Penrith Lakes Scheme

HYDROGEOLOGICAL ASSESSMENT

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NATIONPARTNERS

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1. Introduction

1.1 Background and Objectives

Penrith Lakes Development Corporation (PLDC) is responsible for constructing and implementing the Penrith Lakes Scheme, a series of inter-connected lakes and recreational parklands for the benefit of the local community. The Scheme covers a 1935 hectare former sand and gravel quarry on the edge of the Nepean River, approximately 2 km northwest of Penrith. Sand and gravel have been, and continue to be, extracted and exported from the site to supply Sydney's construction industry since the early 1970's, and the Penrith Lakes Scheme was established as the rehabilitation strategy to provide community, social and environmental benefits through construction of a major water-oriented recreational area.

PLDC is approaching a critical period in the implementation of the Scheme with the planned Stage 2 Water Quality Management Plan submission. In order to develop a comprehensive water quality management plan for the Scheme, an assessment of the relationship between the lakes and local groundwater resources is required. The goal of this hydrogeological assessment is to provide an evaluation of the potential for the Scheme to impact surrounding aquifers, or conversely for local groundwater to adversely impact water quality in the lakes once completed, and to identify potential risks to the future operation of the Scheme as a result of such impacts.

1.2 Scope

The scope of works undertaken for the hydrogeological assessment of the Penrith Lakes Scheme comprised:

- Collection of water level and water quality data from existing groundwater bores present at the site (undertaken by PLDC's Water Operations Officer, Mr Russell Jarman);
- Detailed review of groundwater data for the site and local area, including recent groundwater level and quality data collected for the purposes of this assessment;
- Review and analysis of previous hydrogeological assessments for the site with respect to the final landform and operation for the completed Scheme;
- Review and analysis of previous estimates of groundwater inflows to the completed lakes scheme, including comment on additional data requirements needed to better refine such estimates;
- Preparation of this report summarising the conceptual hydrogeological model for the Scheme and providing an assessment of the type and likelihood of potential adverse impacts of the lakes on local groundwater resources and vice versa.

1.3 Data Sources

For this assessment information and data was reviewed and analysed from the following sources:

- Current and historical groundwater level and (where available) water quality data for the site and surrounding areas, obtained from PLDC records and the NSW Natural Resource Atlas online database (NRAtlas, 2014);
- Wallace, I., 1976. *Prospect and Richmond: Engineering and Environmental Geology*. Excursion Guide No 15B, 25th International Geological Congress, NSW Geological Survey publication.
- Gobert, V., 1978. *Proposed Nomenclature for the Cainozoic Sediments of the Penrith-Windsor Area*. Geological Survey of New South Wales, Quarterly Notes 32, 1 July 1978.
- Coffey & Partners, December 1980. *Penrith Lakes Scheme Groundwater Study*. Prepared for PLDC by Coffey & Partners Pty Ltd.
- Jones, D.C., and Clark, N.R. (Eds), 1991. Geology of the Penrith 1:100,000 Sheet 9030. 201pp. New South Wales Geological Survey, Sydney.
- SKM, May 2004. *Penrith Lakes Development – Penrith Lakes Groundwater Assessment*. Prepared for PLDC by Sinclair Knight Merz Pty Ltd.

- IEP, May 2005. *Penrith Lakes Water Principles and Water Plan Peer Review – Stages 1 and 2 Review*. Prepared for the Penrith Lakes Water Committee by the Independent Expert Panel on Environmental Flows for the Hawkesbury Nepean, Shoalhaven and Woronora Catchments,
- Coffey Environments, December 2010. *Groundwater Quality Assessment Report, Readymix Tip, PLDC Scheme Area, Castlereagh Road, Castlereagh NSW*. Prepared for PLDC by Coffey Environments Pty Ltd.
- Cardno, August 2012. *Penrith Lakes Scheme Water Balance & Lake Operating Levels*. Prepared for PLDC by Cardno (NSW/ACT) Pty Ltd.
- PLDC, August 2012. *2012 Water Management Plan: Stage 1*. Prepared by Penrith Lakes Development Corporation.
- PLDC, August 2012. *Draft Water Quality Strategy*. Prepared by Penrith Lakes Development Corporation.

2. Hydrogeological Setting

This chapter provides an overview of the location and environmental setting of the Penrith Lakes Scheme. Information describing the physical and environmental setting was used to develop a conceptual hydrogeological model for the site and surrounding areas.

2.1 Site Location

The Penrith Lakes Scheme is located within the Penrith local government area approximately 60 km west of Sydney and 2 km northwest of Penrith. The Scheme covers approximately 1935 hectares of Nepean River floodplain, bounded by Castlereagh Road to the east, Smith Road to the north, and the Nepean River to the west and south. Rural and low density residential properties are located to the north and east of the site, as well as to the south beyond the Nepean River. The Blue Mountains extend to the west beyond the river. The site's location is shown in **Figure 1**.

2.2 Topography

Topography for the local area is dominated by the Blue Mountains in the west and flatter, lower-lying alluvial terraces at the site and to the north and east. The mountain terrain drops steeply towards the Nepean River and becomes relatively flat across the lower terrace that comprises the site before increasing again in elevation to the northeast of Castlereagh Road (the upper terrace). Being located in a major floodplain of the Nepean River, the site is generally lower in elevation than its surrounds. Topography across the site is generally between 15 and 25 m AHD, with the physical landform being determined by historical quarrying activities and the final rehabilitation plans for the Scheme. The upper alluvial terrace to the northeast of Castlereagh Road ranges between 40 and 50 m AHD, with the terraces distinguishable by the topographic contour lines shown in **Figure 1**.

2.3 Hydrology

Key surface water features present at the site and surrounding areas include the Nepean River and the lakes to be constructed as part of the Scheme. The Nepean River borders the site to the south and west, flowing in a northerly direction before becoming the Hawkesbury River. Penrith Weir, located approximately 800 m south of the site, controls river flow around the Scheme. The elevation of Penrith Weir is 14.35 m AHD, with normal depths over the weir being less than 1.5 m (Coffey & Partners, 1980). The Scheme borders approximately 7 km of the river, with the typical river elevation at the northern end of the Scheme being approximately 6 m AHD (PLDC, August 2012).

The recreational lakes comprising the Penrith Lakes Scheme have been designed to accommodate the natural water flows that existed in the floodplain prior to quarrying whilst providing recreational, social and environmental benefits for the community. Once completed the lakes system will operate as a gravity flow system that replicates the natural south to north flow direction of the adjacent Nepean River and will include wetlands and water bodies intended to optimise water quality in order to accommodate recreational end uses in nominated lakes. The primary sources of water inflow to the lakes include direct rainfall and runoff from semi-rural and residential catchments to the east and northeast (the upper terrace). The primary outflows from the lakes include evaporation and discharge to the Nepean River at the northern end of the Scheme, where the lake operating levels will allow gravity discharge to the river. The lakes design is shown in **Figure 1**, and further details on the design intent, operational strategy (including lake operating levels), water balance and required infrastructure for the Scheme can be found in PLDC's *2012 Water Management Plan: Stage 1* (PLDC, August 2012).

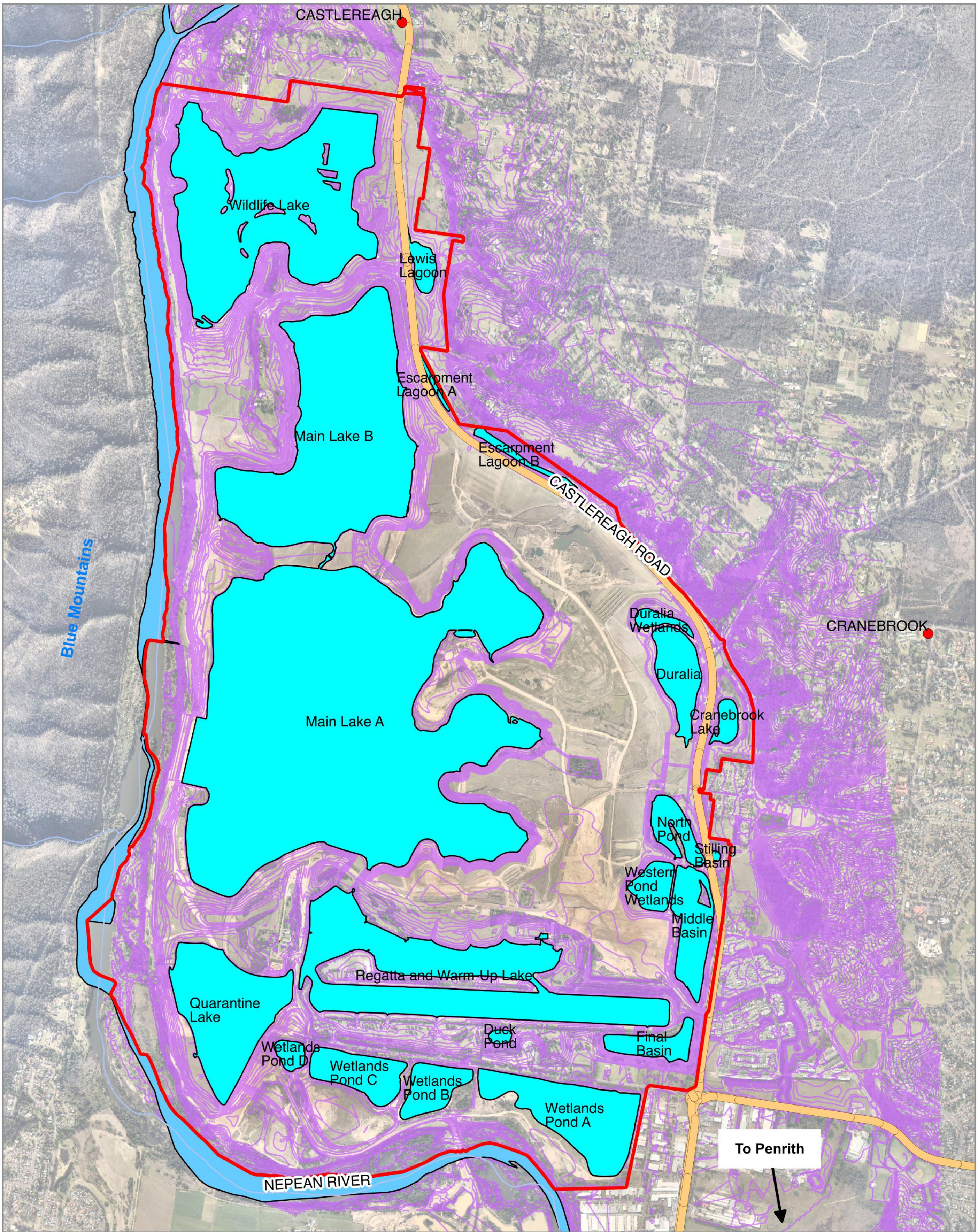

Figure 1: Penrith Lakes Scheme Location and Topography

Penrith Lakes Scheme - Hydrogeological Assessment

Legend

- Lakes Design
- Arterial Road
- Topographic Contours (1 m)
- Penrith Lakes Scheme Boundary (approximate)

DATA SOURCES
PLDC, 2014; Imagery: Nearmaps, 2014

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2.4 Geology

The Penrith area is located near the structural centre of the Sydney Basin, where regional geology is dominated by Hawkesbury Sandstone and the shales, siltstones, laminites and mudstones of the Wianamatta Group (Jones and Clark, 1991). Geological units for the local area, taken from the *Geology of the Penrith 1:100,000 sheet* (Jones and Clark, 1991), are shown in **Figure 2**. Hawkesbury Sandstone is a massive quartz sandstone unit up to 200 m thick that outcrops as the Blue Mountains west of the site and along the western bank of the Nepean River (Coffey & Partners, 1980). The Hawkesbury Sandstone unit continues to dip to the east of the Nepean River, underlying the Ashfield and Bringelly Shales of the Wianamatta Group within the Penrith Basin (Jones and Clark, 1991). In the vicinity of the site fresh, dark grey Ashfield Shale increases in thickness (up to 20 m thick) from west to east, overlying Hawkesbury Sandstone and representing the primary bedrock formation.

The lower alluvial terrace upon which the Scheme is located is composed of Quaternary-aged gravels, sands and silts approximately 10 to 15 m thick (the Cranebrook Formation) that comprise the primary resource being quarried and extracted by PLDC and its predecessors. The gravels and sands within this formation are generally found in the lower 10 m of the unit before fining upwards to silts and clays nearer to the surface (IEP, 2005). Current and historical quarrying operations have targeted the Cranebrook Formation for extraction of sands and gravels for the local construction industry, with the majority of the unit within the Scheme boundary having been excavated and removed to the underlying Ashfield Shale bedrock. To the northeast the upper terrace follows a similar sequence of gravels and sands (Rickabys Creek Gravels) underlying finer silts and clays (Londonderry Clay), though these formations are older, late-Tertiary aged units (IEP, 2005). The alluvial deposits of the upper terrace are between 15 and 25 m thick to the east and northeast of the Scheme, thinning as topography decreases towards the floodplain (IEP, 2005).

2.5 Hydrogeology

2.5.1 Groundwater Bores

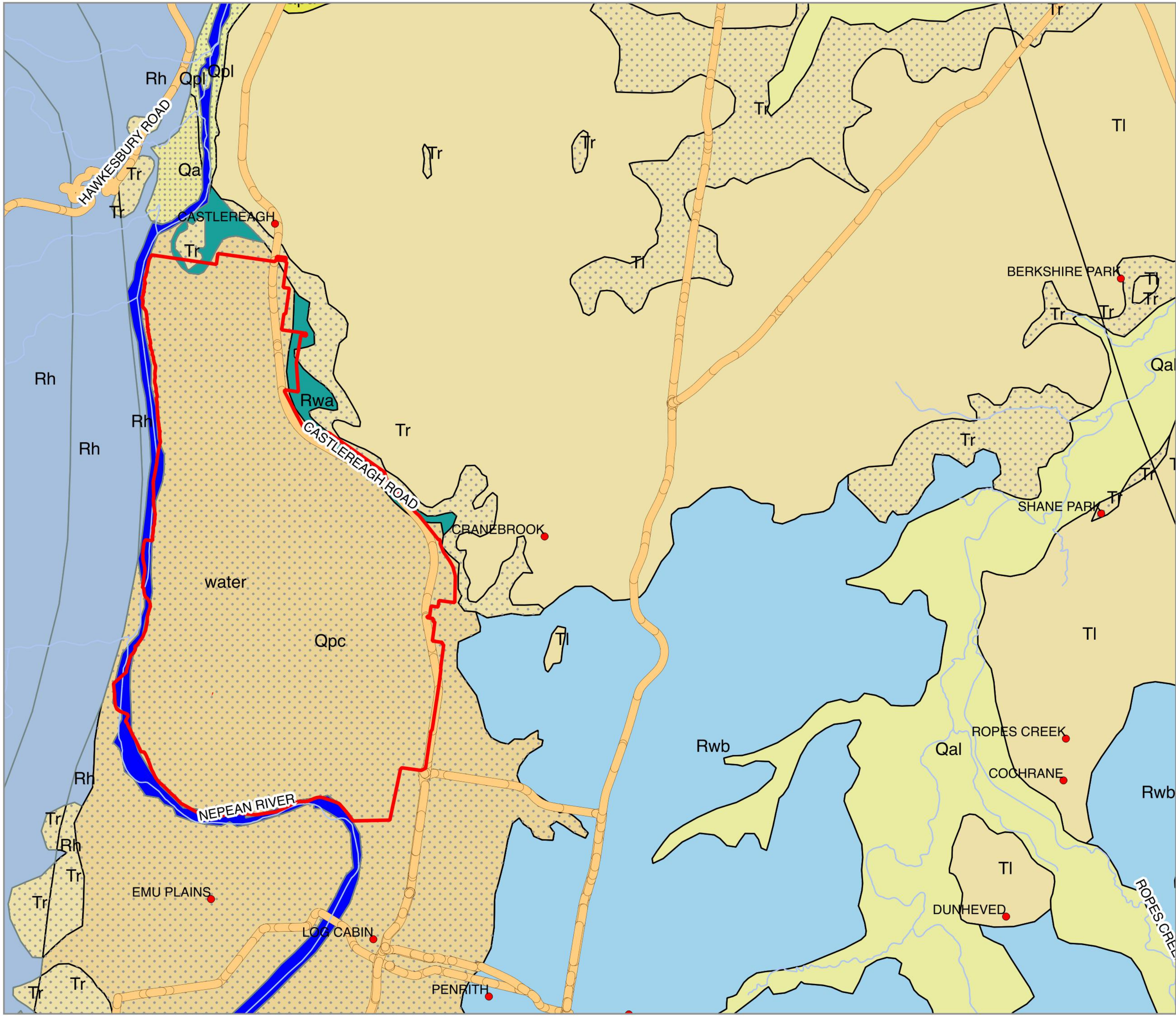
The NSW Natural Resources Atlas online database (NRAtlas, 2014) contains records for over 100 registered groundwater bores within the lower alluvial terrace where the Scheme is located. The majority of these bores were drilled to depths less than 15 meters below ground surface (m bgs) for irrigation, farming, stock and domestic supply purposes. Information on water bearing zones found in individual bores is sparse, however given the shallow depths it is assumed supply was obtained within the alluvial sand and gravel deposits that form the Cranebrook Formation. Given the history of quarrying activities at the Scheme, the majority, if not all, of these bores are likely to have been destroyed or decommissioned.

Approximately 30 registered bores are located within the upper terrace, likely due to the lower yields and poorer water quality associated with the Rickabys Creek Gravels and Londonderry Clay deposits. Site specific information for groundwater bores in the area indicate the bores generally target fresh to slightly saline (less than 1500 mg/L salinity) groundwater within the regional Hawkesbury Sandstone aquifer at depths greater than 100 m bgs (NRAtlas, 2014). Groundwater levels for bores targeting the Hawkesbury Sandstone regional aquifer generally recorded static water levels between 30 and 50 m bgs, indicating that groundwater pressures within the regional aquifer are insufficient to cause upward leakage through the Wianamatta Group (Ashfield and Bringelly Shales) and into the overlying Tertiary and Quaternary alluvial aquifers (NRAtlas, 2014). No bores are registered in the database located in the Blue Mountains to the west of the site and Nepean River (NRAtlas, 2014).

Groundwater observation bores within and around the Penrith Lakes Scheme boundary have been intermittently monitored since the late 1980s, with limited records to describe the location, extent and purpose of bores drilled. The majority of bores are or were located in the southeast corner of the scheme between the planned southern wetlands lakes and the Nepean River (bore series A101A through D401D, E and F), and in the area east of Main Lake A between Duralia to the north and Regatta and Warm Up Lake to the south (bore series CGBH), as shown in **Figure 3**. Other bores (GW and P-series bores and Dalseno) are located along the eastern boundary of the Scheme. Reports and data provided by PLDC did not include records of any groundwater bores along the western boundary of the Scheme (between the lakes and the Nepean River), though Coffey & Partners (1980) referenced a 1961 study by the NSW Water Resources Commission that included bores in this area. These bores are likely to have been decommissioned or destroyed as part of quarrying activities at the site.

Figure 2: Regional Geology

Penrith Lakes Scheme - Hydrogeological Assessment



Legend

Penrith 100K Geological Units

- Cranebrook Formation
- Lowlands Formation
- Quaternary Gravel and Sand
- Rickabys Creek Gravel
- Agnes Banks Sand
- Londonderry Clay
- Clarendon Formation
- Quaternary fine grained sand silt and clay
- Burralow Formation
- Ashfield Shale
- Bringelly Shale
- Hawkesbury Sandstone
- Penrith Lakes Scheme Boundary (approximate)

DATA SOURCES
NSW LPI, 2014; Imagery: Nearmaps, 2014

N

SCALE 1:65,000

500 0 500 1000 1500 m

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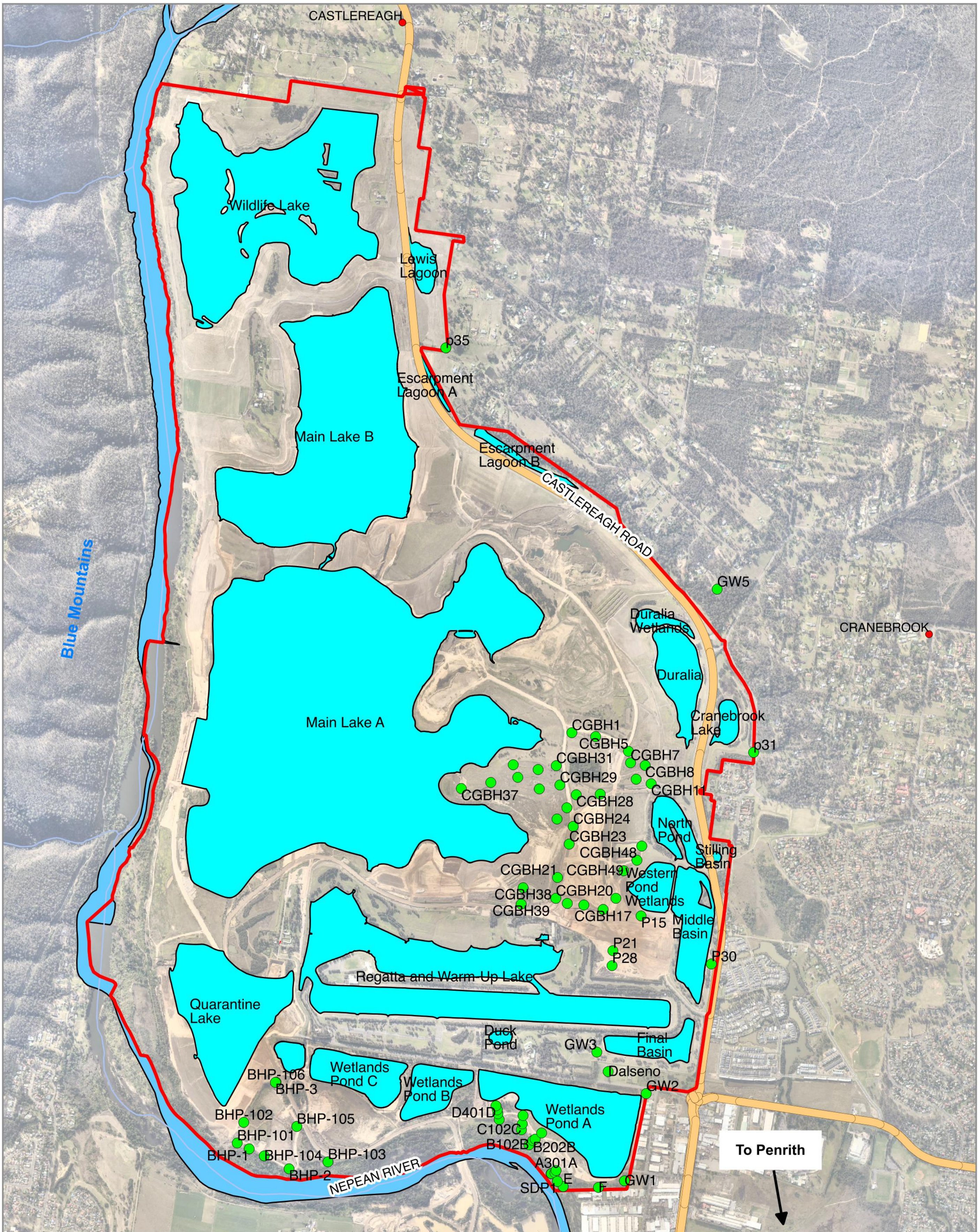

Figure 3: Groundwater Bores at Penrith Lakes

Penrith Lakes Scheme - Hydrogeological Assessment

Legend

- Monitoring Bore
- Lakes Design
- Arterial Road
- Penrith Lakes Scheme Boundary (approximate)

DATA SOURCES
PLDC, 2014; Imagery: Nearmaps, 2014

N

SCALE 1:32,000
250 0 250 500 750 m

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Hydrographs for the bores shown in **Figure 3** are included in **Attachment 1**. Rainfall data for the periods groundwater levels were recorded are also included. Previous groundwater assessments of the Scheme have noted that groundwater levels correlate well with local rainfall (SKM, 2004; IEP, 2005), with such behaviour expected given the shallow, unconsolidated nature of the alluvial aquifer present. Groundwater response to rainfall is less apparent in the hydrographs included in **Attachment 1**, though quarrying activities are likely to have had a significant influence on groundwater behaviour during the periods for which data was available. Several hydrographs indicate a general decline in the groundwater table between July 1990 and June 1991 (bores A101, A301A, E, F, GW1 and GW2). The reason for the decline is not clear, however these bores are located along the southeastern boundary of the Scheme (refer **Figure 3**), and groundwater pumping or related quarrying activities in the area during this period may have been responsible. Hydrographs for the BHP-series bores in the southwestern part of the Scheme were not included as groundwater levels for these bores have been recorded on only two occasions.

2.5.2 Aquifer Systems

Groundwater in the local area is present in two distinct aquifer systems defined by geological formations. Groundwater within the Hawkesbury Sandstone forms the main regional aquifer and is characterised by low yields and low salinity. The overlying Wianamatta Group (including the Ashflied and Bringelly Shales) forms a semi-confining aquiclude above the Hawkesbury Sandstone, with higher salinity groundwater from the shales leaking to the underlying sandstone. Extraction bores targeting the Hawkesbury Sandstone are generally drilled to depths at least 50 m below the base of the Wianamatta Group to obtain useable supply rates (up to 5 L/s) and water quality (Jones and Clark, 1991). In the Penrith area groundwater within the regional Hawkesbury Sandstone aquifer is expected to flow to the west towards the Nepean River that incises the sandstone unit and represents the base level for the regional aquifer.

Groundwater at Penrith Lakes is dominated by the shallow alluvial aquifer of the Quaternary-aged Cranebrook Formation, with some inflows from the adjacent, older Tertiary deposits of the upper terrace to the east and northeast. Groundwater within the Cranebrook Formation found within the lower alluvial terrace is characterised by high yields (up to 25 L/s) and low salinity (typically less than 800 mg/L), making it an ideal resource for groundwater extraction before quarrying commenced (Jones and Clark, 1991). The aquifer is found within the coarse sands and gravels that were targeted for extraction and resides upon the impermeable Ashfield Shale bedrock. The aquifer thickness varies with depth to the shale bedrock, with the overlying finer silts and clays forming a leaky confining layer above the basal sand and gravel aquifer (Coffey and Partners, 1980).

To the east and northeast of the site, groundwater within the upper alluvial terrace is found within older and slightly deeper Rickabys Creek Gravels and Londonderry Clay deposits. Jones and Clark (1991) report low yields (generally less than 0.6 L/s) and slightly saline to brackish water quality (600 mg/L to 4000 mg/L salinity). Groundwater data from the Castlereagh Waste Management Centre to the north of the site also recorded low permeabilities and fresh to brackish water quality within these formations (IEP, 2005). Higher salinity and lower yields within the Tertiary deposits are indicative of slower groundwater movement and increased evapotranspiration in lower topographic areas (Jones and Clark, 1991).

The alluvial aquifer of the upper terrace meets the younger, fresher Cranebrook Formation in the vicinity of Castlereagh Road along the eastern boundary of the Scheme. Higher salinity groundwater from the Tertiary deposits discharges into the Cranebrook Formation at this intersection between the upper and lower terrace alluvial aquifers, forming a more saline plume whose extent is imprecise due to dilution by fresher groundwater within the lower alluvial aquifer.

2.5.3 Flow Patterns

Prior to the commencement of quarrying operations, groundwater flow patterns were driven by the hydrology of the Nepean River and the unconsolidated nature of the alluvial deposits that comprise the Cranebrook Formation. Groundwater contours as of January 1969 were compiled by the NSW Department of Water Resources and reported in Jones and Clark (1991), shown in **Figure 4**, and indicate groundwater generally flows from the southeast corner of the Scheme to the west-northwest before discharging to the Nepean River. The shallow, unconsolidated nature of the alluvial deposits means residence times within the formation are generally low (Jones and Clark, 1991). As the concentrated area of recharge in the southeast opens to a larger discharge area across the floodplain, groundwater flow velocities decrease, allowing intrusion of more saline groundwater from the Tertiary deposits of the upper alluvial terrace in the northeast part of the Scheme (Coffey and Partners, 1980; Jones and Clark, 1991). Woolley, in Jones and Clark (1991), reported the source of recharge in the southeast of the Cranebrook Formation was likely to be the Nepean River northeast of Emu Plains, though Coffey and Partners (1980) disputed the river and Penrith Weir as a recharge source as due to the absence of locally increased groundwater elevations. The water level contours (in m AHD) reported in **Figure 4** appear to be in error, as topography in the lower terrace where the Cranebrook Formation is located, even prior to the commencement of quarrying activities, is between 15 and 25 m AHD.

Over the past 40 years extensive sand and gravel extraction and related activities has altered groundwater flow patterns in the Penrith Lakes area, with groundwater contours influenced by recharge and discharge processes related to the lakes being constructed as part of the Scheme. **Figure 5** shows interpreted groundwater contours based on groundwater level observations as of June 2014. The general west-northwest groundwater flow direction remains apparent across the site, with groundwater discharging to the Nepean River on the western boundary. More localised effects from the lakes within the Scheme are apparent in the southwestern corner of the site (the BHP-series bores south of Wetlands Ponds C and D and Quarantine Lake) and to the east of Main Lake A (bores CGBH31 and CGBH35). Groundwater contours in the southwest corner of the Scheme are consistent with previous levels recorded in this area (Coffey Environments, 2010), with the Wetlands Ponds and Quarantine Lake appearing to act as recharge zones and local groundwater flowing south and southwest before discharging to the river. Groundwater levels decrease rapidly approaching Main Lake A from the east, likely a result of quarrying activities (including pumping) in the excavation voids where Main Lake A is being constructed.

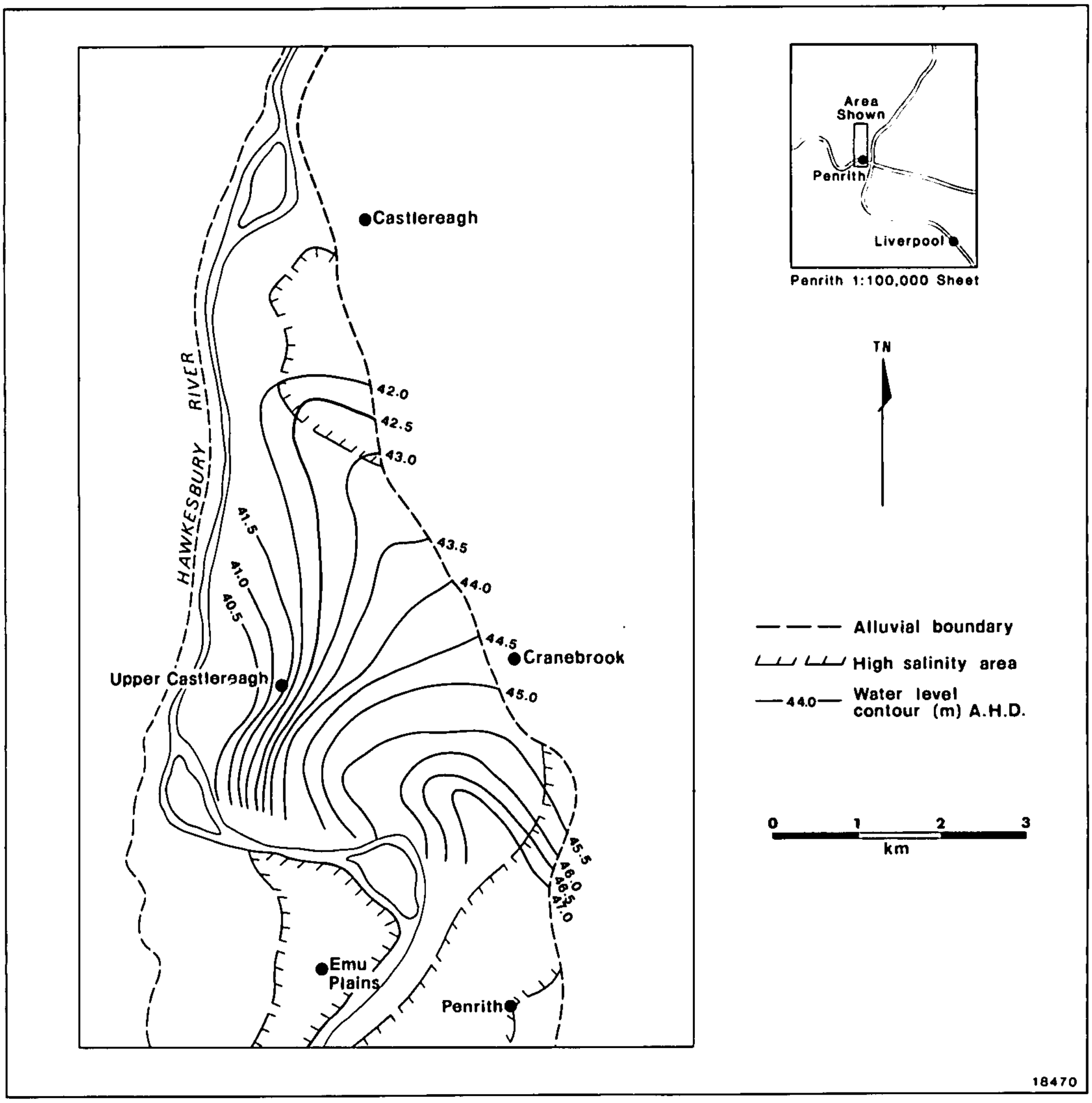

Figure 4: Groundwater contours in the Cranebrook Formation in January 1969 (taken from Jones and Clark, 1991)

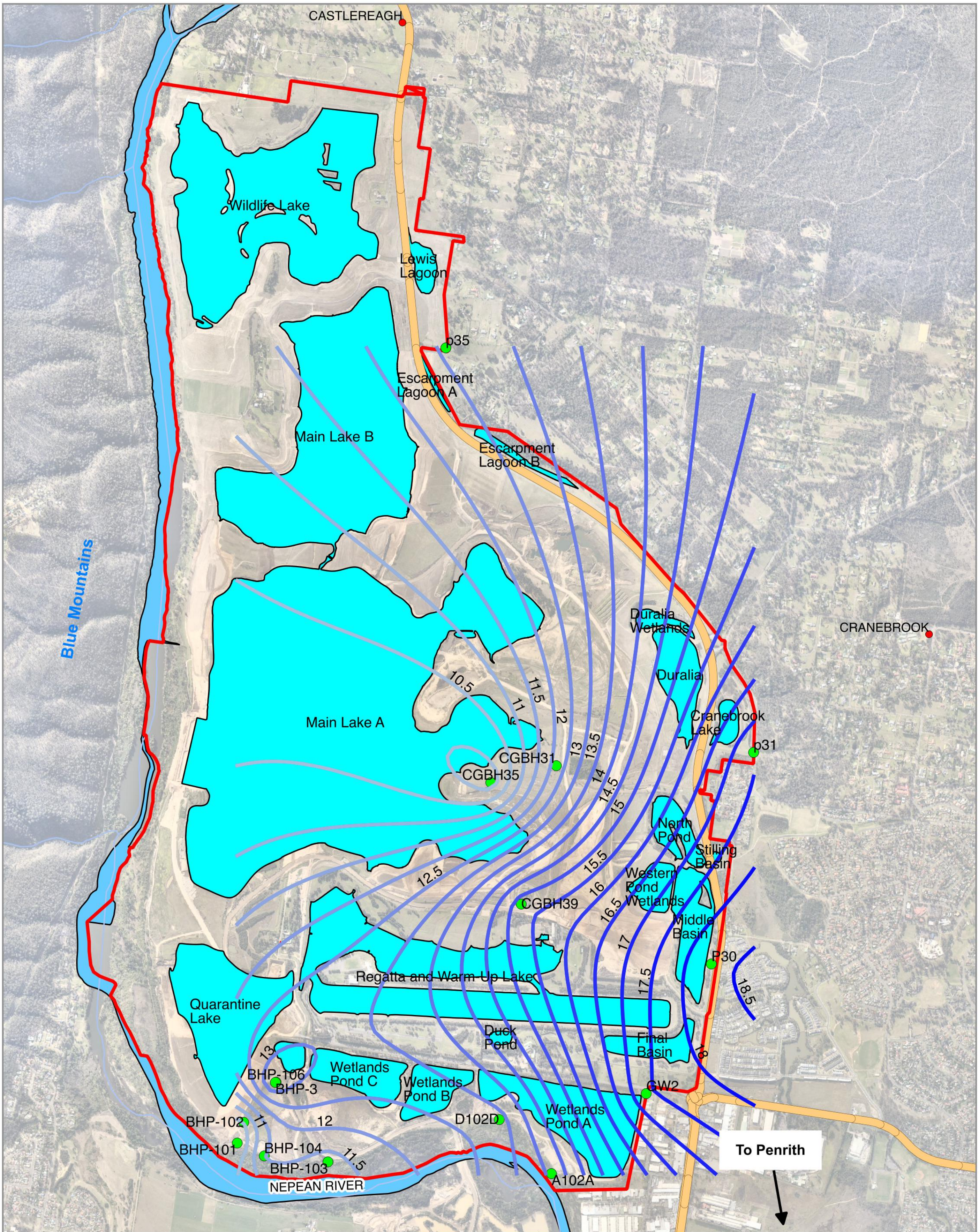

Figure 5: Inferred Groundwater Contours, June 2014

Penrith Lakes Scheme - Hydrogeological Assessment

Legend

- Monitoring Bore
- Groundwater Contour
- Lakes Design
- Arterial Road
- Penrith Lakes Scheme Boundary (approximate)

DATA SOURCES
PLDC, 2014; Imagery: Nearmaps, 2014

N

SCALE 1:32,000
250 0 250 500 750 m

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2.5.4 Groundwater Quality

Groundwater quality in the region is largely determined by the physical and chemical characteristics of the aquifers and geological formations present. Groundwater in the regional Hawkesbury Sandstone aquifer is typically fresh to slightly saline (i.e. less than 1500 mg/L total dissolved solids), low pH, and contains high dissolved iron concentrations that can cause corrosion and/or staining (Jones and Clark, 1991). The overlying shales of the Wianamatta Group are characterised by low yielding, high salinity groundwater that is often too saline for stock watering. Leakage of saline groundwater from the Wianamatta Group into the underlying sandstone increases salinity in the sandstone aquifer, meaning extraction bores are generally required to be at least 50 m beneath the base of the shales in order to obtain usable supply (Jones and Clark, 1991).

Groundwater quality differs between the Quaternary alluvial aquifer of the lower terrace and the Tertiary deposits of the upper terrace. The shallow, unconsolidated nature of the Cranebrook Formation in the lower terrace results in high yields, low residence times and low salinity. The older Rickabys Creek Gravels and Londonderry Clay formations of the upper terrace are more weathered and cemented and contain a higher proportion of clay, resulting in lower yields and higher salinity groundwater (SKM, 2004; IEP, 2005). The impact of the upper terrace aquifer on groundwater quality in the lower terrace is evident in **Figure 4**, where a high salinity plume was noted entering the Cranebrook Formation along the northwestern boundary of the Scheme (Jones and Clark, 1991). Water quality data collected as part of this assessment supports the intrusion of more saline groundwater from the east, with electrical conductivity (EC) readings at bores P31 and P35 (located along the eastern and northeastern boundary of the Scheme, refer **Figure 3**) being 9.3 mS/cm and 17.3 mS/cm, respectively, whilst EC readings for other bores were consistently less than 2 mS/cm. Inflow of saline groundwater from the Tertiary deposits of the upper terrace has been noted in previous groundwater assessments for Penrith Lakes (Coffey and Partners, 1980; SKM, 2004; IEP, 2005).

In their groundwater review SKM (2004) noted that small quantities of saline groundwater from the Wianamatta Group shales may enter the Cranebrook Formation via upward leakage, however static water levels for bores targeting the Hawkesbury Sandstone aquifer in the upper terrace suggests groundwater pressures in these bedrock aquifers are likely insufficient to represent a significant recharge source.

2.5.5 Conceptual Model

The physical and environmental setting, along with current and historical groundwater data, support the conceptual hydrogeological models developed in previous groundwater assessments for the Penrith Lakes Scheme. The conceptual model provided by IEP (2005) is reproduced in **Figure 6** and provides an overview of groundwater movement within the Scheme and between the alluvial aquifers of the upper and lower terraces. The model has been reviewed and modified to include recharge and discharge processes expected to occur following completion of the lakes. Key elements of the conceptual model include:

- The primary source of groundwater recharge is expected to be rainfall infiltration through remnants of the Cranebrook Formation. The quantity and rate of recharge due to infiltration processes is expected to be lower than prior the establishment of the lakes due to the decrease in the volume of the aquifer itself (extraction and removal of sand and gravel, and establishment of the lakes in the resulting voids) and rehabilitation of the final landform to facilitate runoff and reduce infiltration.
- During normal operating conditions groundwater is expected to discharge to the lakes as evaporation from the surface of the lakes will maintain disequilibrium with the surrounding groundwater. However during and after wet weather, including heavy rainfalls and flood events, the lakes will act as recharge sources for local groundwater as lake levels will be higher than the surrounding groundwater table. Low permeability clays in the banks and walls of the lakes and impermeable shale floors will restrict recharge and discharge rates between the lakes and groundwater. An engineered clay core barrier wall has been constructed between the lakes and the Nepean River along the western boundary of the Scheme to prevent seepage losses from the lakes to the river.
- The Tertiary alluvial aquifer of the upper terrace drains towards the Scheme, contributing saline groundwater to the remnant Cranebrook Formation and lakes. The flux of saline groundwater from these eastern aquifers is expected to be small, though potentially significant due to potential impacts on water quality.
- Seepage from the Nepean River upstream of Penrith Weir is expected to contribute groundwater inflows to the aquifer in the southeast portion of the Scheme, with groundwater discharging back to the river in the northwestern part of the Scheme. The lakes designed operating levels and current groundwater contours indicate the overall groundwater flow direction across the Scheme, when not influenced locally by the lakes themselves, will replicate historical behaviour flowing in a west-northwest direction.

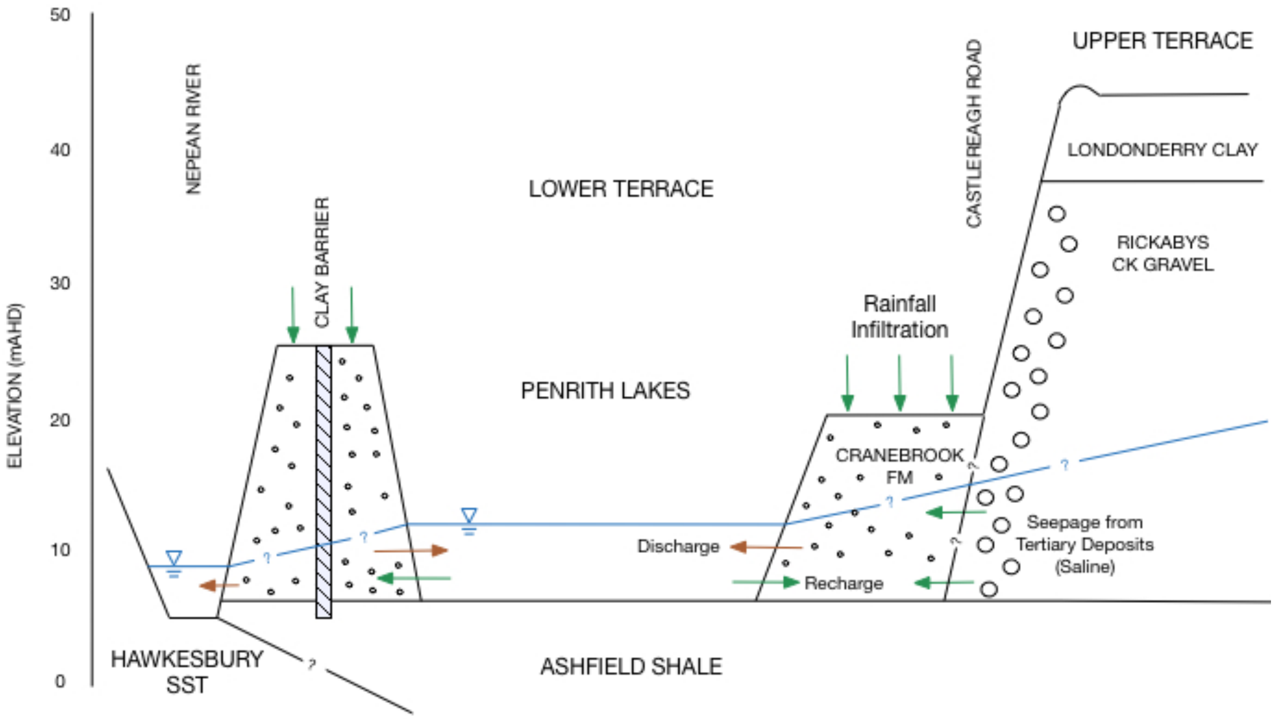

Figure 6 – Conceptual hydrogeological model for Penrith Lakes (modified from IEP, 2005)

3. Groundwater Impacts

3.1 Impacts on Groundwater

Due to its physical and environmental setting, impacts on local and regional aquifers as a result of the Penrith Lakes Scheme are largely limited to the site itself. Historical extraction of sand and gravel essentially removed the deposits that formed the alluvial aquifer upon which the Scheme is located, replacing it with an interconnected series of surface water lakes. Low permeability shales of the Wianamatta Group that signify the base of the former alluvial aquifer and current lakes system limit connectivity to, and potential impacts on, the underlying regional Hawkesbury Sandstone aquifer.

Groundwater in shallow aquifers surrounding the site generally drains towards the Scheme and the Nepean River, resulting in the lakes system acting as a sump for local groundwater (IEP, 2005). Lake operating levels and flow directions within the Scheme have been designed to facilitate natural surface water and groundwater flow processes that were present in the area prior to the commencement of quarrying activities, including natural recharge and discharge zones. The lakes system can be conceptualised as a surface water representation of the alluvial aquifer that was present in the floodplain prior to the commencement of sand and gravel extraction, with the design and operating levels of the lakes serving to diminish the magnitude of groundwater response to rainfall and wet weather events. Under these conditions potential impacts of the Scheme and lakes system on local groundwater resources are likely to be limited.

3.2 Impacts on the Scheme

Potential groundwater impacts on the Penrith Lakes Scheme are governed by recharge sources to groundwater at the site, a result of the location and setting of the Scheme and its behaviour as a groundwater sump. The conceptual model for the site identifies sources of groundwater recharge including:

- Rainfall infiltration through remnants of the Cranebrook Formation;
- Inflows of saline groundwater from older alluvial aquifers to the east of the Scheme; and
- Seepage from the Nepean River near Penrith Weir in the southeast corner of the Scheme.

Amongst these sources, groundwater recharge from rainfall infiltration and seepage from the Nepean River are expected to be low in salinity and have negligible impact on water quality within the Scheme. However inflows of saline groundwater from older alluvial aquifers in the upper terrace to the east and northeast of the Scheme offer the potential to adversely impact water quality within the lakes. Whilst previous groundwater assessments have estimated the maximum potential salt influx from this source and determined it to be negligible in comparison to the salt contribution from rainfall on the lakes (IEP, 2005), the potential impacts from this recharge source must nevertheless be considered. Conditions such as extended dry weather and/or extreme drought would be expected to exacerbate the potential impacts and risks of saline groundwater intrusion, as increased evaporation rates would increase salinity in the lakes whilst also lowering lake water levels, increasing the hydraulic gradient between the eastern aquifers and the lakes.

3.3 Groundwater Budget

The available groundwater data and information for the Scheme and surrounding area makes quantitative estimates of the groundwater budget difficult, especially in light of historical quarrying activities, the lack of available pumping and discharge records, and final landform design and construction requirements for the lakes still under construction. Nevertheless estimates of groundwater inflows and outflows from previous groundwater assessments provide an indication of contributions from various sources.

In their groundwater analysis conducted in 1980, prior to the consolidation and expansion of quarrying activities within the Scheme boundary, Coffey and Partners (1980) estimated total inflows and outflows of 3.8 GL/year and 3.0 GL/year, respectively, and a storage volume of 17 GL for the alluvial aquifer system. The primary sources of inflows were considered direct infiltration from rainfall and runoff on the lower terrace and local irrigation activities, whilst inflow from shallow alluvial aquifers surrounding the site was considered to be negligible (Coffey and Partners, 1980). Recharge from local irrigation activities is no longer considered a significant contributor to groundwater inflows due to expansion of semi-urban and residential development and adoption of reticulated water systems in the area.

Later groundwater assessments for the Scheme (SKM, 2004; IEP, 2005) specifically avoided quantitative estimates of groundwater inflows and outflows, however consultants Cardno reported estimates of groundwater contributions to the Scheme in their recent *Penrith Lakes Scheme – Water Balance & Lake Operating Levels* (2012) report. The groundwater inflow estimates used by Cardno (2012) in their hydraulic modelling for the Scheme included 1.35 GL/year rainfall and runoff infiltration during an average rainfall year, 0.5 GL/year from irrigation within the Scheme, and 0.3 GL/year from aquifers surrounding the site. Actual recharge contributions from direct infiltration and irrigation within the Scheme will largely depend on the final landform and surface of the Scheme once completed, making the estimates used by Cardno (2012) approximate at best. Similarly, the source of the groundwater inflow estimate from off-site sources (0.3 GL/year) is unknown, though for perspective the amount can be compared to inflow contributions to the Scheme from catchment runoff (7.9 GL/year during an average year) and river pumping (4.9 GL/year on average) or to estimated evaporative losses from the lakes themselves (11.4 GL/year; Cardno, 2012). The estimated annual groundwater inflow from off-site sources (0.3 GL/year) used by Cardno (2012) equates to less than 1% of the water volume within the lakes (37.4 GL), supporting previous assessments (Coffey & Partners, 1980) that such contributions can be considered negligible.

Based on a review of the physical and environmental setting, previous groundwater assessments and current and historical groundwater information and data for the Scheme, the contribution of groundwater inflows to the water balance of the lakes system is expected to be minor in comparison to catchment inflows and pumping from the Nepean River. Whilst quantitative estimates of the groundwater budget are difficult to determine with the available data, the conceptual hydrogeological model for the Scheme supports previous studies and the approximation that groundwater will contribute a small component of the water volume within the final lakes system.

3.4 Management Measures

As identified above, saline groundwater intrusion from alluvial aquifers to the east of the Scheme presents a potential risk to water quality within the lakes. Under normal weather and operating conditions the impacts and risks from these aquifers are expected to be minimal, with previous analysis estimating the salt load from these sources to be negligible in comparison to loads from typical rainfall and evaporation processes (IEP, 2005). However during extended dry periods or extreme drought conditions the potential for adverse impacts and risks to water quality within the lakes may increase.

Future managers of the Scheme will be able to monitor potential saline groundwater intrusion from the eastern aquifers through a regular water quality monitoring program of groundwater bores along the eastern boundary of the Scheme and within the lakes themselves. Measures to mitigate impacts on water quality of the lakes should be included in the operation and management of the Scheme. Criteria to evaluate potential saline groundwater intrusion include:

- Extended periods or trends of increasing salinity in groundwater bores at the eastern boundary of the Scheme;
- Extended periods or trends of increasing salinity in the lakes themselves; and
- Extended dry weather periods to trigger increases in the frequency of water quality monitoring.

Potential operation and management measures to mitigate impacts on water quality in the lakes may include increased water transfers to flush the lakes or measures to increase circulation within the lakes themselves. Should monitoring indicate saline groundwater is having a significant impact on water quality within the lakes, further site-specific evaluation and assessment would be required to determine suitable management and/or mitigation measures.

4. Conclusions and Recommendations

4.1 Conclusions

The Penrith Lakes Scheme represents a significant land rehabilitation project to transform a 1935 ha former sand and gravel quarry into a water-oriented recreational area for the benefit of the local community and environment. In order to develop a comprehensive water quality management plan for the Scheme, PLDC wishes to better understand the relationship between the lakes and local groundwater resources. The goal of this hydrogeological assessment was to provide a description of the type and likelihood of potential impacts of the Scheme on local groundwater resources and vice versa, to identify potential risks from such impacts and criteria to trigger management or operational measures designed to mitigate such risks.

The scope of the assessment comprised a detailed review of previous groundwater reports and assessments, historical groundwater data for the site and local area, and current groundwater data collected by PLDC as part of this review. Key conclusions drawn from the assessment are summarised below.

- Located on an alluvial floodplain of the Nepean River, the Scheme is topographically lower than its surrounds and is located on Quaternary-aged alluvial deposits. These sand and gravel deposits comprised the target resource for historical quarrying activities for which the site is being rehabilitated. Natural groundwater flow through the lower alluvial terrace moves in a west-northwest direction, from the southeast part of the Scheme before discharging to the Nepean River to the west and northwest.
- The physical and environmental setting, along with current and historical groundwater data, support the conceptual hydrogeological models developed in previous groundwater assessments. The primary source of groundwater recharge is direct infiltration from rainfall and runoff within the Scheme, with more minor contributions from older, more saline alluvial aquifers to the east and seepage from the Nepean River in the southeast. Within the Scheme boundary more localised recharge and discharge processes between the lakes and surrounding groundwater will occur, largely controlled by weather conditions and lake operating levels.
- The Scheme lies within the footprint of the lower alluvial terrace and has been designed to replicate natural surface water and groundwater flow processes that were present in the area prior to the commencement of quarrying activities. The lakes system can be conceptualised as a surface water representation of the alluvial aquifer that was present in the floodplain prior to the commencement of sand and gravel extraction, meaning potential impacts of the Scheme on local groundwater resources are likely to be limited.
- Potential groundwater impacts on the Scheme include saline groundwater intrusion from the older alluvial aquifers of the upper terrace to the east. Whilst the magnitude of these impacts are estimated to be small, criteria to trigger management or operational measures to mitigate risks from such impacts include:
    - Extended periods or trends of increasing salinity in groundwater bores at the eastern boundary of the Scheme;
    - Extended periods or trends of increasing salinity in the lakes themselves; and
    - Extended dry weather periods to trigger increases in the frequency of water quality monitoring.
- Quantitative estimates of the groundwater budget are difficult to determine with the data available, however the conceptual hydrogeological model for the Scheme supports previous studies and estimates that groundwater will contribute a small component of the water volume within the final lakes system. Annual groundwater contributions to the Scheme from off-site sources that include potential saline groundwater amount to less than 1% of the water volume within the lakes at normal operating levels.

4.2 Recommendations

In order to appropriately monitor and evaluate the potential for adverse impacts on water quality in the lakes, the following recommendations are provided for the future management and operation of the Scheme:

- Installation of two or three additional groundwater monitoring bores along the eastern boundary of the Scheme to monitor groundwater quality. Proposed locations for the new monitoring bores would be between existing bores P31 and P35 (refer **Figure 3**).
- Regular monitoring of groundwater bores along the eastern boundary of the Scheme and within the lakes themselves to monitor water quality and salinity.

Given the limited estimated volumetric contribution of saline groundwater to the Scheme (less than 1%), including groundwater quantity and quality inputs in a calibration or predictive water quality model for the Scheme is not considered necessary. The recommended groundwater monitoring for the future management and operation of the Scheme would inform any future requirement to include groundwater contributions in a water quality model of the Scheme.

5. References

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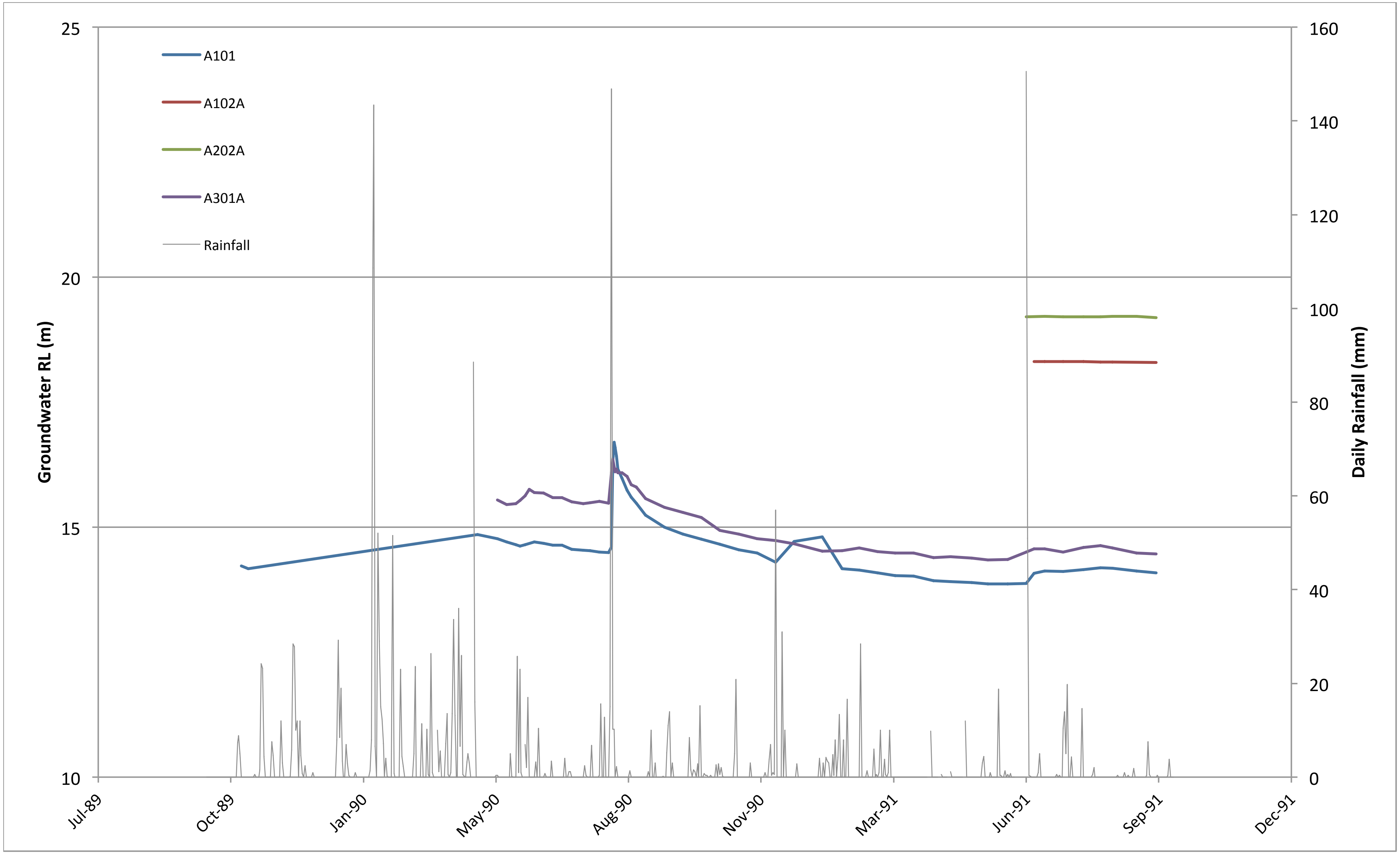
Attachment 1: Bore Hydrographs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A102A
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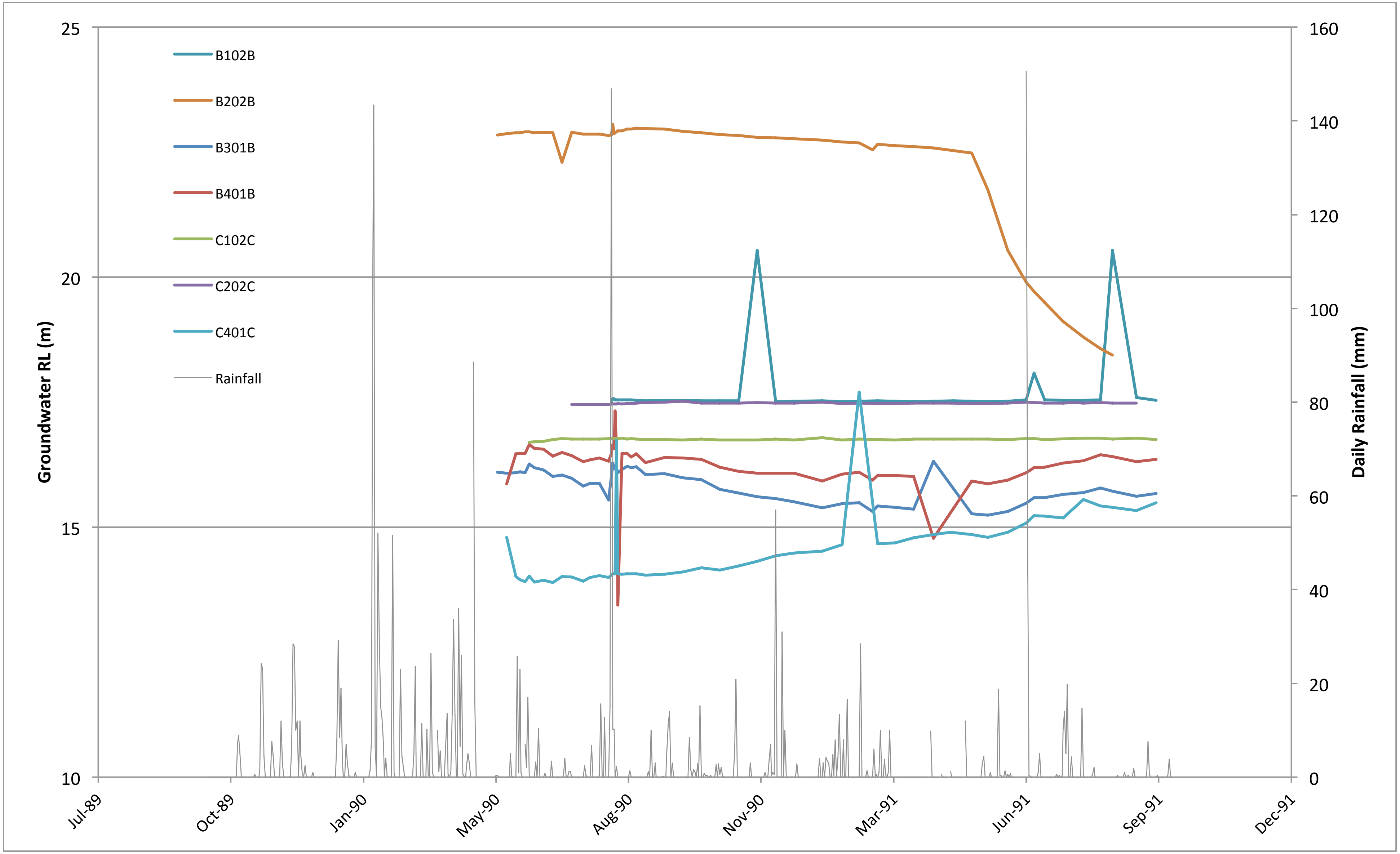
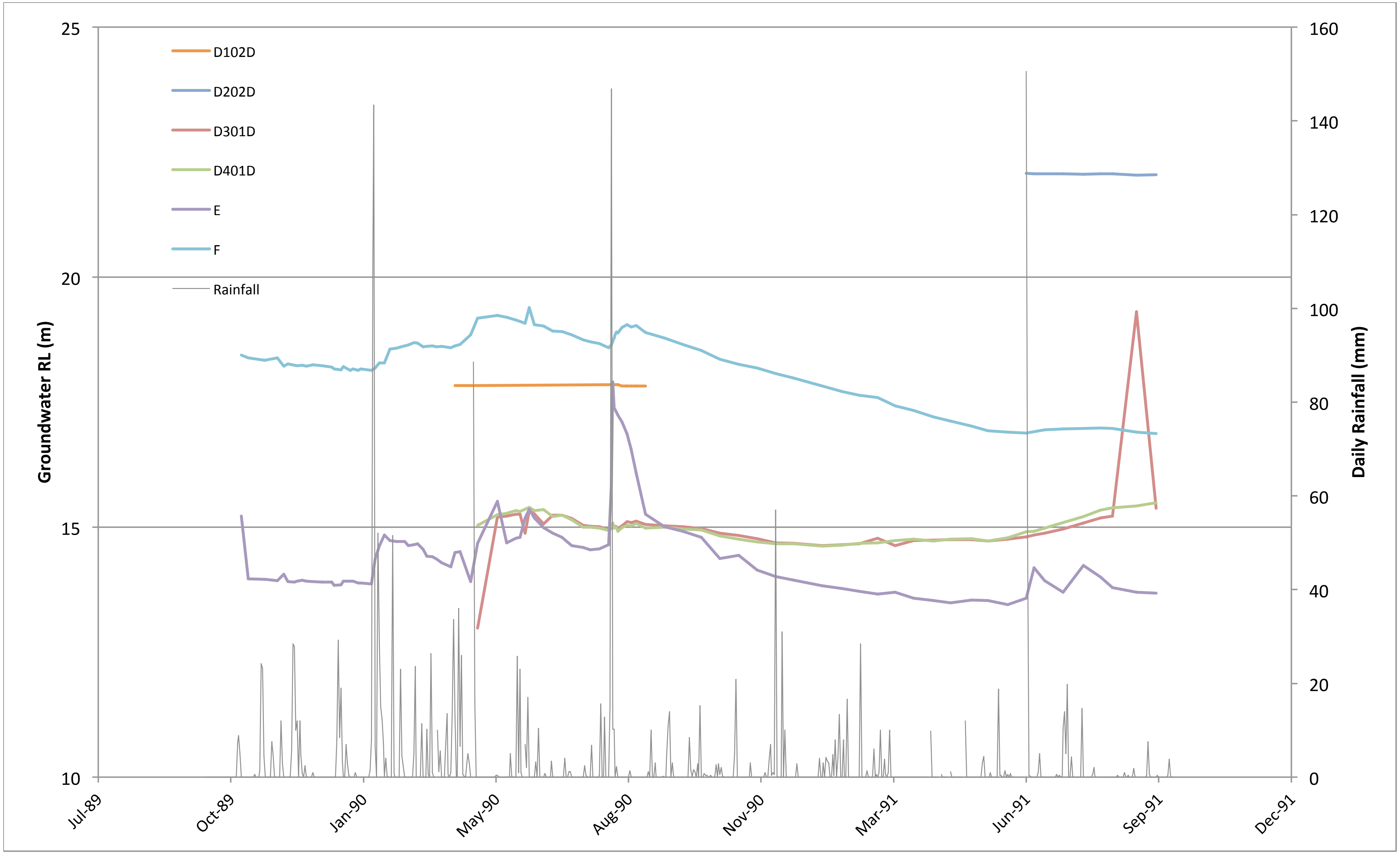
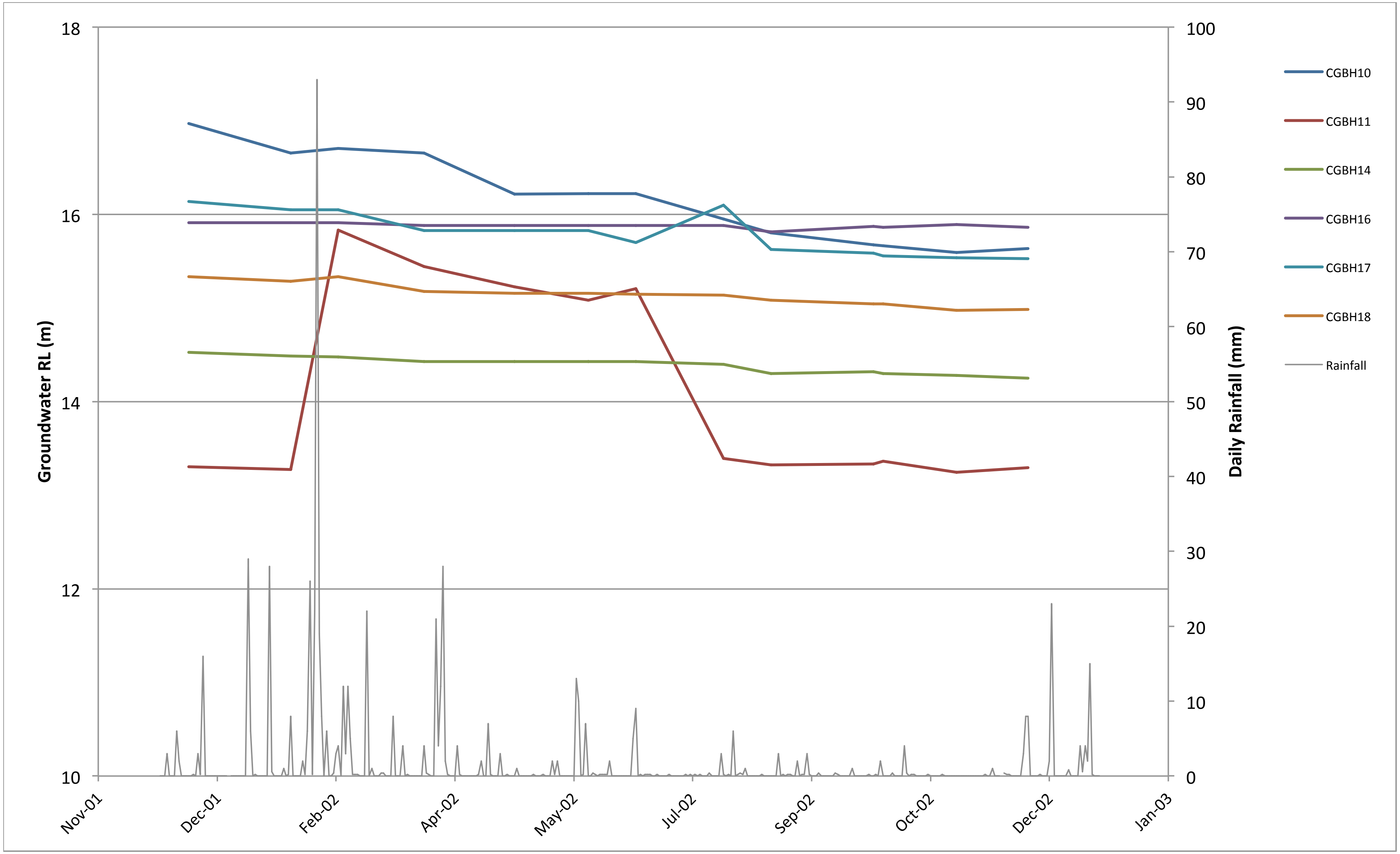
A301A
Rainfall
Groundwater RL (m)
Daily Rainfall (mm)
25
20
15
10
160
140
120
100
80
60
40
20
0
Jul-89
Oct-89
Jan-90
May-90
Aug-90
Nov-90
Mar-91
Jun-91
Sep-91
Dec-91



Groundwater RL (m)
Daily Rainfall (mm)
B102B
B202B
B301B
B401B
C102C
C202C
C401C
Rainfall
25
20
15
10
160
140
120
100
80
60
40
20
0
Jul-89
Oct-89
Jan-90
May-90
Aug-90
Nov-90
Mar-91
Jun-91
Sep-91
Dec-91



D102D
D202D
D301D
D401D
E
F
Rainfall
Groundwater RL (m)
Daily Rainfall (mm)
25
20
15
10
160
140
120
100
80
60
40
20
0
Jul-89
Oct-89
Jan-90
May-90
Aug-90
Nov-90
Mar-91
Jun-91
Sep-91
Dec-91



Groundwater RL (m)
Daily Rainfall (mm)
18
16
14
12
10
100
90
80
70
60
50
40
30
20
10
0
Nov-01
Dec-01
Feb-02
Apr-02
May-02
Jul-02
Sep-02
Oct-02
Dec-02
Jan-03
CGBH10
CGBH11
CGBH14
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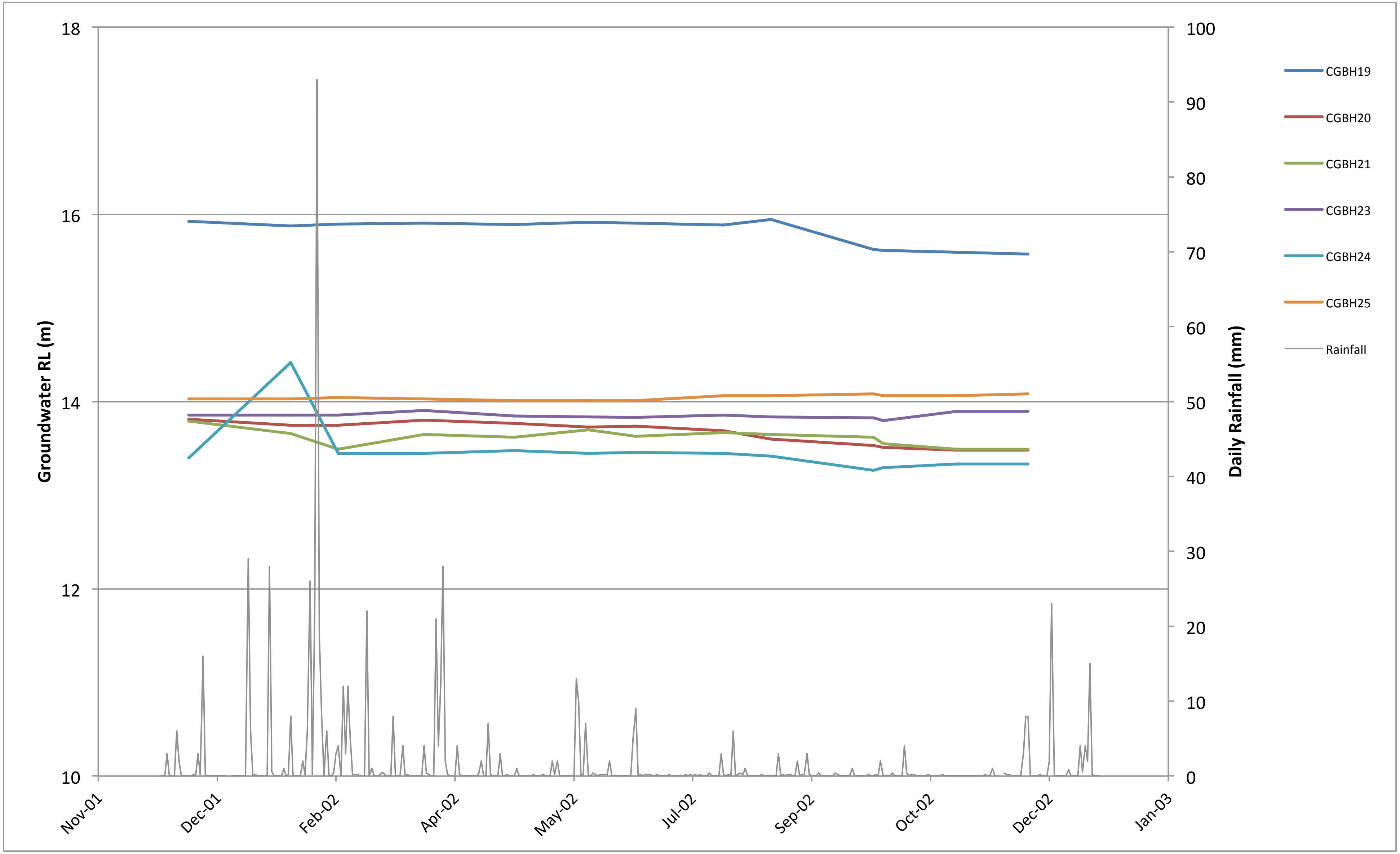
CGBH17
CGBH18
Rainfall



Groundwater RL (m)
18
16
14
12
10
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
Nov-01
Dec-01
Feb-02
Apr-02
May-02
Jul-02
Sep-02
Oct-02
Dec-02
Jan-03
CGBH19
CGBH20
CGBH21
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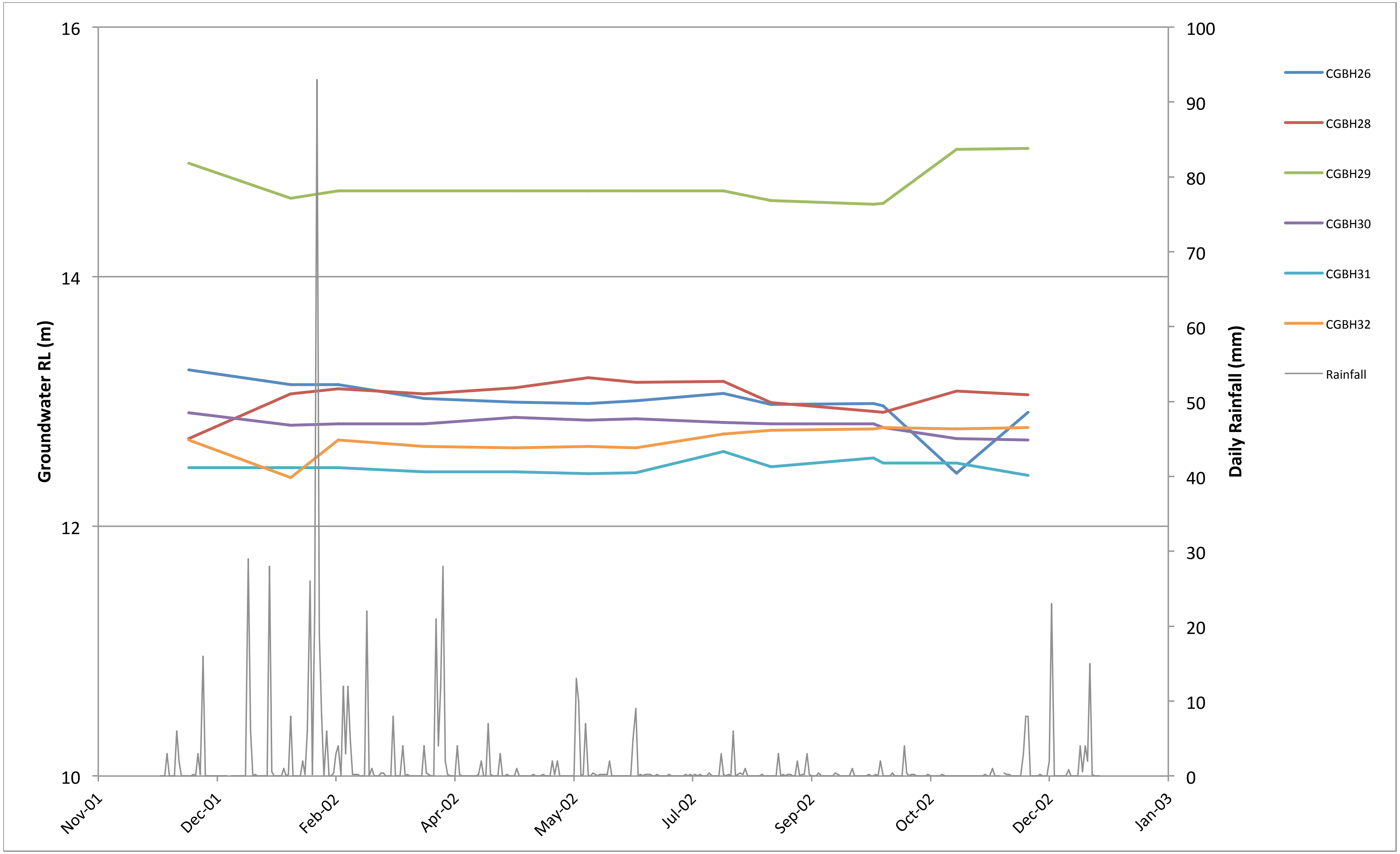
CGBH24
CGBH25
Rainfall



Groundwater RL (m)
Daily Rainfall (mm)
16
14
12
10
100
90
80
70
60
50
40
30
20
10
0
Nov-01
Dec-01
Feb-02
Apr-02
May-02
Jul-02
Sep-02
Oct-02
Dec-02
Jan-03
CGBH26
CGBH28
CGBH29
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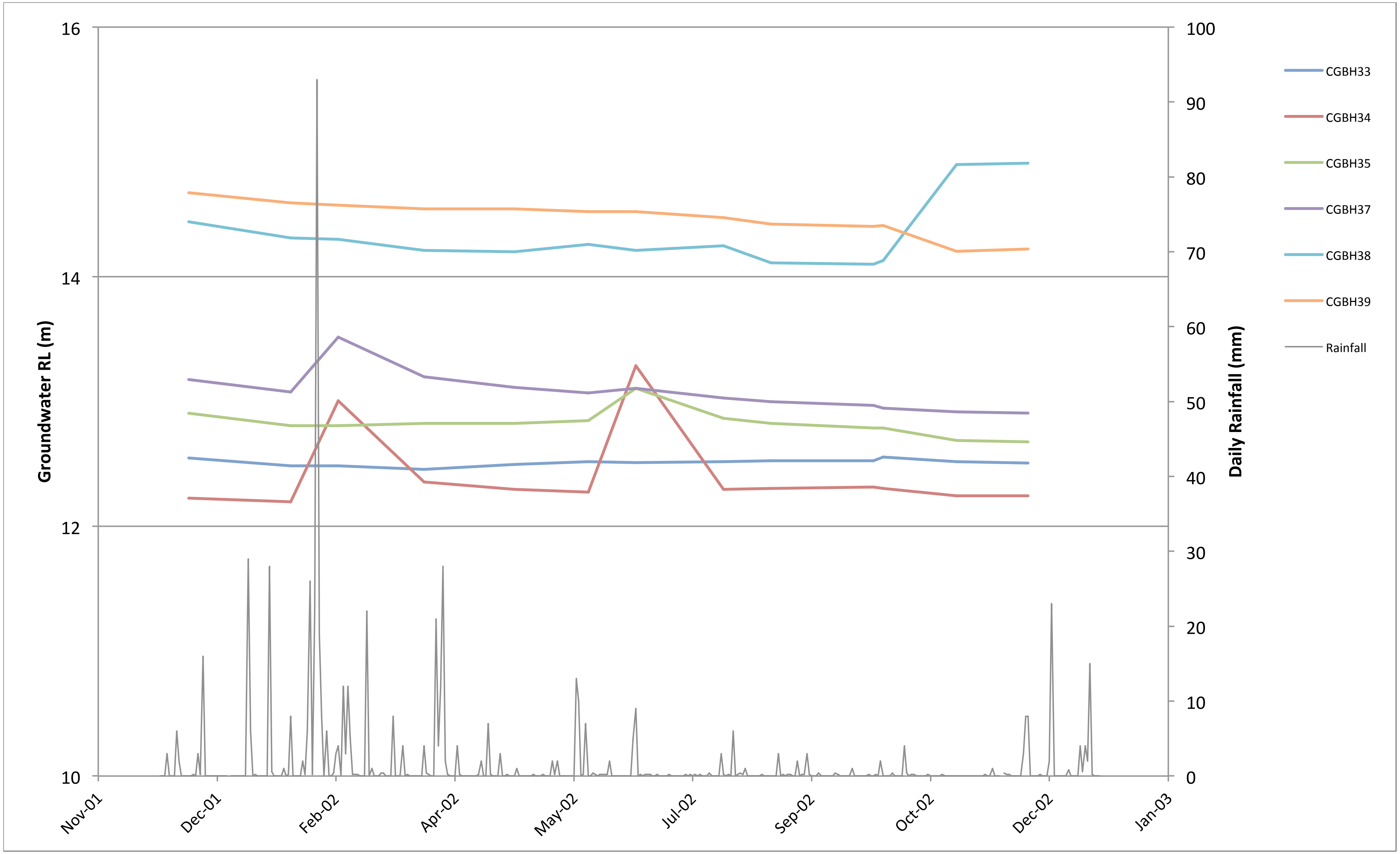
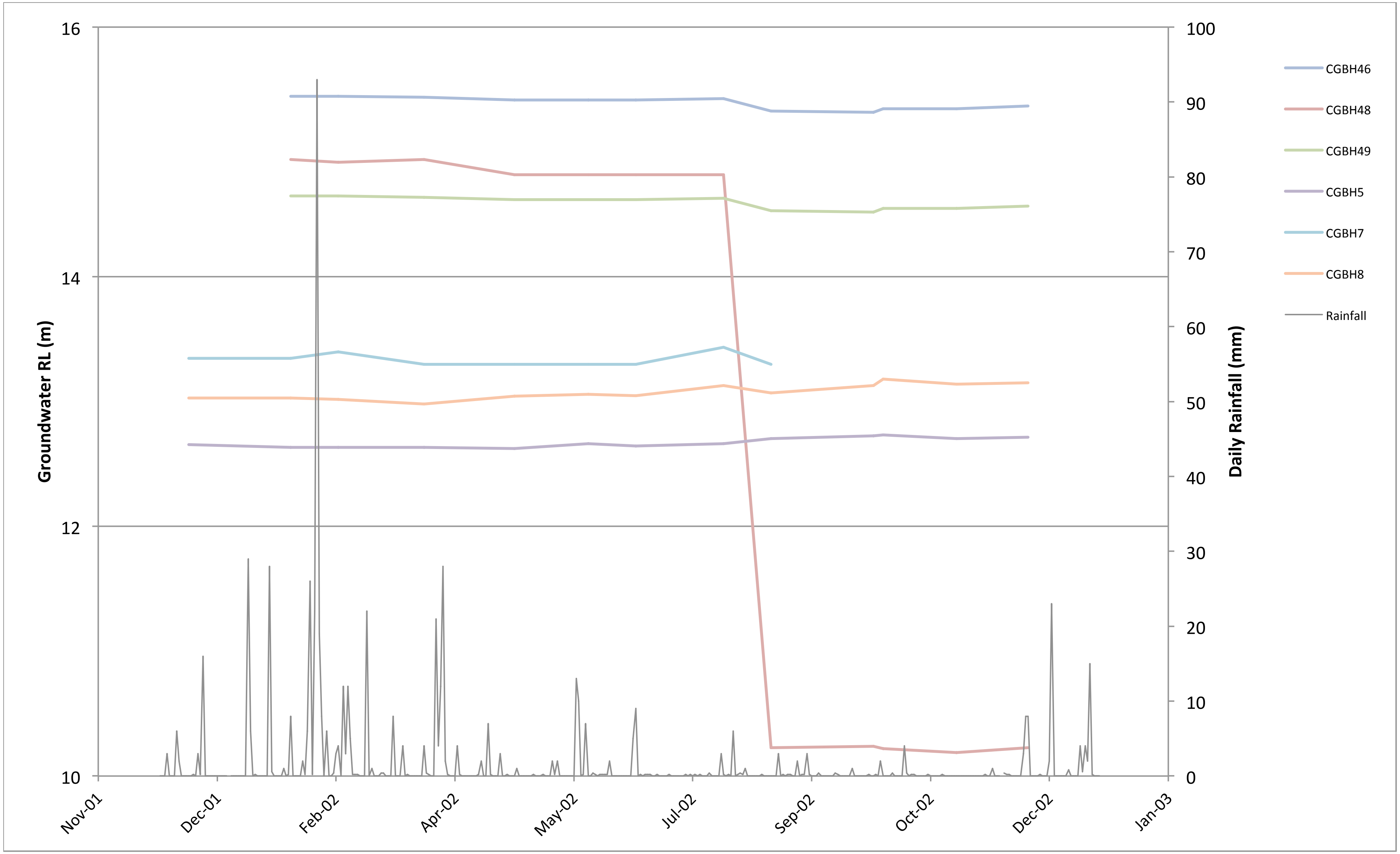
CGBH31
CGBH32
Rainfall



Groundwater RL (m)
Daily Rainfall (mm)
16
14
12
10
100
90
80
70
60
50
40
30
20
10
0
Nov-01
Dec-01
Feb-02
Apr-02
May-02
Jul-02
Sep-02
Oct-02
Dec-02
Jan-03
CGBH33
CGBH34
CGBH35
CGBH37
CGBH38
CGBH39
Rainfall



Groundwater RL (m)
Daily Rainfall (mm)
16
14
12
10
100
90
80
70
60
50
40
30
20
10
0
Nov-01
Dec-01
Feb-02
Apr-02
May-02
Jul-02
Sep-02
Oct-02
Dec-02
Jan-03
CGBH46
CGBH48
CGBH49
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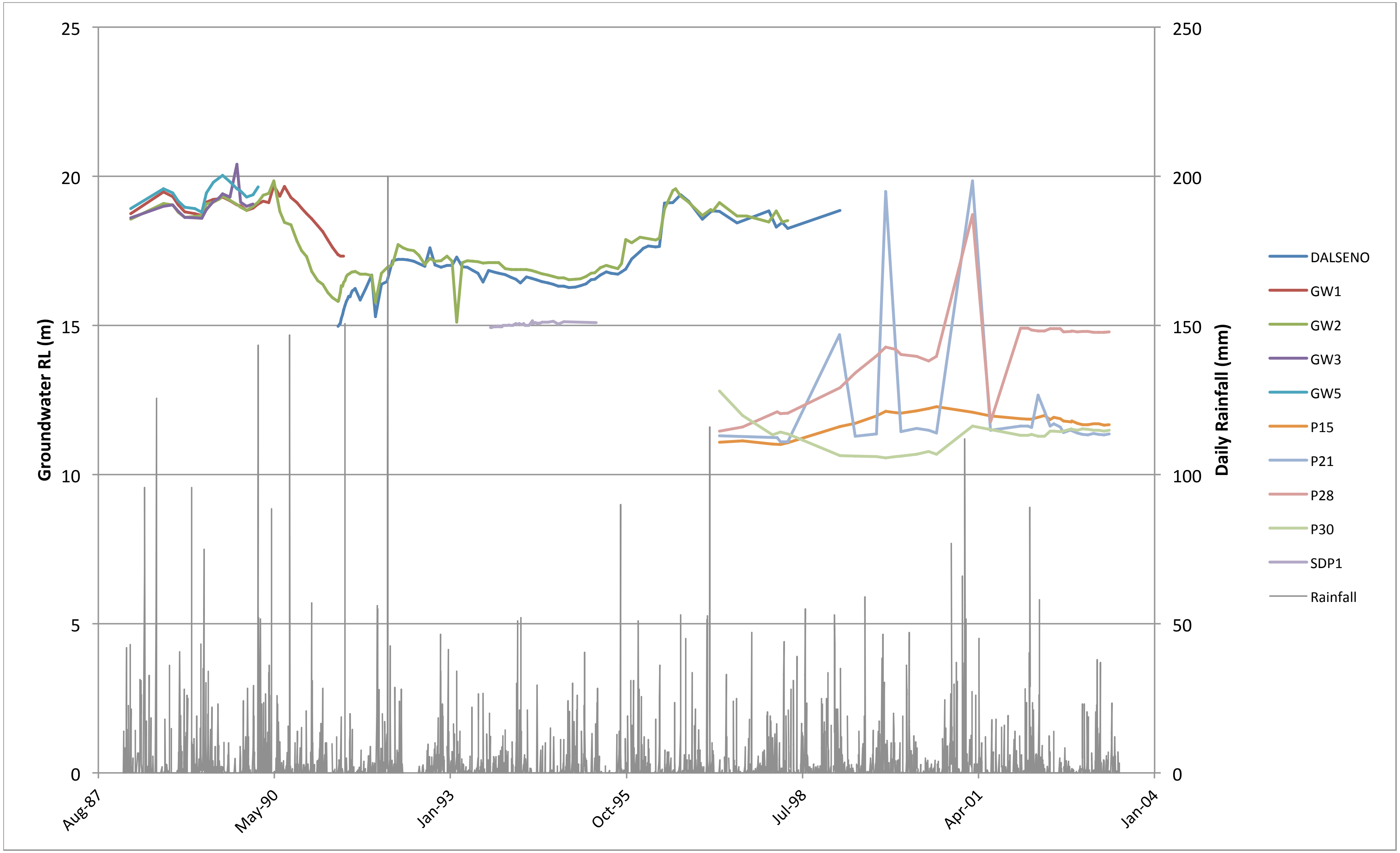
CGBH7
CGBH8
Rainfall


25
20
15
10
5
0
250
200
150
100
50
0
Groundwater RL (m)
Daily Rainfall (mm)
Aug-87
May-90
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
DALSENO
GW1
GW2
GW3
GW5
P15
P21
P28
P30
SDP1
Rainfall