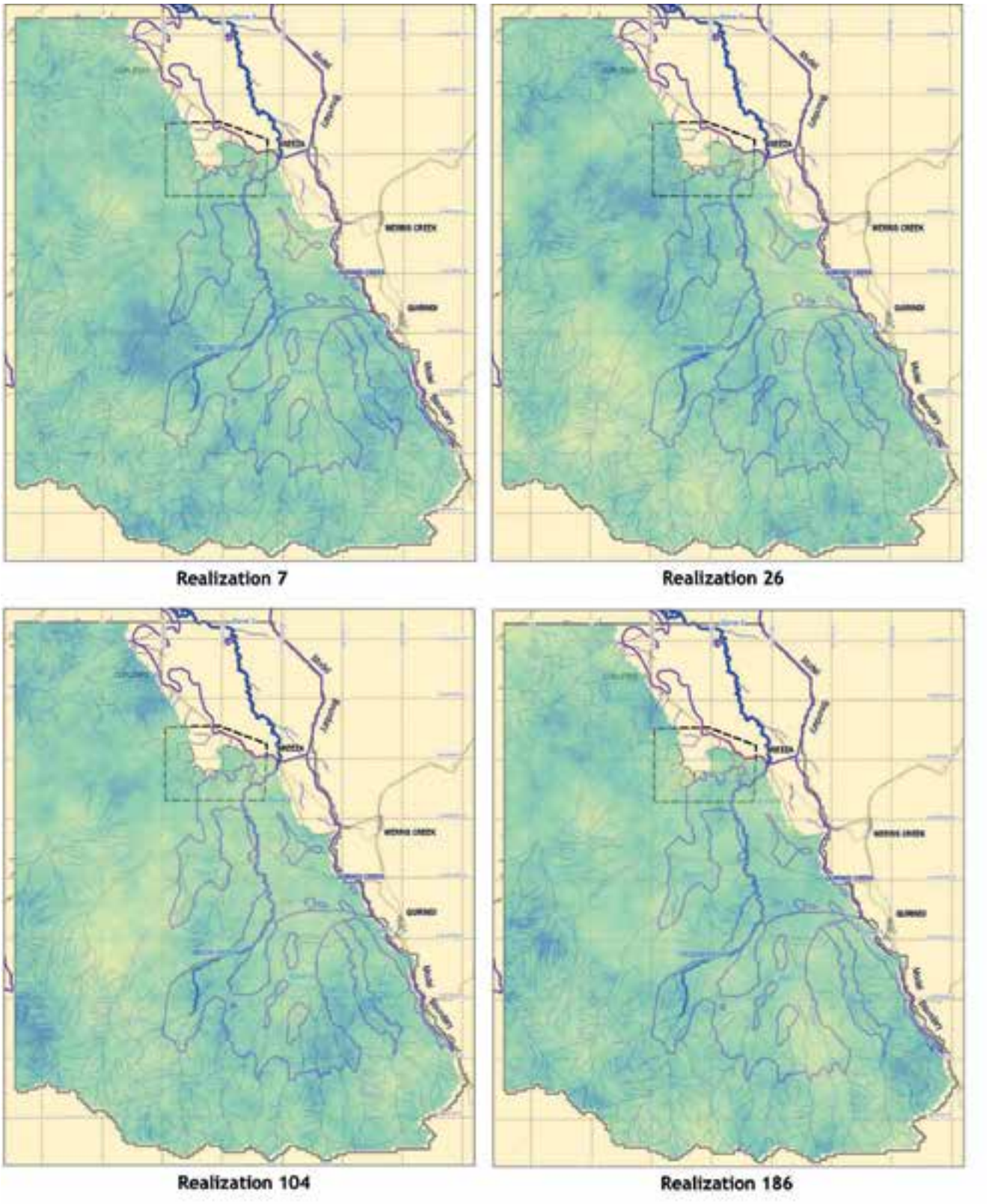
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 9)

Figure 3-42a

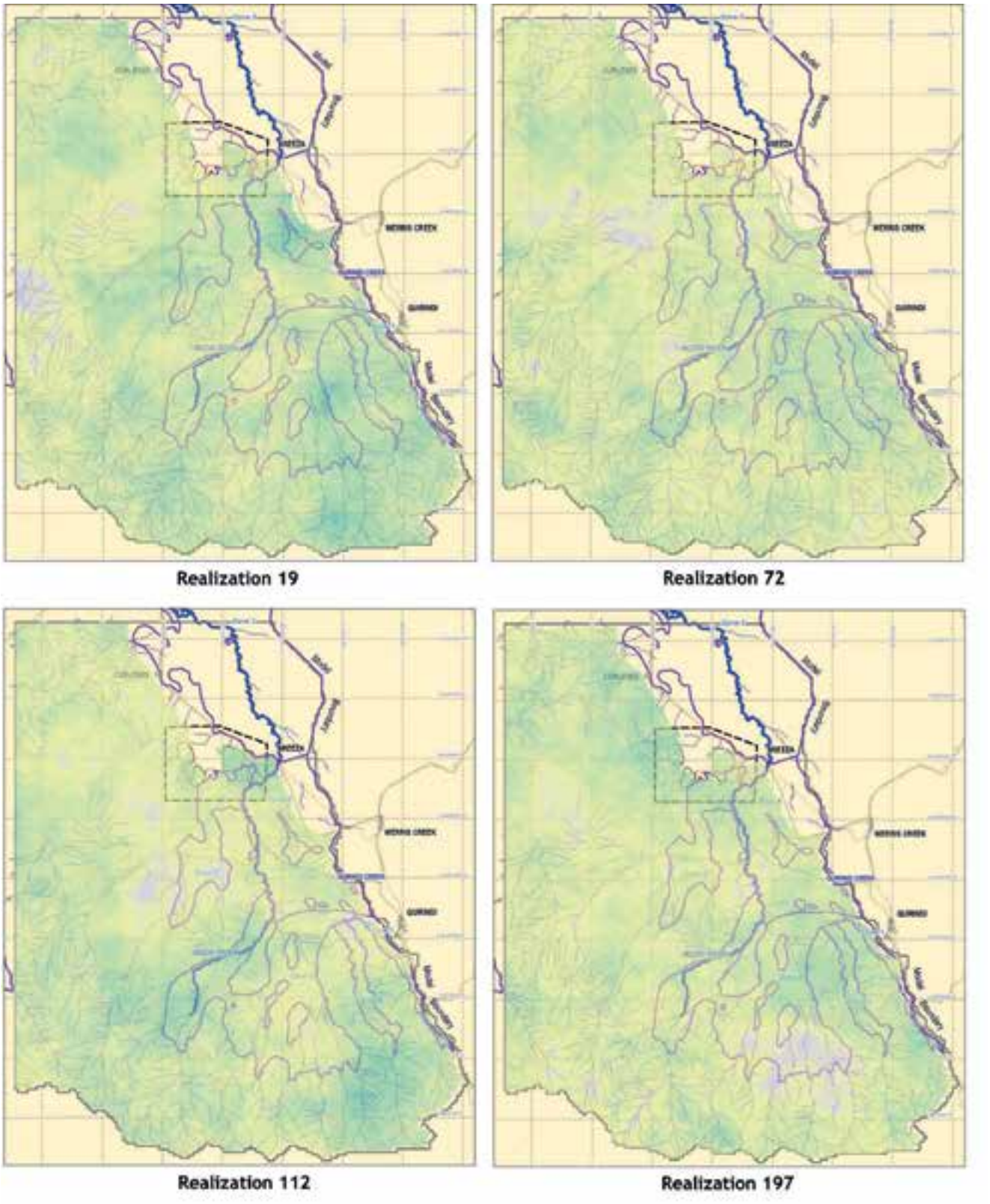
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 9)

Figure 3-42b

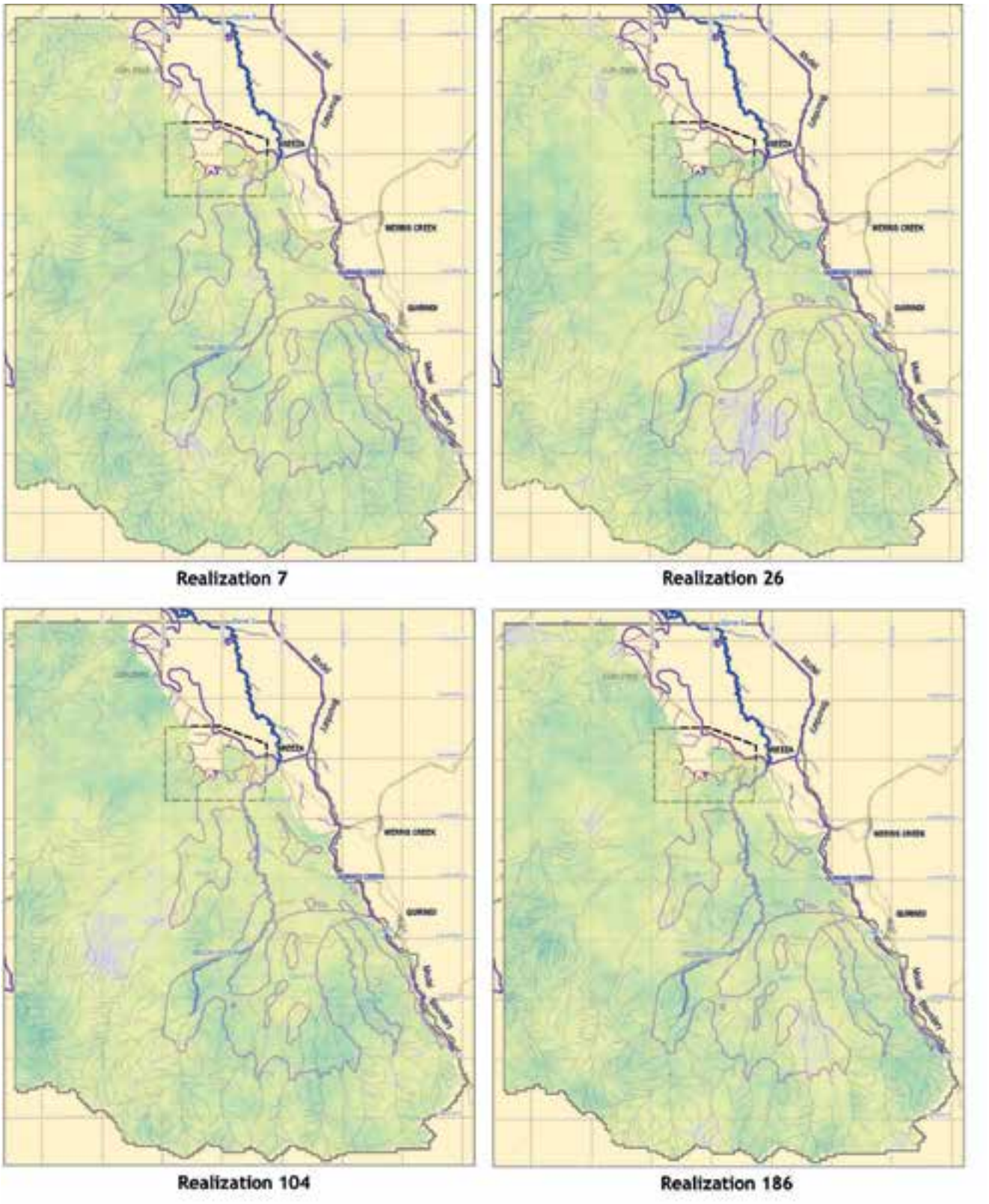
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 10)

Figure 3-43a

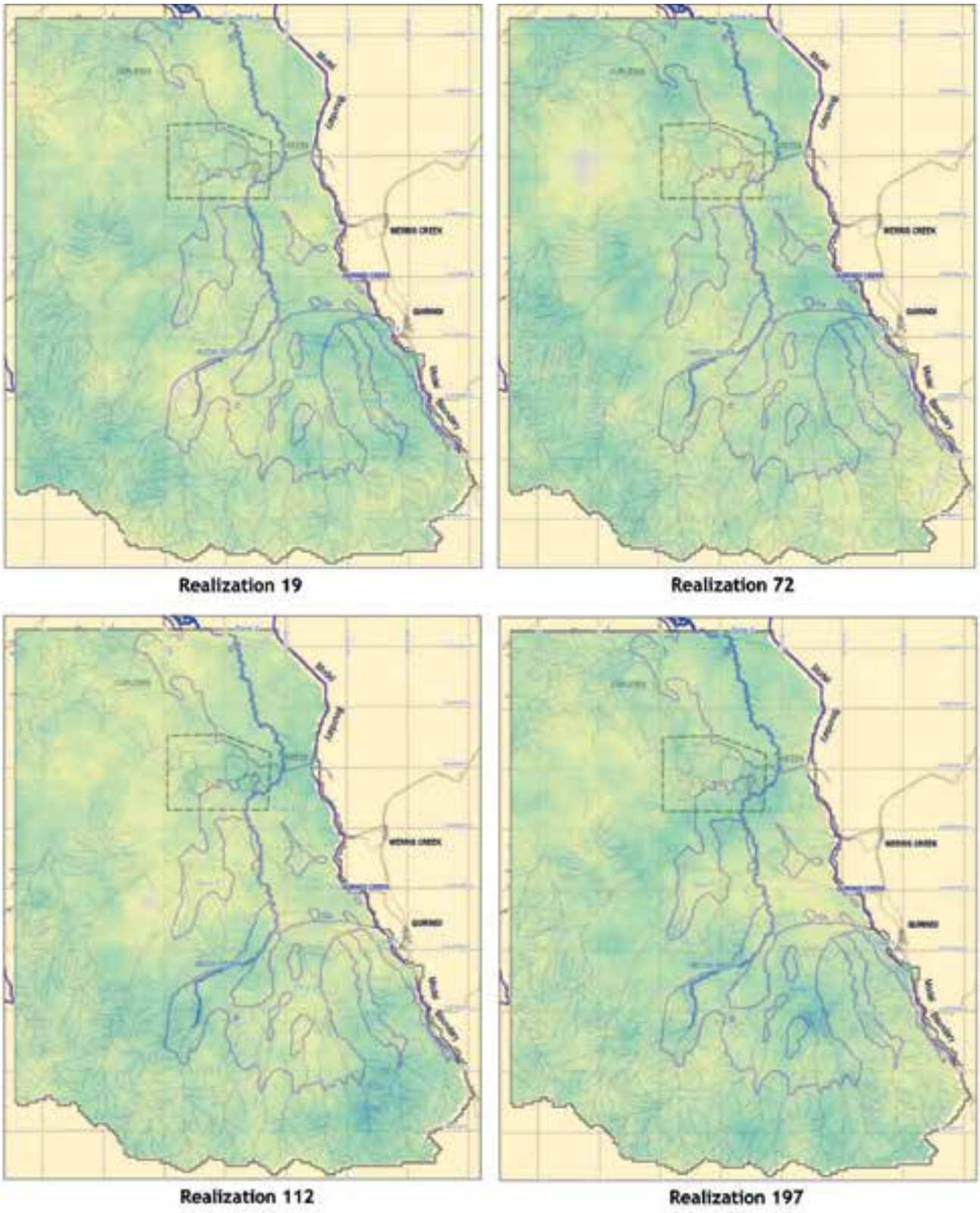
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 10)

Figure 3-43b

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Specific Yield (Layer 11)

Figure 3-44a

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realization 7



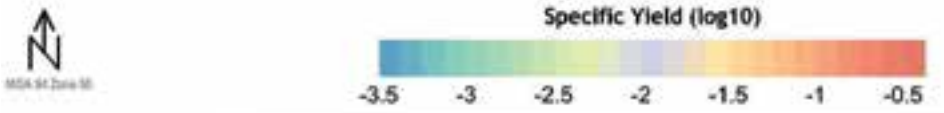
Realization 26



Realization 104



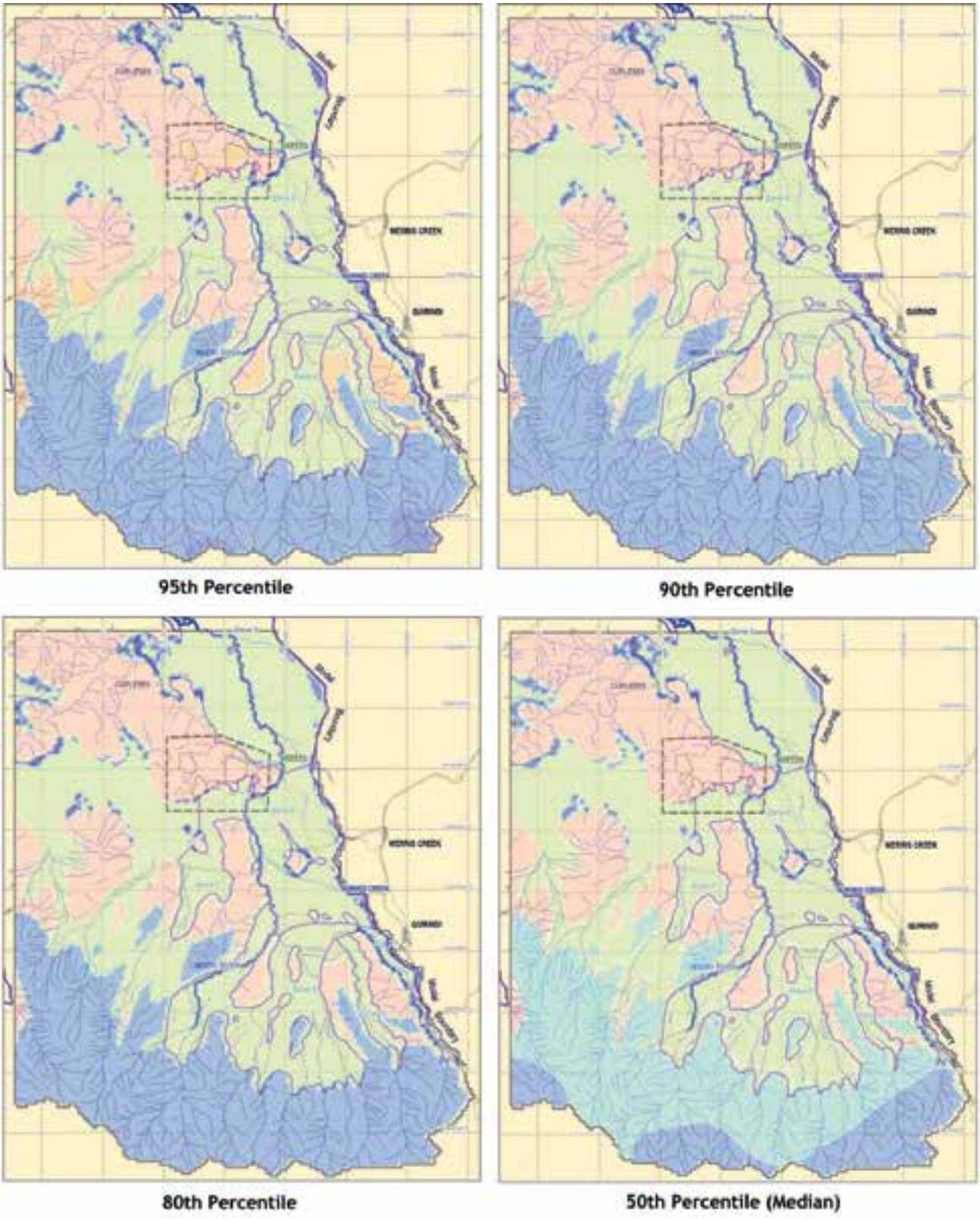
Realization 186



Realizations of Specific Yield (Layer 11)

Figure 3-44b

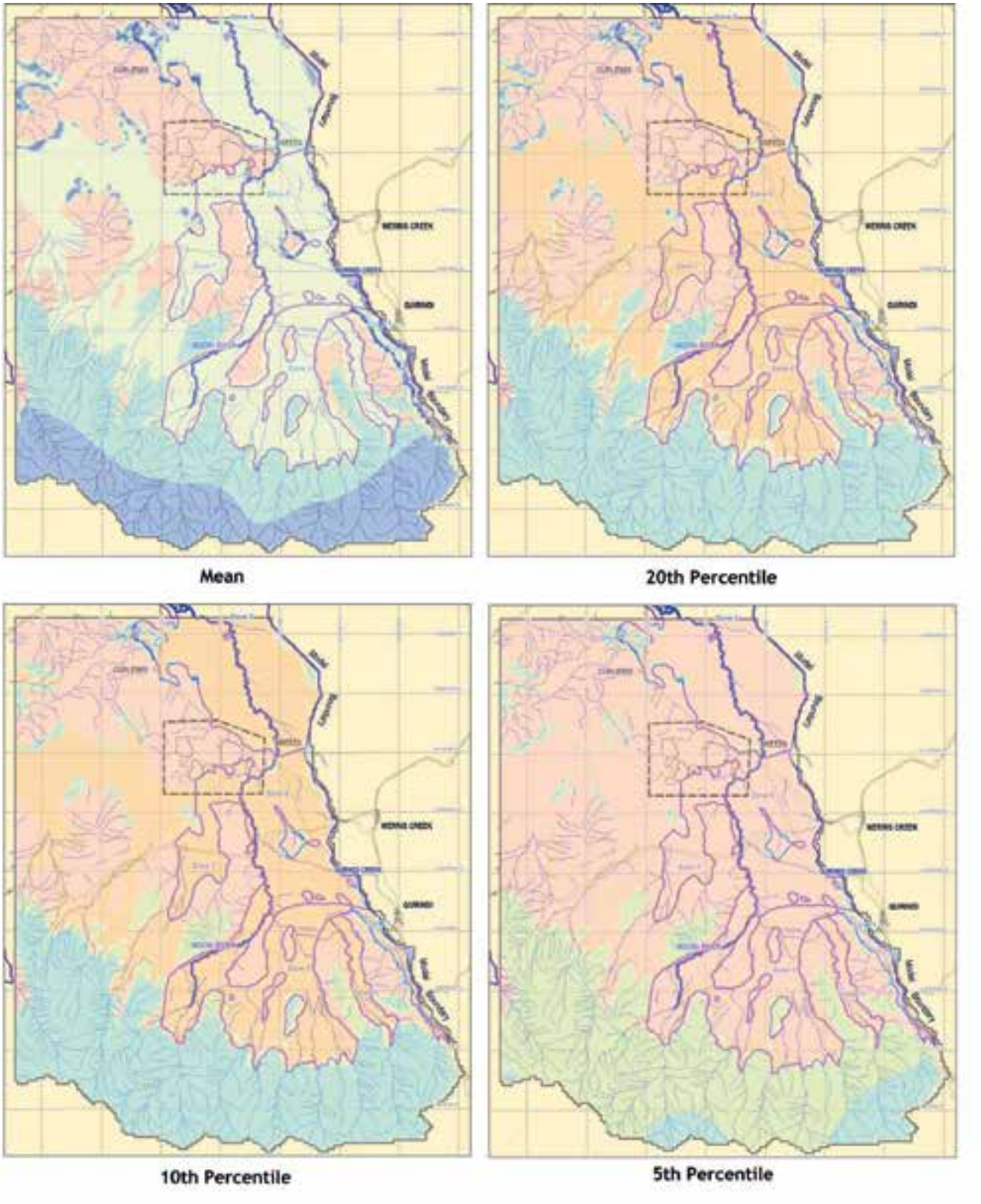
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Average Annual Recharge

Figure 3-45a

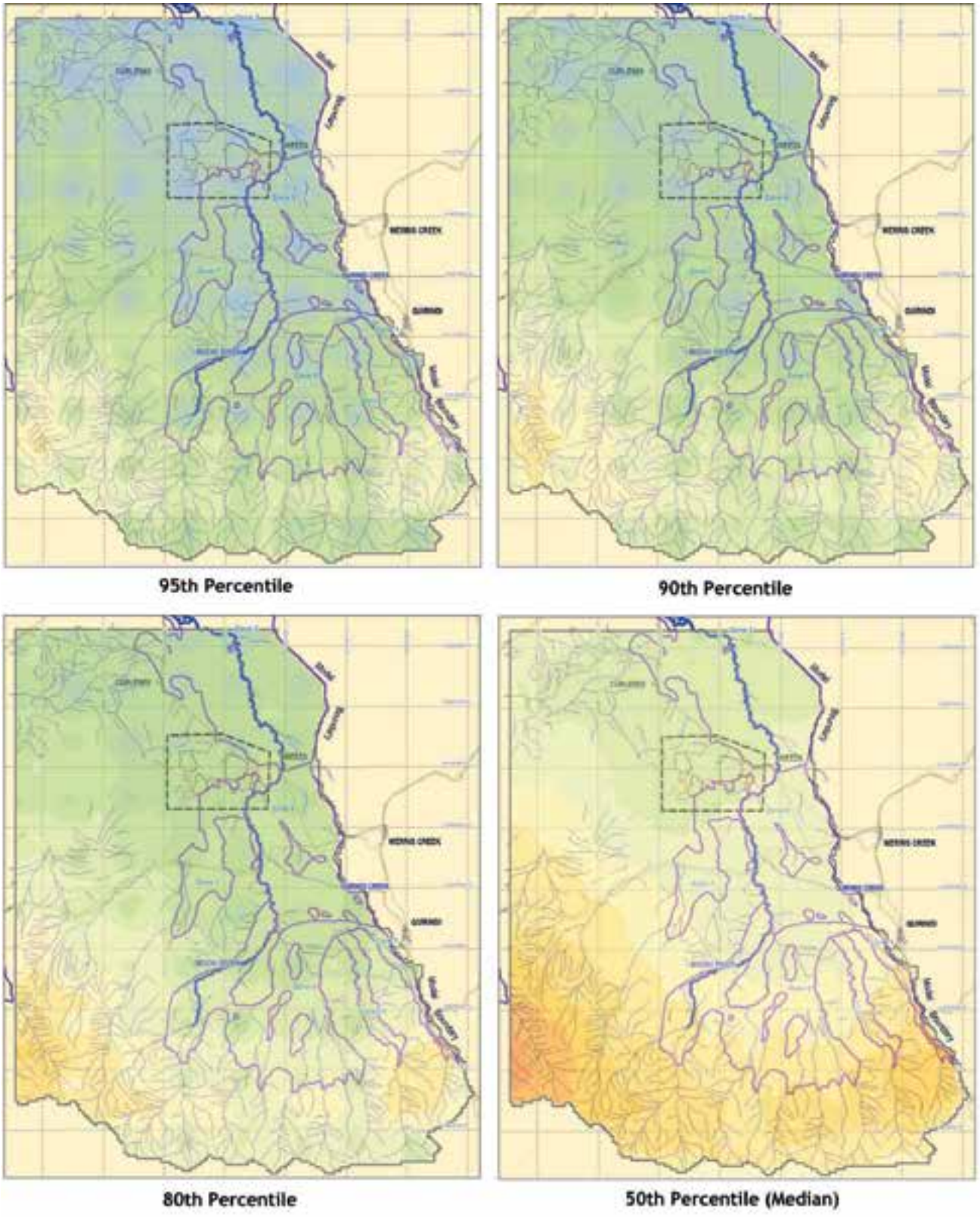
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Average Annual Recharge

Figure 3-45b

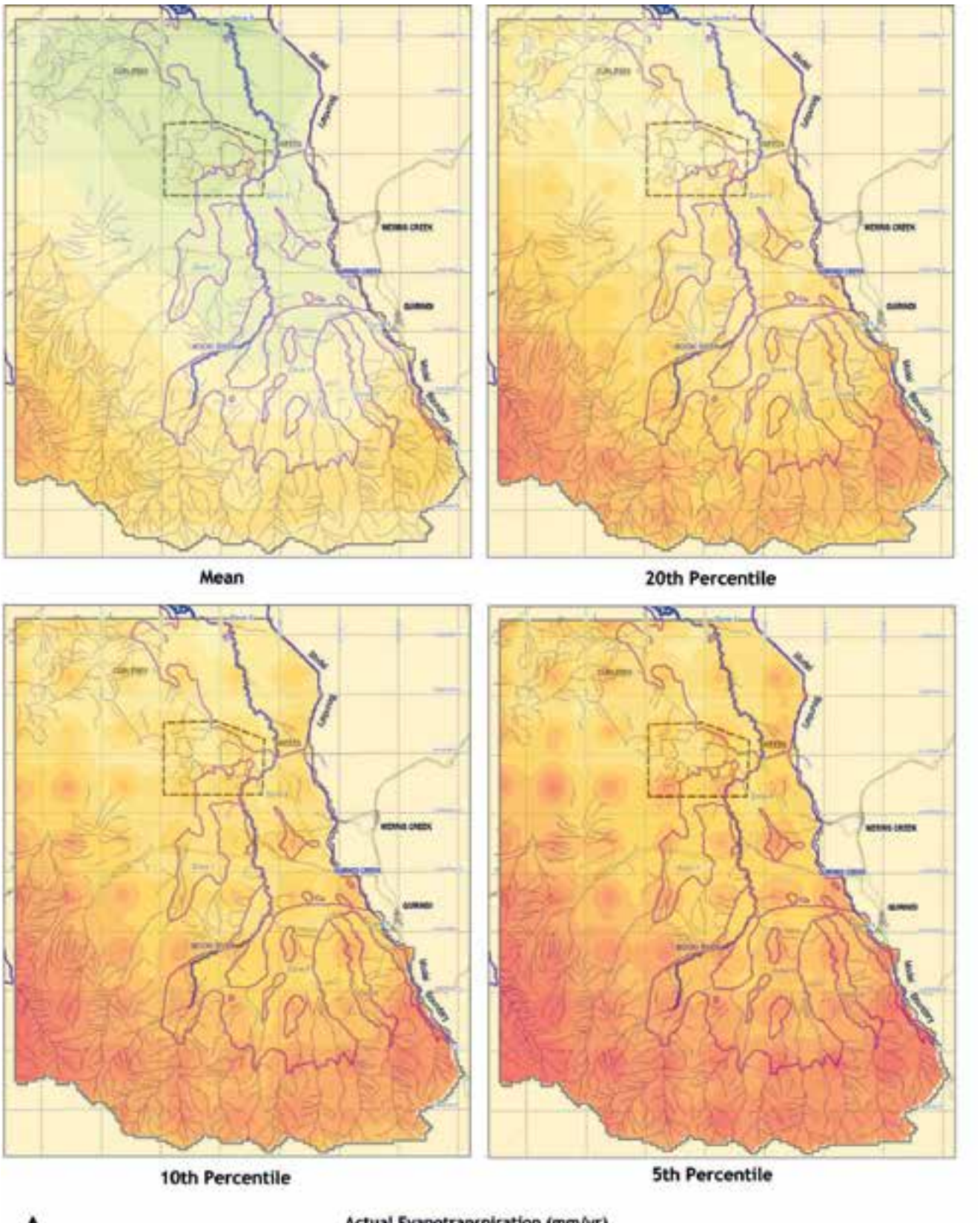
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Average Annual Evapotranspiration

Figure 3-46a

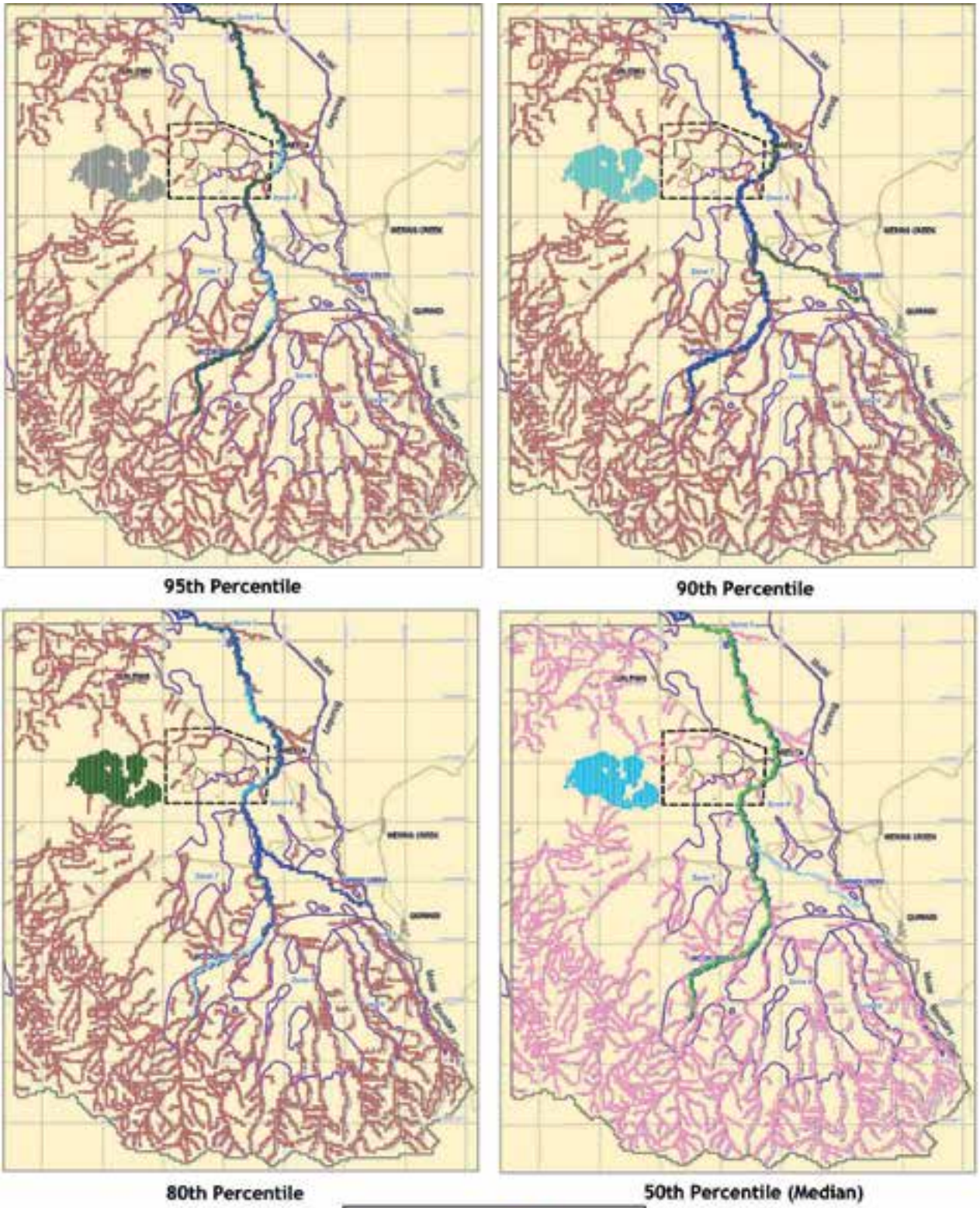
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Average Annual Evapotranspiration

Figure 3-46b

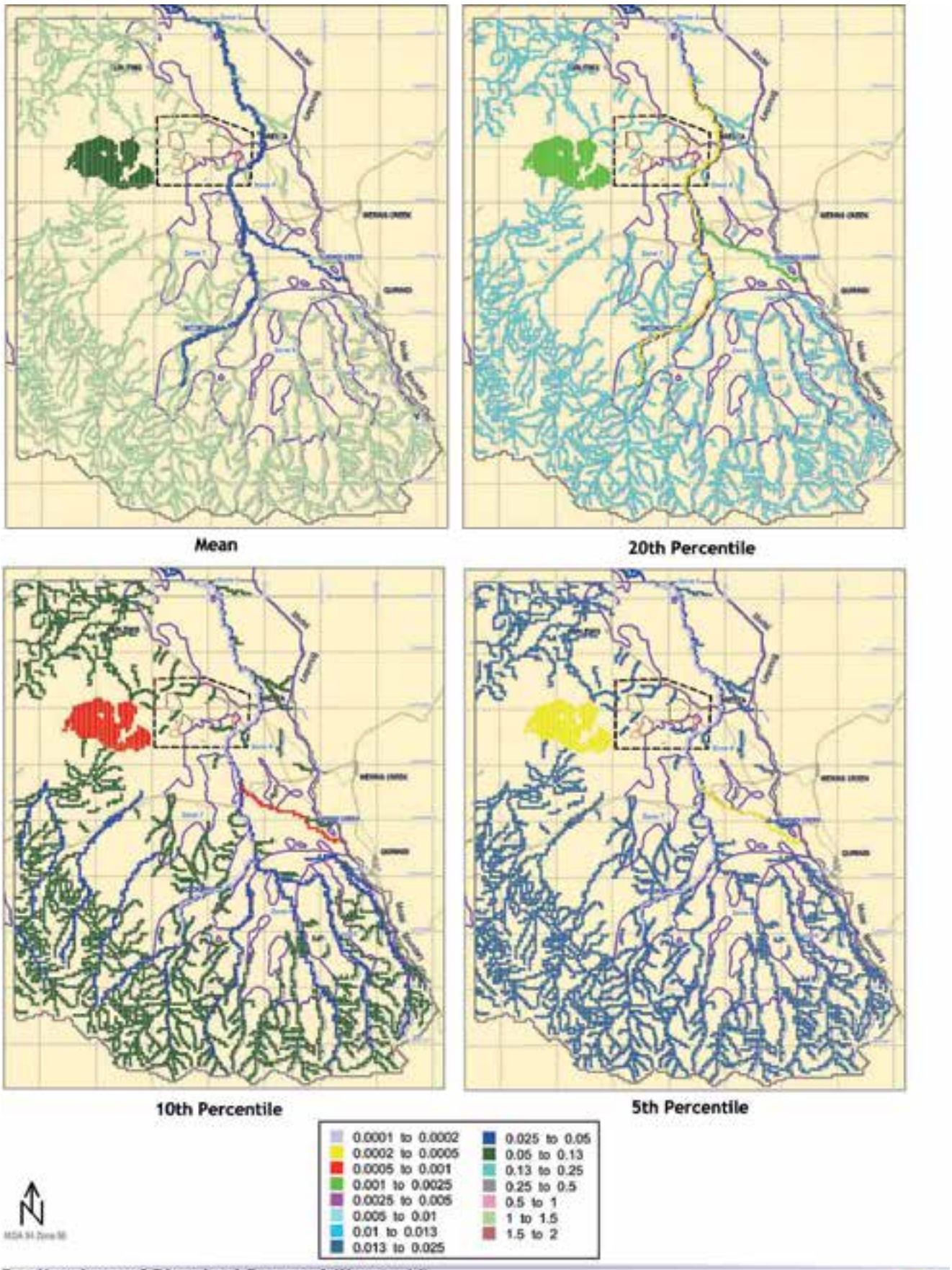
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Riverbed Permeability (m/d)

Figure 3-47a

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Riverbed Permeability (m/d)

Figure 3-47b

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



95th Percentile



90th Percentile



80th Percentile



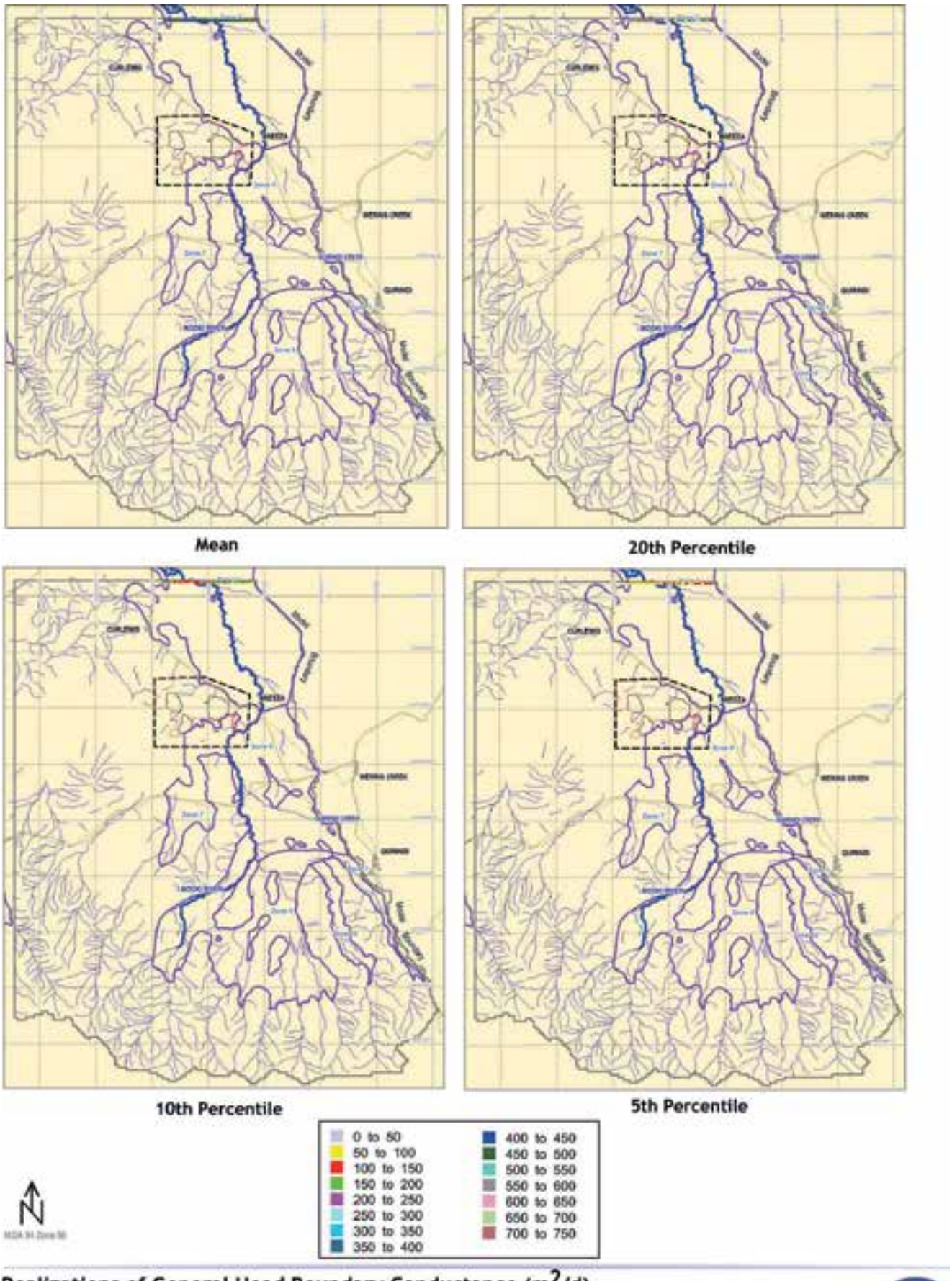
50th Percentile (Median)

0 to 50	400 to 450
50 to 100	450 to 500
100 to 150	500 to 550
150 to 200	550 to 600
200 to 250	600 to 650
250 to 300	650 to 700
300 to 350	700 to 750
350 to 400	

Realizations of General Head Boundary Conductance (m^2/d)

Figure 3-48a

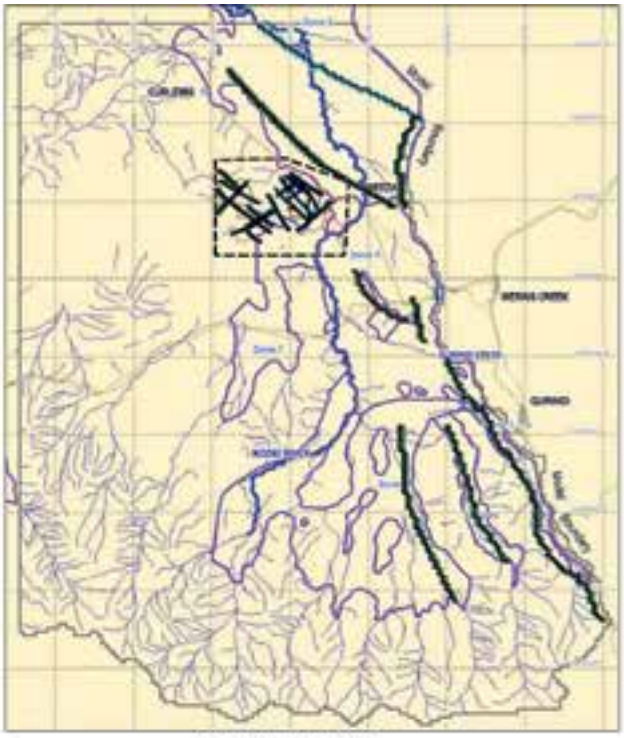
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



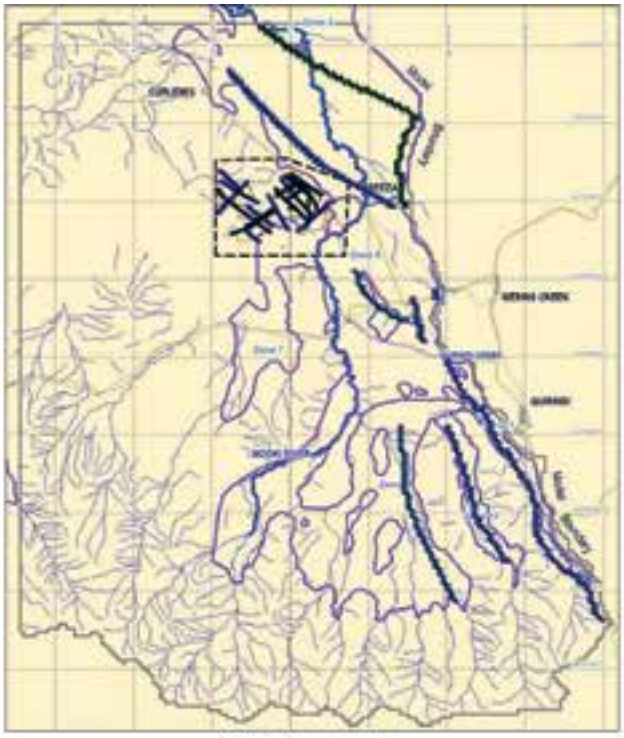
Realizations of General Head Boundary Conductance (m^2/d)

Figure 3-48b

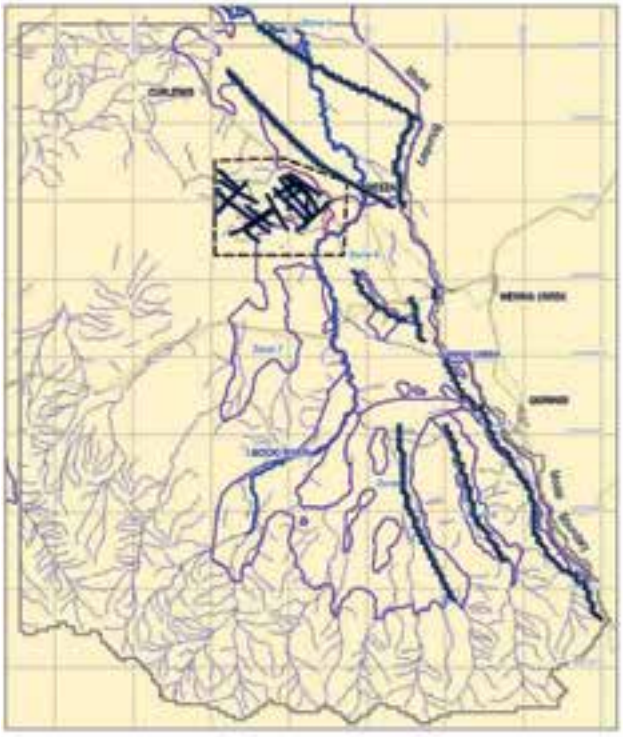
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



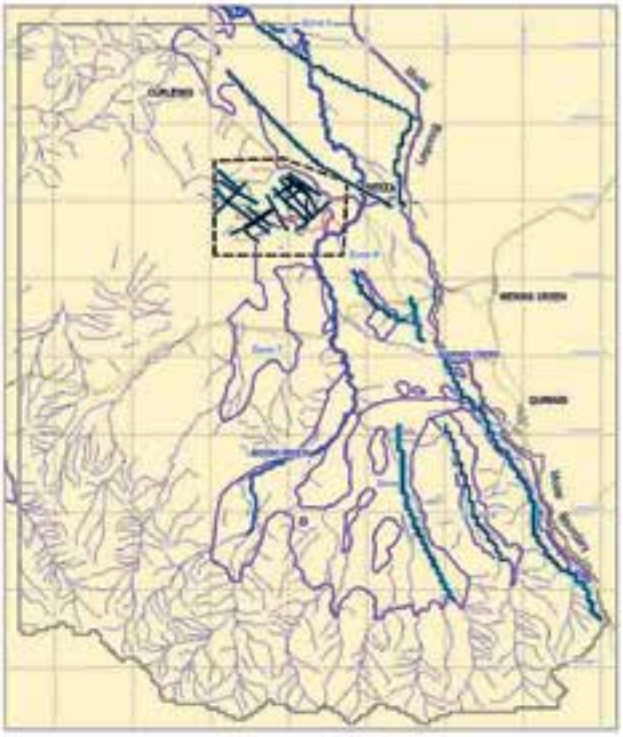
95th Percentile



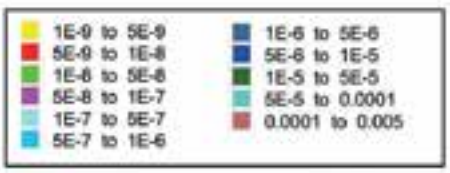
90th Percentile



80th Percentile



50th Percentile (Median)

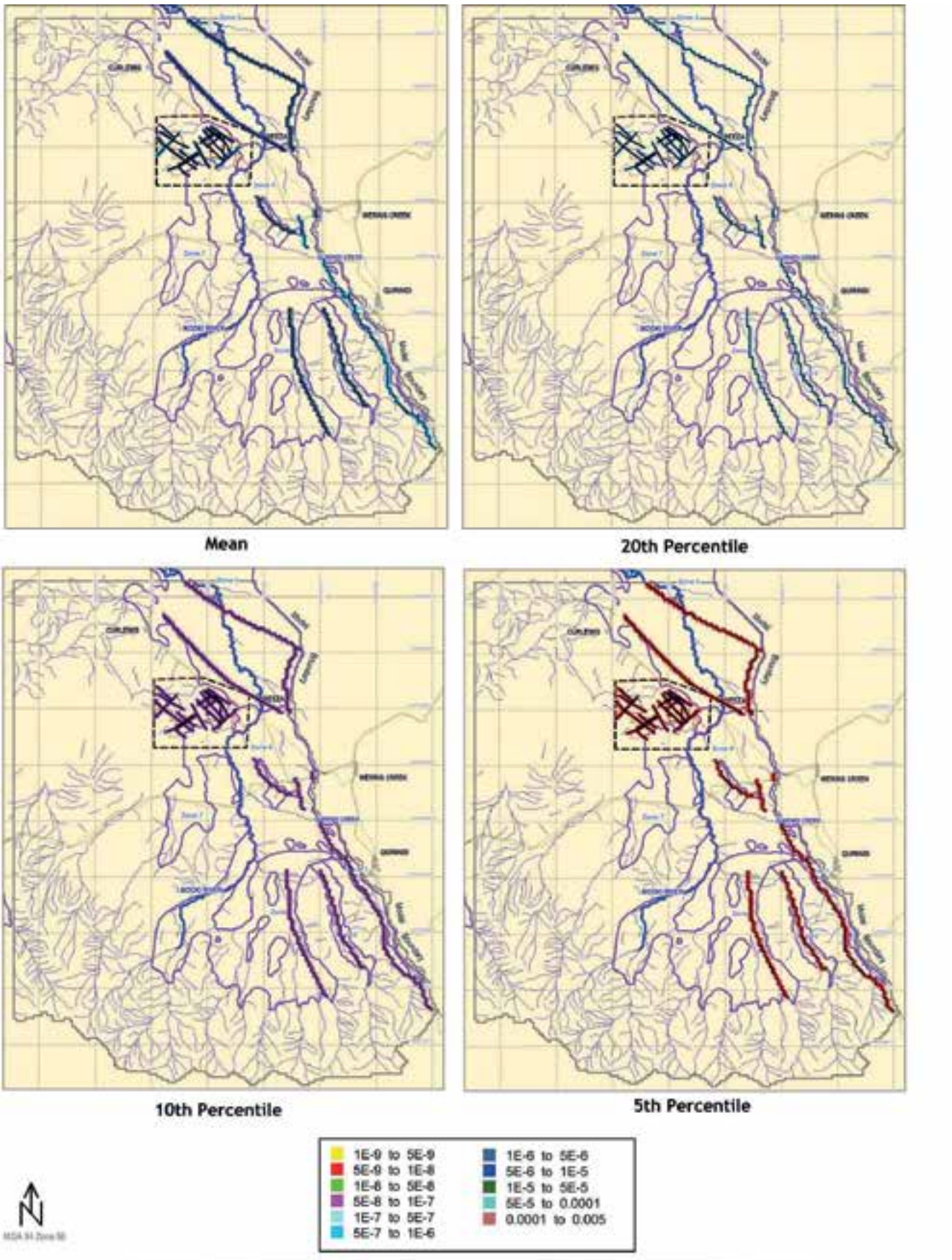




Realizations of Hydraulic Characteristic of Horizontal Flow Barrier (d^{-1})

Figure 3-49a

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Hydraulic Characteristic of Horizontal Flow Barrier (d^{-1})

Figure 3-49b

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



95th Percentile



90th Percentile



80th Percentile



50th Percentile (Median)

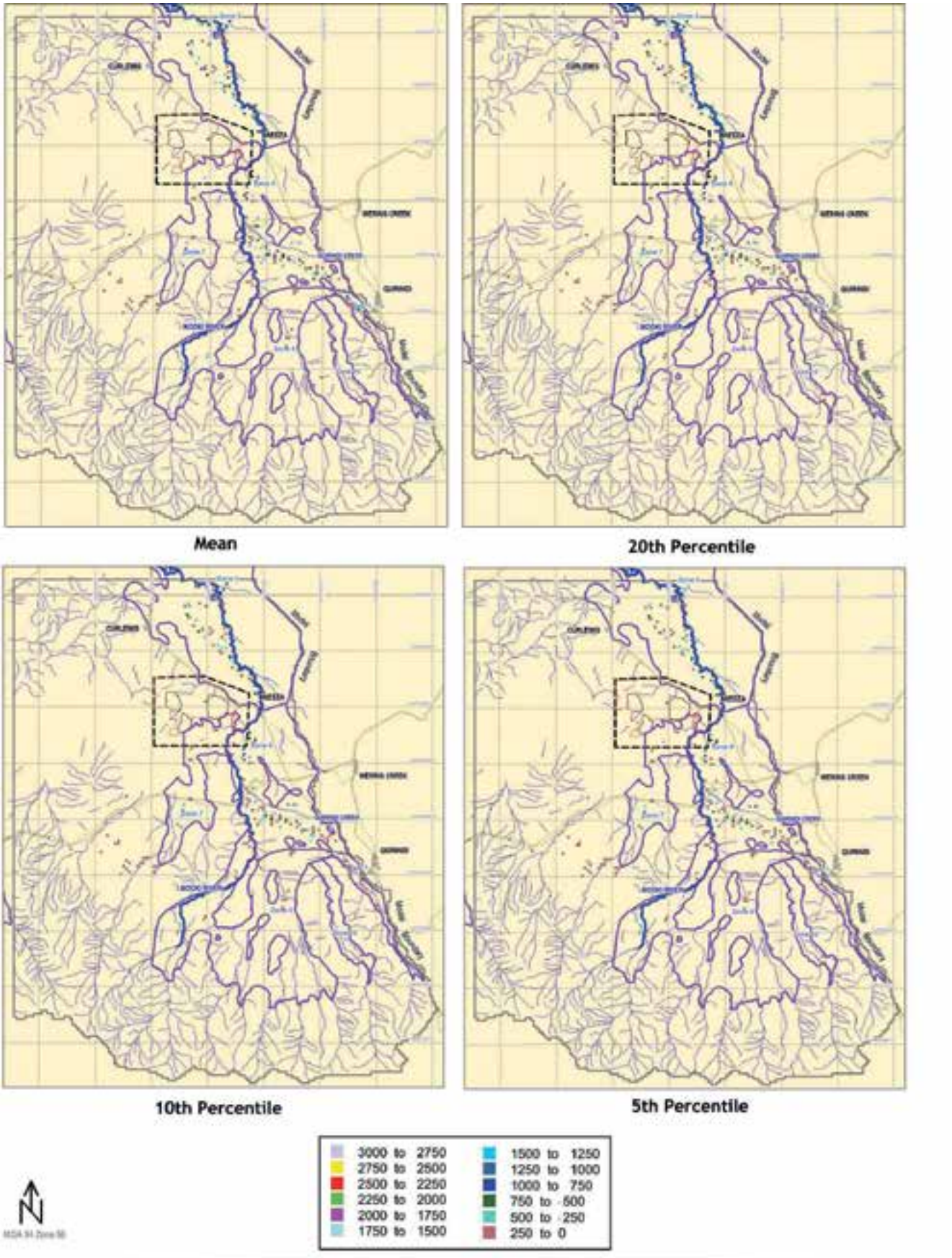
3000 to 2750	1500 to 1250
2750 to 2500	1250 to 1000
2500 to 2250	1000 to 750
2250 to 2000	750 to 500
2000 to 1750	500 to 250
1750 to 1500	250 to 0

MGA 94 Zone 56

Realizations of Extraction Rate (m^3/d)

Figure 3-50a

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Realizations of Extraction Rate (m^3/d)

Figure 3-50b

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)

A8.4 PREDICTIVE UNCERTAINTY RESULTS

A8.4.1 Model Prediction Types

Analysis of the uncertainty of a prediction requires that the prediction(s) be made by the model using all of the parameter fields calculated using the Monte Carlo based methodology. The predictive uncertainty can then be quantified using customary statistical (probabilistic) approaches. For this study, the uncertainty analyses were applied to the same predictions adopted for the sensitivity analyses documented in Section 11 of the main report. Thus for a proposed 30-year open cut coal mine development within the EL 7223 "Watermark" lease starting in July 2013 (following a 1.5 year "warm-up" period) the following predictions were considered:

- sump seepage rates for proposed mining areas over time;
- groundwater management zone 7 alluvial transfer flow over time;
- Mooki River net groundwater leakage over time; and
- maximum spatial extent of aquifer depressurisation at the 1m impact level.

With the exception of sump seepage rate predictions, each of the predictions noted above were evaluated relative to a "no development" baseline prediction of system response.

A8.4.2 Output Measures

The stochastic approach produces a significantly larger quantity of information than from a traditional modelling process; there are effectively 250 "acceptably de-calibrated" models which have been used to simulate groundwater responses (or processed versions thereof) over time that must be synthesised into a form for clear communication of uncertainty limits. To illustrate this point, at each active grid cell in each of three model layers there are 250 sets of influence drawdown responses extending over 120 quarterly stress periods of open-cut pit progress that need to be evaluated.

To interpret this abundance of outputs a statistical approach was adopted, whereby in addition to the mean and median, a range of percentiles (10th, 20th, 80th and 90th) for a given output were computed from the 250 realisations. Such an approach is common practice in probabilistic risk assessments, where a range of outcomes are produced that meet a prescribed set of risk criterion for a representative sample population. Recall that a percentile is the value of a variable (e.g. a sump seepage rate) below which a given percentage of the variable fall. So the 90th percentile is the value below which 90% of the variables may be found (and 10% are greater). Similarly, the 10th percentile represents the value below which only 10% of the variables reside (and 90% are greater).

A8.4.3 Proposed Mining Area Sump Seepage

Figure 4.1 summarises the uncertainty of the predicted sump seepage rate over time within the open-cut voids.

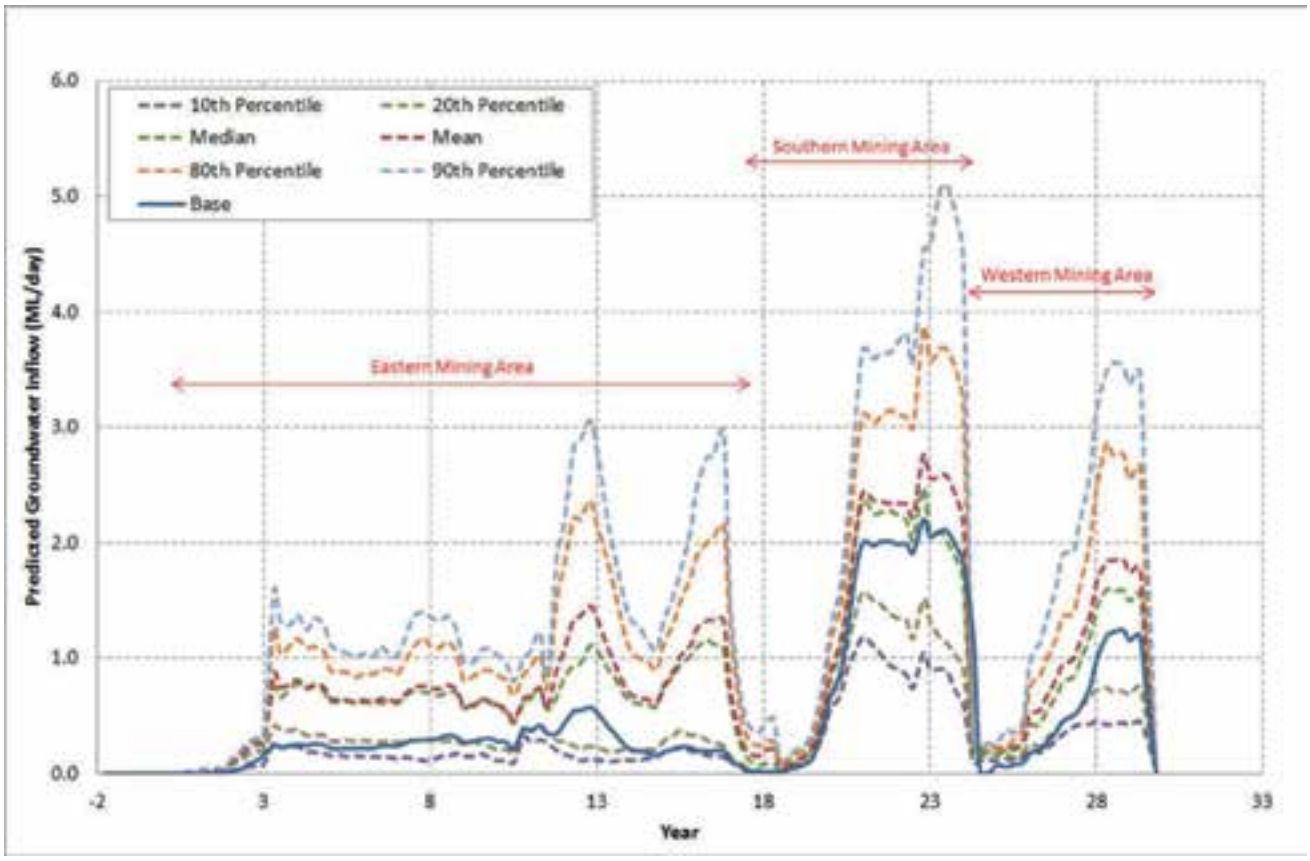


Figure 4.1: Predicted sump seepage rate uncertainty

This shows an increase of approximately 2ML/d to 3ML/d in the peak seepage rate during the southern mining area development above the calibrated (i.e. base) model prediction across the 80th and 90th percentiles respectively. The base model prediction was found to be below the mean and median statistic during the entire simulation period, with the largest relative departures occurring during the eastern mining area development. For the 10th and 20th percentile uncertainty level, the predicted peak seepage ranged between about 50% and 75% of the base case respectively. Overall, these statistical outcomes compared favourably with those produced by the sensitivity analyses, with the peak sump seepage rate for the sensitivity trials approximating the 80th percentile uncertainty band. The most notable differences were demonstrated for the eastern mining area development, for which the 80th and 90th percentile uncertainty level generally exceeded the outermost sensitivity envelope.

Also, Figure 4.2a shows a histogram indicating the frequency distribution of the peak seepage rate in groundwater level at any time, across all 250 realisations, as well as the cumulative probability. These results represent the “worst case” outcome of pit inflows in statistical terms.

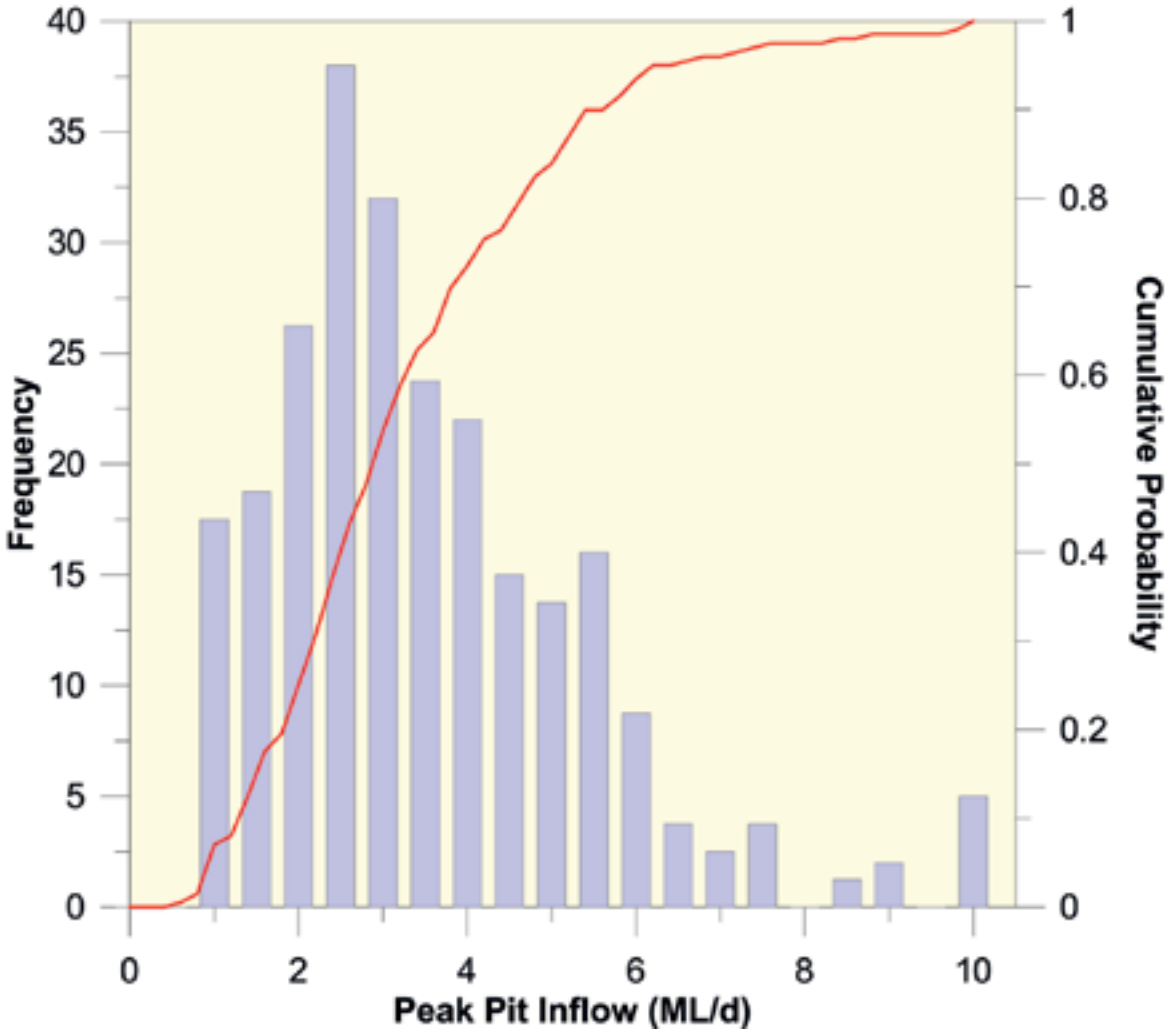


Figure 4.2a: Histogram predicited peak seepage rate

Only a small number of samples transgressed 6M L/d; this value approximates the 95% probability level. A median of around 3M L/d is shown. A percentage exceedance plot for peak seepage rate is also provided in Figure 4.2b, which shows for example that there is only a 10% and 20% exceedance at 5 ML/d and 4 L/d respectively.

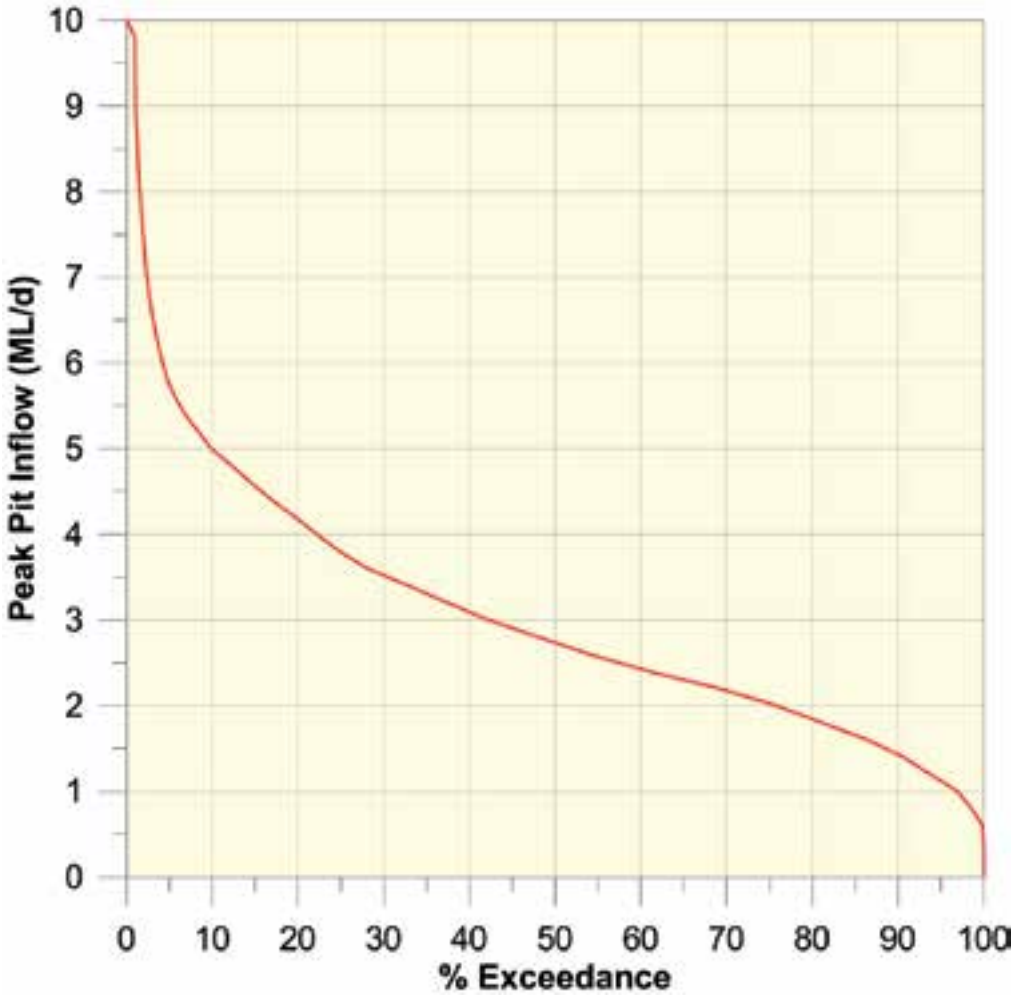


Figure 4.2b: Percentage exceedance plot for peak seepage rate

A8.4.4 Groundwater Management Zone 7 Alluvial Transfer Flow

Another key model prediction was the net groundwater transfer rate of water from the Permian units to the overlying alluvial aquifers within Zone 7 to the south of the proposed mining areas. Figure 4.3 presents the uncertainty statistics of the reduction in transfer between the Permian and alluvium.

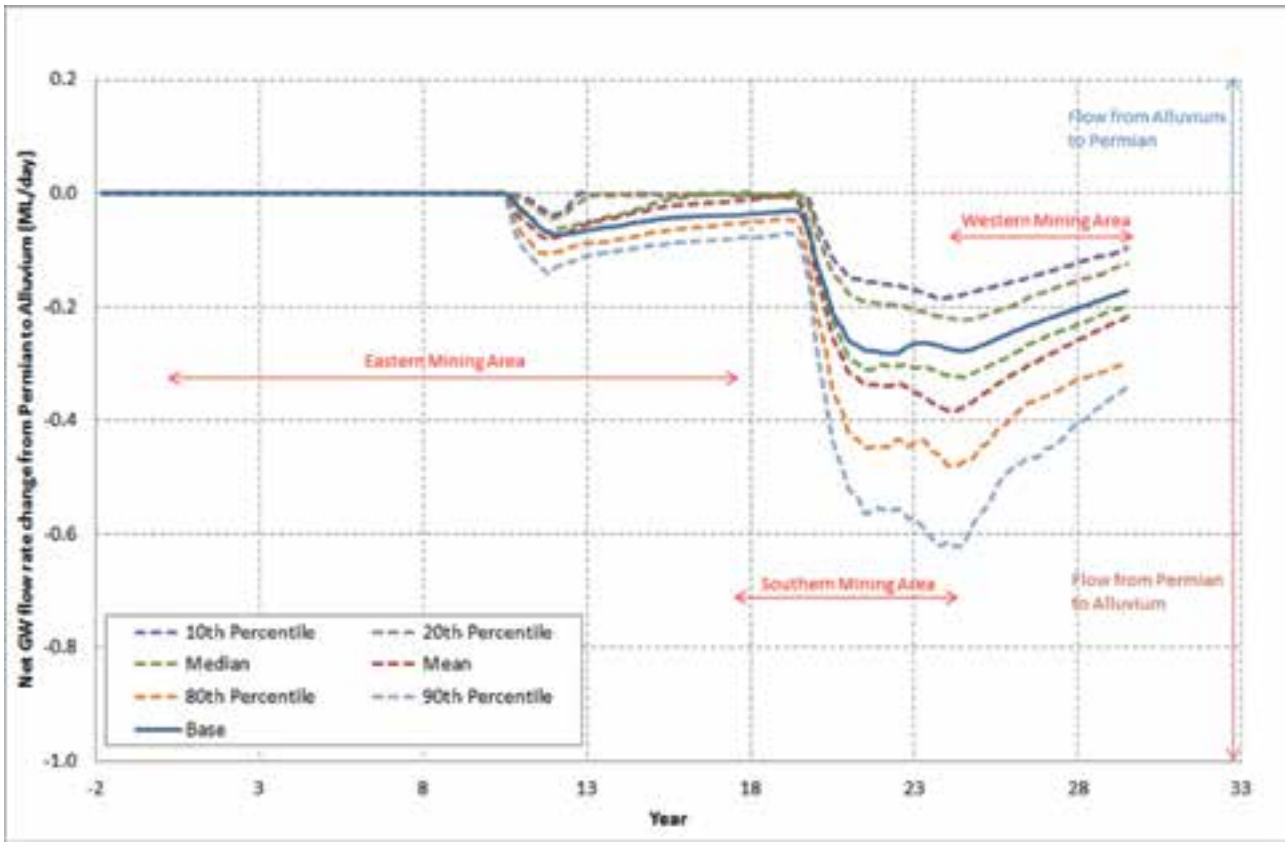


Figure 4.3: Uncertainty statistics of the reduction in transfer between the Permian and alluvium

The base case falls below all but the 10th and 20th percentile uncertainty levels for the vast majority of time corresponding to the development of the southern and western mining areas, while it lies between the mean/median and the 80th percentile during most of the eastern mining development phase. The largest net transfer rate of water from the Permian to the alluvial aquifer system at the 90th percentile (approx. 0.6ML/d) is below the corresponding outermost sensitivity envelope (1.2 ML/d) which was produced on the basis of an order of magnitude increase in horizontal hydraulic conductivity of the weathered zone (represented in the base case as a non-spatially variable property). The remaining sensitivity trials are generally contained within the statistical uncertainty bands, particularly for the southern and western mining development periods.

A8.4.5 Mooki River Net Groundwater Leakage

The change in net leakage from the Mooki River to the underlying aquifer systems was also evaluated. As noted in Section 10.9 of the main report, the base case predicts that mining will increase the rate of leakage from the river to the underlying aquifer by up to 0.13 ML/day. Figure 4.4 presents the results of the uncertainty analysis for the predicted change in net leakage from the Mooki River; these show a maximum change in net leakage from the Mooki River to the groundwater system ranging from 0.05 to 0.18 ML/day across the 10th to 90th percentiles.

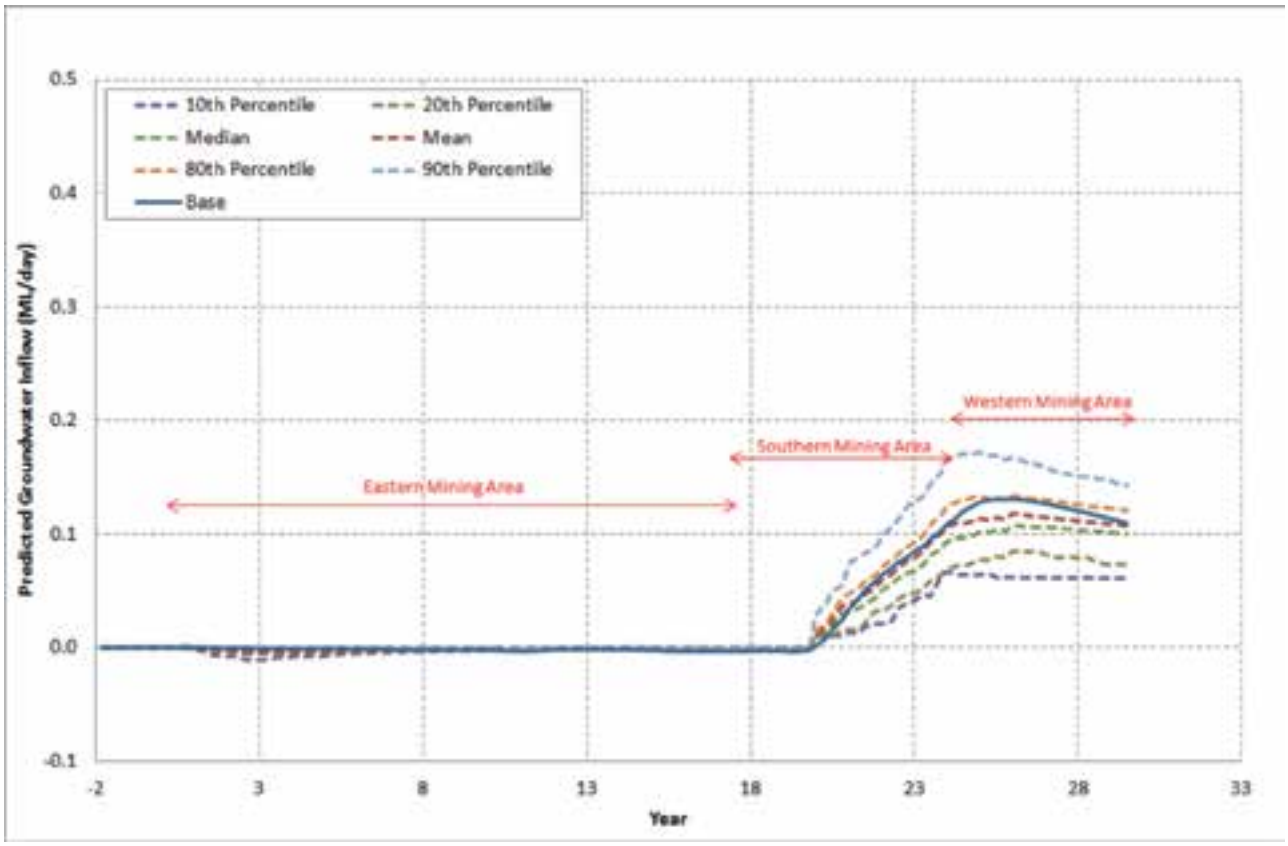
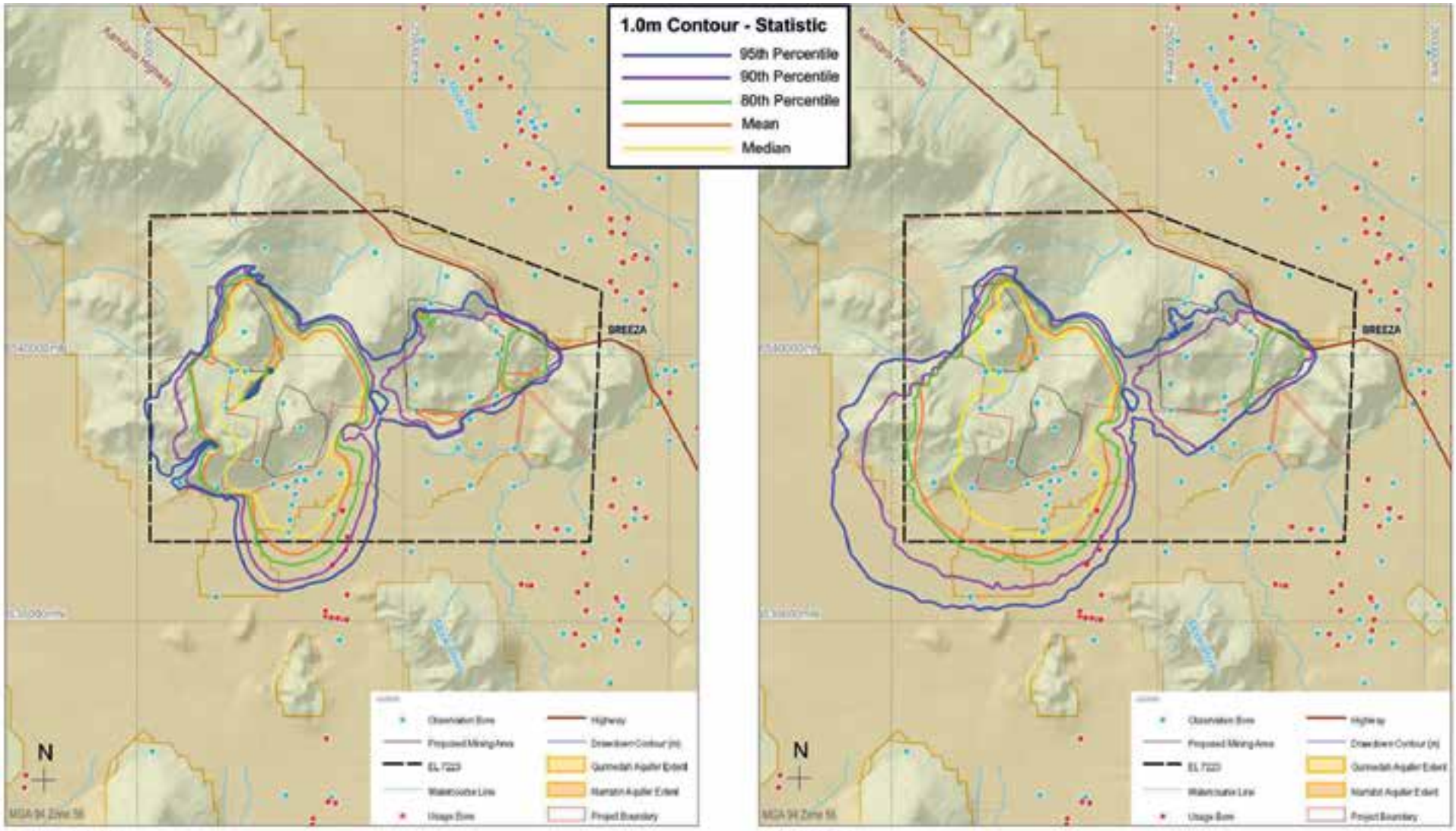


Figure 4.4: Uncertainty analysis for the predicted change in net leakage from the Mooki River

As for the predictive base case and sensitivity analyses, there is little to no influence by the eastern mining areas development on the rate of leakage from the Mooki to the groundwater system. During the southern and western mining area development, the base case prediction lies between the mean and 80th percentile statistic for the majority of the time. Temporal trends are similar across the statistical ranges, with the peak change in net leakage all occurring between the 24 and 26 year period.

A8.4.6 Zone of Depressurisation

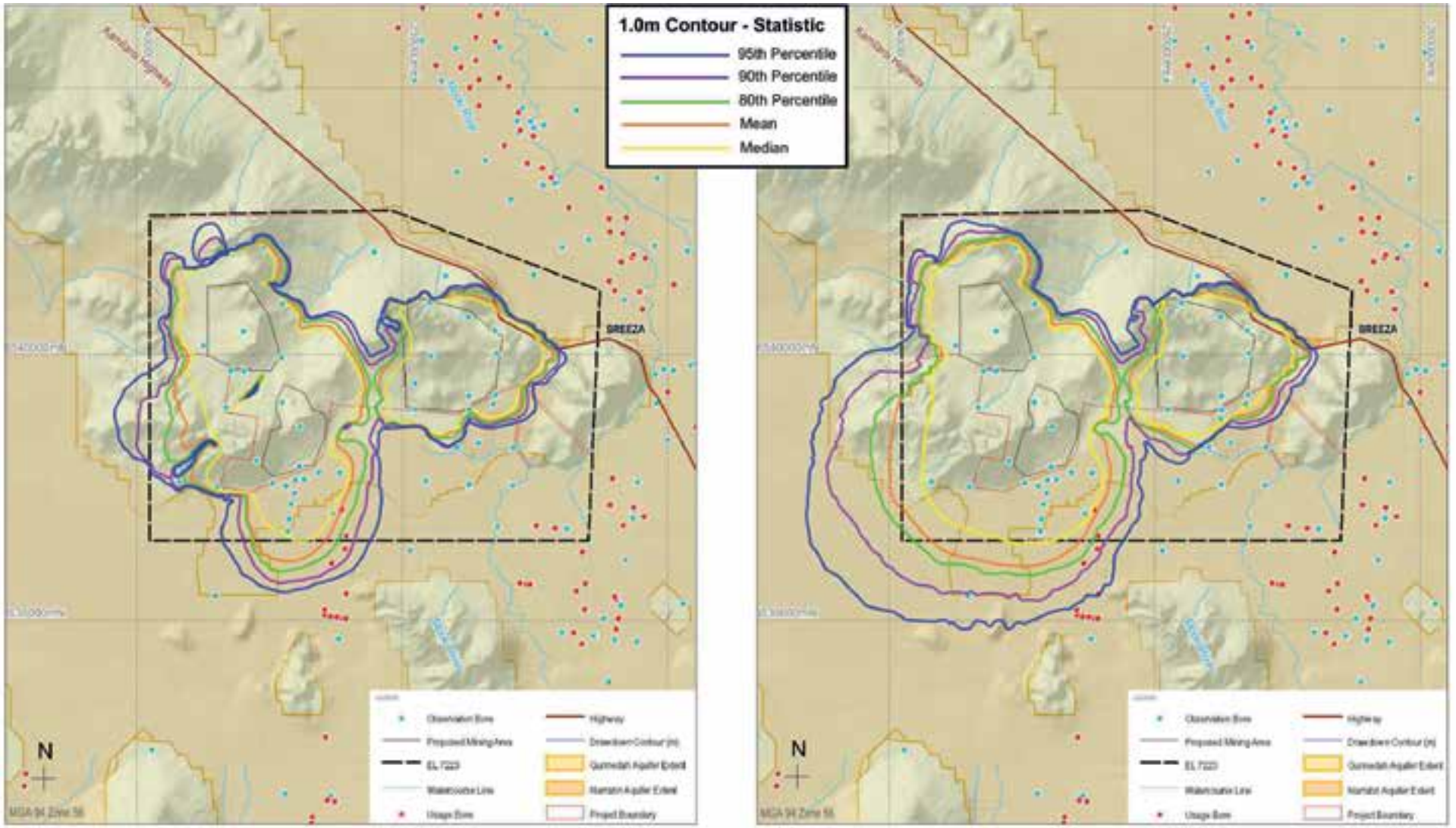
The uncertainty of the predicted zone of depressurisation in the Gunnedah Formation and the Melvilles coal seam was investigated for Year 25 when the Southern Mining area is active and for the maximum impact drawdown recorded in every model cell over time. The 1 m drawdown contour in the Gunnedah formation and Melville coal seam are provided in Figure 4.5 and Figure 4.6 respectively.



Uncertainty of Aquifer Depressurisation -25.5 Years - Statistical Analysis

Figure 4.5

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Uncertainty of Aquifer Depressurisation - Maximum All Time - Statistical Analysis

Figure 4.6

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)

In relation to Year 25.5, the 1 m contour extends in the southerly direction a distance of 2.5km for the median to 4.2 km for the 95th percentile, and extends westwards a distance of 1.5km for the median to 5.0km for the 95th percentile. For the same period, the 1m drawdown contour in the Melvilles coal seam ranges from 2.3km to 4.7 km between the median and 95th percentile in the southerly direction and from 3.1 km to 7.0 km between the median and 95th percentile in the westerly direction. This is comparable with that produced by the sensitivity trials described in Section 11 whereby the 1 m drawdown contour for Year 25 extends from a maximum distance of 3.8 km for the base case, to a maximum of 6.7 km when the Permian hydraulic conductivity is increased by an order of magnitude.

For a more conservative assessment, the maximum recorded depressurisation in every cell irrespective of time showed a range of 2.2 km to 5.8 km between the median and 95th percentile in any direction for the Gunnedah formation, while for the Melvilles coal seam it ranges from 2.7 km to 8.0 km in any direction between the median and 95th percentile.

A8.5 LIMITATIONS IN THE APPLICABILITY OF UNCERTAINTY ANALYSIS

Firstly, the uncertainty approach described above does not take account of those aspects of model construction and parameterisation that may, with further investigation, be shown to make significant contributions to overall predictive uncertainty including:-

(i) marked knowledge gaps in the spatial disposition of aquifer units and their stratification boundaries;

(ii) uncertainty associated with the spatial continuity of faults and their hydraulic effects; and

(iii) potential deviations to the footprint and mining schedule, for example.

In a conventional Monte Carlo analysis, the predictive model is run for many realisations with different parameter fields for each realisation, each of these generated from defined probability density functions for each of the parameters employed by the model. In this study, the multi-Gaussian distributions were ascribed means corresponding to the calibrated parameter values in order to partially constrain the randomly-generated parameter fields and limit the number of realisations deemed appropriate. This approach was favoured over a more formal calibration-constrained uncertainty exercise given the lack of groundwater response data in each aquifer unit under stresses comparable to a large-scale staged excavation. It should be noted however that given calibration-constrained methods ensure that the parameter fields for all realisations are consistent with the calibration dataset, future recalibration efforts which utilise groundwater response data gathered during open pit development would benefit from such approaches (refer Section 7.1 for a brief description of one such technique).

Also, the robustness of the statistical outcomes of Monte Carlo analysis is influenced by the number of realisations undertaken. Obviously, the greater the number of realisations that are used, the greater the exploration of the parameter fields in determining overall predictive uncertainty and the more robust the statistical outcomes. The results of this study were derived from 250 stochastic realisations. While these are likely to provide a satisfactory indication of predictive variability, it is acknowledged that use of say 500 stochastic realisations would have been preferable in order to improve sampling of uncertainty extremes. Computational time limitations prevented a more exhaustive exploration of parameter-based predictive uncertainty, however the use of a ranking scheme based on the transient calibration objective function recorded for each realisation to garner a “acceptably de-calibrated” subset of these realisations from the original

suite of 500 random realisations was a reasonable approach to maintaining computational tractability.

Lastly, the statistical characterization of the innate variability of hydraulic properties and boundary conditions employed by the model for parameter-by-parameter and cell-by-cell based stochastic field generation is subjective. Hence must be chosen with care. Unfortunately, they can never be known exactly and can thus only be chosen on the basis of hydrogeological intuition and available field data. Because of this, some stakeholder involvement may be required in their specification and alternative statistical assessments of parameter variability could be used to re-evaluate the uncertainty estimates.

A8.6 SUMMARY AND CONCLUSIONS

Given the ever-increasing role that models play in the investigation of groundwater impacts in Australia and abroad, it is imperative that the uncertainty associated with predictions made with such models are assessed so that any insights these models may provide are put in an appropriate context. In this study, a stochastic-based uncertainty analysis based on the Monte Carlo approach was performed on the groundwater flow model devised for the Watermark Coal Project. The uncertainty analyses were applied to a model simulation of a potential development of three open-cut pits over a period of 30 years, referenced to a “no development” baseline prediction of system response.

A formal calibration-constrained uncertainty analysis of the potential mine development was not adopted given that a reasonable level of model “de-calibration” was sought in acknowledgment of the calibration referencing a pre-development state, however the current Monte Carlo approach did use the information inherent in the existing dataset as a broad measure for stochastic parameter sample acceptance or rejection. Another important aspect of this study was the enhancements made to the original model parameterisation via inclusion of additional zonal and pilot point parameters to improve the exploration of uncertainty for the predictions of interest.

The results of this study have helped to characterise the level of potential uncertainty associated with key predictions made by the model. Spatial uncertainty “envelopes” have been presented for the maximum “all-time” aquifer depressurisation and at Year 25 when the Southern Mining area is active, which pertain to the comparative “influence” of a proposed pit development in relation to a “no development” groundwater response. Uncertainty bounds were also produced for every time-step in relation to water budgets including open pit inflows, Mooki River net groundwater leakage and the change to the transfer rate of water from the Permian units to the overlying alluvial aquifers for groundwater management zone 7 (the latter two are also relative to the baseline prediction). Broadly speaking, the predictive model uncertainty was consistent with the outcomes of the sensitivity trials documented in Section 11 of the main report, but provides a more robust and detailed appraisal of potential uncertainty bounds.

This work provides a demonstration of the utility of uncertainty analysis for the current model structure with an appropriate level of observance to historical observations. As such, it provides an important examination of the veracity and appropriateness of the model for deployment in evaluating strategies for operational assessment of pit inflow rates over time and spatial and temporal influences of the development on the aquifer resource and nearby watercourses. More detailed explorations of uncertainty are strongly recommended as further system response data becomes available and as the model assemblage is adjusted in future.

Continued development of the groundwater flow model in order to improve calibration performance both temporally and spatially, is imperative. In conjunction with such efforts, several general recommendations for future work that would significantly improve the uncertainty assessment of simulated open cut pit development and hydrological processes of the aquifer system on a regional scale are offered in the following section.

A8.7 REFERENCES

Arabi M., Govindaraju, R.S, Hantush, M.M. 2006. Role of watershed subdivision on evaluation of long-term impact of best management practices on water quality. *Journal of the American Water Resources Association*, 42(2): 513–528.

Beven, K.J., and Binley, A.M. 1992. The future of distributed models: model calibration and uncertainty prediction. *Hydrological Processes*, 6: 279–298.

Campbell, E.P., and Bates, B.C. 2001. Regionalization of rainfall-runoff model parameters using Markov Chain Monte Carlo samples. *Water Resources Research*, 37(3): 731–739.

Dausman, A.M., Doherty, J., Langevin, C.D., and Sukop, M.C. 2010. Quantifying data worth toward reducing predictive uncertainty. *Ground Water*. 48(5): 729–740.

Deutsch, C.V., and Journal, A.G. 1992. *GSLIB: Geostatistical Software Library and User's Guide*. Oxford University Press, Oxford, New York, 340 pp.

Doherty, J. 2010. *PEST: Model Independent Parameter Estimation, User Manual: Fifth Edition,* Brisbane, Australia, Watermark Numerical Computing.

Doherty, J. 2011. *Addendum to the PEST Manual,* Brisbane, Australia, Watermark Numerical Computing, 250 p.

Doherty, J., Hunt, R.J., and Tonkin, M.J. 2010. *Approaches to Highly Parameterized Inversion: A Guide to Using PEST for Model-Parameter and Predictive-Uncertainty Analysis*: U.S. Geological Survey Scientific Investigations Report 2010–5211, 71 p.

Fienen, M.N., Doherty, J., Hunt, R.J., and Reeves, H.W. 2010. *Using Prediction Uncertainty Analysis to Design Hydrologic Monitoring Networks: Example Applications from the Great Lakes Water Availability Pilot Project*: U.S. Geological Survey Scientific Investigations Report 2010-5159, 44 p.

Gallagher, M.R, and Doherty, J. 2007. Predictive error analysis for a water resource management model. *Journal of Hydrology*, 34(3-4): 513–533.

Harmon, R., and Challenor, P. 1997. A Markov chain Monte Carlo method for estimation and assimilation into models. *Ecological Modelling*, 101: 41-59.

Herckenrath, D., Langevin, C.D. and Doherty, J. 2011. Predictive uncertainty analysis of a saltwater intrusion model using null-space Monte Carlo, *Water Resources Research*, 47, W05504, doi:10.1029/2010WR009342.

James, S.C., Doherty, J. and Eddebarh, A.-A. 2009. Post-calibration uncertainty analysis: Yucca Mountain, Nevada, USA. *Ground Water*. 47(6): 851-869.

Keating, E.H., Doherty, J., Vrugt, J.A. and Kang, Q. 2010. Optimisation and uncertainty assessment of strongly nonlinear groundwater models with high parameter dimensionality, *Water Resources Research*, 46, W10517, doi:10.1029/2009WR008584

Kuczera, G., and Parent, E. 1998. Monte Carlo assessment of parameter uncertainty in conceptual catchment models: the Metropolis algorithm. *Journal of Hydrology*, 211: 69–85.

Moore, C., and Doherty, J. 2005. Role of the calibration process in reducing model predictive error. *Water Resources Research,* 41(5): W05050.

Tonkin, M.J., and Doherty, J. 2009. Calibration-constrained Monte Carlo analysis of highly-parameterized models using subspace techniques. *Water Resources Research,* 45: W00B10.

Vrugt, J.A., Gupta, H.V., Bouten, W., and Soorooshian, S. 2003. A shuffled complex evolution metrolopolis algorithm for optimisation and uncertainty assessment of hydrologic model parameters. *Water Resources Research*, 39(8): 1201–1215.

Yu, P.S., Yang T.C., and Chen S.-J. 2001. Comparison of uncertainty analysis methods for a distributed rainfall-runoff model. *Journal of Hydrology,* 244: 43–59.

APPENDIX 9

Peer Review of the Watermark Coal Project Groundwater Model



HERITAGE COMPUTING REPORT

PEER REVIEW OF THE WATERMARK COAL PROJECT GROUNDWATER MODEL

FOR

SHENHUA WATERMARK COAL PTY LTD

By

Dr N. P. Merrick

Report Number: HC2012/18
Date: October 2012

DOCUMENT REGISTER

REVISION	DESCRIPTION	DATE	COMMENTS
A	DRAFT	11 OCTOBER 2012	Original
B	FINAL	18 OCTOBER 2012	Revision based on updated report

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1.0 INTRODUCTION

This report provides a peer review of the groundwater modelling undertaken for open cut mining for the Watermark Coal Project (the Project). The mine is to be situated to the west of Breeza, about 35 km to the south-east of Gunnedah in NSW.

The groundwater assessment is based on field investigations and a regional numerical groundwater model developed by Australasian Groundwater & Environmental Consultants (AGE) Pty Ltd.

The groundwater modelling forms an important component of the environmental assessment for the project. The main purpose of the modelling is to assess potential impacts on groundwater levels on the Project Site and in the surrounding area where private bores are located in the Upper Namoi Alluvium, and also to assess the incidental capture of streamflow and alluvial groundwater associated with the Mooki River and its tributaries. The model also provides an assessment of likely groundwater inflow to the open cut pits as the mine progresses in time.

2.0 SCOPE OF WORK

The agreed scope of work for the review consisted of the following tasks:

- Attend a kickoff/conceptualisation meeting in Brisbane;
- Maintain an overview of AGE's modelling progress at all stages of model development;
- Review a model study plan after the conceptualisation stage;
- Attend a meeting in Brisbane after model calibration;
- Assess the model component in the draft final report by means of the MDBC peer review checklists;
- Review the full groundwater assessment draft report;
- Prepare a report that outlines the key findings from the review; and
- Provide phone/email advice as required.

This report addresses the penultimate dot point (above) by outlining the key findings from the review. As indicated in the second dot point (above), this review was conducted as a progressive review.

The reviewer has been engaged in all phases of the groundwater assessment since the kickoff meeting (dot point 1) on 7 January 2011. The reviewer participated in a number of subsequent meetings with the modelling team,

project managers (Hansen Bailey), Shenhua Watermark Pty Ltd (Shenhua Watermark) and the NSW Office of Water (NoW) on 4 May 2011, 10 June 2011, 13 September 2011, 28 November 2011, 9 February 2012 and 3 May 2012. Several teleconferences were held also.

Peer review was conducted progressively at key milestones:

- model conceptualisation;
- model calibration;
- model prediction; and
- final reporting.

Interim review comments and the MDBC checklists were provided to AGE and Hansen Bailey on 19 September 2012 and a brief meeting with both parties was held on 21 September to discuss the comments.

3.0 MODELLING GUIDELINES

Dot point 5 in the Scope of Work required assessment "*by means of the MDBC peer review checklists".* Accordingly, the review has been structured according to the checklists in the Australian Flow Modelling Guideline (MDBC, 2001). This guide, sponsored by the Murray-Darling Basin Commission, had become a *de facto* Australian standard in the past decade. As this is mostly a generic guide, there are no specific guidelines on special applications such as coal mine modelling.

However, new guidelines were issued by the National Water Commission (NWC) in June 2012 (Barnett *et al*., 2012) after the bulk of the Watermark groundwater assessment had been completed. These guidelines build on the 2001 MDBC guide, with substantial consistency in the areas of model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. In the new guide, there are no specific guidelines on coal mine modelling.

The primary method of assessment of the Watermark modelling has been through the 9-page Peer Review checklist in MDBC (2001). This checklist has 120 questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis.

For completeness, the 117 review questions (excluding solute transport) in the 2012 guide have been addressed also. The revised review checklist is divided into sections on (1) Planning; (2) Conceptualisation; (3) Design and Construction; (4) Calibration and Sensitivity; (5) Prediction; (6) Uncertainty; (7) Solute Transport; and (8) Surface Water - Groundwater Interaction.

The effort put into a modelling study is often dependent on timing and budgetary constraints that are generally not known to a reviewer. In this case, the reviewer is aware that more than normal resources were made available for the groundwater modelling component of this Project.

4.0 EVIDENTIARY BASIS

The primary documentation on which this review is based is:

1. *Australasian Groundwater & Environmental Consultants Pty Ltd, 2012, Watermark Coal Project Groundwater Assessment. August 2012. Version 1.8, 302p + 8 Appendices.*

At the time of writing Version A of this review, report revision was being undertaken by AGE following provision of interim review comments and checklists to AGE on 19 September 2012. The revised report was received on 12 October, a day after release of the Version A review. Given the timing, many, if not all, comments in this review will have been addressed by AGE in their revised report. However, AGE would not have had time to address any comments in the Version A review that were not in the interim review. The revised AGE report is:

2. *Australasian Groundwater & Environmental Consultants Pty Ltd, 2012, Watermark Coal Project Groundwater Assessment. October 2012. Version 1.9, 319p + 9 Appendices.*

Apart from background knowledge of the area, no other documentation has been referenced in doing this review.

As a progressive review has been conducted, comments have been offered progressively by the reviewer on a series of draft AGE report sections and model outputs. Comments of an editorial nature have been offered separately and are not repeated in this report.

At the time of the Version A review, Appendix 8 (Uncertainty Analysis) was not available. That has now been provided in Document #2 as Appendix 9.

5.0 PEER REVIEW

In terms of the MDBC 2001 modelling guidelines, the Watermark Coal Project model is categorised as an *Impact Assessment Model* of medium complexity, as distinct from an *Aquifer Simulator* of high complexity.

The Australian best practice guide (MDBC, 2001) describes the connection between model application and model complexity as follows:

- Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies; and

- Aquifer Simulator - a high complexity model, suitable for predicting responses to arbitrary changes in hydrological conditions, and for developing sustainable resource management policies for aquifer systems under stress.

An Impact Assessment model is the appropriate level of complexity for an Environmental Assessment.

The NWC 2012 guide has replaced the model complexity classification by a "model confidence level". Document #1 gives a thorough defence of the model's Class 3 classification (the highest category) in terms of data, calibration, prediction and key indicator checkpoints. A Class 3 model would be "suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain", and "can be used to design complex mine-dewatering schemes".

The review checklists are presented in Tables 1 and 2 (at the back of this report). The review has been based entirely on a written report, with no reference to electronic model files. Where changes have been made between the Version A and Version B reviews, they are highlighted in a different colour.

The approach taken with this Version B review is to maintain the substance of the Version A review, and provide comment on amendments made by AGE in updating Document #1 to Document #2. This will give the reader the opportunity to see whether initial shortcomings have been addressed. Most of the incremental comments are conveyed through footnotes.

6.0 DISCUSSION

6.1 REPORTING AND PLANNING

The Model Report (Document #1) is a substantial, high quality document of 302 pages in the main body of the report plus eight appendices[1]. To an external reader with no prior knowledge of the study area, the report is very good as a standalone document without need of supporting documents. The report includes a 4-page Executive Summary[2].

[1] Document #2: 319 pages, nine appendices.

[2] Document #2: 3-page Executive Summary, re-written substantially.

The objectives of the groundwater study and the scope of work to address those objectives are summarised in Section 3.3 and are articulated through the list of requirements set down by the Director General (Department of Planning and Infrastructure; DP&I), NoW, and the federal Department of Sustainability, Environment, water, Population and Communities (SEWPaC).

This reviewer considers that the objectives have been addressed in full, have been met satisfactorily and the findings are well substantiated.

There is ample coverage of the modelling component of the study, with full disclosure of assumptions, aquifer/aquitard parameterisation and layer elevations.

The reviewer previously recommended re-ordering of some figures and many editorial corrections. These matters have been addressed in Document #2.

There are substantial sections of the report, premised on the requirements of the Draft Aquifer Interference (AI) Policy, that are now superfluous due to the changes that have been incorporated in the AI Policy issued in September 2012 after Document #1 was printed. The summary of the AI Policy in section 4.3.4 requires updating[3].

Section 11.3 in Document #1addresses model limitations in terms of (1) aquifer properties, where several formations are assumed to have spatially uniform properties; (2) initial heads in hard rock areas; (3) uncertain boundary conditions; (4) limited geological and hydrogeological data in hard rock units outside the Project area; and (5) limited temporal data in hard rock units. These limitations are recognised and unavoidable. In addition, there is always uncertainty in the geometry of designated model layers except at the Project site where a detailed geological model is available. The geometry of the alluvial system is consistent with that defined for the NoW regional model of the Upper Namoi Alluvium.

6.2 DATA ANALYSIS AND CONCEPTUALISATION

Sections 5, 6 and 7 cover the Regional Setting, the Field Investigation Program and the Hydrogeological Regime. These sections lie outside the Scope of Work for this review, except to the extent that they inform the conceptual model for the Project. Sections 2 and 3 of Table 1 (peer review checklist) provide detailed assessment of Data Analysis and Conceptualisation.

[3] This section has been completely re-written in Document #2. Maps of saturated thickness (required only under the draft AI policy) have been removed as they are no longer pertinent.

There is a large body of scientific work associated with the Namoi Basin and this has been considered in a thorough literature review which generated a data gaps analysis and guided the field investigation program. The recent Namoi Water Study (Schlumberger Water Services, 2012) has been referenced.

Shenhua Watermark engaged another company (GHD) to undertake the field program. This included 176 aquifer tests and laboratory measurements on 32 cores. A total of 94 monitoring bores was drilled for the Project, with data collected from August 2009, which supplemented the 351 alluvial monitoring bores of NoW. Overall, there is a very extensive record of groundwater level responses in the form of hydrographs in both the alluvial aquifer and in the hard rock groundwater system.

The hydrographic data have been examined for cause-and-effect by comparison with rainfall residual mass. A good correlation has been demonstrated between alluvial hydrographs and rainfall trends.

Document #1 does not include any information on Mooki River streamflow[4], or on flooding extents[5]. This should be addressed in a revised report. The former is not required for the groundwater model, but it will place in context the magnitude of reported impacts on the river in the form of reduced baseflow or enhanced leakage.

Groundwater usage data, in the alluvial aquifer, was obtained through a freedom-of-information request. This dataset does not always indicate which of the two alluvial aquifers is being used, but it can be assumed that the bulk (probably about 95 percent) would come from the lower Gunnedah Formation. There is considerable uncertainty over the timing of groundwater abstraction, as meter readings are rarely taken more often than six months apart, and sometimes only once a year. An assumption has had to be made as to the seasonal character of abstractions, using the reviewer's assessment of patterns in the Lower Namoi Valley.

A good feature of the Data Analysis stage is that pre-mining estimates of water balance components have been made, informed by prior investigations. This allows a check on the plausibility of post-mining water balances.

It has not been possible to draw a watertable contour map for the entire area that has been investigated, as the study area includes the Liverpool Ranges to the south where groundwater data are scarce. A map is provided for the Project site only. It should have been possible to present a broader map by including alluvial data from hydrogeological zones 3, 7 and 8. Such a map

[4] Document #2 has an expansive section on streamflow; see Figures 7.26 to 7.28; stream recharge expected in the order of 25-30 ML/day for Mooki River downstream to Caroona.

[5] Flooding is addressed in Section 5.3 of Document #2.

would have served as a good check on the reasonableness of initial steady state model calibration of regional hydraulic gradients[6].

The conceptualisation of the local hydrogeology is sensible and is discussed sufficiently in terms of geology and key recharge/discharge processes. Excellent graphics are provided in support of the conceptualisation (Figures 7.45, 7.46).

The stratigraphic division into model layers required a compromise in order to maintain computational efficiency with a large number of layers. There are two target coal seams (Hoskissons and Melville), with plies lumped into single layers having aggregate thicknesses and placed at the base of the respective seam, separated by a single layer of interburden. The overburden of the Hoskissons Seam consists of a number of alternating aquifer and aquitard units, although it is unreasonable to subdivide the aquitard units into more than one layer each. This is a sensible compromise.

The conceptual model is consistent with Project objectives.

6.3 Model Design and Construction

The model has been built with MODFLOW-SURFACT in DOS mode with only incidental use of a commercial Graphic User Interface. This combination is unusual, as it limits transferability of models, but it does allow model refinements not available through other means.

The use of MODFLOW-SURFACT is supported over standard MODFLOW as it is a more powerful version which is better able to handle desaturated conditions caused by mining.

Standard MODFLOW does not permit time-varying material properties (without frequent stops and starts) for the handling of spoil in transient models. MODFLOW-SURFACT has introduced a time-varying facility recently, which provides the best approach to this problem for coal mining simulations. AGE has adopted the stop-start approach, which is still acceptable.

AGE has developed two models with different spatial discretisation. The calibration model has cell sizes from 250 m to 500 m, comprising over 300,000 finite-difference cells. The prediction model, which required finer resolution for impact assessment, has a minimum cell size of 50 m and a total of over 1.2 million model cells. Normally, the modelling fraternity aims to limit the number of model cells to 1 million for computational efficiency and manageable file handling.

[6] Observed contours are provided in Figure 7.15 in Document #2.

Each model covers an area 75 km (east-west) by 91 km (north-south). The model has 11 layers.

The broad model extent isolates the boundaries from likely impacts and reduces the need for accurate representation of boundary fluxes which are set as no-flow for most layers except for prescribed heads in the downgradient alluvial layers. Final predicted drawdowns verify that the adopted boundary conditions have had no undue effect. It is not clear whether the specified heads at the northern boundary were time-invariant, as they should be[7].

The mining operation has been simulated appropriately by MODFLOW "drain" cells in each layer of the open cut excavation.

Watercourses are handled properly using the "river" (RIV) MODFLOW package. There is no need for a more sophisticated algorithm, such as a coupled model for surface water - groundwater interaction. No dynamic variation in river stage is applied, as the main focus of the study is the Project site.

Known fault structures are retained in the conceptualisation, and in the model, across the Project site. They are expected to limit the predicted extent of drawdown effects through compartmentalisation. As the resistive/conductive nature of the faults is not known in advance, a novel approach has been followed in the calibration process by letting the automatic calibration software determine the optimal hydraulic nature of the faults.

Temporal discretisation is quarterly during the calibration period and during prediction. This is reasonable for the long period of calibration (31.5 years) and is commensurate with information on water levels and groundwater pumping. Optimal solution time stepping is chosen automatically by SURFACT software (using the ATO package).

Steady state pre-development conditions are assumed at 1980. In reality, there would have been some pumping effects at that time that have been ignored. While this is recognised in Document #1, the first few years of calibration could be discounted while the model "warms up" from an assumed position of no stress.

The rainfall recharge algorithm is a simple percentage of actual rainfall. Given the low rates of natural infiltration, this approach is adequate.

[7] Document #2 has clarified that the northern boundary heads are time-variant. This assists calibration at sites close to the boundary, but it prejudices the predictive power of a model as time-invariant heads should be assumed for prediction (as their future behaviour cannot be anticipated).

There seems to be confusion between evaporation and evapotranspiration (ET) in Document #1[8]. There is mention of "measured" ET, but it is evaporation that is measured. There are estimates of actual ET on the Bureau of Meteorology website, and these values are more appropriate for modelling. As a result, this reviewer considers that the adopted maximum ET rate is too high and the amount of water discharged through this process is likely to be too high[9]. There is no map of simulated ET discharge, or simulated depth to water, to allow an assessment of where this might be occurring spatially, and whether as a consequence it has any relevance to the Project.

In Section 9.1, Lake Goran is said to be set up as a discharge zone. However, in the conceptualisation stage, it was described as a source of recharge[10].

6.4 CALIBRATION AND VERIFICATION

Calibration has been performed for steady-state 1980 conditions and transient conditions from 1980 to 2011 (31.5 years; 125 stress periods).

Steady state calibration is demonstrated with a scattergram showing 6.5 %RMS error, which is acceptable. Although steady state simulated head contours are presented for the alluvial/regolith layers and the coal seams, there is no reference to the observed contour map to demonstrate spatial calibration performance visually[11].

More lines of evidence are provided in support of transient calibration in the form of a scattergram, performance statistics, hydrograph comparisons and residuals maps. The transient calibration is quite good, with very good performance statistics: 2.7 %RMS and ~6 m absolute RMS. For the Project bores alone, the performance is not as good (8.9 %RMS, 5.7 mRMS) but that is acceptable for measurements in hard rock groundwater systems.

Hydrographs agree quite well, particularly for replication of long-term trends and vertical head differences within alluvium. The residuals maps show best performance near the Project site and worst performance in hydrogeological zone 6 and at the junction of the Mooki River and Quirindi Creek.

[8] Document #2 has clarified this. Pan evaporation was used as a basis for defining the initial ET rate, but this had to be scaled back (as expected) to about 10% during calibration.

[9] This is no longer the case, as much lower ET rates were used in the model than had been indicated in Document #1.

[10] This is unchanged in Document #2.

[11] There is still no reference to the observed contour map in Document #2. Table 9.3 wrongly refers to "transient" calibration statistics.

Calibration has been performed using the best available automation software (PEST SVDA) applied to 380 parameters and 30 super parameters. Pilot points were used to determine optimal spatial distributions for alluvial hydraulic conductivity (horizontal and vertical), alluvial storage terms, and the hydraulic conductivities of the two coal seams and the Permian interburden.

The inferred hydraulic conductivity magnitudes are consistent with aquifer tests and previous modelling, and the inferred rainfall recharge rates are plausible.

It was found that the faults behave optimally as resistive structures.

The water balance for the calibration period is compared with previous studies to ensure consistent ballpark values.

A null (no pumping) scenario was run during the calibration period to ensure model stability and absence of propagating effects due to choice of initial conditions.

A short verification simulation was conducted over 9 months. No undue behaviour was noted.

6.5 PREDICTION

Predictions are based on transient simulation for 30 years of continuous mining of three proposed open cut mining areas, for a single mine plan, followed by 1500 years of recovery after the cessation of mining. Project-specific simulations are performed.

The direction of progression in the Southern and Western pits is hard to see as there is insufficient tonal variation in Figure 10.1. In the model, pit excavation progressed in quarterly steps with 126 time slices to allow frequent updating of spoil properties.

Rain recharge is applied at continuous long-term rates and agricultural pumping is applied continuously (without seasonality) at the average over the last five years. River stages are held constant with no temporal variation, as applied during calibration.

Document #1 presents continuous plots of mine inflow with time, with a correction for evaporative loss from open water in the pits. The maximum predicted inflow rate is about 2 ML/day. Predicting mine inflow magnitude is always difficult in a “greenfields” application.

Impact assessment is done quantitatively for drawdown magnitude and extent in the Melvilles Coal Seam, Clare Sandstone and the two alluvial

formations, towards the end of mining and at the end of mining. Drawdowns in the Narrabri Formation and the Gunnedah Formation are provided also in terms of percentage of saturated thickness. This is no longer necessary, as that requirement has been removed from the AI Policy[12].

For licensing purposes, in compliance with the AI Policy, proper estimates have been made of the time-varying reduction in upflow from the hard rock groundwater system to the alluvium, and also of changes in stream-aquifer fluxes in the form of enhanced leakage or reduced baseflow. The quantity of intercepted groundwater flow normally destined for the alluvial system is reported as an annual average. The maximum rates should also be presented.

The Western Mining Area final void has been simulated by the common practice of treating the air/water space as highly permeable "material" accepting close to full rainfall (90%) and subject to the maximum evaporative rate. There is no argument offered for the use of 90% rainfall instead of 100%[13]. Also, it appears that 100% evaporation is applied, whereas it is likely that rates would be lower in a deep pit. A lower rate would cause a higher final water level in the void lake. The salinity evolution in the void lake was assessed in the surface water assessment.

For the infilled voids in the Eastern and Southern Mining Areas, seepage rates to the surrounding host rock and spoil infill are predicted to reach about 90 kL/day in the Eastern Mining Area and about 30 kL/day in the Southern Mining Area about 30 years after mining ceases. This corresponds with a salt load of less than 1 kg/d and 4 kg/d per hectare of seepage area in the Eastern and Southern Mining Areas respectively. Although the quantities are small, there is no investigation of whether or when this salt might reach the nearest watercourse, or of the ultimate impact on salinity in the Mooki River. The NSW AI Policy requires "*No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity*".

All prediction runs are performed properly and the findings are defensible.

No cumulative impact simulations were performed for proposed coal seam gas operations or the proposed Caroona Coal Project. Instead, the findings of the Namoi Water Study (Schlumberger Water Services, 2012) are summarised in Document #1. It should be noted that the Namoi Water Study model used MODFLOW2000 software which is not capable of simulating time-varying properties which is essential for the fracture zones that develop above underground mines. As fracturing was applied in advance, this model is likely to have over-estimated impacts.

[12] These figures have been removed from Document #2.

[13] Document #2 explains that 90% accounts for rainfall on the pit walls that does not enter the lake

6.6 SENSITIVITY ANALYSIS

A thorough sensitivity analysis has been reported. Perturbations of either 50% or one order of magnitude are applied to seven property groups. In addition, the following conceptual features are selectively removed to assess their significance:

- agricultural pumping;
- fault structures;
- enhanced recharge on spoil;
- break-of-slope recharge cells; and
- diffuse alluvial recharge.

The performance of each sensitivity run is measured in terms of steady state RMS and %RMS statistics, steady state water balance components, transient mine inflow, transient alluvium-rock flux, and transient Mooki River leakage. As very little change is evident in the calibration statistics, there is only mild sensitivity to the perturbed parameters in characterising the properties of the model. This reinforces the expectation of non-uniqueness of model parameters. There are no severe variations in the examined water balance components.

Relative sensitivities are examined by means of a normalised sensitivity index, but only for mine inflow, whereas environmental metrics would have been a better focus for the study. The definition of the index shows that the index must have units of flow (ML/day), but Figure 11.1 reports the index in terms of percentage. This is not correct[14].

Sensitivity to climate change has been assessed by running the prediction simulation for very low rainfall (10th percentile) and very high rainfall (90th percentile). This gives a conservative range of predictions for mine inflow, alluvium-rock flux and Mooki River leakage, but there is not necessarily any association between the assumed rainfall rates and those anticipated by climate change models[15]. The results are presented as time-series graphs, but there are enough data for more informative illustration as cumulative distribution functions (probability graphs).

Document #1 includes thoughtful explanations of sensitivity analysis findings.

Document #2 classifies the key parameters in terms of Type I to Type IV sensitivity. No Type IV sensitivity was found, and that is the only case that would be a cause for concern.

[14] This has been corrected in Document #2 (Figure 11.1).

[15] Document #2 ties the climate change assumptions to a CSIRO scenario.

At the end of Section 11.1.7 in Document #2, there is reference to the use of null-space Monte Carlo uncertainty analysis in Section 11.2, but that is not the type of analysis that was performed.

6.7 UNCERTAINTY ANALYSIS

The sensitivity analysis provides a substantial amount of information on the variability in predicted environmental impacts for perturbed parameters and climate extremes. Presentation as probability graphs would have allowed quantitative statements on the ranges of predictions.

A probability approach has been followed in Section 11.2 and Appendix 9 (of Document #2) through a more robust Monte Carlo uncertainty analysis. This has been done more thoroughly than is normal best practice. However, it is not the null-space Monte Carlo analysis that is at the forefront of research. There appears to be no attribution of Appendix 9 to the rightful authors of this good work.

The approach is relatively straightforward, in principle. Using estimated probability distributions for key model properties, 500 different combinations (realisations) were generated randomly. For each realisation, the transient calibration was run to produce a calibration performance statistic. The 250 runs with the worst performances were rejected. The remaining 250 pseudo-calibrated parameter sets were then used in 250 predictive simulations. The outputs were presented as time series graphs for a number of percentiles, and pit seepage was presented also as a probability distribution.

The key finding of this study was that the simpler sensitivity analysis was in good agreement with this more robust approach.

7.0 CONCLUSION

The Watermark Coal Project groundwater model has been developed competently and is regarded as “fit for purpose” for addressing the potential environmental impacts from three open cut mining operations and for estimating indicative dewatering rates.

The stated objectives of the modelling study have been addressed satisfactorily; namely:

- estimation of mine inflow to the open cut voids for 30 years;
- prediction of drawdown magnitude and extent;

- prediction of reduced flow from the Permian groundwater system to the alluvial aquifer system;
- prediction of impacts on stream baseflow/leakage and other groundwater users;
- assessment of recovery rates and final equilibrium groundwater levels; and
- identification of risks that might necessitate mitigation measures or controls.

Substantial sensitivity analysis has demonstrated that the calibration of the model is robust, and substantial perturbation of model properties will have only a mild impact on predicted environmental impacts. The sensitivity analysis results are confirmed by a more robust Monte Carlo uncertainty analysis.

Drawdown predictions indicate that the Project will not have significant impacts external to the mined area. This conclusion is well substantiated. No private bores are expected to be affected by more than 2 m drawdown, the minimal harm criterion in the NSW Aquifer Interference Policy.

The model anticipates negligible effect on neighbouring stream flows. This conclusion is well substantiated.

There is a prediction of reduced replenishment of alluvial groundwater from the rocks underneath by about 60 ML/a. This amount requires licensing, but sufficient licences appear to be already in place.

As yet there is no calculation of the expected salinity impact in the Mooki River as a result of seepage from infilled mine voids. It is certain to be less than 1 percent as required by the NSW Aquifer Interference Policy, but this should be demonstrated.

8.0 REFERENCES

Australasian Groundwater & Environmental Consultants Pty Ltd, 2012, Watermark Coal Project Groundwater Assessment. August 2012;Version 1.8; 302p. October 2012; Version 1.9; 319p.

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

MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission.
URL: http://www.mdbc.gov.au/nrm/groundwater/groundwater_guides/

Schlumberger Water Services, 2012, Namoi Catchment Water Study Independent Expert Phase 3 – Reference Manual. 50371/P3-R1 Draft. Prepared for Department of Trade and Investment, Regional Infrastructure and Services, New South Wales.

Table 1. Peer Review Checklists According to MDBC (2001)

MODEL REVIEW: 1. THE REPORT[16]

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.1	Is a report provided?		No			**Yes**			
1.2	Are relevant prior or companion reports provided or accessible?		No		**Yes**				
1.3	Is it clear which person(s) did the modelling?		No		**Yes**				
1.4	Is the report well structured?			Deficient	Adequate	**Very Good**			Some re-ordering of figures is suggested.
1.5	Is the report presentation of acceptable quality?			Deficient	**Adequate**	Very Good			Lots of editorial changes required, especially Executive Summary. Addressed in Document #2.
1.6	Is there a clear statement of project objectives?		Missing	Deficient	Adequate	**Very Good**			List of DGRs and requirements of NOW and SEWPaC.
1.7	Is the level of model complexity clear or acknowledged?		Missing	No	**Yes**				Class 3.
1.8	Are model parameter distributions disclosed?		Missing	Deficient	Adequate	**Very Good**			Figures 9.7 – 9.12; 9-15.
1.9	Are model parameter statistics reported (median, range, standard deviation)?		Missing	Deficient	**Adequate**	Very Good			Min and max. Model values compared with field ranges Figures 9.13 - 9.14.
1.10	Is it clear how stress datasets have been compiled?		Missing	Deficient	Adequate	**Very Good**			
1.11	Would it be possible to re-create the structure of the model from what is reported?			No	**Maybe**	Yes			There is sufficient information on geometry and properties.
1.12	Is a water or mass balance reported?		Missing	Deficient	Adequate	**Very Good**			As tables and graphs.
1.13	Are recommendations reasonable and supported by evidence?		Missing	Deficient	Adequate	**Very Good**			
1.14	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	**Very Good**			
1.15	Are the model results of any practical use?			No	Maybe	**Yes**			
1.16	Has the modelling study been cost-effective?	**Unknown**		No	Maybe	Yes			
1.	**TOTAL SCORE**								

[16] The assessments in **RED** were made in the Version A review. Where ratings have been updated in the Version B review, the cells are highlighted in **green**, and additional comments are in **GREEN**.





MODEL REVIEW: 2. DATA ANALYSIS

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
2.1	Have prior investigations been examined and acknowledged?		Missing	Deficient	Adequate	**Very Good**			
2.2	Is current knowledge sufficient for a mathematical model?			No	Maybe	**Yes**			
2.3	Is there a cost-effective alternative to modelling which would satisfy the project objectives?			Yes	Maybe	**No**			
2.4	Has a literature review been completed?		Missing	Deficient	**Adequate**	**Very Good**			Gap analysis done.
2.5	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	**Very Good**			176 aquifer tests & 32 cores.
2.6	Has rainfall data been collected and analysed?		Missing	Deficient	Adequate	**Very Good**			Residual mass curve.
2.7	Has streamflow data been collected and analysed?		**Missing**	Deficient	Adequate	Very Good			
2.8	Has flood event data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Aware of 4 major floods. (Modelled flood recharge not reported).
2.9	Has irrigation data been collected and analysed?	**N/A**	Missing	Deficient	Adequate	Very Good			
2.10	Has groundwater usage data been collected and analysed?		Missing	Deficient	**Adequate**	Very Good			FOI request. As tables and graphs. Unclear if Borambil pre-metering usage data has been corrected for under-reporting.
2.11	Has evapotranspiration data been collected and analysed?		Missing	**Deficient**	Adequate	Very Good			Seeming confusion between evaporation & evapotranspiration. Max ET rate is too high (for MODFLOW). Clarified in Document #2.
2.12	Has drainage data been collected and analysed?	**N/A**	Missing	Deficient	Adequate	Very Good			(Reference to irrigation drains)
2.13	Has other data been collected and analysed?		Missing	Deficient	**Adequate**	Very Good			Other data: water quality; water balances for previous models.
2.14	Have the above stress datasets been analysed for their groundwater response?		Missing	Deficient	**Adequate**	Very Good			
2.15	Is any relevant dataset ignored?		Yes	Maybe		No			Need to comment on the extent of flooding.
2.16	Are residual mass (cumulative deviation) plots prepared for rainfall / streamflow?		Missing	Deficient	**Adequate**	Very Good			Rain, not stream. Stream residual mass also in Document #2.
2.17	Is groundwater hydrographic data available?			No	Maybe	**Yes**			94 sites drilled for Project; From Aug.2009.
2.18	Are representative hydrographs selected logically?		Missing	Deficient	Adequate	**Very Good**			NOW has 351 bores.

2.19	Are field hydrographs compared and analysed?		Missing	Deficient	Adequate	**Very Good**			
2.20	Is water table / piezometric surface data available?			No	**Maybe**	Yes			Not for whole region. Missing on southern Liverpool Ranges.
2.21	Are representative contour maps selected logically?		Missing	**Deficient**	Adequate	Very Good			Data not contoured across zones 3, 7, 8. Included in Document #2.
2.22	Is interpolation reliability clear to the reader (posting of sample points, algorithm)?		Missing	Deficient	**Adequate**	Very Good			
2.23	Are data units consistent?			**No**	Yes				Wrong units for conductance and normalised sensitivity index. Corrected in Document #2.
2.24	Have standard geometrical datums been used?			No	Maybe	Yes			
2.25	If groundwater flow is likely to be affected by density, has allowance been made for the effect in any way?	**N/A**	Missing	Deficient	Adequate	Very Good			
2.	**TOTAL SCORE**								





MODEL REVIEW: 3. CONCEPTUALISATION

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
3.1	Is the conceptual model consistent with prior knowledge?		Unknown	No	Maybe	**Yes**			
3.2	Is the conceptual model consistent with project budget?		**Unknown**	No	Maybe	Yes			
3.3	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	**Yes**			
3.4	Is the conceptual model consistent with project deadline?		Unknown	No	Maybe	**Yes**			
3.5	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	**Very Good**			
3.6	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	**Very Good**			Figures 7.45-46
3.7	Is the conceptual model unnecessarily simple?			Yes	**No**				
3.8	Is the conceptual model unnecessarily complex?			Yes	**No**				
3.9	If any possibly key process is missing, is the justification adequate?	**N/A**	Missing	Deficient	Adequate	Very Good			
3.10	Are limitations and uncertainties described?			No	Maybe	**Yes**			
3.11	Has the conceptual model been reviewed independently?		Unknown	No	Maybe	**Yes**			By client geologist
3.	**TOTAL SCORE**								

MODEL REVIEW: 4. MODEL DESIGN

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
4.1	Is the choice of mathematical model appropriate (analytical / numerical)?			No	Maybe	**Yes**			Numerical
4.2	Is the spatial extent of the model appropriate?			No	Maybe	**Yes**			75km x 91km. Large part of catchment, including Liverpool Ranges
4.3	Is the spatial discretisation scale appropriate?		Missing	No	Maybe	**Yes**			250-500m (calibration). 50-500m (prediction).
4.4	Is the number of model layers justified?		Missing	No	Maybe	**Yes**			11 layers. 2 separate target coal seams.
4.5	Is steady state simulated?		Missing	Deficient	Adequate	**Very Good**			1980 levels. But there will be some prior pumping effect (acknowledged in report).
4.6	Is transient behaviour simulated?		Missing	Deficient	Adequate	**Very Good**			1980-2011. 31.5 years.
4.7	Is the stress period reasonable?		Missing	No	Maybe	**Yes**			Quarterly.
4.8	Is the number of time steps per stress period justified?	**N/A**	Missing	Deficient	Adequate	Very Good			Automatic (ATO).
4.9	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	**Adequate**	Very Good			GHB to north. No flow to east, south, west. Document #2 clarifies that northern heads are time-variant.
4.10	Are boundary condition locations consistent with the model grid configuration?		Missing	No	Maybe	**Yes**			
4.11	Are the initial conditions defensible?		Missing	Deficient	Adequate	**Very Good**			Steady state at 1980 (some prior pumping effect).
4.12	Is it clear what software has been selected?		Missing	No	Maybe	**Yes**			MODFLOW-SURFACT and proprietary pre- & post-processing software.
4.13	Is the software appropriate for the objectives of the study?			No	Maybe	**Yes**			
4.14	Is the software reputable?			No	Maybe	**Yes**			
4.15	Is the software in common use and accessible to reviewers?			**No**	Maybe	Yes			SURFACT- yes. Proprietary software – no.
4.16	How detailed is the rainfall recharge algorithm?		Missing	Deficient	**Adequate**	Very Good			Rain fraction.
4.	**TOTAL SCORE**								





MODEL REVIEW: 5. CALIBRATION

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.1	Is sufficient data available for spatial calibration?			No	Maybe	**Yes**			
5.2	Is sufficient data available for temporal calibration?			No	Maybe	**Yes**			
5.3	Does the model claim to be adequately calibrated for the purpose of the study?		Missing	No	Maybe	**Yes**			
5.4	Are calibration difficulties acknowledged?		Missing	Deficient	Adequate	**Very Good**			Steady state 1980 assumes no prior pumping effects. Uncertain pumping scheduling. Sensors in weathered or fresh Permian.
5.5	Is it clear whether calibration is automated or trial-and-error?		Missing	No		**Yes**			Automation software: PEST SVDA
5.6	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	**Very Good**			Scattergrams; residuals maps; hydrographs.
5.7	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	**Adequate**	Very Good			Hard to assess as no regional observed water level contours are shown. This could be done for Zones 3,5,7,8 & Watermark. Only Watermark is shown (Fig.7.33).
5.8	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	**Very Good**			Good hydrograph trends.
5.9	Are parts of the model well calibrated?		Unknown	No	Maybe	**Yes**			See residuals maps Figs. 9.43-9.45. Good near mine site. Best around 2000.
5.10	Are parts of the model poorly calibrated?		Unknown	**Yes**	Maybe	No			See residuals maps Figs. 9.43-9.45. Worst in Zone 6 and Mooki River-Quirindi Ck confluence (see Merrick, 2001)
5.11	Is the model calibrated to data from different hydrological regimes?		Unknown	No	Maybe	**Yes**			
5.12	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	**Yes**			
5.13	Is a calibration statistic reported?		Missing	No		**Yes**			For transient calibration, not for steady state (p.146).
5.14	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	**Very Good**			All data: 2.7%RMS, 6.0mRMS. Watermark only: 8.9%RMS, 5.7mRMS.
5.15	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	**Adequate**	Very Good			
5.	**TOTAL SCORE**								

MODEL REVIEW: 6. VERIFICATION

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
6.1	Has some data been reserved for a verification exercise?		Missing	No	Maybe	**Yes**			
6.2	Is the reserved data set an extension of the time period?		Missing	No	Maybe	**Yes**			
6.3	Is the reserved dataset a suite of hydrographs not on the representative list?		Missing	**No**	Maybe	Yes			
6.4	Is the volume of reserved data sufficient to establish verification?		Unknown	No	**Maybe**	Yes			9 months
6.5	Does the model claim to be verified?		Missing	No	Maybe	**Yes**			
6.6	Is there sufficient evidence provided for model verification?		Missing	Deficient	**Adequate**	Very Good			4 hydrographs. No statistics. Add a scattergram.
6.7	Are parts of the model well verified?		**Unknown**	No	Maybe	Yes			No spatial performance information.
6.8	Are parts of the model poorly verified?		**Unknown**	Yes	Maybe	No			
6.9	Is the reserved dataset from a different hydrological regime?		Unknown	**No**	Maybe	Yes			
6.10	Does the reserved dataset include stresses consistent with the prediction scenarios?		Unknown	No	Maybe	**Yes**			
6.11	Are there good reasons for an unsatisfactory verification?	**N/A**	Missing	Deficient	Adequate	Very Good			
6.	**TOTAL SCORE**								





MODEL REVIEW: 7. PREDICTION

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
7.1	Is prediction made for steady state conditions?		Missing	**No**	Maybe	Yes			No need.
7.2	Is prediction made for transient conditions?		Missing	No	Maybe	**Yes**			
7.3	Are the assumed stresses reasonable?		Missing	Deficient	Adequate	**Very Good**			Constant rates: rain and pumping averaged for last 5 years. Constant river stages.
7.4	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	**Yes**			Calibration & verification: 32.25 years. Prediction 30 years.
7.5	Have multiple scenarios been run for climate variability?		Missing	Deficient	**Adequate**	Very Good			10th & 90th percentile rain and ET.
7.6	Have multiple scenarios been run for operational alternatives?	**N/A**	Missing	Deficient	Adequate	Very Good			One mine plan. Also investigated reinjection borefield as a mitigation measure.
7.7	Are model predictions made at scales consistent with model space and time scales?		Missing	No	Maybe	**Yes**			Drawdown predictions are regional over long time intervals.
7.8	Are the model predictions plausible?			No	Maybe	**Yes**			
7.9	Are model predictions likely to be impacted by constraining boundary conditions?		Unknown	Yes	Maybe	**No**			Distant boundaries.
7.10	If boundary conditions affect the predictions, are the predictions defensible?	**N/A**	Unknown	No	Maybe	Yes			
7.	**TOTAL SCORE**								

MODEL REVIEW: 8. SENSITIVITY ANALYSIS

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
8.1	Is there discussion of qualitative sensitivities found during calibration?		**Missing**	Deficient	Adequate	Very Good			Robustness tested for zero pumping. Non-uniqueness is recognised.
8.2	Has a post-calibration sensitivity analysis been performed?		Missing	Deficient	Adequate	**Very Good**			
8.3	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	**Very Good**			12 perturbed parameters.
8.4	Is there a graphical presentation of sensitivity behaviour?		Missing	Deficient	Adequate	**Very Good**			Fig.11.1.
8.5	Are sensitivities classified as Type I to Type IV?		Missing	**No**		Yes			See Guidelines Section 5.3
8.6	Has a Type IV sensitivity been recognised?		**Missing**	Yes	Maybe	No			See Guidelines Section 5.3
8.7	Is there a list of ranked sensitivity coefficients?		Missing	Deficient	**Adequate**	Very Good			For impact on pit inflow.
8.8	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	**Adequate**	Very Good			RMS reported.
8.9	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	**Very Good**			9 charts, 6 contour maps.
8.	**TOTAL SCORE**								





MODEL REVIEW: 9. UNCERTAINTY ANALYSIS

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
9.1	Is the uncertainty in aquifer properties acknowledged or described/quantified?		Missing	Deficient	Adequate	Very Good			Non-uniqueness is recognised.
9.2	Are uncertainties in stress datasets acknowledged or described/quantified?		Missing	Deficient	Adequate	Very Good			
9.3	Are uncertainties in observation data acknowledged or described/quantified?		Missing	Deficient	Adequate	Very Good			
9.4	Are uncertainties in predicted outcomes acknowledged or described/quantified?		Missing	Deficient	Adequate	Very Good			
9.5	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	**Yes**			Appendix 9 - **in Document #2.**
9.6	If uncertainty has been quantified, has an acceptable method been used?		Missing	Deficient	Adequate	Very Good			Method: Conventional Monte Carlo analysis with retention only of near-calibrated realisations.
9.7	If uncertainty has been quantified, how extensive is the analysis?		Missing	Deficient	Adequate	Very Good			
9.	**TOTAL SCORE**								

Table 2: Review Checklists According to Barnett *et al.* (2012)

Review questions	*Yes/No*	*Comment*
1. Planning		**Note: Numbers in square brackets refer to appraisal comments in Table 1**
1.1 Are the project objectives stated?	Y	[1.6]
1.2 Are the model objectives stated?	Y	P96. Section 8.2
1.3 Is it clear how the model will contribute to meeting the project objectives?	Y	
1.4 Is a groundwater model the best option to address the project and model objectives?	Y	
1.5 Is the target model confidence-level classification stated and justified?	Y	[1.6] Class 3
1.6 Are the planned limitations and exclusions of the model stated?	Y	
2. Conceptualisation		
2.1 Has a literature review been completed, including examination of prior investigations?	Y	[2.1]
2.2 Is the aquifer system adequately described?	Y	
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Y	
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Y	
2.2.3 aquifer geometry including layer elevations and thicknesses	Y	[1.11]
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	Y	
2.3 Have data on groundwater stresses been collected and analysed?	Y	
2.3.1 recharge from rainfall, irrigation, floods, lakes	YNYY	[2.6][2.7][2.8][2.15] Lake Goran
2.3.2 river or lake stage heights	N	[2.9] Missing streamflow - included in Document #2.
2.3.3 groundwater usage (pumping, returns etc)	Y	
2.3.4 evapotranspiration	Y	[2.11] Confusion between evaporation and ET. Max ET rate too high. Clarified in Document #2.
2.3.5 other?	Y	Water quality. [2.13] water balance
2.4 Have groundwater level observations been collected and analysed?	Y	
2.4.1 selection of representative bore hydrographs	Y	[2.18] 351 NoW bores, 94 onsite bores.
2.4.2 comparison of hydrographs	Y	[2.19]
2.4.3 effect of stresses on hydrographs	Y	[2.19]
2.4.4 watertable maps/piezometric surfaces?	Y	[2.20] Only for site; should be broader
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	N/A	
2.5 Have flow observations been collected and analysed?	N	
2.5.1 baseflow in rivers	Y	There seems to be no check whether model calibration matches the stated 27 ML/day recharge from the Mooki River downstream to Caroona.
2.5.2 discharge in springs	N	

Review questions	*Yes/No*	*Comment*
2.5.3 location of diffuse discharge areas?	N/A	
2.6 Is the measurement error or data uncertainty reported?	N	
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	N	
2.6.2 spatial variability/heterogeneity of parameters	Y	Examined in calibration
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	Y/N	Maps include posted points
2.7 Have consistent data units and geometric datum been used?	Y	[2.23]
2.8 Is there a clear description of the conceptual model?	Y	[3.5]
2.8.1 Is there a graphical representation of the conceptual model?	Y	[3.6]
2.8.2 Is the conceptual model based on all available, relevant data?	Y	
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Y	[3.3]
2.9.1 Are the relevant processes identified?	Y	[3.9]
2.9.2 Is justification provided for omission or simplification of processes?	YN	[3.9] No comment on constant rather than dynamic river stage. No flood extent.
2.10 Have alternative conceptual models been investigated?	Y	Features removed selectively during sensitivity analysis.
3. Design and construction		
3.1 Is the design consistent with the conceptual model?	Y	
3.2 Is the choice of numerical method and software appropriate (**Error! Reference source not found.**)?	Y	
3.2.1 Are the numerical and discretisation methods appropriate?	Y	
3.2.2 Is the software reputable?	Y	[4.14]
3.2.3 Is the software included in the archive or are references to the software provided?		Proprietary processing software will not be included. SURFACT is commercially available.
3.3 Are the spatial domain and discretisation appropriate?	Y	
3.3.1 1D/2D/3D	Y	3D
3.3.2 lateral extent	Y	[4.2]
3.3.3 layer geometry?	Y	[4.4]
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Y	[4.3]
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Y N	[4.4] 11 Layers Too many layers if aquitards were subdivided
3.4 Are the temporal domain and discretisation appropriate?	Y	[4.7] Quarterly; 31.5 years calibration
3.4.1 steady state or transient	Y	Both
3.4.2 stress periods	Y	126
3.4.3 time steps?	N/A	ATO
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	Y	[4.9]
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	Y	
3.5.2 Are the boundary conditions chosen to have a minimal	Y	Set at great distance; no flow and GHB

Review questions	*Yes/No*	*Comment*
impact on key model outcomes? How is this ascertained?		
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Y	Spatial variation
3.5.4 Are lateral boundaries time-invariant?	N	Not stated. Clarified in Document #2.
3.6 Are the initial conditions appropriate?	Y	[4.11] Some error at 1980 by assuming nil pumping.
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?	Y	Model
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	N	But zero pumping sensitivity demonstrates on adverse impact from initial conditions
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	N/A	
3.7 Is the numerical solution of the model adequate?	N/A	
3.7.1 Solution method/solver	N/A	
3.7.2 Convergence criteria	N/A	
3.7.3 Numerical precision	N/A	
4. Calibration and sensitivity		
4.1 Are all available types of observations used for calibration?	Y	
4.1.1 Groundwater head data	Y	
4.1.2 Flux observations	N	No check on baseflow magnitude. There seems to be no check whether model calibration matches the stated 27 ML/day recharge from the Mooki River downstream to Caroona.
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	N	
4.2 Does the calibration methodology conform to best practice?	Y	[5.5] PEST SVDA
4.2.1 Parameterisation	Y	Zones and pilot points
4.2.2 Objective function	Y	Heads RMS
4.2.3 Identifiability of parameters	Y	[8.1]
4.2.4 Which methodology is used for model calibration?		[5.5] PEST SVDA
4.3 Is a sensitivity of key model outcomes assessed against?	Y	[8.3] Thorough
4.3.1 parameters	Y	
4.3.2 boundary conditions	N	Except for conductance
4.3.3 initial conditions	N	
4.3.4 stresses	Y	Zero pumping scenario
4.4 Have the calibration results been adequately reported?	Y	[5.6] Steady state spatial match could be shown better
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Y	[5.6]
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	Y	[5.6] Visually
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Y	[5.13]
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Y	[5.6] [5.8]-[5.10]

Review questions	*Yes/No*	*Comment*
4.5.1 spatially	N	[5.7] Steady state not demonstrated
4.5.2 temporally	Y	[5.8]
4.6 Are the calibrated parameters plausible?	Y	[5.12]
4.7 Are the water volumes and fluxes in the water balance realistic?	Y	[1.12] Compared with pre-mining estimates
4.8 has the model been verified?	YN	Only for 9 months
5. Prediction		
5.1 Are the model predictions designed in a manner that meets the model objectives?	Y	Targeted at AI Policy requirements and licensable volumes of water.
5.2 Is predictive uncertainty acknowledged and addressed?		[7.5] Appendix 8 - yet to see.
5.3 Are the assumed climatic stresses appropriate?	Y	10% and 90%; not tied to climate change predictions. How was ET varied?
5.4 Is a null scenario defined?	YN	Zero pumping for calibration, but not prediction.
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	NA	Only 1 scenario (one mine plan); also climate extremes to assess uncertainty
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	Y N	Agricultural pumping (5 year average). Greenfield site - no prior mining.
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	NA	
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	Y	[7.4] 30 vs 31.5 years
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	Y	Life of mine and 1500 years recovery.
5.6 Do the prediction results meet the stated objectives?	Y	[1.14]
5.7 Are the components of the predicted mass balance realistic?	Y	Mine inflow ~1 ML/day average
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?		Not stated.
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?		Not investigated. There seems to be no check whether model leakage is less than reported streamflow in the Mooki River.
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?		Unlikely. Very few GHB cells and only at great distance to the north.
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	Y	Percentage of rain
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?		Not reported
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	N/A	
6. Uncertainty		
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Y	Using sensitivity analysis for model outcome uncertainty. Also Monte Carlo uncertainty analysis.
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	N/A	Best 250 runs (of 500 trials) are used.
6.3 Are the sources of uncertainty discussed?	Y	Limitations section. Additional comment in Appendix 9.

Review questions	*Yes/No*	*Comment*
6.3.1 measurement of uncertainty of observations and parameters	Y N	K ranges reported. Water level uncertainty not stated, other than uncertainty of screened interval.
6.3.2 structural or model uncertainty	Y	Fault structures considered.
6.4 Is the approach to estimation of uncertainty described and appropriate?	Y	Appendix 9 - Monte Carlo.
6.5 Are there useful depictions of uncertainty?	Y	[8.9] Climate change. Excellent graphics in Appendix 9 - time series percentile plots and two probability distributions.
7. Solute transport	N/A	
7.1 Has all available data on the solute distributions, sources and transport processes been collected and analysed?	N/A	
7.2 Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?	N/A	
7.3 Is the choice of numerical method and software appropriate?	N/A	
7.4 Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?	N/A	
7.5 Is there sufficient basis for the description and parameterisation of the solute transport processes?	N/A	
7.6 Are the solver and its parameters appropriate for the problem under consideration?	N/A	
7.7 Has the relative importance of advection, dispersion and diffusion been assessed?	N/A	
7.8 Has an assessment been made of the need to consider variable density conditions?	N/A	
7.9 Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?	N/A	
7.10 Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?	N/A	
7.11 Is the calibration based on meaningful metrics?	N/A	
7.12 Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis?	N/A	
7.13 Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?	N/A	
7.14 Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings?	N/A	
7.15 Does the report address the role of geologic heterogeneity on solute concentration distributions?	N/A	
8. Surface water–groundwater interaction		
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Y	
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Y	RIV and DRN algorithms
8.3 Is the groundwater model coupled with a surface water model?	N	

Review questions	*Yes/No*	*Comment*
8.3.1 Is the adopted approach appropriate?	N/A	
8.3.2 Have appropriate time steps and stress periods been adopted?	N/A	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	N/A	