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Our Ref:44621(a)

1 December, 2006

Lyz Risby
Project Officer
River Murray Catchment Water Management Board
PO Box 4, Strathalbyn, SA 5255

Dear Ms Risby,

Re: Angas Bremer Flood Infiltration Study

Introduction

Thank you for selecting Australian Water Environments (AWE) to undertake this study. Please find enclosed four copies of the final report, and please contact me if you need further clarification of any aspect of the report.

Yours sincerely,

Dr Juliette Woods
Senior Groundwater Modeller
Australian Water Environments Pty Ltd

Angas Bremer Water Management Committee

Angas Bremer Floodplain Infiltration to January 2005 Final Report

December 2006

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Tony Thomson of DWLBC was the designer and manager of this study. Cliff Hignett installed the equipment and Bruce Allnutt collected and collated the data. Agrilink equipped and monitored for soil moisture at Site A and for well levels at Site E. Additional assistance was provided by, Peta Hansen and Rob Giles.

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Appendices

1. Introduction

The Angas Bremer region is situated on the floodplain of the Angas and Bremer Rivers, between the Eastern Mount Lofty Ranges and Lake Alexandrina (Figure 1). Its centre is the township of Langhorne Creek, which is located 16km east of Strathalbyn. The principal irrigated crops in the region are vines, vegetables, cereals, almonds, lucerne and olives.

In winter, levels in the Angas and Bremer Rivers often rise steeply, and growers release river water onto their properties to saturate the soil for crop use in subsequent months. This method of irrigation will be referred to in this report as “controlled winter flooding”.

The purpose of this study is to quantify the impact of controlled winter flooding on the aquifers underlying the region. This is done using data obtained from wells and soil moisture loggers over the period November 2002 until January 2005. Records of river levels, rainfall, and area flooded also aid interpretation.

The hydrogeology of the Angas-Bremer Region is outlined in AWE (2005). There are two principal aquifers, one unconfined and one confined. In most of the region the unconfined aquifer is in good hydraulic connection to the River Bremer. Near Langhorne Creek the un-confined aquifer is separated from the confined aquifer by a clay and silt aquitard. Further from Langhorne Creek the aquitard thins or is entirely absent and the unconfined and confined aquifers behave as essentially one unit.

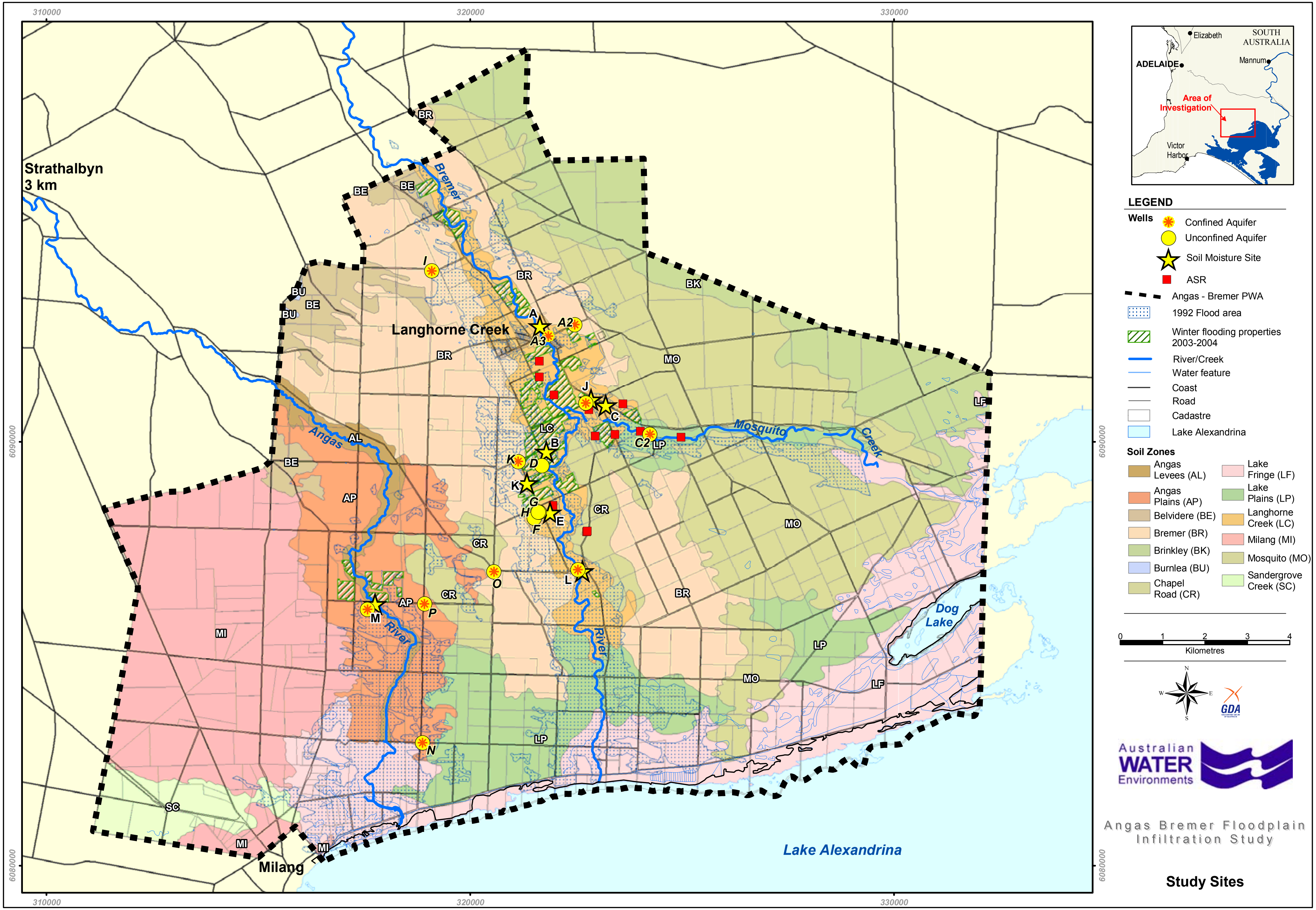

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Figure 1

2. Study sites

Eight sites were chosen for the monitoring of soil moisture with depth: these are sites A, B, C, E, J, K, L and M. The locations of these sites are shown in Figure 1. Seven of the sites (A, B, C, E, J, K and L) are located along the Bremer River, where the majority of controlled winter flooding is conducted; and one (M) is located next to the Angas River. The distance to a river or creek from each soil moisture site ranges from 50 m (M) to 550 m (K).

The sites were chosen to be on different soil types but despite minor differences (Hignett, 2003) all of the sites adjacent to the Bremer are classified by DWLBC as “deep uniform to gradational soils” of “deep friable gradational clay loam and deep hard gradational clay loam” and form part of the Langhorne Creek soil zone shown in Figure 1 (DWLBC GIS database). Site M, adjacent to the Angas, has a very similar classification: “deep uniform to gradational soils” of “deep sandy loam; deep hard gradational clay loam” and is part of the Angas Plains soil zone (DWLBC GIS database). Soil profile descriptions down to 1.5–1.7 m depth were available for each of the sites and were obtained from Cliff Hignett.

The soil moisture logger sites were selected to be close to groundwater observation bores. There are observation bores within 220 m of sites E, J, L and M. Sites A, C and K are matched with bores located within 550 m and 1250 m. Most groundwater observation bores are in pairs, which record heads in the unconfined and confined aquifers. Also included in the study were additional observation bores not matched to any soil moisture logger sites and located at up to 2 km from the rivers: the location of these bores have been named D, F, G, H, I, O and P. All study bores are included on Figure 1.

The monitoring of soil moisture began in 2001 by using handheld readers at sites A, B and C. Deeper probes, automatic data loggers, and additional sites have been added over time. The history of the installation of the soil moisture monitoring equipment is as follows:

- In August 2001 Cliff Hignett installed gypsum block sensors at sites A, B and C.
- In April 2002 Cliff installed additional gypsum blocks and included additional depths at sites A, B and C.
- These sites were visited regularly and all the blocks were read with a hand-held reader and the results were recorded by Bruce Allnutt and charted in an Excel spreadsheet by Tony Thomson.
- In Oct 2001, at site A, Agrilink donated, supplied and installed their data logger attached to a soil probe with Agrilink capacitance sensors at depths of 0.1, 1.0, 1.5, 2.0, 2.5 and 3.0m.
- In Oct 2002, at site A, Agrilink installed an additional probe with capacitance sensors at depths of 3.5, 4.0, 4.5, 5.0, 5.5 and 6.0m. This probe with the deeper sensors was requested and purchased by the ABWMC.
- In November 2002 Cliff Hignett installed gypsum block sensors plus the 8 Measurement Engineering Australia (MEA) data loggers at sites A, B, C, E, J, K, L and M.

- At sites A, B and C some of the gypsum blocks that had been installed in August 01 and in April 02 were connected to the MEA loggers together with the additional sensors that were installed in November 2002.

- At each of the 8 sites, the depths of the gypsum block sensors were 0.2, 0.5, 1.0, 1.5, 2.0, and 3.0m.

- At sites A, L and M additional sensors were included at 4.0 and 6.0m.

Note that there are now three sets of soil moisture sensors at Site A, all within 15 m of each other: the MEA logger, “Agrilink A” with sensors and 0.5 to 3.0 m, and “Agrilink B” with sensors at 3.5 to 6.0 m.

Data has been collected at the soil moisture logger sites since November 2002, but not all of the loggers have been in continuous operation over that time. The soil moisture logger at site L, for example, failed during key winter periods in both 2003 and 2004. Most of the loggers record soil moisture at depths 0.2, 0.5, 1.0, 1.5, 2.0 and 3.0 m. Sites E, K also recorded data at 2.5m. Sites A, L, and M recorded data at greater depths: 6.0, 4.0 and 6.0m respectively. The soil moisture loggers were operated by Bruce Allnutt; an additional logger at Site A was operated by Agrilink.

Data on the height and volumetric flow of the River Bremer was obtained from a DWLBC monitoring site at Hartley. Rainfall records were obtained from the Bureau of Meteorology, for their stations at Langhorne Creek and Mount Barker. Langhorne Creek is within the Angas-Bremer Prescribed Wells Area (ABPWA); the Mount Barker station lies outside the ABPWA but rainfall there supplies water to the Bremer. Some additional Angas Bremer local rainfall data came from Orlando Wines.

The soil moisture loggers, observation bore loggers and river monitors recorded data at fifteen minute intervals. Rainfall records are daily. Table 1summarises information about each site.

Table 1: Study site summary information.

	SOIL MOISTURE LOGGER						UNCONFINED AQUIFER WELL								CONFINED AQUIFER WELL					
Site	***moisture logger***	***easting***	***northing***	***soil group****	***recharge potential*****	***distance to water-course (m)***	***Unit No.***	***Obs. No.***	***easting***	***northing***	***mean depth to watertable (m)***	***distance from soil mositure logger (m)***	***distance to water-course (m)***	***Note***	***Unit No.***	***Obs. No.***	***easting***	***northing***	***distance from soil mositure logger (m)***	***distance to watercourse (m)***
A1	A	321647	6092727	LC	Class C	110								*three soil*						
		321641	6092733											*moisture*						
		321644	6092747											*loggers*						
A2						930	6727-02253	FRL-231	322468	6092765	9.69	822	930		6727-01861	FRL-012	322466	6092763	820	928
B	B	321798	6089769	LC	Class C	*400*					0.00									
C1	C	323197	6090863	LC	Class A	*400*					0.00									
C2						48	6727-01694	FRL-224	324238	6090179	5.90	1246	48		6727-01693	FRL-063	324237	6090179	1245	47
D						*0*	6727-02823	50136	321692	6089439	3.58	347		10m well						
E	E	321885	6088332	LC	Class C	*300*	6727-02661	-	321901	6088347	3.31	22	322	Agrilink well						
F, aka H2						360	6727-02820	50133	321632	6088416	3.83		360	10m well						
G, aka H3						420	6727-02821	50134	321610	6088347	3.85		420	10m well						
H						587	6727-02822	50135	321515	6088204	5.42		587	10m well						
I						893	6727-02244	STY-109	319097	6094029	10.40		893		6727-02245	I-STY-206	319097	6094029		893
J	J	322851	6091000	LC	Class C	519	6727-01680	FRL-225	322729	6090916	4.59	148	372		6727-01679	FRL-062	322727	6090915	150	369
K	K	321342	6089027	LC	Class C	*550*	6727-02415	BRM-243	321139	6089533	6.15	545			6727-02414	BRM-182	321136	6089537	550	
L	L	322649	6086954	LC	Class C	119	6727-01737	FRL-216	322545	6086987	5.12	109	12		6727-01736	FRL-064	322545	6086988	109	12
M	M	317759	6086177	AP	Class C	46	6627-08765	BRM-248	317581	6086050	6.24	219	260		6627-01248	BRM-034	317581	6086050	219	260
N						*850*	6727-02408	BRM-240	318882	6082907	2.25				6727-02267	BRM-158	318882	6082907		
O						1974	6727-02418	BRM-244	320561	6086938	8.29		1974		6727-02259	BRM-155	320564	6086939		1970
P						1150	6727-02407	BRM-245	318929	6086182	8.02		1150		6727-02265	BRM-154	318923	6086181		1144

* **LC** Deep uniform to gradational soils, Deep friable gradational clay loam; Deep hard gradational clay loam, >60% clay loam
AP Deep uniform to gradational soils, Deep sandy loam; Deep hard gradational clay loam, >60% loamy sand

***** Soil map classification***
Class C Negligible high recharge; more than 30% moderate recharge
Class A Negligible high recharge; negligible moderate recharge

3. Observations

3.1 Rainfall

Annual rainfall during the study period has not varied much from year to year. During the two years of the study period, 2003-4 and 2004-5, the cumulative annual rainfall was between 700 and 800 mm at Mount Barker and between 300 and 350 mm at Langhorne Creek. Maximum daily rainfall at Mount Barker peaked at 40 mm (Figure 2) and 26 mm at Langhorne Creek (Figure 3).

3.2 River Bremer

After rain events, the level in the Bremer at Hartley rises rapidly (up to 629 mm in 15 minutes) then falls at up to 300 mm/hr. The Bremer collects rain that falls in the top of its catchment and brings this water to the north of the town of Langhorne Creek. After the first rains, to the south of the town, the Bremer remains dry while it is flowing north of the town. As the amount of rain increases the Bremer flows further along its length and eventually (perhaps after several months) it flows into Lake Alexandrina.

The main flow in the Bremer at Hartley occurred between June and November 2003 and between June and September 2004 (Figure 4). The water level is usually between 1.10 and 1.25 m, but spikes of higher water levels are common. In 2003, the maximum water depth was 2.1 m but in 2004 it reached 4.2 m. Despite the much higher 2004 peak, cumulative flow from June to December of both years was similar, 8.8 or 9.5 GL. However, records from other years show that annual cumulative flow in the Bremer (as measured at Hartley) can vary by almost an order of magnitude, from 2.25 GL to 17.36 GL (Figure 5). A particularly large flood occurred in 1992 and its extent is mapped in Figure 1. Figure 6 shows the relationship between rainfall at Mount Barker and at Langhorne Creek to flow in the Bremer.

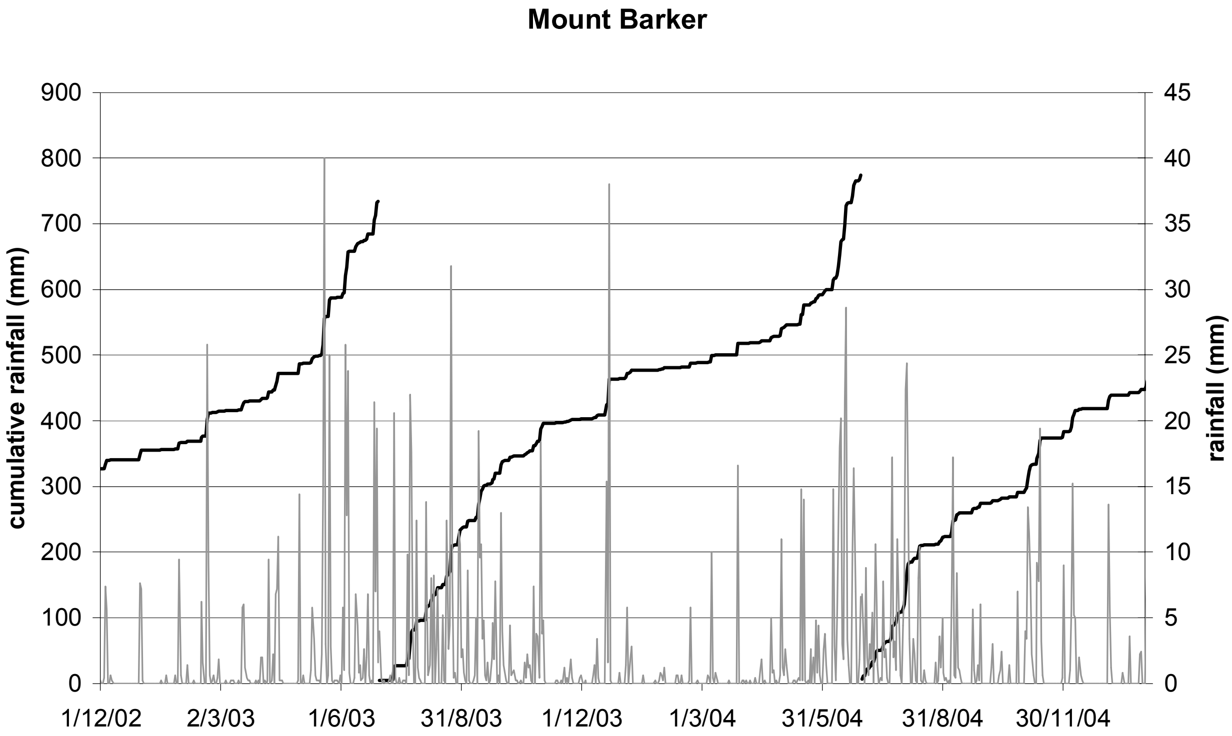


Figure 2: Daily and cumulative annual rainfall at Mount Barker.

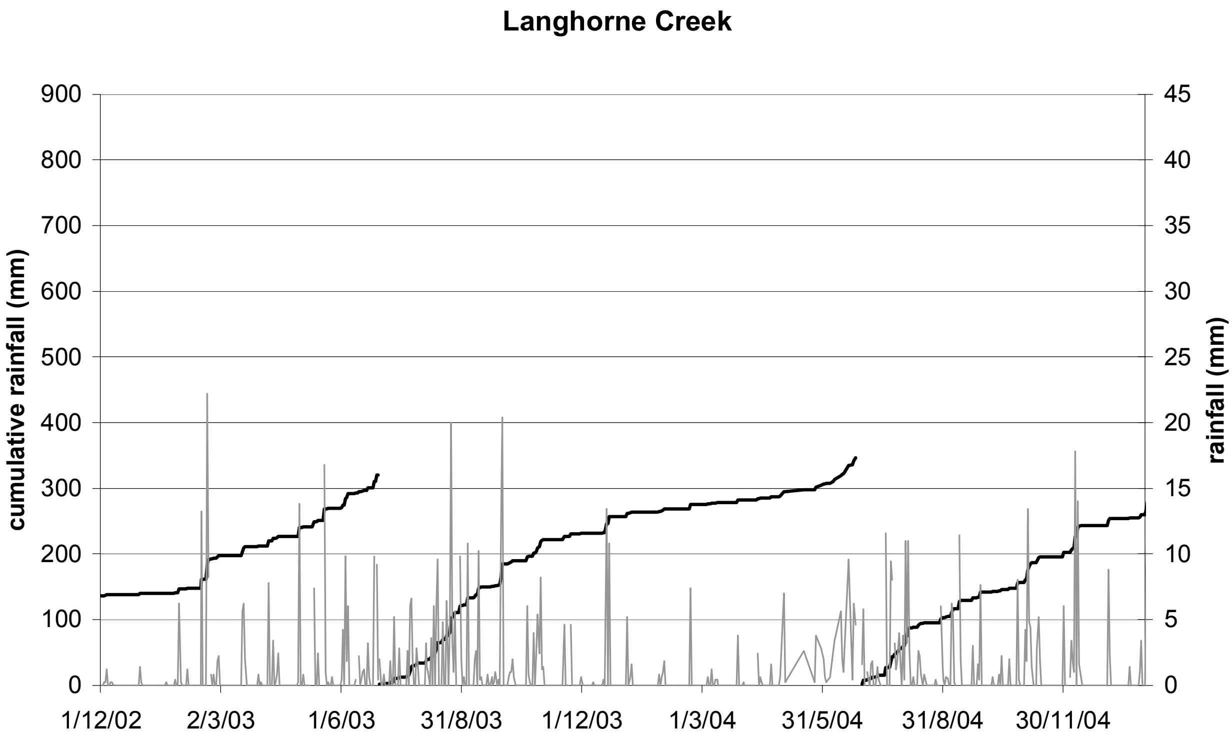


Figure 3: Daily and cumulative annual rainfall at Langhorne Creek.

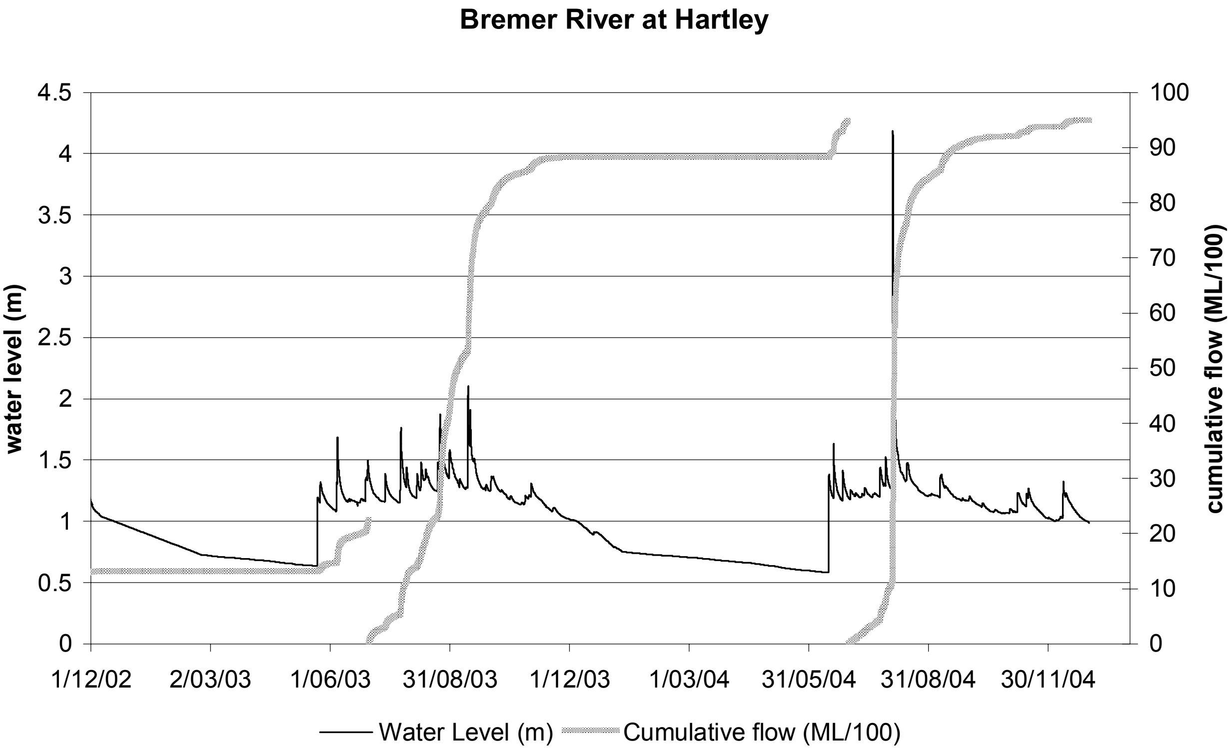
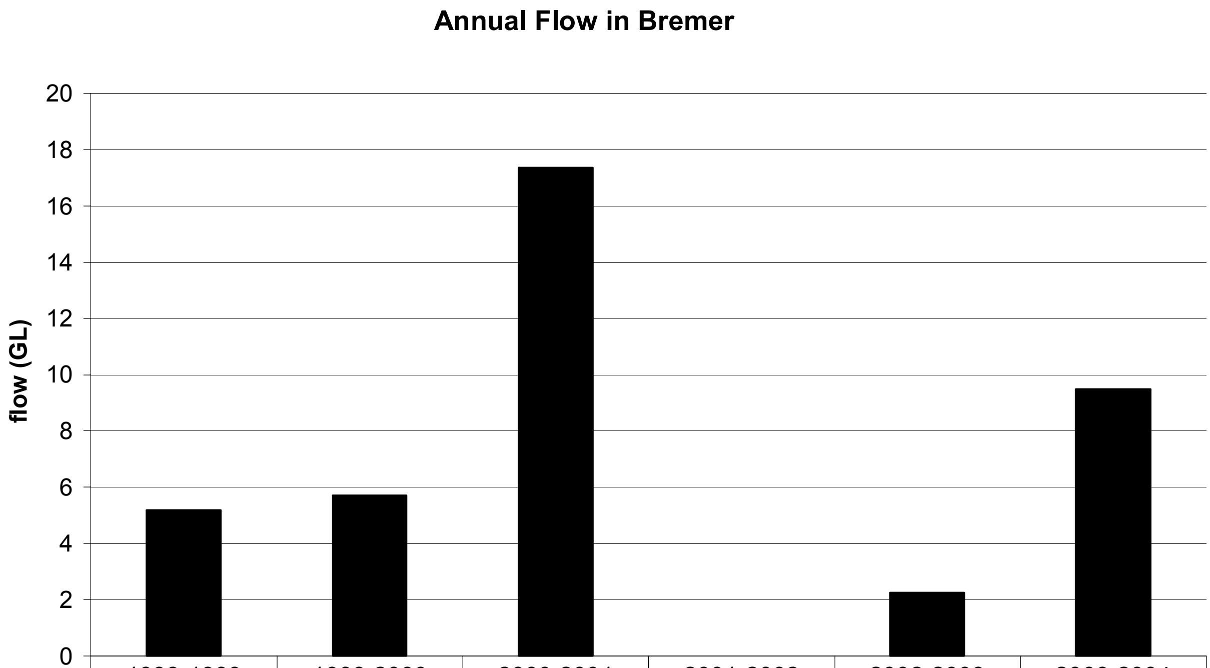


Figure 4: Water level and cumulative flow of the Bremer River.



	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004
■ flow (GL)	5.19	5.71	17.36		2.25	9.49

Figure 5: Cumulative flow in the Bremer, 1998-2004.

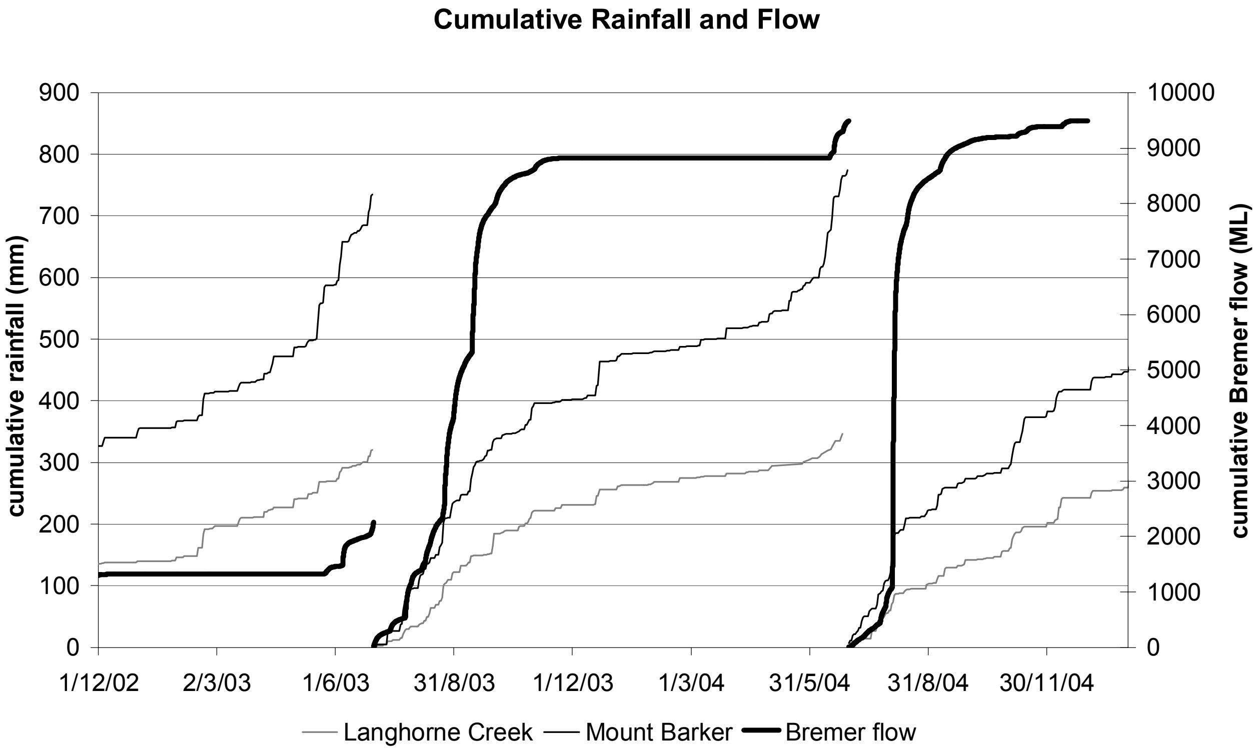
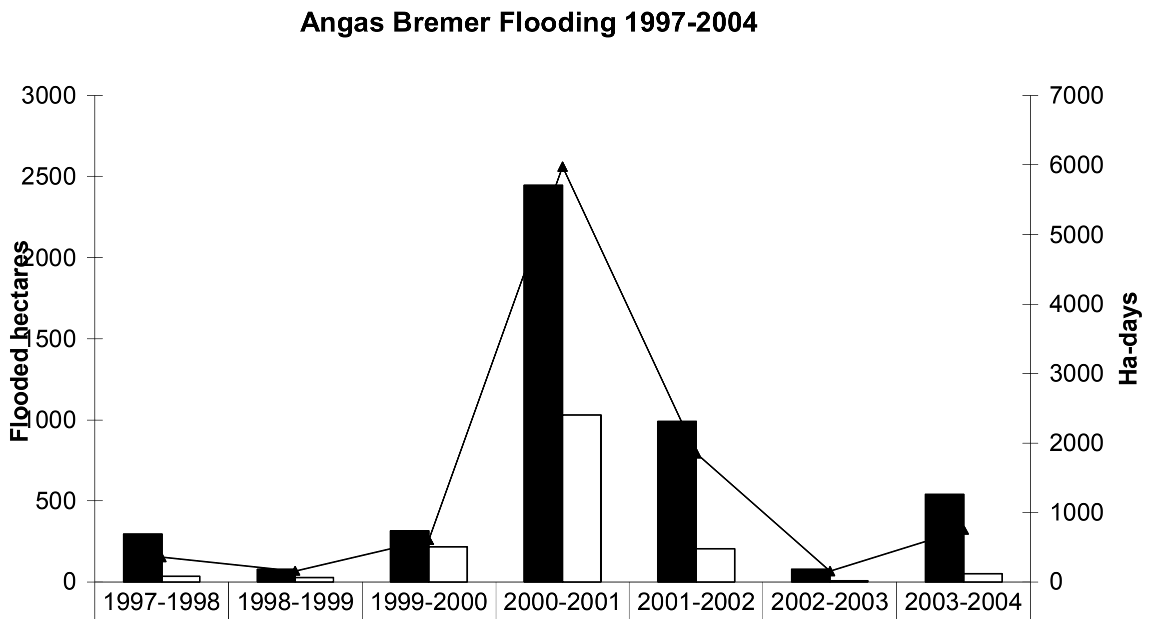


Figure 6: Cumulative Bremer flow and rainfall.

3.3 Use of floodwaters for irrigation

Data on the number of hectares flooded in each year was available for the period July 1997 to July 2004. The present study spans 2003-4 and 2004-5, and when the analysis was done, the irrigation data was not yet available for the latter year.

Figure 7 plots the number of hectares flooded each year. This flooded area is split between land growing an irrigated crop and land without an irrigated crop. It also plots the number of hectare-days, i.e. irrigated hectares are multiplied by the number of days they were flooded, and the total is summed. Unsurprisingly, more controlled winter flooding is recorded in years when the River Bremer has high flows. The number of Ha-days varies by more than an order of magnitude, from 155 in 2002-3 to 5 976 in 2000-1.



	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004
Ha crop	295	78	313	2445	992	80	538
Ha non-crop	35	28	216	1029	207	6	49
total Ha-days	360	158	603	5976	1846	155	752

Figure 7: Angas-Bremer Flooding 1997-2004.

3.4 Confined aquifer

Hydrographs showing potentiometric head within the confined aquifer are given in Figure 8 and Figure 9 and in Appendix A. Figures A1 and A3 plot confined aquifer hydrographs for winter flooding periods in 2003-4 and 2004-5 respectively. Figures A5 to A18 plot hydrographs for each site from December 2002 to early 2005; confined aquifers are indicated by black lines.

The confined aquifer responds very rapidly to changes in the Bremer's water level (Figure 8 and Figure 9). The magnitude and timing of the water-level response at a well depends on (1) the distance between the well and the river, (2) the distance from the well to the lake, (3) the furthest downstream location reached by the water in the river and (4) whether the aquitard is present at the site.

At sites adjacent to the Bremer river, the head in the confined aquifer rises by up to 2 m in a few days, following increases in Bremer water level at Hartley of 0.8 - 2.9 m. Water levels at sites further from the river (e.g. at site C that is east of the Bremer and north-west of Mosquito Creek and at site K to the west of the Bremer) start to rise within (? number) hours of when they rise beside the river at site J.

Site L is located furthest downstream of all the soil moisture logger sites. In September 2003, the confined aquifer well water levels at site L rose about 40 hours after rises at site J (Figure 8). In August 2004 water levels rose at both J and L at approximately the same time, with the level at L rising more slowly (Figure 9). In 2003, if the River Bremer waters took a long time to flow as far downstream as site L, this might explain the 40 hour delay between the responses at J and L.

Confined aquifer water levels rise higher and more rapidly close to the Bremer than further away. When the rise beside the Bremer was 2 m (e.g. at site J), the rise 2 km away at, e.g. site O, was about 0.5m (winter 2003) or 0 m (winter 2004).

Where the aquitard exists, the amplitude of the water level rise in the confined aquifer remains constant as distance downstream along the Bremer increases, e.g. at wells J and K.

Note that a rise in the confined aquifer level is seen in the third week of May 2003, *before* water levels rise in the Bremer. One possible explanation is that this is due to River Murray water that was pumped into the aquifer as part of local Aquifer Storage and Recharge schemes. Eleven ASR sites lie within the ABPWA (Figure 1).

About 1km from the Angas, at each of sites P and N, the water levels in the confined aquifer did not change when the water levels changed in the Bremer.

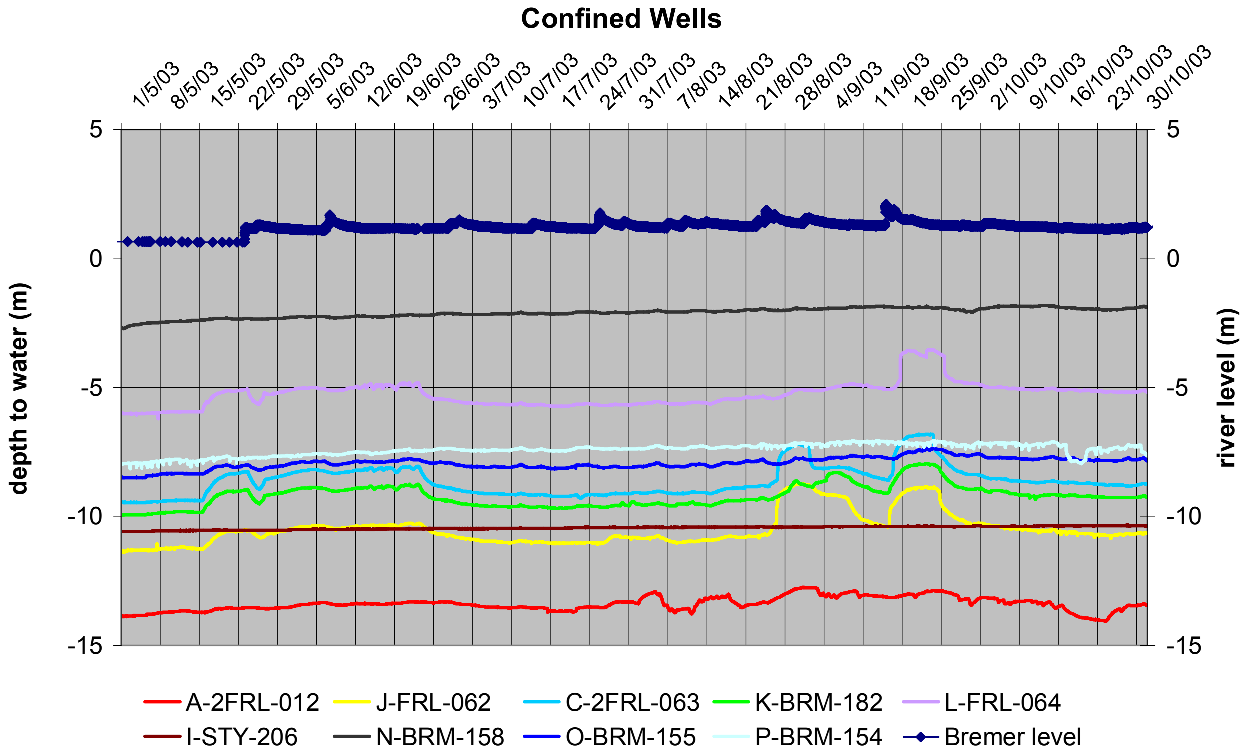


Figure 8: Confined aquifer levels and Bremer River level, May-November, 2003.

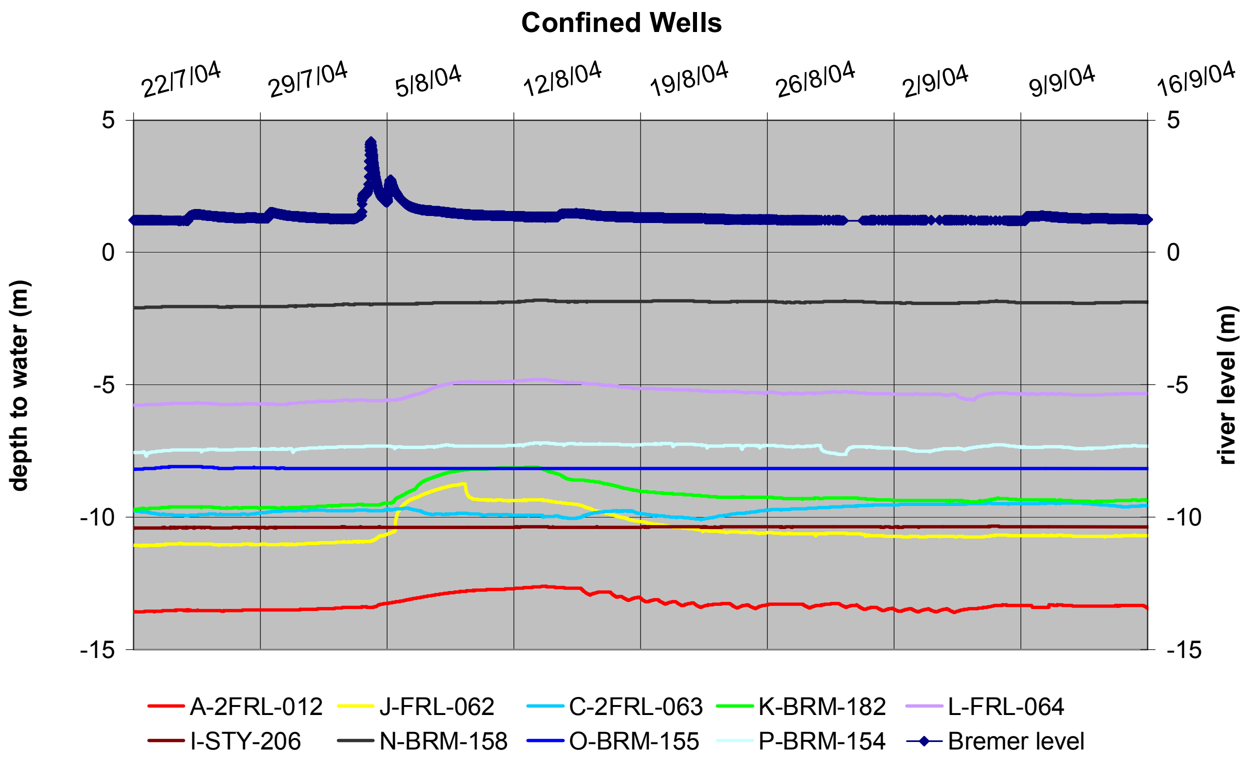


Figure 9: Confined aquifer levels and Bremer River level, August, 2004.

3.5 Unconfined aquifer

Hydrographs showing water levels within the unconfined aquifer are given in Figure 10 and Figure 11 and in Appendix A. Figures A2 and A4 plot unconfined aquifer hydrographs for winter flooding periods in 2003-4 and 2004-5 respectively. Figures A5 to A18 plot hydrographs by site from December 2002 to early 2005; unconfined aquifers are indicated by white lines.

A step pattern of watertable levels is seen at sites C, D, E, F, G and J, i.e. all wells adjacent to the Bremer excepting L (Figure 10 and Figure 11). Sites further away from the Bremer show slower, smoother and lower watertable responses. Along the Bremer, when comparing downstream site L with upstream site J, the unconfined aquifer starts to rise later at L (36 - 44 hrs), rises by a smaller amount (0.4 m less than at J) and rises at a slower rate (5-10 mm/hr at L compared with 12-30 mm/hr at J).

The watertable surface then falls by about one metre over the next month and by a total of 2.5 m (in 2003-4) or 5 m (2004-5) over 12 months (see Figures in Appendix A).

Hydrograph data was available for longer time periods at some sites (not plotted). It could be seen that in years when there is no flow in the Bremer, the surface of the unconfined aquifer falls by about one metre over 12 months. The large flood of December 1992 raised the level of the unconfined by 4 m and the level of the unconfined stayed high for 35 months after the 1992 flood. In 1992, the confined aquifer rose by about 5 m and has remained at or above that higher level ever since.

Recharge to the aquifers from the Bremer causes a mound in the water table. The height of the mound decreases almost linearly with distance from the River Bremer (or River Angas), and extends over a zone 1 600 m wide (Figure 12). The amplitude of the water level rise in the unconfined aquifer peaks beside the Bremer at 5.0 m in 2003-4 and at 3.0 m in 2004-5 and the height decreases with increasing distance from the Bremer. About 800 m to the west of the Bremer, the rise in the unconfined level has reduced to zero. This linear relationship does not hold for site C2, where the change in head is higher than expected. This is due to the fact that C2 lies close to Mosquito Creek in which the creek water levels are linked to and hence they respond quickly to changes in Bremer water levels.

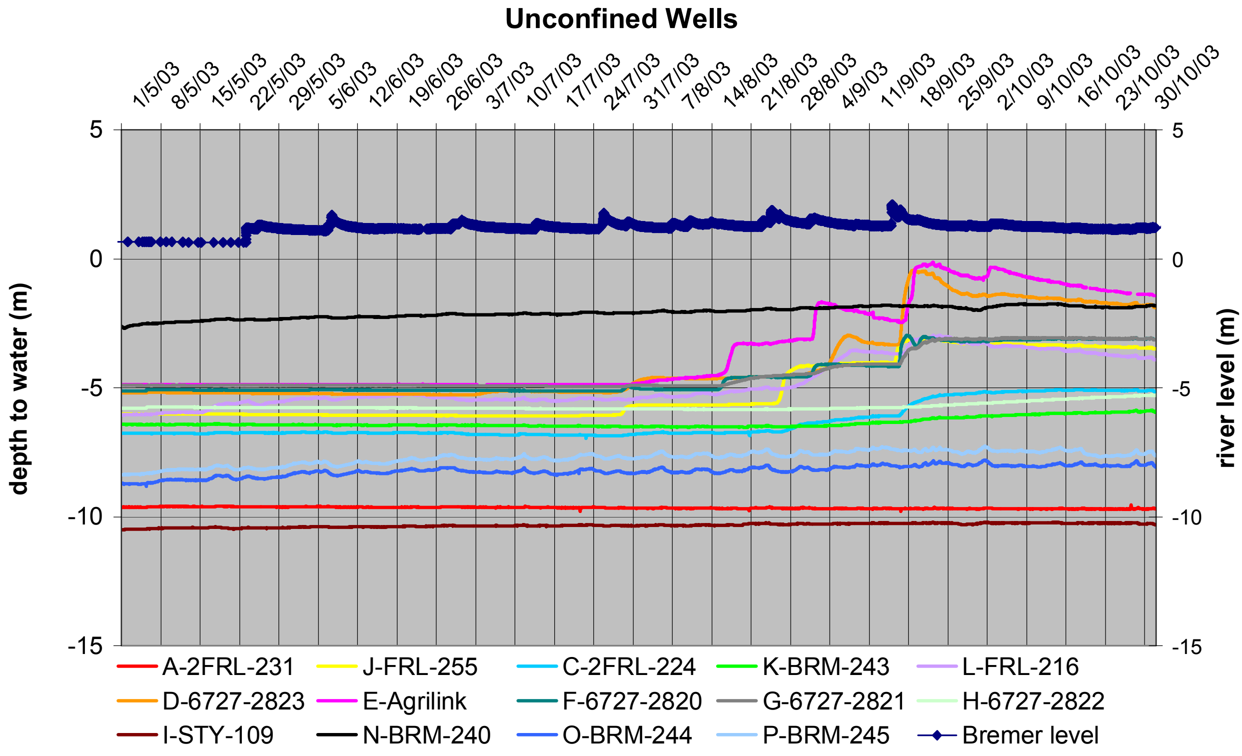


Figure 10: Unconfined aquifer levels and Bremer River level, May-November, 2003.

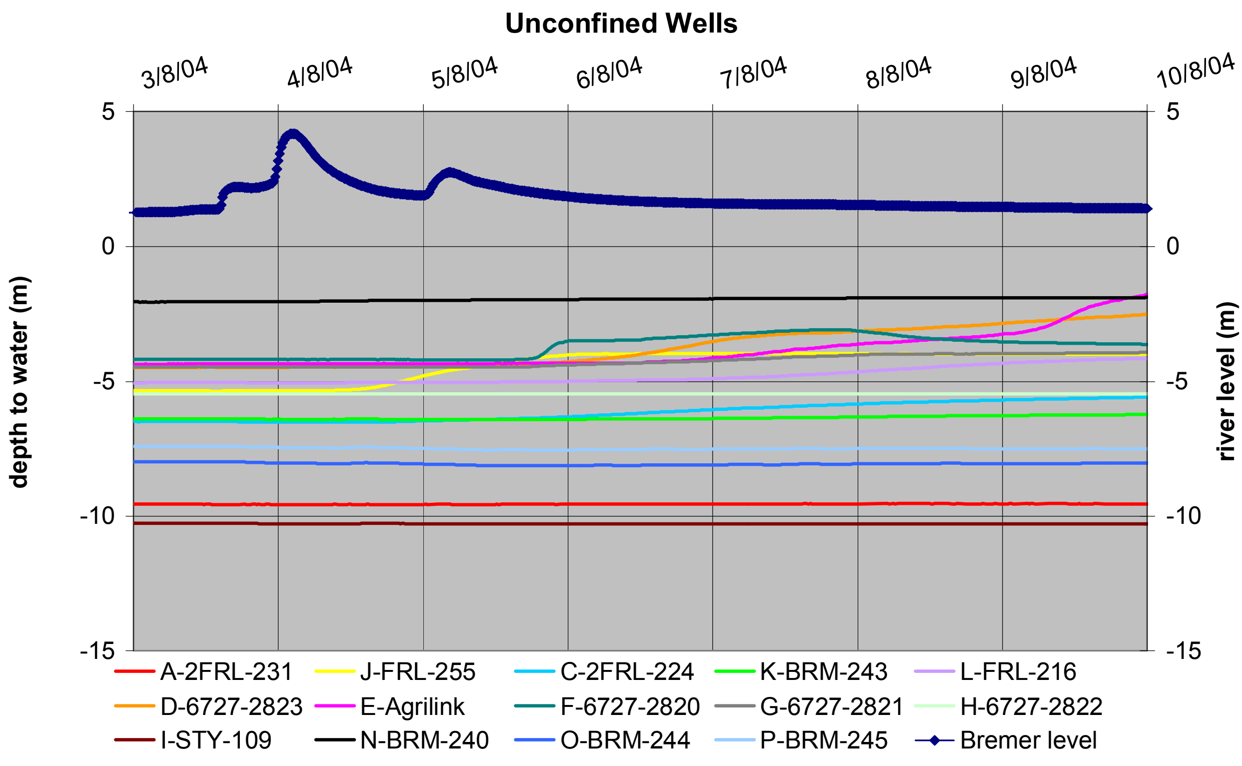


Figure 11: Unconfined aquifer levels and Bremer River level, August, 2004.

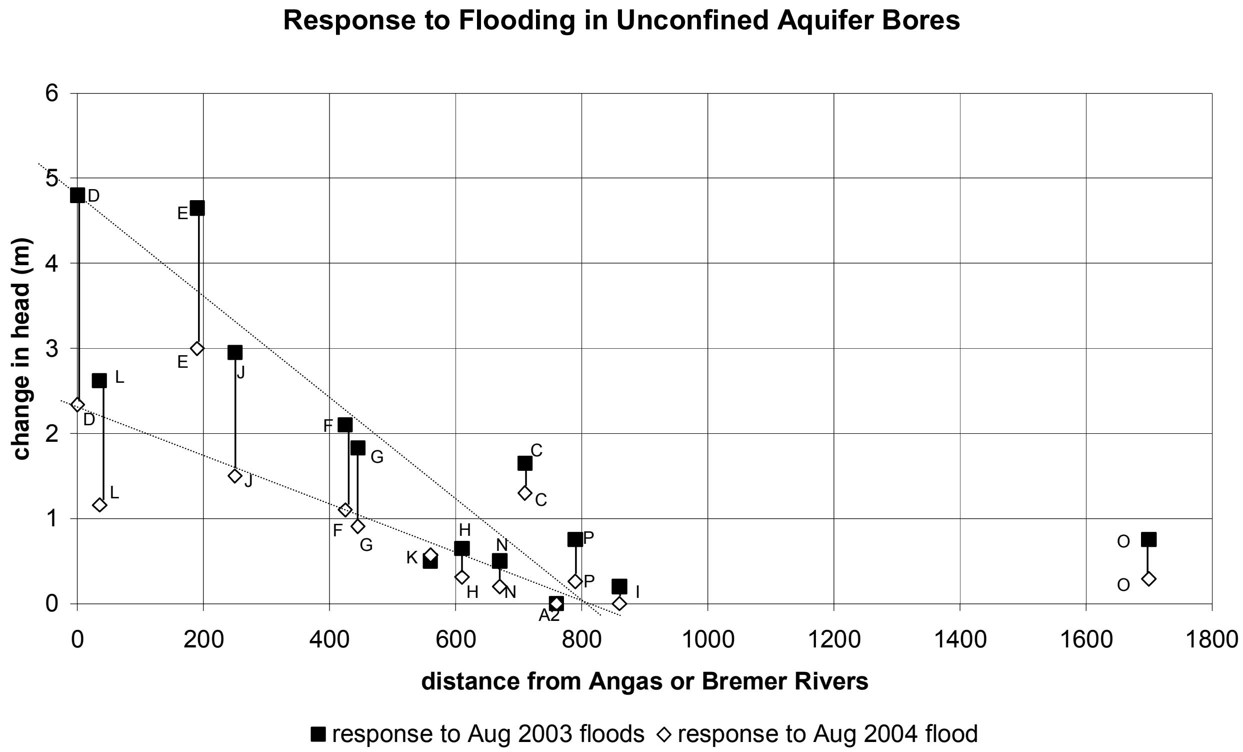


Figure 12: Unconfined aquifer head rise plotted against distance to watercourse.

3.6 Comparison between confined and unconfined aquifers

Plots comparing heads in the unconfined and confined aquifers at each site are given in Appendix A. Figures A1 and A2 show the response of all wells during the 2003 irrigation period; Figures A3 and A4 show the response of all wells during the 2004 irrigation period. Figures A5 to A18 plot well water levels by site from December 2002 to early 2005 (white lines are used for wells in the unconfined aquifer while black lines are used for wells in the confined aquifer).

It can be seen from Figures A1 to A4 that when the Bremer water level rises, water levels rise in the confined aquifer first and then in the unconfined aquifer. At sites where the water level in the unconfined aquifer increases, the rise starts between 2 and 300 hours after the water level starts to rise in the confined aquifer. As the water level in the Bremer falls, the head in the confined aquifer falls quickly (e.g. there is a fall of 1.5m over a week at sites J, K, C) but the level in the unconfined aquifer falls more slowly, gradually returning to its initial level over the following 12 months (a fall of up to 5m).

Close to the Bremer, the amplitude of the water level rise in the unconfined aquifer (3 or 5 m, depending on the year) is larger than the rise in the confined aquifer (2 m).

Based purely on comparisons of head in matched pairs of confined and unconfined observation bores, the aquitard layer separating the two aquifers appears to be present at sites A, C, J and K but not at sites I, N, O or P. Site L on the Bremer and site M on the Angas suggest weak separation between the aquifers at these locations.

At locations where there is presumably no aquitard separating the unconfined aquifer from the confined aquifer (i.e. Sites I, N, O or P), the unconfined level rises and falls almost identically with the confined levels.

At locations where the aquitard separates the unconfined aquifer from the confined aquifer (i.e. Sites A, C, J and K), water levels in the unconfined aquifer move between the same high and the same low levels. Over the 25 years for which we have records, the water level of the unconfined aquifer has not trended either upward or downward (not plotted).

3.7 Soil moisture

Plots of soil moisture at each site are given in Appendix B. The pattern of soil wetting differs in 2003-4 from 2004-5. In 2003-4, rainfall, Bremer flow, rises in the unconfined aquifer level and deep soil wetting occur over several months in a series of steps, primarily in August and September 2003. In 2004-5, watertable rises and deep soil wetting occur only once, starting with a sharp rise in Bremer River levels on 3 August 2004.

Agrilink data from site A shows that soil wetting occurs both from above, through soil infiltration, and from below, as the water level in the unconfined aquifer rises. Wetting from below is seen most clearly at M on the River Angas, where the water table reached the surface in August 2004 (Figure A16 in Appendix A).

Figure 13 and Figure 14 show the date and time when the soil moisture starts to increase at each depth and site, for the key periods of July-August 2003 and August 2004. Increases in soil moisture occur after the level rises in the Bremer at Hartley; the exception to this is at Site A in August 2004, which was irrigated using River Murray water before Bremer levels rose.

Information from Bruce Allnutt (Table 2) indicates that soil wetting often occurs *before* controlled winter flooding takes place at a site. As soil wetting at most sites usually begins within the same few days, regardless of when controlled flooding begins, this indicates that the timing of soil wetting may not be due to flooding. It may instead be due to sprinkler irrigation, as many properties draw water from the Bremer for sprinklers when the river levels first rise (Rob Giles, pers. comm.).

Infiltration rates at each of the soil moisture logger sites were calculated using the estimated time of the first increase in moisture at 0.5 m and at 3.0 m and these are shown in Figure 15. The 0.2 m records were not used because the soil often wets at 0.2 m without the water seeping below afterwards. Rates at each site vary from year to year, either due to difficulties in estimation or to the soil's response to different conditions, such as flood ponding depth and the initial level of soil moisture. Estimates range between 0.21 to 2.89 m/d (excepting two outliers of 0 and 30 m/d). The outliers are Site A in 2003-4, as no increase in soil moisture was recorded at the 3m sensor, and Site M on the Angas in 2004-5, as the watertable rapidly rose to wet the soil from below. Loggers failed at site B in 2003-4 and at site L for both study years.

These rates represent averages through the total depth of each site's soil profile, which should be more representative than rates derived for narrow layers. However, calculations of soil moisture movement from sensor to sensor provide an indication of how particular soil types affect infiltration rates. A presumed clay layer from 3-4m below the surface at Site A slows infiltration to 0.08 m/d in August 2004, while the greatest rate between sensors was recorded in August 2004 at Site C: 48 m/d in sandy loam from 1.5-2.0 m depth. Not all of the calculated rates agreed well with the available soil profile descriptions, as some of the faster rates recorded took place in clay layers. Further studies are needed to establish ways of estimating infiltration rate based on soil profile.

The maximum time for which an area should be flooded will be less than the time taken for water to infiltrate to the bottom of the root zone. Floodwaters ponded for longer than this will recharge the aquifer but be unobtainable to the plant. The maximum time will also depend on the soil type and on the initial water content of the root zone. For a root zone depth of 3m, and conditions as observed in 2003-4 and 2004-5, the time ranges from 1 to 14 days, as shown in Table 3. It is suggested that the higher river levels seen in the Bremer during 2004-5 are more typical and that the 2004-5 times should inform best practice until they can be refined by further work.

	2003-4		**2004-5**	
Site	***first flooding***	***first wetting at 0.5 m depth***	***first flooding***	***first wetting at 0.5 m depth***
A-Agrilink	17/07/2003	13/08/2003	4/08/2004	28/04/2004
B	5/09/2003		8/08/2004	5/08/2004
C1	28/07/2003	15/08/2003	4/08/2004	4/08/2004
E	23/8/03*	13/08/2003	8/08/2004	3/08/2004
J	25/08/2003	13/08/2003	4/08/2004	3/08/2004
K	17/09/2003	27/07/2003	7/08/2004	3/08/2004
L	29/08/2003		6/08/2004	3/08/2004
M	none		5/08/2004	3/08/2004

Table 2: Comparison of dates of controlled winter flooding and initial soil wetting

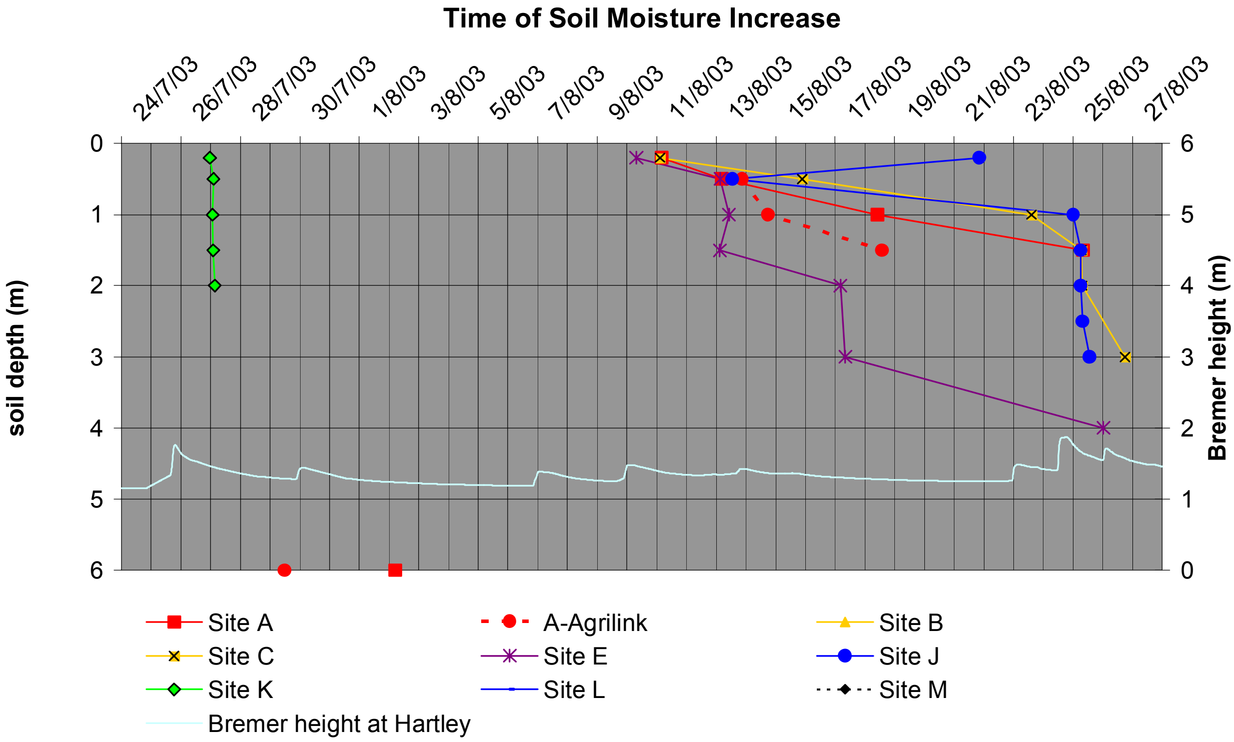


Figure 13: Time of soil moisture increase versus depth, July-August 2003.

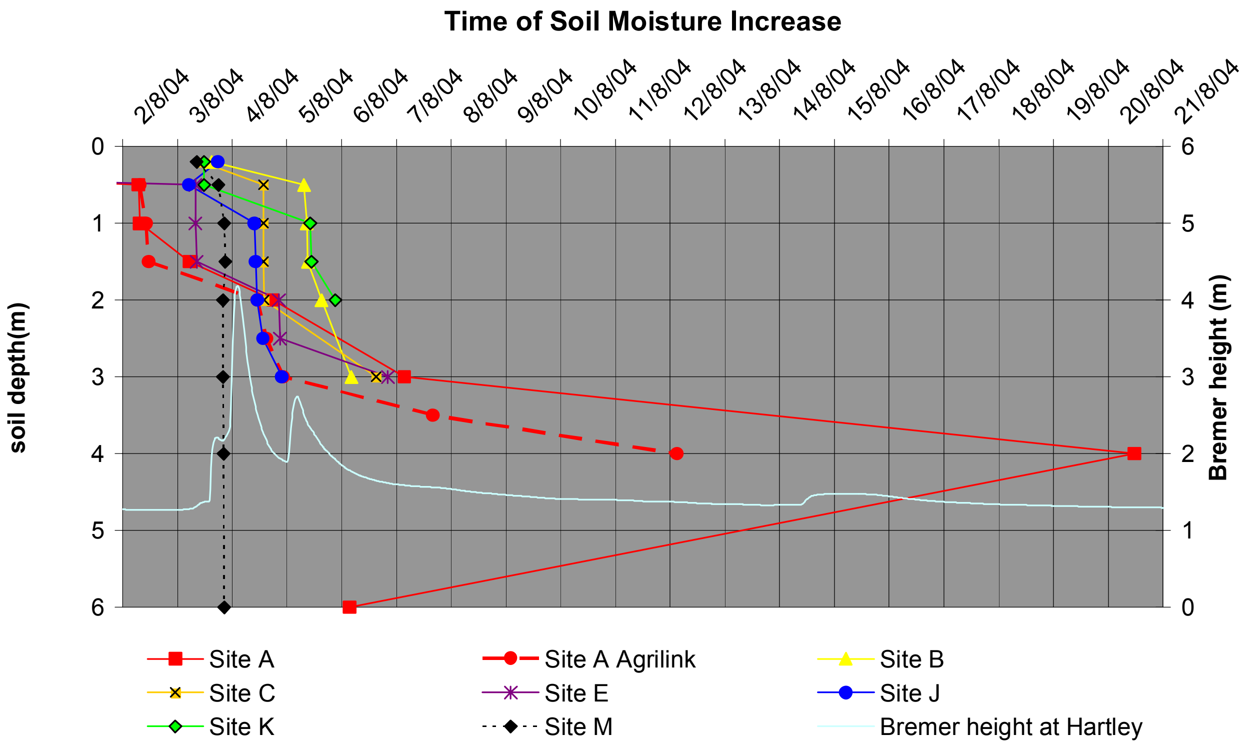


Figure 14: Time of soil moisture increase versus depth, August 2004.

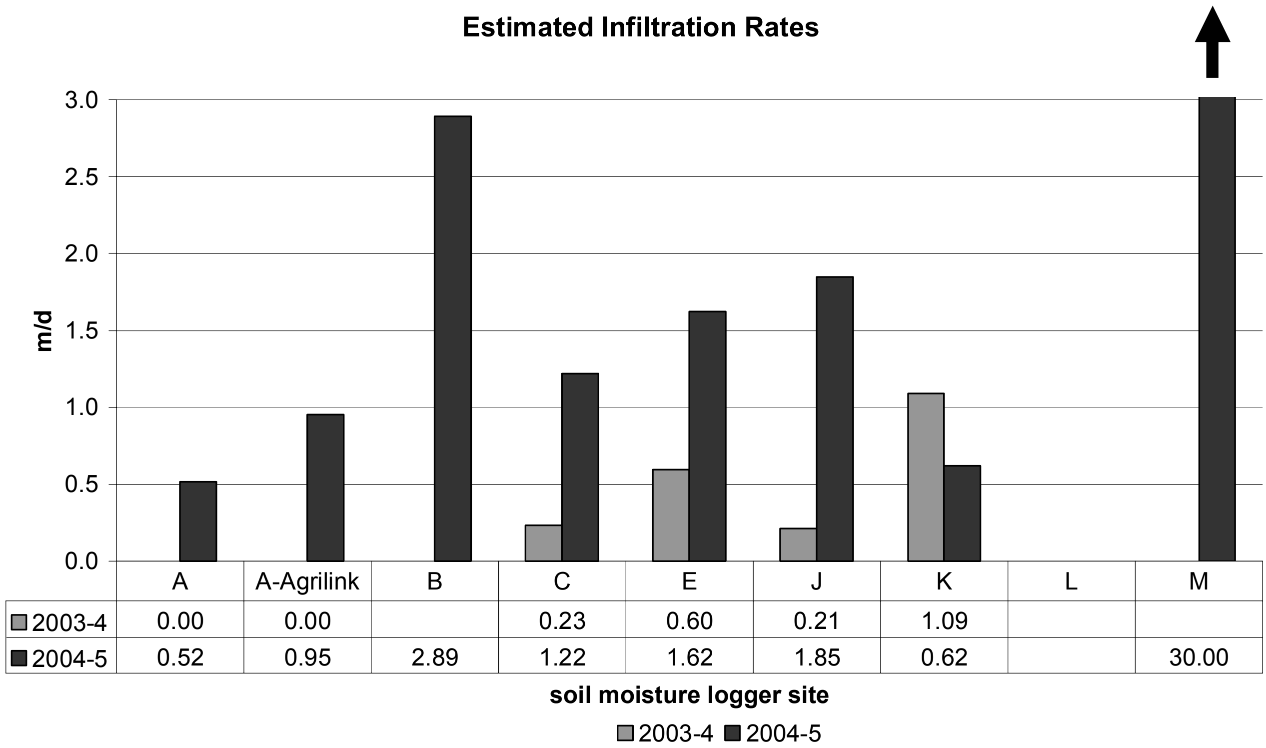


Figure 15: Speed of wetting front from 0.5-3.0m by site and year.

Site	Days until soil moisture increases at 3 m depth	
	2003-4 conditions	2004-5 conditions
A	no increase observed	5.83
A-Agrilink	no increase observed	3.16
B	no data	1.04
C	13.02	2.46
E	5.04	1.85
J	14.14	1.62
K	2.75	4.86
L	no data	no data
M	no data	wet from below

Table 3: Maximum time for ponding of floodwater.

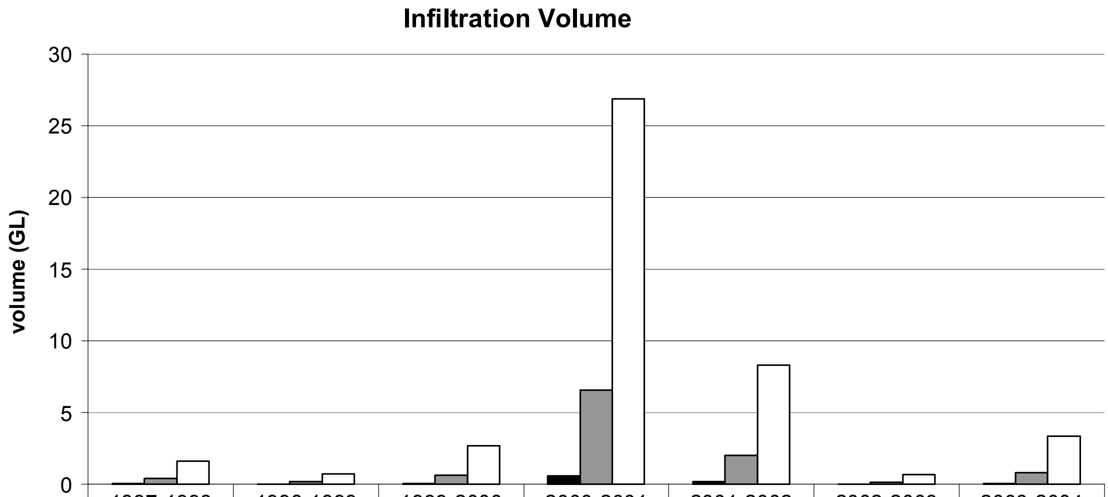
4. Infiltration volume estimation

The calculation of the ***total volume of water that reaches the unconfined aquifer due to infiltration below flooded land*** relies on estimates of three key parameters, given in Table 4. The tabulated parameters are values that have been rounded from measured extremes. The infiltration rate is estimated using the data given in Figure 15. The effective porosity and the soil retention fraction are derived from studies made at sites A, B and C as reported in Hignett (2003). Effective porosity is taken to be the difference in water cc/cc between suctions of 1 kPa and 10 kPa. Soil retention fraction is the difference in water cc/cc between suctions of 10 kPa and 1 000 kPa.

The calculated infiltration volume is the product of the infiltration rate (m/day), the effective porosity (dimensionless) and the total number of flood hectare-days (Ha-days). The estimated values for the years 1997/8 to 2003/4 are plotted in Figure 16; they vary from 0.02 to 26.89 GL, depending on the assumptions made and the number of flooding hectare-days.

Property	**Unit**	**Low infiltration case**	**Most likely infiltration case**	**High infiltration case**
Infiltration rate	m/d	0.20	1.10	3.00
Effective porosity	--	0.05	0.10	0.15
Soil retention fraction	--	0.20	0.12	0.05

Table 4: Estimated properties used for infiltration volume estimation.

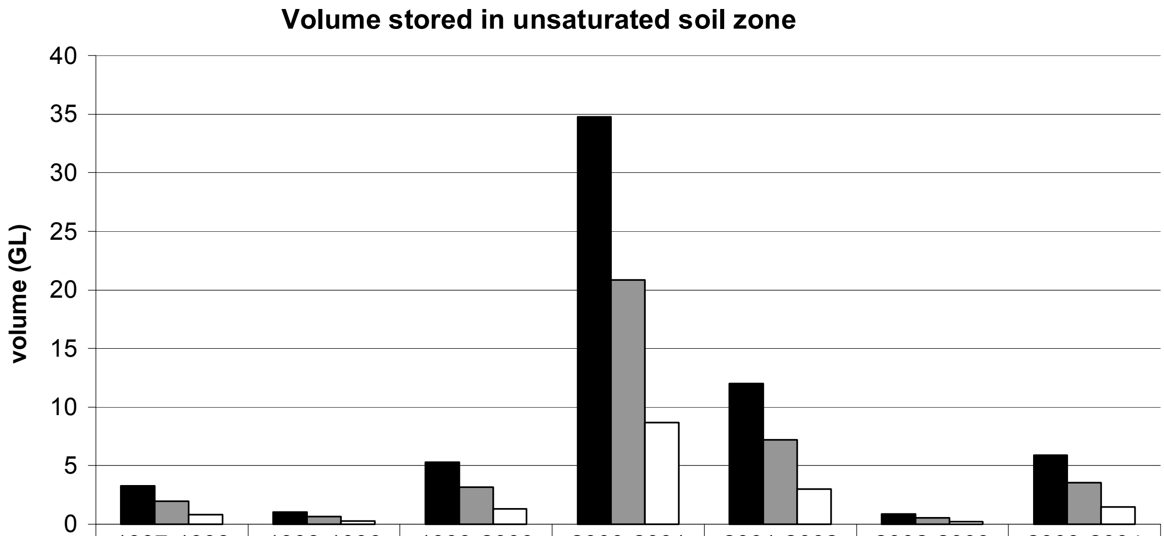


	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004
■ low infiltration	0.04	0.02	0.06	0.60	0.18	0.02	0.08
▒ most probable	0.40	0.17	0.66	6.57	2.03	0.17	0.83
□ high infiltration	1.62	0.71	2.72	26.89	8.31	0.70	3.38

year

■ low infiltration ▒ most probable □ high infiltration

Figure 16: Infiltration volume

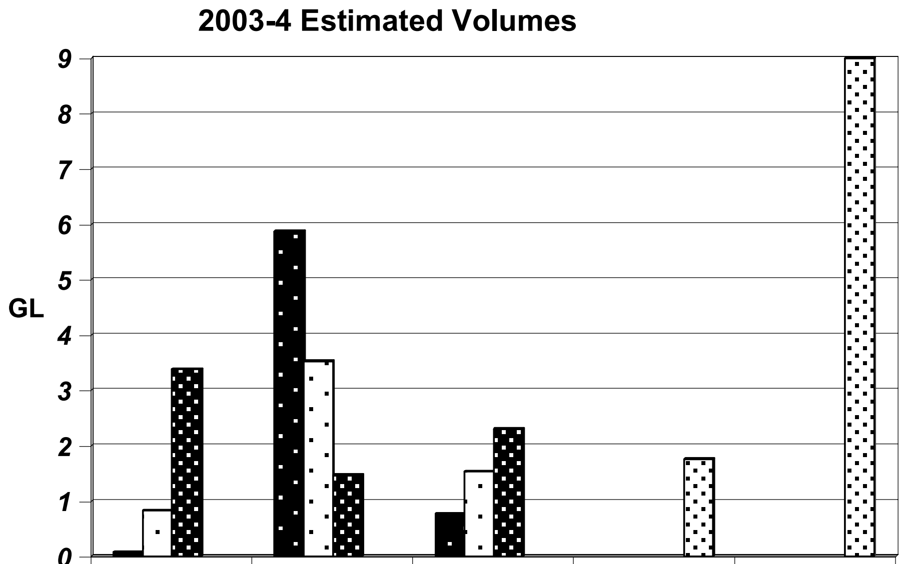


	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004
low infiltration	3.30	1.06	5.29	34.74	11.99	0.86	5.87
most probable	1.98	0.64	3.17	20.84	7.19	0.52	3.52
high infiltration	0.82	0.27	1.32	8.69	3.00	0.22	1.47

Figure 17: Maximum volume stored in the unsaturated zone of the soil.

The ***maximum volume that can be stored below flooded areas and above the watertable in the unsaturated zone soils*** is also estimated. This storage volume is the product of the soil retention fraction, an assumed depth to water of 5 m, and the total number of flooded hectares. The storage volume is plotted in Figure 17 and ranges from 0.22 to 34.74 GL depending upon the assumptions and the year.

Water can also move into the unconfined aquifer laterally from the flooding rivers, as well as vertically as infiltration below the flooded land.. The combined, total impact of both lateral and vertical recharge processes can be estimated by calculating ***the additional volume observed in the unconfined aquifer after a flood***. As seen in Figure 12, the rise in head at the river during 2003-4 was approximately 4.8 m and this decreased almost linearly with distance in a region 800 m to each side of the Bremer. Assuming that this rise is observed over the roughly 4 km stretch where controlled winter flooding is recorded, the additional volume is then 0.5 x 1600 m x 4.8 m x 4000m x effective porosity, where the effective porosity is assumed to range from 0.05 to 0.15. This yields a total volume increase in that area of 0.77 to 2.3 GL, depending on the porosity chosen. (Flooding at the Angas River is not included as most of the controlled winter flooding occurs on the Bremer.)



	infiltration	max storage	overall aquifer increase	rainfall	Bremer flow
low infiltration	0.08	5.87	0.768		
most probable	0.83	3.52	1.536		
high infiltration	3.38	1.47	2.304		
all				1.76	9

Figure 18: Estimated volumes for 2003-4 for the 4 x 1.6 km region of controlled winter flooding adjacent to the River Bremer.

The various volume estimates for 2003-4 in this 4 km x 1.6 km region are plotted in Figure 18 along with cumulative flow in the Bremer and an estimate of rainfall. The low-infiltration case suggests that vertical infiltration through the floodplain (0.1 GL) is an eighth of the total increase in aquifer volume (0.8 GL); i.e. that most of the aquifer recharge occurs through lateral movement from the Bremer. The "most probable" case suggests that vertical infiltration (0.8 GL) accounts for slightly more than half the overall increase in aquifer volume (1.5 GL). The high-infiltration case may over-estimate the vertical infiltration volume (3.3 GL) as it is greater than the estimated total increase in aquifer volume (2.3 GL). All volume estimates are less than the total flow in the Bremer, as would be expected.

5. Conclusions

Based on analysis of the available data as detailed in this report, the following conclusions can be made:

- The area of land covered by the floods during the period 1998/99 to 2003/04 varied enormously from 86 ha in 2002/03 to 3 474 ha in 2000/01. The area flooded is generally determined by the volume of flow in the Bremer River, and presumably the Angas River.
- The area flooded (ha) multiplied by the days of flooding on each property is summed over all properties to provide a unit (ha.days) for analysis of this data. This parameter ranges from 155 ha.days for the 2002/03 flood to 5 976 ha.days for the 2000/01 flood.
- Based on the soil moisture logger data and on the number of flooded hectares, estimates of the infiltration (or recharge) volume to the unconfined aquifer during the 2003/04 flood range from 0.08 GL to 3.38 GL, depending on the parameter values assumed for infiltration rate and for porosity. Average parameter values result in an estimate of 0.83 GL.
- An alternative method of calculating the flood recharge volume to the unconfined aquifer is though analysis of the locations and magnitudes of unconfined aquifer hydrograph responses. This method provides an estimated recharge volume from the 2003/04 flood of 0.77 GL to 2.30 GL, depending on assumed aquifer porosity.
- The above supports the conclusion that a flood recharge volume of 1 to 2 GL occurs under the conditions seen in 2003/04, although it is expected that this value will vary greatly depending on the number of ha.days, on the flood characteristics and on the assumed porosity values for both the unsaturated zone and the unconfined aquifer.
- the fraction of the flood-recharge that infiltrates down through the soil that is directly below the flooded land is estimated to be 10 to 54% of the total flood recharge.
- Additional monitoring during future flood events is required to determine the relationship between flood characteristics and estimated recharge volume.
- Estimates have been made of the maximum time for which flood water should be ponded on an area (defined as the time taken for water to infiltrate to the bottom of the root zone) and this will depend on the soil type and initial water content of the root zone. For a root zone depth of 3m, and the conditions as observed in 2002-3 and 2003-4, the ponding time ranges from 1 to 14 days.

6. References

Australian Water Environments (2005). *Angas Bremer Prescribed Wells Area Hydrogeological Review and Investigations – Phase II.* Report for River Murray Catchment Water Management Board, 2005.

Hignett, Cliff (2003). *Soil Physics of the Angas-Bremer Catchment.* Soil Water Solutions, April 2003.

Appendix A

Site hydrographs

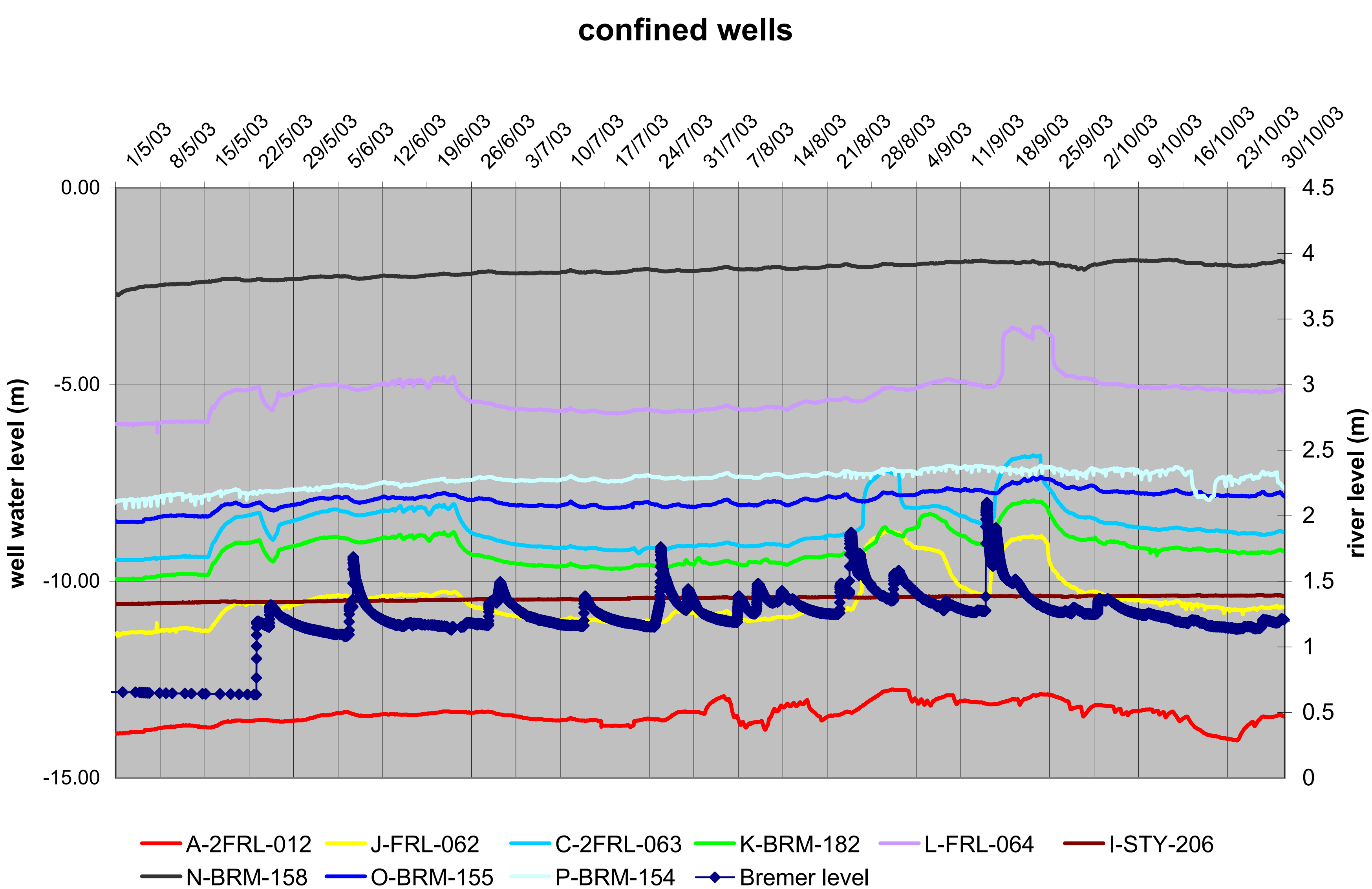

confined wells
1/5/03
8/5/03
15/5/03
22/5/03
29/5/03
5/6/03
12/6/03
19/6/03
26/6/03
3/7/03
10/7/03
17/7/03
24/7/03
31/7/03
7/8/03
14/8/03
21/8/03
28/8/03
4/9/03
11/9/03
18/9/03
25/9/03
2/10/03
9/10/03
16/10/03
23/10/03
30/10/03
well water level (m)
0.00
-5.00
-10.00
-15.00
river level (m)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
A-2FRL-012
J-FRL-062
C-2FRL-063
K-BRM-182
L-FRL-064
I-STY-206
N-BRM-158
O-BRM-155
P-BRM-154
Bremer level

Figure A-02

unconfined wells

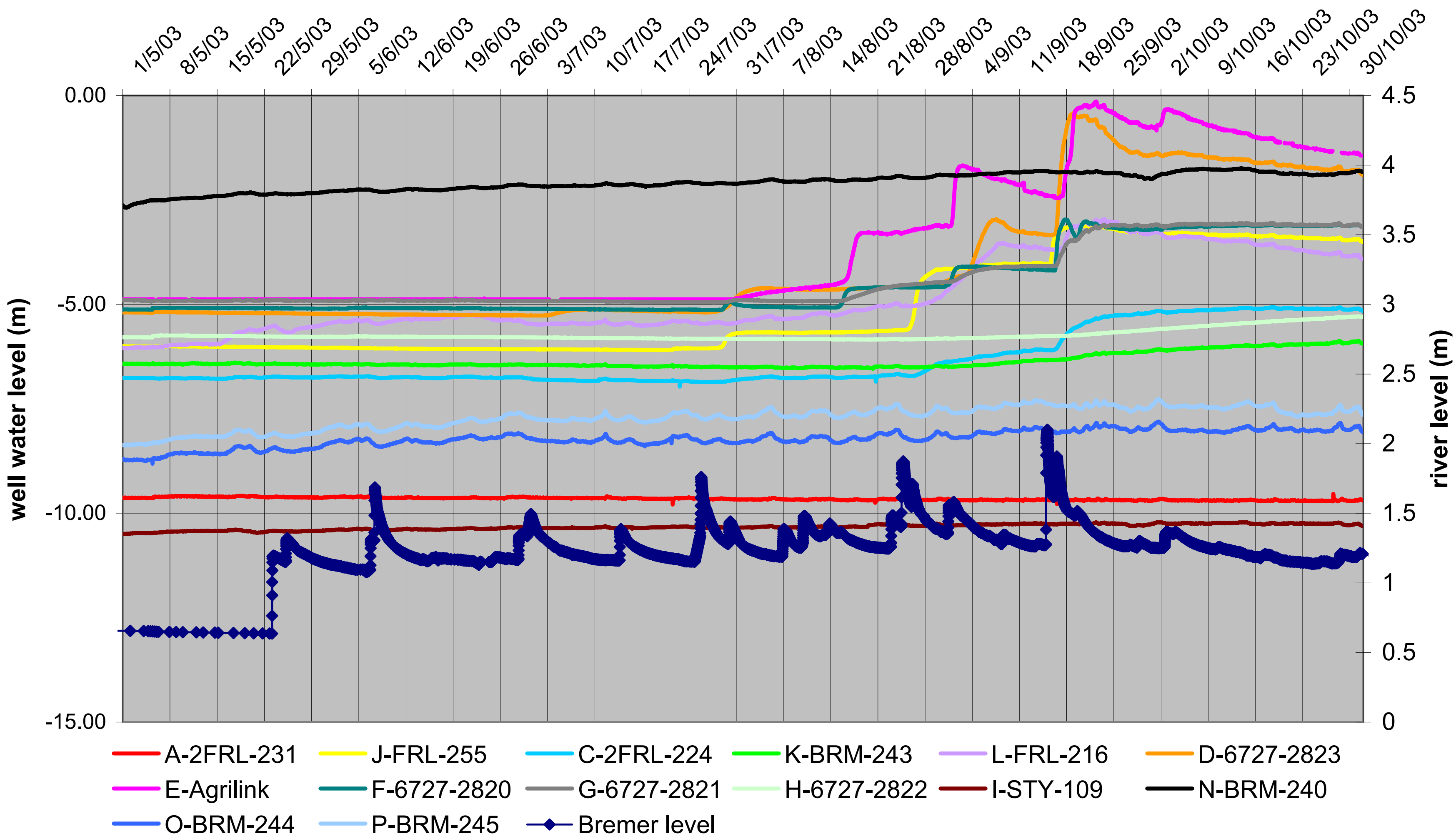
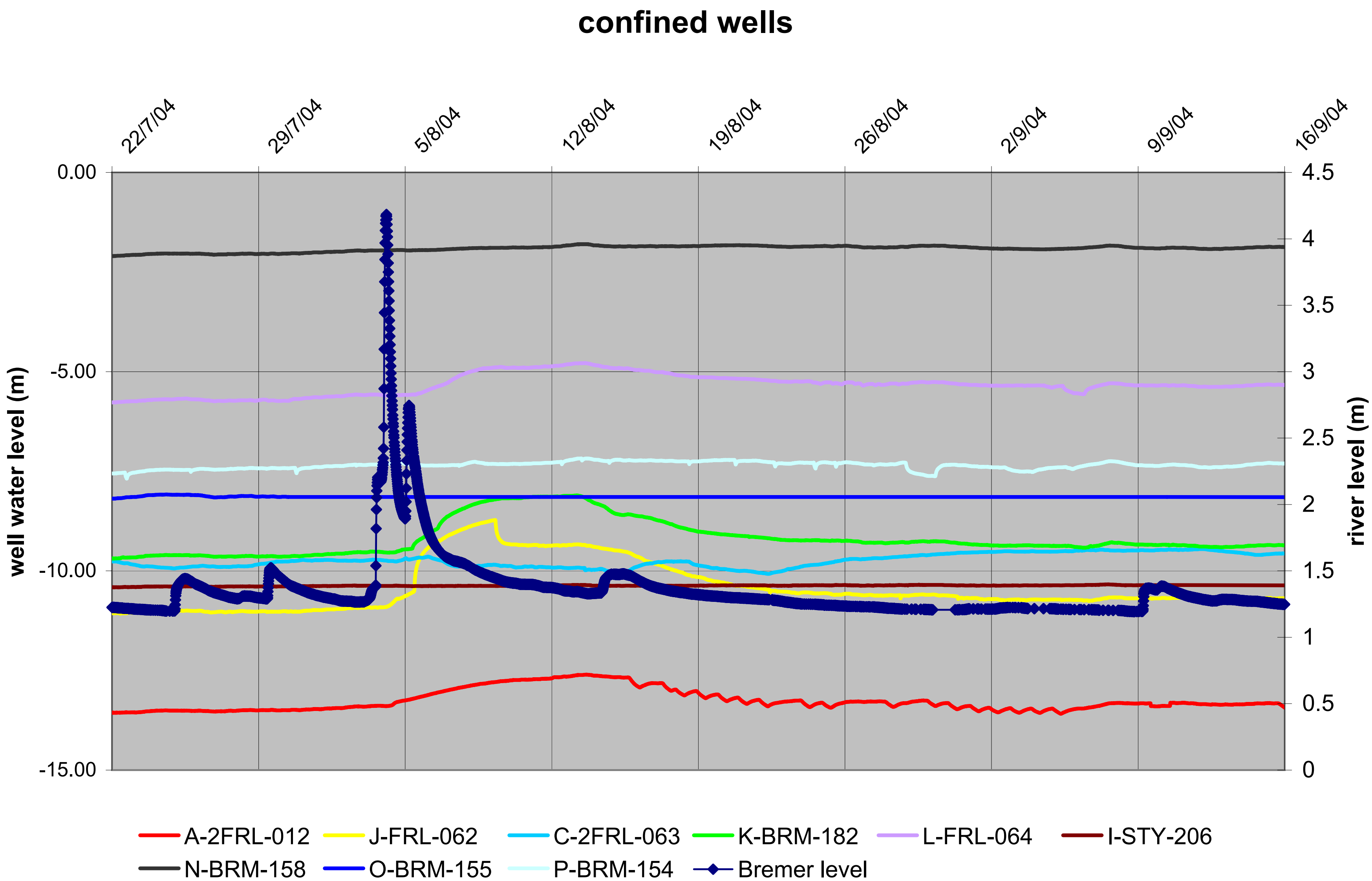


Figure A-03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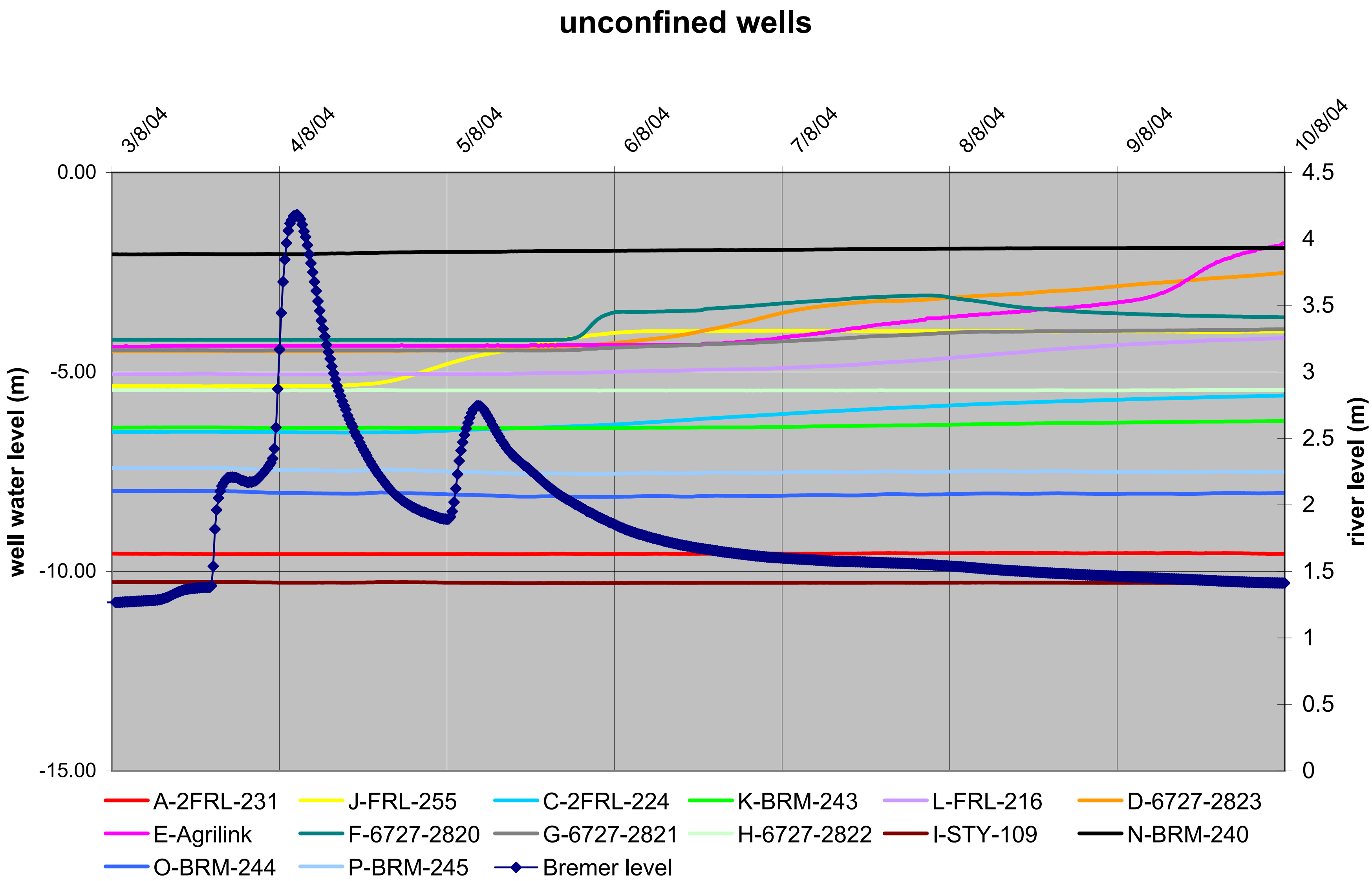
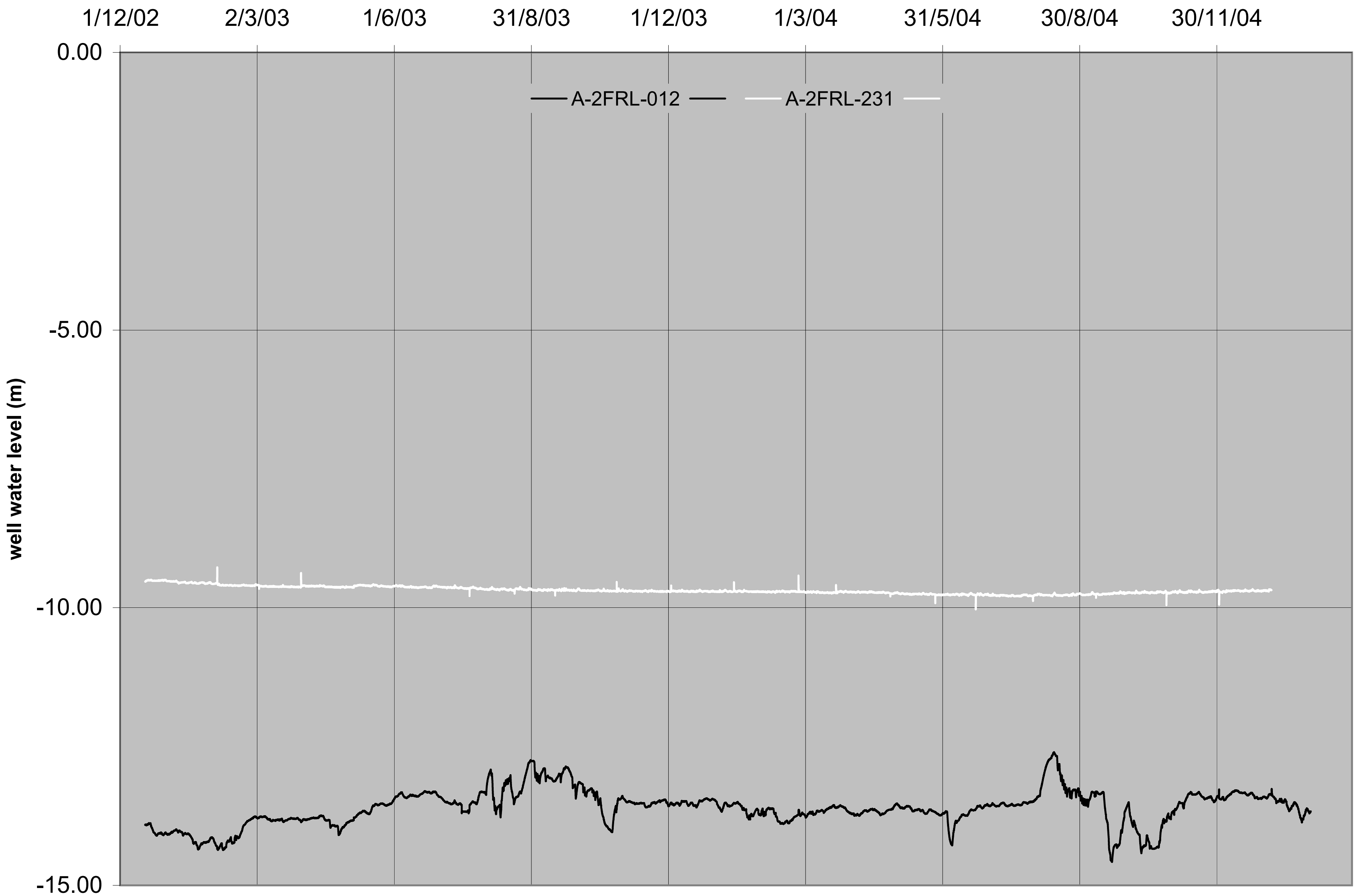
29/7/04
5/8/04
12/8/04
19/8/04
26/8/04
2/9/04
9/9/04
16/9/04
0.00
-5.00
-10.00
-15.00
well water level (m)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
river level (m)
A-2FRL-012
J-FRL-062
C-2FRL-063
K-BRM-182
L-FRL-064
I-STY-206
N-BRM-158
O-BRM-155
P-BRM-154
Bremer level

Figure A-04



unconfined wells
3/8/04
4/8/04
5/8/04
6/8/04
7/8/04
8/8/04
9/8/04
10/8/04
0.00
-5.00
-10.00
-15.00
well water level (m)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
river level (m)
A-2FRL-231
J-FRL-255
C-2FRL-224
K-BRM-243
L-FRL-216
D-6727-2823
E-Agrilink
F-6727-2820
G-6727-2821
H-6727-2822
I-STY-109
N-BRM-240
O-BRM-244
P-BRM-245
Bremer level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2/3/03
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1/12/03
1/3/04
31/5/04
30/8/04
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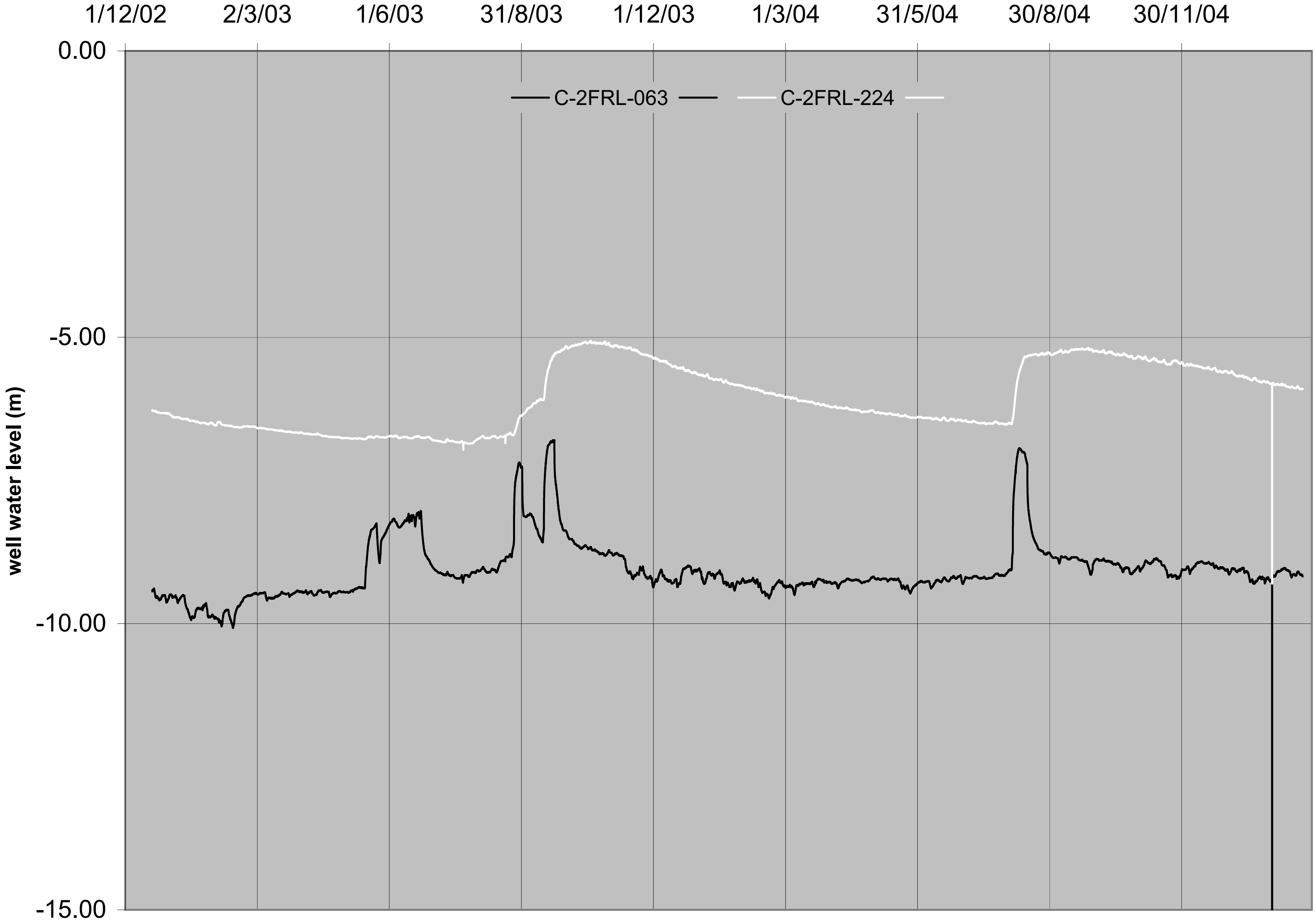
-5.00
-10.00
-15.00
well water level (m)
A-2FRL-012
A-2FRL-231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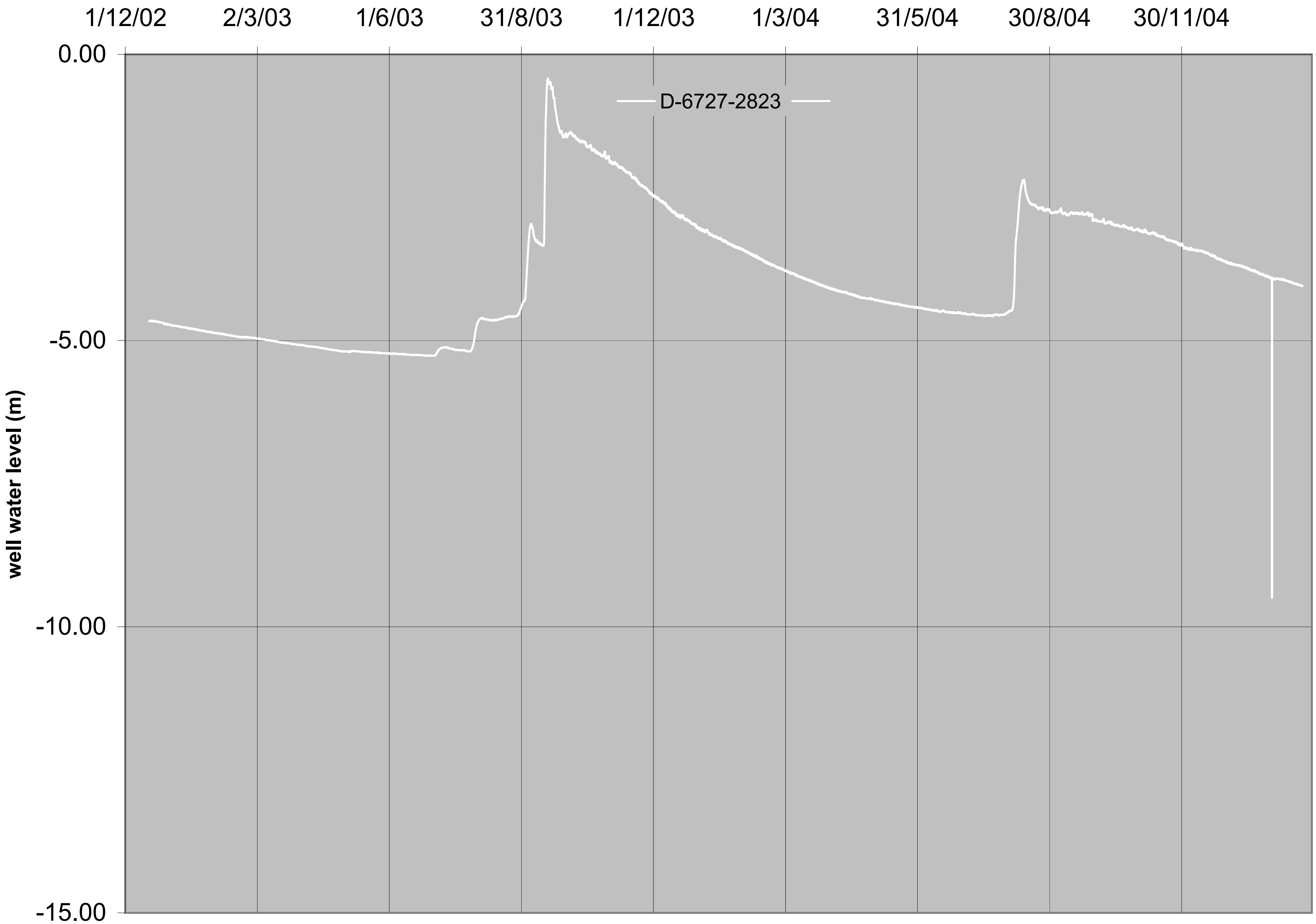
-5.00
-10.00
-15.00
well water level (m)
C-2FRL-063
C-2FRL-224

Figure A-07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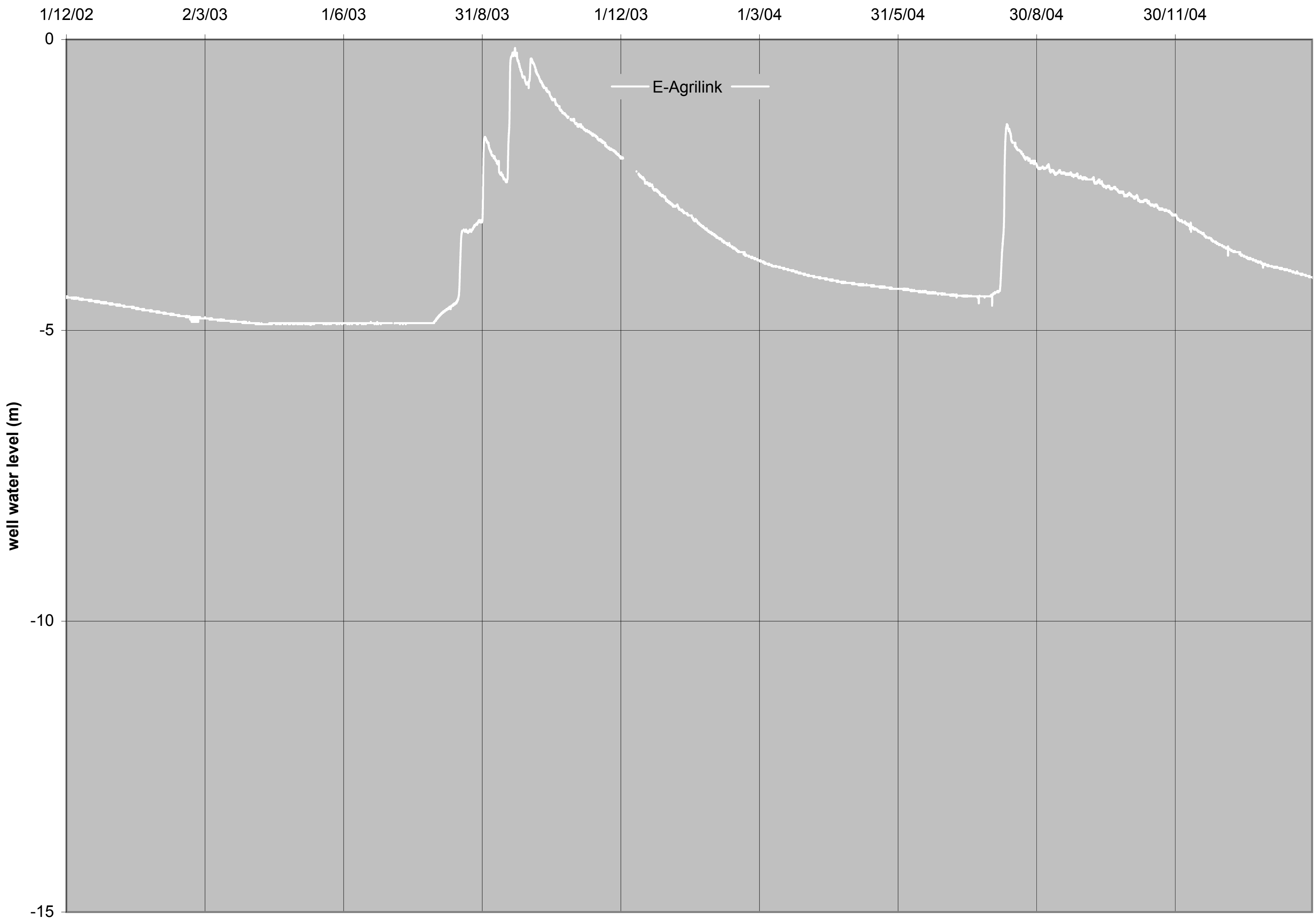
well water level (m)
D-6727-2823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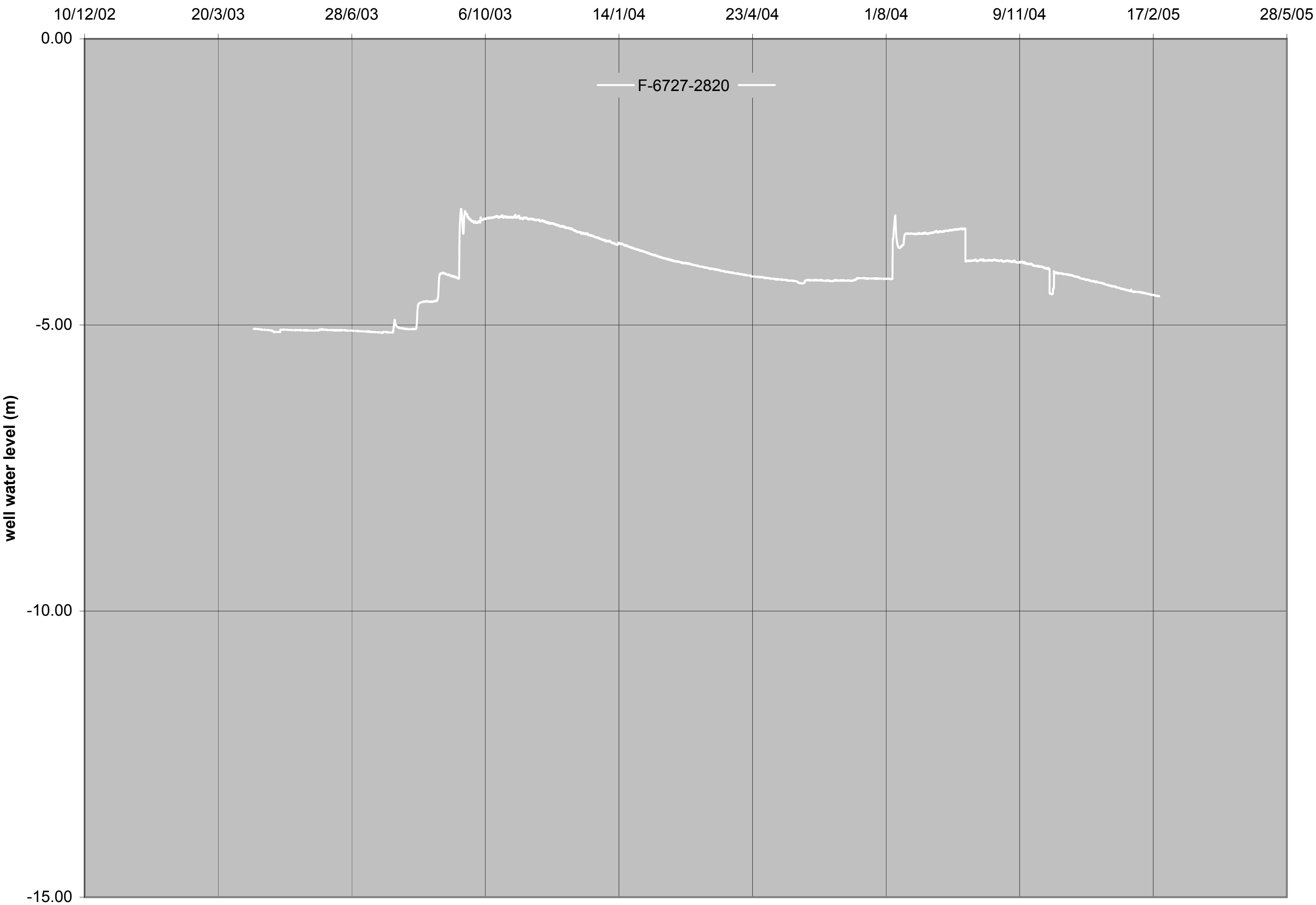
well water level (m)
E-Agrilink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28/5/05
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-5.00
-10.00
-15.00
well water level (m)
F-6727-2820


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31/8/03
1/12/03
1/3/04
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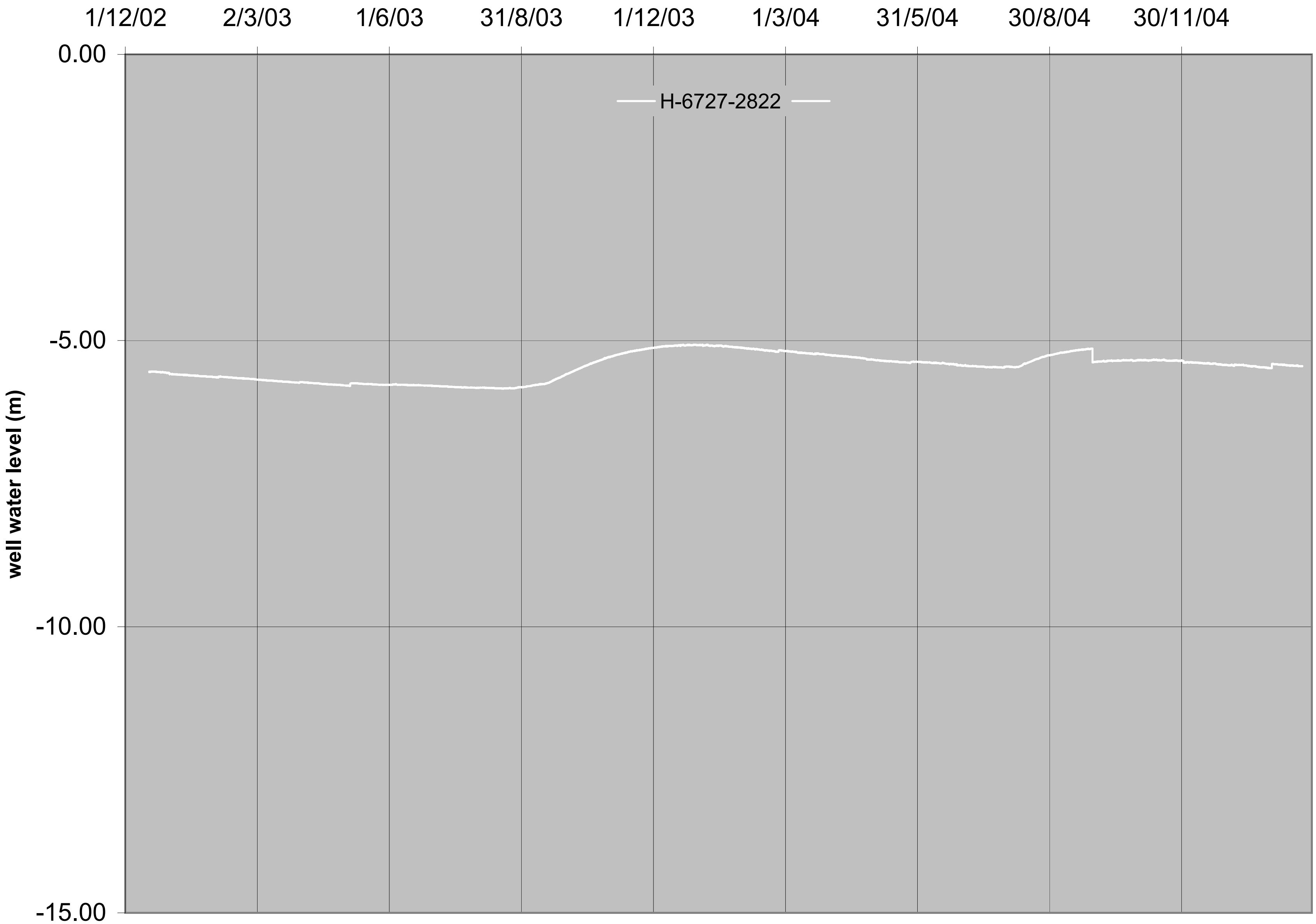
well water level (m)
G-6727-2821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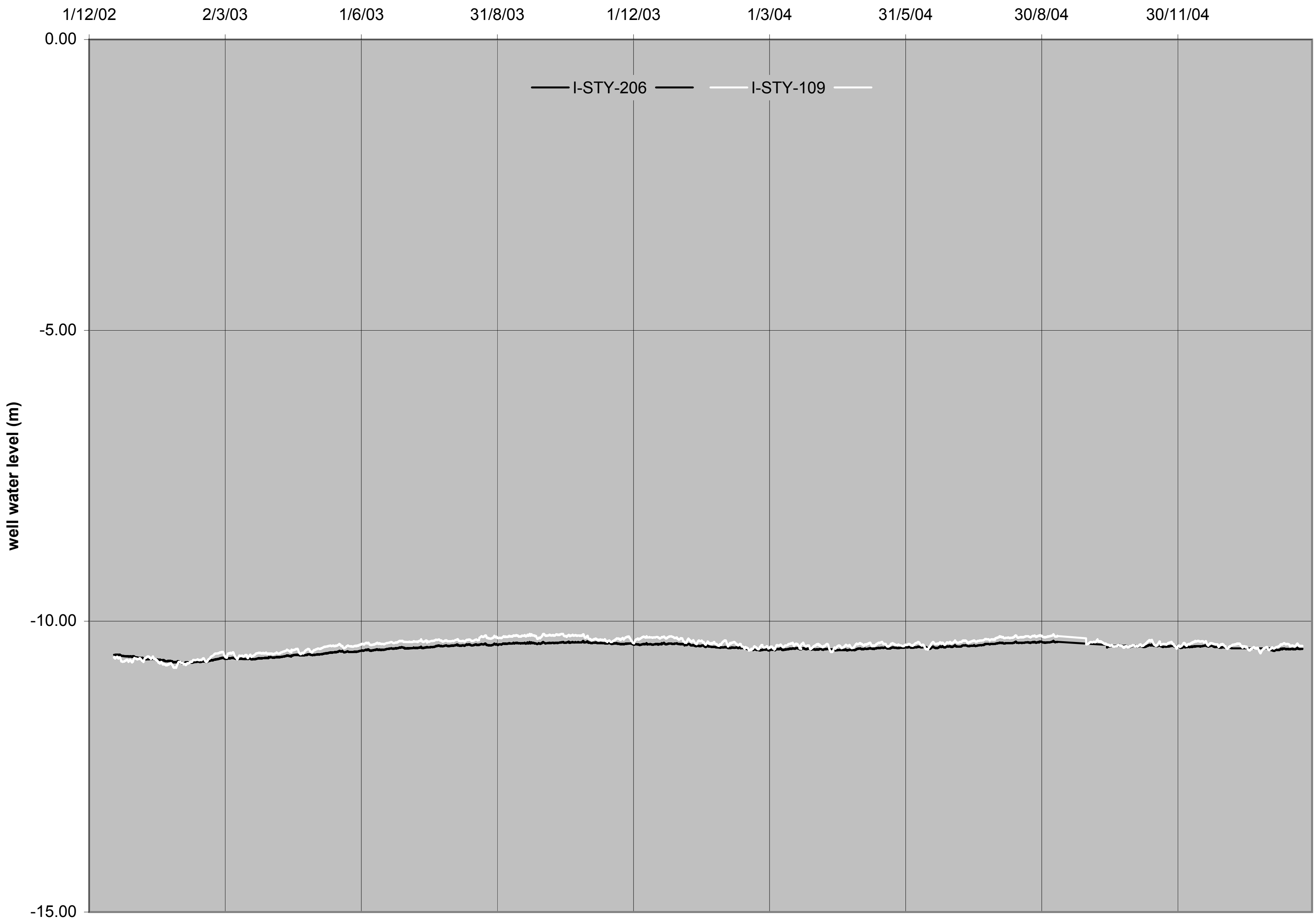
well water level (m)
H-6727-2822

Figure A-12



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31/8/03
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well water level (m)
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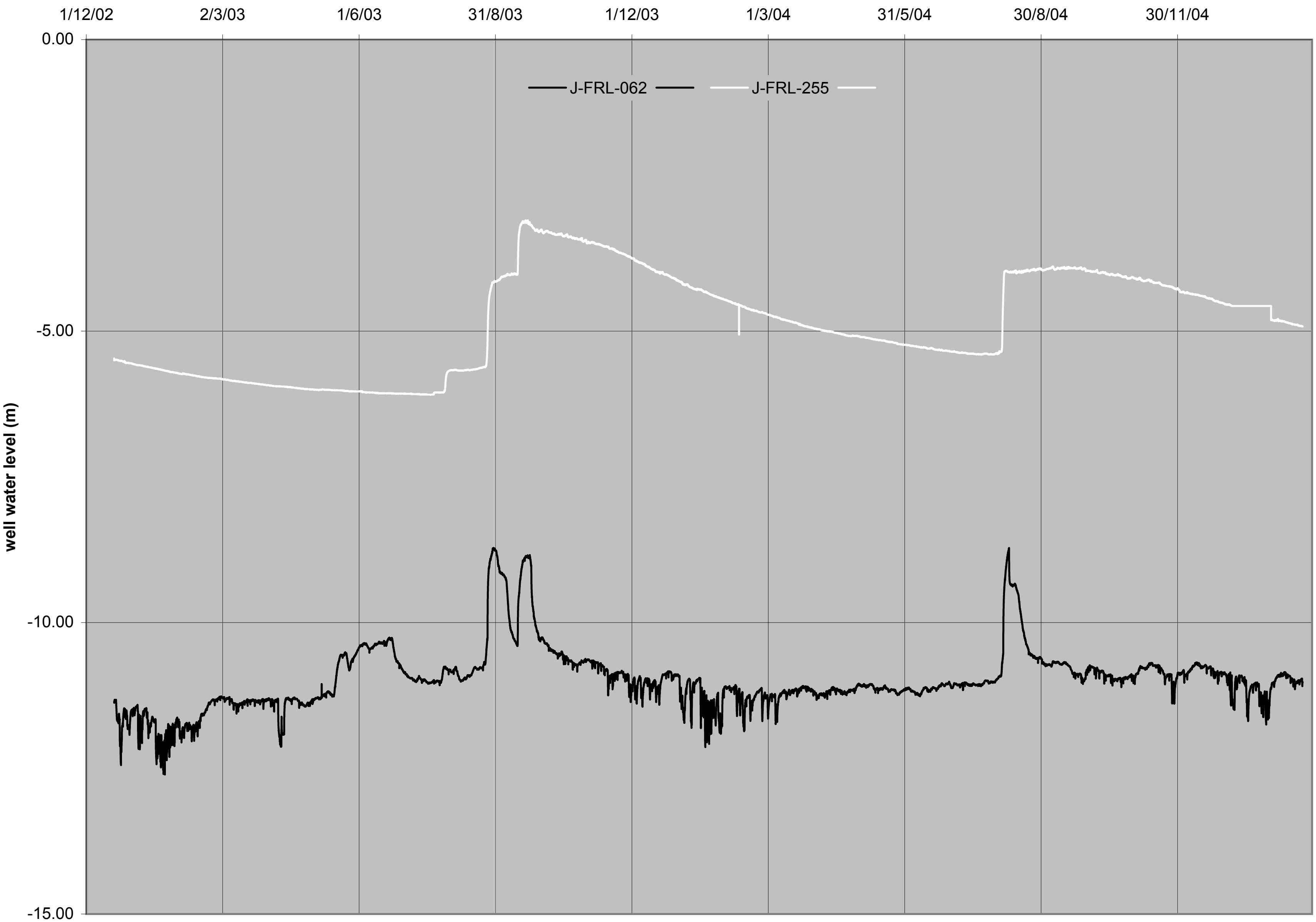
I-STY-109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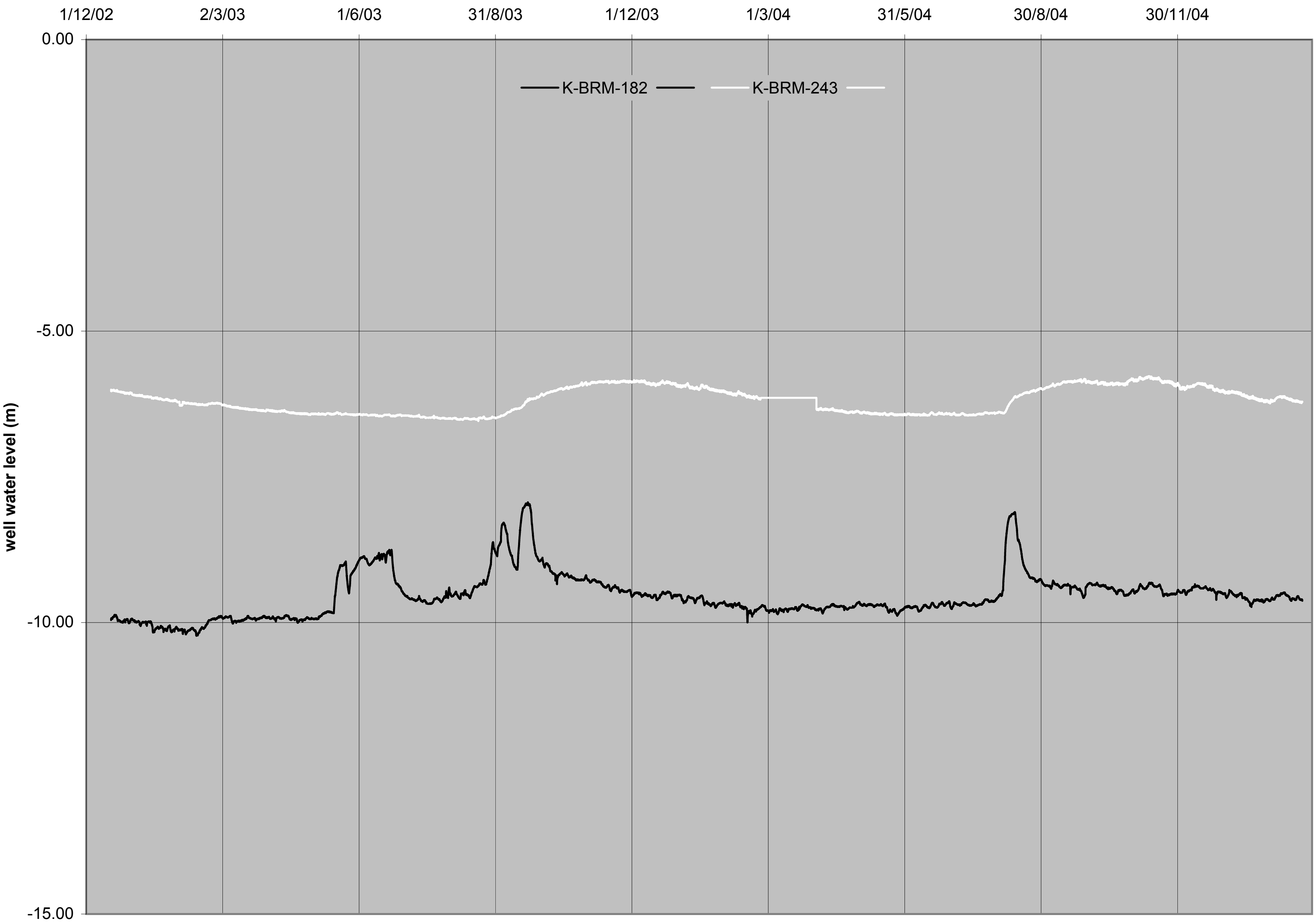
J-FRL-255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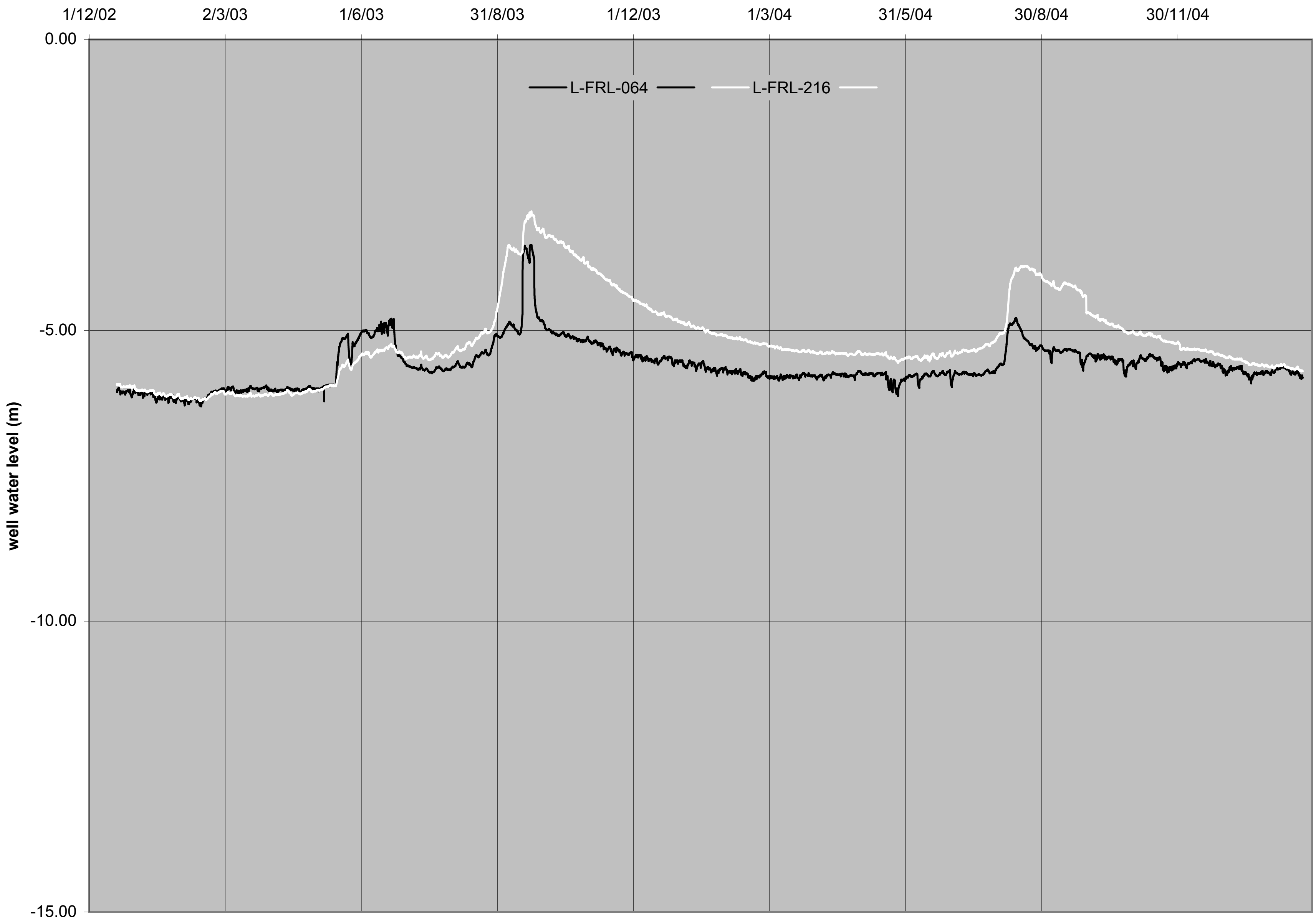
K-BRM-243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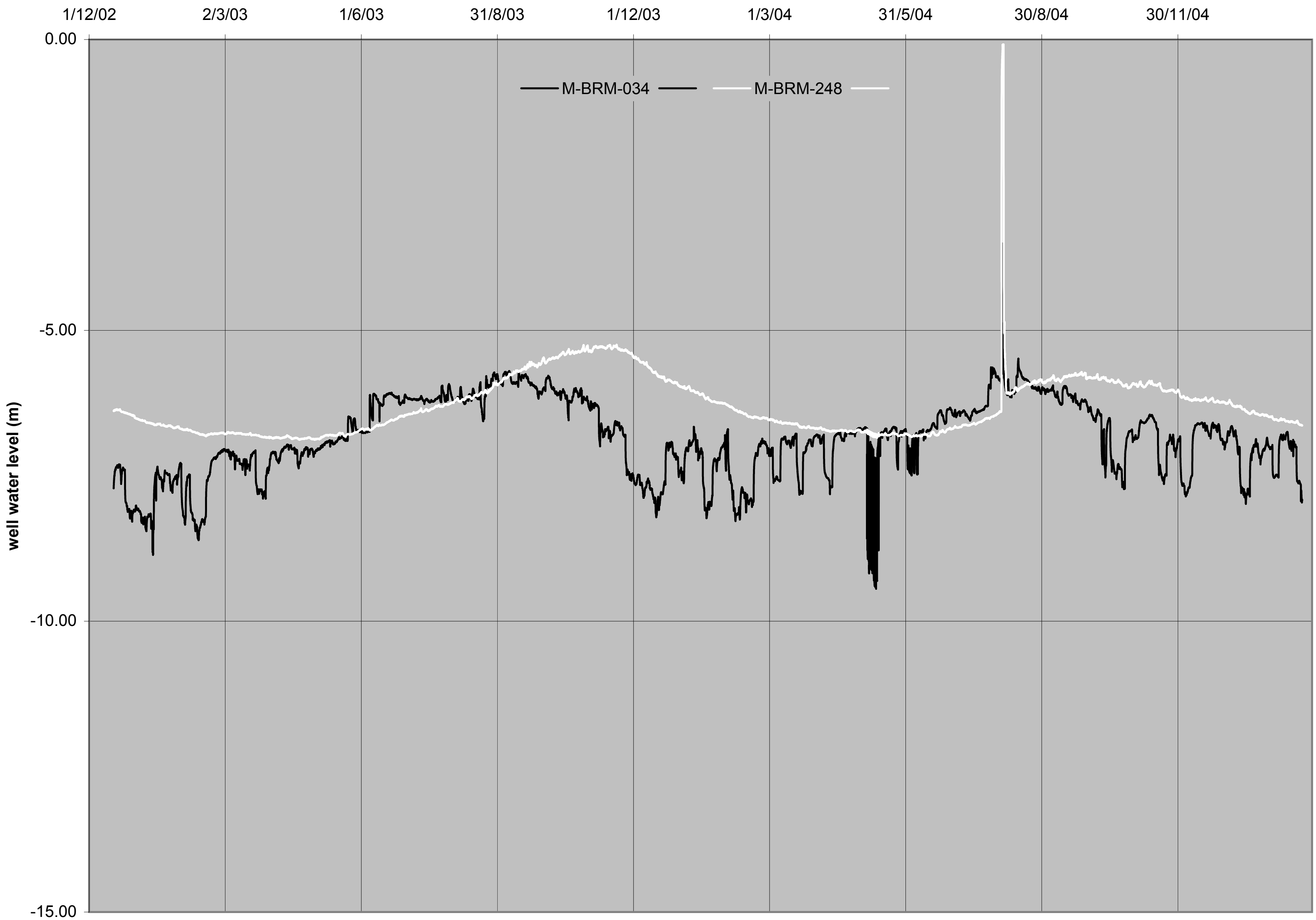
L-FRL-216

Figure A-16



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1/3/04
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30/8/04
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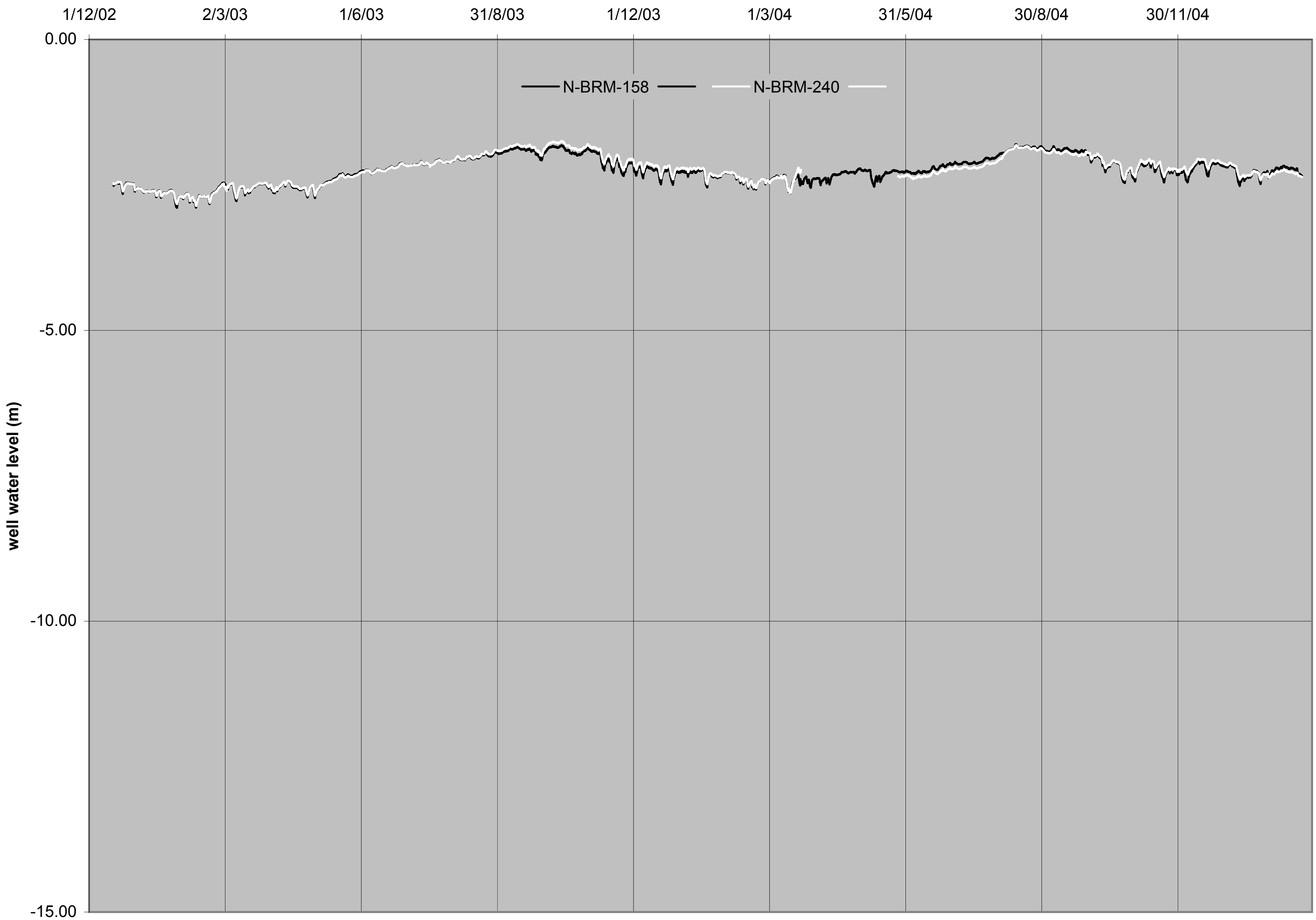
Figure A-17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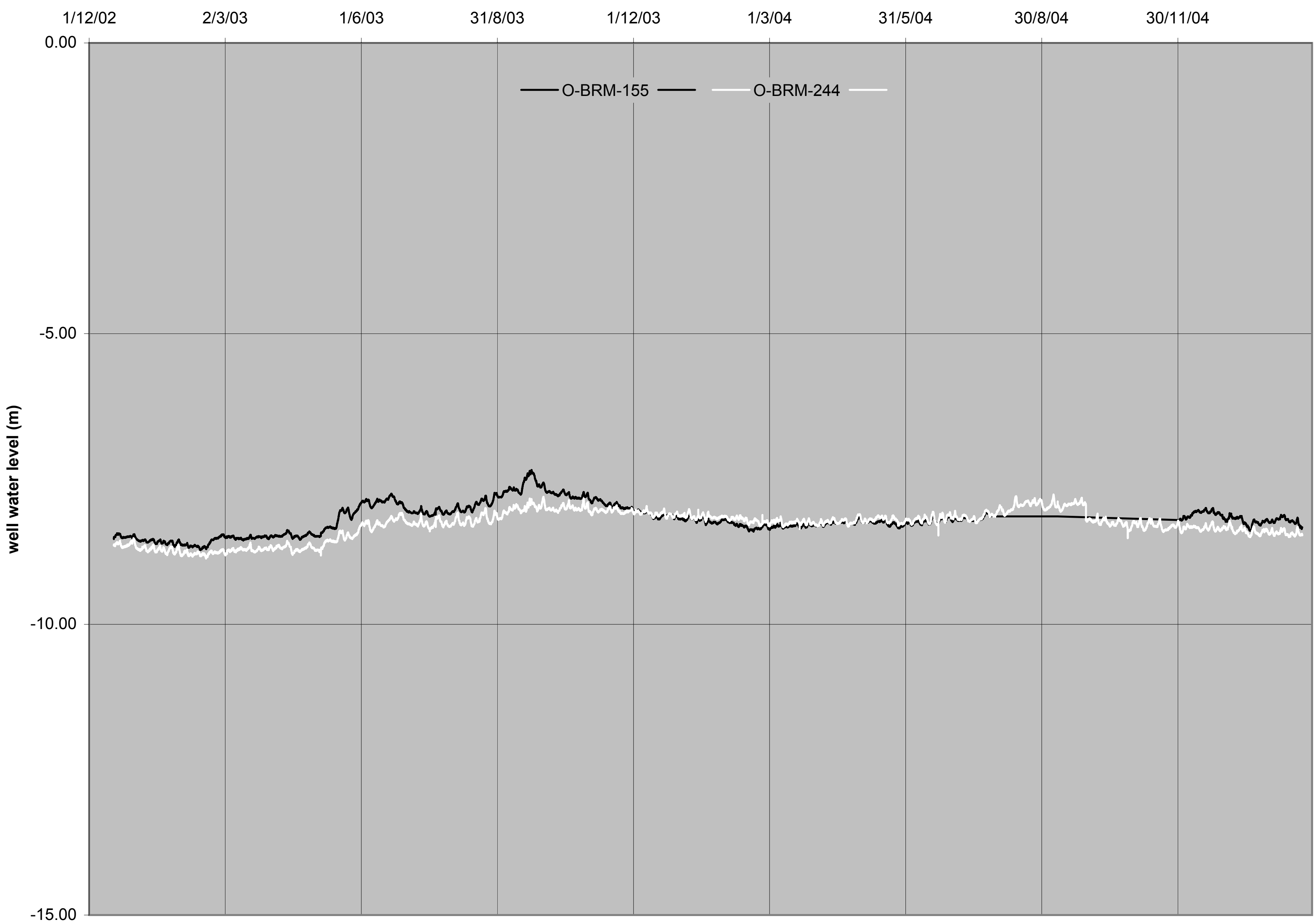
N-BRM-240

Figure A-18



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2/3/03
1/6/03
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1/12/03
1/3/04
31/5/04
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30/11/04
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-15.00
well water level (m)
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O-BRM-244

Appendix B

Soil moisture

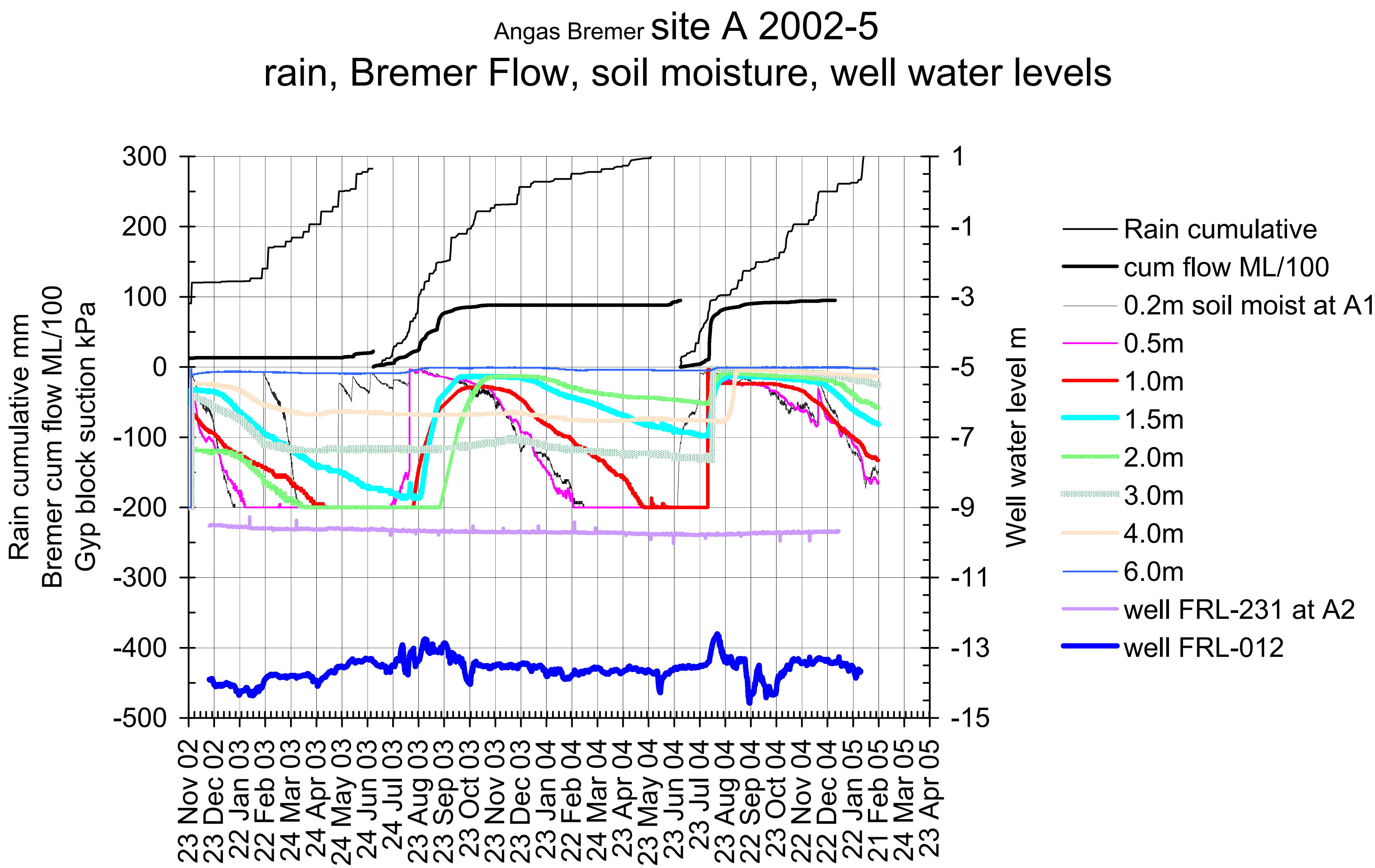
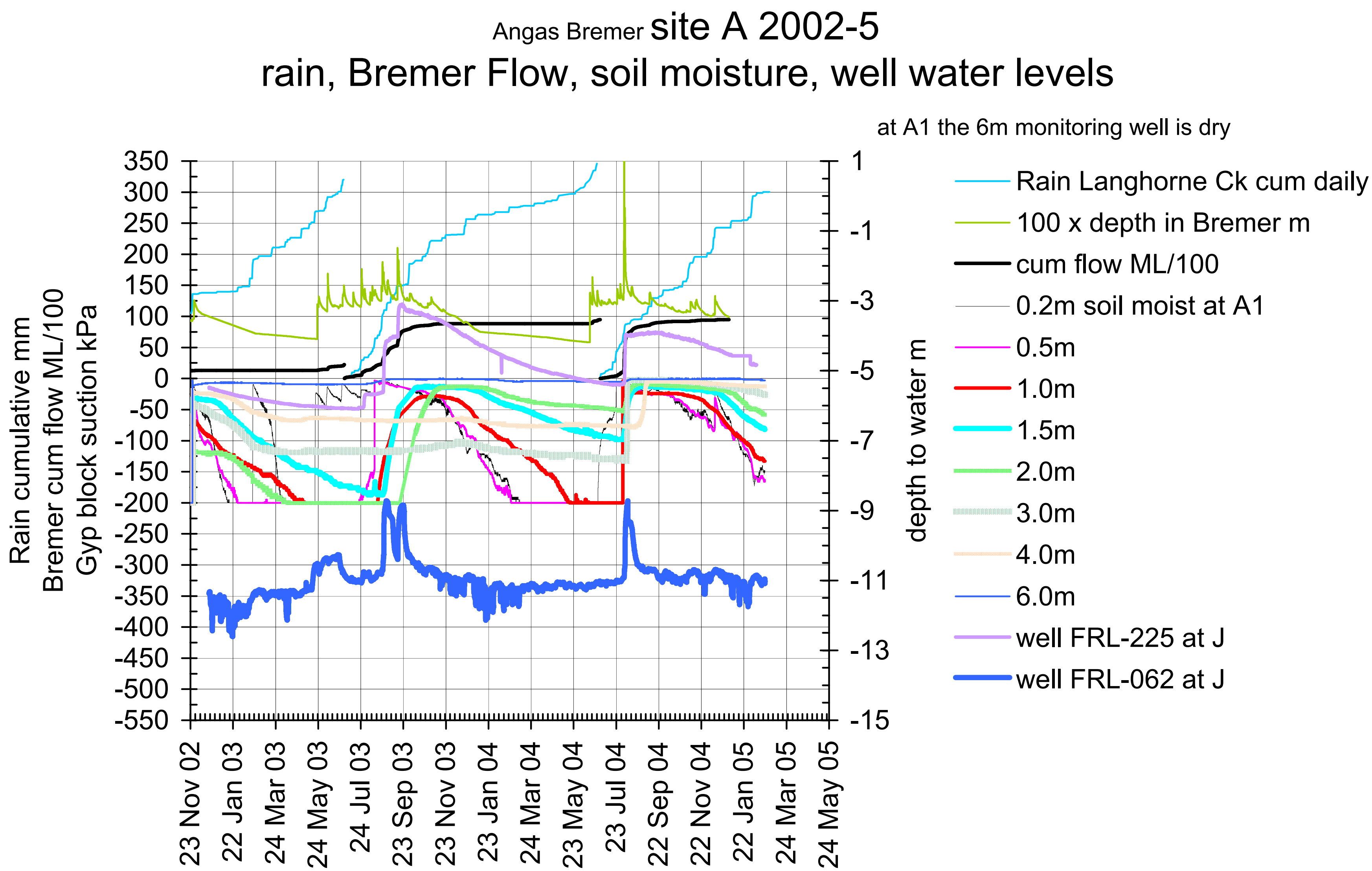
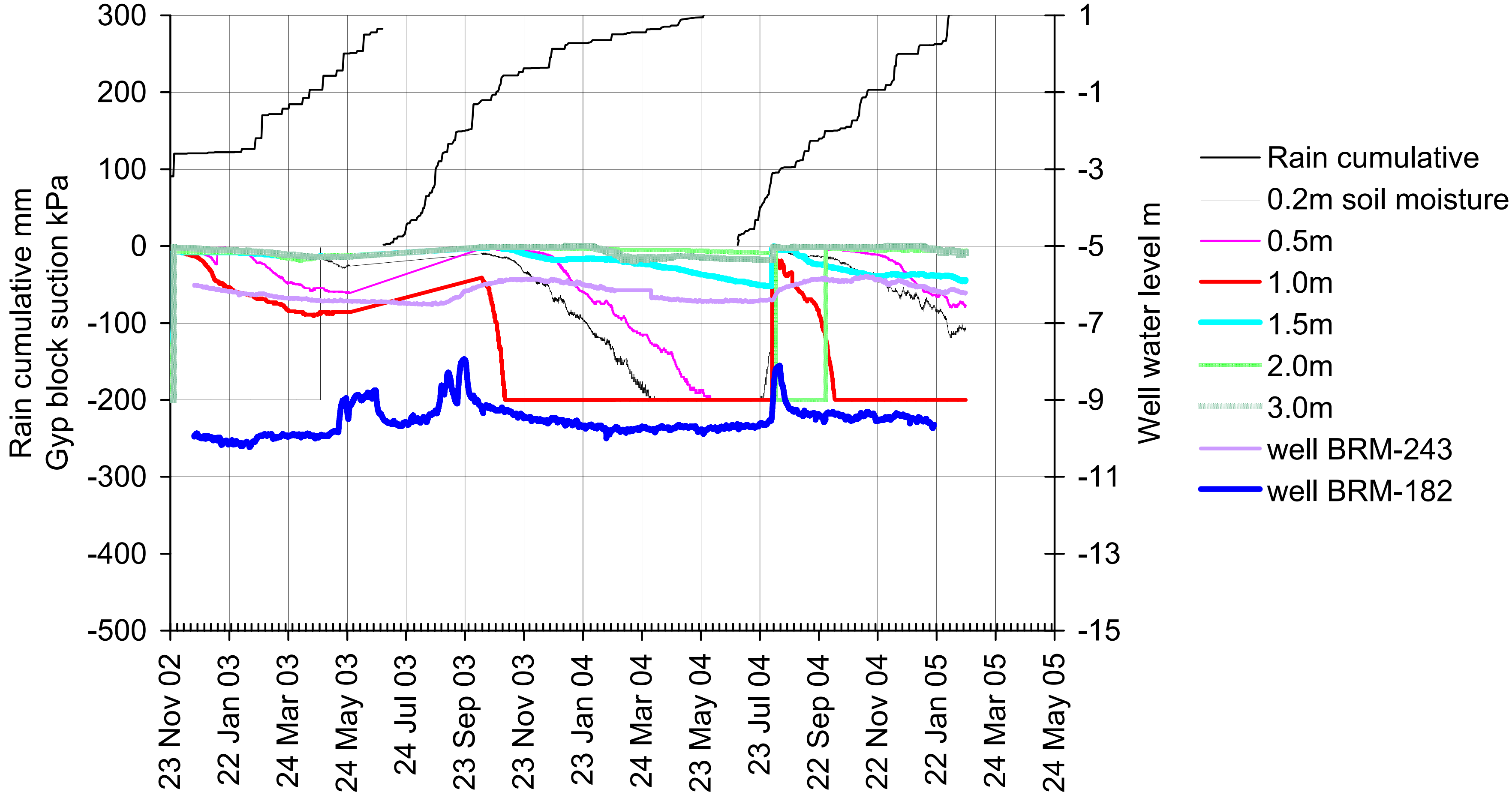

Angas Bremer site A 2002-5
rain, Bremer Flow, soil moisture, well water levels
Rain cumulative mm
Bremer cum flow ML/100
Gyp block suction kPa
Well water level m
300
200
100
0
-100
-200
-300
-400
-500
1
-1
-3
-5
-7
-9
-11
-13
-15
23 Nov 02
23 Dec 02
22 Jan 03
22 Feb 03
24 Mar 03
24 Apr 03
24 May 03
24 Jun 03
24 Jul 03
23 Aug 03
23 Sep 03
23 Oct 03
23 Nov 03
23 Dec 03
23 Jan 04
22 Feb 04
24 Mar 04
23 Apr 04
23 May 04
23 Jun 04
23 Jul 04
23 Aug 04
22 Sep 04
23 Oct 04
22 Nov 04
22 Dec 04
22 Jan 05
21 Feb 05
24 Mar 05
23 Apr 05
Rain cumulative
cum flow ML/100
0.2m soil moist at A1
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
well FRL-231 at A2
well FRL-012

Figure B-02



Angas Bremer site A 2002-5
rain, Bremer Flow, soil moisture, well water levels
at A1 the 6m monitoring well is dry
Rain cumulative mm
Bremer cum flow ML/100
Gyp block suction kPa
depth to water m
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
-550
1
-1
-3
-5
-7
-9
-11
-13
-15
23 Nov 02
22 Jan 03
24 Mar 03
24 May 03
24 Jul 03
23 Sep 03
23 Nov 03
23 Jan 04
24 Mar 04
23 May 04
23 Jul 04
22 Sep 04
22 Nov 04
22 Jan 05
24 Mar 05
24 May 05
Rain Langhorne Ck cum daily
100 x depth in Bremer m
cum flow ML/100
0.2m soil moist at A1
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
well FRL-225 at J
well FRL-062 at J

Angas Bremer site B 2002-4
rain, Bremer flow, soil moisture, well water levels



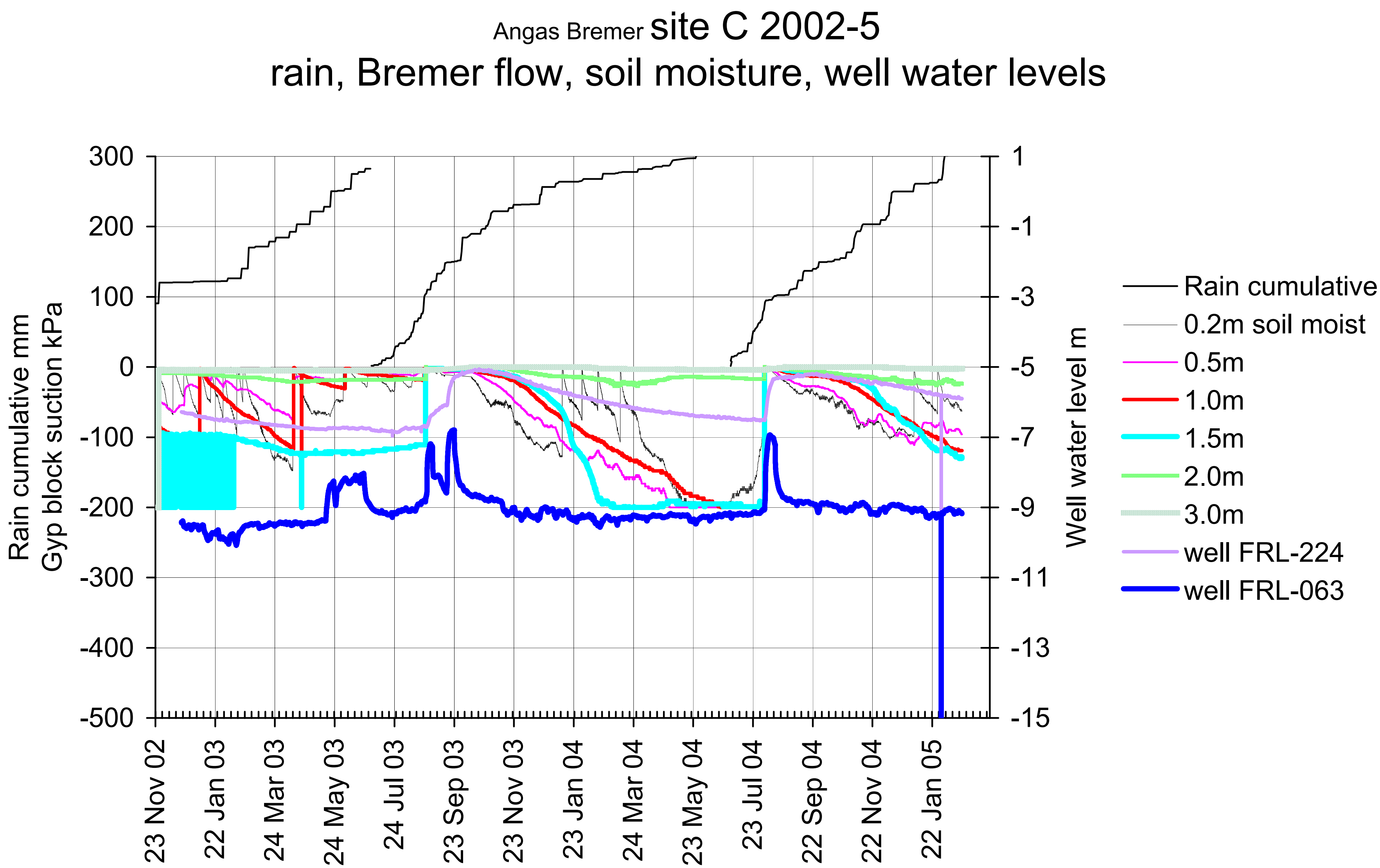

Angas Bremer site C 2002-5
rain, Bremer flow, soil moisture, well water levels
300
200
100
0
-100
-200
-300
-400
-500
Rain cumulative mm
Gyp block suction kPa
1
-1
-3
-5
-7
-9
-11
-13
-15
Well water level m
23 Nov 02
22 Jan 03
24 Mar 03
24 May 03
24 Jul 03
23 Sep 03
23 Nov 03
23 Jan 04
24 Mar 04
23 May 04
23 Jul 04
22 Sep 04
22 Nov 04
22 Jan 05
Rain cumulative
0.2m soil moist
0.5m
1.0m
1.5m
2.0m
3.0m
well FRL-224
well FRL-063

Figure B-05

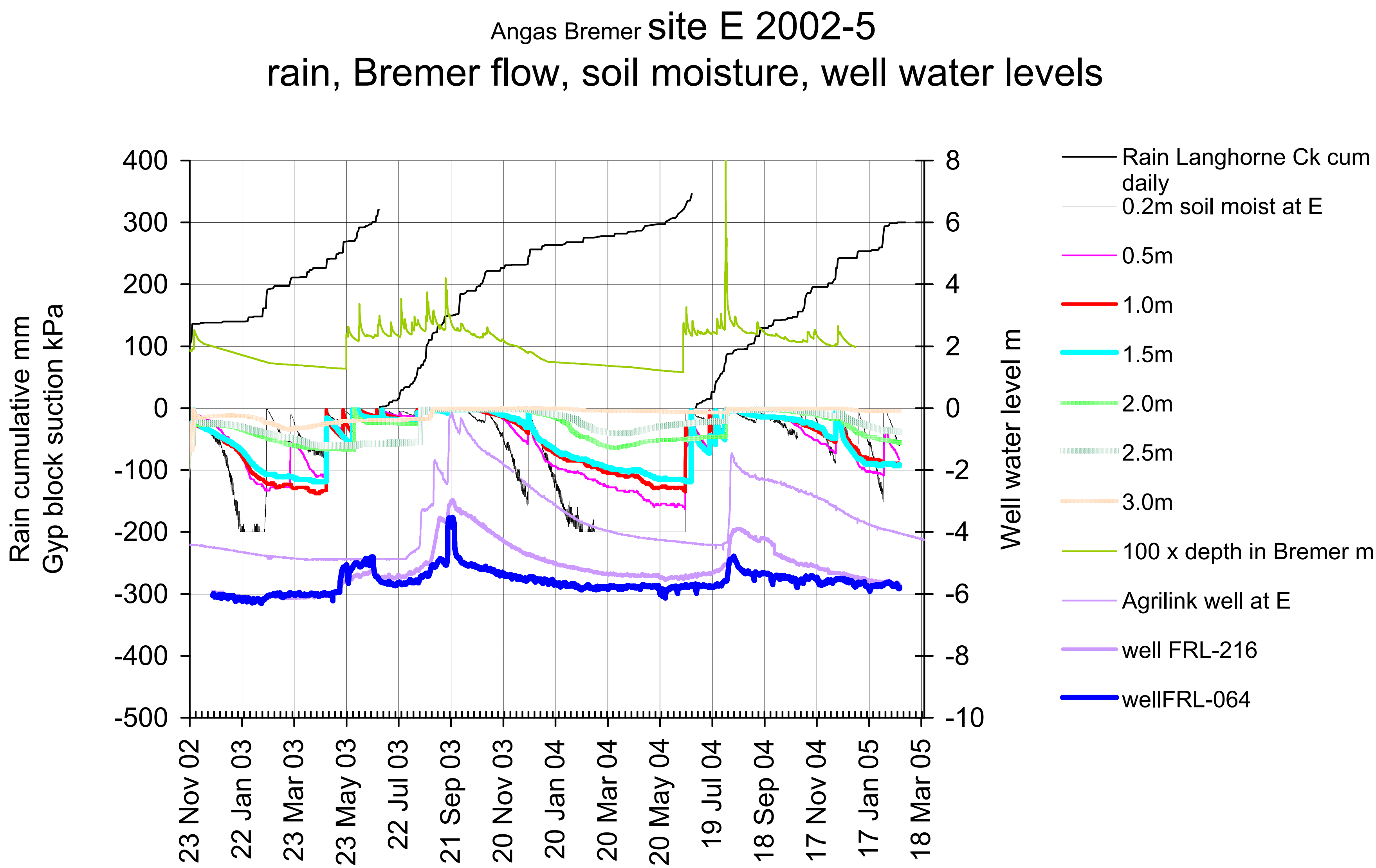
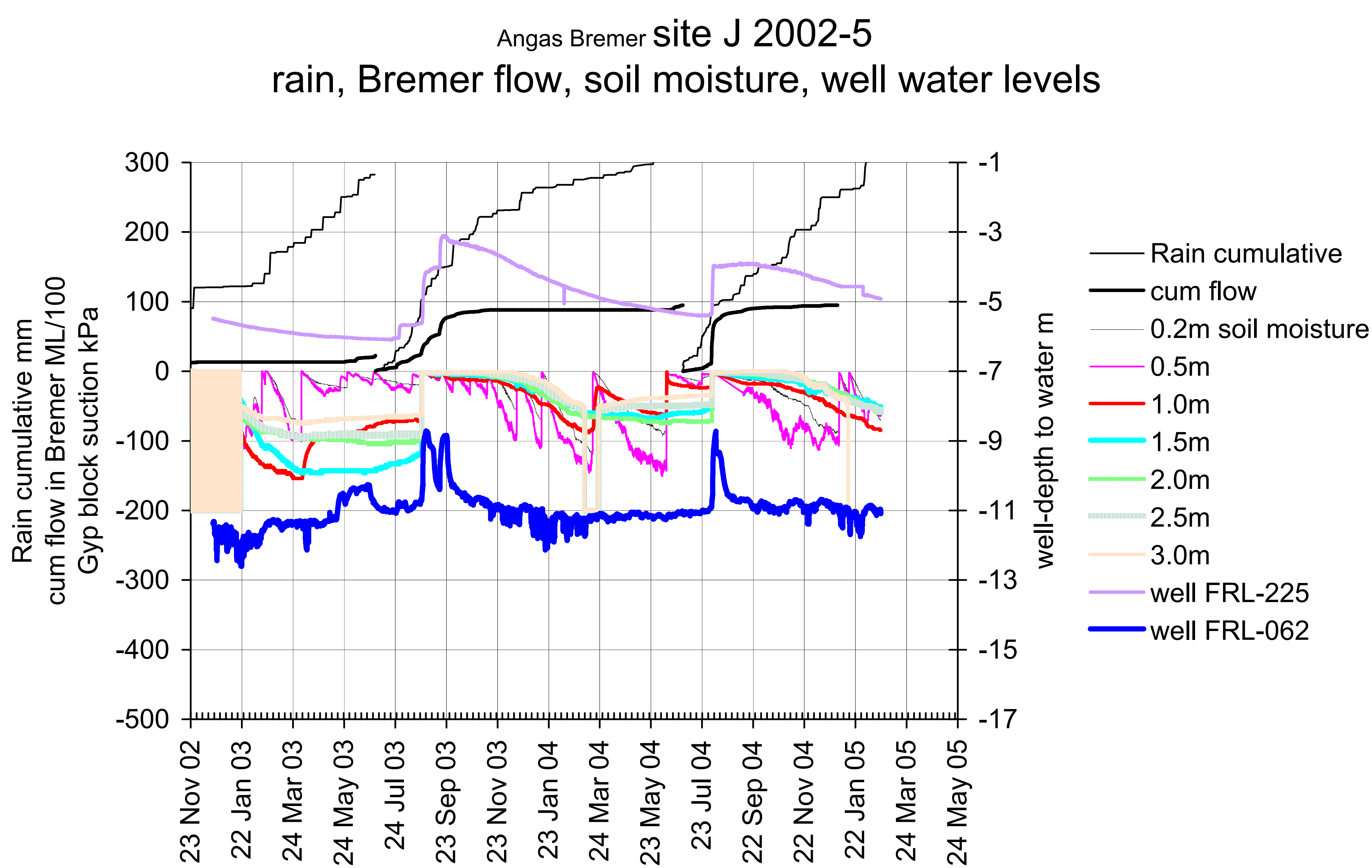

Angas Bremer site E 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
Gyp block suction kPa
Well water level m
400
300
200
100
0
-100
-200
-300
-400
-500
8
6
4
2
0
-2
-4
-6
-8
-10
23 Nov 02
22 Jan 03
23 Mar 03
23 May 03
22 Jul 03
21 Sep 03
20 Nov 03
20 Jan 04
20 Mar 04
20 May 04
19 Jul 04
18 Sep 04
17 Nov 04
17 Jan 05
18 Mar 05
Rain Langhorne Ck cum daily
0.2m soil moist at E
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
100 x depth in Bremer m
Agrilink well at E
well FRL-216
wellFRL-064

Figure B-06



Angas Bremer site J 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
cum flow in Bremer ML/100
Gyp block suction kPa
well-depth to water m
300
200
100
0
-100
-200
-300
-400
-500
-1
-3
-5
-7
-9
-11
-13
-15
-17
23 Nov 02
22 Jan 03
24 Mar 03
24 May 03
24 Jul 03
23 Sep 03
23 Nov 03
23 Jan 04
24 Mar 04
23 May 04
23 Jul 04
22 Sep 04
22 Nov 04
22 Jan 05
24 Mar 05
24 May 05
Rain cumulative
cum flow
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-225
well FRL-062

Figure B-07

Angas Bremer site K 2002-5
rain, Bremer flow, soil moisture, well water levels

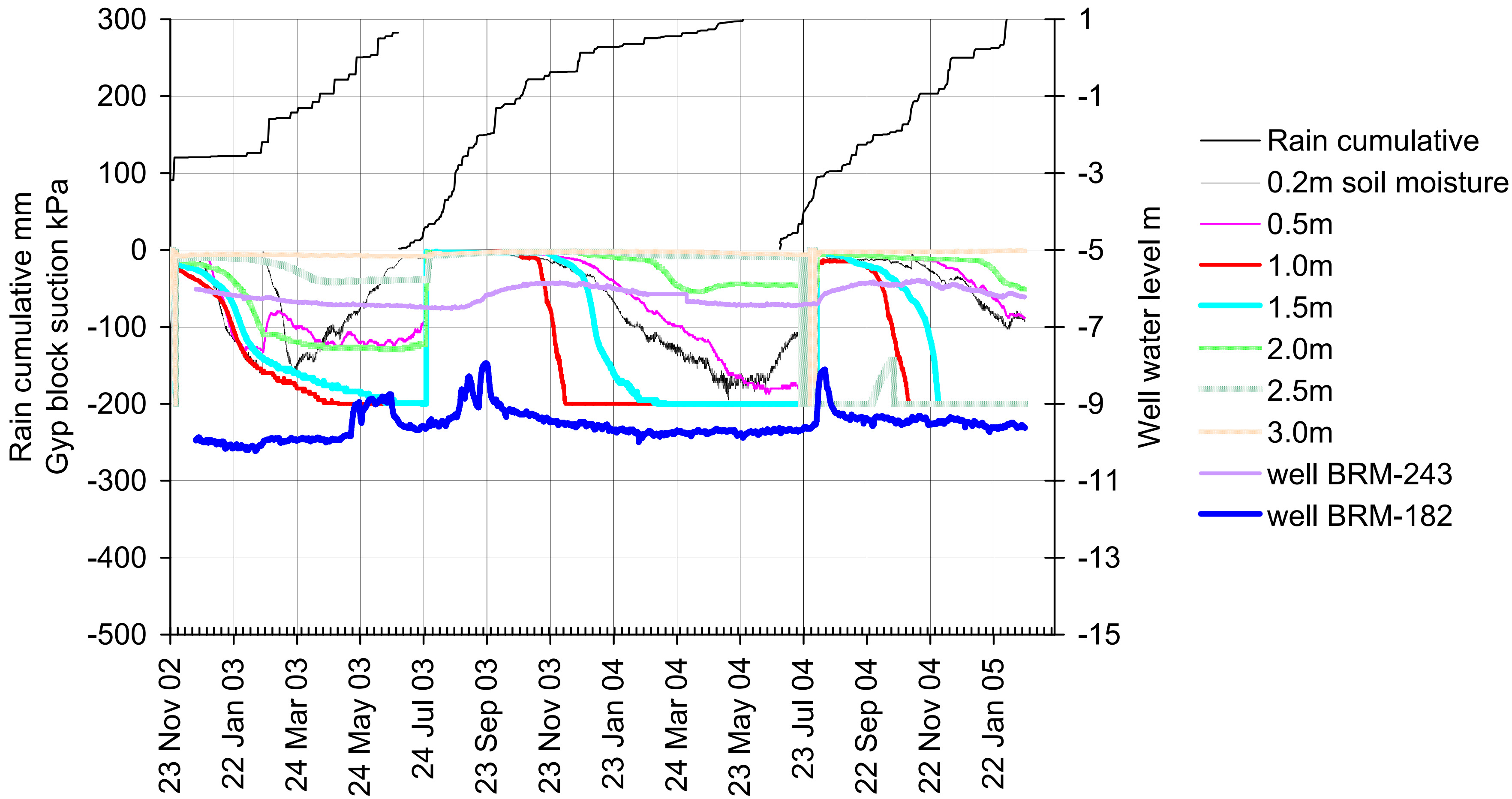
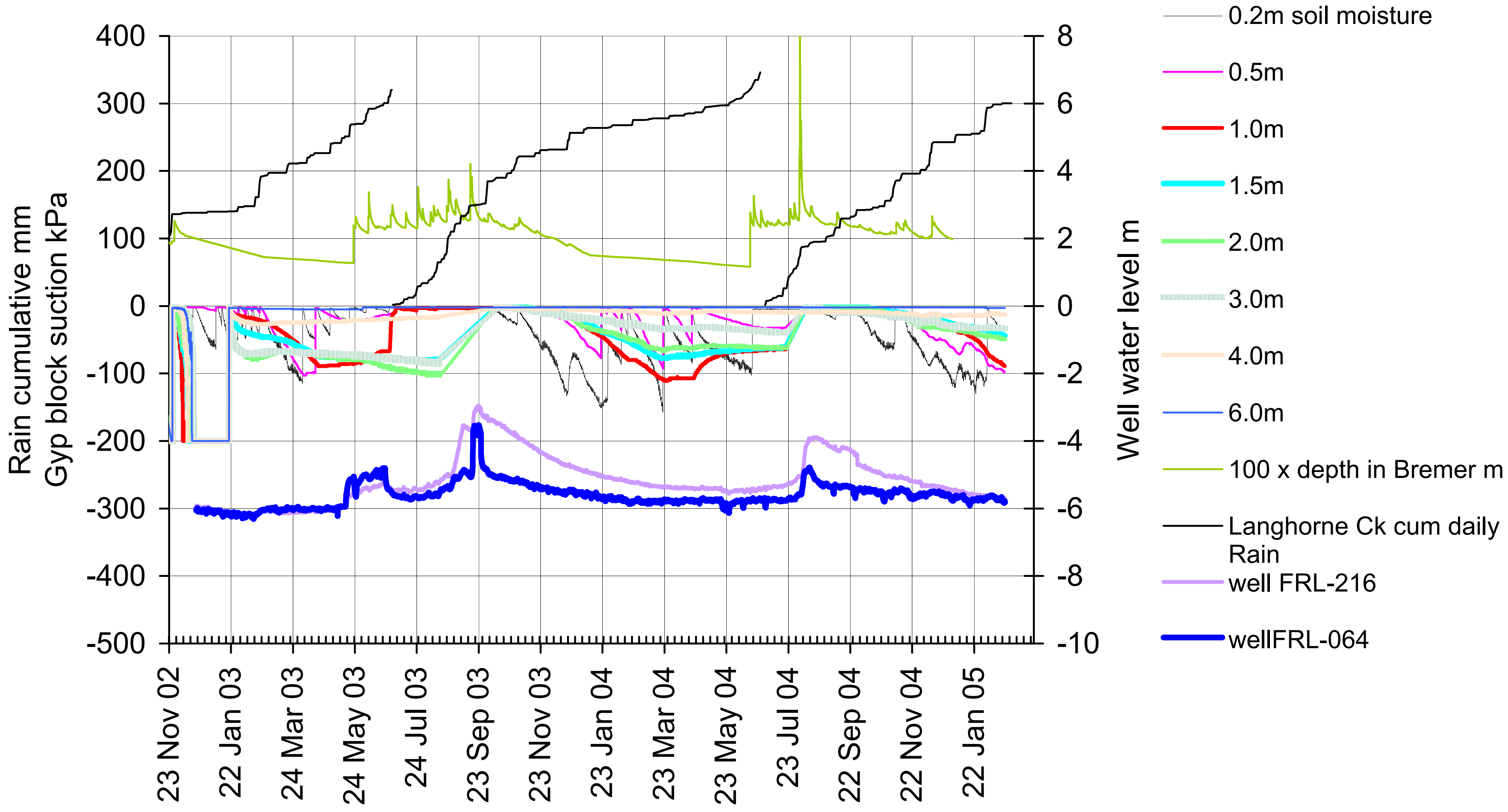


Figure B-08

Angas Bremer site L 2002-5
rain, Bremer flow, soil moisture, well water levels



ABfpL05A

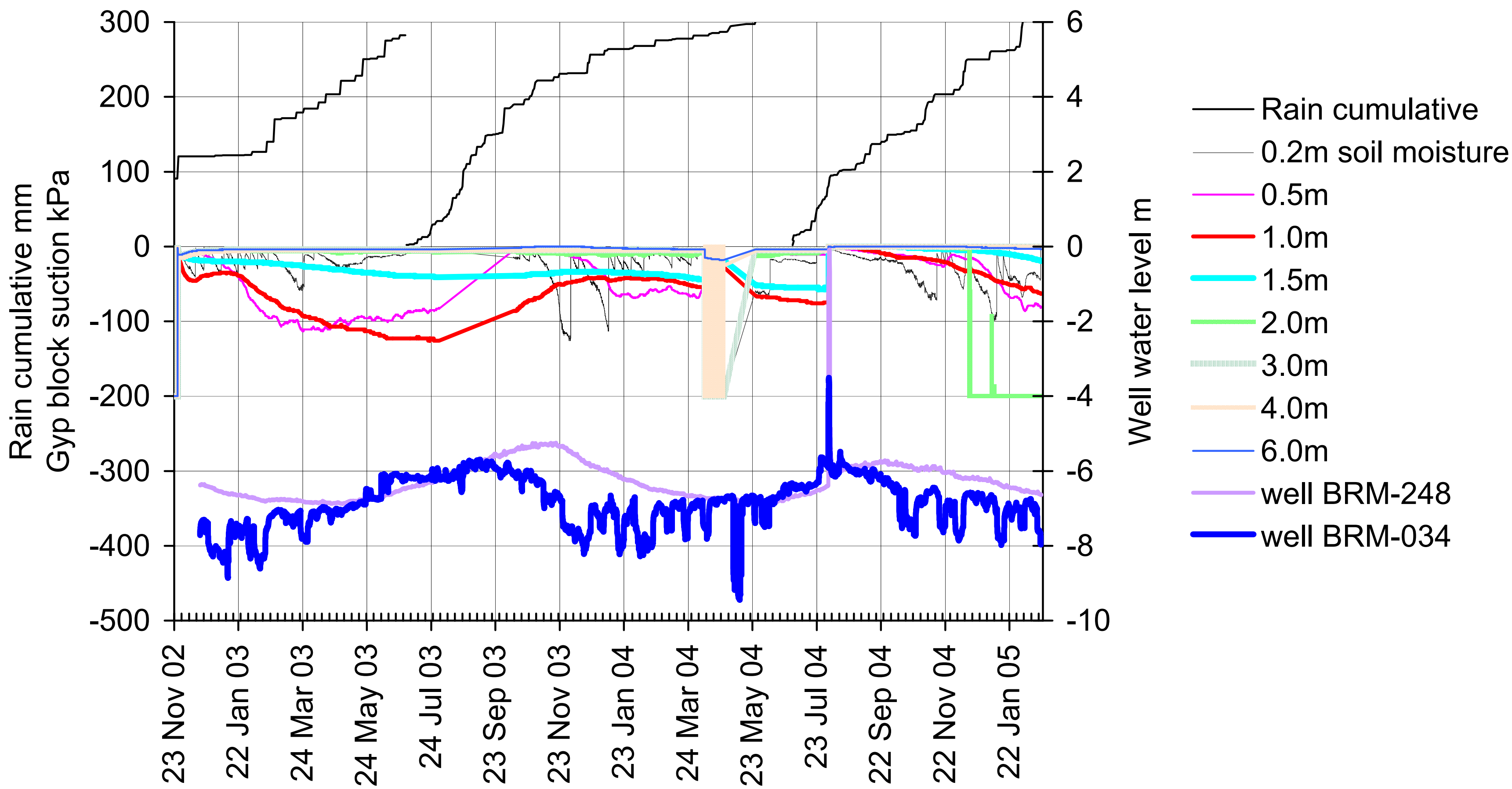
Chart-full period

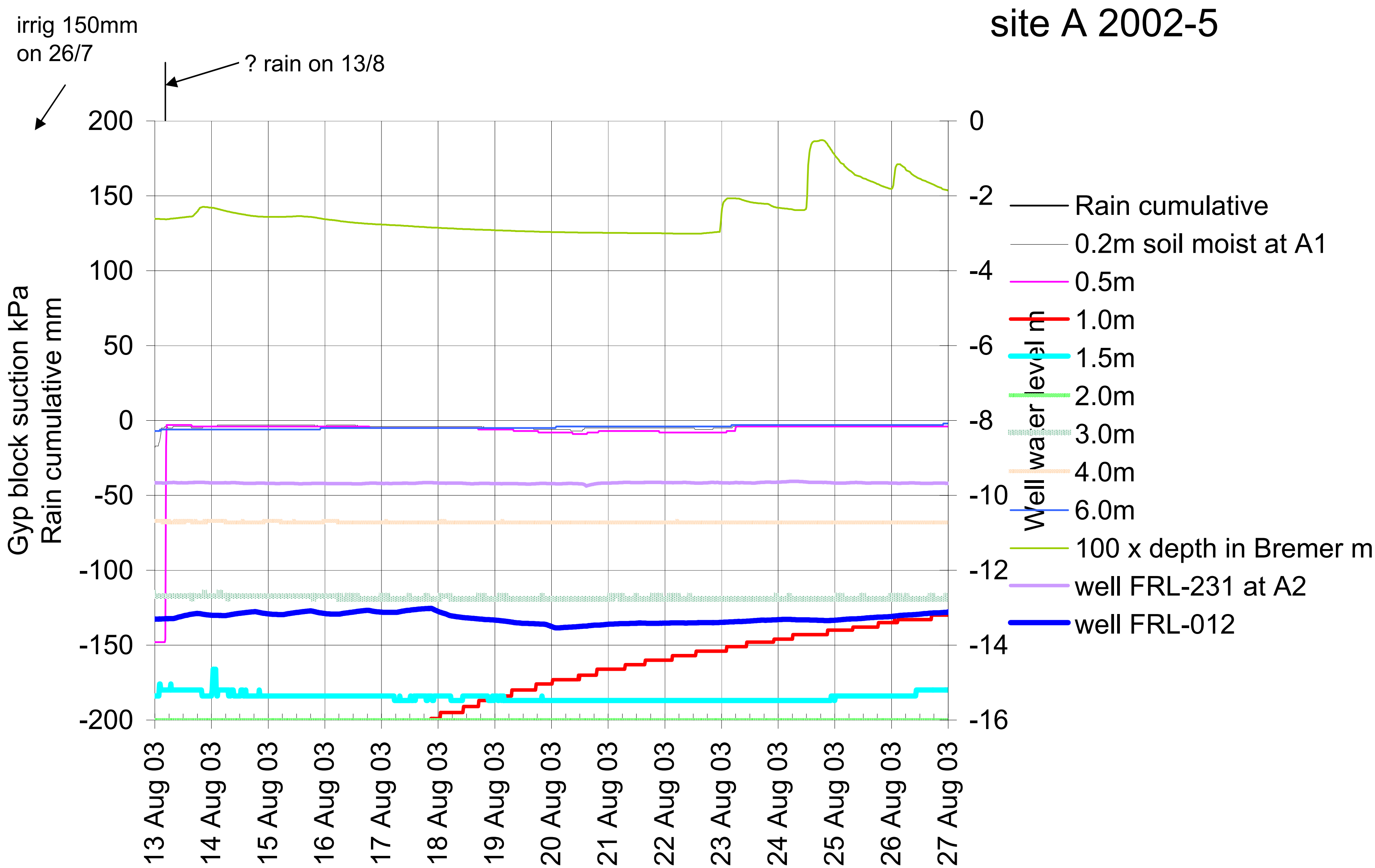
19/04/2005 2:15 PM

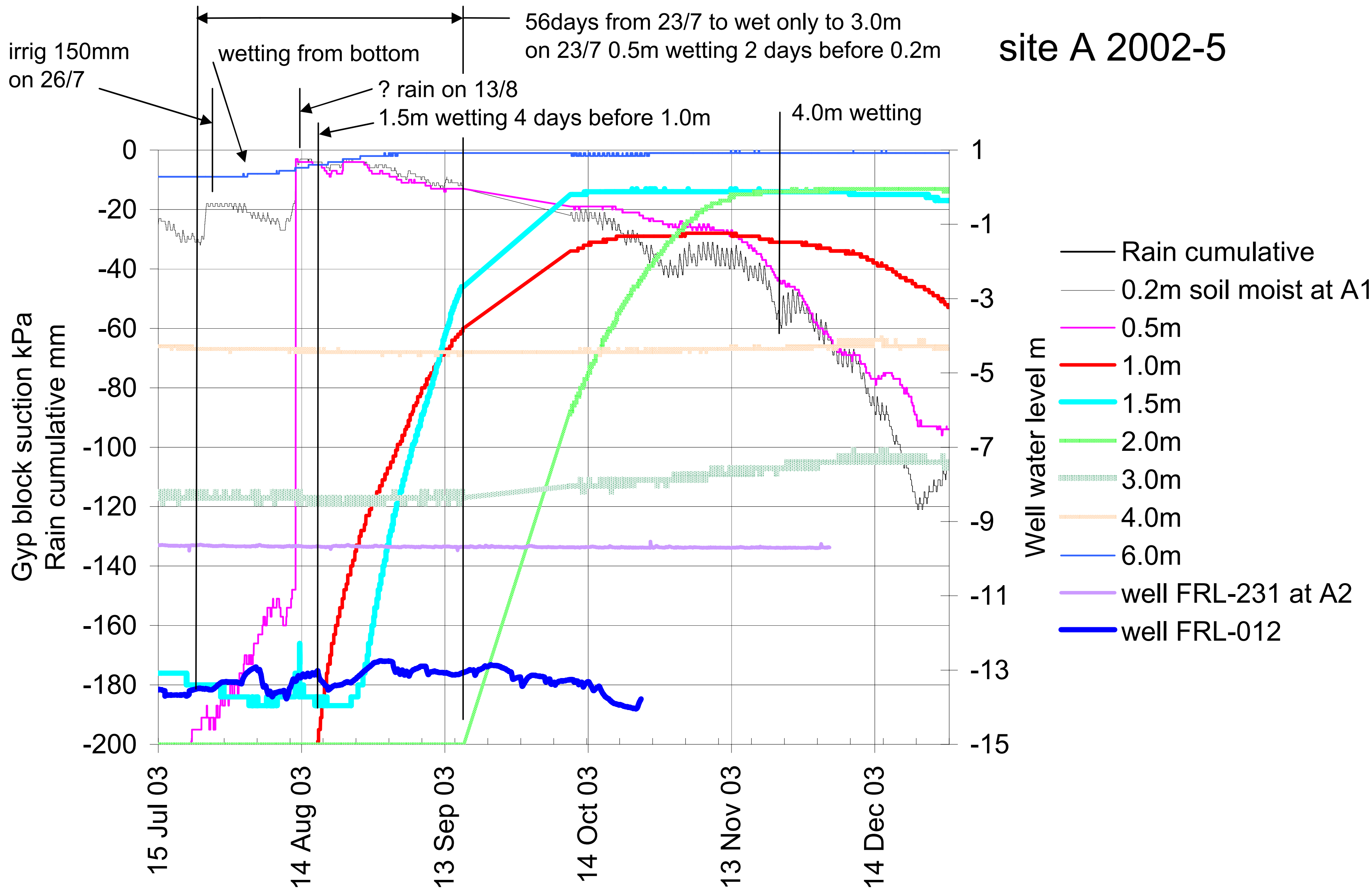
Angas Bremer site M 2002-5

rain, soil moisture, well water levels

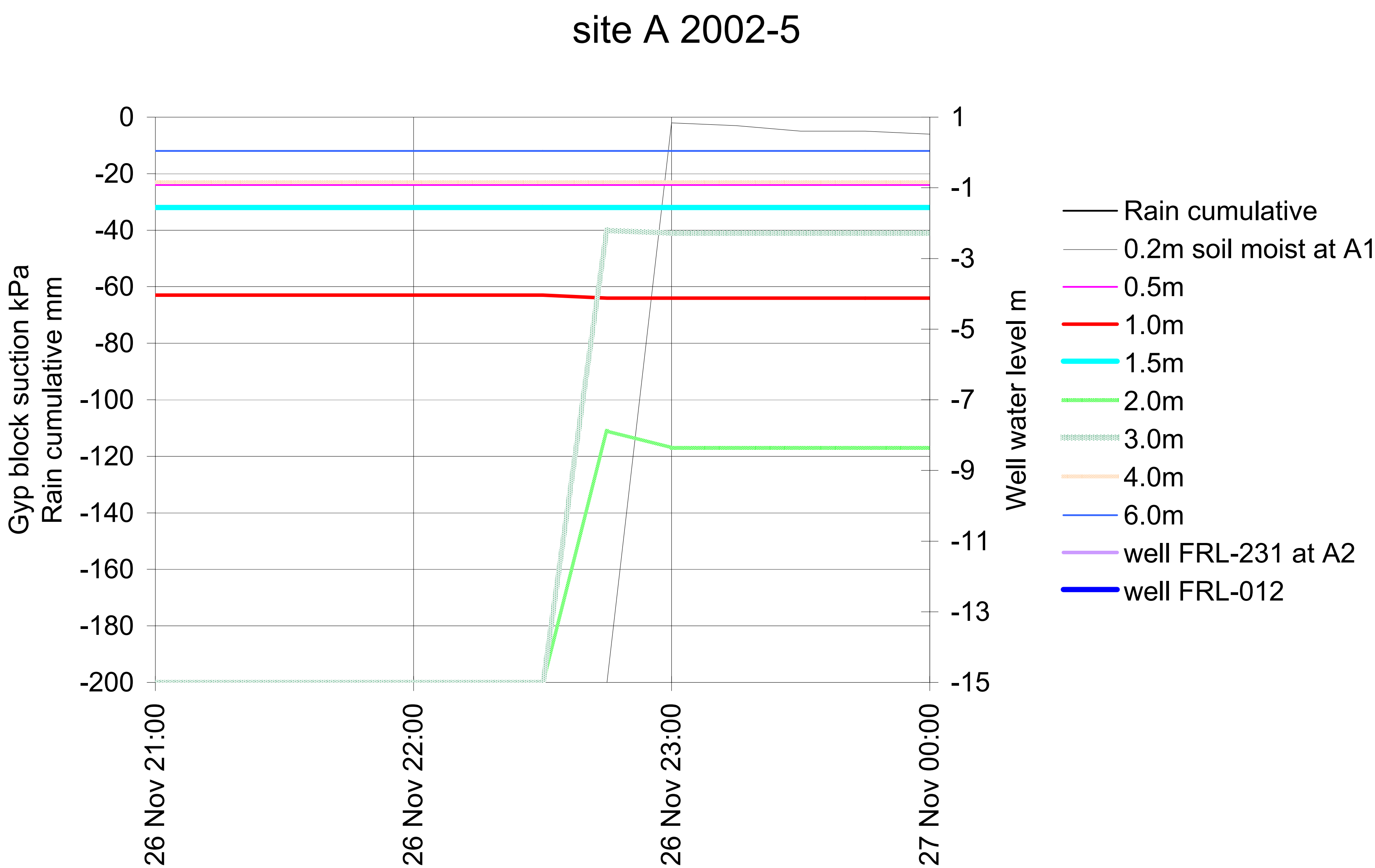
M is central in area of largest groundwater use



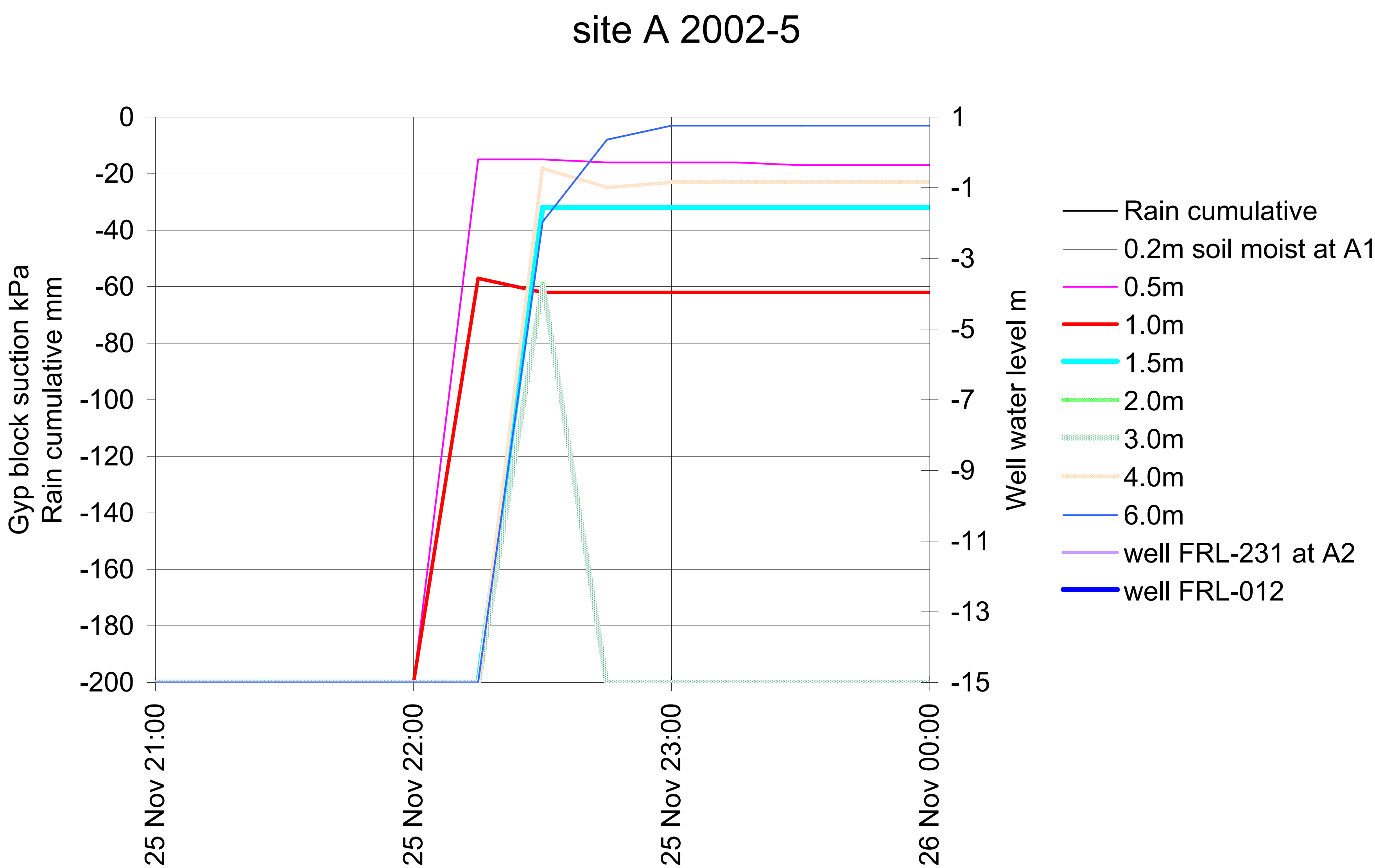

site A 2002-5
irrig 150mm
on 26/7
? rain on 13/8
Gyp block suction kPa
Rain cumulative mm
Well water level m
200
150
100
50
0
-50
-100
-150
-200
0
-2
-4
-6
-8
-10
-12
-14
-16
13 Aug 03
14 Aug 03
15 Aug 03
16 Aug 03
17 Aug 03
18 Aug 03
19 Aug 03
20 Aug 03
21 Aug 03
22 Aug 03
23 Aug 03
24 Aug 03
25 Aug 03
26 Aug 03
27 Aug 03
Rain cumulative
0.2m soil moist at A1
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
100 x depth in Bremer m
well FRL-231 at A2
well FRL-012

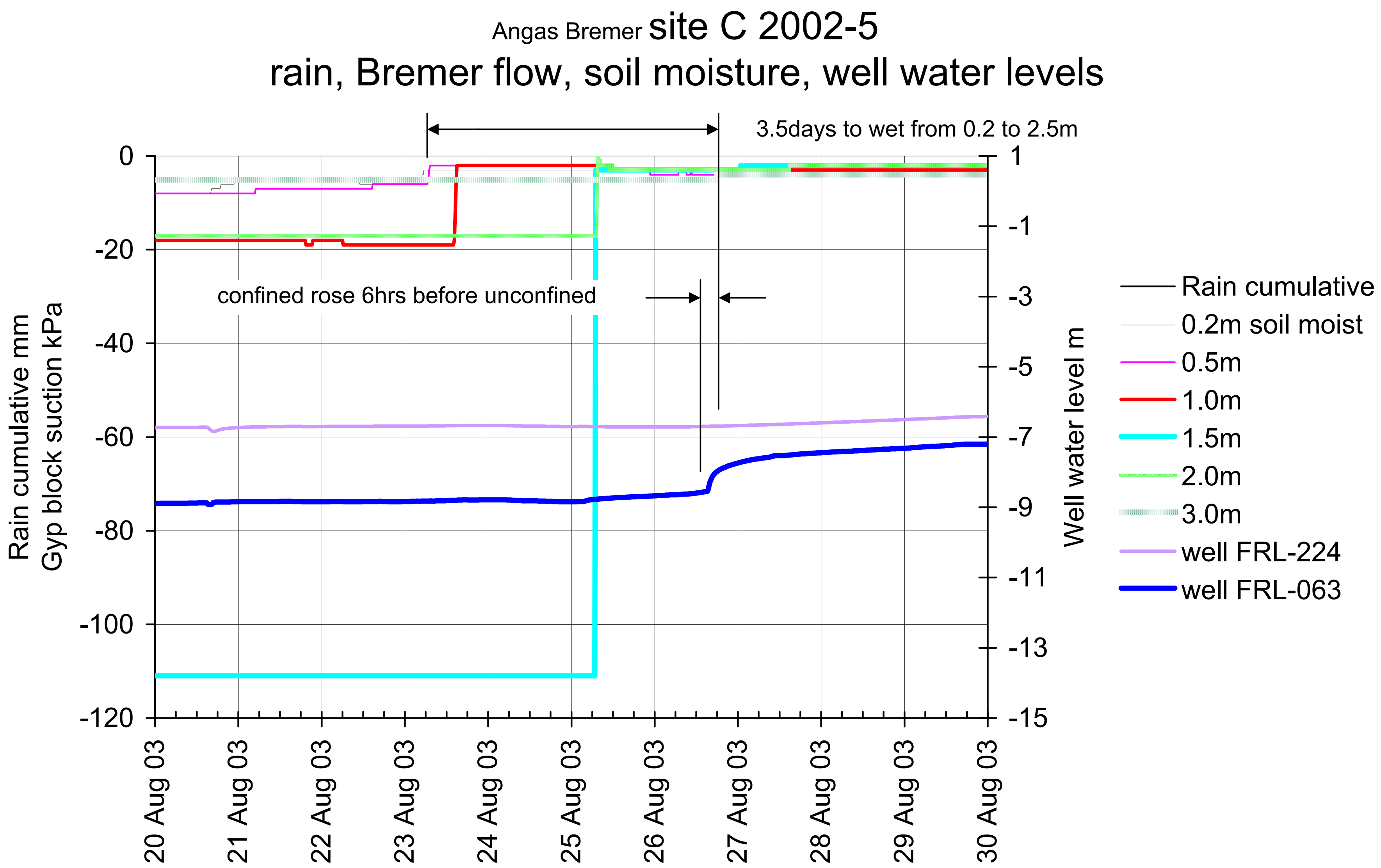


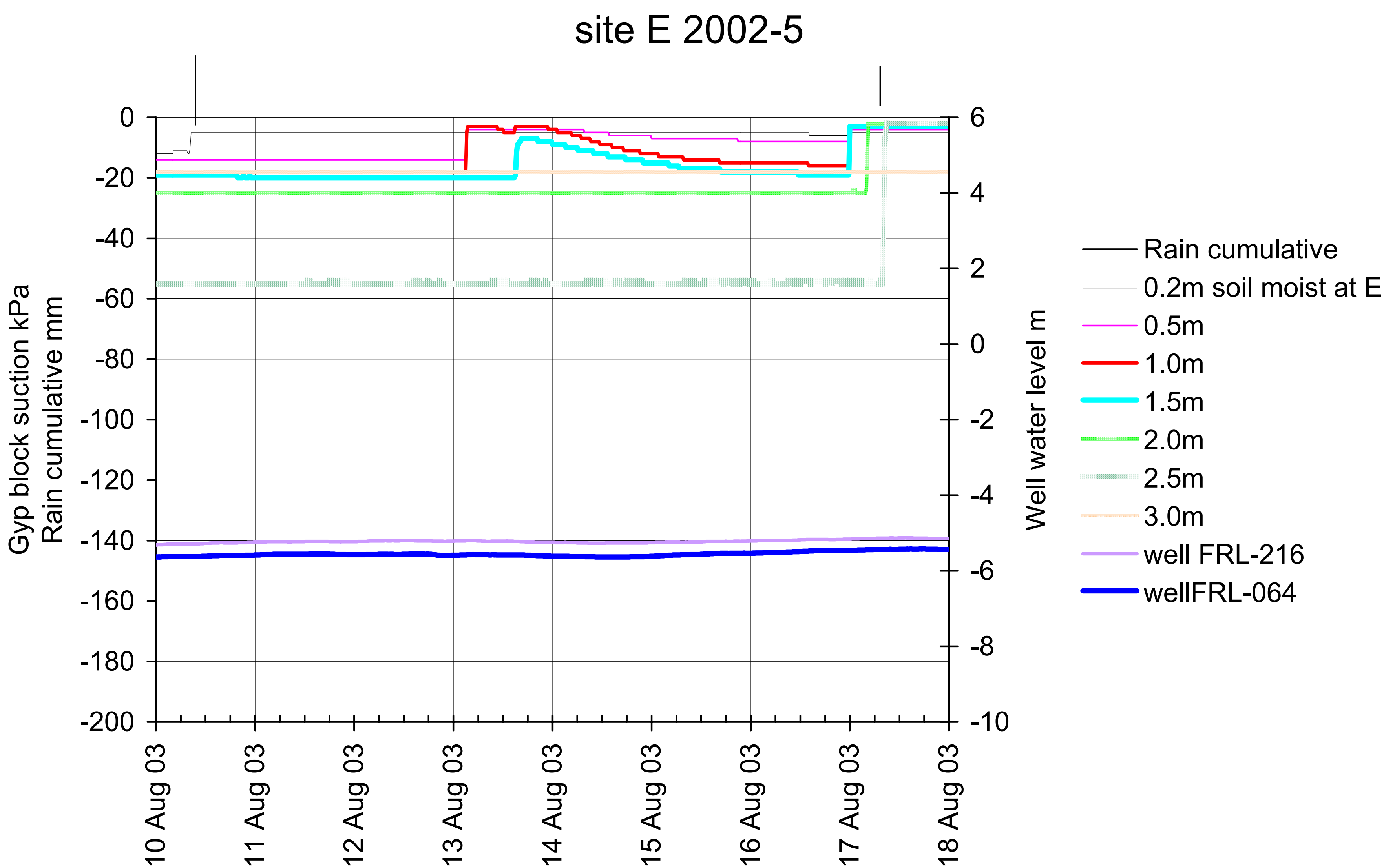
site A 2002-5
56days from 23/7 to wet only to 3.0m
on 23/7 0.5m wetting 2 days before 0.2m
irrig 150mm
on 26/7
wetting from bottom
? rain on 13/8
1.5m wetting 4 days before 1.0m
4.0m wetting
Gyp block suction kPa
Rain cumulative mm
Well water level m
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
1
-1
-3
-5
-7
-9
-11
-13
-15
15 Jul 03
14 Aug 03
13 Sep 03
14 Oct 03
13 Nov 03
14 Dec 03
Rain cumulative
0.2m soil moist at A1
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
well FRL-231 at A2
well FRL-012

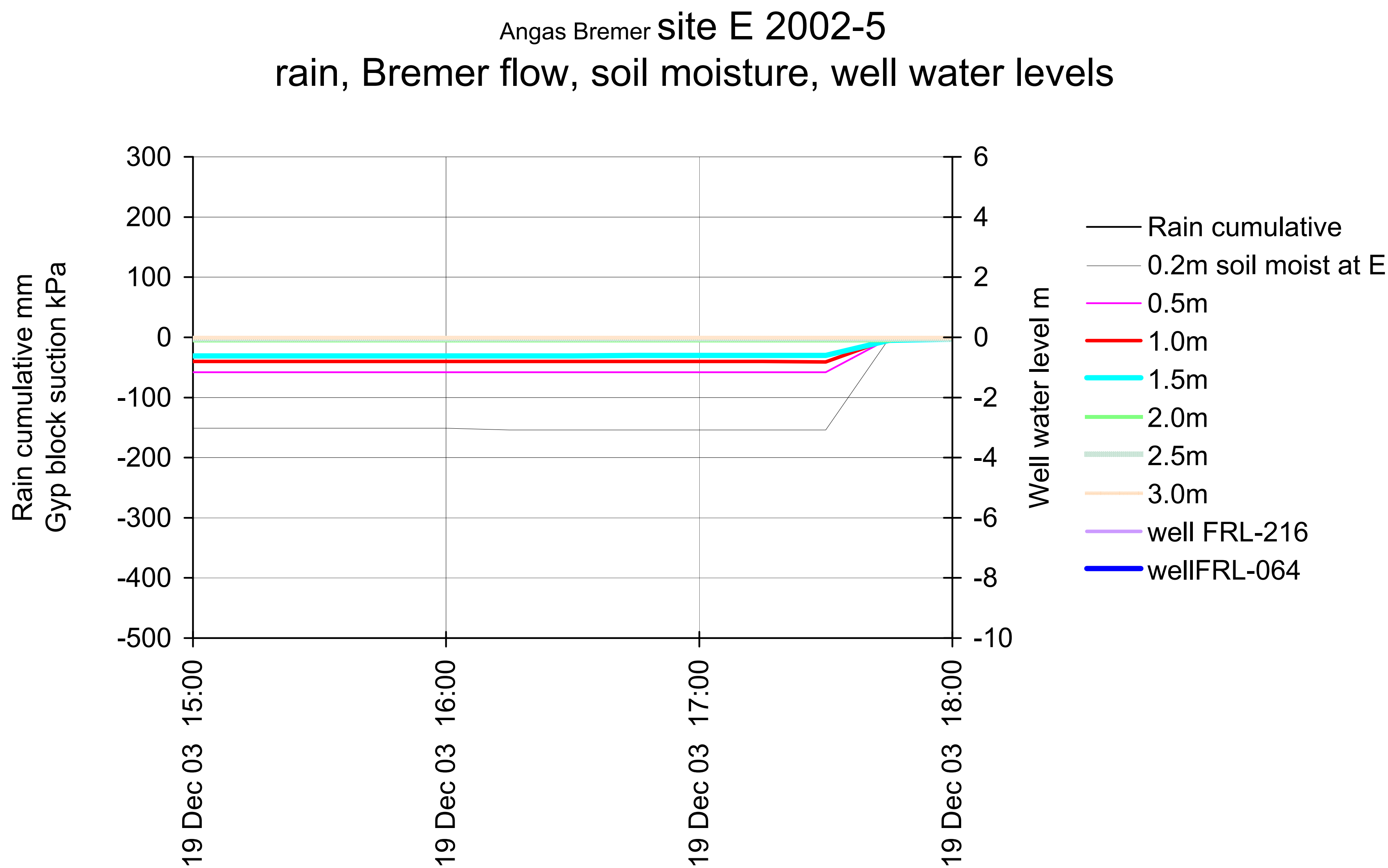


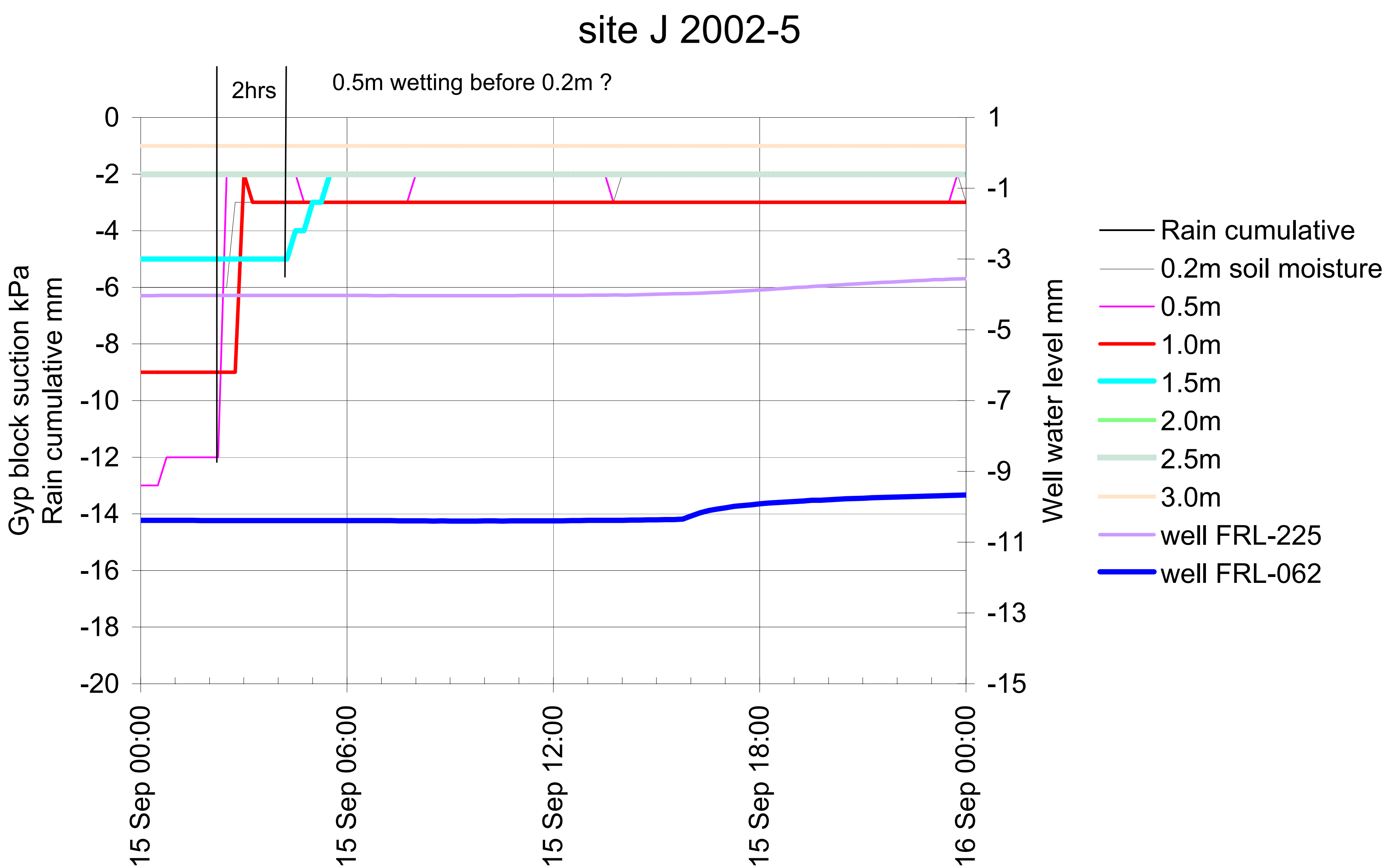
site A 2002-5
Gyp block suction kPa
Rain cumulative mm
Well water level m
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
1
-1
-3
-5
-7
-9
-11
-13
-15
26 Nov 21:00
26 Nov 22:00
26 Nov 23:00
27 Nov 00:00
Rain cumulative
0.2m soil moist at A1
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
well FRL-231 at A2
well FRL-012


site A 2002-5
Gyp block suction kPa
Rain cumulative mm
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Well water level m
1
-1
-3
-5
-7
-9
-11
-13
-15
25 Nov 21:00
25 Nov 22:00
25 Nov 23:00
26 Nov 00:00
Rain cumulative
0.2m soil moist at A1
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
well FRL-231 at A2
well FRL-012

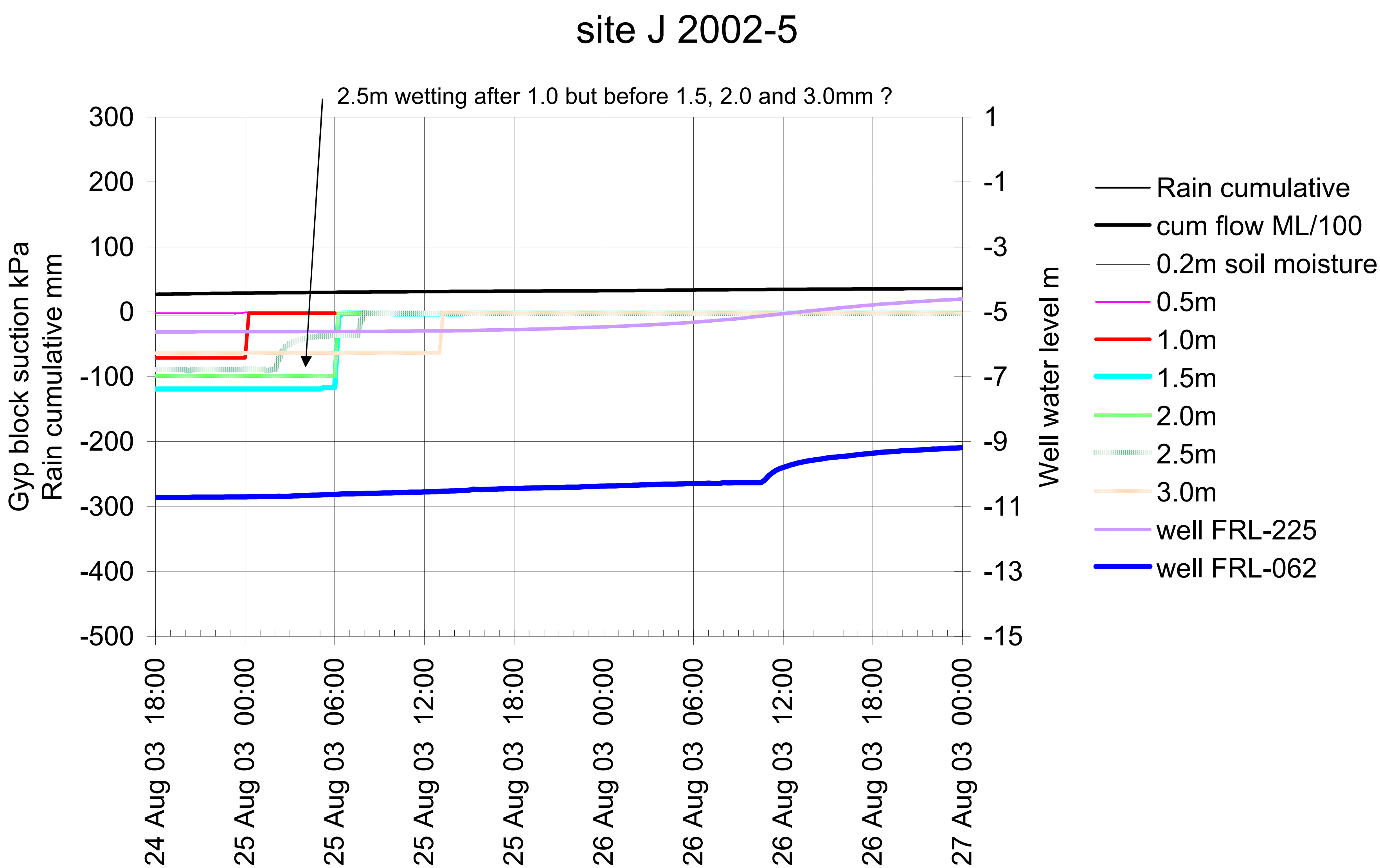

Angas Bremer site C 2002-5
rain, Bremer flow, soil moisture, well water levels
3.5days to wet from 0.2 to 2.5m
confined rose 6hrs before unconfined
Rain cumulative mm
Gyp block suction kPa
Well water level m
0
-20
-40
-60
-80
-100
-120
1
-1
-3
-5
-7
-9
-11
-13
-15
20 Aug 03
21 Aug 03
22 Aug 03
23 Aug 03
24 Aug 03
25 Aug 03
26 Aug 03
27 Aug 03
28 Aug 03
29 Aug 03
30 Aug 03
Rain cumulative
0.2m soil moist
0.5m
1.0m
1.5m
2.0m
3.0m
well FRL-224
well FRL-063


site E 2002-5
Gyp block suction kPa
Rain cumulative mm
Well water level m
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
6
4
2
0
-2
-4
-6
-8
-10
10 Aug 03
11 Aug 03
12 Aug 03
13 Aug 03
14 Aug 03
15 Aug 03
16 Aug 03
17 Aug 03
18 Aug 03
Rain cumulative
0.2m soil moist at E
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-216
wellFRL-064


Angas Bremer site E 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
Gyp block suction kPa
300
200
100
0
-100
-200
-300
-400
-500
Well water level m
6
4
2
0
-2
-4
-6
-8
-10
19 Dec 03 15:00
19 Dec 03 16:00
19 Dec 03 17:00
19 Dec 03 18:00
Rain cumulative
0.2m soil moist at E
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-216
wellFRL-064



site J 2002-5
2hrs
0.5m wetting before 0.2m ?
Gyp block suction kPa
Rain cumulative mm
Well water level mm
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
1
-1
-3
-5
-7
-9
-11
-13
-15
15 Sep 00:00
15 Sep 06:00
15 Sep 12:00
15 Sep 18:00
16 Sep 00:00
Rain cumulative
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-225
well FRL-062



site J 2002-5
2.5m wetting after 1.0 but before 1.5, 2.0 and 3.0mm ?
Gyp block suction kPa
Rain cumulative mm
Well water level m
300
200
100
0
-100
-200
-300
-400
-500
1
-1
-3
-5
-7
-9
-11
-13
-15
24 Aug 03 18:00
25 Aug 03 00:00
25 Aug 03 06:00
25 Aug 03 12:00
25 Aug 03 18:00
26 Aug 03 00:00
26 Aug 03 06:00
26 Aug 03 12:00
26 Aug 03 18:00
27 Aug 03 00:00
Rain cumulative
cum flow ML/100
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-225
well FRL-062

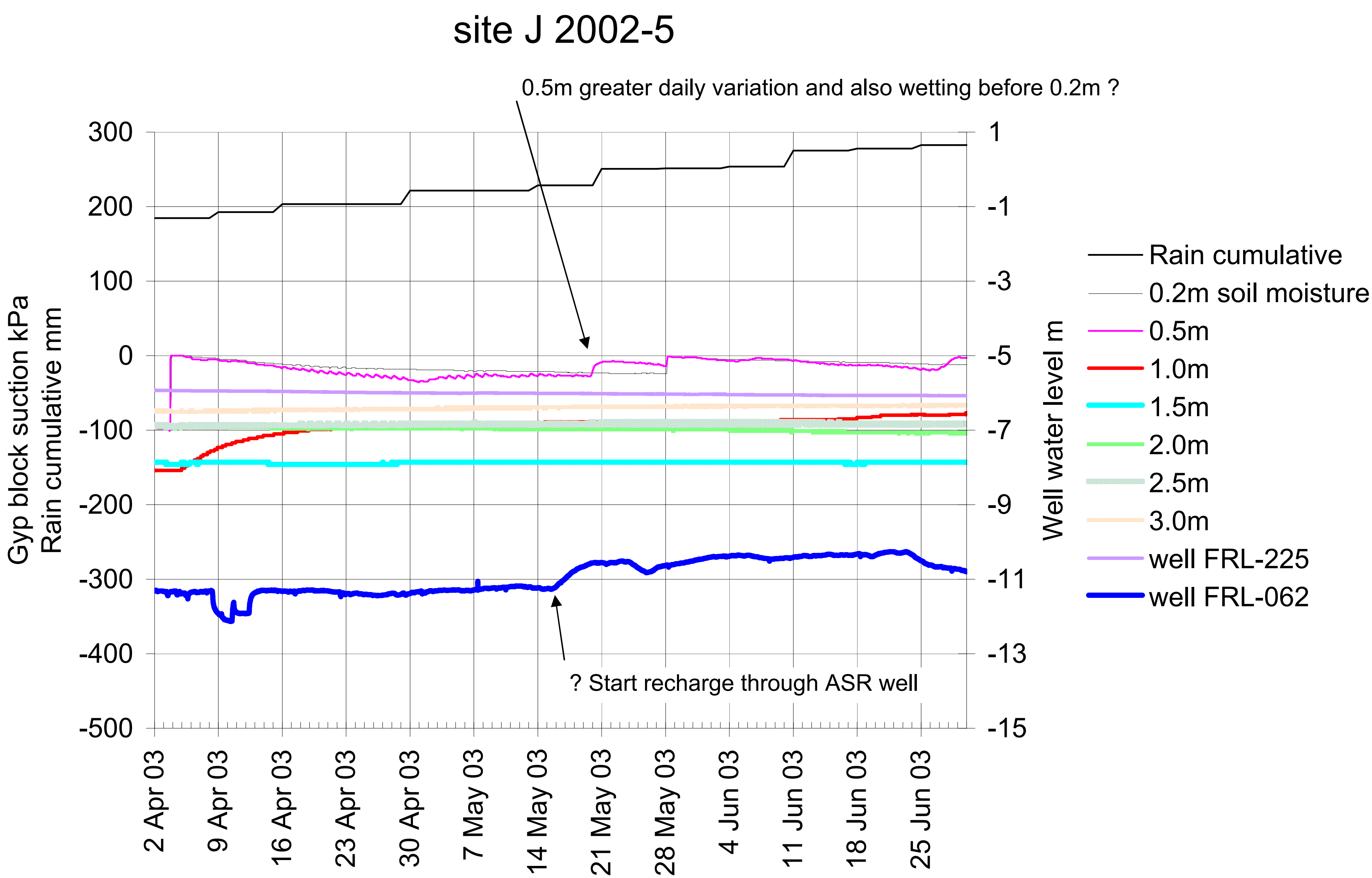
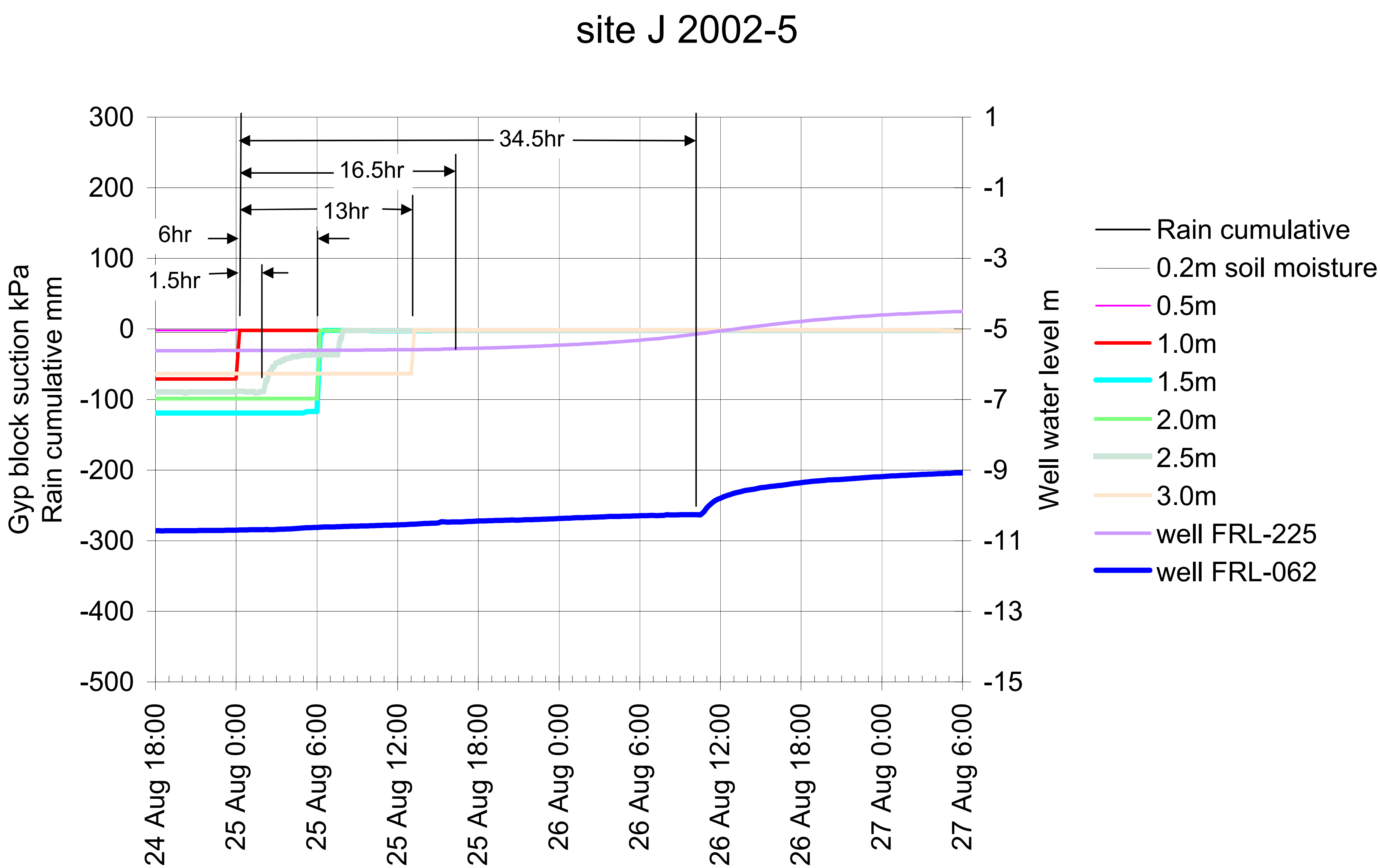
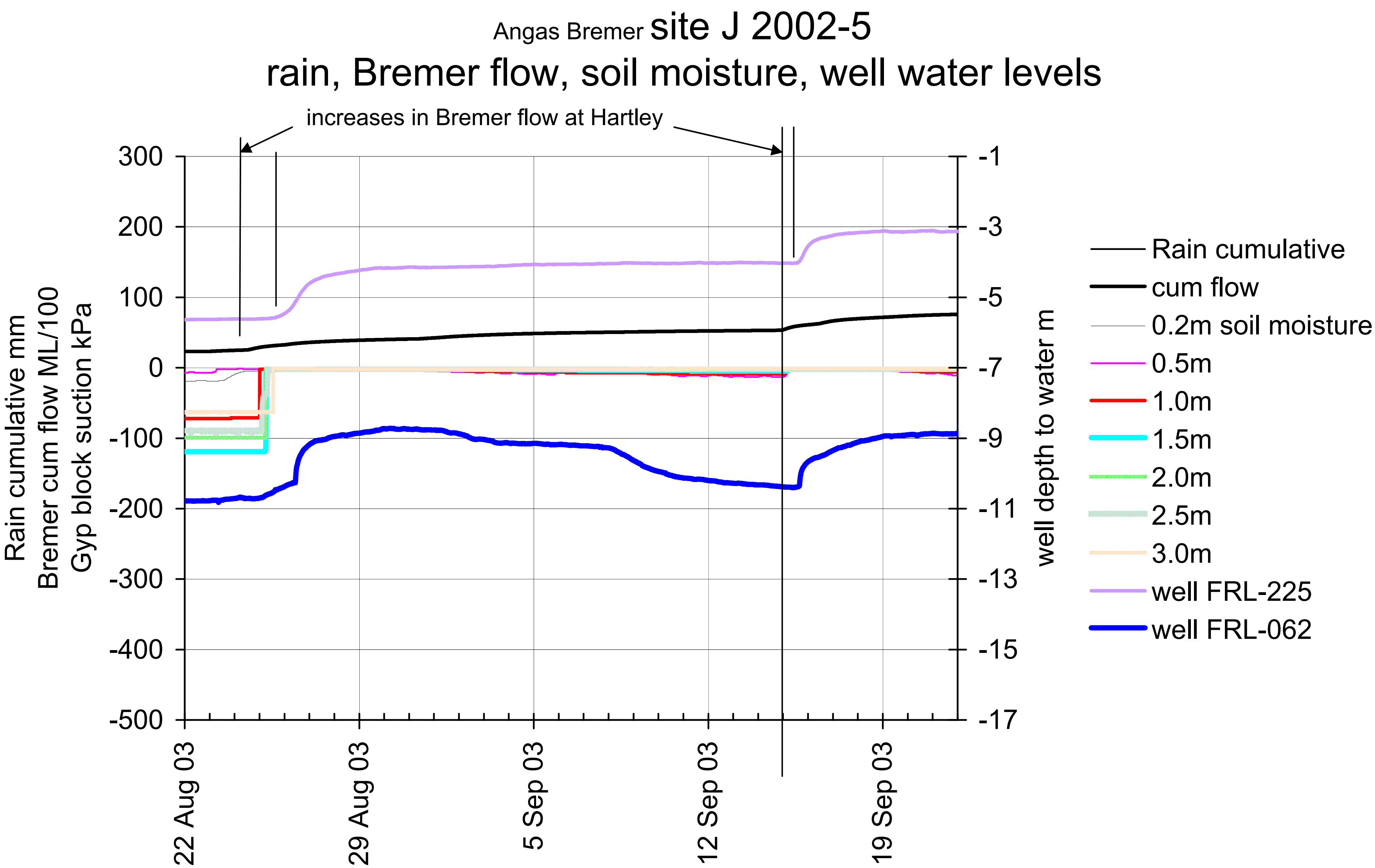
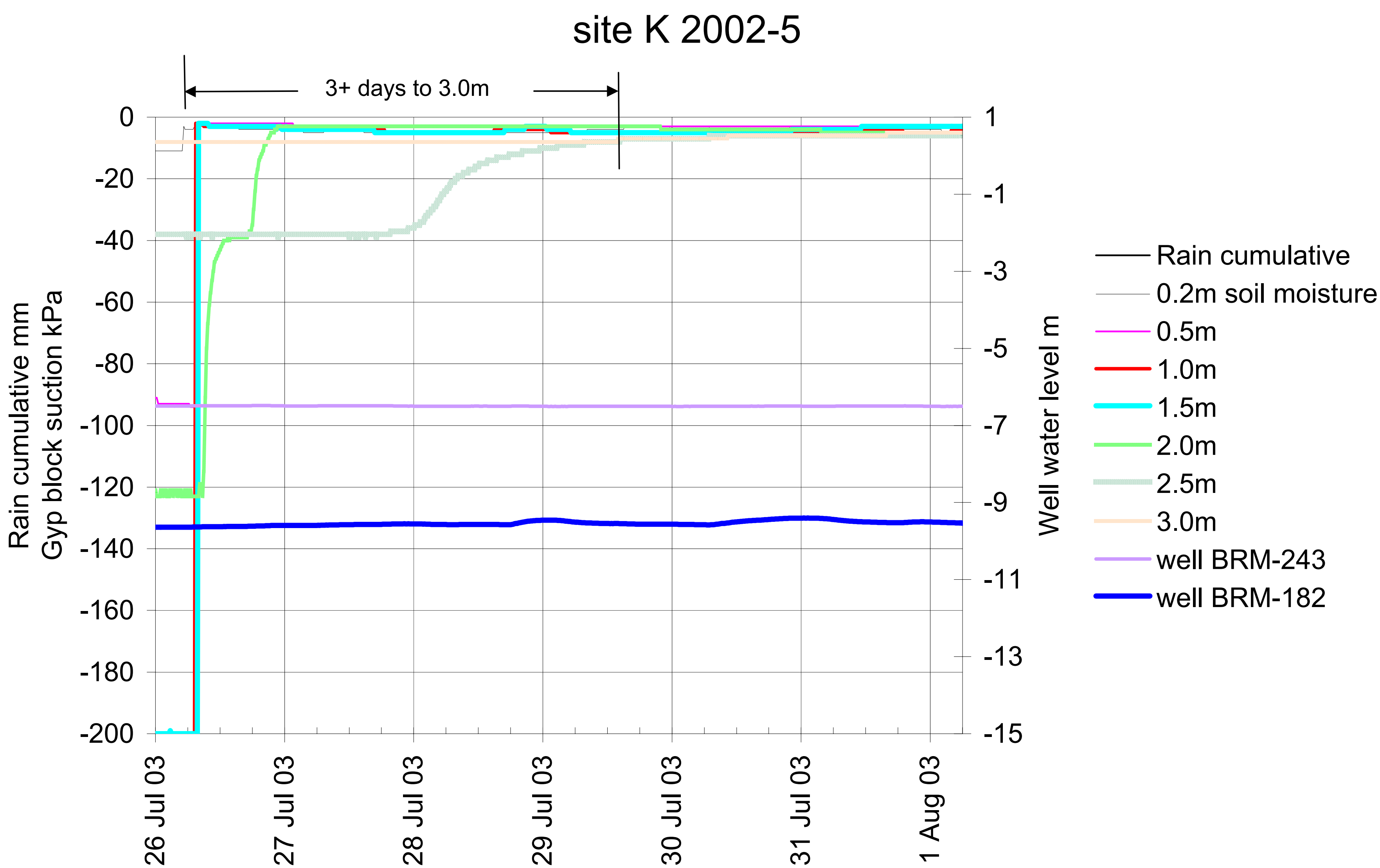

site J 2002-5
0.5m greater daily variation and also wetting before 0.2m ?
? Start recharge through ASR well
Gyp block suction kPa
Rain cumulative mm
Well water level m
300
200
100
0
-100
-200
-300
-400
-500
1
-1
-3
-5
-7
-9
-11
-13
-15
2 Apr 03
9 Apr 03
16 Apr 03
23 Apr 03
30 Apr 03
7 May 03
14 May 03
21 May 03
28 May 03
4 Jun 03
11 Jun 03
18 Jun 03
25 Jun 03
Rain cumulative
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-225
well FRL-062

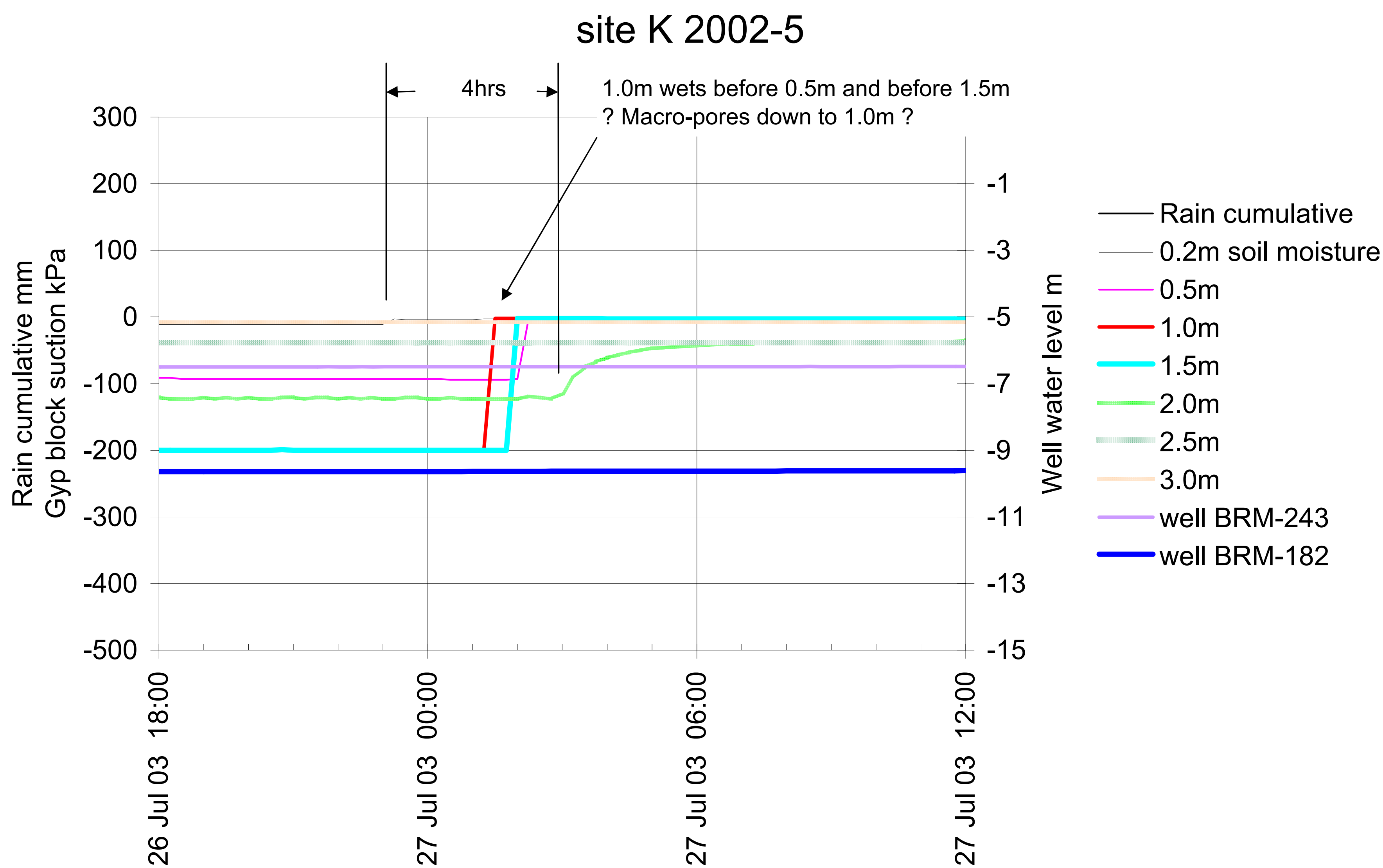
Figure B-20


site J 2002-5
Gyp block suction kPa
Rain cumulative mm
Well water level m
300
200
100
0
-100
-200
-300
-400
-500
1
-1
-3
-5
-7
-9
-11
-13
-15
34.5hr
16.5hr
13hr
6hr
1.5hr
24 Aug 18:00
25 Aug 0:00
25 Aug 6:00
25 Aug 12:00
25 Aug 18:00
26 Aug 0:00
26 Aug 6:00
26 Aug 12:00
26 Aug 18:00
27 Aug 0:00
27 Aug 6:00
Rain cumulative
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-225
well FRL-062

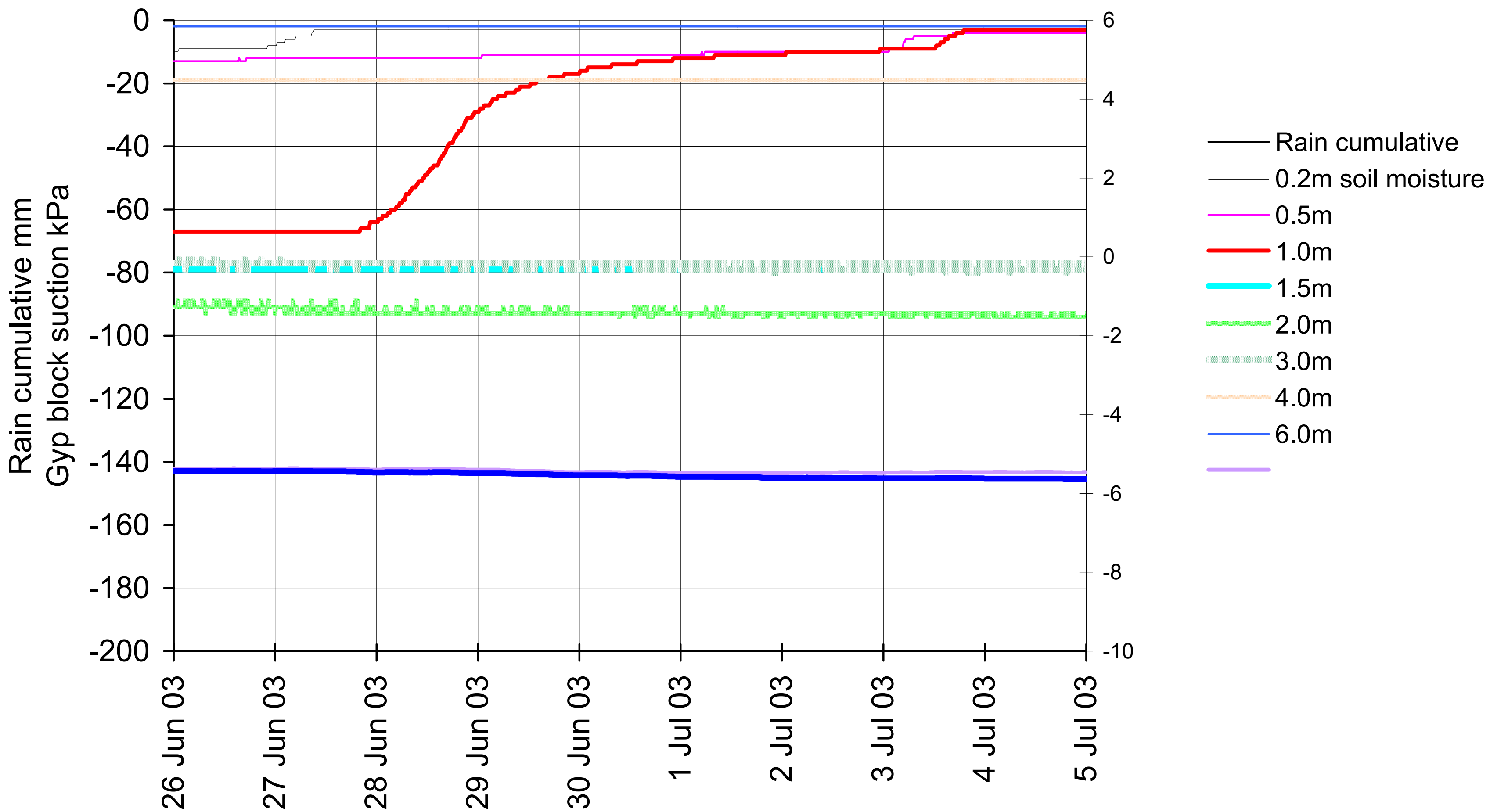


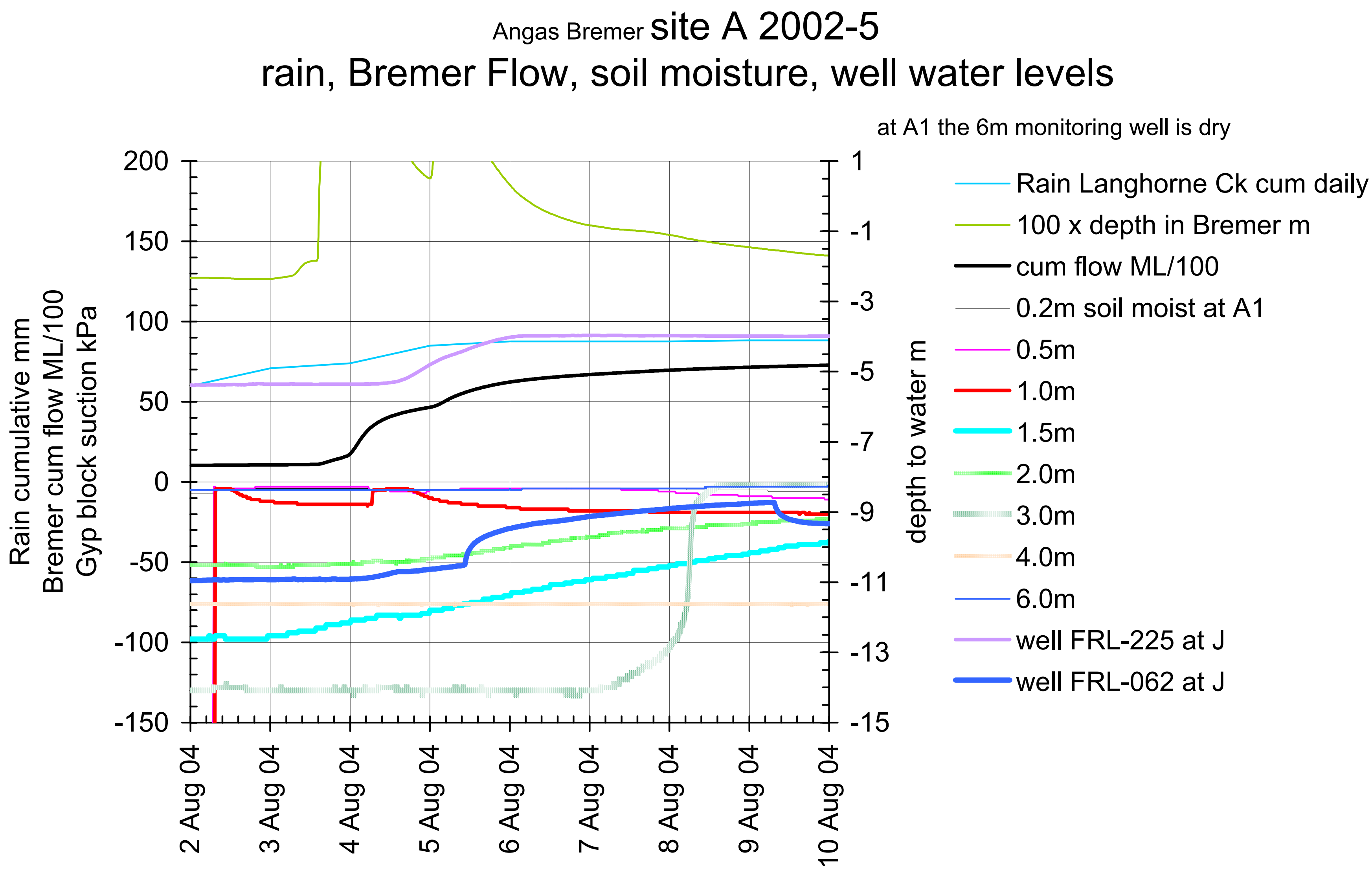
Angas Bremer site J 2002-5
rain, Bremer flow, soil moisture, well water levels
increases in Bremer flow at Hartley
Rain cumulative mm
Bremer cum flow ML/100
Gyp block suction kPa
well depth to water m
300
200
100
0
-100
-200
-300
-400
-500
-1
-3
-5
-7
-9
-11
-13
-15
-17
22 Aug 03
29 Aug 03
5 Sep 03
12 Sep 03
19 Sep 03
Rain cumulative
cum flow
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well FRL-225
well FRL-062


site K 2002-5
3+ days to 3.0m
Rain cumulative mm
Gyp block suction kPa
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Well water level m
1
-1
-3
-5
-7
-9
-11
-13
-15
26 Jul 03
27 Jul 03
28 Jul 03
29 Jul 03
30 Jul 03
31 Jul 03
1 Aug 03
Rain cumulative
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well BRM-243
well BRM-182


site K 2002-5
4hrs
1.0m wets before 0.5m and before 1.5m
? Macro-pores down to 1.0m ?
Rain cumulative mm
Gyp block suction kPa
300
200
100
0
-100
-200
-300
-400
-500
Well water level m
-1
-3
-5
-7
-9
-11
-13
-15
26 Jul 03 18:00
27 Jul 03 00:00
27 Jul 03 06:00
27 Jul 03 12:00
Rain cumulative
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well BRM-243
well BRM-182

Angas Bremer site L 2002-5
rain, Bremer flow, soil moisture, well water levels




Angas Bremer site A 2002-5
rain, Bremer Flow, soil moisture, well water levels
at A1 the 6m monitoring well is dry
Rain cumulative mm
Bremer cum flow ML/100
Gyp block suction kPa
depth to water m
200
150
100
50
0
-50
-100
-150
1
-1
-3
-5
-7
-9
-11
-13
-15
2 Aug 04
3 Aug 04
4 Aug 04
5 Aug 04
6 Aug 04
7 Aug 04
8 Aug 04
9 Aug 04
10 Aug 04
Rain Langhorne Ck cum daily
100 x depth in Bremer m
cum flow ML/100
0.2m soil moist at A1
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
well FRL-225 at J
well FRL-062 at J

Angas Bremer site B 2002-4
rain, Bremer flow, soil moisture, well water levels

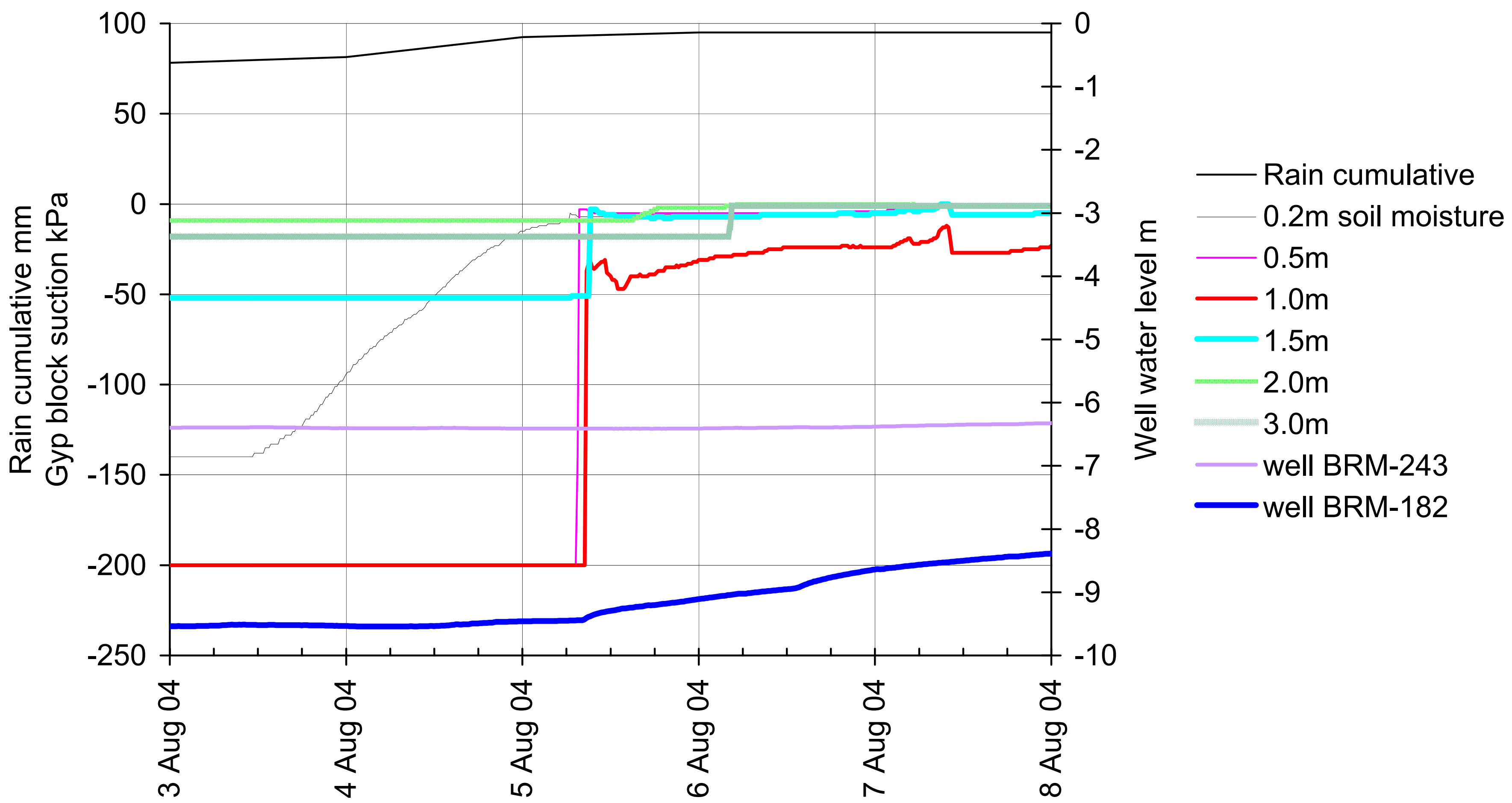
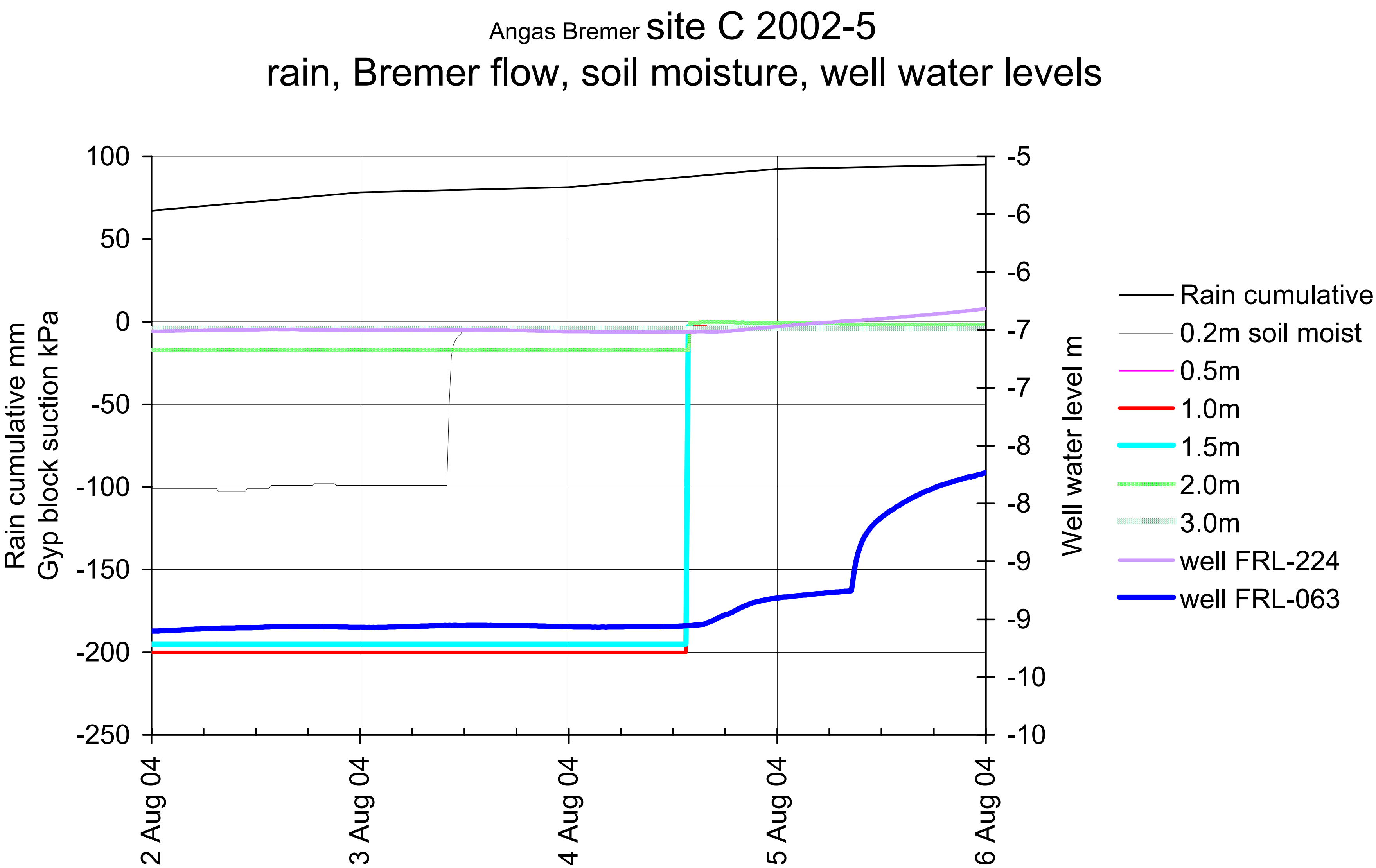


Figure B-27



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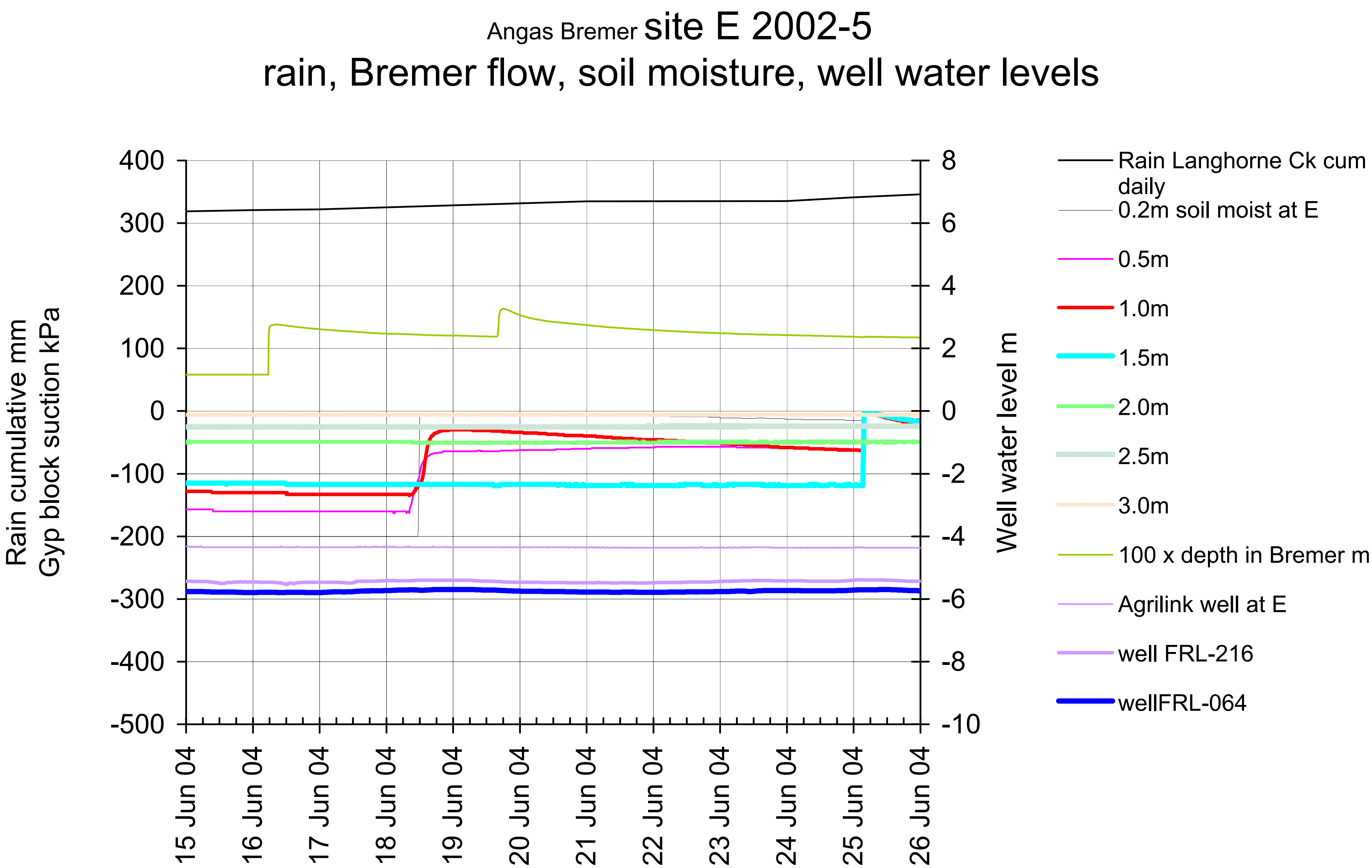
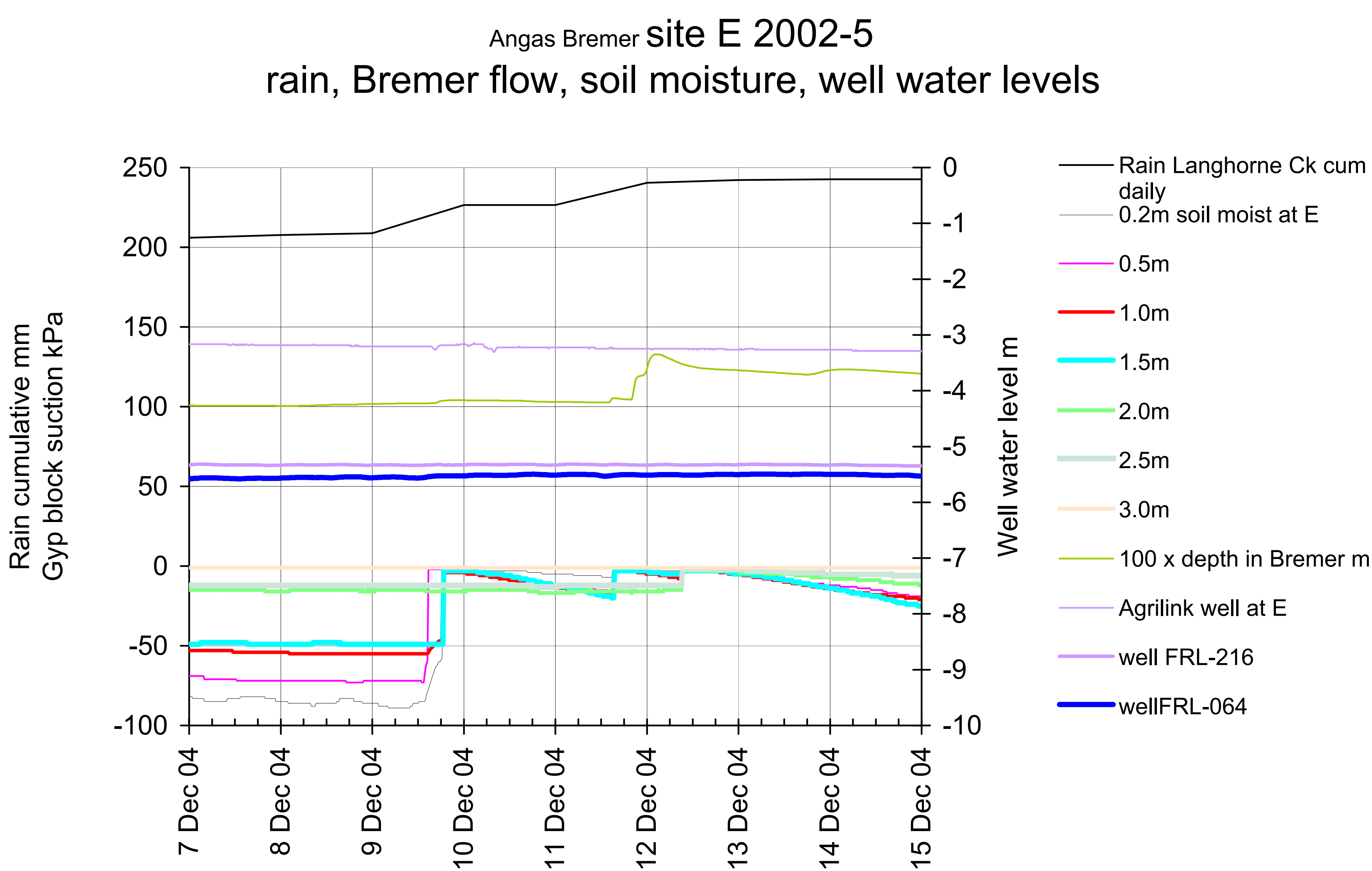
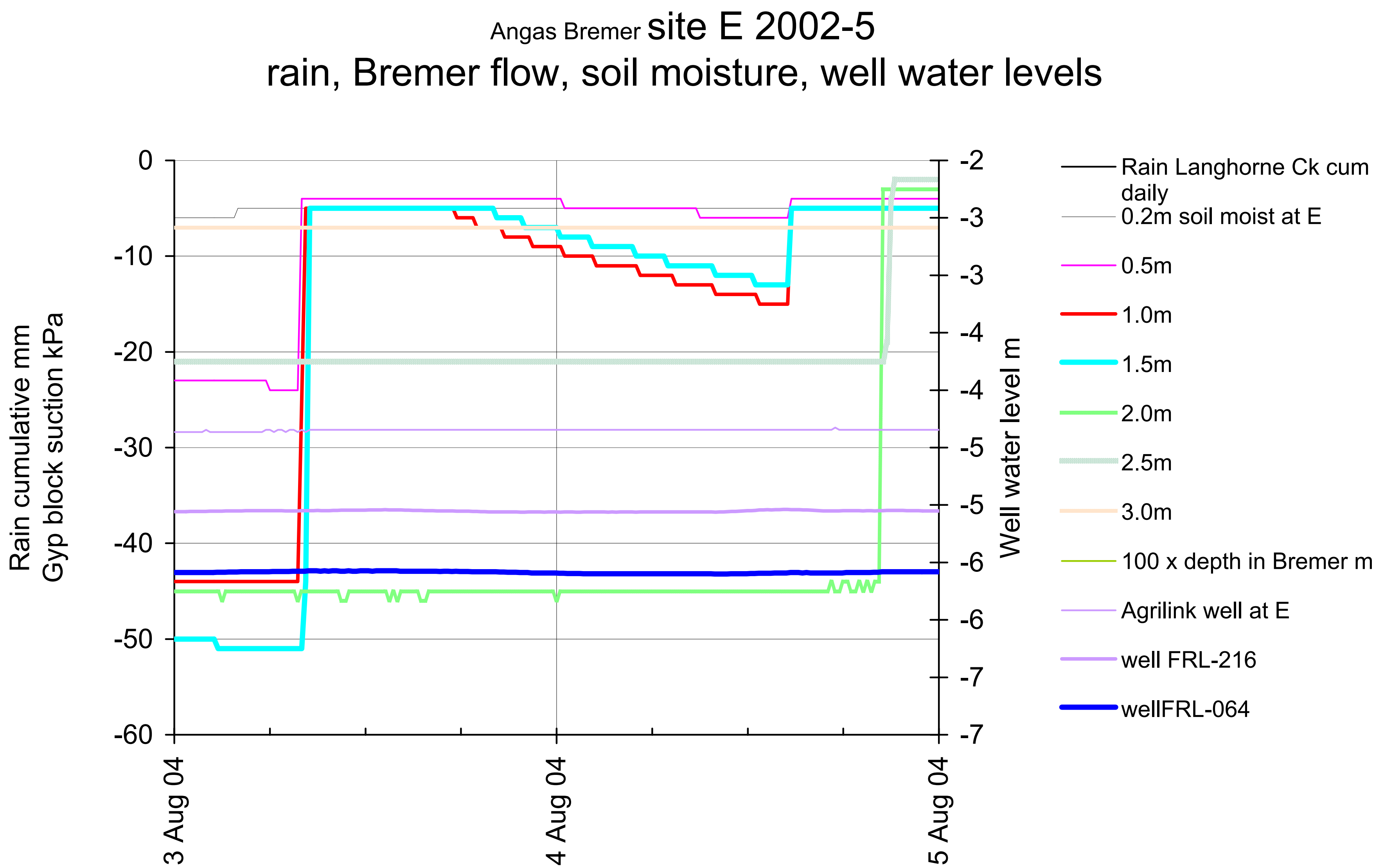
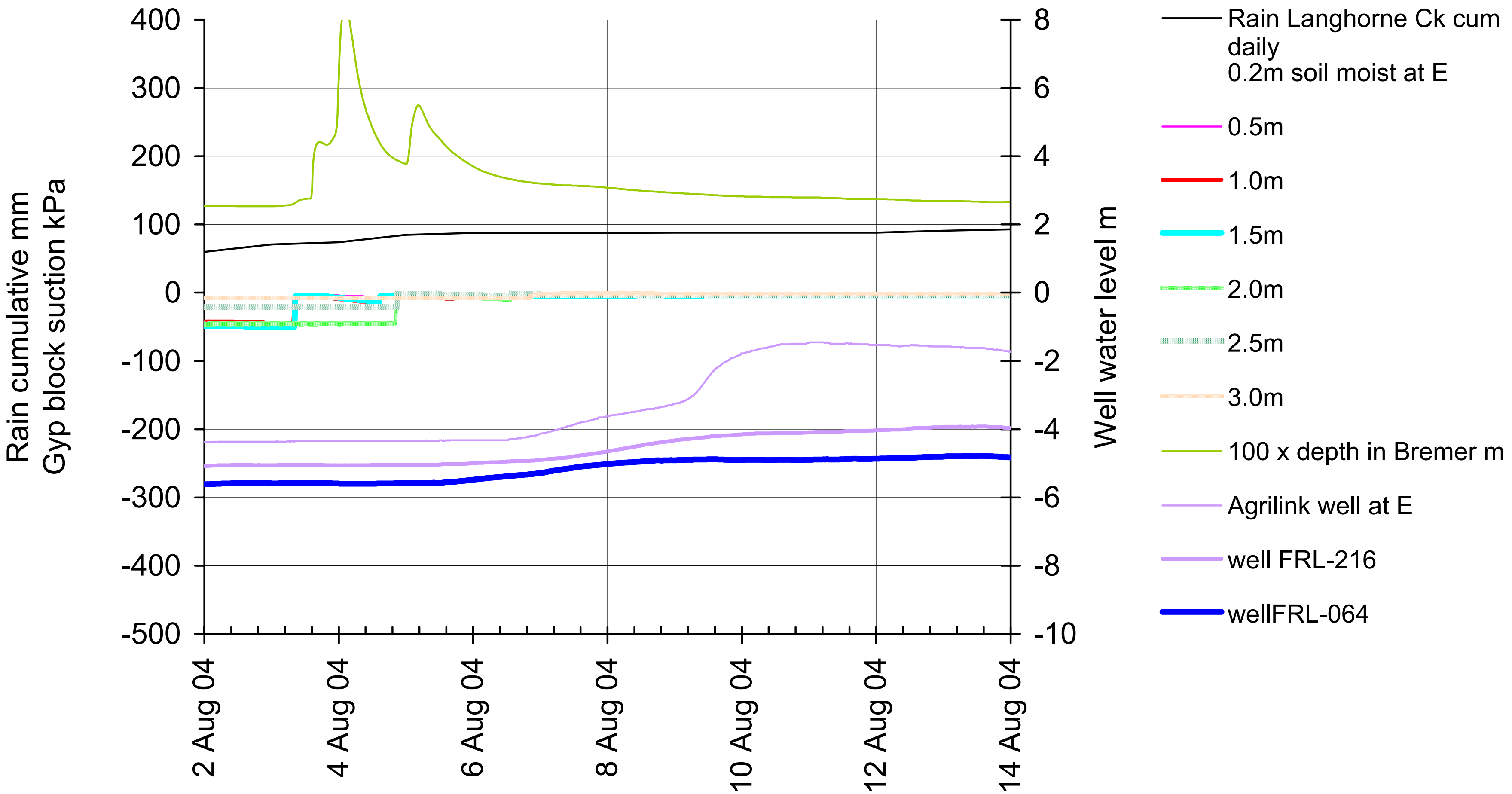

Angas Bremer site E 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
Gyp block suction kPa
Well water level m
400
300
200
100
0
-100
-200
-300
-400
-500
8
6
4
2
0
-2
-4
-6
-8
-10
15 Jun 04
16 Jun 04
17 Jun 04
18 Jun 04
19 Jun 04
20 Jun 04
21 Jun 04
22 Jun 04
23 Jun 04
24 Jun 04
25 Jun 04
26 Jun 04
Rain Langhorne Ck cum daily
0.2m soil moist at E
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
100 x depth in Bremer m
Agrilink well at E
well FRL-216
wellFRL-064

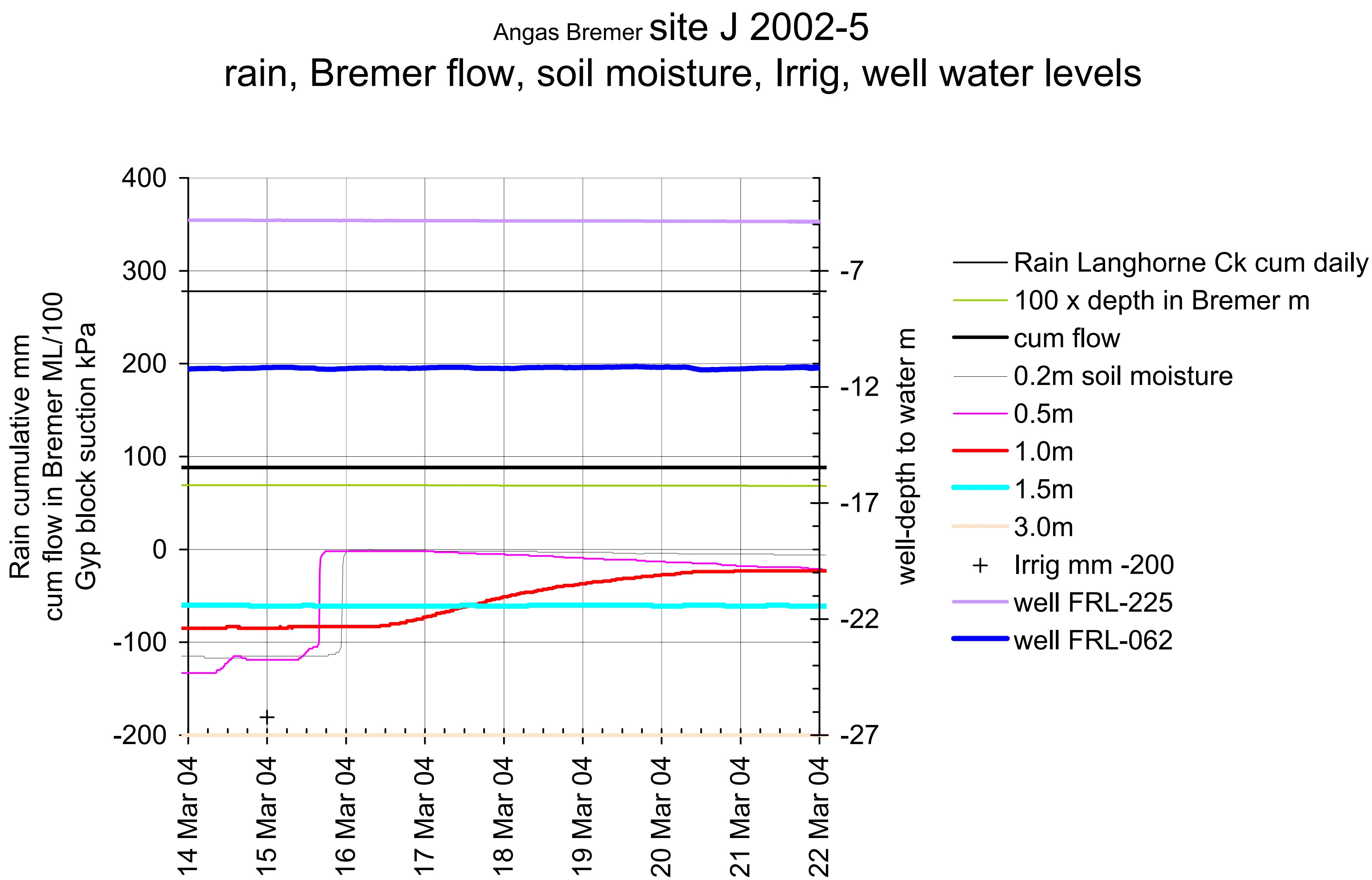
Figure B-29


Angas Bremer site E 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
Gyp block suction kPa
Well water level m
250
200
150
100
50
0
-50
-100
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
7 Dec 04
8 Dec 04
9 Dec 04
10 Dec 04
11 Dec 04
12 Dec 04
13 Dec 04
14 Dec 04
15 Dec 04
Rain Langhorne Ck cum daily
0.2m soil moist at E
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
100 x depth in Bremer m
Agrilink well at E
well FRL-216
wellFRL-064

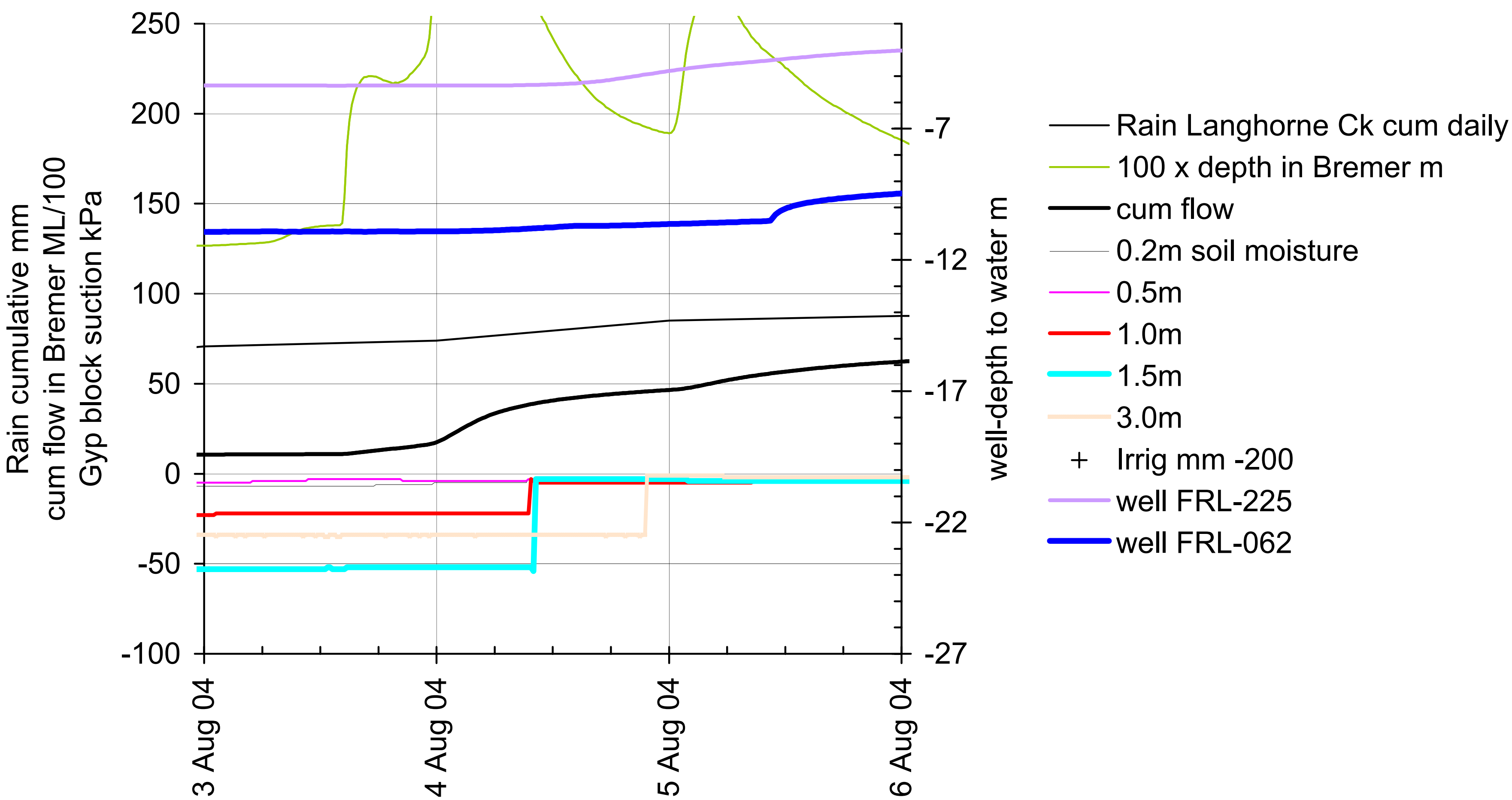

Angas Bremer site E 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
Gyp block suction kPa
Well water level m
0
-10
-20
-30
-40
-50
-60
-2
-3
-3
-4
-4
-5
-5
-6
-6
-7
-7
3 Aug 04
4 Aug 04
5 Aug 04
Rain Langhorne Ck cum daily
0.2m soil moist at E
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
100 x depth in Bremer m
Agrilink well at E
well FRL-216
wellFRL-064

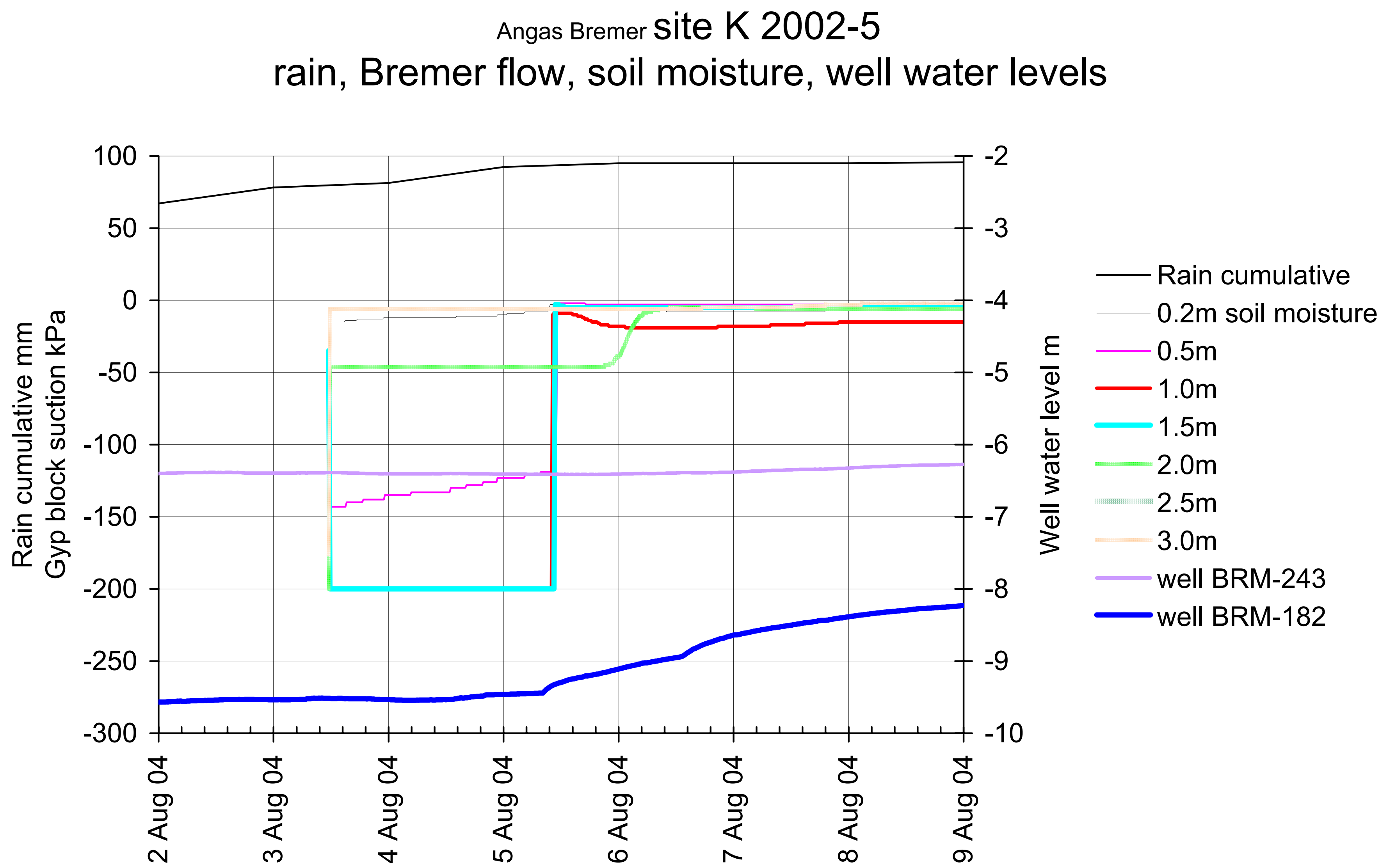
Angas Bremer site E 2002-5
rain, Bremer flow, soil moisture, well water levels

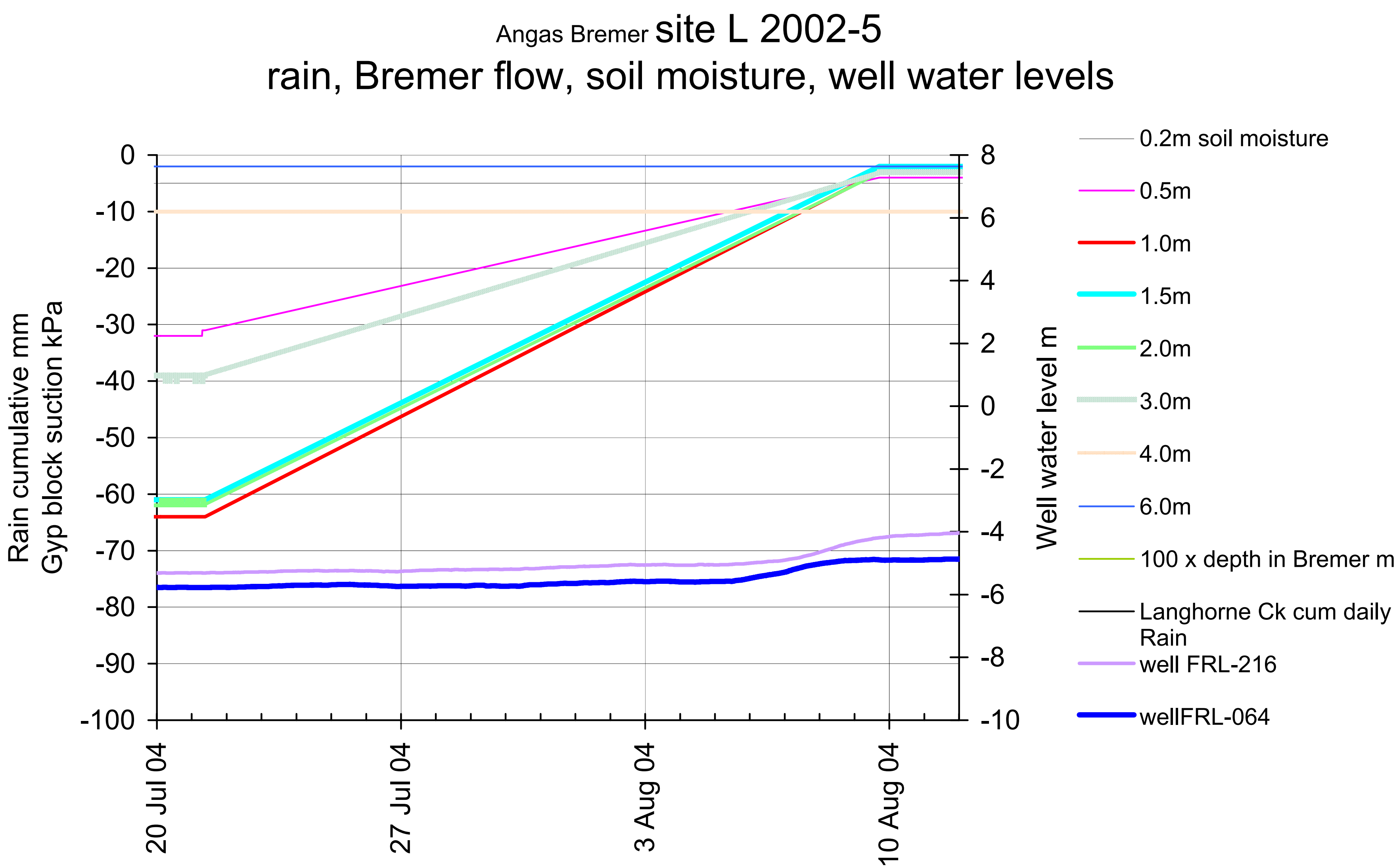



Angas Bremer site J 2002-5
rain, Bremer flow, soil moisture, Irrig, well water levels
Rain cumulative mm
cum flow in Bremer ML/100
Gyp block suction kPa
400
300
200
100
0
-100
-200
well-depth to water m
-7
-12
-17
-22
-27
14 Mar 04
15 Mar 04
16 Mar 04
17 Mar 04
18 Mar 04
19 Mar 04
20 Mar 04
21 Mar 04
22 Mar 04
Rain Langhorne Ck cum daily
100 x depth in Bremer m
cum flow
0.2m soil moisture
0.5m
1.0m
1.5m
3.0m
Irrig mm -200
well FRL-225
well FRL-062

Angas Bremer site J 2002-5
rain, Bremer flow, soil moisture, Irrig, well water levels




Angas Bremer site K 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
Gyp block suction kPa
Well water level m
100
50
0
-50
-100
-150
-200
-250
-300
-2
-3
-4
-5
-6
-7
-8
-9
-10
2 Aug 04
3 Aug 04
4 Aug 04
5 Aug 04
6 Aug 04
7 Aug 04
8 Aug 04
9 Aug 04
Rain cumulative
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
2.5m
3.0m
well BRM-243
well BRM-182


Angas Bremer site L 2002-5
rain, Bremer flow, soil moisture, well water levels
Rain cumulative mm
Gyp block suction kPa
Well water level m
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
8
6
4
2
0
-2
-4
-6
-8
-10
20 Jul 04
27 Jul 04
3 Aug 04
10 Aug 04
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
100 x depth in Bremer m
Langhorne Ck cum daily Rain
well FRL-216
wellFRL-064

Angas Bremer site M 2002-5

rain, soil moisture, well water levels

M is central in area of largest groundwater use

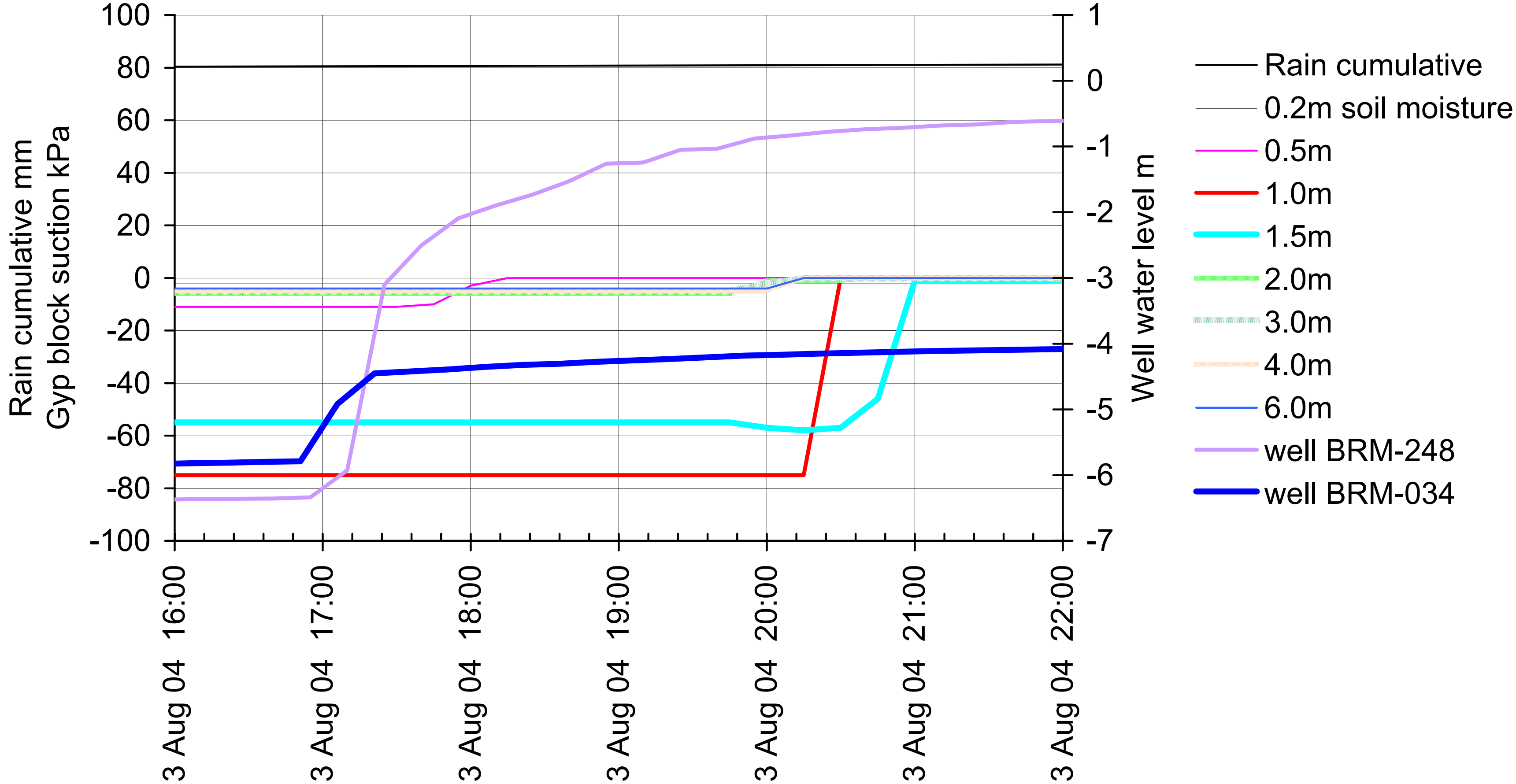
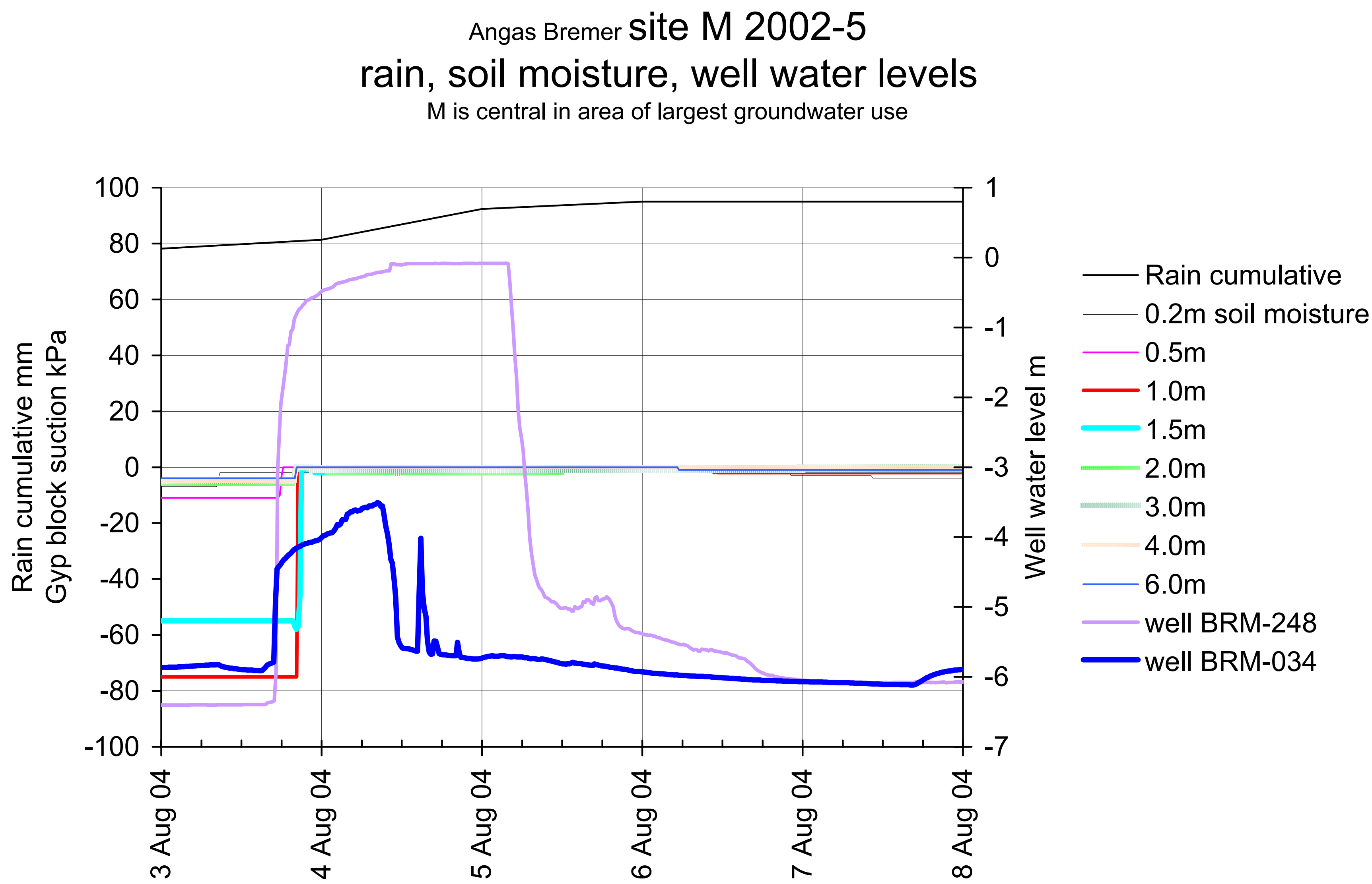
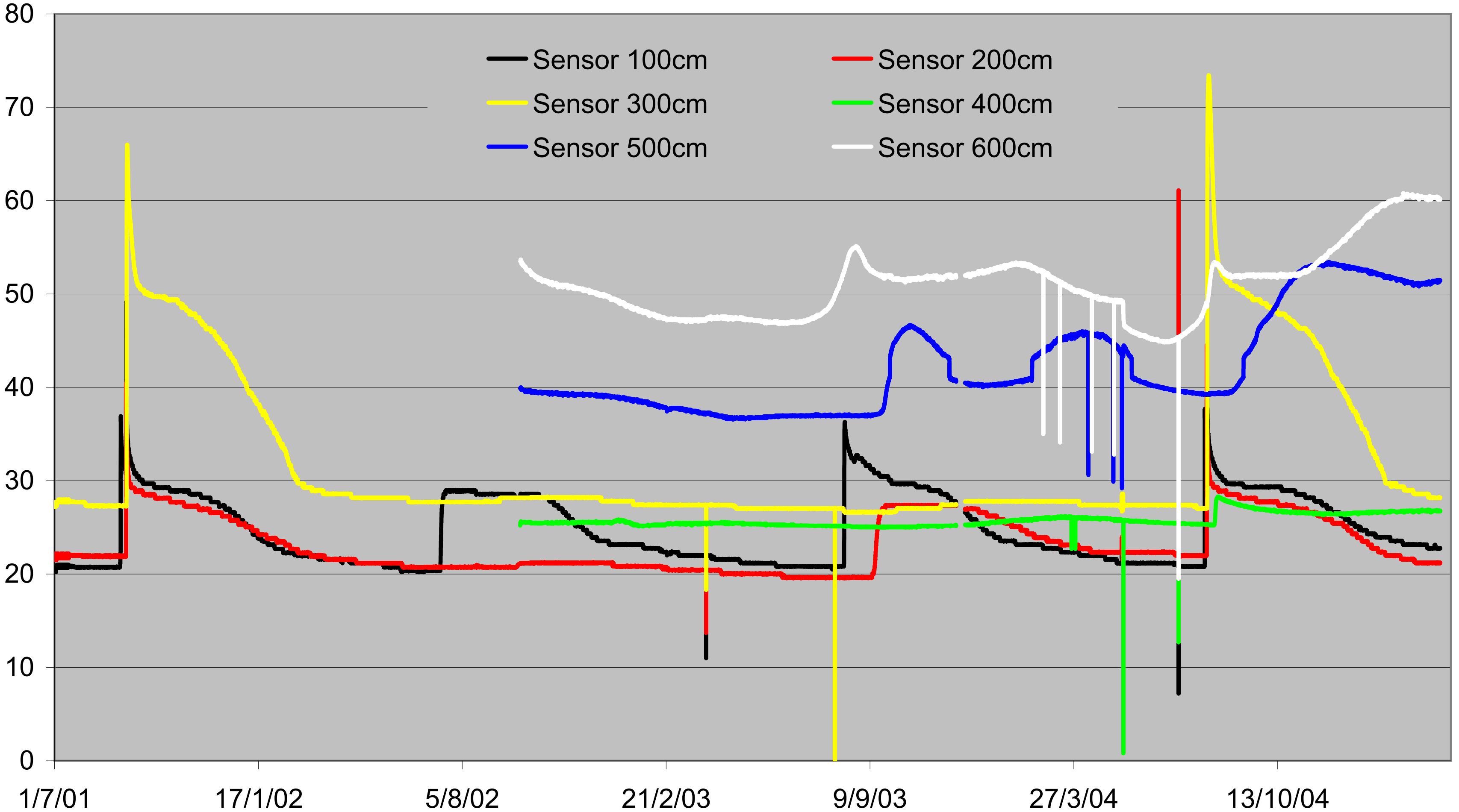


Figure B-37



Angas Bremer site M 2002-5
rain, soil moisture, well water levels
M is central in area of largest groundwater use
Rain cumulative mm
Gyp block suction kPa
Well water level m
100
80
60
40
20
0
-20
-40
-60
-80
-100
1
0
-1
-2
-3
-4
-5
-6
-7
3 Aug 04
4 Aug 04
5 Aug 04
6 Aug 04
7 Aug 04
8 Aug 04
Rain cumulative
0.2m soil moisture
0.5m
1.0m
1.5m
2.0m
3.0m
4.0m
6.0m
well BRM-248
well BRM-034

Angas Bremer Site A 2001-05 Agrlink soil moisture data



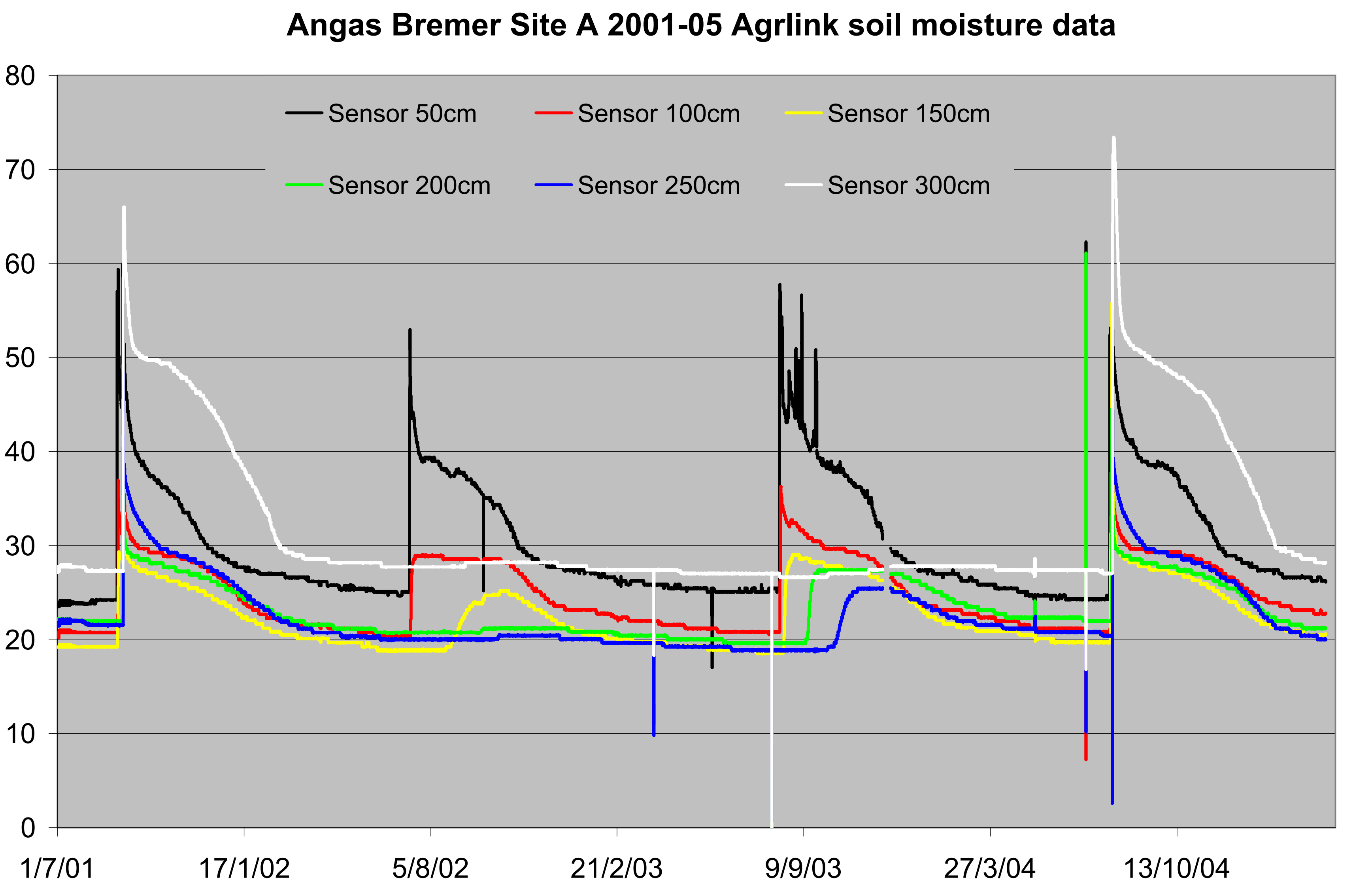
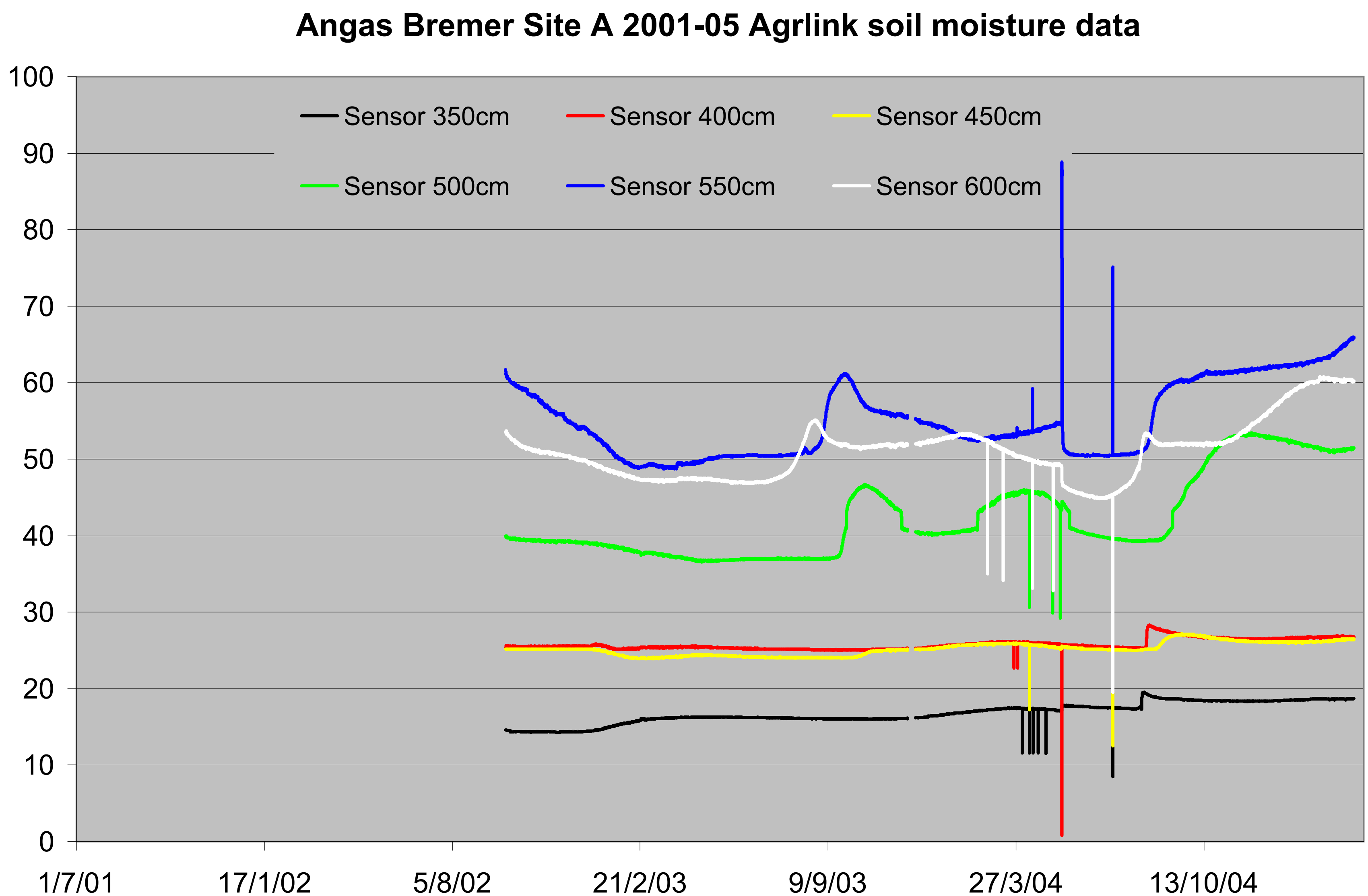

Angas Bremer Site A 2001-05 Agrlink soil moisture data
Sensor 50cm
Sensor 100cm
Sensor 150cm
Sensor 200cm
Sensor 250cm
Sensor 300cm
80
70
60
50
40
30
20
10
0
1/7/01
17/1/02
5/8/02
21/2/03
9/9/03
27/3/04
13/10/04

Figure B-40



Angas Bremer Site A 2001-05 Agrlink soil moisture data
100
90
80
70
60
50
40
30
20
10
0
Sensor 350cm
Sensor 400cm
Sensor 450cm
Sensor 500cm
Sensor 550cm
Sensor 600cm
1/7/01
17/1/02
5/8/02
21/2/03
9/9/03
27/3/04
13/10/04