

Temporal trends of groundwater levels in the Border Rivers alluvia

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Cover Photo

"Callandoon creek's stagnant waters", by "mcoquin"(Google earth)

Abbreviations

asl – Above sea level

CRDC – Cotton Research and Development Corporation

DNRM- Department of Natural Resources and Mines

GCF- Griman Creek Formation (geological unit)

GWDB - Queensland Government GroundWater DataBase

USQ- The University of Southern Queensland

Executive summary

This report analyses the groundwater levels trends in the Queensland section of the Border Rivers alluvia (Macintyre and Weir Rivers), downstream of Goondiwindi to Mungindi. The aquifer in this area is rather thin and contains relatively salty water. Large portion of this area is currently utilized for irrigated and dryland cropping; storages and channels were erected to support the agriculture development. Deep-drainage and rising groundwater levels, which were identified in previous studies and were attributed to the agricultural activities, were re-investigated and constrained.

Major findings are:

- Stable groundwater levels at the outskirts of the floodplain;
- On-going decrease in groundwater levels near Goondiwindi;
- Induced streambed recharge during the 2010-2013 high flow period along several stream sections (but not in others);
- Rising groundwater levels near many irrigated lands which were consistently associated with deep-drainage, in the order of 10-40 mm/yr;
- Induced deep-drainage and leakiness under red-soils in two localities near South Talwood.

It is recommended to increase monitoring frequency at those bores where dynamic changes were identified, especially where the groundwater level is very shallow.

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1 Introduction

The Border Rivers alluvia, between Goondiwindi, Mungindi and the Macintyre River, along the QLD-NSW border, comprises a wide floodplain with extensive irrigated and dryland cropping. The shallow alluvial aquifer under the floodplain is generally regarded as having low recharge rates under non-irrigated land uses (Herczeg 2004; Tolmie et al. 2011). Previous studies observed rising groundwater levels under some irrigated areas, and attributed these trends to deep-drainage from surplus irrigation water which percolated downward (Biggs et al., 2005; Whiting, 2007). The groundwater in the alluvia is typically shallow, very saline and sometimes acid. For these reasons, groundwater rising to the surface is considered a risk for both soil salinity and increased salt discharges to surface water. This report reviews the recent changes and trends in groundwater levels in the lower Border Rivers catchment.

1.1 Scope of the report

The current report was made as an integral part of the DNRM project – ‘The impact of improved WUE on paddock and catchment health’, sponsored by the Cotton RDC. Two of the project aims are to ‘Understand recent groundwater trends in cotton growing areas in the QMDB and risks posed to landscape health, and options for management’ and ‘Determine likely groundwater rise, timeframes and severity for groundwater and salt discharges, and management responses’.

The report presents the up-to-date conceptual understanding of the hydrogeology in the Border Rivers alluvia, followed by a detailed analysis of bore hydrographs. The latter is based solely on DNRM monitoring bores, which are spread throughout the area. Private domestic & stock bores are scarce (especially west of Goondiwindi), as the groundwater is generally saline; inclusion of their hydrological data is not expected to enhance the spatial or temporal insights of this review.

1.2 Aims and Objectives

The hydrogeological review had three primary aims:

- Identify recent trends of groundwater levels in the Border Rivers alluvia, including the cotton growing areas around Goondiwindi, Thaloon, Talwood and Mungindi
- Indicate any association between high stream flow events and groundwater level trends

- Support the hydrogeological conceptual model for the alluvial and sedimentary aquifer systems within the investigation area

In turn, the gathered information will be used to achieve the project aims by-

- Identifying possible risks for cotton growing areas due to groundwater level rise or fall
- Identifying areas where further (new) irrigation schemes are likely to affect landscape health
- Identifying areas where data are not available, and
- Recommend further management and monitoring

2 Study area

The study area covers the central part of the Border Rivers catchment, which bounds within the state of Queensland (the catchment also stretches in NSW). It stretches over an area of about 4,420 km² between Goondiwindi in the east, through Talwood, to Mungindi in the west; it bounds by the Macintyre River, which runs along the QLD-NSW border in the south (Figure 1). The area includes many irrigation and dryland farms. Land uses in the study area include 267,961 ha (60% of total) of grazing, 80,460 ha (18%) of dryland cropping, 72,486 ha (16%) of irrigated cropping, and 9,000 ha of dams (2%).

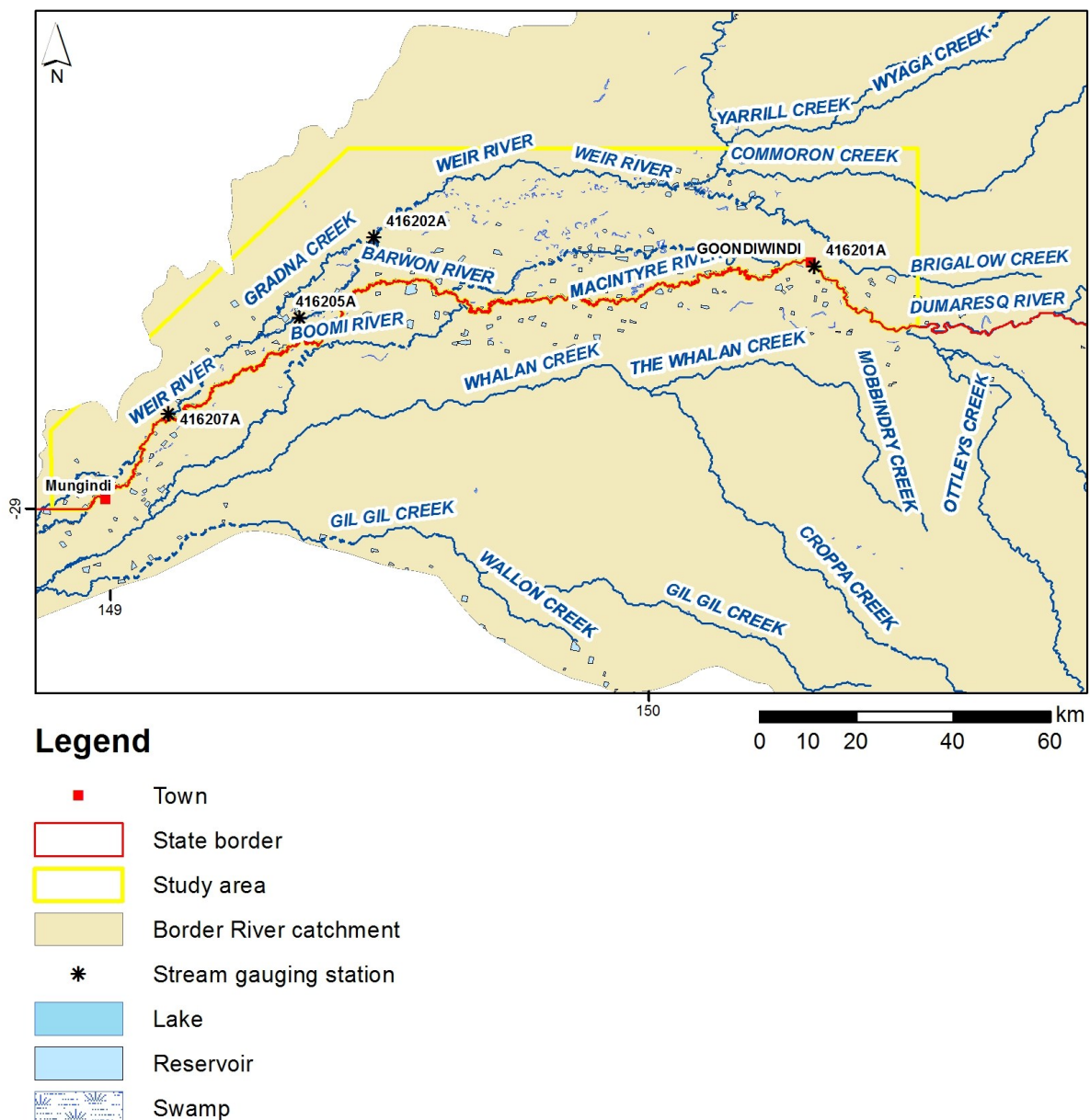


Figure 1: Location map

Ground elevations decrease from ~215 m asl near Goondiwindi to ~160m in the west. Soils on the alluvial plain are predominantly comprised of grey Vertosol , with patches of brown Sodosol on the drainage floors of major creeks or gently undulating areas ('Macintyre Vertosol' and 'Serpentine Sodosol', respectively, Whiting, 2007). Red Dermosol, Chromosol and Kandosol predominant the upland areas, west of Talwood (Biggs et al., 2005).

2.1 Climate

The study area is characterized by a semi-arid sub-tropical climate. The average annual rainfall decreases westward, from ~600 mm near Goondiwindi to ~500 mm near Mungindi. Hot, dry summers (October-March) with prolonged drought periods are common.

The rainfall is summer dominant and highly variable, with occasional periods of high-intensity rain and runoff, and extended periods of severe drought and low stream flow (Figure 2b). Most recently, dry conditions occurred in southern Queensland from 2001 onward (National Climate Centre, 2006) up to 2009.

2.2 Hydrology

The study area is part of the Border Rivers catchment. In its east, Ottleys Creek (NSW) and Dumaresq River join the Macintyre River, and the Brigalow and Commoron creeks join to form the Weir River. The Macintyre and the Weir rivers flow parallel to each other, finally merging into the Barwon River (Figure 1). However, the area in-between these rivers, west of Goondiwindi, comprises a complex braided stream system. The flows are highly variable (Figure 2) and, as with many Queensland systems, prone to extreme high inflow events.

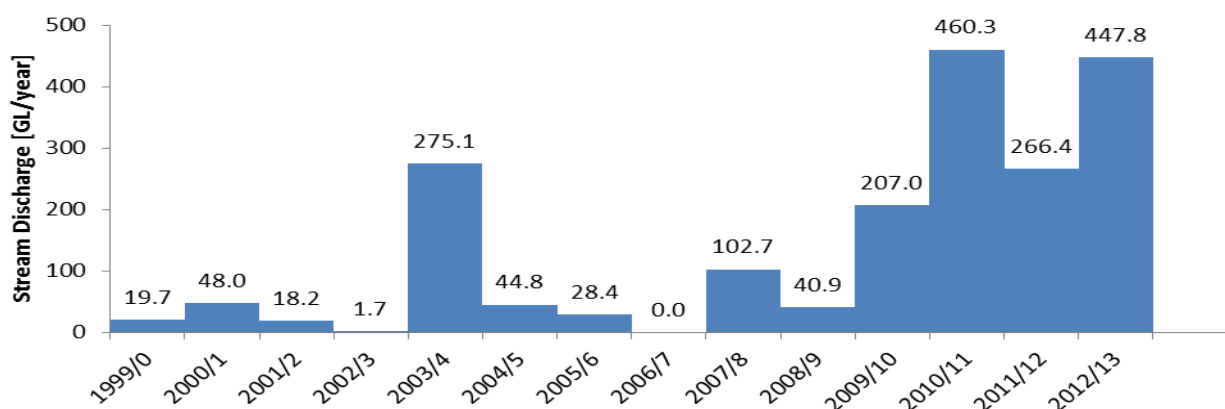


Figure 2: Annual discharge of the Weir River (Station #416202A)

Water for irrigation is released into the Macintyre River from Coolmunda (75,000 ML capacity) and Glen Lyon Dams (254,000 ML) during spring and summer and is pumped out of the river to on-farm storages. The surface water is of low salinity, particularly in respect to other water sources in the study area (Please et al., 2000). In the Macintyre River, three pesticides (atrazine, DEA, metolachlor) were identified in the 1994 audit near Goondiwindi (Please et al., 2000).

2.3 Hydrogeology

The study area is comprised of the Cretaceous Griman Creek Formation (GCF), overlain by young fluvial-alluvial sediments. The GCF (Ksrg, in Figure 3; at the uppermost part of Rolling Downs Group) accumulated as part of the larger Surat Basin, and consists of siltstones, mudstones and sandstones. In later stages, it was eroded into sandy units (Qrc) and covered by a shallow (<30 m) apron of alluvial sediments (Qa).

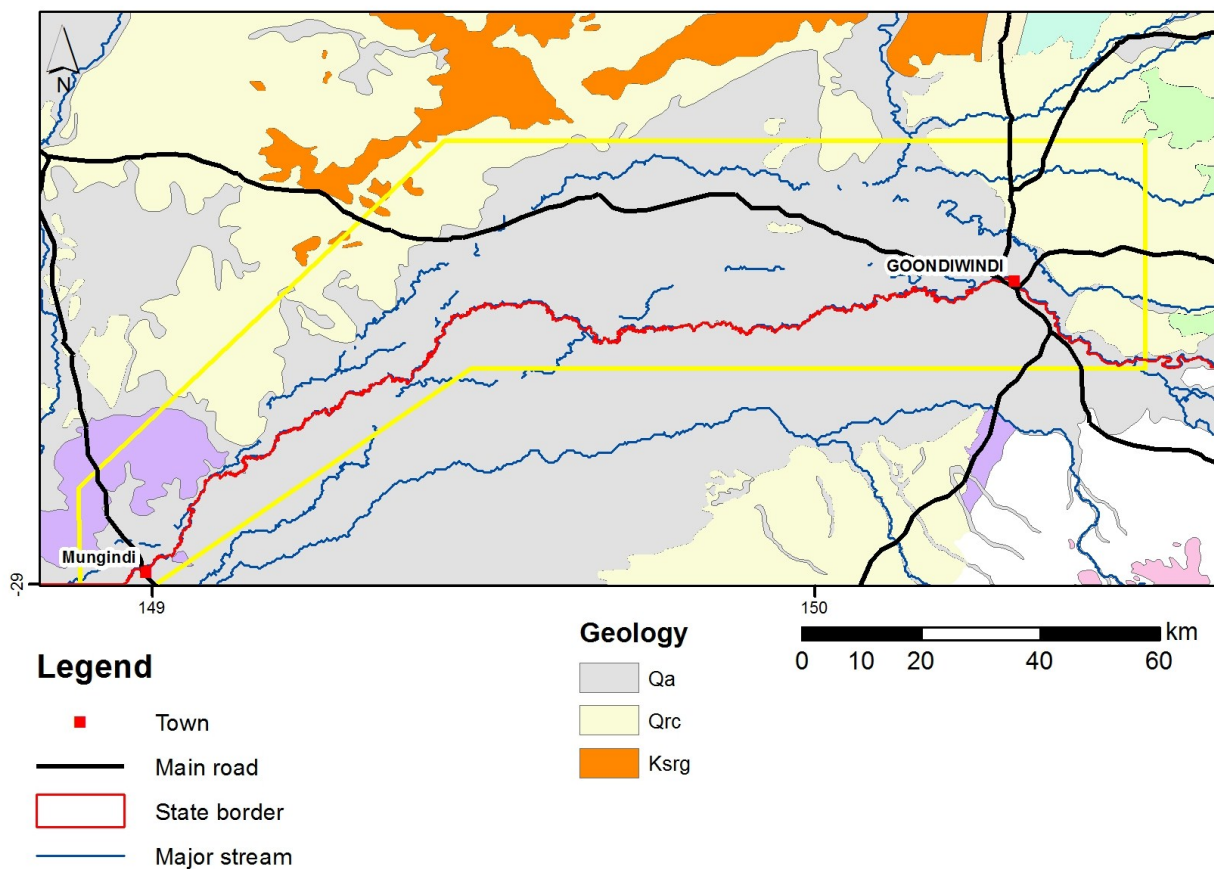


Figure 3: Geological map (see text for geological unit's names)

The two dominant hydrogeological units in the study area are the GCF aquitard and the shallow alluvial aquifer. Typically the GCF has low hydraulic conductivity with little aquifer storage, hence for practical purposes, it serves as the base of the alluvial

aquifer (Biggs et al., 2005; Whiting, 2007). Both units contain fairly saline groundwater, with the exception of the part east of Goondiwindi Fault.

Rainfall recharge rates, estimated from groundwater chloride mass balance, are less than 1 mm/yr on average (Herczeg, 2004). These rates are consistent with deep drainage rates measured using soil chloride mass balance for native vegetation (e.g. 0.2-0.3 mm/yr for coolabah woodland near Nindigully and Billa Billa near Goondiwindi; Tolmie et al., 2011). Streambed recharge was speculated along streams east to Goondiwindi (Williams et al., 1987; Whiting, 2007).

The overall groundwater flow system is comprised of two convergence components: an east to west component, which is pronounced south of the Weir River, and a north to south component, which is pronounced north of the Weir River (Figure 4). Groundwater heads decrease from ~+210 m asl, east of Goondiwindi, to +172 m asl near Talwood and to +142 m asl near Mungindi. Figure 4 show the flow field in the central part of the investigated area.

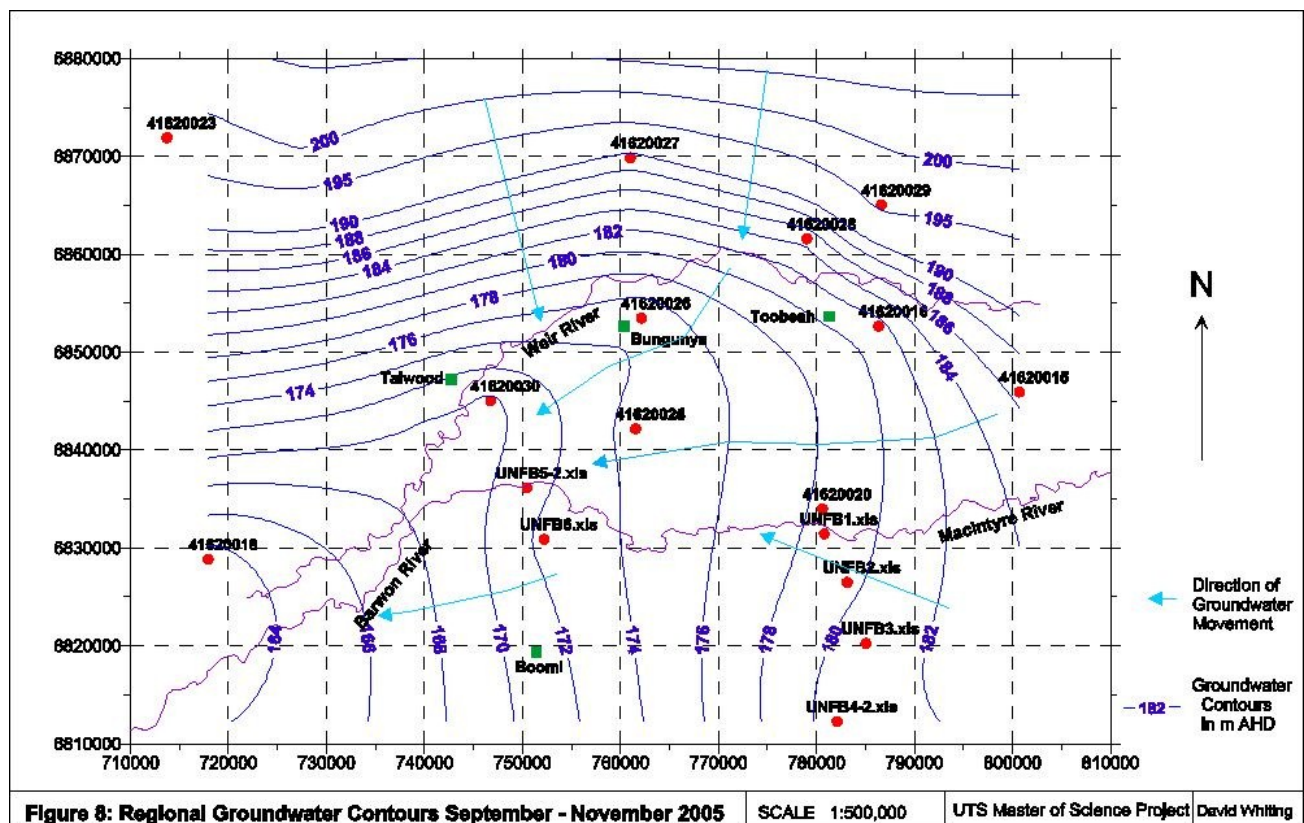


Figure 4: Groundwater level elevation contours for the Alluvial Aquifer (Whiting, 2007)

Deep-drainage from cleared croplands was suggested as an additional source of recharge, to explain the observed trend of rising groundwater levels across the study area (Table 1) (Biggs et al., 2006; Whiting, 2007). The deep-drainage under dryland

cropping areas has been estimated based on chloride mass balance to be 2-5 mm/yr and 10.4 mm/yr from Vertosols and Sodosols, respectively (Tolmie et al., 2011). The deep-drainage under irrigated fields has been estimated, based on numerical modelling, to be 83 mm/yr and 78 mm/yr from Vertosols and Sodosols, respectively, and up to 196 mm/yr under loose-sand units (Whiting, 2007).

Table 1: Groundwater level data from previous studies (Table 4 of Whiting, 2007)

| Bore ID | WL start date | WL Trend | Comments |
|-----------------------------|---------------|---|--|
| Inside Project Area | | | |
| 41620016 | 6/10/2000 | relatively stable | |
| 41620019 | 10/10/2000 | gradual rise with slight fluctuations from 2000 to 2005 followed by slight decline in 2006 | slight mounding - irrigated site near 41620020 |
| 41620020 | 22/05/2000 | slight rise from 2000 to 2005 followed by slight decline in 2006 | control site near 41620019 |
| 41620024 | 28/08/2001 | relatively stable | |
| 41620026 | 27/08/2001 | fluctuations | |
| 41620030 | 27/08/2001 | relatively stable | |
| Outside Project Area | | | |
| 41620015 | 22/05/2000 | relatively stable | |
| 41620017 | 23/05/2000 | gradual rise of 2.34m from May 2000 to May 2006 | mounding - irrigated site near 41620018 |
| 41620018 | 24/05/2000 | fluctuations of about 1m amplitude with similar pattern of rise as site 41620017 from 2004 onwards. | control site near 41620017 |
| 41620027 | 28/08/2001 | relatively stable | higher water level than adjacent bedrock bore 41620031 |
| 41620028 | 23/08/2001 | relatively stable | |
| 41620029 | 24/08/2001 | slight fluctuations | |
| 41620031 | 28/08/2001 | relatively stable | |

3 Methodology

3.1 Data sources

Bore data was extracted from the Queensland Government Groundwater Database (GWDB), which is managed by DNRM. The database includes groundwater depth records for 62 monitoring bores in the studied area; all but two of these bores were selected for analysis, as they contain some records for the years 2000-2013. All of the bores included in the discussion are located in the Weir-Lower Macintyre sub-basin (4162) and are identified by the last 4 digits of their respective RN.

Streamflow data was extracted from the Queensland Government DNRM Water Monitoring Data Portal website (DNRM web site, 2013). Seven gauging stations are located within the study area (Table 2). The raw data include many footnotes relating to the accuracy of the measurement, such as estimations, poor or fair reading; these were disregarded when stream flow time series were created.

The data was extracted in June 2014 and was censored at 31/5/2013.

Table 2: List of selected stream gauging stations

| Station | Location | Location (Order) downstream | | |
|----------------|-------------------------------------|-----------------------------|------------|-----------|
| | | Weir | Callandoon | Macintyre |
| 416201A | Macintyre River at Goondiwindi | | | 1 |
| 416201B | Macintyre River at Goondiwindi Weir | | | 2 |
| 416202A | Weir River at Talwood | 1 | | |
| 416203A | Callandoon Creek at Carana Weir | | 1 | |
| 416205A | Weir River at Jericho | 2 | | |
| 416206A | Callandoon Creek at Oonavale | | 2 | |
| 416207A | Weir River at Mascot | 3 | | |

3.2 Data analysis

The GWDB contains time series of groundwater depths (WD), i.e., the depth of the water table from a reference point, which is found slightly above the surface elevation. These data are given as negative values, and were transformed into absolute water levels (WL) using equation 1 and the reference point elevation (Ref):

1)
$$WL = Ref + WD$$

For consistency, water depths are presented as negative values and water elevation as positive values, representing elevation above sea level (asl); all values are given in meters. In the following report, the use of the latter was preferred for consistency.

4 Results and discussion

4.1 Stream flow

Cumulative stream flow (discharge) at selected stations, arranged in the downstream direction along the Weir (unregulated) and Macintyre (regulated) rivers, is shown in Figure 5 (note the logarithmic scale). Each diagram shows the monthly discharge (columns) in ML (Mega-litre, equivalent to 10^3 cubic meters).

The records show the seasonal flow pattern in both the Weir and Macintyre rivers, with low discharge during the winter months and intermittent 'floods' in the summer, usually between December to March. The flow in the Macintyre River is perennial, while in the Weir River it is intermittent. The discharge in the last three hydrological years (2009/10-2012/13) was substantially higher than that of the 1999/2000 through 2008/9 (see also Figure 2).

There are no detectable relationships (either decrease or increase) of the stream flow between downstream stations. Furthermore, it seems that such relationships cannot be developed given the branching nature of the flow system, extractions for irrigation and current number of gauging station.

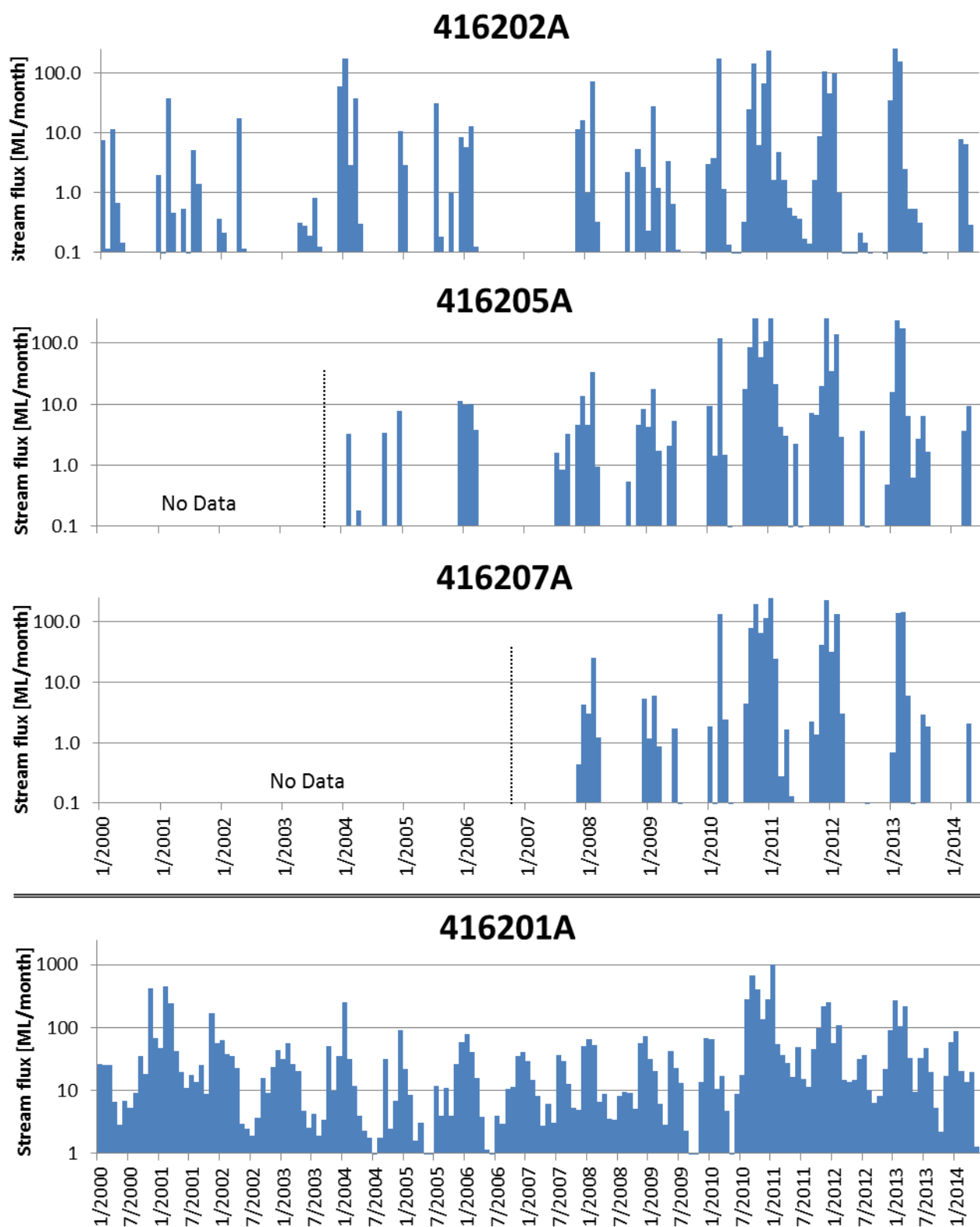


Figure 5: Recent stream flow records (stations location in Table 2).

4.2 Groundwater monitoring status

Data collection from bores in the study area has been increased substantially since initiation in 1985. It was at its peak in 2009-2010, with ~50 bores being monitored, but decreased since to 35 bores in 2013 (Figure 6). The monitoring scheme (which is currently under DNRM review) includes nine bores, all located around Goondiwindi (Figure 7).

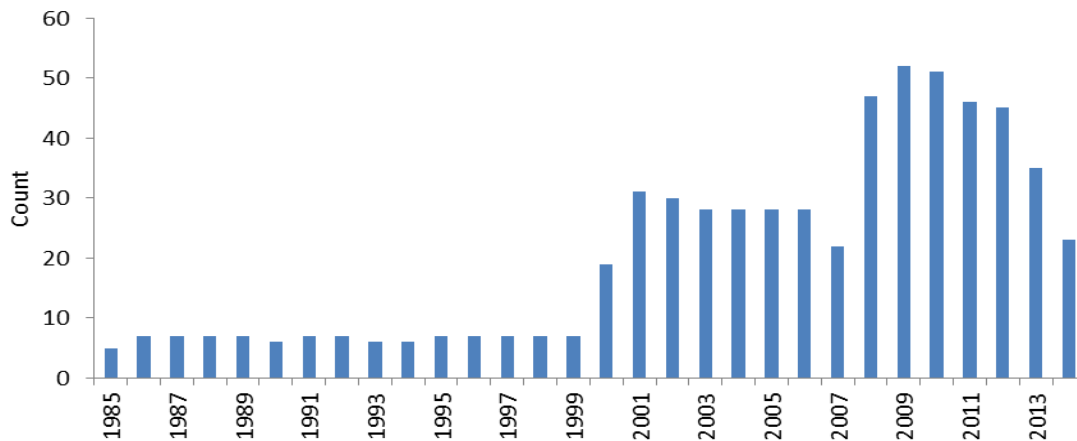
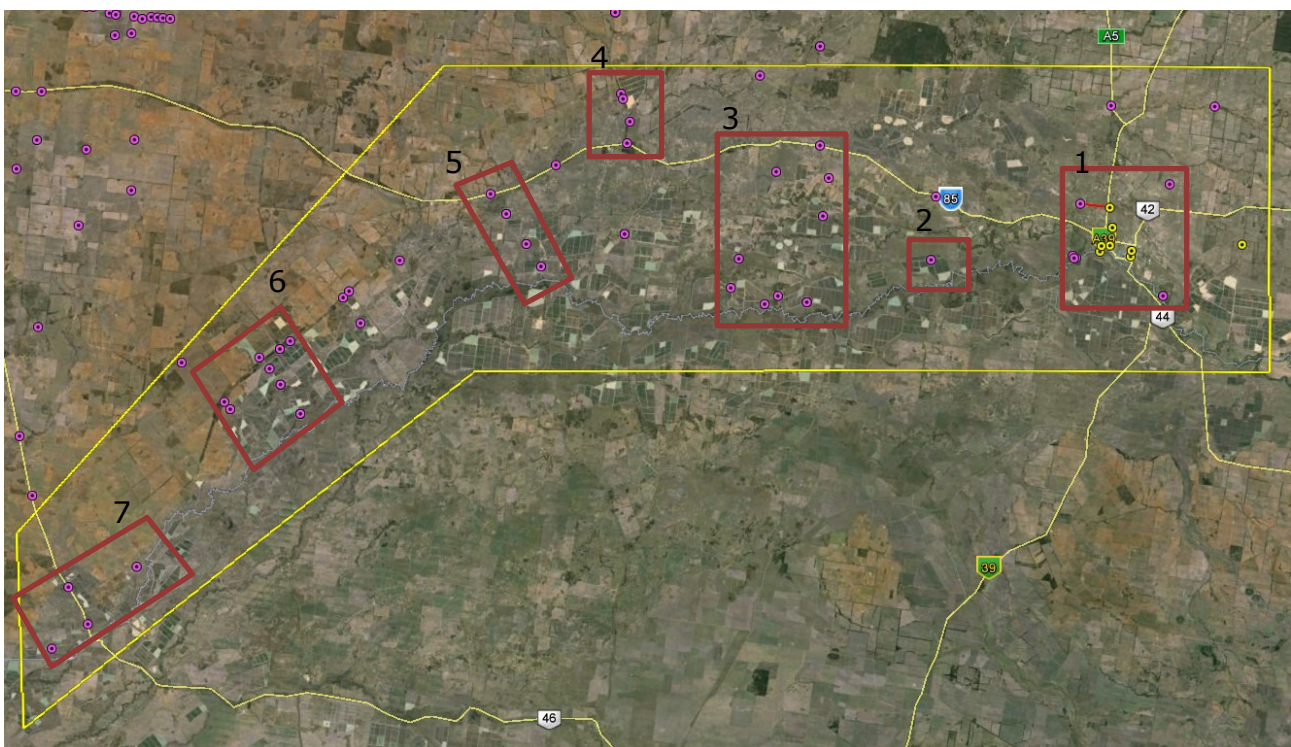


Figure 6: Number of bores being monitored by DNRM in the study area



Legen

- Current monitoring bore ●
- Past monitoring bore ●
- Inset below (Figures 9 -16)

Figure 7: Google earth image of the studied area showing the DNRM bores

4.3 Groundwater levels

The average groundwater levels for the years 2009/10 and 2013/14 are shown in Figure 8a and b, respectively. Individual bore hydrographs are shown in the following figures for specific zones, and in Appendix A. Many bores show on-going rise of groundwater levels in the last decade; some demonstrate a constant rise over time, while, in others, groundwater levels fluctuate, with an over-all rising trend. In contrast, at the bores near Goondiwindi, groundwater levels fall in the last few years.

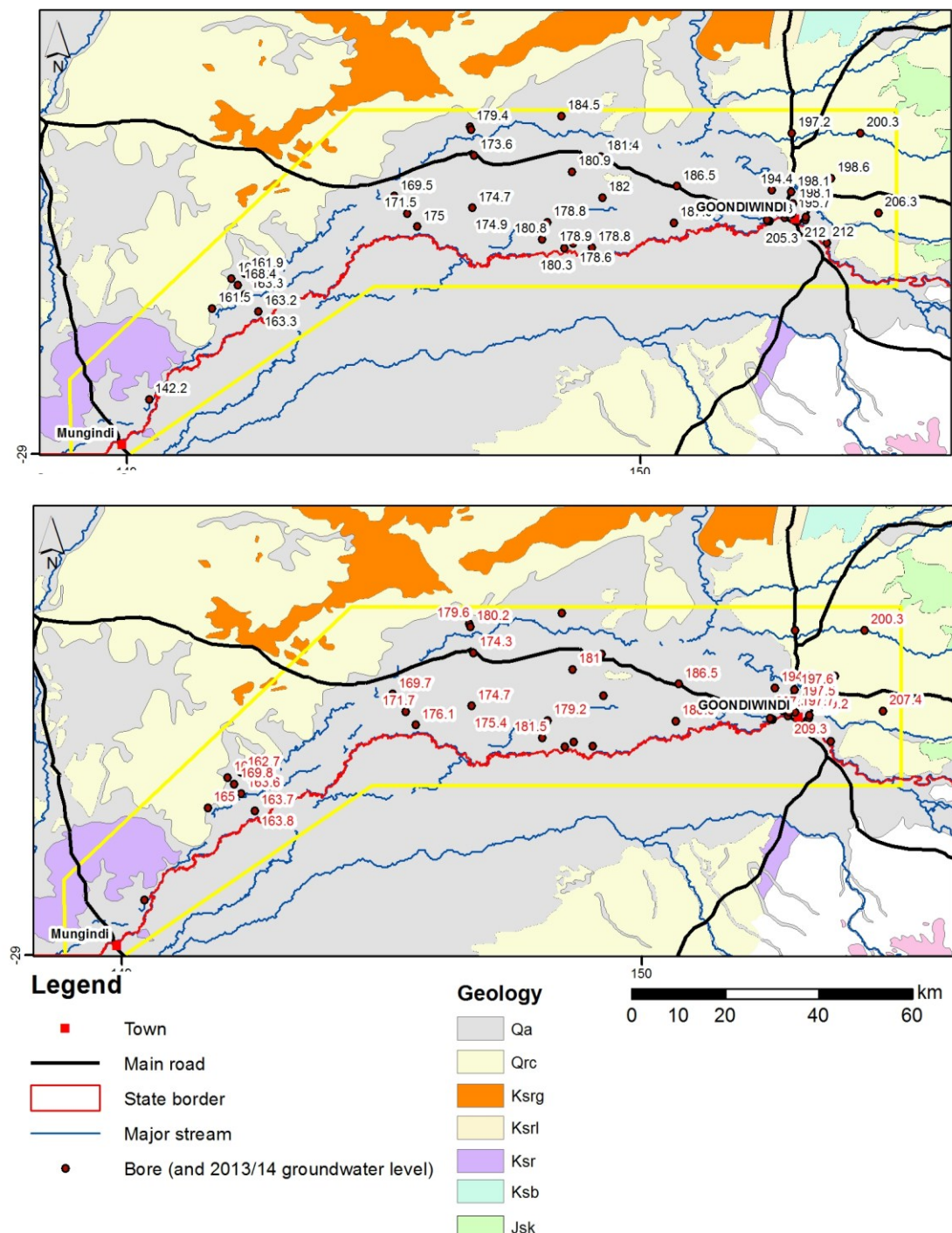


Figure 8: Measured groundwater levels (a) 2009/10, and (b) 2013/14

4.3.1 Goondiwindi

Within the area included in the inset below, there are 16 monitoring pipes nested in 13 sites. One of the bores (#0002B) is dry. Seven of the bores are included in the current monitoring scheme. Within Goondiwindi, there are tens of private bores for domestic supply.

Five monitoring bores penetrate the GCF, and ten penetrate the shallow alluvial system, as also indicated by differences in past (Williams et al., 1987) and current groundwater levels and trends. In bores #0002, #0003, #0005 and #0007, penetrating the deeper aquifer, the groundwater level is $\sim +198$ m asl (Figure 9); in bore #0006, penetrating the GCF as well, groundwater level is lower by ~ 4 m, but probably should be higher and reflects an error in the elevation of the reference point. Bore #0005 shows relatively large fluctuations, which are assumed to be due to nearby pumping. The fact that these fluctuations are constrained to a single monitoring bore, rather than appear in all nearby bores, testifies for the low transmissivity of the GCF. Groundwater levels in bores #0002 and #0003 fell by 17 to 18 cm/yr in recent years. This is probably due to the increasing demand for pumped water in the town.

In bores that penetrate the shallow alluvial aquifer, groundwater levels are higher than the GCF aquifer and vary between $+205 - +214$ m asl (Figure 9). Groundwater levels in bore #0004 show a rise of 1 m between 2010 and 2013 followed by a fall of 0.3 m. Levels in bores #0081 and #0082 fall in the last years by 48 cm/yr in the shallow and 14 cm/yr, in the deeper sub-aquifers, respectively. These trends are attributed to increasing demand for pumped water in the town as well.

Seasonal fluctuations of 2 m are demonstrated in bores #0072 and #0073, which were equipped with continuous monitored device during five seasons. These fluctuations are shown in Figure 10 along with the temporal changes in the river levels (note that the gauging station is located some 5.5 km downstream from the bores); the association between surface water and groundwater is discussed in a later section.

It is concluded that near Goondiwindi, the Macintyre River feeds the shallow alluvial aquifer, with varying discharge rates during flood periods, and that the shallow aquifer leaks to the GCF. Altering vertical gradients, as noticed between bore #0003 and #0004, testifies to the low vertical hydraulic conductivity between both hydrogeological units and slow vertical leakage.

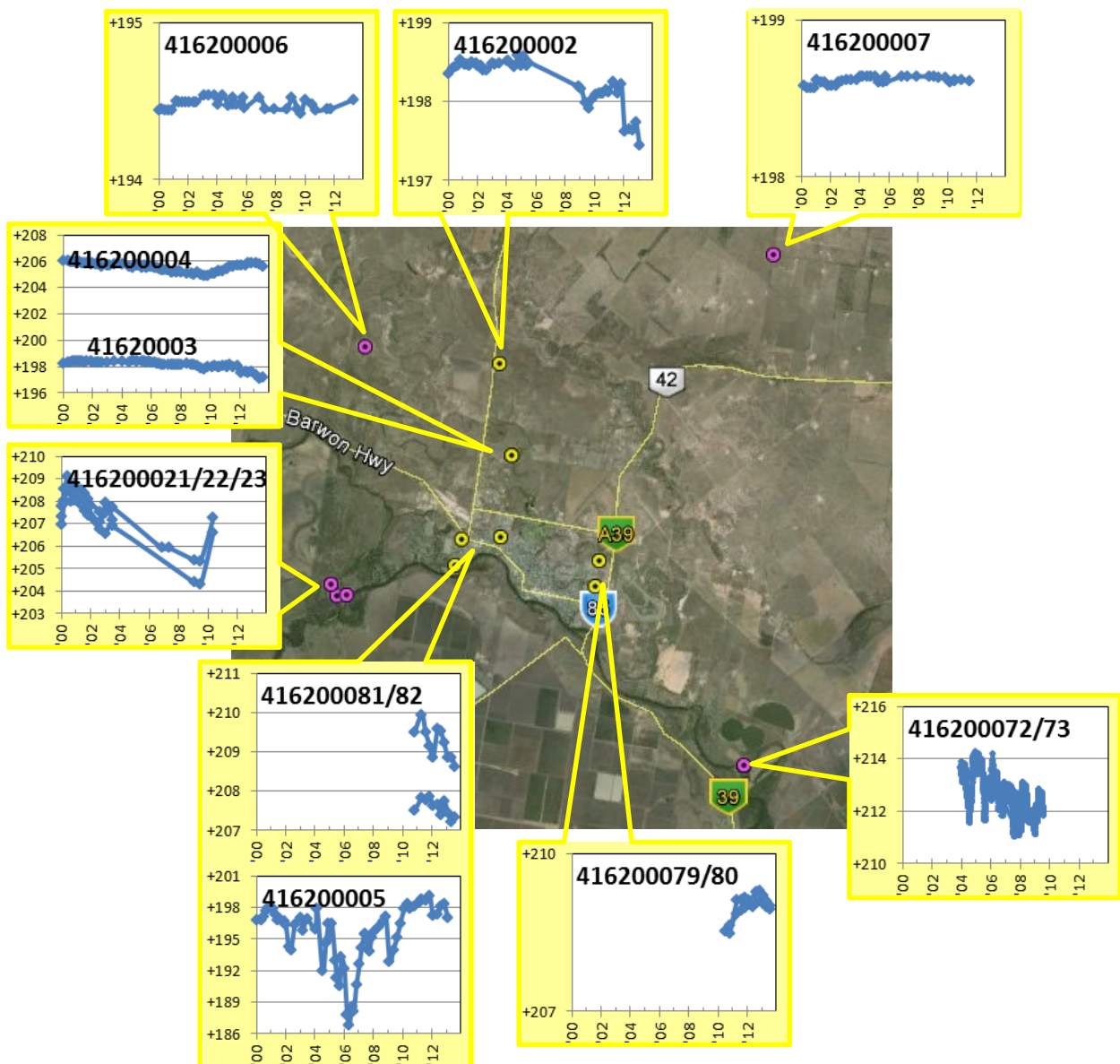


Figure 9: Groundwater levels changes near Goondiwindi (2000-2014)

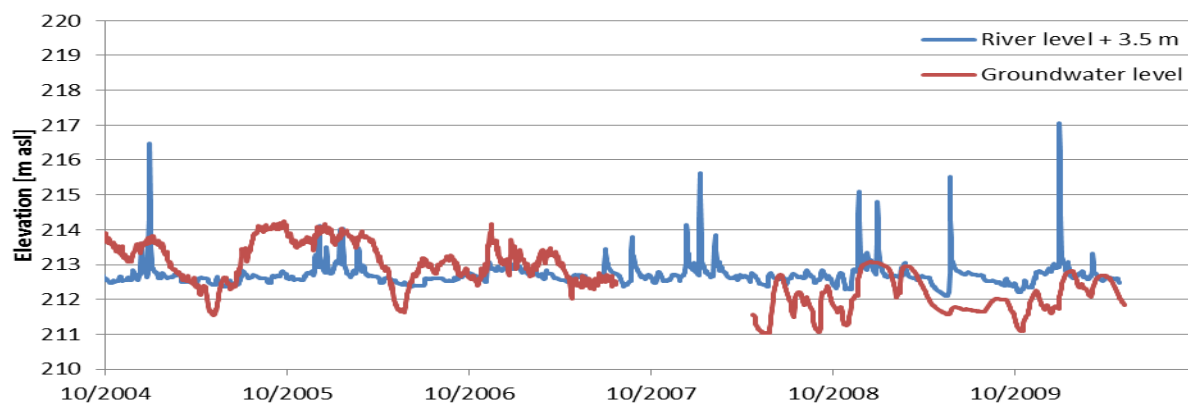


Figure 10: River (station 416201A) and groundwater (bore #0073) levels near Goondiwindi. Note that the river levels were raised by 3.5 m to account for the topographic slope between the bore and the gauging station, located 5.5 km apart.

4.3.2 Bore #0048

Bore #0048 is located 21 km west of Goondiwindi, within a large irrigated area. It was drilled in 2008 to a depth of 42 m, and presumably taps the alluvial aquifer. It's water are of mild salinity, with only 1170 mgCl/l, in respect to much higher salinities in western bores. Since drilling, it shows an on-going rise of 12.6 cm/yr, with an overall rise of 0.76 m and minor fluctuations (summer levels are higher by few cm than the following winter levels). Although the bore is rather deep, this trend may be attributed to a deep-drainage from the nearby fields with confidence. Other option, accordingly the groundwater level in the up-gradient part of the aquifer rises, seems unrealistic.

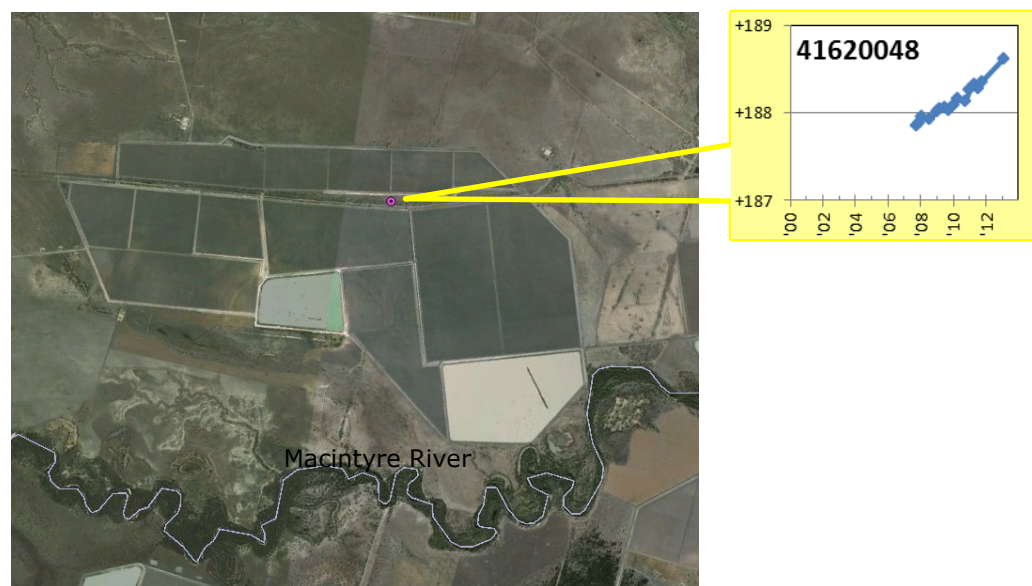


Figure 11: Location and hydrograph of bore #0048

4.3.3 Toobeah - “Macintyre downs”

Within the area covered in the inset below (Figure 12), there are ten bores nested in nine sites. All of the bores penetrate the alluvial aquifer, as demonstrated also by the relative similarities in groundwater levels, in the range of +179 - +182 m asl. Bores #0049 and #0050, drilled at the same site to different depths (28-32 and 17-19, respectively), show similar levels, with only 3-13 cm apart. One bore (#0055) is dry.

In this region, groundwater level ranges between +178.5 m asl and +182.5 m asl, without any apparent spatial trend. Bores #0049, #0050, #0051 and #0054 (each located in the heart of irrigated fields) show a continual rise, with an overall rate of ~5, ~5, ~14 and 12 cm/yr, respectively. These trends are attributed to deep-drainage from the irrigated fields.

The groundwater level in bore #0019, located within an irrigated area, but also near the Macintyre River, rose by 6.6 cm/yr in the period of 2000-2004, before it stabilized in 2004-2010, and rose again by 30 cm/yr in 2010-2012. These trends are associated with deep-drainage (but not streambed recharge, see section 4.4); it is suspected that changes in land-use or irrigation practises may trigger different recharge rates. Nevertheless, any conclusion in this matter should be verified by recent groundwater levels measures. In the nearby ‘control’ bore (bore #0020, located 1.9 km away), groundwater levels in the same period were rather stable, with absolute heads 1.5 m below that of #0019.

Groundwater level in bore #0052 fluctuates over time, but the overall change over the monitoring period is small. These trends are associated with streambed recharge as demonstrated in section 4.4.

Groundwater in the northern part of the area, as observed in bores #0016 and #0053 rose at rates of 1.6 and 3.8 cm/yr, respectively. Both bores are located away from irrigated areas, hence, the rises in both may represent the distal impact of the irrigation deep-drainage or recharge under dryland cropping and pasture.

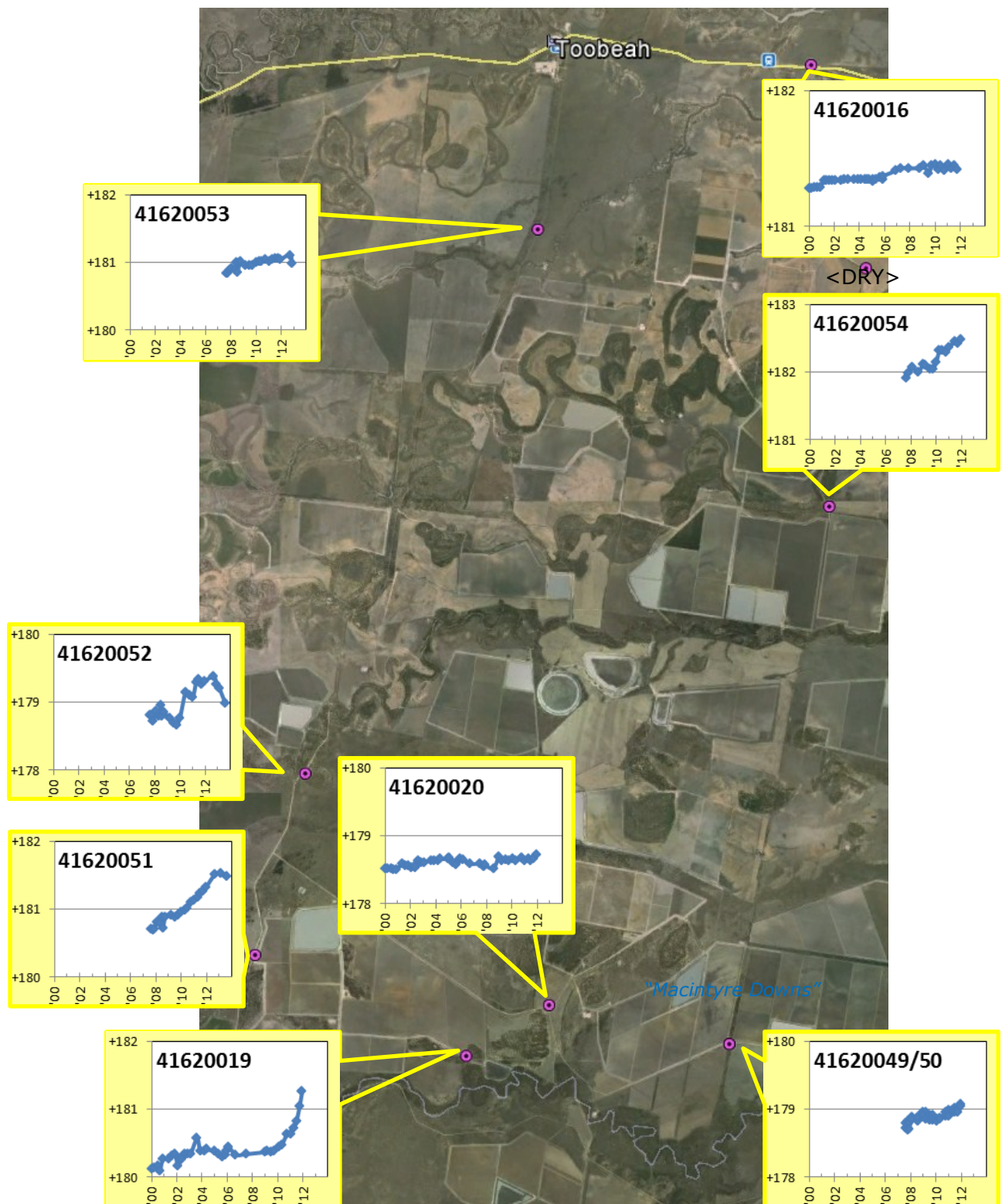


Figure 12: Groundwater levels changes in Toobeah - "Macintyre downs" farm section (2000-2014)

4.3.4 "Tandawanna north" irrigation area

Within the area included in the inset below (Figure 13), there are four bores; one of them (#0075) is dry. Bores #0056 and #0074 were drilled to investigate possible leaks from the nearby irrigation area (Biggs and Silburn, 2009). In bore #0056, an overall rising trend of 7.8 cm/yr was observed between 2009 and March 2013, with mild fluctuations, followed by a slight fall. In the latter, an overall rising trend of 12 cm/yr was observed in the same period of time (2010-2013). These trends are associated either with leaks from the dam or deep-drainage from the nearby irrigation area; the fact that the absolute levels in bore #0074 are higher than bore #0056 favours the first hypothesis.

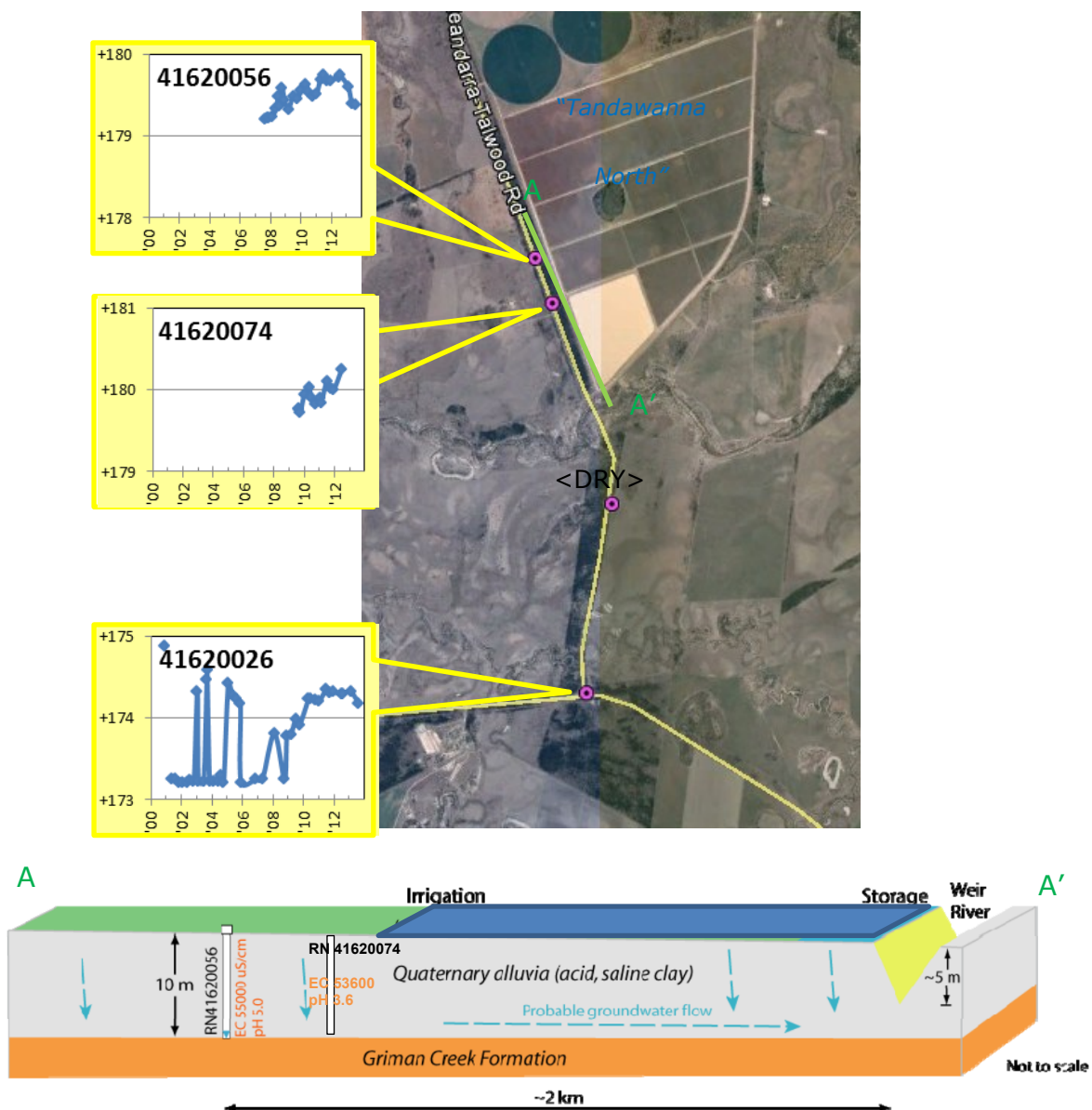


Figure 13: Groundwater levels changes in "Tandawanna North" farm (2000-2014) and (b) Simplified conceptual cross-section of the studied area (Biggs et al., 2006)

The groundwater level in bore #0026 (5.5 km south) is substantially lower than the northern bores. This is in agreement with the speculated north to the south flow direction in this area (Whiting, 2007). However, the bore exhibits alterations of 1.2 m between 'base' and 'high' levels (+173.2 m asl and +174.4 m asl, respectively). Prior to 2007, these are sharp and may represent some errors in respect to the reference point (for example between 17-Aug-2006 and 29-Aug-2006 water levels drop unexpectedly by 97 cm). Another possible explanation is that these fluctuations are related to the flooding of the bore, which frequently occurs (A. Biggs, Personal communication). Nevertheless, between 2009 and 2013 there is an overall shift from the 'base' level toward the 'high' levels. Whatever the reason for these fluctuations, it does not seem to be associated with streambed recharge.

4.3.5 Talwood bore-line

Within the area included in the inset below (Figure 14), there are four bores; one of them (#0058) is dry. In all three 'wet' bores, water levels rose between 2009 and March 2013 at different rates: In bores #0030 and #0059 the rise rates were ~4.4 cm/yr, and may be associated with deep-drainage from dryland areas. In bore #0060, however, the average rising rate was much higher (25.5 cm/yr); further analysis (section 4.4) indicated that deep-drainage accounts for 17.5 cm/yr rise.

It should be noted that the groundwater levels are higher in the south (bore #0060, adjacent to the Macintyre River) than in the north (bore #0030). This suggests excessive deep-drainage from the irrigated area (and rig tank) in the south. Possible conceptualization is shown in Figure 14b.

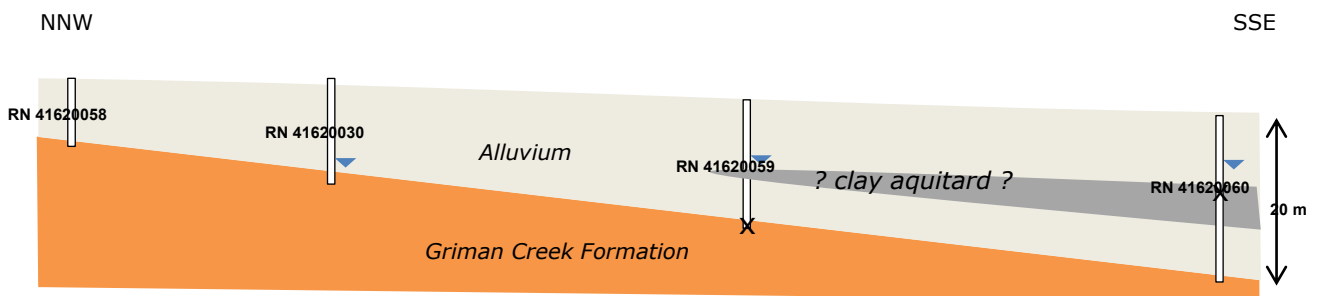
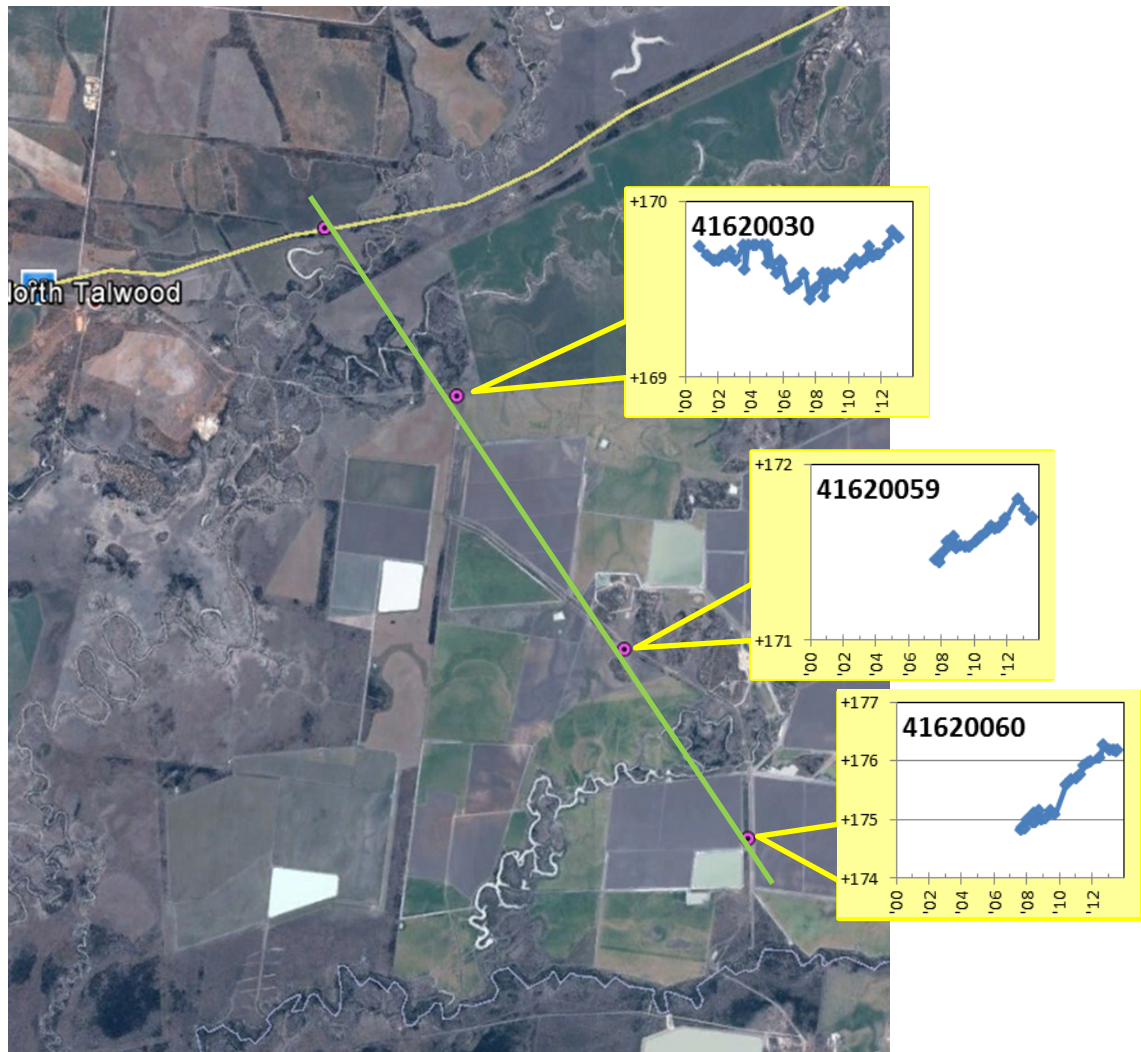


Figure 14: Groundwater levels changes (a) and conceptual cross-section (b) along Talwood bore-line

4.3.6 South Talwood and “Tarawatta” irrigation area

Within the area included in the inset below (Figure 15), there are 11 bores nested in eight sites; two of the bores (#0035 and #0077) are dry.

In all the bores tapping the alluvial units, groundwater levels are $\sim +162 - +163$ m asl; significantly higher levels were recorded in bores #0067 and #0017, which tap the GCF, at $+168 - +170$ m asl. In turn, this suggests a low (but positive) interconnectivity between the GCF and the alluvial units (Figure 15b). The equivalent horizontal hydraulic gradient between the two groups has increased with time; for example, between bores #0017 and #0018 it increased from 1.7‰ to 2.5‰ during the monitored period. This evidence supports the previous assumption of a substantial leak from a nearby irrigation dam which causes local groundwater mounding (Biggs and Silburn, 2009). Furthermore, the dynamic fluctuation in these bores may be related to periods of full/empty dam.

In all ‘wet’ bores, the groundwater levels rose since 2009 (Table 3). Bore #0069 shows the highest rise, of ~ 4 m, at a rate of 79 cm/yr. This rise is associated with higher rates of deep-drainage through irrigated red soils cover.

Levels in each of the bore pairs, #0063/#0064, #0065/#0066 and #0017/#0067, are similar, indicating little difference between the alluvial aquifers monitored.

Table 3: groundwater level changes near “Tarawatta”

| Bore | Change 2000-2013/14 | Change 2009-2013/14 |
|-------------|------------------------|-------------------------------------|
| #0017 | +3.2m; fluctuations | +1.5m; fluctuations |
| #0018 | +0.5m; fluctuations | +0.5m; fluctuations |
| #0063/#0064 | - | +0.4m; fluctuations |
| #0065/#0066 | - | +0.5m @ average rate of 11-12 cm/yr |
| #0067 | - | +0.8m; fluctuations |
| #0069 | - | +3.6m @ average rate of 79 cm/yr |

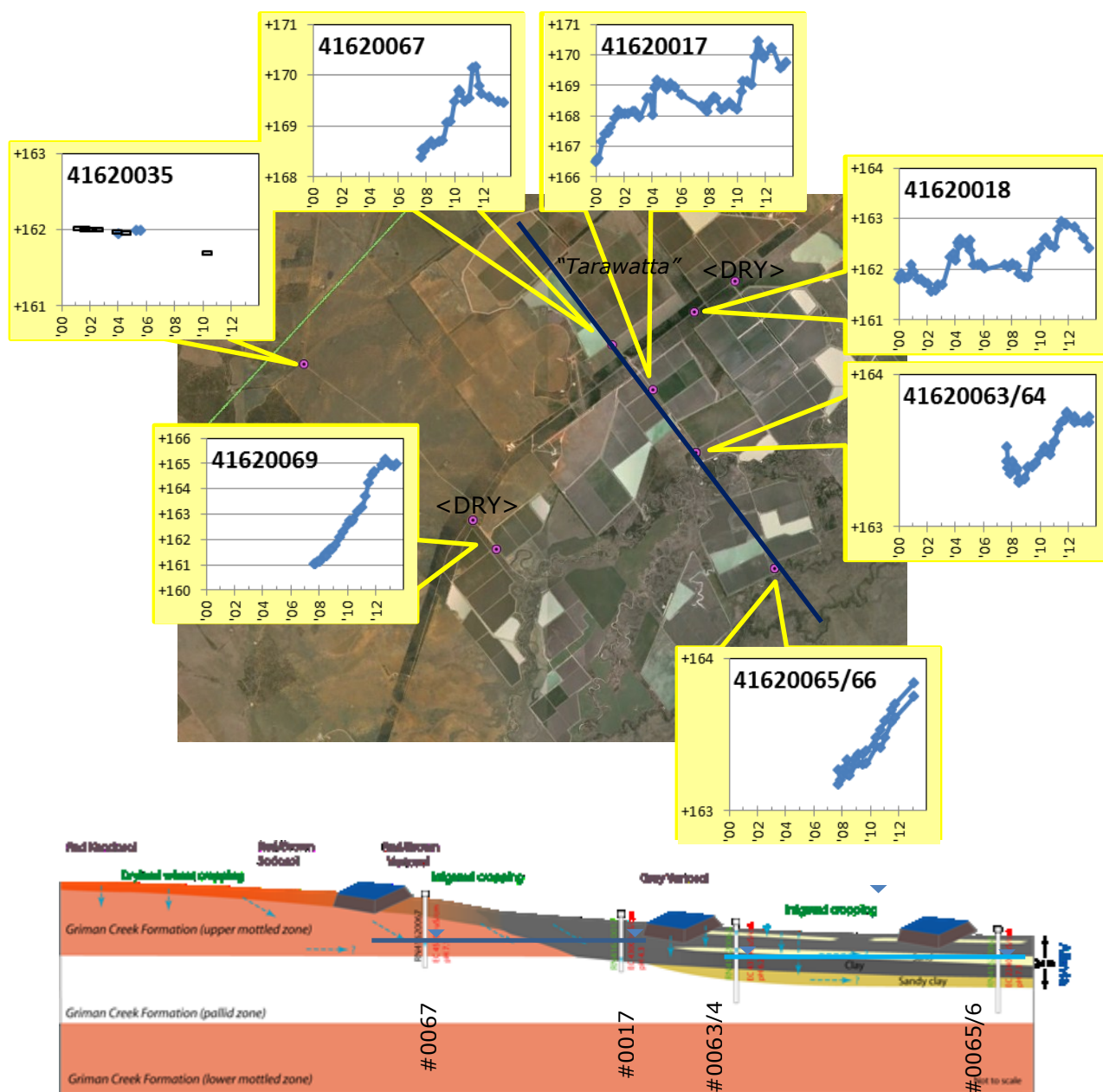


Figure 15: Groundwater levels changes in "Tarawatta" farm (2000-2014) and (b) Simplified conceptual cross-section at studied area (Biggs et al., 2006)

4.3.7 Mungindi

Within the area included in the inset below (Figure 16), there are four bores; three of them (#0032, #0070, #0071) are dry. Bore #0033, located 0.6 km away from irrigated fields and 1.5 km away from the Weir River, shows continual rise, with a 2001-2006 average rate of 5.4 cm/yr and a recent 2009-2012 rate of 11 cm/yr. These trends are associated with deep-drainage from the nearby irrigated fields.

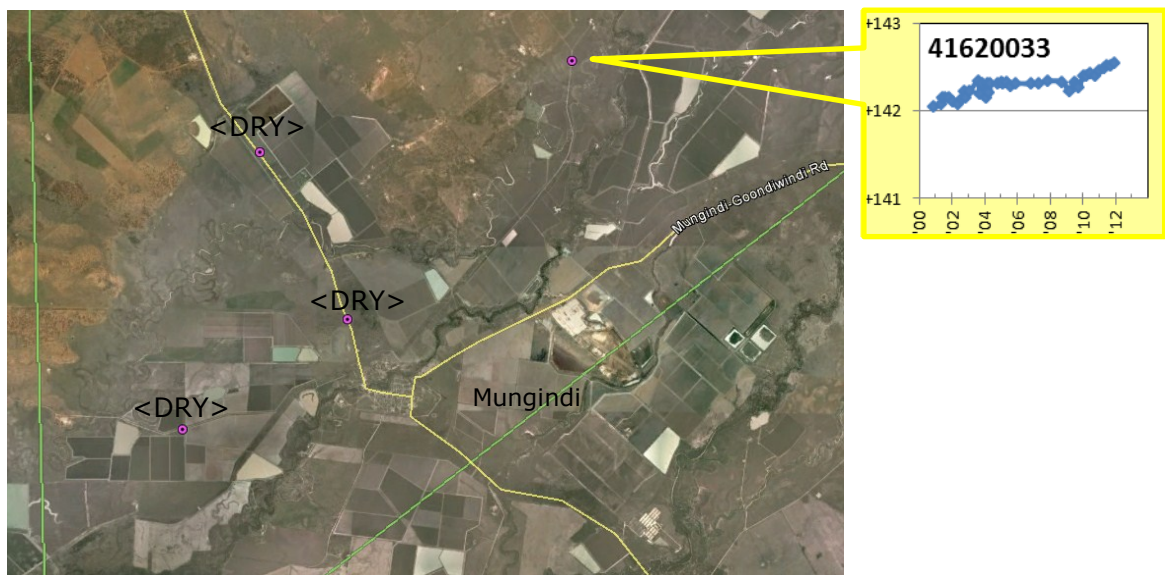


Figure 16: Groundwater levels changes near Mungindi (2000-2014)

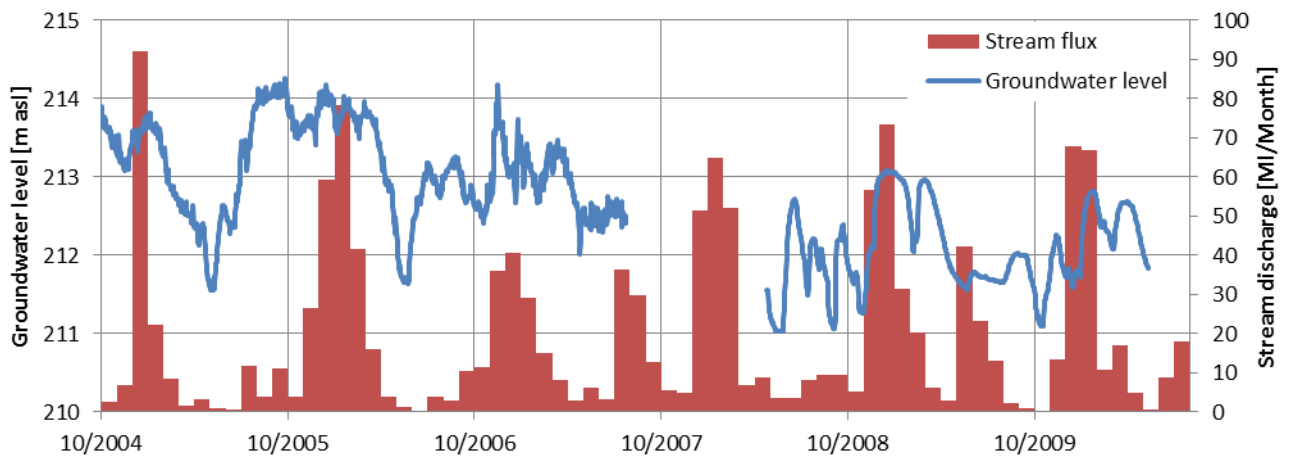
4.4 Streambed recharge

Previous studies noted that one of the recharge sources in the study area is the fluvial system of the Weir-Macintyre Rivers. Typically, streambed recharge rates vary as a response to changes in the flow, depth (and width) of the stream, i.e., increase in time of floods and decrease or cease in times of low-flows. This is reflected in bore hydrographs as sharp upward peak followed by a sloping fall curve. The following sections provide a qualitative analysis of the association of groundwater levels in bores adjacent to the main streams and the monthly stream flow. It is organized in the downstream direction of each of the main streams.

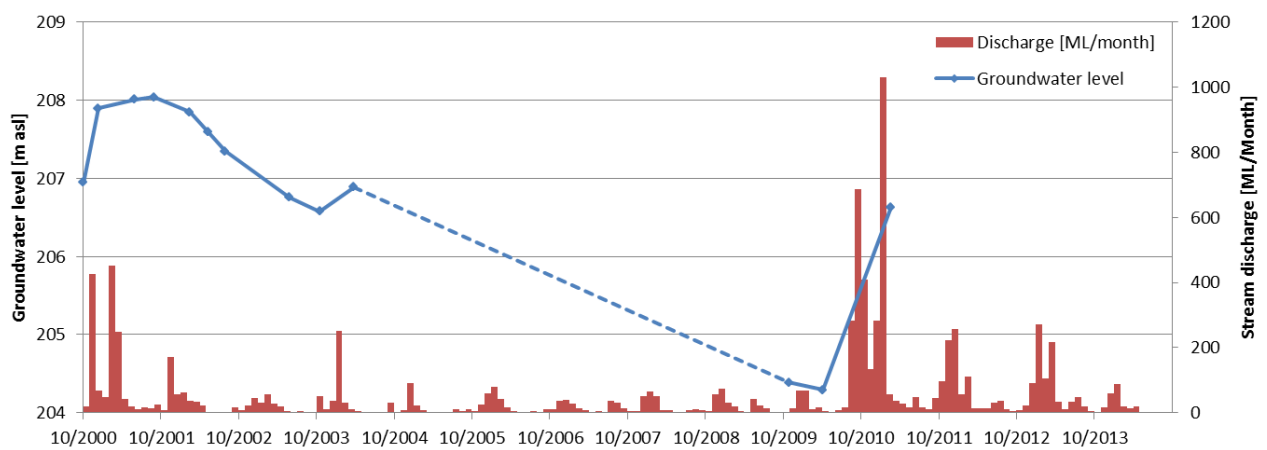
4.4.1 Along the Macintyre River (Figure 17):

- Bore #0073 (km 6.6; east of Goondiwindi) hydrograph shows substantial short-term fluctuation of up to 2 m. The drawdowns (fall limbs of the graph) are associated with pumping in nearby bores; correspondingly, the following recoveries (rise limbs, e.g. 2004/5 and 2005/6) with the cessation of the pumping period. In addition, there are several rise events which are correlated with high flow such as summer 2006, summer 2008 and summer 2009. This association is not linear in its extent and not on a 1:1 basis.
- Bore #0023 (km 8.4; west of Goondiwindi) shows a substantial rise (2.3 m) following the 2010/11 summer floods; another ~1 m rise was recorded in association with 2000/1 summer flood.
- Bores #0019, #0049 and #0050 (km 85) hydrographs do not seem to correlate with the stream discharge. Each record an on-going increase at different periods rather than a sharp rise.
- Bore #0060 (km 141) show an on-going rise due to deep-drainage (indicated by black sloping lines), but also seems to respond to the flood of summer 2010/11 and 2011/12 by additional rise of 60 cm and 15 cm, respectively.
- Bore #0066 (km 209) show an on-going rise due to deep-drainage (indicated by black sloping lines), but also seems to respond to the flood of summer 2011/12. This response is more subtle in compared to bore #0060. A similar though smaller response may have occurred in summer 2010/11, but was not captured in the hydrograph (no measures during this period).
- Bore #0033 (km 263) does not seem to correlate with the stream discharge.

a) Bore #0073



b) Bore #0023



c) Bores #0049/#0050

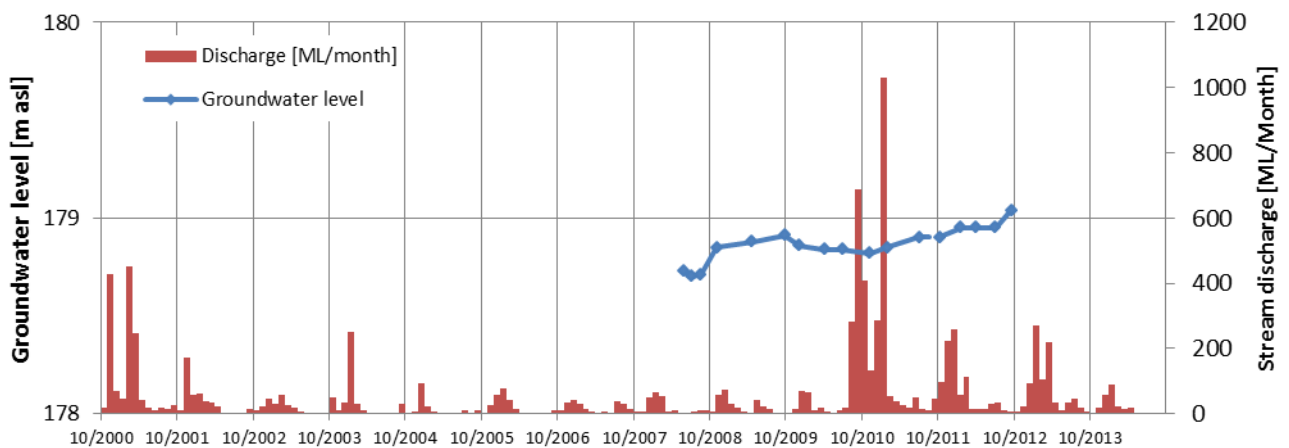
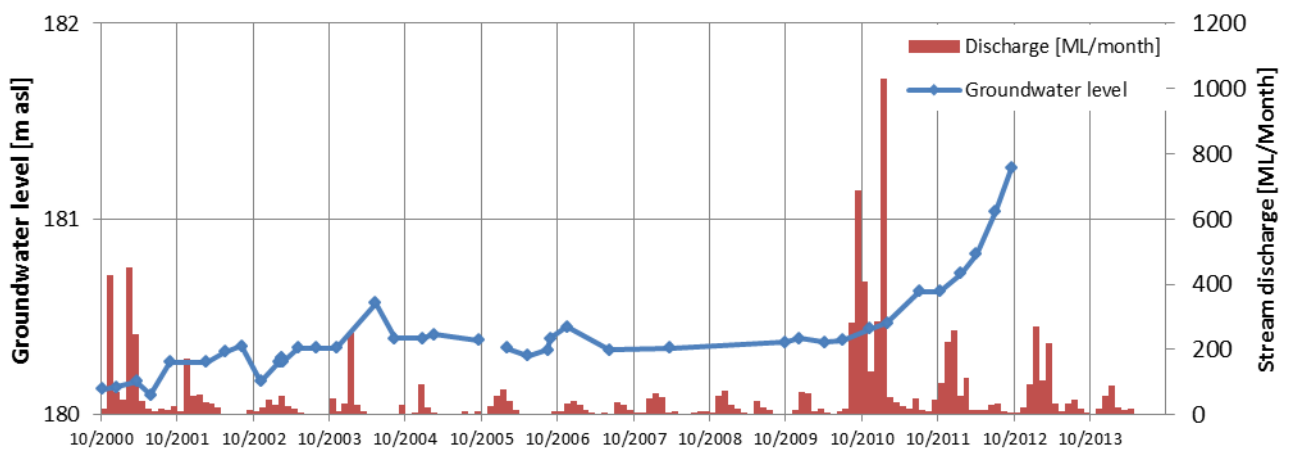
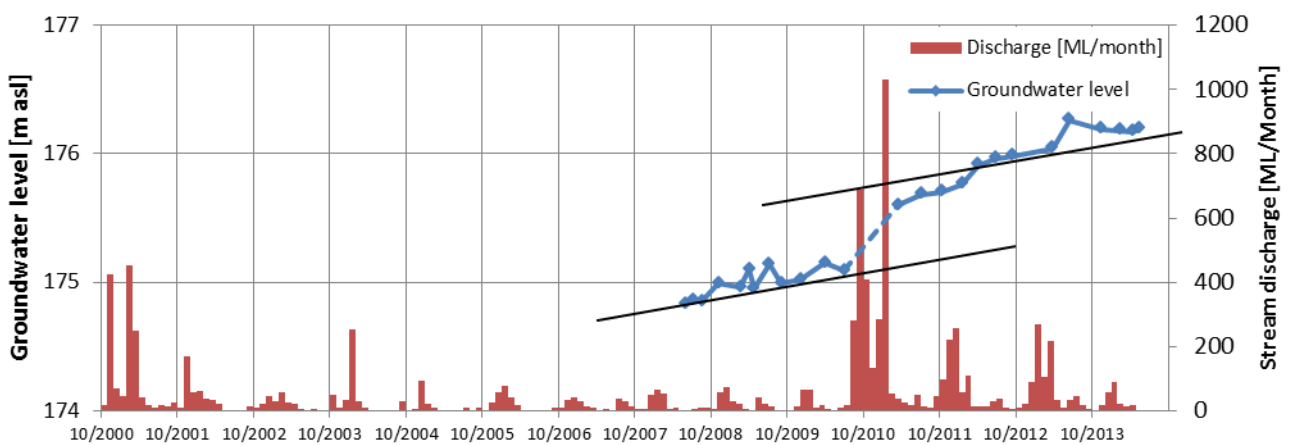


Figure 17: Hydrographs of the Macintyre River and adjacent bores. (a) 2004/5-2009/10; (b-g) 2000/1-2013/14

d) Bore #0019



e) Bore #0060



f) Bore #0066

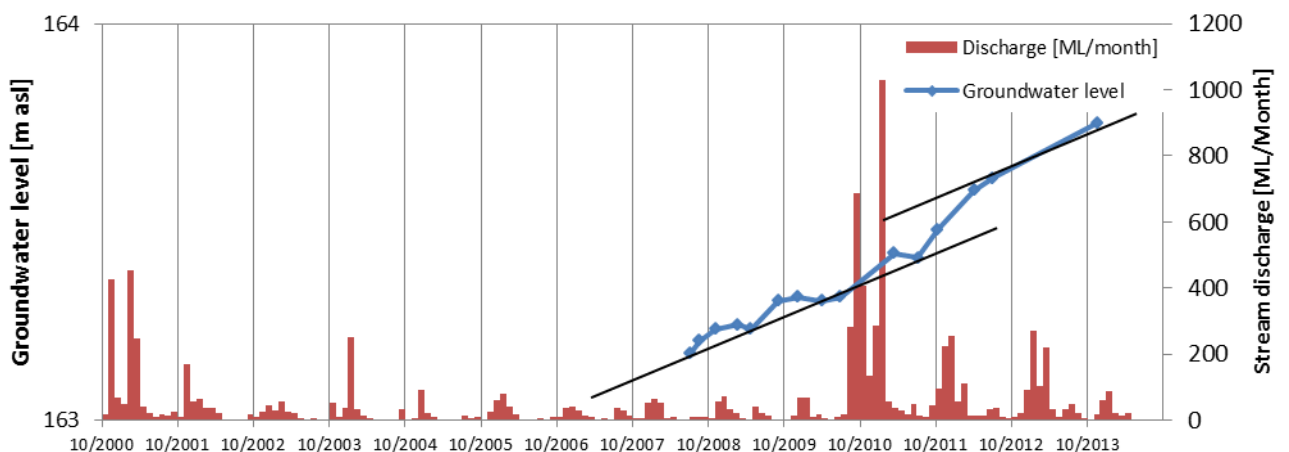


Figure 17: Hydrographs of the Macintyre River and adjacent bores. (a) 2004/5-2009/10; (b-g) 2000/1-2013/14

g) Bore #0033

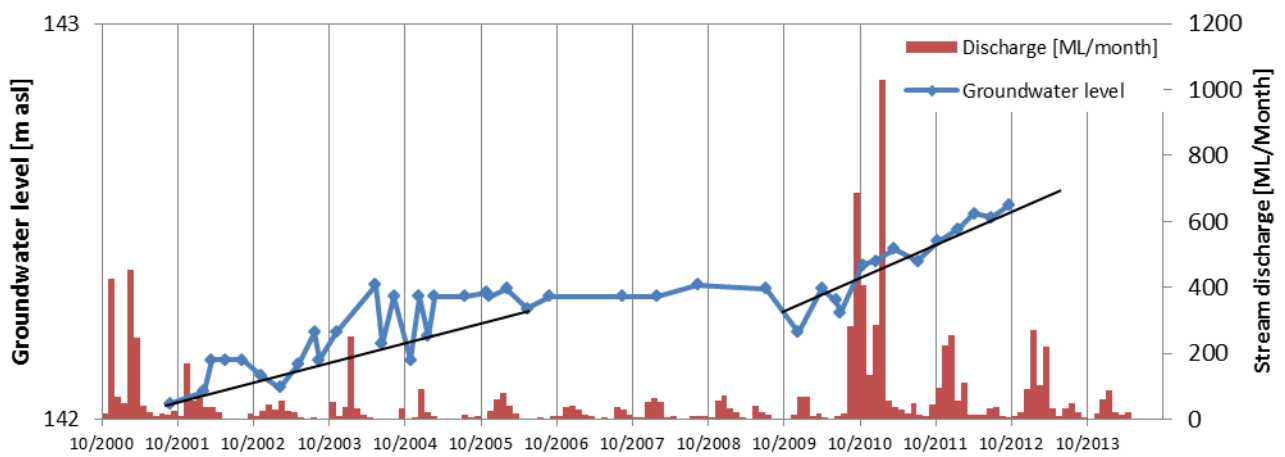
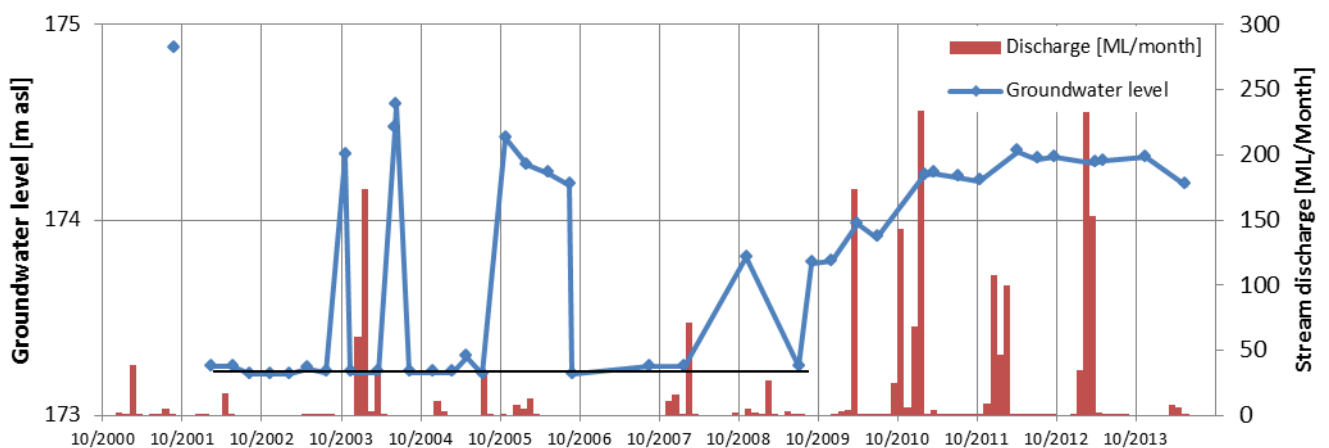


Figure 17: Hydrographs of the Macintyre River and adjacent bores. (a) 2004/5-2009/10; (b-g) 2000/1-2013/14

4.4.2 Along the Weir River (Figure 18):

- Bore #0030 does not seem to correlate with the stream discharge. The last rising trend (2009-current, indicated by black sloping line) is gentle and continuous.
- The interpretation of bore #0026 hydrograph is complex. However, there are indications to relatively substantial rises in association with 2009/10, 2010/11 and 2011/12 summer floods (19 cm, 32 cm and 12 cm, respectively). On the other hand, the 2012/13 flood does not seem to leave its imprint on the bore's hydrograph.

a) Bore #0026



b) Bore #0030

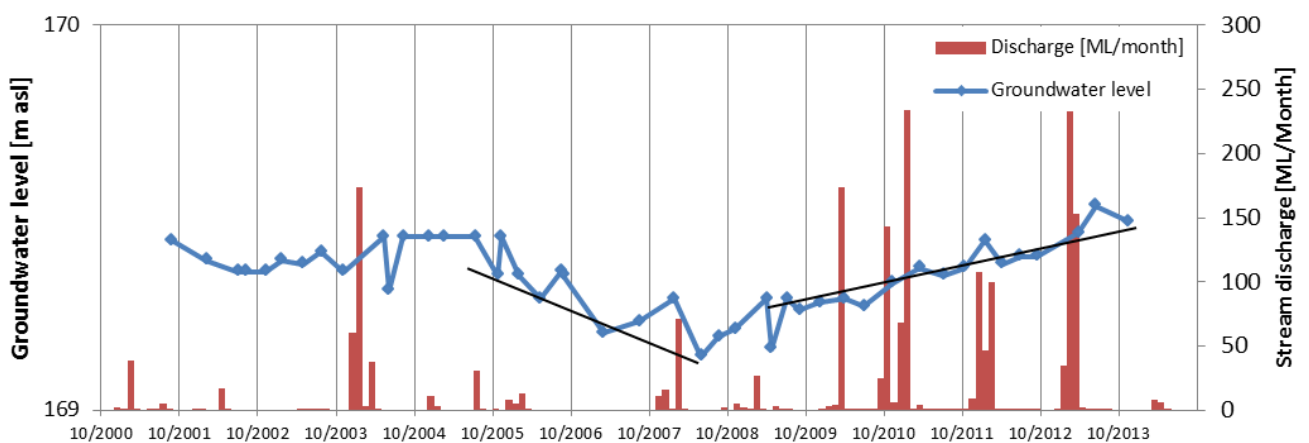
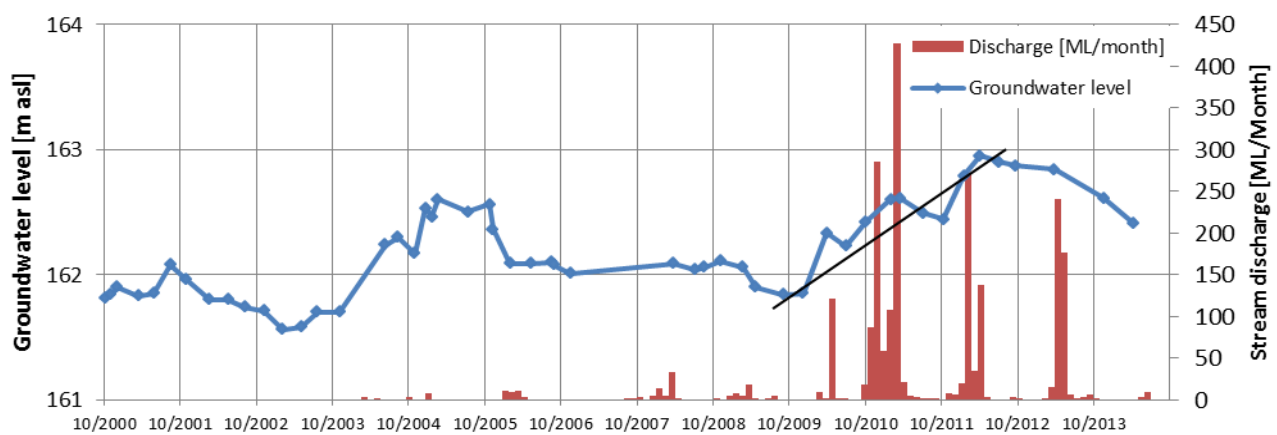


Figure 18: Hydrographs of the Weir River (station 416202A) and adjacent bores

- Bores #0018 and #0063 hydrographs do not seem to correlate with the stream discharge. The last rising trend (2009-2012, indicated by black lines) does not coincide with the surface flow events. In particular, there are no imprints of the largest flood of summer 2010/11 or the flow in 2012/13.

a) Bore #0018



b) Bore #0063

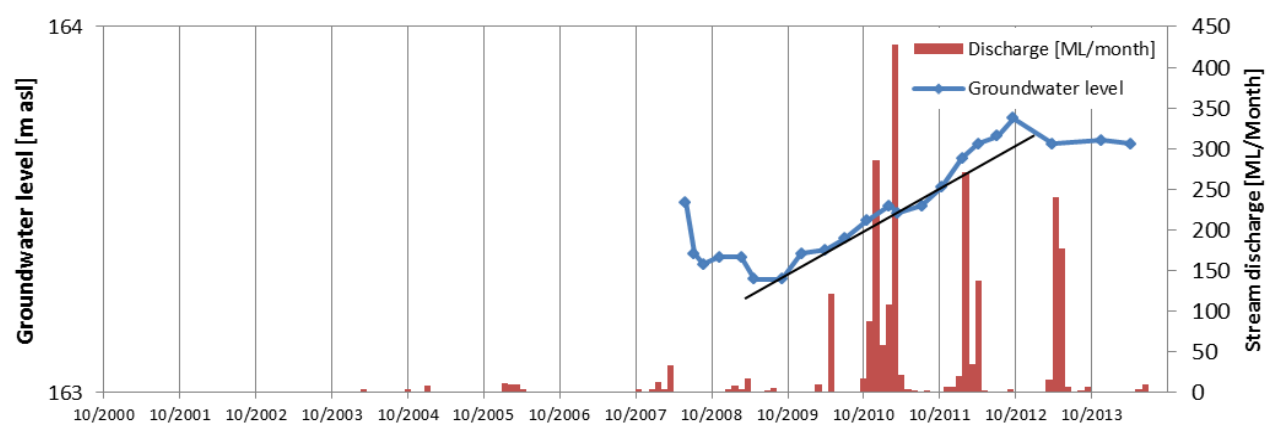


Figure 19: Hydrographs of the Weir River (station 416205A) and adjacent bores

4.4.3 Callandoon Creek (Figure 20):

- Bore #0052 hydrograph suggests a continuous and mild depletion of the storage (indicated by black sloping lines), with several distinct short periods of groundwater level increase. These periods seem to be well-associated with the 2010/11 and 2011/12 summer floods.

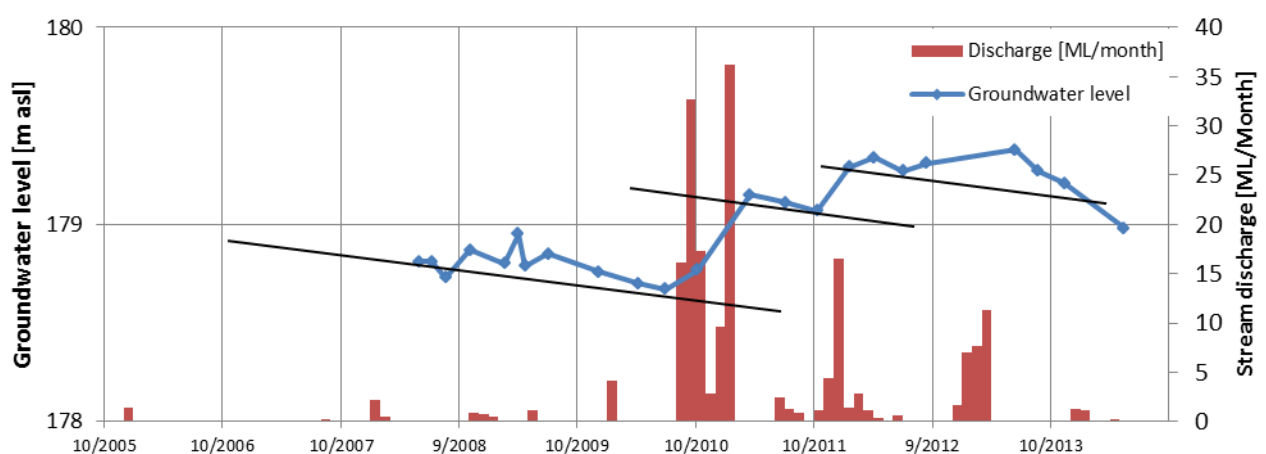


Figure 20: Hydrographs of the Callandoon River (station 416206A) and bore #0052

4.4.4 Summary

In agreement with previous literature, it is concluded that streambed recharge is a minor, localized recharge source for the alluvial aquifer rather than major one. Its effects on bores' hydrographs were observed along several river sections (Figure 21). The total volume of the streambed recharge is unknown, **though it is probably not substantial** as the groundwater remains salty (recall surface water are relatively fresh). In addition, the relationship between stream discharge and groundwater rise are far from being linear. Continuous or frequent long-term monitoring is recommended in order to identify recharge patterns.

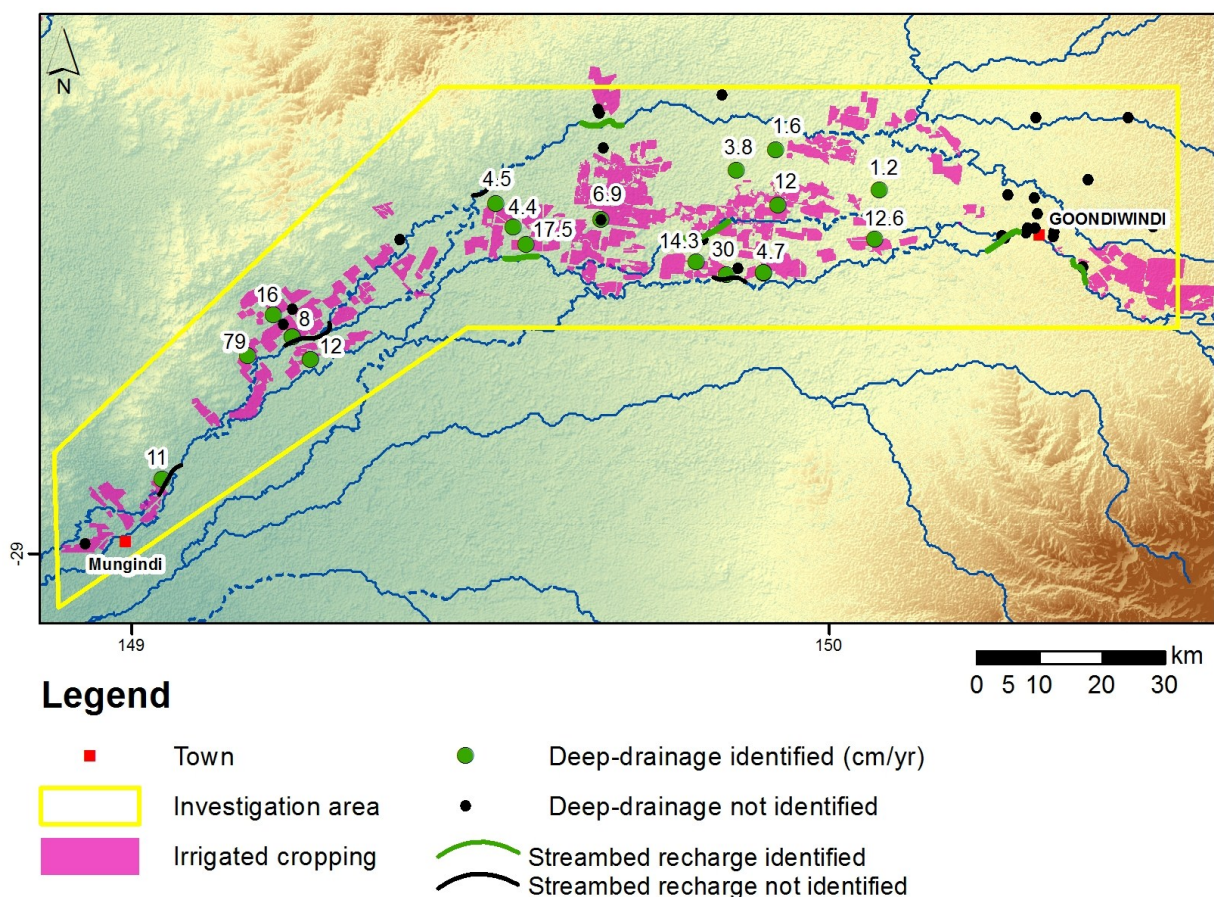
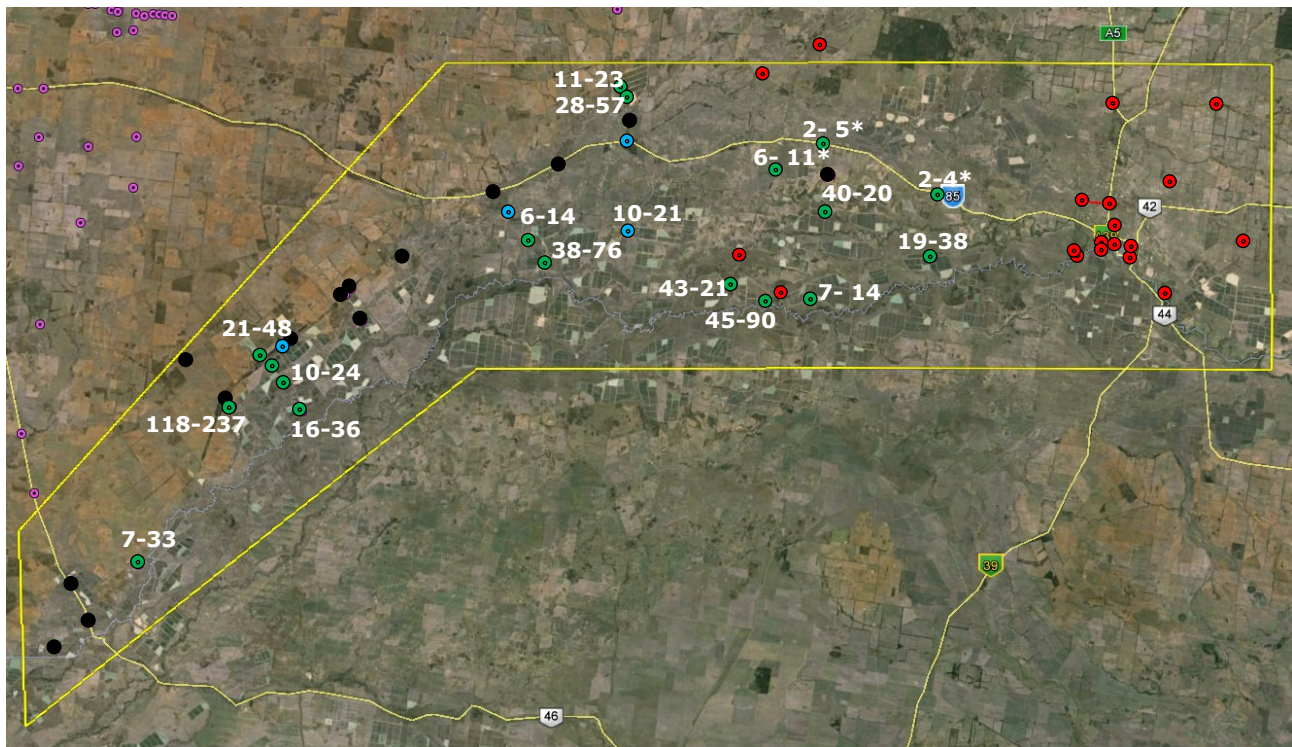


Figure 21: Identified streambed recharge sections and deep-drainage areas based on hydrological analysis of bores hydrographs

4.5 Deep-drainage under the irrigated areas

Deep-drainage from cropping areas (irrigated/dryland) was identified in many monitoring bores as detailed in section 3.3 (Figure 21). Generally, in the east and north of the studied area, the hydrographs do not show an association with deep-drainage while, in the main irrigation zones, most bores show an on-going rise, with

different rates; these is irrespective of bores depth. Deep drainage associated with dryland cropping in the east/north is believed to be slowly filling the unsaturated zone (Tolmie et al., 2011).



Legend

- Dry / No data bore ●
- Rise, probably deep-drainage* ●
- Rise, maybe deep-drainage ●
- Other, no relation to DD ●

* Indicates bores located away from irrigation areas

Figure 22: Estimated deep-drainage rates (mm/yr) as reflected in monitoring bores

The groundwater level rise rates (cm/yr, as appear in Figure 21) can be converted to deep-drainage (mm/yr). Given the uncertainty regarding the porosity of the medium (15-30%, Whiting, 2007), deep-drainage is averaged to 10-40 mm/yr (Figure 22), which is in the range of literature values (Whiting, 2007; Tolmie et al., 2011; Silburn et al., 2013). Substantially higher rates appear in one locality, with rates of 118-237 mm/yr; these rates can be associated with either permeable red-soil or ascribed to leakage from the nearby dam.

5 Summary

The current report reviews the groundwater levels trends in the Border Rivers alluvia, between Goondiwindi and Mungindi. The following observations and interpretations were summarized:

- The alluvial aquifer is fed, along some sections of the rivers (but not others), by 'Streambed recharge'; the total volume of streambed recharge, at least west of Goondiwindi, is small as testified by the high salinity groundwater. As groundwater levels are well below the stream bed, the opposite situation, i.e., discharge to streams, does not occur.
- Groundwater at the northern and eastern outskirts of the floodplain has remained relatively static, reflecting no association with temporal changes in possible recharge sources (rain and river flow).
- Groundwater levels under various irrigation fields are rising at rates of 4.5-30 cm per year due to deep drainage. In some areas, the rise has led to the development of groundwater mounding under the irrigated fields; these may and may not be associated with shallow clay lens within the alluvial section.
- Very shallow (<3 m from the ground surface) groundwater table occurs in one area, as observed in bores #0017 and #0067.
- The estimated deep drainage rates vary in space and, given the uncertainty associated with the aquifers storativity (range 0.15-0.30) are in the range of 7-90 mm per year.
- Red soils are suspected to have relatively high recharge rates as suggested by evidence from (1) leaks from the irrigation dam near bores #0074 and #0056 and (2) high deep-drainage rates near bore #0069.

It is recommended to:

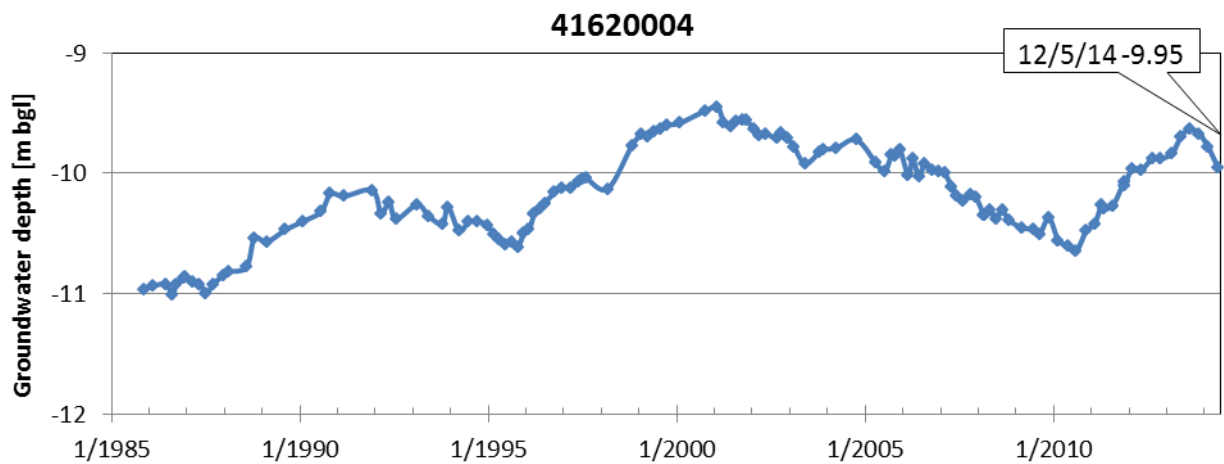
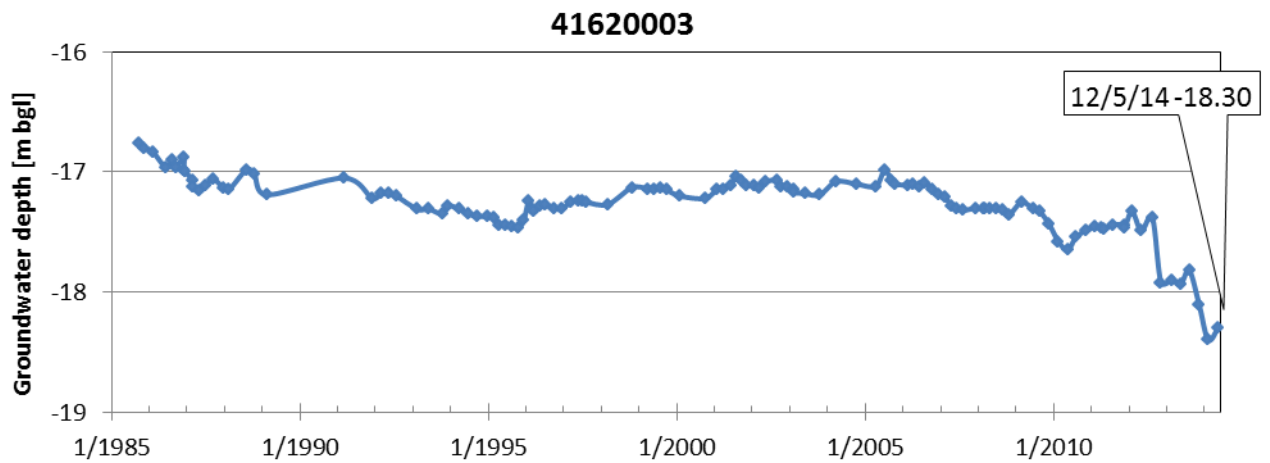
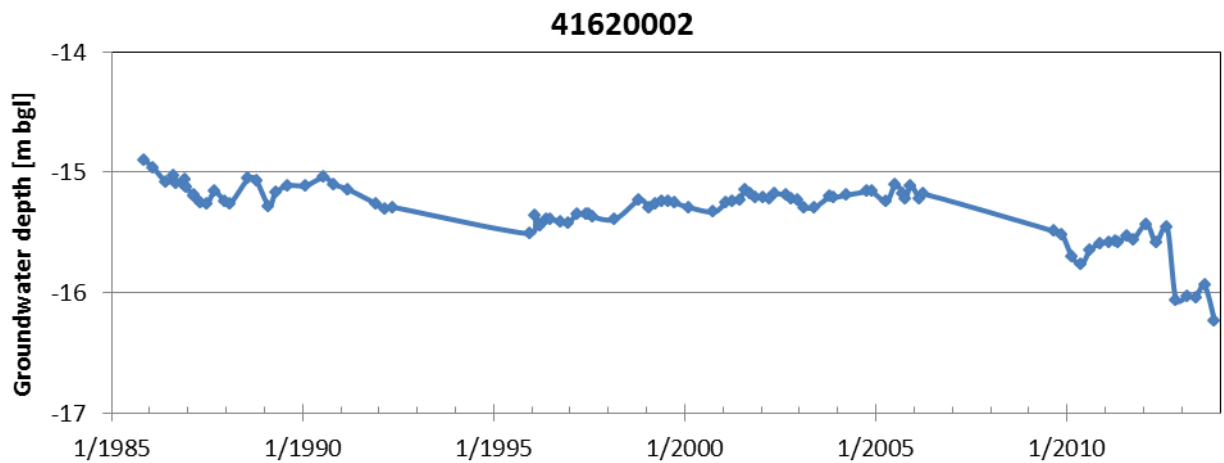
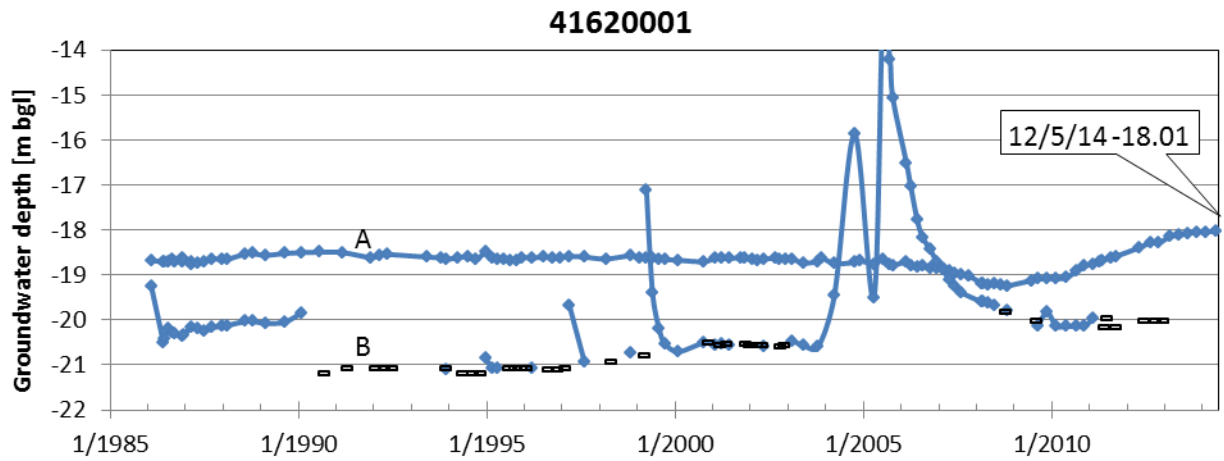
1. Measure current levels in bores #0019, #0023, #0033, #0049, #0050, #0054 and #0074 and verify on-going trends.
2. Install automatic level-loggers in bores #0023, #0052 and #0060 for a long-term period in order to identify streambed recharge patterns.
3. Inspect bore #0026 and suggest further actions to prevent flooding of the bore.
4. Review changes in land-use and irrigation practises around bores #0019, #0026 and #0030 as a mean to understand multi-annual changes in groundwater levels.
5. Review possible errors in the GWDB as indicated in Appendix A.

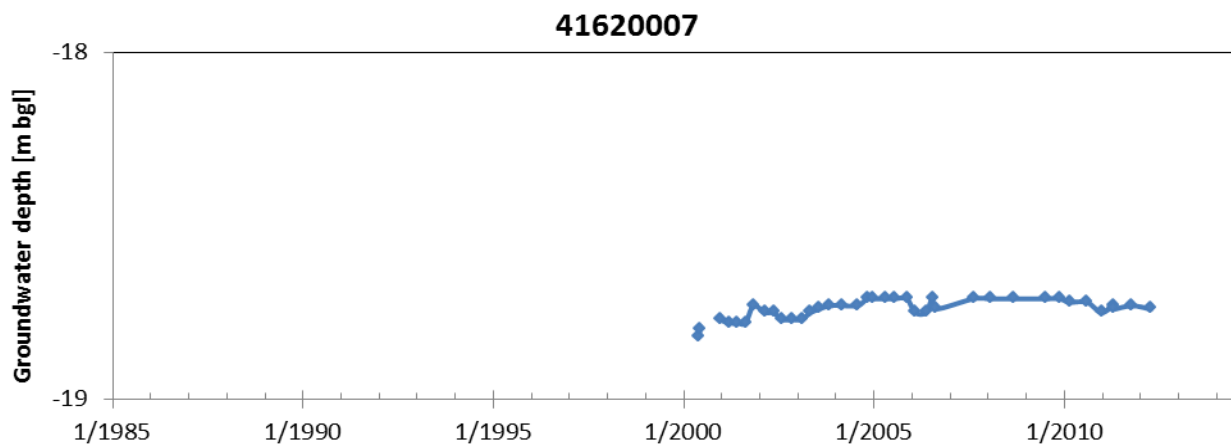
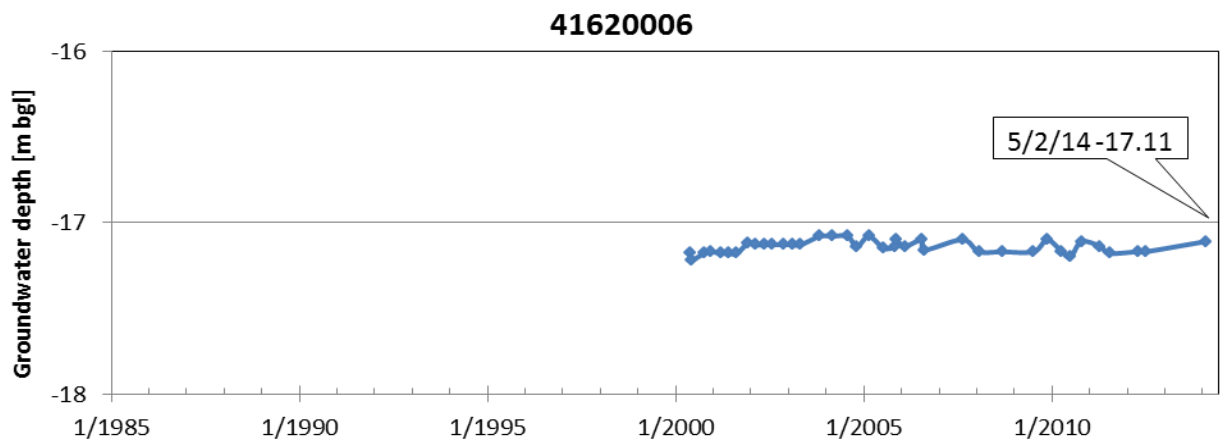
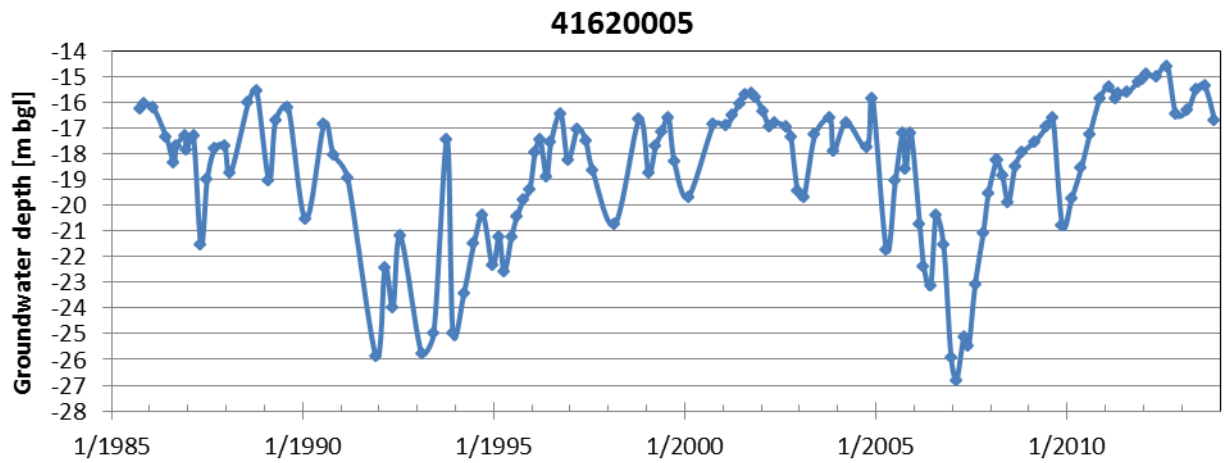
6 Reference

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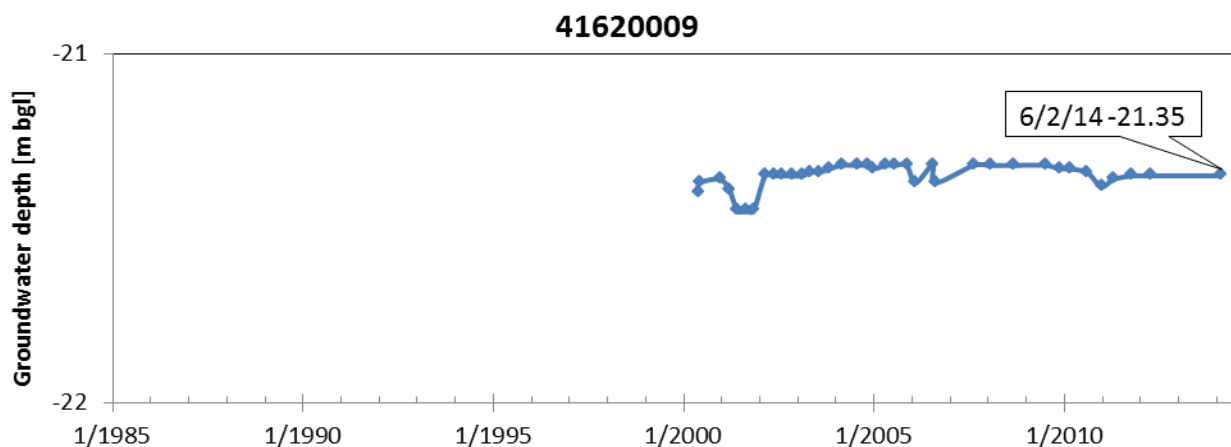
Appendix A - Bore hydrographs

- The following graphs are hydrographs of bores within the study area. In each, the vertical axis presents groundwater depth below the reference point (generally ~0.5 m above the ground elevation) for the years 1985-2014.
- The vertical scales of the graphs are varied according to represented range, but all are scaled at 1 m intervals.
- Black marks represent incidents in which bores have been found dry, and the total depth of the bore at the same date (instead of groundwater level).
- Exceptional or anomalous historical records are noted at the bottom of some graphs.
- Last measure, if occurred in 2014, is indicated in a 'call-out' rectangle.

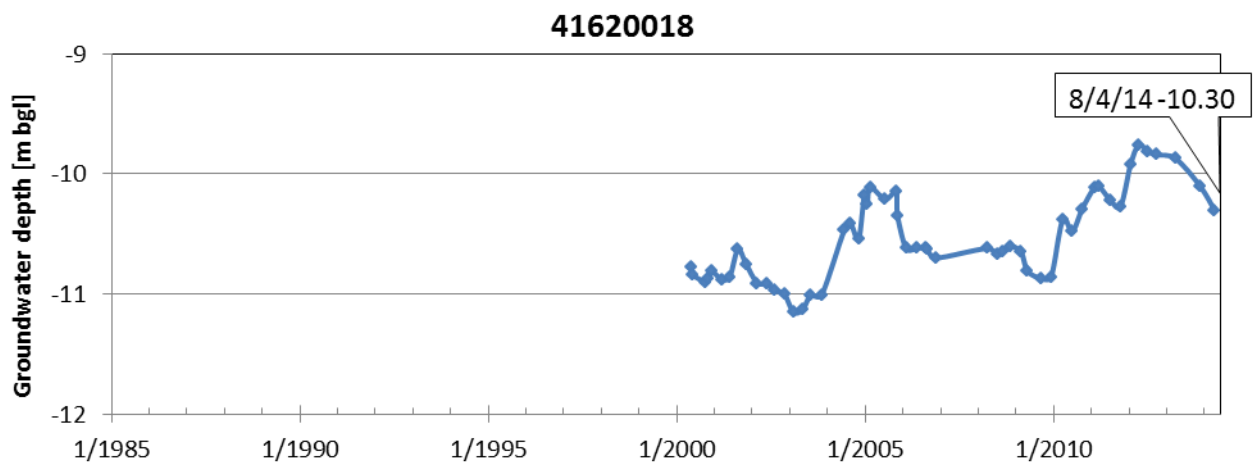
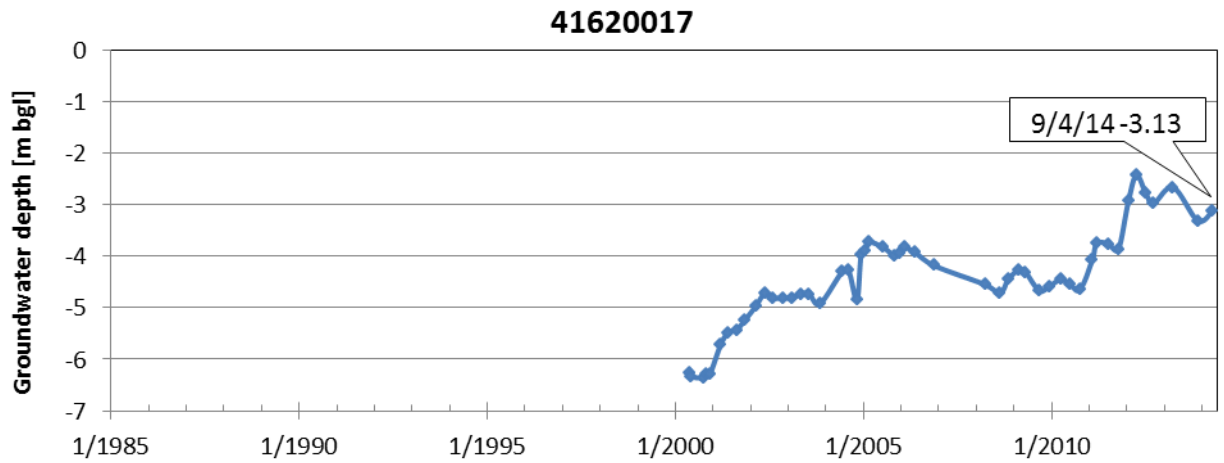
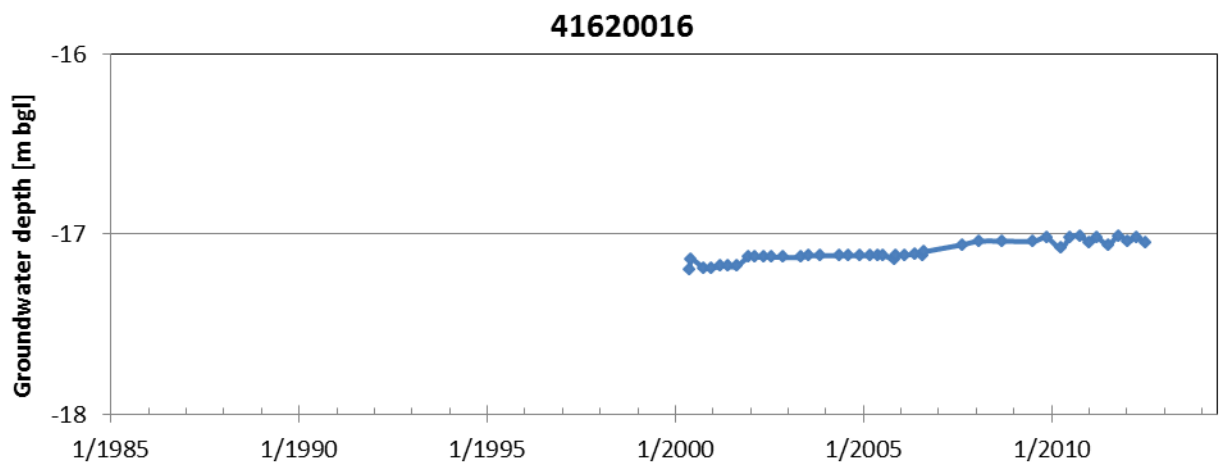
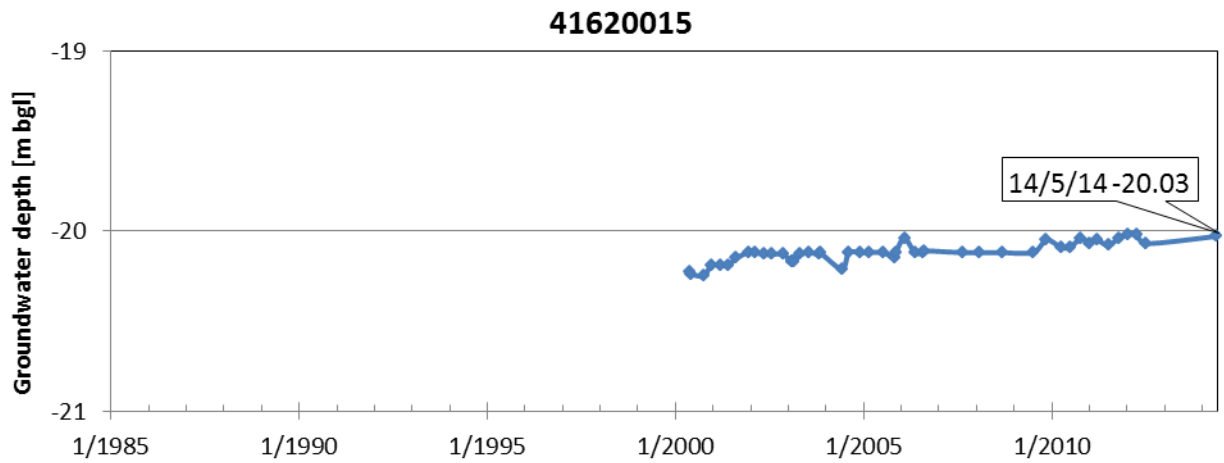


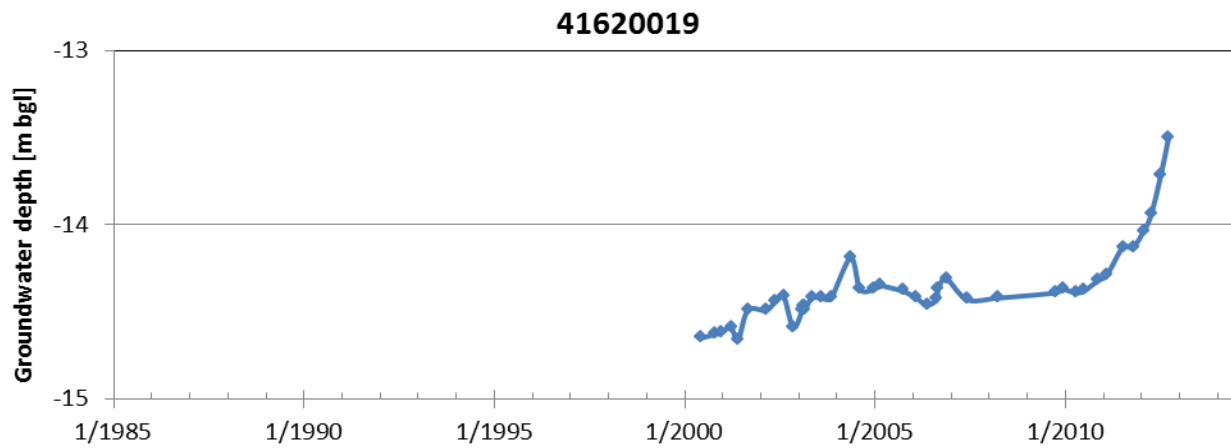


2/10/2000: Error, upward peak (not shown)

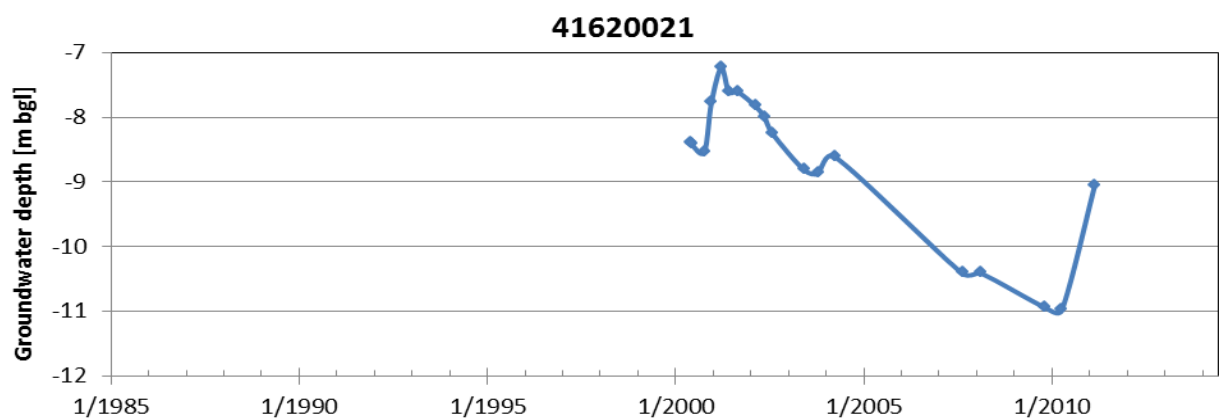
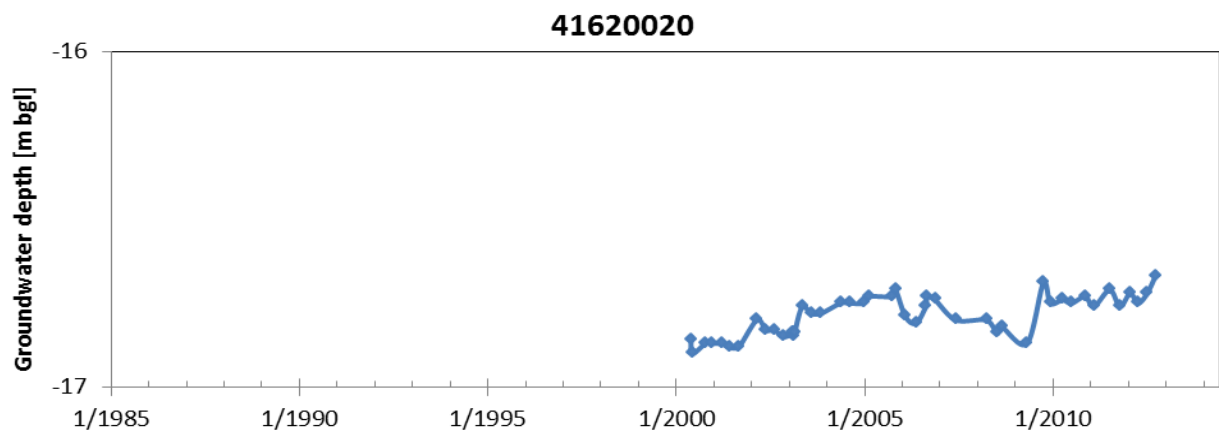


2/10/2000: Error (?), upward peak

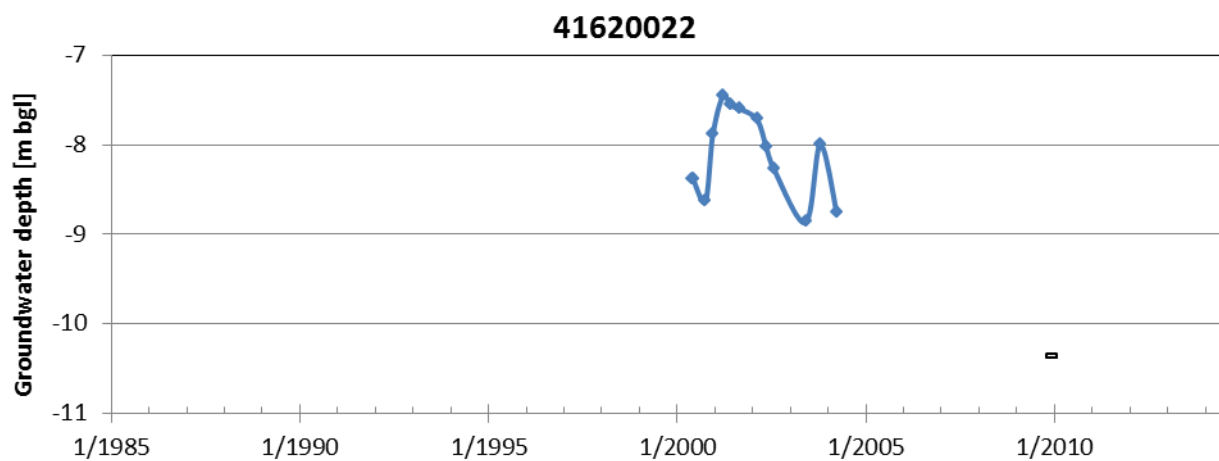




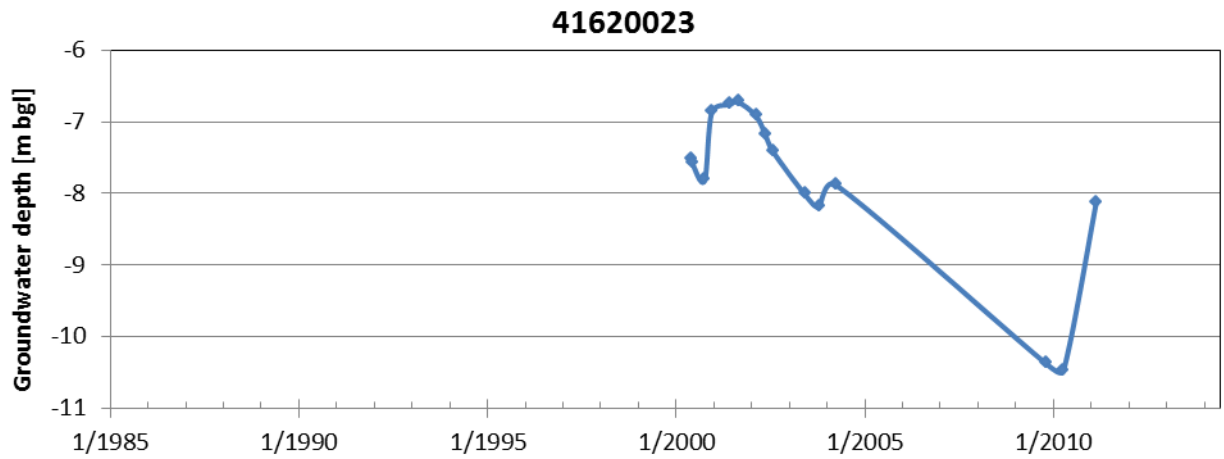
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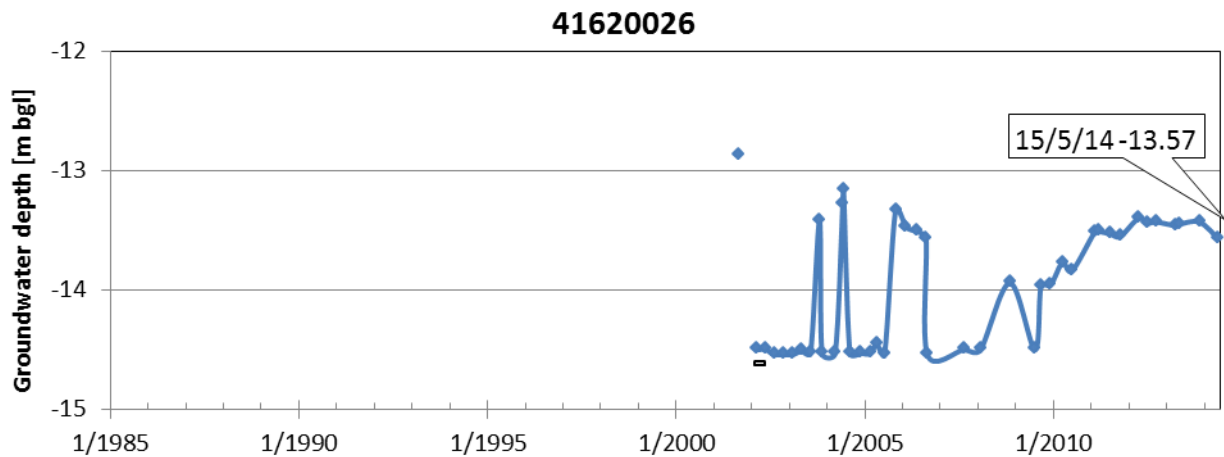
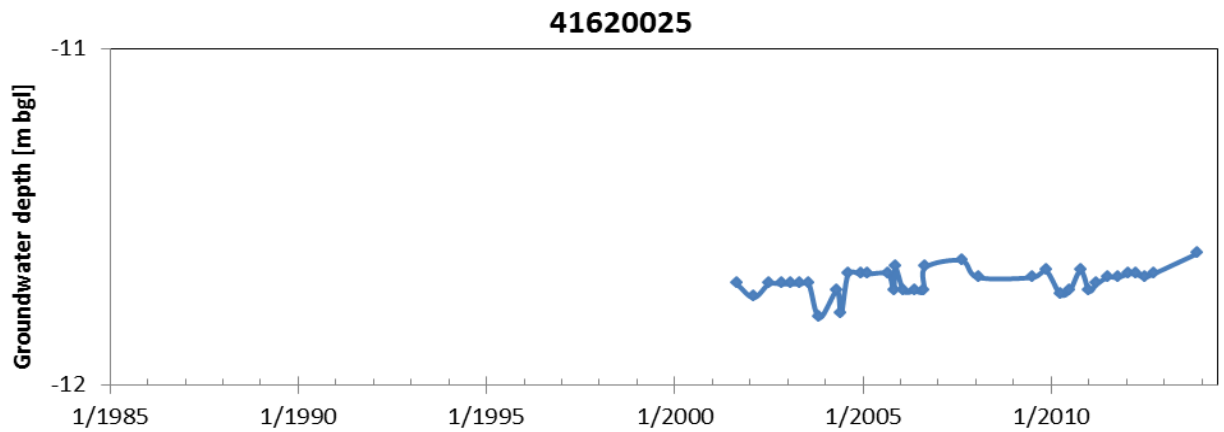
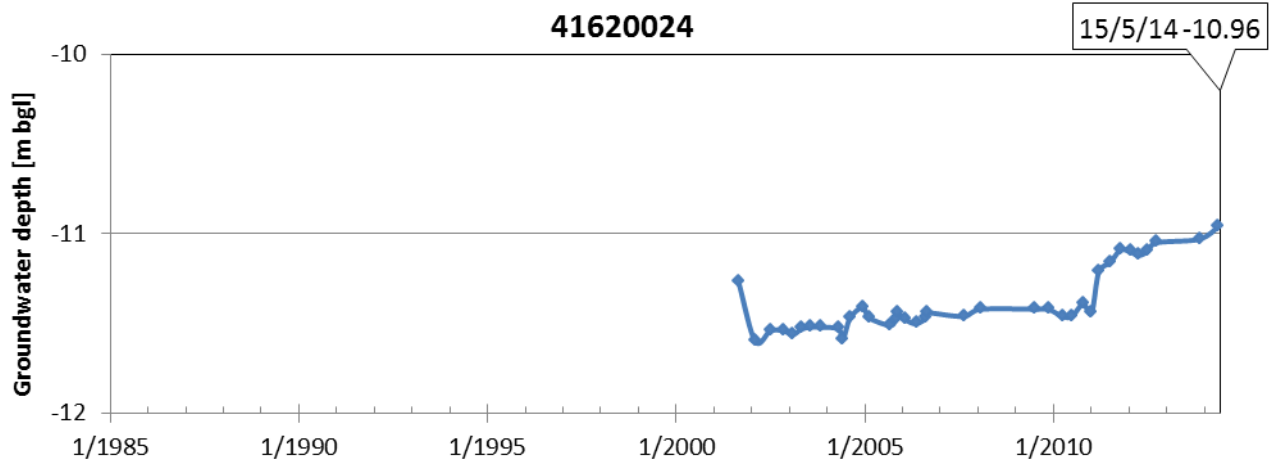
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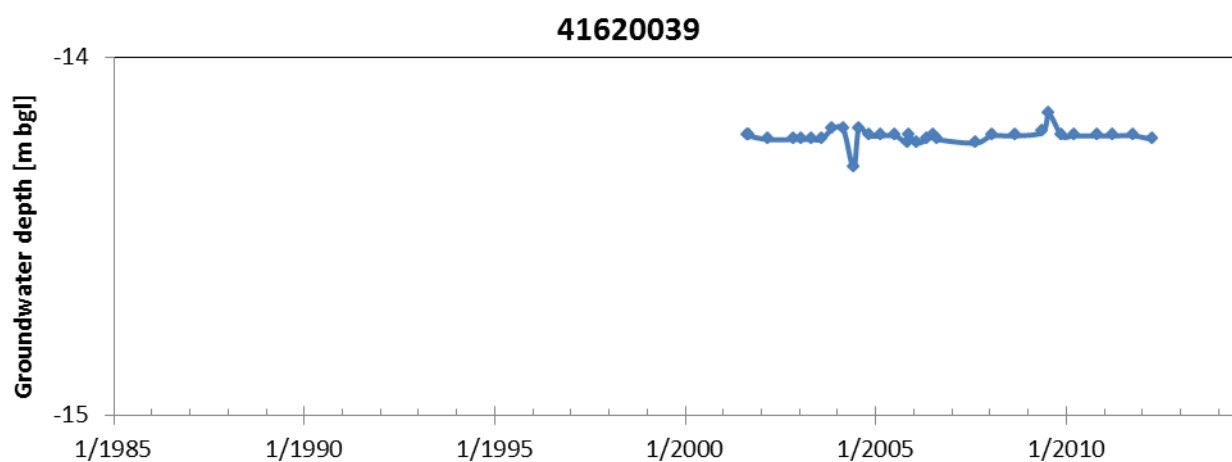
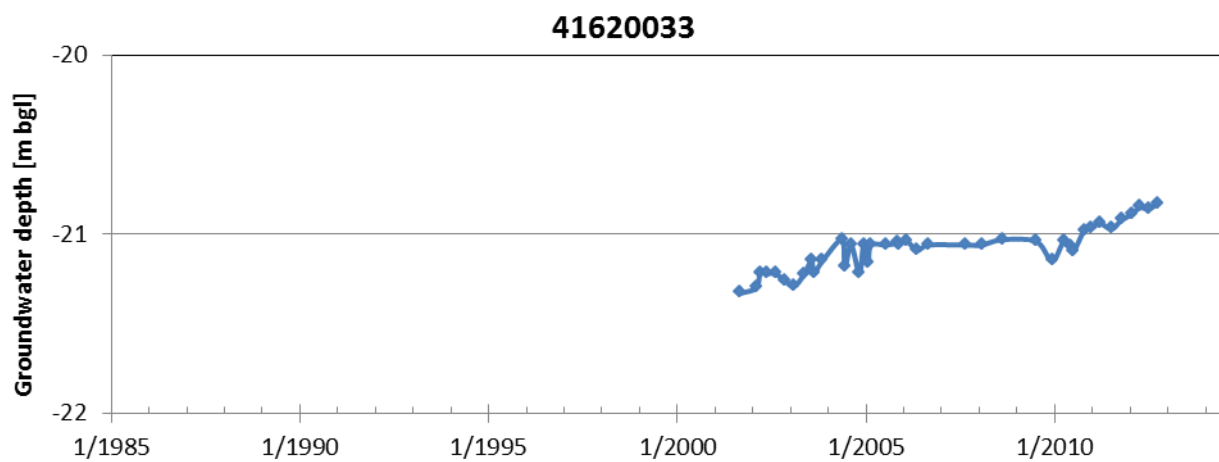
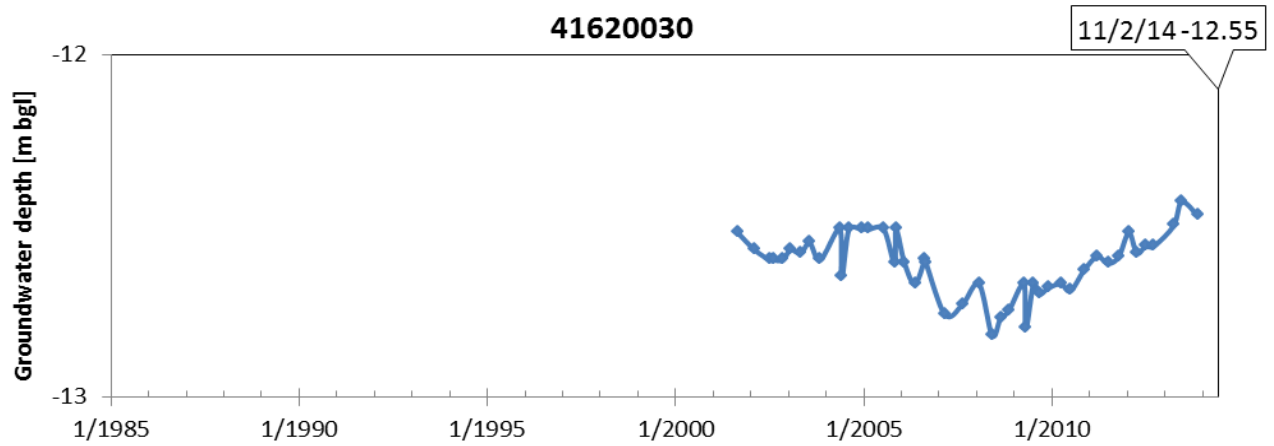
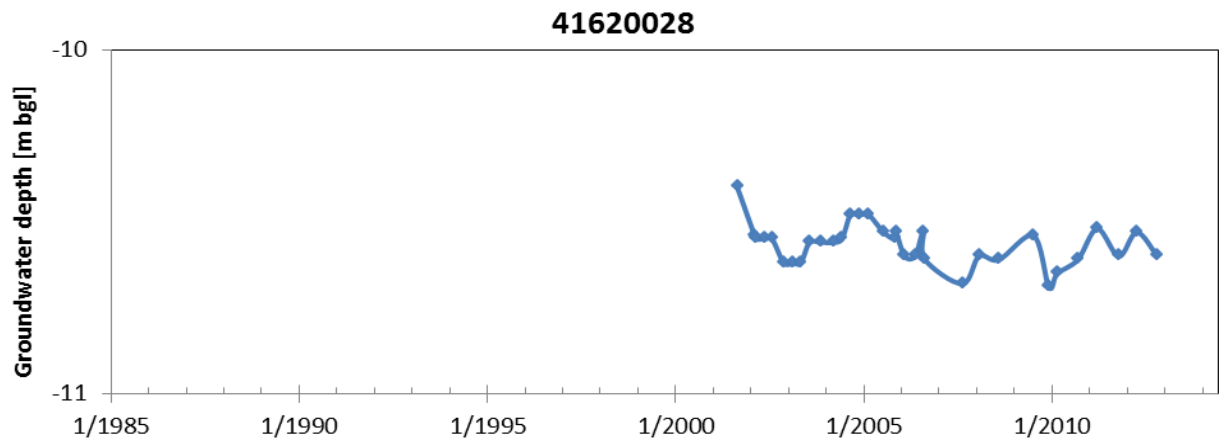


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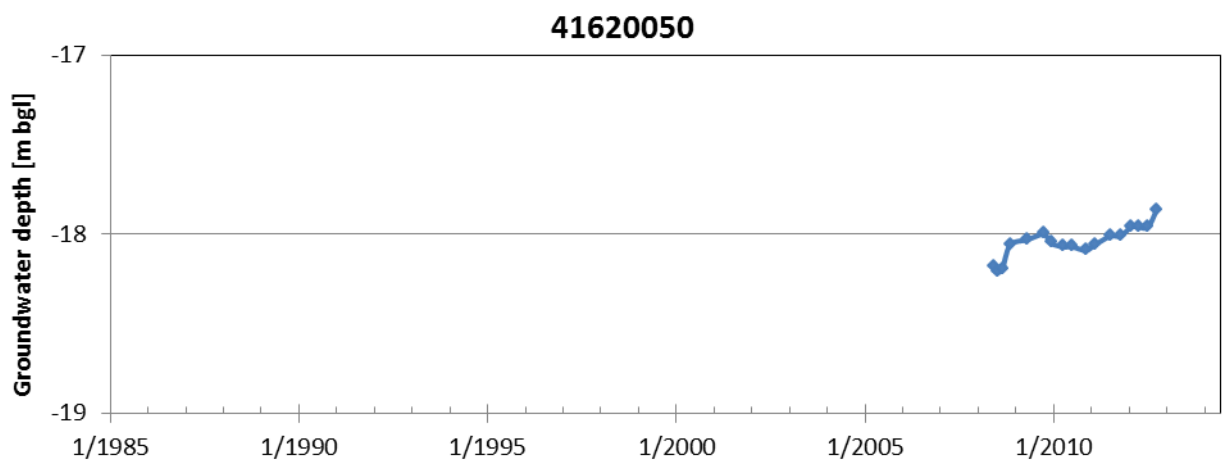
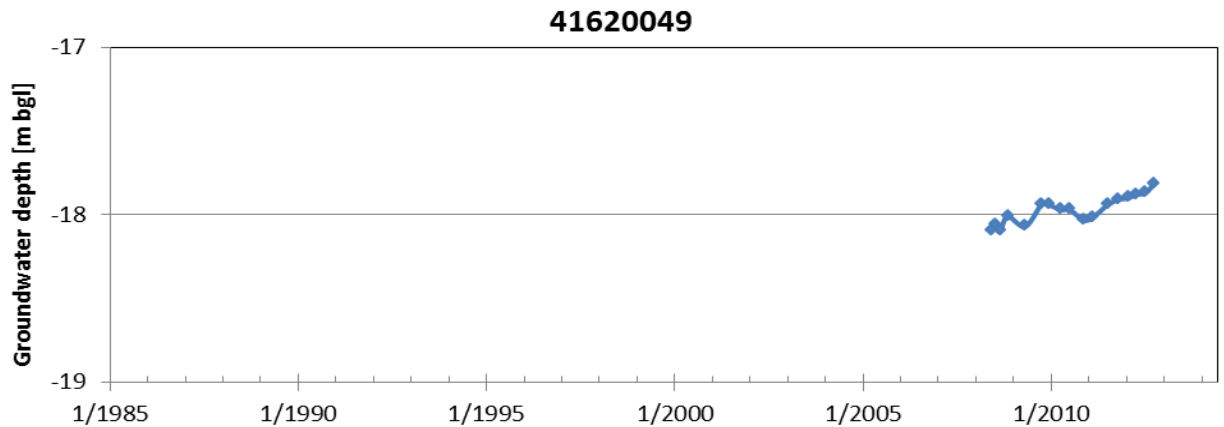
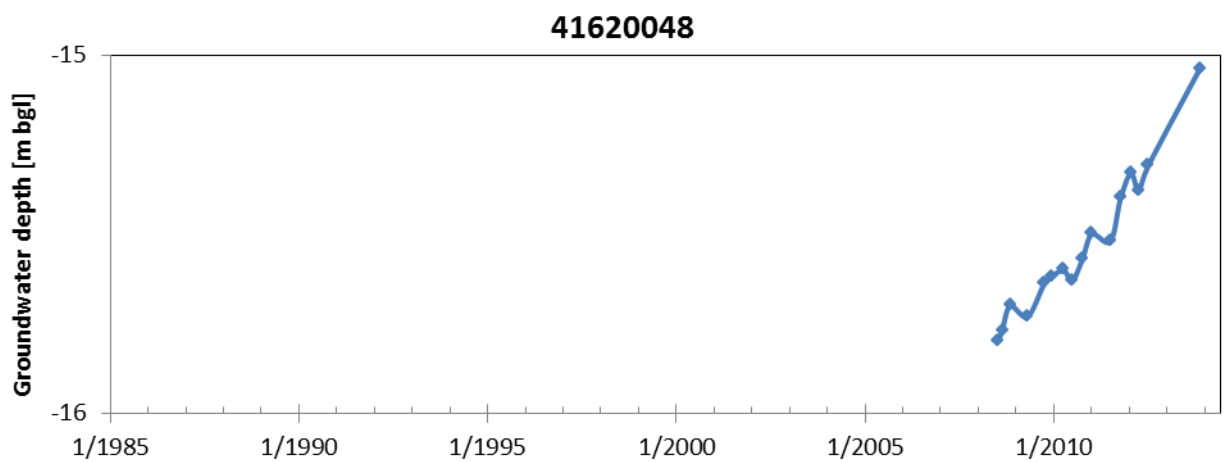
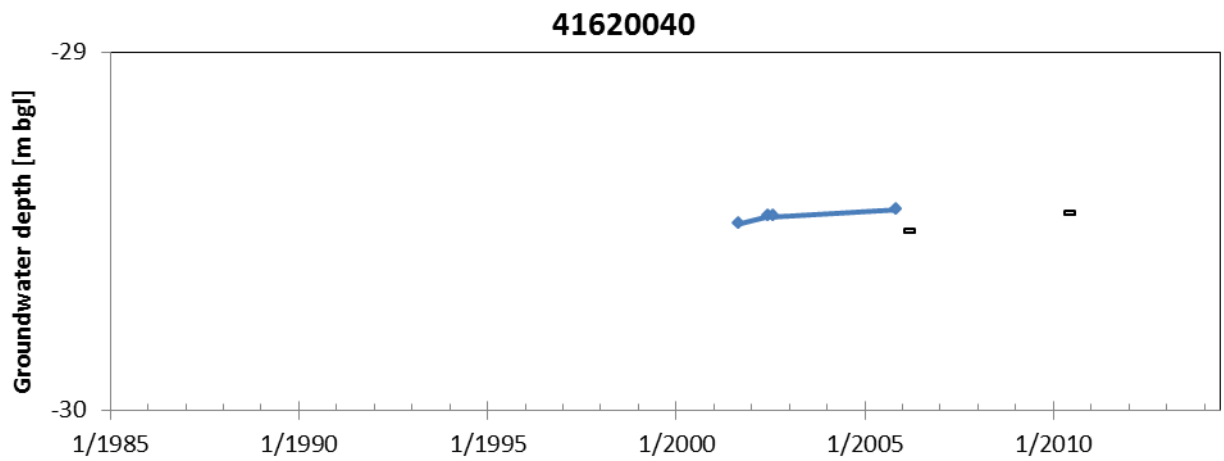


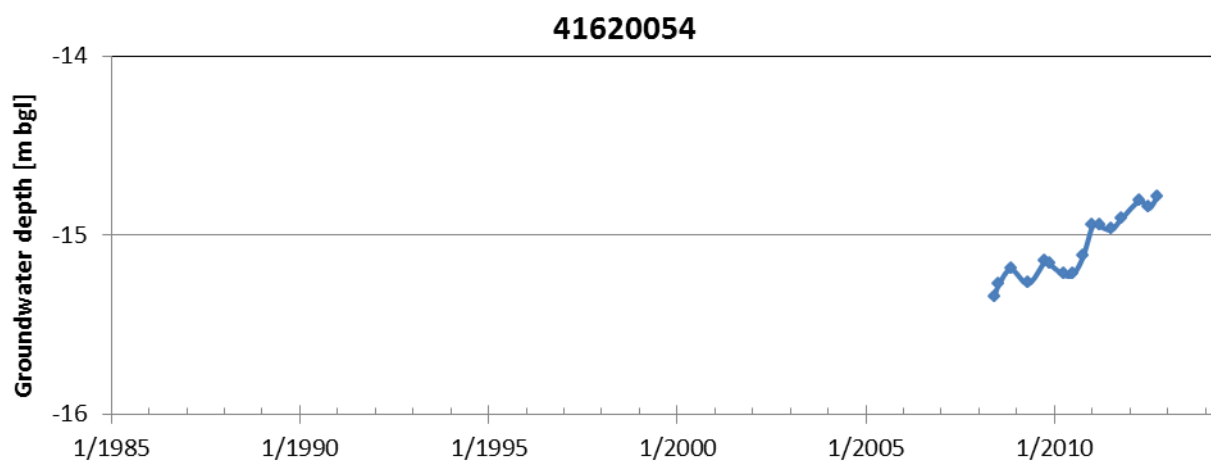
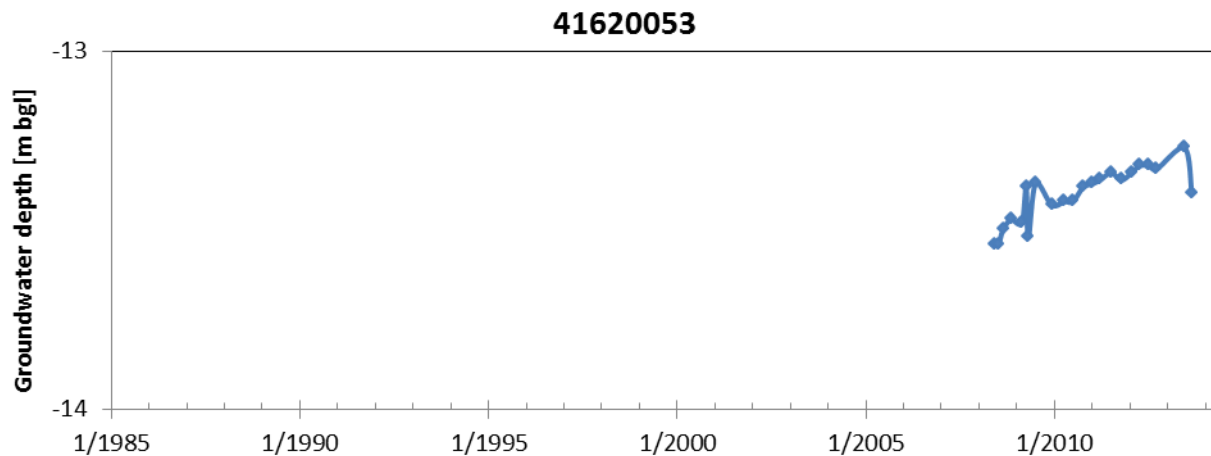
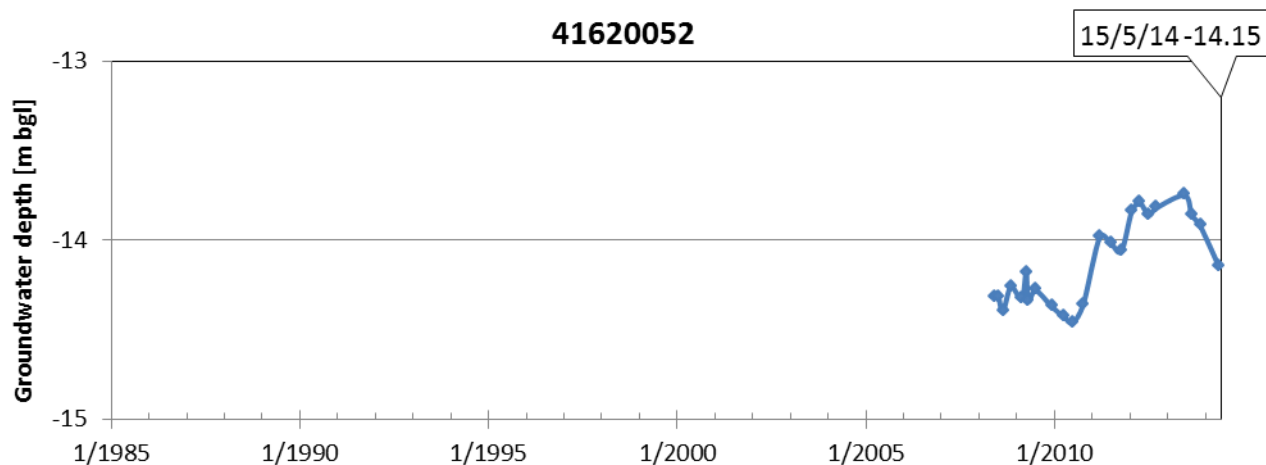
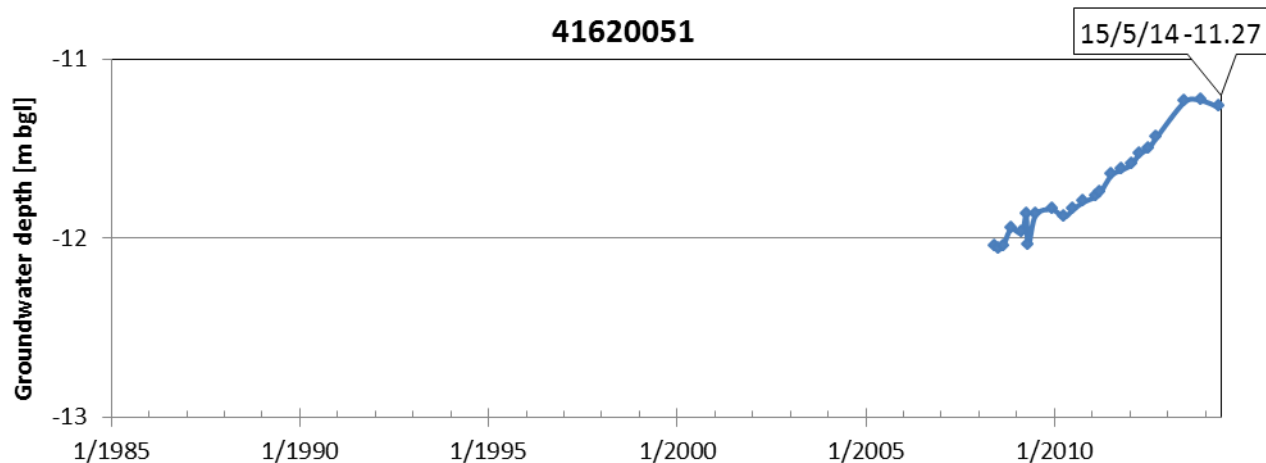
19/3/2001: Error, equal to TD (not shown)

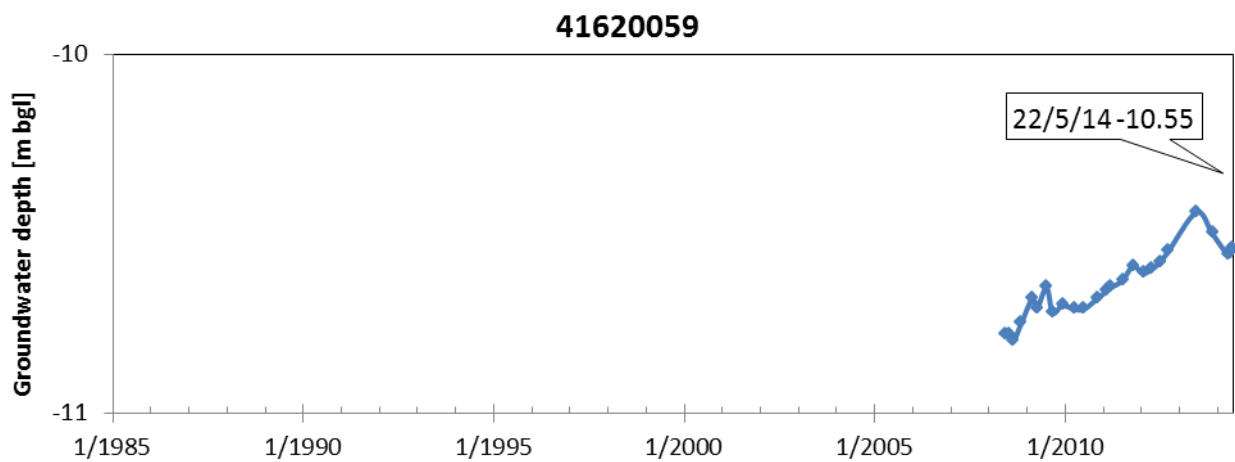
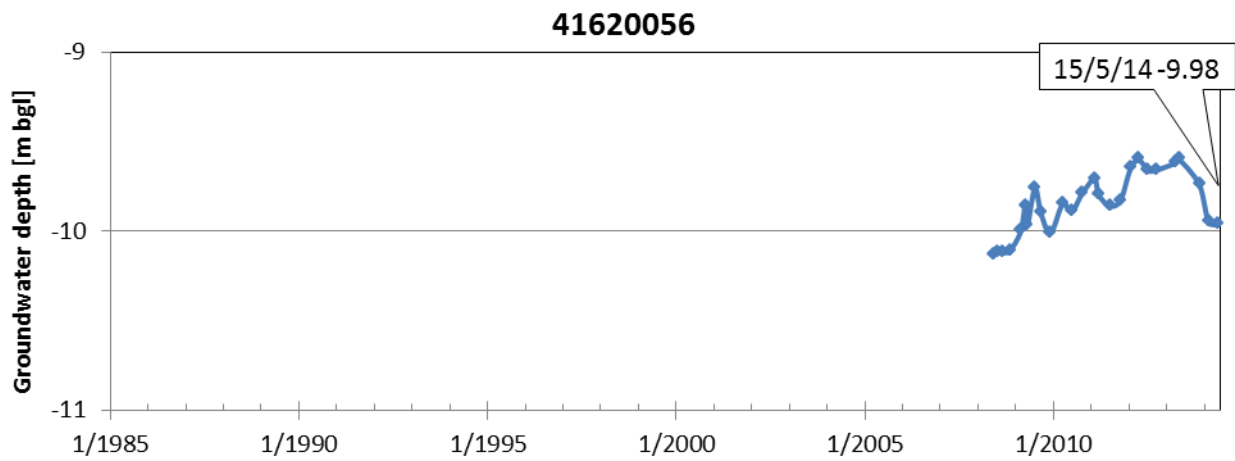




14/2/2002, 17/5/2002, 2/8/2002: Errors, Below TD (not shown).







15/5/2014: error, -9.54 should probably be -10.54 (not shown)

